Appendix L, Shasta Coldwater Pool Management

Attachment L.2   Egg-to-fry Survival and Temperature-Dependent Mortality

L.2.1 Methods

L.2.1.1 Model Overview

The Martin et al. (2017) or Anderson et al. (2022) models can be used to predict egg-to-fry survival for winter-run Chinook salmon as a function of temperature-dependent egg mortality, background mortality, and density-dependent mortality. Both models specify egg mortality as a function of temperature (i.e., temperature-dependent mortality, or TDM), applied over either the entire embryonic developmental period (i.e., stage-independent or Martin model) or only part of it (i.e., stage-dependent or Anderson model), based on an estimated minimum temperature at which no temperature-dependent mortality occurs and a slope term that describes how much increasing temperatures above the minimum affect egg mortality. Density-dependent mortality is specified following the Beverton-Holt function with a corresponding carrying capacity density term. Model parameters were estimated using known redd locations, estimated temperatures, and annual estimates of egg-to-fry survival from either 1996-2015 (Martin et al. 2017) or 2002-2020 (e.g., Poytress 2016; Anderson et al. 2022). Datasets necessary to run the models include the abundance of redds over space and time and corresponding daily temperatures for each redd location; historical aerial redd or carcass survey data and HEC-5Q daily temperature estimates can and have been used as model inputs. These models are available to run as part of the SacPAS Fish Model implementation at: Fish Model. The Martin and Anderson models was used to evaluate the stand-alone temperature-dependent mortality, but Reclamation notes they can evaluate overall egg to fry survival performance metrics for winter-run Chinook Salmon. Model development was not open and participatory. Versions of both models were applied in the 2019 Biological Assessment and Biological Opinion.

The models are sensitive to the temperature target, locations, and timing. The Proposed Action (i.e., Alternative 2) developed bins with different water temperature management biological goals and objectives (i.e., "Bin Criteria"). The Proposed Action additionally included shaping water temperature management to optimize for low TDM. The models used and updated the 2020 Record of Decision into a strategy that may better represent the outcome of temperature shaping by the real-time groups (i.e., "2021 Updated Tier Strategy"). Reclamation staff present all results for Alternative 2 with "Bin Criteria" temperature target, locations, and timing, in addition to select results in which the "2021 tiers" is applied instead to the No Action Alternative

(NAA) and components of the Proposed Action. Reclamation staff explicitly identify all instances in which results reflect the "2021 Updated Tier Strategy".

L.2.1.2   Assumptions/Uncertainty

It is important to note that no direct estimates of TDM or egg incubation survival are available for winter-run Chinook salmon. Redd locations used for modeling are a subset of total redds that can be observed from the aerial surveys and underrepresent deepwater spawning known to occur near Keswick Dam. Female spawners and fry-equivalent abundance are the biological field data used for fitting both TDM models. The egg-to-fry survival metric—calculated by dividing estimated fry-equivalent abundance by estimated number of eggs deposited by female spawners—multiple life stages (adults, eggs, fry, smolts) which are exposed to a variety of stressors and mortality sources in the 95 km between Keswick Dam and Red Bluff. These gaps in biological field data and use of data that span multi-life stages requires an assumption. Specifically, estimating TDM from available biological field data requires the assumption that all sources of mortality not attributable to temperature effects on eggs are a constant value (i.e. "background survival") that does not vary from year-to-year and therefore is not influenced by factors like river flows, temperatures after emergence, or other environmental covariates (Martin et al. 2017; Gore et al. 2018). For example, the Martin and Anderson models assume that survival after fry emerge from spawning gravels is the same in a year with low flows (e.g. 2022) as it is in a year with higher flows (e.g. 2023). The "background survival" constant can be scaled for density-dependence, but this only occurs when female abundance is higher than 9,100 fish and this scaling is unrelated to the influence of other environmental conditions. The assumption that survival of salmon eggs and juveniles is independent of river flows (for example) was questioned by Gore et al. 2018 and the validity of the assumption has not been demonstrated by any studies conducted since the TDM models were originally developed.

L.2.1.3   Analyzing TDM without Parameter/Model Uncertainty

TDM is calculated for each simulated water year (WY) from CalSim 3 (i.e., 1923-2021) using HEC-5Q modeling temperature estimates at three locations in the Sacramento River: below Keswick Dam (RKM 483), near the confluence with Clear Creek (RKM 479), and near Bend Bridge (RKM 474). Expected variability in TDM as a function of the spatial and temporal distribution of spawning timing for each WY is captured by calculating estimates of TDM for annual redd distribution datasets between 2001 and 2021, such that each simulated WY is associated with 21 TDM estimates. The redd distribution datasets were based on carcass surveys and obtained from SacPas (https://www.cbr.washington.edu/sacramento/). Both stage-dependent and stage-independent estimates of TDM are generated for each combination of WY and redd distribution dataset, using the same parameter values used in the SacPAS implementation of TDM models. Modeling results are summarized for each WY using either the full range of estimated TDM values or using the 80th percentile of TDM estimates. These values are provided to help inform assessment of TDM differences between scenarios. Variation in TDM estimates resulting from these analyses do not represent actual statistical uncertainty associated with TDM estimates (see L.2.1.4).

L.2.1.4   Analyzing Stage-Independent TDM with Parameter Uncertainty

Reclamation staff characterized parameter uncertainty associated with TDM for the Martin (i.e., stage-independent) model by refitting the model, using the same model structure and data inputs,

using 'jags' Bayesian software with the R package 'jagsUI'; staff did not characterize parameter uncertainty associated with TDM for the Anderson model due to significant challenges in achieving model convergence. For the model, relatively uninformative priors were specified for each of the main model parameters:

- **Critical temperature (T_{crit}):** Normal(μ=15, σ=5)

- **Effect of temperature on mortality (log(b_t)):** Normal(μ=0, σ=10)

- **Background survival (S_0):** Beta(a=1, b=1)

- **Carrying capacity (K):** Normal(μ=10000, σ=5000)

Reclamation staff specified fixed initial values based on published parameter estimates to start the chains at reasonable starting points (T_{crit}=15, log(b_t)=-3.38, S_0=0.37, K=9100); this was necessary to achieve somewhat consistent model convergence. Reclamation staff ran the model using three chains, each with 5000 burn-in iterations and 5000 retained iterations.

Reclamation observed considerable variability in model convergence and estimated parameters, consistent with results reported in Martin et al. (2017) based on non-Bayesian optimization methods. Parameter R-hat values, which measure the degree to which parameter values are similar among chains, varied between 1.006 and 1.358; values less than 1.1 are generally considered acceptable. Parameter estimates and confidence intervals, alongside those presented in Martin et al. (2017), are presented in Table L.2-1, below.

Table L.2-1. Parameter estimates.

Parameter	Mean (95% CI)	Median	Published Value (95% CI)
T_{crit}	11.80 (9.62, 13.89)	11.88	12.0 (10.8, 13.7)
b_t	1.21e8 (0.005, 428.09)	0.022	0.024 (0.007, 4.21)
S_0	0.41 (0.28, 0.84)	0.38	0.366
K	9562 (3622, 17608)	9298	9107

The extremely high mean value for b_t results from a few outlier estimates during model fitting. Martin et al. (2017) noted covariance between the TDM parameters contributed to high variability in parameter estimates, and noted that smaller parameter ranges were observed when only the more likely parameter sets were considered (i.e., Tcrit ~11-12.5°C). With the model fitting in 'jags', Reclamation staff observed the greatest covariance between T_{crit} and S_0 (Pearson's squared correlation, or r^2, was 0.42), which resulted in parameter combinations with low T_{crit} and high S_0 (and vice versa). When the parameter set was restricted to only those corresponding to a deviance less than 20, the range of Tcrit values was between 11.01-12.47°C, similar to that reported in Martin et al. (2017). Observed deviance values from model fitting ranged between ~10 and ~50, and lower deviance values indicate higher likelihood of parameter estimates.

Reclamation staff used a randomly selected subset of posterior TDM parameter estimates with corresponding deviance values less than 20 (N=1000) to characterize the effects of parameter uncertainty on uncertainty in TDM estimates ('Good posteriors_JAGS_12.19.22_n1000.csv'). For each modeled WY and redd distribution, Reclamation staff obtained separate TDM estimates for each set of posterior parameter estimates. Modeling results were summarized using the full range of estimated TDM values for each WY, rather than using the 80th percentile.

The deviance cut-off value of 20 is somewhat arbitrary, but it removed biologically extreme and infeasible parameter estimates. Ranges of estimated TDM using all posterior estimates were so large as to be meaningless in comparing alternatives or WYs. Strong covariance among parameters, including those either linked or not linked directly to temperature effects, made it difficult to estimate uncertainty surrounding estimates of TDM in isolation from background and density-dependent survival. The representation of parameter uncertainty presented here addresses some of these challenges, but Reclamation staff acknowledge that ad-hoc methods were used to obtain reasonable values of TDM uncertainty resulting from uncertainty from model fitting. Because of these documented challenges in estimating uncertainty surrounding estimates of TDM, the current approach (i.e., using the framework of either Martin et al. 2017 or Anderson et al. 2022) is problematic for forecasting TDM if estimates are to be accompanied with appropriate, corresponding estimates of uncertainty.

L.2.2 Results

The EIS results include comparisons among the No Action Alternative (NAA) and all other management alternatives (Alt1 – Alt4). The BA results include results for the NAA, the EXP1 and EXP3 baseline alternatives, and Alt2.

L.2.2.1 EIS

L.2.2.1.1 Takeaways

Values of proportional TDM are presented in Table L.2-2 and Figure L.2-1 through Figure L.2-7. For the Anderson model, expected proportional TDM values calculated across all WYTs, for only critical WYTs, and for only wet WYTs were 0.096, 0.464, and 0.001, respectively for the Alt2woTUCPwoVA mixed. Relative to the Anderson model, expected proportional TDM values were generally slightly higher for the Martin model across each category of WYT except for Below Normal which was the same (0.038). For expected proportional TDM values calculated across all WYTs, mean TDM values ranged from 0.058 to 0.239 across all alternatives for the Anderson model and from 0.089 to 0.216 for the Martin model. Water year-specific TDM estimates varied from approximately 0 to 1 across alternatives and models, and were highest in critical WYTs (Figure , Figure). For select recent WYs, alternatives, and models, annual TDM estimates varied by as much as 0.25 due to uncertainty in spatial and temporal redd distributions (Figure).

For mean proportional TDM values calculated across each WYTs and model, Alt1 90-5 resulted in increased TDM relative to the NAA across both TDM models and all WYTs (i.e., 0% to 1200% differences in TDM relative to NAA). Alt3 NGO resulted in decreased TDM for all

models and WYTs (i.e., -81.8% to -31.3% differences) except for the Anderson model in Wet WYs which resulted in increased TDM (i.e., 100% difference). Alt4 carryover resulted in decreased TDM for all models and all WYTs, with the exception of Wet and Above Normal WYs for the Anderson model (133.3% and 12.5%, respectively) and Above Normal for the Martin model (14.3% differences relative to NAA). Alt4 2021 tiers resulted in decreased TDM except for the Anderson model in Wet WYTs (12.5%). All four components of Alt2, except Alt2wTUCPwoVA 2021 tiers in Wet WYTs for the Anderson model (100%), resulted in decreased TDM relative to NAA for both models and every WYT (i.e., -87.6% to -12.5% differences).

For the Anderson and Martin models, greater than 70% of modeled WYs resulted in expected proportional TDM values less than 0.125 for every alternative but Alt1 90-5, which produced greater TDM in 40% of years (Figure L.2-4). For Critical WYTs only, at least 12.5% of modeled WYs resulted in expected proportional TDM values less than 0.5 for all alternatives except Alt1 90-5, Alt2woTUCPAllVA mixed, and Alt4 carryover. For Above Normal and Wet WYTs only, expected proportional TDM never exceeded 0.125 for all alternatives (Figure L.2-5).

For recent water years 2011-2020, expected proportional TDM values for both the NAA and Alt2woTUCPwoVA mixed alternatives had noticeably greater variation when both redd and parameter uncertainty were included than when only redd uncertainty was included (Figure L.2-6, Figure L.2-7).

L.2.2.1.2   *Expected TDM without Model Uncertainty*

The following information is expected TDM without model uncertainty.

Table L.2-2. Predicted mean proportional TDM estimates for different models and WYTs, in which presented means are the means of 80th percentile TDM values for relevant CalSim WYs. Parentheses indicate percent different from NAA (negative values indicate a beneficial decrease in expected TDM).

| Model	WYT	NAA	Alt1 90 5	Alt2 wTUCP woVA mixed	Alt2 wTUCP woVA 2021 tiers	Alt2 woTUCP woVA mixed	Alt2 woTUCPDelta VA mixed	Alt2 woTUCPAllVA mixed	Alt3 NGO	Alt4 carryover	Alt4 2021 tiers
Anderson	All	0.190	0.239 (25.8)	0.073 (-61.6)	0.058 (-69.5)	0.096 (-49.5)	0.099 (-47.9)	0.102 (-46.3)	0.065 (-65.8)	0.146 (-23.2)	0.072 (-62.1)
Anderson	C	0.712	0.811 (13.9)	0.337 (-52.7)	0.283 (-60.3)	0.464 (-34.8)	0.472 (-33.7)	0.503 (-29.4)	0.312 (-56.2)	0.608 (-14.6)	0.336 (-52.8)
Anderson	D	0.210	0.286 (36.2)	0.049 (-76.7)	0.026 (-87.6)	0.061 (-71)	0.059 (-71.9)	0.057 (-72.9)	0.042 (-80)	0.123 (-41.4)	0.047 (-77.6)
Anderson	BN	0.135	0.157 (16.3)	0.04 (-70.4)	0.021 (-84.4)	0.038 (-71.9)	0.048 (-64.4)	0.04 (-70.4)	0.017 (-87.4)	0.089 (-34.1)	0.022 (-83.7)
Anderson	AN	0.008	0.021 (162.5)	0.002 (-75)	0.005 (-37.5)	0.002 (-75)	0.002 (-75)	0.003 (-62.5)	0.005 (-37.5)	0.009 (12.5)	0.003 (-62.5)
Anderson	W	0.003	0.039 (1200)	0.001 (-66.7)	0.006 (100)	0.001 (-66.7)	0.001 (-66.7)	0.002 (-33.3)	0.006 (75.3)	0.007 (133.3)	0.008 (166.7)
Martin	All	0.187	0.216 (15.5)	0.1 (-46.5)	0.092 (-50.8)	0.123 (-34.2)	0.124 (-33.7)	0.128 (-31.6)	0.089 (-52.4)	0.147 (-21.4)	0.097 (-48.1)
Martin	C	0.690	0.747 (8.3)	0.456 (-33.9)	0.423 (-38.7)	0.561 (-18.7)	0.552 (-20)	0.6 (-13)	0.389 (-43.6)	0.585 (-15.2)	0.423 (-38.7)
Martin	D	0.193	0.234 (21.2)	0.077 (-60.1)	0.056 (-71)	0.099 (-48.7)	0.102 (-47.2)	0.094 (-51.3)	0.077 (-60.1)	0.129 (-33.2)	0.076 (-60.6)
Martin	BN	0.132	0.14 (6.1)	0.031 (-76.5)	0.029 (-78)	0.038 (-71.2)	0.044 (-66.7)	0.036 (-72.7)	0.024 (-81.8)	0.085 (-35.6)	0.036 (-72.7)
Martin	AN	0.021	0.021 (0)	0.007 (-66.7)	0.011 (-47.6)	0.008 (-61.9)	0.008 (-61.9)	0.008 (-61.9)	0.014 (-33.3)	0.024 (14.3)	0.009 (-57.1)
Martin	W	0.016	0.047 (193.8)	0.008 (-50)	0.014 (-12.5)	0.007 (-56.2)	0.009 (-43.8)	0.008 (-50)	0.011 (-31.3)	0.015 (-6.3)	0.013 (-18.8)
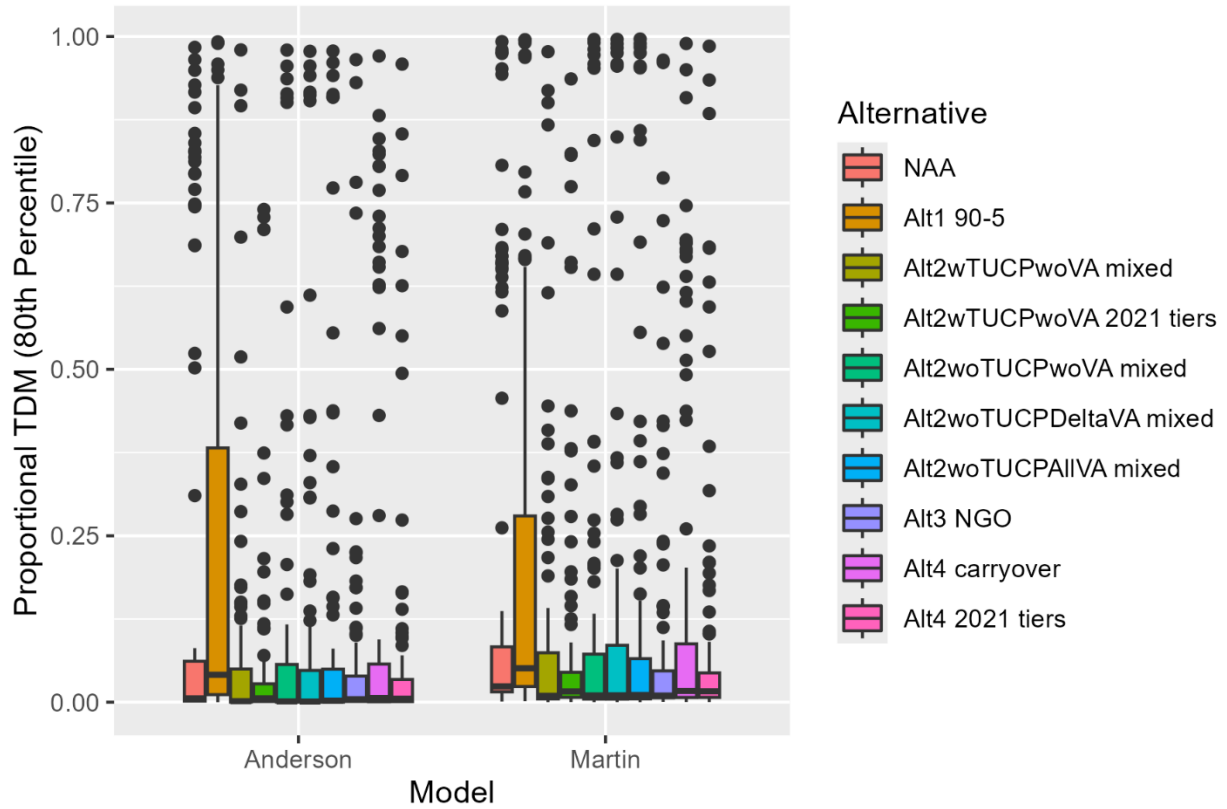
Figure L.2-1. Summaries of proportional TDM estimates across all WYs for the Anderson and Martin TDM estimates, calculated using the 80th percentile of TDM for each WY.
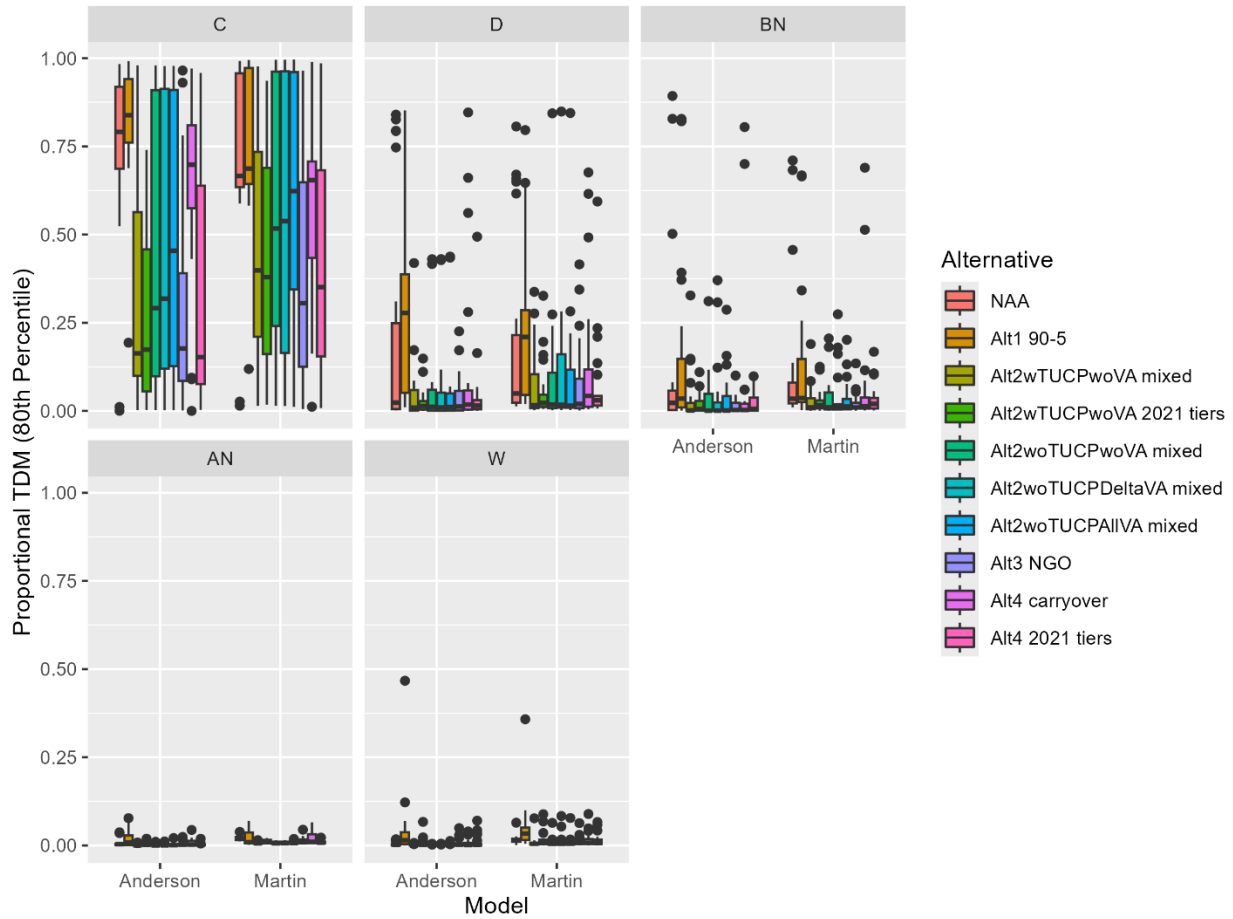
Figure L.2-2. Summaries of proportional TDM estimates for each WYT for the Anderson and Martin TDM models, calculated using the 80th percentile of TDM for each WY.
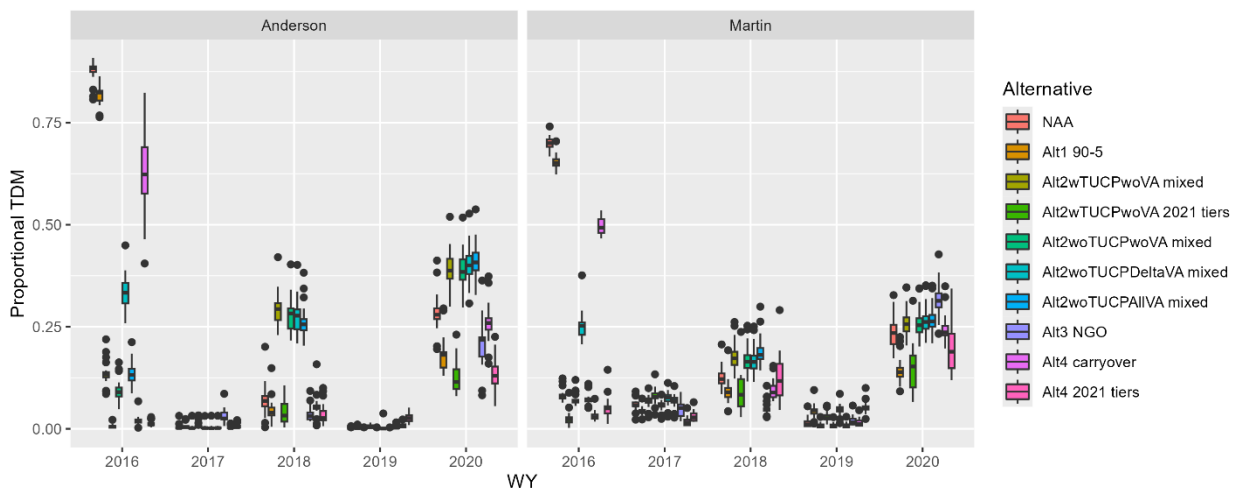

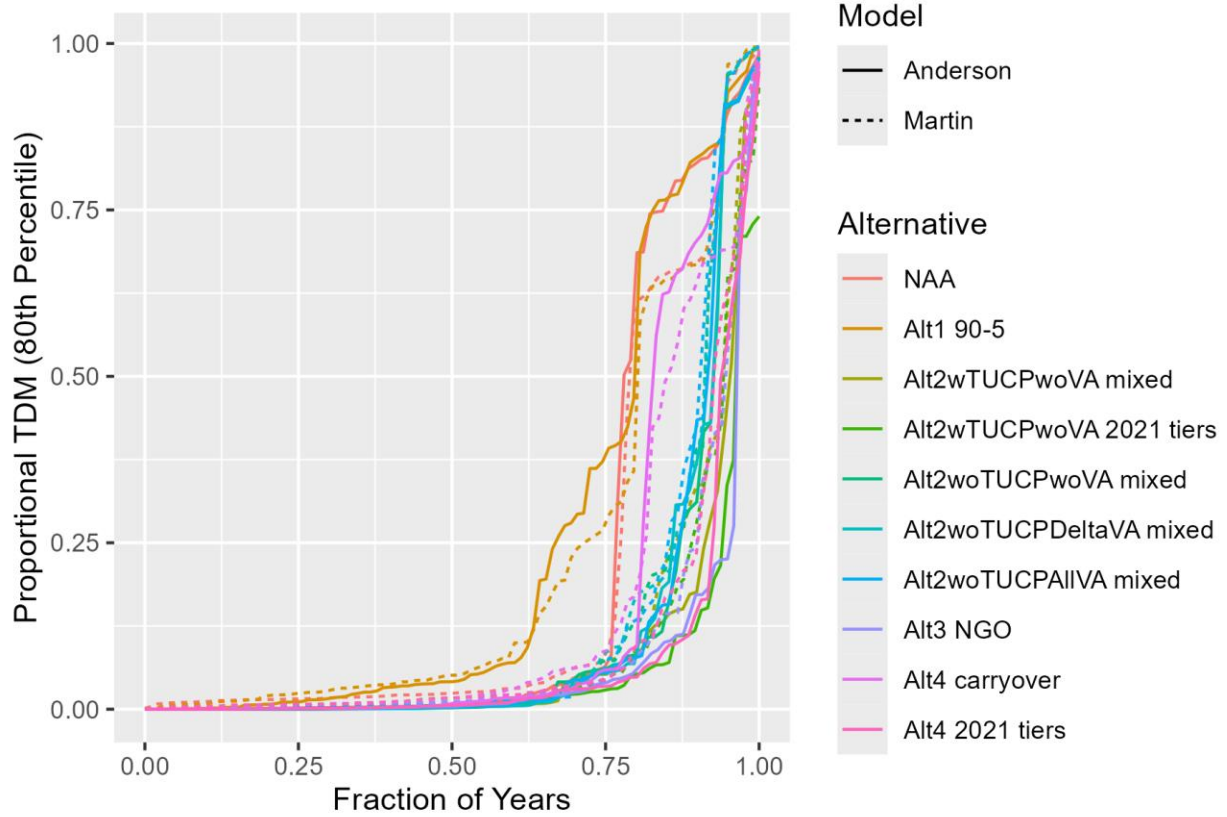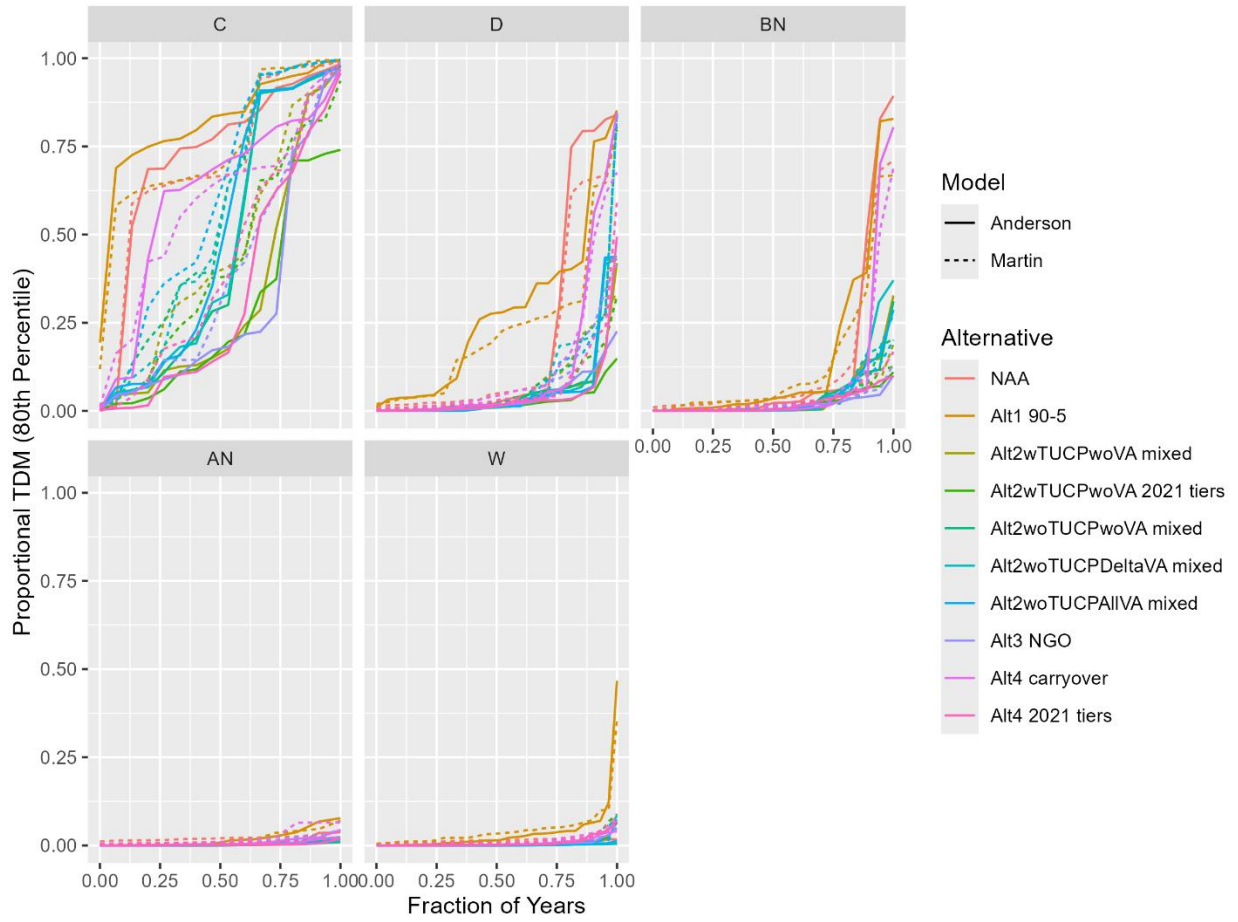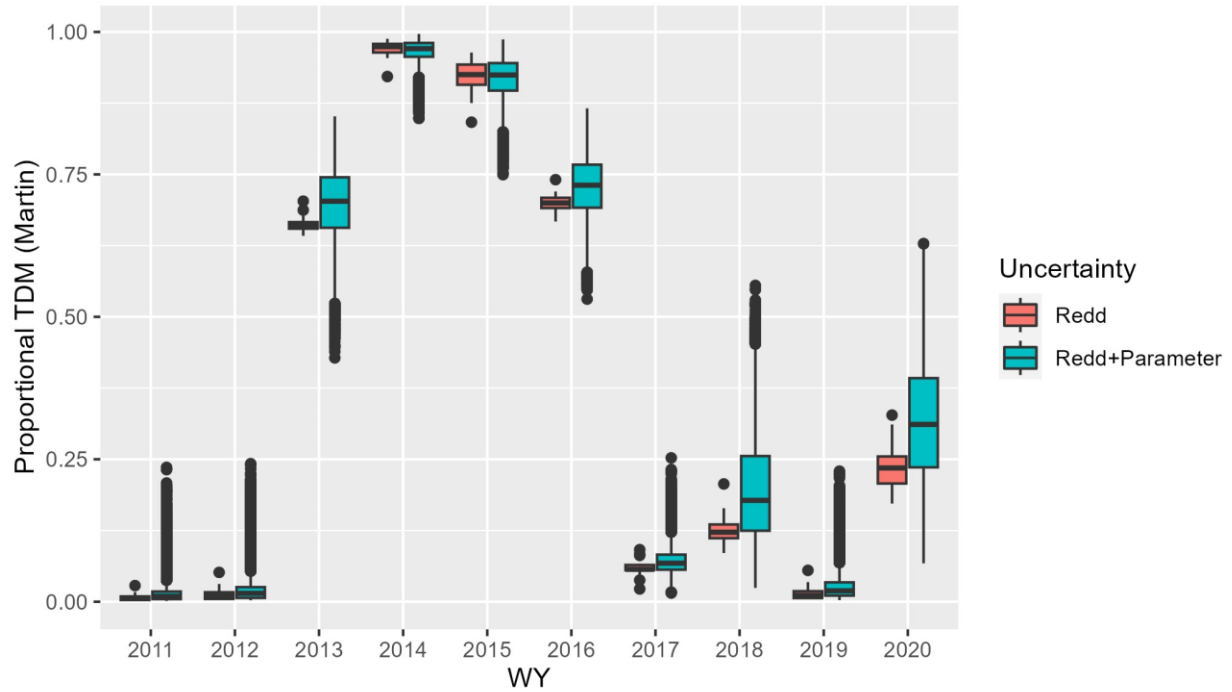Figure L.2-3. Trends in proportional TDM for water years 2016-2020, including the range of TDM values across different redd distributions for each WY.

Figure L.2-4. Exceedance plots of proportional TDM estimates across all WYs for the Anderson and Martin TDM model using the 80th percentile of TDM for each WY.

Figure L.2-5. Exceedance plots of proportional TDM estimates for each WYT for the Anderson and Martin TDM model using the 80th percentile of TDM for each WY.

Figure L.2-6. Trends in proportional TDM (i.e., Martin model only) for water years 2011–2020 for the NAA. Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.
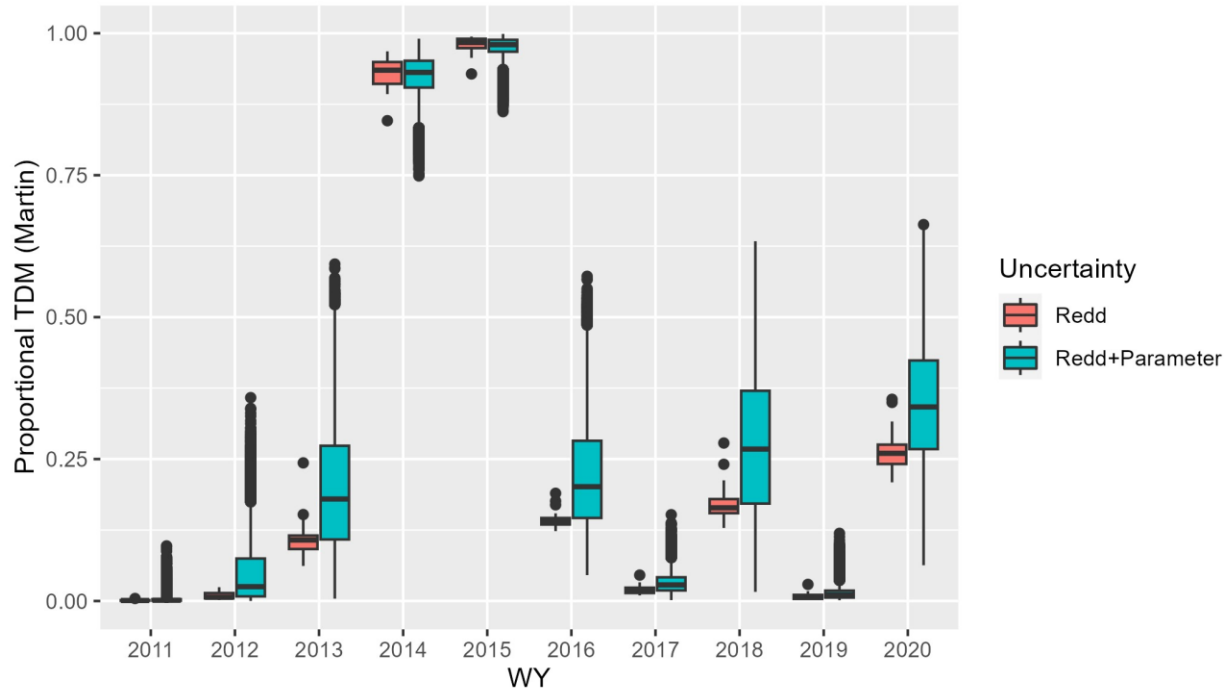
Figure L.2-7. Trends in proportional TDM (i.e., Martin model only) for CalSim 3 water years 2011-2020 for the Alt2woTUCPwoVA mixed alternative. Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.

L.2.2.2   BA

L.2.2.2.1   Takeaways

Values of proportional TDM are presented for relevant alternatives in Table L.2-3 and Figure L.2-8 through Figure L.2-16.

For the Anderson model, expected proportional TDM values calculated across all WYTs, for only critical WYTs, and for only wet WYTs were 0.094, 0.468, and 0.001, respectively for the Alt2woTUCPwoVA (Table L.2-3). Relative to the Anderson model, expected proportional TDM values were slightly higher for the Martin model across all WYTs and for only critical WYTs, but slightly lower for wet WYTs (i.e., 0.118, 0.556, and 0.006, respectively, for Alt2woTUCPwoVA). For expected proportional TDM values calculated across all WYTs, mean TDM values ranged from 0.070 to 0.190 across all alternatives for the Anderson model and 0.093 to 0.187 for the Martin model. Water year-specific TDM estimates varied from approximately 0 to 1 across alternatives and models, and were highest in critical WYTs (Figure L.2-8, Figure L.2-9). For select recent WYs, alternatives, and models, annual TDM estimates varied by as much as 0.25 due to uncertainty in spatial and temporal redd distributions (Figure L.2-10).

For the Anderson and Martin models, greater than 75% of modeled WYs for every alternative resulted in expected proportional TDM values less than 0.125 (Figure L.2-11). For critical WYTs only, at least 12.5% of modeled WYs resulted in expected proportional TDM values less than 0.5 for all alternatives; for above normal and wet WYTs only, expected proportional TDM never exceeded 0.125 for all alternatives (Figure L.2-12).

For the model runs with the "2021 Updated Tier Strategy" applied to NAA and all components of Alt2, greater than 75% of all modeled WYs for every alternative resulted in expected TDM values less than 0.0625 for both the Martin and Anderson models (Figure L.2-13). For the Martin model only, almost all alternatives resulted in expected TDM less than 0.125 for greater than 87.5% of all modeled WYs. For critical WYTs only, at least 37.5% of modeled WYs resulted in expected proportional TDM values less than 0.5 for all alternatives; for both above normal and wet WYTs, expected TDM never exceeded 0.125 (Figure L.2-14). Values of TDM never exceeded 0.25 for below normal WYTs.

For recent water years 2011-2020, expected proportional TDM values for both the NAA and Alt2woTUCPwoVA alternatives had noticeably greater variation when both redd and parameter uncertainty were included than when only redd uncertainty was included (Figure L.2-15, Figure L.2-16).

Table L.2-3. Predicted mean proportional TDM estimates for different models and WYTs, in which presented means are the means of 80th percentile TDM values for relevant CalSim WYs.

| Model	WYT	EXP1	EXP3	NAA	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA
Anderson	All	1	0.056	0.190	0.070	0.094	0.094	0.095
Anderson	C	1	0.273	0.712	0.334	0.468	0.462	0.466
Anderson	D	1	0.023	0.210	0.049	0.051	0.051	0.052
Anderson	BN	1	0.013	0.135	0.023	0.035	0.038	0.040
Anderson	AN	1	0.007	0.008	0.002	0.002	0.002	0.002
Anderson	W	1	0.012	0.003	0.001	0.001	0.001	0.001
Martin	All	1	0.077	0.187	0.093	0.118	0.117	0.115
Martin	C	1	0.349	0.690	0.427	0.556	0.548	0.543
Martin	D	1	0.031	0.193	0.067	0.087	0.085	0.079
Martin	BN	1	0.027	0.132	0.027	0.033	0.036	0.034
Martin	AN	1	0.016	0.021	0.007	0.007	0.007	0.008
Martin	W	1	0.019	0.016	0.008	0.006	0.008	0.008
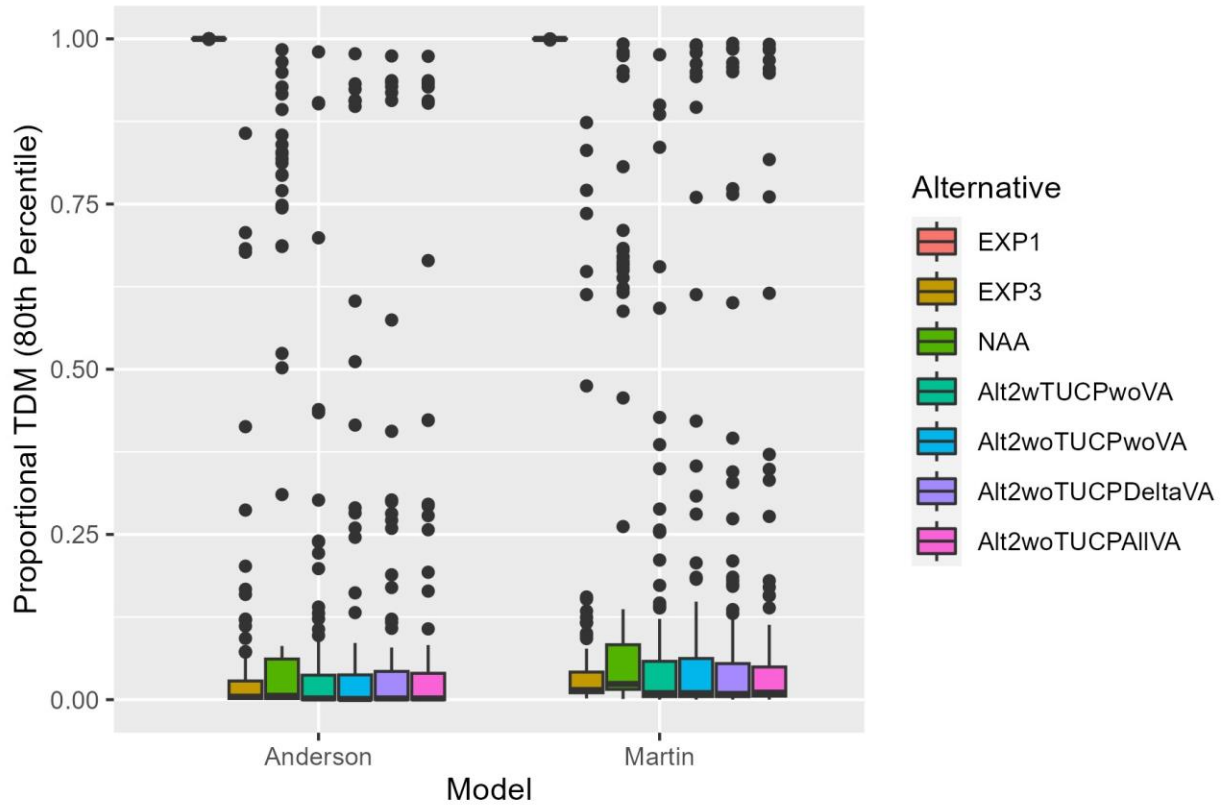
Figure L.2-8. Summaries of proportional TDM estimates across all WYs for the Anderson and Martin TDM estimates, calculated using the 80th percentile of TDM for each WY.

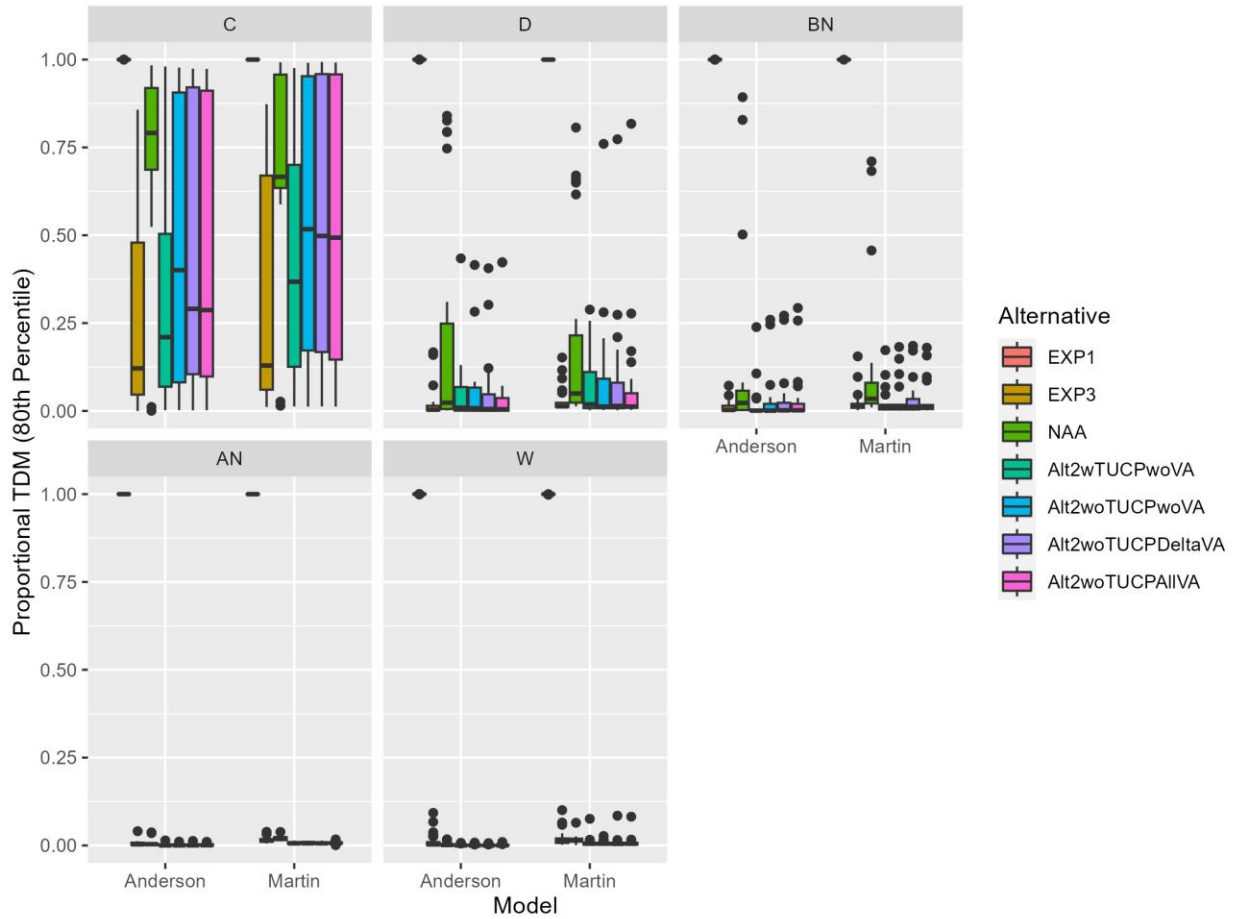Figure L.2-9. Summaries of proportional TDM estimates for each WYT (i.e., facets) for the Anderson and Martin TDM models, calculated using the 80th percentile of TDM for each WY.
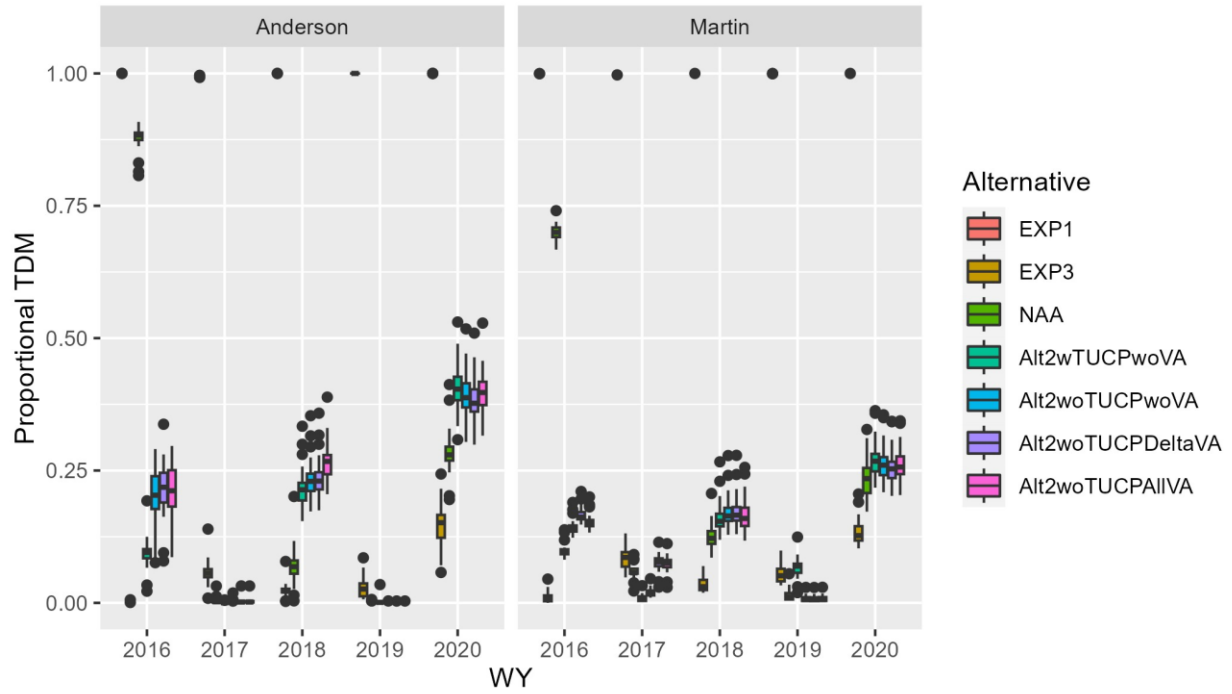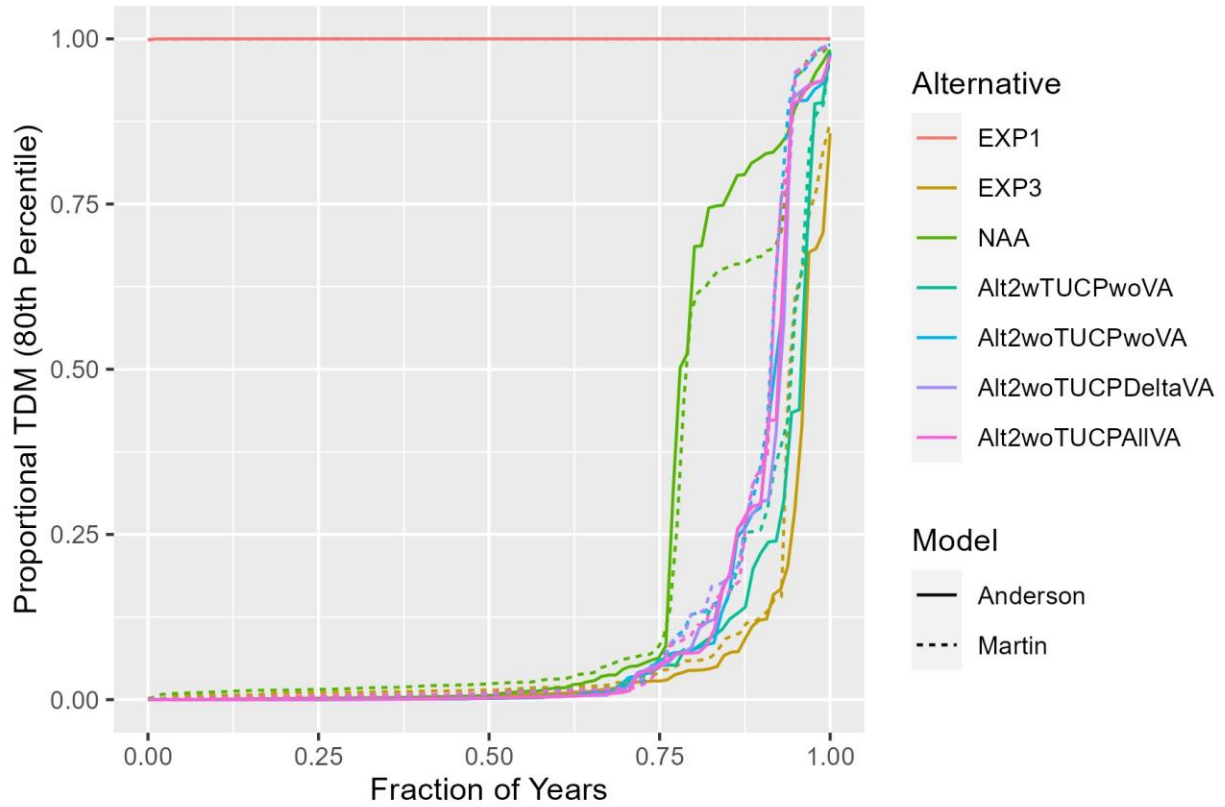
Figure L.2-10. Trends in proportional TDM for CalSim 3 water years 2016-2020, including the range of TDM values across different redd distributions for each WY, for the Anderson and Martin TDM models (i.e., facets).

Figure L.2-11. Exceedance plots of proportional TDM estimates across all WYs for the Anderson and Martin TDM models, calculated using the 80th percentile of TDM for each WY.
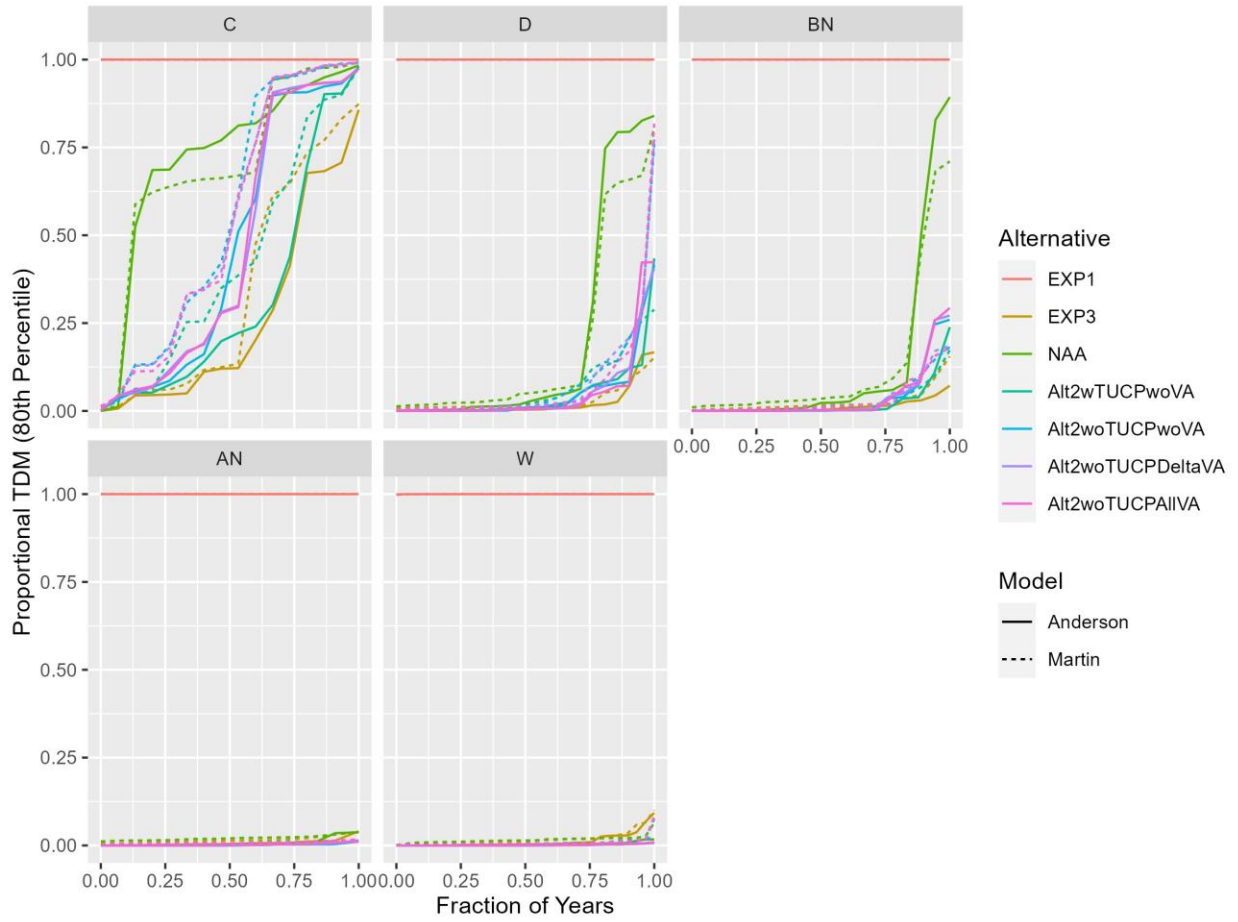
Figure L.2-12. Exceedance plots of proportional TDM estimates for each WYT (i.e., facets) for the Anderson and Martin TDM models, calculated using the 80th percentile of TDM for each WY.
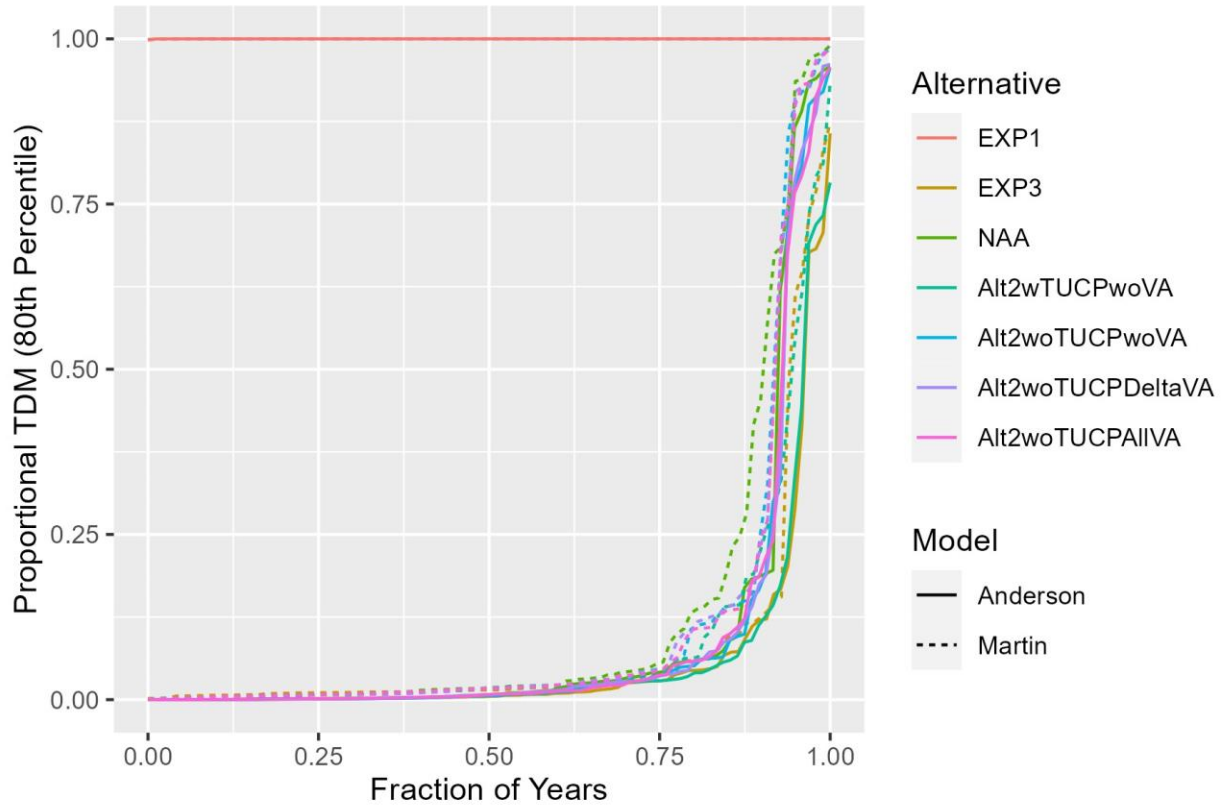
Figure L.2-13. Exceedance plots of proportional TDM estimates across all WYs for the Anderson and Martin TDM models, based on the "2021 Updated Tier Strategy" for NAA and Alt2 and calculated using the 80th percentile of TDM for each WY.
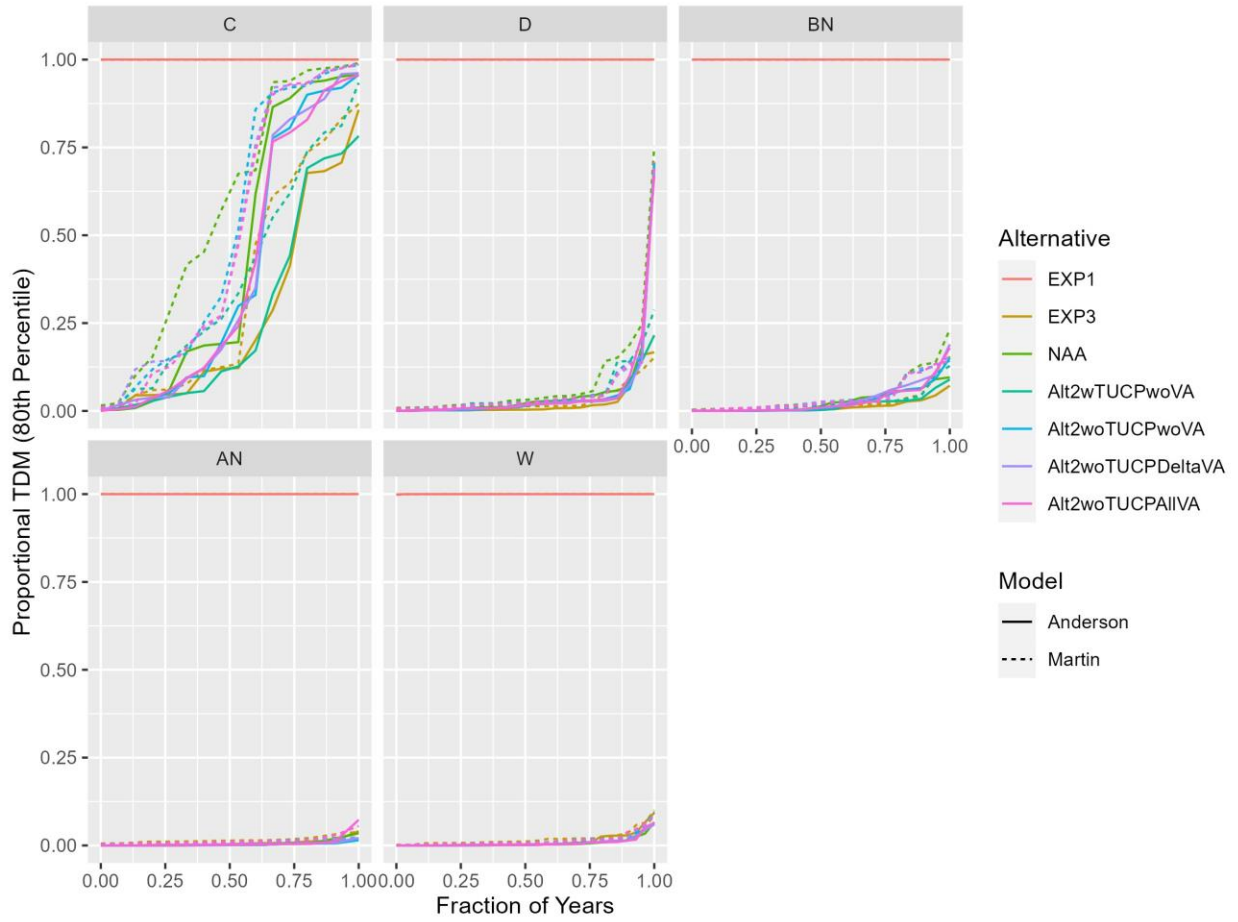
Figure L.2-14. Exceedance plots of proportional TDM estimates for each WYT for the Anderson and Martin TDM models, based on the "2021 Updated Tier Strategy" for NAA and Alt2 and calculated using the 80th percentile of TDM for each WY.
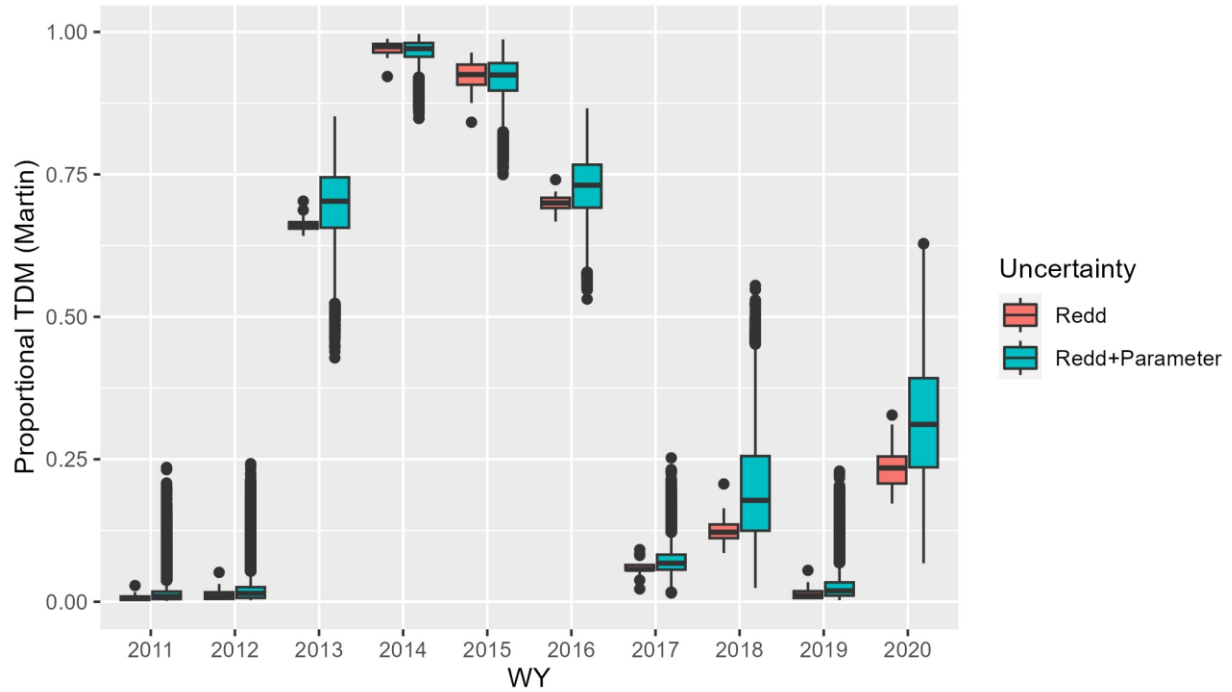
Figure L.2-15. Trends in proportional TDM (i.e., Martin model only) for CalSim 3 water years 2011-2020 for the NAA alternative. Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.
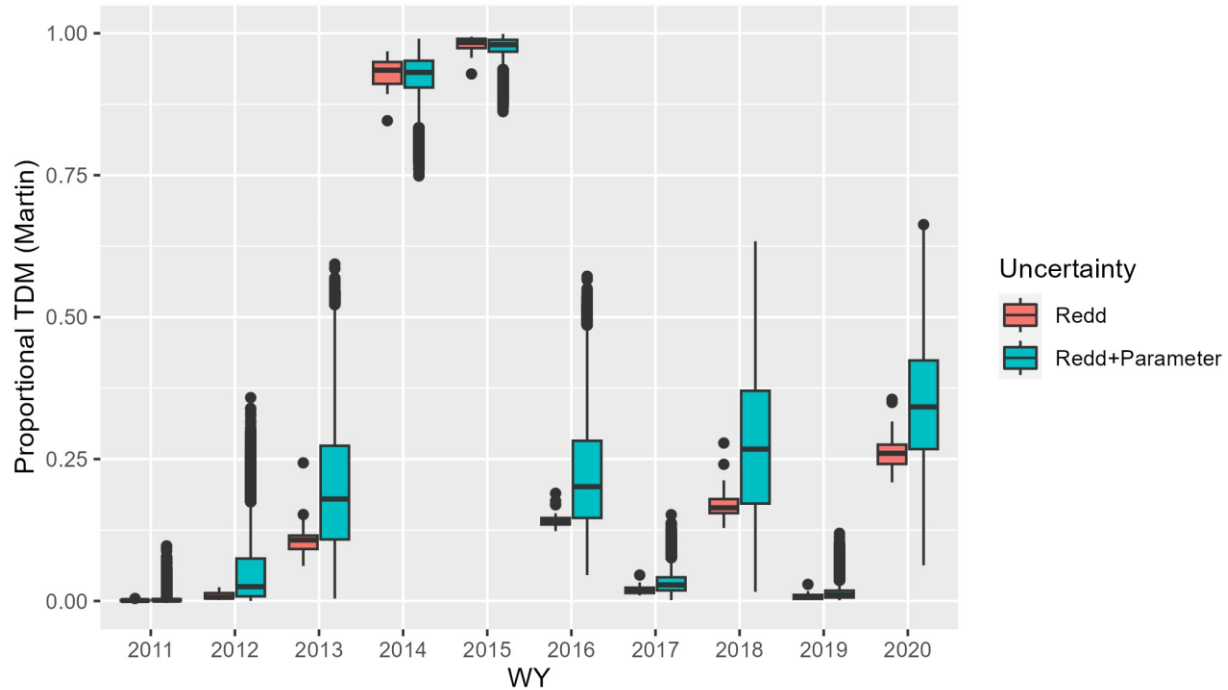
Figure L.2-16. Trends in proportional TDM (i.e., Martin model only) for CalSim 3 water years 2011-2020 for the Alt2woTUCPwoVA alternative. Boxplots summarize TDM variability across either only different annual redd distributions or both different redd distributions and posterior parameter estimates.

L.2.3 References

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