Appendix L Reclamation Salmon Mortality Model

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 SRWQM models estimates.

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 percents of salmon spawning losses.

Model and Application

The Reclamation Salmon Mortality Model was created and developed exclusively for CVP and SWP systems in the Central Valley. Inputs to the salmon mortality model include flows from the CALSIM model and water temperature from the temperature models provided at the river reaches defined in Tables L-1 through L-5. For the SRWQM, temporal downsizing is performed on the CALSIM monthly average flows prior to running SRWQM. Temporal downsizing of flows are described in Appendix H, Attachment H-1. The model also uses DFG and FWS data on Chinook salmon spawning distribution and timing in the five rivers (Reclamation 1991, Loudermilk 1994, and Reclamation 1994). 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 (Tables L-1 through L-5) and output from the Reclamation Temperature Model and SRWQM to compute percents of salmon spawning losses. Because the salmon mortality model operates on a daily time-step, a procedure is required to utilize the monthly temperature model output. 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.

Table L-1. Upper Sacramento River (Revised February 27, 2007) Spawning Distributions.

Salmon Reach	No.	River Reach	Spawning Distribution (%)			
			Fall	Late-Fall	Winter	Spring
UPPER	1	Keswick Dam – ACID Dam	4.26	25.5	41.8	4.5
	2	ACID Dam – Hwy 44	10.54	21.7	27.4	19.0
	3	Hwy 44 – Upper Anderson Bridge	13.98	21.1	28.8	31.5
	4	Upr Anderson Bridge – Balls Ferry	13.05	13.9	1.5	17.5
	5	Balls Ferry – Jellys Ferry	12.88	4.4	0.1	25.5
	6	Jellys Ferry – Bend Bridge	6.96	1.7	0.2	1.5
	7	Bend Bridge – Red Bluff Div Dam	1.88	1.1	0.0	0.0
	Total – Upper Salmon Reach		**63.55**	**89.4**	**99.8**	**99.5**
MIDDLE	8	Red Bluff Div Dam – Tehama Bridge	22.29	5.6	0.2	0.5
	9	Tehama Bridge – Woodson Bridge	6.35	2.2	0.0	0.0
	10	Woodson Bridge – Hamilton City	5.59	1.1	0.0	0.0
	Total – Middle Salmon Reach		**34.23**	**8.9**	**0.2**	**0.5**
LOWER	11	Hamilton City – Ord Ferry	1.54	1.1	0.0	0.0
	12	Ord Ferry – Princeton	0.68	0.6	0.0	0.0
	Total – Lower Salmon Reach		**2.22**	**1.7**	**0.0**	**0.0**

NOTE:

Based on the latest Redd survey data, the salmon spawning distributions for winter-run (2001-2005 survey) and spring-run (2001-2004 survey) were revised on February 27, 2007. Fall-run and late fall-run distributions were not changed since most diversion dams are removed prior to spawning. The revision was a result of communications between John Hannon (Reclamation), Bruce Oppenheim (NOAA), Elizabeth Campbell (NOAA), and Russ Yaworsky (Reclamation).

Table L-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 L-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 L-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 L-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 L-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 L-7), the most sensitive life stage, range from 8 percent in 24 days at 57°F to 100 percent 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 on the Sacramento River main stem for all four Chinook salmon runs, above Watt Avenue on the American River, and above Riverbank on the Stanislaus River. Fall-run salmon spawning usually occurs from mid-October through December, peaking about mid-November. Winter-run salmon usually spawn in the Sacramento River during May-July and spring-run salmon during August-October.

Table L-6. Life-stage development criteria.

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

Table L-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

Model Mathmatics

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 indepth discussion of the model equation is available from Hydrologic Consultants, Inc., 1996.

Rationale

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

This tool is one of many temperature models available for application to the CVP and SWP systems. It is also one of many best available science tools in the absence of guidance (from the collective body of fishery scientists) in selecting a preferred salmon model for the OCAP BA. The results are provided as complementary information to the historical observations and the other fishery mortality, population, and life-cycle models presented.

Quality Assurance and Data Quality Assessment

The development of the Reclamation Salmon Mortality Model was a collaborative and iterative effort by Reclamation, U.S. Fish and Wildlife Service (USFWS), and the California Department of Fish and Game (CDFG) (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.

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 counets at Red Bluff Diversion Dam.*
>
> 2) *The temperature-mortality relationship for unfertilized eggs in the female salmon spawner is the sam as for fertilized eggs reaching the eyed stage (USBR 1991, p.A109, Figure 2).*
>
> 3) *The percent of the adult salmon population entering the projet 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 winter0run 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).*

More 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).

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.

Sensitivity/Uncertainty of Model Inputs

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

Limitations

The salmon 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 SRWQM), 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.

Future Development

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

Reporting Metrics

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

References

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.

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

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

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