Appendix K

Reclamation Salmon Mortality Model. Attachment 5.D.1 of the ROC on Biological Assessment

Attachment 5.D.1, Reclamation Salmon Mortality Model

5.D.1 Reclamation Salmon Mortality Model

5.D.1.1 Introduction

The Reclamation salmon mortality model computes salmon spawning losses in the five rivers, Trinity, Sacramento, Feather, American, and Stanislaus, based on output from the Reclamation Temperature and HEC5Q model estimates of water temperatures.

5.D.1.2 Key Processes

Temperature-exposure mortality criteria for three life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) are used along with the spawning distribution data and output from the river temperature models to compute percentage of salmon spawning losses.

5.D.1.3 Model and Application

The Reclamation Salmon Mortality Model was created and developed exclusively for CVP/SWP systems in the Central Valley. The Reclamation Salmon Mortality Model simulates the early life stage mortality of Chinook Salmon along reaches of the Trinity (below Lewiston Dam to Burnt Ranch), Sacramento (below Keswick Dam to Princeton), Feather (below the Fish Dam to the Sacramento River confluence), American (below Nimbus Dam to the Sacramento River confluence), and Stanislaus Rivers (below Goodwin Dam to Riverbank). The model sets an initial spawning distribution along the different river reaches (as a percentage) and uses water temperature data to simulate egg development and mortality based on temperature relationships specified in the model. Inputs to the Reclamation Salmon Mortality model include water temperature from the temperature models (HEC5Q and Reclamation Temperature Model) provided at the river reaches defined in Table 5.D.1-1 through Table 5.D.1-5. Daily water temperature results for the Sacramento, American, and Stanislaus Rivers from the HEC5Q models and monthly water temperature results for the Trinity and Feather Rivers from the Reclamation Temperature Model are used as input to Reclamation Salmon Mortality Model. The model also uses California Department of Fish and Wildlife (CDFW) and U.S. Fish and Wildlife Service (USFWS) data on Chinook salmon spawning distribution and timing in the five rivers (Reclamation 1991, Loudermilk 1994, and Reclamation 1994). For the Sacramento River reaches, spawning distributions were provided by NMFS based on the 2003–2014 aerial redd survey data. As noted, the temperature-exposure mortality criteria for three life stages (pre-spawned eggs, fertilized eggs, and pre-emergent fry) are used along with the spawning distribution data (Table 5.D.1-1 through Table 5.D.1-5) and output from the Reclamation Temperature Model and HEC5Q to compute percentage of salmon spawning losses. Because the Reclamation Salmon Mortality model operates on a daily time-step, a procedure is required to utilize the monthly Reclamation Temperature Model output for Feather and Trinity Rivers. The salmon model computes daily temperatures based on linear interpolation between the monthly temperatures, which are assumed to occur on the 15th day of the month. The final output from the Reclamation Salmon Mortality Model used in this analysis is the resulting annual percent mortality.

Table 5.D.1-1. Upper Sacramento River Spawning Distributions

Reach	No.	River Reach	Spawning Distribution (%)			
			Fall	Late-Fall	Winter	Spring
UPPER	1	Keswick Dam – ACID Dam	16.28%	67.6%	45.03%	12.43%
	2	ACID Dam – Hwy 44	5.48%	5.0%	42.09%	32.77%
	3	Hwy 44 – Upper Anderson Bridge	12.26%	3.7%	12.23%	27.66%
	4	Upr Anderson Bridge – Balls Ferry	16.19%	7.9%	0.26%	10.90%
	5	Balls Ferry – Jellys Ferry	23.08%	8.0%	0.28%	8.75%
	6	Jellys Ferry – Bend Bridge	6.61%	1.0%	0.06%	2.58%
	7	Bend Bridge – Red Bluff Diversion Dam	3.48%	0.5%	0.00%	0.83%
	Total – Upper Salmon Reach		**83.37%**	**93.8%**	**99.95%**	**95.92%**
MIDDLE	8	Red Bluff Diversion Dam – Tehama Bridge	10.82%	3.1%	0.05%	4.08%
	9	Tehama Bridge – Woodson Bridge	3.07%	1.2%	0.00%	0.00%
	10	Woodson Bridge – Hamilton City	1.82%	1.1%	0.00%	0.00%
	Total – Middle Salmon Reach		**15.71%**	**5.4%**	**0.05%**	**4.08%**
LOWER	11	Hamilton City – Ord Ferry	0.82%	0.00%	0.00%	0.00%
	12	Ord Ferry – Princeton	0.10%	0.00%	0.00%	0.00%
	Total – Lower Salmon Reach		**0.92%**	**0.00%**	**0.00%**	**0.00%**

NOTE:
Sacramento River salmon spawning distributions were revised based on average 2003-2014 Redd survey data, provided by David Swank at National Marine Fisheries Service (NMFS) in April 2015.

Table 5.D.1-2. Lower Feather River Spawning Distributions

Salmon Reach	No.	River Reach	Spawning Distribution (%)
UPPER	1	Fish Dam – RM 65.0	20
	2	RM 65.0 – RM 62.0	20
	3	RM 62.0 – Upstream of Afterbay	20
	Total – Upper Salmon Reach		**60**
LOWER	4	Downstream of Afterbay – RM 55.0	10
	5	RM 55.0 – Gridley	10
	6	Gridley – RM 47.0	10
	7	RM 47.0 – Honcut Creek	10
	8	Honcut Creek – Yuba River	0
	9	Yuba River – Mouth	0
	Total – Lower Salmon Reach		**40**

Table 5.D.1-3. Trinity River Spawning Distributions

No.	River Reach	Spawning Distribution (%)
1	Lewiston Dam – Old Bridge	22
2	Old Bridge – Brown’s Mountain Bridge	20
3	Brown’s Mountain Bridge – Steel Bridge	18
4	Steel Bridge – Douglas City	15
5	Douglas City – Canyon Creek	16
6	Canyon Creek – North Fork	9
7	North Fork – Big Bar Bridge	0
8	Big Bar Bridge – Big French Creek	0
9	Big French Creek – Burnt Ranch	0

Table 5.D.1-4. Lower American River Spawning Distributions

No.	River Reach	Spawning Distribution (%)
1	Nimbus Dam – Sunrise Blvd	31
2	Sunrise Blvd – A. Hoffman/Cordova	59
3	A. Hoffman/Cordova – Arden	5
4	Arden – Watt Ave	3
5	Watt Ave – Filtration Plant	1
6	Filtration Plant – H St	0
7	H St – Paradise	1
8	Paradise – 16th St	0
9	16th St – Mouth	0

Table 5.D.1-5. Lower Stanislaus River Spawning Distributions

No.	River Reach	Spawning Distribution (%)
1	Goodwin Dam – Knights Ferry	8.8
2	Knights Ferry – RM 51.33	18.6
3	RM 51.33 – RM 48.67	18.6
4	RM 48.67 – Orange Blossom Bridge	18.6
5	Orange Blossom Bridge – RM 43.67	9.8
6	RM 43.67 – RM 41.33	9.7
7	RM 41.33 – Oakdale R.A.	9.7
8	Oakdale R.A. – RM 36.50	3.1
9	RM 36.50 – Riverbank	3.1

Temperature units (TU), defined as the difference between river temperatures and 32°F, are calculated daily by the mortality model and used to track life-stage development (Table 5.D.1-6). Eggs are assumed to hatch upon exposure to 750 TUs following fertilization. Fry are assumed to emerge from the gravel after exposure to 750 TUs following egg hatching into the pre-emergent fry stage. The temperature mortality rates for fertilized eggs (Table 5.D.1-7), the most sensitive life stage, range from 8% in 24 days at 57°F to 100% in 7 days at 64°F or above (Reclamation 1994). Most salmon spawning generally occurs above the North Fork on the Trinity River, above Red Bluff Diversion Dam on the Sacramento River main stem for all four Chinook salmon runs, above Watt Avenue on the American River, and above Riverbank Bridge on the Stanislaus River. Fall-run Chinook salmon spawning usually occurs from mid-October through December, peaking about mid-November. Winter-run Chinook salmon usually spawn in the Sacramento River during May–July and spring-run Chinook salmon during August–October.

Table 5.D.1-6. Life-Stage Development Criteria

Life-Stage	Exposure Duration
Fertilized eggs hatch	750 TUs
Fry emerge from gravel	750 TUs

Table 5.D.1-7. Salmon Mortality Criteria

Life-Stage	Mortality	Exposure Duration
Fertilized eggs	8%	24 days at 57°F
Fertilized eggs	100%	7 days at 64°F or above

5.D.1.4 Model Mathematics

The model employs an "absolute" daily or "instantaneous" daily mortality rate for the reference period using the following equation (Hydrologic Consultants, Inc. 1996):

$$Mi = (1-Mn)^{(1/n)}$$

Where:

Mi = daily mortality rate

Mn = mortality rate after exposure time n = exposure time in days

A more in depth discussion of the model equation is available from Hydrologic Consultants, Inc., 1996.

5.D.1.5 Rationale

The Reclamation Salmon Mortality Model has been applied to past CVP/SWP system operational performance evaluations (Reclamation 1994 and 2004) and Reclamation has expertise in the application of Reclamation Salmon Mortality model and companion temperature models.

This tool is one of many fisheries models available for application to the CVP/SWP systems. The results are provided as complementary information to the historical observations and the other fishery mortality, population, and life-cycle models presented.

5.D.1.6 Quality Assurance and Data Quality Assessment

The development of the Reclamation Salmon Mortality Model was a collaborative and iterative effort by Reclamation, USFWS, and the (CDFW) (Reclamation 1991). This interaction serves as the quality assurance and data quality assessment for the model. A formal process documenting the quality assurance and data quality assessment is unavailable. At the present, a peer review of the model has not been performed.

5.D.1.7 Assumptions

The following assumptions are listed in an excerpt documenting the Chinook Salmon Mortality Model (Hydrologic Consultants, Inc. 1996):

> *These fishery assumptions stated in the USFWS memorandum dated January 19, 1990 are listed below.*
>
> 1 *Survival of salmon fry and juveniles is density independent at the average spawning population levels existing from the early 1960's through the 1980's. Numerical estimates of mainstream spawner populations are based upon spawning area surveys and counts at Red Bluff Diversion Dam.*
>
> 2 *The temperature-mortality relationship for unfertilized eggs in the female salmon spawner is the same as for fertilized eggs reaching the eyed stage (USBR 1991, p.A109, Figure 2).*
>
> 3 *The percent of the adult salmon population entering the project area is estimated by the records of passage over Red Bluff Diversion Dam (USBR 1991, pp. A106-107, Table 1).*
>
> 4 *Time of spawning for each run of Chinook salmon displayed in Table 2 (USBR 1991 pp. A110-111) is estimated for the fall-run, late fall-run and winter-run by aerial redd counts and spawning area surveys. Time of spawning for spring-run is estimated by spawning records recorded in the Baird Hatchery at the turn of the century.*
>
> 5 *Sacramento River salmon spawning distributions displayed in Tables 3 through 7 (USBR 1991, pp. A112, and A115-A1118) are from aerial surveys of the spawning grounds. Effort was relatively consistent during the 1980's.*
>
> 6 *Development from fertilized egg to hatching requires 750 (^{o}F) temperature units, and another 750 (^{o}F) temperature units from hatching to emergent fry (32mm), for a total of 1500 (^{o}F) temperature units from egg to emergent fry.*

7 *Mortality of eggs exposed at various temperatures and exposure durations is displayed in Table 8 (USBR 1991, p. A119).*

8 *Temperature induced mortality for pre-emergent fry is displayed in Table 9 (USBR 199, p. A120). There is virtually a total lack of data to base this relationship on other than the apparent increased tolerance of pre-emergent fry as compared to eggs.*

9 *Project benefits in terms of increased adult stock sizes will be determined by applying the percent increase in survival to emergence to three different stock sizes in each of four water year types as proposed in Table 10 (USBR 1991, p. A122).*

Specific details of the assumptions, such as estimated temperature and exposure duration mortality relationships, arrival, and temperature interpolation, are compiled in the Chinook Salmon Mortality Model (Hydrologic Consultants, Inc. 1996).

5.D.1.8 Model Testing

Internal testing of the Reclamation Salmon Mortality model has been performed in the past; however, a formal report documenting the testing of the model is unavailable.

5.D.1.8.1 Sensitivity/Uncertainty of Model Inputs

No sensitivity or uncertainty analyses were performed on the model inputs.

5.D.1.9 Limitations

The Reclamation Salmon Mortality model is limited to temperature effects on early life stages of Chinook salmon. It does not evaluate potential direct or indirect temperature impacts on later life stages, such as emergent fry, smolts, juvenile out-migrants, or adults. Also, it does not consider other factors that may affect salmon mortality, such as in-stream flows, gravel sedimentation, diversion structures, predation, ocean harvest, etc.

Since the Reclamation Salmon Mortality Model is the terminal model in the sequence of two previous models (CalSim II and the Reclamation Temperature Model or the HEC5Q model), the limitations of the previous models should also be taken into consideration. Sensitivity or uncertainty analyses were not performed on the Reclamation Temperature or the Reclamation Salmon Mortality models.

5.D.1.10 Future Development

No future development to the Reclamation Salmon Mortality Model is planned at this time.

5.D.1.11 Reporting Metrics

Metrics used were percent salmon mortality by river by water year type (based on the 40-30-30 indexing).

5.D.1.12 References

Bureau of Reclamation. 1991. Shasta Outflow Temperature Control PR/ES, Appendix A - Modeling, Appendix B - Environmental (Part I - Fisheries). May. Sacramento, CA, May.

Bureau of Reclamation. 1994. CVPIA-PEIS, Impact Assessment Methodology for Fish, Draft Working Paper #3. December. Sacramento, CA.

Bureau of Reclamation, 2004. Long-Term Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. June 30.

Hydrologic Consultants, Inc. 1996. Water Forum Issue Paper Chinook Salmon Mortality Model: Development, Evaluation, and Application as One Tool to Assess the Relative Effects of Alternative Flow and Diversion Scenarios on the Lower American River.

Loudermilk, W. E. for Neillands, W. G., "...chinook salmon spawning distribution and timing in the Stanislaus River for CVPIA-PEIS Modeling", CA Department of Fish and Game, Fresno, CA, letter to USBR, July 21, 1994.