Appendix L, Shasta Coldwater Pool Management

Attachment L.5 Sacramento River Juvenile Stranding Analysis

L.5.1 Model Overview

Juvenile stranding of salmon and steelhead occurs when the water level (stage) falls and water recedes from habitats occupied by juveniles in such a way as to isolate the juveniles from river mainstem. This typically occurs on gravel bars or side channel habitats and can be a natural process and part of a river's disturbance regime (Larrieu et al. 2020). Juveniles in pools are especially at risk, becoming stranded as the pool loses its fluvial connection to the main channel. Stranded juveniles are vulnerable to predation, reduced water quality, and exposure to air (Nagrodski et al. 2012; Revnak et al. 2017). Sublethal effects can range from temporary metabolic stress to chronic hypoxia (Larrieu et al. 2020). This analysis on juvenile stranding in the Sacramento River is based on results of field studies and analyses reported in U.S. Fish and Wildlife Service (USFWS) 2006.

L.5.2 Model Development

L.5.2.1 Methods

The USFWS (2006) juvenile stranding analysis estimates the total surface area of potential stranding sites that become stranded when the river flow drops from an initial flow to the minimum flow (stranding flow) during a subsequent period of time. A period of 3 months after the initial flow is used for the juvenile stranding analysis in this report because the juveniles are expected to be most vulnerable to stranding during their first 3 months (i.e., fry stage) (Hunter 1992; Jones and Stokes 2009; Larrieu et al. 2020). The USFWS (2006) analysis converts the total surface area of the stranded sites to numbers of stranded juveniles using estimates of fish densities from snorkel survey observations. Estimates of the surface area of the potential stranding sites at different flows are based on a combination of field measurements, aerial photos, and hydraulic modeling output (USFWS 2006). Not all potential stranding areas were included in the study because the areas had to meet several criteria for inclusion (USFWS 2006). Therefore, the USFWS stranding results provide relative rather than absolute estimates of numbers of juveniles stranded, which can provide some comparison between alternatives.

The USFWS (2006) field study included surveys of potential stranding sites on both banks of the Sacramento River from Keswick Dam to Battle Creek. These surveys identified locations where reductions in flow could isolate nearshore habitats from the main river channel, potentially trapping and stranding juvenile salmonids. A total of 107 potential sites were identified. Stranding flow was defined as the flow where the fluvial connection between the stranding site and the main river channel has a maximum depth of 0.1 feet, which is just below the minimum depth at which juvenile salmon were observed during the study. Many of the juvenile stranding sites were the same as those included in the hydraulic habitat modeling used for the rearing WUA studies (see Attachment O.3, *Sacramento River Weighted Usable Area Analysis*). For these sites, the stranding flow was estimated from the modeling results. For other sites, the stranding flow was determined from direct observation of the sites under stranding conditions. For the remaining sites, stage-discharge relationships determined for the main river channel were linked to conditions in the stranding site to estimate the stranding flow (USFWS 2006). Tables for converting initial and stranding flows to number of juveniles stranded were developed by USFWS (2006) for periods when the ACID Dam boards are in and when they are out (Table L.5-1 and Table L.5-2).

For this analysis juvenile stranding was computed using USRDOM daily flow estimates for the alternative model scenarios at three locations in the upper Sacramento River: Keswick Dam, Clear Creek, and Battle Creek. Table L.5-1 and Table L.5-2 were used for all three locations and for all salmonid species and races. The initial flow for each day of the USRDOM period of record was used with the minimum (stranding) flow of a 90-day period following the initial flow date to look up the estimated number of juveniles stranded from Table L.5-1 or Table L.5-2. Table L.5-1 was used for periods when the ACID Dam boards are not installed (November through March) and Table L.5-2 was used for the rest of the year. The boards are normally installed each year from April through October.

Juvenile stranding was computed independently for each day of the period of record, which would potentially lead to overcounting of stranded fish when the results are summarized. Therefore, the results are treated as estimates of daily stranding potential rather than as estimates of total stranding.

Table L.5-1. Juvenile Stranding Look-up Table for Chinook Salmon and Steelhead in the Sacramento River with ACID Dam Boards Out (numbers of juveniles stranded are looked up at the intersection of the “Initial Flow” columns and “Stranding Flow” rows)

		Initial Flow																				
		3,500	**3,750**	**4,000**	**4,250**	**4,500**	**4,750**	**5,000**	**5,250**	**5,500**	**6,000**	**6,500**	**7,000**	**7,500**	**8,000**	**9,000**	**10,000**	**11,000**	**12,000**	**13,000**	**14,000**	**15,000**
Stranding Flow	**3,250**	1,097	11,227	11,895	13,095	14,598	16,654	16,819	16,939	17,494	20,250	20,860	20,954	21,024	21,953	22,764	23,084	23,193	23,230	23,239	23,253	23,420
	3,500	-	10,130	10,798	11,998	13,501	15,557	15,722	15,842	16,397	19,153	19,763	19,857	19,927	20,856	21,668	21,987	22,096	22,133	22,142	22,156	22,323
	3,750	-	-	668	1,868	3,371	5,427	5,592	5,712	6,267	9,023	9,633	9,727	9,797	10,726	11,538	11,857	11,966	12,003	12,012	12,026	12,193
	4,000	-	-	-	1,200	2,703	4,759	4,925	5,044	5,599	8,355	8,965	9,059	9,129	10,059	10,870	11,189	11,298	11,335	11,344	11,358	11,525
	4,250	-	-	-	-	1,503	3,559	3,725	3,844	4,399	7,155	7,765	7,859	7,929	8,858	9,670	9,989	10,098	10,135	10,144	10,158	10,325
	4,500	-	-	-	-	-	2,056	2,222	2,341	2,896	5,652	6,262	6,356	6,426	7,355	8,167	8,486	8,595	8,632	8,641	8,655	8,822
	4,750	-	-	-	-	-	-	185	304	859	3,615	4,225	4,319	4,389	5,319	6,130	6,449	6,558	6,595	6,604	6,618	6,785
	5,000	-	-	-	-	-	-	-	139	694	3,450	4,060	4,154	4,224	5,153	5,964	6,284	6,393	6,430	6,439	6,453	6,620
	5,250	-	-	-	-	-	-	-	-	574	3,330	3,940	4,034	4,104	5,033	5,845	6,164	6,273	6,310	6,319	6,333	6,500
	5,500	-	-	-	-	-	-	-	-	-	2,775	3,385	3,479	3,549	4,479	5,290	5,609	5,718	5,755	5,764	5,778	5,945
	6,000	-	-	-	-	-	-	-	-	-	-	629	723	793	1,723	2,534	2,853	2,962	2,999	3,008	3,022	3,189
	6,500	-	-	-	-	-	-	-	-	-	-	-	114	183	1,113	1,924	2,243	2,353	2,390	2,399	2,413	2,579
	7,000	-	-	-	-	-	-	-	-	-	-	-	-	89	1,018	1,830	2,149	2,258	2,295	2,304	2,318	2,485
	7,500	-	-	-	-	-	-	-	-	-	-	-	-	-	949	1,760	2,079	2,188	2,226	2,234	2,249	2,415
	8,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	811	1,131	1,240	1,277	1,286	1,300	1,466
	9,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	319	428	466	474	489	655
	10,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	109	146	155	169	336
	11,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37	46	60	227
	12,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	23	190
	13,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	181
	14,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		167

Table L.5-2. Juvenile Stranding Look-up Table for Chinook Salmon and Steelhead in the Sacramento River with ACID Dam Boards In (numbers of juveniles stranded are looked up at the intersection of the "Initial Flow" columns and "Stranding Flow" rows)

		Initial Flow																				
		3,500	**3,750**	**4,000**	**4,250**	**4,500**	**4,750**	**5,000**	**5,250**	**5,500**	**6,000**	**6,500**	**7,000**	**7,500**	**8,000**	**9,000**	**10,000**	**11,000**	**12,000**	**13,000**	**14,000**	**15,000**
Stranding Flow	**3,250**	1,097	11,227	11,895	13,095	14,598	16,671	17,441	17,847	18,402	21,158	21,768	21,893	21,932	22,861	23,823	23,602	23,711	23,753	23,757	23,771	23,938
	3,500	-	10,130	10,798	11,998	13,501	15,574	16,344	16,750	17,305	20,061	20,671	20,796	20,835	21,765	22,186	22,505	22,614	22,656	22,660	22,675	22,841
	3,750	-	-	668	1,868	3,371	5,444	6,214	6,620	7,175	9,931	10,541	10,666	10,705	11,635	12,056	12,375	12,485	12,526	12,531	12,545	12,711
	4,000	-	-	-	1,200	2,703	4,776	5,546	5,953	6,507	9,264	9,873	9,998	10,037	10,967	11,388	11,708	11,817	11,858	11,863	11,877	12,044
	4,250	-	-	-	-	1,503	3,576	4,346	4,753	5,307	8,063	8,673	8,798	8,837	9,767	10,188	10,508	10,617	10,658	10,663	10,677	10,843
	4,500	-	-	-	-	-	2,073	2,843	3,249	3,804	6,560	7,170	7,295	7,334	8,264	8,685	9,004	9,114	9,155	9,160	9,174	9,340
	4,750	-	-	-	-	-	-	789	1,196	1,751	4,507	5,116	5,241	5,281	6,210	6,631	6,951	7,060	7,101	7,106	7,120	7,287
	5,000	-	-	-	-	-	-	-	426	981	3,737	4,346	4,471	4,510	5,440	5,861	6,181	6,290	6,331	6,336	6,350	6,517
	5,250	-	-	-	-	-	-	-	-	574	3,330	3,940	4,065	4,104	5,033	5,455	5,774	5,883	5,925	5,929	5,943	6,110
	5,500	-	-	-	-	-	-	-	-	-	2,775	3,385	3,510	3,549	4,479	4,900	5,219	5,329	5,370	5,375	5,389	5,555
	6,000	-	-	-	-	-	-	-	-	-	-	629	754	793	1,723	2,144	2,463	2,572	2,614	2,618	2,633	2,799
	6,500	-	-	-	-	-	-	-	-	-	-	-	144	183	1,113	1,534	1,854	1,963	2,004	2,009	2,023	2,190
	7,000	-	-	-	-	-	-	-	-	-	-	-	-	58	988	1,409	1,729	1,838	1,879	1,884	1,898	2,065
	7,500	-	-	-	-	-	-	-	-	-	-	-	-	-	949	1,370	1,690	1,799	1,840	1,845	1,859	2,025
	8,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	421	741	850	891	896	910	1,077
	9,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	319	428	470	474	489	655
	10,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	109	151	155	169	336
	11,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41	46	60	227
	12,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	19	185
	13,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	181
	14,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	167

As noted above, fry are most vulnerable to stranding and, therefore, stranding flows are assumed to cause juvenile mortality to salmon or steelhead primarily during the months that fry are present. The seasonal presence of fry of each of the salmonid races and species (Table L.5-3) was estimated from information on the spawning, incubation, and fry emergence periods. The analysis assumes that under equal flow conditions the fry stage of all runs and species are equally vulnerable to stranding and therefore the results tables combine results for all races and species. To determine the results for a given species or run, the estimated months for which the fry stage are most likely to be present (Table L.5-3) are selected for analysis. All the estimates of juvenile stranding potential may be biased high because the analysis methodology assumes no movement of juveniles out of rearing habitat as the water level drops (U.S. Fish and Wildlife Service 2006). Juveniles may be able to avoid stranding by moving into deeper areas as habitat is dewatered. This bias likely affects all the alternatives similarly and therefore is not expected to affect their relative values.

Juvenile stranding potential was determined for EXP1, EXP3, the NAA and the BA and EIS modeled alternative scenarios from USRDOM flow data for each day of the 100-year period of record. Stranding under the NAA and the EIS modeled alternatives was compared using the monthly mean stranding potential under each water year type. Composite estimates of juvenile stranding for each race or species under each water year type and all water year types combined were computed from the mean of the strandings determined using Keswick, Clear Creek, and Battle Creek flows and the monthly means for the estimated periods of fry rearing (Table L.5-3). Only the fry stage was included in the analyses because this stage is expected to be the most vulnerable to stranding. The fry rearing periods were estimated from various sources, including information on life-history timings of listed anadromous salmonids of the Central Valley in Appendix C.

Table L.5-3. Estimated Months of Greatest Occurrences of the Fry Life Stage , Used for Juvenile Stranding Analyses of Sacramento River Salmonids.

Species/Run	**Fry (<60mm)**
Winter-run	July–October
Spring-run	November–February
Fall-run	December–March
Late fall–run	March–June
Steelhead	February–May

Note: Only the fry stage is included in the stranding analysis.

L.5.2.2 Assumptions / Uncertainty

1. As noted above, this analysis estimates the juvenile stranding for each day of the USRDOM period of record independently of the estimates for any other days, which would potentially lead to overcounting of stranded fish when the results are summarized. Therefore, stranding cannot be summed over days to estimate total numbers of juvenile stranded. Rather, the stranding for each day is treated as a daily stranding potential and the mean stranding potentials are used to evaluate differences among the alternatives. The results may overestimate the actual level of juvenile stranding, but this bias would be equally applied to all alternatives and therefore would be unlikely to bias comparisons among the alternatives.

2. As discussed in the methods, the analysis is limited to the fry stage because this stage is considered much more vulnerable to stranding than older juveniles (Hunter 1992; Jones and Stokes 2009; Larrieu et al. 2020). Furthermore, many juveniles will have migrated downstream of the study reach (Keswick Dam to Battle Creek) by the time they have outgrown the fry stage.

3. An important assumption of the juvenile stranding analysis is that stranding of the juvenile habitat results in 100% mortality of the juveniles present. This assumption may overestimate mortality for two reasons: 1) it assumes no movement of juveniles out of rearing habitat as the water level drops (U.S. Fish and Wildlife Service 2006) and 2) it assumes juveniles cannot survive in the stranded habitat. Neither of these assumptions is correct because: 1) juveniles often avoid stranding by moving into areas of deeper water as the habitat is being dewatered (Larrieu et al. 2020), and 2) stranded habitat, particularly pool habitat, may retain enough water during periods of diminished flow to sustain juvenile survival until the site is reconnected to the main channel (Nagrodski et al. 2012). The assumption of 100% mortality likely affects all the alternatives similarly and therefore is not expected to affect their relative values.

4. Factors that cause juveniles to reduce activity, such as low temperature and concealment behaviors, tend to increase stranding rates (Nagrodski et al. 2012; Larrieu et al. 2000, Larrieu and Pasternack 2001). However, these factors are not expected to differ among the alternatives enough to affect comparisons of stranding rates.

5. USRDOM incorporates tributary inflow and flow variability not caused solely by reservoir releases. There is uncertainty in the source of potential stranding since it is not solely caused by releases and instead incorporates variable hydrometeorology. This is likely more the case during wetter water years than drier water years.

6. Estimates of juvenile stranding are an order of magnitude greater than observed in recent years for all species. This bias likely results from the multiple counting of stranding events discussed in the first assumption listed above. In addition, as noted in Section L.5.2.1, *Methods*, the analysis assumes 100% mortality of stranded juveniles, which is often not true. The results should not be considered as absolute values, but are likely still useful for comparison between alternatives.

7. The juvenile stranding analysis assumes that channel characteristics of the river, such as proportions of mesohabitat types, during the time of field data collection by U.S. Fish and Wildlife Service (1998-2001) have remained in dynamic equilibrium to the present time and will continue to do so through the life of the Project (USFWS 2010). If the channel characteristics substantially changed, stranding habitat characteristics would likely change as well (Larrieu and Pasternack 2001).

L.5.2.3 Code and Data Repository

Data for this analysis are available upon request.

L.5.3 Results

The following results provide the estimates of juvenile stranding for winter-run, spring-run, fall-run, and late fall-run Chinook salmon, and steelhead. The results are provided separately for each race and species, with tables and figures for the BA and EIS modeled scenarios included in each section. As noted in Section L.5.2.1, *Methods*, the composite juvenile stranding results by water year type in the tables were computed from the mean results for flows at three sites in Sacramento River and the mean monthly results for the fry rearing periods given in Table L.5-3.

L.5.3.1 Winter-run Chinook

Table L.5-4 and Table L.5-5 provide the juvenile stranding results for Sacramento River winter-run Chinook salmon fry during July through October under the BA modeled scenarios and EIS modeled scenarios, respectively. The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table L.5-5).

The results for both the BA and EIS modeled scenarios show consistent variation with water year type in stranding of winter-run fry under the NAA and all BA and EIS modeled scenarios for the alternatives, with stranding peaking in dry or critical water years and the lowest stranding in wet water years (Table L.5-4 and Table L.5-5). For EXP1, the stranding peaks in wet years and for EXP3 it peaks in below normal water year types. During winter, juvenile stranding is generally higher during wet water years because flow fluctuations, which increase the likelihood of stranding, tend to be more frequent in wet winters. However, winter-run fry rearing occurs primarily during summer through early fall, when flows tend to be less variable. The minimum rates of stranding for winter-run fry during wet years (Table L.5-4 and Table L.5-5) may result from increased stability in project operations related to greater reservoir storage levels. 3

Table L.5-4. Potential Juvenile Stranding (Number of Individuals) for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and Four Phases of Alternative 2.

WYT	EXP1	EXP3	NAA	Alt2wTUCPwo VA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	8,461	9,883	6,183	5,936	5,945	6,045	6,077
AN	7,083	10,973	7,917	7,923	7,962	7,889	7,938
BN	5,301	11,830	9,128	7,759	7,758	7,799	7,987
D	3,885	11,702	9,650	9,704	9,611	9,381	9,653
C	2,518	10,646	10,469	9,451	10,837	9,589	9,585
All	5,660	10,934	8,481	8,013	8,224	7,993	8,108

Table L.5-5. Potential Juvenile Stranding (Number of Individuals) for Winter-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	NAA	Alt 1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt 3	Alt 4
W	6,183	5,991	5,936	5,945	6,045	6,077	6,301	6,333
AN	7,917	7,662	7,923	7,962	7,889	7,938	7,297	7,972
BN	9,128	8,418	7,759	7,758	7,799	7,987	8,708	8,293
D	9,650	9,960	9,704	9,611	9,381	9,653	9,723	9,252
C	10,469	10,155	9,451	10,837	9,589	9,585	9,900	9,561
All	8,481	8,288	8,013	8,224	7,993	8,108	8,272	8,134
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	6,183	-3.1	-4.0	-3.8	-2.2	-1.7	1.9	2.4
AN	7,917	-3.2	0.1	0.6	-0.3	0.3	-7.8	0.7
BN	9,128	-7.8	-15.0	-15.0	-14.6	-12.5	-4.6	-9.1
D	9,650	3.2	0.6	-0.4	-2.8	0.0	0.8	-4.1
C	10,469	-3.0	-9.7	3.5	-8.4	-8.4	-5.4	-8.7
All	8,481	-2.3	-5.5	-3.0	-5.7	-4.4	-2.5	-4.1

The results for winter-run juvenile stranding grouped by months are represented in Figure L.5-1 and Figure L.5-2. Under the BA modeled scenarios, the NAA and four phases of Alternative 2 generally have peak stranding in October (Figure L.5-1). The highest median value for stranding is under EXP3 in August, and the lowest median value for stranding is in August and September under EXP 1. For the EIS modeled scenarios, stranding also peaks in October for the NAA and Alternatives 1-4 (Figure L.5-2). The highest median value for stranding occurs in October under the NAA and the lowest median value for stranding occurs in July under Alternative 2 without TUCP Systemwide VA and Alternative 4.

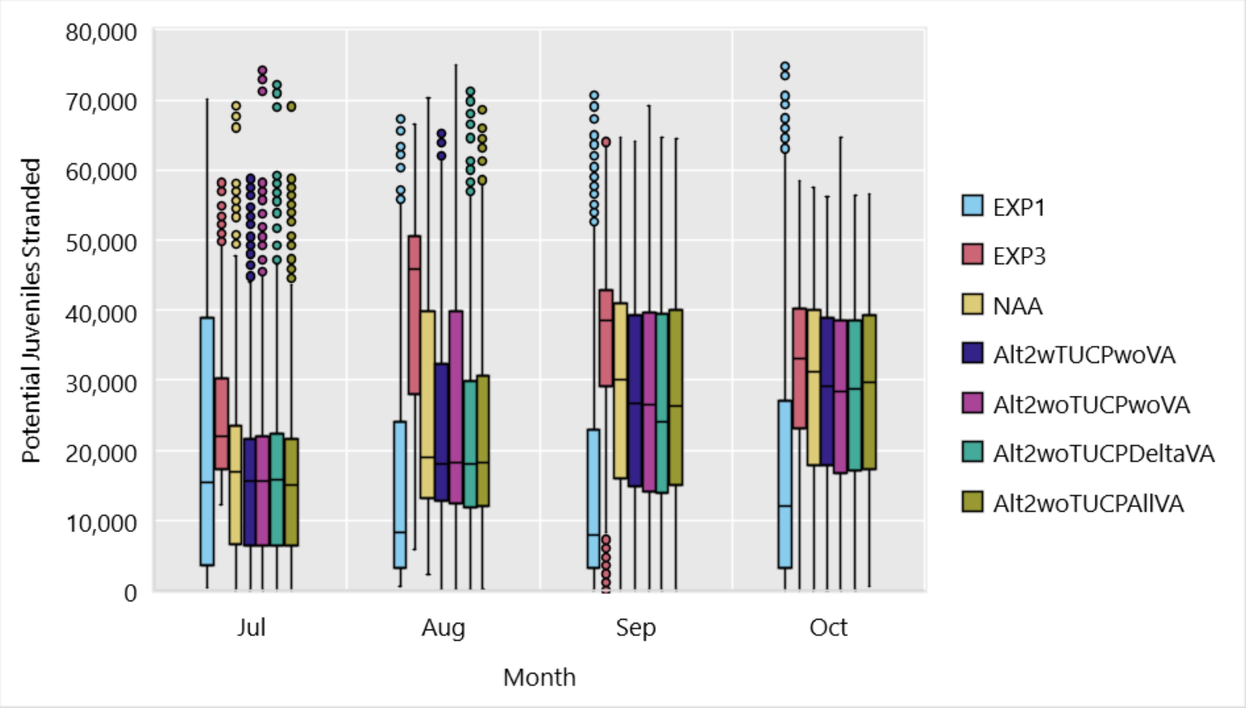

Figure L.5-1. Potential Juvenile Stranding for Winter-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Month

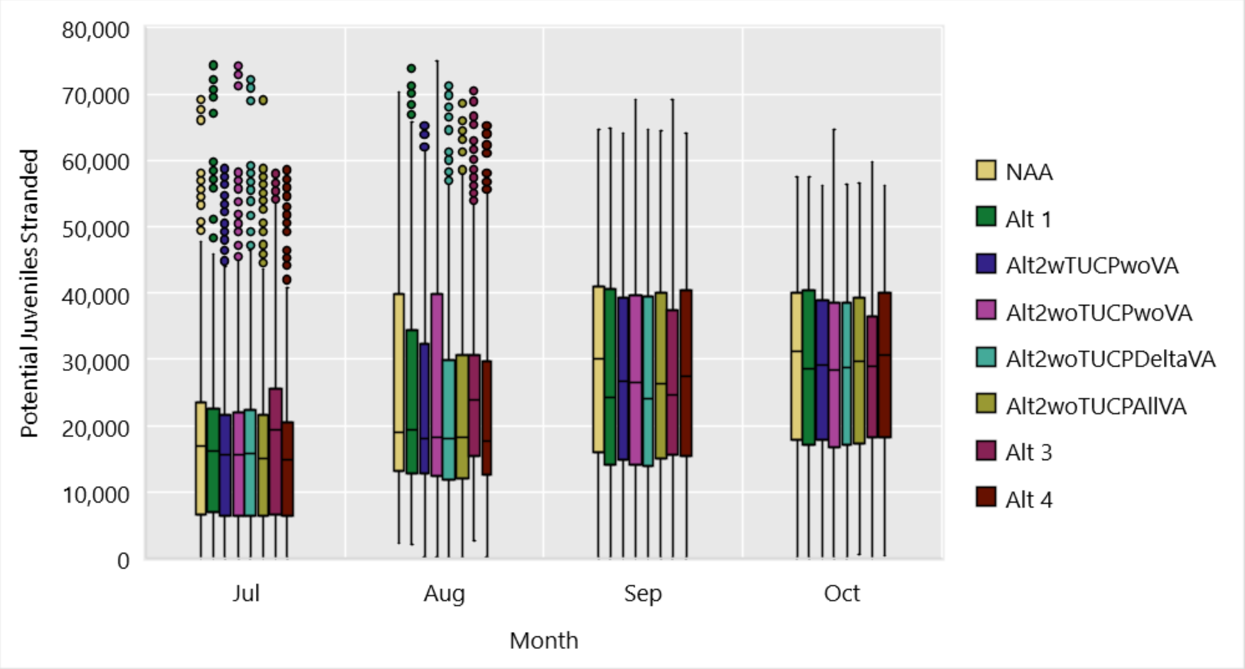

Figure L.5-2. Potential Juvenile Stranding for Winter-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1- 4, by Month.

Figure L.5-3 and Figure 5-4 give the results for winter-run juvenile stranding grouped by water year type. The results are the same as those provided in Table L.5-4 and Table L.5-5, but additionally show variation in the results.

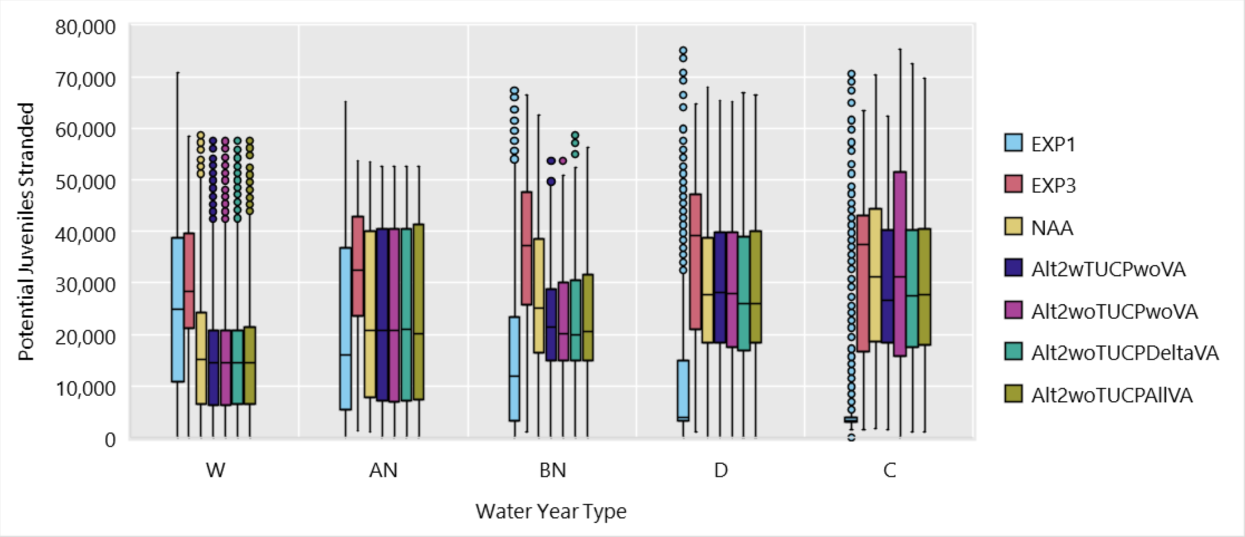

Figure L.5-3. Potential Juvenile Stranding for Winter-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Water Year Type

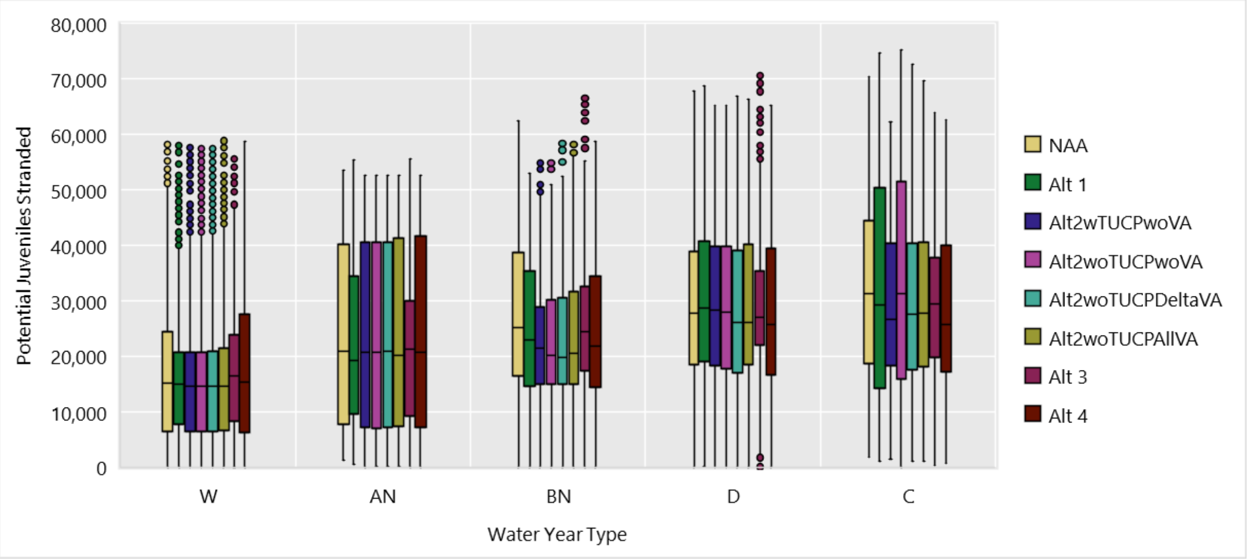

Figure 5-4. Potential Juvenile Stranding for Winter-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1- 4, by Water Year Type.

L.5.3.2 Spring-run Chinook

Table L.5-6 and Table L.5-7 provide the juvenile stranding results for Sacramento River spring-run Chinook salmon fry during November through February under the BA modeled scenarios and EIS modeled scenarios, respectively. The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table L.5-7).

The results for both the BA and EIS modeled scenarios show modest and inconsistent variation with water year type in stranding of spring-run fry under the NAA and all BA and EIS modeled scenarios for the alternatives (Table L.5-6 and Table L.5-7). Stranding peaks in wet years under EXP3, the NAA, and all the BA and EIS modeled scenarios, but the lowest stranding varies from critical water years to below normal years, depending on the scenario. For EXP1, stranding peaks in critical years and is lowest in wet years (Table L.5-6). The high levels of stranding in wet years are expected for spring-run fry because their rearing occurs from late fall through winter. During wet winters, periodic storms and high runoff increase flow fluctuations, which tends to result in greater juvenile stranding. In drier winters, flow fluctuations are reduced and fewer fry are stranded. For the EIS modeled scenarios, the alternative scenarios have lower stranding than the NAA in the majority of water year types (Table L.5-7). The largest difference between the NAA and the alternative scenarios is a 12.8% reduction in stranding for Alternative 1 in critical water years (Table L.5-7). The largest increase is 10.0% for Alternative 4 in critical water years.

Table L.5-6. Potential Juvenile Stranding (Number of Individuals) for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and Four Phases of Alternative 2

WYT	EXP1	EXP3	NAA	Alt2wTUCPwo VA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	2,939	11,335	9,639	9,302	9,354	9,266	9,143
AN	3,815	9,226	8,837	8,688	8,632	8,615	8,036
BN	4,166	6,542	7,231	7,244	7,250	7,466	6,482
D	5,061	6,726	7,422	7,028	7,087	7,674	7,428
C	7,994	5,787	7,384	8,131	6,703	7,121	7,655
All	4,604	8,199	8,213	8,114	7,916	8,132	7,864

Table L.5-7. Potential Juvenile Stranding (Number of Individuals) for Spring-run Chinook Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA, and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	NAA	Alt 1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt 3	Alt 4
W	9,639	10,534	9,302	9,354	9,266	9,143	9,386	9,140
AN	8,837	9,200	8,688	8,632	8,615	8,036	9,006	8,619
BN	7,231	7,789	7,244	7,250	7,466	6,482	7,126	7,190
D	7,422	7,527	7,028	7,087	7,674	7,428	7,285	6,930
C	7,384	6,436	8,131	6,703	7,121	7,655	7,961	8,118
All	8,213	8,484	8,114	7,916	8,132	7,864	8,190	8,023
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	9,639	9.3	-3.5	-3.0	-3.9	-5.2	-2.6	-5.2
AN	8,837	4.1	-1.7	-2.3	-2.5	-9.1	1.9	-2.5
BN	7,231	7.7	0.2	0.3	3.3	-10.4	-1.4	-0.6
D	7,422	1.4	-5.3	-4.5	3.4	0.1	-1.8	-6.6
C	7,384	-12.8	10.1	-9.2	-3.6	3.7	7.8	10.0
All	8,213	3.3	-1.2	-3.6	-1.0	-4.2	-0.3	-2.3

The results for spring-run fry stranding grouped by months are represented in Figure L.5-5 and Figure L.5-6. Under the BA modeled scenarios, peak stranding occurs in November and February (Figure L.5-5). The highest median value for stranding is under EXP3 in November, and the lowest median value for stranding is in January under EXP1. For the EIS modeled scenarios, stranding also peaks in November and February (Figure L.5-6). The highest median value for stranding occurs in February under Alternative 1 and the lowest median value for stranding occurs in December under Alternative 3.

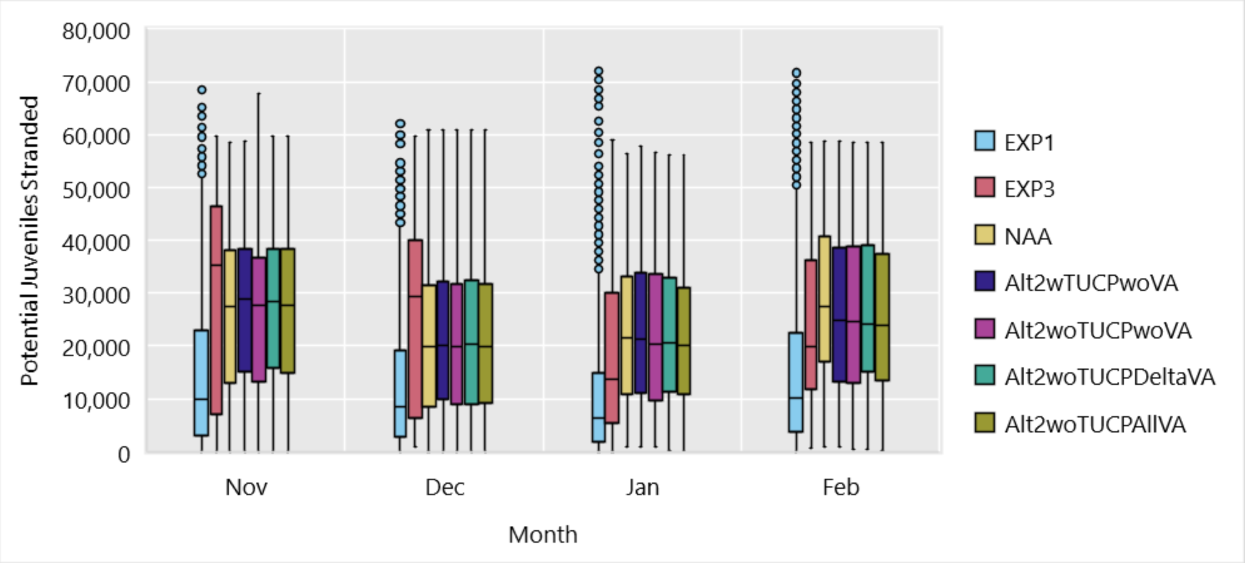

Figure L.5-5. Potential Juvenile Stranding for Spring-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Month

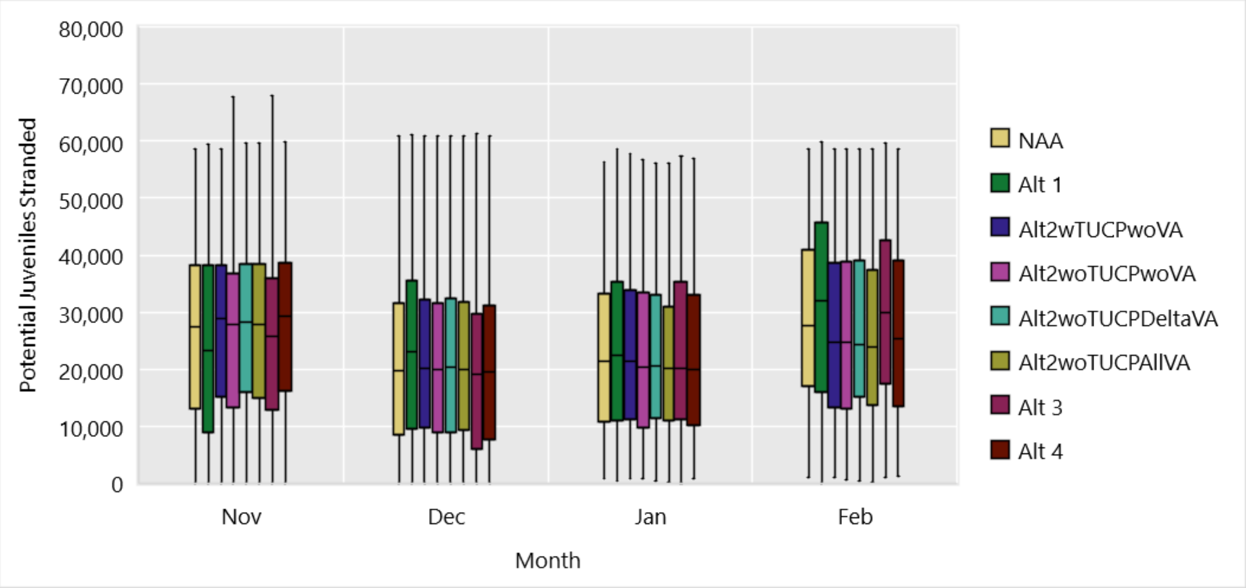

Figure L.5-6. Potential Juvenile Stranding for Spring-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Month.

Figure L.5-7 and Figure L.5-8 give the results for spring-run juvenile stranding grouped by water year type. The results are the same as those provided in Table L.5-6 and Table L.5-7, but additionally show variation in the results.

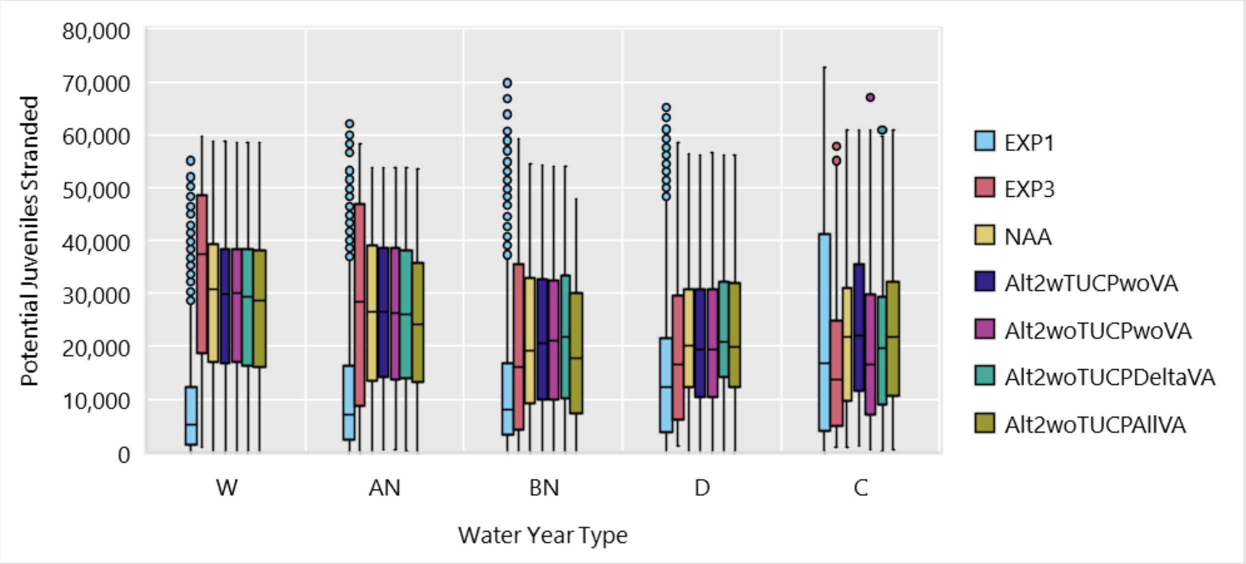

Figure L.5-7. Potential Juvenile Stranding for Spring-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Water Year Type.

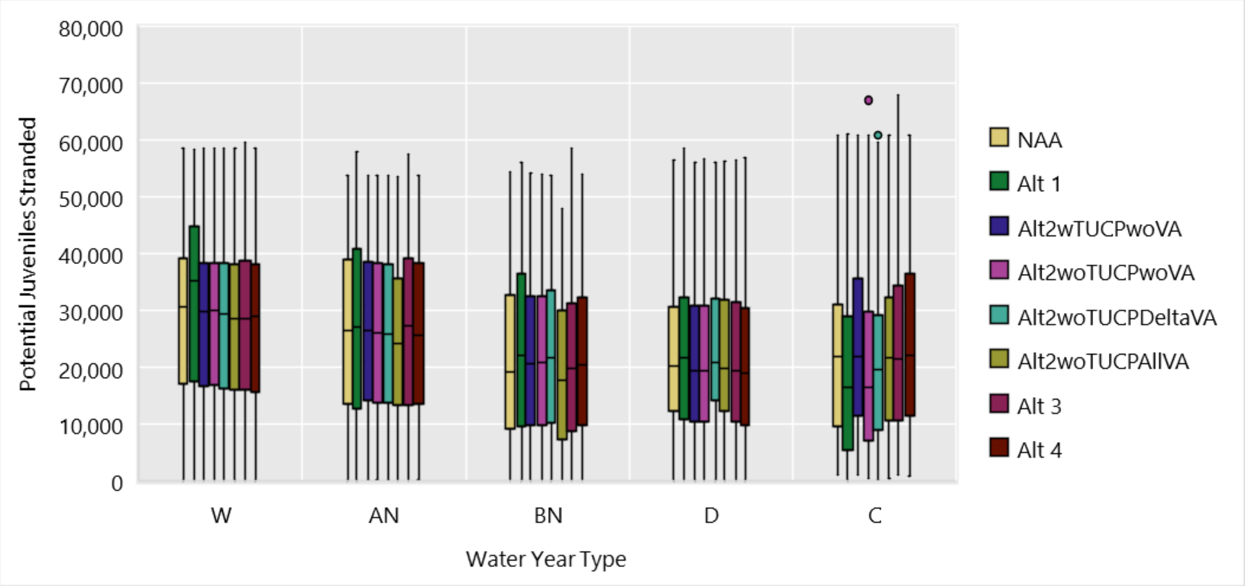

Figure L.5-8. Potential Juvenile Stranding for Spring-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Water Year Type.

L.5.3.3 Steelhead

Table L.5-8 and Table L.5-9 provide the juvenile stranding results for Sacramento River steelhead fry during February through May under the BA modeled scenarios and EIS modeled scenarios, respectively. The table for the EIS modeled scenarios includes the percent differences between the results of the NAA and the alternatives (Table L.5-9).

The results for both the BA and EIS modeled scenarios show modest and inconsistent variation with water year type in stranding of steelhead fry under the NAA and all BA and EIS modeled scenarios for the alternatives (Table L.5-8 and Table L.5-9). Stranding peaks in wet years under EXP3, the NAA, and all the BA and EIS modeled scenarios, but the lowest stranding varies from critical water years to below normal years, depending on the scenario. For EXP1, stranding peaks in dry water years and is lowest in wet years (Table L.5-8). The high levels of stranding in wet years for the scenarios other than EXP1 is expected for steelhead fry because their rearing occurs from mid-winter through mid-spring. During wet winters, periodic storms and high runoff increase flow fluctuations, which tend to result in greater fry stranding. In drier winters, flow fluctuations are reduced and fewer fry are stranded. The reason for the very different pattern of stranding variation with water year type under EXP1 is uncertain. For the EIS modeled scenarios, differences in stranding between the alternative scenarios and the NAA are relatively large (Table L.5-9). The largest differences are a 30.0% reduction for Alternative 2 Without TUCP Systemwide VA in below normal water years and 25.0% increase for Alternative 3 in above normal water years (Table L.5-9).

Table L.5-8. Potential Juvenile Stranding (Number of Individuals) for Steelhead Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and Four Phases of Alternative 2

WYT	**EXP1**	**EXP3**	**NAA**	**Alt2wTUCPwo VA**	**Alt2woTUCPwoVA**	**Alt2woTUCPDeltaVA**	**Alt2woTUCPAllVA**
W	10,245	8,127	8,337	7,978	7,973	7,985	7,764
AN	13,706	6,172	5,331	5,246	5,242	5,192	4,274
BN	14,697	3,864	4,425	4,264	4,175	4,406	3,099
D	15,406	4,167	4,374	3,511	3,544	3,914	3,955
C	14,820	3,526	4,437	4,118	4,434	4,828	4,791
All	13,503	5,398	5,636	5,237	5,277	5,466	5,045

Table L.5-9. Potential Juvenile Stranding (Number of Individuals) for Steelhead Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA, and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	8,337	9,086	7,978	7,973	7,985	7,764	8,724	7,959
AN	5,331	6,192	5,246	5,242	5,192	4,274	6,664	5,261
BN	4,425	4,317	4,264	4,175	4,406	3,099	5,022	4,269
D	4,374	3,824	3,511	3,544	3,914	3,955	4,498	3,350
C	4,437	3,964	4,118	4,434	4,828	4,791	4,247	4,019
All	5,636	5,739	5,237	5,277	5,466	5,045	6,038	5,180
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	8,337	9.0	-4.3	-4.4	-4.2	-6.9	4.6	-4.5
AN	5,331	16.1	-1.6	-1.7	-2.6	-19.8	25.0	-1.3
BN	4,425	-2.4	-3.6	-5.6	-0.4	-30.0	13.5	-3.5
D	4,374	-12.6	-19.7	-19.0	-10.5	-9.6	2.8	-23.4
C	4,437	-10.6	-7.2	-0.1	8.8	8.0	-4.3	-9.4
All	5,636	1.8	-7.1	-6.4	-3.0	-10.5	7.1	-8.1

The results for steelhead juvenile stranding grouped by months are represented in Figure L.5-9 and Figure L.5-10. Under the BA modeled scenarios, peak stranding occurs in February under the NAA and four phases of Alternative 2 (Figure L.5-9). The highest median value for stranding is under EXP1 in April, and the lowest median value for stranding is in May under the four phases of Alternative 2. For the EIS modeled scenarios, stranding also peaks in February (Figure L.5-10). The highest median value for stranding occurs in February under Alternative 1 and the lowest median value for stranding occurs in May under Alternative 1, the four phases of Alternative 2, and Alternative 4.

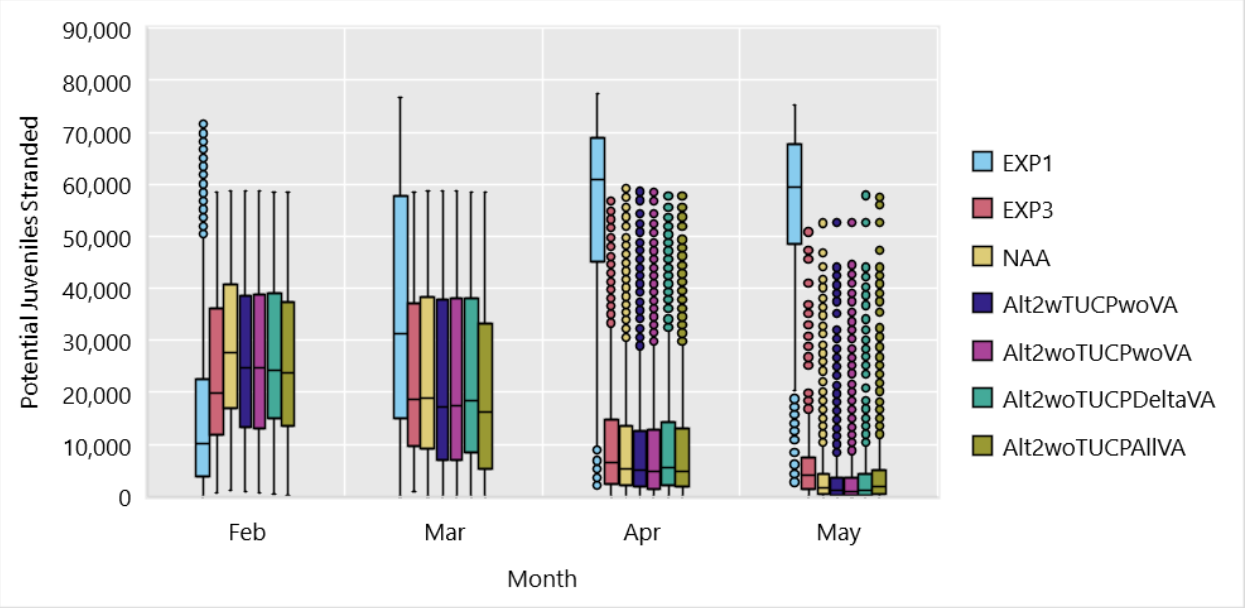

Figure L.5-9. Potential Juvenile Stranding for Steelhead in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Month

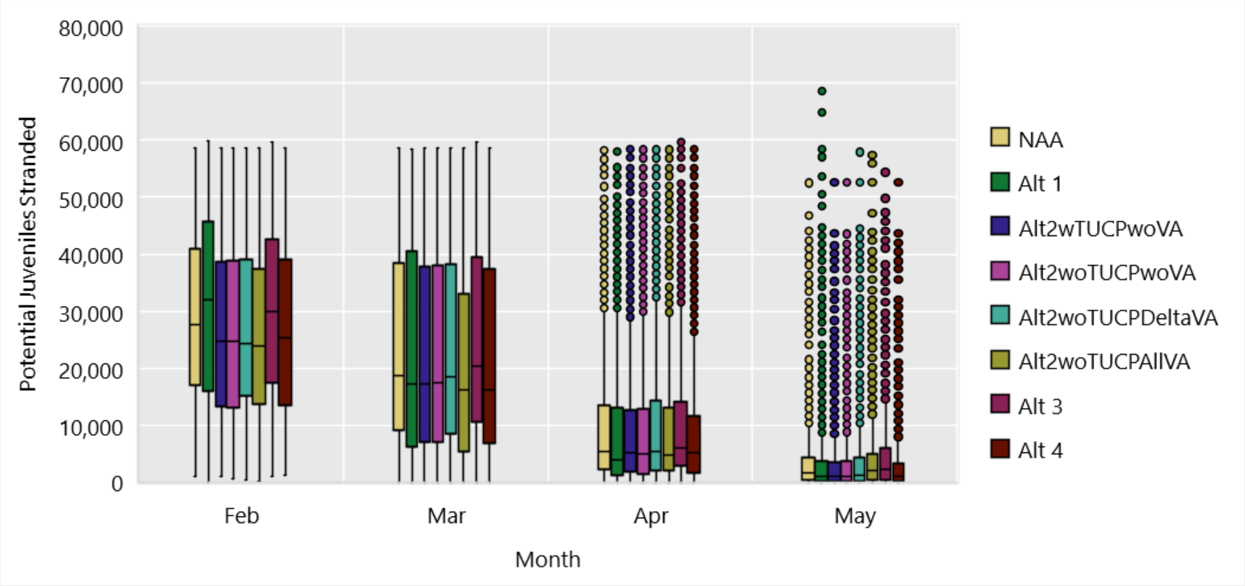

Figure L.5-10. Potential Juvenile Stranding for Steelhead in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Month.

Figure L.5-11 and Figure L.5-12 give the results for steelhead juvenile stranding grouped by water year type. The results are the same as those provided in Table L.5-8 and Table L.5-9, but additionally show variation in the results.

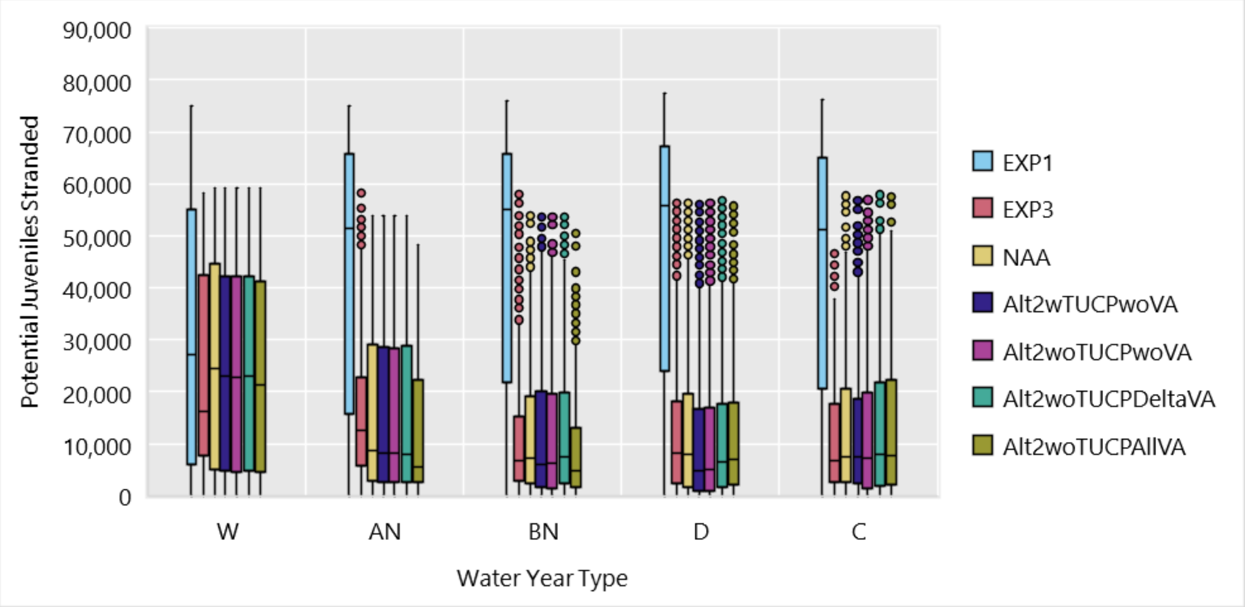

Figure L.5-11. Potential Juvenile Stranding for Steelhead in the Sacramento River from Keswick Dam to the Battle Creek Confluence for EXP1, EXP3, the NAA, and four phases of Alternative 2, by Water Year Type.

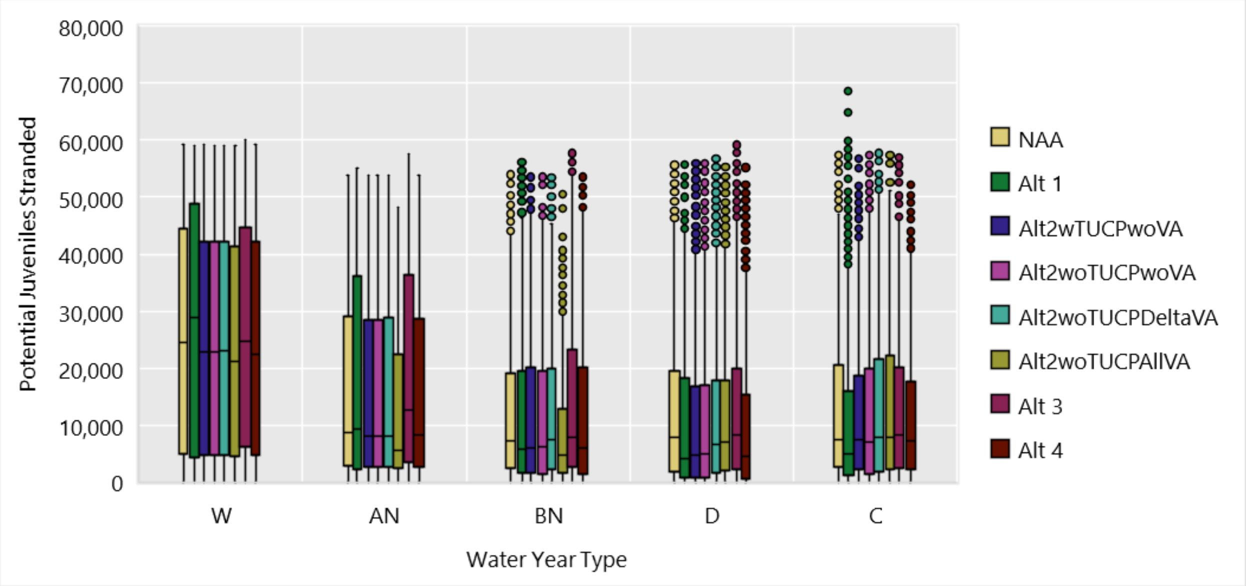

Figure L.5-12. Potential Juvenile Stranding for Steelhead in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Water Year Type.

L.5.3.4 Fall-run Chinook

Table L.5-10 provides the juvenile stranding results for Sacramento River fall-run Chinook fry during December through March under the EIS modeled scenarios. The table includes the percent differences between the results of the NAA and the EIS modeled alternatives (Table L.5-10).

The results show consistent variation with water year type in stranding of fall-run fry under the NAA and all EIS modeled scenarios for the alternatives (Table L.5-10). Stranding peaks in wet years for the NAA and all EIS modeled scenarios and is consistently lowest in critical water years (Table L.5-10). The high levels of stranding in wet years are expected for fall-run fry because their rearing occurs during winter. In wet winters, periodic storms and high runoff increase flow fluctuations, which tend to result in greater fry stranding. In drier winters, flow fluctuations are reduced and fewer fry are stranded. For the EIS modeled scenarios, differences in stranding between the alternative scenarios and the NAA vary considerably depending on water year type. Increases greater than 10% occur for Alternative 1 in wet and above normal water years and for Alt 3 in above normal years (Table L.5-10). Reductions greater than 10% occur for Alternative 1, Alt 2 Without TUCP Without VA, and Alt 2 Without TUCP Delta VA in critical years as well as for Alt 2 Without TUCP Systemwide VA in above normal years (Table L.5-10). The largest differences are a 19.0% increase for Alternative 1 in above normal years and a 15.4% reduction for Alt 2 Without TUCP Without VA in critical years (Table L.5-10).

Table L.5-10. Potential Juvenile Stranding (Number of Individuals) for Fall-run Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA, and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	9,618	10,901	9,345	9,374	9,206	9,023	9,462	8,926
AN	7,612	9,056	7,404	7,327	7,317	6,656	8,565	7,285
BN	6,689	6,928	6,801	6,786	6,964	5,718	6,448	6,528
D	7,027	7,169	6,874	6,936	7,615	7,457	6,931	6,751
C	6,292	5,433	6,338	5,321	5,509	5,819	5,915	6,244
All	7,663	8,171	7,544	7,397	7,574	7,215	7,627	7,316
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	9,618	13.3	-2.8	-2.5	-4.3	-6.2	-1.6	-7.2
AN	7,612	19.0	-2.7	-3.7	-3.9	-12.6	12.5	-4.3
BN	6,689	3.6	1.7	1.4	4.1	-14.5	-3.6	-2.4
D	7,027	2.0	-2.2	-1.3	8.4	6.1	-1.4	-3.9
C	6,292	-13.7	0.7	-15.4	-12.4	-7.5	-6.0	-0.8
All	7,663	6.6	-1.6	-3.5	-1.2	-5.8	-0.5	-4.5

The results for fall-run juvenile stranding grouped by months are represented in Figure L.5-13. For the EIS modeled scenarios, stranding peaks in February (Figure L.5-13). The highest median value for stranding occurs in February under Alternative 1 and the lowest median value for stranding occurs in March under Alternative 4 and the phase of Alternative 2 without TUCP Systemwide VA.

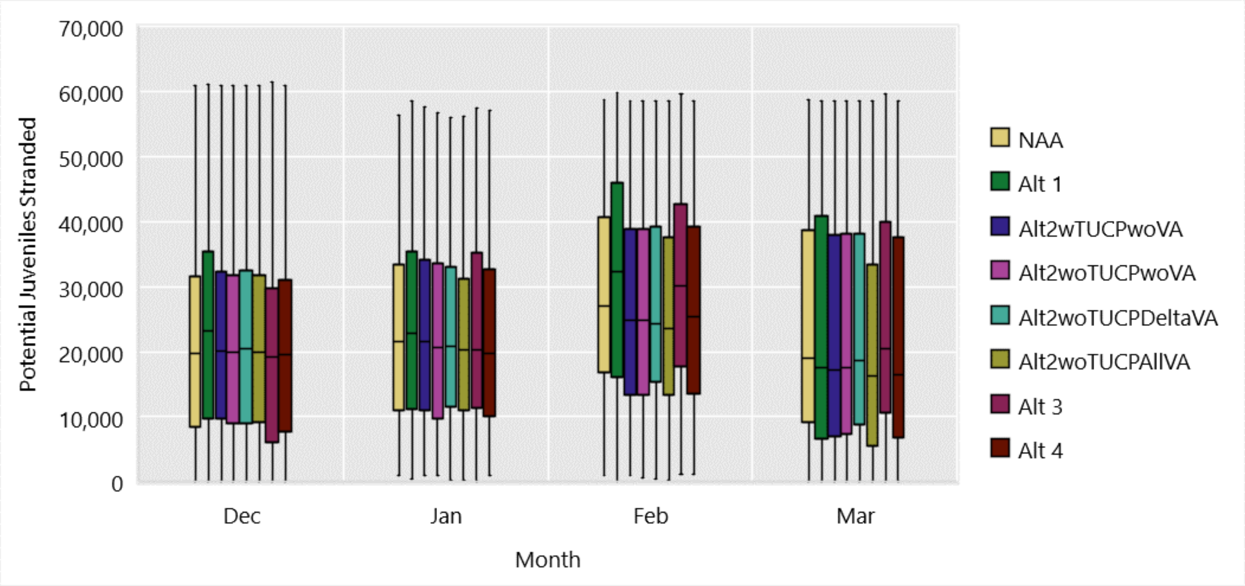

Figure L.5-13. Potential Juvenile Stranding for Fall-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Month.

Figure L.5-14 gives the results for fall-run juvenile stranding grouped by water year type. The results are the same as those provided in Table L.5-10, but additionally show variation in the results.

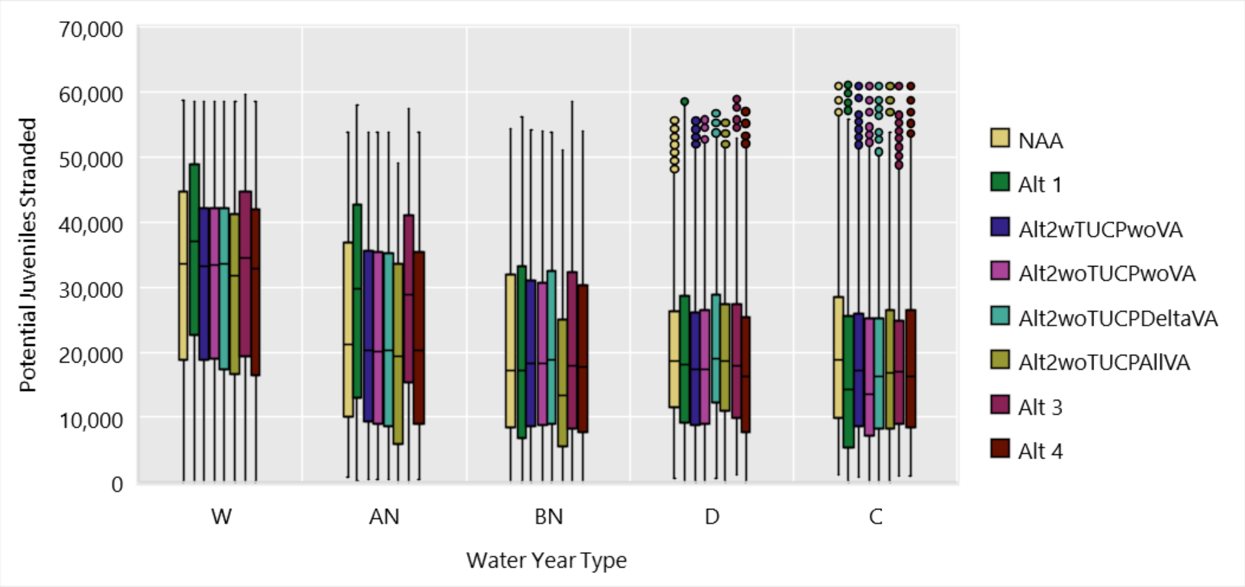

Figure L.5-14. Potential Juvenile Stranding for Fall-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Water Year Type.

L.5.3.5 Late Fall-run Chinook

Table L.5-11 provides the juvenile stranding results for Sacramento River late fall-run Chinook fry during March through June under the EIS modeled scenarios. The table includes the percent differences between the results of the NAA and the EIS modeled alternatives (Table L.5-11).

The results show modest and inconsistent variation with water year type in stranding of late fall-run fry under the NAA and all EIS modeled scenarios for the alternatives (Table L.5-11). Stranding consistently peaks in wet years for the NAA and all EIS modeled scenarios, but the lowest stranding levels vary from above normal water years under the NAA to dry water years under all the EIS modeled scenarios for the alternatives except Alt 2 Without TUCP Systemwide VA, for which the lowest stranding is in below normal water years (Table L.5-11). The low variation in stranding for fall-run fry reflects the time of year in which they rear, March through June, when runoff from periodic storms occurs much less frequently than during the winter months. For the EIS modeled scenarios, differences in stranding between the alternative scenarios and the NAA are relatively large (Table L.5-11). Most of the largest differences, which primarily constitute increases in stranding, are in critical years, including a 41.1% increase for Alt 2 Without TUCP Delta VA. The largest reduction is a 31.4% reduction for Alt 2 Without TUCP Systemwide VA in below normal water years (Table L.5-11).

Table L.5-11. Potential Juvenile Stranding (Number of Individuals) for Late Fall-run Fry Rearing in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA, and Alternatives 1-4. The Lower Panel Gives the Percent Differences of the Alternatives and the NAA

WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	5,339	5,831	5,123	5,121	5,111	4,991	5,719	5,119
AN	3,313	4,017	3,269	3,273	3,243	2,648	4,274	3,280
BN	3,510	2,912	3,282	3,209	3,328	2,408	3,843	3,234
D	3,332	2,783	2,808	2,826	3,037	3,086	3,500	2,606
C	3,414	4,311	3,525	4,446	4,826	4,500	3,938	3,260
All	3,936	4,077	3,721	3,859	3,985	3,662	4,362	3,622
WYT	**NAA**	**Alt 1**	**Alt2 wTUCP woVA**	**Alt2 woTUCP woVA**	**Alt2 woTUCP DeltaVA**	**Alt2 woTUCP AllVA**	**Alt 3**	**Alt 4**
W	5,339	9.2	-4.1	-4.1	-4.3	-6.5	7.1	-4.1
AN	3,313	21.3	-1.3	-1.2	-2.1	-20.1	29.0	-1.0
BN	3,510	-17.0	-6.5	-8.6	-5.2	-31.4	9.5	-7.9
D	3,332	-16.5	-15.7	-15.2	-8.8	-7.4	5.0	-21.8
C	3,414	26.3	3.2	30.2	41.4	31.8	15.3	-4.5
All	3,936	3.6	-5.5	-2.0	1.2	-7.0	10.8	-8.0

The results for late fall-run juvenile stranding grouped by months are represented in Figure L.5-15. For the EIS modeled scenarios, stranding peaks in March (Figure L.5-15). The highest median value for stranding occurs in March under Alternative 3 and the lowest median value for stranding occurs in May under Alternatives 1 and 4.

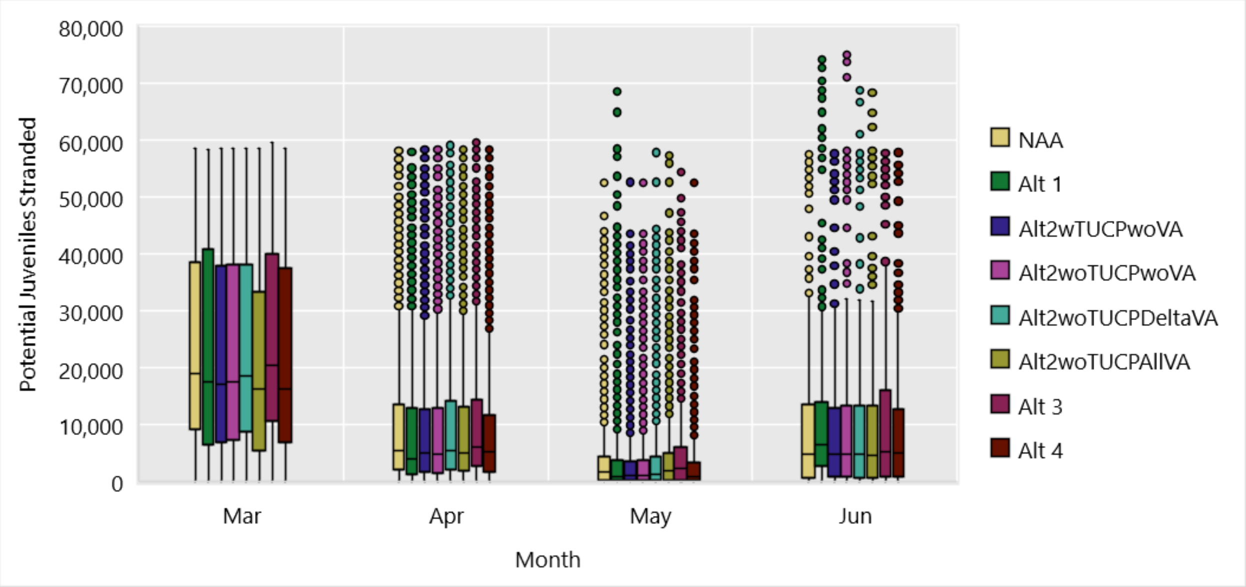

Figure L.5-15. Potential Juvenile Stranding for Late Fall-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Month.

Figure L.5-16 gives the results for late fall-run juvenile stranding grouped by water year type. The results are the same as those provided in Table L.5-11, but additionally show variation in the results.

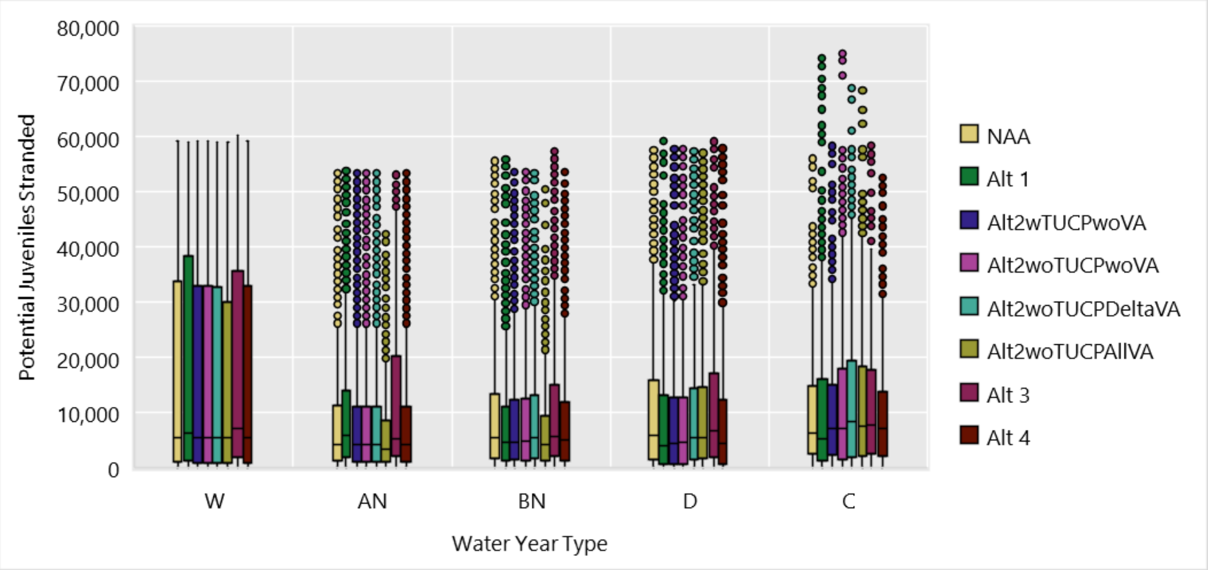

Figure L.5-16. Potential Juvenile Stranding for Late Fall-run Chinook Salmon in the Sacramento River from Keswick Dam to the Battle Creek Confluence for the NAA and Alternatives 1-4, by Water Year Type.

L.5.4 References

Larrieu, K. G., G. B. Pasternack, and S. Schwindt. 2020. Automated analysis of lateral reiver connectivity and fish stranding risks – Part 1: Review, theory and algorithm. *Ecohydrology* 14(2). e2268. https://doi.org/10.1002/eco.2268.

Larrieu, K. G., G. B. Pasternack. 2021. Automated analysis of lateral river connectivity and fish stranding risks. Part 2: Juvenile Chinook salmon stranding at a river rehabilitation site. *Ecohydrology* 14(6). https://escholarship.org/uc/item/91q918f6.

Nagrodski, A., G. D. Raby, C. T. Hasler, M. K. Taylor, and S. J. Cooke. 2012. Fish stranding in freshwater systems: Sources, consequences, and mitigation. *Journal of Environmental Management*. 103:133-141.

Revnak, R., M. Memeo, and D. Killam. 2017. *Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2016-2017.* Pacific States Marine Fisheries Commission and Department of Fish and Wildlife. RBFO Technical Report No. 02-2017.

U.S. Fish and Wildlife Service. 2006. *Sacramento River (Keswick Dam to Battle Creek) redd dewatering and juvenile stranding.* June 22, 2006. Sacramento, CA.

U.S. Fish and Wildlife Service. 2010. *Relationships between flow fluctuations and redd dewatering and juvenile stranding for Chinook Salmon and Steelhead/Rainbow Trout in the Yuba River.* September 15, 2010. Sacramento, CA.