APPENDIX A Average dimensions and features of principal streams (order 3 to 5) in the Wenatchee, Entiat, and Methow river drainages (Summary of Appendix B).

Steam name (river miles)	Mean area (acres)	Mean low flow in summer (cfs)	Mean flow (cfs)	Mean width (ft)	Mean gradient (%)	Pool/riffle ratio	Drainage area (sq. mile)
			Wenatchee River drainage				
Wenatchee R.							
(0.0-17.5)	442	961	3376	208	0.34	27:73	1327
(17.5-27.0)	196	871	3137	170	0.38	60:40	1000
(27.0-35.8)	118	702	2273	110	1.3	58:42	591
(35.8-54.2)	450	538	1795	182	0.21	61:39	273
Icicle Cr.							
(0.0-26.0)	170	165	625	54	1.45	55:45	211
White R.							
(0.0-13.1)	91	341	816	57	0.20	73:27	150
Little Wenatchee R.							
(0.0-15.0)	90	82	453	50	0.88	72:28	140
Mission Cr.							
(0.0-9.4)	15	2	13	13	2.02	38:62	82
Chumstick Cr.							
(0.0-13.0)	10	9	59	6	2.21	43:57	76
Nason Cr.							
(0.0-24.7)	126	57	314	42	1.17	53:47	108
Chiwaukum Cr.							
(0.0-4.3)	15	34	142	29	4.98	56:44	50
Peshastin Cr.							
(0.0-17.0)	64	13	117	31	2.62	33:77	133
Chiwawa R.							
(0.0-30.0)	181	167	488	50	0.45	43:57	462
			Entiat river drainage				
Entiat R.							
(0.9-16.0)	146	122	385	80	1.1	6:94	419
(16.0-29.2)	107	68	316	67	1.1	48:52	203
Mad R.							
(0.0-13.9)	50	17	69	30	2.9	19:81	92
			Methow River drainage				
Methow R.							
(1.8-27.1)	478	491	1592	155	0.4	41:59	1792
(27.1-50.1)	432	310	1352	156	0.3	55:45	
(50.1-73.0)	176		820	63		43:57	480
W. Fk. Methow R.							
(0.0-10.5)	28	30	149	29	2.6	22:78	83
Lost R.							
(0.0-7.1)	49	58	146	57	1.6	19:81	146
Early Winters Cr.							
(0.0-7.5)	28	24	119	32	2.9	17:83	79
Chewack R.							
(0.0-32.3)	249	57	375	64	1.7	52:48	525
Lake Cr.							
(0.0-6.5)	19	31	81	25	4.4	41:59	54
Twisp R.							
(0.0-28.2)	169	66	226	49	1.7	29:71	247
Gold Cr.							
(0.0-2.2)	7	7	33	26	3.7	35:65	87

Appendix B. Physical measurements of principal streams in the Wenatchee, Entiat, and Methow river drainages

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5– 1.0	1.0– 1.5	1.5– 3.0	>3.0
WENATCHEE R											
(0.0–1.0)	27.9	100	0.95	85:15		0.25	No field measurements				
(1.0–2.0)	27.9	100	0.95	25:75		0.27	because Wenatchee R				
(2.0–3.0)	27.9	100	0.95	20:80		0.34	area was estimated from				
(3.0–4.0)	27.9	100	0.95	25:75		0.26	aerial photographs. However,				
(4.0–5.0)	27.9	100	0.95	30:70		0.22	in descending order of abun–				
(5.0–6.0)	28.0	100	0.95	16:84		0.36	dance, cobble, gravel, sand,				
(6.0–7.0)	28.4	100	0.95	22:78		0.28	boulders, and bedrock predominate				
(7.0–8.0)	28.4	100	0.95	40:60		0.32	at low gradients (<0.5%), whereas				
(8.0–9.0)	28.4	100	0.95	25:75		0.38	boulders, cobble, and bedrock predominate				
(9.0–10.0)	28.4	100	0.95	20:80		0.31	at higher gradients (0.7%).				
(10.0–11.0)	29.6	100	0.95	17:83		0.43					
(11.0–12.0)	28.1	100	0.95	15:85		0.44					
(12.0–13.0)	27.9	100	0.95	25:75		0.40					
(13.0–13.8)	27.9	100	0.95	20:80		0.43					
(13.8–15.0)	29.5	100	0.66	25:75		0.48					
(15.0–16.0)	27.6	100	0.66	20:80		0.63					
(16.0–17.0)	29.5	100	0.66	25:75		0.44					
(17.0–17.5)	16.2	100	0.66	10:90		0.60					
(Dryden Dam)											
(17.5–18.0)	12.3	100	0.81	100:00		0.67					
(18.0–19.0)	24.6	100	0.81	70:30		0.74					
(19.0–20.0)	24.6	100	0.81	35:65		0.29					
(20.0–21.0)	24.6	100	0.81	50:50		0.19					
(21.0–22.0)	24.6	100	0.81	85:15		0.17					
(22.0–23.0)	24.6	100	0.81	25:75		0.25					
(23.0–23.9)	30.8	100	0.81	15:85		0.39					
(23.9–25.6)	57.3	100	0.81	80:20		0.75					
(25.6–27.0)	18.4	100	0.81	91:09		<.01					
(Tumwater Canyon)											
(27.0–35.8)	128.8	100	0.92	66:34		1.30					
(Tumwater canyon to Lake Wenatchee)											
(35.8–41.9) c	196.1	100	0.89	45:44	8	0.26					
(41.9–46.4)	115.6	100	0.89	58:42		0.26					
(46.4–47.4)	37.3	100	0.89	8:92		0.34					

Appendix B continued.

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5– 1.0	1.0– 1.5	1.5– 3.0	>3.0
ICICLE CREEK											
(0.0–4.0)	45.4	11	1.00	83:17	6	0.27	40	45	15		
(4.0–9.8)	26.2	4	1.00	48:52	68	3.00	1	1	98		
(9.8–12.8)	19.7	17	1.00	33:77	14	1.70	30	45	25		
(12.8–15.0)	13.6	25	1.00	28:72	12	1.70	30	45	25		
(15.0–16.0)	5.8	49	1.00	60:40	10	0.80	25	65	10		
(16.0–17.3)	8.1	43	1.00	23:77		1.60	30	45	25		
(17.3–18.0)	4.3	80	1.00	22:78		2.16	30	45	25		
(18.0–26.0)	46.4	6	1.00	60:40	36	0.76	25	65	10		
WHITE R											
(0.0–10)	65.9	7	1.00	72:28	14	0.10	95	4	1		
(10.0–13.1)	24.5	45	1.00	74:26	18	0.49	65	32	1		
LITTLE WENATCHEE R											
(0.0–7.0)	48.3	13	1.00	87:13	25	0.22	98	1	1		
(7.0–7.6)	3.6	37	1.00	87:13	41	0.72	50	25	25		
(7.6–11.0)	24.7	8	1.00	35:65	35	0.71	1	1	98		
(11.0–15.0)	13.0	3	1.00	80:20	177	1.80	5	5	90		
MISSION CR											
(0.0–5.6)	9.1	5	1.00	43:57	87	1.49	10	10	.80		
(5.6–9.4)	5.9	5	1.00	30:70	109	2.79	10	35	55		
CHUMSTICK CR											
(0.0–2.8)	2.6	2	1.00	38:62	301	1.42	98	1	1		
(2.8–5.0)	1.7	4	1.00	68:32	156	1.29	98	1	1		
(5.0–8.3)	2.9	1	1.00	38:62	200	1.32	40	25	35		
(8.3–9.2)	0.6	3	1.00	37:63	232	2.13	98	1	1		
(9.2–13.0)	1.7	2	1.00	22:78	192	4.09	80	15	5		
NASON CR											
(0.0–7.1)	39.0	14	1.00	46:54	27	0.66	58	42	2		
(7.1–15.4)	52.8	11	1.00	62:38	21	0.33	98	1	1		
(15.4–16.8)	7.2	23	1.00	47:53	43	3.79	45	15	40		
(16.8–19.8)	13.1	25	1.00	47:53	23	1.96	58	42	2		
(19.8–20.9)	4.4	89	1.00	45:55	33	1.03	58	42	2		
(20.9–22.6)	5.6	12	1.00	62:38	51	2.79	50	40	10		
(22.6–23.7)	2.5	36	1.00	39:61	30	1.21	58	42	2		
(23.7–24.7)	1.7	26	1.00	27:63	43	3.03	50	40	10		

Appendix B continued.

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5– 1.0	1.0– 1.5	1.5– 3.0	>3.0
CHIWAUKUM CR											
(0.0–1.0)	3.7	19	1.00	83:17	102	3.60	10	45	50		
(1.0–4.3)	11.7	5	1.00	57:43	121	5.40	20	20	60		
PESHASTIN CR											
(0.0–3.8)	20.2	17	1.00	21:79	20	1.51	50	30	20		
(3.8–9.0)	29.5	9	1.00	11:89	23	1.93	25	37	38		
(9.0–11.5)	6.0	3	1.00	49:51	213	3.86	1	40	59		
(11.5–13.7)	4.7	7	1.00	48:52	132	1.81	1	40	59		
(13.7–15.4)	2.1	6	1.00	59:41	205	2.45	70	20	10		
(15.4–17.0)	1.6	4	1.00	69:31	224	6.87	10	40	50		
CHIWAWA R											
(0.0–4.0)	30.6	16	1.00	23:77	21	0.57	30	30	40		
(4.0–13.0)	65.2	7	1.00	23:77	21	0.81	30	30	40		
(13.0–16.0)	18.9	15	1.00	68:32	36	0.09	83	10	7		
(16.0–21.0)	28.3	9	1.00	68:32	54	0.15	83	10	7		
(21.0–24.0)	15.7	15	1.00	68:32	55	0.32	83	10	7		
(24.0–30.0)	22.4	11	1.00	63:37	59	0.32	83	10	7		
ENTIAT R											
(0.9–2.0)	8.1	45	1.00	10:90	4	0.50	36	24	22	15	3
(2.0–3.0)	10.3	43	1.00	4:96	4	1.25	12	13	29	45	1
(3.0–4.0)	8.5	40	1.00	1:99	5	0.85	15	20	40	21	4
(4.0–5.0)	8.9	41	1.00	12:88	5	1.08	14	22	38	22	4
(5.0–6.0)	8.9	41	1.00	12:88	5	1.02	13	23	37	24	3
(6.0–7.0)	8.9	41	1.00	12:88	5	1.12	17	20	34	28	1
(7.0–8.0)	11.2	60	1.00	4:96	7	1.27	15	36	33	15	1
(8.0–9.0)	11.5	71	1.00	4:96	5	1.29	25	25	33	12	5
(9.0–10.0)	11.5	35	1.00	14:86	10	0.97	15	38	22	15	1
(10.0–11.0)	11.5	48	1.00	8:92	8	1.19	18	25	36	20	1
(11.0–12.0)	10.3	31	1.00	17:83	16	0.76	23	30	29	16	2
(12.0–13.0)	8.7	39	1.00	1:99	2	1.06	25	35	20	15	5
(13.0–14.0)	8.2	46	1.00	1:99	2	0.81	4	11	17	40	28
(14.0–15.0)	9.8	52	1.00	1:99	2	1.17	5	11	27	34	23
(15.0–16.0)	9.8	52	1.00	1:99	2	1.27	6	11	36	30	17
(16.0–17.0)	8.2	51	1.00	51:49	16	0.30	16	19	29	25	11
(17.0–18.0)	8.2	51	1.00	51:49	16	0.27	19	26	21	24	10
(18.0–19.0)	8.6	52	1.00	73:27	12	0.23	11	32	36	20	1

Appendix B continued.

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5– 1.0	1.0– 1.5	1.5– 3.0	>3.0
ENTIAT R											
(19.0–20.0)	7.5	38	1.00	67:33	21	0.23	20	18	46	15	1
(20.0–21.0)	9.1	37	1.00	53:47	24	0.40	67	30	1	1	1
(21.0–22.0)	7.5	42	1.00	75:25	26	0.38	79	18	2	1	1
(22.0–23.0)	8.5	63	1.00	33:67	13	0.57	41	19	18	17	1
(23.0–24.0)	8.9	44	1.00	37:63	18	0.70	54	29	10	5	2
(24.0–25.0)	9.1	46	1.00	60:40	20	0.42	67	21	10	1	1
(25.0–26.0)	7.6	37	1.00	35:65	16	0.49	50	33	14	2	1
(26.0–27.0)	8.0	48	1.00	45:55	19	2.12	40	35	19	5	1
(27.0–28.0)	7.4	43	1.00	29:71	35	2.01	37	28	21	11	3
(28.0–28.7)	5.1	56	1.00	13:87	44	3.88	15	25	30	24	6
(28.7–29.2)	3.5	84	1.00	20:80	91	2.44	2	2	8	10	78
MAD R											
(0.0–1.0)	3.3	28	1.00	28:72	30	1.61	16	29	34	17	4
(1.0–2.0)	3.6	29	1.00	17:83	53	1.33	20	35	24	14	7
(2.0–3.0)	3.6	26	1.00	22:78		2.88	22	22	28	18	5
(3.0–4.0)	3.6	31	1.00	15:85		2.23	19	26	27	22	6
(4.0–5.0)	3.5	26	1.00	20:80		3.03	11	24	30	27	8
(5.0–6.0)	3.6	29	1.00	17:83		3.31	10	31	29	21	9
(6.0–7.0)	3.8	36	1.00	9:91		4.81	8	27	23	26	16
(7.0–8.0)	3.4	22	1.00	21:79	68	3.14	21	23	28	21	7
(8.0–9.0)	3.4	32	1.00	31:69	37	2.46	23	27	30	18	2
(9.0–10.0)	3.9	33	1.00	18:82	34	2.99	19	27	26	26	2
(10.0–11.0)	4.0	26	1.00	13:87	53	2.12	16	26	23	27	8
(11.0–12.0)	3.6	20	1.00	11:89	40	4.32	8	19	27	29	17
(12.0–13.0)	3.4	22	1.00	25:75	74	3.11	9	17	27	22	25
(13.0–13.9)	3.1	24	1.00	26:74		2.80	10	19	29	20	22
METHOW R											
(1.8–5.5)	52.4	17	2.08	32:68	6	0.42	31	24	29	14	2
(5.5–8.5)	42.0	19	1.41	36:64	4	0.72	9	18	37	24	12
(8.5–13.3)	77.0	14	1.33	15:85	15	0.49	26	36	21	12	5
(13.3–16.1)	49.9	21	1.26	39:61	10	0.41	42	25	19	11	3
(16.1–18.4)	37.0	28	1.20	38:62	8	0.33	32	35	18	8	7
(18.4–20.6)	31.7	24	1.23	32:68	19	0.49	32	30	26	10	2
(20.6–24.0)	50.5	18	1.20	54:46	10	0.33	24	29	21	19	7
(24.0–27.1)	54.2	19	1.22	52:48	7	0.37	40	25	22	11	2
(27.1–29.4)	40.8	24	1.22	67:33	4	0.18	53	28	10	8	1

Appendix B continued.

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5–1.0	1.0–1.5	1.5–3.0	>3.0
METHOW R											
(29.4–31.7)	42.6	21	1.24	63:37	8	0.29	30	35	20	10	5
(31.7–34.5)	40.9	24	1.23	33:67	18	0.31	66	26	6	1	1
(34.5–37.2)	50.4	25	1.29	66:36	6	0.28	66	26	6	1	1
(37.2–40.1)	36.3	21	1.15	45:55	7	0.31	35	35	25	4	1
(40.1–43.6)	56.4	18	1.08	63:37	10	0.37	49	36	13	1	1
(43.6–45.5)	26.6	19	1.11	28:72	8	0.32	45	40	12	2	1
(45.5–49.9)	63.8	14	1.29	60:40	10	0.30	39	49	9	2	1
(49.9–51.8)	20.3	24	1.19	34:66	11	0.29	34	34	25	5	2
(51.8–54.1)	23.1	18	1.10	10:90	12	0.39	46	33	17	3	1
(54.1–56.6)	22.6	21	1.15	40:60	15	0.48	40	35	17	7	1
(56.6–59.4)	21.4	23	1.12	58:42	19	0.42	60	28	9	2	1
(59.4–63.5)	29.9	14	1.23	67:33	14	0.43	37	33	20	9	1
(63.5–67.4)	12.5	22	1.27	40:60	14	0.50	27	40	19	12	2
(67.4–73.0)	dry channel		(in a normal summer 18.4 acres of wetted area estimated)								
W.FK METHOW											
(0.0–0.6)	dry channel										
(0.6–3.6)	11.7	8	1.18	24:76	53	2.17	8	18	32	31	11
(3.6–4.5)	4.3	25	1.28	25:75	41	2.45	8	20	32	32	5
(4.5–7.7)	10.1	18	1.21	17:83	38	2.73	10	25	35	26	4
(7.7–10.5)	8.3	10	1.05	25:75	70	2.98	8	21	31	29	11
LOST R											
(0.0–0.9)	4.5	30	1.18	49:51	52	1.52	36	33	28	2	1
(0.9–3.1)	11.7	15	1.28	14:86	31	1.19	33	47	14	5	1
(3.1–3.9)	4.3	74	1.21	33:67	31	1.54	15	29	33	20	3
(3.9–7.1)	22.2	13	1.05	12:88	24	2.25	14	32	23	25	6
EARLY WINTERS CR											
(0.0–1.2)	5.5	21	1.08	11:89	11	1.60	7	17	32	28	16
(1.2–2.2)	5.1	23	1.10	10:90	22	3.88	4	25	33	29	9
(2.2–5.1)	10.6	12	1.07	18:82	64	3.19	9	21	32	26	12
(5.1–7.5)	6.4	11	1.00	21:79	42	3.01	20	32	26	19	3

Appendix B concluded.

Stream name (river mile)	Area (ac)	Sample size (%)	Factor [a]	Pool/ riffle ratio	Diver- sity index [b]	Grad- ient (%)	Percentage substrate particle size (ft) <0.5	0.5– 1.0	1.0– 1.5	1.5– 3.0	>3.0
TWISP R											
(0.0–2.7)	13.8	14	1.10	18:82	26	0.76	19	29	30	21	1
(2.7–4.2)	6.7	23	1.20	43:57	47	1.44	15	24	35	23	3
(4.2–7.0)	15.4	17	1.20	34:66	29	2.00	11	23	31	30	5
(7.0–9.2)	12.5	19	1.29	27:73	22	1.26	12	22	32	28	6
(9.2–10.2)	7.3	38	1.52	41:59	17	0.39	42	28	10	9	1
(10.2–12.5)	13.7	23	1.53	31:69	23	0.81	17	27	30	22	4
(12.5–14.5)	7.4	23	1.45	63:37	34	0.68	51	45	2	1	1
(14.5–16.8)	11.6	19	1.84	20:80	9	0.86	35	21	23	17	4
(16.8–18.2)	5.1	30	1.43	20:80	38	1.72	43	28	21	6	2
(18.2–20.9)	10.9	13	1.33	3:97	17	1.76	12	35	28	21	4
(20.9–21.9)	3.7	28	1.26	30:70	91	1.86	36	32	19	10	3
(21.9–23.7)	dry channel (in a normal summer 5.2 acres of wetted area estimated)										
(23.7–26.2)	6.5	10	1.44	27:73	86	2.86	37	45	15	2	1
(26.2–28.2)	4.0	4	1.41	51:49	191	5.89	10	16	20	23	30
CHEWACK R											
(0.0–7.4)	47.2	6	1.56	62:38	26	0.58	26	58	14	1	1
(7.4–8.9)	10.3	15	1.47	25:75	32	0.80	10	20	27	35	8
(8.9–10.9)	13.6	24	1.40	40:60	17	0.63	72	24	2	1	1
(10.9–13.4)	14.7	17	1.30	58:42	24	0.55	57	40	1	1	1
(13.4–14.8)	11.1	32	1.29	67:33	27	0.32	58	38	1	1	1
(14.8–17.9)	18.4	13	1.28	50:50	23	0.49	46	39	13	1	1
(17.9–19.3)	9.7	19	1.32	35:65	18	0.39	24	32	25	18	1
(19.3–20.7)	9.6	20	1.23	19:81	22	1.23	26	34	20	14	6
(20.7–22.9)	11.7	14	1.17	45:55	28	1.24	27	31	35	6	1
(22.9–24.0)	5.2	22	1.21	27:73	45	2.97	7	13	19	34	27
(24.0–25.4)	5.3	19	1.19	21:79	49	2.33	17	28	40	12	3
(25.4–27.2)	7.8	7	1.20	51:49	128	3.26	7	12	28	28	25
(27.2–28.0)	3.5	18	1.21	46:54	121	2.10	2	8	11	19	60
(28.0–30.2)	13.0	11	1.03	95:50	4	0.47	65	23	10	1	1
(30.2–30.7)	1.7	52	1.02	95:50	5	0.02	95	2	1	1	1
(30.7–31.8)	3.2	6	1.10	53:47	86	0.26	13	27	28	7	5
(31.8–32.3)	1.1	45	1.08	61:39	124	8.86	7	14	13	24	42
LAKE CR											
(0.0–1.6)	4.9	13	1.12	38:62	91	3.55	7	26	27	13	27
(1.6–4.2)	7.5	7	1.10	37:63	72	5.90	10	26	15	21	28
(4.2–5.2)	2.3	11	1.15	64:36	110	2.69	71	20	7	1	1
(5.2–6.5)	3.1	9	1.09	35:65	98	5.35	9	28	27	22	14
GOLD CR											
(0.0–0.8)	2.3	21	1.20	24:75	73	3.31	16	23	28	29	4
(0.8–2.2)	3.8	11	1.20	46:54	94	4.13	19	26	29	24	2

a Factor to convert measured dimensions to average late summer wetted area associated with mean low flow.

b A ratio relating the number of pools and riffles in a mile of stream.

APPENDIX C

ESTIMATES OF DISCHARGE IN THE METHOW AND CHEWACK RIVERS AND GROUND-WATER CONTRIBUTION TO FLOW IN MID-COLUMBIA RIVER TRIBUTARIES

by

Granville Rhodus and James W. Mullan

The Methow River basin consists of three major drainages--the Chewack River drainage, the Methow River upstream from Winthrop (RM 50), and the southern drainage. Hydrologic records are scarce for the Chewack River and the Methow River upstream from Winthrop. With existing information, we estimate discharge and provide perspective on ground water contribution to flow in these and other mid-Columbia River tributaries.

Upper Methow River Drainage

The drainage area of the Methow River above Winthrop is 480 mi^2. Its major tributaries are Early Winters Creek (79.2 mi^2), Lost River (146 mi^2), and West Fork Methow (83 mi^2).

Goat Creek, a smaller sub-drainage (36 mi^2), contributes little run-off during summer low-flow periods because of thin soils, abundance of bedrock, and south slope aspect. However, this highly insolated watershed can produce high spring flows. Few discharge measurements are available for Goat Creek.

Wolf Creek sub-drainage (38 mi^2) has an estimated annual run-off of 14 in with a mean flow of 39.7 cfs. Much of the water is diverted and stored in Patterson Lake for release later during the irrigation season. There is little or no surface flow at its mouth in summer.

Climate

Annual precipitation is estimated at 40 in for the upper Methow River basin, although no complete determination has been made. Mean precipitation at Winthrop is 13.6 in. The basin's upper Cascade Mountain crest (8,000-9,000 ft elevation) receives up to 80 inches of precipitation. About 72% of the precipitation falls as snow.

The estimated evapotranspiration for the Methow Basin is 15 in annually (Walters and Nassar 1974). Long-term air temperature at Winthrop ranges from minus 58° F to 110° F. Air temperature data does not exist for the upper elevations.

Run-Off Pattern

In the Methow Basin, mean annual run-off and precipitation decreases from about 60 in the west to about 1 in in the east. Estimated mean run-off is 25 in. The timing and volumes of run-off are influenced by winter snow packs, glaciers, weather, and other climatic variables. The monthly run-off distribution for lower Methow River gaging stations shows that 69% of the annual discharge occurs in April, May, June, and July.

Irrigation Diversions

In August 1935, 26 diversions on the upper Methow River diverted more than 500 cfs (Bryant and Parkhurst 1950). Abstraction differs today because of reduced agricultural demands and changes in irrigation techniques. The following is an estimate of water now diverted for irrigation in August (Milhous et al. 1976; Westell Canal, our estimate):

Diversion	Estimated irrigated acres	Estimated August diversion (cfs)
Early Winters Canal Co.	650	23
Westell Canal	330	20
McKinney Mountain Ditch	350	23
Wolf Creek Irrigation Co.	677	44
Foghorn Ditch	400	21
TOTAL	2,407	131

Walters and Nassar (1974) reported six ditches above Winthrop diverting 93.8 cfs August 25-27, 1971. Existing water rights are 90-131 cfs.

Ground Water

Alluvial and glacial deposits ranging from a few to several hundred feet thick constitute the ground-water reservoir in the Methow River Basin. Deposits are thickest principally in the bottoms and along the lower slopes of the major valleys (Walters and Nassar 1974).

Of the 14,000 ac irrigated in the Methow Basin, only 1,000 ac depend on ground water (Walters and Nassar 1974). Ground-water development north and west of Winthrop is chiefly along the floor of the Methow River Valley. In the upper Methow Valley, few wells penetrate more than 90 ft. Ground water levels range from 6 ft, or less, to 85 ft (Walters and Nassar 1974).

Low-Flow Characteristics

Streams flowing over permeable materials lose water to the ground-water aquifer. If the water table is higher than the stream level, ground water discharges into the stream channel (Walters and Nassar 1974). This gain and loss in stream flow occurs in many mid-Columbia River tributaries. It is most noticeable in the upper Methow River where reaches are alternately watered and dewatered during dry summers.

Between August and October 1987, we made a physical survey of the Methow River and its major tributaries. The Methow River was at extreme low-flow stage; it dried from RM 63.3 to RM 73.7. This distance of 10 miles normally carries the combined flow of Early Winters Creek, Lost River, and West Fork Methow. These sub-watersheds comprise 65% of the basin area above Winthrop. The 308 mi^2 area has an above-average basin elevation with proportionately higher run-off, when compared with the entire 1,794 mi^2 Methow drainage.

The minimum-flow potentials of streams can be defined by four indexes based on the 7- and 183-day low-flow frequency curves and mean annual discharge (Walters and Nassar 1974). Table 1 lists the four indexes for 15 gaging stations (Williams and Pearson 1985) in mid-Columbia River tributaries. Nassar (Walters and Nassar 1974, Nassar 1973) considered the low-flow index an excellent measure of average, dry-weather (base) flows for streams depending largely on ground, lake, glacier, or snow storage. The smaller the index number, the smaller the water yield per square mile. Nassar (1973) believed the slope index is a good indicator of variability of low flows over the years; larger quantities of storage decrease variations and small quantities increase them. Streams with large storage capacity produce frequency curves with flat slopes (low index numbers); streams having small storage capacity produce frequency curves with steep slopes (high index numbers).

The spacing index is influenced by the extent of storage. Basins with slight storage will show widely spaced frequency curves and high numbers on the spacing index; basins with greater storage will have small spacing index numbers, as their frequency curves are closely spaced. The base flow index is a measure of the contribution of stored water to total stream flow. A high base-flow index reflects a relatively large contribution, whereas a low index reflects a small contribution (Nassar 1973).

Table 1. Low-flow indexes for the Okanogan, Methow, Entiat, and Wenatchee river basins (calculated from data in Williams and Pearson 1985).

STATION NAME	Period of record	Mean ann'l discharge (cfs)	Drainage area (sq. mi.)	Low-flow indexes* (1) Yield	(2) Slope	(3) Spacing	(4) Base flow
Okanogan Basin							
Okanogan R.(RM 78.0)	1943-79	665	3195	0.06	5.75	2.37	0.27
Similkameen R.(RM 15.8	1913-28	2132	3550	0.10	2.54	1.65	0.16
Methow Basin							
Methow R.(RM 40.0)	1920-62	1327	1301	0.16	1.37	1.59	0.15
Methow R.(RM 6.7)	1959-70	1540	1772	0.17	1.25	1.35	0.19
Methow R.(RM1.0)	1904-20	1655	1794	0.17	1.41	1.42	0.19
Beaver Cr.(RM 8.9)	1960-78	21	62	0.07	1.62	1.47	0.23
Andrews Cr.(RM 3.5)	1961-78	21	22	0.10	1.62	1.90	0.14
Entiat Basin							
Entiat R.(RM 18.1)	1959-79	660	203	0.27	1.47	1.67	0.08
Entiat R.(RM 0.3)	1911-25 1951-58	509	419	0.22	1.68	1.54	0.19
Wenatchee Basin							
White R.(RM 6.4)	1956-79	816	150	0.89	1.58	2.35	0.16
Chiwawa R.(RM 6.3)	1938-57	488	172	0.48	1.41	1.73	0.17
Wenatchee R.(RM 54.1)	1932-58	1317	273	0.80	1.65	2.42	0.17
Wenatchee R.(RM 46.2)	1912-79	2274	591	0.71	1.83	2.17	0.19
Wenatchee R.(RM 21.5)	1931-79	3137	1000	0.55	1.62	2.18	0.18
Wenatchee R.(RM 5.8)	1964-79	3376	1301	0.45	1.36	2.09	0.18

*The yield index (1) is the ordinate of the annual 7-day minimum low-flow frequency curve at a 2-yr. interval. It is expressed in cfs (cubic feet/second) per square miles to compare streams whose drainage areas differ in size.

The slope index (2) is the ratio of the ordinates of the annual 7-day minimum low-flow-frequency curve at the 2- and 20-yr. recurrence intervals.

The spacing index (3) is the ratio of the ordinates, at the 2-yr. recurrence interval, of the 183- and 7-day low-flow-frequency curves.

The base-flow index (4) is the ratio between the yield index, in cfs, and the mean annual discharge.

The minimum flow indexes of Table 1 indicate that ground water is the primary contributor to the Methow River at RM 40.0 (Twisp) during the low-flow period (Walters and Nassar 1974). For those Methow River stations not affected by irrigation diversion--Beaver and Andrews creeks--the indexes indicate that the ground-water reservoir, albeit small, is characterized by high permeability (Table 1). Also, the slope indexes indicate slight fluctuations in low-flow patterns from year to year. Low-flow index characteristics of the Entiat River, which is not affected by irrigation diversion at the upstream station, are similar (Table 1). Ground-water recharge and storage above the upstream station on the Entiat River, where most of the precipitation originates, is a small part of the low flow as reflected in lowest base-flow index (0.08) of any of the 15 stations (Table 1). This is because of narrow valleys with shallow soils and surrounding ridges of bedrock.

The White River in the Wenatchee River drainage has a comparatively high spacing index, 2.35 (Table 1). Although its large glacier area (main text, Table 3) might lead one to assume a large storage capability for this basin, the base flow index of 0.16 is poor, indicating that the contribution of glacier melt to the total flow is small. Low flow of the adjacent Chiwawa River is also well sustained as a result of the high altitude of the snow fields and glaciers, but the yield per unit area is only about half that of the White River (Table 1). Although the ridges in the Entiat Mountains at the head of the Chiwawa River are as high as those in the Cascade Range, they are in the rain shadow.

Low flow-index values for four mainstem Wenatchee River stations, from below Lake Wenatchee to near the river mouth, are consistent with the regulating effect of a large lake upstream and irrigation diversion (decreasing yield index) downstream (Table 1).

The Methow River basin is similar to the Similkameen River basin, and their headwaters are intertwined along the border between Canada and the United States. Where the Similkameen River joins the Okanogan River near Oroville, Washington, their basins have almost the same area, but the average annual flow of the Similkameen is almost four times that of the Okanogan (Table 1). This difference in flow between the two basins occurs because the Cascade Mountains shield the upper Okanogan from coastal precipitation and because the Similkameen has broader headwaters at higher elevations (Osborn and Sood 1973).

The differences between the Similkameen and Okanogan river basins are reflected in the low-flow indexes. The Similkameen has a slightly higher yield index than the Okanogan, while the slope index was two-fold greater for the Okanogan with its large quantities of storage in lakes (106,000 surface acres) (Table 1). Once in about every 20 years the Okanogan drops 60% from 321 cfs to 129 cfs as a result of withdrawals for irrigation and lack of precipitation (Osborn and Sood 1973). By contrast, low flows of the Similkameen River drop only 43% from 360 cfs to 207 cfs about every 20 years (Osborn and Sood 1973). The spacing index suggests that seasonal storage in the geologic materials underlying the Okanogan basin is less than that of the Similkameen, while the base flow index of the Similkameen is comparable to those of the Methow River (Table 1).

The low-flow characteristics of the Wenatchee, Entiat, and Methow basins are different based on the low-flow indexes (Table 1). Although differences in index numbers are small, indicating a high degree of homogeneity between basins, there is an inverse north-south relationship between storage contribution to base flow of streams. The southerly Wenatchee basin has the highest water yield per mi^2, the most variability in stream low flow, the highest water storage extent (because of Lake Wenatchee) and contributes least stored water to base flow of streams. In the more arid Methow basin to the north, the reverse is generally true.

The principal influences on low stream flows are precipitation and the structure of the rock formation (Riggs 1972). The Wenatchee basin receives more precipitation than the Methow basin, but the geology of the latter favors storage and later release of precipitation that falls.

Available geologic data are inadequate for delineating formations and aquifers that have relatively good or poor water-yielding characteristics in the Methow Valley. The actual contribution to the stream depends not only on the storage characteristics of the aquifer, but also on the local hydraulic gradient and the degree of transmissivity between the stream and the ground water (Nassar 1973). In the Methow Valley the ground water aquifer of glacial and alluvial deposits is underlaid by impermeable granite. Evidently the Methow Basin above Winthrop acts as a snow melt reservoir for the Methow River, as a result of favorable hydraulic gradient and shallower underlay of bedrock downstream.

Discharge Estimation

Table 2 presents estimates of the Methow River flow, by month. We used three methods to estimate flows:

Method 1. Richardson (1976) estimated the mean monthly flow (MMF) of the Methow River with 1912 US Geological Survey (USGS) records at Winthrop. He adjusted the flows by comparing them with records at Twisp and by subtracting the estimated flows of the Chewack River.

Method 2. We used the 43-year period of records at the USGS gaging station on the Methow River at RM 40 (Table 1) as a base flow; we then subtracted the flow of the Twisp and Chewack rivers to estimate Methow River flows.

Table 2. Estimated average monthly discharge (cfs) for Methow River above Winthrop, Washington.

DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Ancillary discharges												
Twisp R. (USGS 1975-79)	75	87	119	72	67	94	239	697	908	433	114	66
Chewack R. (Richardson 1976)	123	129	111	63	52	72	258	1690	1600	354	107	67
Methow R.below Twisp (USGS 1919-62)	434	474	404	318	321	411	1562	4967	4906	1663	468	310
Methow R.above Chewack R. (USGS 1912)	191							3170	2120	655	328	238
Estimated discharges; irrigation diversion not included.												
Method* 1	238	295	254	209	199	256	1139	2880	2757	990	376	241
Method 2	236	258	174	183	202	245	1065	2580	2398	876	247	177
Method 3	237	277	214	196	201	251	1102	2730	2578	933	312	209
Average	237	277	214	196	201	251	1102	2730	2578	933	312	209

*See text.

Method 3. We regressed data from Method 2 with Richardson's (1976) Method 1 estimates (r = 0.99). Richardson in 1976 did not have the full benefit of the USGS gaging records on the Twisp River 1975 to 1979 (Table 2).

Chewack River Drainage

The Chewack River and its tributaries drain from the Canadian border to Winthrop. Although the Chewack River drains a larger area than does the Methow River to the west, it discharges considerably less water, because its basin receives less precipitation. Over the Methow River drainage above Winthrop, annual precipitation ranges from 15 to 80 in; over the Chewack River drainage, precipitation ranges from 15 to 35 inches.

Irrigation Diversions

Current information is scarce on irrigation diversion of the Chewack River. Principal diversions below Boulder Creek (RM 8.8) are listed below (Richardson 1976):

Diversion	Estimated Irrigated acres	Estimated August diversions (cfs)
Chewack Canal Co.	1,200	37
Skyline-Pierce LaRue Ditch Co.	260	19
Fulton Ditch Co.	400	18
Jones Ditch	100	16
TOTAL	1,960	90

Discharge measurements of these ditches were made on September 1, 1971, totaling 87.1 cfs (Walters and Nassar 1974) and presumably are the basis of the above estimates.

Richardson (1976) adjusted USGS discharge figures for 1921 to reflect long-term flow. He estimated discharges of 102 and 64 cfs for August and September, respectively. Considering a total diversion of 90 cfs, the flow downstream for most years in August and September would have been only 12 and 0 cfs, respectively. USGS randomly gages the Chewack River downstream of the major diversions (Table 3). Zero discharge was recorded only on August 28, 1985--a severe drought year. Twelve other determinations in August show a mean flow of 114 cfs below the diversions; 10 September determinations gave a mean of 65 cfs.

The data indicates that the Chewack River is not usually dewatered by irrigation withdrawal to the extent indicated by

Table 3. Instantaneous discharge measurements (USGS) taken below Boulder Creek (RM 8.8) and major irrigation diversion, Chewack River.

Date	Discharge (cfs)	Date	Discharge (cfs)
10/02/13	77	06/02/87	670
10/02/19	73	07/13/79	237
10/13/21	72	07/09/86	225
10/22/75	105	07/16/87	119
10/03/78	26	08/13/15	165
10/03/78	263	08/13/19	127
10/02/80	34	08/23/77	27
10/07/80	59	08/03/81	241
10/07/81	59	08/10/82	236
10/13/82	106	08/02/83	313
10/12/83	99	08/15/84	149
10/16/84	108	08/06/85	44
10/08/85	61	08/06/85	46
10/07/86	77	08/20/85	21
10/08/87	37	08/28/85	0
11/20/11	99	08/13/86	77
01/13/76	70	08/04/87	82
02/04/77	48	09/11/12	170
04/05/76	151	09/15/70	29
04/21/77	33	09/16/70	16
04/21/87	250	09/25/71	54
05/12/76	2060	09/01/85	13
05/20/87	1000	09/03/85	13
05/11/89	1200	09/11/85	65
06/01/78	151	09/30/85	37
06/07/79	503	09/03/86	27
06/03/80	1400	09/03/87	230

Richardson's (1976) estimates of average flow. Recharge by ground water could account for the discrepancy.

Discharge Estimation

Table 4 presents estimates of the Chewack River flow, by month. We used five methods to estimate flows:

Method 1. MMFs of the Chewack River were estimated by Richardson (1976) based on the USGS records of 1921. Above average run-off occurred in 1921. Richardson's flow estimates for the Chewack River below Boulder Creek were compared with discharge records for the Methow River at RM 40 and then adjusted to reflect the annual mean monthly run-off (1920-62).

Method 2. We used the 40-year record at the USGS gaging station on the Methow River at RM 40 as a base flow. We subtracted flows of major tributaries from the base flow, assumed the difference as Chewack River flow, and added irrigation withdrawals to reflect flow above the major diversions.

Method 3. Richardson's MMF estimates (Method 1) for the Chewack River were regressed against USGS discharges for Beaver and Andrews Creek (r = 0.99).

Method 4. Richardson's MMF estimates in Method 1 were regressed against the Methow River below Twisp (RM 6.7 and 1.0), (Table 1).

Method 5. MMF were estimated from 54 USGS miscellaneous discharge measurements below the major diversions on the Chewack River, with estimated irrigation diversion volumes added.

Conclusions

Flow estimates for the Methow and Chewack rivers are not based on current appraisals of water abstraction, but are instead based on past field data and discharge measurements. These data are used in this report to arrive at correct rather than precise judgments. It would have been desirable to evaluate the standard error of the discharge estimates, but the data did not permit valid comparisons. Obviously, most, if not all, of the methods used are interconnected to some degree. On the other hand, stream flow regimes are remarkably stable over time. This could be reflected in the small variation between estimates, as well as the reasonableness between predicted and actual values (Tables 3 and 4).

Table 4. Estimated average monthly discharge (cfs) for Chewack River below Boulder Creek.

DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Ancillary discharges												
Twisp R. (USGS 1975-79)	75	87	119	72	67	94	239	697	908	433	114	66
Methow R. above Winthrop (Table 2, this report)	237	277	214	196	201	251	1102	2730	2578	933	312	209
Methow R.below Twisp (USGS 1919-62)	434	474	404	318	321	411	1562	4967	4906	1663	468	310
Chewack R.near Winthrop (USGS 1921)	240	152	98	61	53	85	210	1990	2380	443	136	70
" 1912								1080	931	286	131	126
" 1913	94						230	989	1620	430	137	111
Irrigation	10						10	50	60	60	80	80
Estimated discharges												
Method* 1 (below Boulder Creek)	118	123	106	60	50	69	247	1620	1530	338	102	64
Method 2 (includes diversions)	132	110	71	50	53	66	231	1590	1480	359	122	115
Method 3 (includes diversions)	104	109	90	74	80	99	277	1663	1587	424	154	106
Method 4 (includes diversions)	103	106	83	54	55	85	477	1648	1638	561	184	132
Method 5 (includes diversions)	95	99	80	70	48	70	155	1470	1080	254	201	145
Average	110	109	86	62	57	78	277	1598	1463	387	153	112

*See text.

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APPENDIX D

STREAM CATALOG

by

James W. Mullan, Granville Rhodus, and Kenneth Williams

This appendix summarizes available information on the streams of this study. Water abstractions are not current appraisals, but past estimates used to arrive at correct rather than precise judgments. Similarly, we have used predicted flow values in lieu of actual discharge records when none existed (i.e., Lomax et al. 1981; Appendix C this report). More often sources of information were incisive, but largely acknowledged only in the attached bibliography. Commonly used water resource units of measure in all source material had been recorded in the English Gravitational System of measurement. We did not convert to the Standard International System (metric) so as to avoid errors and because the English units were easier to visualize and to track.

Information obtained from any source was evaluated before being used. Only the more pertinent data were generally included--primarily environmental features of the streams and upstream limits of anadromy. We have, however, included information on fish populations not found elsewhere, particularly the qualitative distribution of salmonid species in the Methow River drainage. While this results in some redundancy and unevenness, the biophysiographics provide a general idea of type of stream, hydrology, irrigation diversion, climate, geology, and other interrelated information. The intention is to provide a ready reference having interpretive value, stressing similarities, diversities, and themes as much as numbers.

Stream or river mile (RM) designations come from the River Mile Index (Hydrology Subcommittee 1964) or were measured on U.S. Geological Survey (USGS) topographic maps. Stream gradient and order were estimated from USGS topographic maps (scale 1:24,000 and 1:162,500). Mean basin elevation, in feet above mean sea level, was either taken from Williams and Pearson (1985) or computed from topographic maps by weighing the area between major contour lines. Elevations are given in feet above mean sea level as shown on contour maps. They are taken from the nearest contour lines unless specifically shown at a certain elevation.

Every attempt has been made to indicate the size of unmeasured headwater streams--length, watershed area, flows if available, and stream order: the smallest, unbranched, perennial tributaries, terminating at an outer point, are designated 1; the junction of two first-order streams produces a stream segment of order 2; the junction of two second-order streams produces a stream segment of order 3, etc. Only a sampling of order 1 streams is included in the tabulations, because most do not support fish. Likewise, most streams or stream reaches with a gradient over 4 to 5% do not provide passage for anadromous salmonids.

A number of abbreviations are used to conserve space:

ac	acre
anadr	anadromous salmonids
resid	resident salmonids
basin el	mean basin elevation, in feet above sea level
BT	bull trout
cfs	cubic feet per second of discharge
Ch	chinook salmon
Cr	creek
CT	cutthroat trout
div	diversion
drain	drainage
EBT	Eastern brook trout
el	elevation, in feet above mean sea level
GCFM	Grand Coulee Fish Maintenance Project (US Fish and Wildlife Service)
intermit	intermittent (non-perennial stream)
irri	irrigated (irrigation)
Jan	January; February = Feb, etc.
Lk	lake
mi^2	square miles of drainage
mi	linear mile
mm	fork length in millimeters
Mt	mountain(s)
no.	number
nr	near
ppt	precipitation
ord	order (stream)
QF	flood discharge (maximum recorded or in intervals of 2-25-50 years)
QL	low or minimum discharge
QML	mean low discharge
QM	mean annual discharge
R	river
Res	reservoir
RM	river mile
RT	rainbow trout
TUs	temperature units
trib(s)	tributary (ies) streams
USFS	U.S. Forest Service

USGS	U.S. Geological Survey gaging station identifying number
WDW	Washington Department of Wildlife
veg	vegetation
"	inches
'	feet

Wenatchee River Drainage

Wenatchee R (0.0-54.2 RM); Columbia R (RM 468); 1,327 mi^2 drain; basin el 3,890'; 75% forest; 60" ppt; 80% public land; QM 3376 cfs; QL 544 cfs; QF 34,600 cfs.

The Wenatchee basin lies on the east side of the Cascade Mts in north central Washington. It embraces a nearly oval area whose long axis extends northwest. The southwest rim of the oval follows the crest of the Cascade Mts and the Wenatchee Mts, and the northeast rim follows the Entiat Mts. The Wenatchee and Entiat mts are spurs of the Cascades with peaks higher (9,100' to 9,470') than the Cascade summits (4,060' to 8,500').

The river and its tributaries occupy deeply incised valleys, whose steep slopes rise to jagged peaks and ridges. The only appreciable tract of level land is near the mouth of the river (600' to 900'el). Most of the agricultural and urban development occurs here.

Most of the mountains are composed of granite gneiss, a hard durable rock, and bordered on the east by Swauk sandstone. Swauk sandstone consists of medium to fine-grained sandstones, generally massive, with interbedded shale and coarse conglomerate. These formations are only moderately compacted and weather quickly when exposed.

During the Ice Age, the area was invaded by glaciers moving from the north and west. Glaciers in the valley of the White and Little Wenatchee rivers scoured the basin now occupied by Lk Wenatchee. The Wenatchee R begins in Lk Wenatchee. About 15 mi below Lk Wenatchee, the Wenatchee R enters Tumwater Canyon, a narrow V-shaped trough about 9 mi long, carved by melt water from the ancient glaciers upstream. The gradient between the lake and the canyon is about 15'/mi; within the canyon, 68'/mi; and below the canyon 20'/mi.

Sizable deposits of alluvial--i.e., sand and gravel--materials for storing ground water can be identified at only a few locations. The city of Cashmere rests on alluvium washed down from the Mission Cr drain, and wells supply most of the water to the city. Where available, ground water is used as a source of domestic, industrial, and irri water. Large quantities can be obtained at only a few locations, usually where alluvial fans have been created at the mouths of streams, as in Mission Cr. Wells drilled into alluvium adjacent to watercourses, as in lower Icicle and Peshastin creeks, in all likelihood are merely tapping water in direct hydraulic continuity with the stream.

In its various advances and retreats, the glacier ice, 3,000' thick, laid down tremendous masses of alluvium. The original alluvium left below Lk Wenatchee was largely washed away by the melt water that carved Tumwater Canyon. Salmonids are attracted to upwelling of ground water for spawning. Although spawning gravel and water velocities appear suitable, only a small number of the Ch salmon that spawn in the Wenatchee R use the reach between Lk Wenatchee and Tumwater Canyon.

The estimated annual depletion in river discharge from irrigation corresponds to a reduction in stream flow of 298 cfs over a five-month period (DOE 1982). Assuming a consumptive use of 2.0 ac-ft/ac (Simons 1953), this div would result in a return flow, prorated over 12 months, of 50 cfs--26,000 ac irri x 1.4 ac-ft/ac = 36,400 ac-ft x 0.5042 = 18,353 cfs ÷ 365 days = 50 cfs--or a net reduction in stream flow during the irri season of 248 cfs. This amounts to 16%, 28%, and 21% of the mean monthly flow for Aug, Sep, and Oct as measured at RM 21.5 (USGS), below which most irri div occurs. At RM 7.0, the irri return flow of 50 cfs would make up only 3%, 5%, and 5% of the mean monthly flow for Aug, Sep, and Oct.

<u>Mission Cr (0.0-9.4 RM)</u>; Wenatchee R (RM 10.5); 3rd ord; 82 mi^2 drain; 78% USFS, 17% logged; 4 lakes (4 ac):

RM 0.0 mouth, 766' el in the city of Cashmere.

RM 1.5 USGS #4620, 81 mi^2 drain, 3,100' basin el, 80% forest, 21" ppt, 3.5% grad, QF 560 cfs.

RM 6.9 Sand Cr, 6 mi, 2nd ord, 8% grad, 3.0 mi (2.2 ac) anadr, USGS #4615, 19 mi^2 drain, 95% forest, 24" ppt, 3,060' basin el, 3.5% grad, QF 325 cfs, QL < 1 cfs.

RM 7.0 USGS #4614, 11.1 mi, 2nd ord, 6% grad, 40 mi^2 drain, 3,400' basin el, 88% forest, 25" ppt, QM 13 cfs, QL 1-2 cfs, QF 226 cfs.

RM 9.4 East Fork, 7.4 mi, 2nd ord, 9% grad, USGS #4611, 15 mi^2 drain, 3,530' basin el, 90% forest, 25" ppt, QF 114 cfs, QL 1 cfs.

Mission Cr represents the worse case for human influence on a subbasin of the Wenatchee R. The watershed amounts to 6% of the area of the Wenatchee R drain, but it contributes less than 1% of the mainstem flow. Mission Cr, however, is one of two major sources that deliver sediments to the Wenatchee R (the other is Chumstick Cr). Geologic and soil conditions in the watershed are extremely unstable because the predominant rock formation is Swauk sandstone.

The effects of overgrazing cannot be separated from logging, road-building, and other land disturbances associated with early 1900 settlement in the Mission Cr watershed. Doubtless, however, grazing was a factor in destabilizing a sensitive watershed. In 1931, 7,200 sheep grazed the watershed, and five times this number were trailed through the area (Ciolek 1975).

The first recorded flood to cause damage to the town of Cashmere at the mouth of Mission Cr occurred in 1933. The 1933 flood damage was the result of deplorable land use (SCS 1938). Mission Cr was then channelized. Between 1927 and 1946, all but 11,000 ac of the watershed was acquired by the Wenatchee National Forest. In 1953 the watershed was chosen as one of 50 in the United States to demonstrate watershed restoration. The program included construction of trail (28 mi) for fire protection; installation of stock fence (10 mi); channel clearing (10 mi); stream bank stabilization (6 mi); roadside erosion control (3 mi); contour furrowing and revegetation (400 ac); 2 fire protection ponds; and closure of 71% of the watershed to grazing (Ciolek 1975).

Irrigation div in the lower 6 mi of the creek has been severe. The numerous shallow riffles and small pools, nevertheless, contain an abundance of small RT--e.g., 102 collected 8/15/86, 37-71 mm--which in all likelihood are steelhead, based on observations of spawning adults. Habitat available to anadr salmonids amounts to about 15 ac; another 8 ac in headwaters is occupied by resid salmonids. But what of the yellowish turbidity that occasionally pours out of Mission Cr? In all probability, this deleterious influence on fish habitat results from natural causes now as discussed elsewhere in the main report. The principal trib was called Sand Cr by pioneers for good reason.

Mission Cr today is not considered an important fish producer. Historically, it may have had value for coho salmon (Ciolek 1975). Assuredly, however, it has influenced fish habitat in the lower Wenatchee R in the past. There have been no major wildfires in the drain since 1900; the many lightning fires have burned less than 3 ac a year. A major wildfire now would be a catastrophe similar to those in the Entiat R in recent years, which caused massive sedimentation of stream channels.

Peshastin Cr (0.0-15.4 RM); Wenatchee R (RM 17.6); 3rd ord; 2.6% grad; 133 mi^2 drain; 82% USFS (29% wilderness); 18% logged; 3 lakes (26 ac):

RM 0.0 mouth, QM 117, QL 0-5 cfs (Lomax et al 1981), QM 102 cfs.

RM 4.7 QM 102 cfs, QL 5 cfs.

RM 4.8 Mill Cr, 4.0 mi, 1st ord, 15% grad, 5 mi^2, QL $\geq$1 cfs.

RM 6.0 Camas Cr, 2.5 mi, 1st ord, 7% grad, 9 mi^2, QL $\geq$1 cfs.

RM 7.3 Allen Cr, 2,9 mi, 1st ord, 24% grad, 2 mi^2.

RM 8.4 Hansel Cr, 3.0 mi, 2nd ord, 22 grad, 4 mi^2, QL <1 cfs.

RM 9.0 Ingalls Cr, 16.1 mi, 2nd ord, 5 % grad, 4.7 mi (13.6 ac) anadr, 37 mi^2, QL 24 cfs, Ingalls Lk 6,463'.

RM 13.7 Tronsen Cr, 9.4 mi, 2nd ord, 3% grad, 0.9 mi (0.7 ac) anadr, 16 mi^2.

RM 14.2 Shaser Cr, 2.5 mi, 3rd ord, 7% grad, 9 mi^2, QL 1 cfs.

RM 15.4 Scotty Cr, 2.5 mi, 2nd ord,, 7% grad, 7 mi^2, QL >1 cfs.

Habitat available to anadr salmonids amounts to about 58 ac. About 20 ac in the lower reaches of Peshastin Cr are dewatered by irri div. There is a minimum of 30 ac for resid salmonids in headwaters.

Elevations in the Peshastin Cr basin range from 9,470' to 967' at the mouth of the creek. It is a high gradient, boulder-cobble stream more suited to steelhead than Ch salmon. Small numbers of spring Ch salmon spawn in the stream, availing themselves of patches of gravel and limited large holding pools. By contrast, there is a large number of small pools and riffles in a mile of stream for small salmonids. In addition to excellent cover (Appendix B, Diversity Index) for small salmonids, there is a comparative abundance of macro-invertebrates for food.

Channel disruption and sedimentation occurred from placer mining, 1860 to 1940. There is urban and agricultural encroachment. The Blewett Pass highway runs along much of the creek with bridges, revetments, and some channelization. In this steep, boulder-filled channel, however, stair-stepping, rather than meandering, creates the excellent salmonid habitat. Because of the tremendous power of Peshastin Cr at flood and the bedrock-boulder substrate, the stream quickly reverts to stair- stepping following physical disturbances. By far the most damage to fish habitat has been caused by irri div in the lower 4.8 mi of the creek.

Chumstick Cr (0.0-13 RM); Wenatchee R (RM 23.5); 2.2% grad; 3rd ord; 76 mi^2:

RM 0.0 mouth, 1,068' el.

RM 1.9 Eagle Cr, 10.3 mi, 3rd ord, 4% grad, 1.0 mi (0.5 ac) anadr, QL 0-3 cfs, 28 mi^2 drain.

RM 2.2 Freund Cr, 2.5 mi, 2nd ord, 15% grad.

RM 13.0 headwaters, 2,400' el.

The entire stream area of 10 ac accessible to anadr salmonids has been degraded by agricultural and urban encroachment. Chumstick Cr joins the Wenatchee R 2.1 mi downstream of the confluence of Icicle Cr and presents sharp contrast to the latter. The average of run-off/mi^2 of drain is 3.0 cfs for Icicle Cr, vs 0.8 cfs for Chumstick. The Icicle drainage bedrock is stable granite vs unstable Swauk sandstone in Chumstick. Icicle's mean basin el is 5,260', vs under 2,000' for Chumstick. The Icicle drainage is lightly populated and mostly in public ownership while the Chumstick is not.

Bryant and Parkhurst (1950) concluded that Chumstick Cr and its major trib, Eagle Cr, were of little value to anadromous fish because of irri div. They reported that a few steelhead and Ch salmon purportedly spawned in the streams, with the upper reaches of Eagle Cr supporting resident trout. Since the survey of 1935 not much seems to have changed, including the brushy banks, sandy substrate, and large numbers of pools and riffles in a mile of channel (Appendix B, Diversity Index).

Chumstick Cr's contribution of water to the Wenatchee R during periods of low flow is negligible. In its pristine state it may have had average and low flows of 30 cfs and 10 cfs at its mouth (Lomax et al. 1981). With such flows its contribution to coho salmon runs in the Wenatchee R could have been appreciable, considering habitat preferences of coho.

Icicle Cr (0.0-31.8 RM); Wenatchee R (RM 25.6)(20% contrib to flow); 4th ord; 211 mi^2; 87% USFS (74% wilderness); 1% logged; 14 glaciers (420 ac); 102 lakes (1,363 ac):

RM 0.0 mouth, 1,102' el, in town of Leavenworth, WA.

RM 2.8 Leavenworth National Fish Hatchery and barrier dam.

RM 5.4 Snow Cr, 4.0 mi, 2nd ord, 19% grad, 11 mi^2 drain, QL 4-5 cfs.

RM 5.7 Dam and Icicle Diversion Canal.

RM 5.8 USGS 4580, 193 mi^2 drain, basin el 5,260', 85% forest, 88" ppt, QM 625 cfs, QL 60, QF 11,600 cfs.

RM 7.9 Rat Cr, 3.5 mi, 2nd ord, 29% grad, 31 mi^2.

RM 9.0 Eight mile Cr, 3.5 mi, 3rd ord, 11% grad, 31 mi^2; QM 73 cfs, QL 12 cfs.

RM 12.8 Victoria Cr, 2.0 mi, 2nd ord, 31% grad.

RM 14.5 Ida Cr, 2.0 mi, 1st ord, 39% grad, QL <1 cfs.

RM 15.5 Doctor Cr, 2.5 mi, 1st ord, 33% grad, QL 0 cfs.

RM 16.8 Trout Cr, 3.5 mi, 2nd ord, 6% grad, QL 1 cfs.

RM 17.2 Jack Cr, 11.0 mi, 3rd ord, 5% grad, 29 mi^2, QM 82 cfs, QL 13 cfs.

RM 17.3 Black Pine Cr, 3.5 mi, 1st ord, 17% grad, QL <1 cfs.

RM 21.6 French Cr, 6.4 mi, 3rd ord, 6% grad, 25 mi^2, QM 90 cfs, QL 14 cfs.

RM 22.2 Spanish Camp Cr, 2.0 mi, 2nd ord, 27% grad.

RM 23.4 Frosty Cr, 2.0 mi, 2nd ord, 23% grad.

RM 24.0 historical barrier to anadr, QM 145 cfs, QL 23 cfs (Lomax et al 1981).

RM 25.0 Doughgod Cr, 3.0 mi, 2nd ord, 14% grad.

RM 27.4 Leland Cr, 4.4 mi, 3rd ord, 7% grad, 14 mi^2.

RM 29.0 Trapper Cr, 3.6 mi, 2nd ord, 12% grad.

RM 31.8 Outlet Josephine Lk, 4,681' el.

Icicle Cr is a boulder-strewn, torrential stream except below RM 3.8. Mean, min, and max flows are 625, 60, and 11,600 cfs (USGS RM 5.8). Several diversions occur between RM 5.8 and RM 3.8, downstream from which the gradient is low and the channel is depositional and meandering. Diversions are for irri (130 cfs), water supply for Leavenworth, and Leavenworth National Fish Hatchery (LNFH)(RM 2.8).

LNFH was built in 1939-40, and the hatchery dam became a barrier to anadromous fish. Historically, anadr salmonids had access to RM 24.0, or 170 ac rather than the 32 ac now available downstream from LNFH. To assure cold water for the LNFH in dry summers, a supplementary water supply (12,000 ac-ft) was developed in Upper Snow Lk, about 7 mi from the LNFH and 1 mi above it in elevation. Without the releases (50 cfs) from Upper Snow Lk, the downstream reaches of Icicle Cr would go dry in some years. Irrigation div removes 48%, 79%, and 54% of the mean Aug, Sep, and Oct flows.

The numerous tributaries to Icicle Cr above LNFH literally fall off the mountains; it is doubtful they were ever important as nursery areas for anadr salmonids. The high basin relief of the drain has other effects as well. About 21% of the flow in a hot, dry summer is estimated to originate from glacier melt. These glaciers have the highest mean altitude (8,227') of any glaciers in the North Cascades. There is a valley relief change of 6,900 ft over a horizontal distance of less than 3 mi at LNFH. Nevertheless, below the downstream divs, summer temperatures of Icicle Cr exceed 21° C on many days.

In its natural state, Icicle Cr was not only very cold, as the name implies, but unproductive (45 micromhos conductance, 20 mg/l total alkalinity, 7.3 pH). The numerous alpine lakes in the drain are even more impoverished (10 micromhos conductance, 4 mg/l total alkalinity, 6.7 pH).

Resident fishes include RT, CT, BT and EBT, mountain whitefish, sculpins, dace, and suckers. The abundance of bridgelip suckers spawning below LNFH suggests that they could originate as far downstream as Rock Island Res on the Columbia R.

<u>Chiwaukum Cr (0.0-11.5 RM)</u>; Wenatchee R (RM 35.9); 3rd ord; 5% grad; 50 mi^2; mostly USFS; 1 glacier (25 ac); 16 lakes; QM 142 cfs; QL 23 cfs (Lomax et al. 1981):

RM 0.0 mouth, 1,666' el.

RM 0.6 Skinney Cr, 3.0 mi, 1st ord, 5% grad, QL 1-2 cfs.

RM 1.8 Battle Canyon Cr, 2nd ord, 23% grad.

RM 4.3 limits of anadromy (falls).

RM 6.2 South Fk, 3.0 mi, 2nd ord, 8% grad, 18 mi^2 drain.

RM 7.9 Glacier Cr, 2.5 mi, 1st ord, 22% grad.

RM 11.5 Larch Lk, 6,078' el.

This is a high gradient, boulder stream more suitable to steelhead than Ch salmon, although a few Ch evidently do spawn in the stream. Late summer habitat available to salmon and steelhead amounts to 15 ac. There is a minimum of 120 ac of stream above the barrier to anadr salmonids.

A hatchery was constructed on Chiwaukum Cr in 1899. It was closed in 1904 due to extreme cold weather, heavy snow, isolated location, freshets, and purportedly "because it was too far upriver to secure Ch salmon [for brood stock]." The State Fish Commissioners did report taking an "inferior run" of coho, but it is unclear whether these came from the Wenatchee R or Chiwaukum Cr. There are no diversions of water.

Beaver Cr (0.0-5.8 RM); Wenatchee R (RM 46.5); 2nd ord; 0.6 ac anadr; 10 mi^2; QL 1-2 cfs.

This is an 8' to 9' wide stream at its confluence with the Wenatchee R. Bryant and Parkhurst (1950) reported (survey 7/13/37): "It is 5 mi long, and quite brushy. It had a flow of 4 cfs, but is largely used for local irri and becomes almost dry later in the summer. It is of no value to salmon."

We collected 47 Ch (64-107 mm), 33 RT (106-187 mm), and 3 EBT (65-70 mm) at the confluence (300') with the Wenatchee R 9/24/84. The Ch and RT observed probably had merely moved in from the Wenatchee R to rear. Although the gradient remains low (1.6%) for 2.2 mi above the mouth, several beaver dams are barriers to upstream migration beginning at about RM 0.5. We also found the stream brushy with a flow of about 4 cfs.

Chiwawa R (0.0-36.0 RM); Wenatchee R (RM 48.4) (15% contrib to flow); 4th ord; 182 mi^2; 96% USFS (32% wilderness); 6 lakes (127 ac); 5 glaciers (173 ac):

RM 0.0 1,850' el.

RM 1.9 Clear Cr, 1.6 mi, 2nd ord, 3% grad.

RM 3.6 irri div 12 cfs (1,400 ac irri nr Plain).

RM 4.0 Deep Cr, 2.2 mi, 2nd ord, 26% grad, QL <1 cfs.

RM 5.8 Goose Cr, 1.4 mi, 2nd ord, 22% grad, QL <1 cfs.

RM 6.3 USGS 4565, 172 mi^2 drain, basin el 4,440', 87% forest, 78" ppt, Jan air 16° F, QM 488 cfs, QML 264 cfs, QL 64 cfs, QF 5,580 cfs.

RM 6.9 Alder Cr, 5.9 mi, 2nd ord, 12% grad, 1.0 mi (1.0 ac) anadr, 7 mi^2, QL 1-2 cfs.

RM 9.2 Big Meadow Cr, 7.1 mi, 2nd ord, 2% grad, 0.1 mi (0.2 ac) anadr, 17 mi^2, QL 5 cfs.

RM 9.7 Twin Cr, 3.8 mi, 1st ord, 10% grad.

RM 11.7 Grouse Cr, 0.8 mi, 1st ord, 10% grad.

RM 12.6 Brush Cr, 2.9 mi, 2nd ord, 5% grad, 0.1 mi (0.2 ac) anadr, QL <1 cfs.

RM 13.8 Chikamin Cr, 7.4 mi, 3rd ord, 5% grad, 3.7 mi (6.2 ac) anadr, 21 mi^2, QM 43 cfs, QL 7 cfs.

RM 21.3 Rock Cr, 11.7 mi,, 3rd ord, 5% grad, 2.5 mi (7.1 ac) anadr, 21 mi^2, QL 11 cfs.

RM 30.2 Phelps Cr, 8.0 mi, 3rd ord, 7% grad, 0.8 mi (2.2 ac) anadr, 16 mi^2, basin el 5,823', QM (Aug-Mar) 19 cfs, QL (Sep) 12 cfs, QL (Oct-Mar) 13 cfs, USGS 4560.

RM 30.5 Chiwawa R, QM 98 cfs, QL 20 cfs.

RM 33.0 Buck Cr, 3.3 mi, 2nd ord, 9% grad, 0.5 (1.0 ac) anadr.

RM 33.1 Barrier to anadromy (falls and cascades).

RM 37.0 Terminus 5,500' el.

The Chiwawa Valley is U-shaped bounded by steep mountains. Elevations range from 9,077' to 1,850'. Soils are shallow and unstable except in the valley bottom (4-10'). Because the storage capacity of the watershed is limited, rain and snow melt cause the stream to rise rapidly. Nevertheless, the flow is well sustained during the summer and fall on account of the high altitude of snow fields and glaciers.

The steep headwater tributaries are dominated by CT. The five high lakes also contain CT as a result of stocking, although the largest, Schaefer Lk, contained EBT before their removal in 1968. The headwater may contain more macro-invertebrates than the main river (Holtby and Tiedmann 1973).

The river from RM 30 to RM 14 meanders through its widest but limited flood plain. Gradient is less than 0.32% and substrate glacial outwash. Some 30 log jams are in the reach and many deep pools (to 15')(Bryant and Parkhurst 1950). Spawning gravel exceeds 100,000 yd^2. As many as 600 spring Ch salmon redds have been noted in the reach since re-introduction by the GCFM Project. Naturally propagated RT were not found above RM 21.5 in our sampling and appeared to be replaced by BT. The upper Chiwawa R is much colder (annual TUs 1,771; mean Jul, Aug, Sep temp 9.4° C) than the lower river (annual TUs 2,447; mean Jul, Aug, Sep temp 11.8° C). Gradient in the lower river is about double that of the upper river, velocities are much higher, and the dominant substrate is cobble and boulders.

Essentially, the Chiwawa R is pristine. There was limited hard rock mining in the watershed with limited or no impact to the stream. Intensive logging has been limited (15% of watershed) and carefully controlled except possibly on the small private in-holdings. Irrigation div, affecting the lower 3.6 mi of the river, has amounted to only 5%, 7%, and 7% of the mean monthly flow for Aug, Sep, and Oct. Minimum winter flows are as low or lower than in summer with irri div.

Spawning and rearing area available to spring Ch salmon amounts to 40.2 mi and 195 ac. Spawning and rearing habitat for steelhead is about 28.8 mi and 158 ac.

<u>Nason Cr (0.0-26.5)</u>; Wenatchee R (RM 53.6) (18% contrib to flow); 3rd ord, 108 mi^2; 78% USFS (28% wilderness); 7% logged; 16 lakes (159 ac):

RM 0.0	mouth, 1,869' el, QM 314 cfs, QL 48 cfs.
RM 5.1	Kahler Cr, 3.5 mi, 1st ord, 11% grad, QL <1 cfs.
RM 9.3	Roaring Cr, 5.2 mi, 2nd ord, 11% grad, 0.8 mi (1.0 ac) anadr, 7 mi^2.
RM 10.1	Gill Cr, 3.5 mi, 1st ord, 18% grad.
RM 14.4	2,320' el, QM 102 cfs, QL 41 cfs.
RM 15.4	Whitepine Cr, 9.4 mi, 3rd ord, 5% grad, 1.5 mi (5.5 ac) anadr, QM 87 cfs, QL <1 cfs.
RM 16.8	Gaynor Falls, barrier to anadr.
RM 20.5	Mill Cr, 10.2 mi, 2nd ord, 3% grad.
RM 26.5	Outlet Lk Valhalla, 4,830' el.

Nason Cr and Little Wenatchee R drain the lowest part of the Cascade Mts within the Wenatchee R drain. Precipitation at their sources is therefore less than that farther north or south. Because the snow melts earlier than in drainages at higher elevations, there is a low min flow during Aug and Sep. There are no irri diversions.

From about RM 5 to RM 10 the stream meanders in a fairly extensive flood plain, with braiding and eroded banks. Bryant and Parkhurst (1950) estimated 100,000 yd^2 of spawning gravel. It is unclear whether these conditions are natural. Much of the private land lies between RM 5 and 10. A railroad runs along the stream here with rock rip-rap extending into the channel. Much of the railroad right-of-way has been repeatedly burned by fires set by locomotives.

Between 1939 and 1944 the GCFM Project maintained a weir just above the mouth and transplanted adult Ch salmon and steelhead from the Columbia R into Nason Cr. These species are now dominant. Purportedly, coho salmon were once common as well (Bryant and Parkhurst 1950).

Average late summer spawning and rearing habitat available to salmon and steelhead in the Nason Cr drain amounts to about 106 ac; another 52 ac of streams above natural barriers support resid salmonids.

Lake Wenatchee, source of Wenatchee R at RM 54.2, 2,445 ac; mean depth 180 ft; transparency 20.7'; morphoedaphic index 0.17.

Lk Wenatchee is an ultra-oligotrophic, glacial lake that acts as an equalizing aquifer for the Wenatchee R, allowing more of the annual run-off to occur in the low-flow period, Aug through Mar. It is also the only lake accessible to anadr salmonids in the three study drainages. It rears the progeny of an average escapement of 24,000 adult sockeye. Inasmuch as there is more rearing area for anadr salmonids in this one lake (2,445 ac) than in the streams of the entire Wenatchee system (1,808 ac), we explored its potential for rearing Ch salmon. Based on the following observations, we concluded that there is little or no Ch salmon rearing in Lk Wenatchee.

Using gill nets (0.75 to 2" mesh), Allen and Meekin (1973) fished in Lk Wenatchee on eight days during May - Oct 1972. The nets measured 100 x 12' horizontally, and 200 x 6' vertically. They caught 43 sockeye salmon (84-158 mm), 2 Ch salmon (102-107 mm), 9 BT (250-375 mm), 24 squawfish (170-425 mm), and 1 redside shiner (95 mm). The Ch salmon juveniles came from a net site in the White R inlet area in May and likely were smolts from the river. Fulton (1950) did similar sampling 1949 to 1950 and captured about three times the number of fish, but took no Ch salmon. No juvenile Ch salmon were found in 208 BT and 447 squawfish stomachs examined from Lk Wenatchee in three studies reviewed by Mullan (1986), though juvenile sockeye salmon were commonly found ingested.

A boat survey of the Ch salmon rearing possibilities was begun at the upper end (Cougar Inn) of Lk Wenatchee on 23 Jul 1987. The lake was calm and the sun was shining, providing conditions ideal for observing fish in shallow water. Virtually no fish were sighted in the sandy lip area, which varies in width from 20 to several hundred ft, despite water level back into brush. At best we sighted a half-dozen small fish, except for 50 to 60 redside shiners and perhaps 20-40 salmonids, 50-100 mm, at a large beaver brush dump along the drop-off. The salmonids could have been Ch, although redside shiners and Ch are easily confused aerially (Griffith 1987).

We cruised the White R inlet but could see nothing because of glacial turbidity. Littoral areas between the White and Little

Wenatchee river inlets and beyond were similar to that previously described. A few large squawfish were observed as well as pelagic schools of sockeye salmon fry.

Cruising the rocky west shore for several hundred yds revealed only a few juvenile salmonids in the vicinity of trib inlets, plus a school (200-300) of some cyprinid fry. Pelagic-feeding sockeye fry were abundant in offshore areas.

We then crossed the lake and transversed the east shore back to starting point (Cougar Inn). The shoreline was more precipitous and rocky and built up with docks. This shoreline seemed devoid of fish life, although the wind came up about halfway back and the resulting wave action distorted viewing.

A snorkel survey was conducted near the Lk Wenatchee outlet on 20 August 1987 (Griffith 1987). Water surface temperature was 13.9° C. Underwater visibility was about 10'.

A total of 190 yds of shoreline and some deeper water was snorkeled to where the outlet becomes river; 15 suckers, 4 mountain whitefish, and 1 squawfish were observed. These fish were all adults. One hundred forty-two yds of the outlet were snorkeled; 20 whitefish adults and 5 parr were observed in the first 32 yds. After that more whitefish were observed but not counted.

Aerially, the shoreline looked like it might have possibilities as Ch rearing habitat, but underwater there was little cover.

Another 100 yds of shoreline was snorkeled in the southwest portion of the lake. Only two large suckers were observed. Again, lack of cover suggested that this area was poor habitat for small salmonids.

A snorkel survey was also conducted in the impoundment created by Tumwater Dam on the Wenatchee R the same day. Water temperature was 16.1° C, the sun was shining and underwater visibility was 10'. Traverse of about 300 yds of shoreline and some deeper water areas revealed an abundance of redside shiners, Ch salmon (perhaps 50/100 m^2), and RT juveniles, along with adult mountain whitefish. In contrast to Lk Wenatchee, the substrate was festooned with logs from the days of river log-driving, boulders, and aquatic veg. The juvenile salmon and steelhead were scattered throughout this cover.

<u>White R (0.0-26.7 RM)</u>; Wenatchee R (RM 58.6)(25% contrib); 4th ord; 150 mi^2 drain; 97% USFS (61% wilderness); 6% logged; 13 glaciers (1,928 ac); 14 lakes:

RM 0.0   mouth, 1,872' el.

RM 6.4 USGS 4540, basin el 4,590', 51% forest, 108" ppt (310"snow), Jan temp 17° F, QM 816 cfs, QL (Sep) 341 cfs, QL (Jan) 83 cfs.

RM 9.5 Canyon Cr, 3.5 mi, 2nd ord, 17% grad, QL 1 cfs.

RM 11.0 N. Fk (Napeequa R), 16.4 mi, 3rd ord, 5% grad, 3.3 mi (21.0 ac) anadr, 40 mi^2, QM 191 cfs, QL 34 cfs.

RM 13.1 Cougar Cr, 6.8 mi, 3rd ord, 8.5% grad, 1.0 mi (3.1 ac) anadr, 19 mi^2, QM 32 cfs, QL 12 cfs.

RM 14.3 barrier to anadromy (falls).

RM 17.8 Indian Cr, 8.4 mi, 2nd ord, 5% grad, 21 mi^2, QM 78 cfs, QL 14 cfs.

RM 19.2 Boulder Cr, 2.5 mi, 1st ord, 24% grad.

RM 21.7 Thunder Cr, 3.5 mi, 2nd ord, 23% grad.

RM 23.2 Amber Cr, 2.5 mi, 2nd ord, 27% grad.

RM 24.7 Lightning Cr, 2.5 mi, 2nd ord, 27% grad.

RM 26.7 Foam Cr, 1.5 mi, 1st ord, 28% grad, 5,800' el.

Late summer habitat available to salmon and steelhead in the White R drain amounts to about 115 ac; another 71 ac upstream supports CT. The habitat is pristine.

The White R enters Lk Wenatchee through a swamp, and the stream bed is covered with a layer of glacial silt. In the next 8 mi to the confluence with the N Fk (Napeequa), the gradient gradually increases and there are extensive spawning areas suited to sockeye salmon. Above the N Fk, the spawning gravel is larger and the gradient steeper. Ch salmon primarily spawn here to the confluence of Cougar Cr. More than 27% of the substrate contains suitable spawning gravel (Bryant and Parkhurst 1950).

During spring and early summer, and for short periods during fall, the river becomes turbid (milky) with glacial silt (flour), hence the name White R. Most of the glacial flour comes by way of the North Fork. Sockeye and some Ch spawn in the lower 3.3 mi of the N Fk. Aside from being the major sockeye spawning area in the Wenatchee R system, the White R subsystem is a major spawning area for Lk Wenatchee kokanee salmon and BT.

The White R drains a higher part of the Cascade Mts, is farther north, and receives more precipitation than the paralleling Little Wenatchee R. The snow and glaciers melt slowly, for they are at a higher altitude, so that the flow is well-sustained throughout the summer and fall. There are no irri diversions.

Little Wenatchee R (0.0-22.7 RM); Wenatchee R (RM 58.6)(15% contrib; 3rd ord; 100 mi^2 drain; 97% USFS (61% wilderness); 7% logged; 13 lakes (232 ac):

RM 0.0 mouth, 1,872' el, QM 453 cfs, QL 60 cfs.

RM 4.0 Lost Cr, 2 mi, 2nd ord, 29% grad, Lost Lk 4,930' el.

RM 7.3 Cedar Cr, 0.5 mi, 1st ord, 24% grad.

RM 7.8 barrier to anadr (cascades and falls).

RM 7.9 Rainy Cr, 7.0 mi, 3rd ord, 7% grad, 17 mi^2 drain, QM 65 cfs QL 18 cfs.

RM 12.5 Lake Cr, 6.4 mi, 2nd ord, 7% grad, QL 17 cfs, 17 mi^2 drain, Heather Lk 3,953' el.

RM 12.5 L. Wenatchee R, QM 162 cfs, QL 65 cfs.

RM 15.8 Fish Cr, 4.4 mi, 2nd ord, 5% grad, QL 10 cfs.

RM 16.5 Caddy Cr, 4.0 mi, 2nd ord, 5% grad, QL 9 cfs.

RM 22.7 Terminus, 5,000' el.

Little Wenatchee R and Nason Cr drain the lowest part of the Cascades within the Wenatchee R drain. Because there is less snow and it melts earlier than in drainages at higher elevations, there is a low minimum flow during Aug and Sep. There are no irri diversions.

The Little Wenatchee R flows into Lk Wenatchee through a swamp. Here the gradient is slight and the channel sedimented with sand. Upstream the gradient gradually increases. Deep sluggish pools alternate with shallow riffles consisting mostly of pea-size gravel. The channel is meandering and braided, with log jams and eroded banks common. It isn't until just below the cascades blocking anadromous salmon that the channel becomes steep and rocky like most other streams in the Cascade mountains.

Late-summer habitat available to salmon and steelhead in the Little Wenatchee R amounts to about 52 ac. Another 80 ac above the anadromous zone supports primarily CT. CT and RT are uncommon below the barrier to salmon and steelhead. Sockeye and kokanee salmon primarily spawn in the lower reaches, and Ch salmon in the upper reaches of the 7.8 mi of river available to them.

Aside from log-jam clearance to "enhance" salmon passage, the fish habitat is in pristine condition. In 1931 irrigators petitioned the U.S. Forest Service for protection from logging and grazing in the Little Wenatchee R watershed. Putnam (1936) demonstrated that the marked diminution in summer flow beginning in 1922 occurred not as a result of impaired ground storage or run-off resulting from fire, overgrazing, or logging; but from decreases in precipitation. He wrote as follows:

> When the Forest Service took charge of the Little Wenatchee watershed in 1908, there were about 3,200 acres of burns. These burns contain the only denuded areas and essentially all materially accelerated erosion. . . . Since 1908 the area burned over in the Little Wenatchee watershed has been held at 740 acres. This is about 1% of the total area of the watershed [0.04% annually], and could not be expected even at worst to have perceptible effects on streamflow.
>
> Accelerated erosion is highly localized because the coarse soils of the watershed absorb water very rapidly even when barren, and large volumes of water are ordinarily deposited on the soil slowly by melting snow instead of rapidly by torrential rains. Because the soils are very shallow and incapable of supporting true water tables except in the valley fills or perhaps in pockets on side slopes in localized areas, soil storage capacity is very limited. Whenever (as during spring thaws) large volumes of water are deposited on the soil the storage capacity of the watershed is overburdened, and the rivers rise very rapidly, but the run-off takes place not over the surface but along the steeply sloping bedrock beneath the soil. This subsurface run-off is facilitated by the soil's extreme permeability.
>
> Domestic stock [3,400 sheep for two months] under regulation have overgrazed 205 [of 6,890] acres or less than 1% of the total area of the watershed. These areas are similar to the recently burned areas in being too small [and widely dispersed at high elevations] to affect streamflow perceptibly under any conditions.
>
> Upon the average, range areas erosion is not accelerated. Even in burns at low elevation (below about 3,500 feet), no damage is done by grazing because weeds, brush, and reproduction come in rapidly after fire and resume control of the area. The conditions most conducive to accelerated erosion are found along sheep driveways [these unique effects of sheep grazing were confirmed in Idaho by Platts (1981)] in old burns at high elevation (above about 3,500 feet) where the fires were apparently unusually hot and destructive and where

growing conditions are unfavorable. In such places grazing tends to delay recovery, but the original and by far the most damage was caused by fire.

At the time of Putnam's report, logging had been limited to the huge red cedar in the floodplain of the Little Wenatchee R during the early 1900s (USFS 1972). Logging resumed in 1941 (57 ac) but did not increase substantially until 1952. Between 1952 and 1979, 4,113 ac were logged. Area impacted amounted to 6.5% of the drain or 0.002% annually.

Entiat River Drainage

<u>Entiat R (0.0-53.4 RM)</u>; Columbia R (RM 484); 419 mi^2 drain; 16 lakes (158 ac), basin el 4,390', 92% forest, 45" ppt; QM 509 cfs; QL 266 cfs; QF 10,800 cfs.

The Entiat R basin is less than one-third as large as the Wenatchee basin, which it adjoins on the northeast. The Entiat Mts form its southwestern boundary and the Chelan Mts its northeastern boundary, with peaks to 9,249' el. The Entiat basin does not reach the Cascade Range crest and therefore does not receive as much precipitation as adjoining basins.

Topography is extremely steep and dissected. Soils are generally highly erodable and unstable (USDA 1979). Vegetation ranges from semi-arid steppe in the southeast, through temperate forest, to alpine meadows in the northwest. The arctic-alpine zone is small and confined to barren summits of higher peaks. Most of the basin (87%) is in public ownership, primarily national forest.

During the last ice age a valley glacier extended downstream to about RM 15.1. Above the resulting terminal moraine, the valley is the characteristic glacial U-shape. Below the moraine, the valley and tributaries are V-shape. Gradient in its lower course is uniform, about 55 ft (1%) to the mile, and the stream lacks pools.

The upper Entiat R descends in a series of steps carved by glaciers. The glaciers' greatest erosive force was exerted between RM 29, the upstream limits to anadromy, and RM 15. The gradient drops from an average 2.3% to less than 0.3%; the river begins to meander on its broadest floodplain; and the basin acts as a catchment for sediments brought down from the upper watershed. These glacial deposits constitute the limited groundwater aquifer. Most Ch salmon spawn in this reach.

The Entiat R begins as melt water from 11 glaciers (346 ac) and semi-permanent snowfields at the head of the valley. Perennial tributaries include the N Fk, Mad R, Lake, Stormy, Preston, Ice, Snow Brushy, and Mud creeks; remaining streams are intermit and flow only during snow-melt and intense rainstorms, at least in the alluvial fans near their mouths. Major tributaries are the North Fk (20% of flow) and Mad R (14%). The North Fk flows in a hanging valley, and the stream cascades to the main Entiat valley floor in a deep postglacial gorge. In the Mad R valley, glaciation left a terminal moraine just above the mouth of Cougar Cr.

RM 0.0 mouth, 707' el.

RM 0.3 USGS 4530 and limits of Rocky Reach Res; 419 mi^2 drain; basin el 4,390'; 92% forest; 45" ppt, Jan air 17° F, QM 509 cfs, QL 275 cfs, QF 3,158 cfs.

RM 3.5 Mills Canyon Cr, 4.8 mi, 2nd ord, 7% grad, intermit lower, 11 mi^2 drain, mud flows 1989 after wildfire 1988.

RM 6.1 Roaring Cr, 7.8 mi (6.8 ac), 2nd ord, 8% grad, intermit lower, 25 mi^2 drain, mud flows 1989 after wildfire 1988, 0.8 mi (0.7 ac) anadr.

RM 6.8 Entiat NF Hatchery.

RM 10.1 Mad R, 24.5 mi (64.6 ac), 3rd ord, 2.9% grad, 13.9 mi (50 ac) anadr; 94 mi^2 drain; 1,262' to 5,800' el; mostly forest; 20"-60" ppt; catastrophic fire 1800s; meadow-like RM 24.5 to 19.0, largely cascades in a gorge downstream; well-shaded, lacks aquatic veg; <25 macro-invert/ft^2; very little spawning gravel; QM 69 cfs, QL 17 cfs (Lomax et al. 1981).

- RM 2.0 Tillicum Cr, 10.6 mi (7.2 ac), 2nd ord, 5% grad, 2.9 mi (3.0 ac) anadr, 22 mi^2 drain, 3,990' basin el, 93% forest, 40" ppt.
- RM 5.0 Hornet Cr, 3.8 mi, 2nd ord, 10% grad, 7.3 mi^2 drain.
- RM 11.2 Young Cr, 4.0 mi (4.0 ac), 2nd ord, 4.7% grad.
- RM 13.9 Cougar Cr, 5.5 mi (5.5 ac), 2nd ord, 9% grad. 13 mi^2 drain.
- RM 24.5 Mad Lk, 5,800' el.

RM 11.7 Mud Cr, 10.6 mi (10.6 ac) 2nd ord, 6% grad, 23 mi^2.

RM 15.2 Potato Cr, 7.1 mi (7.1 ac), 2nd ord, 11% grad, 10 mi^2.

RM 18.1 USGS #4528, 203 mi^2 drain, 5,230' basin el, 91% forest, 56" ppt, Jan air 16° F.

RM 18.4 Stormy Cr, 5.2 mi (5.2 ac), 2nd ord, 11% grad, 9 mi^2.

RM 23.1 Preston Cr, 3.0 mi (3.0 ac), 2nd ord, 11% grad, 7 mi^2.

RM 25.4 Burns Cr, 3.0 mi (2.2 ac), 1st ord, 27% grad, 2 mi^2.

RM 28.2 Fox Cr, 2.4 mi, 1st ord, 22% grad, 2 mi^2 drain.

RM 28.6 Tommy Cr, 6.6 mi, 2nd ord, 11% grad,, 13 mi^2 drain.

RM 28.9 Lake Cr, 8.0 mi (10 ac), 3rd ord, 9% grad, 14 mi^2.

RM 29.2 limit of anadromy (falls).

RM 29.2 -34.0 Entiat R, 5.1 mi (35.9 ac).

RM 30.5 Entiat R, QM 218 cfs, QL 63 cfs (Lomax et al 1981).

RM 34.0 North Fk, 10.2 m (18.5 ac), 3rd ord, 8% grad, 28 mi^2.

RM 35.5 Entiat R, QM 121 cfs, QL 35 cfs, basin el >5,800'.

RM 34.0 -48.1 Entiat R, 14 mi (49.6 ac).

RM 47.8 Snow Brushy Cr, 5 mi (2.5 ac), 2nd ord, 14% grad, 7 mi^2.

RM 47.8 -53.4 Entiat R, 5.6 mi (9.6 ac).

RM 48.1 Ice Cr, 5.3 mi, 2nd ord, 11% grad, 9 mi^2 drain, Ice Lks 7,000' el.

RM 53.4 Entiat R, 6,000' el.

Typically, the floodplain invited settlement, and the lower 25 mi of the Entiat R remain in private ownership. In 1970, wildfire destroyed 58,000 ac of vegetation within the Entiat R watershed. Although efforts to re-establish vegetation were begun immediately, high intensity rainstorms in June 1972, and again in January 1974, caused major erosion and flooding. Houses, bridges, roads, water systems, irri diversions, and fish habitat were destroyed. Large areas of stream bank vegetation and adjacent land were lost. Four people died in one mud slide.

Wildfires occurred naturally in north central Washington long before humans became a major factor in the ecosystem (Helvey 1980). Wildfires in 1970, 1976, and 1988 burned 62% of the Entiat R watershed. Although the frequency of wildfires has decreased with modern suppression efforts, they will continue to destroy vegetation in the Entiat watershed whenever the climatic conditions culminating in past fires are repeated. And fire, which destroys ground stabilizing vegetation, will cause sedimentation of streams in the future.

Owing to its mountainous nature, there has been little irrig development in the Entiat R basin. Most of the land irri (1,600 ac, USDA 1979) lies along the lower river. The estimated annual depletion in river discharge from irri corresponds to a reduction in stream-flow of 15 cfs for five months (annual application of 2.8 ac-ft/ac x 1,600 ac x 0.5042 ÷ by 150 days = 15 cfs). With consumptive use of 1.75 ac-ft/ac (Simons 1953), this div would result in a return flow, prorated over 12 months, of only 2 cfs, or a net reduction in stream flow during the irri season of about 13 cfs. This amounts to about 5%, 9%, and 8% of the mean monthly flow for Aug, Sep, and Oct at RM 0.3.

We could find no direct record of Ch salmon spawning in the Mad R (Bryant and Parkhurst 1950). Holtby (1973), however, reported large runs of both Ch salmon and steelhead had once occurred in the lower 4 mi of the Mad R. Earlier, Craig and Suomela (1941, Appendix J) could find no information, except for folklore, that salmon had once ascended the Entiat R. They concluded that the runs were exterminated by impassable dams beginning in 1889.

Holtby (1973) also stated that steelhead and Ch salmon, presumably juvenile fish, are found in very small numbers up to RM 4.0. Although our sampling of the Mad R was meager, it was consistent with other observations (T. Hillman unpub, L. Brown, WDW, unpub) that depict RT as common below RM 13.9 (Cougar Falls, 6-7% grad, 4,202'el). Also, to help control a debris avalanche in Tillicum Cr, a trib that enters the Mad R at RM 2.0, some 70 rock and log dams were installed in 1970 and RT stocked. A latter angling survey disclosed that the habitat had recovered and that a flourishing RT population was re-established (G. Rhodus).

Holtby (1973) made visual observations of fish distribution in the Mad R, but, like us, found no Ch, so that the basis of his Ch occurrence is unclear. Nevertheless, we can see no reason why at least an occasional Ch would not spawn in the lower Mad R, or why juveniles would not enter from the Entiat R for rearing. However, considering the lack of holding pools for adults, lack of spawning gravel, and torrential nature, it can be concluded that the Mad R is only marginally suitable for Ch salmon.

Holtby (1973) and Brown (WDW unpub) show CT above Cougar Falls (RM 13.9), along with a scattering of BT both above and below the falls. Thus, species distribution and abundance appears similar to that commonly observed in the Entiat R, where RT predominate at lower elevations and CT at higher elevations, with a scattering of BT from the mouth upstream.

The area available to anadr salmonids--now and historically--in the Entiat R drain is about 46 mi (308 ac). Resident salmonids occupy another 117 mi (199 ac).

Chelan River Drainage

Chelan R (0.0-4.0 RM); Columbia R (RM 503); 924 mi^2 drain; basin el 4,530'; 76% forest; 55" ppt; 97% public land; QM 2,047 cfs.

The Chelan R drain lies between the Entiat R drain on the south and the Methow R drain on the north. While not studied, some information (mostly hydrologic) on the Chelan R drain is circumstantial to more fully understanding the three drainages studied.

The Chelan Valley, scoured to a depth of 400' below sea level by mountain glaciers, is now occupied by Lk Chelan (33,104 ac). The Chelan R flows 4 mi from Lk Chelan, but in that distance it drops 390', a barrier falls dating to glacial times, and passes through a powerhouse shortly before joining the Columbia R. Summer/fall Ch salmon spawning below the powerhouse has been noted back to 1937. The largest number of spawners observed was 143 in 1981 (Mullan 1987).

On 25 July 1987, the mouth of the Chelan R was surveyed to determine if it was being used as rearing habitat by juvenile salmonids (Griffith 1987). Two snorkelers worked the entire margin from immediately below the powerhouse to the railroad trestle at the confluence with the Columbia R. Flow was low, water temperature was 21.1° C and underwater visibility of 20-30' was excellent.

No juvenile Ch salmon were present. Seventeen RT parr were seen scattered along the shoreline in the lower half of the area. One adult Ch was observed.

Other species present, in declining order of abundance, were adult suckers, adult northern squawfish, about 2 dozen adult walleye, 15 adult and a dozen age-0 (40-60 mm) smallmouth bass, adult carp, a few clusters of sunfish, possibly pumpkinseed, and three adult tench. Rearing cover was essentially non-existent in the area and small salmonids would be very vulnerable to predation under such circumstance. However, summer/fall Ch salmon juveniles could be expected to have migrated by the time of this survey.

Methow River Drainage

Methow R (0.0-73.0 RM); Columbia R (RM 524); 1,792 mi^2 drain; basin el 4,780 ft; 78% forest; 32" ppt; QM 1,592 cfs; QL 264 cfs; QF 46,700 cfs.

Glaciers once covered the entire Methow R basin. Mountainous areas were scoured and rounded by the action of the ice and mantled by relatively thin glacial deposits. Thick accumulations of glacial deposits were left behind in valley bottoms. Since the disappearance of the glaciers, many streams have eroded and redeposited glacial deposits at their mouths, a process that is still active.

Much of the basin is forested and devoted to logging and grazing. Farming is restricted to valley bottoms and adjacent river terraces. Although 80% of the basin is in national forest, 64.5 mi of the lower Methow R is in private ownership. Air temperatures range from -58° to 110° F and precipitation 8 to 80 inches. Granite is the most common type of bedrock.

The Methow R basin consists of three drainages: the Chewack R drain, the Methow R upstream from Winthrop, and the southern drainage.

Chewack River Drainage: The Chewack R drains from the Canadian border to Winthrop. Although the Chewack R drains a larger area than does the Methow R to the west, it discharges less water. Over the Methow drain above Winthrop, precipitation ranges from 15 to 80 in; over the Chewack R drain from 15 to 35 in.

About 87 cfs of water are diverted below Boulder Cr (RM 8.8) during the irri season. This amounts to a 57%, 78%, and 79% depletion of mean monthly flow for Aug, Sep, and Oct (Appendix C, Table 3, average). The water irrigates 1,960 ac below Winthrop. Considering a consumptive use of 1.75 ac-ft/ac (Simons 1953), the diversion would result in a return flow, prorated over 12 months, of 31 cfs to the Methow R below Winthrop, or a net ecosystem reduction of 37%, 50%, and 51% for the months of Aug, Sep, and Oct.

Methow River upstream from Winthrop: The upper Methow R basin drains from the crest of the Cascades to Winthrop. Some of the channel may dry in summer, even when not subject to irri div. About 131 cfs of water are diverted between RM 67.3 (includes Early Winters Cr) and RM 51.5 to irrigate 2,407 ac both upstream and downstream from Winthrop. This amounts to a 42%, 67%, and 55% depletion of mean monthly flow for Aug, Sep, and Oct (Appendix C, Table 2, average). With a consumptive use of 1.75 ac-ft/ac (Simons 1953), the div would result in a return flow, prorated over 12 months, of 48 cfs, or a net reduction in stream flow during Aug, Sep, and Oct of 27%, 40%, and 35%.

Southern drainage: The drier southern drain, can be divided into the middle river (RM 50 to 27) and the lower river (below RM 27). In the middle river the valley is wider than in areas to the north and south, and unconsolidated glacial deposits are thicker. The lower river valley is narrow, the terraces that flank it are discontinuous, and bedrock is exposed frequently on the valley floor and in the valley walls.

Four ditches from the Twisp R and one canal from the Methow R (RM 44.8) divert about 210 cfs of water to about 3,357 ac of land along the middle Methow R for five months (Milhous et al. 1976; Walters and Nassar 1974). This amounts to a 45%, 66%, and 49% depletion of mean monthly flow for Aug, Sep, and Oct at RM 40.0 (USGS). With a consumptive use of 1.75 ac-ft/ac (Simons 1953), this div would result in a return flow prorated over 12 months, of 80 cfs, or a net reduction in stream flow during Aug, Sep, and Oct of only 28%, 42%, and 30%, respectively.

About 3,000 ac along the lower river are irri by pumping from the Methow R. This delivery by pipe involves little loss of water to the orchards, which largely replace hay and pasture upstream. We can assume a depletion of 40 cfs (4 ac-ft/ac x 3,000 ac x 0.5042 ÷ 150 days = 40 cfs), with about 9 cfs (4 ac-ft/ac - 1.75 ac-ft/ac = 2.25 ac-ft/ac x 0.5042 = 1.13 cfs x 3,000 ac = 3,390 cfs ÷ 315 days = 9.3 cfs) returned to the Methow R prorated over 12 months.

Ground and surface water are related in ways other than their common source, precipitation. Streams flowing over permeable materials lose water to the ground. This recharge of the ground-water may occur naturally, or may be induced if pumping from wells lowers the water table near the stream. Withdrawal of ground water from Methow Valley wells amounts to about 6,000 ac-ft annually. Most is used for irri (1,000 ac) and fish propagation at RM 50.4, a nonconsumptive use. On the other hand, about 100,000 ac-ft of water are diverted annually from surface water sources to irrigate 13,000 ac in the basin. About 36,000 ac-ft does not reach the crops because of leaks from unlined earth canals and ditches (Walters and Nassar 1974). This loss explains why 100,000 ac-ft of water per year are required from surface water sources to irrigate only 13,000 ac. It also helps explain why ground water sustains low flow (estimated 48% Aug, 46% Sep, and 31% Oct at RM 6.7 (USGS) using the logic and methodology demonstrated) in the Methow R below Winthrop even though the features of the river are those of a surface run-off stream. The permeable glacial deposits are continually recharged by return irri water in the dry months, so the water table remains high and discharges into the channel.

Black Canyon Cr (0.0-7.2 RM); Methow R (RM 8.1); 2nd ord; 10% grad; 960-4,600' el; 25 mi^2 drain; QM 1.8 cfs; QL ≤ 1.0 cfs, div unknown (60 ac irri). Steelhead spawn in lower 0.4 mi; beaver dams are common in mid-reaches.

Squaw Cr (0.0-4.4 RM); Methow R (RM 9.0); 2nd ord; 10% grad; 992-2,360' el; 16 mi^2 drain; QM 1.2 cfs; QL ≤ 1.0 cfs; div ≤0.6 cfs (30 ac irri).

French Cr (0.0-3.5 RM); Methow R (RM 13.9); 1st ord; 4.5% grad; 1,100-1,930' el; 30 mi^2 drain; QM 1.8 cfs; QL $\leq$ 1.0 cfs.

An intense storm occurred over this arid drain 9/2/86. For two weeks after the Methow R downstream was highly turbid (see Mission Cr, Wenatchee R, for implications).

McFarland Cr (0.0-8.4 RM); Methow R (RM 18.2); 2nd ord; 8% grad; 1,205-4,700' el; 13 mi^2 drain; QM 1.0 cfs; QL $\leq$ 0.5 cfs; div 2.8 cfs (193 ac irri).

Cow Cr (0.0-2.2 RM); Methow (RM 21.7); 2nd ord; 8% grad; 1,278-2,200' el; 6 mi^2; QM 0.4 cfs; QL 0.1 cfs; div 0.04 cfs (3 ac irri).

Gold Cr (0.0-10.2 RM); Methow R (RM 21.8); 87 mi^2 drain; 4th ord; basin el >4,000'; QM 33 cfs; QL 6.5 cfs; QF 2-25-50 = 657, 1,560, and 1,807 cfs; div 2.2 cfs (88 ac irri); 1 glacier (25 ac); 11 lks (82 ac):

RM 0.0-2.2 — Gold Cr, 3.7% grad; 7 ac anadr, RT stocked in past; beaver common.

RM 0.8-13.8 — South Fk, 0.8% grad, 3rd ord; QL 1.7 cfs, man-made dam at RM 0.5, multiple beaver dams below Rainy Cr, RT stocked in past, distribution to large falls at RM 11.8 (3,400" el), no other salmonid sampled (Table 1).

  RM 3.6 — Rainy Cr, 3.8 mi, 2nd ord, QL 3 cfs, QF 168 cfs, 8.5 mi^2 drain, 100% forest, 30" ppt, 3.0 ac resid.

RM 0.8-10.2 — North Fk, 3.4 ac anadr, 5.1 ac resid salmonids.

RM 2.2 — Middle Fk, 5.6 mi (3.6 ac) resid, 2nd ord, apparently only CT through 1937, RT subsequently stocked.

RM 3.9 — Foggy Dew Cr, 6.4 mi (6.4 ac) resid, 2nd ord; QL 2 cfs, N Fk originates Cooney Lk 7,241' el, CT introduced from downstream 1917; CT extend downstream below last falls at RM 4.3 (3,840' el), where RT also occur (Table 1).

RM 5.2 — Crater Cr, 6.4 mi (6.4 ac) resid, 2nd ord 24 mi^2 drain. QL 2 cfs, outlet Crater Lk 6,841' el, with CT introduced 1924, source unknown. RT dominate CT RM 1.9. Upstream sampling Hunter Cr (RM 2.4, 3,240' el) to just above confluence of Crater and Martin Crs (RM 3.4, 3,800' el), sites of barrier falls, showed only RT at first, then a few CT,

Table 1. Distribution of salmonid species (excluding mountain whitefish) in the Methow River drainage, Washington.

Subbasin, stream, river mile, barrier falls	Method and year(a)	Catch per hour	Number of trout and salmon documented					
			Rainbow trout	Cut-throat trout	Cutt/ Rain hybrid	East. brook trout	Bull trout	Chinook salmon
METHOW RIVER								
0.0–50.0	HL 90	3.0	120* 28	3			2	
0.0–50.4	S,C 85,86		47* 6298	5		1	10	3870
50–64.0	HL 90	1.5	3* 30	1			1	
50.6–67.4	C 85,86		210			2	2	546
GOLD CR (10.2)								
S. Fk. (0.8)								
3.8	C 88		32					
5.9	C 88		23					
5.9–6.9, falls	HL 90	3.3	9					
13.0	C 88		0	0	0	0	0	0
N. Fk. (3.5)	C 87		301				2	
Foggy Dew Cr (3.9)								
3.4	C 88		25	32				
4.3, falls	HL 90	13.5	4	6	3			
4.8	HL 90			19				
Crater Cr (5.2)								
0.0–0.3	HL 75	11.0	9	1			1	
1.9	C 88		86	41				
2.4–3.1, falls	HL 90	12.0	14	15	13			
Martin Cr (3.4)								
0.1	HL 90	14.0		7				
3.4	HL 90	8.0	2					
LIBBY CR (26.4)								
2.7	E 90	12.0	12					
5.9–6.8	E 90	13.4	14			9		
N. Fk. (6.8)								
0.8–1.0	E 90	8.0		8				
S. Fk. (6.8)								
0.5	E 90	10.0	5					
1.3	E 90	8.0	1	1	2			
BEAVER CR (22.3)								
7.5	HL 85	6.9	12					
S. Fk. (9.0)								
0.0	C 88		41			5		
3.2	C 88		1			50		
M. Fk. (2.0)								
2.6	C 88					95		
5.2	C 88					21		
TWISP RIVER (28.2)								
2.0–16.0	HL 90	7.7	55* 86	11			1	15
4.0–15.6	E,C 85,86		9* 229	1				493
24.4	C 87		13* 79	1			7	37
27.1	C 87		78* 1				61	
27.3–28.1, falls	HL 90	7.8	2* 1	19			15	
28.1–28.2	HL 90	10.7		16				
S. Fk. (28.2)								
0.0	C 89			46				
1.9	C 89			96				
N. Fk. (28.2)								
0.0–0.3	HL 90	6.0		3				

Table 1. Distribution of salmonid species (excluding mountain whitefish) in the Methow River drainage, Washington.

Subbasin, stream, river mile, barrier falls	Method and year(a)	Catch per hour	Number of trout and salmon documented					
			Rainbow trout	Cut-throat trout	Cutt/ Rain hybrid	East. brook trout	Bull trout	Chinook salmon
North Cr (26.1)								
0.4-1.0	HL 90	18.7		14				
South Cr (24.4)								
0.0	C 89		14* 9					
0.2-0.8, falls	HL 82	8.0	10	2				
0.2-0.8, falls	E 85	14.0	14	2	1		1	3
0.0-0.8, falls	HL 90	20.0	5	5	5			
2.2	HL 90	17.5		7				
3.6	HL 90	32.5		13				
Reynolds Cr (20.9)								
0.0-0.1	E 85	25.0	17* 2				4	2
0.2	E 86	12.0					6	
0.0-0.5, falls	HL 90	12.0	2*				5	
0.0-0.5, falls	HL 82	4.0	1				2	
0.5-0.7	HL 90	0.0						
War Cr (16.3)								
0.0-1.8, falls								
2.5	C 89		21		1	15		
3.0-5.0	HL 90	27.4		11		3		
5.0-6.2	HL 90	22.0		11				
6.2+	HL 90	9.3		7				
Eagle Cr (15.3)								
0.0-0.5, falls	HL 90	7.0	6		1			
0.5-2.2	HL 90	8.0		2	4			
Oval Cr (2.2)								
0.0-0.7	HL 90	16.0		8				
3.0	HL 90	8.0		4				
Buttermilk Cr (12.7)								
E. Fk. (2.5)								
0.0	C 88		113				1	
1.3	C 88		90				2	
1.3-1.8	HL 83	4.9	5					
2.7	C 89		30				34	
2.9	HL 90	32.0	2	4	2			
3.2, falls	HL 90	11.3		17				
3.8	C 88			132				
W. Fk.								
0.0	C 88		127					
0.5-2.3, falls	HL 90		15				1	
2.3+	HL 83	1.5					3	
2.3+	HL 90	3.7	1				5	
Little Bridge Cr, (9.0)								
0.0	C 88		8* 57					13
5.2	C 88		37					
CHEWACK RIVER (50.1)								
0.0-16.0	HL 90	3.3	11* 62	3		3		14
7.8-17.4	C 85,86		2* 510					307
23.3-30.8	C 85,86		2* 155	1			3	303
25.6-32.3, falls	HL 90	5.7	53* 10	2				
32.3-34.1	HL 90	10.0	4		1			
34.1-37.2	HL 90	12.0	2		4			
37.2-39.3	HL 90	10.0	6		4			

Table 1. Distribution of salmonid species (excluding mountain whitefish) in the Methow River drainage, Washington.

Subbasin, stream, river mile, barrier falls	Method and year(a)	Catch per hour	Number of trout and salmon documented: Rainbow trout	Cut-throat trout	Cutt/ Rain hybrid	East. brook trout	Bull trout	Chinook salmon
Andrews Cr (25.6)								
0.0–0.3	HL 90	10.0	5					
1.2	C 88		2		82			
Lake Cr (23.4)								
2.8	C 87		72		2		2	28
8.1	E 90	9.3	3		1		3	
9.5	E 90	9.3		7				
Twentymile Cr (18.9)								
3.2	C 88		86					
4.5	E 90	3.0	4			8		
7.0 (N Fk)	E 90	5.3	1			3		
10.2 (S Fk)	C 88			43		7		
Falls Cr (13.5)								
0.4, falls	HL 85	5.3				8		
Eightmile Cr (11.2)								
3.0	E 90	10.0	2* 4			9		
8.3	C 89		4* 7			41		
14.6	C 89					3		
Boulder Cr (8.8)								
1.3, falls								
1.8–2.0	HL 85	6.7				5		
5.8	C 89					117		
8.5 (M Fk)	HL 85	2.7		1		2		
9.6 (M Fk)	C 89			12		21		
12.5 (Bernhardt Cr)	C 89		0 0	0	0	0	0	0
Cub Cr (6.6)								
0.4, falls								
3.0	C 89					94		
WOLF CR (52.8)								
0.4–1.0	E 87		59					11
1.4	C 87		118				1	
5.7	HL 90	8.7	8	1	3		1	
N. Fk (6.9)								
0.0–0.5	HL 90	9.1	14				2	
6.4	HL 90	8.8	1	10				
7.2	C 89			102			51	
9.6	C 89			209				
10.3, falls								
12.4	C 89			175				
GOAT CR (64.0)								
1.0–1.5	HL 77	6.9	10	1	1			
3.0	C 89		126					
6.5–6.9	HL 77	16.0	12					
7.0	E 90		17				1	
9.0	C 88			1	25		2	
9.0–9.8	HL 90	1.3		2			2	
10.0–11.3	HL 90	1.5					6	
EARLY WINTERS CR (67.3)								
0.0	C 86		2* 14		1			43
1.5	C 87		45				4	97
Cedar Cr (1.9)								
0.0–0.5	HL 90	11.2	6	3	4		1	
0.9–1.1	HL 90	5.3		3	1			
1.5	C 89			96	9		30	

Table 1. Distribution of salmonid species (excluding mountain whitefish) in the Methow River drainage, Washington.

			Number of trout and salmon documented					
<u>Subbasin,</u> stream, river mile, barrier falls	Method and year(a)	Catch per hour	Rainbow trout	Cut-throat trout	Cutt/ Rain hybrid	East. brook trout	Bull trout	Chinook salmon
1.9–2.4, falls	HL 90	14.0		17	4		1	
2.4–3.4	HL 77	8.5		17				
2.4–2.6	HL 88	4.0		12				
3.5	HL 77	2.0	2*	1				
5.0	C 86		166	1			12	2
6.0–7.0	HL 77	4.0	2				3	1
7.4	HL 90	2.0	1				1	
7.5, falls								
8.8	C 89						35	
9.5	HL 77	1.3					2	
11.1–11.3	HL 76	0.7		1				
12.3	C 89						32	
<u>LOST RIVER (73.0)</u>								
0.0	C 86		21* 26					147
Monument Cr (7.1)								
0.0	C 89		103				4	
12.7	C 89		1	3			1	
14.1	HL 83	7.3					11	
<u>WEST FORK (73.0)</u>								
Robinson Cr (1.6)								
0.2–0.4	HL 83	3.1	4	2			1	
0.6, falls								
0.6–0.7	HL 90	4.8		6				
1.4	C 89			52				
3.4	C 86		83				3	
Trout Cr (4.9)	C 89		28					
0.4	HL 85	2.0					1	
9.6	HL 85	3.4		6			6	
9.6	C 89			12			61	
9.8, falls								
13.8	C 89			52				

a) Includes C (cyanide), E (electroshocker), S (snorkel), HL (hook-and-line); 85 = 1985, etc.) Quantitative sampling (C,E,S) described in the main text (e.g., Tables 6,7,8); qualitative sampling (some E and HL) represents only fish landed (examined in-hand) and not the more numerous ones observed and not landed.

* Residualized hatchery steelhead "smolts," marked with a clipped adipose fin; the latter generally would not be recognized in snorkel sampling.

then a zone of RT x CT hybrids, followed mostly by CT. Only CT were found above falls in Martin Cr and only RT above falls in Crater Cr (Table 1). Both RT and CT above barriers originated from stocking of headwater lakes. The warming influence of Crater Lk explains the atypical presence of RT at 3,800'el in upper Crater Cr. Conversely, BT were scarce in Crater Cr and in the Gold Cr drain in general (Table 1).

Because of the steep gradient and acute irri div, Bryant and Parkhurst (1950) considered Gold Cr to be of no value to anadr salmonids (survey 4/30/37). However, steelhead have been observed spawning up to Foggy Dew Cr (RM 3.9), and poaching of spring Ch was common upstream of RM 2.2 in the early 1970s. Kohn (1988) found 4 Ch redds between RM 1.8 and 3.8 in 1988, and we observed 1 redd at RM 3.9 in 1987.

Gold Cr flows over permeable glacial deposits below RM 3.0, and there are alternating reaches dewatered due to loss of flow to the aquifer, in addition to irri div.

<u>Libby Cr (0.0-13.8 RM)</u>; Methow R (RM 26.4); 3rd ord; 40 mi^2 drain (41% selectively logged 1963-65 and 17 mi of roads constructed); 3,500' basin relief; QM 14.8 cfs; QL 3.0 cfs; div 3 cfs (279 ac irri); QF 577 cfs; 3 lks (20.6 ac):

RM 0.0	mouth, 1,360 ft el.
RM 3.2	Smith Cr, 3.2 mi, 1st ord, 7% grad, 8 mi^2 drain.
RM 4.4	Hornet Cr, 1.8 mi, 2nd ord, 13% grad.
RM 4.6	unnamed, 1.4 mi, 1st ord, 16% grad.
RM 6.8	N Fk, 7.0 mi, 3rd ord, 14% grad, QL 3-4 cfs.
RM 6.8	S Fk, 4.4 mi, 3rd ord, 18% grad, QL 2.5 cfs.

Eleven redds and 4 adult steelhead observed below beaver dams (RM 1.2), but no redds or adults above beaver dams (RM 2.0 to 2.7) Apr 1987. RT and EBT, the latter introduced 1960s, sampled RM 5.9 to 6.8 1990, but found only RT at RM 2.7 (Table 1).

The N. FK. originates Libby Lk, the highest (7,618' el) lk in Okanogan Co that contains fish. It is deep and cold and supports only CT. Only CT sampled RM 0.8 to 1.0 (3,000' to 3,080' el); there are no barriers to upstream migrants below this reach.

The S. FK. originates in 2 alpine lks, which are shallower, warmer, and lower elevation (6,930' and 6,870' el) than Libby Lk on the N. FK. The upper Lk supports mostly RT and some CT. At RM 1.3 (3,480' el) found CT, RT, and RT x CT hybrids; at RM 0.5 (3,000' el) only RT.

Libby Cr is an important steelhead spawning/rearing trib in need of improved fish passage and screening of irri divs. Spawning steelhead target ground water discharge in lower mile. W. FK. and S. FK. are too small and brushy for much sport fishing.

Texas Cr (0.0-0.6 RM); Methow R (RM 26.8); 1st ord, 11 mi^2; 1,400-1,800'el; 13% grad; QM 0.6 cfs; QL 0.1 cfs; div 0.4 cfs (24 ac irri).

Benson Cr (0.0-7.4 RM); Methow R (RM 32.2); 2nd ord; 39 mi^2 drain; 1,400-3,280'el; 5% grad; QM 2.6 cfs; QL 0.5 cfs; div 1.7 cfs (118 ac irri); EBT in headwaters, lower reaches intermit because of irri div.

Alder Cr (0.0-1.0 RM); Methow R (RM 33.2); 1st ord; 1,600-1,800' el; QM 0.9 cfs; QL 0.2 cfs; naturally intermit.

Beaver Cr (0.0-22.3 RM); Methow R (RM 35.2); 3rd ord; 111 mi^2 drain; 5 lks (35 ac):

RM 0.0 mouth, 1,550' el, QM 58 cfs, QF 1,493 cfs; QL 0.0.

RM 2.8 Frazer Cr, 4.4 mi, 1st ord, 11% grad, 21 mi^2 drain, QM 3.9 cfs, QL 0.8 cfs.

RM 6.2 USGS #4,497, 68 mi^2 drain, QM 37.4 cfs, QF 1,029 cfs.

RM 8.9 USGS #4496, 62 mi^2 drain, 5,090' basin el, 24" ppt, Jan air 12° F, QM 20.5 cfs, QF 853, QL 3-4 cfs.

RM 9.0 South Fk, 9.7 mi, 2nd ord, 4% grad, 27 mi^2 drain.

- RM 0.0 mouth.
- RM 2.0 Middle Fk, 5.4 mi, 2nd ord, 5% grad.

RM 9.0 North Fk, 13.3 mi, 2nd ord, 6% grad, 35 mi^2 drain.

- RM 0.0 mouth, 2,800' el.
- RM 0.5 Volsted Cr, 4.4 mi, 2nd ord, 13% grad,5 mi^2.
- RM 1.7 Lightning Cr, 3.2 mi, 2nd ord, 16% grad.

The distribution of salmon and steelhead in Beaver Cr is an enigma. Gradient in the lower 9 mi is slight (1.4%); but as the name suggests, beaver dams now, and probably historically, limit upstream fish passage. In addition, virtually the entire flow is used for irri. Because of return irri flow, however, the lowest 0.3 mi of Beaver Cr remains a substantial stream until the end of the irri season. In 1988 we observed hundreds of RT parr in this reach until irri was turned off in Oct, after which the reach dried and the fish perished.

We estimate that historically there were about 27 ac of stream contributing, at least periodically, to anadromous fish production, and that a minimum of another 24 ac of streams support resid salmonids. EBT dominate at higher elevations and RT at lower elevations (Table 1). EBT originated from stocking Beaver Lk in 1933 and presumably have replaced CT and BT in the drain.

<u>Twisp R (0.0-28.2 RM)</u>; Methow R (RM 40.2); 4th ord; 247 mi^2 drain; basin el 4,957'; QM 226 cfs; QL 66 cfs, QL at mouth 13-18 cfs; QF 2-50 = 2,880 and 7,920 cfs; 29 lks (238 ac):

RM 0.0 mouth, 1,580' el.

RM 1.6 USGS #448998.

RM 4.2 Poorman Cr, 4.8 mi, 1st ord, 6% grad, 12 mi^2 drain, QL 1.0 cfs, 1.0 cfs div (54 ac irri).

RM 9.0 Little Bridge Cr, 9.6 mi, 3rd ord, 7% grad, 7.0 mi (4.8 ac) anadr, 24 mi^2 drain: USGS #448900 RM 1.8, 7.8 mi, 10% grad, 16.6 mi^2 drain, 4,390" basin el, 74% forest, 35" ppt, Jan air 9° F, QM 19 cfs, QF 374 cfs, QL 2 cfs, irri div RM 1.9, div 0.6 cfs (28 ac irri). No fish W Fk (RM 6.8) due steep grad (28%); RT dominant to about RM 7.0 where stream virtually dries.

RM 12.3 Canyon Cr, 3.4 mi, 2nd ord, 9% grad, 9 mi^2, QL 0.8 cfs.

RM 12.7 Buttermilk Cr, 37 mi^2 drain.

- RM 0.0 mouth, 2,220' el, QL 5.2 cfs.
- RM 1.8 irri div, 0.8 cfs (36 ac irri).
- RM 2.5 confluence E and W Fks, 4th ord, 4.6% grad, 4 ac anadr.
- RM 2.5 E. FK., 9.2 mi, 3rd ord, 8.4% grad, 17 mi^2 drain, QL 6.7 cfs. CT are present up to the beginning of a series of barrier falls at RM 3.2; RT to RM 2.9. CT probably stocked above falls. No BT caught below falls, but must assume they have reached there (Table 1). Channel is stairstepped and discharge thunders

over woody debris dams wedged in huge boulders. Plunges are imposing, but none are judged wholly impassable to upstream migrants, and all are temporary.

RM 2.5 W. FK., 9.6 mi, 3rd ord, 9% grad, 2.0 mi (3.0 ac) anadr, 17 mi^2 drain, QML 4-10 cfs. Surveyed RM 0.5 (3,000' el) to RM 2.3 (3,760' el) 1990. There are no complete barriers to upstream migrants in this reach, though there are 3 log jams that inhibit passage at low flow. The upper log jam (RM 2.0), sits atop a bedrock outcropping, creating a drop of 10-12'. RT are scarce above the falls, but abundant downstream, and replaced by BT upstream. One adfluvial BT (500 mm) was seen downstream (Table 1).

RM 15.3 Eagle Cr, 7.6 mi, 2nd ord, 11% grad, 14 mi^2 drain, QL 2.4 cfs. At RM 0.5 a spectacular series of falls, perhaps 100' high, terminates upstream fish passage. RT are most abundant below the falls, with a few RT x CT hybrids. Hybrids are most common upstream of the falls to Oval Cr (RM 2.2) with some pure CT. Just above the confluence with Oval Cr (3,680' el), only pure CT are found in both creeks. RT and CT above downstream barrier falls were either planted in the creek or in the Oval Lks. If the latter, RT didn't establish themselves until reaching lower and warmer elevations downstream. There are no lakes in Eagle Cr above Oval Cr and the presence of CT above barrier falls in the upper end of Eagle Cr indicates they were stocked there.

RM 16.3 War Cr, 11.5 mi, 3rd ord, 6% grad, 0.4 mi (0.5 ac) anadr, 27 mi^2 drain, QL 6.7 cfs, large barrier falls at RM 1.8 (2,960' el). RT, CT, and EBT introduced above falls. No EBT above Mack Cr (RM 6.2). EBT are most abundant between Mack Cr (4,540' el) and S. FK. (RM 3.2; 3,500' el); CT dominant even in the EBT zone of abundance. Downstream, RT largely replace CT, with some RT x CT hybrids (Table 1).

RM 19.2 Little Slate Cr, 4.4 mi, 2nd ord, 17% grad, Slate Lk 6,645' el, QL 0.9 cfs.

RM 19.9 Williams Cr, 3.4 mi, 2nd ord, 22% grad, Williams Lk 6,492' el; USGS #448700 RM 0.0; 5,320' basin el; 73% forest; 30" ppt; Jan air 8.0° F; QM 2.3 cfs, QL 0.5 cfs, QF 97 cfs.

RM 20.9 Reynolds Cr, 6.0 mi, 2nd ord, 15% grad, 8.3 mi^2 drain, QL 1.5 cfs, heavy stocking recommended 1937. A high vertical bedrock falls terminates upstream fish movement at RM 0.5 (3,210' el). No fish were observed or caught above the falls (Table 1). One adfluvial and 4 resident BT were observed in the pool below the falls. Two residual hatchery steelhead were also caught. These were mature males, 280 and 250 mm stocked in the Twisp R 5 yrs earlier.

RM 23.8 Scatter Cr, 3.2 mi, 2nd ord, 23% grad, 3 mi^2 drain, QL 0.6 cfs.

RM 24.4 South Cr, 6.0 mi, 3rd ord, 7% grad, 0.8 mi (1.2 ac) anadr (3 spr Ch redds, 1 live fem, 8/12/89), only CT above falls (Table 1). Mosquito Lk 5,280' el, 16 mi^2 drain, QL 7.2 cfs.

RM 26.1 North Cr, 5.0 mi, 2nd ord, 9% grad, 6.7 mi^2 drain, QL 4.8 cfs, no barriers to upstream migrants RM 0.0 to 1.0 (4,000' el). Only CT RM 0.4 to 1.0 (Table 1).

RM 26.2 Limits of anadromy, begin abundance of BT (Table 1).

RM 28.2 Confluence of N and S Fks, 4,120' el, end of BT, 15' falls. Below falls, 8 adfluvial BT observed, 457 to 686 mm. A good population of juvenile and mature CT and BT also observed RM 27.5 to falls (Table 1).

RM 28.2 S. Fk, 2.9 mi, 2nd ord, 12% grad, QL 4 cfs, outlet Twisp Lk 5,950' el, CT abundant lk and cr, typical high grad, stable habitat, abundance of cover. CT originated from high lake stocking.

RM 28.2 N. Fk 2.9 mi, 2nd ord, 15% grad, similar to S Fk (boulder cascades etc.). CT invaded from S Fk over 4 to 5' cascades.

Current and historical stream area accessible to anadromous fish 36 mi (163 ac); resid salmonids 76 mi (80 ac). About 62 cfs diverted for irri at RM 4.0. The valley bottom contains appreciable ground water; glacial and alluvial sediments obscure bedrock along the entire river. Thirteen mi of the lower river are not within national forest.

Bear Cr (0.0-6.8 RM); Methow (RM 47.8); 2nd ord; 1,700-3,400' el; 18.4 mi^2; QM 4.0 cfs; QL 0.8 cfs; div 0.9 cfs (64 ac irri).

Chewack R (0.0-44.8 RM); Methow R (RM 50.1); 4th ord; 525 mi^2 drain; 1,745-6,300' el; QM 374 cfs; QL 43-61 cfs; QF 11,193 cfs; 53 lakes (575 ac):

RM 0.0 mouth, 1,745' el.

RM 0.2 USGS #4480 (records discussed in Appendix C).

RM 2.0 Pearrygin Cr, 0.8 mi, outlet Pear. Lk, intermit, 11 mi^2 drain.

RM 6.6 Cub Cr, 7.5 mi, 2nd ord, 5% grad, 0.4 mi (0.4 ac) anadr, 24 mi^2 drain, QL 1.4 cfs, EBT established by 1937 above falls (Table 1).

RM 8.7 USGS #4475 (records discussed in Appendix C).

RM 8.8 Boulder Cr, 14.5 mi, 3rd ord, 7% grad, 1 mi (3.3 ac) anadr, 81 mi^2 drain, QL 4-5 cfs; RT, CT, & EBT stocked in past; EBT now dominant lower el & EBT & CT. higher el.

RM 11.2 Eightmile Cr, 14.3 mi (stream occupies a fault, drain linear not dendritic), 3rd ord, 5% grad (steep canyon 0.5 mi above mouth), 0.5 mi (1.0 ac) anadr, QL 11 cfs, 46 mi^2 drain (a hanging valley), 87% forest, 22" precip ppt, CT and BT apparently replaced by EBT since 1937.

RM 13.5 Falls Cr, 10.4 mi, 3rd ord, 8% grad, 46 mi^2, QL 4 cfs, anadr to RM 0.4, EBT and some CT above falls, RT below.

RM 17.1 Doe Cr., 5.0 mi, 1st ord, 16% grad, 4 mi^2, QM 2.4 cfs.

RM 18.9 Twentymile Cr, 10.4 mi, 3rd ord, 5% grad, 1.0 mi (1.2 ac) anadr, 42 mi^2 drain, QL 1 cfs. At RM 10.2 (5,840' el) we found an impoverished population of EBT and CT, at RM 7.0 and 4.5 (5,220' and 4,320' el) EBT and RT, and at RM 3.0 (3,730' el) only RT (Table 1). RT and EBT also present in lower N FK (5,600' el). The atypical distribution of RT at high elevations relates to high solar radiation in summer of open meadows or boulder fields through which small volumes of stream flow (<2-3 cfs) pass.

RM 23.4 Lake Cr, 6.5 mi, 3rd ord, 4% grad, 5.2 mi (14.7 ac) anadr, outlet Black Lk, 54 mi^2 drain, QL 11-17 cfs. Small numbers of Ch spawn to RM 5.2 (3,500' el). Ch and RT dominated the fish population sampled at RM 2.8 (3,160' el), with some BT and CT. Just above Black Lk at RM 8.1 (4,040' el), RT and BT were found in about equal numbers, plus RT x CT hybrids. At RM 9.5 (4,520' el) only CT were found. We couldn't be sure that a barrier to upstream migrants existed below RM 9.5 (gradient 11%). The existence of RT above 4,000' el can be attributed to the warming affects of Black Lk and two small, shallow alpine lks upstream, as well as the insolation of this north-south oriented stream in summer.

RM 25.6 Andrews Cr, 11.2 mi, 3rd ord, 6% grad, 34 mi^2 drain, 22 mi^2 gaged (USGS)(Paysayten Wilderness), 79% forest,35" ppt, Jan air 8° F, QM 33 cfs, QL 1.7 cfs, QF 874 cfs, limited anadr, CT contaminated by RT, only RT found nr mouth (Table 1).

RM 31.6 Windy Cr, 7.4 mi, 2nd ord, 9% grad, no fish 1937, RT planted 1939.

RM 32.3 Limit of anadromy (cascades and falls), QM 134 cfs, QL <20 cfs.

RM 44.8 Confluence Kemmel and Cathedral creeks, 5,600' el.

Current and historical area accessible to anadr salmonids is about 42.8 mi (272 ac). Minimum estimate of streams above barriers occupied by resid salmonids 74 mi (103 ac). About 87 cfs diverted for irri below Boulder Cr (Appendix 3); 3-6 cfs diverted from Eightmile Cr near mouth. Records of well-drillers indicate that permeable materials in considerable thickness underlie the valley floor. Thus, ground water could be significant in some reaches (see Appendix C). Only 500 ac of the Chewack drain are not within the Okanogan National Forest; much of the headwaters lie within the Paysayten Wilderness.

Apparently, RT and CT, but not BT, were introduced above the barrier falls at RM 32.3 (not to be confused with Chewack Falls at RM 34.1) (Table 1). The persistence of RT to at least 4,630' el (RM 39.3) probably relates to the warming effects of 5 alpine lakes and southern exposure that currently support only CT.

<u>Winthrop National Fish Hatchery; Methow R (RM 50.4)</u>.

<u>Thompson Cr</u> (above Winthrop, but below Wolf Cr on right bank, but has no surface channel to Methow R); QM 4.0 cfs; QL 0.8 cfs; div 0.9 cfs (677 ac irri); contains EBT.

<u>Wolf Cr (0.0-14.0 RM)</u>; Methow R (RM 52.8); 38 mi^2 drain; 3rd ord, basin el 4,500', 6% grad, QM 39.7 cfs, QL 8.0 cfs, all but lower 2 mi in USFS; 6.8 mi, Sawtooth Wilderness.

RM 3.0 Little Wolf Cr, 5.2 mi, 2nd ord, 6% grad.

RM 4.2 Irri div to Patterson Lk.

RM 5.9 North Fk, 3.5 mi, 2nd ord, 10% grad, 10 mi^2 drain.

RM 10.3 Impassable Falls.

RM 14.0 Headwaters.

Most of the flow (3,100 ac ft annually) is diverted at RM 4.2 to Patterson Lk. The stream is usually dry in summer near its mouth. Wolf Cr flows over permeable glacial deposits in its delta and loses water to the ground-water aquifer in summer. Possibly the water table was higher before irri div, and there was year-round flow in the lower creek. On the other hand, there are similar dry sections of streams nearby not subject to upstream divs (e.g., West Fk Methow, RM 0.0-0.6).

Ch salmon distribution lies below RM 1.4, while RT distribution extends to RM 6.4, above which BT become common. CT overlap with BT but are dominant at higher elevations (Table 1). CT were planted above RM 10.3 (falls) in 1960s by WDW.

Unlike the delta area, bedrock is exposed along the upstream channel and includes Cretaceous age shales, sandstones, and conglomerates. Some volcanic flow and lastic rocks also occur.

Little Boulder Cr (0.0-4.5 RM); Methow R (RM 63.5); 2nd ord; QM 8.6 cfs; QL $\geq$ 2 cfs; delta usually dry in summer, 8 mi^2 drain, basin el 4,500'; RT present at lower el, with a scattering of Ch juveniles.

Goat Cr (0.0-12.5 RM); Methow R. (RM 64.0); 3rd ord, QL 3 cfs, 16% grad, 36 mi^2 drain, el 2,080 to 6,400'.

In the lower section the gradient is moderate to steep, and the stream contains a fair amount of spawning area. There are several divs for irri of farms along the lower part of the course. These divs take the entire flow during the summer and early fall" (Bryant and Parkhurst 1950, survey 5/14/37). Thus, the stream was considered of no value to salmon. Whether the irri divs at the mouth are responsible for the dry stream bed is questionable. The delta of Goat Cr is floored with glacial till, and even if the summer flow was not used for irri, it would probably mostly disappear into this aquifer before reaching the Methow R.

There are about 13 ac of stream containing RT at lower elevations. Fish distribution ends RM 11.0 (5,360' el). BT appear to be the only fish downstream to RM 9.5, where CT begin to occur. CT were planted early 1980s at RM 9. There are no physical barriers to upstream migrants above RM 11.0. At RM 9.0 (4,680' el), CT x RT hybrids dominate, with a few CT and BT present. Only RT were found downstream at 7.0 (Table 1). Headwater habitat is essentially pristine, with QL flow 3 to 5 cfs.

Early Winters Cr (0.0-15.7 RM); Methow R (RM 67.3); 4th ord; 79 mi^2; basin el >5,000'; 61.7" ppt; QM 119 cfs; QF 2,816 cfs; QL 24 cfs (below irri div of 23 cfs at RM 0.5) (66 ac irri); winter QL 29 cfs without irri div (permeable materials in considerable thickness underlie the valley floor and it would appear that the stream loses flow to this ground aquifer in the valley delta where deposits are thickest); 7 glaciers (272 ac); 4 lakes (16 ac):

RM 0.0 mouth, 2,140'el.

RM 1.9 Cedar Cr, 9.4 mi, 3rd ord, 8% grad, 31 mi^2, QL 14 cfs, RT stocked above barrier falls (RM 2.4) 1939; CT 1960s. It would appear that CT have displaced RT (Table 1). BT also present below falls.

RM 5.1 Varden Cr, 4.4 mi, 2nd ord, 20% grad.

RM 7.5 20 ft. falls impassable to anadromous fish.

RM 9.7 Pine Cr, 3.6 mi, 3rd ord, 16% grad, 4.6 mi^2, 63% forest, 80" ppt, 5,790' basin el, QL 2.4 cfs, QF 386 cfs.

RM 10.7 Cutthroat Cr, 3.2 mi, 2nd ord, 7% grad, Cutthroat Lk 4,935' el, CT stocked, barrier falls near mouth.

RM 15.7 headwaters, 5,800' el.

This is a very cold stream, as the name implies. As much as 44% of the flow in a hot dry summer may be glacier melt. Ch spawning is completed by mid-August (Kohn 1987, 1988).

There are 28 ac of stream available to anadr salmonids; a minimum of 32 ac for resid salmonids. Ch and RT are dominant below the barrier falls (RM 7.5); BT above, with only an occasional CT evidently recruited from Cutthroat Cr (Table 1).

Habitat is pristine, except for an old div dam at RM 0.5; irri takes about half of the flow at this point.

<u>Lost R (0.0-22.5 RM)</u>; Methow R (RM 73.0); 3rd ord; QM 164 cfs; QLM 43 cfs (Lomax et al. 1981); 146 mi^2 drain; basin el> 5,000'; mostly USFS (Paysayten Wilderness); 20 lakes (126 ac):

RM 0.0 mouth, 2,340' el.

RM 3.9 Eureka Cr, 6.5 mi, 3rd ord, 12% grad (35' falls nr mouth), 6,722' el lake source, 36 mi^2 drain.

RM 3.9 Upstream limits of anadr fish spawning, grad $\leq$ 1.5% and rounded rock substrate (much gravel) downstream; grad $\geq$ 2.0% upstream and substrate angular rock (virtually no spawning gravel), begin Lost R gorge.

RM 7.1 Monument Cr, 7.9 mi, 2nd ord, 10% grad, 17 mi^2, QL 35 cfs.

RM 7.2 Rock slide across river (barrier).

RM 8.5 Hurricane Cr, 3.0 mi, 2nd ord, 21% grad, 5 mi^2 drain.

RM 11.7 Drake Cr, 8.0 mi, 2nd ord, 8% grad, 15 mi^2 drain.

RM 12.0 Rock Slide across river (barrier).

RM 12.8 Pinnacle Cr, 1.8 mi, 2nd ord, 28% grad.

RM 14.3 Rampart Cr, 1.6 mi, 1st ord, Rampart Lk 6,907' el, 37% grad.

RM 16.9 Diamond Cr, 6.0 mi, 2nd ord, 8% grad.

RM 18.9 Johnny Cr, 2.8 mi, 2nd ord, 14% grad, Johnny Lk, 6,212'.

RM 20.3 Cougar Lk 4,260 el'.

RM 21.7 Ptarmigan Cr, 4.8 mi, 2nd ord, 10% grad.

RM 21.9 First Hidden Lk 4,303' el.

RM 22.5 Middle Hidden Lk 4,309' el.

Ch salmon spawning (26 ac) occurs primarily below Eureka Cr (RM 3.9) in Lost R. Above Eureka Cr, channel substrate size increases, there is little gravel, and rocks become angular rather than rounded. Gradient also increases. The river is entirely underlain by arkosic sandstone of Cretaceous age. Above Eureka Cr the river follows a half-mile finger of Monument Peak brotile-granite. This forms Lost R Gorge, a remote and deep gorge with a variety of geologic features.

The Lost R below Eureka Cr either loses water to the ground water aquifer or ground water discharges to the channel. In several places, the ground water can be seen boiling to the surface in a dry summer. The river also dries between Monument Cr and 0.5 mi upstream of Drake Cr, a distance of about 5 mi.

RT are found to RM 12.7. A scattering of BT occurs below RM 12.7, but this species doesn't seem to gain dominance until about RM 14 (Table 1). CT are dominant at still higher elevations in Ptarmigan, Diamond, and Drake creeks. Rock slides at RM 7.2 and RM 12.0 seem to be comparatively recent barriers to fish distribution. Apparently RT, CT, and BT all had access to the upper Lost R in the past.

West Fork (0.0-13.8 RM); Methow R (RM 73.0); 3rd ord; 1.2 to 3.0% grad; 83 mi^2 drain; basin el >5,000', mostly USFS; above av ppt; hydrology poorly documented, but permeable materials underlie the valley floor, and ground water could be significant in some reaches; 1 lake (1 ac):

RM 0.0	mouth, 2,340' el, dry to RM 0.6 some summers.
RM 1.6	Robinson Cr, 9.0 mi, 3rd ord, 7% grad, 20 mi^2 drain, QL 6 cfs, native CT above falls near mouth (Table 1).
RM 1.8	QF 4,130 cfs, QM 149 cfs, QL 39 cfs (Lomax et al.1981).
RM 3.4	Rattlesnake Cr, 5.2 mi, 2nd ord, 10% grad, 6 mi^2 drain.
RM 3.4	QL 10 cfs (USFS 1989).
RM 4.9	Trout Cr, 2.8 mi, 2nd ord, 23% grad, QL 1.8 cfs.
RM 5.6	Hardscrabble Cr, 2.2 mi, 2nd ord, 31% grad.
RM 9.0	Two impassable falls (11' and 8')(Bryant and Parkhurst 1950), but we were unable to verify.
RM 9.6	Tower Cr, 3.3 mi, 2nd ord, 13% grad, QL 5 cfs.
RM 9.8	Brush Cr, 2.8 mi, 2nd ord, 23% grad, QL 4 cfs, falls.
RM 11.4	Jet Cr, 0.8 mi, 1st ord, 41% grad.
RM 13.8	4,385' el, QL 5.8 cfs.

Despite being accessible to RM 9.0 at high water, Bryant and Parkhurst (1950) concluded that the West Fk had little potential for salmon, though possibly of value to steelhead. Kohn (1987 and 1988) found no spring Ch spawning. On 8/1/89, Williams (this report) observed 2 spr Ch redds and 2 live females at RM 5.7. There is a minimum of 64 ac used by resident trout. CT are dominant at the higher elevations, RT at the lower elevations, and BT distribution overlaps that of CT and RT in between (Table 1).

Upstream of Brush Cr (RM 9.8), the W Fk is underlain by granite and granodiorite of the Tertiary Golden Horn Batholith. Downstream of Brush Cr, the stream is underlain by shale, sandstone, and conglomerates of Cretaceous age. The upstream intrusive has altered and mineralized the older sedimentary rocks downstream.

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APPENDIX E. Average (sample number in parentheses) nitrogen (NO^3),conductance, total alkalinity, total dissolved solids, pH, and maximum reported turbidity at different locations in the Wenatchee, Entiat, and Methow river drainages (USEPA Storet System; Sylvester 1957).

Stream name (river mile)	Nitrate nitrogen (mg/l)	Conductance (micromhos)	Total alkalinity (mg/l)	Total dissolved solids (mg/l)	pH	Maximum recorded turbidity*
Wenatchee R						
(1.1)	0.125 (62)	64 (174)	28 (79)	42 (83)	7.5 (174)	33 (88)
(21.5)	0.059 (24)	51 (24)			7.4 (24)	8 (24)
(35.8)	0.059 (34)	38 (156)		28 (48)	7.3 (156)	31 (112)
(54.1)	0.085 (14)	22 (14)	10 (14)		7.2 (14)	
Mission Cr.						
(6.9)		191 (24)	97 (7)	126 (7)	7.8 (25)	83 (23)
Icicle Cr						
(5.8)	0.025 (32)	45 (24)	20 (7)	38 (7)	7.3 (24)	3 (30)
Chiwawa R						
(2.1)	0.005 (2)	35 (14)	16 (12)		7.2 (14)	7 (3)
Nason Cr						
(0.8)	0.007 (4)	32 (42)	11 (20)	32 (33)	7.0 (23)	2 (28)
White R						
(6.4)	0.005 (1)	26 (8)	11 (8)	21 (7)	7.0 (7)	1 (6)
21 Lakes (headwaters)		10 (42)	4 (16)	9 (16)	6.7 (16)	
Entiat R						
(0.3)	0.138 (64)	82 (198)	38 (22)	55 (27)	7.5 (197)	34 (165)
(25.2)		38 (38)	18 (30)	33 (13)	7.0 (24)	7 (165)
(31.0)	0.05 (2)	34 (7)	21 (3)	20 (2)	6.9 (5)	340 (233)
Mad R						
(0.3)	0.004(7)	104 (29)	50 (18)	63 (14)	8.4 (1)	165 (28)
(2.1)		79 (20)			8.3 (12)	48 (51)
Methow R						
(6.7)	0.196 (86)	153 (216)	71 (60)	95 (57)	7.8 (94)	77 (190)
(40.0)	0.147 (60)	127 (119)	77 (1)	98 (1)	7.7 (66)	33 (131)
(65.4)	0.060 (41)	97 (67)	45 (47)		7.5 (67)	8 (29)
Libby Cr						
(2.0)		244 (11)			7.8 (10)	77 (16)
Gold Cr						
(0.7)		150 (10)			7.5 (11)	13 (16)
Beaver Cr						
(6.5)		77 (10)			7.3 (12)	12 (18)
Twisp R						
(9.0)		111 (15)			7.5 (14)	40 (23)
(9.0)L.Bridge Cr		215 (14)			7.7 (13)	38 (22)
(16.3)		82 (13)			7.3 (12)	7 (17)
Chewack R						
(0.3)	0.061 (22)	105 (22)			7.6 (22)	9 (22)
(8.8)Boulder		77 (10)			7.4 (16)	280 (27)
(11.2)Eightmile		174 (9)			7.8 (10)	8 (16)
(11.2)		105 (10)			7.4 (15)	12 (24)
(25.6)Andrews Cr						
(3.0)	0.050 (90)	47 (128)	23 (96)	38 (103)	7.6 (127)	3 (15)
Goat Cr						
(0.5)		117 (37)			7.4 (30)	17 (48)
Early Winters Cr						
(0.5)		75 (20)			7.0 (274)	13 (360)

* Jackson and Formazin Turbidity Units--considered comparable.

APPENDIX F

COMMON AND SCIENTIFIC NAMES OF FISHES
MENTIONED IN TEXT

Pacific Lamprey	Entosphenus tridentatus
White Sturgeon	Acipenser transmontanus
American shad	Alosa sapidissima
Coho salmon	Oncorhynchus kisutch
Sockeye salmon	Oncorhynchus nerka
Chinook salmon	Oncorhynchus tshawytscha
Mountain whitefish	Prosopium williamsoni
Cutthrout trout	Oncoryhnchus clarki
Rainbow trout	Oncorhynchus mykiss
Atlantic salmon	Salmo salar
Brown trout	Salmo trutta
Brook trout	Salvelinus fontinalis
Dolly Varden	Salvelinus malmo
Bull trout	Salvelinus confluentus
Chiselmouth	Acrocheilus alutaceus
Carp	Cyprinus carpio
Peamouth	Mylocheilus caurinus
Northern squawfish	Ptychocheilus oregonensis
Speckled dace	Rhinichthys osculus
Longnose dace	Rhinichthys cataractae
Redside shiner	Richardsonius balteatus
Tench	Tinca tinca
Bridgelip sucker	Catostomus columbianus
Largescale sucker	Catostomus macrocheilus
Brown bullhead	Ictalurus nebulosus
Black bullhead	Ictalurus melas
Burbot	Lota lota
Threespine stickleback	Gasterosteus aculeatus
Pumpkinseed	Lepomis gibbosus
Smallmouth bass	Micropterus dolomieui
Black crappie	Pomoxis nigromaculatus
Walleye	Stizostedion vitreum vitreum
Slimy sculpin*	Cottus cognatus

*Identified from Wenatchee River. Other Cottus species are probably present as well.

APPENDIX G

RELATING INDIAN SUBSISTENCE CULTURES TO SALMON AND STEELHEAD ABUNDANCE IN MID-COLUMBIA TRIBUTARIES

by

James W. Mullan and Kenneth R. Williams

The Historical Record

It is the purpose of this appendix to arrive at objective estimates of the Wenatchee, Entiat, and Methow Indian populations in the pre-settlement era (1850s) and of the Indians' maximum catch of salmonids.

The extent of the Indian catches sheds some light on the maximum production of salmon in mid-Columbia tributaries prior to the impacts of settlement. There are, however, numerous informational gaps in matching fish to consumers. Some early explorers, fur traders, and missionaries have provided remarkably detailed observations, so-called "ethnohistoric data." Ethnographic data have been generated by anthropologists through native informants, field observations and ethnohistoric accounts (Schalk 1986).

Ethnographers have usually represented the Indian cultures in the early 19th century as being similar to pre-contact culture. However, the arrival of horses in the Columbia Plateau during the early 1700s set in motion changes in subsistence and population distribution that carried into the 19th century. Subsequently came epidemics of white man diseases (Schalk 1986). Nevertheless, population decline and the importance of fish in aboriginal subsistence were highly variable from area to area.

Indian population estimates and per capita fish consumption have become a "house of cards" begun with Craig and Hacker in 1940. They assumed that an estimated 50,000 Columbia Basin Indians ate an average of one pound of salmon per day, and arrived at 18 million pounds of salmon harvested per year. Hewes (1973) calculated an Indian harvest of 22 million pounds of salmonids in pre-contact times prior to major disease impacts (i.e., 1780). Schalk (1986) recently increased to 42 million pounds the extent of salmon harvested by Indians in the early 1800s: he adjusted Hewes' per capita consumption estimates for certain Indian groups, and included a migration calorie loss factor and also an inedible waste loss factor.

These and other conflicting accounts exemplify the need to sift historical data with regard to the conclusions that may be logically speculated from them.

Northwest Indian groups, distinguished mainly on the basis of linguistics, were composed of loosely organized bands of people who lived together in the same area (Schalk 1986). Because the available food varied, the best ethnographic accounts are those which provide details about individual bands or tribes rather than average behavior for all Indians within the Columbia Basin (Schalk 1986).

The Chelan, Entiat, Wenatchee, Columbia, and Methow tribes spoke a common language, Salish, and inhabited the mid-Columbia study area. Smith (1983b) modeled the first four of these tribes according to population dimensions, sociopolitical and territorial parameters, location of known winter villages and summer camps, subsistence resources available, and food acquisition patterns.

Chelan Model

The Chelan occupied twice as many sites on the shores of Lake Chelan (33,104 acres) as they did along the Columbia River (13 vs. 6). Using Ray's (1974) data, Smith (1983b) estimated the winter population along the Columbia River at about 225 people and about 1185 people around the lake. Summer camp figures were 230 to 990. This lake focus is notable in light of the absence of anadromous fish in Lake Chelan.

The Chelan were nearly entirely west of the Columbia River by about four miles. Their territory transected four vegetative zones and apparently possessed sufficient roots, berries, and other vegetable foods, as well as game. The lake itself contained cutthroat trout, burbot, and other resident fish species. While the Chelan made considerable use of resources along the Columbia River upstream and downstream from the river mouth, there evidently was no settlement of any consequence at this location. The only evidence suggesting that salmon were at least sometimes available to the Chelan is that fur trader Ross Cox (1957) obtained some from an Indian group along the Columbia River just above the mouth of the Chelan River in the summer of 1817 (Smith 1983a).

Entiat Model

Data relating to the Entiat are meager. This may be because they never were a numerous people and because they appear to have begun to dissolve as a cohesive entity early in the post-contact period (Smith 1983b).

The single winter village and all four summer camps of the Entiat tribe were located on or near the banks of the Columbia River. About 125 persons occupied their one winter village at the mouth of the Entiat River (Smith 1983b). Ray (1936, 1974) reported the Entiat caught fish in the Entiat River, but that this stream was of no great importance as a fish source because of its small size. The small summer fishing camp above the mouth and adjacent to winter quarters described in the Wilkes expedition (1845) would seem to verify this.

In 1881, Symons and Downing (1882, in Smith 1983a) carried out a mapping survey of the Columbia River. Symons' narrative of October 6 reads:

> There is quite an Indian village on . . . [the] banks [of the Entiat River], and several of the Indians were engaged in spearing salmon from canoes, paddled and poled along the shallows by assistants. Just below the mouth of the Entiat-qua River there are a number of bar islands, and the river is very shallow. We apparently went in the main channel, and I found only three feet of water over the bar. . . . This is the shallowest water met with yet. At the lower end of the bar is quite a strong little rapid.

Symons does not make clear whether the spearing "shallows" were in the Entiat River at its mouth or were those he described in detail in the Columbia itself. However, it is of interest that these natives were spearing salmon in early October--either coho or chinook.

Wenatchi Model

The Wenatchi occupied seven summer camps along the Columbia River and five on the Wenatchee River. They had four winter villages on the Columbia; and at least one but probably two on the Wenatchee--at Mission Creek and perhaps at Icicle Creek. Population figures show the same orientation:

	Winter	Summer
Columbia Valley	1,013	1,073
Wenatchee Valley	415	675
Total	1,428	1,748

These figures suggest that there was little movement of the Wenatchi population from winter to summer. There was, however, an influx of summer visitors to the upper Wenatchee Valley (Smith 1983b).

Yakima Kittitas constituted the principal visitors. They occupied the upper Yakima River drainage south of the Wenatchee Mountains. The Kittitas spoke a different language (Sahaptin) than the Wenatchi, but frequently crossed the Wenatchee Mountains to fish at the Wenatshapan fisheries at present-day Leavenworth, Washington (Scheuerman 1982).

One observer who visited the Wenatshapan fisheries in July 1882 recorded the following scene:

> I then came to the junction of the Neysickel (Icicle) and Wenatchee Rivers, called for the canoe in Indian yells, when the old man of the camp recognized my call--he being at the camp a 1/2 mile distant, came and rowed me over the high waters in his canoe. He then led me to the camp where are formed tepees of . . . men and women of five different bands (Wenatchi, Kittitas, Columbia and others). . . .

The observer, Francis Streamer, estimated that there were about two hundred Indians gathered there representing some forty families. He saw hundreds of dressed salmon which had been caught in a weir stretching across the river. The fish were hung on drying racks, which he described:

> [The fish] are carried to the camps where they are dressed by the women and hung up on long poles in front of the sail-covered sleeping compartments of which there are two long rows facing each other across a wide way. In the center of these are posts twelve feet apart . . . upon the tops of which are stringers and cross poles, one to two feet apart, upon which the dressed salmon are hung to air dry, above the salmon are roof poles upon which are laid branches of trees to protect the scarlet fish meat from rain and sun.

Earlier, in the Yakima War, a Colonel Wright led about 135 soldiers over the Wenatchee Mountains "to carry off the large mass of the Yakima Nation," who had fled the fighting and sequestered themselves among the Wenatchi (Scheuerman 1982). On July 6, 1856, Wright found a large number of Indians with their families gathered at the Wenatshapan fisheries busily engaged in catching and drying salmon. Wright writes in his journal: "This is beyond question the greatest fishery that I have seen."

In normal times most of these Upper Yakima presumably would have been among the 1,000 natives gathered in July to fish sockeye salmon at the outlet of Cle Elum Lake (1,982 acres) in the Kittitas Valley (Ray 1936). Nevertheless, the Wenatshapan fisheries, of which the Wenatchi had been assured in the Walla Walla Treaty of 1855 but lost 40 years later when it was sold to build an irrigation project on the Yakima Reservation (Scheuerman 1982), possessed a unique salmon-taking potential.

Where Icicle Creek joins the Wenatchee River in Leavenworth, the highest meander and lowest gradient (0.03%) of both streams occur, making them ideal for fishing weirs. Upstream, the Wenatchee River cascades in a torrent of white water through the precipitous, boulder-filled Tumwater canyon, ideal for dip netting. Appropriately, the river was called by the visiting Yakima "Winatsa," which means "Water Flowing Out" (Scheuerman 1982).

Contemporary run-timing suggests that the species caught during July in the Wenatshapan fisheries would have included spring chinook and possibly some early summer chinook, but mainly sockeye salmon. And the salmon could have been concentrated downstream of the Tumwater Canyon in years of high snow melt when a hydrologic barrier to fish migration occurs in the canyon upstream (Mullan 1986).

Salmon, however, were not the only food of the Wenatchi. The fact that all four known Wenatchi winter village sites on the Columbia, as well as the site(s) on the Wenatchee, were likewise summer camp sites speaks convincingly of the abundance and distribution of food resources throughout the Wenatchee territory.

Wenatchi hunters commonly took bear, goat, deer, and elk. Winter villages sheltered in the limited foothills of the Cascades occupied the same winter range big game herbivores are forced to concentrate in at this season. Smaller game taken included beaver, marmot, and rabbit as well as geese, ducks, and grouse (Scheuerman 1982).

Balsam root or sunflower appeared in March, turning the hillsides yellow in this and in the last century. The shoots and bulbs were eaten raw, and a flavoring made from the seeds. Each April, families from many Indian tribes gathered on the Columbia Plateau to dig bitterroots. Roots were boiled and dried to be eaten or pounded into cakes for later consumption. Most of the Wenatchi returned from the root grounds of Badger Mountain on the east side of the Columbia River in late spring and early summer to fish, dig roots, and pick berries near their home villages. Among their important roots were two varieties of camas which were and are abundant in the Camas Meadows about five miles west of present day Cashmere. These roots are very nutritious and were boiled, baked, or dried and pounded to make a flour (Scheuerman 1982).

Spear-fishing stations were located at the mouth of the Wenatchee River and probably in the Columbia River off the mouth of the Squilchuck and Stemilt creeks, adjacent to the more populous year-round villages. Aside from Icicle Creek, important salmon weirs are known to have been built each year near the mouth of the Chiwawa River below Lake Wenatchee. Francis Streamer in 1882 described the building of such a weir, measuring about 300 feet by 5 feet. He reported hundreds of salmon taken daily. However, the Indians apparently did not catch hundreds of salmon every day, because Streamer (1882) described how the weir was moved several hundred yards to a site deemed more favorable.

Present-day run-timing and salmon spawning indicates the foregoing catch would have consisted largely of sockeye salmon destined for the Little Wenatchee and White rivers above Lake Wenatchee (2,445 acres). Species harvested by Indians can only be inferred. Coho salmon present a particularly difficult question; although we know that a coho run once existed in the Wenatchee River, we do not know where they spawned or much about the run timing (Mullan 1984).

Records of an early (1882-1904) hatchery on the Wenatchee River show that coho salmon ascended at least to river mile 15.9 (Chiwaukum Creek), and recollections of non-Indian old-timers suggest runs as early as September (Mullan 1984). Alex Saluskin, a descendant of Chief Saluskin of the Kittitas Yakimas, recalled in 1966 that as a boy his family, with many others, spent the summer and fall on the Wenatchee and Chiwawa rivers, where chinook, blueback (sockeye), and silver (coho) salmon were abundant, as well as steelhead and other trout (Davidson 1966).

In August the Wenatchi entered their final seasonal round before winter, and newly arrived coho salmon could have been an important addition to their diet at this season. Numerous varieties of wild berries abounded along the Wenatchee Valley and at higher elevations. Chokeberries and huckleberries, two of the most important berries in the Wenatchi diet, were gathered from August to October. Indian families often congregated during this time near the Chiwawa River, famous for huckleberrying. McCall Mountain's eastern slope abounded in huckleberry bushes; to insure their continued growth, the Wenatchi burned the site periodically.

Temporary camps at the mouth of Rock and Chikamin creeks likely served as bases for fishing and hunting as well as huckleberrying. A similar camp of about ten tepees situated in the vicinity of Grasshopper Meadows on the White River was evidently destroyed by the U.S. Army in August 1857 (Scheuerman 1982).

Columbia Model

The Columbia grouping of Indians represents a major population focus of 16 sites along the Columbia River in winter; and 29 sites within the distant Columbia Basin in summer. Only two summer camps are known along the Columbia River, in spite of all the salmon that ascended the river during the warm months (Rock Island and below Colockum Creek). But the Columbia Basin, with its rich root grounds, game, and resident fish, was the locale of no fewer than 29 summer camps. The summer population along the Columbia River may have been about 345 versus 1470 in the Columbia Basin (Smith 1983a).

The tribes of the Columbia grouping were substantially different from surrounding Indian tribes (Smith 1983b). The Wanapan and other tribes to the south along the mid-Columbia River spoke Sahaptin. Although they fished at Priest Rapids and other sites, instead of spending their summers along streams like their Salish-speaking neighbors most Columbia groups dispersed over the sagebrush steppe. The subsistence quest became even more wide-ranging when they began regular journeys to Montana for buffalo early in the 19th century (Ruby and Brown 1965).

Methow Model

The basic settlement data used in developing the Chelan, Entiat, Wenatchi, and Columbia models does not exist for the Methow Indian (A. H. Smith, WSU, pers. comm.). A less satisfactory but semi-quantitative estimate of the number of Methow comes from the Presidential Executive Order of 1872 establishing the Colville Indian Reservation (USDI 1872). The document listed 316 Methow or 7.5% of the Indians assigned to the reservation. Ray (1977), relying on native informants and settlement data believed more reliable than government figures, estimated 5,500 Indians for the Colville reservation in the year 1872; and 5,600-5,900 for years 1855-1860. Assuming the Methow representation of 1872 applied in the earlier years of 1855-1860, a Methow Indian population of 400 to 500 people is suggested.

The Methow seem almost always to have been irretrievably lumped with the nearby Southern Okanogan (Sinkaieth), Chelan, Entiat, Wenatchi, or Columbia groups by early explorers and fur traders as well as by later government agents and ethnographers (Smith 1983b; Ruby and Brown 1986). This may be because they never were a numerous people and played only a minor role in 19th century conflicts between Indians and whites (Ruby and Brown 1986).

Population size of the individual tribes agrees reasonably well with the size of their territories. The populous Columbia roamed the large region of varied scablands east and southeast of the Columbia River. The Methow, Chelan, Entiat, and Wenatchi occupied, from north to south, the very deep and steep-sided valleys along the eastern slope of the Cascade Mountains. However, while the river basin boundaries between the latter four tribes was quite precise, with estimated populations levels roughly correlated with basin size, the Methow territory overlapped with that of the Southern Okanogan tribe to the east. One Methow band, the Chillwists, is even known to have wintered along the lower Okanogan River, wedged between two Southern Okanogan bands (Walters 1938).

The Okanogan and Methow River Basins appear similar on a map, but a closer examination shows that the basins are quite diverse (Orsborn and Sood 1973). The Methow Basin lies south of the Canadian border between the crest of the Cascade Mountains, and it parallels the Okanogan Basin which is less rugged with vegetation more characteristic of lowlands. The confluences of the two rivers with the Columbia River are less than 10 miles apart. Typically, the winter focus of the tribes was in the more sheltered locations along the river bottoms. The lower Okanogan River afforded a much more moderate climate (e.g., average January temperature of 23.8° F at Okanogan and 27.6° F at confluence) than the higher elevations on the Methow River (e.g., 17.9° F at Winthrop) (USDA 1941). Thus, while the Methow River fronted the Columbia River, as in the case of the river valleys to the south, physical barriers between the Methow and Okanogan rivers were less formidable in terms of the subsistence quest.

The Methow, Chelan, Entiat, and Wenatchi tribes shared a sub-culture of the north central Plateau pattern that did not vary greatly from tribe to tribe; there was amicable intercourse among all the Salish tribes (Ray 1977). During the salmon seasons, tribes from great distances congregated at fishing sites for fishing, trading, and socializing. If few salmon were being caught in the home territory, any band was welcome to fish in neighboring territory. Many Northern Okanogan from Okanogan Lake and the upper part of the Okanogan River (spelled "Okanagan" in Canada and "Okanogan" in the United States), where salmon were scarce, went to the lower Okanogan River to fish for salmon. Similarly, the Lake Indians of British Columbia went to Kettle Falls and other places along the Columbia River in the home territory of the Colville (Walters 1938; Ray 1972). Moreover, the large catches of salmon taken at the great communal fisheries were divided equally among all present (Ray 1977), at least once the runs were well underway (Chance 1973).

These facts make it difficult to estimate a harvest of fish for the Methow Indians. The difficulty is intensified because Okanogan summer camps at good fishing stations were composed indiscriminately of families from any of the four bands and from neighboring tribes (Walters 1938).

Little is known about the subsistence quest of the Methow. Presumably, it was similar to that of the Southern Okanogan; the Methow (Chillwists) band wedged between two Okanogan bands possessed similar customs and intermarried (Walters 1938).

The foods consumed by lower Okanogan River natives were typical of those eaten by nearby tribes with only minor variations. They took every variety of fish and game, root and berry available--even moss and the cambium layer of pine trees. Very little camas grew in the valley and no bitterroot, but these foods were available through trade and trips to root grounds (e.g., Camas

Meadows west of Cashmere in the Wenatchee Valley; Winthrop area in the Methow Valley [Post 1938]).

The nomadic summer generally began during the last of April, when many families would go to McLaughlin Falls (the lower falls or rapids 20 miles below Oroville) to catch and dry enough suckers to last until the first salmon runs in June. The run of steelhead at this season was not so important on the Okanogan River, but on other streams (e.g., Sanpoil River) people would gather to fish for them. From these locations some people went directly to the summer salmon camps along the Okanogan and to Kettle Falls on the Columbia River (Post 1938).

During late April and May the people remaining in the winter villages left for the bitterroot areas on the Columbia Plateau, in the Methow Valley, or the camas lands to the south. From June to October the salmon were running, and the bulk of the roots and berries ripening along the rivers. The people were then living in semi-permanent camps at the salmon weirs and traps or temporarily at the berry and root grounds. During October came the hunts for deer in the hills. Some families camped at the mouth of the Okanogan to spear dog salmon (chinook with large canine teeth and dog-like snouts). Nearly all were settled in winter quarters by the middle of November (Post 1938).

Each family would go to the same general vicinity each year for hunting, fishing, digging, or berrying, and almost always wintered at the same site. The band wintering above the present location of Omak (RM 32) hunted east above Moses Mountain and Omak Lake; the band wintering near Monse (RM 5) went west into the Methow River country (Twisp) for summer hunting, returning in September for salmon fishing in the Okanogan River (Post 1938).

Fisheries of major importance occurred at the upper falls (Oroville rapids below Osoyoos Lake), and lower falls (Mclaughlin Falls), and near the mouth (Monse) of the Okanogan River. This river originates in Canada's Okanogan Lake (85,990 acres), flows through Osoyoos Lake (5,729 acres), which extends across the international boundary, and continues southward to the Columbia River--a distance of 124 miles. In the 84 miles within the United States, the river falls only 165 feet, making it ideal for fishing weirs at the few locations with shallow rapids. Sockeye salmon, destined for the upstream lakes, was the primary species harvested in summer (Craig and Suomela 1936; Post 1938; Craig and Suomela 1941; Bryant and Parkhurst 1950; Ray 1972; Koch 1976). There was also a summer-fall run of chinook salmon which spawned in the lower Similkameen River, the major tributary of the Okanogan River, and in the waters associated with the weir fishing sites on the mainstream Okanogan River (Craig and Suomela 1941). These chinook were mostly speared, at least late in the season, as were the comparatively few coho that ran in November (Post 1938; Craig and Suomela 1941). Spring chinook, which formerly entered the

Okanogan to spawn in tributaries such as Salmon and Omak creeks, were pursued with a variety of fishing gear (Post 1938; Bryant and Parkhurst 1950). Steelhead evidently were a target of opportunity almost year-round (Post 1938; Ray 1972).

In contrast to the Okanogan River, information on the fisheries of the Methow River is scanty. According to Ray (1972), the great fishery at the mouth of the Methow River was another summer gathering place of the kind described by Walters (1938) for the nearby Okanogan River. Aside from folklore, the only evidence for such a claim are the visits of David Thompson on July 7, 1811, and Alexander Ross on August 28, 1811. Thompson said only that he received a gift of three salmon from the Methow Indians (Smith 1983a). Ross described friendly crowds of natives who presented his party with an abundance of fresh salmon.

The Methow River drainage never supported an indigenous sockeye run (Mullan 1986), eliminating the species availability in early July 1811 when Thompson visited. Historically, the Methow River primarily supported runs of coho salmon, followed by steelhead trout, with some chinook salmon (Craig and Suomela 1941). Craig and Suomela found evidence only of spring chinook, although they pointed out that it was possible some summer chinook spawned in the lower Methow River.

It is likely most spring chinook would have been in headwaters areas and unavailable at the mouth of the Methow River at the time of Thompson's visit. It is also likely summer chinook could have been unavailable at the mouth of the Methow river in August, the time of Alexander Ross's visit. It is intriguingly possible that the fish presented to Ross may have been from the large run of coho salmon (Mullan 1984), now extinct, which ascended the Methow River during September and October and perhaps later (Craig and Suomela 1941).

One of the reasons the Indian fishery on the Okanogan River is comparatively well known is that it persisted into the 1930s (Bryant and Parkhurst; Ray 1977). The silence of the historical record regarding the Indian fishery on the Methow River perhaps may be traced to the early extirpation of the coho run, illustrated by the records of an early hatchery.

In 1889 a hatchery was built at the confluence of the Methow and Twisp rivers (Craig and Suomela 1941). Between 1904 and 1914, almost 12 million coho eggs were taken, representing 360 brood females annually. In 1915, a dam was constructed near the mouth of the river (Bryant and Parkhurst 1950). Because the dam was without a fishway and impassable, the upstream hatchery was moved downstream to the dam site. A total of 3.5 million coho salmon eggs were taken from 1915 to 1920. The estimated average of 194 brood females per year during this period suggests a 50% decline in the runs of coho between the periods 1904-1914 and 1915-1920. No coho salmon eggs were taken after 1920. The hatchery continued to operate until 1931, using eggs of steelhead and salmon species shipped from other hatcheries (Mullan 1984).

Folk memory suggests that fishing locations existed near the mouths of the Chewack and the Lost rivers (Bryant and Parkhurst 1950). Certainly other favorable fishing locations existed, including the hatchery location at the confluence of the Methow and Twisp rivers, also the site of the Indian village of Chilkotahp (Majors 1975), and at the mouth, near the Indian village of Little Rocky Gate (Majors 1975), where hatchery spawners were captured by seining. Fur trader Alexander Ross reported the Indian name for the Methow River as "Butte-mule-emauch," or "Salmon fall river."

The hatchery's peak egg take of 2.3 million, in 1909, suggests that the maximum run was between 3,100 and 7,800 coho salmon (780 females plus 780 males multiplied by 2 or 5, depending on a seining efficiency of 20 to 50 percent). The magnitude of the maximum escapement to the Methow River reconciles reasonably well with the estimated total run size, which included harvest in the lower Columbia River of 23,000 to 31,000 coho salmon for the drainage (Mullan 1984).

We conclude that the Methow River supported substantial runs of salmon--chinook as well as coho--available to native Americans, perhaps on a par with the runs to the nearby Okanogan River. We can only assume that Methow Indian fishing of the Okanogan River was balanced by Okanogan Indian fishing of the Methow River. Reciprocity is possibly illustrated by about 100 Chelan Indians moving into the village of Little Rocky Gate, adjacent to the great fishery (Ray 1972) at the mouth of the Methow River, when the Methow Indians moved to the Colville Reservation in the last century (Majors 1975).

Determining Factors

Indian Population Levels

Population figures for Indians in the 19th century are at best crude estimates (A. H. Smith, WSU, pers. comm.). Nevertheless, they have more usefulness and probity than the usual pageantry of thousands of Indians and millions of salmon.

Per Capita Consumption of Salmon

Pivotal to determining the pristine level of salmon abundance is knowing aboriginal population levels and per capita consumption. Ray (1977) noted that he knew of no authority who disputed Craig and Hacker's 1940 figure of one pound of salmon per person, per day, or 365 pounds per year, as a reasonable average consumption for aboriginal populations. Supposedly, 365 pounds of salmon is equivalent to somewhat less than half the minimum annual caloric requirement for an average individual. Based upon a survey by the Bureau of Indian Affairs among 55 families of Yakima, Columbia, Warm Springs, and Umatilla Indians, the U.S. Fish and Wildlife Service (1948) estimated that 795 Indian families living in the vicinity of Celilo Falls consumed an average of 1,611 pounds of fish per year each. This is .981 pounds of fish per day, per person, based on a family size of 4.5, which is in close correspondence with the figure of Craig and Hacker (1940).

The dependence on anadromous salmonids by aboriginal peoples varied according to the geographic location of any particular tribal grouping and the availability of fish at that location. The most productive fisheries were always at cascades or falls, lake outlets, or shallow rapids that impeded fish passage; and Indian tales, myths, and anecdotes abound with references (e.g., Walters 1938; Cox 1957) to such fortuitous fishing locations, alluding to their rarity. Even at such locations, however, the catch was influenced by the extent to which migrating fish had been intercepted by other groups situated downstream (Schalk 1977; Schalk and Mierendorf 1983).

The Celilo Falls Indian fishery had no parallel, and was followed by Kettle Falls in importance. Fall run chinook were most important at Celilo Falls (Schoning et al. 1951) and summer run chinook at Kettle Falls (Gilbert and Everman 1894; Kennedy 1975; Ray 1977), minimizing competition for the same resource. The summer run chinook passed Celilo Falls during the spring run off and were much less vulnerable to capture than the fall run chinook that arrived at low water. Ray (1977) estimated 1.25 pounds of fish per person, per day, of salmon and steelhead by the Colville Indians who were dependent on the Kettle Falls fishery. His text suggests, however, that the foregoing figure represents a total use, including trade. Furthermore, he concurred with the Craig and Hacker estimate of one pound of salmonids per person or 365 pounds per year and supported the use of these figures in estimates of Indian catches of salmon and steelhead from the Okanogan River upstream, prior to the late 1800s (Koch 1976).

Ray (1977) estimated that anadromous salmonids and such other fish species as sturgeon, lamprey, and suckers provided around half of the Colville subsistence. He also reported that the Colville fished more salmon than any of the other tribes within the Colville Confederated Tribes group. They and the Southern Okanogan reportedly engaged in more intertribal trade than their immediate neighbors (Walters 1938; Ray 1972); and dried salmon brought them the greatest variety and quantity of other goods in trade.

The Sanpoil tribe, a key group among what became known as the Colville Confederated Tribes, engaged only minimally in these trading activities (Ray 1972). According to Ray, the Sanpoil were not disposed to jeopardize their winter food supply by trading, and their isolation and annual subsistence quest (NPPC 1986), similar to that of the Wenatchi, kept them out of the trade that characterized the Colville and the Okanogan.

Post (1938) estimated that vegetable food constituted 50% of the subsistence of natives along the Okanogan River, while game made up 25% and fish 25%. Post (1938) noted that 20 salmon were stored in a single sack and that each family stored about 10 sacks of these and as many of deer meat for winter subsistence.

Packages of furs, buffalo pemmican, and salmon in the historical period weighed 90 to 100 pounds each (two packages per horse) (Devoto 1953; Schalk 1986). Thus, if each family stored 900 to 1,000 pounds of salmon for subsistence between the last of the salmon runs in November to the first of the salmon runs beginning the following June, and the average family size was 4 to 5, the salmon consumption during the six month period would be 1.0-1.2 pounds per day per family member.

While the above figures are in close agreement with other per capita fish-consumption figures discussed, none include the use of a variety of other fishes, which were available and eaten. The importance of suckers to the Okanogan has been noted. Besides suckers, lampreys, whitefish, trout, and squawfish were taken (Post 1938). Although middens of mussel shells have been reported all along the Okanogan River (Grabert 1968), such anthropologists as Post and Ray have tended to discount the importance of such animal intake. Ray (1972) did, however recognize as significant the sturgeon catch at Kettle Falls, though overshadowed by the salmon catch.

The questions raised by the use of nonanadromous fishes by native people are matched in interest by those surrounding the role of spent salmon carcasses. The Lewis and Clark journal of October 17, 1805 (Devoto 1953) reads:

> The number of dead salmon on the shores and floating in the river is incredible to say--and at this season they have only to collect the fish, split them open and dry them on their Scaffolds on which they have great numbers.

Along the Okanogan River, these dog salmon--so-called because of the prominence of canine-like teeth at this stage of the life-cycle--were roasted immediately or hung on poles, minus head, tail, and backbone, out of reach of coyote over the winter; coho taken in November and not eaten immediately were hung in the eaves of the houses (Post 1938). Despite the aura of the partially decomposed fall chinook, which along with the coho were allowed to freeze and thaw and deteriorate further over the winter, they were said to have tasted good (Post 1938).

Were such fish a form of insurance against starvation? The fact that most families kept the surplus of each season's catch of dried salmon for two or three years, wormy though it may have been, suggests this was the case (Post 1938). Expendable fish stores also could have been opportunistically bartered with neighboring tribal groups having an excess of some other commodity (e.g., Okanogan salmon for Chelan roots).

Importance of Other Food Resources

Hunn (1981) has argued that anthropologists tend to overestimate the general importance of anadromous salmonids in native subsistence over the Columbia River plateau, while they underestimate root resources. Such a bias, he suggests, is partly a result of male anthropologists' tendency to collect information from male informants. The more glamorous, male-oriented, hunting and fishing were overemphasized. Soil-grubbing has little glamour, and root gatherers were women.

The importance of salmon is usually recognized as the key factor that accounts for the high population densities, large villages, and other unusual features of Northwest fishing societies (Schalk 1986). However, the Columbia, Wenatchi, Entiat, Chelan, and Okanogan were also dependent on other food.

Chief Moses of the Columbia was the most articulate spokesman for all North Central Washington Indians in the last century (Ruby and Brown 1965). In a letter from Moses to the Seattle Daily Intelligence, describing his negotiations in establishing a reservation while in the nation's capital in 1879, he wrote:

> People who raise hogs in my country must go with their hogs, because they kill out the young camas, and to kill that is to starve us. It's our bread and we cannot eat with earth. . .

Congregations of Indians along river corridors gave fishing encampments a high ethnohistoric profile and presented the illusion of sole dependence on salmon and steelhead. To overlook the importance of hunting is not surprising considering the dispersed and remote hunting camps compared to gatherings at fishing sites, with salmon straining the drying racks, but to do so trivializes the crucial subsistence role of hunting and the rich cultural traditions associated with it.

At least a few Okanogan Indians preferred hunting and lived scattered in the hills, subsisting mainly on deer (Post 1938). Fresh deer meat was preferred by the Okanogan tribe to all other food and was equal to salmon as food preserved for winter. Most Okanogans participated in great deer drives in the fall. Sophisticated hunting technologies--employing dogs, fences, drives, traps, snares, nets, and bows-and-arrows--point to something more than fortuitous foraging. This is reinforced by the diverse uses and preparations of the meat, blood, fat, bones, brain, hide, intestines, and internal organs. The celebrated status of deer is unmistakably evidenced by rituals and taboos, bestowed only on critical forms of sustenance or other spiritual elements of life.

Bears were hunted spring through fall by the most skillful hunters (Post 1938). Deadfall traps were operated in the spring. Bear meat was mostly eaten fresh but some pemmican was prepared. Bear hunting, however, seemed to have more cultural than subsistence significance, in that the crowning status of manhood was to kill a grizzly bear unassisted.

Small game was taken at all seasons, mostly by boys, older people, or women between berrying and root-digging (Post 1938). Rabbits (cottontails and jack rabbits), beaver, marmots, ground squirrels, ducks and geese (when molting), several types of grouse, and a wide variety of other birds were most commonly taken. Large quantities of bird eggs were gathered by children and older girls. Although welcomed and frequently used to supplement or replace the staples, small game did not merit ceremony.

Waste Loss Factor

Schalk (1986) used a waste loss factor of 20% in revising Hewes' (1947) salmon consumption estimates by Indian groups. This seems excessive as the literature is replete with references to the fact that native people, living under the constant threat of starvation, wasted little.

Post (1938) described three methods of preparing salmon heads by the Okanogan. (Pertinently, supermarkets currently sell smoked salmon heads at $5.00 to $6.00 per pound.) According to Post (1938), the Okanogan always ate the eyes (but never uncooked). The same author described how the viscera, along with blood clots, was boiled with berries, to create a specialty dish; and how bones, fins, gills, and cartilage from feasts of roasted salmon were collected and prepared to create another. Salmon eggs, prepared in various ways, were a treat for all the tribes (Post 1938; Scheuerman 1982); Colvilles even dug them from redds at low water in the Columbia River. Hearts and livers were eaten; even the oil from roasting salmon was collected and used. Obviously, the waste factor of a salmon amounted to bones only, under 10% of body weight.

Calorie Losses as a Result of Migration

Hunn (1981) criticized the neglect of calorie loss in the Indian salmon consumption estimates of Hewes and others (Schalk 1986). Schalk revised the Hewes' estimates so as to include a calorie loss in relation to migration distance traveled.

Caloric losses in salmon are generally related to mileage of migration, but not directly. Work and temperature between cessation of ocean feeding and completion of spawning is a more appropriate measure (Don Chapman Consultants, pers. comm.). Idler and Clemens (1959) show much higher energy expenditures by sockeye in some river reaches than others, and higher rates (by 17%) for females than males. In other words, caloric content is not linear in relation to distance.

Caloric loss during migration may be largely compensated for in averaging the mean weight of salmon caught within a subbasin of the Columbia River. With cessation of ocean feeding, the gonads undergo differentiation. Upon re-entering fresh water, the gonad mass of salmon is very small, but with migration increases drastically. By the time of spawning the gonad mass of coho, for example, may be nearly half the body weight (Hasler and Scholz 1983). In migration and maturation, the fish mobilize fat reserves and resorb organs (e.g., gastro-intestinal tract). Thus they lose weight, but not necessarily caloric content, between cessation of ocean feeding and nominal freshwater capture.

Miscellaneous

Schalk (1986) also argued that allowances be made for the use of salmon for dog food and fire fuel in relating pristine salmon abundance to Indian cultures. Dogs probably got what humans didn't want, as a converter of waste salmon to a usable form in a starvation period (Post 1938).

Use of old and deteriorating salmon stores as fuel by Indians in the vicinity of Celilo Falls, a location noted by Lewis and Clark (Devoto 1953) and others as lacking in firewood, would seem a possibility. Firewood in mid-Columbia River tributaries would not seem to have been a limiting factor to human habitation, judging from the permanency and size of villages used year-round (e.g., village of about 400 Wenatchi at Cashmere, Washington).

Estimates of Aboriginal Fish Catches

It is reasonable to conclude that no more than 1,000 Indians relied on the salmon and steelhead runs in the Wenatchee River. Wenatchi and other Indian groups (e.g., Columbia at Rock Island) situated downstream of the mouth of the Wenatchee River along the Columbia River relied to an unknown extent on fish destined for the Wenatchee River. This interception cannot be differentiated any more than that at Celilo Falls and other downstream fishing sites.

Maximum population estimates for the Entiat and Methow rivers in the mid-19th century are 140 and 500 Indians, respectively. It is probable that the Entiat Indians relied on fish primarily from the Columbia River, though we assume that 50% of their catch came from the Entiat River.

We assumed one pound of salmon per day as a reasonable per capita consumption. We assumed a total use of 1.25 pounds per capita, allowing for that portion of the catch not consumed to be traded with neighboring Indian groups who made only limited use of salmon (e.g., Chelan, the majority of the Columbia). We did not correct for a waste loss factor believing that the catch of nonanadromous fishes probably more than compensated for such loss. We ignored migration calorie loss, an omission offset by other factors noted.

Using the above functions we arrive at aboriginal catches of 456,250, 31,938, and 228,125 pounds of anadromous salmonids from the Wenatchee, Entiat, and Methow rivers, respectively. It is difficult to convert these numbers to numbers of fish because the proportion of the catch represented by any particular species cannot be determined with any precision. Loose inference from the historical information suggests that sockeye were mostly caught in the Wenatchee, chinook in the Entiat, and coho in the Methow drainage.

For converting the catch by indigenous people to numbers of fish, we assumed that the primary species caught in each of the river systems amounted to about half of the weight. For example, half of the catch in the Methow River translates to about 12,000 coho salmon, with an average weight of 9.5 pounds. This is a harvest rate of 39% of the maximum habitat estimate of 31,000 coho salmon returning to the river in the last century (Mullan 1984). A harvest rate of 39% fits reasonably well with the early hatchery seining efficiency of 20 to 50% for brood stock coho in the Methow River (Mullan 1984), an average minimum harvest rate of 34% (range 20 to 47%) for fall chinook, which also returned at low water, in the Indian dip net fishing at Celilo Falls in the period 1938-50 (Mullan 1986), and an overall maximum fishing rate of 29 to 33% by Columbia River Indians in the 19th century (Chapman 1986).

The last step in this logic-train is to assign a catch value to steelhead, with the difference between the combined steelhead and coho portions of the catch representing chinook. Steelhead comprised about 5%, by number and weight, of the anadromous salmonids in the Columbia River (Chapman 1986). Because steelhead were relatively ubiquitous, we used 5% in converting catch weight to numbers for all the drainages.

The procedure is repeated for the aboriginal catches from the Wenatchee and Entiat rivers with appropriate modification (Table 1). Habitat-based estimates of numbers of coho salmon are 6,000-7,000 for the Wenatchee Drainage and 9,000-13,000 for the Entiat Drainage (Mullan 1984). We used only a 20% fishing rate (minimum of seining efficiency range for Methow River) on coho salmon in the Wenatchee, reasoning that major demand for salmon likely was satisfied by earlier arriving sockeye salmon.

Mean weights of species are critical in converting fish catches to numbers. Chapman (1986) shows some striking differences in the mean weights of salmon and steelhead landed in the lower Columbia River between the 19th and 20th centuries, after some stocks had been eliminated. Moreover, remaining stocks may not be typical of original stocks because of hatchery releases, translocation of stocks, or genetic alteration through overfishing. In an attempt to consistently estimate the mean weights of fish species as they may have once existed, we used 14.0 pounds for chinook salmon, 9.5 pounds for coho salmon, 3.0 pounds for sockeye salmon, and 9.4 pounds for steelhead (Fulton and Pearson 1981 assessed mean weights of initial hatchery progeny from mostly wild stocks collected at Rock Island Dam as part of the salvage of up-river runs blocked by Grand Coulee Dam.)

The mean weight of 14.0 pounds for chinook salmon was assessed from a sample of only 1,092 fish. It is also suspect in being significantly smaller than mean weights typically reported for chinook salmon from the lower Columbia River (e.g., Smith 1895 in Chapman 1986; Young and Robinson 1974; Beiningen 1976). However, it is interesting that John Work estimated the mean weight of chinook salmon caught at Kettle Falls as only 16 pounds. (He referred to mostly summer chinook as did Fulton and Pearson 1981.) Craig and Hacker (1940) had assumed 20 pounds and so did Wilkes (1845; reviewed by Chance 1973). Chance believed Work's mean weight of 16 pounds to be most reliable because Work had charge of rationing fish to his men in the starvation of 1827-29.

Table 1. Conversion of aboriginal maximum catch weight to estimated numbers of fish.

	Wenatchee River drainage	Entiat River drainage	Methow River drainage
Total Catch in Pounds	456,250	31,938	228,125
SOCKEYE			
Number	76,042		
Weight	228,125		
(% of total wt.)	(50%)		
STEELHEAD			
Number	2,427	170	1,213
Weight	22,812	1,597	11,406
(% of total wt.)	(5%)	(5%)	(5%)
COHO			
Number	1,300	1,513	12,006
Weight	12,350	14,372	114,062
(% of total wt.)	(2%)	(45%)	(50%)
CHINOOK			
Number	13,783	1,141	8,066
Weight	192,963	15,969	112,923
(% of total wt.)	(43%)	(50%)	(45%)

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APPENDIX H

DETERMINANTS OF STEELHEAD ABUNDANCE IN THE MID- AND UPPER-COLUMBIA RIVER, 1800s-1991

by

Kenneth R. Williams and James W. Mullan

In this appendix we develop pre- and post-hydroelectric development run sizes needed for understanding population dynamics of steelhead in the mid-Columbia River. First, we describe the distribution, relative abundance, and aboriginal harvest of steelhead from the ethnohistoric record. Next, we develop recruitment curves to ascertain carrying capacity and maximum sustained yield (MSY). Last, we assess effects of the Grand Coulee Fish Maintenance Project (GCFMP) and hatchery steelhead.

Methods

We used Ricker ($R = aSe^{-bs}$) and Beverton-Holt ($R = S/(S*a+b)$) models (Ricker 1975) to develop recruitment curves (R = number of recruits; S = number of spawners; a and b are parameters in the models, derived from linear regressions). The curves were fitted with SAS (1988).

Smolt production was calculated from observed juvenile densities in the Wenatchee, Entiat, and Methow rivers (Tables 6 and 8, main report), and from life history (Chapter 5 and Appendix K), including 349 naturally spawned (wild), adult steelhead from the Wells Hatchery broodstock, 1982-90.

Early Development (1933-54)

Rock Island Dam (RM 453) steelhead counts were converted from calendar year (published counts) to cycle totals (i.e., fall count of year y added to spring count of y+1) (Table 1). Incomplete counts were expanded from mean percentages of steelhead passing at weekly intervals in years when counting was complete. Counts were then increased 5.0% to account for fish failing to pass the dam (NPPC 1986; Pratt and Chapman 1989).

Table 1. Annual harvest rate, escapement to Rock Island Dam, and total run size of wild steelhead originating above Rock Island Dam, 1933-61.

Run cycle	Rock Island Dam count			Harvest rate (%) [c]			Escapement (%)	Total run at ocean
	Published count	Corrected count[a]	Expanded for dam loss[b]	Commercial[d]	Sport	Total		
1933-34	1055	3326	3501	68.2	0.1	68.3	31.7	11609
1934-35	583	2232	2349	67.8	0.1	67.9	32.1	7697
1935-36	5418	5358	5640	66.2	0.1	66.3	33.7	17601
1936-37	2373	3380	3558	72.0	0.1	72.1	27.9	13409
1937-38	2214	3572	3760	68.0	0.1	68.1	31.9	12396
1938-39	2399	2314	2571	72.6	0.1	72.6	27.4	9891
1939-40	5425	6066	6740	56.8	0.1	56.9	43.1	16460
1940-41	5220	4945	5494	66.2	0.1	66.3	33.7	17160
1941-42	3513	2277	2530	81.9	0.1	82.0	18.0	14777
1942-43	3693	3568	3964	63.4	0.1	63.5	36.5	11420
1943-44	2315	1853	2059	72.7	0.1	72.8	27.2	7961
1944-45	1338	1173	1303	75.9	0.1	76.0	24.0	5711
1945-46	1118	1553	1726	71.5	0.1	71.5	28.5	6381
1946-47	1779	1475	1639	65.6	0.1	65.7	34.3	5031
1947-48	1971	2230	2478	64.3	0.1	64.4	35.6	7319
1948-49	2360	2360	2622	61.0	0.1	61.1	38.9	7103
1949-50	2470	1599	1777	50.7	1.0	51.7	48.3	3871
1950-51	1852	2180	2422	51.3	1.1	52.4	47.6	5357
1951-52	3121	3516	3907	58.0	2.0	60.0	40.0	10291
1952-53	2883	3053	3392	47.0	1.7	48.8	51.2	6969
1953-54	4001	3662	4308	56.9	5.3	62.2	37.8	11986
1954-55	5406	5198	6115	47.7	2.5	50.2	49.8	12914
1955-56	3141	3830	4506	50.3	1.5	51.8	48.2	9849
1956-57	1540	2218	2609	49.6	1.3	50.9	49.1	5597
1957-58	3927	6461	7601	40.0	6.5	46.5	53.5	14960
1958-59	3970	6261	7366	40.1	5.1	45.1	54.9	14129
1959-60	4138	6844	8052	44.8	7.8	52.6	47.4	17877
1960-61	6226	6355	7476	44.0	4.3	48.3	51.7	15222
1961-62	7042	8714	10252	39.8	3.3	43.1	56.9	18962

[a] Corrections (incomplete counts and conversions from calendar year to run cycle) based on Fish and Hanavan (1948), the original count ledger, and Zimmer et al. 1961, Zimmer and Davidson 1961; Zimmer and Broughton 1962 and 1964.

[b] Adjusted for loss at Rock Island, Bonneville, and McNary dams; 5% - (1933-37), 10% - (1938-52), 15% - (1953-61) based on the number of turbines that were operational in the years shown (Collins et al. 1975).

[c] Commercial harvest rate includes Indian harvest.

[d] Commercial harvest rates from 1933-37 computed from $Y = 47.161 + 0.1076(X)$. Regression equation was developed by regressing harvest rate on catch. $.1 > P > .05$, $r = 0.50$

Spawning escapement was the adjusted dam count, less fish harvested upstream, plus a 2.4% prespawning loss, estimated by doubling broodstock loss observed at Wells Hatchery, 1982-89.

All salmon and steelhead were trapped in fishways at Rock Island Dam and hauled to upstream tributaries or to the new GCFMP hatcheries, 1939-43 (Fish and Hanavan 1948). We included only successfully spawned hatchery adults in escapements (Table 2).

Sport harvest estimates were available from bias-corrected punchcards starting in 1947-48 for the Columbia River and 1953-54 for the Wenatchee and Methow rivers (WDW undated). Prior to 1947, harvest above Rock Island Dam was estimated at 5.0%. Harvest for the Wenatchee and Methow rivers, 1947-52, were from the annual rate of change in Columbia River catches.

Substantial fisheries developed on the Columbia River in the 1950s above Rock Island Dam (Ayerst 1958), but data from the entire Columbia River were lumped, and punchcards were required only from December to April. We compared annual harvests of Wenatchee and Methow river steelhead in mid-Columbia River reservoirs with that from those tributaries (1982-89) to determine the percentage of total harvest. The respective percentages, 45.8 and 10.0%, were then divided into the 1947-54 Wenatchee and Methow river punchcard estimates and summed to estimate harvest above Rock Island Dam.

Total run size for mid-Columbia steelhead was derived by dividing adjusted Rock Island Dam counts by the escapement rate from downriver harvests (Table 1).

Sport harvest from the lower Columbia River before the 1949-50 cycle was estimated at 500 fish annually (0.1% of total run) (WDW undated). Starting with the 1949-50 cycle, sport harvest estimates were extrapolated from December-April punchcard returns. First, the annual total was computed by dividing the December-April return by 0.342, the mean percentage that the reported period represented for the year, 1962-66. Second, the total sport catch (including the Oregon component) was divided by 0.478, which was the mean percentage of Washington sport catch below Bonneville Dam, 1964-68 (ODFW and WDF 1988; WDW undated). The final adjustment involved reducing estimates of the June through August (A-run destined for the mid-Columbia) harvest (multiplied by 0.528), which was the mean A-run harvest component of Washington catch from 1962-66 (WDW undated). Escapement rate was the commercial and Indian (Beiningen 1976) and sport catch divided by run size.

Before Bonneville Dam in 1938, there were no estimates of run size that allowed calculation of harvest rates. We regressed the harvest rate on catch (Beiningen 1976), 1938-50, ($P<0.01, r^2 = 0.50$) to estimate the harvest rate, 1933-37.

Table 2. Stock-recruitment data for adult steelhead above Rock Island Dam, 1933-53. To track chronology of brood return start with the first number in the 2.1 age class column and move across the column head diagonal through the >5.1 column. Shifting up to the head of the 2.2 column and traversing the 2-ocean column head diagonal identifies all recruits produced from the 1934 broodyear (1933-34 run cycle). Recruit total for each broodyear is listed in the last column and correspond to the appropriate broodyear in column one. For example, 12,507 recruits are estimated to have been produced from 3,084 spawners of broodyear 1934.

Cycle year	Spawning escapement	Cycle count (mouth Col. R.)	Age class									Recruits per broodyear (mouth Col. R.)
			2.1	3.1	4.1	5.1	>5.1	2.2	3.2	4.2	>4.2	
			Mean percentage of age class									
			16.0	8.9	4.6	0.6	0.3	41.3	24.4	3.2	0.6	
1933-34	3084											12507
1934-35	2069											15486
1935-36	4968											16039
1936-37	3134											13829
1937-38	3313	12396	1983									10681
1938-39	2437	9891	1582	880				4085				7768
1939-40	5725	16460	2634	1465	757			6798	4016			6249
1940-41	1881	17160	2746	1527	789	103		7087	4187	549		5918
1941-42	1195	14777	2364	1315	680	89	44	6103	3606	473	89	5974
1942-43	1587	11420	1827	1016	525	69	34	4717	2787	365	69	6734
1943-44	1345	7961	1274	709	366	48	24	3288	1943	255	48	6156
1944-45	1088	5711	914	508	263	34	17	2359	1394	183	34	5087
1945-46	1440	6381	1021	568	294	38	19	2635	1557	204	38	6666
1946-47	1368	5031	805	448	231	30	15	2078	1228	161	30	8616
1947-48	2150	7319	1171	651	337	44	22	3023	1786	234	44	9200
1948-49	2277	7103	1137	632	327	43	21	2934	1733	227	43	11302
1949-50	1437	3871	619	345	178	23	12	1599	945	124	23	11604
1950-51	1995	5357	857	477	246	32	16	2212	1307	171	32	9329
1951-52	3088	10291	1647	916	473	62	31	4250	2511	329	62	9422
1952-53	2487	6969	1115	620	321	42	21	2878	1700	223	42	13319
1953-54	1941	11986	1918	1067	551	72	36	4950	2925	384	72	15420
1954-55	4446	12914	2066	1149	594	77	39	5334	3151	413	77	16557
1955-56		9849	1576	877	453	59	30	4067	2403	315	59	
1956-57		5597	895	498	257	34	17	2311	1366	179	34	
1957-58		14960	2394	1331	688	90	45	6178	3650	479	90	
1958-59		14129	2261	1257	650	85	42	5835	3447	452	85	
1959-60		17877		1591	822	107	54	7383	4362	572	107	
1960-61		15222			700	91	46		3714	487	91	
1961-62		18962				114	57			607	114	
							62				125	

Recruitment from a given brood year was the sum of all cohort age classes (Table 2). The first age class to return was 2.1 (2 freshwater years and 1 ocean year); they spawned at age-4. For example, age-2.1 recruits from the 1933-34 run cycle (1934 broodyear) returned summer-fall, 1937, and spawned in spring 1938.

The number of age-2.1 fish from the 1934 brood year was derived from the percentage of this cohort (16.0%) among the 12,396 returning adults of the 1937-38 cycle (Table 2). Age-3.1 and -2.2 adults returned concurrently, amounting to 50.2% (8.9% plus 41.3%) of the 8,902 returning adults of the 1938-39 run cycle, the single largest return for a given brood. The 1934 brood concluded ten years later when age-7.2 fish returned in the 1943-44 cycle. Because fish aged over 5 were rare (0.9%), we combined older age classes.

Post-Hydroelectric Development (1979-89)

The spawner-recruit analysis was confined to the Methow River above Wells Dam during post-development. Run size of the steelhead that returned above Wells Dam was back-tracked to the Columbia River mouth by a reverse recapitulation accounting of mortalities occurring as the run progressed upriver (Table 3). The initial step was to expand the Wells Dam count (including adults taken in the fishway for hatchery broodstock) by 5.0% to account for fish that did not pass the dam. Next, the number of steelhead harvested in downstream Rocky Reach Reservoir was determined from punchcards. Entiat River fish were also landed in Rocky Reach Reservoir. The ratio of steelhead taken in the Methow and Entiat rivers (WDW 1982-89) was used to estimate the Wells contribution.

In Rock Island Reservoir during July-October, when stocks were commingled, mean exposure time for Wenatchee River fish (determined by inter-dam counts) less about 75% of the run which entered the Wenatchee River and remained there (L. Brown, WDW, pers. comm.), averaged about 60 days compared to 1.23 d for Wells fish (Strickland 1965). Thus, we apportioned (1.23 x N:60d x n) the punchcard catch of Wenatchee River steelhead and those bound for Wells Dam.

The sport catch in Wanapum and Priest Rapids reservoirs was proportional to run size for upriver stocks. All have similar travel rates through these reservoirs except that about 100 steelhead may spawn in a few small tributaries of Wanapum annually.

The number of adult steelhead going upriver that were harvested in the unimpounded Hanford Reach (McNary Reservoir above Highway 12) cannot be estimated directly because of inconsistencies in counts among Ice Harbor, Priest Rapids, and McNary dams. We reasoned that the monthly harvest profile in such a terminal fishery (local stocks only) as the Wells Reservoir would be similar to that for local fish holding in the Hanford Reach. For example,

Table 3. Estimates of run size of adult steelhead originating above Wells Dam at ocean and reverse recapitulation of mortalities acting upon the run as it progressed upriver, 1982-88.

	Year							
Mortality location and type	1982	1983	1984	1985	1986	1987	1988	1989
Total run over Wells Dam (includes broodstock)	8395	20200	17353	20462	13901	6168	5010	5297
Rocky Reach Reservoir								
Inter-dam loss expansion (5%)	8837	21263	18266	21539	14633	6493	5274	5576
Sport harvest	110	295	519	375	800	322	172	178
Rock Island Reservoir								
Inter-dam loss expansion (5%)	9418	22693	19774	23067	16245	7173	5732	6057
Sport harvest	39	68	87	93	100	17	13	23
Wanapum Reservoir								
Inter-dam loss expansion (5%)	9954	23959	20906	24379	17205	7569	6048	6400
Sport harvest	2	8	12	20	5	4	17	9
Priest Rapids Reservoir								
Inter-dam loss expansion (5%)	10480	25228	22019	25683	18116	7971	6384	6746
Sport harvest	11	12	26	82	43	37	31	37
McNary Pool above Hwy 12								
Inter-dam loss expansion (5%)	11044	26569	23206	27122	19115	8430	6753	7140
Sport harvest	642	1021	1412	1460	2531	717	726	804
Indian harvest							36	
John Day Reservoir								
Inter-dam loss expansion (5%)	12301	29042	25913	30086	22785	9628	7910	8362
Dalles Reservoir								
Inter-dam loss expansion (5%)	12948	30570	27277	31669	23984	10135	8326	8802
Bonneville Reservoir								
Inter-dam loss expansion (5%)	13630	32179	28713	33336	25246	10668	8765	9265
Indian harvest rate	0.025	0.040	0.164	0.200	0.096	0.167	0.217	0.148
Indian harvest	349	1290	4714	6688	2430	1786	1902	1372
Below Bonneville Reservoir								
Inter-dam loss expansion (5%)	14714	35231	35187	42131	29133	13110	11228	11198
Sport harvest rate	0.025	0.019	0.022	0.016	0.021	0.015	0.030	0.027
Sport harvest	366	653	784	678	619	197	334	300
Total to ocean	15080	35884	35970	42809	29751	13307	11563	11498
Ocean harvest expansion (1%)	15232	36246	36333	43241	30052	13441	11680	11614
Hatchery fish	14242	35775	35425	41252	29150	12010	10619	10336
percent hatchery	0.935	0.987	0.975	0.954	0.970	0.894	0.909	0.890
Natural origin fish	990	471	908	1859	902	1432	1061	1278
Percent natural	0.065	0.013	0.025	0.043	0.030	0.107	0.091	0.110

punchcards for 1982-89 showed that 2,506 steelhead represented the mean annual harvest in Wells Reservoir and that 1,061 fish or 42.3% were taken from November 15 to July 15. This is equivalent to the November 1 to June 30 period (a two-week advancement owing to its downriver position) for the Hanford Reach when only local fish remained after upriver fish had passed. Dividing this value into the total number of local steelhead caught (818) in 1982 estimated the total harvest of local fish (1,995). This estimate was then subtracted from the punchcard estimate for adult steelhead taken in the Hanford Reach (2,865) to estimate the number of upriver fish harvested (870). The procedure was repeated for years 1983-89.

Sport harvest of steelhead destined for Wells Dam downstream between McNary Reservoir (Highway 12) and Bonneville Dam was considered negligible; it mostly occurred outside of the time-frame when Wells Dam steelhead passed (ODFW 1989; WDW 1982-89).

We assumed that all stocks were equally exploitable in Zones 1-6 fisheries (ODFW and WDF 1988) from June through August. If the harvest rate of steelhead in Zone 6 was 10%, then the size estimate for the run headed for Wells Dam at that point was expanded by 10%. The procedure was completed when run size was expanded by the harvest rate of the sport fishery in Zones 1-5.

The portion of Methow River wild steelhead was estimated by multiplying the final total by the percentage of wild fish observed at Wells Dam. Very few wild steelhead are produced in the Okanogan and Similkameen rivers, and they are not differentiated from Methow River fish. Since 1987, when all hatchery steelhead were adipose-clipped, wild fish have been protected. The resulting sport harvest of hatchery fish progressively increased the percentage of wild fish upriver. The percentage of wild fish entering the Columbia River was adjusted for this effect.

Habitat quality indexing (HQI) of densities of juvenile steelhead observed in the Wenatchee, Entiat, and Methow rivers was used to estimate smolt numbers (Table 19, main report). We assumed that winter survival, stratified by age classes, of parr was 40% (Gibbons et al. 1985). The number of survivors was reduced by 15% to reconcile the preponderance of females (65%) of wild adult steelhead 1982-90 (Appendix K, Table 6). Large or record spawning escapements (mostly hatchery fish) of steelhead from 1983 to 1986 assured full seeding. We used site-specific age and maturity to determine if fish were anadromous or resident (Appendix K).

Historical Abundance

Pre-Development

Chinook salmon commanded the attention of early settlers (Scholz et al. 1985). The steelhead was a phantom, best known for its aerial assaults on falls, but whose identity was generally a mystery on the frontier.

Aboriginals were effective fishermen, but adult steelhead were not easy prey. They passed Indian fisheries located at cascades and rapids with little delay. Spearmen found them small, elusive targets. Runs were not fully blocked by weirs and traps spanning entire stream channels (Scholz et al. 1985). Steelhead, under no biological urgency to spawn, overwinter in the Columbia River or in the deep pools of larger tributaries where they are nearly unobservable and invulnerable. At ice-out, in rising and turbid water, adult steelhead diffuse into tributaries or remote headwaters to spawn in obscurity. Iteroparity (life after spawning) precluded the easy gathering of spent carcasses.

The unique basket fishing of Kettle Falls, the most important Indian fishing area on the upper Columbia River, 80 mi upriver from the Grand Coulee Dam site, was not employed in the winter-spring because of the cold and high flows. Steelhead should have been most vulnerable at Kettle Falls because they had to pass upstream at low flows; historical accounts clearly center peak fishing in August for chinook salmon (Scholz et al. 1985). Wilkes (1852) said that harvest persisted on spawned-out chinook to September and October--a time when steelhead runs should have peaked; but there is no evidence of a directed fishery for steelhead.

Steelhead-specific fisheries occurred at many sites on the Spokane River, which enters the Columbia River below Kettle Falls, and one site on the Little Spokane River was named for steelhead (Scholz et al. 1985).

Elsewhere, steelhead were not taken by native Americans in large numbers. J.B. Adams reported that the spring run to the Wenatchee River did not attract Indians (Craig and Suomela 1941). Joe Atkins reported that his grandfather and a few other Indians built traps in Mission and Peshastin creeks to get trout and steelhead prior to salmon season (Greene 1991). Post (1938) noted that steelhead were not important for Indians on the Okanogan River. In fact, they dismantled their weirs in early October (Ross 1849) when steelhead runs should have peaked. Indians on the Sanpoil River emerged from their winter pithouses to roam the plateaus for small game and roots until returning to fish in May, when some steelhead presumably were taken (NPPC 1986).

Because Indians survived over winter on monotonous diets of dried foods and because there were frequent famines, it seems inconceivable that they would not have fished large runs of steelhead. Yet, spring fisheries most often targeted suckers, and it was this fish that was preserved and ceremonialized (Post 1938; NPPC 1986). Harold Culpus, a Warm Springs Indian, suggested that there was no steelhead ceremony because steelhead were available year around (CRITFC 1985). A more likely reason is found in his comment, "the return of chinook and other salmon each spring was a tremendous event--an embodiment of the earth mother's change from scarcity to bounty."

Early explorers raved about the size and abundance of chinook salmon in the Columbia River, not steelhead. The earliest written record involved the sport catch of 12 steelhead in the Spokane River in 1896 (Scholz et al. 1985).

Taxonomic confusion is responsible for some of the vague reporting. Indians along the upper Columbia River appeared to use the term for steelhead interchangeably with trout (Scholz et al. 1985). Six of sixteen knowledgeable settlers interviewed by Craig and Suomela (1941) confused steelhead with salmon. Post (1938) was led to believe by Okanogan Indians that spawned-out steelhead returned to the Columbia River to fatten up by winter and spawn the following spring. Nevertheless, because the information is scant on winter-early spring fishing, when steelhead could not be confused with salmon, we infer that such fishing was minor.

Scholz et al. (1985) made a series of deductions from ethnohistoric information to formulate the caloric requirements of Indians, divided by literature catch rate, to estimate run size for the upper Columbia River (500,000 fish) and the entire Columbia basin (1,200,000 fish). The Pacific Fishery Management Council used habitat data to estimate the pre-1850 production of coho salmon (PFMC 1979). From Fulton (1970), who suggested that steelhead were 1.7 times more abundant than coho, PFMC estimated a pre-1850 run of 2,042,000 steelhead. Run size during 1892, a peak year after settlers first arrived, has been estimated at between 793,000 and 1,348,000 steelhead, based on commercial catches and exploitation rates (Table 4).

Early Development

We now examine available evidence for clues of early status of steelhead and their habitat.

Mid-Columbia River.

Wenatchee River (CRM 468): The Wenatchee River was at least partially obstructed by a mill dam at Leavenworth (RM 26) in 1904-05. Dryden Dam (RM 17.6) appeared in 1908 and Tumwater Dam (RM 32) in 1909. Both had ineffective fish ladders. The Wenatchee watershed contained 23 dams and 58 irrigation diversions 1937-42 (Bryant and Parkhurst 1950).

In 1899, a hatchery was built on Chiwaukum Creek (RM 36) (Craig and Suomela 1941). Only 20,000 steelhead eggs were collected and only after the hatchery was moved down stream to Leavenworth in 1903. The hatchery was abandoned in 1931.

Table 4. Run size of adult steelhead from the Columbia River during peak years based on commercial catches and estimated exploitation rates.

Catch	Run size (1000s) Chapman 1986	Junge 1980	Northwest Power Planning Council 1986
	Peak year (1892)		
674	793 (85%) to 977 (69%)	1,348 (50%)	
810*			1,010 (80%)
	High five year mean (1892-1896)		
382	449 (85%) to 554 (69%)	764 (50%)	
566*			850 (67%)

*Includes Indian and settler catch above the range of commercial fisheries.

Table 5. Estimated adult steelhead at Methow River Hatchery, RM 6.7, 1915-21 based on egg take. Corrected totals are based on average fecundity of 5,300 eggs per female (WDF 1938) and a male /female sex ratio of 0.655 (unpublished Washington Department Wildlife, Wells Dam broodstock analyses, 1982-90).

	Craig and Suomela 1936			Corrected number of steelhead	
Year	Number of eggs (100s)	Number females	Total number adults	Females	Total adults
1915	2,015	548	1096	387	591
1916	3,037	765	1530	573	875
1917	2,962	687	1374	559	853
1918	1,841			347	530
1919	3,760	810	1620	709	1082
1920	2,399	526	1052	453	692
1921	638	129	258	120	183

Only 7 steelhead were counted over Tumwater Dam in 1935-36 (Craig and Suomela 1936). Mission and Peshastin creeks down stream were judged prime habitats; 20 steelhead were noted spawning in Mission Creek in 1936. Bryant and Parkhurst (1950) felt that runs had dwindled greatly from the early part of the century; Nason Creek (above Tumwater Dam) was identified as the leading steelhead tributary. At Tumwater Dam, counts of steelhead in 8 years between 1954 and 1967 ranged from 502 to 926, a large increase over the 1935-36 counts. Anglers reported catching 41 steelhead in the 1955-56 season (Ayerst 1958).

Half of the steelhead intercepted and relocated from Rock Island Dam 1939 to 1943 were programmed for the Wenatchee River (WDF 1938).

Entiat River (CRM 483): The Entiat River (RM 1-11) had three sawmill dams, the first of which appeared in 1898, and a hydroelectric dam. The last salmon run was reported in 1904. None of the dams remained by 1935, though 19 irrigation diversions continued to operate (Bryant and Parkhurst 1950).

Modest (Ayerst 1958; Ray 1974) to good (Bryant and Parkhurst 1950) runs of steelhead occurred in the Entiat River. The Mad River was considered a significant steelhead tributary by Bryant and Parkhurst (1950), but not by Ayerst (1958). The small Entiat River was to receive only 1/6 of the steelhead trapped at Rock Island Dam 1939-43 (WDF 1938). Anglers reported taking 15 steelhead during 1955-56, though none were reported in a pre-impoundment survey for Rocky Reach Dam on the Columbia River (Ayerst 1958). A record count of 77 steelhead over the Entiat Hatchery weir occurred in 1961, when Strickland (1961) set run size for mitigation at 50 fish.

Methow River (CRM 524): In 1915 a dam blocked the Methow River at RM 6.7; coho salmon disappeared by 1921 (Bryant and Parkhurst 1950; Mullan 1983). Nine dams and at least 59 irrigation diversions were operating in the drainage in 1934-38.

Craig and Suomela (1941) underestimated steelhead escapements in the Methow River during the 1930s. Also, they wrongly deduced from the 1915-21 Methow Hatchery egg-take data (Table 5) that runs then were larger than those counted at Rock Island Dam in 1933 and 1934 by assuming a 50:50 sex ratio and using a low fecundity value (Table 5). Conversely, they underestimated Rock Island Dam counts, which were incomplete.

Assuming that 1915 was the last year steelhead had access to the Methow River for spawning, then the 3.2-age class returning in 1920 should have been the last substantial run. A few steelhead eggs were collected in 1921, the last egg-take from any species in that river.

Steelhead were not extirpated in the Methow River, as were coho, probably because headwater dwarf forms (sensu Balon 1984) sustained the run. Some chinook salmon were dipnetted below the dam and released above it (Mullan 1987), but there is no evidence that steelhead and coho salmon were so passed, and the extirpation of coho salmon testifies to that. The dam was removed in 1929.

The Methow River was to receive 1/3 of the GCFMP fish trapped at Rock Island Dam (WDF 1938). Bryant and Parkhurst (1950) concluded that the Methow River was a large producer of steelhead; Fulton (1970) concurred. The largest catch of steelhead (66) among mid-Columbia River tributaries during the 1955-56 cycle occurred in the Methow River (Ayerst 1958). Strickland (1961) estimated the 1961 run at 600 fish. This estimate is low because it does not adequately account for steelhead overwintering in the Columbia River.

Okanogan River (CRM 534): The Okanogan River produced few steelhead. None were counted over the weir at the outlet of Osoyoos Lake, 1934-35 (Craig and Suomela 1941). Early settlers indicated that few steelhead used the Okanogan River. Anglers reported catching 12 steelhead, 1955-56 (Ayerst 1958). Strickland (1961) reported only 6 steelhead caught in the Okanogan River, 1950-60. He estimated run size at 50 fish. In the GCFMP, the Okanogan River was not considered suitable for steelhead (WDF 1938).

Salmon Creek (RM 25.7) and the Similkameen River (RM 74.1) were the main tributaries of the Okanogan River used by steelhead (Bryant and Parkhurst 1950). Salmon Creek was dammed, and the lower reaches dried by irrigation withdrawal beginning in 1916. The Similkameen River was obstructed by a 15 ft falls and dam at RM 6.0; good spawning gravel is limited to the lower 1.5 mi. Three early settlers agreed that anadromous fish did not pass the falls, while another suggested they occasionally did (Appendix J). Omak Creek produced some steelhead, and one was caught by an angler in 1961 (Strickland 1961).

Upper-Columbia River.

Sanpoil River (CRM 616): The Sanpoil River was the only tributary to the upper Columbia in which falls did not block large areas of habitat to anadromous fish. Sources prior to Grand Coulee Dam mentioned only a few steelhead (Craig and Suomela 1936; Bryant and Parkhurst 1950; Scholz et al. 1985); Fulton (1970) did not include the Sanpoil River in his atlas of steelhead habitat in the Columbia Basin.

Spokane River (CRM 643): An abundance of steelhead in the Spokane River was noted by Gilbert and Evermann in 1895. Eleven major Indian fishing sites were identified (Ray 1936). Accounts of superb sports fishing appeared in a local newspaper at the turn of the century (Scholz et al. 1985).

Chamokane Creek (RM 32.5) and the Little Spokane River (RM 56.3) were the primary spawning and rearing tributaries for steelhead. In 1909, a dam ended migrations at RM 28; by 1918, steelhead had nearly vanished from the Spokane River (Scholz et al. 1985).

Colville River (CRM 695): Impassable Myers Falls confined access to the lower four miles of the Colville River, where many salmon spawned and Indians fished (Bryant and Parkhurst 1950). Steelhead were of little importance (Fulton 1970).

Kettle River (CRM 706): Steelhead were stopped by falls at RM 25 on the Kettle River (Bryant and Parkhurst 1950; Scholz et al. 1985). Smelters may have killed fish with slag effluents, but remnant salmon persisted until Grand Coulee Dam was built. Indians reportedly placed weirs at the mouth (NPPC 1986). Fulton's (1970) atlas of steelhead habitat does not include the Kettle River.

Pend Oreille River (CRM 745.5): The record is inconclusive as to whether Big Eddy and Metaline Falls (RM 20) were passable to anadromous fish (Bryant and Parkhurst 1950; Fulton 1970; Scholz et al. 1985; NPPC 1986). Kalispell Indians primarily fished below these falls, at Kettle Falls on the Columbia River, and on the Spokane River (Scholz et al. 1985; NPPC 1986), indicating that the falls blocked fish passage or that there was little production above them. The lower 20 mi was listed in Fulton (1970) as used by steelhead.

Kootenai River (CRM 774): Upstream migrants were barred from this large drainage by Bonnington Falls at RM 20 (Bryant and Parkhurst 1950; Scholz et al. 1985; NPPC 1986). Kootenai Indians fished salmon below the falls (Scholz et al. 1985); no sources mention steelhead in this drainage.

Upper Tributaries: Only the Salmon River (near Golden) and Toby Creek (tributary to Windermere Lake) have verified salmon runs (Bryant and Parkhurst 1950; Scholz et al. 1985). High gradient, lack of spawning gravel, inaccessibility due to cascades, and high glacial silt loads and cold water created doubts about the suitability of the remaining tributaries for salmon (Bryant and Parkhurst 1950). Steelhead were not mentioned or implied as being present.

Mainstem Columbia River (Snake River at CRM 343 to source): Mitigation for inundation by Rocky Reach and Wells reservoirs was founded on the probable annual loss of 1,800 steelhead spawners in the Columbia River. These claims have no basis in fact. That maximum sport catches occurred in the areas where steelhead were found almost ready to spawn, was taken to mean that they spawned there (Strickland 1961). Dam counts and returns to Wells Hatchery show that large numbers of female steelhead remain in the Columbia River until they are almost gravid before ascending tributaries to spawn.

Fulton (1970) and Watson (1973) apparently were led to believe, by steelhead returning to Ringold Hatchery in the unimpounded Hanford Reach where they were obliged to spawn, that mainstem spawning was common before dams. We find nothing to support this notion. Extensive sampling of the Hanford Reach, 1960-80, revealed abundant chinook salmon juveniles during early spring, but no steelhead (or rainbow) fry and only a scattering of larger juveniles, except for migrating smolts (Becker 1973; Gray and Dauble 1977; C.D. Becker, pers. comm.).

The Columbia River is generally unsuitable for steelhead spawning and rearing. Assessments made before Grand Coulee Dam was built identified no steelhead spawning in the Columbia River. Spawning and rearing were found only in tributary streams (Fish and Hanavan 1948; Fulton 1970). Abundance of steelhead parr in western Washington rivers declines as gradient diminishes and stream size increases (Johnson 1985).

Summer/fall chinook salmon have adapted to the depth (spawning to 35 ft), large gravel, and thermal regime of the Columbia River. Fall spawning is an advantage because it allows early, largely uncontested, access to food resources after spring emergence, enabling fry to grow while ocean-bound at age-0. Steelhead, by contrast, spawn in spring in high-gradient, smaller tributaries, above the range of most non-salmonid competitor-predators, where they generally rear for 2 or more years before attaining requisite size for smoltification (Miller and Brannon 1981). Young steelhead cope with spring-summer emergence and are sympatric with salmon by size specific habitat segregation (Chapman and Bjornn 1969; Hanson 1977; Allee 1981; Chapter 4). But the Columbia River may provide winter refuge for steelhead pre-smolts in excess of carrying capacities of tributaries, not unlike the Salmon River, Idaho (Chapman and Bjornn 1969; Bjornn 1971).

About 300 mi of the Columbia River in Canada flows through lakes (Bryant and Parkhurst 1950). Such a large area should have reared a large number of anadromous salmonids. And it did, namely, pelagic dwelling sockeye salmon. We find no exceptions to an obligatory fluvial life history for steelhead with rubble-riffle habitat best (Hartman 1965; Nilsson 1967; Everest 1969; Allee 1981; Johnson 1985). The inescapable conclusion is that headwater lacustrine environments produced negligible numbers of steelhead. This conclusion, combined with the inaccessibility or infertility of nearly all tributary systems above the Sanpoil River, helps to explain why steelhead were confined to a relatively few tributary habitats.

There also is the possibility that adults did not migrate through the 100-mi-long Arrow Lakes in the upper Columbia River. McGregor (1986) reported that adult steelhead did not migrate through two lakes in the Thompson River, a drainage adjoining the upper Columbia River, or through lake systems in the Bella Coola, Chilcotin, Harrison, and Morice river systems in British Columbia. A few steelhead migrate through Lake Wenatchee to spawn in tributaries, but the lake is only 5 mi long and there is no evidence that it rears steelhead (Appendix D).

Steelhead presence cannot be documented above the Pend Oreille River (CRM 745.5). Even so, we interpret Bryant and Parkhurst's (1950) comment that the usual "trout were taken in the neighboring streams of Columbia Lake" (the genesis of the Columbia River), to include some form of O. mykiss. Historically, "the trout" likely included both dwarf (rainbow trout) and precocial (steelhead) forms (sensu Balon 1984), but at the present, with the dams, only the dwarf form, as suggested in a common ancestry (Utter and Allendorf 1977).

Epilog

Overfishing of preferred chinook salmon runs to the Columbia River forced commercial fishermen to turn to steelhead in the 1880s (Craig and Hacker 1940). Average catch for the five years of greatest harvest was 382,000 steelhead (1892 to 1896), with a record harvest of 674,000 fish in 1892 (Chapman 1986). Harvest then plummeted and hovered around 100,000 fish annually through the first decade of the 20th century. In 1912, the catch of steelhead escalated, peaked again in the mid-1920s at an average of about 306,000 fish, then stabilized at about 203,000 fish from 1929 to 1942.

Depressed salmon runs in mid-Columbia River tributaries became the linchpin of the GCFMP plan to salvage stocks originating above what was to be Grand Coulee Dam (WDF 1938). That salmon runs had become greatly depressed, or even moribund, in the case of coho, is unquestionable; however, inferences about the status of steelhead founded on the depressed salmon runs were dubious.

Precisely timed salmon migrations and reproduction during low water of summer-fall became a liability when even minor diversion dams blocked passage and reduced stream flows. Spawning migration under favorable spring flows, and before annual irrigation depletion allowed steelhead to pass the same obstacles that reduced or extirpated late-returning salmon. Headwater spawning of steelhead above areas of human development tended to place them out of harm's way. Although juvenile steelhead and salmon are niche-segregated in sympatry, there is evidence that this is the result of interactive segregation (Nilsson 1967). Accordingly, we would expect some increase for species living in allopathy, which was nearly the situation for steelhead at the time of the GCFMP.

Run Status

Abundance Immediately Before and Shortly After Grand Coulee Dam

Suomela (Craig and Suomela 1936) spent 8 days at Kettle Falls during the peak of the run in 1935, routinely seeing as many as five steelhead in the air attempting to jump the falls. Based on run timing at Wells Dam, 1980-87, at least 12% (44% for peak month) of a steelhead run could be expected at Kettle Falls during Suomela's visit. If half of the 5,398 fish passing Rock Island Dam (Table 1) migrated on to Kettle Falls and were delayed 1-2 days, roughly 100 fish might be present on any given day. Such a number seems compatible with Suomela's observations and the Indian catch of 126 steelhead (5%) (Craig and Suomela 1936).

Because only four data points were available before Grand Coulee Dam began reducing smolt survival in 1937, a spawner-recruit curve was not fitted (Table 2). Annual mean number of steelhead recruits before damming was 14,495, 2.33 times the mean of 6,215 immediately after (1940-43) damming.

The MSY run size and escapement were 19,169 and 7,126 steelhead, respectively, from 1940 to 1954 according to Beverton-Holt-curve analysis; Ricker curve equivalents were 16,041 and 4,904 steelhead (Fig. 1). The curves diverge only in the area of maximum recruitment. The lack of high-escapement data points confound fitting of the right limb of the curves. Chapman et al. (1982) felt that recruitment curves for salmon and steelhead in the Columbia River were most aptly described by the Ricker (1975) B curve, but agreed with Ricker that there was no valid way to select one over the other.

Chapman et al. (1982) may have overestimated escapement because they did not include sport harvest, which blossomed after World War II. Because data points responsible for the downturn of their curve's right limb were from the 1950s, there is the possibility of its shape being an artifact. Hence, recruitment, may approach maximum asymptoticality more in a Beverton-Holt's curve (A = 0.9, Ricker 1975), used to describe spawner-recruitment of Snake River steelhead (Bjornn 1977). Due to more realistic shape, however, we chose our Ricker curve MSY (16,041) and escapement (4,904) as most reliable. We then apportioned values to the Wenatchee (7,443 and 2,275), Entiat (1,363 and 417), and Methow (7,234 and 2,212) rivers, according to percentage of smolts produced (46.4%, 8.5%, and 45.1% respectively) (Table 7).

Since the number of steelhead recruits were reduced by trapping and hauling mortality at Rock Island Dam 1940-43, the 1:2.33 ratio between mid- and upper Columbia River steelhead production likely is biased for upper Columbia River fish. The earlier loss of the Spokane River stock, however, may have been

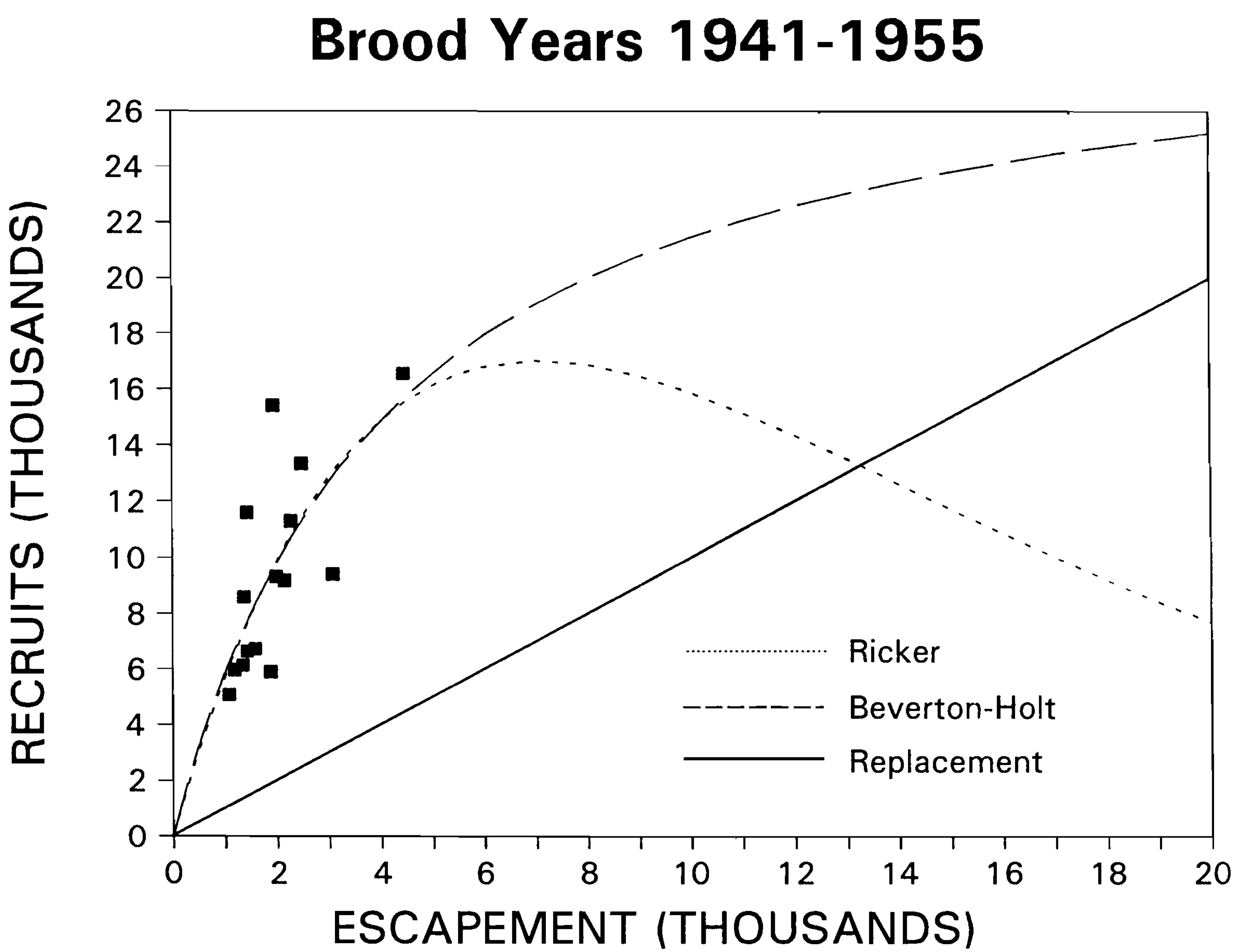

Fig. 1. Mid-Columbia River steelhead recruitment curves, 1941 - 1954.

Table 6. Stock-recruitment data for Methow River steelhead, 1982-89: (1) Extrapolated number of recruits to the mouth of the Columbia River and (2) actual number of recruits to the Methow River.

		Cycle	Age class									Recruits per	
		count	2.1	3.1	4.1	5.1	>5.1	2.2	3.2	4.2	>4.2	broodyear	
Cycle	Spawn	mouth	Mean percentage of age class									mouth	Methow
year	escape	Col. River	16.0	8.9	4.6	0.6	0.3	41.3	24.4	3.2	0.6	Col. River	River
1978-79	669											740	192
1979-80	2094											1122	256
1980-81	1261											1407	320
1981-82	1944											1221	407
1982-83	3818	990	158									1233	591
1983-84	8387	471	75	42				195				1196	614
1984-85	6718	908	145	81	42			375	222				
1985-86	6850	1859	298	165	86	11		768	454	60			
1986-87	4790	902	144	80	41	5	3	372	220	29	8		
1987-88	2935	1431	229	127	66	9	4	591	349	46	13		
1988-89	1890	1060	170	94	49	6	3	438	259	34	10		
1989-90	2170	1277	204	114	59	8	4	528	312	41	11		
1990-91						8	4			42	11		
							4				11		

Table 7. Minimum and maximum estimates of steelhead smolts based on habitat quality indexing (HQI) of observed steelhead juvenile densities in the Wenatchee, Entiat, and Methow rivers.

Age class	Number	Overwinter survival	Nonmigrants		Smolts
		Minimum production			
Age-1	172,898	69,159	10,374		58,785
Age-2	104,974	41,990	6,298		35,691
Age-3	27,787	11,115	1,667		9,448
Age-4	3,087	1,235	185		1,050
Age-5[a]					944
				Total	105,918
		Optimum production			
Age-1	378,546	151,418	22,713		128,705
Age-2	229,832	91,932	13,790		78,142
Age-3	60,838	24,335	3,650		20,685
Age-4	6,759	2,704	406		2,298
Age-5[a]					2,068
				Total	231,898

[a] Older age classes (5+ to 7+) 0.9% of smolt population.

offset by the impaired production of mid-Columbia River steelhead. We speculate that the actual ratio ranged between 1:1 and 1:2. MSY run size for all stocks above Rock Island Dam may have ranged from 32,000 to 48,000 fish. The systemwide contribution of both areas amounted to about 6% if mean counts of steelhead at Bonneville and Rock Island Dams, 1939-44, 110,320 and 3,314, respectively, are adjusted for loss due to Grand Coulee Dam (2.33X).

Abundance After Hydroelectric Development

The reduced number of wild steelhead following hydroelectric development is shown by the Methow River recruitment curves (Figs. 2 and 3, Tables 3 and 6). Although it appears that the stock cannot replace itself at any level with either curve, such a conclusion is based on only 1 or 2 data points and is sensitive to error and natural variation. Stock-recruitment theory holds that a stock can replace itself on the doorstep of oblivion, and we discuss later why this is likely the case for steelhead.

One Methow River spawner today produces only 0.18 recruits (400 recruits from 2,212 spawners), compared to 3.27 pre-development recruits (7,234 recruits from 2,212 spawners). Maximum run size is about 700 recruits.

Smolt Production Estimates

Habitat Quality Index (HQI) estimates for steelhead smolts range from 105,918 to 231,898 fish (Table 7). Other methods have been used to estimate smolt production in mid-Columbia River tributaries (Table 8). Smolt estimates by the NPPC's System Planning Model (SPM) are highest, and had the SPM model been used to estimate smolts in the Wenatchee and Entiat rivers instead of the PPP model (modified by L. Brown, WDW, and renamed the Gradient Area Flow Model [GAFM]), production estimates in the mid-Columbia River would have exceeded 600,000 smolts. That SPM estimates are unrealistic is seen in the 97,156 smolt estimate for the Okanogan River. This river is warm and sluggish, with a sandy bottom that primarily supports warmwater fishes; as discussed earlier, it enjoys little record as a producer of steelhead.

The Petersen method (ratio between marked hatchery smolts and wild smolts moving down stream; Peven and Hays 1989; Peven 1990, 1991a) also results in excessive smolt numbers. For example, the expected returns of steelhead to Wells Dam, based on 134,776 and 117,273 wild smolts for 1986 and 1987 (we assumed that the percentage of Methow River production was 45 and 48% of the 1986 and 1985 Petersen estimates; Peven 1990), were 1,456 and 844 adults, using 1.08% and 0.72% survival for hatchery fish for the same two years. Actual returns were 417 and 765 adult steelhead, respectively.

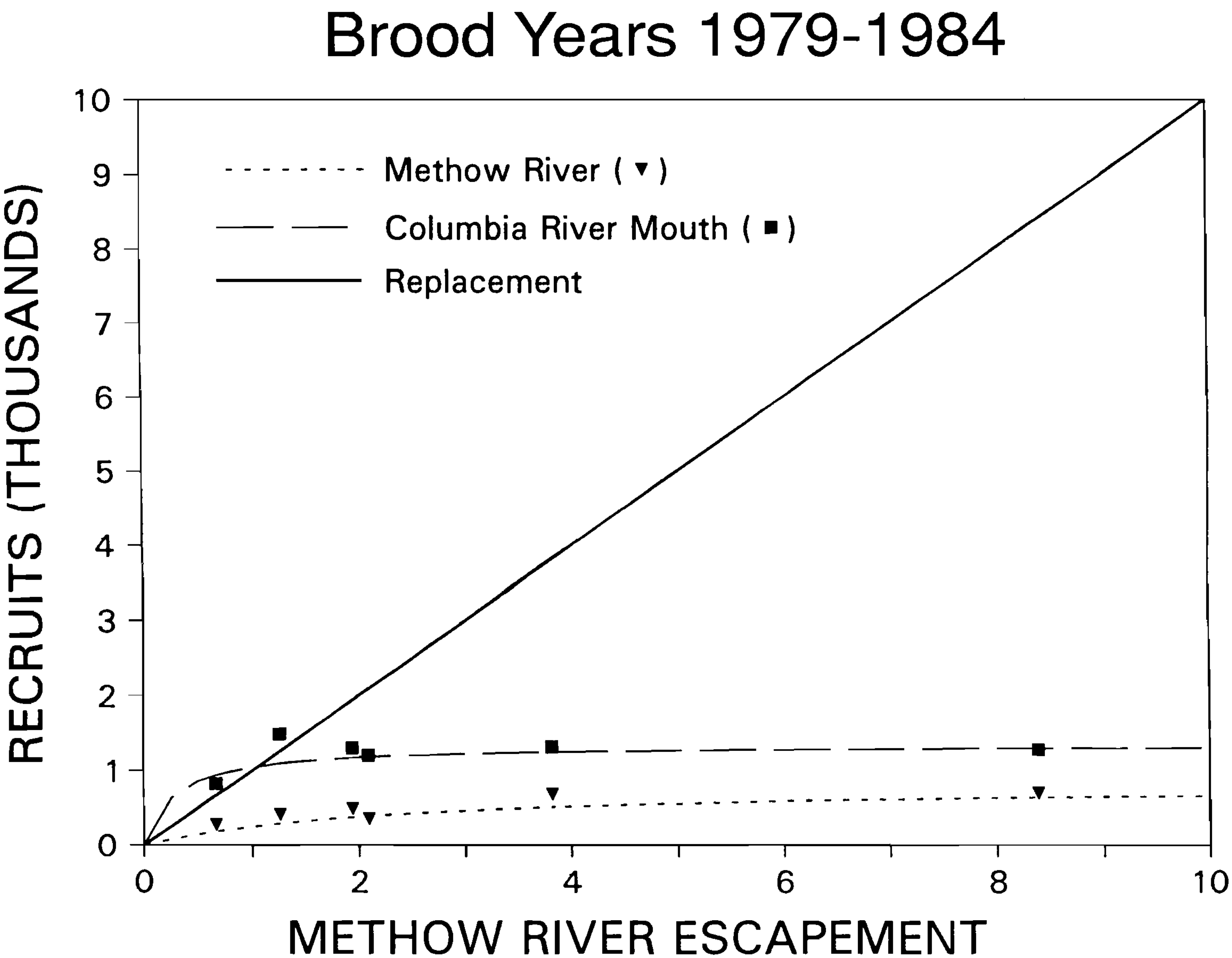

Fig. 2. Methow River steelhead recruitment curves (Beverton-Holt Model), 1979 - 1984.

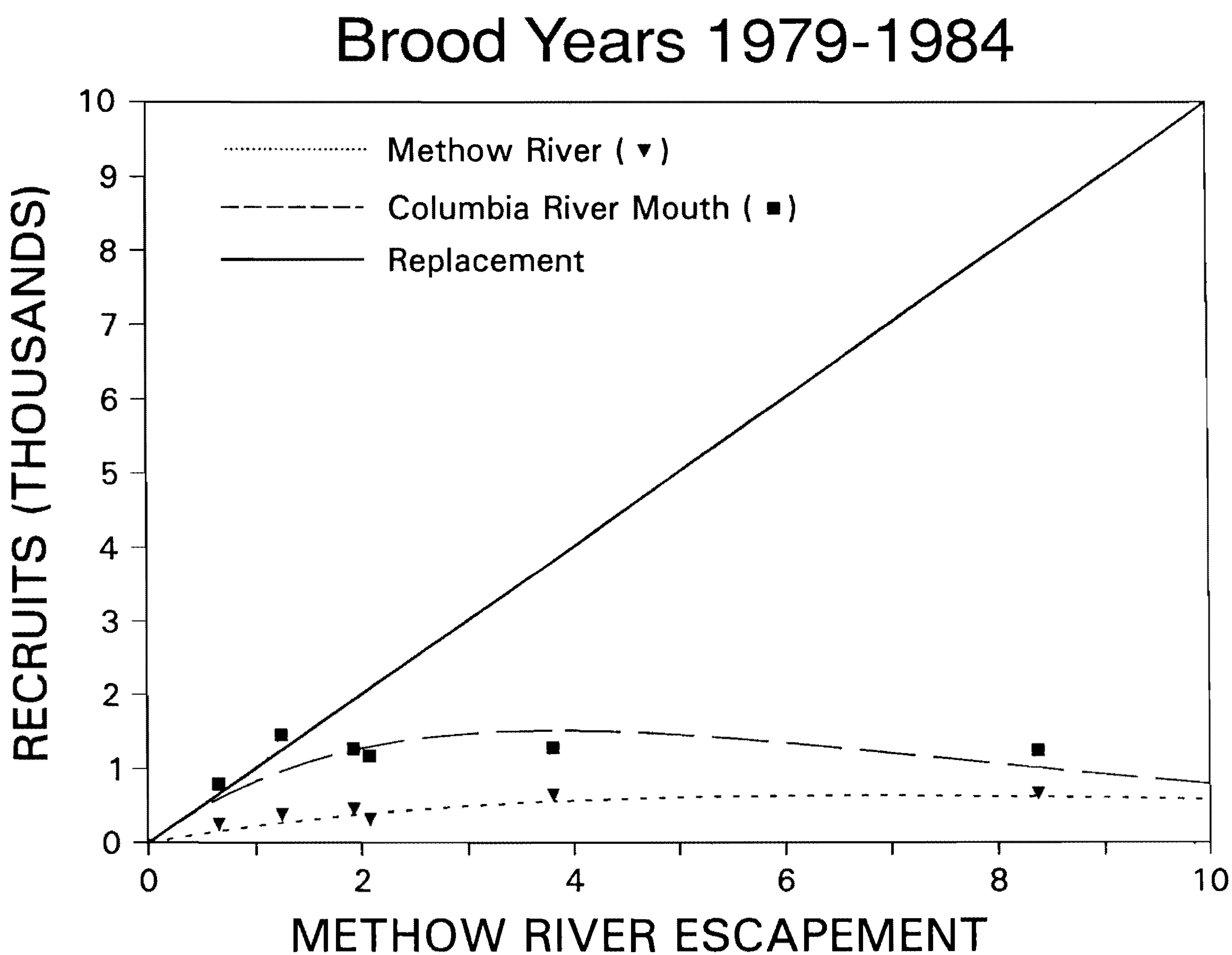

Fig. 3. Methow River steelhead recruitment curves (Ricker Model), 1979-1984.

Table 8. Estimates of steelhead smolt production in mid-Columbia River tributary streams.

Year	Method	Source	Smolts
	Wenatchee River		
1986	Petersen[a]	Peven (1990)	145,211
1987	Petersen[a]	Peven (1990)	113,056
1988	Petersen[a]	Peven (1990)	121,753
1985-87	HQI Model	Present study	49,146-107,601
1989	PPP (GAFM)Model	NPPC (1989)	100,000
	Entiat River		
1986	Petersen[a]	Peven (1990)	18,515
1987	Petersen[a]	Peven (1990)	26,134
1988	Petersen[a]	Peven (1990)	15,709
1985-87	HQI Model	Present study	9,003-19,711
1989	PPP (GAFM) Model	NPPC (1989)	22,300
	Methow River		
1985	PPP (GAFM)Model	Present study	58,552
1986	Petersen[a]	Peven (1990)	135,777
1987	Petersen[a]	Peven (1990)	117,273
1988	Petersen[a]	Peven (1990)	115,202
1985-87	HQI Model	Present study	47,769-104,586
1989	SPModel	NPPC (1989)	169,610
1987	H/W Ratio[b]	Present study	35,097
1988	H/W Ratio[b]	Present study	36,448
1989	H/W Ratio[b]	Present study	53,910
	Okanogan River		
1989	SPModel	NPPC (1989)	97,156
	Mid-Columbia River total		
1986	Petersen[b]	Peven (1990)	299,503
1987	Petersen[b]	Peven (1990)	246,321
1988	Petersen[b]	Peven (1990)	252,664
1989	Petersen[b]	Peven (1991a)	232,401
1990	Petersen[b]	Peven (1991a)	292,527
1989	SPM/PPP	NPPC (1989)	396,162
1985-87	HQI Model	Present study	105,918-231,898

[a] Life history production estimates (Peven 1990) are converted to Petersen estimates by multiplying the tributary-specific production fraction by the Petersen estimate of mid-Columbia River production (Peven 1991a). Mean production fractions of 0.475, 0.063, and 0.462 for Wenatchee, Entiat, and Methow river production agrees closely with HQI-derived fractions of 0.464, 0.085, and 0.451, respectively..

[b] Outmigration ratio of hatchery (H) to wild (W) fish as measured at Rocky Reach and Rock Island dams.

The PPP model was developed from parr densities/gradient correlations in coastal streams of Washington (Gibbons et al. 1985); its use in inland streams is untested. The model was modified (GAFM) to incorporate the older age (and higher egg-to-smolt mortality) of eastern Washington steelhead parr. It may slightly overestimate production, because the higher rates of residualism (Appendix K) that occur in mid-Columbia streams is not considered.

Extrapolating rearing densities to cover all rearing areas in the drainages according to HQI ranking produced a range in population estimates (Table 19, main report). From these data we developed estimates of standing crop that covered temporal variations in abundance (Table 7). If a homogeneous reach of stream had an HQI ranking of, say, 41 to 60, the HQI for that rearing area was multiplied by both the "average" density value (3.6 parr/100 m^2) and the "good" value (6.2 parr/100 m^2).

We tested our minimum (observed) smolt estimate by comparing pre-development run sizes of wild Methow River adults with Wells Hatchery survival rates and reported smolt-to-adult survival rates (Table 9). Mean run size for the three highest returns during the 1940-54 period was 6,810 Methow River steelhead (15,099 x .451). Our estimate of 47,769 smolts required 14% smolt-to-adult survival to achieve this run size. Such a survival was achieved in 1982 by Wells Hatchery smolts (Table 9). The highest smolt-to-adult survival for Snow Creek, Washington, a small coastal, winter-run steelhead stream, was 10.7% (R. Cooper, WDW, pers. comm.) (Table 9). The Keogh River, Vancouver Island, B.C., averaged 16.6% survival, with a high of 26.1% (Ward and Slaney 1988; B. Ward, pers. comm.).

Alternatively, if the hatchery component of the smolt population is known, the number of hatchery fish released could be used to estimate the number of wild smolts (H/W ratio estimates, Table 8). We used the return percentage of hatchery adults to estimate the hatchery component because, as we show later, hatchery and wild smolts survived at the same rate, at least for 1987-89.

We used low-range HQI values to estimate: 49,146, 9,003, and 47,769 smolts (Table 8) for the Wenatchee, Entiat, and Methow rivers, respectively, during pre-development.

Discussion

Review of Methods

To assume that the commercial fishing rate for mid-Columbia River steelhead stocks was equal to that of other stocks is risky, especially for the post-development period when fishing seasons have been short. Also, poaching, gillnet dropout, and hooking

Table 9. Percentage of steelhead smolt-to-adult survival for Wells Hatchery smolts (interior Columbia River) and for wild smolts from two coastal streams.

Year	Wells Hatchery smolts: To Wells Dam (RM 516 above nine mainstem dams)	To mouth of Columbia River (RM 0.0)	Wild smolts: Snow Creek, WA (WA Dept. Wildl. unpub.)	Keogh River, B.C. (Ward and Slaney 1988 and B. Ward pers. comm.)
1977				15.19
1978			6.51	7.41
1979			10.67	15.23
1980			5.65	8.40
1981			2.19	25.36
1982	7.31[a]	14.28	6.06	26.09
1983	3.39	7.32	10.51	15.48
1984	3.85	8.42	4.78	18.00
1985	1.72	3.99	3.51	25.00
1986	1.08	2.80	7.07	10.00
1987	0.72	1.32		
Means	3.01	6.36	6.33	16.62

[a] Survival for 1982 was extraordinary due to high Columbia River flows and high marine survival (probably an El Nino effect). Many steelhead stocks in North America had high marine survival that year, although the Snow Creek stock did not. Survival rate estimates for hatchery fish include unique sources of mortality (residualism, trapping, hauling, tagging, fin clipping, branding, sampling, and post-release predation). When such losses are considered, it is obvious that Wells Hatchery smolts frequently survive better than wild smolts from Snow Creek.

Table 10. Sequential backcalculation of inriver mortality for wild steelhead produced in the Methow River.

Year	Total number wild fish	Dam loss	%	Total tribal catch	%	Sport catch: Above Wells	%	Mid-Col. River	%	Zone 1-5	%	Combined total	%	System total loss	%
1982	990	336	33.9	31	3.1	239	24.1	52	5.3	24	2.4	315	31.8	682	68.8
1983	471	160	34.0	20	4.2	137	29.1	18	3.9	8	1.8	164	34.7	344	73.0
1984	908	277	30.4	122	13.4	225	24.8	51	5.7	20	2.2	296	32.6	694	76.5
1985	1859	557	29.9	319	17.1	482	25.9	87	4.7	29	1.6	598	32.2	1474	79.3
1986	902	280	31.0	97	10.7	202	22.4	104	1.6	19	2.1	325	36.0	702	77.8
1987	1431	457	31.9	226	15.8	0	0.0	0	0.0	0	0.0	0	0.0	683	47.7
1988	1060	334	31.5	204	19.2	0	0.0	0	0.0	0	0.0	0	0.0	539	50.8
1989	1277	421	33.0	166	13.0	0	0.0	0	0.0	0	0.0	0	0.0	587	46.0

mortality cannot be evaluated. Recently, Chapman et al. (1991) called attention to a new imponderable--predation by a growing population of harbor seals in the lower river. The problem seems less acute for steelhead than salmon. Delayed mortality in the 1990 run was not significant (x^2 = 0.92, p <0.05) for wounding rates observed at Bonneville Dam (6.1%, n = 313, L. Gilbreath, NMFS, pers. comm.), Priest Rapids Dam (3.9%, n = 435; C. Morrill, WDW, pers. comm.), and at Wells Dam (3.4%; n = 643) in contrast to a 19.2% wounding rate for chinook salmon at Lower Granite Dam on the Snake River (Chapman et al. 1991). That our theoretical run size at the Columbia River outlet reconciles well with observed returns to Wells Dam, and that it expands closely to smolt-production estimates when appropriate marine survival rates are used, indicate that our methods, and at least the sum of our mortality estimates, are reasonable. However, this is somewhat contingent upon the correctness of the inter-dam loss estimate because of its potential impact and unknown nature.

Our analysis for 1933-54 contained the minimum 15 data points (Ricker 1975), but was complicated by steelhead recolonizing the Methow River, GCFMP relocation/hatchery releases, installation of fishways and screens, and escalating terminal fisheries. Data points for high escapements would have been desirable, but high exploitation prevented this. Age data did allow us to avoid using a simplistic 5-year spawning cycle (Bjornn 1977; Chapman et al. 1982). Nevertheless, our MSY harvest fraction (70%) is similar to the 66% of Bjornn (1977) and the 69% of Chapman et al. (1982).

Spawner-recruitment analysis is an inexact tool for evaluating environmental change unless adult spawners are accurately assessed as to their age, sex, harvest, and density-independent variation (Reisenbichler 1989). The dramatic "flattering" of recruitment curves (Figs. 2 and 3) is mostly the result of fish passage problems. Habitat degradation in natal streams has been minor (Chapter 6). Arguably, our analysis is suspect by including hatchery spawners, which may be less productive than wild spawners (McIntyre and Reisenbichler 1977; Goodman 1990; Nehlsen et al. 1991; Leider et al. in press), but later we will show that hatchery steelhead are as viable as wild steelhead from smolt-to-adult.

The use of hatchery steelhead in estimating smolt production is hampered by the unknown fraction of smolts that die or do not migrate (residualize after release). Stress from handling, tagging, fin clipping, and branding, in addition to the possible effects of domestication, may directly cause death or increase post-release disease and predation.

Of pen-reared steelhead smolts released in the Keogh River, B.C., 42% failed to pass a counting fence 10K downriver compared to 100% passage for smolts released 0.4K above the fence (Ward and Slaney 1990). Similarly, 26% of hatchery-reared smolts released within 5K of the Snow Creek counting fence, failed to migrate in

1990 (R. Cooper, WDW, pers. comm.) The extent of residualism is largely unknown (Light et al. 1989), though greater for summer steelhead than for winter steelhead (Royal 1972).

Residualism amounted to 2.5% and 0.0% for winter steelhead in the Keogh River for two years (Ward and Slaney 1990). For summer steelhead, 17% of smolts released above Rock Island Dam failed to pass the dam, but residualism could not be differentiated from mortality (Peven and Hays 1989). Tag returns for smolts released above Wells Dam in 1988 showed that 2 of 28 (7.1%) fish had residualized one year (D. Sheffield, WDW, pers. comm.) to return as 1-ocean adults in 1990 and the percentage will increase if 2-ocean fish return in 1991. At Chelan Hatchery, 1979-80, 14% of production was estimated as precocious or non-migrants (L. Brown, WDW, pers. comm.), whereas 7.0% of Wells Hatchery smolts in 1991 were non-migrant, precocious males. Sexual maturity was not the sole factor determining residualism, however, as indicated by the modest (22%, n = 143) incidence of maturity among Methow River residuals (Fig. 4). Size of residual fish varied around the reported smolt size (mean, 173 mm; range 143-207 mm) (Appendix K), indicating that some fish are too small or too large (Ward and Slaney 1990).

Grand Coulee Fish Maintenance Project (GCFMP) Evaluation

The premise of the GCFMP was that steelhead were limited by habitat dysfunction. The clustering of points in early years on the ascending limb of our recruitment curve (Fig. 1) points to overfishing in the lower river. The highest landings of steelhead in this century occurred in the 1920s (Beiningen 1976). Commercial fisheries overexploited the resource (mean rate 0.75) in five of the first eight years that exploitation data became available, 1938-45 (Table 1). Considering all mortality, escapements of about 0.15 probably were common during the 20 years before the GCFMP. Ricker's curve B (Table 11-2, Ricker 1975) indicates that at an exploitation rate of 0.85, recruit numbers should have stabilized at about one-third of MSY escapement; we show that runs tripled from 1940 to 1954 as harvests were reduced (Fig. 5).

GCFMP translocation and hatchery supplementation failed to increase the number of recruits, contrary to Fish and Hanavan (1948) and Raymond (1988). Indeed, the poorest recruitment occurred during the GCFMP era (Fig. 5). The record return of 5,866 spawners in the 1939-40 cycle yielded only 6,270 recruits (Table 2). The failure stemmed from high losses of translocated broodstock, both in hatcheries and in streams.

Other Estimates of Abundance

The estimate of pre-development (1933-37) run size at 500,000 steelhead above Grand Coulee Dam by Scholz et al. (1985) is

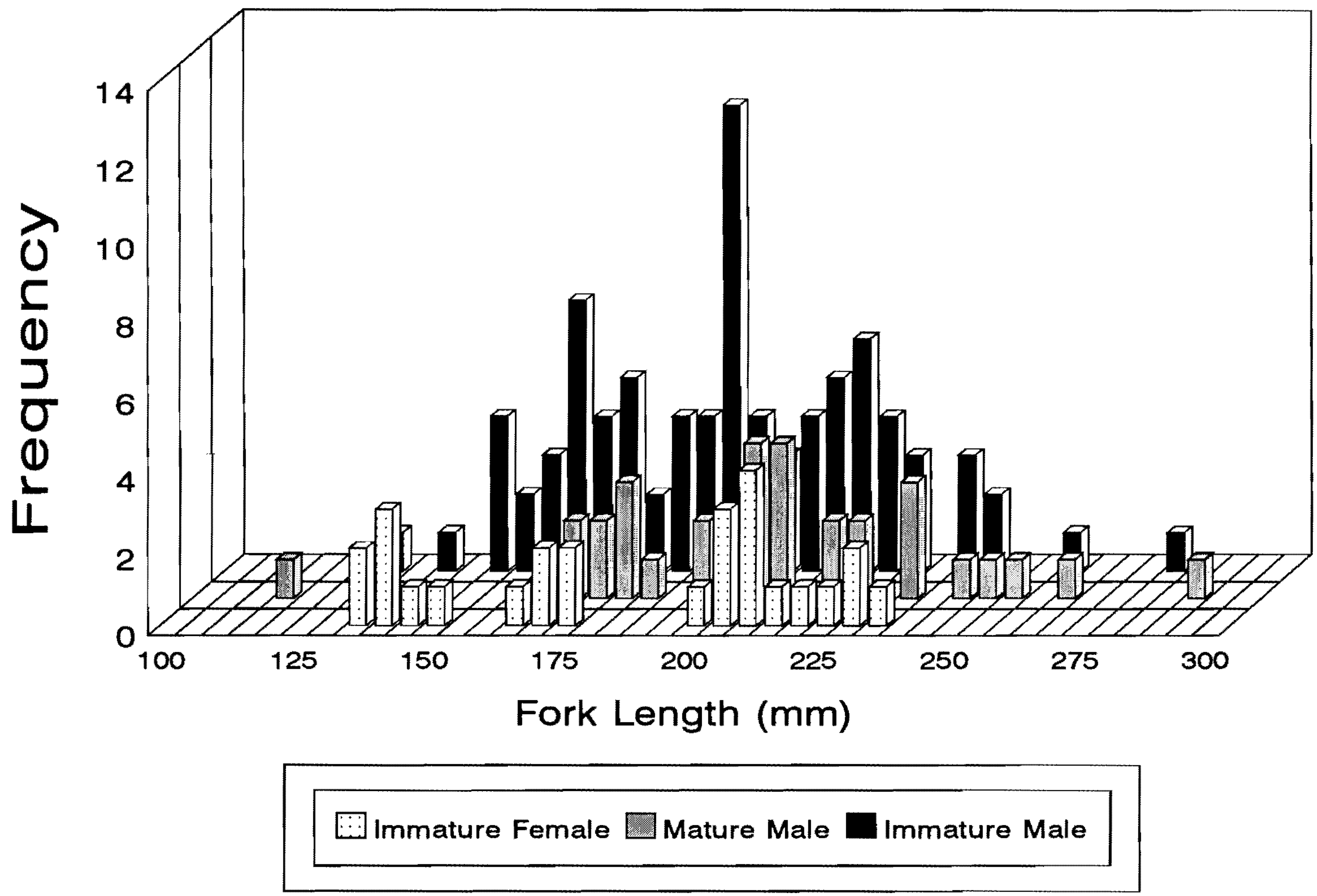

Figure 4. Length, sex and maturity of mainstem Methow River residual hatchery steelhead sampled 1985 to 1991.

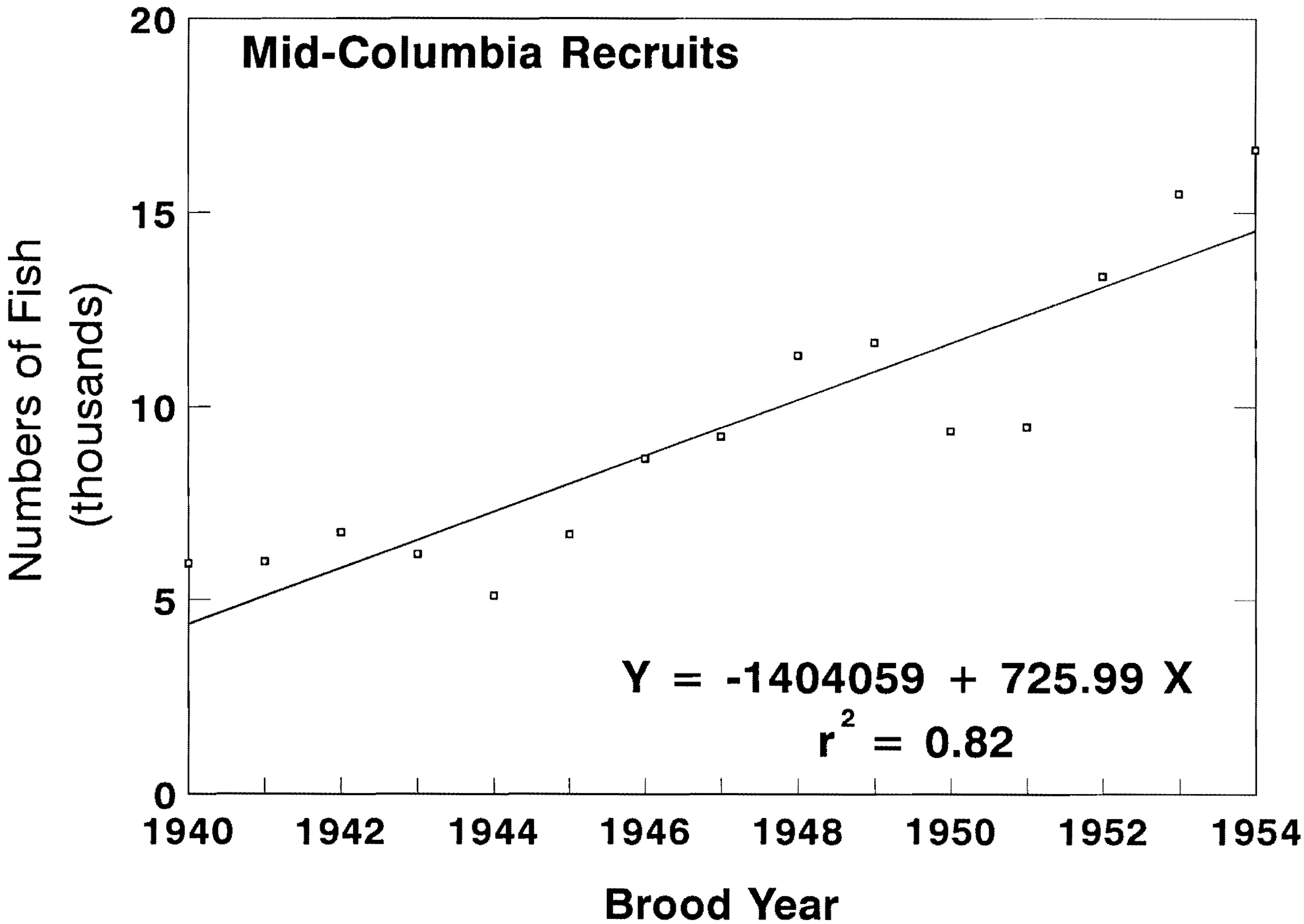

Fig. 5. Correlation between steelhead broodyear and recruits above Rock Island Dam, 1940-54 (see Table 2 for data).

unsupportable. They reasoned that the run had already been severely reduced by construction of Rock Island (1930) and Grand Coulee (1933) dams, that Rock Island Dam partially blocked runs, and that many of the steelhead that did pass Rock Island Dam were not counted.

Grand Coulee Dam did not affect passage until 5 years after counting began at Rock Island Dam (Table 2). Any loss during construction of Rock Island Dam was less than Grand Coulee Dam, because Rock Island Dam was much smaller and spilled a much greater portion of the flow.

Chinook salmon did encounter passage problems at Rock Island Dam, but not sockeye salmon. By 1936, a third fishway was installed midway in the dam and no further problems for returning adults of any species were observed (Bell 1937). Mortality of adult fish at Rock Island Dam from 1953 to 1956 was neither substantial nor consistent (French and Wahle 1964). Improvement of tag detection by counters in the 1960s likely was due to the installation of glare suppressing hydroscopes over counting boards (Paulik and Major 1966) rather than improvements to fishways as suggested by Scholz et al. We find no evidence (Weiss 1970; Monan and Liscom 1973; Junge and Carnegie 1976; Liscom et al. 1978; Raymond 1988) suggesting a lower percentage of adult steelhead passed Rock Island Dam in 1933 than the 5% loss used in our computations. We agree with Scholz et al. (1985) that some early counts at Rock Island Dam were incomplete, and we reconstructed the missing portions (Table 1).

Run size adjustments to Rock Island Dam counts, 1933-37, by Scholz et al. (1985) were based on the decline of the Indian catch of chinook salmon at Kettle Falls. For steelhead, the adjusted estimates (mean = 11,168 adults) are problematical: (1) dam counts and chinook catch, 1933-38, are not correlated (r^2=0.00); (2) the chinook salmon:steelhead ratio at Rock Island Dam far exceeds that of their ultimate run size estimates of these species; and (3) an enormous difference (79,700 vs. 500,000) remains between their expanded Rock Island Dam counts of steelhead when adjusted for mid-Columbia River stocks and catch in the lower river.

Currently, MSY escapement is 4,500 steelhead for the Wenatchee and Methow rivers. Our MSY escapement is 4,900 steelhead, which includes the Entiat and Okanogan subbasins. Recently, AITCBFWA (1990) proposed doubling MSY escapement to 9,560 adults, an excessive figure, because smolt carrying capacity is over-estimated.

Determinants of Man-Caused Mortality

Smolts: Loss of smolts at dams or in reservoirs is now recognized as the major factor reducing steelhead abundance in the Columbia River. In the Methow River the mean shortfall of 5,554 adults between pre-development run size (6,810 adults - of three peak years), 1940-54, and the mean number of recruits (1,256 adults), 1987-89, represents differences in mortality of outmigrants and marine survival between the two periods. With 48,000 smolts for the Methow River, 14% ocean survival is required to yield 6,810 adult recruits. If marine survival did not vary, then all of the 82% loss (17% per dam) between pre- and post-development can be ascribed to outmigration mortality. Marine survival during 1984-86 outmigrations for Keogh River steelhead averaged 18% (Table 9). Methow River steelhead before development likely were as viable, but we use the lowest Keogh River value of 7.4% to estimate the lower bound of outmigration loss--75% (11% loss per dam).

Adults: From a mean population of 1,033 wild adult steelhead in the Methow River (1982-86), the mean cumulative loss of adults returning past nine mainstem dams is about 322 fish (31.2%) (Table 10). Anglers harvested 338 (33.2%) on average; Indians, 126 adults (12.2%). Mortality totalled 786 adults (76.1%), leaving 247 (23.9%) to spawn.

After catch-and-release of wild steelhead, which anglers identified by presence of adipose fin, the mean number of wild fish returning to the Columbia River mouth 1987-89 was 1,274. Mean cumulative dam loss was 401 fish (31.5% of run), Indian harvest 213 (16.7%), system loss 614 (48.2%), and spawning escapement 539 (42.3%). Ending the Indian harvest would increase escapement by 138 fish (213 minus 75 fish lost to interdam travel) to 677 (53.1% of run).

Before catch-and-release for wild steelhead, 93% of the run was lost, 23% more than MSY harvest (70%) (Table 11). Ending sport and Indian harvest reduced the total loss to 80%. In reality the situation is worse, because some types of mortality--e.g., predation--have not been considered. Further, our model assumes average in-river smolt mortality of 70% and 14% marine survival. In years when smolt mortality reaches 90% or more (Raymond 1988), mortality to the spawning stage can easily exceed 98% when marine survival is less than 10%. Conversely, when favorable flows limit smolt loss per dam to 8% (37% cumulative mortality), and when ocean survival is 14% or so, spawning escapements can approximate pre-development MSY, assuming sport and Indian harvests remain at the 1987-89 level.

Direction for Remedial Action

Wild steelhead sustain themselves only at threshold population size today. But, biologically fit hatchery spawners combine with wild spawners to ensure pre-development MSY escapement and smolt production most years. Because pre-development freshwater production has not been impaired, efforts to increase numbers of wild smolts with added hatchery production or habitat improvement

Table 11. Comparison of man-caused mortality of wild steelhead from the Methow River when: smolt production is 48,000, inriver smolt survival is 30%, and marine survival is 14%. See Table 10 for mean period inter-dam losses and Indian and sport harvests.

	1982-86			1987-89		
Source of mortality	Number	STD[a]	% of total	Number	STD[a]	% of total
Smolt migration	33600	33600	75	33600	33600	83
Adult inter-dam	654	4670	10	659	4705	12
Indian harvest	200	1428	3	326	2328	6
Sport harvest	689	4919	11	0	0	0
Total		44617	99[b]		40633	101[b]
Total percentage lost [c]		93			85	

[a] STD is the standardization of adult mortality of its smolt equivalency so that mortality of smolts and adult can be compared. Since it takes 7.14 smolts to equal 1 adult at 14% marine survival, each adult is multiplied by 7.14 to convert to smolt loss.

[b] Rounding error.

[c] Individual estimates for each form of mortality are high but the total is low because several significant but unmeasured forms of mortality are not included, such as hooking mortality, gillnet dropout, poaching, ocean harvest, etc.

Table 12. Percentages of wild steelhead in the smolt outmigration at Rock Island Dam (Peven 1990; 1991) and in the adult return at Priest Rapids Dam (C. Morrill, WDW, personal communication).

	Percentage of wild fish		
Year	Smolts Rock Island Dam	Adults Priest Rapids Dam	Smolt equivalent
1987	18.9	25.9 (22.4) [a]	18.7 [b]
1988	17.4	20.2 (16.8)	18.0
1989	17.8	24.8 (20.7)	14.5
1990	20.9	17.7 (15.0)	
1991	15.8	16.8 (14.1)	
Mean	18.2	21.1 (17.8)	

[a] Adjusted for disproportionate sport harvest of hatchery fish only.

[b] To compare percentages of smolts to their adult cohort (smolt equivalency), the mean of 1-salt component is weighted by its percentage of the wild-origin run one year after the smolt migration and the 2-salt component weighted by its percentage two years later. There is no significant difference (X^2=0.28, $p<0.05$) between survival rates of hatchery and wild fish after they passed Rock Island Dam for the 1987, 1988, and 1989 year classes.

are ineffective. The problem clearly occurs after smolts leave natal streams and the solution requires substantial reduction in passage mortality of migrating smolts.

The dependance on hatchery fish carries genetic risks (Goodman 1990; Hilborn 1991). Although initially successful, the efforts to perpetuate a stock of salmon at Little White Salmon NF Hatchery led instead to its demise, 1896 to 1986 (Nelson and Bodle 1990). The ideal is managing the wild run at pre-development MSY. All harvesting of wild steelhead should cease until that level is exceeded. The number of hatchery spawners should be limited to the shortfall between the number of wild spawners and pre-development MSY escapement by controlling hatchery releases, harvest, or both.
Hatchery Supplementation and Genetic Contamination

The GCFMP's dual practice of taking gametes for artificial propagation and of placing adults above racks in streams to spawn naturally, from admixtures of returning steelhead collected at Rock Island Dam (Fish and Hanavan 1948), had to have caused genetic introgression. Contrary to some opinion (Loeppke et al. 1983; Kendra 1985; Riggs 1986; Hershberger and Dole 1987; Peven 1991b), however, reproductive contribution from the large numbers of relocated adults was small. Some of the exotics escaped. A tagged steelhead planted above a rack in the Wenatchee River was recovered near Grand Coulee Dam, and four such fish were recovered near Kettle Falls (Chapman 1941). Other translocated steelhead either suffered higher mortality than indigenous fish or were less effective spawners. Hatchery supplementation was reduced by large losses of brood fish.

Genetic mixing of Wenatchee River steelhead may have begun in 1918, when Methow River eggs were shipped to the Chiwaukum Hatchery (Craig and Suomela 1941). Small releases of non-endemic progeny originating from Tokul Creek, Chambers Creek, Carson, Skykomish, and Samish rivers came later (1933-60) (Peven 1991b). Skamania-origin smolts were introduced in 1977, and they were planted annually along with smolts of Icicle Creek and Wells Dam origin from 1983 to 1989.

Exotic progeny originating from Asotin Creek were released to the Methow River in 1961-62; 60% of the 1974 smolt release came from Skamania stock.

A common broodstock was developed for mid-Columbia River hatcheries by collecting commingled stocks of returning steelhead at Priest Rapids Dam, 1961-73. In 1974 the Wells Dam Hatchery developed its own broodstock from adults collected in the west fishway. In 1982 Chelan Hatchery discontinued collecting broodfish at Priest Rapids Dam and relied on Wells Hatchery eggs.

Given the extent of forced interbreeding between steelhead stocks, particularly when the proportion of wild fish fell below

10%, introgressive loss of genetic discreetness seems inevitable. It is not surprising that electrophoretic analyses show no unique stocks in the mid-Columbia, except for the non-endemic Skamania stock (Hershberger and Dole 1987) and no genetic difference between hatchery and wild stocks (Loeppke et al. 1983). We recognize the impropriety of concluding, however, that steelhead stocks are genetically identical simply because electrophoretic variation was not detected.

Viability remains as high today for hatchery steelhead as it was for pre-development wild stocks, which we show by adjusting adult returns by accepted levels of marine and dam-related smolt mortality. When flows and ocean conditions optimized survival, 1981-82, runs to the Methow River--particularly the hatchery component--increased to more than five times pre-development run size, albeit at 10 times pre-development smolt numbers. And the Methow became the top summer steelhead fishery in the state of Washington--a paradoxical distinction for a river 500 mi from the sea above 9 dams.

Large numbers of residual hatchery steelhead flourished in the Methow River, in summer-fall, 1990 (Table 1, Appendix D). Several exceeded 305 mm and had probably overwintered one or more years. Two mature males (240 and 250 mm) were planted in 1985.

There was no difference ($X^2=0.28, p<0.05$) between hatchery and wild smolts in their survival to the returning adult stage (Table 12). This is consistent with findings for Snake River steelhead (Steward and Bjornn 1990; Raymond 1988, Table 3). That hatchery and wild smolts survived at equal rates to adulthood does not imply that this holds for the entire life cycle.

Natural selection should improve relative fitness of wild survivors compared to hatchery-reared steelhead (McIntyre and Reisenbichler 1977). Under circumstances of hatchery-wild introgression in the Kalama River, the reproductive fitness of wild steelhead was eight to nine times greater than that of hatchery fish over a full life cycle (Leider et al. in press).

Why, then, have Methow River steelhead remained so viable? The collection of broodfish from many locally adapted sources, including both hatchery and wild fish, helped. Natural selection against inappropriate coastal genotypes (the lack of lipid reserves, Appendix K) may explain the lack of gene flow between coastal and interior stocks. Some hatchery steelhead residualize for one or more years before going to sea, and the most desirable genotypes for this life history phase emerge from natural selection in fresh water as well as salt water. Protection of wild steelhead from sport harvest in recent years has increased the proportion of wild fish and their genetic contribution in returning runs. Polymorphism is an agent of genetic diversity, and that portion of the gene bank held by headwater rainbow trout pays dividends when some become anadromous. Hatchery supplementation helped retain genetic diversity in years when the effective population size of wild adult steelhead fell below 20 fish (e.g., 1974-75) (Allendorf and Ryman 1986).

Status in Relation to the Endangered Species Act

Adaptable Animal: How long steelhead stay in mid-Columbia River tributaries is mostly a function of water temperature. Smoltification may occur in 2 years in warm mainstems or may take 7 years in cold headwaters. This results, together with 1-2 years in the ocean, in as many as 10 overlapping brood years and 16 age classes, without considering a third year at sea and repeat spawning before development. Steelhead may hedge their bets also by spawning over a 3 to 4 month period, both before and after spring runoff.

O. mykiss is also an extremely adaptable species in much of the developed world where it has been introduced. Many stocks, strains, and life forms are recognized, and the species has become the aquatic counterpart to the white rat in laboratory research (Wolf and Rumsey 1985).

Polymorphism as applied to arctic char (Balon 1984) is equally applicable to summer steelhead of the upper Columbia River, where distribution ranges throughout thermal bounds (Hokanson 1990). Upstream distribution, however, is limited by low heat budgets (Appendix K). The response of steelhead to these cold temperatures is residualism, presumably because slow growth results in maturity before smoltification for all but a few of the fastest growing individuals. These headwater rainbow trout contribute to anadromy by emigration or displacement to lower reaches where better growth enables some to attain the requisite size for smoltification, while others (virtually all males) retain a fluvial life history regardless of size. Their contribution to anadromy probably is low when steelhead predominate in lower stream reaches and high when they do not. We believe that this life history plasticity explains why headwater populations above a barrier in Icicle Creek since 1940 continue to produce steelhead (Chapter 4); why a 500-year flood (1948) had no discernible effect on subsequent recruitment; and why dam blockage of the Methow River for 14 years extirpated coho but not steelhead.

Although salmon are more advanced phylogenetically, the steelhead's life history is more fail-safe when habitat or populations are perturbed. Stochastic effects of environmental variability that would extirpate a salmon population would affect steelhead far less. Indeed, preserved as headwater dwarfs (rainbow), steelhead above Grand Coulee Dam may not yet be extinct.

Criteria for Endangerment: Nehlsen et al. (1991) used declining run size (one spawner producing less than one recruit) and population size (below 200) as criteria to declare the Methow River steelhead at high risk of extinction. The 1:1 spawner-recruit criterium is met if the stock replaces itself at some very low population level. Although the number of wild steelhead spawners may fall short of the 200 fish criterium, resident rainbow spawners number in the thousands. Gene flow between resident and anadromous O. mykiss ensures a protracted, albeit declining level of anadromy, if the anadromous genetic influence wanes over the longterm. Hatchery and wild recruits approached pre-development MSY escapement in 12 of the last 13 years (Table 6). High risk of extinction presumes that fitness of hatchery steelhead is poor or wild fish become so; this has not been demonstrated in 22 generations of Wells Hatchery steelhead. The demise of a hatchery stock of salmon on the lower Columbia, however, did not become obvious until after 90 generations (Nelson and Bodle 1990).

The status of Wenatchee and Entiat river wild steelhead are slightly less precarious than those of the Methow River, because of downriver location below two and one dams, respectively (Table 13). Nevertheless, prudence is also mandated in their management.

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Table 13. Escapement of wild steelhead into mid-Columbia tributary streams, 1987-90. Pre-development (1941-54) MSY escapement estimates for the Wenatchee, Entiat, and Methow river stocks are 2,275; 417; and 2,212 adults, respectively.

Location	Year			
	1987	1988	1989	1990
Priest Rapids Dam				
Count	14,011	10,208	10,730	7,830
Percentage of wild fish	25.9	20.2	24.8	17.7
Number of wild fish	3,629	2,062	2,661	1,899
Rock Island Dam				
Number of wild fish	3,276	1,861	2,402	1,709
Fraction[a]				
Wenatchee River	2,204	1,123	1,455	945
Entiat River[b]	211	130	168	126
Methow River	765	541	694	568

[a] Fraction total does not equal the Rock Island Dam total because of 5% interdam mortality.

[b] The Entiat fraction is derived from the relation between the actual Methow escapement to expected (0.451 x Rock Island Dam wild fish count) MSY escapement. The percentage difference between estimates represents loss due to two upriver dams. Since the Entiat River stock is one dam upriver, the percentage is halved and multiplied by 8.5% (Entiat stock MSY fraction), which is then multiplied by the Rock Island Dam wild fish total.

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APPENDIX I

STREAM WATER TEMPERATURES: FIELD AND ANALYTIC METHODS

by

Kenneth R. Williams, John D. McIntyre,
Danny C. Lee[1], and James W. Mullan

While there is universal recognition of the importance of water temperature to fish, meaningful temperature records can be elusive and often are scarce (Binns 1982). This appendix describes the temperature records used in the present study.

Methods

We used "Datapods" (Model DP112 by Omnidata International, Inc.) in 18 streams to measure daily maximum, mean, and minimum temperatures. We changed the batteries and data storage module (DSM) in each recorder at about 6-month intervals. Temperature determinations were retrieved by a Model 217 Reader (Omnidata) and transmitted to a desktop computer which summarized them in data files via a Fortram program. If the Datapod measurement varied by more than one-half degree from the measurement obtained with a pocket-thermometer, the accuracy of which had been established in the laboratory, the record was corrected by the difference when the data were removed from the DSM.

We also used other thermograph and periodic water temperature records (i.e., U.S. Geological Survey, U.S. Forest Service, stream surveys, fish hatcheries). Many were incomplete on an annual basis for one or more reasons, including loss or malfunction of continuous recorders, or partial year use. In all, thermal regime was determined at 33 stream locations, either continuously through the use of thermographs (56 years of record) or intermittently by thermograph, miscellaneous temperature measurements, or both (Table 1). Temperature units (TUs) were summed to derive annual heat

[1]U.S. Forest Service, Intermountain Research Station, Boise, Idaho.

Table 1. Annual temperature units (heat budgets) and mean July through September water temperatures for streams in the Wenatchee, Entiat, and Methow river drainages.

Stream (river mile)	Elevation (feet)	Annual temperature units (°C)	Mean July-Sept. temp. (°C)	Data source[a]		
Wenatchee R. (1.2)	625	3311	16.1	cont.	01/20/87-03/17/88	this rep.
Wenatchee R. (19.6)	975	2699	16.2	"	12/16/86-03/17/88	" "
				"	08/05/55-12/31/56	Sylvester 1957
Wenatchee R. (33.7)	1600	2931	15.7	"	12/16/86-03/17/88	this rep.
Wenatchee R. (53.6)	1880	2486	15.1	"	01/20/87-03/17/88	" "
				"	08/04/55-12/31/56	Sylvester 1957
Beaver Cr. (0.0)	1810	2452	14.0	"	07/08/87-06/12/88	this rep.
Icicle Cr. (0.2)	1102	2596	14.4	"	06/17/86-06/01/88	" "
Icicle Cr. (3.4)	1121	2562	14.1	"	06/17/86-06/01/88	" "
Chiwaukum Cr. (1.8)	1810	1921	11.6	"	06/02/87-07/31/88	" "
Chiwawa R. (2.1)	1930	2447	11.8	"	06/17/86-11/09/88	" "
				"	08/10/55-12/31/56	Sylvester 1957
Chiwawa R. (27.1)	2661	1771	9.4	"	06/17/86-11/09/88	this rep.
Nason Cr. (0.8)	1869	2297	14.4	"	06/17/86-04/29/88	" "
				"	06/20/73-06/16/74	U.S. Geo. Sur. (USGS)
				"	08/01/55-12/31/56	Sylvester 1957
Peshastin Cr. (9.3)	1850	2435	13.2	"	07/08/87-06/01/88	this rep.
White R. (6.4)	1882	1677	8.5	"	08/01/70-04/07/71	+35 misc. USGS
Entiat R. (6.7)	700	2537	13.6	"	1974-77, 1980-86	Entiat NFH records
Entiat R. (18.1)	1580	2268	12.8	"	04/01/69-09/21/70	USGS
Entiat R. (25.2)	1730	1945	10.5	"	04/01/67-09/30/78	Copenhagen 1978
Mad R. (2.1)	1414	2431	12.4	misc.	n=233, 1973-79	U.S. Forest Service
Methow R. (5.0)	902	2917	14.8	misc.	n=148, 1955-71	USGS
Methow R. (6.7)	985	3201	16.9	cont.	10/01/68-09/30/70	"
Methow R. (37.2)	1500	2470	12.7	misc.	n=119, 1955-71	"
Methow R. (40.0)	1580	2571	13.9	misc.	n=167, 1945-62	"
Methow R. (50.4)	1760	2438	12.2	misc.	+cont., 1985-87	Winthrop NFH records
Methow R. (51.5)	1710	2716	11.4	cont.	09/02/88-08/31/89	this rep.
Methow R. (69.8)	2350	1923	11.5	misc.	n=82, 1976-88	USGS
Beaver Cr. (6.5)	2800	1857	13.7	"	n=159, 1956-71	"
Gold Cr. (0.8)	1380	1932	10.8	cont.	08/07/84-10/22/84	+21 misc. this rep.
Foggy Dew Cr. (7.0)	3380	1377	9.2	"	08/07/84-11/01/84	+59 misc. this rep.
Early Winters Cr. (5.0)	2940	1703	9.0	"	07/09/88-11/01/88	+65 misc. this rep.
Chewack R. (23.3)	2575	2358	12.5	"	07/09/88-08/28/88	+67 misc. this rep.
Twisp R. (16.3)	2360	2185	11.3	"	07/09/88-11/03/88	+78 misc. this rep.
Twisp R. (27.1)	3680	1242	8.1	"	07/09/88-11/05/88	+8 misc. this rep.
Little Bridge Cr. (0.0)	2130	2193	11.7	misc.	n=25, 1972-75	USGS
Andrews Cr. (3.0)	4300	1137	7.5	"	n=139, 1967-86	"

[a] Cont. = Continuous-record thermograph installation; Misc. = periodic (spot) observations.

budgets (the number of degrees by which the average temperature exceeded 0° C in a 24-h period) so as to characterize thermal regimes.

Most streams reach their peak temperatures in August. August is relatively free from the cooling influence of snowmelt. In September stream temperatures decrease, even though the weather may still be hot and dry. This trend reflects shorter days and the approach of fall. Thereafter the decrease in temperature is precipitous, reaching winter lows close to freezing December to February. Winter snowpack and spring melting depress water temperatures in ascent back to summer highs. Conceptually, an annual thermogram consists of five lines--the summer high, the fall decline, the winter low, the spring ascent, and the spring hiatus resulting from snowmelt (Fig. 1).

Two procedures were used to correct for incomplete annual thermograms. In one, the following algorithm was used in establishing the five lines or data points of the thermogram: (1 - summer high) average temperature July 31 to August 29; (2 - winter low) average temperature December 3 to February 10; (3 - fall decline) connect August 30 temperature to December 2 temperature; (4 - beginning of spring ascent) average temperature February 11 to April 6 times two, minus average temperature December 3 to February 10, plotted for April 6; (5 - spring hiatus resulting from snowmelt) lowest temperature April 7 to July 30. This procedure was used when there were random data points over a full year. The actual temperature determinations were overlaid on the trend lines developed (Fig. 2).

In procedure two, the incomplete station data was estimated from a related station having a complete year of data. The average temperatures available were subtracted by corresponding days for the known station, and an average daily difference added or subtracted from the temperature values of the control station and overlaid on the actual data available for the incomplete station. This procedure was used when there was thermograph data for a partial year and no data for the remainder of the year, except for miscellaneous temperatures (Figs. 3 and 4).

We also used instantaneous water temperatures and regressions to develope a model (Bartholow 1989) to predict heat budgets in the Methow River drainage, July 1988 to July 1989. Water temperatures were taken monthly with a calibrated hand thermometer at more than 110 stations (69 biological stations, Table 2). Streams were categorized as (1) west/north orientation, (2) east/south orientation, and (3) the north/south mainstem Methow River (Fig. 1, main report). Streams within the first category generally flowed east or north from perpetual snowfields or glaciers along the crest of the deeply incised ridge dividing the Chelan River drainage from the Methow River drainage or the Cascade Mountains at the head of the valley. Sunlight tends to strike streams tangentially for

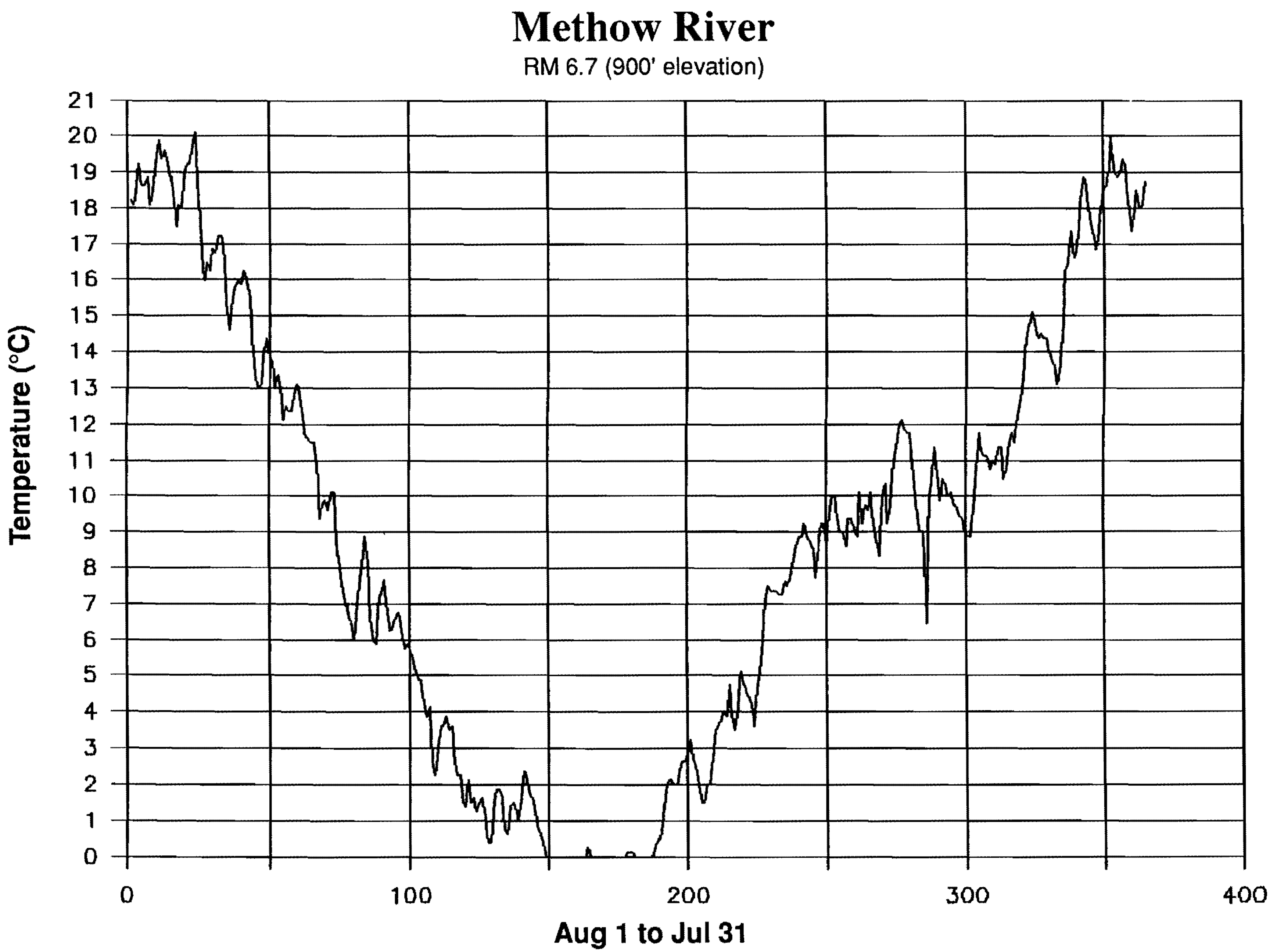


Fig. 1. Conceptually, an annual thermogram consists of five lines—the summer high, the fall decline, the winter low, the spring ascent, and the spring hiatus resulting from snowmelt.

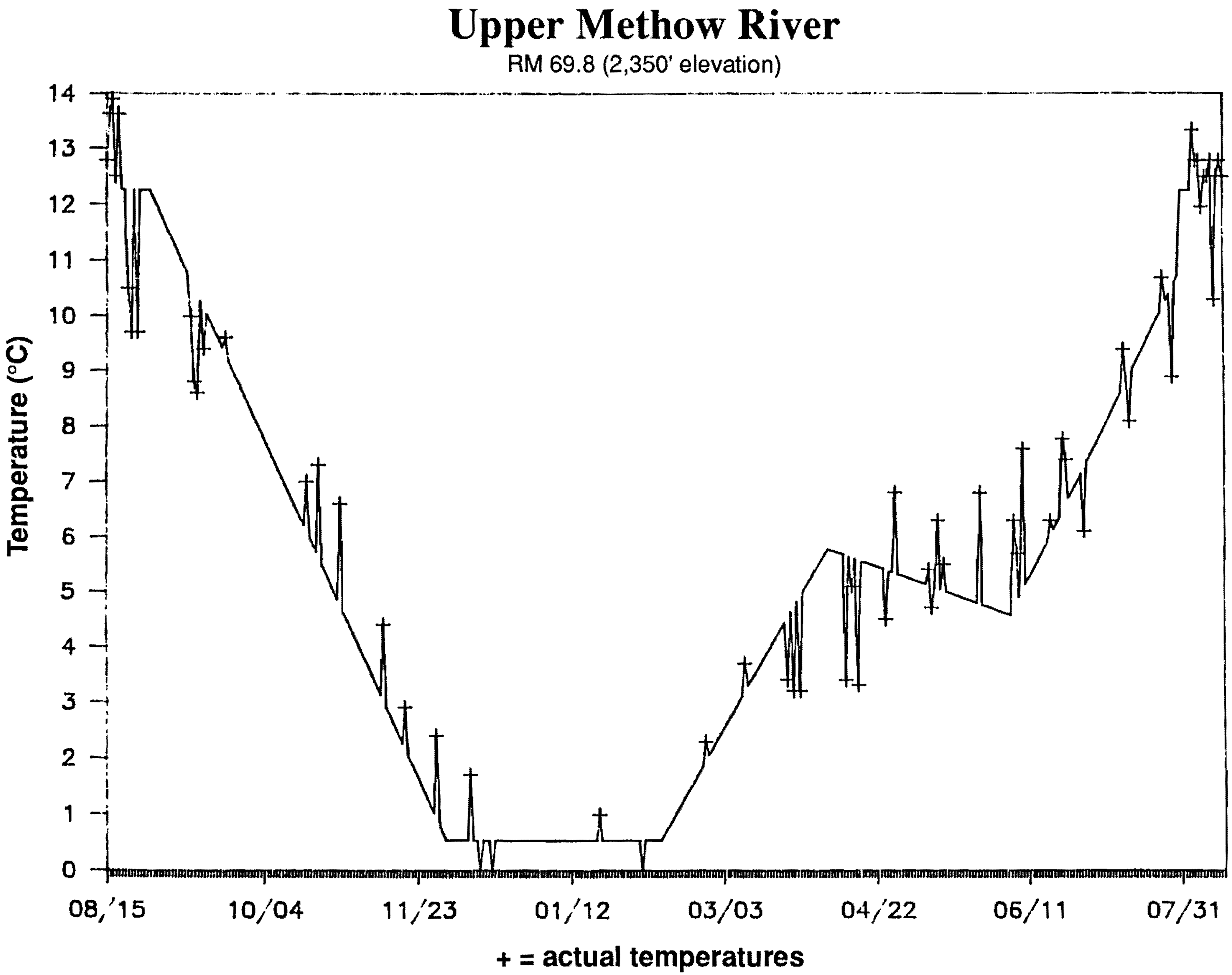


Fig. 2. Miscellaneous temperature measurements over a full year used to develop an annual thermogram.

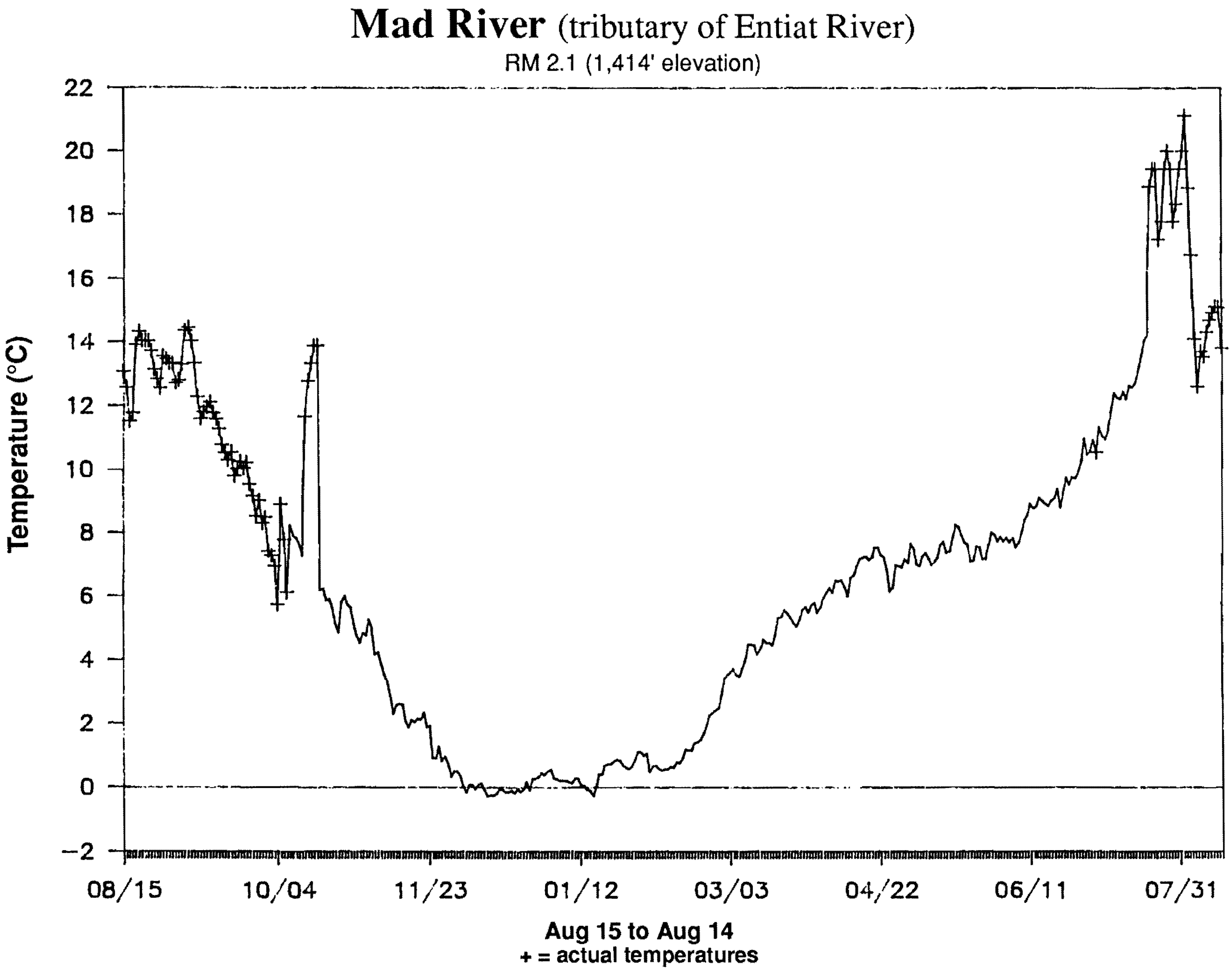


Fig. 3. Miscellaneous temperature measurements for part of a year used in conjunction with a related station (Fig. 4) having a complete year of data in developing an annual thermogram.

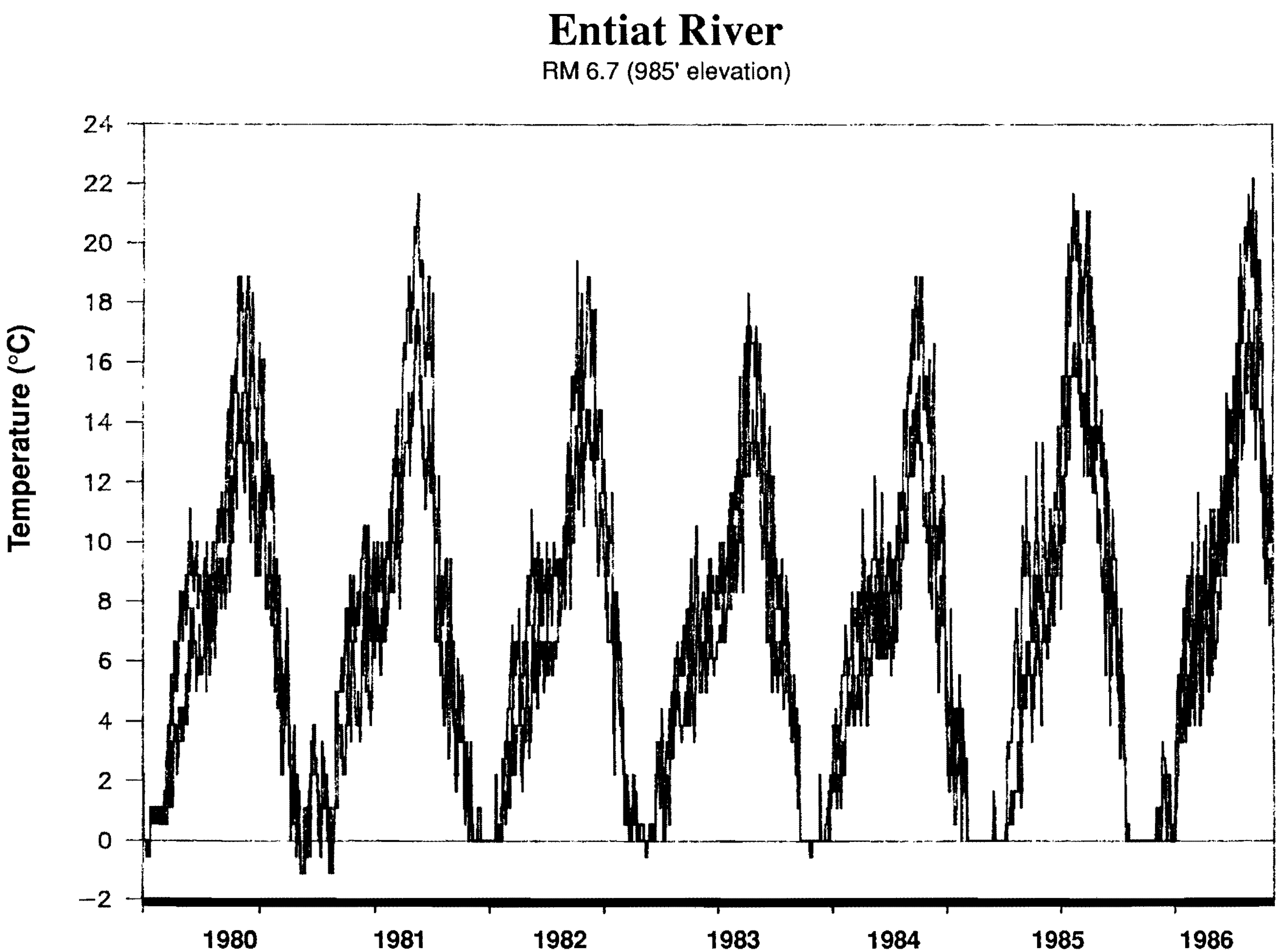


Fig. 4. Example of continuously recorded thermograms used to calibrate miscellaneous temperatures of Mad River (Fig. 3), a tributary of the Entiat River.

Table 2. Annual heat budgets (temperature units), mean temperature for July, August, and September, 1989, and annual heat budget regressions at stream stations in the Methow River drainage.

Stream (river mile)	Elevation (m)	Annual temperature units (°C)	Mean monthly temperature (°C) Jul	Aug	Sep	mean	Peak weekly mean temperature (°C)
	North-south aspect Methow River mainstem			**Y = 3595.6 - 1.454 (x)**			
Methow R. (7.0)	279	3232	17.9	17.9	14.4	16.7	20.6
Methow R. (14.0)	329	3127	17.0	16.9	13.9	15.9	19.3
Methow R. (23.8)	399	2998	15.6	15.5	13.1	14.7	17.5
Methow R. (24.4)	404	2989	15.6	15.4	13.0	14.7	17.4
Methow R. (40.2)	482	2878	14.1	14.0	12.1	13.4	15.4
Methow R. (42.3)	491	2862	13.9	13.8	12.0	13.2	15.1
Methow R. (44.8)	505	2862	13.8	13.6	11.9	13.1	14.7
Methow R. (50.4)	533	2822	13.1	13.0	11.5	12.5	14.0
Methow R. (55.0)	535	2801	12.6	12.5	11.2	12.1	13.3
Methow R. (60.7)	561	2761	11.7	11.6	10.7	11.3	12.1
Methow R. (67.4)	649	2709	10.9	10.6	10.2	10.6	11.2
	West-south aspect streams			**Y = 3289.2 - 1.482 (x)**			
Chewack R. (7.8)	607	2478	13.3	14.1	11.6	13.0	15.8
Chewack R. (14.7)	666	2328	12.9	13.6	11.3	12.6	15.3
Chewack R. (17.4)	683	2302	12.8	13.5	11.2	12.5	15.2
Chewack R. (23.5)	785	2138	12.1	12.8	10.6	11.8	14.5
Chewack R. (30.8)	1023	1758	10.6	11.1	9.2	10.3	12.8
Lake Cr. (2.8)	966	1830	11.0	11.5	9.5	10.7	13.2
Andrews Cr. (1.2)	1097	1638	10.1	10.5	8.7	9.8	12.2
Goat Cr. (3.0)	853	2013	11.7	12.3	10.2	11.4	14.0
Goat Cr. (9.0)	1426	1159	8.0	8.2	6.8	7.7	9.9
Lost R. (0.0)	719	2213	12.6	13.3	10.9	12.3	15.0
Lost R. (12.7)	1106	1625	10.0	10.5	8.7	9.7	12.2
Beaver Cr. SF (0.0)	837	2024	11.8	12.4	10.2	11.5	14.1
Beaver Cr. SF (5.2)	1134	1575	9.9	10.3	8.5	9.6	12.0
Beaver Cr. MF (2.6)	1356	1248	8.4	8.7	7.2	8.1	10.4
Beaver Cr. MF (5.2)	1556	1000	7.1	7.3	6.0	6.8	9.0
Twentymile Cr. (3.2)	1137	1570	9.8	10.3	8.5	9.5	12.0
Twentymile Cr. SF (10.2)	1780	739	5.6	5.7	4.7	5.3	7.4
Cub Cr. (3.0)	805	2100	12.0	12.6	11.4	12.0	14.4
	East-north aspect streams			**Y = 3073.0 - 1.540 (x)**			
Twisp R. (0.0)	482	2389	13.2	13.8	11.1	12.7	15.0
Twisp R. (4.0)	547	2297	12.7	13.3	10.7	12.2	14.5
Twisp R. (11.1)	671	2061	11.8	12.3	9.9	11.3	13.5
Twisp R. (24.4)	963	1579	9.6	10.0	8.2	9.3	11.2
Twisp R. (27.1)	1122	1331	8.5	8.7	7.2	8.1	9.9
Twisp R. SF (0.0)	1256	1128	7.5	7.7	6.4	7.2	8.9
Twisp R. SF (1.9)	1506	776	5.6	5.7	4.9	5.4	6.9
Early Winter Cr. (0.0)	652	2058	12.0	12.5	10.1	11.5	13.6
Early Winter R. (1.5)	721	1948	11.4	11.9	9.6	11.0	13.1
Early Winter R. (5.0)	896	1673	10.1	10.5	8.6	9.7	11.7

Table 2. Concluded.

Stream (river mile)	Elevation (m)	Annual temperature units (°C)	Mean monthly temperature (°C) Jul	Aug	Sep	mean	Peak weekly mean temperature (°C)
Early Winter R. (8.8)	1079	1395	8.8	9.1	7.5	8.5	10.3
Early Winter R. (12.3)	1280	1094	7.3	7.5	6.3	7.0	8.7
Cedar Cr. (1.5)	945	1599	9.8	10.1	8.3	9.4	11.3
Gold Cr. (4.5)	607	2181	12.3	12.8	10.3	11.8	14.0
Gold Cr. SF (3.8)	728	1966	11.4	11.9	9.6	11.0	13.0
Gold Cr. SF (5.9)	904	1672	10.1	10.5	8.5	9.7	11.7
Foggy Dew Cr. (3.4)	1030	1470	9.1	9.5	7.8	8.8	10.7
Crater Cr. (1.9)	994	1525	9.4	9.7	8.0	9.0	10.9
Wolf Cr. (1.4)	603	2178	12.3	12.9	10.4	11.9	14.0
Wolf Cr. (7.2)	1103	1358	8.6	8.9	7.3	8.3	10.1
Wolf Cr. (9.6)	1378	951	6.6	6.7	5.7	6.3	7.9
Wolf Cr. (12.4)	1734	522	3.9	3.8	3.5	3.7	5.1
Buttermilk Cr. EF (0.0)	873	1747	10.3	10.7	8.7	9.9	11.9
Buttermilk Cr. EF (1.3)	971	1588	9.6	9.9	8.1	9.2	11.1
Buttermilk Cr. EF (2.7)	1085	1404	8.7	9.0	7.5	8.4	10.2
Buttermilk Cr. EF (3.8)	1353	978	6.7	6.9	5.8	6.5	8.1
South Cr. (0.0)	969	1562	9.6	9.9	8.1	9.2	11.1
Little Bridge Cr. (0.0)	649	2065	12.0	12.5	10.1	11.5	13.7
Little Bridge Cr. (5.2)	963	1571	9.6	10.0	8.2	9.3	11.2
Trout Cr. (0.0)	899	1669	10.1	10.5	8.6	9.7	11.7
Monument Cr. (0.0)	927	1627	9.9	10.3	8.4	9.5	11.5
Eightmile Cr. (8.3)	975	1553	9.6	9.9	8.1	9.2	11.1
Eightmile Cr. (14.6)	1304	1047	7.1	7.3	6.1	6.8	8.5
War Cr. (2.5)	975	1553	9.6	9.9	8.1	9.2	11.1
Boulder Cr. MF (5.8)	1036	1460	9.1	9.4	7.7	8.7	10.6
Boulder Cr. MF (9.6)	1414	903	6.3	6.4	5.5	6.1	7.6
Methow R. WF (76.4)	817	1797	10.7	11.2	9.1	10.3	12.3
Methow R. WF	1119	1325	8.5	8.7	7.2	8.1	10.0
Methow R. WF (13.8)	1336	1015	6.9	7.0	5.9	6.6	8.2
Robinson Cr. (1.4)	957	1581	9.7	10.0	8.2	9.3	11.2

brief periods because of topographic shade from valley walls. Dense old-growth forests in most headwaters minimize insolation.

Streams in the second category drain the west slopes of the mountains that divide the Methow and Okanogan river drainages. The topography is less elevated, incised, and forested, and there is less precipitation. Solar exposure and heating is generally higher because of perpendicular insolation.

The lower Methow River courses through a steepsided canyon that broadens upstream. The wide channel and sparse riparian vegetation expose the Methow River to direct insolation for much of the day during the summer. Ground water is the primary contributor to flow in the middle river during the low-flow period (Appendix C).

All sites were accessible by vehicle from June to November and required three days per month to sample. Sampling was restricted to the Methow River and tributaries along plowed roads from December through March and was completed in an afternoon.

A Datapod was placed in the lower Methow River (RM 5.8, July - October 1988) and moved to RM 50.8 (November - July 1989) to record thermal datum. Four Ryan thermographs in the middle and upper Twisp River and Early Winters Creek recorded daily variation in temperature at other elevations. Diel curves from recording thermographs were used to calibrate instantaneous temperatures collected at different stations or at different times of day.

Calibration and Verification

Because the volume of data accumulated precluded presentation of all records in a manageable document, we use examples to illustrate relationships.

Simulated heat budgets from miscellaneous temperature determinations (Procedure One): Both in respect to time of day and season, 159 random temperature determinations were made on Beaver Creek (RM 6.5), 1956 to 1971 (Walter and Nassar 1974) (Table 1, Methow River). From these data an average annual heat budget of 1,857 TUs was predicted.

Two sets of long-term daily temperatures served as control for evaluating predicted heat budgets, both from the Entiat River. Upstream at RM 25.2, 11 years of data (1967-1978, Fig. 5) (Copenhagen 1978), maximum, mean, and minimum heat budgets were 2,260, 1,932, and 1,712 TUs, respectively, an annual variation of -11% to +17%. Downstream at RM 6.7, nine years of data (1974-1977 and 1980-1986) (Entiat NF Hatchery), maximum, mean, and minimum heat budgets were 3,058, 2,537, and 2,281 TUs, respectively, an annual variation of -10% to +17% (1980-86, Fig. 4).

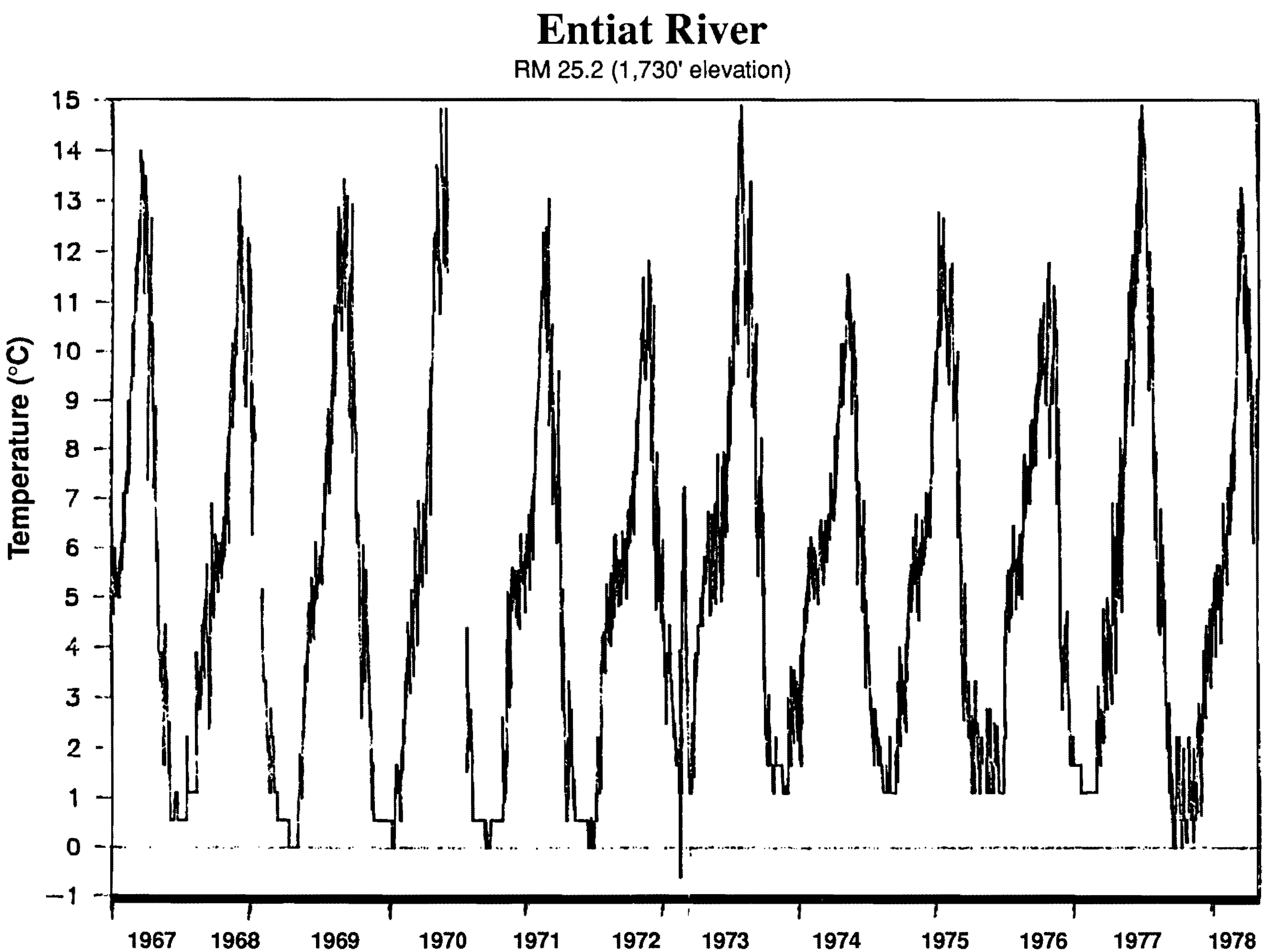


Fig. 5. Interannual variation in the above thermograms amounts to +17% or -11% of 1,932 temperature units.

About 10 temperature determinations were available annually (1956-1971) from Beaver Creek in estimating an average annual heat budget. Applying the same level of random (Snedecor 1946) subsampling (n=96) to the years of continuous temperature records at RM 25.2, Entiat River, results in an average heat budget of 1,895 TUs, a value only slightly different (-2.0%) than that calculated from 4,200 data points (1932 TUs). Random selection of one biweekly average temperature (n=24), replicated three times, for maximum, nearest to mean (1,920 TUs vs arithmetic mean of 1,932 TUs), and minimum heat budget year, resulted in estimated heat budgets -5.9% to +6.2% (Table 3) of actual values calculated for a complete year of data (365 data points).

Simulated heat budgets from partial year data (Procedure Two): A thermograph was maintained in the Winthrop NF Hatchery adult holding pond for 11 to 17 weeks in the summers of 1985 to 1987. The water was taken from the Methow River about one mile above the hatchery (RM 51.5). These records combined with hand thermometer temperatures from adjoining raceways at other seasons, involving +0.8 to -1.1° C error from recirculated ground water, were used to calculate 2,314, 2,357, and 2,642 TUs, respectively, for 1985, 1986, and 1987. A continuous-record thermograph at the hatchery intake for the 1987-88 water year resulted in a heat budget of 2,715 TUs. The heat budget for water year 1987-88 was 3 to 15% higher than in calendar years 1985 to 1987, and within the bounds of year-to-year variation shown for long-term records of the Entiat River.

Simulated heat budgets from correlation regression model: Semi-quantitative comparison between predicted and observed heat budgets correlated well, especially considering the vagaries of the reference data set (Table 4).

We tested the accuracy of our model by the frequency that instantaneous temperatures (converted to daily mean) fell within the predicted range for the day and site in question (Table 5). No daily mean temperature out of 31 failed to fall within the predicted range and only one instantaneous temperature was outside the predicted range.

Predicted temperature range is not the same as confidence limits. As a result, we chose to use a modified version of a commonly used model of stream temperature (Steele 1978), adjusted for elevation to fit the data. In the analysis, the adjusted mean daily temperature (t), is expressed as a function of elevation (h), and day of year (d) according to the following relationship:

$$t = \text{maximum}\ (0, b0 + b1h + (b2 + b3h)\ (\sin\ (\frac{2\pi}{365\ \text{days}})\ (d + b4))))$$

where t is measured in degrees C, h in meters, and d in days (1-366). The units on b0-b4 are b0 = C, b1 = $C \bullet m^{-1}$, b2 = C, b3 = $C \bullet m^{-1}$, and b4 = days.

Table 3. Simulated annual heat budgets (cumulative temperature units August 15 to August 14) using one random biweekly mean water temperature (n=24) vs. observed maximum, minimum and mean annual heat budgets (n=365), Entiat River (RM 25.2, 11 years of data).

	Random days chosen																	
	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		Test 7		Test 8		Test 9	
Month																		
1	6	25	4	24	7	19	5	29	3	26	3	26	10	24	12	26	2	21
2	9	24	10	18	14	18	15	27	5	28	14	27	13	19	7	27	9	18
3	10	17	2	16	5	16	14	20	4	23	1	27	8	26	12	20	9	27
4	2	18	3	26	13	24	3	22	3	26	13	20	3	17	11	21	4	25
5	3	27	8	16	5	27	9	21	9	29	8	24	2	23	11	16	3	18
6	3	26	9	23	14	28	9	28	8	16	12	26	4	18	10	26	6	30
7	5	20	7	29	14	26	15	25	9	22	5	24	1	20	8	18	9	22
8	6	30	9	18	5	22	3	21	4	22	14	21	13	25	1	23	10	20
9	15	30	7	22	6	16	14	20	14	30	3	17	14	21	11	25	4	24
10	13	24	15	20	9	30	6	30	11	20	11	18	15	16	3	30	11	17
11	8	17	9	19	10	18	10	24	14	18	9	24	15	22	5	20	9	18
12	12	19	10	25	9	16	10	25	14	29	14	19	15	23	6	27	4	23
Simulated heat budget	2191		2209		2400		1687		1641		1664		1806		2001		1865	
Observed heat budget			2260 (Maximum)						1712 (Minimum)						1932 (Mean)			
Deviation	-3.1%		-2.3%		+6.2%		-1.5%		-4.2%		-2.9%		-5.9%		+4.0%		-2.9%	

Table 4. Semi-quantitative comparison between predicted and observed water temperatures (°C) in the Methow River drainage (note: there are spatial and temporal differences between data sets).

Model simulation temperatures 1988-89			Reference or observed temperatures			
Elevation (ft)	Mean TUs	Mean Jul-Sep	Elevation (ft)	Mean TUs	Mean Jul-Sep	Data source
		Methow R.				
990	3232	16.7	985	3201	16.9	thermograph 10/1/68-9/30/70
1557	2878	14.1	1500	2470	12.7	119 misc. 1971-76
1586	2862	13.2	1580	2571	13.9	167 misc. 1945-62
1760	2822	12.5	1760	2438	12.2	partial thermograph + misc. 1985-87
2097	2709	10.6	2350	1923	11.5	82 misc. 1975-79
		Beaver Cr.				
2704	2024	11.5	2800	1857	13.7	159 misc. 1956-72
		Gold Cr.				
1961	2181	11.8	1380	1932	10.8	thermograph 8/7-10/22/84 +21 misc.
		Foggy Dew Cr.				
3328	1470	8.8	3380	1377	9.2	thermograph 8/7-11/1/84 +59 misc
		Early Winters Cr.				
2895	1673	9.7	2940	1703	9.0	thermograph 7/9-11/1/88 +65 misc
		Chewack R.				
2536	2138	11.8	2575	2358	12.5	thermograph 7/9-8/28/88 +67 misc.
		Twisp R.				
2168	2061	11.3	2360	2185	11.3	thermograph 7/9-11/3/88 +78 misc.
3625	1331	8.1	3680	1242	8.1	thermograph 7/9-11/5/88 +8 misc.
		Little Bridge Cr.				
2097	2065	11.5	2065	2193	11.7	25 misc.
		Andrews Cr.				
3544	1638	9.8	4300	1137	7.5	139 misc. 1967-86

Table 5. Comparison of observed (adjusted, instantaneous) and model predicated temperatures (°C) in the Methow River drainage, 1988-89.

Stream		Observed temperature		Model estimate		
(river mile)	Date	instantan.	adjust. mean	mean	min.	max.
Cedar Cr. (2.4)	07-31-88	11.7	10.2	11.3	7.7	14.9
Cub Cr. (2.8)	09-01-88	13.3	13.0	12.4	8.8	16.0
E. Winters Cr. (0.0)	03-22-89	2.5	1.9	4.8	1.1	8.5
Foggy Dew Cr. (3.4)	06-11-89	6.1	6.4	6.9	4.0	9.8
Foggy Dew Cr. (3.4)	06-22-89	6.4	6.4	6.9	4.0	9.8
Goat Cr. (9.0)	05-12-89	2.5	1.7	2.2	0.0	5.9
L. Bridge Cr. (0.0)	03-22-89	2.2	1.7	4.8	1.1	8.5
Lost R. (12.0)	09-07-89	7.8	8.1	9.7	6.2	13.2
Methow R. (5.8)	03-08-89	4.2	4.4	6.5	3.1	9.9
Methow R. (5.8)	08-01-88	17.8	16.4	18.4	16.2	20.6
Methow R. (5.8)	08-13-88	20.6	18.9	18.5	16.3	20.7
Methow R. (5.8)	09-01-88	20.6	18.9	17.8	15.6	20.0
Methow R. (42.4)	03-08-89	7.5	6.1	6.6	3.3	9.9
Methow R. (50.8)	03-08-89	8.1	6.1	6.6	3.3	9.9
Methow R. (52.8)	08-01-88	12.8	10.9	12.9	10.8	15.0
Methow R. (67.3)	03-08-89	8.1	6.7	5.2	1.8	8.6
Methow R. WF (8.1)	08-29-89	8.3	7.4	9.1	5.1	13.1
Methow R. WF (13.8)	08-30-89	7.2	5.9	6.9	2.8	11.0
Monument Cr. (0.0)	09-06-89	9.4	9.2	10.5	6.9	14.1
Trout Cr. (0.0)	08-31-89	10.8	10.0	10.2	6.6	13.8
Twisp R. (0.4)	08-01-88	15.0	12.2	13.9	9.8	18.0
Twisp R. (0.4)	03-22-89	5.3	3.9	5.7	2.0	9.4
Twisp R. (4.5)	03-22-89	4.4	3.3	5.3	1.6	9.0
Twisp R. SF (0.0)	08-28-89	7.2	7.9	8.1	4.1	12.1
Twisp R. SF (1.9)	08-27-89	7.2	5.3	6.1	2.0	10.2
War Cr. (2.5)	10-05-89	5.6	6.1	7.9	4.7	11.1
Wolf Cr. (1.4)	08-01-88	13.3	11.9	13.0	9.3	16.7
Wolf Cr. (1.4)	09-01-88	14.4	13.4	12.9	9.3	16.5
Wolf Cr. (7.2)	08-25-89	9.4	7.8	9.1	5.1	13.1
Wolf Cr. (9.6)	08-25-89	8.6	7.8	6.9	2.8	11.0
Wolf Cr. (12.4)	08-24-89	8.3	7.2	3.8	0.0	8.1

Exhibit 1 expands on this relationship, generated using MathCAD software. We used the SAS statistical package to estimate the parameters of this model for each of the three classes of streams: mainstem Methow, north-east tributaries, and south-west tributaries. From the results of the parameter estimation process, one sees that the model explained 96% or more of the variation in stream temperatures for each stream type. The difference in the parameter estimates reflect differences due to aspect. The residual plots suggest that while this model provides a good fit to the data, some improvement is possible. However, due to the nonlinearity of the model, we still could not place confidence intervals on annual heat budgets.

Conclusions

Stream water temperature is generally related to altitude. Exceptions include temperature in streams influenced by outflow from a lake (e.g., Wenatchee River, just below Lake Wenatchee, RM 53.6, heat budget of 2,486 TUs vs 1,677 TUs for inflowing White River, Table 1), glaciers (e.g., White River), cold tributary inflow (e.g., Wenatchee River, RM 19.6, as a result of Icicle Cr confluence upstream, Table 1), aspect, and groundwater (Fig. 22, main report).

Temperature has a dominant effect on aquatic life in streams. Rarely can stream-temperature data be collected at every point in time and space where such information is needed. Many case-study analyses show that periodic observation at a site, involving as few as 10 spot-temperature measurements, can provide nearly as much information as a continuous-record thermograph (Collings 1969; Lowham et al. 1975; Steele 1978, 1983; Smith 1981; Bartholow 1989). Surprisingly, to us as well, was that interannual variation in heat budgets ranged from -11% to +17% (two data sets = 20 years). Accordingly, we conclude that our spatial and temporal interpolation and extrapolation determinations of temperatures in mid-Columbia River tributary streams are sufficiently accurate for reconnaissance purposes.

Stream flow regimes are remarkably stable over time, and apparently temperatures are as well. Aside from the fact that water temperature in small streams is inversely proportional to discharge (Brown 1971), there would seem to be two basic reasons for such stability. First, water temperature variation is profoundly suppressed in the vicinity of freezing due to the latent heat of fusion (Song and Leung 1978 in Bartholow 1989). Second, surface water temperature is increased primarily by solar radiation and cooled by back radiation, evaporation, and conduction that limit summer water temperature in temperate and tropical waters (Edinger et al. 1974 in Hokanson et al. in press). Thus, surface water temperatures do not reach any higher levels in tropical climates than they do in temperate climates (Hutchinson 1957).

Exhibit 1

This program uses a harmonic function to model daily stream temperature data. The function, f(ev,x), estimates mean daily temperature for a given elevation (ev) and day (x). The example below uses parameters that were fit to data from the mainstem Methow. The SAS statistical package, Proc NLIN, was used to estimate parameter values.

The parameters and associated estimates are:

$b0 := 12.25 \qquad b1 := -0.009 \qquad b2 := 13.0323 \qquad b3 := -0.016 \qquad b4 := 248$

The general form of the harmonic function is:

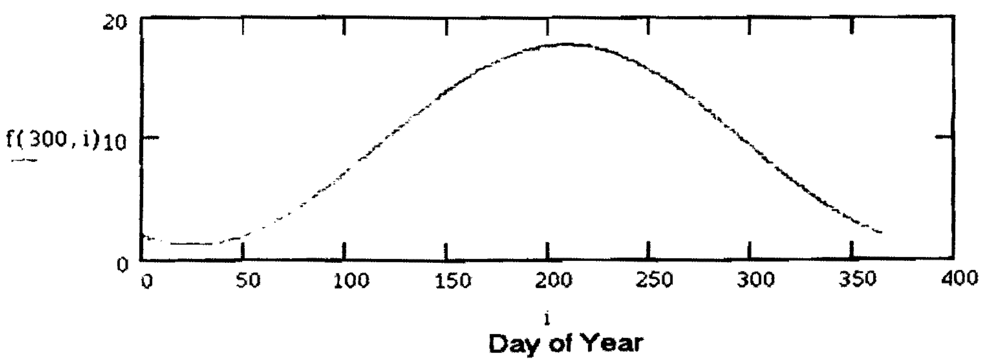
$$v(ev,x) := \begin{bmatrix} 0 \\ \left[b0 + b1\cdot ev + (b2 + b3\cdot ev)\cdot \sin\left[2\cdot\frac{\pi}{365}\cdot(x + b4)\right]\right] \end{bmatrix}$$

$$f(ev,x) := \max(v(ev,x))$$

where ev = elevation in meters, and x = day of year (1-365). This two-part form of the equation does not allow for temperatures less than zero.

For a given elevation, a plot of this function looks like this:

$i := 1 .. 365$



An annual cumulative heat budget for a given elevation can be obtained by integrating the function above. For the harmonic portion:

$$Ct(ev) := \int_0^{365} b0 + b1\cdot ev + (b2 + b3\cdot ev)\cdot \sin\left[2\cdot\frac{\pi}{365}\cdot(x + b4)\right] dx$$

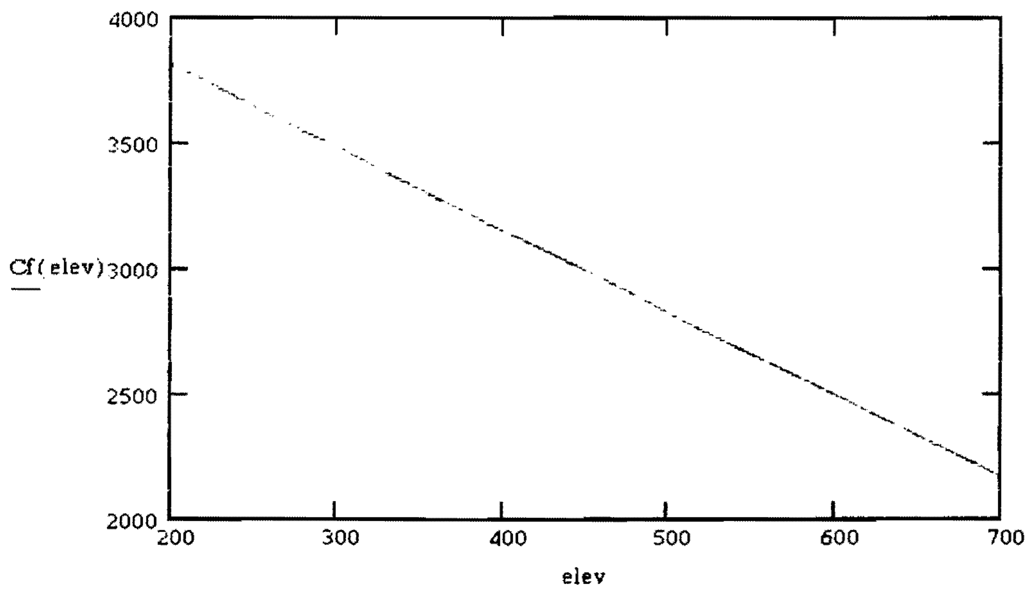
expanding terms gives

$$Ct(ev) := \frac{365}{2}\cdot\frac{\left[-\cos\left[\frac{2}{365}\cdot\pi\cdot(365 + b4)\right]\cdot b2 + 2\cdot b0\cdot\pi - \cos\left[\frac{2}{365}\cdot\pi\cdot(365 + b4)\right]\cdot b3\cdot ev + 2\cdot b1\cdot ev\cdot\pi\right]}{\pi} \ldots$$
$$+ \frac{365}{2}\cdot\cos\left[\frac{2}{365}\cdot\pi\cdot b4\right]\cdot\frac{(b2 + b3\cdot ev)}{\pi}$$

One can calculate annual heat budgets over a range of elevations and produce the following graph:

$$elev := 200, 220 .. 700$$

$$Cf(ev) := \int_{1}^{365} f(ev, x)\, dx$$



Alternatively, if one wants to know an elevation that is associated with a specific heat budget, one can use the following equations:

$y := 1000$ = initial guess (used by MathCAD to solve below)

$$Elev(budget) := root((budget - Cf(y)), y)$$

example:

$$Elev(1600) = 872.454$$

For North-East aspect streams:

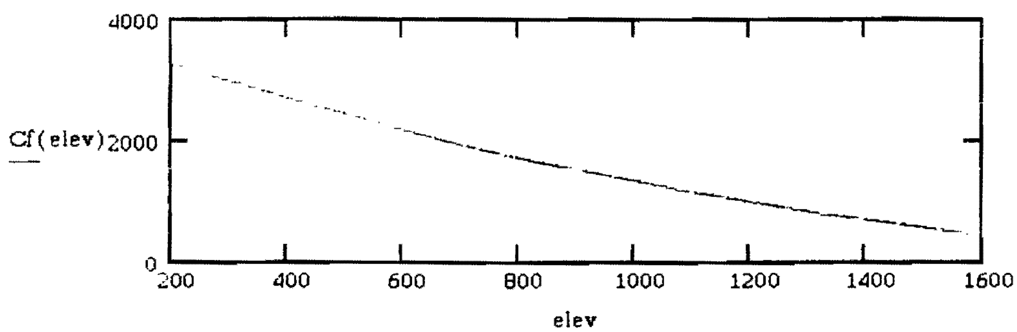
$b0 := 10.45$ $b1 := -0.0076$ $b2 := 6.304$ $b3 := 0$ $b4 := 238$

$$v(ev,x) := \left[\begin{array}{c} 0 \\ \left[b0 + b1\cdot ev + (b2 + b3\cdot ev)\cdot \sin\left[2\cdot\frac{\pi}{365}\cdot(x + b4)\right]\right]\end{array}\right]$$

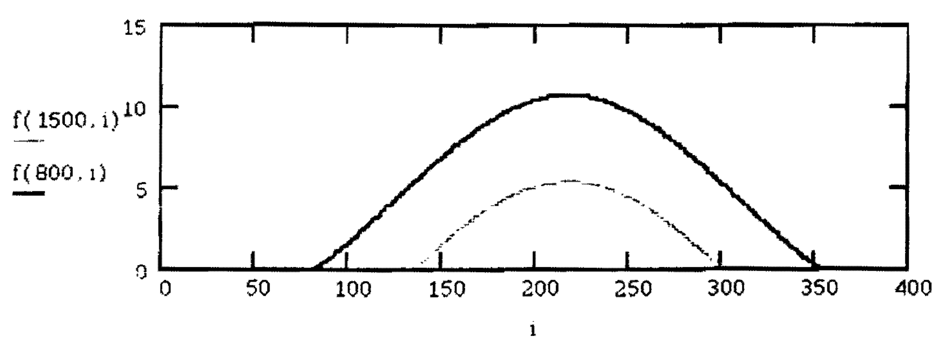
$$f(ev,x) := \max(v(ev,x))$$

$$Cf(ev) := \int_{1}^{365} f(ev,x)\,dx$$

$elev := 200, 325 .. 1600$



At higher elevations, the harmonic function looks like this:



For South-West aspect streams:

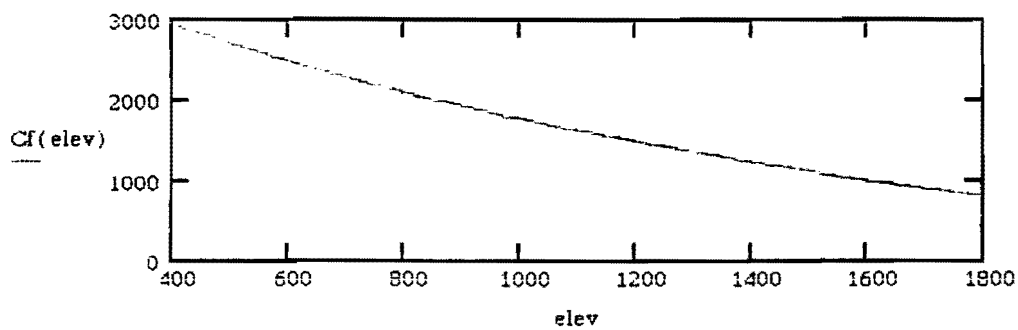
$b0 := 10.6 \qquad b1 := -0.00636 \qquad b2 := 6.285 \qquad b3 := 0.00104 \qquad b4 := 239$

$$v(ev,x) := \begin{bmatrix} 0 \\ \left[b0 + b1 \cdot ev + (b2 + b3 \cdot ev) \cdot \sin\left[2 \cdot \frac{\pi}{365} \cdot (x + b4) \right] \right] \end{bmatrix}$$

$$f(ev,x) := \max(v(ev,x))$$

$$Cf(ev) := \int_{1}^{365} f(ev,x)\, dx$$

$elev := 400, 425 .. 1800$



At higher elevations, the harmonic function looks like this:

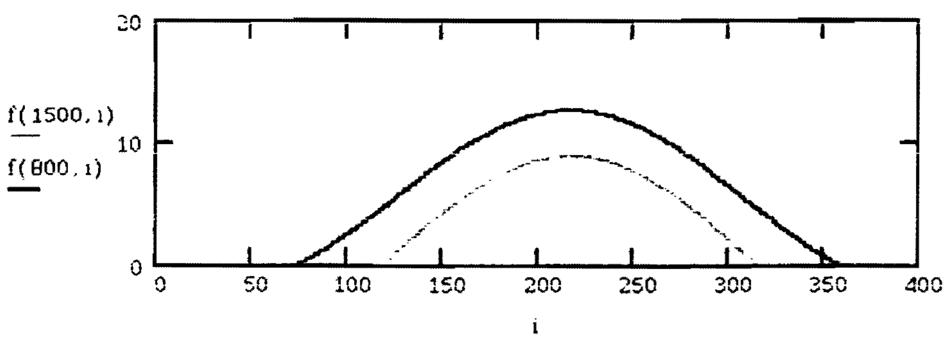


Exhibit 1 cont. p. 5

ASPECT=Mainstem

Variable	N	Mean	Std Dev	Minimum	Maximum
ELEV	506	450.6383399	128.8378428	237.0000000	652.0000000
DAY	506	173.4624506	100.5213320	1.0000000	366.0000000
MTEMP	506	8.9274704	5.1313998	0	20.7000000

ASPECT=North-East

Variable	N	Mean	Std Dev	Minimum	Maximum
ELEV	898	895.7260579	299.7697121	305.0000000	1585.00
DAY	898	221.0311804	55.7404513	95.0000000	310.0000000
MTEMP	898	7.5783964	3.1696549	0.1000000	17.6000000

ASPECT=South-West

Variable	N	Mean	Std Dev	Minimum	Maximum
ELEV	564	850.1968085	323.5873607	466.0000000	1780.00
DAY	564	188.7624113	58.9596931	95.0000000	310.0000000
MTEMP	564	8.6586879	3.8288165	0.4000000	18.3000000

Exhibit 1 cont. p. 6

ASPECT = Methow Mainstem

Non-Linear Least Squares Iterative Phase
Dependent Variable MTEMP   Method: Marquardt

Iter	B0 / B4	B1	B2	B3	Sum of Squares
0	10.000000	0	10.000000	0	37513.855818
	150.000000				
1	14.517094	-0.012564	0	0.000354	9073.715723
	180.794367				
2	17.700141	-0.019664	4.922901	-0.006595	6584.089627
	180.794367				
3	17.559668	-0.019715	4.895542	-0.006643	4160.116133
	244.483947				
4	12.243980	-0.009028	12.993317	-0.015893	1388.036575
	256.452775				
5	12.220841	-0.009009	13.022874	-0.016084	1189.569985
	248.507405				
6	12.251864	-0.009060	13.034623	-0.015988	1188.634858
	248.438792				
7	12.252224	-0.009060	13.032457	-0.015983	1188.634669
	248.430743				
8	12.252256	-0.009060	13.032323	-0.015983	1188.634669
	248.430522				

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics   Dependent Variable MTEMP

Source	DF	Sum of Squares	Mean Square
Regression	5	52436.715331	10487.343066
Residual	501	1188.634669	2.372524
Uncorrected Total	506	53625.350000	
(Corrected Total)	505	13297.288162	

$\frac{SSR}{SST} = 0.978$

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B0	12.2522556	0.31403776003	11.63525284	12.86925844
B1	-0.0090603	0.00064096225	-0.01031966	-0.00780101
B2	13.0323230	0.48183692941	12.08563828	13.97900764
B3	-0.0159830	0.00098043378	-0.01790926	-0.01405666
B4	248.4305225	0.95210842748	246.55987621	250.30116877

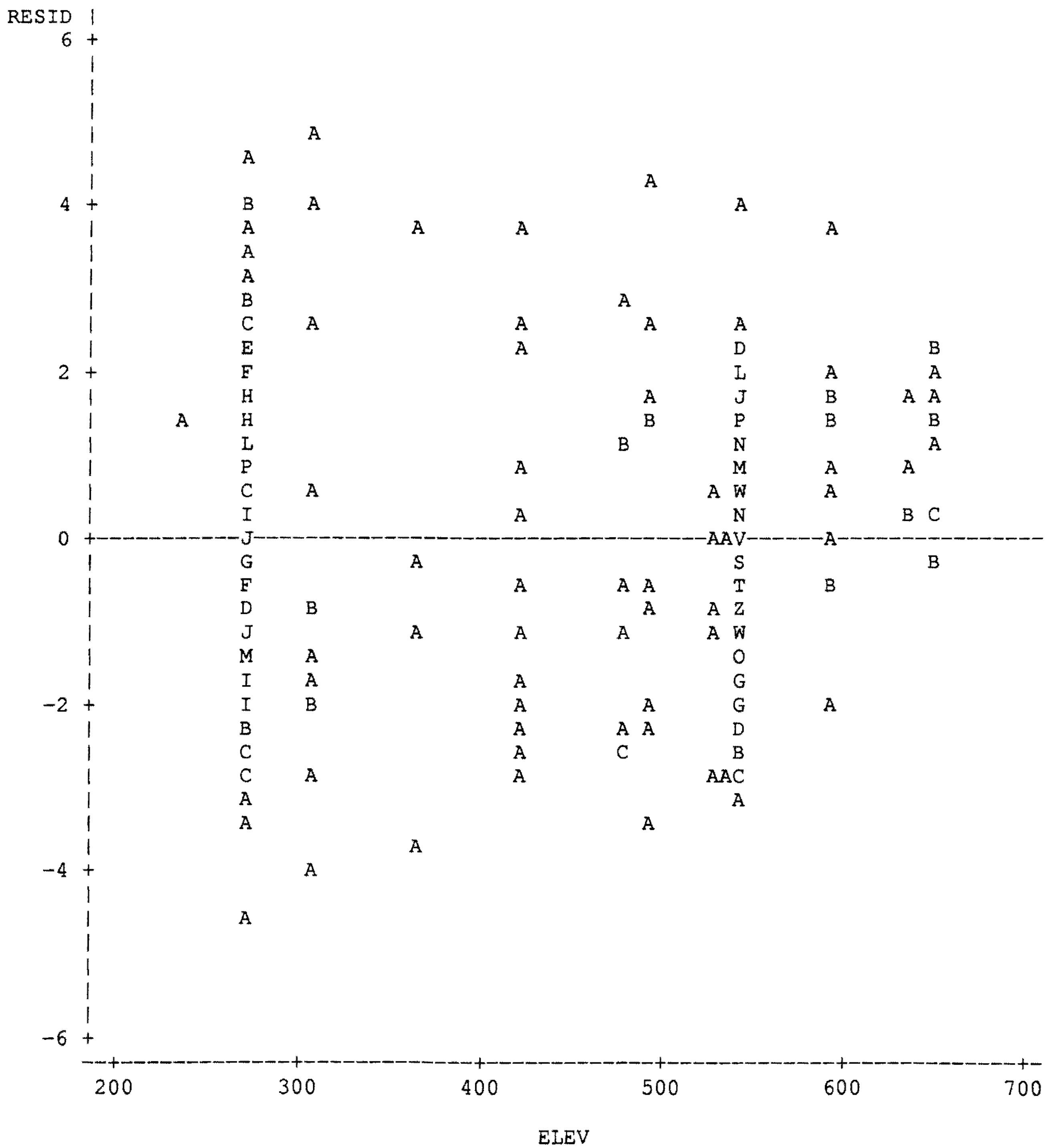
Asymptotic Correlation Matrix

Corr	B0	B1	B2	B3	B4
B0	1	-0.96949249	-0.549084321	0.483048489	-0.047503124
B1	-0.96949249	1	0.465817088	-0.393210412	-0.003603227
B2	-0.549084321	0.465817088	1	-0.974654811	0.3116459647
B3	0.483048489	-0.393210412	-0.974654811	1	-0.31511169
B4	-0.047503124	-0.003603227	0.3116459647	-0.31511169	1

Exhibit 1 cont. p. 7

ASPECT = Methow Mainstem

Plot of RESID*ELEV. Legend: A = 1 obs, B = 2 obs, etc.



NOTE: 9 obs hidden.

Exhibit 1 cont. p. 8

ASPECT = Methow Mainstem

Plot of RESID*DAY. Legend: A = 1 obs, B = 2 obs, etc.

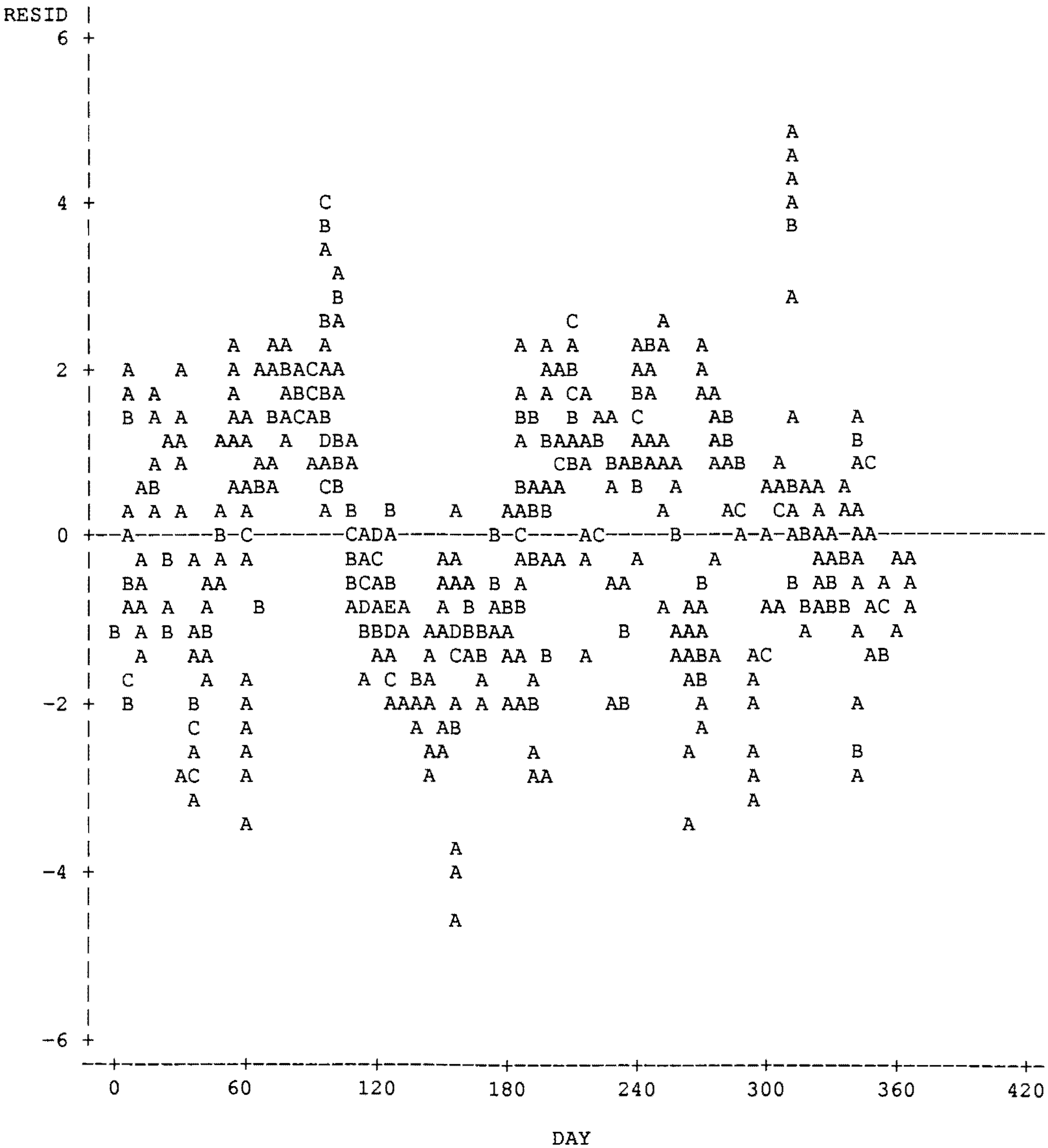


Exhibit 1 cont. p. 9

ASPECT = Methow Mainstem

Plot of PRED*MTEMP. Legend: A = 1 obs, B = 2 obs, etc.

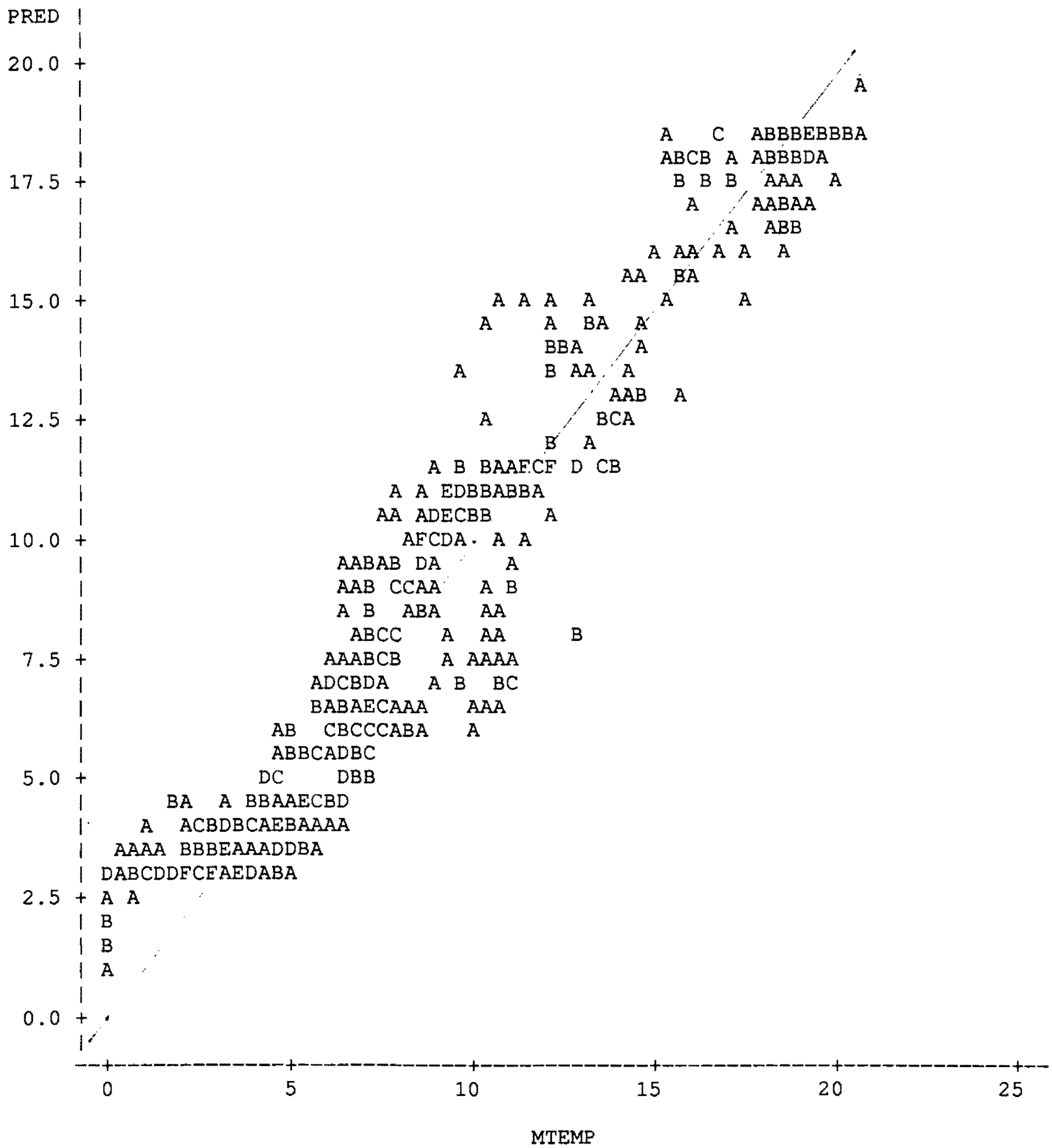


Exhibit 1 cont. p. 10

ASPECT = North-East Tribs

Non-Linear Least Squares Iterative Phase
Dependent Variable MTEMP Method: Marquardt

Iter	B0 / B4	B1	B2	B3	Sum of Squares
0	10.000000 / 150.000000	0	10.000000	0	67303.891456
1	10.561991 / 185.456799	-0.007353	1.800363	-0.001821	18177.038304
2	7.920391 / 365.000000	-0.001216	6.314978	-0.006210	13613.110368
3	7.282242 / 331.622697	-0.000242	8.8817842E-16	-0.0000225798	9086.688471
4	7.282242 / 331.622697	-0.000242	0	-0.0000225798	9086.688471
5	10.823977 / 331.622697	-0.003560	0	0.000680	7240.530497
6	10.727426 / 268.971962	-0.003779	0	0.000696	6678.556087
7	10.534402 / 250.089104	-0.004122	0.673057	0.001131	5587.861182
8	10.090826 / 228.405248	-0.005974	3.450056	0.001313	3567.453694
9	10.142627 / 242.604031	-0.007060	6.681222	-0.000596	2636.058101
10	10.630415 / 237.696053	-0.007776	6.021474	0.000394	2533.991660
11	10.437222 / 238.117819	-0.007534	6.324027	0.0000535299	2532.782539
12	10.450913 / 238.057402	-0.007551	6.303807	0.0000771778	2532.753311
13	10.450849 / 238.060169	-0.007551	6.304121	0.0000768461	2532.752615
14	10.450842 / 238.060293	-0.007551	6.304150	0.0000768176	2532.752594

NOTE: Convergence criterion met.

Exhibit 1 cont. p. 11

ASPECT = North-East Tribs

Non-Linear Least Squares Summary Statistics   Dependent Variable MTEMP

Source	DF	Sum of Squares	Mean Square
Regression	5	58053.167406	11610.633481
Residual	893	2532.752594	2.836229
Uncorrected Total	898	60585.920000	
(Corrected Total)	897	9011.900891	

$\frac{SSR}{SST} = 0.958$

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B0	10.4508420	0.34433396385	9.77503258	11.12665145
B1	-0.0075510	0.00044445470	-0.00842335	-0.00667872
B2	6.3041500	0.44190535284	5.43684145	7.17145864
B3	0.0000768	0.00053086991	-0.00096510	0.00111873
B4	238.0602932	0.82712900615	236.43692275	239.68366368

Asymptotic Correlation Matrix

Corr	B0	B1	B2	B3	B4
B0	1	-0.952502719	-0.820191338	0.8435256463	-0.40651397
B1	-0.952502719	1	0.7695759314	-0.883125297	0.4270536163
B2	-0.820191338	0.7695759314	1	-0.936380833	0.3076681365
B3	0.8435256463	-0.883125297	-0.936380833	1	-0.344533987
B4	-0.40651397	0.4270536163	0.3076681365	-0.344533987	1

Exhibit 1 cont. p. 12

ASPECT = North-East Tribs

Plot of RESID*ELEV. Legend: A = 1 obs, B = 2 obs, etc.

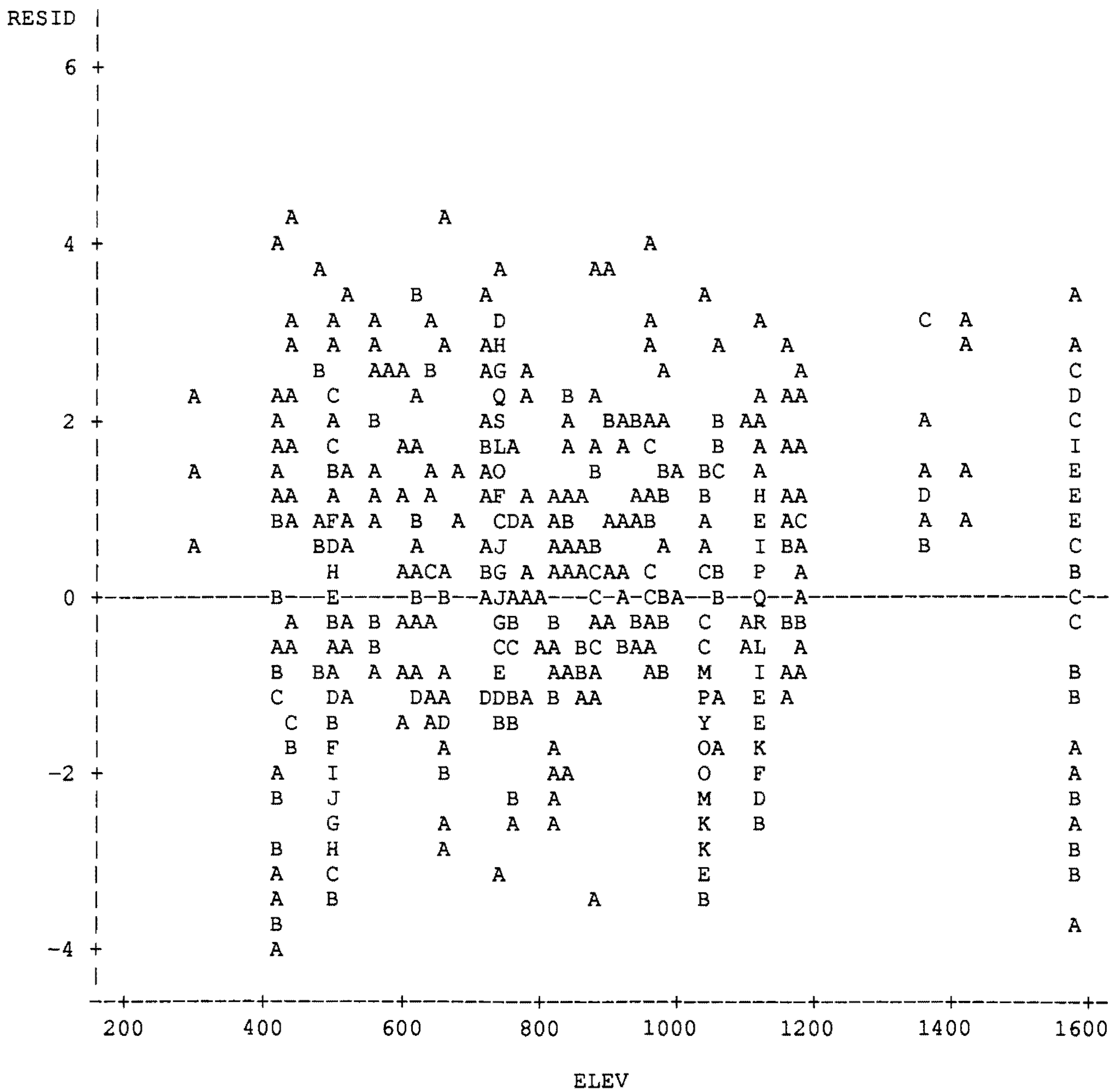


Exhibit 1 cont. p. 13

```
                         ASPECT = North-East Tribs

          Plot of RESID*DAY.  Legend: A = 1 obs, B = 2 obs, etc.

RESID |
      |
    6 +
      |
      |
      |
      |
      |
      |      A                           A
    4 +             A                    A
      |                                  B       A  A
      |                                  D      AA
      |      A      A                   BC       A A       B AA   A
      |            AA            A       B     BCA  A      ABA  A A
      |      A      C                   AC   AC  AAB    B  AA  A
      |      B      C                   ACCAAAB BCB    AB BB B  A A
    2 +        A    DA       A   A   A  EDAAACA BC AA   C  AA  AA A
      |      A A    D        A      E   CB CBABBDBB   A  AB  AA    A
      |      AAA    DB           A AA    CB BBB ABEB A A    B   A  D
      |      AA     BC      CB      DA AAAAB   AFB AAAA  A B      C
      |        AB  CC       BB   B  J   BC BC  AABA    A   B AA B A
      |       B A  A A      AB       C AA DB    CDABAAAAB  AC A   AC
      |      A  ABB CB       AF   A  EA BEB  AAD BAAA    C  CA A A DA
    0 +----------BA-AD------BB---A--F-A-AA-AB-A-BF---A-CCB-BBBAAA-F-----
      |           A AA       BD  A A GAB  A  ACB AA AAABB AAEA BBA EA
      |              A       C   A  CAAA       BB AABAAE BBB   A  FA
      |              A      AFB   A A    BDBAB BA B A ADAA AAC  ABD
      |              A C    AHA   A B  ABA  A A B  C AAA B FBA  BAI
      |               A     AB A A   A BAAC A C ACA  ABA  BDA AB AFA
      |               AA   A AAA AA AAA AA  AA BAB ABA CCB   AB AB
   -2 +               A    AACC BA  A B   BCE  AA  AA B B    A AA
      |               A  A BC CAAA  AAAA      CE     A AAAA   A  C
      |                 D      BB A    A AAA   A     A CBC         A
      |                  AB    CC A A A    A  CB      ABA     A  A
      |                  AA    B     AB       AA       B         A
      |                  AA     A     B                A
      |                        AA               A
   -4 +                        A
      |
      ---+---------+---------+---------+---------+---------+---------+--
        80        120       160       200       240       280       320

                                      DAY
```

Exhibit 1 cont. p. 14

ASPECT = North-East Tribs

Plot of PRED*MTEMP. Legend: A = 1 obs, B = 2 obs, etc.

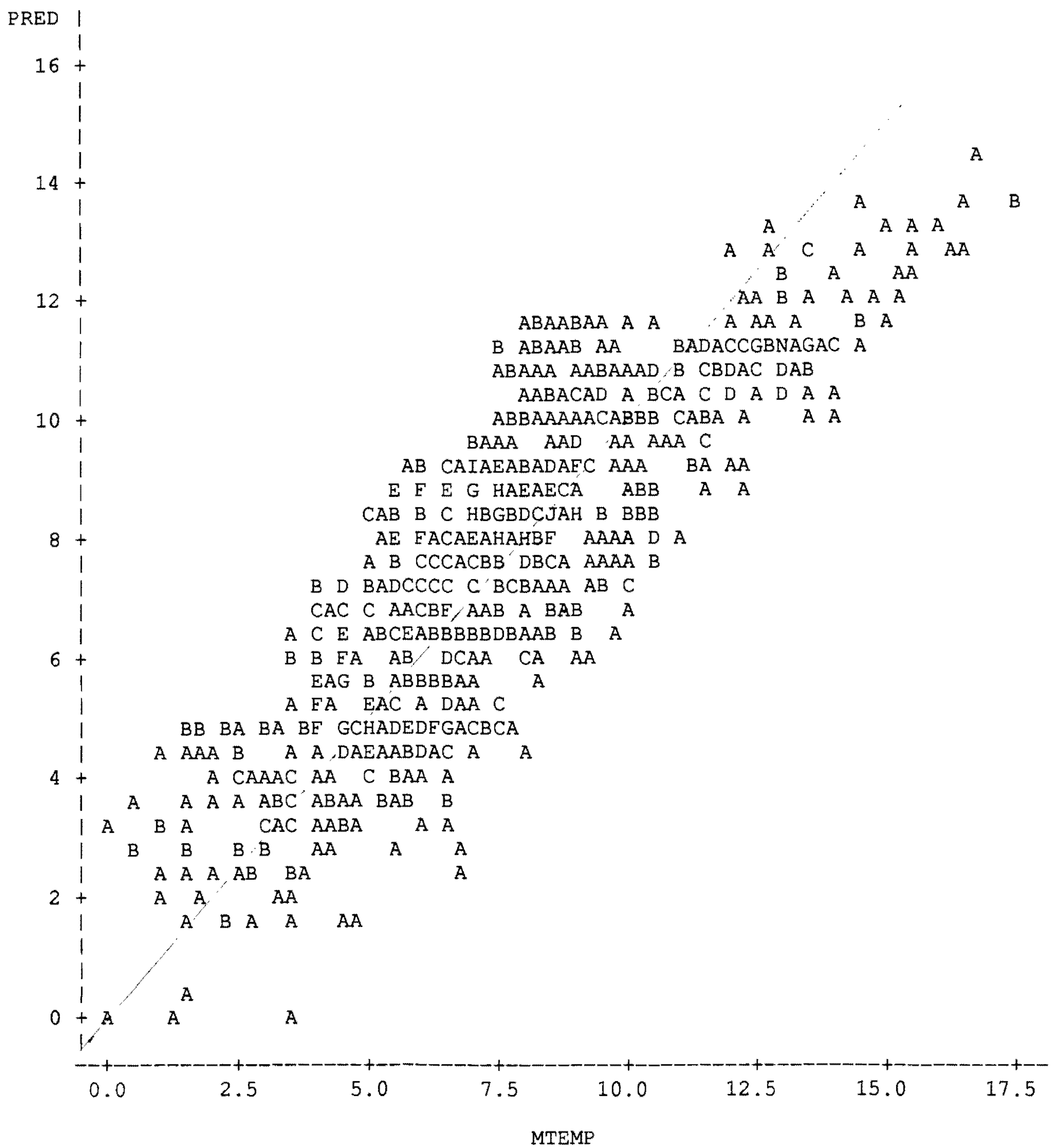


Exhibit 1 cont. p. 15

ASPECT = South-West Tribs
Non-Linear Least Squares Iterative Phase
Dependent Variable MTEMP Method: Marquardt

Iter	B0 B4	B1	B2	B3	Sum of Squares
0	10.000000 150.000000	0	10.000000	0	31491.438250
1	10.243189 191.113780	-0.005850	0.553217	-0.000298	13746.122720
2	12.724136 191.113780	-0.005009	4.879832	-0.001951	4852.140513
3	11.094472 250.710198	-0.005276	5.397952	-0.001371	3456.370170
4	10.918731 230.102714	-0.006645	5.888854	0.001228	2233.994892
5	10.565999 238.888562	-0.006316	6.305879	0.000913	1916.058666
6	10.598873 238.611553	-0.006365	6.279914	0.001044	1914.222633
7	10.595704 238.622192	-0.006362	6.284626	0.001039	1914.222086
8	10.595818 238.621888	-0.006362	6.284451	0.001039	1914.222085

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable MTEMP

Source	DF	Sum of Squares	Mean Square
Regression	5	48623.967915	9724.793583
Residual	559	1914.222085	3.424369
Uncorrected Total	564	50538.190000	
(Corrected Total)	563	8253.487429	

$\frac{SSR}{SST} = 0.962$

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B0	10.5958183	0.3636471694	9.88152510	11.31011144
B1	-0.0063620	0.0004314130	-0.00720939	-0.00551459
B2	6.2844508	0.5158526716	5.27118832	7.29771333
B3	0.0010393	0.0006034885	-0.00014609	0.00222471
B4	238.6218883	1.0053505507	236.64713066	240.59664598

Asymptotic Correlation Matrix

Corr	B0	B1	B2	B3	B4
B0	1	-0.933801374	-0.758102226	0.7475750177	-0.389248369
B1	-0.933801374	1	0.7271679443	-0.814739311	0.2349010156
B2	-0.758102226	0.7271679443	1	-0.935852974	0.2564092915
B3	0.7475750177	-0.814739311	-0.935852974	1	-0.18040244
B4	-0.389248369	0.2349010156	0.2564092915	-0.18040244	1

Exhibit 1 cont. p. 16

ASPECT = South-West Tribs

Plot of RESID*ELEV. Legend: A = 1 obs, B = 2 obs, etc.

```
RESID |
    6 +
      |        A  A
      |
      |
      |
      |                                 A
      |        C    A          B
    4 +        C   A B
      |        A     A                 A
      |        D
      |        C A A        A           B    A
      |        D     A AA               A              A
      |        A  A BA A            A   A    B   A
      |    A   C    AB     C  A      A                 A
    2 +    A   D     A     DAA A    AA  A
      |        E  ABAB A   EA  A         A       A       AAAA
      |    A   B    AA A   KA       AA  B    A           AA        A       A
      |        H    BE  B  B      B     A        A      AB  A     B        A
      |        I  A AB B   E A A  A     A                BAAA      A       B A
      |        B AA  E AA  BA BA     A      AA          A  AA      A       A
      |        C  A  GB A  CCBA    ABA  EA   A   A    A  A D               B
    0 +--------G--A--B-----BBAA----CDA--DA---B--------A---AA------BA-------C----
      |        A    BJ AB  B ABB  A B   A                 A C      A       A
      |        H   CBIBA   E   B  A AB  C    B   A    A    CA
      |        C     BAAA  B AA    BA   B    A   A      A ABB      A       B
      |        D    BGB A  C A    A  A       B            AAA              C
      |        D     C  A  A        C        A        A     A
      |        A     I  B  A A A   AAA  A        A    A                    B
   -2 +        F    AD AA                                 A
      |        F  A AF A       A     A                            A
      |        B     F         A     A
      |        A     CAA                                          B
      |        A     D      A        A                    A
      |            A C        A         A
      |              D  A   A        A
   -4 +              F
      |              D  A     A
      |
      |              A
      |
      |              A
      |
   -6 +
      --+---------+---------+---------+---------+---------+---------+---------+-
       400       600       800      1000      1200      1400      1600      1800

                                         ELEV
```

Exhibit 1 cont. p. 17

ASPECT = South-West Tribs

Plot of RESID*DAY. Legend: A = 1 obs, B = 2 obs, etc.

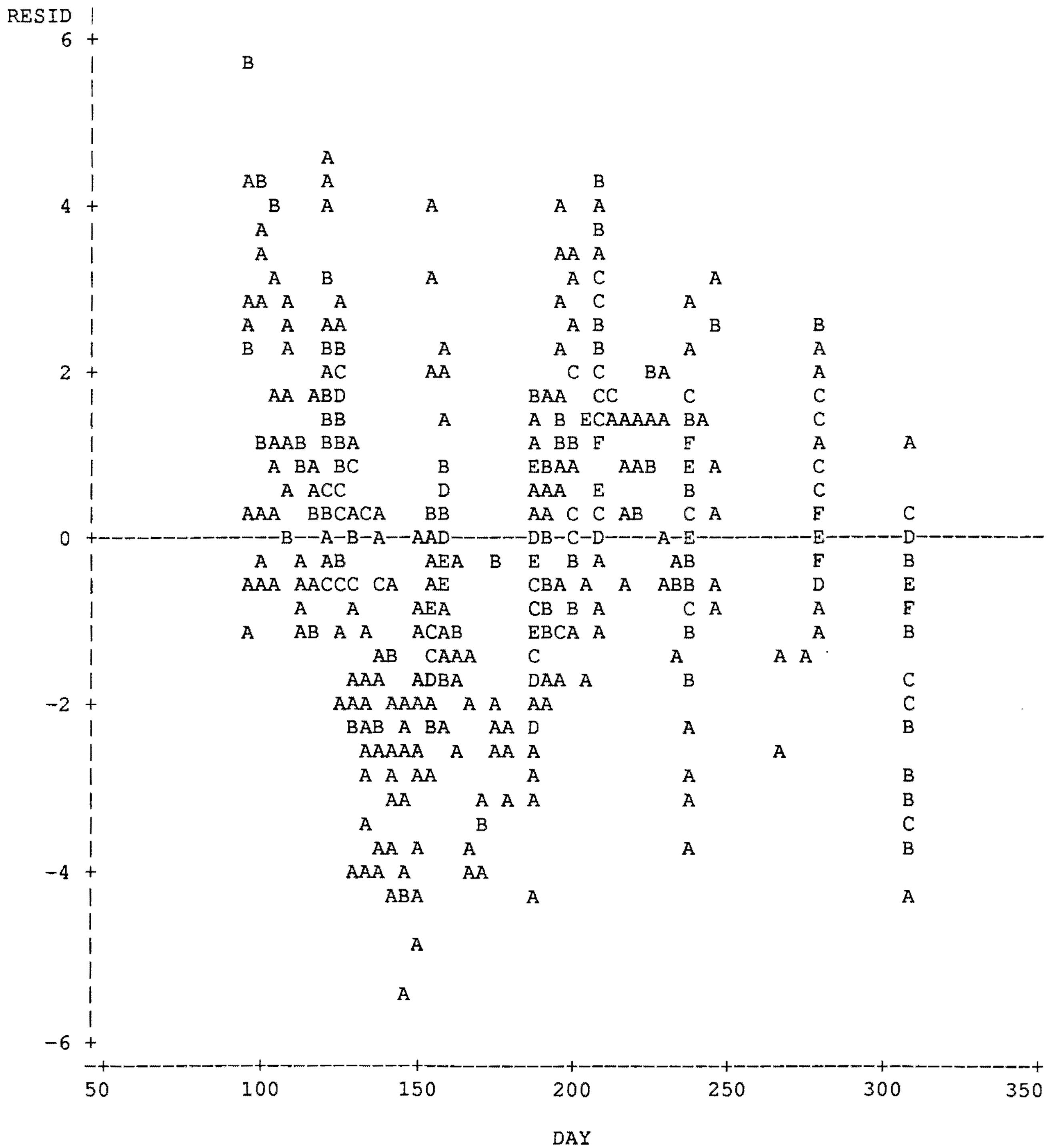
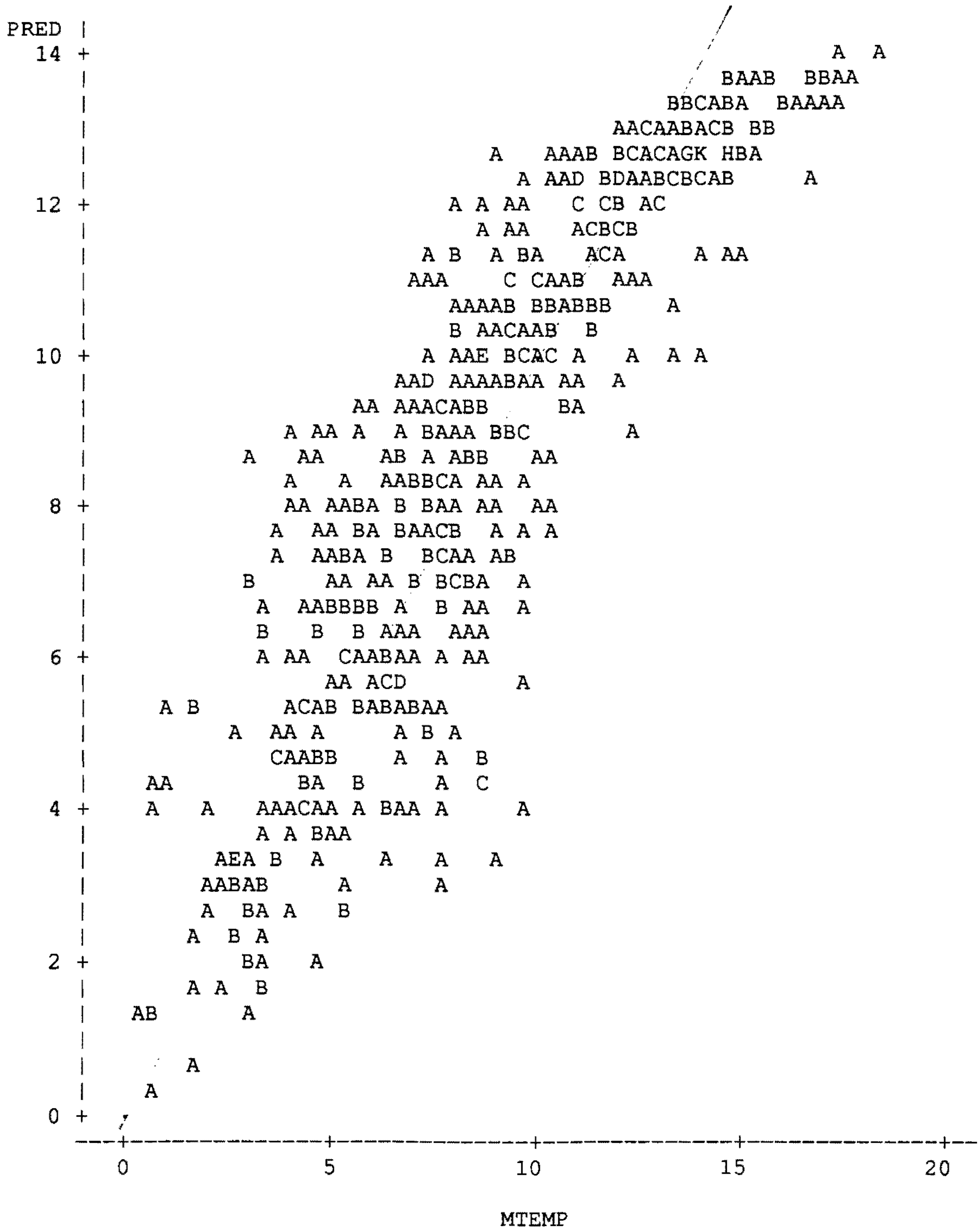


Exhibit 1 cont. p. 18

ASPECT = South-West Tribs

Plot of PRED*MTEMP. Legend: A = 1 obs, B = 2 obs, etc.



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APPENDIX J

INTRODUCTION

Periodically, questions are raised relative to salmon and steelhead runs of former years in mid-Columbia River tributaries.

A report titled "Time of Appearance of the Runs of Salmon and Steelhead Trout Native to the Wenatchee, Entiat, Methow, and Okanogan Rivers," by J. A. Craig and A. J. Suomela, was prepared in 1941 to answer such questions. Unfortunately, the report was neither published nor widely circulated. It was regarded as a confidential administrative report by the U.S. Fish and Wildlife Service to the U.S. Bureau of Reclamation.

Ten years ago I retrieved the U.S. Bureau of Reclamation's copy from their Denver, Colorado, archives. I had a few copies made and circulated, but the legibility of the original copy was poor. The controversy that engendered the report has long expired while the content has grown in import. Accordingly, the report was retyped verbatim for inclusion here.

James W. Mullan

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
WASHINGTON

May 12, 1941

Mr. John C. Page, Commissioner
Bureau of Reclamation

My dear Mr. Page:

Transmitted herewith is a report entitled "Time of Appearance of the Runs of Salmon and Steelhead Trout Native to the Wenatchee, Entiat, Methow, and Okanogan Rivers," by J. A. Craig and A. J. Suomela. This report has been prepared specifically at the request of Mr. F. A. Banks of the Bureau of Reclamation to answer as conclusively as data permit the question raised by Mr. B. M. Brennan, Director of the Washington State Department of Fisheries, regarding the existence of summer and fall spawning stocks of salmon under primitive conditions in the Wenatchee River and other tributaries of the Columbia River where fish from these late runs are now being transferred in connection with the Grand Coulee salmon salvage program.

This question was raised by Mr. Brennan during a meeting held in his office with representatives of the Bureau of Reclamation and the Fish and Wildlife Service, at which time an attempt was made to place responsibility for stream improvement and adjustment of water flow to assure successful migration and spawning in these streams during the extremely low water which is expected during the coming summer.

This report is not for publication in its present form because of the inclusion of confidential material related to the controversy which has arisen. It should be regarded an administrative report to aid the agencies concerned in developing a proper program.

A carbon copy of the report is also enclosed for Mr. Banks, who desires to have the information in the very near future.

Very truly yours,
/s/ CHAS. E. JACKSON
Acting Director

UNITED STATES DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

Time of Appearance of the Runs of Salmon and Steelhead Trout Native to the Wenatchee, Entiat, Methow, and Okanogan Rivers

J. A. Craig, Associate Aquatic Biologist

A. J. Suomela, Associate Aquatic Biologist

May 2, 1941

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INTRODUCTION

A conference was held on March 6, 1941, in the office of Mr. B. M. Brennan, Director, Department of Fisheries, State of Washington, for the purpose of discussing means of securing proper passage for fish in the streams directly affected by the Grand Coulee fish salvage program. These streams are the Wenatchee, Entiat, Methow, and Okanogan Rivers. Representatives of the U.S. Fish and Wildlife Service, Washington State Game Commission, and Washington State Fisheries Department were present.

In planning for the protection of the salmon runs interfered with by Grand Coulee Dam, it was decided that it was not possible to have the runs continue on beyond that structure because the difficulties of getting both adult and downstream migrants over it without injury. The plan decided upon, and now in operation, provides for the trapping of the entire run of migrating fish at Rock Island Dam in the Columbia River. From Rock Island, the fish are transported in specially built tank trucks to the hatchery at Leavenworth, Washington. At that location the adult fish are held in ponds in the Icicle River until mature. The spawn is then taken and the eggs hatched and fry reared at the central Leavenworth Hatchery and branch hatcheries on the Entiat and Methow Rivers. The location of these streams is shown in Fig. 1 (main report). The young fish resulting from these operations will be planted in the Wenatchee, Entiat, Methow, and Okanogan River systems. All these streams enter the Columbia River below Grand Coulee Dam, and it is believed that, because of the homing habit of the salmon, the adults returning from these plants will ascend the rivers in which they were reared and liberated. In that way the runs that formerly went past Grand Coulee Dam will be transferred to the tributaries on the Columbia River below that structure. After one generation of fish have been so handled and tests have been made to determine the exactness of the homing of the salmon, it is expected that trapping operations at Rock Island can be discontinued, and the runs allowed to enter the streams to which they have been transferred.

This program has been under way since the season of 1939, so it is a matter of but a few years until the runs of salmon must migrate up the rivers in which they were planted. Therefore, provisions must be made so that all of the streams present free passage to the fish and a minimum hazard to up and down stream migration. The irrigation ditches on these rivers have been screened to protect downstream migrants through the action of the Department of Fisheries, State of Washington, in securing W.P.A. funds and labor for their screening projects. Also, proper fish ladders have been erected at practically all of the dams. However, there remain several places where so much water is diverted for power and irrigation purposes that sections of the streams may not carry enough water during the summer to give the migrating salmon an unobstructed path up stream. This condition does not prevail on the Okanogan or Entiat Rivers at present. There are some locations on the Methow where danger of such obstruction is possible, and one section of the Wenatchee River which may possibly be an obstruction at extremely low water, and another on that same stream which is an acute case and must be remedied before adult salmon migrants can go through during the late summer and early fall. This latter situation is caused by the diversion of water at the Dryden Power Dam, where 1,300 second feet of water is diverted for the combined purpose of power and irrigation. About 1-1/2 miles below this diversion a good part of this water is returned to the Wenatchee River. Therefore, the section in which there is danger of insufficient water to supply fish passage lies between the Dryden Dam and the powerhouse and is about 1-1/2 miles in length. This diversion was the particular case taken up at the conference of March 6, since it is the most important acute case of diminished stream flow interfering with salmon migration in any of the streams related to the Grand Coulee fish salvage program.

Mr. F.A. Banks, of the U.S. Bureau of Reclamation, stated that his office was not inclined to assume responsibility for any stream improvement work such as would be necessary. His argument was that such conditions exist contrary to state laws or because of lack of enforcement of such laws. He also pointed out that the Board of Consultants which approved the Grand Coulee fish salvage program had specifically stated that all such improvements should be financed and carried out by the State of Washington. He further stated that his department had no choice but to adhere to the recommendations of this Board. Mr. B.M. Brennan, Director of Fisheries, State of Washington, replied that his department was willing to assume responsibility for providing proper conditions for populations of fish which were native to the stream. However, he maintained that under the Grand Coulee salvage program strange races of salmon were being introduced to the Wenatchee River and other streams. He maintained that the original runs of salmon native to the Washington streams were parts of the early Columbia River run which entered the tributary streams before these low water conditions prevailed. Therefore he believed that any expense necessary to provide additional stream flows in July, August, or September, was not the responsibility of his department, since the reasons for such expenditures were caused directly by the introduction of late run fish into the streams.

Mr. Banks replied that he would refer this matter to the Board of Consultants and would act upon their advice. The question of responsibility for the maintenance of proper stream conditions for salmon returning, in cases where low water interferes with late summer or fall migration, as a result of the Grand Coulee salvage activities, appears to depend upon the time of run of the original salmon populations of the area in which they have been planted, namely the Wenatchee, Entiat, Methow and Okanogan River systems.

It is not the purpose of this report to enter into this question of responsibility on one side or the other, but rather to present the facts that are available regarding the time of original runs, and to draw unbiased conclusions from them. Since the Dryden diversion on the Wenatchee River is at present the chief source of contention, the greater part of this report will be devoted to a study of conditions on the Wenatchee River.

Dryden Power and Irrigation Diversion

Since the diversion at the Dryden Dam, which takes out 1300 second feet of water, returning part of that flow 1-1/2 miles down stream through the powerhouse, was the chief point of controversy, it appears advisable to examine the conditions actually existing at that place.

At present when the river flow reaches 1300 second feet or less, the entire river is diverted into the diversion canal with the exception of the small amount of water seeping through the dam and going down the two fishways. This minimum flow through the section depleted of water has been estimated at between 40 and 50 second feet. This is not sufficient to provide proper passage for salmon.

Conditions could be much improved by confining this water to a small channel. However, it is believed that with present channel conditions a flow of 200 second feet, or slightly more, would be sufficient for the fish. Therefore, if the Dryden canal diverts 1300 second feet there should be approximately 1500 second feet in the river to provide an excess of 200 which we estimate to be satisfactory.

Wenatchee River at Peshastin, Washington
Number of days in each month, on which flow was less than 1500 second feet

Table 1.

Year	April	May	June	July	August	Sept.	Oct.
1929	23	_	_	5	31	30	31
1930	_	_	_	6	31	30	31
1931	_	_	_	15	31	30	31
1932	_	_	_	_	22	30	29
1933	2	_	_	_	5	27	5
1934	_	_	_	_	27	30	24
1935	_	_	_	_	16	30	31
1936	11	-	-	7	31	30	31
1937	9	_	_	_	30	30	28
1938	3	_	_	1	31	30	(1)

(1) No records available.

Table 1 shows the number of days during April, May, June, July, August, September, and October of the years 1929-1938 inclusive, when the flow of the Wenatchee River measured at the Peshastin was less than 1500 second feet. This gauging station is the nearest available to the Dryden diversion and is above that point. Peshastin Creek enters between the gauging station and the diversion and may at times contribute significantly to the river flow below the station. However, since most of the flow is taken from Peshastin Creek during dry seasons for irrigation, it is thought that it will not contribute enough during the critical periods to alter the situation. Table 1 then gives an estimate of the number of days during each month over a 10-year period when lack of water in the Wenatchee River at the Dryden diversion would make conditions unfavorable for salmon to migrate past that location. Examination of this table shows that such conditions prevail rather rarely in April, occasionally during July and almost continuously during August, September, and October. Therefore, it is evident that while the early chinook run arriving at Rock Island in April, May,and June will ordinarily find no hindrances at Dryden, the later run of fish is quite apt to find not enough water to successfully pass that point. The first half of the blueback run would probably not be adversely affected, but that portion of the fish arriving at Rock Island during the latter part of July and later, would have some difficulty in passing this diversion during years of unusually low run-off. The statement of the Department of Fisheries, State of Washington, that the early run fish are not subject to hindrances of low water conditions, appears to be well founded.

It now remains to inquire into whether or not all of the original populations of the Wenatchee, Methow, Entiat, and Okanogan Rivers were of this early variety. Unfortunately, most of the original salmon populations of these streams have been so seriously depleted by unscreened diversions, dams with improper ladders, and other bad conditions that it is very difficult to secure any first hand information regarding their time of appearance in these tributary streams.

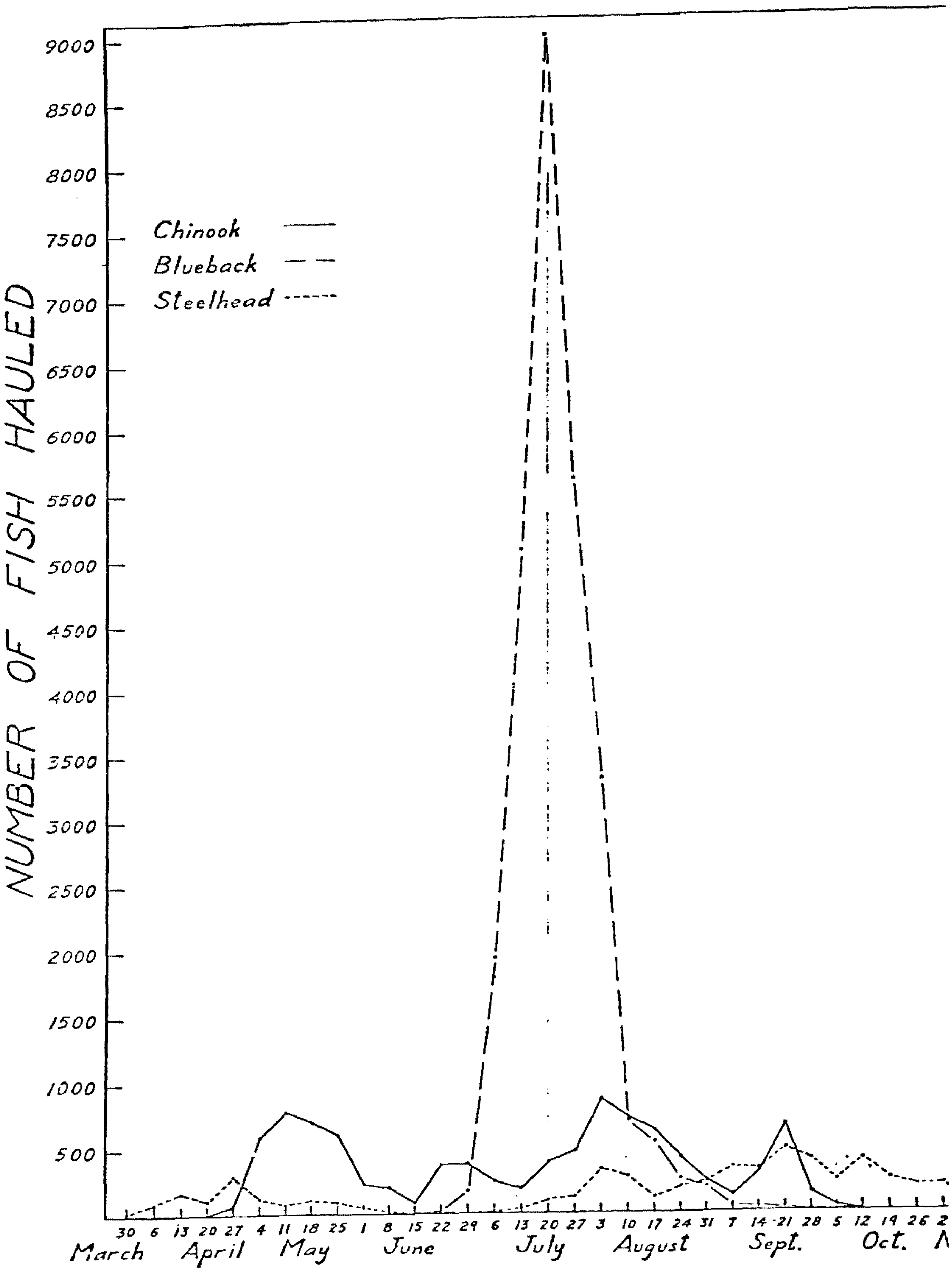
We have found three main sources of information relating to this problem, they are: records of hatchery operations of the Washington State Fisheries Department; statements (see attached) of residents who have been on these streams for many years and who are interested in fish, and who had been interviewed by our staff; and observations on the streams made by the staff of the Columbia River investigations before the runs were intercepted at Rock Island.

Time of Salmon Runs At Rock Island Dam

Since the time of migration of the fish in the tributary streams where salmon resulting from propagation of the Rock Island runs are to be planted, is the chief point of controversy, it seems advisable to briefly consider the dates of arrival of the various runs of salmon at Rock Island where they are not intercepted.

Figure 2 presents a graph showing the number of migratory, salmonid fishes trapped at Rock Island during each seven-day period of the season of 1940. This particular year was selected because it is fairly representative of the runs occurring since the third fish ladder was constructed at Rock Island Dam in 1936. It will be noted that the chinook salmon (Oncorhynchus tschawytscha) first appeared on April 20 and steadily increased in number until the middle of May; the catch then fell off steadily until after June 20 when another small mode appeared. The catch then declined until about the middle of July, after which it increased and large catches were made through most of August, with another smaller peak during September. The first part of the run which arrives at Rock Island during April, May, and June is that which is commonly called the early or spring run, while July, August, and September arrivals are commonly called the late or summer run fish. The contention of the Department of Fisheries, State of Washington, is that the original populations of salmon inhabiting the streams under consideration

Fig. 2.



NUMBER OF FISH HAULED
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Chinook
Blueback
Steelhead
30 6 13 20 27 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28 5 12 19 26
March
April
May
June
July
August
Sept.
Oct.

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were all part of the early, or May and June, migrations, and that they should not be held responsible for salmon arriving at Rock Island in July, August and September, and planted in the streams of Washington because of the Grand Coulee fish salvage program. There appears little doubt but that there is a racial difference between the May and June run and those coming to Rock Island at a later date. The fish taken in the latter part of June and first part of July are probably a mixture of the two racial components. There are, also, no doubt, many distinct races or populations of salmon mixed together in each of these two large divisions. These smaller components cannot be distinguished when they arrive at Rock Island.

In this same figure, the time of arrival of the bluebacks (Oncorhynchus nerka) is shown. It is evident that their time of run is quite concentrated, with a few fish in the latter part of June and during August, but the great majority of this species arrives in July, with a sharp peak in about the middle of that month. The steelheads (Salmo gairdnerii) are split into two groups. Many of these fish come to Rock Island in March, April, and May, very few are present during June and July, and another run appears in August, September, and October. In several other years few steelheads have come to Rock Island in August, the main body of the late run being in September and even late in October.

Time of Spawning of Spring and Late Run Chinooks

During the first two years of the Grand Coulee fish salvage program, 1939-1940, the hatchery facilities were not completed, therefore it was necessary to haul all of the adult fish during 1939 and a portion of the run of 1940 from Rock Island Dam and liberate them in the tributary streams and to depend upon natural spawning rather than artificial propagation for the transfer of these runs. Weirs were placed in these streams below the location where the fish were liberated so that they could not descend into the Columbia River, and from intensive observations made of their spawning activities, mortality, and upon the young fish resulting from these spawnings, it appears evident that this natural spawning was extremely successful.

When this program of hauling adult fish was first started it was recognized that the early April, May, and June fish were of different racial stock than those coming later in the season. Therefore it was decided to confine that part of the run in one particular area in order to avoid mixing the racial stocks any more than was necessary. These early fish were placed in Nason Creek and spawned with good success. The later run of chinook were placed in the upper Wenatchee River and the Entiat River. During the course of the observations made on these fish, it was possible to discover the exact times when the two groups spawned. The difference in spawning time of the two groups was quite pronounced. This is shown by the following facts.

Observations made on the early spring fish liberated in Nason Creek during 1940 showed that spawning started on about August 5, with the peak of spawning activities occurring during the last ten days of August and the first week of September. After September 14 all spawning was practically completed. This can be seen from the following: 254 live chinooks were observed in Nason Creek between August 31 and September 7. From September 8 to 14 some were still in evidence. During the week September 15 to 21, the entire creek was carefully covered by men on foot and only 1 live chinook was found. A like survey made between September 22 and 28 also revealed only 1 live chinook. Spawning was considered as completed at that time and no further observations were made. This clearly indicates that the spawning of the early spring fish is almost entirely completed by September 15. The fish placed in Nason Creek were hauled during the period of time from April 22 to June 8, 1940 inclusive. A total of 3165 of these early run salmon were liberated in Nason Creek during that time.

In 1939, a part of the late run chinooks were placed in the upper Wenatchee River between Wenatchee Lake and Tumwater Canyon. These fish were taken at Rock Island Dam between July 18 and October 20. A total of 3584 late run chinooks were hauled and liberated in this stream section during that period. Our observers reported that during the week of September 11 to 17 inclusive, no chinooks had yet been observed digging or making redds, although many appeared well advanced towards spawning. On September 25 the first spawned-out chinooks were found in this area. Their spawning activities continued until about November 18, at which time no spawning salmon could be observed but 3 freshly dead chinooks were found. It was considered at that time that the spawning had been completed and observations were discontinued.

The results of these observations indicate that the spawning time of the early run of chinooks, those arriving at Rock Island in April, May, and early June, extends from about August 5 to approximately September 15, with the peak of their spawning activities occurring during the latter part of August and first part of September. On the other hand, the later run fish, those appearing at Rock Island from the middle of July until the run is over in October, begin their activities on about September 20 and continue spawning until approximately November 20. The greatest concentration of spawning of this latter group occurred during the period from October 20 to 30.

This information indicates that there is a distinct difference in spawning time of the chinook salmon of the early run and those of the late summer run. Apparently the individuals of the early run have completed their spawning activities by about September 18, while those of the later run do not start until about September 20. The peak of the spawning of the two groups is distinctly separated by a period of over a month. This segregation of spawning time can be used in determining what groups of fish were observed in the

Wenatchee River during earlier years and these facts will be applied to the results of information which will be recorded later in this report.

Time of Original Salmon Runs of the Wenatchee River--Information Obtained from Local Residents

Messrs. Les Hart, Bill Smith, and John Brender were interviewed in Leavenworth regarding the original runs of salmon and steelheads in the upper Wenatchee River. All of these men contributed to the conversation and their composite ideas appeared to be as follows:

Before construction of the Leavenworth mill dam in 1904 or 1905, the fall run of salmon was much larger than the spring run. This fall run was composed of both silvers and chinooks; a good fall run of steelheads also occurred at about the same time. They believe that these fish came about September 1. This fall run continued until about 1914-1915, after which it rapidly declined. Before the Leavenworth dam was built, the Indians' fishing grounds were near the mouth of Tumwater Canyon and on Nason Creek. After the construction of this dam they fished below that structure.

Mr. Burroughs, Superintendent of the Dryden Power Station for the Puget Sound Power & Light Co., was also interviewed. He stated that in the early days the fall run of salmon reaching the power dam was often much larger than the spring run. This fall run arrived in August and September and was composed of at least two kinds of salmon, big black fish which he assumes were chinook, and smaller fish which were more numerous, probably silvers and bluebacks. He remembers that one of the larger fish reached from his shoulder to the ground. That was quite evidently a chinook. He said that few fish were in evidence in July and late June, the spring run of chinooks and steelheads going up with the spring high water, which usually occurred in late May or early June. It should be noted that his statements correspond fairly well with Messrs. Hart, Smith, and Brender, and that all agree that chinook salmon, as well as steelheads and bluebacks, appeared in the upper Wenatchee River in August and September, as well as in May and June.

Observations Made On Chinook Salmon Runs of the Wenatchee River Before Rock Island Trapping

During the course of the regular stream survey program of the Columbia River investigation and other activities, which made observations on that stream necessary, some data were gathered concerning the original chinook runs into that stream.

During summer and early fall of the years 1935 and 1936, a counting weir was placed in the fish ladder of the Tumwater power dam, situated in Tumwater Canyon on the main Wenatchee River. The primary purpose of this weir was to make an accurate count of the bluebacks ascending the Wenatchee River to Wenatchee Lake, therefore the weir was not placed in operation until July of these years. However, all chinooks passing through the weir were counted. In 1935, 9 chinooks passed through the ladder. The first of these arrived on August 14 and the last one on September 10. In 1936, the count was 5 chinooks, with the first recorded on August 8 and the last on September 2. These fish were, of course, some of the original stock of the Wenatchee River since at that time the Grand Coulee salvage programmed had not yet been undertaken. On the days mentioned above, these fish were actively migrating upstream and had not yet begun any of their spawning operations. It seems improbable that any of the fish passing Rock Island at the time of the early run, April, May, or June, would have ascended the Wenatchee River as far as Tumwater dam so slowly that their arrival would have been as late as August 8 or 14. Therefore, it appears probable that these few individuals were part of the summer run rather than the early or spring group. It should be pointed out that no count was made of the fish passing Tumwater Dam during May and June, and it may be that the early run of chinooks used the ladder at that time although we have no record of such fish.

On September 27, 1935, one of our regular stream survey parties surveyed Icicle Creek, a large tributary of the Wenatchee River entering that stream at the town of Leavenworth. The main hatchery for the Grand Could project is located on this stream. During the course of the survey of the lower portion of the Icicle River, made on the date referred to above, 21 chinook salmon were observed. Two were dead and nineteen alive. Some were engaged in spawning activities and others were seen quietly resting in pools. These fish were of the original Wenatchee River stock and apparently were just beginning their spawning activities on September 27. When one refers to the spawning time of the early and late runs already discussed in this paper, it becomes evident that they appear to fall into a classification of the late run fish rather than that of the early run since the early run chinooks had completed their spawning activities by September 27, while the late run chinooks were just well started by September 25. This observation indicated that the group of fish observed probably belong to the late run variety.

Another observation was made on October 19, 1934, when Messrs. A.J. Suomela and J.A. Craig found 4 chinooks on a riffle just below the powerhouse in Tumwater Canyon. This small group of fish would certainly fall into the late run stock since all of the early run fish in Nason Creek completed their spawning considerably before October 19.

Observations Made On Blueback Salmon On the Wenatchee River Before Rock Island Trapping

A run of blueback salmon ascended the Wenatchee River to Wenatchee Lake before any of the Grand Coulee salvage work was undertaken. These fish were observed on their spawning grounds in the Little Wenatchee River above Wenatchee Lake in 1934 by Messrs. Suomela and Craig. During 1935 and 1936 counts of these fish were made in the ladder of the Tumwater power dam. The total count in 1935 was 889 bluebacks and in 1936 there were 29 bluebacks. The first blueback passed through the ladder on August 8 in 1935 and the last on September 20. In 1936 the first fish was recorded on July 22 and the last on September 2. It can be seen by referring to Figure 2 that the main portion of the bluebacks arrive at Rock Island during July. This natural run of the Wenatchee River may have taken a considerable length of time to ascend the short section of the Columbia from Rock Island dam to the mouth of the Wenatchee and then the Wenatchee to Tumwater dam, or perhaps that particular race is one which constitutes some of the later part of the run as it arrives at Rock Island. In any event it seems evident that the original blueback population of the Wenatchee River passes through that stream from the latter part of July to the first part of September. Inspection of Table 2 will indicate that there are often dangerously low water conditions prevailing at the Dryden diversion during that time.

Salmon Hatcheries On the Wenatchee River

The records of artificial propagation carried on in the Wenatchee River system offer information that has considerable bearing on the question under discussion. These data are presented in Tables 2 and 3.[1] The 9th annual report of the State Fish Commissioner of Washington stated that:

> "On the Wenatchee River we are satisfied that an extensive hatchery can be located from which a large amount of the May and June run of the Royal Chinook salmon and also of the summer run of Columbia River steelheads may be produced. We advise that a hatchery be at once located in this stream in order that it maybe

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[1]The data presented in Tables 2,3,4, and 5 were obtained from the following sources: 1899-1934: Annual Reports of the Washington State Fish Commissioner, State Supervisor of Fisheries, State Department of Fisheries and Game-Division of Fisheries and State Department of Fisheries. Annual reports numbered serially from the tenth to the forty-fifth. Supplementary information was also found in the reports of the Oregon Fish Commission.

Table 2. EGGS TAKEN AND FRY PLANTED, WENATCHEE HATCHERIES

	EGGS TAKEN			FRY PLANTED					
Year	Chinook	Silver	Steelhead	Chinook	Silver	Species not stated	Steelhead	Chum	Hatchery Location
1899						7,810,000			Tumwater
1900						6,025,000			"
1901						(1)			"
1902						7,934,560			"
1903				600,000	3,836,000				"
1904									closed
1910		(2)30,000							"
1913									Leavenworth
1914		38,500		1,037,800					"
1915	105,000		20,000				(3) 7,950		"
1916				1,464,100					"
1917				1,383,590					"
1921								484,955	"
1922									closed
1927				593,000					New Leavenworth
1928				1,702,600					"
1929				1,632,880					"
1930				1,445,275					"
1931									closed
1932									Chiwaukum

(1) No report available
(2) Taken at Leavenworth
(3) Eggs planted

Table. 3. Eggs Received and eggs and fry shipped, Wenatchee hatcheries.

YEAR	EGGS RECEIVED				EGGS AND FRY SHIPPED			
	Chinook	Steelhead	Chum	from:	Chinook eggs	Silver eggs	Steelhead fry	to:
1900								Spokane htch.
1910						30,000(2)		Kalama htch.
1914	2,076,400(3)			Oregon	902,500	27,800		
1915	1,350,000(4)			Oregon				
1915		213,818						
1916	1,872,000			Chinook hatchery				
1916		250,000					113,875(5)	
1917	1,500,000							
1918		150,000		Methow hatchery			138,820	
1919		500,000					494,400	
1920								
1926	600,000		500,000					
1927	1,750,000			Little White htch.				
1928	1,650,000							
1929	1,500,000							
1932	2,000,000(6)							

(1) 300,000 eggs chipped--species not given.
(2) Hatchery closed; eggs taken experimentally at Leavenworth Dam.
(4) 1,350,000 from Willamette and McKenzie R. hatcheries.
(5) Many steelhead fry planted in Wenatchee R. tributaries.
(6) Total loss--eggs frozen at Chiwaukum hatchery.

ready for operation by the time the early run of this salmon begin to spawn in the Wenatchee River."

This hatchery was built in 1899 on the Wenatchee River, near the Chiwaukum railroad station just above Tumwater Canyon. Eggs were at once taken and fry liberated as can be seen by referring to Table 2. Unfortunately, the species of salmon spawned is not mentioned in these records. This hatchery was closed in 1904. The reasons given were: extreme cold weather, heavy snow, isolated location and consequent expense of operating, freshets, and the fact that it was too far up the river to secure the best variety of fish. A quotation from the 14th and 15th annual reports of the State Fish Commissioner of Washington is as follows:

"If it had been below the Tumwater Canyon, the early chinook could have been secured, as it is it takes only an inferior run of silversides."

After the closure of this hatchery there were no activities connected with artificial propagation on the Wenatchee River until 1913 when a new hatchery was constructed at the town of Leavenworth, which is located below Tumwater Canyon. This new location was selected because it was thought that better weather and transportation conditions would exist and that large numbers of the early spring chinooks could be taken. Reference to Table 2 shows that the results were disappointing as far as the take of chinook eggs was concerned. Very few eggs of this or any other species were secured at any time by this hatchery until it was abandoned in 1931. Attempts were made to utilize this hatchery by means of shipping in chinook eggs from other places. Table 3 contains as complete a record of these shipments as can be secured at this time; unfortunately, in many cases there is no record as to the streams from which the eggs were originally taken before shipment to Leavenworth. However, in 1914, 1,076,400 eggs were shipped from Oregon. By checking the Oregon state records it is found that such a shipment to Washington is recorded from the Willamette Hatchery, located on the upper Willamette River. This hatchery takes early run spring fish entirely so this shipment was apparently of that variety.

1,350,000 eggs were received at Leavenworth in 1915, from the McKenzie and Willamette hatcheries of Oregon. Again, these were eggs from an early spring run. Other shipments of chinook eggs to the Wenatchee were made up to 1932. One of these was from the U.S. Bureau of Fisheries hatchery at Little White Salmon and the others were from Washington State Hatcheries. Most, or probably all, of these eggs were from fall run parents.

The records of the hatchery operations at both above Tumwater Canyon and Leavenworth indicate that it was not found possible at either location to secure either early run chinook or any other variety of that species in significant numbers. Also, numerous shipments were made to the Leavenworth station from streams on the lower Columbia and from outside the state. Some of these eggs were undoubtedly taken from the early run chinooks of the Willamette River system. However, other shipments, such as those made from Little White Salmon River by the U.S. Bureau of Fisheries, and probably some of those made by other Washington hatcheries on the lower Columbia, could have supplied only extremely late fall running chinooks. Therefore, it appears evident that the Washington State fisheries authorities have from time to time made attempts to introduce exotic populations of salmon to the Wenatchee River, many of which were of a late appearing variety, and that they carried on this program for many years before the Grand Coulee fish salvage activities made necessary the transfer of strange runs of fish to that river.

Original Salmon Runs Of the Methow River
Salmon Hatchery Activities On the Methow River

The first salmon hatchery was built on the Methow River in 1899. It was located at the junction of the Twisp and Methow Rivers. This station was operated until 1914. It and all other hatcheries on this stream were built and operated by the State of Washington. The chief fish it produced were silver salmon (Oncorhynchus kisutch), with very few chinook eggs being taken. The data showing the results of the hatchery operations on the Methow River are presented in Tables 4 and 5.

In 1915 a new hatchery was built at Pateros on the main Methow River. This change was made in order to obtain better operating conditions and with the idea that large quantities of early spring chinook eggs could be secured at this new location. Table 4 indicates that the silver salmon continued to be taken and that large numbers of steelheads were also spawned; however, chinooks were never obtained in any quantity. Table 5 shows that some eggs were transferred to Methow from other locations. Even chum salmon eggs were shipped there in 1916 and 1917. However, it is not thought probable that any of the fish from plants of that species returned to the Methow. In many cases there is no indication as to where the transferred chinook eggs were taken, but some were obtained from the U.S. Bureau of Fisheries hatcheries on the lower Columbia and probably some of the Washington hatcheries from that section also contributed late run stock to the Methow River. It is very questionable whether any of these fish were able to return to the Methow River, since the distance they would have to migrate is much greater than that to which the original stock was accustomed. However, these records do indicate that the Washington State Fisheries authorities made attempts to introduce strange runs of salmon to the Methow as well as to the Wenatchee.

One of the parties of the Columbia River investigation surveyed the Methow River system during the late summer of 1935.

Table 4. EGGS TAKEN AND FRY PLANTED, METHOW HATCHERIES

	EGGS TAKEN			FRY PLANTED					
Year	Chinook	Silver	Steelhead	Chinook	Silver	Species not stated	Steelhead	Chum	Hatchery Location
1900						152,500			Twisp
1901						(1) -			"
1902						2,969,350			"
1903				100,000	2,200,800				"
1904		35,000							"
1905		500,000							"
1906		1,500,000							"
1907		708,950							"
1908	10,000	1,120,000							"
1909	7,500	2,337,000							"
1910	30,000	997,000							"
1911	68,000	320,000							"
1912	5,000	2,015,000							"
1913		924,000							"
1914		1,427,000			148,559				"
1915					1,095,000				"
"		18,000	2,051,000				1,543,800		Pateros
1916	2,000	1,496,000	3,037,500	1,342	252,150		1,662,280	1,318,800	"
1917		1,517,000	2,962,000	3,136,211	999,374		897,510	887,400	"
1918		130,500	1,841,000		1,269,130		691,250		"
1919		3,000	3,760,000		116,100				"
1920		328,000	2,399,000		2,700		945,500	938,450	"
1921			638,000		301,700				"
1922									Closed
1926				400,000					Pateros
1927				593,000					"
1928				230,000					"
1929				760,800					"
1930				99,450					"
1931				(3)500,000					"

(1) 1901 No report available
(2) Methow Eyeing Station
(3) Planted in lakes

Table 5. EGGS RECEIVED AND EGGS AND FRY SHIPPED, METHOW HATCHERIES

	EGGS RECEIVED			STEELHEAD EGGS & FRY SHIPPED		
Year	Chinook	Chum	From	Eggs	Fry	To
1916		2,760,000		630,000	315,000	
1917	1,500,000			600,000	1,050,000	
1918				125,000		Pend Oreille Co.
				150,000		Leavenworth H.
					575,000	
1919				540,200		Stevens Co.
				500,000		Spokane Co.
				52,000		Dumpka Lake
				500,000		
1920		1,000,000		200,000		Chelan Co.
				200,000		Stevens Co.
				50,000		Connecticut
				50,000		Dumpka Lake
1921						(1)Okanogan Co.
1926	400,000					
1928	700,000		Quilcene H.			
1929	500,000					
1931	500,000		Little White			

(1) 32,000 shipped - not listed as eggs or fry

During the course of these investigations 23 chinook salmon were observed in the main Methow River from just above the mouth to the confluence of Lost River. These fish were observed from August 13 to 24 inclusive, and all were either dead or carrying on spawning activities.

In the Chewack River 63 chinooks were observed on the spawning beds between August 11 and 16. From August 17 to 25, 44 chinooks were counted in the Twisp River. These fish were either spawning or already spent. Both the Chewack and Twisp Rivers are upper tributaries of the Methow. These observations indicate that the chinook salmon observed were part of the early spring run which passes the Rock Island Dam. This appears to be definitely so because their time of spawning was well within the range of that of the early run fish and earlier than any of the late summer run have been observed to spawn.

General statements have been heard that some late summer chinooks entered the lower part of the Methow River and spawned there, however no direct evidence is available to support those statements. It appears that the Methow River originally supported runs of silver salmon in the river in September and October which have been exterminated, and steelhead which probably came in both early in the spring and during the fall, and a population of the early spring run chinooks. There is no definite evidence that later run chinooks have inhabited this river, although because of the fact that we had no observations made at the time during which these fish would spawn, it is not impossible that some of these fish have been present in that stream.

Original Salmon Runs of the Entiat River

Unfortunately the salmon runs of the Entiat River have been practically exterminated for many years because of dams built on that stream, which were provided with either inadequate fish ladders or no fish ladders at all. There is, therefore, very little information available as to the time of appearance of those fish. Information was obtained from a man who had resided at Entiat, Washington, since 1895. According to his statement, there was an excellent run of chinook salmon in the Entiat River during May and June in the early years. In 1898 a dam was built at a sawmill at a point about 1 mile above the mouth of the river. While a crude fishway was built on this dam, only a few salmon ascended the river. Shortly thereafter another dam, with no fish ladder, was constructed, and the salmon were completely cut off from the spawning areas. Statements have also been heard to the effect that the silver salmon ascended the Entiat before the building of these obstructions. No information was obtained to indicate the presence of any late run chinooks. Chinooks entering the Entiat in May and June would certainly fall into the category of early or spring run populations.

Original Salmon Runs of the Okanogan River

While there is no need of stream improvement to make the Okanogan River suitable for the upstream passage of salmon, it appears advisable at this time to record the information that is available concerning the time of appearance of the original salmon runs through that stream. This is considered to be proper because the Okanogan River is one of the streams into which salmon are being introduced because of the Grand Coulee fish salvage program.

The Indians residing near the Okanogan River made a practice of catching the salmon by means of weirs built across the stream so that all fish were stopped in their upstream migrations. These weirs were operated each year until 1931. Some of these were located about 4 miles above the mouth of the river in the vicinity of the town of Monse, Washington. Residents along the Okanogan River have stated that chinook salmon had been observed spawning in that stream during the early part of October. This was, of course, before the runs were intercepted at Rock Island. If these statements are to be relied upon it would place those fish definitely in the summer or late run classification.

In 1934, 1935, and 1936 counts of blueback entering Osoyoos Lake were made by the Fish and Wildlife Service (then the Bureau of Fisheries), and in 1937 the counts were continued by the Department of Fisheries, State of Washington, with funds secured from the U.S. Bureau of Reclamation. The fish were counted through a weir which was constructed at a mill dam located just outside the town of Oroville, Washington, a short distance below the outlet of Osoyoos Lake. The counters on this weir observed a few chinook salmon which spawned in the Okanogan River below the weir during the last week in September. This agrees fairly well with the statements obtained from the residents and makes it appear probable that those fish belonged in the late run category.

The Similkameen River enters the Okanogan River at the town of Oroville. There is a short portion of this stream, about 6 miles in length, extending from its confluence with the Okanogan River to an impassable power dam, in which chinook salmon spawned when the runs were permitted to pass Rock Island Dam. These fish were observed each week by the men counting bluebacks at Oroville during 1934, 1935, and 1936. In 1934, 40 chinooks were observed in that area; 20 were seen in 1935; and in 1936 the run was considerably larger, 50 being counted in one pool. These salmon made their appearance in the Similkameen in August, the 9th to the 17th being the earliest date or occurrence. The bulk of these fish arrived during September and most of the spawning activities began during the latter part of that month. In 1934, the first spawning commenced about September 21st and in 1936 the first pre-spawning activities were noted on September 27th. These observations indicate that this portion of the original populations going up the

Okanogan River belong to the summer or late part of the Rock Island run.

The first complete counts of the blueback run in the Okanogan River were secured in 1935, when 264 fish passed the Oroville weir. The operations in 1934 were not successful in securing a count because the weir could not be installed sufficiently early to intercept the run. In 1936, 895 individuals of this species were counted and a total of 2161 bluebacks was recorded in 1937. In each year the first of these fish arrived during the latter part of July and the greater part of the run passed through the weir and into the lake by September 1st. This indicates that the original runs of bluebacks on the Okanogan River passed up that stream during the latter half of July and the entire month of August in significant numbers.

Summary and Conclusions

1. Evidence now available indicates that in its original state the Wenatchee supported runs of chinook salmon which would arrive at Rock Island dam during the last half of July and the month of August, thus forming part of the summer or late run. The original run of blueback salmon was present in the river during the latter half of July, all of August and the first part of September. Steelhead apparently migrated upstream in that river in September and October. It is probable that there was also an early spring run of both chinook and steelheads. A run of silver salmon, now extinct, ascended the river during September and October and perhaps later. Efforts were made by the Department of Fisheries, State of Washington, to transplant chinook salmon from other streams to the Wenatchee River. This procedure was carried on over a period of about 17 or 18 years. Some of these transplanted fish were from early spring run stock and others from late fall run parents.

2. Attempts were also made to establish runs of both fall and spring run chinooks in the Methow River. No success was had there in attempting to secure chinook salmon eggs for artificial propagation. Silver salmon and steelhead trout entering the river in September and later were at one time common in the stream. Spawning chinooks have been observed in the main stem of the Methow and in upper tributaries which were definitely of the early spring run variety. No definite evidence of late run chinooks entering the stream is available.

3. Spring run chinooks and fall run silver salmon were apparently abundant in the Entiat River before the runs were destroyed by dams which were not provided with adequate fishways.

4. The Okanogan River and its tributary, the Similkameen, contained runs of chinook salmon which appear to have belonged to the summer or late run group. The bluebacks ascending that stream were present there during July and August.

July 14, 1941

From: Supervising Engineer

To: Resident Engineer, Wenatchee

Subject: Rehabilitation of tributaries--Migratory fish control--Columbia Basin Project

1. The Fish & Wildlife Service has indicated its willingness, under date of July 9, to allow us to obtain affidavits from several men who were at or near Leavenworth 25 to 40 years ago, and who can testify that a summer and fall run of salmon existed in the Wenatchee River before becoming exterminated by neglect on the part of the state to maintain a river negotiable for upstream and downstream migrants. The names of these men are as follows:

Les Hart	Leavenworth
Bill Smith	"
John Brender	"

Their composite testimony as taken from the Wildlife report reads as follows: "Before construction of the Leavenworth mill-dam in 1904 or 1905 the fall run of salmon was much larger than the spring run. This fall run was composed of both silvers and chinooks; a good fall run of steelhead also occurred at about the same time. They believe these fish came about September 1. This fall run continued until about 1914-15, after which it rapidly declined. Before the Leavenworth dam was built the Indians' fishing grounds were near the mouth of Tumwater Canyon and on Nason Creek. After the construction of this dam they fished below that structure."

2. It is suggested that the affidavits be prepared embodying the pertinent statements contained in the above quotation and that these gentlemen be contacted for signatures thereto. It would be well to ascertain if there are any incidents which support the belief of these men that the run in question occurred about September 1. This date is very important and any evidence to support its definite fixation will be advantageous. Possibly these three men can give you the names of other early settlers who might corroborate their statements and possibly add to the available information.

3. While similar data for the other tributaries, particularly the Okanogan and Methow Rivers, are not quite as important as the Wenatchee River record, whatever evidence along these lines is readily obtainable should be secured as soon as practicable.

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F. A. Banks

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Ephrata, Washington
April 23, 1942

From: Resident Engineer

To: Supervising Engineer

Subject: Affidavits to salmon run in the Wenatchee, Methow and Okanogan Rivers

1. There is enclosed herewith signed affidavits by the following parties:

C. C. Beery
Mrs. Henry L. Staples
Guy Gilmour
John Johnson
Arthur S. Michel
R. J. Smith
Geo. Siverly
Chas. Burbank
Geo. R. Schmitten
Mike Mahoney
George Whistler
Ed J. Brown
Fay Larkin
William Wentworth
J. B. Adams
J. A. Adams

2. I am enclosing also copy of letter received from Mr. M. M. Fruit, Supervisor of Plantings, of the State Department of Game. This letter, while not being very definite, is interesting and may be of some assistance, since it follows closely the same line as the attached certificates.

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V. W. Russell

AFFIDAVITS

[In April and May of 1942 a number of affidavits were obtained from long-time residents of Chelan County regarding the extent and times and locations of salmon runs, and the locations of spawning grounds with respect to the Wenatchee, Okanogan, and Methow Rivers.]

Wenatchee River

"I, R. J. SMITH, do hereby certify that in the years previous to the building of the Lumber Company Dam at Leavenworth, which was built in 1904 and 1905, the Silver, Chinook, and Steelhead Salmon all came up the Wenatchee River in large numbers, so many that the stream bed would be covered with them. This run began in September and continued on until late fall. There was a small run in the spring but it was not considered important. Very few salmon were found in the Icicle Creek; Nason Creek was an especially attractive spawning ground, and nearly all the smaller creeks had runs of Silvers and Steelhead. While some of the salmon were able to get over the Leavenworth Dam and also over the Dryden Dam, the Salmon run began to decrease after these structures were in operation."

"I, GEO. SIVERLY [Siverge], do hereby certify that Steelheads and big Chinook Salmon, and some Silver Salmon used to come up the Wenatchee River in large quantities. In 1899 there were large numbers of Salmon. The gravel bar at the lower end of Lake Wenatchee just below the site of the present fish weir was a favorite spawning bed and the road crossed the river at this point. The salmon were so thick they would scare the horses when people were crossing the ford during the spawning season. The run decreased steadily after the building of the power dams at Dryden and Tumwater Canyons."

"I, CHAS. BURBANK, do hereby certify that in the years previous to the building of the Lumber Company Dam at Leavenworth, which was built in 1904 and 1905, the salmon came up the Wenatchee River in large numbers. Silvers, Chinook, and Steelhead all came up about the same time, the run beginning in the latter part of August and ending in the late fall. This was the time the Indians caught their fish for drying."

"I, GEO. SCHMITTEN, do hereby certify that in the years previous to the building of the Lumber Company Dam at Leavenworth in 1904 and 1905 and the power dams at Dryden and Tumwater Canyon in 1908, the Chinook, Steelhead and some Silvers came up the Wenatchee."

"I, FAY LARKIN, do hereby certify that in the years previous to the building of the power dams in the Wenatchee River that salmon came up the River in large quantities; Silvers, Chinook, and Steelhead all came up about the same time, the run beginning the last of August and continuing into late fall."

"I, J. B. ADAMS, do hereby certify that in the years previous to the building of the Lumber Company Dam at Leavenworth, which was built in 1904 and 1905, the salmon came up the Wenatchee River in very large numbers. Silvers, Chinook, and Steelhead all came up about the same time, beginning about the first of September and continuing on into November before they were all gone. All the creeks had their runs of Silvers and Steelhead. Nason Creek was especially attractive to Silvers and Steelhead. Very few salmon, however, were found in the Icicle Creek. As soon as the Leavenworth Dam was built, the salmon runs began to weaken and by the time the Dryden Dam was put into operation in 1908 the runs were practically at an end. The spring run was not considered of any importance and the Indians never came up in the spring but about September 1 they came in large numbers and caught and dried all the salmon they needed for the winter supply."

"I, J. A. ADAMS, do hereby certify that in the years previous to the building of the Lumber Company Dam at Leavenworth, which was built in 1904 and 1905, the salmon came up the Wenatchee River in very large numbers. Silvers, Chinooks, and Steelhead all came up about the same time, beginning about the first of September and continuing on into November before they were all gone. All the creeks had their runs of Silvers and Steelheads. Nason Creek was especially attractive to Silvers and Steelhead. Very few salmon, however, were found in the Icicle Creek. As soon as the Leavenworth Dam was built, the salmon runs began to weaken and by the time the Dryden Dam was put into operation in 1908 the runs were practically at an end. The spring run was not considered of any importance and the Indians never came up in the spring but about September they came in large numbers and caught and dried all the salmon they needed for the winter supply."

Okanogan River

"I, ARTHUR S. MICHEL, Sheriff of Okanogan County, do hereby certify that I have been familiar with the salmon runs in the Okanogan River since 1909, and that Silvers and Chinook came up the Okanogan River in large numbers, mostly Chinook. These runs began to diminish with the building of the Rock Island Dam. The spring run were a smaller fish and probably were steelhead. The salmon did spawn to some extent in the lower twenty miles of the Okanogan River. The Methow River was an important salmon stream and I have seen the salmon thick below the old dam at the old hatchery site about 2 1/2 mi up the Methow River from Pateros and I have seen the salmon at the falls 32 mi up the North Fork of the Methow River above Winthrop."

C. C. BEERY:

"Some thirty years ago about 1910-11, there were heavy runs of large 'king' salmon in the Okanogan near Oroville, and many Indians camped near the rapids below Lake Osoyoos during the last of August and early September to capture salmon. They speared a great many and fished at night with flashlights.

"I recall catching a 50# 'King' on August 26 about thirty years ago. The largest one I ever caught in that vicinity weighed 55#, but there were large quantities caught weighing 35# or 40#.

"I recall borrowing an Indian's spearing rig at one time and fastening the cord attached to the spear around my waist, as was the Indian custom, and spearing a big 'King,' who rushed off with such power that I was pulled backward into the river and nearly drowned.

"On Salmon Creek great numbers of 'King' Salmon crowded this small stream and I have seen big fellows five miles above its mouth in pools too shallow to cover the fish and wondered how they managed to work their way so far upstream over the many ledges and falls.

"The 'King' run on the Okanogan was followed by a run of 'Dog' or Chum Salmon--a white-meated variety--not considered very desirable."

"I, MRS. HENRY L. STAPLES, do hereby certify that the spring run of salmon at Oroville was a small variety but do not know the name. The fall run was mostly the big Chinook; a few Silvers and Steelheads. These fish came up in August and September and some in October. The Indians camped at the forks of the rivers and caught and cured their fish during August and September. They used the regular Indian willow traps across the Okanogan River and caught all the salmon they needed. I found at one time a few Chinook Salmon in the sloughs at the lower end of Palmer Lake, but do not believe any number ever went beyond the falls of the Similkameen River. Salmon spawned in the beds of both rivers."

HENRY L. STAPLES. Same as above.

"I, MIKE MAHONEY, do hereby certify that big Chinook Salmon came up the Okanogan River in August and September; some Silvers and Steelhead came with this run. There was a spring run of a smaller variety, species unknown. The beds of both the Similkameen and the Okanogan Rivers were excellent spawning beds. The salmon did not go above the falls of the Similkameen."

"I, GEORGE WHISTLER, do hereby certify that in August and September the salmon came up the Okanogan River in large quantities mostly chinook. There was a spring run of salmon of unknown name, but of very high quantity. In 1887 and 1888, I know salmon went up to Conconully during the high water. Salmon did not go above the falls of the Similkameen."

"I, ED J. BROWN, do hereby certify that before the dam was put in Salmon Creek just above the town of Okanogan, the Salmon came up to Conconully in considerable numbers in the latter part of May and June and I am sure these Salmon were the small Chinook."

"I, WILLIAM WENTWORTH, do hereby certify that before the dam was built across the Salmon Creek above the town of Okanogan that I used to catch Salmon at Conconully in latter part of May and June which was during the high water period."

Methow River

"I, JOHN JOHNSON, do hereby certify that I have been familiar with the salmon runs in the Okanogan River since 1909, and that Silvers and Chinook came up the Okanogan River in large numbers, mostly Chinook. These runs began to diminish with the building of the Rock Island Dam. The spring run were a smaller fish and probably were steelhead. The salmon did spawn to some extent in the lower twenty miles of the Okanogan River. The Methow River was an important salmon stream and I have seen the salmon thick below the old dam at the old hatchery site about 2 1/2 miles up the Methow River from Pateros and I have seen the salmon at the falls 32 miles up the North Fork of the Methow River above Winthrop."

State of Washington

THE DEPARTMENT OF GAME
515 Smith Tower
Seattle

April 1, 1942

Mr. V. W. Russell
Resident Engineer
Bureau of Reclamation
Ephrata, Wash.

Dear Sir:

Your letter of March 30, relative to salmon runs in the Okanogan River is at hand. Will say that I have been more or less familiar with fish runs in waters of that district for the last twenty odd years and that the information obtained by you from Mr. Michel, the sheriff at Okanogan, is fairly accurate to the best of my knowledge. Will say that the various salmon runs in the Okanogan River were never large in my experience and with the exception of small tributary streams did not spawn to any great extent in the State of Washington but proceeded on into both the Okanogan and Similkameen water shed in Canada. To the best of my recollection these runs started to decline before the construction of Rock Island Dam, probably due to the fact that the spawning tributaries were facing an ever increasing drain for irrigation purposes as the area was developed agriculturally. The construction of the Washington Water Power Dam above the town of Oroville and certain pollution of the river by the Smelter British Columbia, not there before the early 1920's, no doubt had a contributary effect to the depletion of the fish runs.

While there was a run in the early spring, which was of steelhead, this run was small in comparison to the runs of fish which came into the upper Okanogan from August 1, through the fall. Blueback in considerable number were found in the Okanogan River proper during the month of August. These fish all went up the Okanogan River through Lake Osoyoss and eventually into those streams above that body of water and did not utilize any small tributary within the state of Washington. This run was followed by a run of extremely large Chinook salmon which for the most part turned into the Similkameen below Oroville.

The Methow River was much more important from the standpoint of salmon runs. Up until comparatively recent years, runs of steelhead and Chinook have been found in that river. As in the Okanogan the run declined gradually as there was heavier utilization of the streams for power and irrigation. Both the North Fork of the Methow to the falls some 32 miles above Winthrop, mentioned by Mr. Mitchel, and the Twisp River were heavily utilized as spawning tributaries.

The above recollections are as I remember them from an intimate knowledge of the streams named and from my work as a Game Warden in that county during the period mentioned, but are not to be considered as scientifically correct data.

Hoping that this information will be of assistance to you, I am

Yours very truly,

THE DEPARTMENT OF GAME

/s/ M. M. Fruit
Supervisor of Plantings

APPENDIX K

IMPLICATIONS OF AGE, GROWTH, DISTRIBUTION, AND OTHER VITAE FOR RAINBOW/STEELHEAD, CUTTHROAT, BROOK, AND BULL TROUT IN THE METHOW RIVER, WASHINGTON

by

Kenneth R. Williams and James W. Mullan

It is the purpose of this appendix to integrate information scattered in the main report and other appendices with the life histories of the trout species studied. Age and growth is emphasized in this knowledge.

Methods

We used whole otoliths (sagittae) to assess age. Otoliths were examined with a binocular microscope under reflected light on a black background. Summer growth appeared as opaque rings and annuli as dark (hyaline) rings (Kim and Koo 1963; Davis and Light 1985). We separated freshwater age from marine age by a period in notations (Koo 1962).

We present photographs of otoliths and scales to show assessment of otolith aging (Figs. 1-9). Otoliths were mounted, lateral face down, on a microscope slide with a drop of clear epoxy and ground thin. Scales were taken immediately above the lateral line in the caudal peduncle area (Lentsch and Griffith 1987). We photographed otoliths under reflected light at 32-64X magnification. Scales were photographed with transmitted light at 40-200X magnification.

Fish were measured to the nearest mm (fork length) and weighed to the nearest 0.1 gram. Large collections of the same size fish were sometimes subsampled (e.g., young-of-the-year [Y-O-Y]). Von Bertalanffy's ultimate length estimate (L) was computed after Ricker (1975) for <u>Oncorhynchus mykiss</u> reared under varied heat budgets. We used annual heat budget and temperature units (TUs) interchangeably, defined by the number of degrees by which the average temperature exceeded 0° C in a 24-hr period (Appendix I).

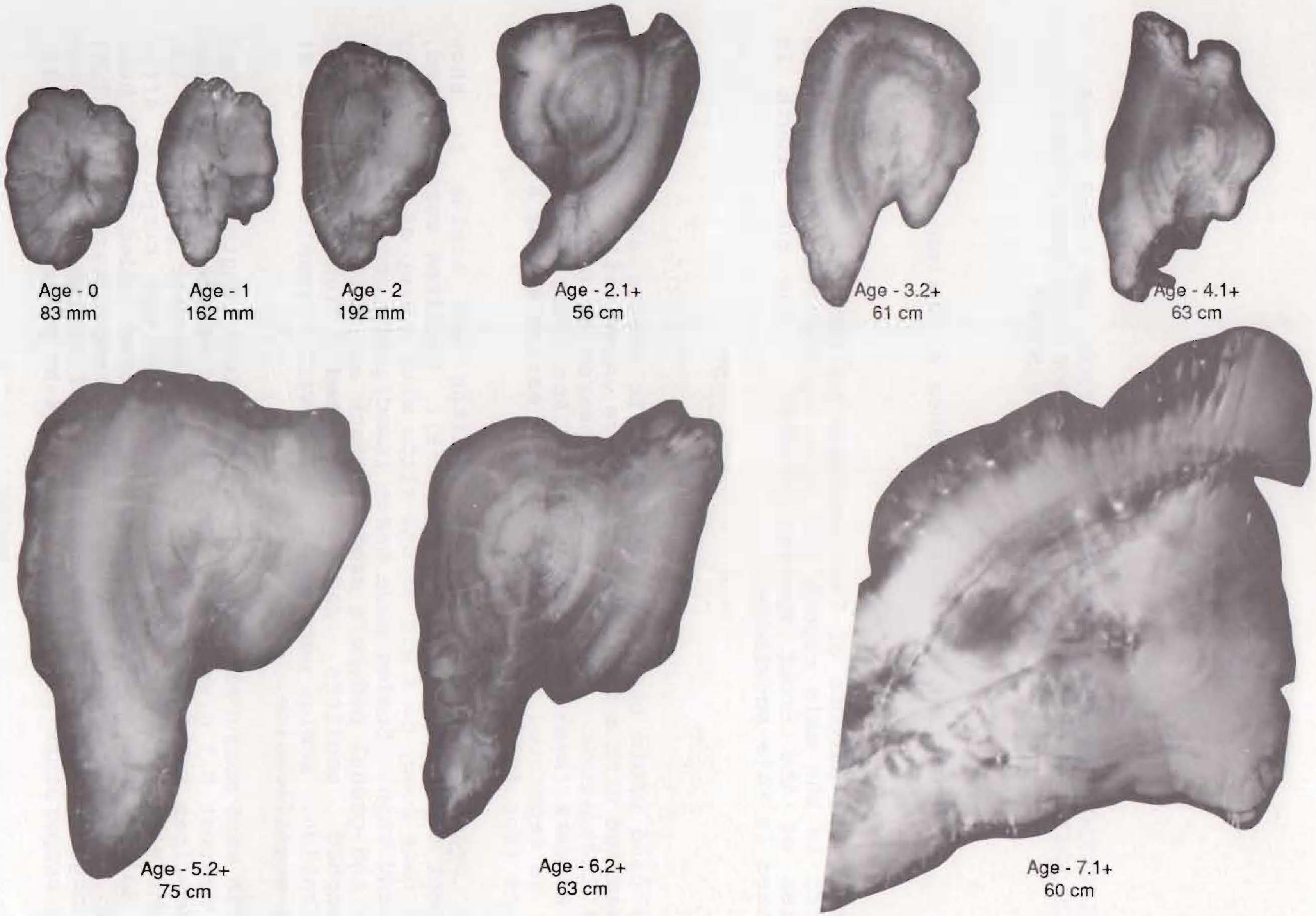

Fig. 1. Steelhead otoliths, ages, and fork lengths (mm and cm) for parr and adults from the Methow River drainage, Washington.

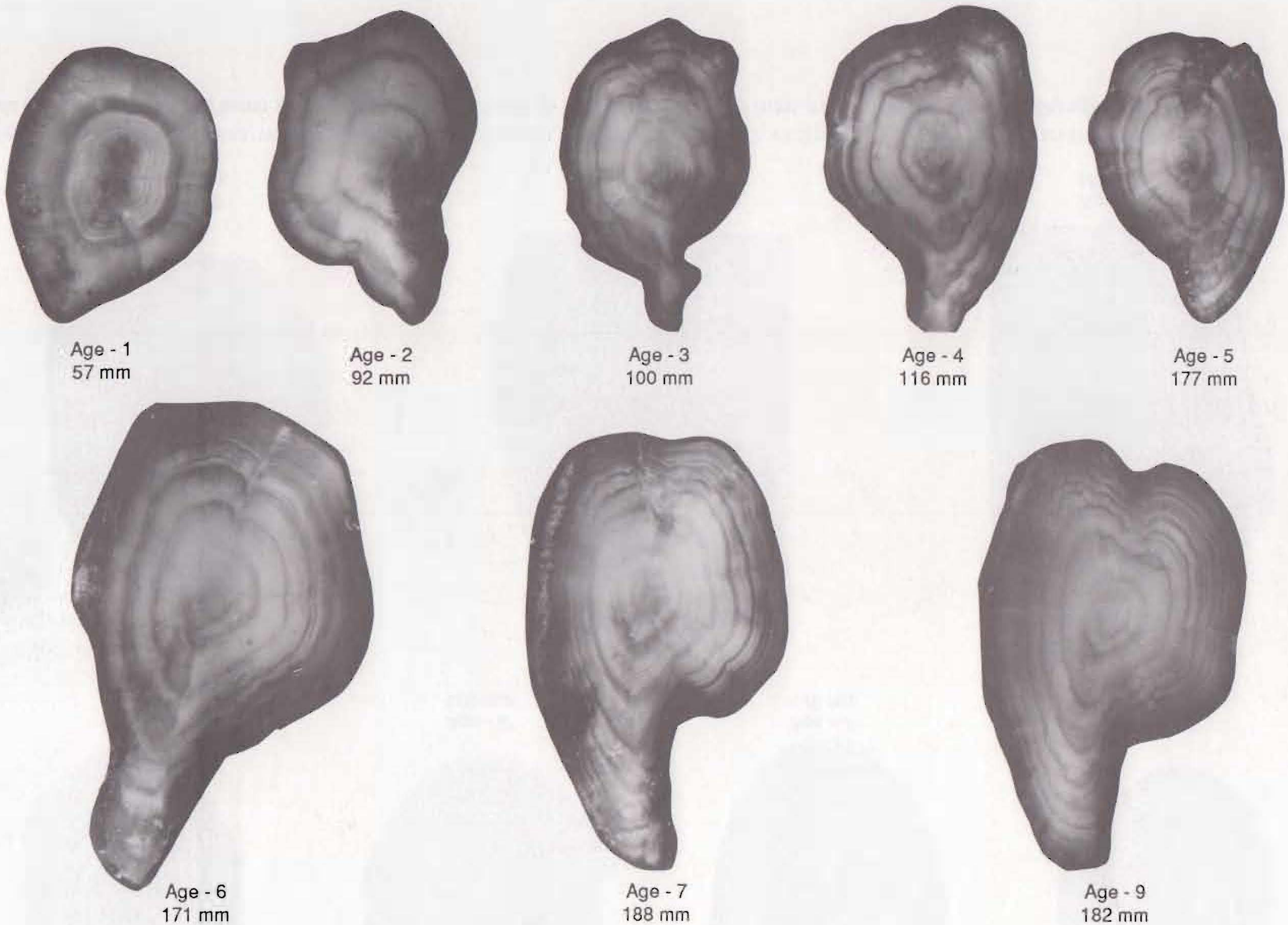

Fig. 2. Rainbow trout otoliths, ages, and fork lengths (mm) from the Methow River drainage, Washington.

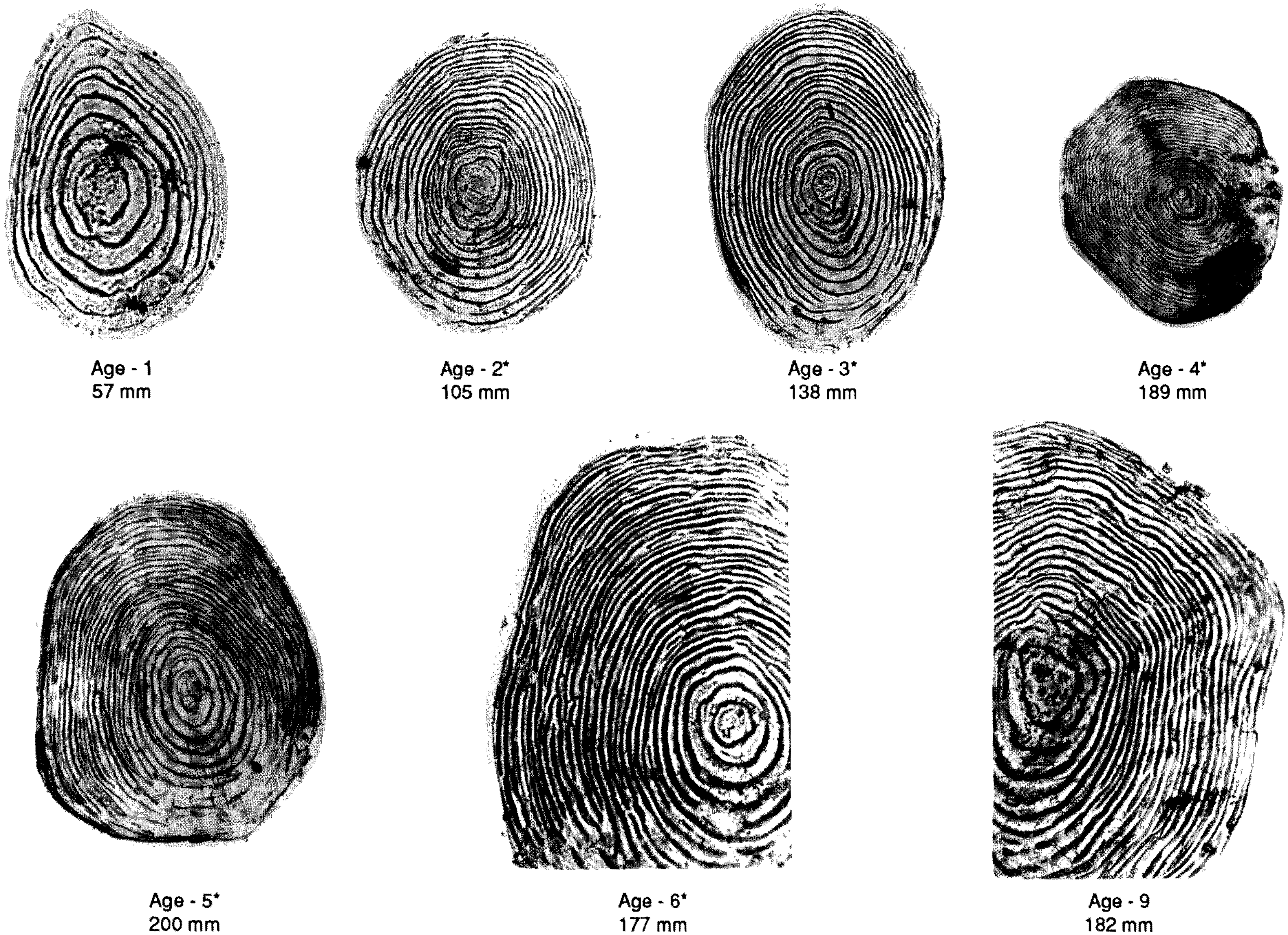

Fig. 3. Rainbow trout scales, with otolith age and fork length (mm) depicted in Fig. 2, except for those marked with an asterisk (*). Asterisk denotes that scale is not from the same fish whose otolith is shown in Fig. 2, but is a scale from another fish of like (otolith) age.

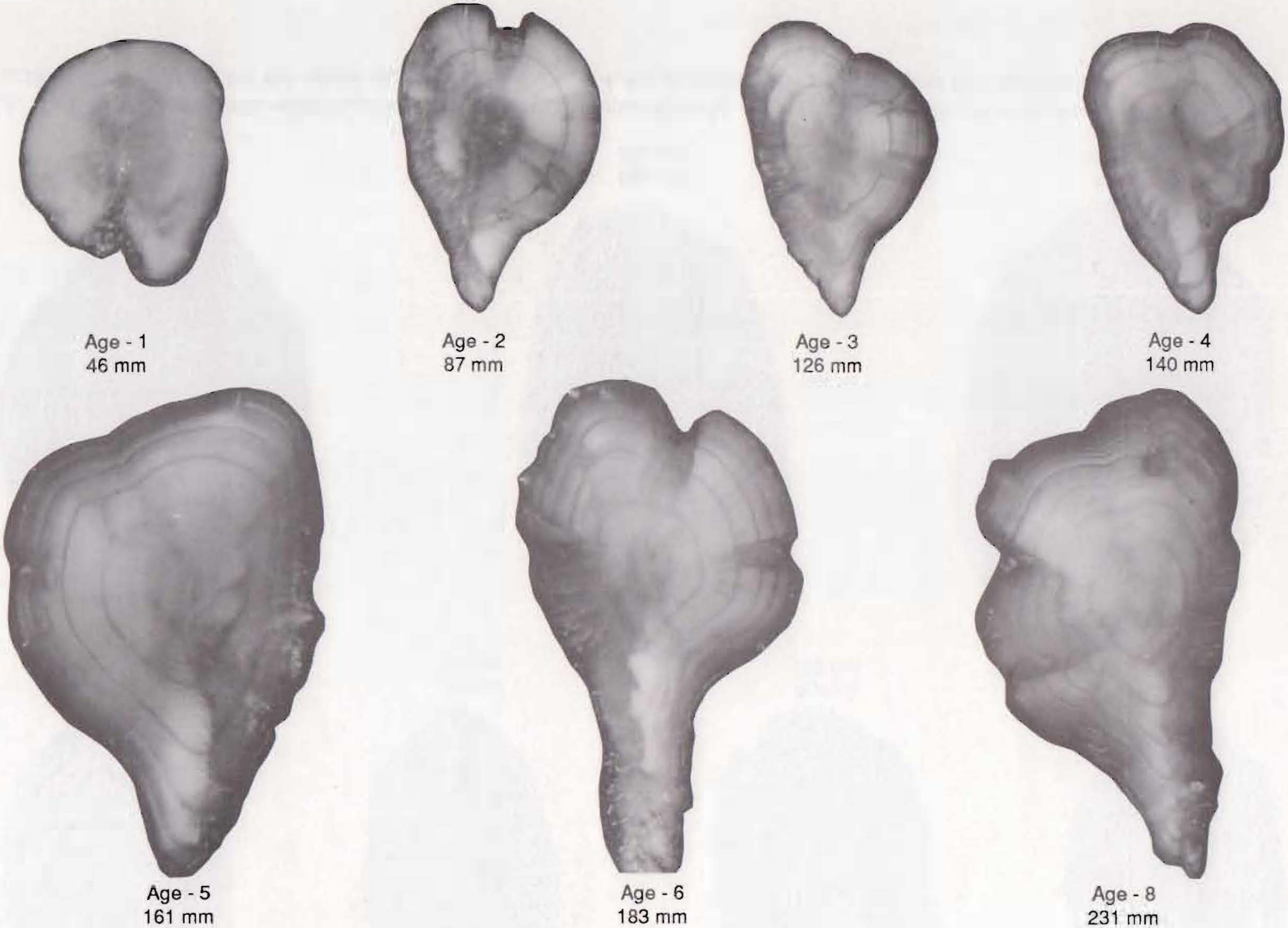

Fig. 4. Brook trout otoliths, ages, and fork lengths (mm) from the Methow River drainage, Washington.

Fig. 5. Brook trout scales, with otolith age and fork length (mm) depicted in Fig. 4, except for those marked with an asterisk (*). Asterisk denotes that scale is not from the same fish whose otolith is shown in Fig. 4, but is a scale from another fish of like (otolith) age.

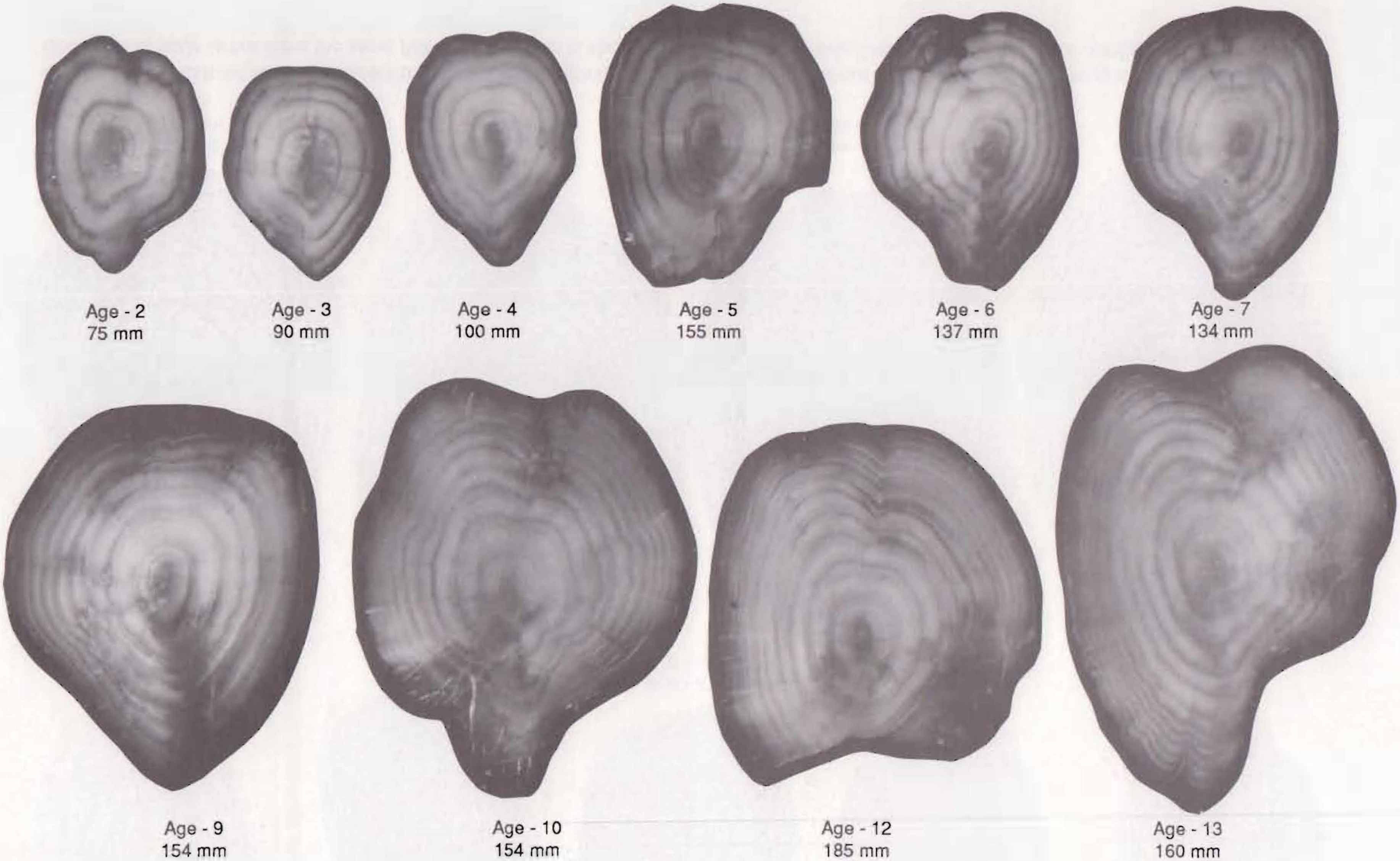

Fig. 6. Cutthroat trout otoliths, ages, and fork lengths (mm), Wolf Creek (RM 12.3, 5,690 ft. elevation, 508 annual temperature units), Methow River drainage, Washington.

Fig. 7. Cutthroat trout scales, with otolith age and fork length (mm) depicted in Fig. 6, except for those marked with an asterisk (*). Asterisk denotes that scale is not from the same fish whose otolith is shown in Fig. 6, but is a scale from another fish of like (otolith) age.

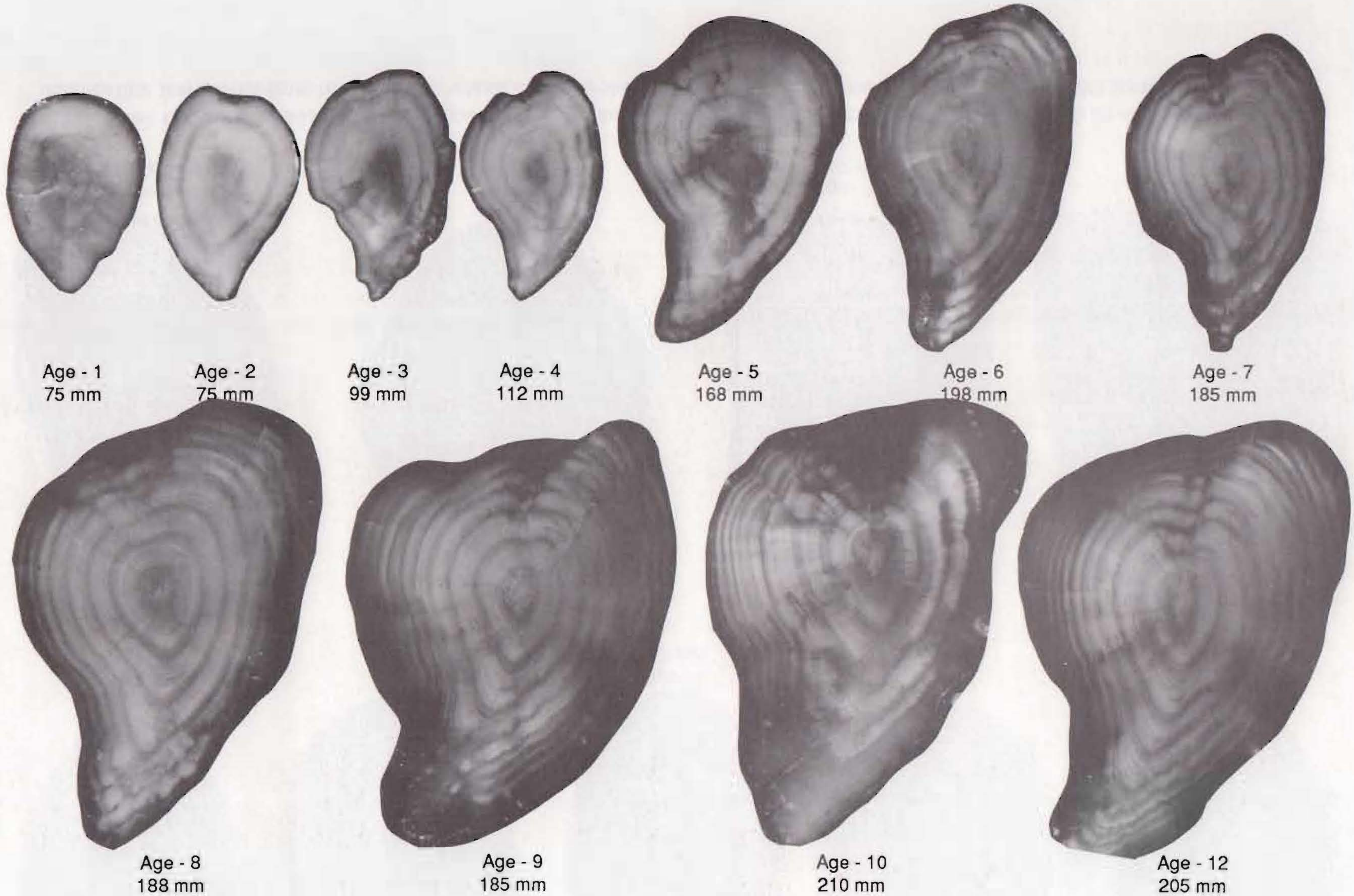

Fig. 8. Bull trout otoliths, ages, and fork length (mm) from the Methow River drainage, Washington.

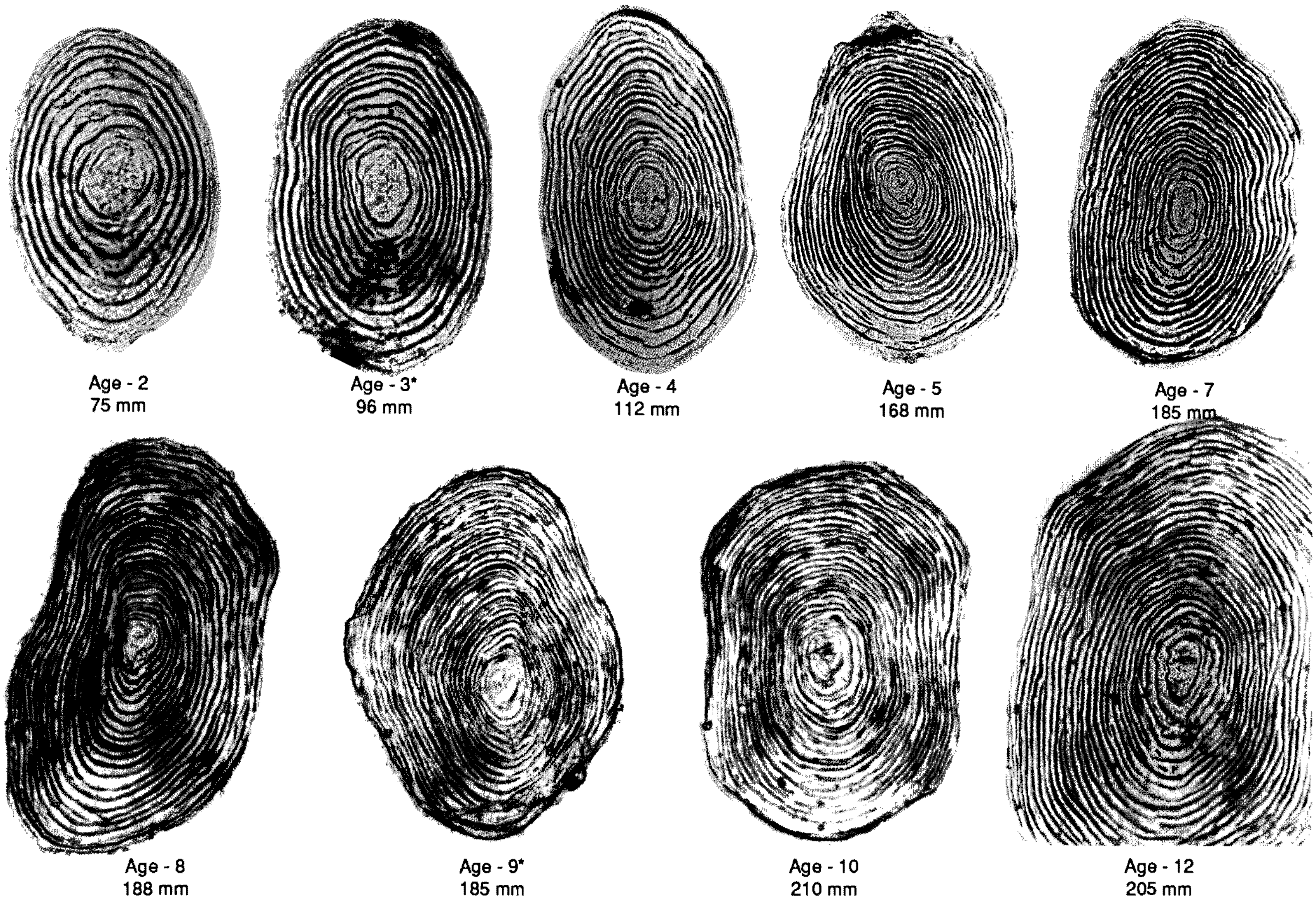

Fig. 9. Bull trout scales, with otolith ages and fork length (mm) depicted in Fig. 8, except for those marked with an asterisk (*). Asterisk denotes that scale is not from the same fish whose otolith is shown in Fig. 8, but is a scale from another fish of like (otolith) age.

Results and Discussion

Assessment of Otolith Aging

Rainbow/Steelhead Trout (O. mykiss). In headwater streams the first annulus on otoliths encircled tightly the nucleus. Care was needed to distinguish it from the metamorphic check of the nucleus (Fig. 1, Age-4.1+). Faster growth from more favorable water temperatures at lower elevations placed annuli farther from the nucleus and caused them to become faint in many fish (Fig. 1, Age-3.2+). The added mass of otoliths of larger fish, especially adult steelhead, transmitted less light for annuli recognition unless thinned. We found no evidence of a migration check in adult steelhead otoliths (McKern et al. 1974). Otolith marking stems from starvation (Volk et al. 1990) or depressed temperature (Brothers 1985).

Some O. mykiss reared at the thermal minima (about 1600 TUs this report; Hokanson 1990[1]) do not reach the minimum size necessary for scale formation prior to their first winter and, hence, lack the first annulus when the scale is formed the following summer. Y-O-Y under 40 mm were common in several streams sampled within days of ice coverage (Table 1). Our finding that scales do not appear until length reaches 46 mm agrees with Hooton et al. (1987). Mina (1973) reported missing first-year annuli on scales of O. mykiss. The scale in Fig. 3, Age-1 exhibits no annuli in contrast to an obvious annulus in its otolith counterpart (Fig. 2, Age-1).

Cutthroat Trout. Cutthroat trout otoliths were excellent age-recording structures (Fig. 6). Body length at scale formation varies from 25 to 66 mm (TL) (Carlander 1969; Shepard et al. 1984; Lentsch and Griffith 1987). We found no scales on fish up to 60 mm (FL). This length was common among cutthroat that concluded their second growing season in the coldest waters (Table 2). That some of these fish had no scales, as determined by otolith age, is shown by the Age-2 scale of Fig. 7, a fish concluding its third growing season with only 5 circuli and no annulus. The defect of scales for aging cutthroat from highest (and coldest) elevations is shown in Fig. 6, Age-13; no more than 3 scale annuli (Fig. 7) vs. 13 otolith annuli.

O.mykiss and Cutthroat Hybrids. We found no obvious differences in growth patterns between hybrids (confirmed by R.

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[1]Zero net growth occurs at 2.5° C (913 TUs) to 3.0° C (1,095 TUs); median tolerance limits (TL 50) based on normal hatch of eggs incubated at constant temperature from fertilization to hatch occurs at 3.7° C (1,351 TUs, if projected for an entire year); and we found only two breeding populations in the 1,400 TUs range, five in the 1,500 TUs range, and 39 above 1,600 TUs (4.7° C) (Table 1).

Table 1. Age, fork length (mm), and weight (g) of rainbow/steelhead in order of decreasing annual temperature units, Methow River drainage.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Methow R.	7.0	0+	101	79.1	10.2	51	107	148	6.1	-	-	-
3232	10-16-85	1+	30	135.8	26.7	97	186	0	-	-	-	-
		2+	27	154.0	14.6	135	168	0	-	-	-	-
		3+	3	155.3	7.1	148	165	0	-	-	-	-
Methow R.	14.0a	0+	49	77.1	9.6	61	102	49	6.0	-	-	-
3127	10-17-85	1+	19	142.9	17.3	109	170	19	29.3	12.7	8	49
		2+	4	151.0	13.1	135	168	4	34.3	11.1	21	48
		3+	2	177.0	0.0	177	177	2	58.5	0.5	58	59
Methow R.	14.0a	0+	16	62.2	8.8	46	85	16	3.5	-	-	-
3127	8-27-86	1+	46	134.4	18.4	104	185	45	29.0	11.9	13	70
		2+	7	136.1	9.4	123	150	7	27.7	4.7	20	35
Methow R.	14.0b	0+	87	74.8	10.5	56	97	307	6.0	-	-	-
3127	10-17-85	1+	23	149.0	22.7	114	193	23	36.9	17.8	13	83
		2+	2	160.5	11.5	149	172	2	46.0	12.0	34	58
Methow R.	23.8	0+	91	84.6	12.2	65	118	91	7.5	-	-	-
2998	10-18-85	1+	6	158.8	20.5	125	178	6	44.0	15.4	20	63
Methow R.	24.4	0+	108	76.8	15.2	52	126	286	5.9	-	-	-
2989	10-18-85	1+	24	158.3	23.4	112	206	24	43.1	17.9	17	80
		2+	12	164.3	14.0	136	181	12	46.2	12.4	25	65
Methow R.	42.3	0+	74	81.3	10.6	61	104	74	6.7	-	-	-
2862	10-18-85	1+	1	161.0	-	-	-	1	46.0	-	-	-
Methow R.	44.8	0+	18	62.6	6.5	50	74	18	2.9	-	-	-
2862	8-28-86	1+	3	148.0	20.8	129	177	3	38.7	18.0	24	64
Methow R.	50.4	0+	61	59.4	8.5	33	81	61	2.6	-	-	-
2822	8-27-86	1+	2	137.7	16.5	102	175	0	-	-	-	-
		2+	2	204.0	7.0	197	211	0	-	-	-	-
Methow R.	50.6	0+	35	62.6	8.2	44	80	35	2.9	-	-	-
2822	8-28-86	1+	11	140.5	15.7	104	162	11	30.3	9.5	13	46

Table 1 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
Methow R.	55.0	0+	32	71.0	5.3	61	82	32	3.9	–	–	–
2801	9–11–86	1+	16	133.1	15.0	115	160	16	25.8	8.5	16	42
		2+	4	145.0	12.6	126	159	4	33.2	8.8	20	44
Methow R.	60.7	0+	28	57.3	7.3	42	70	28	2.4	–	–	–
2761	9–11–86	1+	26	132.4	16.1	110	165	26	25.5	9.5	12	47
		2+	10	144.0	21.7	120	193	10	35.2	19.0	17	85
Methow R.	67.4	0+	4	63.5	2.3	61	67	4	3.3	–	–	–
2709	9–12–86	1+	9	151.9	11.8	121	164	9	36.6	7.9	17	44
		2+	4	142.5	19.2	122	174	4	32.5	14.9	20	58
Chewach R.	7.8	0+	36	67.1	11.2	36	83	251	3.3	–	–	–
2478	8–19–85	1+	39	146.1	13.8	101	170	0	–	–	–	–
		2+	8	168.5	14.8	145	192	0	–	–	–	–
		3+	4	213.2	22.7	182	246	0	–	–	–	–
Twisp R.	0.0	0+	121	78.1	11.0	55	104	121	7.7	–	–	–
2389	10–17–85	1+	18	146.8	13.6	129	185	18	33.0	10.3	20.3	65.9
		2+	7	163.4	31.4	116	220	7	50.1	32.9	15.4	123.8
Chewach R.	14.7	0+	40	61.5	7.2	44	75	72	2.4	–	–	–
2328	8–19–85	1+	9	139.6	5.6	128	146	9	28.1	3.7	21	33
Chewach R.	17.4	0+	10	66.1	7.4	54	79	10	3.3	–	–	–
2302	9–9–86	1+	1	135.0	–	–	–	1	30.0	–	–	–
Twisp R.	4.0	0+	42	62.5	6.8	50	80	41	3.0	–	–	–
2297	9–8–86	1+	34	127.4	17.7	87	171	34	24.2	10.0	7	54
		2+	10	146.8	23.7	112	185	10	35.8	15.5	18	65
		3+	3	139.7	10.3	128	153	3	29.0	5.4	22	35
		4+	1	155.0	–	–	–	1	38.0	–	–	–
		5+	0	–	–	–	–	0	–	–	–	–
		6+	1	366.0	–	–	–	1	650.0	–	–	–
Lost R.	0.0	0+	5	48.2	7.1	40	61	5	1.0	–	–	–
2213	9–9–86	1+	18	111.2	14.1	77	135	18	15.7	5.2	6	27
		2+	1	150.0	–	–	–	1	38.0	–	–	–
Gold Cr.	4.3	0+	102	50.0	6.0	39	68	138	1.6	–	–	–
2181	9–23–87	1+	67	87.9	9.7	67	110	5	8.4	1.0	7	10
		2+	22	125.4	16.9	92	159	22	23.0	10.2	9	50
		3+	6	150.3	12.4	128	165	6	40.2	10.1	25	54

Table 1 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
Wolf Cr.	1.4	0+	17	72.7	14.6	61	115	15	2.7	–	–	–
2178	9-25-87	1+	61	112.1	9.9	93	144	8	20.1	6.2	10	30
		2+	25	144.2	15.6	121	197	25	34.4	13.4	20	80
		3+	4	158.5	13.9	140	178	4	43.5	11.5	28	60
Chewach R.	23.5	0+	0	–	–	–	–	0	–	–	–	–
2138	9-9-86	1+	15	117.5	9.7	102	137	15	18.3	4.5	13	32
		2+	15	147.5	12.8	130	175	14	35.7	9.7	26	58
		3+	4	162.2	8.2	150	173	4	44.8	7.3	36	55
		4+	3	132.7	9.0	120	140	3	28.0	2.2	26	31
		5+	2	173.0	23.0	150	196	2	56.0	26.0	30	82
Little Bridge Cr.	0.0	0+	40	64.2	6.4	52	81	40	3.2	1.0	1.6	5.9
2065	10-10-88	1+	9	109.6	23.3	87	157	9	17.5	11.9	7.9	41
		2+	8	123.0	16.9	95	145	8	23.7	8.5	10.2	37.2
Twisp R.	11.1	0+	33	54.7	7.7	25	66	33	1.9	–	–	–
2061	9-8-86	1+	7	140.6	20.4	100	172	7	32.6	11.5	13	53
		2+	1	126.0	–	–	–	1	21.0	–	–	–
Early Winters Cr.	0.0	0+	3	54.0	9.9	40	62	3	1.7	–	–	–
2058	9-12-86	1+	9	133.8	18.0	102	166	9	27.8	11.8	11	56
		2+	1	319.0	(jack steelhead)			1	362.0	–	–	–
		3+	1	169.0	–	–	–	1	52.0	–	–	–
SF Beaver Cr.	0.0	0+	10	42.6	6.3	33	53	10	0.8	–	–	–
2024	9-10-88	1+	5	73.4	5.5	65	81	5	4.6	0.8	4	6
		2+	11	106.6	8.9	82	118	11	13.9	3.2	7	18
		3+	8	124.0	14.4	93	140	8	23.3	7.1	10	34
		4+	5	141.2	29.3	97	188	5	35.6	20.9	10	71
		5+	1	167.0	–	–	–	1	55.0	–	–	–
Goat Cr.	3.0	0+	29	42.6	8.1	24	54	29	1.2	0.6	0.1	2.4
2013	10-5-89	1+	28	83.0	6.1	70	92	28	7.7	1.6	4.3	11.0
		2+	32	107.6	7.2	93	124	32	16.6	4.0	9.8	25.4
		3+	17	132.6	11.2	113	159	17	31.6	7.8	20.0	50.0
		4+	8	154.2	9.2	145	169	8	51.9	8.7	42.2	65.3
		5+	3	181.0	9.2	168	188	3	86.4	14.9	65.7	100.2
		8+	1	206.0	–	–	–	1	93.4	–	–	–

Table 1 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
SF Gold Cr.	3.8	0+	6	61.0	2.5	56	63	6	2.3	–	–	–
1966	9–15–88	1+	16	99.6	7.7	88	115	16	10.6	3.0	7	17
		2+	12	133.2	10.2	120	154	12	27.0	6.9	18	42
		3+	13	144.8	18.1	113	177	13	39.5	14.5	17	68
		4+	2	165.0	15.0	150	180	2	60.0	18.0	42	78
		5+	0	–	–	–	–	0	–	–	–	–
		6+	1	207.0	–	–	–	1	106.0	–	–	–
Early Winters Cr.	1.5	0+	12	45.9	4.3	39	54	12	0.8	–	–	–
1948	9–25–87	1+	20	88.2	9.7	69	102	7	8.9	2.4	5	12
		2+	9	116.9	11.3	100	140	9	17.9	4.9	12	28
		3+	3	140.0	4.1	135	145	3	31.0	3.6	26	34
		4+	4	162.5	16.9	143	183	4	46.2	15.3	31	63
		5+	2	164.0	13.0	151	177	2	54.0	15.0	39	69
Lake Cr.	2.8	0+	17	55.9	5.9	46	64	17	2.1	–	–	–
1830	9–24–87	1+	6	91.3	9.5	75	103	6	7.7	2.7	3	12
		2+	9	139.1	17.0	108	167	9	30.4	12.0	10	55
		3+	12	137.8	12.3	114	162	12	28.1	7.0	17	42
		4+	1	223.0	–	–	–	1	126.0	–	–	–
		5+	1	190.0	–	–	–	1	79.0	–	–	–
WF Methow R.	76.4	0+	15	40.9	5.9	31	48	15	1.0	–	–	–
1797	9–10–86	1+	17	90.2	14.7	68	128	6	14.8	6.3	7	26
		2+	28	132.2	14.3	110	178	28	26.1	8.4	14	55
		3+	9	160.0	14.7	130	183	9	48.2	12.6	28	74
		4+	2	210.5	0.5	210	211	2	103.0	6.0	97	109
		5+	1	220.0	–	–	–	1	118.0	–	–	–
Chewach R.	30.8	0+	10	44.3	4.2	34	50	10	0.4	–	–	–
1758	9–24–87	1+	58	84.9	9.2	67	121	10	9.9	3.3	5	17
		2+	13	123.2	17.6	93	155	13	22.8	10.1	9	42
		3+	4	126.8	7.6	117	136	4	24.5	5.0	19	30
		4+	1	148.0	–	–	–	1	30.0	–	–	–
		6+	1	184.0	–	–	–	1	68.8	–	–	–
Buttermilk Cr.	0.0	0+	67	36.5	5.6	25	47	33	0.5	0.3	0.2	1.2
EF & WF		1+	63	72.0	6.9	60	85	39	4.6	1.2	2.4	7
1747	9–11–88	2+	42	94.7	6.1	82	106	42	9.6	1.9	6	15
		3+	46	116.3	9.2	97	144	46	18.5	4.8	9.2	33.8
		4+	16	133.2	8.3	122	150	16	28.0	6.3	20	42.4
		5+	5	147.4	10.7	133	164	5	38.1	7.9	27.1	47.8
		6+	1	162.0	–	–	–	1	50.8	–	–	–
		7+	0	–	–	–	–	0	–	–	–	–
		8+	1	181.0	–	–	–	1	59.2	–	–	–

Table 1 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Early Winters Cr.	5.0	0+	61	40.3	8.0	27	58	101	0.4	-	-	-
1673	9-12-86	1+	11	87.0	8.2	75	104	11	7.4	1.7	6	12
		2+	8	116.9	8.0	103	132	8	16.2	4.1	10	24
		3+	8	141.6	6.2	135	145	8	29.8	4.1	24	38
		4+	9	150.7	12.7	135	180	9	37.1	11.3	26	66
		5+	6	170.3	10.9	152	183	6	56.7	11.7	39	71
		6+	2	213.0	4.0	209	217	2	102.0	6.0	96	108
		7+	1	225.0	-	-	-	1	142.0	-	-	-
		8+	1	210.0	-	-	-	1	87.0	-	-	-
SF Gold Cr.	5.9	0+	1	46.0	-	-	-	1	0.9	-	-	-
1672	10-11-88	1+	3	106.0	14.9	94	127	3	12.7	5.5	8.6	20.5
		2+	8	124.3	5.4	115	133	8	20.7	2.5	16.2	24.2
		3+	7	158.4	16.4	140	187	7	46.2	16.1	27.7	73
		4+	4	164.2	12.1	145	175	4	55.5	13.0	36.1	68
Trout Cr.	0.0	0+	0	-	-	-	-	0	-	-	-	-
1669	8-31-89	1+	5	81.4	16.3	65	112	5	8.0	4.9	4.5	17.6
		2+	12	113.4	6.7	104	130	12	18.0	3.2	13.7	26.2
		3+	4	144.8	22.3	113	175	4	43.2	18.1	19.5	69.0
		4+	2	145.5	3.5	142	149	2	37.6	2.85	34.8	40.5
		5+	1	168	-	-	-	1	59.5	-	-	-
Andrews Cr.	1.2	0+	6	28.7	2.6	26	33	6	0.2	-	-	-
1638	9-12-88	1+	7	75.9	8.2	60	86	7	4.9	1.7	2.0	8.0
		2+	6	96.7	3.5	92	101	6	10.3	3.0	6.0	14.0
		3+	18	116.1	8.5	93	133	18	15.6	3.4	8.0	24.0
		4+	10	132.7	10.8	110	148	10	24.7	6.6	13.0	32.0
		5+	2	167.5	5.5	162	173	2	56.0	4.0	52.0	60.0
		6+	1	178.0	-	-	-	1	78.0	-	-	-
		7+	3	177.0	6.2	170	185	3	68.3	7.1	61.0	78.0
		8+	1	195.0	-	-	-	1	94.0	-	-	-
Monument Cr.	0.0	0+	84	28.8	3.3	23	37	No weights				
1627	9-6-89	1+	17	76.1	7.8	65	93					
		2+	6	119.5	5.4	110	125					
		3+	1	128	-	-	-					
		4+	3	162.3	3.9	157	166					
		5+	1	169	-	-	-					
Lost R.	12.7	4+	1	195	-	-	-	1	100.2	-	-	-
1625	9-7-89											

Table 1 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
EF Buttermilk Cr.	1.3	0+	6	38.0	8.1	30	53	6	0.7	-	-	-
1588	9-11-88	1+	27	68.4	7.3	58	87	6	3.4	1.3	2	6
		2+	10	95.0	7.7	83	107	10	8.9	3.4	4	13
		3+	8	119.1	12.2	104	135	8	19.4	6.5	11	30
		4+	3	138.3	12.7	127	156	3	31.3	7.7	24	42
		5+	4	153.8	2.9	150	158	4	39.5	4.2	35	45
Twisp R.	24.4	0+	1	33	-	-	-	-	-	-	-	-
1579	9-22-87	1+	16	57.2	2.8	50	62	16	2.1	-	-	-
		2+	21	86.1	8.4	70	102	6	7.3	2.7	4	11
		3+	22	132.5	15.3	107	159	22	25.8	8.7	11	42
		4+	8	147.8	15.4	119	173	8	35.6	10.9	17	54
		5+	1	149.0	-	-	-	1	34.0	-	-	-
SF Beaver Cr.	3.5	4+	1	190.0	-	-	-	1	86.2	-	-	-
1575	10-11-88											
Little Bridge Cr.	5.2	0+	13	39.8	3.9	34	45	13	0.6	0.2	0.3	1
1571	10-10-88	1+	6	76.7	5.0	69	82	6	4.8	0.9	3.5	6.1
		2+	8	98.5	7.3	88	110	8	10.1	2.1	6.7	13.8
		3+	3	120.7	10.0	110	134	3	19.4	4.7	14	25.5
		4+	2	143.0	2.0	141	145	2	33.0	2.9	30.1	35.8
		5+	3	164.0	7.0	155	172	3	52.2	5.3	45.3	58.3
		6+	1	156.0	-	-	-	1	37.8	-	-	-
		7+	1	188	-	-	-	1	74.1	-	-	-
Twenty Mile Cr.	3.2	0+	29	48.9	4.3	41	59	29	1.2	-	-	-
1570	9-12-88	1+	9	80.9	7.7	62	90	9	5.0	0.9	3	6
		2+	2	97.5	1.5	96	99	2	11.0	1.0	10	12
		3+	14	116.4	6.7	103	132	14	17.3	3.3	11	26
		4+	4	131.0	4.2	127	137	4	23.8	1.8	22	26
		5+	3	134.0	10.2	121	146	3	26.0	5.9	20	34
		6+	3	161.3	3.3	157	165	3	49.0	2.9	46	53
		7+	1	159.0	-	-	-	1	44.0	-	-	-
South Cr.	0.0	0+	2	34.5	0.5	34	35	2	0.5	0.1	0.4	0.5
1562	10-11-88	1+	3	77.7	9.5	69	91	3	5.6	2.0	4	8.4
		2+	1	101.0	-	-	-	1	11.4	-	-	-
		3+	2	140.5	14.5	126	155	2	32.2	11.8	20.3	44
		4+	2	144.5	1.5	143	146	2	34.8	1.8	33.1	36.6

Table 1 concluded.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
War Cr.	2.5	0+	0	–	–	–	–	0	–	–	–	–
1553	10-6-89	1+	1	57	–	–	–	1	2.6	–	–	–
		2+	7	103.1	4.8	95	111	7	14.7	3.2	10.8	21.1
		3+	6	131.7	9.5	117	145	6	31.0	7.3	22.8	42.8
		4+	4	159	19.8	135	189	4	57.6	24.7	32.5	97.3
		5+	3	196.3	8.2	185	204	3	106.1	12.4	89.2	118.6
Crater Cr.	1.9	0+	38	39.2	4.7	29	51	38	0.8	–	–	–
1525	9-15-88	1+	10	91.7	8.5	74	103	10	7.1	2.0	5	11
		2+	15	120.8	11.6	100	149	15	19.5	5.9	13	36
		3+	21	146.5	16.6	119	187	21	39.2	16.4	17	83
		4+	3	154.0	5.9	146	160	3	45.3	8.2	36	56
Foggy Dew Cr.	3.4	0+	2	37.0	2.0	35	39	0	–	–	–	–
1470	9-15-88	1+	2	81.5	1.5	80	83	2	6.0	0.0	6	6
		2+	3	123.3	15.8	108	145	3	22.0	11.8	10	38
		3+	17	135.3	12.4	110	156	17	30.0	8.3	16	44
		4+	0	–	–	–	–	0	–	–	–	–
		5+	0	–	–	–	–	0	–	–	–	–
		6+	1	194.0	–	–	–	1	92.0	–	–	–
EF Buttermilk Cr.	2.7	0+	2	27.0	1	26	28	2	0.2	–	–	–
1404	10-6-89	1+	0	–	–	–	–	0	–	–	–	–
		2+	5	100.4	9.3	92	118	5	11.7	3.5	9.0	18.5
		3+	2	117.5	17.5	100	135	2	19.4	8.0	11.5	27.4
		4+	14	126.8	9.9	103	139	14	23.8	4.5	16.9	32.1
		5+	5	147.2	8.8	139	164	5	39.8	8.6	31.2	56.1
		6+	1	177.0	–	–	–	1	65.0	–	–	–
		9+	1	182.0	–	–	–	1	70.9	–	–	–
Twisp R.	27.1	4+	1	228.0	–	–	–	1	100.0	–	–	–
1331	9-22-87											

Table 2. Age, fork length (mm), and weight (g) of cutthroat trout in order of decreasing annual temperature units, Methow River drainage.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
Methow R. 3127	14.0a 8-27-86	4+	1	136.0	-	-	-	1	59.0	-	-	-
Chewach R. 2138	23.5 9-9-88	4+	1	136.0	-	-	-	1	24.0	-	-	-
Lake Cr. 1830	2.8 9-24-87	2+	2	113.5	0.5	113	114	2	15.0	0.0	15.0	15.0
Andrews Cr. 1638	1.2 9-12-88	4+	1	132.0	-	-	-	1	22.0	-	-	-
		5+	1	145.0	-	-	-	1	28.0	-	-	-
Lost R. 1625	12.7 9-7-89	4+	4	213.8	9.0	204	227	4	113.9	15.9	97.2	137.4
Cedar Cr. 1599	1.5 10-4-89	0+	22	44.3	5.0	33	56	22	0.9	0.4	0.3	1.9
		1+	14	72.3	5.8	59	78	14	4.2	0.8	2.5	5.1
		2+	18	100.3	6.4	85	109	18	11.5	2.2	6.4	15.0
		3+	10	124.3	6.8	112	132	10	23.7	5.8	15.7	35.6
		4+	15	153.9	16.0	119	182	15	43.9	14.4	18.1	71.5
		5+	12	177.4	16.9	150	206	12	68.3	21.2	37.3	113.2
		6+	5	190.8	15.6	165	214	5	86.9	22.5	61.7	127.5
Robinson Cr. 1581	1.4 10-2-89	0+	15	36.5	4.2	28	42	15	0.4	0.1	0.3	0.7
		1+	3	78.0	5.1	73	85	3	5.5	1.3	4.0	7.1
		2+	16	128.8	11.4	108	148	16	26.2	6.4	14.4	35.8
		3+	5	164.2	16.1	143	189	5	58.4	19.8	37.3	94.0
		4+	5	179.4	18.9	148	200	5	75.0	24.2	41.3	108.2
		5+	1	178.0	-	-	-	1	68.4	-	-	-
		6+	1	200.0	-	-	-	1	113.8	-	-	-
Twisp R. 1579	24.4 9-22-87	7+	1	205.0	-	-	-	1	90.0	-	-	-
Crater Cr. 1525	1.9 9-15-88	1+	36	79.9	8.1	63	96	36	6.5	-	-	-
		2+	2	120.0	10.0	110	130	2	16.0	6.0	10.0	22.0
		3+	0									
		4+	2	168.0	11.0	157	179	2	58.5	15.5	43.0	74.0
		5+	1	225.0	-	-	-	1	104.0	-	-	-

Table 2 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Foggy Dew Cr.	3.4	0+	0									
1470	9-15-88	1+	18	82.5	9.8	60	95	18	5.9	1.6	2.0	9.0
		2+	5	110.6	2.6	107	115	5	14.4	5.3	9.0	24.0
		3+	6	132.8	16.9	109	162	6	29.5	11.0	18.0	50.0
		4+	1	162.0	-	-	-	1	50.0	-	-	-
Wolf Cr.	7.2	0+	2	29.0	1.0	28	30	0	-	-	-	-
1358	8-23-89	1+	12	72.0	6.9	61	82	12	4.6	1.2	2.9	6.4
		2+	11	126.5	10.4	105	140	11	24.1	5.3	14.3	30.3
		3+	8	156.9	10.3	146	180	8	47.1	9.0	36.6	66.4
		4+	13	192.5	13.2	179	226	13	86.0	18.7	64.8	134.3
		5+	10	220.0	17.6	194	254	10	128.6	34.0	79.5	200.5
		6+	3	242.7	14.4	232	263	3	173.4	37.7	145.0	226.7
		7+	1	222.0	-	-	-	1	141.2	-	-	-
		8+	1	237.0	-	-	-	1	149.3	-	-	-
		9+	0	-	-	-	-	0	-	-	-	-
		10+	1	205.0	-	-	-	1	95.5	-	-	-
WF Methow R.	8.1	0+	0	-	-	-	-	0	-	-	-	-
1325	8-29-89	1+	1	69.0	-	-	-	1	3.4	-	-	-
		2+	5	102.2	8.1	90	112	5	13.3	2.6	9.7	16.1
		3+	1	171.0	-	-	-	1	60.1	-	-	-
		4+	0	-	-	-	-	0	-	-	-	-
		5+	2	211.5	9.5	202	221	2	119.2	15.6	103.7	134.8
		6+	1	218.0	-	-	-	1	118.6	-	-	-
		7+	1	248.0	-	-	-	1	194.5	-	-	-
Goat Cr.	9.0	6+	1	231.0	-	-	-	1	147.7	-	-	-
1159	10-10-88											
SF Twisp R.	0.0	0+	0	-	-	-	-	0	-	-	-	-
1128	8-27-89	1+	9	65.6	3.1	60	70	9	3.4	0.3	3.0	4.1
		2+	7	94.0	2.4	90	97	7	10.5	1.0	9.1	11.8
		3+	9	117.0	6.5	110	131	9	18.7	4.1	13.9	27.2
		4+	13	139.3	8.7	125	150	13	34.5	7.0	23.5	44.3
		5+	2	160.0	18.0	142	178	2	58.4	19.6	38.9	78.0
		6+	0	-	-	-	-	0	-	-	-	-
		7+	1	177.0	-	-	-	1	67.6	-	-	-

Table 2 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
WF Methow R.	13.8	0+	9	25.8	1.9	23	29	0	–	–	–	–
1015	8-30-89	1+	6	58.0	3.7	53	63	6	1.6	0.3	1.2	2.1
		2+	10	74.1	8.9	63	98	10	4.6	1.9	2.9	10.0
		3+	4	91.0	4.9	83	95	4	8.6	1.2	6.8	10.0
		4+	7	121.3	8.4	105	131	7	21.2	4.5	14.8	27.2
		5+	1	149.0	–	–	–	1	37.0	–	–	–
		6+	2	140.5	13.5	127	154	2	33.5	10.5	23.0	44.0
		7+	4	158.2	31.5	128	206	4	53.2	34.2	23.0	108.2
		10+	1	223.0	–	–	–	1	136.7	–	–	–
EF Buttermilk Cr.	3.8	0+	22	29.8	2.7	23	32	22	0.3	–	–	–
978	9-11-88	1+	7	69.9	4.4	60	74	7	4.1	1.0	3.0	6.0
		2+	12	100.5	8.1	89	113	12	11.1	2.3	8.0	14.0
		3+	23	136.5	16.1	97	190	23	29.7	13.6	10.0	83.0
		4+	1	152.0	–	–	–	1	42.0	–	–	–
		5+	4	169.2	8.6	155	178	4	57.8	8.5	44.0	67.0
		6+	1	176.0	–	–	–	1	60.0	–	–	–
		7+	1	168.0	–	–	–	1	62.0	–	–	–
Wolf Cr.	9.6	0+	0	–	–	–	–	0	–	–	–	–
951	8-23-89	1+	6	66.0	5.4	58	72	6	4.2	0.8	3.1	5.3
		2+	19	94.4	8.1	80	115	19	10.9	2.8	6.8	19.5
		3+	7	117.7	12.9	100	138	7	23.8	8.1	13.2	38.0
		4+	11	143.1	12.6	120	163	11	36.5	7.2	24.8	50.0
		5+	5	152.8	8.6	143	165	5	42.0	6.4	34.0	50.8
		6+	1	165.0	–	–	–	1	50.5	–	–	–
		7+	2	180.0	15.0	165	195	2	62.0	23.6	38.5	85.6
		8+	4	183.5	21.2	169	220	4	74.6	26.1	51.4	118.9
		9+	4	197.5	9.3	185	207	4	82.2	11.1	66.9	93.8
		10+	4	189.8	14.5	173	213	4	71.2	25.1	51.4	114.2
		11+	4	207.0	21.6	180	238	4	95.7	33.2	57.9	145.5
		12+	1	200.0	–	–	–	1	81.6	–	–	–
MF Boulder Cr.	9.6	0+	4	47.0	2.7	44	51	4	1.4	0.4	1.0	2.0
903	10-3-89	1+	4	81.0	16.7	58	105	4	8.1	4.9	2.3	15.8
		2+	1	120.0	–	–	–	1	23.6	–	–	–
		3+	3	149.0	20.4	121	169	3	47.9	19.3	21.4	66.9

Table 2 concluded.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
SF Twisp R.	1.9	0+	0	–	–	–	–	0	–	–	–	–
776	8-27-89	1+	6	59.0	11.9	47	82	6	3.0	1.9	1.3	6.8
		2+	29	82.7	6.9	72	94	29	7.0	1.6	4.2	9.7
		3+	21	104.3	7.8	95	125	21	14.2	3.9	10.2	24.0
		4+	20	127.6	14.8	104	183	20	27.0	12.2	13.6	76.8
		5+	1	153.0	–	–	–	1	43.0	–	–	–
		6+	0	–	–	–	–	0	–	–	–	–
		7+	4	175.5	8.0	166	188	4	63.0	10.4	54.0	80.8
		8+	3	185.3	13.2	175	204	3	64.9	3.2	60.3	67.5
SF Twentymile Cr.	10.2	1+	30	65.4	5.4	53	75	30	2.9	0.8	1.5	4.5
739	10-10-88	2+	12	100.4	7.1	86	112	12	11.3	2.9	6.5	16.8
		7+	1	210.0	–	–	–	1	113.7	–	–	–
Wolf Cr.	12.4	0+	0	–	–	–	–	0	–	–	–	–
508	8-23-89	1+	22	53.5	4.4	44	61	21	1.8	0.4	1.3	2.7
		2+	20	74.1	5.0	65	86	20	5.2	1.2	3.4	8.3
		3+	4	93.0	3.3	90	98	4	9.9	1.1	8.9	11.8
		4+	9	115.4	10.8	100	137	9	19.6	5.8	12.1	31.6
		5+	2	140.0	3.0	137	143	2	32.6	3.5	29.1	36.1
		6+	4	145.0	7.7	134	154	4	32.8	4.4	28.0	39.9
		7+	3	163.3	17.0	140	180	3	49.9	15.1	28.6	60.9
		8+	1	149.0	–	–	–	1	30.5	–	–	–
		9+	1	164.0	–	–	–	1	50.3	–	–	–
		10+	2	159.5	5.5	154	165	2	36.4	6.6	29.8	43.1
		11+	2	163.0	3.0	160	166	2	46.4	0.3	46.2	46.7
		12+	1	185.0	–	–	–	1	64.2	–	–	–

Behnke, CO St. Univ., pers. comm.) and parental species, though the number of fish aged was small (Table 3, n = 89).

Bull Trout. Owing to slightly thicker mass, hence, reduced light transmission, annuli in otoliths of bull trout reared in headwaters were slightly less distinctive (Fig. 8) than cutthroat trout otoliths (Fig. 6). Early Winters Creek age-1 fish (45-47 mm) (Table 4, RM 12.3) had no scales, but the smallest age-2 fish did (68 mm). First-year annuli were missing on scales of fewer bull trout, a fall spawner, than cutthroat, a spring spawner. Scale annuli under-represented the age of older bull trout (Figs. 8 and 9; Brown 1984a; Schill 1991).

Brook Trout. Annuli recognition in otoliths of brook trout reared in streams of the highest elevations was easier than in otoliths of fish that reared in warmer zones downstream. Larger fish downstream with thicker otoliths, having innately narrow annuli, made this species the most difficult to age.

Fall spawning of brook trout generally ensures scale formation during their first year. Others reported that scales first formed at from 35 to 43 mm (TL) (Cooper, 1951), and 46 mm (TL) (Stewart 1959). Domrose (1983), however, reported missing first-year annuli on brook trout from alpine lakes. Power (1980) speculated that slow growth in northern Quebec and Labrador precluded scale formation during the first year. We found at least one population (Middle Fork Beaver Creek, Table 5) where scales were absent on age-1 fish (37 mm).

Power (1980) concluded that scales were adequate for aging brook trout in southern areas of Eastern Canada, where fish grow rapidly, and that otoliths were best in northern areas where growth is slow. Reimers (1979) followed known-age brook trout in an alpine lake in California for 24 years and validated sectioned otoliths at that age; only 2 annuli on the scales were discernable. For stunted brook trout in alpine lakes of California, growth virtually ceases by age 5, but there is no indication that annuli do not continue to form on otoliths throughout their life (Hall 1991).

Scarnecchia (1983) and Kozel and Hubert (1987) compared scales and whole otoliths for brook trout from high-elevation Rocky Mountain streams and concluded that both structures gave unreliable ages. The difficulty of interpreting annuli on scales of old brook trout, compared to ground otoliths, is apparent (Figs. 4 and 5).

Epilog

Otoliths have found increasing favor as aging structures for fish (Beamish and McFarland 1987; Carlander 1987; Barber and McFarlane 1987; Scoppettone 1988; Sharp and Bernard 1988; Peven 1990; Schill 1991). Sagittae are the first calcified structures

Table 3. Age, fork length (mm), and weight (g) of rainbow/cutthroat hybrids in order of decreasing annual temperature units, Methow River drainage.

Stream and temperature units	River mile date	Age	Fork length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Early Winters Cr.	0.0	2+	1	148.0	-	-	-	1	33.0	-	-	-
2058	9-12-86											
Andrews Cr.	1.2	0+	6	28.7	2.6	26	33	6	0.2	-	-	-
1638	9-12-88	1+	7	75.9	8.2	60	86	7	4.9	1.7	2.0	8.0
		2+	6	96.7	3.5	92	101	6	10.3	3.0	6.0	14.0
		3+	18	116.1	8.5	93	133	18	15.6	3.4	8.0	24.0
		4+	10	132.7	10.8	110	148	10	24.7	6.6	13.0	32.0
		5+	2	167.5	5.5	162	173	2	56.0	4.0	52.0	60.0
		6+	1	178.0	-	-	-	1	78.0	-	-	-
		7+	3	177.0	6.2	170	185	3	68.3	7.1	61.0	78.0
		8+	1	195.0	-	-	-	1	94.0	-	-	-
Cedar Cr.	1.5	4+	4	170.5	12.1	155	189	4	60.2	7.3	50.7	71.3
1599	10-4-89	5+	3	174.7	5.2	170	182	3	63.5	10.2	53.2	77.3
		6+	2	178	20	158	198	2	72	30	41.9	102
War Cr.	2.5	4+	1	183	-	-	-	1	84.7	-	-	-
1553	10-6-89											
Goat Cr.	9.0	0+	4	35.3	2.8	32	38	4	0.4	0.1	0.3	0.6
1159	10-10-88	1+	0									
		2+	12	121.0	12.0	104	145	12	20.8	6.6	9.2	32.0
		3+	8	157.0	14.1	128	177	8	51.0	13.9	23.8	71.2

Table 4. Age, fork length (mm), and weight (g) of bull trout in order of decreasing annual temperature units, Methow River drainage.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Methow R.	50.4	5	1	257.0	-	-	-	1	176.0	-	-	-
2822	8-27-86											
Methow R.	60.7	4	2	188.0	10.0	178	198	2	72.0	12.0	60.0	84.0
2761	9-11-86											
Gold Cr.	4.3	5	2	230.5	2.5	228	233	1	136.0	-	-	-
2181	9-23-87											
Wolf Cr.	1.4	1	1	68.0	-	-	-	1	3.0	-	-	-
2178	9-27-87											
Early Winters Cr.	1.5	1	3	60.0	4.5	54	65	3	1.3	-	-	-
1948	9-25-87	3	1	140.0	-	-	-	1	24.0	-	-	-
Lake Cr.	2.8	1	1	49.0	-	-	-	1	-	-	-	-
1830	9-24-87	5	1	152.0	-	-	-	1	55.0	-	-	-
WF Methow R.	76.4	1	2	61.2	4.5	57	66	2	3.0	2.0	1.0	5.0
1797	9-10-86	5	1	190.0	-	-	-	1	58.0	-	-	-
Chewach R.	30.8	6	1	255.0	-	-	-	1	180.0	-	-	-
1758	9-24-87											
EF Buttermilk Cr.	0.0	3	1	112.0	-	-	-	1	12.4	-	-	-
1747	9-11-88											
Early Winters Cr.	5.0	1	4	56.5	5.4	50	65	4	1.0	-	-	-
1673	9-12-86	2	1	108.0	-	-	-	1	12.0	-	-	-
		3	4	130.5	14.7	107	143	4	21.5	6.8	11.0	28.0
		4	3	148.7	16.4	132	171	3	28.3	8.3	21.0	40.0
Monument Cr.	0.0	1	3	42.3	1.2	41	44	0	-	-	-	-
1627	9-8-89	5	1	179.0	-	-	-	0	-	-	-	-
Lost Cr.	12.7	4	1	195.0	-	-	-	1	100.2	-	-	-
1625	9-6-89											

Table 4 continued.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Cedar Cr.	1.5	1	28	51.6	4.2	44	61	28	1.4	0.4	0.8	2.1
1599	10-4-89	5	2	172.0	0.0	172	172	2	48.0	2.1	45.9	50.1
EF Buttermilk Cr.	1.3	4	1	130.0	-	-	-	1	19.0	-	-	-
1588	9-11-88	5	1	204.0	-	-	-	1	106.0	-	-	-
Twisp R.	24.4	2	3	105.3	10.9	90	114	3	11.3	2.5	8.0	14.0
1579	9-22-87	3	1	126.0	-	-	-	1	22.0	-	-	-
		4	2	201.5	3.5	198	205	2	79.5	5.5	74.0	85.0
South Cr.	0.0	3	1	116.0	-	-	-	1	14.9	-	-	-
1562	10-11-88											
EF Buttermilk Cr.	2.7	1	7	48.3	3.0	44	53	7	1.3	0.3	0.9	1.8
1404	10-6-89	2	18	87.4	4.4	76	94	18	7.0	1.0	4.8	9.0
		6	1	231.0	-	-	-	1	146.4	-	-	-
		10	1	324.0	-	-	-	1	342.2	-	-	-
Early Winters Cr.	8.8	1	18	47.7	4.2	42	59	18	1.3	0.4	0.7	2.4
1395	10-5-89	2	4	87.8	3.3	84	93	4	7.6	1.4	6.6	10.0
		3	0	-	-	-	-	0	-	-	-	-
		4	4	137.5	12.2	122	156	4	29.1	8.2	19.7	42.2
		5	1	181.0	-	-	-	2	65.3	19.8	45.5	85.1
		6	1	198.0	-	-	-	1	81.1	-	-	-
		7	6	215.5	10.3	200	227	6	109.3	20.0	79.0	137.9
Wolf Cr.	7.2	1	2	48.5	2.5	46	51	2	1.2	0.2	1.0	1.3
1358	8-25-89	2	33	86.8	4.8	77	95	33	7.6	1.3	5.0	10.5
		3	0	-	-	-	-	0	-	-	-	-
		4	4	168.2	7.3	156	175	4	52.2	9.2	36.8	61.1
		5	2	199.5	11.5	188	211	2	83.8	9.2	74.6	93.0
		6	0	-	-	-	-	0	-	-	-	-
		7	2	229.5	1.5	228	231	2	118.8	4.2	114.7	123.0
		8	1	250.0	-	-	-	1	171.0	-	-	-
Twisp R.	27.1	1	6	58.3	2.8	55	63	6	1.7	-	-	-
1331	9-22-87	2	18	89.9	6.1	76	100	2	6.0	1.0	5.0	7.0
		3	28	114.9		102	125	6	17.0	2.3	14.0	21.0
		4	2	126.0	1.0	125	127	1	17.0	-	-	-

Table 4 concluded.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
WF Methow R.	8.1	1	10	40.4	2.7	35	45	10	0.9	0.1	0.7	1.1
1325	8-29-89	2	27	82.4	9.7	62	104	27	6.7	2.3	3.0	12.4
		7	1	207.0	-	-	-	1	94.2	-	-	-
Goat Cr.	9.0	3	1	130.0	-	-	-	1	24.7	-	-	-
1159	10-10-88	4	1	157.0	-	-	-	1	41.8	-	-	-
Early Winter Cr.	12.3	1	3	46.0	0.8	45	47	3	0.9	0.1	0.8	1.0
1094	10-5-89	2	8	73.2	2.6	68	76	8	3.8	0.5	3.0	4.4
		3	4	101.5	6.7	96	113	4	10.0	2.1	8.5	13.5
		4	7	122.3	7.9	112	132	7	17.9	3.5	13.7	24.4
		5	1	168.0	-	-	-	1	45.5	-	-	-
		6	0	-	-	-	-	0	-	-	-	-
		7	2	185.0	0.0	185	185	2	61.4	1.7	59.7	63.1
		8	2	186.0	2.0	184	188	2	64.4	0.9	63.5	65.2
		9	1	210.0	-	-	-	1	81.1	-	-	-
		10	3	188.7	8.2	181	200	3	63.3	9.3	52.8	75.5
		11	0	-	-	-	-	0	-	-	-	-
		12	1	205.0	-	-	-	1	81.1	-	-	-

Table 5. Age, fork length (mm), and weight (g) of brook trout in order of decreasing annual temperature units, Methow River drainage.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm) No.	Mean	SD	Min.	Max.	Weight (g) No.	Mean	SD	Min.	Max.
Methow R.	50.4	3	1	97.0	-	-	-	1	10.0	-	-	-
2822	8-27-86											
Methow R.	55.0	2	2	78.5	3.5	75	82	2	5.0	-	-	-
2801	9-11-86											
Cub Cr.	3.0	1	34	67.9	7.2	50	82	34	3.4	1.0	1.1	5.8
2100	10-2-89	2	40	107.4	7.4	85	125	40	12.5	2.4	7.9	19.6
		3	10	135.0	12.0	120	162	10	26.9	8.2	16.6	42.8
		4	9	152.4	12.7	140	179	9	42.0	12.4	30.3	69.0
		5	1	165.0	-	-	-	1	41.3	-	-	-
SF Beaver Cr.	0.0	2	2	102.5	2.5	100	105	2	11.5	0.5	11.0	12.0
2024	9-10-88	3	1	125.0	-	-	-	1	20.0	-	-	-
SF Beaver Cr.	3.5	1	19	63.4	6.0	48	72	19	2.8	0.7	1.1	4.3
1575	10-11-88	2	18	112.9	4.8	106	123	18	15.6	2.2	12.4	19.2
		3	11	140.9	12.0	123	159	11	30.7	8.0	19.2	45.7
		4	2	176.0	6.0	170	182	2	63.4	13.4	50.1	76.8
Eightmile Cr.	8.3	1	8	58.2	6.6	51	68	8	2.1	0.5	1.5	3.2
1553	10-2-89	2	6	89.0	5.0	80	97	6	7.8	1.0	6.3	9.3
		3	7	123.3	7.7	110	137	7	21.0	3.3	15.2	26.9
		4	8	145.6	13.9	127	167	8	36.4	10.4	22.2	52.7
		5	11	167.6	13.6	136	193	11	57.6	16.1	30.2	94.3
		7	1	192.0	-	-	-	1	78.9	-	-	-
War Cr.	2.5	1	1	46.0	-	-	-	1	1.8	-	-	-
1553	10-6-89	2	2	90.5	3.5	87	94	2	8.8	0.8	8.0	9.7
		5	2	169.5	8.5	161	178	2	67.6	11.6	55.9	79.2
		6	2	194.5	11.5	183	206	2	99.3	14.6	84.7	113.9
		7	2	205.5	9.5	196	215	2	116.4	12.6	103.8	128.9
		8	1	231.0	-	-	-	1	153.3	-	-	-
MF Boulder Cr.	0.0	1	41	61.4	8.6	43	79	41	3.1	1.2	1.1	6.2
1460	10-3-89	2	24	108.3	7.7	94	120	24	16.1	3.6	10.5	23.3
		3	15	140.7	12.0	125	166	15	35.5	7.9	24.9	53.9
		4	2	185.0	9.0	176	194	2	78.6	13.1	65.5	91.7

Table 5 concluded.

Stream and temperature units	Rivermile and date	Age	Fork Length (mm)					Weight (g)				
			No.	Mean	SD	Min.	Max.	No.	Mean	SD	Min.	Max.
MF Beaver Cr.	2.6	1	16	49.2	6.0	37	62	16	1.4	-	-	-
1248	9-10-88	2	0	-	-	-	-					
		3	10	102.4	12.3	83	128	10	11.8	4.7	7.0	23.0
		4	17	128.8	8.2	111	141	17	26.0	5.4	16.0	36.0
		5	5	150.0	12.7	139	166	5	38.6	11.0	28.0	53.0
		6	4	172.0	19.3	145	199	4	70.5	24.0	38.0	105.0
		8	1	188.0	-	-	-	1	91.0	-	-	-
Eightmile Cr.	14.6	1	2	65.0	1.0	64	66	2	2.8	0.3	2.5	3.1
1047	10-2-89	2	1	143.0	-	-	-	1	36.0	-	-	-
MF Beaver Cr.	5.2	1	1	30.0	-	-	-	0	-	-	-	-
1000	9-10-88	2	6	73.5	3.3	69	79	6	4.8	0.6	4.0	6.0
		3	8	100.4	6.2	91	112	8	10.9	2.6	7.0	16.0
		4	4	118.2	0.4	118	119	4	19.8	1.1	18.0	21.0
		9	1	195.0	-	-	-	1	92.0	-	-	-
MF Boulder Cr.	9.6	5	10	178.4	19.2	155	227	10	78.0	28.6	46.8	157.6
903	10-3-89	6	8	199.5	16.5	171	217	8	101.6	26.5	65.0	140.5
		7	3	214.3	26.6	186	250	3	97.0	9.6	84.6	107.9
SF Twentymile Cr	10.2	1	6	58.3	3.2	54	64	6	2.0	0.4	1.6	2.5
739	10-10-88	2	1	108.0	-	-	-	1	16.4	-	-	-

formed in steelhead embryos, appearing 14 d before hatching (McKern et al. 1974). This circumvents the problem of the missing first-year annulus in some scales.

Scales develop annuli only during periods of active growth. Annuli are subject to removal by starvation or when calcium is limited and diverted to the elaboration of other tissue (e.g., gametes) (Beamish and McFarland 1987). The erosion of scales among Pacific salmon after cessation of feeding during migration and spawning is well known (Bilton and Jenkinson 1969). Comparable energetic deficits exist in resident salmonids (Cunjak and Power 1987).

Age Composition

Rainbow/Steelhead (O. mykiss). Populations included older fish in colder upstream areas (Fig. 10). Even in the headwaters, few O. mykiss exceeded age-6 and only 1 fish had reached age-9.

Most (57.3%) wild adult steelhead returning to the Methow River spent 2 years in freshwater (Table 6); about one-third, 3 years. Although only 9.5% of the adults had resided 4 years or longer in freshwater, a few (0.9%) had remained 7 years before migrating to sea. Most (69.6%) remained at sea for 2 years and the remainder (30.3%) 1 year.

Each run consists of a minimum of 10 broodyears and 16 age classes (Table 7). Prior to damming, repeat spawners were more prevalent and would have increased the number of broodyears to 16 and age classes to 24 (sensu Leider et al. 1986). Maher and Larkin (1955) reported 13 combinations of stream and ocean ages of adult steelhead in the Chilliwack River, and McGregor (1986) documented 10 to 15 age classes for Thompson River summer steelhead, British Columbia. Leider et al. (1986) identified 17 age classes for summer, versus 22 for winter, steelhead in the Kalama River, Washington, the result of a higher incidence of repeat spawners among winter steelhead.

The 9-year freshwater age that we found exceeds by 1 year the maximum freshwater age reported for fluvial stocks in North America (Carlander 1969; Scott and Crossman 1973; Wydoski and Whitney 1979), but equaled that of Asian stocks (Behnke 1979). Freshwater age of steelhead over its southern range is generally 1 to 3 years compared to 2 to 5 years for northern latitudes (Table 8). Variance in age is a function of growth rate in freshwater (Chapman 1958; Keating 1958; Hoar 1976; Fessler and Wagner 1969). Withler (1966) showed that freshwater age of steelhead is related inversely to latitude (temperature) similar to the cline documented for Atlantic salmon (Randal et al. 1987). Disparate ages of mid-Columbia River steelhead smolts in watersheds having diverse elevations (and temperature) form microcosms of Withler's latitudinal cline.

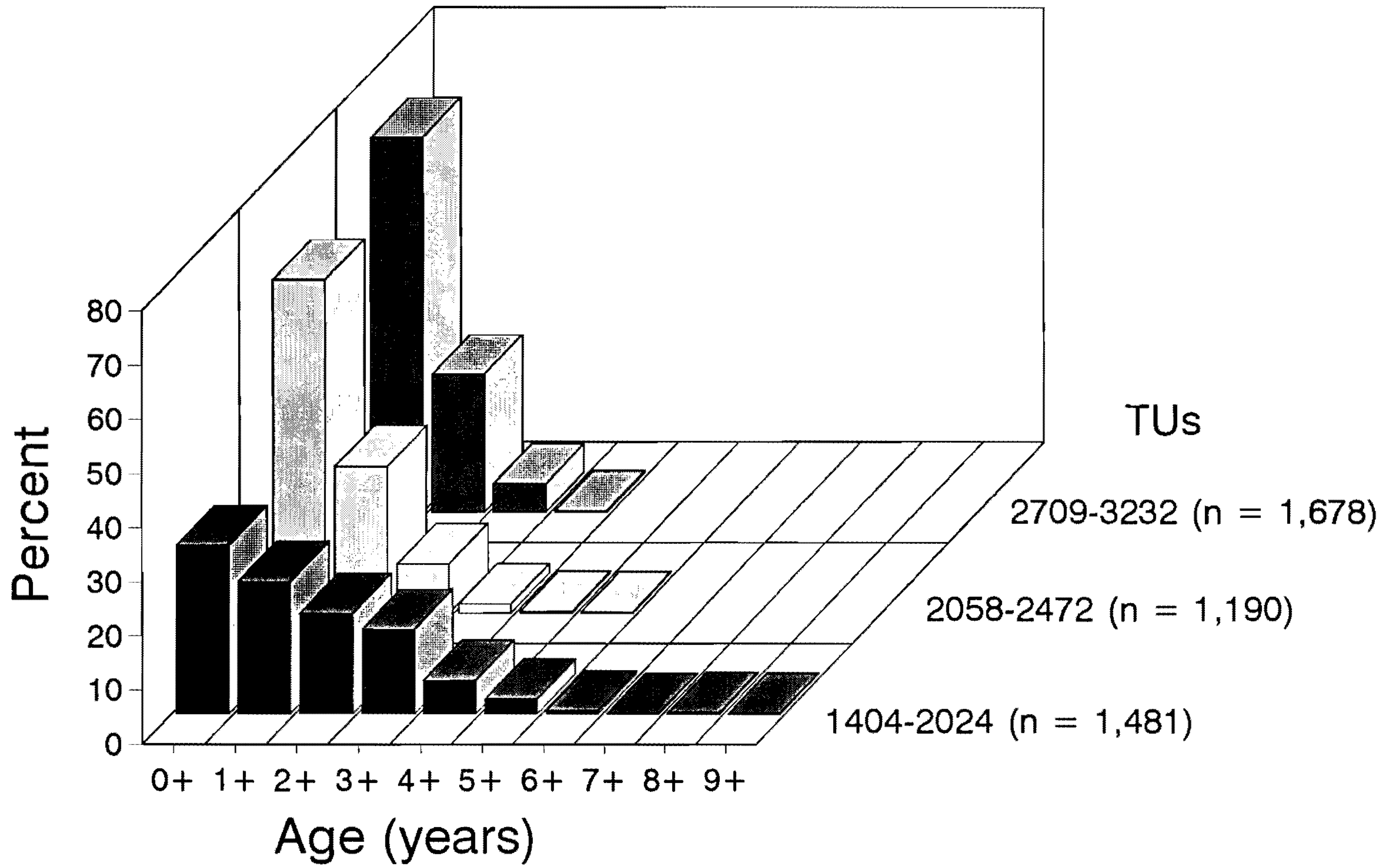

Fig. 10 Age composition of rainbow/steelhead trout by annual temperature units (TUs) in the Methow River drainage.

Table 6. Age and sex of wild adult steelhead passing Wells Dam, 1982-90.

		1-Salt					2-Salt					Total
Year	Sex	2.1	3.1	4.1	5.1	7.1	2.2	3.2	4.2	5.2	7.2	fish
1982	Composite	2	2	4			10	8				26
1984	Composite	1	2				2	2				7
1987	M	8	2	1		1	5	3				
	F	7	7	2			21	11	3			71
1988	M	5	2	2			7	4	1			
	F	4	3	1	1		17	17	3			67
1989	M	8	7	1			19	6				
	F	8	4	3	1		20	8	3			88
1990	M	4	1				15	7	1	1		
	F	9	1	2			28	19			2	90
	Sum	56	31	16	2	1	144	85	11	1	2	349
	Percent	16.0	8.9	4.6	0.6	0.3	41.3	24.4	3.2	0.3	0.6	

Summaries:

							Years - marine	
Age composition	2	3	4	5	6	7	1	2
Number	200	116	27	3	0	3	106	243
Percent	57.3	33.2	7.7	0.9	0.0	0.9	30.3	69.6

Sex ratio (M/F)	1-ocean:	41/53	= 0.77:1
	2-oean:	67/15	= 0.44:1
	composite:	108/205	= 0.53:1

Table 7. Matrix of a broodyear and age classes of steelhead passing Wells Dam over time. Shaded line represents maximum broodyears and age classes of a given run.

BROODYEAR

	1.1	2.1	3.1	4.1	5.1	6.1	7.1	1.1						
Y_1	7.2	1.2	2.2	3.2	4.2	5.2	6.2	7.2						
		1.1	2.1	3.1	4.1	5.1	6.1	7.1	1.1					
Y_1+1		7.2	1.2	2.2	3.2	4.2	5.2	6.2	7.2					
			1.1	2.1	3.1	4.1	5.1	6.1	7.1	1.1				
Y_1+2			7.2	1.2	2.2	3.2	4.2	5.2	6.2	7.2				
				1.1	2.1	3.1	4.1	5.1	6.1	7.1	1.1			
Y_1+3				7.2	1.2	2.2	3.2	4.2	5.2	6.2	7.2			
					1.1	2.1	3.1	4.1	5.1	6.1	7.1	1.1		
Y_1+4					7.2	1.2	2.2	3.2	4.2	5.2	6.2	7.2		
						1.1	2.1	3.1	4.1	5.1	6.1	7.1		
Y_1+5						7.2	1.2	2.2	3.2	4.2	5.2	6.2	1.1	
													7.2	
							1.1	2.1	3.1	4.1	5.1	6.1	7.1	
Y_1+6							7.2	1.2	2.2	3.2	4.2	5.2	6.2	
Y_1+7								1.1	2.1	3.1	4.1	5.1	6.1	7.1
Y_2								7.2	1.2	2.2	3.2	4.2	5.2	6.2
	Y_0	Y_2+1	Y_3+2	Y+3	Y+4	Y+5	Y+6	Y_2 Y_1+7						

AGE CLASS[a]

[a] Does not include 3-ocean fish or repeat spawners.

Table 8. Mean fork length (mm) of wild steelhead at the end of each freshwater growing season and at smolting as determined from direct measurement (M) of parr and smolts and back-calculating (B) from smolt (S) and adult (A) scales.

Location	Race	Life stage	Method	Age in Years 1	2	3	4	5	Mean smolt length	Range	Source
Central coast, CA											
Sacramento R.	W	Parr	B/A	108	190	–	–	–	–	–	Hallock et al. 1961
	W	Smolt	B/A	196	222	–	–	–	213	–	Hallock et al. 1961
North coast, CA											
Klamath R.	S	Smolt	B/A	124	174	243	–	–	166	118–310	Kesner and Barnhart 1972
South coast, OR											
Rogue R.	S	Smolt	B/A	205.	224	239	–	–	224	–	Everest 1973
Central coast, OR											
Alsea R.	W	Smolt	M	–	–	–	–	–	160	–	Chapman 1958
	W	Smolt	B/A	–	–	–	–	–	174	–	Chapman 1958
North Fork											
1949	W	Parr	B/S	107	147	167	–	–	–	–	Chapman 1958
1950	W	Parr	B/S	112	153	164	–	–	–	–	Chapman 1958
1951	W	Parr	B/S	108	152	171	–	–	–	–	Chapman 1958
1952	W	Parr	B/S	117	161	167	–	–	–	–	Chapman 1958
1956	W	Smolt	M	–	–	–	–	–	166	–	Chapman 1958
Lower R.											
1949	W	Parr	B/S	107	149	168	–	–	–	–	Chapman 1958
1950	W	Parr	B/S	108	149	155	–	–	–	–	Chapman 1958
1951	W	Parr	B/S	104	134	158	–	–	–	–	Chapman 1958
1952	W	Parr	B/S	112	149	143	–	–	–	–	Chapman 1958
Fall Cr.	W	Smolt	M	–	–	–	–	–	158	–	Chapman 1958
Five Cr.	W	Smolt	M	–	–	–	–	–	157	–	Chapman 1958
South Fork	W	Smolt	M	–	–	–	–	–	157	–	Chapman 1958
Lower Columbia tributary, WA											
Kalama R.											
1978	Mix	Smolt	M	–	–	–	–	–	163	2 SE 1.80	Crawford et al. 1979
1979	Mix	Smolt	M	147	154	168	–	–	159	–	Chilcote et al. 1980
1983	Mix	Smolt	M	–	–	–	–	–	161	–	Chilcote et al. 1984
Gobar Cr.											
1977	S	Smolt	M	–	–	–	–	–	147	2 SE 2.82	Crawford et al. 1978
1978	S	Smolt	M	–	–	–	–	–	157	2 SE 5.90	Crawford et al. 1978

Table 8 continued.

Location	Race	Life stage	Method	Age in Years 1	2	3	4	5	Mean smolt length	Range	Source
North coastal Washington											
Snow Cr.											
1985	W	Smolt	M	–	–	–	–	–	168	129–216	Johnson and Cooper 1986
1986	W	Smolt	M	–	–	–	–	–	167	124–230	Johnson and Cooper 1986
Eastern WA											
Columbia R. (Rock Island Dam)											
1986	S	Smolt	M						172	–	Peven 1990
1988	S	Smolt	M	156	162	171	172	164	167	127–270	Peven 1990
1989	S	Smolt	M						179	SD 24.7	Peven 1990
Southern mainland, B.C.											
Chilliwack R.											
1948–49	W	Parr	B/A	111	160	193	211	–	170	–	Maher and Larkin 1954
1949–50	W	Parr	B/A	100	157	208	248	–	171	–	Maher and Larkin 1954
1950–51	W	Parr	B/A	123	163	193	224	–	170	–	Maher and Larkin 1954
1951–52	W	Parr	B/A	–	170	198	–	–	183	–	Maher and Larkin 1954
1952–53	W	Parr	B/A	99	166	20.4	232	–	180	–	Maher and Larkin 1954
Vancouver Is., B.C.											
Big Qualicum R.	W	Parr	B/P	88	141	180	–	–	–	–	Hooton et al. 1987
	W	Parr	B/A	88	146	186	170	–	–	–	Hooton et al. 1987
	W	Smolt	B/A	162	176	198	170	–	177	–	Hooton et al. 1987
	W	Smolt	M	159	181	209	–	–	179	126–232	Hooton et al. 1987
Ash, Stamp,											
Somas R.	W	Parr	B/P	64	114	178	–	–		–	Hooton et al. 1987
	W	Parr	B/A	84	163	185	234	–	–	–	Hooton et al. 1987
	W	Smolt	B/A	171	180	186	234	–	182	–	Hooton et al. 1987
Gold, Heber R.	Mix	Parr	B/P	53	92	116	133	–	–	–	Hooton et al. 1987
	W	Parr	B/A	87	151	185	162	–	–	–	Hooton et al. 1987
	W	Smolt	B/A	152	165	186	162	–	175	–	Hooton et al. 1987
Salmon R.	W	Parr	B/P	69	106	149	–	–	–	–	Hooton et al. 1987
	W	Parr	B/A	86	142	166	–	–	–	–	Hooton et al. 1987
	W	Smolt	B/A	–	172	175	–	–	173	–	Hooton et al. 1987
Campbell,											
Quinsam R.	W	Parr	B/P	70	132	168	196	–	–	–	Hooton et al. 1987
	W	Parr	B/A	74	147	177	151	–	–	–	Hooton et al. 1987
	W	Smolt	M	154	168	177	200	–	172	132–212	Hooton et al. 1987
	W	Smolt	B/A	136	182	191	186	–	185	–	Hooton et al. 1987
Cowichan R.	W	Parr	B/P	66	135	–	–	–	–	–	Hooton et al. 1987
	W	Parr	B/A	91	151	226	–	–	–	–	Hooton et al. 1987
	W	Smolt	B/A	171	181	240	–	–	183	–	Hooton et al. 1987

Table 8 concluded.

Location	Race	Life stage	Method	Age in Years 1	2	3	4	5	Mean smolt length	Range	Source
Vancouver Is., B.C.											
Amor de											
Cosmos R.	W	Parr	B/A	81	146	178	–	–	166	–	Hooton et al. 1987
Englishman R.	W	Parr	B/A	88	144	181	–	–	170	–	Hooton et al. 1987
L. Qualicum R.	W	Parr	B/A	85	158	170	–	–	177	–	Hooton et al. 1987
Nanaimo R.	W	Parr	B/A	86	147	168	–	–	163	–	Hooton et al. 1987
Nimpkish R.	W	Parr	B/A	62	107	156	–	–	132	–	Hooton et al. 1987
Oyster R.	W	Parr	B/A	89	147	187	–	–	165	–	Hooton et al. 1987
Sooke R.	W	Parr	B/A	89	151	196	201	–	171	–	Hooton et al. 1987
Puntledge R.	W	Parr	B/A	90	156	167	–	–	171	–	Hooton et al. 1987
Keogh R.											
1977	W	Smolt	M	–	152	180	221	–	174	136–244	Ward and Slaney 1988
1978	W	Smolt	M	–	149	176	221	–	160	137–233	Ward and Slaney 1988
1979	W	Smolt	M	–	151	179	225	–	180	139–256	Ward and Slaney 1988
1980	W	Smolt	M	–	151	164	191	252	161	137–252	Ward and Slaney 1988
1981	W	Smolt	M	–	156	186	226	281	187	142–290	Ward and Slaney 1988
1982	W	Smolt	M	–	153	177	222	272	170	145–281	Ward and Slaney 1988
1983	W	Smolt	M	–	160	180	218	–	176	147–235	Ward and Slaney 1988
East mainland, B.C.											
Thompson R.	S	Smolt	M	–	144	193	–	–	151	84–238	Tredger 1980
Northern mainland, B.C.											
Babine R.											
1967	S	Parr	B/A	71	120	146	179	–	–	–	Narver 1969
1967	S	Smolt	B/A	–	–	192	212	246	195	127–315	Narver 1969
1968	S	Parr	B/A	65	111	134	197	–	–	–	Narver 1969
1968	S	Smolt	B/A	–	130	186	197	–	186	124–252	Narver 1969
South Southeastern, AK											
Petersburg Cr.											
1972	W	Smolt	M	–	–	–	–	–	161	–	Jones 1975
1973	W	Smolt	M	–	–	–	–	–	169	–	Jones 1975
1974	W	Smolt	M	–	–	–	–	–	177	123–255	Jones 1975

Minima and maxima of n are given unless otherwise specified, except that length ranges of fish from Vancouver Island Rivers represent 2 standard deviations.

Royal (1972), Hooton et al. (1987), and others have noted that summer steelhead are generally older than winter steelhead, which implies that the low heat budget of headwater distributions preferred by summer steelhead retards growth. It is well known that in coastal systems that support both races, winter steelhead use mainstem reaches, summer steelhead tributaries (Briggs 1953; Royal 1972). Where the two races use the same tributary, spatial isolation occurs, with summers occupying headwaters and winters downstream.

Ultimate age for steelhead is reported as 7 years (Pautske and Meigs 1940; Shapovalov and Taft 1954; Maher and Larkin 1955; Withler 1966; Narver 1969; Ward and Slaney 1988), 8 years (Carlander 1969; Scott and Crossman 1973; Behnke 1979; Davis and Light 1985; Hooton et al. 1987), and 9 years (Sutherland 1973). Our 7.2 steelhead equaled the 7-year freshwater age of a mid-Columbia River smolt (Peven 1990) and a 9-year-old fish taken in the ocean (Washington 1970).

Cutthroat Trout. Reported life expectancy for cutthroat trout is 5 to 7 years (Carlander 1969; Scott and Crossman 1973; Behnke 1979; Wydoski and Whitney 1979; Liknes and Graham 1988). We found cutthroat from age-5 in the lower, warmer streams to age-13 in cold headwaters (Table 2).

Brook Trout. Brook trout achieve maximum age at 3 years in warm, heavily fished streams and 7 years in cold, lightly fished streams (Bridges 1958; Cooper 1967; Power 1980). We found maximum age from 4 years in the warmer streams to 9 years in the colder streams at highest elevation (Table 5).

Bull Trout. Bull trout have reached 20 years of age but the maximum age of 10 to 12 years that we found (Table 4) was also reported by Scott and Crossman (1973) and Goetz (1989).

Growth

Size of O. mykiss reared at the lowest heat budget (1,581 TUs) was greater (246 mm) than that (165 mm) of fish reared in warmer water (2,950 TUs) (Fig. 11). This was due to the seaward migration of the fastest growing fish. Anadromy in the warmer water was also reflected by the absence of fish over age-3 and no sexually mature females. Ultimate freshwater size, considering the spurt of growth accompanying smoltification, agrees with the mean smolt size of 173 mm for years 1986, 1988, and 1989 at Rock Island Dam (Peven 1990). Conversely, resident fish in headwaters attain comparatively large size over many growing seasons. Ultimate length of these oldest fish is overestimated, because the intercept with the asymptotic diagonal of the Walford graph, used to fit Von Bertalanffy's length estimate (Fig. 11), occurs beyond their life expectancy.

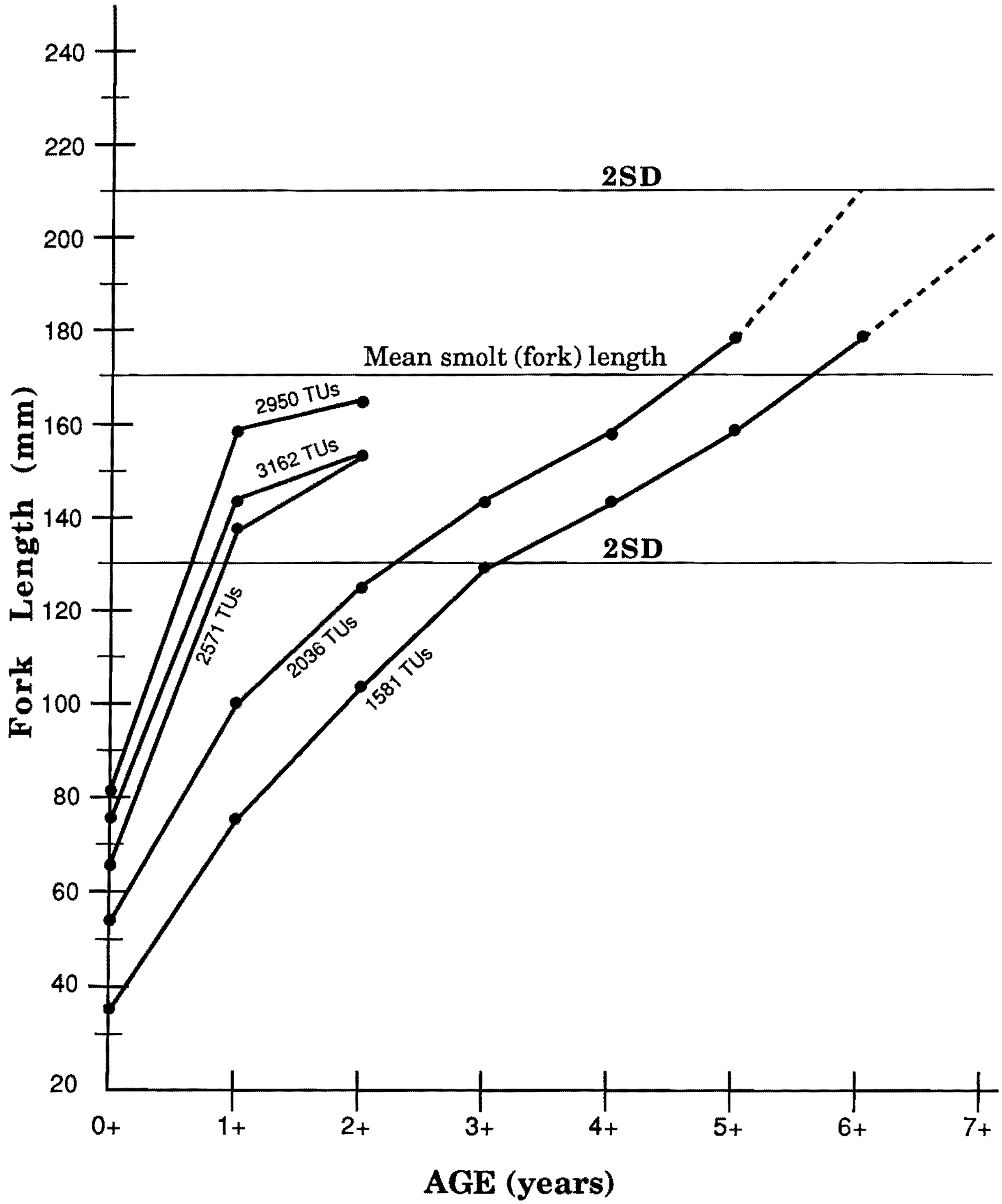

Fig. 11. Age and length (Walford graph) of rainbow/steelhead in the Methow River drainage at different heat budgets (temperature units, TUs).

The lower Methow River was too warm during the summer for optimum growth and led to a higher percentage of age-3 smolts than the middle Methow River, where fish required only two summers to reach size for smoltification (Fig. 11). The retardation of growth from the cooler water in the upper Methow River was equal in effect to the excessive heat of the lower river, resulting in about the same percentage of age-3 smolts. Still further upstream, low heat budgets delayed fish from reaching the mean threshold size for smoltification to about 4.5 years (3-7 year range) and we noted a resident life history here. In the coldest headwaters, growth was so slow that it took 5.5 years (4-8+ year range) to attain smolt size (173 mm) (Fig. 11). But, only 26.3% of the females and 6.7% of the males remained immature at age-6; no immature fish of either sex persisted to age-7. Most fish here that do not emigrate downstream early in life are thermally-fated to a resident life history regardless of whether they were the progeny of anadromous or resident parents (also, see Chapter 4).

No length gradient of steelhead smolts was observed over their latitudinal distribution in North America (Table 8). Difference in mean smolt size between summer (176 mm) and winter steelhead (172 mm) was not significant. The average mean length was 173 mm and 95% fell within 143-207 mm, the same as mid-Columbia River smolts. Most populations also have fish that do not become smolts until they reach larger size (e.g., 250-300+ mm) (Table 8). Minimum lengths to protect smolts of average size from sport harvest may reduce genetic diversity by eliminating these life history variants. Large smolt size may be an advantage for coping with dams, similar to natural selection for large smolts in the ocean (McCormick and Saunders 1987; Ward and Slaney 1988).

Sizes at given ages of Methow River cutthroat, bull and brook trout are the lowest ever reported for streams (Tables 9,10,11). As with O. mykiss, growth declined with elevation and temperature. Bull trout did not grow better in cooler water, contrary to Shepard et al. (1984) and Pratt (1989). Maximum size of resident bull trout ranged from 210 to 324 mm, in general agreement with maximum size noted by Meehan and Bjornn (1991) (250 mm) and Goetz (1989) (300 mm). We have creel-checked adfluvial bull trout in the Methow River to nine pounds in weight.

Liknes and Graham (1988) noted that cutthroat trout in cold, sterile habitats rarely exceeded 300 mm. They also noted that growth increased two-fold for adfluvial fish. Similarly, we have creel-checked adfluvial cutthroat in the Methow River to 406 mm, but found in contrast only one tributary with fish over 200 mm in length.

High densities of small, slow-growing brook trout in headwater streams are common (e.g., Cooper et al. 1962). But the slowest growth that we measured rivaled early growth of the stunted

Table 9. Comparison of mean total length (mm) of fluvial cutthroat trout at the end of each year of life. For Washington, fork length at the end of the growing season are given for selected streams in order of increasing annual temperature units (TUs).

	Age (years)												
Location	1	2	3	4	5	6	7	8	9	10	11	12	13
Idaho													
Priest L. tribs.[a]	89	127	170	201	254								
St. Joe R.	67	104	162	222	287	308							
St. Joe R. lower tribs.	71	135	226	292									
St. Joe R., Upper upper tribs.	53	102	152	224									
M.F. Salmon R.	57	95	165	241	305	352							
S.F. Salmon R.	51	92	137	199	244								
Kelly Cr.	66	101	153	213	251	306							
Montana													
Mainstem Flathead R.	55	103	157	242	305	336							
N.F. Flathead R.	54	97	138	166	214								
N.F. Flathead R. tribs.	54	100	145	189	247								
M.F. Flathead R. tribs.	54	100	149	205	254	293							
Washington													
Methow R. tributary creeks[b]													
Wolf (TUs 508)		54	74	93	115	140	145	163	149	164	160	163	185
Wolf (TUs 951)		66	94	118	143	153	165	180	183	198	190	207	200
Wolf (TUs 1358)	29	72	126	157	192	220	243	222	237		205		
Cedar (TUs 1599)	44	72	100	124	154	177	191						

a From Wydoski and Whitney, otherwise data for Idaho and Montana from Thurow 1987.

b All populations were allopatric except lower Wolf Cr. (TUs 1358), which was sympatric with bull trout.

Table 10. Comparison of mean total length (mm) of fluvial bull trout at the end of each year of life. For Washington, fork length at the end of the growing season are given for selected streams in order of increasing annual temperature units (TUs).

	Age (years)											
Location	1	2	3	4	5	6	7	8	9	10	11	12
Idaho												
S.F. Salmon R.[a]	68	110	154	217	284							
Montana												
Middle Fork Flathead R.	52	100	165	297	399	488	567	655				
North Fork Flathead R.	73	117	165	301	440	538	574					
Oregon												
Upper Willamette R.	93	142	165			264	284	347	452			
Roberts Cr.												
John Day R.	67	111	132									
Metolius R.	51	92	141									
British Columbia												
Ram Creek, Wigwam R.	78	137	218	303								
Wigwam R.	64	114	176	385	476	557	668					
Alberta												
Bow R.		165	211	246	269	320	335					
Washington												
Methow R. tributary creeks												
Early Winters (TUs 1094)	46	73	102	122	168		185	186	210	189		205
Early Winters (TUs 1395)	48	88		138	181	198	216					
Early Winters (TUs 1673)	57	108	130	149								

[a] From Thurow 1987, otherwise data for Montana, Oregon, British Columbia, and Alberta from Goetz 1989.

Table 11. Comparison of mean total length (mm) of fluvial brook trout at the end of each year of life. For Washington, fork length at the end of the growing season are given for selected streams in order of increasing annual temperature units (TUs).

	Age (years)									
Location	1	2	3	4	5	6	7	8	9	Source
Maine										
Sunkhaze Stream	165	191	239	300						Bridges 1958
Massachusetts										
Five river drainages	84	135	170	213	277					Bridges 1958
Michigan										
Pigeon River	99	152	201	226						Bridges 1958
Montana										
Streams	76	127	203	279	406					Carlander 1969
New Hampshire										
Four Streams	99	132	165							Bridges 1958
Nova Scotia										
Moser River	130	185	213	267	328					Bridges 1958
Pennsylvania										
Larry's Creek	79	124	168	203	229					Cooper 1967
Big Spring Creek	109	178	249	312	371					Cooper 1967
Mud Lick Run Cr. (upper)[a]	66	98	118	146						Cooper et al. 1962
Mud Lick Run Cr. (lower)[a]	73	125	161	168						Cooper et al. 1962
Washington										
Methow River tributary creeks										
M.F. Beaver (TUs 1000)	30	74	100	118					195	This study
M.F. Beaver (TUs 1248)	49		102	129	150	172	188			This study
S.F. Beaver (TUs 1575)	63	113	141	176						This study
Cub (TUs 2100)	68	107	135	152	165					This study

[a] Total length at time of capture (October 6, 1960).

population of Bunny Lake, California, which produced a 24-year-old brook trout that measured only 238 mm (Reimers 1958, 1979).

Slow growth of brook trout in Bunny Lake retarded maturation until age 16 (Reimers 1979). Maturation of brook trout at age 2 or 3 is common in more benign areas. We found brook trout matured from age 1 (all males) to age 5. In the warmer zone (1645 TUs) most fish of either sex spawned between age 2 and age 3 (Table 12). Upstream (922 TUs), most males continued to mature at age 2, whereas a higher percentage of females spawned at age 3 compared to downstream.

The statement by Goetz (1989) that resident bull trout mature early and are short-lived did not apply to the populations that we examined (Table 12). Maiden spawning occurred at age 9 for a few fish, or two years older than the published maximum age at first spawning (Fraley and Shepard 1984).

Female _O. mykiss_ matured in headwaters at age 3 to age 7 (Table 13). In downstream reaches, some of the fastest-growing males matured precociously and attained lengths of up to 406 mm and 6 years of age. Upstream, mean age of males at maturity was 3 to 4 years and ranged from 2 to 7 years. Typically (Thorpe 1987), mature fish averaged larger than immature fish and males matured at smaller sizes than females for all species.

Spawning

Steelhead spawn from March to early July. Hatchery fish spawn earlier than wild fish. Mainstem spawning is earliest and tributary spawning is last. Although most fish breed prior to spring runoff, we know from early dam counts that some mature fish were still passing Rock Island Dam in early July and spawning was observed until early July (Fish and Hanavan 1948). These late-spawning fish seem to have disappeared today.

Fry in mainstems emerge from the gravel before spawning in tributaries is completed. The lower bound of steelhead spawning is about 1,600 TUs. About 639 TUs are required for emergence (Carlander 1969), which places median emergence at about September 15 for the coldest spawning sites. These headwater tributaries are important spawning habitat for steelhead (Tredger 1980; Thurow 1987). They are too cold for optimum production and many fry emigrate downstream for rearing (Tredger 1980), while others stay and complete their life cycle in freshwater. Small males (resident or anadromous) spawning with anadromous females has not been observed for steelhead (probably because spring runoff obscures visibility), though common for many anadromous salmonids (Bley 1987; Gross 1987; Mullan et al. in press).

Cutthroat and bull trout spawn upstream from the zones that thermally limit _O. mykiss_. Unlike _O. mykiss_, cutthroat and bull

Table 12. Maturity and sex ratio of cutthroat, bull and brook trout by thermal zonation (TUs).

Mean annual temp units	Age class	Number of females		Percent mature females		Number of males		Percent mature males	
		Immature	Mature	Within age class	Between age class	Immature	Mature	Within age class	Between age class
				Cutthroat trout					
1414	1+	20	0	0.0	0.0	11	0	0.0	0.0
	2+	23	0	0.0	0.0	14	16	53.3	24.2
	3+	18	3	14.3	9.4	3	11	78.6	16.7
	4+	22	12	35.3	37.5	0	15	100.0	22.7
	5+	4	11	73.0	34.4	0	14	100.0	21.2
	6+	0	3	100.0	9.4	0	7	100.0	10.6
	7+	0	2	100.0	6.3	0	1	100.0	1.5
	8+	0	1	100.0	3.1	0	1	100.0	1.5
	10+	0	0	0.0	0.0	0	1	100.0	1.5
	Subtotal	87	32	Percent mature: 26.9		28	66	Percent mature: 70.2	
	Sex ratio (f/m): 119/94 = 1.27:1								
839	1+	3	0	0.0	0.0	4	0	0.0	0.0
	2+	20	0	0.0	0.0	4	12	75.0	13.0
	3+	19	1	5.0	2.9	2	23	92.0	25
	4+	18	3	14.3	8.8	1	25	96.2	27.2
	5+	1	4	80.0	11.8	0	8	100.0	8.7
	6+	0	7	100.0	20.6	0	2	100.0	2.2
	7+	0	8	100.0	23.5	7	100.0	7.6	0
	8+	1	4	80.0	11.8	0	3	100.0	3.3
	9+	0	1	100.0	2.9	0	4	100.0	4.3
	10+	0	2	100.0	5.9	0	4	100.0	4.3
	11+	0	3	100.0	8.8	0	3	100.0	3.3
	12+	0	1	100.0	2.9	0	1	100.0	1.1
	Subtotal	62	34	Percent mature: 35.4		11	92	Percent mature: 89.3	
	Sex ratio (f/m): 96/103 = 0.93:1								
				Bull trout					
1701	2+	1	0	0.0	0.0	3	0	0.0	0.0
	3+	11	0	0.0	0.0	3	0	0.0	0.0
	4+	6	0	0.0	0.0	3	0	0.0	0.0
	5+	2	0	0.0	0.0	3	1	25.0	100.0
	6+	1	0	0.0	0.0	0	0	0.0	0.0
	Subtotal	21	0	Percent mature: 0.0		12	1	Percent mature: 7.7	
	Sex ratio (f/m): 21/13 = 1.62:1								

Table 12. Concluded

Mean annual temp units	Age class	Number of females		Percent mature females		Number of males		Percent mature males	
		Immature	Mature	Within age class	Between age class	Immature	Mature	Within age class	Between age class
1295	2+	14	0	0.0	0.0	11	0	0.0	0.0
	3+	2	0	0.0	0.0	4	0	0.0	0.0
	4+	10	0	0.0	0.0	7	0	0.0	0.0
	5+	2	0	0.0	0.0	5	1	16.7	11.1
	6+	1	0	0.0	0.0	0	1	100.0	11.1
	7+	5	1	16.7	16.7	0	5	100.0	55.6
	8+	1	1	50.0	16.7	1	0	0.0	0.0
	9+	0	0	0.0	0.0	0	1	100.0	11.1
	10+	0	3	100.0	50.0	0	1	100.0	11.1
	11+	0	0	0.0	0.0	0	0	0.0	0.0
	12+	0	1	100.0	16.7	0	0	0.0	0.0
	Subtotal	35	6	Percent mature: 14.6		28	9	Percent mature: 24.3	
	Sex ratio (f/m): 41/37 = 1.11:1								
				Brook trout					
1645	1+	0	0	0.0	0.0	2	0	0.0	4.0
	2+	33	0	0.0	0.0	20	2	9.1	21.6
	3+	16	9	36.0	26.5	10	7	41.2	41.5
	4+	3	13	81.3	38.2	7	18	72.0	18.2
	5+	1	8	88.9	23.5	2	8	80.0	9.7
	6+	0	3	100.0	8.8	0	3	100.0	1.7
	7+	0	1	100.0	2.9	0	2	100.0	1.7
	8+	0	0	0.0	0.0	0	3	100.0	1.7
	Subtotal	53	34	Percent mature: 39.1		41	43	Percent mature: 51.2	
	Sex ratio (f/m): 87/84 = 1.04:1								
922	1+	0	0	0.0	0.0	0	0	0.0	0.0
	2+	8	0	0.0	0.0	9	9	50.0	34.6
	3+	12	0	0.0	0.0	1	7	87.5	26.9
	4+	2	0	0.0	0.0	0	4	100.0	15.4
	5+	0	5	100.0	45.5	0	0	0.0	0.0
	6+	0	4	100.0	36.4	0	4	100.0	15.4
	7+	0	2	100.0	18.2	0	1	100.0	3.8
	8+	0	0	0.0	0.0	0	0	0.0	0.0
	9+	0	0	0.0	0.0	0	1	100.0	3.8
	Subtotal	22	11	Percent mature: 33.0		10	26	Percent mature: 72.00	
	Sex ratio (f/m): 33/36 = 0.92:1								

Table 13. Maturity and sex ratio of rainbow/steelhead in order of decreasing annual temperature units, Methow River.

Mean annual temp units	Age class	Number of females		Percent mature females		Number of males		Percent mature males	
		Immature	Mature	Within age class	Between age class	Immature	Mature	Within age class	Between age class
3162	1+	66	0	0.0	0.0	51	1	1.9	100.0
	2+	17	0	0.0	0.0	23	0	0.0	0.0
	3+	3	0	0.0	0.0	2	0	0.0	0.0
	Subtotal	86	0	Percent mature:	0.0	76	1	Percent mature:	1.3
	Sex ratio (f/m): 86/77 = 1.12.:1								
2950	1+	15	0	0.0	0.0	18	1	5.3	100.0
	2+	8	0	0.0	0.0	4	0	0.0	0.0
	Subtotal	23	0	Percent mature:	0.0	22	1	Percent mature:	4.3
	Sex ratio (f.m): 23/23 = 1.00:1								
2571	1+	85	0	0.0	0.0	65	6	8.5	42.9
	2+	24	0	0.0	0.0	16	4	20.0	28.6
	3+	4	0	0.0	0.0	0	3	100.0	21.4
	4+	2	0	0.0	0.0	0	0	0.0	0.0
	6+	0	0	0.0	0.0	0	1	100.0	7.1
	Subtotal	21	0	Percent mature:	0.0	81	14	Percent mature:	14.7
	Sex ratio (f/m): 115/95 = 1.21:1								
2036	1+	45	0	0.0	0.0	54	7	11.5	10.4
	2+	56	1	1.8	12.5	49	24	32.9	35.8
	3+	19	4	17.4	50.0	9	24	72.7	35.8
	4+	4	1	20.0	12.5	0	7	100.0	10.4
	5+	1	2	66.7	25.0	0	3	100.0	4.5
	6+	0	0	0.0	0.0	0	1	100.0	1.5
	7+	0	0	0.0	0.0	0	0	0.0	0.0
	8+	0	0	0.0	0.0	0	1	100.0	1.5
	Subtotal	125	8	Percent mature:	6.0	112	67	Percent mature:	37.4
	Sex ratio (f/m): 133/179 = 0.74:1								
1583	1+	46	0	0.0	0.0	59	7	10.6	4.0
	2+	69	1	1.4	1.7	50	38	43.2	21.6
	3+	77	8	9.4	13.3	30	73	70.9	41.5
	4+	21	21	50.0	35.0	4	32	88.9	18.2
	5+	2	17	89.5	28.3	1	17	94.4	9.5
	6+	0	8	100.0	13.3	0	3	100.0	1.7
	7+	0	3	100.0	5.0	0	3	100.0	1.7
	8+	0	1	100.0	1.7	0	3	100.0	1.7
	9+	0	1	100.0	1.7	0	0	0.0	0.0
	Subtotal	215	60	Percent mature:	21.8	144	176	Percent mature:	55.0
	Sex ratio (f/m): 275/320 = 0.86:1								
	System Sex ratio (f/m): 632/694 = 0.91/1								

trout have adfluvial forms which migrate from natal streams and back when they mature to spawn. Cutthroat, extremely vulnerable to angling, were almost eliminated from the large rivers of Idaho before catch-and-release regulation (Thurow 1987). Bull trout also are easily caught (Behnke 1980; Brown 1984a), and large adfluvial fish have become rare in the Methow River. Migratory tendency of cutthroat and bull trout progressively gives way to residency in an upstream direction, similar to O. mykiss.

Steelhead and Bull Trout Fecundity

Mid-Columbia River steelhead are highly fecund, as are other interior summer steelhead (Table 14), a response to harsh environments (Neave 1948). Theoretically, shortening of ocean residency by hatchery rearing, should reduce fecundity of steelhead. The difference in fecundity between 1-ocean (609 mm) and 2-ocean (760 mm) females amounted to 2,023 eggs per female (4,944 to 6,967 eggs) in 1983 at Wells Hatchery. However, early maturation mostly (x^2 = 8.0, p>0.005) affects males (29% increase) and the slight increase (5%) in 1-ocean female spawners was not significant (X^2 = 0.46) (Table 16).

Overfishing likely has diminished reproductive potential of bull trout. A 300 mm resident bull trout has fewer than 200 eggs (this report) compared to more than 3,000 eggs for a 600 mm adfluvial female (Martin 1992).

Residency Versus Anadromy

Fish may mature as soon as they are developmentally able (Policansky 1983). Growth is the means to reach this state (Calow and Townsend 1981). Growth determines the developmental conflict of maturation or smoltification (Thorpe 1987). Several workers (e.g., Saunders et al. 1982) have experimentally induced maturation in Atlantic salmon, resulting in resident populations, while others have increased the anadromous fraction by reducing growth. Nevertheless, surplus energy is required for somatic growth in achieving necessary size for smoltification (Gross 1987).

Summer steelhead in colder environments have the added demand of storing sufficient energy to sustain themselves through periods of winter deficit. Lipid gain and loss is a result of food supply and the period of foraging, and fish that face the longest period of starvation will accumulate the most fat (Nikolskii in Weatherly and Gill 1987). Steelhead in mid-Columbia River tributaries may endure torpor in near darkness (ice bridging beneath snow) at temperatures near 0° C for 5 months. On the other hand, juvenile winter steelhead tend to vacate tributaries favored in summer to overwinter in warmer mainstem reaches (Cederholm and Scarlett 1982). A mean low temperature of about 6° C permits some winter growth in winter steelhead in coastal rivers as far north as southern British Columbia (Withler 1966). This may explain why

Table 14. Comparison of winter-run (w) and summer-run (s) steelhead fecundity at a constant fork length of 571 mm.

Location	Race	Regression equation	Fecundity
Scott Cr., CA[a]	W	E = 0.941 x L2.11(in.)	4964
Trinity R., CA[a]	W	N.A.	3540
Big Creek, OR[a]	W	E = -2078 + 9.03L	3107
Alsea R., OR[a]	W	E = -5054 + 13.1L	2424
Queets R., WA[b]	W	E = -5593 + 14.7L	2801
Skagit R., WA[b]	W	E = -4414 + 14.6L	3923
Mid-Columbia R., WA[c]	S	E = -3217 + 13.4L	4434
Skeena R., B.C.[a]	S	E = -6443 + 17.7L	3641
Thompson R., B.C.[a]	S	E = -11,873 + 28.3L	4307

a From McGregor 1986.

b From T. Johnson, WDW, unpublished report.

c Composite of egg counts of 21 wild fish collected in 1937 (WDF 1938) and 38 Wells Hatchery females in 1983. There was no significant difference (p = 0.05) in fecundity between the two groups of fish.

Table 15. Freshwater age structure (percentage) of wild steelhead smolts and adults for North American.

Location		Race	Life stage	Age in years 1	2	3	4	5	6	7	Source
L. Manistee R., MI											
	1982	W	Smolt	10.7	87.8	1.2	–	–	–	–	Seelbach 1986
	1983	W	Smolt	7.3	90.8	1.7	–	–	–	–	Seelbach 1986
	1984	W	Smolt	15.1	83.0	1.9	–	–	–	–	Seelbach 1986
Central Coast, CA											
Sacramento R.		S	Adult	29.0	70.0	1.0	–	–	–	–	Hallock et al. 1961
Waddell Cr.		W	Smolt	8.3	87.9	3.7	0.1	–	–	–	Shapovalov and Taft 1954a
		W	Adult	10.1	72.3	16.7	0.9	–	–	–	Shapovalov and Taft 1954a
North Coast, CA											
Klamath R.		S	Adult	27.1	65.0	7.9	–	–	–	–	Kesner and Barnhart 1972
South Coast, OR											
Rogue R.		S	Adult	9.7	79.0	10.9	0.3	–	–	–	Everest 1973
Composite (4 rivers)		W	Adult	0.7	43.0	53.3	3.0	–	–	–	Withler 1966
Central Coast, OR		W	Adult	–	54.4	44.4	1.2	–	–	–	Withler 1966
Alsea R.		W	Smolt	7.3	70.8	21.6	–	–	–	–	Royal 1972
Alsea R.		W	Adult	1.4	80.2	18.2	0.2	–	–	–	Chapman 1958
North Coast, OR											
Composite (9 rivers)		W	Adult	6.9	71.7	21.4	–	–	–	–	Withler 1966
Lower Columbia Tributary, OR											
N. Santiam R.		W	Adult	–	88.6	8.6	–	–	–	–	Howell et al. 1985
		W	Smolt	1.6	85.2	13.1	–	–	–	–	Howell et al. 1985
Eastern Oregon Rivers											
Deschutes R.		S	Adult	29.0	55.0	14.0	2.0	–	–	–	Howell et al. 1985
John Day R.		S	Adult	–	62.5	37.5	–	–	–	–	Howell et al. 1985
South Coast, WA											
Chehalis R.		W	Adult	9.5	88.5	2.0	–	–	–	–	Royal 1972
Puget Sound, WA											
Minter Cr.		W	Smolt	3.0	85.0	12.0	–	–	–	–	Royal 1972
Minter Cr.		W	Smolt	16.0	73.0	11.0	–	–	–	–	Meigs and Pautzke 1941
Green R.		W	Adult	18.1	71.8	8.6	–	–	–	–	Royal 1972
Snow Cr.	1985	W	Smolt	2.5	95.1	2.4	–	–	–	–	Johnson and Cooper 1986
	1984–85	W	Adult	10.1	73.9	15.9	–	–	–	–	Johnson and Cooper 1986
	1986	W	Smolt	21.7	72.2	6.2	–	–	–	–	Johnson and Cooper 1986
	1985–86	W	Adult	20.0	80.0	–	–	–	–	–	Johnson and Cooper 1986

Table 15 continued.

Location		Race	Life stage	Age in years 1	2	3	4	5	6	7	Source
North Coast, WA											
Hoh R.		W	Adult	3.1	87.4	4.7	–	–	–	–	Royal 1972
Lower Columbia Tributaries, WA											
Cowlitz R.		W	Adult	13.0	82.5	4.5	–	–	–	–	Royal 1972
Cowlitz R.		W	Adult	–	91.4	8.6	–	–	–	–	Tipping 1984
Kalama R.	1976–83	S	Adult	–	90.9	8.9	0.2	–	–	–	Leider et al. 1986
	1976–83	W	Adult	–	88.5	11.4	0.1	–	–	–	Leider et al. 1986
	1978	Mix	Smolt	2.0	95.0	3.0	–	–	–	–	Chilcote et al. 1983
	1979	Mix	Smolt	7.1	64.3	27.9	0.7	–	–	–	Chilcote et al. 1983
	1980	Mix	Smolt	2.7	80.5	16.6	–	–	–	–	Chilcote et al. 1983
	1981	Mix	Smolt	5.5	88.0	6.5	–	–	–	–	Chilcote et al. 1983
	1982	Mix	Smolt	12.7	81.0	6.3	–	–	–	–	Chilcote et al. 1983
Gobar Cr.	1978	S	Smolt	7.0	93.0	–	–	–	–	–	Chilcote et al. 1983
	1979	S	Smolt	12.7	69.9	17.4	–	–	–	–	Chilcote et al. 1983
	1980	S	Smolt	14.7	79.4	5.9	–	–	–	–	Chilcote et al. 1983
	1981	S	Smolt	14.8	83.3	1.9	–	–	–	–	Chilcote et al. 1983
	1982	S	Smolt	24.2	72.6	3.2	–	–	–	–	Chilcote et al. 1983
Wind R.		S	Adult	5.3	89.5	5.3	–	–	–	–	Morrill 1982
Klickitat		S	Adult	–	94.0	6.0	–	–	–	–	Schuck 1980, Schuck et al. 1981
Eastern WA											
Columbia R. (Priest Rapids Dam)											
	1986	S	Adult	9.2	66.2	24.6	–	–	–	–	B. Leland, WDW, per. comm.
	1987	S	Adult	4.9	83.2	11.2	0.7	–	–	–	B. Leland, WDW, per. comm.
	1988	S	Adult	2.0	86.9	11.1	–	–	–	–	B. Leland, WDW, per. comm.
Columbia R. (Rock Island Dam)											
	1988	S	Smolt	0.7	43.2	46.4	8.6	0.8	0.1	0.1	Peven 1990
Methow R.	1987	S	Adult	–	59.4	31.1	8.1	–	–	0.9	This study
Methow R.	1988	S	Adult	–	49.3	38.8	10.4	1.5	–	–	This study
Methow R.	1989	S	Adult	–	62.9	28.1	7.9	1.1	–	–	This study
Methow R.	1990	S	Adult	–	62.2	31.1	3.3	1.1	–	2.2	This study
Icicle R.	1988	S	Adult	–	39.1	30.4	17.4	8.7	4.3		This study
Idaho											
Clearwater R	1952	S	Adult	27.0	59.2	13.7	–	–	–	–	Whitt 1954
Clearwater R	1952	S	Adult	4.2	67.1	28.6	–	–	–	–	Keating 1958
South Mainland, B.C.											
Aloutte R.		W	Adult	8.4	65.6	25.2	0.8	–	–	–	Withler 1966
Coquitlam R.		W	Adult	–	33.6	65.8	0.7	–	–	–	Withler 1966
Chehalis R.		W	Adult	–	18.9	68.5	12.6	–	–	–	Withler 1966
Cheakamus R.		W	Adult	–	45.3	53.1	1.6	–	–	–	Withler 1966
Chilliwack R.		W	Adult	1.9	62.2	35.5	0.6	–	–	–	Maher and Larkin 1954
Capilano R.		W	Adult	–	45.7	52.9	1.4	–	–	–	Withler 1966
		S	Adult	1.3	16.3	82.6	–	–	–	–	Withler 1966
Seymour R.		W	Adult	–	32.8	65.5	1.8	–	–	–	Withler 1966
		S	Adult	–	40.0	60.0	–	–	–	–	Withler 1966
Coquillalla R.		W	Adult	–	28.2	66.7	5.1	–	–	–	Withler 1966
		S	Adult	0.7	18.0	75.3	6.0	–	–	–	Withler 1966

Table 15 continued.

Location		Race	Life stage	Age in years 1	2	3	4	5	6	7	Source
Vancourver Is., B.C.											
Big Qualicum R.		W	Adult	15.4	72.0	12.3	0.3	–	–	–	Hooton et al. 1987
Gold/Heber R.		W	Adult	1.1	50.6	47.2	1.1	–	–	–	Hooton et al. 1987
Salmon R.		W	Adult	–	66.7	33.3	–	–	–	–	Hooton et al. 1987
Campbell/Quinsam R.		W	Adult	0.4	65.8	32.7	1.1	–	–	–	Hooton et al. 1987
Cowichan R.		W	Adult	54.5	31.8	13.6	–	–	–	–	Hooton et al. 1987
Amor de Cosmos R.		W	Adult	–	55.6	44.4	–	–	–	–	Hooton et al. 1987
Englishman R.		W	Adult	–	75.0	25.0	–	–	–	–	Hooton et al. 1987
L. Qualicum R.		W	Adult	–	90.0	10.0	–	–	–	–	Hooton et al. 1987
Nanaimo R.		W	Adult	–	90.0	10.0	–	–	–	–	Hooton et al. 1987
Nimpkish R.		W	Adult	–	69.2	30.8	–	–	–	–	Hooton et al. 1987
Oyster R.		W	Adult	3.0	84.8	12.1	–	–	–	–	Hooton et al. 1987
Sooke R.		W	Adult	–	63.3	33.3	3.3	–	–	–	Hooton et al. 1987
Puntledge R.		W	Adult	3.6	78.6	17.9	–	–	–	–	Hooton et al. 1987
Keogh R.	1977	W	Smolt	–	39.0	52.0	10.0	–	–	–	Ward and Slaney 1988
	1978	W	Smolt	–	53.0	38.0	9.0	–	–	–	Ward and Slaney 1988
	1979	W	Smolt	–	12.0	71.0	17.0	–	–	–	Ward and Slaney 1988
	1980	W	Smolt	–	28.0	61.0	10.0	1.0	–	–	Ward and Slaney 1988
	1981	W	Smolt	–	29.0	47.0	23.0	1.0	–	–	Ward and Slaney 1988
	1982	W	Smolt	–	38.0	59.0	3.0	–	–	–	Ward and Slaney 1988
	1983	W	Smolt	–	32.0	61.0	7.0	–	–	–	Ward and Slaney 1988
North Mainland, B.C.											
Babine R.											
	1967	S	Adult	–	–	85.4	10.4	2.1	–	–	Narver 1969
	1968	S	Adult	–	3.8	77.5	18.9	–	–	–	Narver 1969
East Mainland, B.C.											
Thompson R.											
	1976	S	Adult	–	78.7	21.3	–	–	–	–	McGregor 1986

Table 16. Comparison of ocean age by sex of hatchery reared and naturally reared steelhead, 1987-90.

Year	Number of females		Number of males	
	1-ocean	2-ocean	1-ocean	2-ocean
		Naturally reared		
1987	16	35	12	8
1988	9	37	9	12
1989	16	31	16	25
1990	12	54	5	24
Subtotals	53	157	42	69
Percent	25	75	38	62
Sex ratio (f/m): 210/111 = 1.89				
		Hatchery reared		
1987	103	203	150	55
1988	62	249	144	107
1989	154	149	237	55
1990	71	312	136	108
Subtotals	390	913	667	325
Percent	30	70	67	33
Sex ratio (f/m): 1303/992 = 1.31				

juvenile winter steelhead had significantly less visceral fat than summer steelhead juveniles in British Columbia (Smith 1969), but not in California (Winter 1987). It also may explain why summer steelhead generally grow more slowly than winter steelhead in streams and in hatcheries (Royal 1972).

Summer steelhead from coastal streams in California and Oregon are the largest smolts at age in North America (Tables 8 and 15). Large size and high energy reserve result in the only case of amphidromy (juveniles cross the fresh-saltwater boundary more than once) in the genus Oncorhynchus, enigmatically known as "half-pounder" steelhead. Ample surplus energy is available to bear smoltification and osmoregulatory costs (McCormick and Saunders 1987). Precocious maturation does not occur, as would be expected in Atlantic salmon, though maturation does occur at early age, small size and with little time at sea or in travel (Kesner and Barnhart 1972; Everest 1973). Some hatchery steelhead in the mid-Columbia River may have been induced to adopt this life history strategy by the improved hatchery diets of the early 1960s (Cleaver 1969). Between 1947 and 1960, only two "rainbow trout" were counted annually at Rock Island Dam compared to 90 for years 1961 to 1966 (Mullan et al. 1986). A few of these fish were small, sexually immature steelhead returning from a 2- or 3-month stay in the estuary or ocean.

To the north, a very different steelhead life history evolved, one that favored the sea (Rounsefell 1958; Gross 1987). In interior rivers of British Columbia, natural selection was for large body size and high fecundity attained by delayed maturation at sea for up to 4 years and extended freshwater rearing and migration (McGregor 1986).

Summer and winter steelhead probably became genetically different because of spatial and temporal isolation (Briggs 1953; Withler 1966; Smith 1969; Everest 1973; Thorgard 1977; Utter and Allendorf 1979; Chilcote et al. 1980; Leider et al. 1984). The lipid storage differential marks an important difference between races. Winter steelhead cannot invade coldwater systems where prolonged starvation must be endured, which probably explains why they inhabit reaches downstream from summer steelhead and why they exclusively inhabit short, coastal rivers. Racial isolation in some coastal rivers of southeast Washington, without high-elevation or glacial sources, however, may depend on temporal barriers to maintain separation (B. Lucas, WDW, pers. comm.).

Geographically (Sheppard 1972) summer steelhead are limited to but a few headwater tributaries in their southern range (Roelofs 1984; Winter 1987). They share with winter steelhead some large drainages in the intermediate zone of their distribution (coastal Oregon, Washington, and southern British Columbia), and almost exclusively inhabit the coldest inland streams from northern British Columbia to higher latitudes (Light et al. 1989).

Virtually only resident O. mykiss exist north of the Alaska Peninsula (Behnke 1979; Van Hulle 1985; R. Behnke, pers. comm.), or in the coldest waters of the Methow River.

Adaptations of salmonids, though genetically defined, run under environmental instruction (Thorpe 1987). Improved growth rate probably is the primary reason for resident sockeye in many lakes at mid-latitudes, but rarely in Alaska (Rounsefell 1958; R. Behnke, pers. comm.), though large increases in growth failed to produce solely kokanee (Ricker 1972). The existence of two forms of O. mykiss in the same watershed may depend largely on there being a sufficiently warm lake in the system that encourages rapid growth and residualism (Rounsefell 1958). "Half-pounder" steelhead did not mature in freshwater under exceptional growing conditions, but matured in an analogous saltwater environment. The optimum diet and rapid growth of steelhead at Wells Hatchery (1990-91) raised male precocity only 5.5% above the natural level (1.3%) in the lower Methow River (Appendix H).

The acute developmental conflict confronting steelhead seems to be how long to remain at sea. That males residualize in freshwater earlier and at higher rates than females stems from the lower cost of producing testes compared to ovaries (Thorpe 1987). This also holds at sea. However, variance in growth is greater among males and the slowest growing males tend to remain at sea a second year, as do small fish of both sexes (Royal 1972).

Smolt transformation in the headwaters tends toward: (1) the fastest growing females; (2) genetic variants that defer sexual maturity beyond the norm; or (3) fish that move downstream. In downstream reaches females of all trout species that we studied, in all cases, outnumbered males whereas the opposite was true in headwaters (Tables 12 and 13). This seems to increase fitness by placing females in the most productive, anadromous or adfluvial-inducing habitat.

Residency or anadromy is defined in part by genetic predilection of life form for a given stock. The anadromy option may be vestigial in a population where a waterfall has interrupted gene flow between anadromous and resident fish for 10,000 years compared to a system where indefinite sympatry exists (Northcote 1981; Michael 1983; Parkinson et al. 1984). Conversely, the degree of anadromy from spawning in the lower reaches of major streams will, over time, be higher than that from populations where gene flow tends to favor the resident form. Bley (1987) felt that the shift to high percentages of small resident males in some Atlantic salmon stocks was due to the near absence of anadromous males, a result of overfishing.

Genetic Concepts

The perception is that steelhead and rainbow trout are genetically distinct. This idea began in the 19th century after incorrect classification as two different species (R. Behnke, pers. comm.). In the 20th century, Neave (1944) concluded that hereditary differences existed between a lacustrine stock and an anadromous stock. Briggs (1953) inferred that the two forms were spatially isolated during spawning. Ricker (1972) subsequently reemphasized Neave (1944). Behnke (1979) also concluded racial distinction between the two forms when a resident population persisted in the Clearwater River, Idaho, after the anadromous run was blocked by a dam. Parkinson et al. (1984) determined that populations isolated by impassable barriers for 10,000 years were distinct electrophoretically. This, too, was equivocal because populations in streams upstream from barriers also differed.

Currens et al. (1990) did find genetic distinction between resident stocks and anadromous stocks isolated by barrier falls in the Deschutes River, Oregon. Other attempts to demonstrate racial distinction have failed (Keating 1958; Utter and Allendorf 1979; Neilson et al. 1985; Hershberger and Dole 1987; Winter 1987; Currens et al. 1988).

Headwater populations of resident salmonids above adfluvial or anadromous conspecifics are common: bull trout (Goetz 1989; Meehan and Bjornn 1991), Dolly Varden char (Armstrong and Morrow 1980), Arctic char (Pechlaner 1984), brook trout (Power 1980), cutthroat trout (Neave 1949; Hartman and Gill 1968; Royal 1972; Johnston 1982; Michael 1983; Parkinson et al. 1984; Meehan and Bjornn 1991), steelhead (Neave 1949; Royal 1972; Crawford 1979; Tredger 1980; Parkinson et al. 1984; Winter 1987), chinook salmon (Healy 1991; Mullan et al. in press), coho salmon (Scott and Crossman 1973), Atlantic salmon (Meehan and Bjornn 1991), and brown trout (Solomon 1982; Jonsson 1985). Where topographic relief is high, as in most summer steelhead distributions, low temperatures cause headwater residualism. Low temperature can be ruled out as the cause for resident populations in winter steelhead streams, which drain maritime (homothermic) climates (Neave 1949; Briggs 1953; Rounsefell 1958; Behnke 1979). One-to-one sex ratios, common to most winter steelhead populations, however, indicates a high degree of anadromy. Royal (1972) stated that winter steelhead in Washington were almost wholly anadromous and that residuals were mostly precocious males.

Females make up 57 to 73% of interior stocks of summer steelhead (Jordan and Evermann 1902; Narver 1969; McGregor 1986). A predominance of females indicates male residualism, similar to Atlantic salmon (Thorpe 1986), spring chinook salmon (Mullan et al. in press), and sea-run brown trout (Jonsson 1985). We found equal numbers of female and male parr in mid-Columbia tributaries, but wild female adults outnumbered males 1.89:1 (Table 16). Peven

(1990) counted 1.88 females for every male during the 1988 smolt migration at Rock Island Dam. Virtually all winter steelhead and those coastal summer steelhead inhabiting warmer southerly streams have essentially 1:1 sex ratios (Pautzke and Meigs 1940; Sumner 1953; Shapovolov and Taft 1954; Chapman 1958; Kesner and Barnhardt 1972; Jones 1975; Johnson and Cooper 1986a, 1986b; Leider et al. 1986; Ward and Slaney 1988). Even though the female fraction declined from 66 to 57% in summer steelhead at Wells Hatchery, a common phenomenon in hatcheries (Thorpe 1987), sexual parity was not achieved ($X^2 = 42.1$, $p < 0.005$).

Polymorphism as applied to Arctic char (Balon 1984) is equally applicable to summer steelhead of the upper Columbia River, where distribution ranges throughout thermal bounds (Hokanson et al. in press). Nordeng (1983) concluded that resident, anadromous, or adfluvial Arctic char belong to the same gene pool.

Polymorphism is common among salmonids. Mullan (1958) and Naiman et al. (1987) induced anadromy in populations of nonanadromous brook trout by translocation. Kokanee salmon that originated from anadromous sockeye in the Frazer River, Canada, have been resident in freshwater lakes in New Zealand for 18 to 25 generations (Graynoth 1987). Kokanee commonly produce sockeye salmon (Rounsefell 1958; Mullan 1986); rainbow trout, steelhead (Appendix H); brown trout and landlocked Atlantic salmon all produce sea-run fish (Rounsefell 1958). Resident populations of coastal cutthroat (O. c. clarki) also probably contribute to anadromy (Royal 1972; Edie 1975; Jones 1979). This did not appear to be the case for two coastal streams in Washington (Michael 1983), which, however, were isolated from anadromous fish by 10,000-year barriers (Parkinson et al. 1984).

Original Distribution

Interglacial advance and retreat of O. mykiss occurred in the Columbia Basin, although populations south of the Columbia Basin in warmer lacustrine environments, persisted (Behnke 1979; Currens et al. 1990). Since cutthroat and bull trout existed upstream from barriers created as the land rose from the melting of the ice mass, they persisted through at least the last ice age. The Columbia River Basin was then recolonized by an anadromous form of O. mykiss (Mottley 1934). By virtue of its capacity to accumulate fat reserves for enduring periods of starvation, the summer steelhead likely was the invader. But, how did O. mykiss and cutthroat maintain species integrity in view of their propensity to hybridize (Campton and Utter 1985)?

Most salmonids examined in the Methow River had normal body condition ($K = W/L^3 \times 100$), ranging from 1.0 to 1.4 (Fig. 12), unlike the starving brook trout of Bunny Lake (Reimers 1979). Aside from comparable lipid storage, bull and cutthroat trout have lower thermal optima than O. mykiss. Therefore, the path was clear

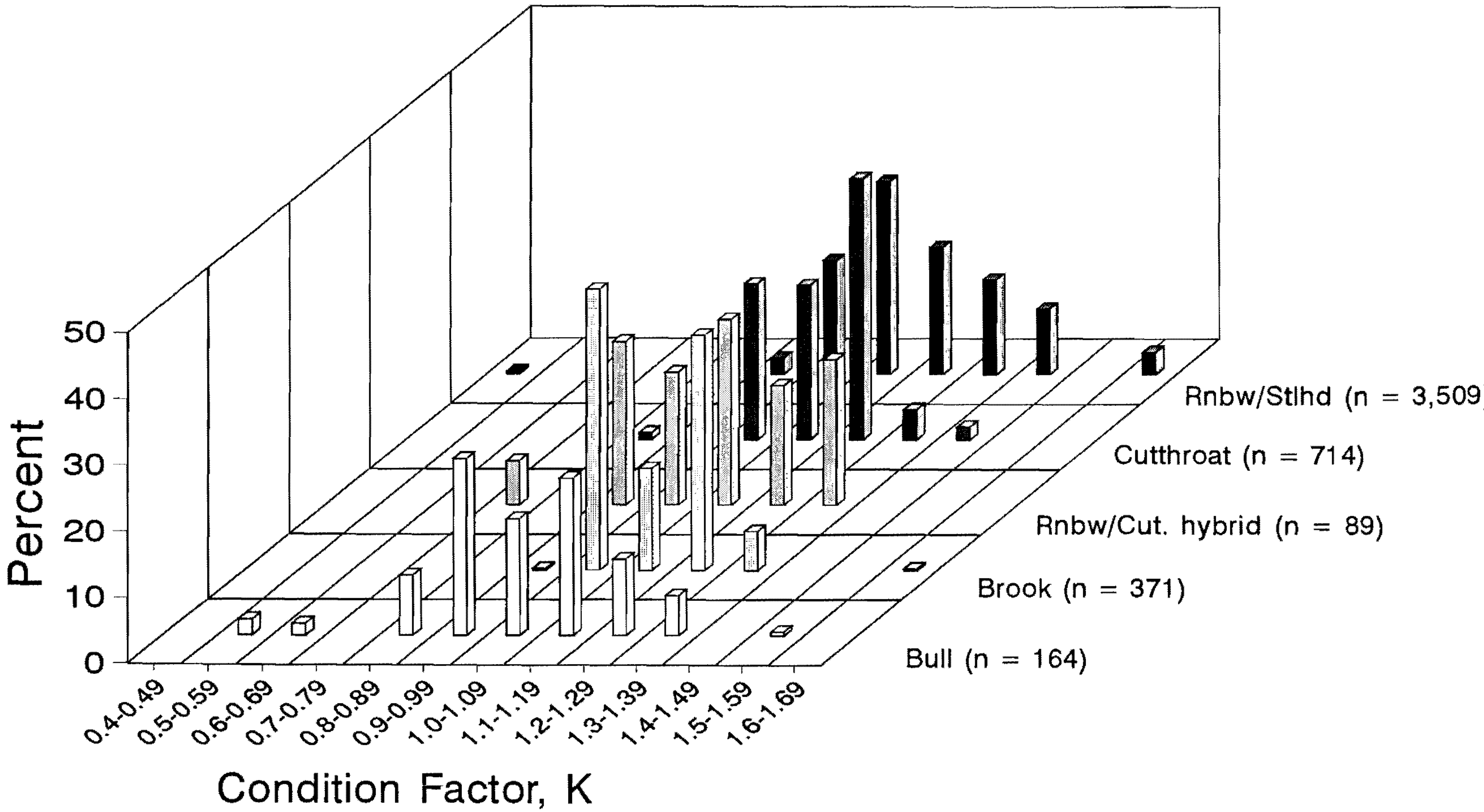

Fig. 12 Average condition factor, K+W/L^3 x 100, (W is weight in g and L is fork length in mm), expressed as a frequency distribution (%), for rainbow/steelhead, cutthroat, rainbow/cutthroat hybrids, brook and bull trout from the Methow River drainage.

for some anadromous form of these species to penetrate the headwaters of the Columbia Basin in the early Pleistocene, where they endured multiple glacial periods and dispersed widely during post-glacial flooding. Anadromy was not well developed in these species and its loss can be attributed to inter-glacial dominance of O. mykiss, which forced retreat of spawning populations to headwaters (Fig. 13).

Several unique adaptations (e.g., tolerance of warm, highly mineralized water and a lacustrine, piscivorous life) evolved in some cutthroat trout in Pleistocene lakes which were continued in vestigial lakes after the last ice age (Behnke 1979, 1988). Such specialization always occurred in the absence of O. mykiss and cutthroat almost always disappeared wherever the two species came into contact (Behnke 1979, 1988). When the land rose following the melting of the ice mass in the Wenatchee, Entiat, and Methow drainages, the resulting barrier falls halted re-intrusions of cutthroat and bull trout, and more contact occurred when O. mykiss arrived. Post-glacial flooding allowed upriver colonization of populations of cutthroat and bull trout to Lake Chelan and barrier falls at the outlet precluded later invasion of O. mykiss (Behnke 1979).

The bull trout originated in the Columbia River, but had an anadromous history (Cavender 1978). They diverged from a Dolly Varden type ancestor by evolving into a piscivore (Cavender 1978). Being the only apex predator in the fish community likely was an energetic advantage and a pathway away from anadromy.

Bull trout from the Columbia and Klamath rivers diverged genetically to the subspecific level within the last post-glacial period (Leary et al. 1991). Warming contracted their distribution to the coldest headwaters in the southern portion of their range. Climate change, together with activities by man, have eliminated bull trout in California (Goetz 1989) and nearly so in Nevada (Hass and McPhail 1991).

Climate warming also brought O. mykiss, which displaced cutthroat and bull trout below falls. A few historical notes suggest that some cutthroat did exist in the Methow River in reaches of those streams where the falls are found above the thermal minimum for O. mykiss (USFS 1937-61). Stocking of westslope cutthroat in alpine lakes has resulted in the establishment of self-sustaining populations in every major sub-drainage. Bull trout have not been propagated and re-introduced above barrier falls. Eleven breeding populations now occupy only 1.4% (29 ac of stream) of the Methow River watershed. They appear to have disappeared from Lake Chelan after introduction of kokanee (O. nerka) and O. mykiss in 1917 (Brown 1984b).

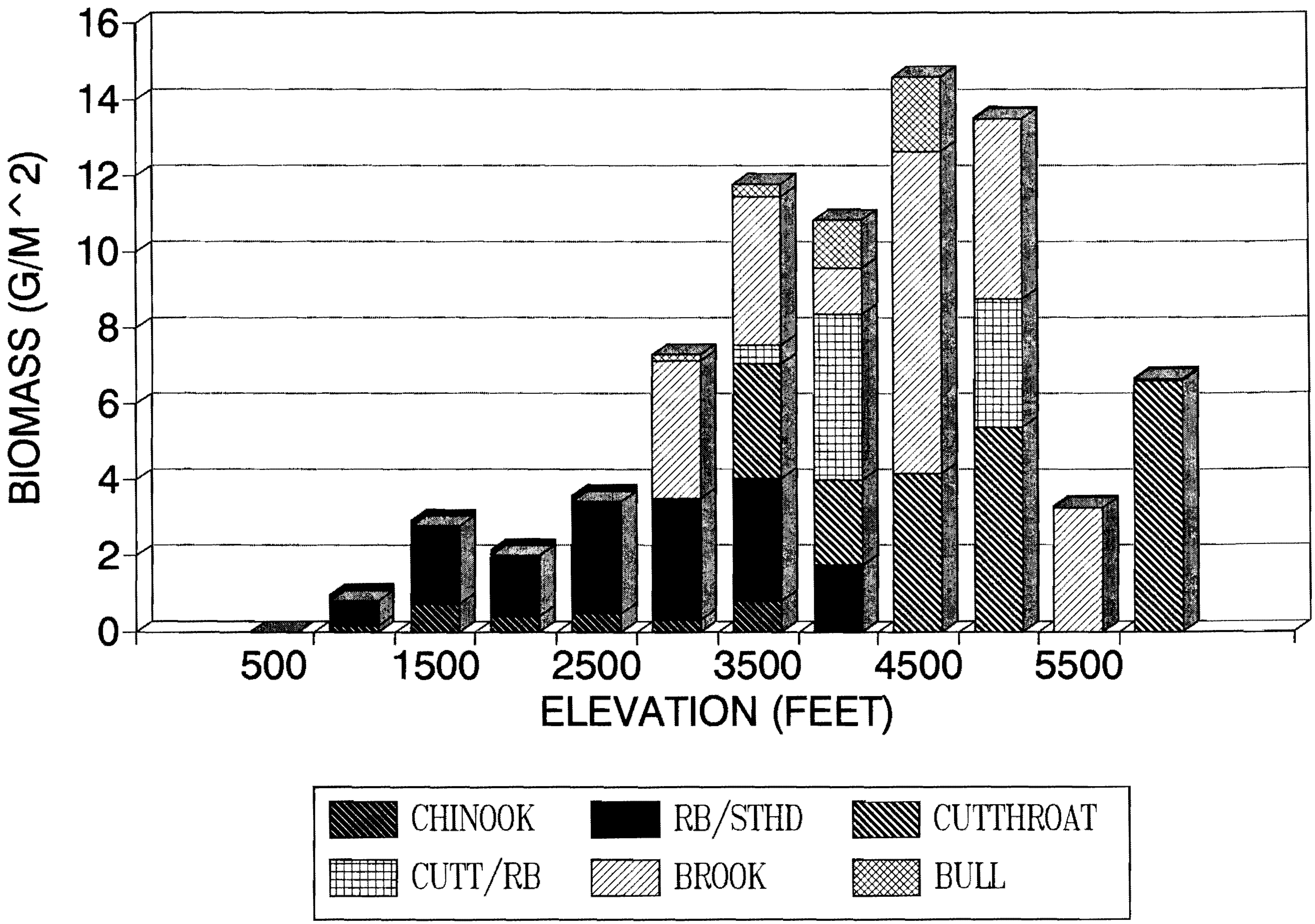

Fig. 13. Indigenous biomasses (g/m^2) of chinook salmon, rainbow/steelhead, cutthroat, cutthroat/rainbow hybrids, brook, and bull trout according to elevation in the Methow River drainage (data from Chapter 3, Tables 7 and 8).

Longitudinal Distribution

Cutthroat, bull, and exotic brook trout were distributed in headwaters above O. mykiss populations in the Methow River. Some large juveniles and adults were sympatric with O. mykiss, but separation of spawning populations was complete. A short zone of sympatry occurred with a high incidence of hybridization between cutthroat and O. mykiss. From the upper steelhead zone downstream, the species complex becomes additive (Sheldon 1968). Many similar distributions of salmonids have been reported (Hartman and Gill 1968; Gard and Seegrist 1974; Hanson 1977; Cavender 1978; Behnke 1979; Moore et al. 1983; Thurow 1987; Fausch 1989; Griffith 1988; Fraley and Shepard 1989; Goetz 1989; Meehan and Bjornn 1991).

Gradient and temperature, particularly the latter, have been cited as the major factors responsible for longitudinal succession (Burton and Odum 1945; Huet 1959; Vincent and Miller 1969; Gard and Flittner 1974; Erman 1986; Fausch 1989). Our results show that O. mykiss excludes the first two or three age classes of cutthroat, brook, and bull trout up to where temperatures decline to about 1,600 TUs, regardless of gradient.

Headwater, allopatric distributions of westslope cutthroat trout above O. mykiss occur throughout their range. Hanson (1977) found no sympatric populations in Idaho streams. Platts (1974) found cutthroat abundant in the Salmon River, Idaho, in headwaters only. Some adfluvial fish lived in sympatry with steelhead part of the year (Moffit and Bjornn 1964; Bjornn 1971), but adults appeared to spawn in allopatry in natal streams. In inland Oregon, cutthroat did not become sympatric with introduced O. mykiss, but rather were replaced by them (Nicholas 1978). The failure of cutthroat to increase after Dworshak Dam eliminated steelhead in the North Fork Clearwater River, Idaho, was due to resident populations of O. mykiss, contrary to the explanation of Griffith (1988). Coexistence of the two species in the lower Flathead River, Montana, occurs only during part of the life history--spawning and early rearing appear isolated (Liknes and Graham 1988).

Interactions of bull trout and O. mykiss are unknown. Bull trout likely are as vulnerable to replacement by O. mykiss as cutthroat. The requisite of cold, headwater streams for spawning and juvenile rearing for bull trout is clear. Exclusion of bull trout populations by introduced O. mykiss may partly explain their geographic decline in this century (Leary et al. 1991).

Fausch (1988) concluded that O. mykiss is a competitor superior to brook trout. Our contention is that species dominance depends on temperature. Where annual heat budgets are less than 1,600 TUs, exotic brook trout have replaced O. mykiss in the Methow River. Downstream water temperatures are too warm for brook trout to compete effectively with O. mykiss.

Bull, brook, and cutthroat trout appear to have similar temperature preferences. We suspect that factors other than temperature determine the outcome of their competition. Bull and cutthroat trout evolved together (Behnke 1979) and competition is minimized by ecological segregation (Pratt 1984). Nevertheless, abundance of allopatric populations of cutthroat in the headwaters of Wolf Creek and the Twisp River (Appendix D) were markedly greater than those produced in sympatry with bull trout a short distance downstream (Chapter 3, Table 8).

Brook trout replace cutthroat in most streams (MacPhee 1966; Behnke 1979; Griffith 1988; Gresswell and Varley 1988; Liknes and Graham 1988; Fausch 1989). Fausch (1989) surmised that brook trout preferred lower gradient habitat than cutthroat and seldom replaced them in high gradient habitat (usually headwaters). We found a high density of brook trout adults and large juveniles, but no Y-O-Y in a high gradient, boulder reach of War Creek (Appendix D). These fish probably recruited from populations located in low gradient reaches upstream. Brook trout seem to be replacing cutthroat in Boulder and Twentymile creeks (Appendix D), but not in the more torrential War Creek.

Brook and bull trout may occupy the same habitat and hybridize extensively, leading to extirpation of bull trout (Leary et al. 1991). This may have happened in Eightmile, Boulder, and Beaver creeks (USFS 1937-61) (Appendix D), especially considering that bull trout require 6-9 years to reach sexual maturity versus 2-4 years for brook trout. Bull trout may require larger streams than brook or cutthroat trout because populations terminated in headwater reaches not blocked by barriers (e.g., Goat, West Fork Buttermilk, and Wolf creeks; Appendix D).

The contraction of brook trout to headwaters of the southern Appalachian Mountains (Larson and Moore 1985) with encroachment by introduced O. mykiss points to water temperature as the regulating mechanism (Burton and Odum 1945; Cunjak and Green 1984). Hahn (1977) found that aggressive behavior in steelhead fry persisted over fluctuating or constant temperatures ranging from 8.5° to 19.0° C. However, Reeves et al. (1987) showed that temperature plays a key role in determining the outcome of interactions between redside shiner and juvenile O. mykiss, and Hillman (1991) detailed the same for redside shiner and chinook salmon.

Magnuson et al. (1979) argued that ecothermic vertebrates responded to temperature in a manner remarkably similar to more traditional resources such as food. They used niche theory and competition to explain distribution patterns among cold, cool, and warm water fishes. Niche width, as determined from preference curves and temperature gradients, was about 4° C for all fish species regardless of thermal guild. But compression of thermal niche was suspected in natural environments where interspecific competition occurred.

Cherry et al. (1975, 1977) found that at 18° C, acclimation and preferred temperature for O. mykiss coincided. Brook trout preferred 16.7° C. Conversely, where acclimation and preferred temperature were identical (15° C) for brook trout, O. mykiss preferred 16.9° C. Our interpretation is that O. mykiss will prevail when mean summer temperatures exceed 18° C, sympatry will occur in the 15-18° C range, and temperatures less than 15° C will favor brook trout. However, in the natural environment, preferred (physiologically optimum) temperature almost certainly would be less because such temperatures are a function of food ration (Brett 1979).

Temperature preference for bull trout has not been determined, but it is evident from their distribution with brook and cutthroat trout that thermal preferences are similar for all three species. In allopatry they are capable of inhabiting the entire Methow River and their confinement to headwaters represents interactive niche compression. For example, a barrier falls on lower Boulder Creek (Appendix D) blocks O. mykiss and brook trout are distributed down to the falls but not below it. In nearby Twentymile Creek (Appendix D), similar to Boulder Creek in size and heat budget, but without a barrier, O. mykiss extends 1,200 feet higher in elevation before brook trout dominate. An allopatric bull trout population exists in Reynolds Creek (Appendix D), which is more thermally suited for O. mykiss but not successfully colonized by them because of intermittent flows at its mouth. A dense population of brook trout in lower Cub Creek (Appendix D), a stream thermally favoring O. mykiss (>2,000 TUs), is sheltered from O. mykiss invasion by falls.

The outcome of interactions apparently is decided within the first few weeks of emergence because fry of the subordinate species are seldom found with the dominant species, though larger individuals occur routinely. Hanson (1977) found that age-0 steelhead could establish territories whether cutthroat were present or not, whereas age-0 cutthroat could only establish territories in the absence of steelhead. However, these tests were conducted at temperatures (diel low and high of 10° and 15° C) that we believe favored steelhead.

Social status, which is nearly always governed by body size, is believed to determine the outcome of competition (Hahn 1977; Magnuson et al. 1979; Cunjak and Green 1984). Logically, social equality is a requisite for cutthroat-O. mykiss interbreeding, which likely is tied to temperatures favoring neither species. In most watersheds, reaches of thermal neutrality are probably rare, which may answer Campton and Utter's (1985) question of why O. mykiss and cutthroat can maintain species integrity in view of their propensity to hybridize. The narrow zones where bull and brook trout are sympatric with O. mykiss is the analog to the O. mykiss-cutthroat hybridization zone. Preferred temperature may increase with ontogeny of cutthroat and bull trout, which may explain how fluvial and adfluvial fish can live in sympatry with steelhead parr. Achieving critical size from rearing in isolation is first required, however.

Replacement of O. mykiss by brook, bull, or cutthroat trout has not been documented to our knowledge. However, the release of cutthroat fry in upper Goat Creek (Appendix D) in 1985, led to the replacement of O. mykiss by cutthroat about 1.4 mi downstream of the release site. Although there are no barriers to upstream movement, the cutthroat have not extended their range into the bull trout population upstream. Another example is the convergence of a pure O. mykiss population in Crater Creek (Appendix D) with a pure population of cutthroat in Martin Creek at an impassable falls. Successionally, cutthroat dominated for a short distance downstream, succeeded by an equally short hybrid zone, downstream from which only O. mykiss was found. Further, a release of brook trout fry in 1933 (USFS 1937-61) apparently caused the elimination of O. mykiss from the Middle Fork of Beaver Creek (Appendix D). Although a proliferation of plants of cutthroat and brook trout in the Methow River have resulted in the contraction of O. mykiss distribution, the net effect has been minimal because temperatures generally favor O. mykiss.

Meisner (1990) predicted that the fate of brook trout with global warming will be determined by the volume of groundwater discharge and the amount of headwater refuge to which they can retreat in summer. We predict that if stream temperatures rise the projected 4-5° C by mid-21st century (Meisner et al. 1988; Hokanson et al. in press), cutthroat and bull trout in the Methow River basin will be replaced by O. mykiss (with trade-offs for mykiss downstream), except for populations above falls.

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APPENDIX L

PROBABLE CUMULATIVE EFFECTS OF LOGGING AND ROAD-BUILDING ON FOUR WATERSHEDS OF THE EASTERN CASCADE MOUNTAINS, WASHINGTON

by Granville Rhodus

Introduction

Logging and road construction are the forest-management practices that contribute most to sedimentation of streams (Cederholm et al. 1980). However, the impacts to the land from these practices are variable, depending on whether they occur singly or in combination and on the nature of the watershed. This paper concerns itself only with these two main categories of forest activities and their resulting cumulative effects.

Cumulative effects are the impacts resulting from a series of management activities occurring within a defined watershed over a span of time (Geppert et al. 1984). Klock (1985) developed a model to determine if the summation of forest practices over time and space creates a risk to lower elevation streams different than what might be expected from natural hydrological events. Klock's model is used here to look at the potential cumulative effects of logging and haul roads within four watersheds of the Cascade Mountains in eastern Washington.

Model Overview and Methods

The Cumulative Watershed Effects Risk (CWER) model of Klock (1985) uses the Universal Soil Loss Equation modified for forest conditions.

The CWER analysis value indicates the state of condition of the watershed, or the implied cumulative effects of risk resulting from forest practices, for the year of analysis. CWER values less than 1.0 indicate an impact no greater than that of natural hydrological events. CWER values between 1.0 and 2.5 indicate moderate cumulative effects risk. Index values between 2.5 and 6.0 indicate a high potential cumulative effects risk. Forest practices leading to an index value in this range are likely to seriously affect the downstream aquatic ecosystem during a major storm run-off or snow melt event. CWER values greater than 6.0 represent worst case conditions (Klock 1985).

CWER values are calculated annually from historical data, beginning with the first year of entry into the watershed, or a reference year, to the present. Alternative forest practices or timber harvest schedules are evaluated for their potential impact on the downstream ecosystems in future years by applying the appropriate projected data.

The CWER model equation is

$$CWER\ f = (R*E*S*H*T)\ (A_1)\ (C/A_2).$$

CWER = Cumulative Watershed Effects Risk

R = the site erosivity energy potential values taken from special precipitation maps showing 2 yr., 6 hr., or other (e.g. 24 hr) storm durations.

E = site surface erosion factor based on disturbance values reflecting 23 combinations of forest practices. All disturbance values decline from one year following an activity to ten years. For example, "tractor logging, bare ground," under "clearcutting" declines from 0.45 one year following the activity to 0.01 after 10 years (Table 1).

S = the slope stability factor, reflecting the "failure frequency" that results from logging and road construction. The failure factor is a compilation of "Land Stability Ratings." Its components include soil stability values, slope percent components, size of forest activity, position on the landscape--e.g., midslope, ridge, etc. Each disturbed unit is assessed to determine a land stability rating. The "failure frequency" reflects the grouping of stability levels with a range of 1 to 7 (very stable to most unstable). The roading failure frequency factors are similar in derivation (Tables 2 to 5).

H = hydrologic sensitivity, reflecting a hydrologic recovery period of 20 years. This period is highly variable by watershed because recovery depends on rainfall, elevation, soils, aspect, etc. Hydrologic maturity for conifer forests in the Pacific Northwest is considered to be reached when timber achieves an average height of 5 meters and a minimum stocking of 50% of the maximum site capability. This factor is also expressed by a matrix with values derived from years following forest activity (1 to 20) and years to forest site hydrological maturity 1 to 20 (Table 6).

Table 1. Forest site disturbance coefficients (D).

Forest activity	Activity line number	Years following activity 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Transportation																					
System roads	1	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
Perm. roads & landings	2	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
Abandoned roads & landings																					
Treated	3	0.90	0.70	0.40	0.30	0.20	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Not treated	4	1.00	0.90	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
Rec. vehicle trails																					
Treated	5	0.90	0.70	0.40	0.30	0.20	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Not treated	6	1.00	0.90	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
Harvest and Site Preparation																					
Clearcut:																					
Tractor log.bare ground	7	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. mech.	8	0.80	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. b. burn	9	0.60	0.60	0.55	0.50	0.40	0.30	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Tractor log. over snow	10	0.20	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. mech. snow	11	0.30	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. mech. bare	12	0.60	0.60	0.55	0.50	0.40	0.30	0.20	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. b.burn	13	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log.not supported	14	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. b. burn	15	0.60	0.55	0.50	0.45	0.40	0.30	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log. one end supported	16	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. b. burn	17	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log. fully supported	18	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site prep. b. burn	19	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Partial cut:																					
Tractor log.bare ground	20	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Tractor log.snow	21	0.20	0.15	0.10	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log.not supported	22	0.30	0.2	0.15	0.10	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log. one end supported	23	0.20	0.15	0.10	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cable log. fully supported	24	0.10	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Helicopter	24	0.10	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Modified from "A Method to Assess and Predict Cumulative Watershed Effects," by Richard O. Hanes, et al., USDA Forest Service, Sequoia National Forest, February 1981.

Site surface erosion factor E = D x (I + K) where K is the soil erodability factor developed for the modified universal soil loss equation.

Table 2. Slope stability coefficients for clearcut harvest areas (Sh).

Years following activity	Years to forest site hydrologic maturity																			
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.3	4.0	2.5	1.6	1.0
2	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	7.0	6.3	4.0	2.5	1.6	1.0	1.0
3	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	8.4	7.0	6.3	4.0	2.5	1.6	1.0	1.0	1.0
4	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	8.4	7.0	6.3	4.0	2.5	1.6	1.0	1.0	1.0	1.0
5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	8.4	7.0	6.3	4.0	2.5	1.6	1.0	1.0	1.0	1.0	1.0
6	8.6	8.5	8.4	8.3	8.1	8.0	7.8	7.6	7.2	6.8	6.3	4.0	2.5	1.6	1.0	1.0	1.0	1.0	1.0	1.0
7	7.3	7.2	7.0	6.8	6.6	6.4	6.0	5.7	5.2	4.7	4.0	2.5	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	6.3	6.1	5.9	5.6	5.3	5.1	4.7	4.3	3.7	3.2	2.5	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
9	5.4	5.2	4.9	4.7	4.3	4.0	3.6	3.2	2.7	2.2	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	4.6	4.4	4.1	3.8	3.5	3.2	2.8	2.4	1.9	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	4.0	3.7	3.4	3.2	2.8	2.5	2.2	1.8	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	3.4	3.2	2.9	2.6	2.3	2.0	1.7	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
13	2.9	2.7	2.4	2.1	1.8	1.5	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
14	2.5	2.3	2.0	1.8	1.5	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	2.2	1.9	1.7	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	1.9	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
17	1.6	1.3	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18	1.3	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
19	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Harvest site slope stability coefficient Sh = log 10 (failure freq. x maturity coefficient).

If Sh is less than 1 then equals 1. Failure frequency based on increased frequency of debris avalanches or other mass soil movement under mature forest conditions. Increased failure frequency ranges from 1 to 7, depending upon soil mass stability, in most Pacific Northwest conifer forests.

Hydrologic maturity in Pacific Northwest conifer forests is assumed to have been reached when 90% of harvested or disturbed areas are revegetated and one-third of the conifer stand is 5 m or taller.

Table 3. Slope stability coefficients for roads (Sr).

Years following activity	Years to forest site hydrologic maturity																			
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
2	8.8	8.8	8.7	8.7	8.6	8.5	8.4	8.3	8.2	8.0	7.8	7.6	7.3	6.9	6.3	5.7	4.6	3.0	1.0	1.0
3	7.8	7.7	7.6	7.5	7.4	7.2	7.1	6.8	6.6	6.3	6.0	5.7	5.2	4.7	3.9	3.3	2.2	1.0	1.0	1.0
4	7.0	6.8	6.7	6.5	6.3	6.1	5.9	5.7	5.4	5.0	4.6	4.2	3.7	3.2	2.5	1.7	1.0	1.0	1.0	1.0
5	6.2	6.0	5.8	5.6	5.4	5.2	4.9	4.7	4.3	4.0	3.6	3.1	2.7	2.2	1.5	1.0	1.0	1.0	1.0	1.0
6	5.5	5.3	5.1	4.9	4.7	4.4	4.1	3.9	3.5	3.2	2.8	2.3	1.9	1.5	1.0	1.0	1.0	1.0	1.0	1.0
7	4.8	4.7	4.4	4.2	4.0	3.7	3.5	3.2	2.9	2.5	2.1	1.7	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	4.3	4.1	3.9	3.7	3.5	3.2	2.9	2.7	2.3	2.0	1.7	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
9	3.8	3.6	3.4	3.2	3.0	2.7	2.5	2.2	1.9	1.6	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	3.4	3.2	3.0	2.7	2.5	2.3	2.1	1.8	1.5	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	3.0	2.8	2.6	2.4	2.2	1.9	1.7	1.5	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	2.7	2.5	2.3	2.1	1.9	1.7	1.5	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
13	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
14	2.1	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	1.9	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	1.7	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
17	1.5	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18	1.3	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
19	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Road site stability coefficient Sr = log10 (failure frequency x maturity coefficient from table).

If Sr is less than 1 then equals 1. Failure frequency based on increased frequency of debris avalanches or other mas soil movement expected from road construction. Increased failure frequency ranges from 1 to 140 in the Pacific Pacific Northwest conifer region.

Hydrologic maturity in Pacific Northwdstg conifer forest is assumed to have been reached when 90% of harvested or disturbed areas are revegetated and one-third of the conifer stand is 5 m or taller.

Table 4. Land stability ratings.*

		Value	Known failures
Projected stability		**Value**	**Known failures**
I	Very stable	1	none
II	Stable	5	few
III	Moderately stable	15	common
IV	Unstable	30	common
V	Very unstable	40	many
Slope			
	Gentle (0-20%)	1	
	Moderate (21-45%)	5	
	Steep (46-60%)	15	
	Very steep (61% +)	25	
Size of opening			**Hectares**
	Very small (0-3 acres)	1	1.2
	Small (4-10 acres)	3	4.1
	Moderate (10-20 acres)	5	8.1
	Large (20-40 acres)	10	16.2
	Very large (>40 acres)	20	16.3+
Position on landscape			
	Valley bottom	1	
	Ridge top	3	
	Toe slope	5	
	Mid slope	15	
Additive table value			**Failure frequency**
	76-100		7
	51-75		5
	24-50		3
	5-23		2
	1-4		1

*Tables 4 and 5 from Klock (1984), modified by P. McColley and C. Blackburn, U.S. Forest Service.

Table 5. Road stability rating.*

Projected stability (natural features)	Value	Known failures (road assoicated)
Very stable	1 (1-3)	none
Stable	10 (4-10)	few
Moderately stable	20 (11-20)	common
Unstable	35 (21-35)	common
Very unstable	50 (36-50)	many
Side slope		
Gentle	1 (1-6)	
Moderate (21-45%)	10 (7-17)	
Steep (46-60%)	25 (18-30)	
Very steep (>61%)	50 (31-50)	
Position on the slope (macro)		
Ridge top	1	
Valley bottom	2	
Toe slope	10	
Mid-slope	28	
Surface type		
Asphalt	1	
Gravel	5	
Coarse soil	10	
Fine soil	12	

*Note: description of the road at the reference year.

Table 6. Watershed hydrologic sensitivity coefficients (H).

Years following activity	Years to forest site hydrologic maturity																			
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.01
2	0.33	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.31	0.30	0.30	0.29	0.28	0.26	0.24	0.18	0.01	0.01
3	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.29	0.29	0.28	0.27	0.26	0.25	0.23	0.21	0.17	0.12	0.01	0.01	0.01
4	0.29	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.25	0.24	0.23	0.22	0.20	0.18	0.14	0.08	0.01	0.01	0.01	0.01
5	0.27	0.27	0.27	0.26	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.17	0.15	0.12	0.07	0.01	0.01	0.01	0.01	0.01
6	0.26	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.18	0.15	0.13	0.10	0.06	0.01	0.01	0.01	0.01	0.01	0.01
7	0.24	0.23	0.23	0.22	0.21	0.20	0.18	0.17	0.16	0.14	0.10	0.08	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	0.21	0.21	0.20	0.20	0.19	0.18	0.16	0.15	0.13	0.10	0.07	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
9	0.19	0.19	0.18	0.17	0.16	0.15	0.13	0.12	0.10	0.07	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.17	0.17	0.16	0.15	0.14	0.12	0.11	0.08	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11	0.15	0.15	0.14	0.13	0.12	0.10	0.07	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
12	0.13	0.13	0.12	0.11	0.10	0.08	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
13	0.11	0.11	0.10	0.09	0.08	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
14	0.09	0.09	0.08	0.07	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
15	0.07	0.07	0.06	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
16	0.05	0.05	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
17	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
18	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
20	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Basal area coefficient	
% removed	
10	0.01
20	0.035
30	0.07
40	0.125
50	0.20
60	0.295
70	0.42
80	0.58
90	0.77
100	1.00

H = 1 + (maturity coefficient x basal area coefficient).

Hydrologic maturity in Pacific Northwest conifer forest is assumed to have been reached when 90% of the harvested areas are revegetated and one-third of the conifer stand is 5 m or taller.

Years prior to July 1 in Pacific Northwest.

T = the topographic factor, determined with a nomograph. The average percent of slope and the distance from the center of the forest activity to the closest second-order perennial stream are used to find the T factor.

A_1 and A_2 = Areal factors

A_1 = the area of the activity (ha)

A_2 = the area of the watershed (ha)

C = The normalizing coefficient is a function of the percent of sale area presumed disturbed during a typical forest activity.

If a management activity exceeds ten ha in area or road lengths exceed 1 km in length, the disturbed area must be broken into additional segments. The CWER equation evaluates all the above factors to derive a single value. The value changes each time a different soil type is encountered, a logging method altered, or the silvicultural prescription is changed.

For greater detail of the methodology the reader is referred to Klock (1985).

Results

Meadow Crest Drainage

The drainage is 5,056 ac with checkerboard federal, state, and private holdings. Elevation ranges from 2,800 to 5,100 ft. Soils are moderately well to well-drained with a high degree of stability. Annual precipitation ranges from 80 in at the lower elevations to 120 in at the higher elevations (NOAA's state isohyetal maps).

The drainage was essentially pristine until the late 1950s. About 70% of the original forest was removed by logging in the next 25 years. Harvest plans for a 1978 timber sale were developed to benefit wildlife, timber harvest, or both:

					CUTTING PRESCRIPTIONS		
Alternative	No. of units	Area (ac)	Roads (mi)	Timber (mmbf)	Clear-cuts	Shelter-wood cut	Over-story cut
Timber	14	294	1.5	13.4	10	3	1
Wildlife	11	319	1.5	15.1	7	4	0
Combo.	13	303	1.7	14.7	9	3	1

Meadow Crest CWER assessment. Maximum risk of just over 2.0 (Fig. 1) occurred in 1979 for the 70% cutover disturbances which began in the 1950s. The input reference year is typically one year following the land disturbance. The roading, logging, and slash disposal of timber sales normally take two to four years to complete. Only minor differences in risk rating for alternative management prescriptions were noted: timber, 0.46; wildlife, 0.48; and timber and wildlife, 0.47. The potential risk was no greater than that expected as a result of natural hydrologic events.

The minimum impacts of the 1978 timber sale are presumably a result of the dispersed location of the cutting units and the fact that new roads were not needed. Rapid hydrologic recovery following years of heavy timber harvest and earlier road construction can be attributed to stabilized soils, aggressive reforestation efforts, vigorous natural regeneration, and the favorable moisture regime.

Thomson Creek Drainage

Soil stability varies within the watershed with soils derived from Swauk sandstone dominating the area. These soils are moderately stable to unstable. Run-off during a storm about 1982 caused significant downcutting of Thomson Creek at its mouth.

Both the lower elevations and the upper elevations of the watershed are in private ownership; U.S. Forest Service lands occupy the mid-drainage elevations. Annual precipitation is estimated at 45 in and mean elevation at 3,250 ft.

The upper watershed had several ownership changes since the 1970s and various timber cutting prescriptions and harvest methods. By 1983, the heavy timber stands of the upper drainage were reduced to a low basal area/ac. Land use in the lower elevations is limited to pasture and hay production.

Thomson Creek CWER assessment. In 1983, a timber sale at mid-elevation on FS lands was proposed. The heavy run-off and channel scouring during the early 1980s was of concern. The private lands in the upper watershed experienced various degrees of harvest and re-entry between 1975 and 1983; about 473 ac were involved in road construction and timber harvest between 1980 and 1983.

Private timber harvest between 1980 and 1983 affected 39% of the 1,215 ac watershed. The FS lands lower in the drainage were essentially pristine with limited individual tree removal in the 1950s. The risk of the proposed 1983 timber harvest on FS land was deemed acceptable by the model when viewed as a single perturbation. However, when the effects of timber harvest on private lands were input and run concurrently, the cumulative

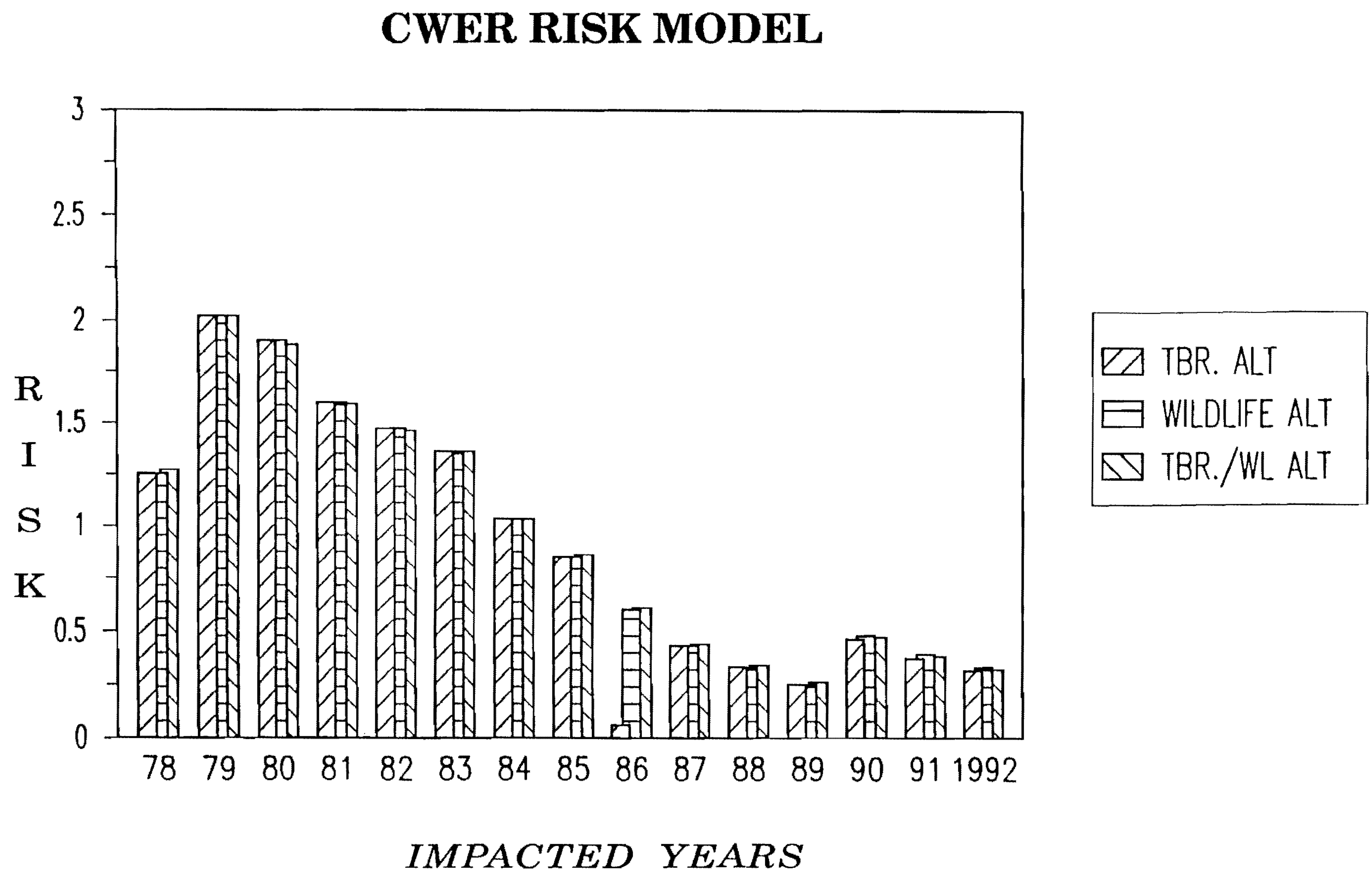

Fig. 1 Maximum risk of just over 2.0 occurred in 1979 for the 70% cutover disturbances which began in the 1950s combined with effects of private, state, and federal timber harvest in 1978 on the Meadow Creek drainage. Only minor differences in risk rating for alternative management prescriptions of timber, wildlife, and timber and wildlife occurred.

effects risk was unacceptable (Fig. 2). The proposed FS sale was then postponed.

The postponed 1983 Thomson sale was revised with a proposed sale date of 1987. As a result of the four-year delay of harvest, the proposed sale's risk was within the acceptable limits (Fig. 3).

Mission Creek Drainage

The Mission Creek drainage (47,267 ac) was severely overgrazed by sheep and subjected to deplorable logging practices prior to 1933 (Ciolek 1975). Since then, 87% of the watershed has been acquired by the U.S. Forest Service, and the watershed has undergone extensive restoration, including virtual elimination of livestock grazing (Ciolek 1975).

The Mission Creek watershed consists of extremely steep slopes with unstable soils derived from Swauk sandstone. About 25% of the drainage is exposed parent rock; the remainder is rock with a relatively thin soil mantle. Soils, in addition to being highly erodible, are of low productivity. Elevations range from 800 ft to 6,887 ft; mean basin elevation is 3,100 ft.

Annual rainfall ranges from 15 in at the lowest elevations to 35 in at the highest elevations; the mean is 21 in. Convective, high-intensity storms are common. There have been no major wildfires since 1900; the many lightning fires have been Class A fires--0.25 ac or less. A total of 613 fires were recorded in the Mission Creek drainage between the 1920s and 1974, for a mean of 11.8 fires (3 ac maximum) per year.

The Mission Creek watershed is now used primarily for recreation, with only limited timber harvest. It includes the 25,122 ac Devil's Gulch roadless area--53% of the drainage--formerly heavily grazed, but never logged.

CWER was determined for two subbasins of the Mission Creek drainage.

King Bee timber sale (U.S. Forest Service). The sale area is located at the head of King Canyon and East Fork Mission Creek. About 50% of the 28 sale units drain outside of the Mission Creek drainage. Logging was limited to selective cutting and clearcutting of small blocks. Yarding methods included tractor skidding on slopes under 25% grade in winter, skyline yarding (short span cable up to 1,700 ft with one end of log suspended), and low ground pressure (LGP) skidding, e.g., track skidder.

The King Bee timber sale roads were constructed in the early 1980s, but the timber harvest did not begin until winter 1988. The delay was a result of a FS buy-back program. Seventeen mi of road were constructed or reconstructed. Most of the permanent roads were surfaced with gravel to reduce erosion.

CWER RISK MODEL

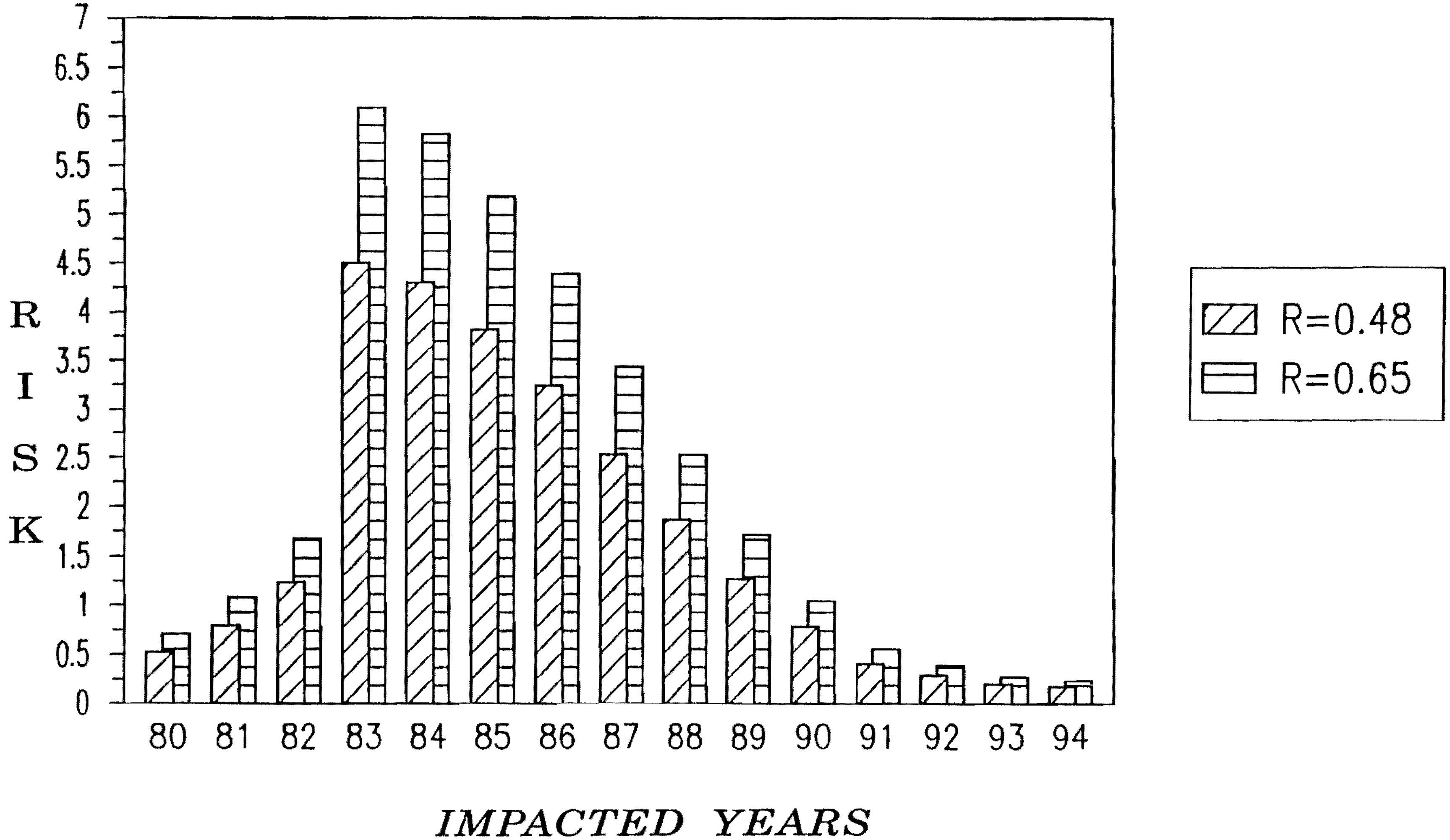

Fig. 2 Proposed 1983 Thomson Creek U.S.F.S. timber harvest—combined with effects of private timber harvests carried out between 1975 and 1983 in the upper watershed. (Two R values - precipitation/erosivity levels - were postulated to simulate frontal vs. convective storms.)

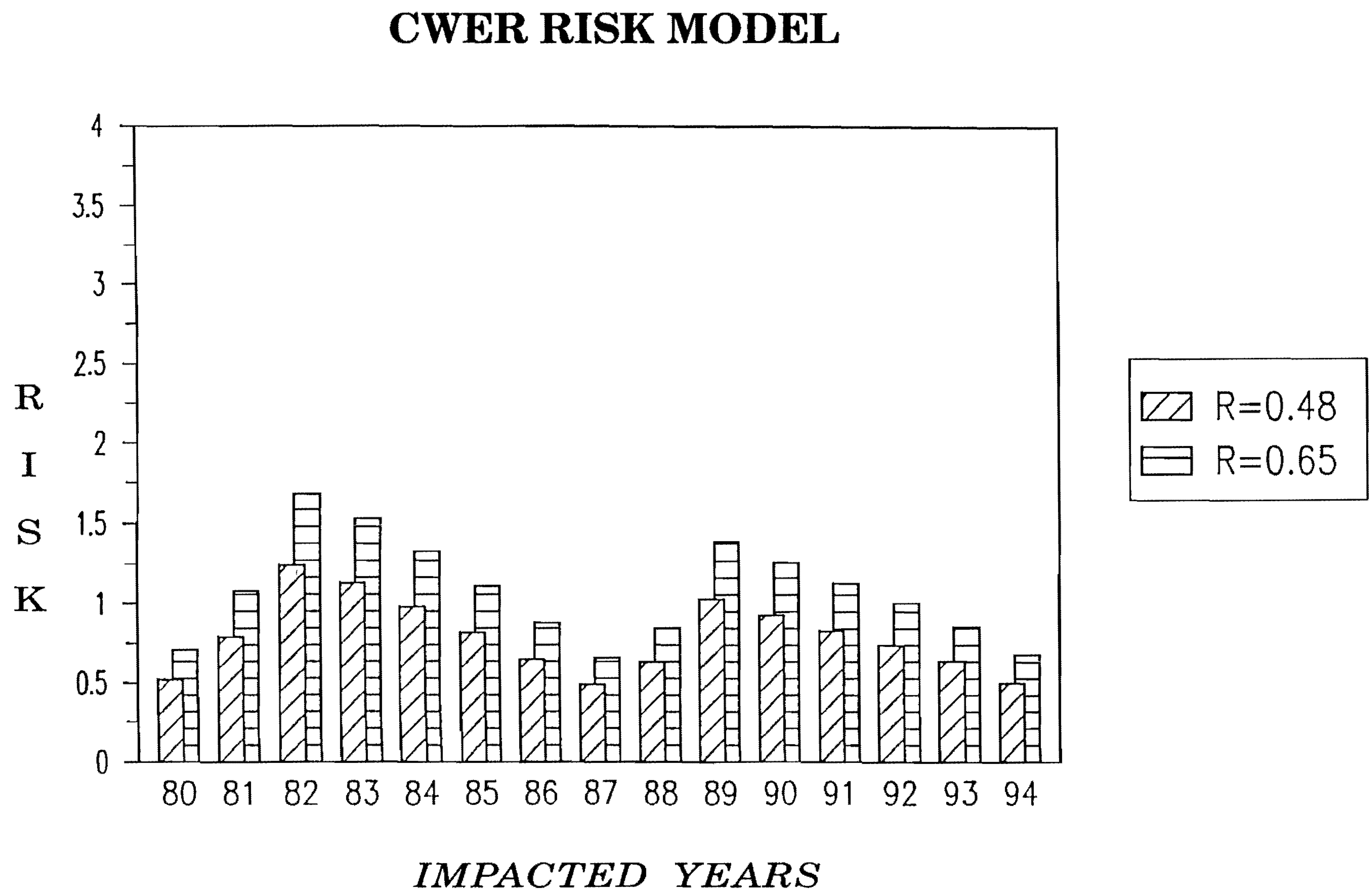

Fig. 3 U.S.F.S. Thomson Creek timber harvest proposed to occur in 1987 combined with effects of private timber harvests carried out between 1975 and 1983 in the upper watershed. *(Continued)*

CWER RISK MODEL

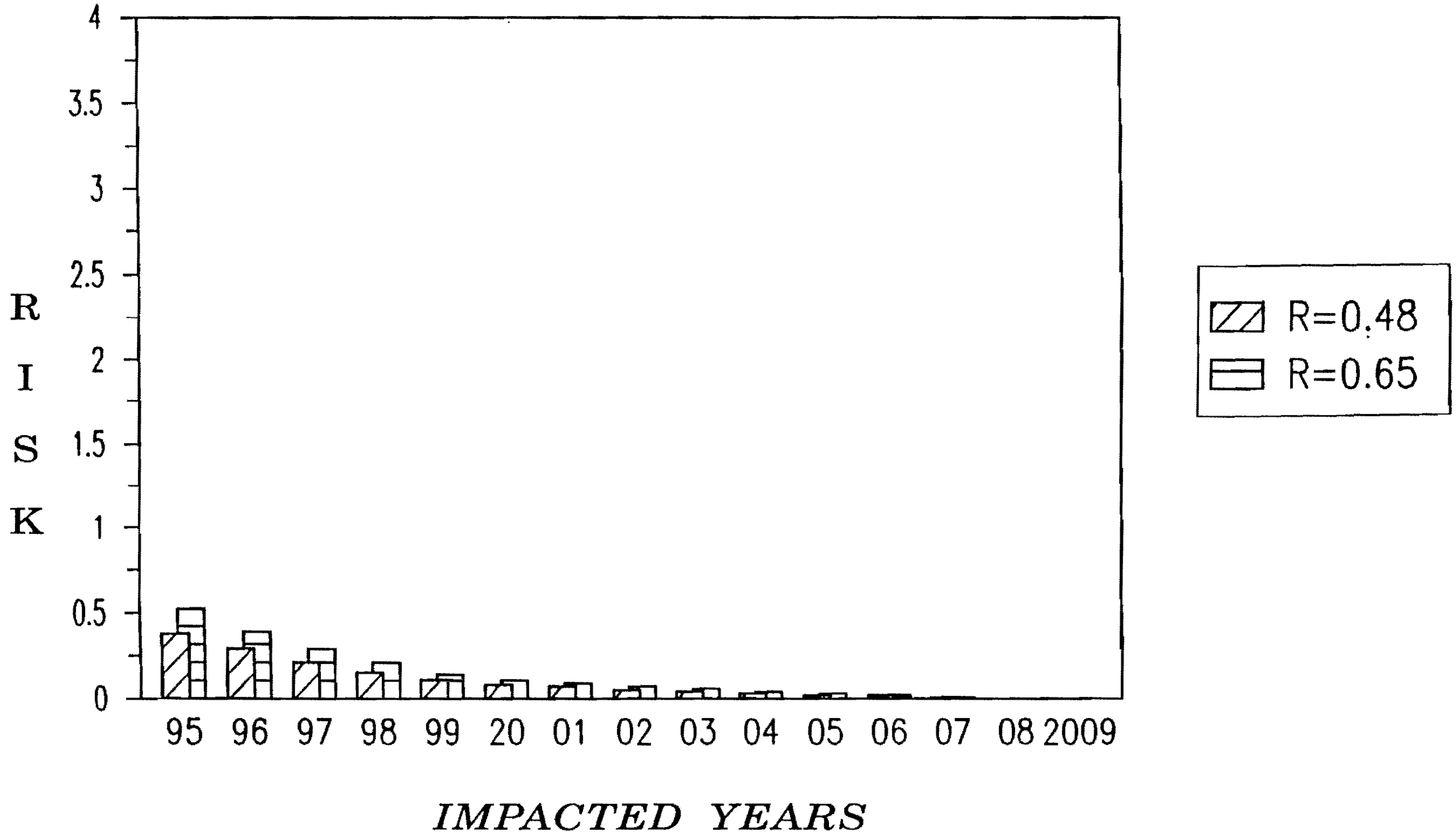

Fig. 3 Concluded

The sale units ranged from 4.4 ac to 150.8 ac (individual tree measurement/skyline yarded). Four clear-cut units ranged from 7 to 13.5 ac. The 28 harvest units, totaling 1,543 ac, were essentially selectively logged.

CWER assessment. As noted, the CWER assessment covers only that part of the sale area draining to Mission Creek. Road construction had minimal impact: only 6 mi of road were constructed, and construction activities occurred in 1980--eight years before the beginning of timber harvest in winter of 1988 (Fig. 4). The highest CWER risk presented by road construction occurred in 1981, one year following the activity.

The highest anticipated risk levels for timber harvest occur in 1990--two years following initial harvest (Fig. 4). (Three different "R" values--precipitation/erosivity levels--were postulated to simulate frontal vs. convective storms.) Values reflect both road construction and timber harvest involving 274 ac of winter logging with an ITM prescription, 340 ac of ITM cable logging, and 18.6 ac of clearcutting using cable yarding.

Sand Creek Timber Sales (Private Lands)

About 16% (4,721 ac) of the forested lands lying within the Mission Creek FS boundary are privately owned and tributary to Sand Creek. Ownership changes since 1960 have resulted in varying timber harvest practices.

Although the record of harvest activities is incomplete, sufficient information was available to piece together a scenario for two parcels totaling 1,490 ac. The earliest harvest occurred as partial cutting in 1972. Re-entries were difficult to track. Overlapping logging and yarding methods differed with past ownership, log prices, and timber-harvest technologies. The most recent logging, in 1986, saw an estimated 83% of the area subjected to practices ranging from partial cutting (PC), i.e. selective logging; shelterwood (SW); seed tree (ST); to clearcutting (CC). Yarding methods included tractor skidding, cable logging, jammer skidding, and helicopter removal.

CWER assessment. The road construction mileage was derived from 1985 aerial photographs. An estimated 12.6 mi (40 ac) of skid and haul roads were constructed over the 1,490 ac area in about 15 years.

The years of construction were determined to be relative to the year of harvest minus time for road completion prior to logging activity.

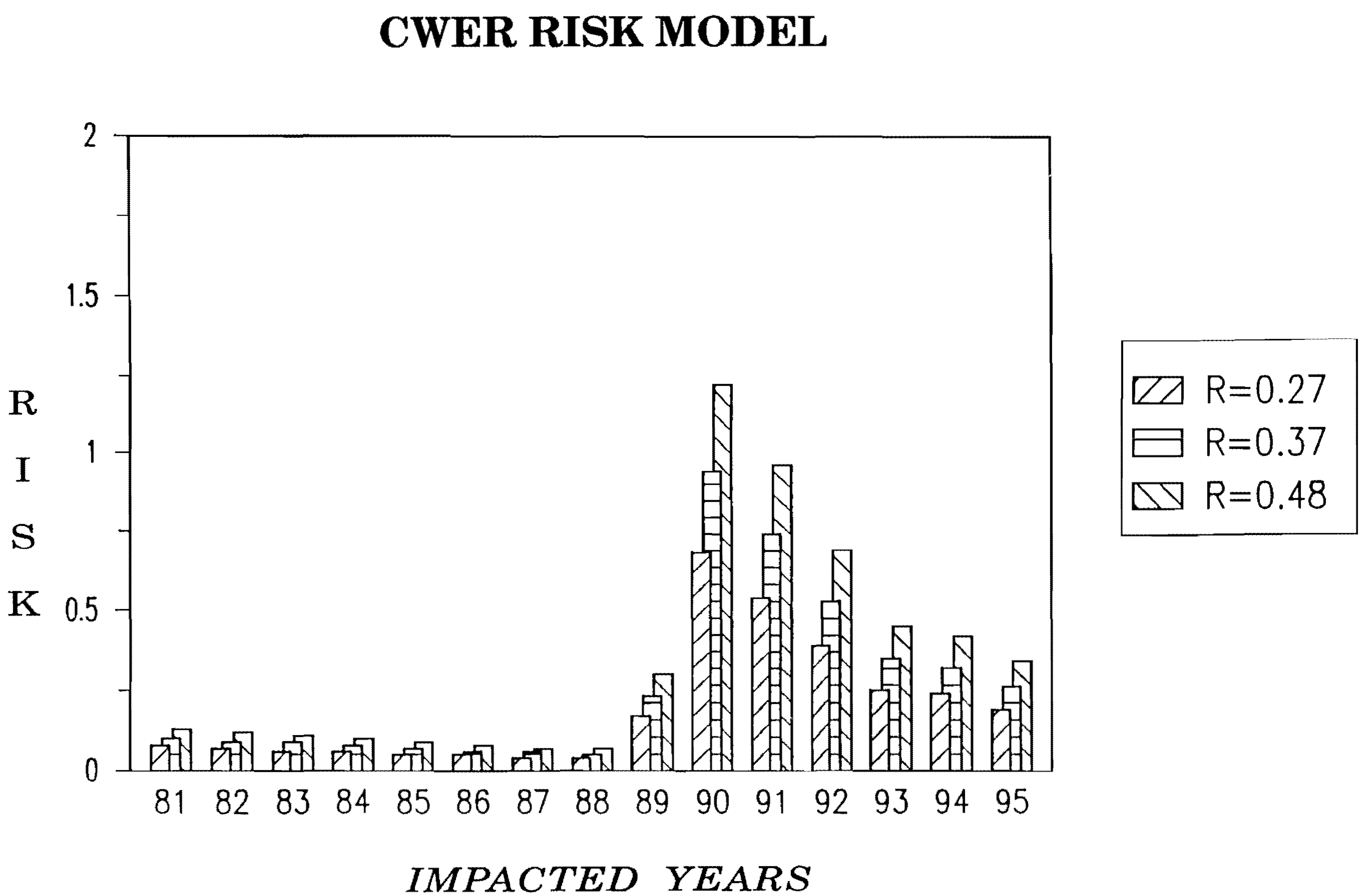

Fig. 4 The highest anticipated risk values for timber harvest occur in 1990—two years following initial harvest on federal land in the Mission Creek drainage. Road construction occurred in 1980—eight years before the beginning of timber harvest in winter of 1988. (Three precipitation/erosivity "R" values postulated). *(Continued)*

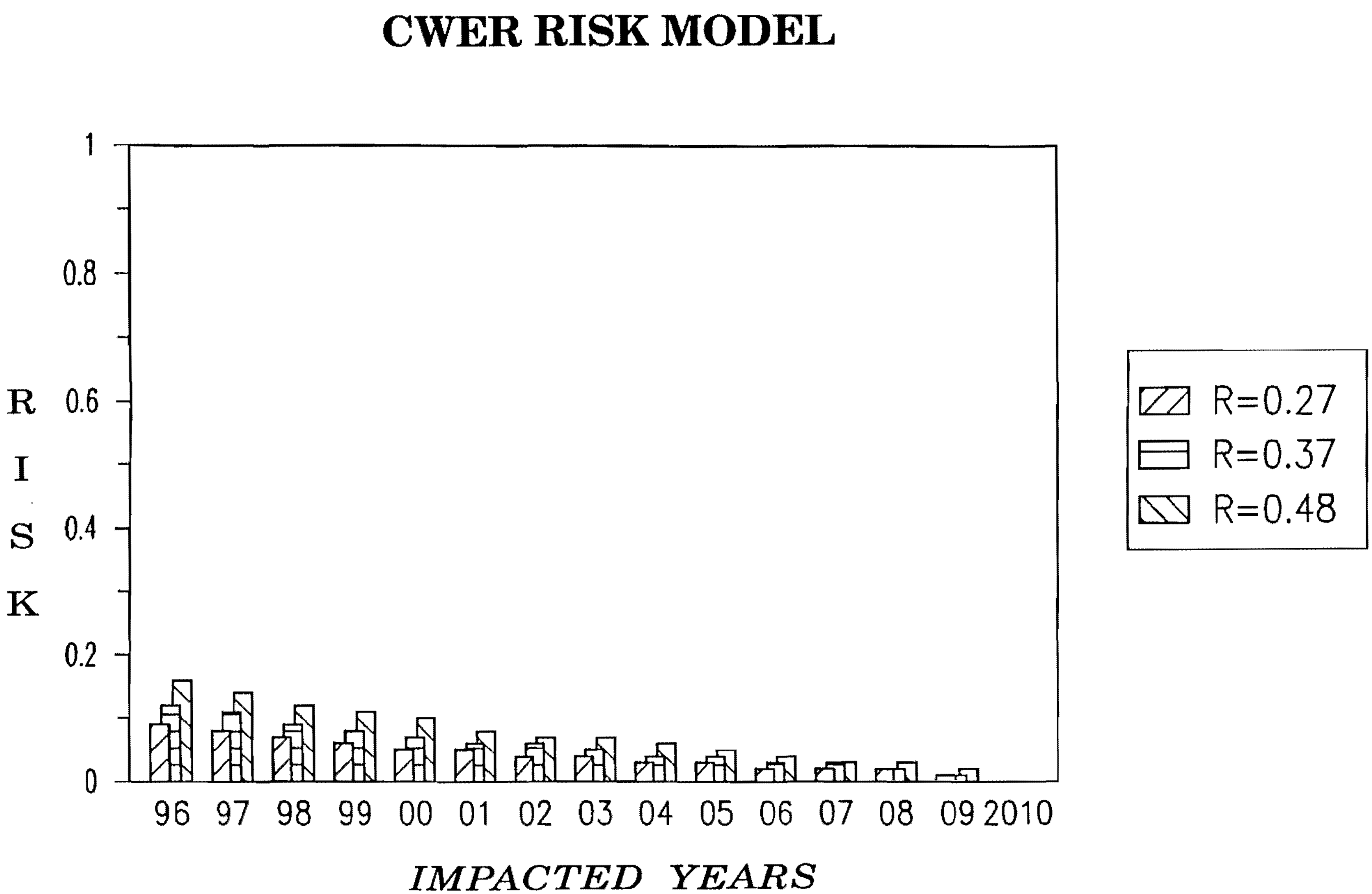

Fig. 4 Concluded

The following is a consolidation of silvicultural practices and yarding techniques:

Tractor (acres)			Cable (acres)		Helicopter (acres)		
CC	PC	SW	CC	SW	CC	PC	ST
362.7	216.9	268.1	307.4	59.0	4.8	127.2	38.7

This tabulation indicates that 1,385 ac were collectively yarded by tractor (61.2%), cable (26.5%), and helicopter (12.3%). Total acreages do not tally with cut vs. uncut ac. This is a result of re-entry into previously harvested areas.

CWER risk factors fluctuated dramatically during the 29- year evaluation period (Fig. 5). Harvest re-entry to previously logged areas caused a marked increase in the risk factor within one year, e.g., 1985 to 1986. High predicted risk was indicated, with quasi-hydrologic recovery of the Sand Creek watershed from logging disturbances requiring about 10 years (Fig. 5).

Conclusions and Discussion

The Klock model has disadvantages which should be recognized if downstream effects from logging are to be rationally judged by this method. The methodology is extremely data-intensive, and the data is not always available, as illustrated in the case of Sand Creek. The model accommodates only annual precipitation, with no provision for high-intensity convective storms characteristic of the lower elevation rainshadow of the Eastern Cascades. The three R values used in the two Mission Creek CWERs were an attempt to correct for this weakness; adjustments not needed for the two higher elevation, wet-forest analyses. Similarly, wildfire, a potential variable in the dry forest of Mission Creek, had to be accounted for.

The C factor--the normalizing coefficient--of the Klock model assumes a 12% disturbance of the sale area. My experience suggests 18-20% is a more realistic and, perhaps, conservative estimate for the east side of the Cascade Mountains.

The most serious criticism of the Klock model is that it has not been rigorously validated. Predicted and measured sediment delivery in one of five study streams examined by Fowler et al. (1988) increased with road construction, but declined to nearly background levels within two years (Fig. 6). This and the findings of Megahan and Kidd (1972) in Idaho, support the general conclusion of this report that risk from logging roads is relatively short-lived.

CWER RISK MODEL

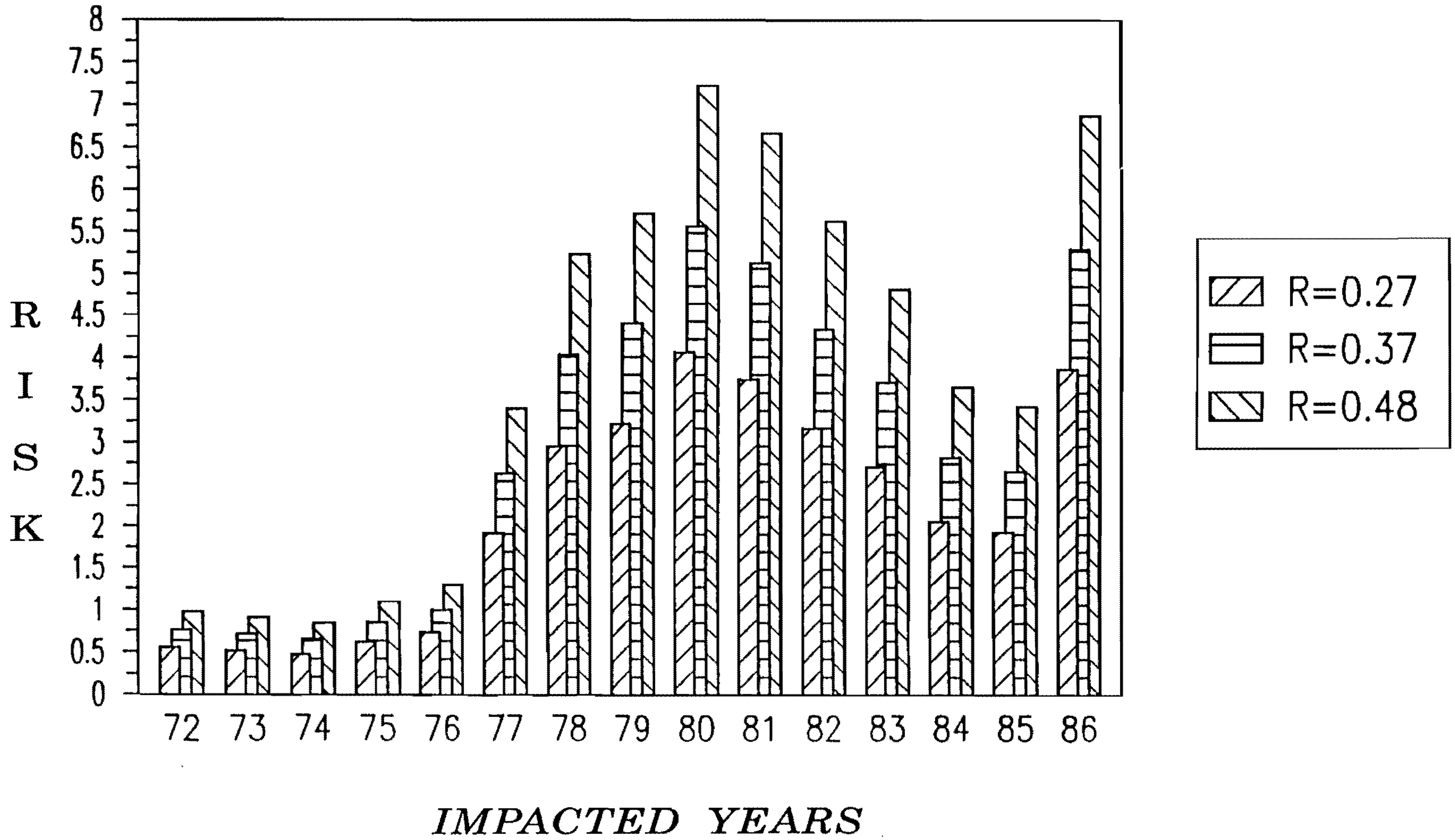

Fig. 5 Harvest re-entry to previously logged areas caused a marked increase in the risk factor within one year, e.g., 1985 to 1986, on private lands in the Mission Creek drainage. High or worst case risk was predicted, with quasi-hydrologic recovery of the watershed from logging disturbances requiring about 10 years. *(Continued)*

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CWER RISK MODEL

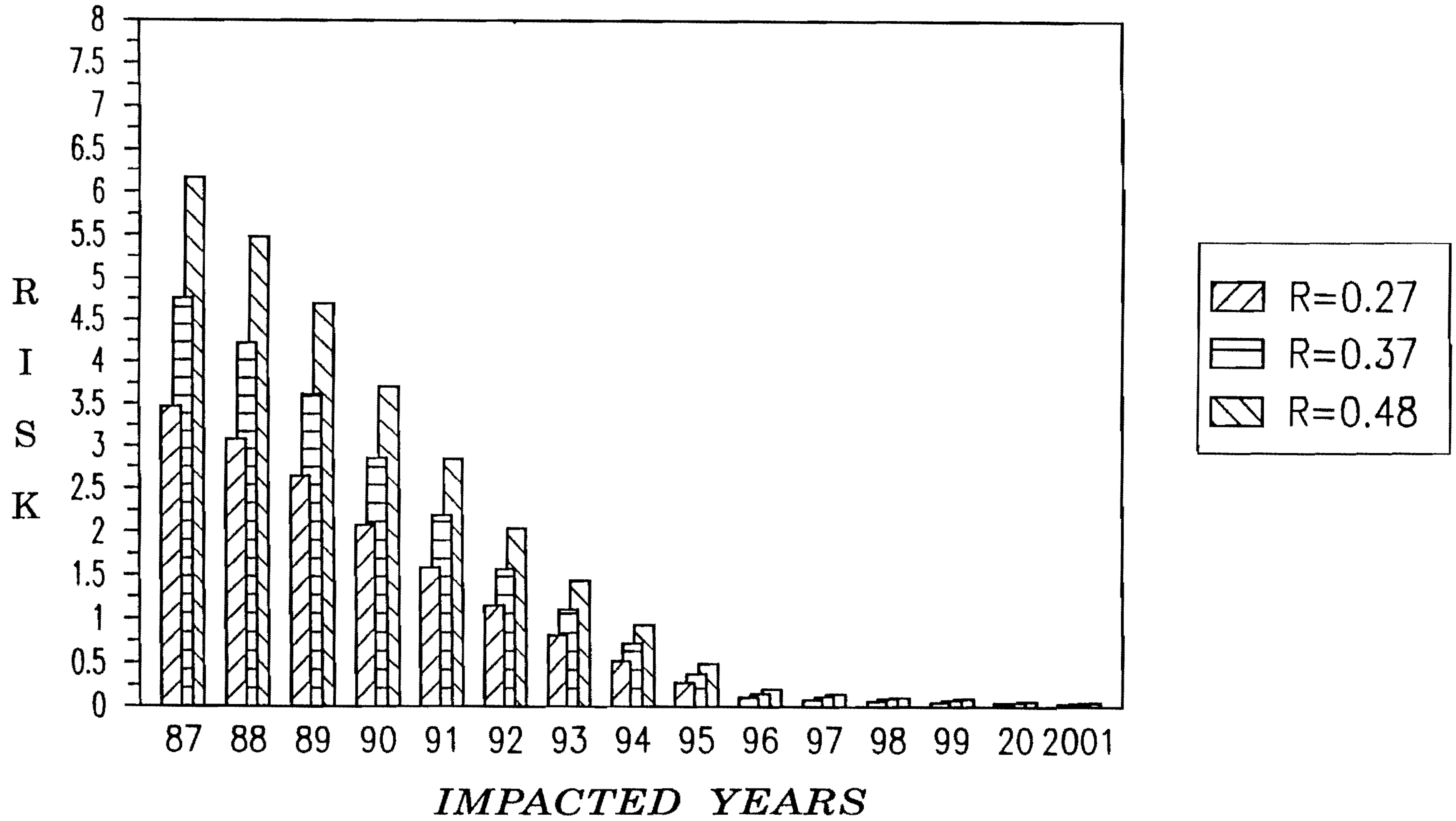

Fig. 5 Concluded

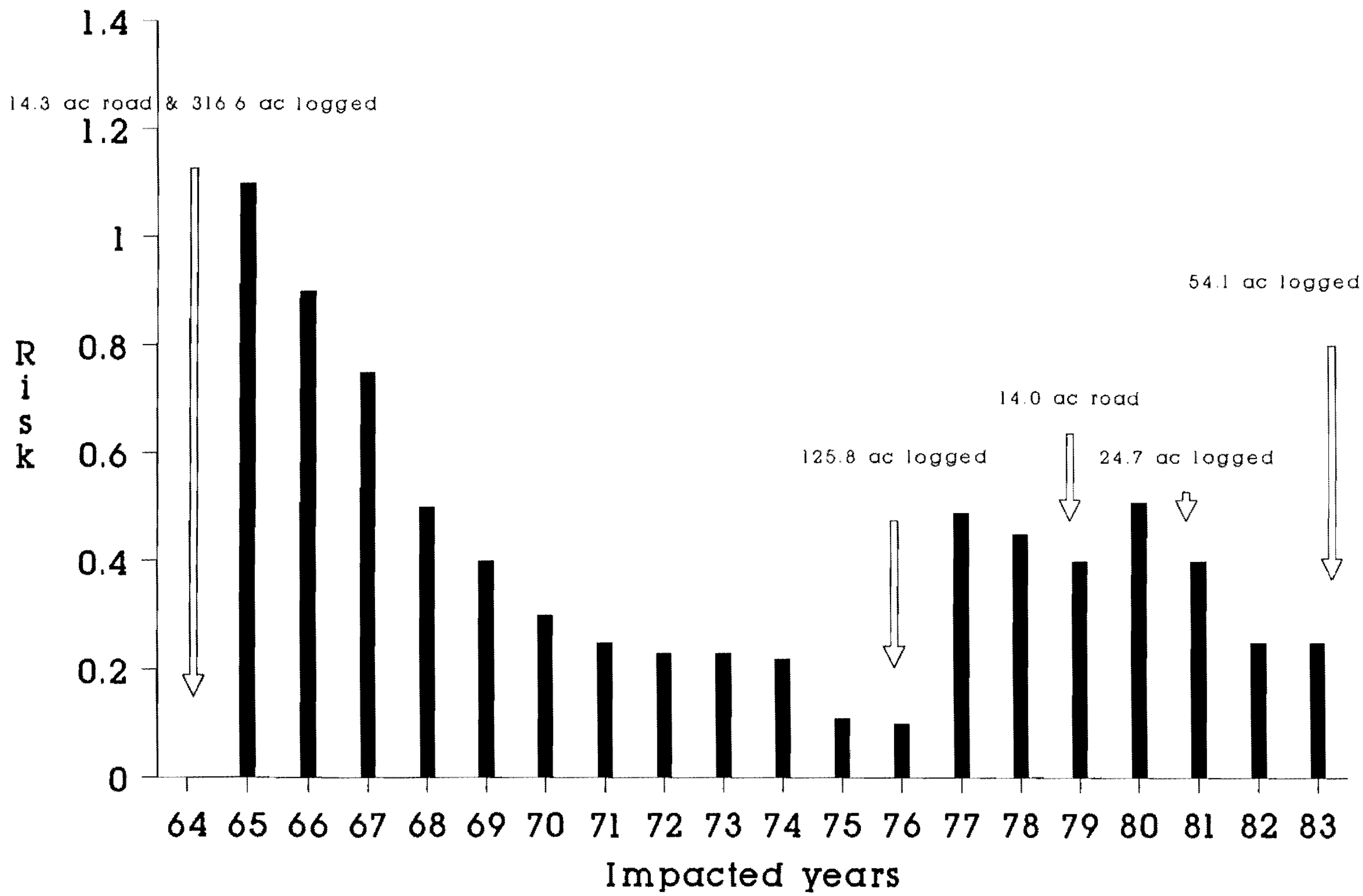

Fig. 6. Predicted (CWE risk shown above) and measured sediment delivery in one of 5 study streams examined by Fowler et al (1988), 1978-83, increased with road construction, but declined to nearly background levels within two years.

The methodology also has advantages. Of the seven model variables, only two require professional judgment--the potential slope-stability failure frequency and the time period for a disturbed area within a watershed to become hydrologically mature (revegetated). Guides are provided to assist in making these judgments (Klock 1985).

Variables used in the Klock model are, at best, an average estimate of real conditions. However, they do allow comparison of trends and do indicate relative risk. Relative risk was higher and hydrologic recovery slower in the dry Mission Creek watershed compared to the wet, higher-elevation watersheds. This suggests the overriding importance of precipitation in hydrologic recovery.

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