additional mortality because of the NDD[21] would cancel out the gains from south Delta export reductions under the PA, judged from the probability of having escapement equal to or less than NAA.

In contrast to OBAN, which suggested that the benefits of less south Delta exports could offset additional mortality from the NDD, the IOS escapement estimates suggested that lower through-Delta survival would result in increasing divergence of PA and NAA escapement estimates, resulting in a median 25% lower escapement for the PA over the 81 years simulated. However, the variability in through-Delta survival estimates across the 75 randomized iterations of IOS meant that as median escapement diverged, so too did the 95% confidence intervals, so that the escapement confidence intervals for the PA and NAA overlapped in all years; in the years with greatest differences in escapement between PA and NAA, the 95% confidence intervals spread over two orders of magnitude. This likely reflects the uncertainty in the underlying model parameters (e.g., flow-survival and export-survival relationships), as well extrapolation beyond the range of the data upon which the model parameters were based. OBAN was similar to IOS in that the differences in escapement between NAA and PA scenarios usually were within 90% probability intervals[22]. For both life cycle models, the uncertainty in the relationships between environmental parameters and fish survival, coupled with extrapolation beyond the data from which the relationships were established, gave wide variation in the range of escapement estimates.

5.4.1.3.1.2.2 Habitat Suitability

5.4.1.3.1.2.2.1 Bench Inundation

Channel margin habitat in the Delta, and in much of the Sacramento/San Joaquin Rivers in general, has been considerably reduced because of the construction of levees and the armoring of their banks with riprap (Williams 2009). This has reduced the extent of high-value rearing habitat for rearing Chinook salmon juveniles, for such shallow-water habitat provides refuge from unfavorable hydraulic conditions and predation, as well as foraging habitat. Although the benefits of such habitat are most often associated with smaller, rearing individuals (McLain and Castillo 2009; H.T. Harvey & Associates with PRBO Conservation Science 2011), good quality channel margin habitat also functions as holding areas during downstream migration (Burau et al. 2007; Zajanc et al. 2013), thereby improving connectivity between higher value habitats along the migration route. Whereas, historically, riverbank protection from erosion was undertaken with riprap alone, in recent years there has been an emphasis from DWR and USACE to install bank protection that incorporates riparian and wetland benches, as well as other habitat features, to restore habitat function (HT Harvey and PRBO Conservation Science 2011). These benches are shallow areas along the channel margins that have relatively gentle slopes (e.g., 10:1 instead of the customary 3:1) and are designed to be wetted or flooded during certain parts of the year to provide habitat for listed species of fish and other species. Wetland benches are at lower elevations where more frequent wetting and inundation may be expected, and riparian benches

[21] That is, (PA Delta survival)*0.95 (i.e., 5% lower Delta survival)

[22] The exception was one year in which the PA with 50.0% additional NDD mortality had lower escapement than the NAA, and the percentage difference did not include zero within the 90% probability interval.

occupy higher portions of the slope where inundation is restricted to high-flow events. These benches were planted and often secured with riprap or other materials.

5.4.1.3.1.2.2.1.1 Operational Effects

Several levee improvements projects along the Sacramento River have been implemented by the USACE and others, and have included the restoration of benches intended to be inundated under specific flows during certain months to provide suitable habitat for listed species of fish. Restored benches in the north Delta could potentially be affected by the PA because of changes in water level; for example, less water in the Sacramento River below the NDD could result in riparian benches being inundated less frequently. This possibility was examined by calculating bench inundation indices for juvenile Chinook salmon (see detailed method description in Appendix 5.D, *Quantitative Methods and Detailed Results for Effects Analysis of Chinook Salmon, Central Valley Steelhead, Green Sturgeon, and Killer Whale*, Section 5.D.1.3.1, *Bench Inundation*). These indices range from 0 (no availability of bench habitat) to 1 (water depth on the bench is optimal for juvenile Chinook salmon all of the time). The analysis was undertaken for a number of riparian and wetland benches in five geographic locations within the north Delta, by linking bench elevation data to DSM2-HYDRO-simulated water surface elevation.

The bench inundation analysis suggested that the effects of changes in water surface elevation caused by PA operations would vary by location and bench type (Table 5.4-19). As noted above, wetland benches are located at lower elevation than riparian benches and are intended to be inundated much of the time; this results in relatively high bench inundation indices in all water year types, and makes them less susceptible to differences in water levels that could be caused by the NDD, as reflected by the minimal differences between NAA and PA in all locations and water year types. In the Sacramento River above the NDD, the wetland bench inundation indices were greater in drier than wetter years, reflecting the water depth becoming shallower and therefore moving toward the optimum for juvenile Chinook salmon (i.e., 2.2-2.5 feet; see Appendix 5.D, *Quantitative Methods and Detailed Results for Effects Analysis of Chinook Salmon, Central Valley Steelhead, Green Sturgeon, and Killer Whale*, Section 5.D.1.3.1, *Bench Inundation*).

In contrast to wetland benches, riparian benches are at higher elevations and are intended to be inundated only for portions of winter/spring. Riparian bench inundation indices were higher in wetter years and were minimal in drier years, particularly in spring (Table 5.4-19). Although there were some large *relative* differences in bench inundation indices between NAA and PA (e.g., ~40–90% lower under PA in below normal to critical years in the Sacramento River below the NDD to Sutter/Steamboat sloughs), these differences occurred in drier years when there was little habitat value under either PA or NAA. The greatest differences during the periods when the riparian benches would provide more than minimal habitat value (assumed here, based on best professional judgement, to be a bench inundation index > 0.05[23]) were:

[23] A bench inundation index of 0.05 equates to optimal depth (suitability = 1) 5% of the time within a season (with no other inundation occurring); or equates to poor depth (suitability = 0.05) 100% of the time within a season; or in reality, equates to a combination of time and depth between these ranges. It is acknowledged that an index of 0.05 is an arbitrary choice, but one that seemed reasonable.

- 29% lower riparian bench inundation index under PA in the Sacramento River from Sutter Steamboat sloughs to Rio Vista in spring of above normal years;
- 24% lower riparian bench inundation index under PA in the Sacramento River below the NDD to Sutter/Steamboat sloughs in spring of above normal years
- 19% lower riparian bench inundation index under PA in Sutter/Steamboat Sloughs in spring of wet years.

Channel margin enhancement would be implemented to offset these deficits, as described in the following section.

Table 5.4-19. Mean Bench Inundation Index by Location, Bench Type, Water Year Type, and Season, for NAA and PA.

Location	Bench Type (Total Length)	Water Year Type	Winter (December-February)			Spring (March-June)		
			NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
Cache Slough	Riparian (2,950 ft)	W	0.011	0.010	-0.001 (-6%)	0.003	0.003	0.000 (-9%)
		AN	0.004	0.004	0.000 (-6%)	0.001	0.001	0.000 (-8%)
		BN	0.003	0.003	0.000 (-4%)	0.000	0.000	0.000 (-7%)
		D	0.002	0.002	0.000 (-8%)	0.000	0.000	0.000 (-6%)
		C	0.002	0.002	0.000 (-4%)	0.000	0.000	0.000 (-4%)
	Wetland (3,992 ft)	W	0.232	0.229	-0.003 (-1%)	0.189	0.186	-0.003 (-2%)
		AN	0.202	0.199	-0.003 (-2%)	0.158	0.157	-0.001 (-1%)
		BN	0.181	0.178	-0.002 (-1%)	0.135	0.134	-0.001 (-1%)
		D	0.176	0.173	-0.003 (-2%)	0.139	0.138	-0.001 (-1%)
		C	0.158	0.157	-0.002 (-1%)	0.132	0.132	0.000 (0%)
Sacramento River above NDD	Riparian (18,521 ft)	W	0.170	0.186	0.016 (9%)	0.186	0.180	-0.007 (-4%)
		AN	0.162	0.169	0.007 (4%)	0.105	0.103	-0.001 (-1%)
		BN	0.100	0.100	0.000 (0%)	0.015	0.009	-0.005 (-35%)
		D	0.111	0.112	0.000 (0%)	0.023	0.017	-0.006 (-28%)
		C	0.038	0.038	0.000 (0%)	0.004	0.003	-0.001 (-27%)
	Wetland (3,766 ft)	W	0.360	0.364	0.004 (1%)	0.398	0.412	0.014 (3%)
		AN	0.398	0.396	-0.002 (-1%)	0.471	0.470	0.000 (0%)
		BN	0.447	0.450	0.003 (1%)	0.493	0.492	-0.001 (0%)
		D	0.424	0.429	0.005 (1%)	0.489	0.489	0.000 (0%)
		C	0.475	0.466	-0.009 (-2%)	0.393	0.391	-0.002 (-1%)
Sacramento River below NDD to Sutter/Steamboat Sl.	Riparian (3,037 ft)	W	0.247	0.227	-0.020 (-8%)	0.180	0.142	-0.039 (-21%)
		AN	0.210	0.175	-0.035 (-17%)	0.084	0.064	-0.020 (-24%)
		BN	0.116	0.098	-0.018 (-15%)	0.002	0.000	-0.002 (-77%)
		D	0.144	0.123	-0.020 (-14%)	0.008	0.005	-0.003 (-40%)
		C	0.041	0.036	-0.004 (-11%)	0.000	0.000	0.000 (0%*)
	Wetland (3,115 ft)	W	0.318	0.331	0.013 (4%)	0.357	0.343	-0.014 (-4%)
		AN	0.319	0.322	0.003 (1%)	0.289	0.280	-0.009 (-3%)
		BN	0.281	0.276	-0.006 (-2%)	0.203	0.192	-0.011 (-5%)
		D	0.281	0.278	-0.003 (-1%)	0.212	0.199	-0.014 (-6%)
		C	0.226	0.221	-0.005 (-2%)	0.171	0.168	-0.003 (-2%)
Sacramento River from Sutter/Steamboat Sl. to Rio Vista	Riparian (1,685 ft)	W	0.257	0.219	-0.039 (-15%)	0.171	0.126	-0.045 (-26%)
		AN	0.206	0.159	-0.047 (-23%)	0.075	0.053	-0.022 (-29%)
		BN	0.118	0.092	-0.025 (-22%)	0.002	0.000	-0.001 (-75%)
		D	0.146	0.115	-0.031 (-21%)	0.006	0.004	-0.003 (-43%)
		C	0.044	0.036	-0.008 (-18%)	0.000	0.000	0.000 (0%**)
	Wetland (2,430 ft)	W	0.410	0.421	0.011 (3%)	0.437	0.420	-0.017 (-4%)
		AN	0.412	0.409	-0.003 (-1%)	0.362	0.350	-0.013 (-3%)
		BN	0.361	0.354	-0.007 (-2%)	0.265	0.254	-0.012 (-4%)
		D	0.365	0.360	-0.005 (-1%)	0.276	0.262	-0.014 (-5%)
		C	0.295	0.290	-0.005 (-2%)	0.230	0.226	-0.003 (-1%)
Sutter/Steamboat Sloughs	Riparian (5,235 ft)	W	0.262	0.233	-0.028 (-11%)	0.196	0.159	-0.037 (-19%)
		AN	0.220	0.186	-0.034 (-15%)	0.103	0.085	-0.018 (-17%)
		BN	0.138	0.117	-0.020 (-15%)	0.024	0.021	-0.003 (-12%)
		D	0.160	0.135	-0.025 (-16%)	0.030	0.026	-0.004 (-14%)
		C	0.066	0.059	-0.007 (-11%)	0.019	0.018	-0.001 (-4%)
	Wetland (2,670 ft)	W	0.515	0.528	0.014 (3%)	0.562	0.548	-0.014 (-2%)
		AN	0.528	0.526	-0.001 (0%)	0.499	0.486	-0.013 (-3%)
		BN	0.488	0.482	-0.006 (-1%)	0.401	0.387	-0.014 (-3%)
		D	0.487	0.483	-0.004 (-1%)	0.414	0.397	-0.017 (-4%)
		C	0.420	0.415	-0.005 (-1%)	0.356	0.352	-0.004 (-1%)

Notes: *Value was changed from -92% because absolute change was extremely small. **Value was changed from -80% because absolute change was extremely small.