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HETCH HETCHY RESERVOIR TUOLUMNE RIVER

711

Summary report - Vol. II

River releases for fish enhancement and environmental aesthetics - a systems study

The City and County of San Francisco
Hetch Hetchy
Department of Water and Power

Bechtel Incorporated
1972

- HETCHY HETCHY RESERVOIR
- TUOLUMNE RIVER
- SUMMARY REPORT - VOLUME II

RIVER RELEASES FOR FISH
ENHANCEMENT AND ENVIRONMENTAL
AESTHETICS

-- A SYSTEMS STUDY

- FOR
THE CITY AND COUNTY OF
SAN FRANCISCO
HETCH HETCHY
DEPARTMENT OF WATER AND POWER

- BY
BECHTEL, INCORPORATED
1972

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APPENDIX III

RELEASE STATISTICS AND ESTIMATING EQUATIONS

1. GENERAL

This appendix contains statistical tables and estimating equations to permit estimation of secondary releases that are optimum under STROFAM-S (Stochastic Reservoir Operations, Forecasting and Allocation Model - Simulation Version) operating policy. The STROFAM-S model is fully described in Volume I of this report.

2. APPROACH

The general approach consisted of statistical analysis of the secondary releases determined in a simulation environment from five stochastically generated 50-year traces. The five traces were selected by stratification of the probability space of storage requirements, which in turn was based on 1000 stochastically generated 50-year monthly traces. This resulted in a sample of size 250 for each of the twelve months of the year. Stratified sampling affords a valid and economical means for sampling the statistical effect of range, which effect cannot be effectively sampled considering the historical trace alone.

Secondary releases under STROFAM-S are determined under optimality criteria that are based on having some stated percent assurance of holding to the primary rule curve at the end of the forecast period or at the month of minimum drawdown, if the former includes the latter. The releases determined under STROFAM-S policy are thus a function of the reservoir balance over the forecast period, and the "state" components of inflow, content, primary releases and evaporation. Of these, inflow and content are of primary importance, the others being essentially constant.

Inflow can be considered in terms of (1) inflow previous to the current month, and (2) forecasted inflow over the forecast period. We have chosen to use only the previous month's inflow as a state variable for previous inflow although it would be possible to use, say, the previous two, three, or k months. For Hetch Hetchy, the expected benefit of considering more than one previous monthly inflow would be small. If the reservoir were larger relative to the mean annual flow, a two- to six-month auto-regressive lag might have been useful.

Forecasted inflow, including the inflow forecasted for the current month, is the other component of the inflow state variable. It can be regarded separately from previous inflow in statistical analysis providing the forecast is independent of the previous month's inflow. The Bartell Forecast, which is derived from precipitation-snowmelt relations, thus qualifies as a state variable; however, the lag-K Markov forecast equation does not, since it is a linear function of last month's inflow.

STROFAM-S includes a procedure for breaking down a Bartell Forecast through June 30 and apportioning it to individual months in the forecast period. However, this procedure is not suitable for practical use with desk calculating machines. Therefore, the Bartell Forecast state variable is considered to be the total forecast through June 30th for months in which such forecasts are made (Nov 1 - June 1).

The decision variables are the releases. Given some end-of-month content, last month's inflow and a Bartell Forecast (if applicable), what should the releases be? This analysis addresses only the problem of estimating the secondary releases. The primary releases cannot be subjected to statistical analysis since these were essentially constant and equal to the primary demand in the five traces subjected to simulation studies and considered here.

The secondary releases consist of the secondary river releases and the secondary tunnel releases. However, there is a "structural" relationship between these two releases, which is the allocation mechanism discussed in Volume I and illustrated Figure 11 of that volume. For development of valid statistical estimating equations such structural relations must be removed. We therefore consider only the statistics of the total secondary release. After this is determined, the allocation mechanism can be used to allocate the total secondary release between the river and the tunnel.

In all the analyses to follow, percent values are used rather than acre-feet, since it is believed that this gives operating personnel a better feel for the data and enables them to more readily recognize critical situations. Total secondary release is considered in terms of total secondary demand. Inflow is considered in percent of the mean historical inflow. Content is considered in terms of percent of maximum content (360,173 acre-ft). The Bartell Forecast is considered in terms of percent of the mean historical inflow (not forecast) summed through June 30th.

3. PURPOSE

The purpose of these investigations is to provide equations for estimating secondary releases one month in advance that are statistically consistent with the simulation results presented in Volume I.

4. STATISTICAL TECHNIQUES

A. General. Each of the twelve monthly data sets were first subjected to bracketing in terms of the total secondary release vector. Table III-1 shows the results of this analysis, which was conducted in two ways. In the first case the release data were bracketed according to the total release (Y) as follows:

Bracket	Release (%)
1	$Y = 0$
2	$0 < Y < 100$
3	$Y = 100$

In the second case the release brackets were as follows:

Bracket	Release (%)
1	$0 \leq Y < 25$
2	$25 < Y \leq 50$
3	$50 < Y \leq 75$
4	$75 < Y \leq 100$

The data within each of the above seven brackets were then subjected to several sets of two-way classification as follows:

Inflow vs. Content
Inflow vs. Bartell Forecast
Content vs. Bartell Forecast

The two-way tabulations were useful for judging the type of statistical analysis to follow. These tables are available for inspection but are not reproduced here. In general, they are of little direct use in estimating secondary release since the divisions are in 20 or 25 percent increments (of inflow, content and forecast). However, the inflow-content cross tabulation is of some value in that they display combinations of inflow and content above which 100 percent releases are optimal. Since this information would save computing releases using the more elaborate methods to be discussed below, it is provided as a means of making an initial check on whether further computation is necessary. Results are given in Table III-2.

The statistical techniques used for analysis of the 250 sample points for each of the 12 months varied considerably between months. Different techniques were necessary for different months because of grossly non-normal distributions of release. In some months, 100 percent secondary release prevailed a large proportion of the time. In other months there were a large number of events of zero release; in several months there were a considerable number of events at both ends of the release spectrum, with a variable number of points in between. Standard regression techniques are of little value in such cases unless the data can be segregated so that the regression sampling is over a range of all state variables.

To overcome this problem, a multivariate statistical technique known as discriminant analysis was utilized. A discriminant function is a linear combination of the state variables which divides the total "population" of releases into sub-populations, with different basic characteristics. For Hetch Hetchy Reservoir and the STROFAM-S secondary demand rates considered herein, it was found that this technique was extremely useful for categorizing combinations of state variables that indicated releases to be in either of two (or more) of the following categories (or " populations"):

(1) $Y = 0$

(2) $Y = 100$

(3) $0 < Y < 100$

(4) $0 \leq Y < 100$

(5) $0 < Y \leq 100$

If the discriminant analysis shows that either $Y = 0$ or $Y = 100$, then no further analysis is required. However, if the discriminant function classifies the current state variables as indicating a release in one of the last 3 populations in the above list, then further analysis is required to determine what the total secondary release should be. Regression equations are invoked at this stage; these equations are derived from that subset of the 250 data points (for each of the twelve months) with release values Y within the appropriate brackets (3) through (5) as given in the above listing of release categories.

B. Classification by Discriminant Analysis. Discriminant analysis involves matrix algebra and multivariate statistical techniques; it is described in a number of sources, including Anderson (1958), Miller (1962), and Overall and Klett (1972). We give here a brief summary to permit utilization of the results.

The discriminant function is a linear combination of state variables of the form

$$L = a_1x_1 + a_2x_2 + a_3x_3 \qquad (1)$$

where x_1 = last month's inflow, pct of average

x_2 = end-of-month content (for last month), pct of maximum content

x_3 = Bartell Forecast of remaining inflow through June 30th, in pct of the mean inflow through June 30th (for applicable months)

a_i, i = 1, 2, 3, are optimal weighting coefficients

L = value of the discriminant function

It is seen that the discriminant value reduces the 3 state variables to one state variable, L; the value of L relative to a critical value of L, L_c, then determines whether the total secondary release belongs in one category or another, e.g., either Y = 100 pct or Y < 100 pct.

The determination of the critical value of L_c was based on the following equation:

$$L_c = \frac{\bar{L}^{(1)} + \bar{L}^{(2)}}{2} \tag{2}$$

where $\bar{L}^{(1)}$ consists of the value of L obtained by inserting the mean values of the state variables $\bar{X}_{ik}$, i = 1,2,3, k = 1,2, where the k subscript applies to those mean values associated with groups 1 and 2, respectively. Thus, if $L - L_c \geq 0$, the release belongs to category 1; if $L - L_c < 0$, the release pattern belongs to category 2. It is possible to consider multiple categories of release, however, the number of discriminants must be one less than the number of categories, or, less than or equal to the number of state variables. For the purposes of this study, adequate results were obtained with a binary split of the data into two groups, resulting in one discriminant function. However, for four months it was found useful to make two different binary splits, one to categorize releases as being either equal to 100 pct or less than 100 pct, and the other to categorize secondary releases as being either equal to zero or greater than zero.

Equation (2) assumes that the critical value of $L = L_o$ is half-way between the mean values of L for the two groups under consideration. This value was used in computer studies to classify a particular set of state variables (out of the set of 250 for each month). Generally, excellent results were obtained, so further refinement was not undertaken. However, in operational use better results can be obtained by considering a refinement based on the apriori probability of the releases belonging to a particular population. These probabilities are given in Table III-1. Equation (2) assumes that the apriori probability of each group is equal to 0.5, or that there is a 50 percent apriori chance of being in either group. Under the 3-way classification results presented in Table III-1, it can be seen that the apriori probabilities of any two-way combination are generally not equal. For example, referring to Table III-1, the apriori probability that the October release would be in a category of Y = 0.0 is 0.376, or 37.6 pct of the time. The apriori probability that the release would be greater than zero is 0.164 + .460 = .624 = 1 - .376. Since the chance of a particular combination of state variables indicating zero release is less than 0.5, and the chance of being greater than zero is greater than 0.5, a modification of L_c is warranted.

The modification consists of adding to L_c the quantity $\log_e (q_2/q_1)$ where q_2 is the apriori probability of group 2 and q_1 is the a priori population of group 1. Thus

$$L_c^1 = \frac{L^{-(1)} + L^{-(2)}}{2} + \log_e (q_2/q_1) \qquad (3)$$

Table III-3 gives the derived discrimant function in the form:

$$L - L_c = a_o + a_1x_1 + a_2x_2 + a_3x_3 \qquad (4)$$

The rules for applying equation (4) are as follows:

If $L - L_c \geq 0$, Y belongs to category 1

If $L - L_c < 0$, Y belongs to category 2

Table III-3 identifies category 1 and 2 for each discriminant function.

Table III-3 also gives the probability that the particular discrimant function will result in a correct assignment of release to the proper category. These probabilities of successful classification range between 0.821 and 0.984, indicating that the discriminating power of the functions is exceedingly good, even though based on equal apriori probabilities. With operational addition of the term $\log_e (q_2/q_1)$ to L_c even better results will be obtained.

C. Regression Studies. Standard stepwise regression analysis was used to supplement the discriminant analysis for estimating the magnitude of a secondary release between but usually not including 0 and 100 percent. However, if a particular month included only a few instances of release events at these two extremes, one or the other was included in the data set used for regression analysis. For example, February included only 7 events of zero release and 146 events of non-zero release that were less than 100 pct of demand. The set used to derive the February regression relation consisted of the 7 zero release events and the 146 non-zero events that were less than 100 pct for a total sample size of 153.

The derived regression equations are given in Table III-4 and are of the form

$$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 \qquad (5)$$

Table III-4 gives the standard error of estimate (in terms of pct of demand) for each equation. This ranges from 2.7 pct in September to 22.5 percent in March and is usually less than 10 percent. Table III-4 also gives the regression multiple correlation coefficients ranging from .584 in March to .992 in December, in most cases being above 0.9.

The months of June, July, and August provided insufficient data for developing a regression equation valid for the range $0 < Y < 100$. There were, respectively, only 11, 3, and 21 events out of the total sample size of 250. The August data provided a sufficient number of events for a rough regression relation, however, the resulting standard error exceeded the standard deviation of releases in the $0 < Y < 100$ range. The optimum release estimators for these months for this range are the mean of the 11, 3, and 21 events, respectively. These means are the constants (b_o) given in Table III-4 for these months; the standard error column contains the standard deviation for the events within this bracket.

Full computer output listings are available indicating the computed release and the error for each event in the subset of events that was used to derive a particular equation. These are bulky and are not reproduced here but are available for inspection.

D. Summary. The combination of discriminant analysis and regression within discriminant groups resulted in a highly satisfactory set of estimating equations for mimicking the secondary release policies of STROFAM-S. These results can be used with confidence that optimal statistical estimates of release policy can be made on an operational basis by monthly application of the equations given herein.

5. OPERATIONAL USE OF ESTIMATING EQUATIONS

For operational estimation of releases a standardized blank form is suggested as shown in Figure 1. Figure 3 shows an application of the form for a typical case. Table III-5 contains a listing in acre-ft of demand (Y), average inflow for the previous month (x_1), and average inflow for the remainder of the Bartell forecasting period (to June 30th). The maximum content used in computer studies was 360,173 acre-ft. The form provides locations to convert current state variables in acre-ft to their percentage values in terms of the 100 percent values given in Table III-5.

The procedure consists of successively applying statistical state estimators of increasing complexity until a decision is reached. If a clear signal is not given at any one step the analysis is carried to the next step. The steps are as follows:

(1) Convert current state variables x_1, (inflow), x_2 (content), and x_3 (Bartell Forecast) to percentages of the base values given in Table III-5.

(2) Check rough rules of Table III-2. If these give a clear signal of 100 pct secondary release no further analysis is required. If they do not, proceed to step (3).

(3) Make a discriminant analysis using the first discriminant function in Table III-3 for the current month. This function will either give a clear indication of whether the release equals 100 pct or is less than 100 pct.

If the indication is a 100 pct release no further analysis is required. If less than 100 pct, first check to determine whether a second discriminant function is given in Table III-3 for the current month. If so, use it to determine whether a further classification can be made.

(4) If as a result of step 3 it is indicated that the release is between 0 and 100 pct, complete this step which consists of a regression equation to determine the best estimate of the release if the discriminant analysis places the release in this range.

(5) Summarize the results and convert the release in percent to acre-ft. using Table III-6, which summarizes demand in acre-ft. At this point the total secondary release can be allocated between tunnel and river demand. If the total secondary release is less than 100 pct, the blank form provided in Figure 3 can be used to allocate the water between the tunnel and the river on an equal percent curtailment basis.

6. EXAMPLE

An example is given in Figures 3 and 4, for the month of February, 1968. From the STROFAM-S historical simulation print-out the following data are obtained:

Last month's inflow (January)	11,621 ac.ft.
Content, January 31st	131,469 ac.ft.
February 1st Bartell Forecast of remaining seasonal runoff, through June 30th*	527,022 ac.ft.
*Note that this is the simulated Bartell Forecast used in STROFAM-S	
STROFAM-S Optimum Secondary Releases:	
Tunnel	16,885 ac.ft.
River	2,869 ac.ft.
Total	19,754 ac.ft.

On Figure 3, a total secondary release of 18,581 ac.ft. is estimated, corresponding to a difference of -5.93 percent compared to the value computed by STROFAM-S. On figure 4 the secondary releases are computed using the same ALCATE allocation mechanism embodied in STROFAM-S. The releases obtained for the tunnel and river respectively are 15,738 acre-ft. and 2842 acre-ft., yielding percent differences of -6.79 percent and -0.94 percent.

These small differences are not representative. The standard error for the February regression equation is 15.47 percent (of total secondary demand). Among the 153 sample points from the 5 stochastic traces used to derive the regression relation for February, the errors ranged from -61.24 pct to +27.09 pct. Also, there is a finite probability that a discriminant function may fail to identify a zero release condition, and at the same time regression equation may yield a positive release value; this would result in an infinite error, percentage-wise, however it would likely be small compared to total demand.

7. REFERENCES

Anderson, T. W., "An Introduction to Multivariate Statistical Analysis", Ch. 5, pp. 126-153, John Wiley & Sons, Inc., New York: 1958.

Miller, Robert G., "Statistical Prediction by Discriminant Analysis" Meteorological Monograph No. 25, American Meteorological Society, Boston, Mass.: 1962.

Overall, John E. and Klett, C. James, "Applied Multivariate Analysis", Ch. 9-11, McGraw Hill Book Co., New York: 1972.

TABLE III-1

NO. OF OCCURRENCES AND A PRIORI PROBABILITY OF TOTAL SECONDARY RELEASE IN VARIOUS BRACKETS

Month	3 WAY CLASSIFICATION RESULTS				4 WAY CLASSIFICATION RESULTS				
	$y = 0\%$	$0 < y < 100$	$y = 100\%$	Total	$0 \leq y < 25$	$25 \leq y < 50$	$50 \leq y < 75$	$75 \leq y \leq 100$	Total
October	94	41	115	250	112	23	0	115	250
November	20	222	8	250	66	113	55	16	250
December	19	217	14	250	64	111	37	38	250
January	6	141	103	250	16	25	49	160	250
February	7	146	97	250	24	32	55	139	250
March	24	109	117	250	46	31	30	143	250
April	8	54	188	250	17	23	13	197	250
May	10	31	209	250	23	13	4	210	250
June	9	11	230	250	15	5	0	230	250
July	18	3	229	250	20	1	0	229	250
August	33	21	196	250	52	2	0	196	250
September	61	20	169	250	81	0	0	169	250

A PRIORI PROBABILITY OF RELEASE BEING IN BRACKET INDICATED

Month	$y = 0\%$	$0 < y < 100$	$y = 100\%$	Total	$0 \leq y < 25$	$25 \leq y < 50$	$50 \leq y < 75$	$75 \leq y \leq 100$	Total
October	.376	.164	.460	1.0	.448	.092	.0	.460	1.0
November	.080	.888	.032	1.0	.264	.452	.220	.064	1.0
December	.076	.868	.056	1.0	.256	.444	.148	.152	1.0
January	.024	.564	.412	1.0	.064	.100	.196	.640	1.0
February	.068	.584	.388	1.0	.096	.128	.220	.556	1.0
March	.096	.436	.468	1.0	.184	.124	.120	.572	1.0
April	.032	.216	.752	1.0	.068	.092	.052	.788	1.0
May	.040	.124	.836	1.0	.092	.052	.016	.840	1.0
June	.036	.044	.920	1.0	.060	.020	.0	.920	1.0
July	.072	.012	.916	1.0	.080	.004	.0	.916	1.0
August	.132	.084	.784	1.0	.208	.008	.0	.784	1.0
September	.244	.080	.676	1.0	.324	.0	.0	.676	1.0

TABLE III - 2

ROUGH RULES FOR 100 PCT. SECONDARY RELEASE

	Last Month's Inflow $\geq$:	End of Month Content $\geq$:
October	75	75
November	75	75
December	100	75
January	50	75
February	100	55
March	75	55
April	100	55
May	75	75
June	75	95
July	85	90
August	75	85
September	75	85

Both conditions above must apply before using rough rules to permit 100 pct. release. If one or both conditions are not met, discriminant analysis is required to determine whether 100 pct. release is feasible.

TABLE III - 3

DISCRIMINANT FUNCTIONS FOR VARIOUS RELEASE CATEGORIES

Month		Release Category 1	Release Category 2	A Priori Probability q_1	A Priori Probability q_2	Discriminant Function Coefficients a_0	a_1	a_2	a_3	$\log_e(q_2/q_1)$	Pr. of Correct Classification Assuming equal a-priori prob.
October	(1)	y = 100%	y < 100%	.460	.540	-25.4606	+.006388	+.371378	-	0.1603	0.984
	(2)	y > 0%	y = 0%	.600	.400	-13.0138	+.003272	+.194891	-	-.4055	0.821
November	(1)	y > 0%	y = 0%	.920	.080	-33.4687	+.005317	+.479673	+.097248	-2.4423	0.987
December	(1)	y = 100%	y < 100%	.056	.944	-36.2720	+.021308	+.503703	+.038946	+2.8248	0.956
	(2)	y > 0%	y = 0%	.924	.076	-22.3487	-.008428	+.499544	+.014126	-2.4978	0.972
January	(1)	y = 100%	y < 100%	.412	.588	-28.5846	-.010025	+.342411	+.141577	+0.3557	0.913
February	(1)	y = 100%	y < 100%	.388	.612	-16.6820	+.016530	+.072315	+.118533	+0.4557	0.892
March	(1)	y > 0%	y = 0%	.904	.096	- 9.911143	+.011910	+.051952	+.091448	-2.2425	.836
	(2)	y = 100%	y < 100%	.468	.532	-16.075072	+.017198	+.118240	+.110900	+ .1282	.844
April	(1)	y = 100%	y < 100%	.752	.248	-12.521447	+.021067	+.045013	+.105981	-1.1093	.868
May	(1)	y = 100%	y < 100%	.836	.164	- 8.396341	+.021307	+.006818	+.076854	-1.6288	.876
June	(1)	y = 100%	y < 100%	.920	.080	- 7.477080	+.0236336	+.063852	+.017048	-2.4423	.824
July	(1)	y = 100%	y < 100%	.916	.084	-66.097691	-.012712	+.816651	-	-2.3892	.950
August	(1)	y = 100%	y < 100%	.784	.216	-55.849354	+.013920	+.691364	-	-1.2891	.978
	(2)	0<y<100%	y = 0%	.389*	.611*	- 9.599888	+.075106	+.110066	-		
September	(1)	y = 100%	y < 100%	.676	.324	-44.225601	-.021127	+.620067	-	-1.2976	.981

*These are a-priori probabilities given that the first discriminant function has identified the release category as y < 100%.

TABLE III - 4

REGRESSION EQUATIONS

Month	Constant b_o	Regression Equation Coefficients b_1	b_2	b_3	Mult. Coeff. Correlation R	Std. Error - $S_{y\|x}$	Pct. of Dmd	No. of Cases (out of 250)	Limits on y
October	-648.874	+0.0642	+11.2563	—	0.947	4.11		41	$0 < y < 100$
November	-186.486	+0.0222	+ 3.2788	+0.3781	0.946	6.84		230	$0 < y \leq 100$
December	-286.217	+0.0098	+ 5.5646	+0.3793	0.992	2.91		217	$0 < y < 100$
January	-213.844	+0.0948	+ 2.8730	+1.6784	0.910	10.73		147	$0 \leq y < 100$
February	-180.506	+0.1613	+ 2.7926	+1.5207	0.816	15.47		153	$0 < y < 100$
March	-129.368	+0.1132	+ 3.0979	+1.0261	0.584	22.52		109	$0 < y < 100$
April	-108.807	+0.1239	+ 0.8528	+1.6879	0.957	7.87		62	$0 \leq y < 100$
May	-119.536	+0.0968	+ 1.1157	+1.8407	.904	9.33		41	$0 \leq y < 100$
June*	27.100	—	—	—	—	12.8		11	$0 < y < 100$
July*	22.522	—	—	—	—	30.5		3	$0 < y < 100$
August*	10.939	—	—	—	—	10.0		21	$0 < y < 100$
September	- 44.0346	—	+ .7589	—	.701	2.67		20	$0 < y < 100$

* Insufficient points for valid regression relation.

TABLE III - 5

LONG TERM AVERAGE VALUES OF INFLOW

Date of Decision on Release Policy	Last Month's[1] Average Inflow (af)	Expectant Average Inflow[2] through June 30 (For Nov. 1 - Jan. 1 Forecasts)(af)
October 1	4,141	-
November 1	5,747	639,027
December 1	10,276	625,449
January 1	20,513	602,946
February 1	19,400	583,282
March 1	23,729	559,553
April 1	36,857	522,695
May 1	91,053	431,643
June 1	220,582	211,060
July 1	211,060	-
August 1	70,646	-
September 1	12,173	-

(1) Use as denominator for computing X_1

(2) Use as denominator for computing X_3

TABLE III - 6

DEMANDS FOR SECONDARY WATER

ACRE FT.

Month	Tunnel DW	River DF	Total DT
October	26,142	3,689	29,831
November	25,288	3,570	28,858
December	26,142	3,689	29,831
January	26,142	3,689	29,831
February	23,772	3,356	27,128
March	26,142	3,689	29,831
April	25,288	3,570	28,858
May	26,142	8,300	34,442
June	25,288	8,033	33,321
July	26,142	8,300	34,442
August	26,142	8,300	34,442
September	25,288	5,802	31,090

REFERENCE: Vol. II, Hetch Hetchy - Tuolumne River Releases
Bechtel, Inc., San Francisco, California, 1972

HETCH HETCHY RESERVOIR
DEPARTMENT OF WATER AND POWER - CITY OF SAN FRANCISCO
WORKSHEET FOR ESTIMATING TOTAL SECONDARY RELEASES
FOR COMING MONTH

Date ____________

Release Estimate for Month ____________

Step 1. Compute Percent Values for State Variables

State Variables Symbol	Description	Current Value ac Ft.	Base Value Table III-5	Current Value in % of Base Value
x_1	Inflow last month:			
x_2	Content end of month:		360,173	
x_3	Bartell Forecast thru June 30:			

Step 2. Check State Variables X_1 and X_2 against rough rules of Table III-2 for 100 pct. release.

Rough rule: Inflow must be $>$ ______ % X_1 = ______

Content must be $>$ ______ % X_2 = ______

This rule indicates 100 pct. release: Yes ______ No ______

If not, go to Step 3.

Step 3. Discriminant Analysis (if required)

Function No. 1. Discriminates between:
Category 1: ______
Category 2: ______

	Discriminant Coefficients Table III - 3	Product $a_i x_i$ (x_i in pct.)
(1) a_1		
(2) a_2		
(3) a_3		
(4) L = Subtotal (li (1) to (3))		
(5) a_o (Tab. III-3) =		
(6) $L-L_c$ = total (li. (4) + (5))		
(7) A Priori Pr. Correction $\log_e (q_2 / q_1)$ - Tab. III-3		
(8) $L-L_c'$ = total (li. (6) - (7))		

(9) Assignment of release to category 1 or category 2

If line (8) ≥ 0.0 : Cat. 1 Rel. Cat. No. ______

If line (8) < 0.0 : Cat. 2 Y ______

Step 3a. (if required)

Function No. 2 Discriminates between:
Category 1: ______
Category 2: ______

	Discriminant Coefficients Table III - 3	Product $a_i x_i$ (x_i in pct.)
(1) a_1		
(2) a_2		
(3) a_3		
(4) L = Subtotal (li (1) to (3))		
(5) $-L_c = b_o$ (Tab. III-3) =		
(6) $L-L_c$ = total (li. (4) + (5))		
(7) A Priori Pr. Correction $\log_e (q_2 / q_1)$ - Tab. III-3		
(8) $L-L_c'$ = total (li. (6) + (7))		

(9) Assignment of release to category 1 or category 2

If line (8) ≥ 0.0 : Cat. 1 Rel. Cat. No. ______

If line (8) < 0.0 : Cat. 2 Y ______

Step 4. (if required)

Regression analysis, limits on region of applicability (Table III-5): ______

	Coefficients (Table III-5)	Product $b_i x_i$
(1) b_1		
(2) b_2		
(3) b_3		
(4)	Subtotal	
(5) b_o = Constant		
(6)	Total	
(7) Y = Min (0.0, Li. 6) Y = Max (Li. 6, 100.0)		

Step 5. Summary

Y = total secondary vol, pct. of demand ______

Total demand, ac ft. ______

Y = total secondary release, ac ft. ______

FIGURE 1

HETCH HETCHY RESERVOIR
DEPARTMENT OF WATER AND POWER
WORKSHEET FOR ALLOCATION OF TOTAL SECONDARY
WATER TO TUNNEL AND RIVER
(For Case of TW < DT)

Month__________
Date__________

1. Refer to Fig. 11, Vol. I, Hetch Hetchy Reservoir Tuolumne River - River Releases, Bechtel Inc., San Francisco, California

2. <u>Compute Ratios:</u>

	Acre Ft.	Decimal % (Fraction) of Total Demand
DW = Tunnel demand	________	d_w = .
DF = River demand	________	d_f = .
DT = Total demand	________	d_t = 1.0
TW = Available Water	________	t_w = .

3. <u>Identify Case (equal % curtailment).</u>

1.	2.	3.
$d_w < t_w \leq 1.00$	$d_f < t_w \leq d_w$	$0 \leq t_w \leq d_f$
☐	☐	☐

Check applicable box and use equations in column below to compute tunnel and river releases.

Column 1

$r_w = t_w d_w$

$r_w = \_\_\_\_ \times \_\_\_\_$

$r_w = \_\_\_\_\_\_\_\_$

$r_f = t_w d_f$

$r_f = \_\_\_\_ \times \_\_\_\_$

$r_f = \_\_\_\_\_\_\_\_$

Column 2

$r_w = t_w{}^2/(d_f + t_w)$

$r_w = \dfrac{(\_\_\_\_)^2}{(\_\_\_\_ + \_\_\_\_)}$

$r_w = \_\_\_\_\_\_\_\_$

$r_f = t_w d_f / (d_f + t_w)$

$r_f = \dfrac{(\_\_\_\_)(\_\_\_\_)}{(\_\_\_\_ + \_\_\_\_)}$

$r_f = \_\_\_\_\_\_\_\_$

Column 3

$r_w = r_f = 0.5\, t_w$
$= 0.5\,(\_\_\_\_)$

$r_w = r_f = \_\_\_\_\_\_\_\_$

Convert to Acre Ft.

$RW = r_w \cdot DT$

$= (\_\_\_\_)(\_\_\_\_)$

$= \_\_\_\_\_\_\_\_$ af

$RF = r_f \cdot DT$

$= (\_\_\_\_)(\_\_\_\_)$

$= \_\_\_\_\_\_\_\_$ af

FIGURE 2

REFERENCE: Vol. II, Hetch Hetchy - Tuolumne River Releases
Bechtel, Inc., San Francisco, California, 1972

HETCH HETCHY RESERVOIR
DEPARTMENT OF WATER AND POWER - CITY OF SAN FRANCISCO
WORKSHEET FOR ESTIMATING TOTAL SECONDARY RELEASES
FOR COMING MONTH

Date ____

Release Estimate for Month ____

Step 1. Compute Percent Values for State Variables

State Variables Symbol	Description	Current Value ac Ft.	Base Value Table III-5	Current Value in % of Base Value
x_1	Inflow last month:	11,621	19,400	59.902
x_2	Content end of month:	131,469	360,173	36.502
x_3	Bartell Forecast thru June 30:	527,022	583,282	90.355

Step 2. Check State Variables X_1 and X_2 against rough rules of Table III-2 for 100 pct. release.

Rough rule: Inflow must be > 100 % X_1 = 59.902
Content must be > 55 % X_2 = 36.502

This rule indicates 100 pct. release: Yes ____ No X

If not, go to Step 3.

Step 3. Discriminant Analysis (if required)

Function No. 1. Discriminates between:
Category 1: Y=100%
Category 2: Y<100%

	Discriminant Coefficients Table III - 3	Product $a_i x_i$ (x_i in pct.)
(1) a_1	+0.016530 x 59.902	0.9902
(2) a_2	+0.072315 x 36.502	2.6396
(3) a_3	+0.118533 x 90.355	10.7100
(4) L = Subtotal (li (1) to (3))		14.3398
(5) a_o (Tab. III-3) =		-16.6820
(6) $L-L_c$ = total (li. (4) + (5))		-2.3422
(7) A Priori Pr. Correction $\log_e(q_2/q_1)$ - Tab. III-3		+.4557
(8) $L-L_c'$ = total (li. (6) - (7))		-2.7978

(9) Assignment of release to category 1 or category 2

If line (8) ≥ 0.0 : Cat. 1 Rel. Cat. No. 2

If line (8) < 0.0 : Cat. 2 Y < 100%

Go to step 4

Step 3a. (if required)

Function No. 2 Discriminates between:
Category 1: ____
Category 2: ____

	Discriminant Coefficients Table III - 3	Product $a_i x_i$ (x_i in pct.)
(1) a_1		
(2) a_2		
(3) a_3		
(4) L = Subtotal (li (1) to (3))		
(5) $-L_c = b_o$ (Tab. III-3) =		
(6) $L-L_c$ = total (li. (4) + (5))		
(7) A Priori Pr. Correction $\log_e(q_2/q_1)$ - Tab. III-3		
(8) $L-L_c'$ = total (li. (6) + (7))		

(9) Assignment of release to category 1 or category 2

If line (8) ≥ 0.0 : Cat. 1 Rel. Cat. No. ____

If line (8) < 0.0 : Cat. 2 Y ____

Step 4. (if required)

Regression analysis, limits on region of applicability (Table III-5): ____

	Coefficients (Table III-5)	Product $b_i x_i$
(1) b_1	+0.1613 X 59.902 =	9.662
(2) b_2	+2.7926 X 36.502 =	101.935
(3) b_3	+1.5207 X 90.355 =	137.403
(4)	Subtotal	249.000
(5) b_o = Constant		-180.506
(6)	Total	68.494
(7) Y = Min (0.0, Li. 6) Y = Max (Li. 6, 100.0)		68.494

Step 5.

Summary

Y = total secondary vol, pct. of demand	68.494
Total demand, ac ft.	27,128
Y = total secondary release, ac ft.	18,581

Example

Figure 3

HETCH HETCHY RESERVOIR
DEPARTMENT OF WATER AND POWER
WORKSHEET FOR ALLOCATION OF TOTAL SECONDARY WATER TO TUNNEL AND RIVER
(For Case of TW < DT)

Month Feb 1969
Date 11-20-72

1. Refer to Fig. 11, Vol. I, Hetch Hetchy Reservoir Tuolumne River - River Releases, Bechtel Inc., San Francisco, California

2. Compute Ratios:

	Acre Ft.	Decimal % (Fraction) of Total Demand
DW = Tunnel demand	23,772	d_w = .87629
DF = River demand	3,356	d_f = .12371
DT = Total demand	27,128	d_t = 1.0
TW = Available Water	18581	t_w = .68494

3. Identify Case (equal % curtailment).

1.	2.	3.
$d_w < t_w \leq 1.00$	$d_f < t_w \leq d_w$	$0 \leq t_w \leq d_f$
☐	☒	☐

Check applicable box and use equations in column below to compute tunnel and river releases.

Column 1:

$r_w = t_w d_w$

r_w = ________ x ________

r_w = ________________

$r_f = t_w d_f$

r_f = ________ x ________

r_f = ________________

Column 2:

$r_w = t_w^{\,2}/(d_f + t_w)$

$$r_w = \frac{(.68494)^2}{(.12371 + .68494)}$$

r_w = .58015

$r_f = t_w d_f \,/\, (d_f + t_w)$

$$r_f = \frac{(.68494)(.12371)}{(.12371 + .68494)}$$

r_f = .10478

Column 3:

$r_w = r_f = 0.5\, t_w$
$= 0.5$ (________)

$r_w = r_f$ = ________________

Convert to Acre Ft.

$RW = r_w \cdot DT$

= (.58015)(27128)

= 15738 af

$RF = r_f \cdot DT$

= (.10478)(27128)

= 2842 af

Example
Figure 4