Barker Creek Instream Flow Study – Final Report

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As part of a 10-year Comprehensive Plan Update process required by the Growth Management Act (RCW 36.70A) and associated with watershed management planning conducted in accordance with the Watershed Planning Act (RCW 90.82), Kitsap County Department of Community Development (DCD) seeks information on how different land use and water management options will affect the natural resources of Kitsap County. One of the resources of interest is the fish community of Barker Creek, which flows into the northern end of Dyes Inlet east of Silverdale. Specifically, Kitsap County recognized that additional growth could occur in the Barker Creek watershed, resulting in more impermeable surface, which could be expected to modify hydrology of Barker Creek. Kitsap County DCD Natural Resources Division staff asked how changed hydrology would affect fish in Barker Creek and requested the Washington Department of Fish and Wildlife (WDFW) Habitat Science Division's Water Team to conduct an instream flow study to evaluate how different flows would affect fish habitat. At the same time, Kitsap County contracted with Dr. Brian Skahill of the United States Army Corps of Engineers Vicksburg Laboratory to model how different land use management would affect Barker Creek hydrology.

This report is intended for the use of Kitsap County and the Silverdale Citizens Advisory Committee. In the opinion of the authors, this report complies with the criteria for "Best Available Science" contained in WAC 365-195-905.

Study Sites

Barker Creek (mouth is located at 47 38' 11.79" N, 122 40' 20.98"W) flows generally south from Island Lake (47 40' 54"N, 122 39' 33" W) with parallel tributaries, approximately 4 miles (6 km) to the northeast shore of Dyes Inlet (Figure 1). Land use in the watershed is suburban and rural-suburban, with some second-growth forest and pasture along riparian areas, but the Silverdale commercial area is immediately west of the watershed.

Based on salmon and steelhead distributions shown in WDFW's Salmonscape (http://wdfw.wa.gov/mapping/salmonscape/index.html) and Kitsap County staff knowledge of Barker Creek, we selected two sites for our study. Both sites are within the range of chum and coho salmon, as well as cutthroat trout and steelhead. Sites were selected as representative of Barker Creek habitats downstream of Bucklin Hill Road (salmon use is limited upstream of the Bucklin Hill Road/Waaga Way culvert).

The upper site was at the Latter Day Saints Church (47 38' 47" N, 122 39' 32"W) upstream from Nels Nelson Road and downstream from NW Bucklin Hill Road. The upper site had a low gradient, incised channel, and considerable fine sediment and woody debris. It flowed through a small alder-dominated floodplain. This site represents approximately 55% of the channel downstream of Bucklin Hill Road.

The lower site was upstream from NW Barker Creek Road (47 38' 25" N, 122 40' 06" W). The lower site had a higher gradient, incised channel, and coarser (bedrock, cobble, and gravel) substrate with a moderate amount of large woody debris. This site represents approximately 45% of the channel downstream of Bucklin Hill Road.

Figure 1: Barker Creek Watershed, Kitsap County, Washington
Source: Kitsap County Department of Community Development

Instream Flow Study Approach (Methods)
The goal of the study was to measure habitat at different flows, then use the relationships between habitat and flow to interpolate and extrapolate the amount of habitat at different flows. We used RHABSIM (Riverine Habitat Simulation Software, Thomas R. Payne and Associates, Arcata California) to generate weighted usable area (WUA), an index of habitat (physical microhabitat), at each flow of interest. RHABSIM, which is a user-friendly version of the US Geological Survey's Physical Habitat Simulation System (PHABSIM), uses field-measured depth, velocity, substrate, and cover recorded at 3 (or more) different flows or discharges to predict depth and velocity distribution at different flows, then calculates WUA as a function of the values of the different combinations of depth, velocity, substrate, and cover.

The study process starts with site selection and transect selection, followed by surveying and measurement of hydraulic conditions at several different flows, then constructing and calibration of an hydraulic model, which is merged with habitat suitability criteria to generate WUA at different flows. The relationship of WUA to flow for each species and life stage can be used determine potential effects of changing flow.

Study site selection was discussed above. Study sites were chosen to represent major sections of Barker Creek that are used by salmon and steelhead and cutthroat trout.

Transects or cross-sections were selected to cross hydraulic controls (downstream lip of a pool, the point where the upstream water surface will be at the instant that flow stops), riffles (which may be hydraulic controls), pools, runs, and transition areas. Transects should cross all significant mesohabitat types. Transects were marked with stakes and flags.

Surveys are tied to an arbitrary benchmark elevation (assigned as 100.00 ft). Using stadia rod and level, we surveyed elevations at stakes ("headpins" or "headstakes") at the ends of each transect, selected dry points along each transect that define the channel cross-section shape, and the water surface elevation at each transect at each measured flow. (Bed elevations within the wetted part of the cross-section are determined by subtracting depth from water surface elevation.) Dry elevations are surveyed once. Water surface elevations are surveyed at each flow, resulting in 3 calculations of bed elevation. Distances between transects are also measured.

Hydraulic measurements are made at fixed points along each transect. A measuring tape is stretched across each transect so that the ends are at the same reading at the stakes at each flow measured. Then depth and velocity are measured at the same point on the tape at each measured flow. Substrate and cover are classified and recorded at each depth-velocity measurement point, as well as at dry points along the transect. We try to measure at least 20 points in the water at the lowest flow, so more points are measured at the high flows. It is best to measure a higher flow, a medium flow, then a low flow at the end, to minimize the potential for confounding, flood-caused channel changes during instream-flow studies.

The goal of hydraulic modeling is to simulate what depths and velocities occur in what locations relative to substrate (e.g., sand, cobble, or bedrock) and cover at each flow (discharge) of interest. The first step is to enter bed elevations as coordinates for each measurement/survey point along each transect and enter the water surface elevation at each measured flow at each transect, along with a stage of zero flow (SZF) elevation. Then water surface elevation and flow are related in a stage-discharge log-log regression (a statistical technique for fitting a line through a number of points). This should produce a stage-discharge relationship for each transect, so that putting them side-by-side the water surfaces at sequential transects always flow downhill and are reasonably close to what was measured.

The second step of hydraulic modeling is to calibrate velocities so that they are reasonably close to the measured velocities at simulations of measured flows. Extrapolated velocities should be reasonable. One of the quality control indicators, the velocity adjustment factor (VAF), compares two ways of calculating flow at a transect; good models have VAFs that are reasonably close to 1.0. WDFW prefers to use a log-log regression of stage and velocity at each point. The degree to which the hydraulic model can be extrapolated to higher or lower flows can be determined by VAFs and the reasonableness of individual velocities. In order to extend the flow range of our assessment at the upper site, we exceeded the VAF range of 0.8-1.2 at some upper site transects at higher flows (7-10 cfs); review of hydraulic output leads us to believe that this approach did not drastically impair model performance.

WDFW and Ecology maintain a set of fish habitat suitability criteria for use in PHABSIM or RHABSIM (see appendices in http://www.ecy.wa.gov/pubs/0411007.pdf). Habitat suitability criteria range from 0.0 to 1.0. At each cell at each simulated flow, the habitat suitability criteria are compared to simulated depths, velocities, substrate, and/or cover to weight the value of the segment of habitat. This process is repeated at each simulation point at each flow for each species and life stage of interest. The habitat suitability criteria act as weighting factors for the depth, velocity, and substrate/cover at each point. At each point at each flow, weighting factors for depth, velocity, and substrate/cover are multiplied together to yield a point weighting factor which will range from 0.0 to 1.0. For each flow, all the weighting factors (multiplied by the areas of the stream to which they apply) are summed to yield WUA.

Modeling habitat through time with hydrology driven by different land use options

We used a spreadsheet developed by Dr. Brian Skahill (U.S. Army Corps of Engineers, Vicksburg Laboratory) that generated daily streamflows at different points in the Barker Creek watershed from 1 October 1995 through 1 October 2003 (2923 daily mean flows for each site for each land use scenario) based on measured flows and modeled hydrology as a function of impermeable surfaces based on projected land use. We used whole months, so we did not use the flows for 1 October 2003. Under each land use scenario a flow was generated at each of our two study sites. We compared the habitat indices (WUA) that correspond to the flows at each site for each land use scenario.

Scenarios modeled by Dr. Skahill include: Current, Historic, Plan Trend (PT), Alternative 2 (ALT2), Alternative 3 (ALT3) and Mitigation (MIT). The Historic scenario represents the presumed historical conditions in the watershed. The Plan Trend scenario presumes the watershed is built out under current zoning regulations. Alternative 2 presumes the watershed is built out with a moderate degree of development, with the Urban Growth Area (UGA) boundary being retracted in the vicinity of the intersection of Waaga Way and Nels Nelson Road (Figure 2). Alternative 3 presumes the watershed is built out under a more expansive growth scenario, with the UGA expanding to include Hoot Creek (the tributary to the east of the mainstem). The Mitigation scenario represents the flows generated by Alternative 2 augmented by 2 cfs of streamflow when the flow at the upper site falls below 30 cfs.

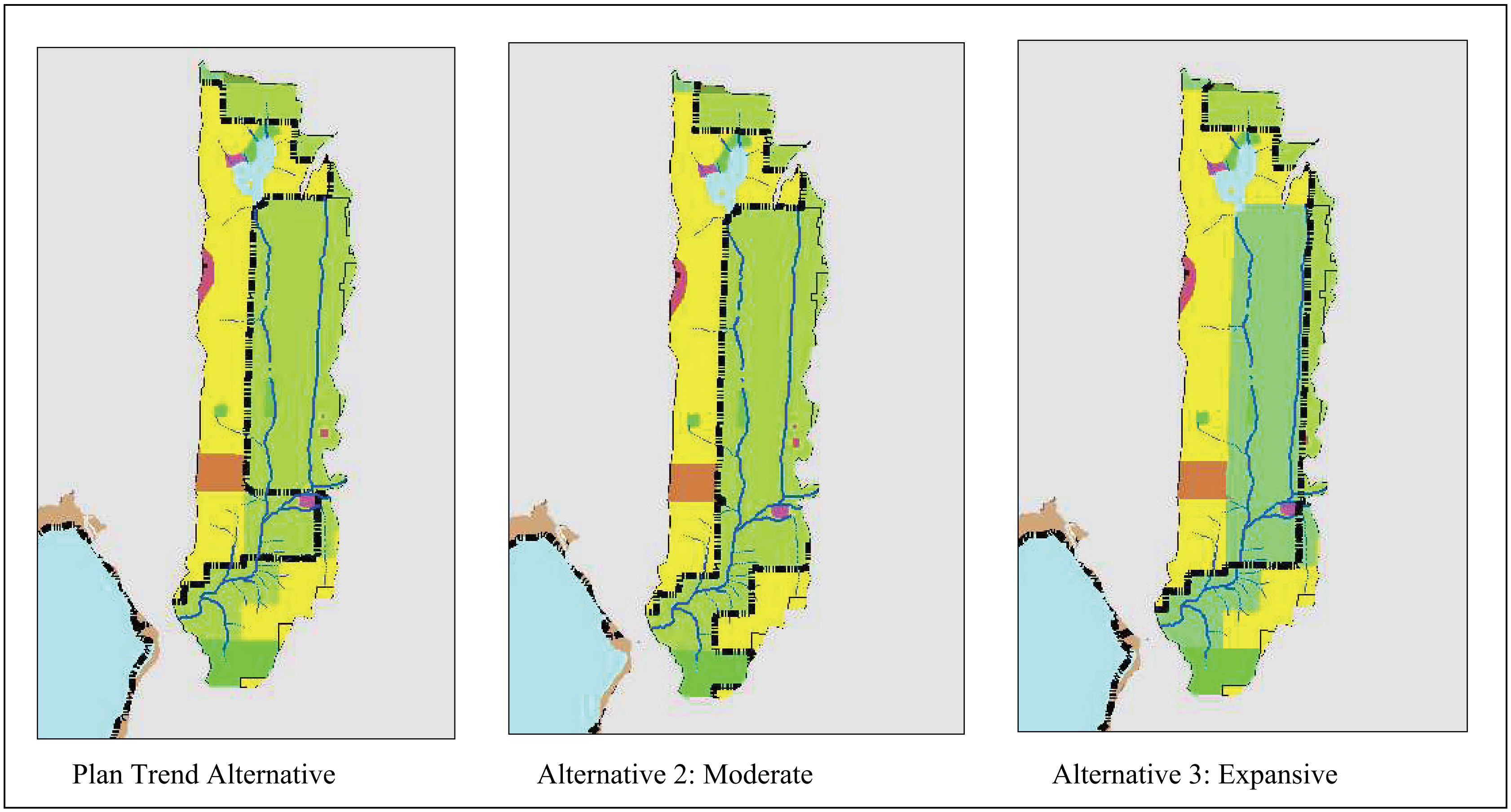


Figure 2: Alternative Land Use Scenarios' Urban Growth Area Boundaries
Source: Kitsap County Department of Community Development

Under each land use scenario, we tabulated flows equal to or greater than 50 cfs as an index of flood scour at reach 3, the lower PHABSIM study site. This serves as an index of scour, not necessarily a true threshold for scouring. Although flood scour will occur on microhabitat and mesohabitat scales over a continuum of flows, the 50 cfs threshold is subjectively expected to cause some redd scour; this is roughly 10 times the highest flow we measured. Flood scour is a significant source of mortality for salmonids, particularly fall spawners.

Some (<20%) of the flows modeled by Dr. Skahill are outside the range of flows that could be modeled reliably with the instream flow study (Table 1). At the lower site a few flows were extremely low, below the lowest level the RHABSIM model could simulate while still meeting hydraulic modeling quality control criteria. In all such cases reducing the flow below the model limits would lead to less WUA because the trend was toward decreasing WUA with decreasing flow and habitat suitability criteria for all life stages and species modeled would approach zero as flow approaches zero. The same cannot be stated across the board for flows above the limits of the RHABSIM model. Although trends were generally increasing, those trends might change as velocities exceed fish preferences at higher flows. In some months WUAs, means, and medians were based on only some of the dates (i.e., those dates when flows were within the range of the RHABSIM models).

Table 1. Proportion of projected flows under different land use scenarios that are within and outside the range of flows for the instream flow models.

		Upper site			Lower site		
		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
Current	Oct	0	0.976	0.024	0	0.976	0.024
	Nov	0	0.883	0.117	0	0.887	0.112
	Dec	0	0.734	0.266	0	0.770	0.230
	Jan	0	0.560	0.440	0	0.613	0.387
	Feb	0	0.730	0.270	0	0.780	0.220
	Mar	0	0.738	0.262	0	0.786	0.214
	Apr	0	0.925	0.075	0	0.954	0.046
	May	0	0.996	0.004	0	0.996	0.004
	Jun	0	0.992	0.008	0	0.996	0.004
	Jul	0	0.996	0.004	0	1.000	0
	Aug	0	0.992	0.008	0	0.996	0.004
	Sep	0	1.000	0	0	1.000	0
	All	0	0.877	0.123	0	0.896	0.104
		Upper site			Lower site		

		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
Historic	Oct	0	0.996	0.004	0.544	0.452	0.004
	Nov	0	0.967	0.033	0.273	0.697	0.029
	Dec	0	0.782	0.218	0	0.823	0.177
	Jan	0	0.468	0.532	0	0.532	0.468
	Feb	0	0.611	0.389	0	0.668	0.332
	Mar	0	0.593	0.407	0	0.730	0.270
	Apr	0	0.908	0.092	0	0.962	0.037
	May	0	1.000	0	0	1.000	0
	Jun	0	1.000	0	0	1.000	0
	Jul	0	1.000	0	0	1.000	0
	Aug	0	1.000	0	0	1.000	0
	Sep	0	1.000	0	0.079	0.921	0
	All	0	0.861	0.139	0.075	0.816	0.109
		Upper site			Lower site		
		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
PT	Oct	0	0.972	0.028	0.282	0.694	0.024
	Nov	0	0.879	0.121	0.083	0.800	0.117
	Dec	0	0.665	0.335	0	0.718	0.282
	Jan	0	0.427	0.573	0	0.496	0.504
	Feb	0	0.588	0.412	0	0.668	0.332
	Mar	0	0.617	0.383	0	0.690	0.310
	Apr	0	0.883	0.117	0	0.925	0.075
	May	0	0.992	0.008	0	0.996	0.004
	Jun	0	0.987	0.012	0	0.996	0.004
	Jul	0	0.996	0.004	0	0.996	0.004
	Aug	0	0.996	0.004	0	0.996	0.004
	Sep	0	1.000	0	0.066	0.934	0
	All	0	0.834	0.166	0.036	0.826	0.138
		Upper site			Lower site		

		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
ALT2	Oct	0	0.940	0.060	0.024	0.919	0.056
	Nov	0	0.783	0.217	0.021	0.772	0.207
	Dec	0	0.544	0.456	0	0.581	0.419
	Jan	0	0.391	0.609	0	0.419	0.581
	Feb	0	0.618	0.382	0	0.677	0.323
	Mar	0	0.613	0.387	0	0.681	0.319
	Apr	0	0.904	0.096	0	0.921	0.079
	May	0	0.988	0.012	0	0.996	0.004
	Jun	0	0.979	0.021	0	0.983	0.017
	Jul	0	0.996	0.004	0	0.996	0.004
	Aug	0	0.992	0.008	0	0.992	0.008
	Sep	0	1.000	0	0.012	0.987	0
	All	0	0.813	0.187	0.005	0.827	0.168
		Upper site			Lower site		
		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
ALT3	Oct	0	0.935	0.065	0.024	0.915	0.060
	Nov	0	0.776	0.224	0.021	0.775	0.204
	Dec	0	0.536	0.464	0	0.581	0.419
	Jan	0	0.399	0.601	0	0.452	0.548
	Feb	0	0.611	0.389	0	0.698	0.302
	Mar	0	0.625	0.375	0	0.690	0.310
	Apr	0	0.904	0.096	0	0.921	0.079
	May	0	0.984	0.016	0	0.992	0.008
	Jun	0	0.979	0.021	0	0.979	0.021
	Jul	0	0.996	0.004	0	0.996	0.004
	Aug	0	0.988	0.012	0	0.992	0.008
	Sep	0	1.000	0	0.012	0.987	0
	All	0	0.811	0.189	0.005	0.832	0.164
		Upper site			Lower site		

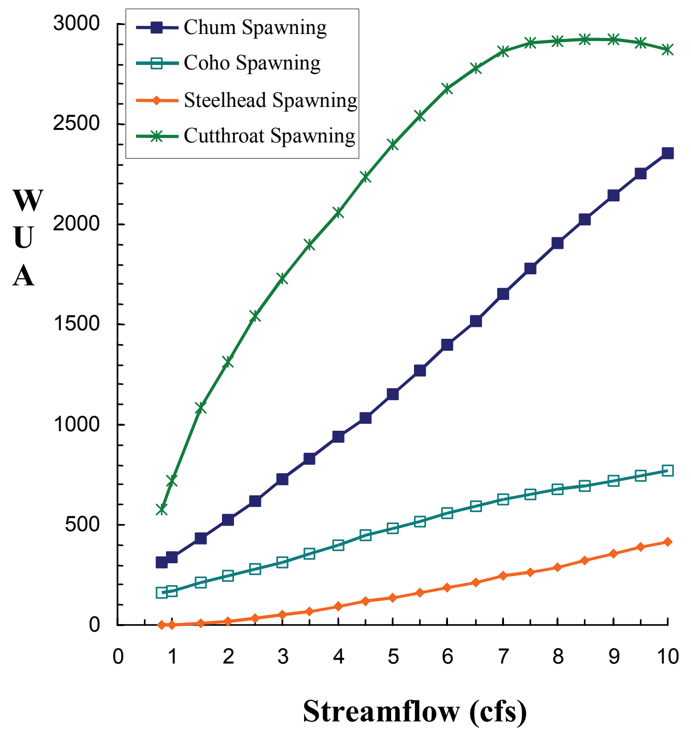
		Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit	Below RHABSIM limit	Within RHABSIM range	Above RHABSIM limit
MIT	Oct	0	0.911	0.089	0	0.931	0.066
	Nov	0	0.700	0.300	0	0.767	0.233
	Dec	0	0.440	0.560	0	0.516	0.484
	Jan	0	0.270	0.730	0	0.448	0.552
	Feb	0	0.412	0.588	0	0.556	0.442
	Mar	0	0.516	0.484	0	0.585	0.415
	Apr	0	0.787	0.212	0	0.875	0.125
	May	0	0.968	0.032	0	0.984	0.016
	Jun	0	0.971	0.029	0	0.975	0.025
	Jul	0	0.996	0.004	0	0.996	0.004
	Aug	0	0.988	0.012	0	0.988	0.012
	Sep	0	0.992	0.008	0	1.000	0
	All	0	0.747	0.253	0	0.803	0.197

Results

We modeled WUA for the following species and life stages:
- Fall chum salmon – spawning
- Coho salmon – spawning and rearing (including winter)
- Steelhead – spawning and rearing
- Coastal cutthroat trout – spawning and rearing
- Rainbow trout – winter rearing, to represent steelhead and cutthroat habitat use during winter. Results are shown in Figures 3-4 and Table 1.

At both sites, WUA increases with flow over the range of flows modeled, except that cutthroat trout spawning habitat shows a maximum WUA and subsequent decline in WUA at higher flows. Hence, flow appears to be a year-round limiting factor for larger-bodied salmonids in Barker Creek. But it is not realistic to assume that the relationship continues at higher flows much beyond the flows modeled (approximately 20% of flows were out of range for modeling WUA).

Barker Creek, Kitsap County, lower site: Habitat (in Weighted Usable Area*) vs Flow (in c second) - -

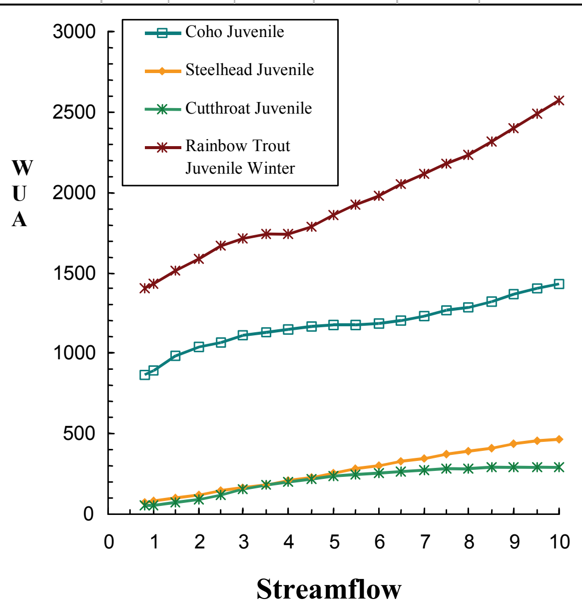


Flow (cfs)	Chum Spawning	Coho Spawning	Steelhead Spawning	Cutthroat Spawning
0.8	315	159	1	572
1	336	172	2	717
1.5	428	210	9	1081
2	522	247	19	1316
2.5	619	280	32	1545
3	727	315	49	1728
3.5	834	357	68	1895
4	938	402	90	2056
4.5	1037	446	115	2235
5	1148	483	140	2399
5.5	1273	521	163	2542
6	1394	559	189	2680
6.5	1518	594	216	2783
7	1651	626	243	2861
7.5	1781	653	265	2904
8	1907	675	288	2919
8.5	2025	696	320	2923
9	2145	719	353	**2925**
9.5	2257	744	387	2905
10	**2354**	**771**	**416**	2876

*Weighted Usable Area or WUA denotes square feet of habitat per 1,000 linear feet of stream

Figure 3a. WUA vs. flow (cfs) at lower Barker Creek study site for spawning salmonids.

Barker Creek, Kitsap County, lower site: Habitat (in weighted usable area*) vs Flow (in second) - -

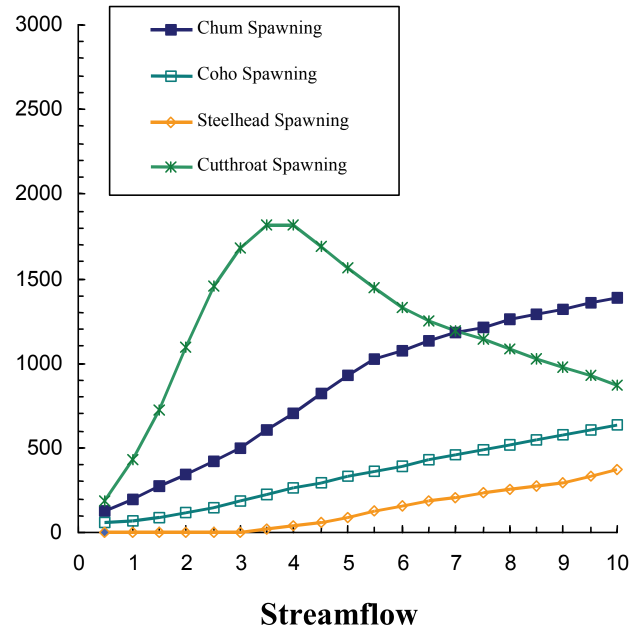


Flow (cfs)	Coho Juvenile	Steelhead Juvenile	Cutthroat Juvenile	Rainbow Trout Juvenile
0.8	867	76	51	1401
1	898	82	56	1433
1.5	981	102	72	1513
2	1036	123	95	1591
2.5	1069	144	123	1668
3	1111	165	154	1715
3.5	1133	187	180	1746
4	1145	208	201	1738
4.5	1168	231	221	1790
5	1177	256	238	1861
5.5	1175	279	250	1920
6	1184	302	260	1980
6.5	1208	325	267	2047
7	1235	348	274	2114
7.5	1263	370	280	2180
8	1287	392	285	2233
8.5	1324	413	288	2315
9	1364	434	290	2402
9.5	1401	452	293	2488
10	**1434**	**468**	**296**	**2571**

*Weighted Usable Area or WUA denotes square feet of habitat per 1,000 linear feet of stream

Figure 3b. WUA vs. flow (cfs) at lower Barker Creek study site for rearing salmonids.

Barker Creek, Kitsap County, upper site: Habitat (in Weighted Usable Area*) vs Feet per second) - -

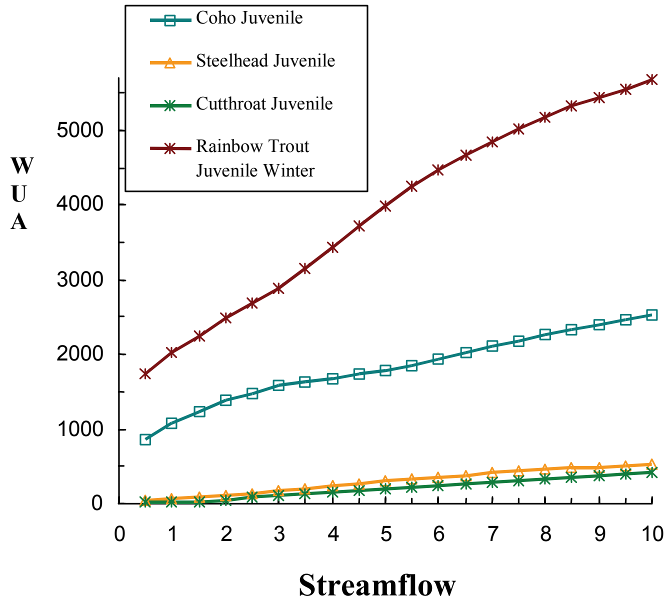


Flow (cfs)	Chum Spawning	Coho Spawning	Steelhead Spawning	Cutthroat Spawning
0.5	128	57	0	183
1	199	68	0	429
1.5	270	89	0	724
2	344	116	0	1092
2.5	418	151	0	1456
3	501	190	4	1681
3.5	601	227	15	**1814**
4	706	262	36	1813
4.5	824	296	61	1686
5	932	330	92	1564
5.5	1023	359	124	1446
6	1075	394	156	1327
6.5	1131	428	182	1247
7	1181	459	206	1193
7.5	1214	490	232	1145
8	1263	518	251	1085
8.5	1289	546	270	1029
9	1322	576	294	976
9.5	1354	605	328	926
10	**1386**	**634**	**368**	874

*Weighted Usable Area or WUA denotes square feet of habitat per 1,000 linear feet of stream

Figure 4a. WUA for spawning vs. flow (cfs) at upper study site.

Barker Creek, Kitsap County, upper site: Habitat (in Weighted Usable Area*) vs Feet per second) - -



Flow (cfs)	Coho Juvenile	Steelhead Juvenile	Cutthroat Juvenile	Rainbow Trout Juvenile Winter
0.5	859	48	14	1746
1	1071	66	19	2036
1.5	1238	86	31	2252
2	1382	109	54	2488
2.5	1481	139	84	2681
3	1576	173	108	2887
3.5	1631	208	134	3152
4	1683	242	159	3437
4.5	1737	275	183	3709
5	1777	307	204	3985
5.5	1851	335	219	4240
6	1932	360	238	4459
6.5	2020	384	260	4659
7	2104	409	287	4839
7.5	2187	433	314	5020
8	2266	455	338	5177
8.5	2334	477	360	5317
9	2402	495	379	5435
9.5	2471	514	395	5556
10	**2538**	**533**	**410**	**5683**

*Weighted Usable Area or WUA denotes square feet of habitat per 1,000 linear feet of stream

Figure 4b. WUA for rearing vs. flow (cfs) at upper study site.

Although the habitat increases with increasing flow may continue somewhat beyond modeled flows, velocities in much of the channel will exceed favorable velocities at even higher flows, so the amount of suitable habitat probably declines at those flows. Additional measurement and modeling would be necessary to address those higher flows and determine at what flows the flow-habitat relationships change. Additional discussion of high flows is presented below.

Not all species and life history stages are present year-round. In Barker Creek, we have assigned the timing in Table 2, based partly on Williams et al. (1975), WDFW and WWTIT (1994), and Blakely et al. (2000). Winter habitat selection by juvenile steelhead and cutthroat trout is best represented by rainbow trout winter habitat because we have not developed winter habitat preference criteria specific to these species. Although some spawning may occur outside the times listed in Table 2, the months in the table can be expected to account for over 90% of the individuals' behavior.

Table 2. Timing of life history stages of Barker Creek salmonids. [1]As discussed in text, winter rearing habitat for juvenile cutthroat and steelhead are better simulated using rainbow trout winter rearing criteria.

Species	Life stage	Months
Fall chum salmon	Spawning	November-December
Fall chum salmon	Incubation	November-April
Coho salmon	Spawning	November-January
Coho salmon	Incubation	November-April
Coho salmon	Juvenile rearing	Year-round
Coastal cutthroat trout	Spawning	January-March
Coastal cutthroat trout	Incubation	January-April
Coastal cutthroat trout	Juvenile rearing	Year-round (April-October)[1]
Steelhead	Spawning	February-April
Steelhead	Incubation	February-July
Steelhead	Juvenile rearing	Year-round (April-October)[1]
Rainbow trout (represents steelhead and cutthroat during winter months)	Winter rearing	November-March[1]

Very high flows can change the channel. In doing so, some eggs buried in gravel are likely to be scoured if these floods occur during incubation, which is when they are most likely to occur. If the channel is significantly modified by high flows, then the habitat-flow relationships shown in Figures 3-4 would change, but the direction of change cannot be predicted. Nevertheless, floods often cause channels to widen and shallow, especially after logging impacts (Vadas 1997), which may require higher flows (than for present WUA-flow curves) to maximize fish habitat.

Rapid decline in flows can leave fish stranded. If flow decline becomes more pronounced during spring incubation, eggs can be dewatered, making emergence of fry difficult and potentially leading to mortality.

Comparison of land use scenario effects on salmonid species

Chum salmon
We modeled chum salmon spawning habitat (WUA) in November and December (Table 3). The MIT option had the highest chum salmon spawning habitat consistently, followed by ALT3, ALT2, current, PT, and historic. WUA over time (within spawning months) ranged from 56% of maximum for historic to 83% of maximum for ALT3, while MIT was nearly 100%. A similar picture emerges if median WUA is considered: MIT is highest, followed by ALT2, ALT3, current, PT, and historic.

Table 3. Chum salmon spawning mean WUA averaged over both study sites (55% weighting on upper site and 45% weighting on lower site). Mean WUA is calculated for those dates for which projected flows are within the RHABSIM modeling limits.

Mean WUA	current	Historic	PT	ALT2	ALT3	MIT
Nov '95	1,013.45	555.11	855.14	1,116.35	1,131.40	1,316.98
Dec '95	1,489.45	1,510.15	1,616.64	1,658.96	1,634.17	1,810.90
Nov '96	560.17	274.16	475.88	570.71	580.16	964.83
Dec '96	1,159.50	704.86	1,076.55	1,350.47	1,359.63	1,584.81
Nov '97	1,198.63	948.51	1,162.06	1,393.00	1,388.87	1,646.71
Dec '97	1,065.13	1,097.37	1,100.90	1,180.70	1,167.31	1,514.48
Nov '98	837.21	357.93	765.52	973.22	980.10	1,145.45
Dec '98	1,389.84	1,183.40	1,295.35	1,563.62	1,561.09	1,776.63
Nov '99	826.43	322.23	637.53	778.17	801.63	1,165.17
Dec '99	1,180.52	888.22	1,116.11	1,315.56	1,313.87	1,578.37
Nov '00	618.92	290.83	499.85	530.37	517.03	830.74
Dec '00	982.01	509.83	758.55	1,121.35	1,136.88	1,462.70
Nov '01	979.08	978.35	793.58	955.63	967.09	1,216.54
Dec '01	1,633.72	1,758.50	1,719.89	1,758.54	1,741.45	1,135.13
Nov '02	613.18	239.94	486.50	705.14	721.64	1,003.69
Dec '02	1,070.35	859.75	1,066.80	879.09	852.21	1,125.07

In addition to the influence of flow on spawning habitat, incubation is also influenced by flow. Once eggs are deposited in the gravel redd (nest) they remain in place, subject to whatever conditions occur at that immediate location. One of the significant controlling factors for egg survival to hatching is flood scour. Flood scour can remove the eggs and cause high mortality. The flood index as it affects chum salmon egg incubation is listed in Table 4. The flood scour index is worst under ALT3, followed by MIT, ALT2, PT, with the least flood scour index under current and historic. Flood scour is probably most detrimental to chum salmon eggs in January, when all eggs are in the gravel (spawning is complete) and before any fry have emerged. In January the same sequence occurs except that current has one more flood scour (hence, worse) than historic.

Table 4. Number of days during chum and coho salmon incubation months in which flow at the lower study site was equal to or greater than 50 cfs, as modeled by Dr. Skahill.

Month	current	historic	PT	ALT2	ALT3	MIT
Nov ‘95					1	1
Dec ‘95			1	3	3	3
Feb ‘96			1	1	1	1
Dec ’96			1	1	1	1
Jan ‘97				1	1	1
Mar ‘97	3	3	3	3	3	3
Oct ‘97				1	1	1
Dec ‘97				1	1	1
Jan ‘98				3	3	3
Dec ‘98				2	2	2
Jan ‘99				3	3	3
Feb ‘99	2	3	4	4	5	5
Dec ‘99				1	1	1
Feb ‘00				1	1	1
Nov ‘00				1	1	1
Nov ‘01			1	2	2	2
Dec ‘01	2	2	2	4	4	4
Jan ‘02	2	2	2	3	3	3
Mar ‘02				1	1	1
Dec ‘02					1	
Jan ‘03	1		2	3	5	4
Mar ‘03	3	3	4	4	4	4

Coho salmon

Coho salmon spawn from November through January. Coho spawning WUA generally increased over the course of each spawning season as flows increased above summer base flows. Over the course of the spawning season, MIT provided the greatest amount of spawning habitat (average 97% of maximum WUA in a given month), although there was some variation among months within seasons (Table 5). MIT was followed by ALT2 (81%), ALT3 (81%), current (79%), PT (74%), and historic (64%). Ranks of median WUA followed the same pattern: MIT provided the greatest amount of spawning WUA, followed by ALT2, ALT3, current, PT, and historic.

Table 5. Coho salmon spawning habitat (mean WUA) by month. Mean WUA is calculated for those dates for which projected flows are within the RHABSIM modeling limits.

Mean WUA	current	historic	PT	ALT2	ALT3	MIT
Nov ‘95	389.07	227.03	336.86	420.68	428.06	494.08
Dec ‘95	557.71	560.51	598.36	618.15	603.66	682.48
Jan ‘96	570.02	675.61	665.01	639.74	632.93	710.51
Nov ‘96	227.77	120.09	192.80	229.92	233.26	378.22
Dec ‘96	441.09	288.46	414.41	509.92	513.95	591.96
Jan ‘97	561.83	641.61	612.95	624.93	629.93	706.37
Nov ‘97	457.54	372.87	445.07	522.78	522.01	614.97
Dec ‘97	414.71	424.50	422.50	450.99	446.24	567.73
Jan ‘98	588.96	589.33	587.72	568.00	563.74	656.96
Nov ‘98	323.88	154.31	300.16	370.98	372.11	457.54
Dec ‘98	520.70	451.99	490.03	578.65	577.73	664.04
Jan ‘99	543.57	592.57	582.62	606.82	599.19	682.86
Nov ‘99	323.83	137.32	255.45	309.21	314.16	444.28
Dec ‘99	456.36	343.05	424.83	495.28	495.29	590.42
Jan ‘00	530.07	516.66	559.14	566.95	564.25	654.88
Nov ‘00	245.81	132.12	200.85	214.04	206.77	332.68
Dec ‘00	382.59	212.42	299.66	431.38	437.11	549.56
Jan ‘01	375.78	304.97	371.49	426.07	427.66	548.11
Nov ‘01	373.46	370.98	306.38	363.38	367.65	467.41
Dec ‘01	608.41	661.94	642.58	658.65	649.19	388.65
Jan ‘02	660.94	409.33	704.51	711.22	706.23	419.41
Nov ‘02	244.45	110.24	197.28	276.24	282.42	389.18
Dec ‘02	406.54	332.13	405.51	340.49	326.45	433.04
Jan ‘03	607.33	673.29	648.69	647.56	637.21	395.07

The incubation period for coho salmon matches that for chum salmon, so Table 4 applies to coho salmon as well as chum salmon. The flood scour index is worst under ALT3, followed by MIT, ALT2, PT, with the least flood scour index under current and historic.

Flood scour is probably most detrimental to coho salmon eggs in February, when all eggs are in the gravel (spawning is complete) and before any fry have emerged. In February the same sequence occurs except that MIT and ALT3 have the same highest flood scour index, followed by ALT2, PT, historic, and current.

Following emergence in spring, coho salmon fry or juveniles rear for a year (rarely more) before they migrate to the sea the following spring. In some western Washington streams, coho salmon rearing habitat has been found to be the limiting freshwater life stage and within the rearing phase summer low flow has been found to be limiting: dry summers led to low production of smolts (young fish migrating to sea). Juvenile coho salmon rearing mean WUA is summarized for different land use scenarios in Table 6. Whether the WUA is considered on the basis of an entire rearing year (April-March), spring-summer-fall (April-October), or the single month with the lowest WUA, the MIT land use scenario provides the greatest amount of WUA for rearing coho salmon. Relative positions of the other land use scenarios differ depending on whether April-March, April October, or dry month is used. When April-March is used, MIT is followed by ALT2 (92%), ALT3 (92%), current (91%), PT (91%), and historic (90%). When April-October is used, MIT is followed by current (63%), PT (62%), historic (61%), ALT2 (57%), and ALT3 (56%). When the month with the lowest WUA is used, MIT is followed by current (42%), ALT3 (33%), ALT2 (33%), PT (31%), and historic (29%). Clearly the lowest flow month is the most sensitive to land use alternatives. When median WUA is used, there are minor changes in the orders, but MIT is in all cases clearly greater than the other land use alternatives, which cluster together. WDFW has used low summer flow during rearing as an index to predict coho salmon run size in Puget Sound; higher summer low flows correspond to higher adult returns (Zillges 1977).

Table 6. Juvenile coho salmon mean WUA projected under different land use scenarios.

Mean WUA	current	historic	PT	ALT2	ALT3	MIT
Apr ’96-Mar ‘97	760.04	754.66	774.14	782.44	784.91	779.48
Apr ’96-Oct ‘96	127.40	126.55	130.08	119.89	119.10	201.81
Low month ‘96	66.97	56.20	57.45	56.08	56.00	155.64
Apr ’97-Mar ‘98	805.12	829.62	826.39	818.04	814.64	932.45
Apr ’97-Oct ‘97	179.15	181.90	182.78	170.36	169.74	244.36
Low month ‘97	98.07	64.26	78.66	85.66	86.56	178.76
Apr ’98-Mar ‘99	551.15	520.28	543.79	570.01	566.74	676.53

Apr ’98-Oct ‘98	102.58	105.67	100.90	89.74	87.85	170.92
Low month ‘98	45.39	35.06	33.84	34.33	34.31	123.08
Apr ’99-Mar ‘00	762.04	733.70	759.00	767.87	765.10	883.81
Apr ’99-Oct ‘99	145.14	145.61	138.21	122.80	121.62	205.96
Low month ‘99	66.79	43.49	44.82	47.16	47.16	142.46
Apr ’00-Mar ‘01	660.57	598.05	637.46	662.25	660.92	787.83
Apr ’00-Oct ‘00	108.62	102.35	107.37	99.36	98.18	185.90
Low month ‘00	48.36	36.22	35.96	37.87	37.89	132.00
Apr ’01-Mar ‘02	685.89	751.59	682.94	687.55	686.22	677.43
Apr ’01-Oct ‘01	85.30	60.92	75.63	80.06	79.95	167.92
Low month ‘01	61.00	33.56	43.00	57.09	58.33	159.92
Apr ’02-Mar ‘03	751.00	733.03	743.14	734.97	729.07	741.18
Apr ’02-Oct ‘02	128.15	130.81	124.31	108.06	106.79	194.55
Low month ‘02	48.08	33.74	35.96	36.05	36.06	126.70
Apr ’03-Mar ‘04						
Apr ’03-Oct ‘03						
Low month ‘03	41.61	30.84	30.40	30.74	30.61	84.72

Cutthroat trout

Coastal ("sea-run" – note that not all coastal cutthroat trout go to saltwater) cutthroat trout spawn in small streams and tributaries in January-March. The highest mean WUA for cutthroat spawning was with ALT3, followed by current (98%), ALT2 (98%), PT (96%), historic (95%), and MIT (95%) (Table 7).

Table 7. Cutthroat trout spawning habitat (mean WUA) by month.

Mean WUA	Current	historic	PT	ALT2	ALT3	MIT
Jan '96	1,939.84	1,844.65	1,847.46	1,874.16	1,882.37	1,785.45
Feb '96	1,915.58	1,834.74	1,831.25	1,830.74	1,839.68	1,814.51
Mar '96	2,004.24	1,910.67	1,939.32	1,980.98	1,983.18	1,892.65
Jan '97	1,955.02	1,872.52	1,902.47	1,897.65	1,882.78	1,785.38
Feb '97	1,972.01	1,896.47	1,936.77	1,948.62	1,954.95	1,854.86
Mar '97	1,857.19	1,789.18	1,795.94	1,829.33	1,812.46	1,271.13
Jan '98	1,920.41	1,924.20	1,925.69	1,956.41	1,959.11	1,845.18
Feb '98	1,930.57	1,821.49	1,854.17	1,873.35	1,879.36	1,789.99
Mar '98	1,990.00	1,895.79	1,937.89	1,974.89	1,979.10	1,874.19
Jan '99	1,958.25	1,926.57	1,937.87	1,914.22	1,922.85	1,813.12
Feb '99	1,255.51	No data	No data	No data	No data	No data
Mar '99	1,826.41	1,245.51	1,300.39	1,845.26	1,847.61	1,258.41
Jan '00	1,971.38	1,977.18	1,947.15	1,941.37	1,943.53	1,852.66
Feb '00	1,961.51	1,932.28	1,932.99	1,913.19	1,924.49	1,846.58
Mar '00	1,968.77	1,922.56	1,948.96	1,959.65	1,962.86	1,867.11
Jan '01	1,954.53	1,883.28	1,961.70	2,009.43	2,009.49	1,950.52
Feb '01	1,896.23	1,948.47	1,950.26	1,965.05	1,961.96	1,961.88
Mar '01	1,781.29	1,790.33	1,788.58	1,821.82	1,813.58	1,982.80
Jan '02	1,847.43	1,250.33	1,796.78	1,784.60	1,794.80	1,242.78
Feb '02	1,901.19	1,802.00	1,848.16	1,887.34	1,895.74	1,786.60
Mar '02	1,943.49	1,884.15	1,930.00	1,964.01	1,956.48	1,853.48
Jan '03	1,917.82	1,841.76	1,872.02	1,866.24	1,878.93	1,260.26
Feb '03	1,958.38	1,888.66	1,926.99	1,946.37	1,952.39	1,854.24
Mar '03	1,948.52	1,956.73	1,979.28	1,989.95	1,992.62	1,921.39

Cutthroat trout egg incubation extends from the beginning of spawning in January through May. Current and historic land use scenarios produce the lowest scour index over the incubation period, followed by PT, ALT2, MIT, and ALT3. The greatest impact from scour would be April, but there was no scour index in April under any of the land use scenarios (Table 4). March scour would affect most of the redds because most spawning would have occurred by then. March scour follows the same pattern as the entire cutthroat incubation period.

Juvenile cutthroat trout rear in their natal stream year-round, but may go to saltwater as older fish. In the saltwater they feed along shorelines and may move into other nearby streams or may return to or remain in the natal stream. We modeled cutthroat rearing with two sets of habitat suitability criteria, resulting in two sets of rearing WUA: summer (Table 8) and winter (Table 9). Over the summer months (April though October), the mean cutthroat rearing WUA is greatest under MIT, followed by historic (64%), PT (64%), ALT2 (58%), ALT3 (58%), and current (44%). In summer (April though October), the amount of WUA declines as flow declines through the summer (Table 8). These low WUA values correspond generally with warmer water temperatures, when juvenile trout have the highest metabolic needs and thus the greatest need for habitat for foraging (Annear et al. 2004). Many biologists consider these low flow-low habitat-high temperature months to be limiting for stream-rearing salmonids. If we consider the lowest WUA month of each year for comparison of land use scenarios, MIT is again the most favorable, followed by current (39%), ALT3 (37%), ALT2 (37%), PT (33%), and historic (27%).

Table 8. Cutthroat trout mean monthly summer rearing WUA listed by land use planning scenario.

Mean WUA	Current	historic	PT	ALT2	ALT3	MIT
Oct ‘95	63.62	32.56	75.16	82.61	84.36	173.03
Apr ‘96	128.82	255.83	246.49	222.75	221.08	275.05
May ‘96	120.87	228.72	228.51	194.14	192.76	254.50
Jun ‘96	92.21	168.11	154.84	116.70	114.86	208.68
Jul ‘96	69.15	101.41	83.84	62.59	61.61	167.10
Aug ‘96	60.00	56.20	57.45	56.08	56.00	155.64
Sep ‘96	58.79	39.85	55.91	64.14	64.85	153.72
Oct ‘96	81.44	35.75	83.56	122.79	122.53	197.99
Apr ‘97	140.56	326.30	314.95	298.48	295.60	338.44
May ‘97	130.98	277.35	264.67	235.92	233.96	286.53
Jun ‘97	116.55	217.99	213.13	171.42	170.20	245.35
Jul ‘97	104.84	176.83	165.26	133.83	132.80	220.68
Aug ‘97	77.30	108.90	95.02	72.72	72.25	176.12
Sep ‘97	74.98	64.26	78.66	85.66	86.56	178.76
Oct ‘97	111.47	101.65	147.79	194.49	196.81	264.64
Apr ‘98	124.18	248.78	236.50	209.80	207.07	270.14

May ‘98	105.29	182.23	172.15	145.33	143.62	228.05
Jun ‘98	89.52	137.40	125.51	103.27	100.97	199.77
Jul ‘98	69.74	81.41	68.25	59.71	58.90	163.73
Aug ‘98	60.47	46.18	49.02	52.31	45.49	139.39
Sep ‘98	48.06	35.06	33.84	34.33	34.31	123.08
Oct ‘98	61.47	8.65	83.32	67.21	69.21	154.22
Apr ‘99	142.11	323.40	304.51	265.38	262.51	317.68
May ‘99	126.65	243.54	224.38	187.22	183.93	253.17
Jun ‘99	106.81	175.79	156.62	130.53	128.26	217.93
Jul ‘99	91.96	127.95	113.31	92.81	91.57	191.98
Aug ‘99	69.54	71.19	57.76	53.94	53.25	157.98
Sep ‘99	59.59	43.49	44.82	47.16	47.16	142.46
Oct ‘99	67.21	34.86	67.20	83.45	85.53	161.26
Apr ‘00	111.63	208.72	196.74	175.70	173.94	246.02
May ‘00	104.62	162.01	166.26	151.14	150.24	231.56
Jun ‘00	96.42	137.84	138.36	121.71	121.11	206.25
Jul ‘00	77.30	89.27	85.57	79.22	78.92	180.62
Aug ‘00	58.75	49.78	46.72	47.26	46.91	149.19
Sep ‘00	49.80	36.22	35.96	37.87	37.89	132.00
Oct ‘00	63.43	32.60	81.99	82.65	78.22	155.64
Apr ‘01	93.09	126.25	142.19	148.48	142.98	217.94
May ‘01	78.59	101.87	106.26	100.52	100.53	197.62
Jun ‘01	79.14	72.21	95.63	95.55	96.40	188.97
Jul ‘01	62.48	47.64	59.03	61.69	62.17	164.67
Aug ‘01	68.03	36.83	56.06	67.59	68.59	165.19
Sep ‘01	56.74	33.56	43.00	57.09	58.33	159.92
Oct ‘01	65.50	8.04	73.61	73.96	75.74	168.05
Apr ‘02	136.90	290.07	274.02	252.89	251.24	306.92
May ‘02	120.37	218.34	208.10	176.73	174.94	247.47
Jun ‘02	101.20	158.74	152.20	119.74	115.32	208.80
Jul ‘02	83.61	113.48	100.89	78.57	77.80	180.84
Aug ‘02	64.00	60.70	56.02	49.33	48.85	152.16
Sep ‘02	55.53	40.63	42.96	43.15	43.30	138.96
Oct ‘02	50.09	33.74	35.96	36.05	36.06	126.70
Apr ‘03	144.42	346.01	330.89	316.96	316.39	340.50
May ‘03	130.07	256.38	243.76	213.51	207.06	272.57
Jun ‘03	102.84	174.93	153.74	121.16	118.94	211.84
Jul ‘03	81.37	105.50	85.18	68.50	66.96	172.77
Aug ‘03	64.17	56.41	50.88	47.85	47.27	150.08
Sep ‘03	53.79	39.13	38.58	38.99	38.77	133.85

Winter rearing mean WUA was greatest under MIT, followed by ALT3 (90%), ALT2 (90%), current (88%), historic (85%), and PT (70%). These values (Table 9) are used for both juvenile steelhead and juvenile cutthroat trout during winter.

Table 9. Mean monthly winter rearing WUA for trout and steelhead.

Mean WUA	Current	historic	PT	ALT2	ALT3	MIT
Nov '95	2,917.50	2,171.35	2,709.10	3,056.24	3,066.05	3,324.73
Dec '95	3,649.34	3,651.71	3,816.25	3,921.15	3,912.70	4,177.72
Jan '96	3,728.04	4,163.98	4,112.91	4,017.12	4,008.13	4,282.24
Feb '96	3,852.85	4,152.36	4,149.95	4,135.62	4,124.34	4,216.03
Mar '96	3,342.56	3,883.61	3,744.51	3,446.89	3,441.14	3,927.37
Nov '96	2,271.04	1,778.67	2,107.66	2,271.86	2,274.89	2,879.67
Dec '96	3,134.69	2,470.08	3,029.59	3,456.66	3,461.76	3,830.07
Jan '97	3,667.80	4,010.43	3,894.12	3,950.91	3,938.62	4,276.91
Feb '97	3,540.21	3,944.88	3,785.41	3,696.00	3,687.67	4,080.75
Mar '97	4,073.59	4,283.13	4,272.32	4,185.59	4,177.63	4,320.21
Nov '97	3,215.92	2,835.05	3,163.79	3,522.59	3,522.50	3,900.90
Dec '97	3,014.29	3,063.48	3,052.76	3,198.81	3,194.46	3,722.36
Jan '98	3,767.35	3,797.18	3,783.67	3,708.60	3,703.22	4,114.85
Feb '98	3,821.80	4,181.11	4,088.93	4,012.40	4,004.70	4,271.80
Mar '98	3,500.80	3,950.49	3,784.82	3,564.77	3,558.14	4,022.04
Nov '98	2,650.25	1,854.14	2,453.60	2,862.17	2,872.75	3,201.68
Dec '98	3,483.31	3,174.51	3,348.04	3,752.81	3,751.05	4,124.82
Jan '99	3,611.68	3,813.27	3,760.49	3,870.33	3,860.98	4,200.18
Feb '99	no data	no data	no data	no data	no data	no data
Mar '99	1,200.98	1,326.26	1,253.55	1,168.56	1,169.11	1,281.09
Nov '99	2,648.99	1,864.41	2,373.49	2,585.45	2,590.09	3,169.88
Dec '99	3,204.62	2,711.10	3,079.68	3,380.71	3,381.34	3,814.17
Jan '99	3,531.17	3,494.75	3,656.89	3,714.66	3,712.65	4,085.01
Feb '00	3,588.32	3,795.45	3,768.65	3,823.39	3,819.85	4,111.54
Mar '00	3,489.91	3,825.04	3,710.24	3,618.78	3,614.62	4,018.54
Nov '00	2,337.05	1,726.39	2,052.61	2,193.01	2,197.09	2,695.01
Dec '00	2,890.13	2,181.29	2,550.72	3,100.62	3,107.00	3,647.19
Jan '01	2,840.15	2,534.17	2,822.37	3,074.03	3,076.32	3,652.03
Feb '01	2,681.80	2,642.22	2,769.92	2,847.63	2,847.63	3,484.40
Mar '01	2,557.44	2,404.01	2,564.18	2,633.55	2,636.62	3,187.57

Nov ‘01	2,893.26	2,712.17	2,541.02	2,811.81	2,814.82	3,236.10
Dec ‘01	3,881.20	4,079.06	4,015.32	4,076.98	4,063.75	4,302.04
Jan ‘02	4,110.94	4,393.27	4,257.32	4,284.61	4,285.97	1,334.14
Feb ‘02	3,928.33	4,236.86	4,113.39	3,979.02	3,969.76	4,274.90
Mar ‘02	3,711.27	4,004.00	3,828.17	3,643.06	3,651.94	4,084.20
Nov ‘02	2,327.23	1,686.82	2,077.75	2,406.83	2,414.88	2,925.53
Dec ‘02	2,992.49	2,677.80	2,955.12	2,747.94	2,749.55	3,096.79
Jan ‘03	3,864.53	4,137.08	4,034.58	4,059.03	4,043.26	4,358.81
Feb ‘03	3,633.94	3,976.30	3,823.74	3,693.81	3,685.96	4,080.52
Mar ‘03	3,592.19	3,663.83	3,562.37	3,354.91	3,348.69	3,813.41

Steelhead

Steelhead spawn slightly later than cutthroat trout, in February through April. Table 10 lists mean spawning WUA for steelhead by month under each land use scenario. Spawning habitat is greatest under MIT, followed by historic (86%), PT (80%), ALT2 (72%), ALT3 (71%), and current (69%).

Table 10. Steelhead spawning habitat (mean WUA) by month.

Mean WUA	Current	historic	PT	ALT2	ALT3	MIT
Feb ‘96	287.19	353.85	357.29	352.70	346.34	384.61
Mar ‘96	182.10	291.37	262.38	201.95	196.88	300.07
Apr ‘96	139.45	191.72	175.06	131.24	129.32	226.53
Feb ‘97	224.61	305.32	273.44	254.77	248.05	334.62
Mar ‘97	335.64	383.54	381.47	364.70	374.55	211.69
Apr ‘97	242.16	325.75	302.12	273.95	269.00	349.41
Feb ‘98	278.22	360.90	338.13	322.12	317.30	383.27
Mar ‘98	215.81	306.84	270.24	225.36	220.23	319.40
Apr ‘98	104.63	175.48	152.62	110.47	106.98	214.84
Feb ‘99	222.03	no data	no data	no data	no data	no data
Mar ‘99	360.14	no data	214.10	345.13	343.39	219.69
Apr ‘99	230.32	321.37	282.74	205.94	200.41	304.01
Feb ‘00	233.00	275.27	272.12	283.00	275.25	341.86
Mar ‘00	213.29	281.14	258.59	239.95	236.21	322.25
Apr ‘00	60.69	104.10	87.77	63.49	61.87	168.91

Feb '01	81.47	66.69	91.26	98.73	98.23	205.98
Mar '01	62.21	35.43	63.38	77.53	78.88	151.82
Apr '01	46.03	26.32	49.21	63.44	58.57	124.10
Feb '02	302.72	375.64	343.86	313.64	307.54	385.42
Mar '02	260.15	318.29	278.85	242.60	246.36	334.06
Apr '02	192.14	256.76	224.97	182.61	179.13	281.22
Feb '03	240.76	312.38	279.52	252.80	246.87	335.03
Mar '03	238.66	245.64	230.28	189.19	184.57	275.58
Apr '03	300.93	372.95	339.69	310.59	308.17	358.90

Steelhead egg incubation extends from January into June. Scour is not a significant factor for later spawners, but it can affect earlier spawners. The current land use scenario produced the lowest steelhead scour index, followed by historic, PT, ALT2, and ALT3 and MIT (Table 4). Later spawners are likely to be affected by dewatering of redds, but the rates of decline of flows under the different land use scenarios are unlikely to differ significantly except from rainstorm peaks.

Steelhead fry emerge in spring or early summer and typically rear for two years as juveniles before migrating to sea. Many biologists consider juvenile rearing habitat to be a major limiting factor for steelhead production (Beecher 1981, Vadas 2000). Steelhead rearing habitat for summer months (April-October) is shown in Table 11. Maximum WUA is provided by MIT, followed by historic (69%), current (68%), PT (68%), ALT2 (63%), and ALT3 (62%). If the month with lowest WUA is compared, maximum WUA is again provided by MIT, followed by current (56%), ALT3 (49%), ALT2 (48%), PT (47%), and historic (37%). When median WUA is tallied, similar, but not identical, rankings are found. Winter rearing is characterized in Table 9 above. Winter rearing mean WUA was greatest under MIT, followed by ALT3 (92%), ALT2 (91%), current (89%), historic (87%), and PT (71%).

Table 11. Mean monthly steelhead summer (April-October) rearing WUA under each land use scenario.

Mean WUA	Current	historic	PT	ALT2	ALT3	MIT
Oct '95	126.64	65.81	122.71	127.84	129.85	225.80
Apr '96	303.34	353.27	337.13	294.49	292.01	381.95
May '96	258.95	303.87	302.89	252.62	250.91	349.71
Jun '96	169.37	214.03	197.77	155.38	153.79	269.71
Jul '96	124.97	140.35	124.41	105.43	104.44	212.80
Aug '96	110.77	99.02	101.59	99.90	99.90	201.19
Sep '96	110.28	78.91	97.67	109.25	110.24	201.65
Oct '96	164.77	72.55	132.43	180.25	178.32	265.60

Apr '97	394.76	462.26	443.95	420.81	416.57	479.53
May '97	313.34	386.04	365.99	315.85	312.74	401.17
Jun '97	249.18	286.58	278.87	221.62	220.20	330.62
Jul '97	204.95	225.12	211.43	176.05	175.14	289.01
Aug '97	138.87	147.33	134.53	114.85	114.45	224.43
Sep '97	141.51	107.27	124.73	134.73	136.18	233.54
Oct '97	252.47	145.30	196.66	258.66	262.24	361.30
Apr '98	270.99	339.25	317.73	275.32	271.32	373.25
May '98	202.00	232.34	220.03	187.70	185.84	300.84
Jun '98	164.14	176.32	164.90	143.56	141.80	256.68
Jul '98	125.93	122.27	110.43	102.45	101.61	208.70
Aug '98	113.33	87.78	91.12	95.60	87.47	180.22
Sep '98	86.73	71.07	68.28	69.64	69.57	162.09
Oct '98	57.68	29.97	45.93	52.03	53.59	112.73
Apr '99	386.21	458.35	428.81	365.57	360.69	446.72
May '99	276.99	331.21	298.32	239.53	234.93	345.96
Jun '99	207.72	223.68	199.03	168.55	166.13	283.62
Jul '99	168.01	165.31	150.84	131.80	130.80	244.49
Aug '99	125.27	113.40	100.54	96.84	96.10	201.50
Sep '99	110.68	84.11	84.18	88.05	88.12	185.60
Oct '99	129.41	70.98	108.48	135.10	138.06	217.32
Apr '00	221.77	271.63	253.79	224.46	222.20	333.32
May '00	201.46	205.66	213.14	195.52	194.68	307.32
Jun '00	184.65	176.66	182.38	163.83	163.52	265.94
Jul '00	140.59	129.13	128.05	122.93	122.85	231.77
Aug '00	106.82	92.05	88.39	89.21	88.76	191.12
Sep '00	90.68	73.11	72.57	75.87	75.87	171.89
Oct '00	119.72	65.93	121.76	131.33	126.30	204.24
Apr '01	183.09	164.17	188.63	199.47	193.32	289.06
May '01	143.84	140.07	147.54	144.40	144.76	255.41
Jun '01	154.47	114.48	143.09	142.50	143.68	245.17
Jul '01	113.66	89.47	101.44	104.63	105.12	210.65
Aug '01	129.90	74.19	98.99	110.63	111.81	214.30
Sep '01	103.74	67.93	82.00	99.62	100.99	204.62
Oct '01	65.43	27.97	56.23	60.90	62.31	123.85
Apr '02	352.17	407.66	381.83	344.88	341.83	430.00
May '02	251.19	286.90	271.17	226.87	224.61	335.39
Jun '02	195.08	201.95	196.40	161.52	154.33	270.22
Jul '02	151.01	151.81	140.27	120.30	119.54	230.81
Aug '02	116.10	103.48	98.99	91.72	91.18	194.71

Sep '02	101.57	80.02	81.83	82.18	82.23	180.31
Oct '02	90.03	68.39	71.22	72.24	72.20	166.13
Apr '03	442.09	492.51	470.56	448.23	446.38	484.76
May '03	301.06	352.18	330.27	281.96	273.72	375.11
Jun '03	194.87	222.94	196.08	159.24	156.90	274.11
Jul '03	145.81	144.22	125.61	111.03	109.63	219.94
Aug '03	116.14	99.29	93.38	89.96	89.17	192.23
Sep '03	98.33	77.74	76.76	77.38	76.98	174.05

Comparison of land use planning alternatives

In Table 12 we ranked each of the six land use planning scenarios by their impacts to salmonids. Most favorable scenarios are assigned a rank of 1; least favorable are assigned a rank of 6. In some cases two scenarios may share a rank.

If all life stages and species are ranked equally, MIT is the most favorable, followed closely by current. Even though these two were generally the most favorable, they were the least favorable in specific cases (e.g., cutthroat spawning and trout winter rearing). As noted above, in some cases there was little difference in WUA between most and least favorable, but in others the differences were significant; this distinction is lost with ranking, as used here. For fall spawners (chum and coho salmon), spawning and incubation showed opposite trends, but favorable spawning can be rendered unsuccessful by flood scour of incubating eggs. It may be more favorable to emphasize incubation if spawning habitat is still available in reasonable supply with a land use plan that minimizes scour, if coho and chum salmon are a priority.

Table 12. Land use planning scenarios ranked by species and life stage where 1 is most favorable.

	current	historic	PT	ALT2	ALT3	MIT
Chum spawning	4	6	5	3	2	1
Chum incubation	2	1	3	4	6	5
Coho spawning	4	6	5	2	3	1
Coho incubation	1	2	3	4	6	5
Coho rearing	2	6	5	3	4	1
Cutthroat spawning	2	5	4	3	1	6
Cutthroat incubation	1	1	3	4	6	5

Cutthroat summer rearing	2	2	2	2	2	1
Cutthroat winter rearing	4	5	6	3	2	1
Steelhead spawning	6	2	3	4	5	1
Steelhead incubation	1	2	3	4	5	5
Steelhead summer rearing	2	3	4	4	4	1
Steelhead winter rearing	4	5	6	3	2	1
	current	historic	PT	ALT2	ALT3	MIT
Combined rank	2	4	6	3	5	1

Some results of this study appear surprising: the low WUA values of the historic land use. This result should be qualified by caveats about channel form.

The RHABSIM model applies a fixed channel geometry to the hydraulics of the stream. Historical land use, with old growth forest, would undoubtedly have had a different channel. The quantity of fine sediment at the upper study site would probably have been less as the watershed would have had more vegetation and less exposed soils. Less fine sediment and more gravel and cobble would have increased spawning habitat quality and WUA.

High flows increase in intensity with land use. For example, at the upper study site, on March 19, 1997, current land use resulted in a flow of 105 cfs. This flow was projected to be 20% less (85.7 cfs) under historic land use. With increasing land use the flow was projected higher: PT – 102 cfs (slightly less than current), ALT2 – 114 cfs, ALT3 – 118 cfs, and MIT – 114 cfs. The erosive forces of progressively higher flows, combined with the concentration of those flows over less vegetated soils, can be expected to change the channel form. Changed form can result in changed WUA for a given flow. Although we do not have the expertise to predict channel form, additional sediment deposition at the mouth of Barker Creek would be expected and this could make upstream migration of adult salmonids more difficult and limited to high tides or high flows.

Migration of fish is essential to life history and survival of salmon and steelhead. Migration depends upon flows, but this relationship is not as readily modeled as spawning and rearing. Vadas (2000) has found that flows that are adequate for upstream migration by salmon and steelhead in California coastal streams are similar to those flows that maximize spawning habitat. Upstream migration precedes and is concurrent with the spawning season.

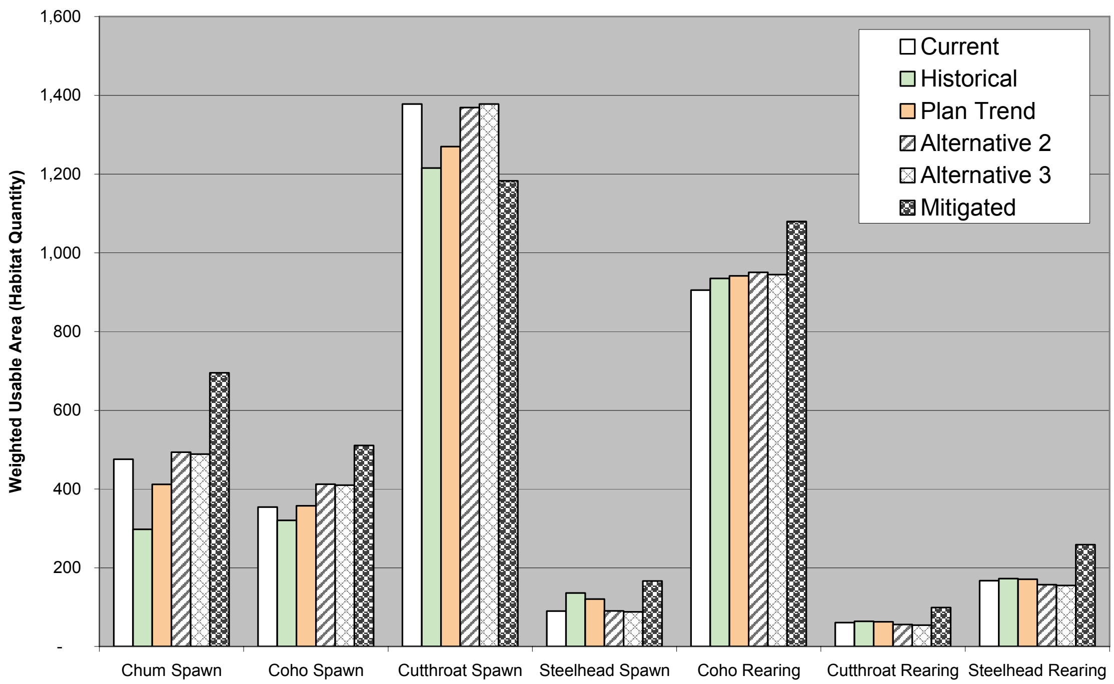


Figure 5a: Quantity of Habitat Available by Life Cycle and Scenario, Upper Site

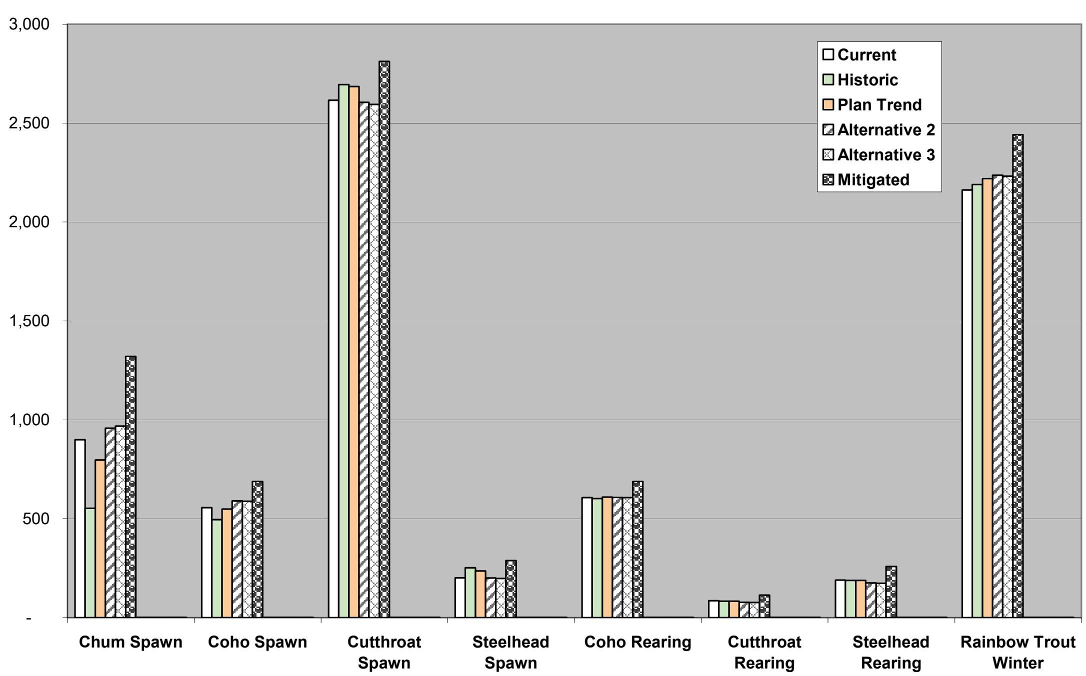


Figure 5b: Quantity of Habitat Available by Life Cycle and Scenario, Lower Site

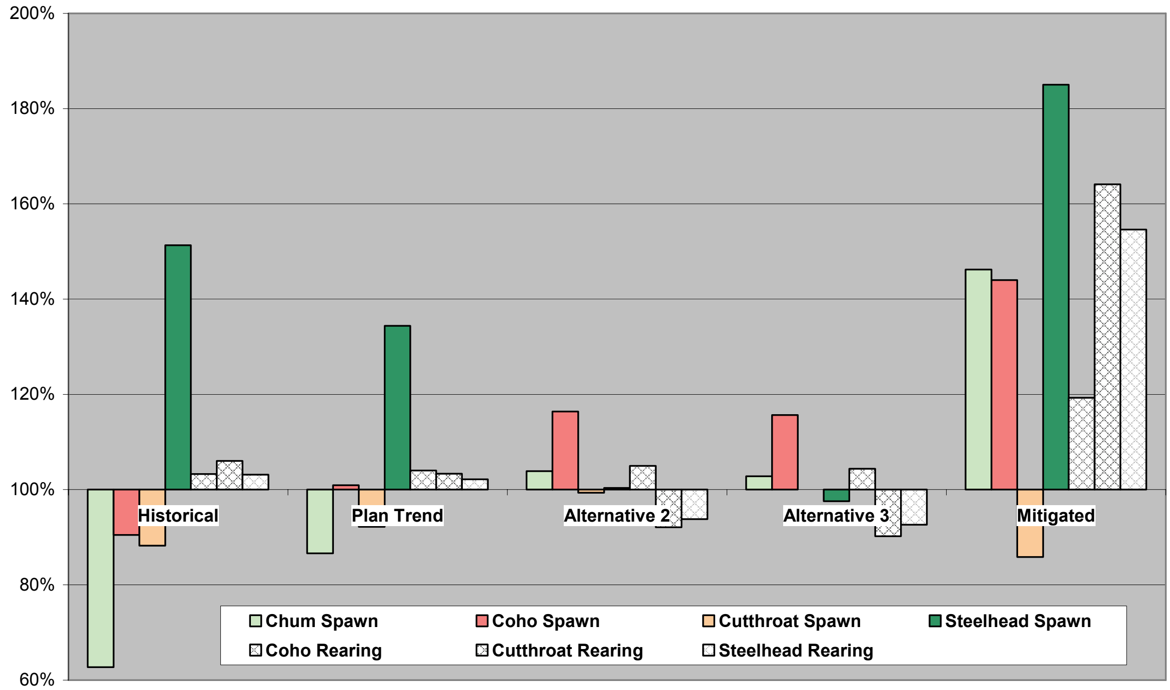


Figure 6a: Quantity of Habitat Available by Scenario and Life State, Upper Site, Change from Current Conditions.

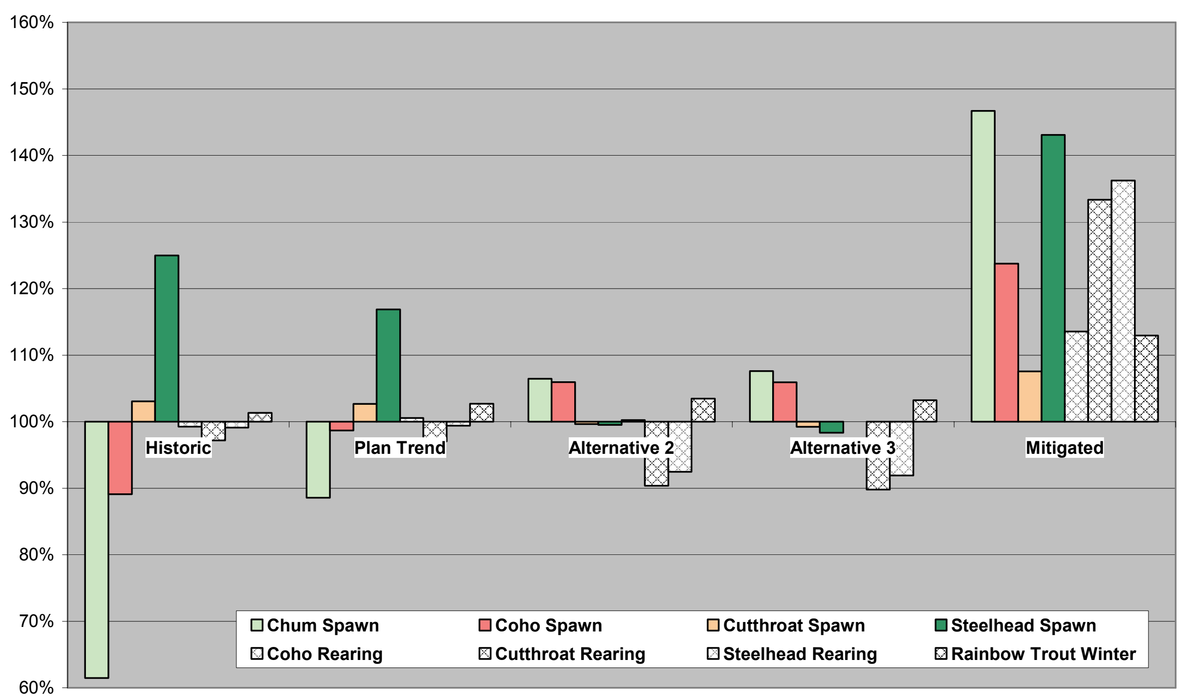


Figure 6b: Quantity of Habitat Available by Scenario and Life State, Lower Site, Change from Current Conditions.

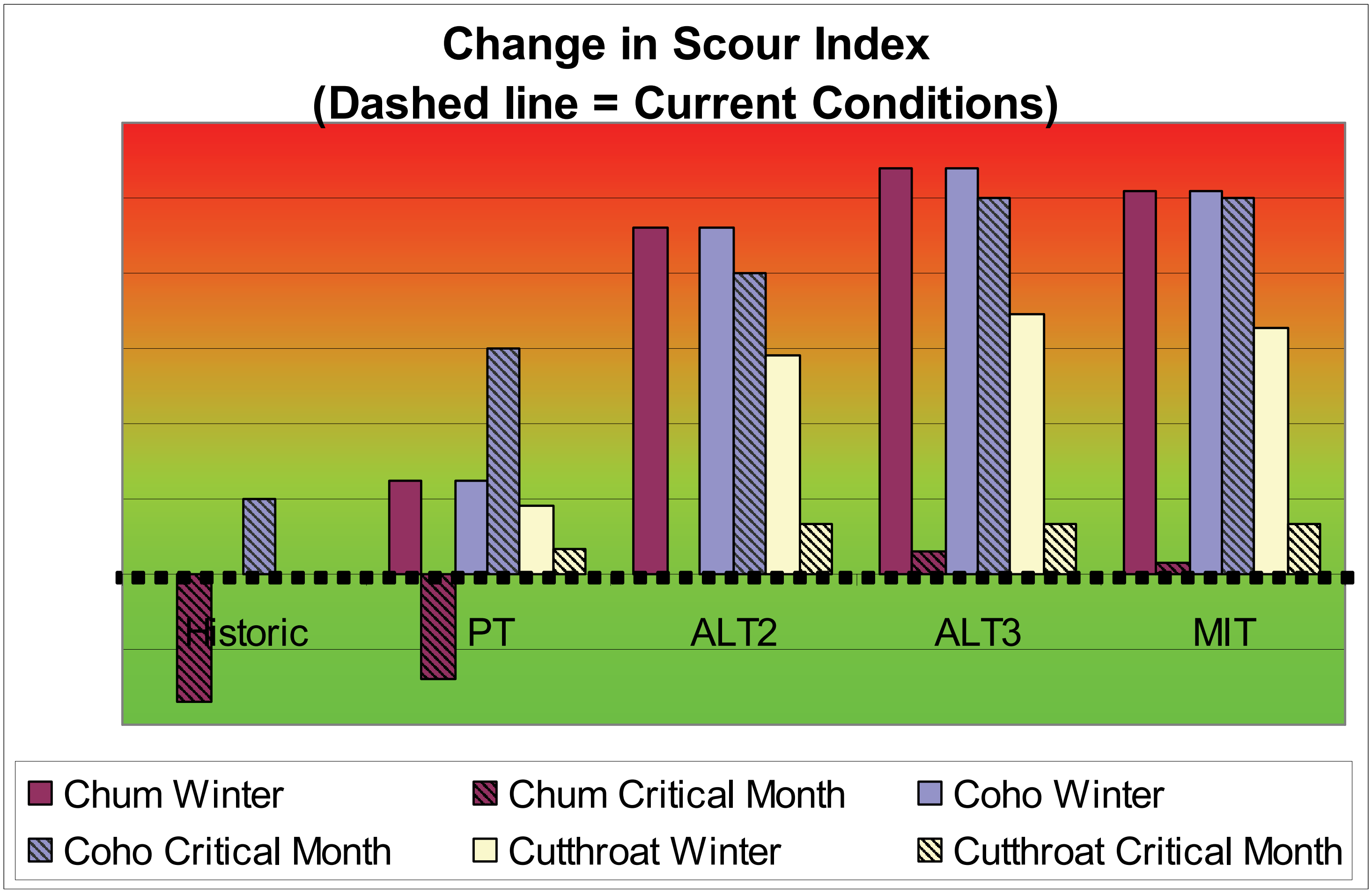


Figure 7: Scour Index by Scenario and Life Stage, Change from Current Conditions.

Figure 5 presents the average quantity of habitat (WUA) for each scenario by life stage. Figure 6 presents the quantity of habitat provided by each scenario and life stage relative to current conditions. In other words, current conditions are represented by the 100% line, improvements from current conditions are shown by bars reaching upwards, while declines from current conditions are shown by bars reaching downwards. Figure 7 depicts how the Scour Index (the number of days with flows that exceed 50 cfs) changes from current conditions for each of the scenarios for over-wintering species. In this table upward reaching bars represent more frequent flood flows.

This report is not intended as a set of instream flow recommendations, and for many of the species and life stages addressed, the optimal flows are not modeled; consequently, it is not possible to identify the flows needed to ensure successful upstream migration. Developing instream flow recommendations would require consideration of WUA peaks and inflection points relative to hydrologic possibilities, life history stages, transitions and sequential effects. Complete instream flow determination and management should include consideration of hydrology, biology, water quality, geomorphology, and connectivity (Annear et al. 2004).

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