Trinidad Reservoir Operation Study for Review of Operating Principles 2007 Computer Model Development Effort

Introduction

A model has been developed to re-create the analytical processes used in the 1961/1964 Irrigation Project Report for the Trinidad Project (1964 Report) and in the 1988 Trinidad Project Review of Operating Principles (1988 Review).

The 1964 Report includes a description of the analysis process and hand-written spreadsheets of most model data and results for potential operations of the Trinidad Reservoir for the period of water years 1925-1957. In this analysis, November-March is treated as a single timestep, and data is not available for evaporation assumptions and other input data items that are computed from daily data.

The 1988 Review used a FORTRAN program to reproduce the 1964 analysis and to perform multiple scenarios of reservoir operations. This effort expanded the single November-March period into monthly timesteps. No computer code for this effort could be located, but printouts of the results from each scenario are available. Detailed documentation of the computer model logic is included in the Review.

Using the information in the 1964 Report and the 1988 Review, and the monthly results from the 1988 model, an Excel spreadsheet model was built to reproduce the previous efforts and to provide an analytical foundation for use in future operating reviews and project studies.

This report documents the new modeling effort.

Input Data

The file "2007 Trinidad Reservoir Model.xls" contains the spreadsheet model along with a description of formulas in each column and plots of selected output.

Columns labeled with blue letters contain hydrologic input data.

- Trinidad Reservoir Inflow – monthly data from the 1988 model match very closely with data developed from USGS records

- Late Month Unusable Inflow – taken from the monthly printouts of the 1988 model results, this time series represents water which arrives late in the current month and cannot be assumed to be useable for diversion, but can nevertheless be stored. The 1988 Review states that it was taken from daily flow analysis included in supporting data for the 1964 study – this supporting information cannot be located, and logic for the development of this timeseries cannot be readily identified from observations of the existing data.

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- John Martin Spills – data taken from Column 42, Table 23 of the 1961 Study

- Stock Water Release – 1.5 taf, distributed as .3 taf in each month November-March

- Estimated Headgate Requirements – the approach developed for the 1961/64 model and preserved in the 1988 model is continued here. Annual values for effective heat units and growing season precipitation were used to calculate a total annual irrigation requirement. Estimates of on-farm and transportation losses were used to calculate the headgate requirement in af/acre. Multiplying this by the number of acres gives the total annual demand, which is distributed by an average monthly (April-October) pattern. Details can be found on pages 23-30 of the 1964 Report.

- High Inflow Bypass – the monthly total of daily inflows in excess of 700 cfs. These must be bypassed unless John Martin Dam is spilling. These values were calculated from available daily USGS data for flow at the Trinidad Gage. Values used in the 1988 model were not exactly the same, but there is no clear explanation of why they would be different. Table 1 summarizes the differences between 1988 model data and the newly calculated values for all occurrences of this input element. The new values are used in the 2007 model.

Table 1 – differences in high inflow bypass between 1988 model data and USGS data

	1988 Model	USGS		1988 Model	USGS
Jul-25	7.2	7.7	**May-44**	2.1	2.5
Jul-27	4.2	4.5	**Jun-44**	3.2	4.1
Aug-27	2.3	2.6	**Jul-44**	0.1	0.4
May-28	0.5	0.8	**Jul-45**	0.5	0.7
Jun-28	0.0	0.2	**Aug-45**	0.0	0.1
May-29	1.8	1.9	**Aug-46**	0.0	0.2
Aug-29	0.4	0.7	**May-47**	0.6	1.1
Jul-30	2.6	3.3	**Aug-47**	0.0	0.5
Aug-30	4.3	0.7	**May-48**	1.8	1.6
Aug-33	1.6	1.9	**Jun-48**	0.0	7.8
Aug-37	2.2	1.0	**Jun-49**	1.7	2.6
Jun-38	0.5	0.8	**Jul-49**	0.0	0.1
Jul-38	0.0	0.1	**Aug-50**	1.2	1.4
May-41	5.5	6.3	**Aug-52**	0.1	0.3
Sep-41	1.9	2.0	**Aug-53**	0.1	0.3
Apr-42	52.1	53.4	**Jul-54**	0.0	0.3
May-42	0.1	0.5	**Aug-54**	0.1	0.5
Jul-42	1.6	0.9	**May-55**	42.8	44.1
Aug-42	0.1	0.5	**Aug-55**	8.0	1.0
Sep-42	0.2	0.3	**May-57**	0.3	0.5
Oct-42	0.5	0.7	**Jun-57**	0.0	2.9
Aug-43	0.1	0.4	**Jul-57**	0.0	0.3
Apr-44	0.0	0.0	**Sep-57**	0.0	0.1

- Historic Ninemile Canal Diversion – monthly data taken from the monthly printouts of the 1988 model results

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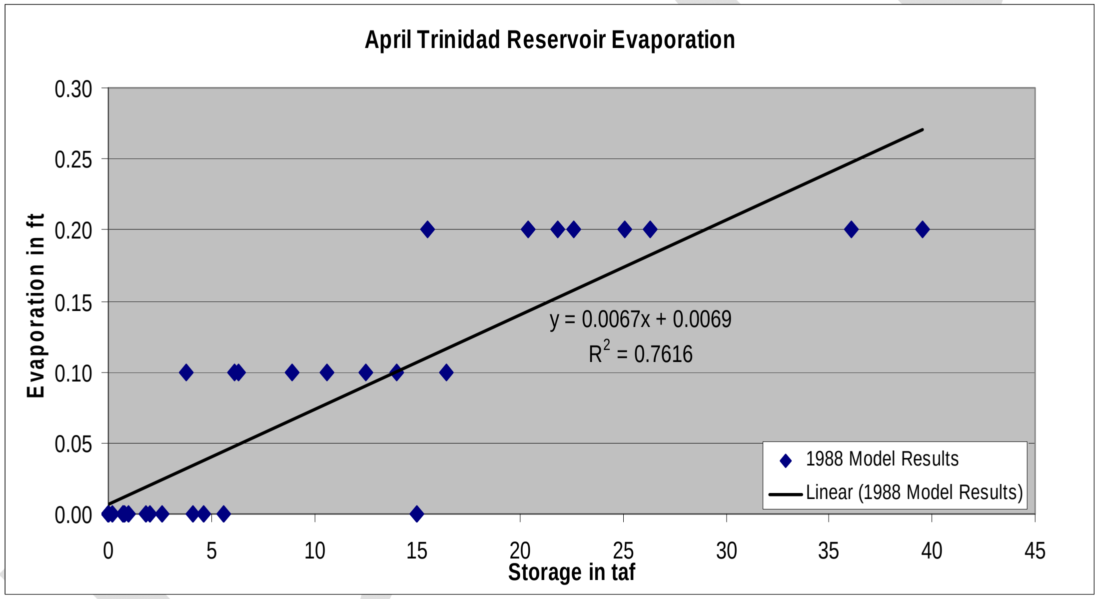
- Historic Highland Canal Diversion – monthly data taken from the monthly printouts of the 1988 model results

- Evaporation – the 1988 model documentation states that the evaporation was taken from data supporting the 1964 model. It is not possible to locate this supporting data, so a re-construction of evaporation relationships was necessary. Evaporation rates for December through March are zero in the 1988 model. Regression relationships were developed for evaporation as a function of storage for each month April through November from the 1988 monthly results. Because the precision of the earlier model results is limited to 100's of acre-feet, the replacement linear function effectively draws a straight line through a sequence of stair-steps, guaranteeing that new results for evaporation will be slightly different from previous efforts. The plot below illustrates this effect.

Figure 1 – evaporation parameter estimation example



2007 Model Logic

Table 2 presents the logic in the columns of the 2007 spreadsheet model. The order of calculation is not identical to that described in the two previous efforts – this is due to the differences in structure among the three efforts. The 1988 model documentation describes lines of data presented in the results and not necessarily the full procedural logic of model calculations. The 1964 model documentation covered several different tables of data and logic and left out some detail on interim calculation steps.

Table 2 – Model Logic Documentation

Column		Heading	Description	Formula
A		Year	Wateryear (starts in Nov, ends in Oct)	
B			# of days in timestep	
C		Mon	Month of the year	
D	1	Trinidad Reservoir Inflow	USGS gage flow for Trinidad (taf)	
E	2	Trinidad Reservoir Inflow	USGS gage flow for Trinidad (cfs)	+D*1000/(1.98347*B)
F	3	Late Month Unseable Inflow	Taken from 1988 model output, the formula for this is uncertain. Conceptually, a monthly inflow that is concentrated in a high cfs period at the end of the timestep cannot be assumed available for diversion to meet demands over the entire period. This amount cannot be delivered, but it can be stored.	
G	4	John Martin Reservoir Spills	Data from the 1964 and 1988 models	
H	5	Required Inflow Bypass	The sum of daily flows in excess of 700 cfs. Calculated from daily USGS flow data and aggregated to a monthly value.	
I	6	Stock Water Release	5 cfs Nov-Mar is approximately .3 taf per month	
J	7	Est HG Req't Trinidad to Hoehne	Headgate Requirements for the three modeled diversions. Computed in accordance with the logic described on pages 23-30 of the 1964 Report	
K	8	Est HG Req't Model Ditch		
L	9	Est HG Req't Hoehne to Alfalfa		
M	10	Total Est HG Req't	Total of the previous 3 columns	SUM(J:L)
N	11	Reduced HG Delivery	Total demand less calculated shortage; this is the total actual delivery to irrigation from which RF can be calculated	SUM(J:L)-BA-BB
O	12	Base Project RF (from prev yr)	19% of previous year's delivery, distributed evenly over the entire (nov-oct) year	SUM(N(prevyr))*0.19*B/SUM(B(nov-oct))
P	13	RF from Prev Month Delivery	Constant 19% return flow from previous month delivery	+N(-1)*0.19
Q	14	Return to Trinidad to Hoehne	22% of the total return flow	+(O+P)*0.22
R	15	Return to Hoehne to Alfalfa	53% of the total return flow	+(O+P)*0.53
S	16	Return Below Alfalfa	25% of the total return flow	+(O+P)*0.25
T	17	Trinidad to Hoehne RF Useable In Reach	The lesser of estimated HG req'ts for diversions above Hoehne and return flow arriving above Hoehne	MIN(J+K,Q)
U	18	Flow @ Trinidad Useable in the Trinidad to Hoehne Reach	Trinidad flow that does not have to be bypassed and which is available to be used	+AR-F

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Column		Heading	Description	Formula
V	19	Allocation of (all) Useable Flows to Model Ditch	Model Ditch can take 1/3 of the available water, up to its headgate requirement	MIN((T+U)/3,K)
W	20	Allocation of Useable Flows to Other Demands Above Hoehne	Other demands above Hoehne can take the rest of the available water, including unused Model allocation, up to the total headgate requirement	MIN(T+U-V,J)
X	21	Remaining Model Demand	Model Ditch demand that is not satisfied by the 1/3 allocation of available water	+K-V
Y	22	Remaining Other Dems Above Hoehne	Non-Model demands above Hoehne that are not satisfied by the available water	+J-W
Z	23	Trinidad to Hoehne RF Not Used	Return flows to the Trinidad-to-Hoehne reach that are not used by diversions	MAX(0,Q-T)
AA	24	RF Avail Hoehne to Alfalfa	RF remaining from the Trinidad-to-Hoehne reach plus that which returns to the Hoehne-to-Alfalfa reach	+Q+R-T (could also be Z+R)
AB	25	Hoehne to Alfalfa Dems met by RF Above Alfalfa	The lesser of total RF available below Hoehne and the estimated headgate requirement Hoehne-to-Alfalfa	MIN(R+Z,L) (could also be MIN(AA,L)
AC	26	Hoehne to Alfalfa Dems met by Avail Flow @ Trinidad	Delivery of Trinidad flow to Hoehne-to-Alfalfa demands	MIN(L-AB,MAX(0,AR-(J+K-T)))
AD	27	Remaining Hoehne to Alfalfa Demands	Hoehne-to-Alfalfa demands that cannot be met by return flow or Trinidad flow	+L-AB-AC
AE	28	Total RF's Available Below Alfalfa	All return flow in this month that is not used by diversions	+Z+R+S-AB
AF	29	Channel Loss Alfalfa to Ninemile (5.25%)	Channel loss from Alfalfa to Ninemile of the return flow amount in column AF	+AE*0.0525
AG	30	Irrigation Return Flows Available at Ninemile	All return flow (from above Alfalfa) that is available at Ninemile	+AE-AF
AH	31	Historic Ninemile Canal Div		
AI	32	Ninemile MIN(hist,wr)	Lesser of historic diversion and 18 cfs water right (not currently used)	MIN(AH,18*1.98347*B/1000)
AJ	33	Bypass Needed for Ninemile	Because the Highland Canal has rights senior to Ninemile Canal, only those return flows in excess of Highland Canal's historic diversion are available for diversion by Ninemile. The balance, increased by 5.25% to account for channel loss, is the bypass requirement.	MAX(0,AI-MAX(0,AG-AO))*1.0525
AK	34	Base Ninemile RF (from prev yr)	19% of previous year's delivery, distributed evenly over the entire (nov-oct) year	SUM(AI(prevyr))*0.19*B/SUM(B(nov-oct))
AL	35	Ninemile RF (from prev month)	Constant 19% return flow from previous month delivery	+AI(-1)*0.19
AM	36	Ninemile RF's Avail to Highland	Total return flow from Ninemile	SUM(AK:AL)
AN	37	Historic Highland Canal Div		
AO	38	Highland MIN(hist,wr)	Lesser of historic diversion and 24 cfs water right (not currently used)	MIN(AN,24*1.98347*B/1000)

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Column		Heading	Description	Formula
AP	39	Bypass Needed for Highland	If return flow below Alfalfa and Ninemile Canal returns are not sufficient to meet Highland Canal needs, the balance, increased by 5.25% to account for channel loss, is the bypass requirement.	MAX(0,AO-AM-MIN(AG,AO))*1.0525
AQ	40	Bypass for Ninemile, Highland, & Flow abv 700	Total amount of Flow at Trinidad that must be bypassed - for Ninemile and Highland, or because flow exceeds 700 cfs	IF(G>0.01,0,H)+AP+AJ
AR	41	Flow at Trinidad Avail for Deliv or Storage	Remaining flow at Trinidad that is available for direct delivery or storage	D-AQ
AS	42	Direct Deliv of Trinidad Flow	Total available flow at Trinidad that is used for direct delivery to the project	+AC+(V+W-T)+I
AT	43	Demand for Stored Water	Total remaining project demands after delivery of available return flow and Trinidad flow	+X+Y+AD
AU	44	First Model Account Rel	Release from Model Account to meet remaining Model Ditch demand, leaving a reserve of 1.2 taf	MIN(X,MAX(0,BP-1.2))
AV	45	Project Account Release for Project Demands	Release from Project Account to meet remaining (non-Model) Project demands	MIN(AD+Y,BO)
AW	46	Project Account Release for Model Demands	Release of up to the remaining storage in the Project account to meet any Model Ditch demand remaining after the initial release from the Model Account	MIN(X-AU,BO-AV)
AX	47	Second Model Account Release	Release from the final 1.2 taf in Model account to meet any remaining Model Ditch demand in the event that the releases in columns AU and AW were not sufficient	MIN(X-AU-AW,BP-AU)
AY	48	Unused Sediment Capacity Release for Model Demands	Release from the Joint Use Pool to meet any remaining Model Ditch Demand	MIN(X-AU-AW-AX,BQ(-1)-BW)
AZ	49	Unused Sediment Capacity Release for Project Demands	Release from the Joint Use Pool to meet any remaining Project Demand	MIN(AD+Y-AV,BQ(-1)-BW-AY)
BA	50	Model Delivery Shortage	Model Ditch Demand that could not be met with Model account, Project Account, or Joint Use Account storage releases	+X-AU-AW-AX-AY
BB	51	Project Delivery Shortage	Project Demand that could not be met with Project Account or Joint Use Account storage releases	+AD+Y-AV-AZ
BC	52	Trinidad Flow Available for Storage	Trinidad flow less what must be bypassed and what is to be delivered.	AR-AS
BD	53	Model Account Right	1/3 of storable inflow November-March	+BC/3
		Model Account Right	Portion of inflow over 300 cfs that is not needed for direct delivery or bypass in April-October	MAX(D-AS-AQ-BG,MAX(E-300,0)*1.98347*B/1000)
BE	54	Model Account Accrual	Amount of accrual right limited by storage capacity and annual accrual capacity	MIN(BD, 6-BL(oct)-BF(-1), 20-BM(oct)-BF(-1)-BI(-1), 20-BM(-1))

Column		Heading	Description	Formula
		Model Account Accrual	April-October	MIN(BD, 6-BL(oct)-BF(-1), 20-BM(oct)-BF(-1)-BI(-1)-BH, 20-BM(-1)-BH)
BF	55	Cumulative Model Accrual Nov-Oct	Running total of what has been accrued this year to the Model account	+BF(-1)+BH
BG	56	Project Account Right	2/3 of Storable inflow November - March	+BC-BE
		Project Account Right	Whatever portion of the first 300 cfs of inflow is not used for direct delivery or bypass April - October	MAX(0,MIN(300*B*1.98347/1000,D)-AS-AQ)
BH	57	Project Account Accrual	Amount of accrual right limited by storage capacity and annual accrual capacity	MIN(BG,20-BM(oct)-BF(-1)-BI(-1)-BE,20-BM(-1)-BE)
		Project Account Accrual	April-October	MIN(BG,BC,20-BM(oct)-BF(-1)-BI(-1),20-BM(-1))
BI	58	Cumulative Project Accrual Nov-Oct	Running total of what has been accrued this year to the Project account	BI(-1)+BH
BJ	59	Joint Use Account Accrual	Zero in November through March.	0.00
		Joint Use Account Accrual	Storable inflow that is not accrued to the Model or Project Accounts in April-October	IF(G>0.01,MIN(19.5-BP(-1),+BC-BH-BE),0)
BK	60	Project Storage	Mass balance of storage in the project account	+BK(-1)+BH-AV-AW-BW
BL	61	Model Storage	Mass balance of storage in the model account	+BL(-1)+BE-AU-AX-BX
BM	62	Total Model Pool Storage	Total of Project and Model pool accounts	SUM(BK:BL)
BN	63	Project Storage Available	Prev month eom storage - evap	+BK(-1)-BW
BO	64	Model Storage Available	Prev month eom storage - evap	+BL(-1)-BX
BP	65	Joint Use Storage	Mass balance of storage in the Joint Use Pool	+BP(-1)+BJ-BV-AY-AZ
BQ	66	Total Storage	Total Model Pool and Joint Use Pool Storage	+BP+BL+BK
BR	67	Passthrough/Spill	Inflow available for storage for which there is no capacity	BC-BE-BH-BJ
BS	68	Evap Slope	Regression values that define evaporation functions for each month	
BT	69	Evap Intercept	Regression values that define evaporation functions for each month	
BU	70	Total Evap	Application of regression equation to determine evaporation for the entire pool – function of previous month storage	MAX(0,MIN(BQ(-1),BQ(-1)*BS+BT))
BV	71	Joint Use Evap	Distribution of monthly evap to Joint Use portion of the storage	IF(BQ(-1)<0.001,0,+BU*BP(-1)/BQ(-1))
BW	72	Project Evap	Distribution of monthly evap to the Project account portion of the storage	IF(BQ(-1)<0.001,0,+BU*BK(-1)/BQ(-1))
BX	73	Model Evap	Distribution of monthly evap to the Model account portion of the storage	IF(BQ(-1)<0.001,0,+BU*BL(-1)/BQ(-1))
BY	74	Flow Above Ninemile Canal	Return flow below Alfalfa, bypass for Ninemile and Highland, required high inflow bypass, and Trinidad Reservoir passthrough/spill, all adjusted for 5.25% channel loss between Alfalfa and Ninemile	+(AE+AJ+AP+H+BR)*(1-0.0525)

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2007 Model Results Discussion

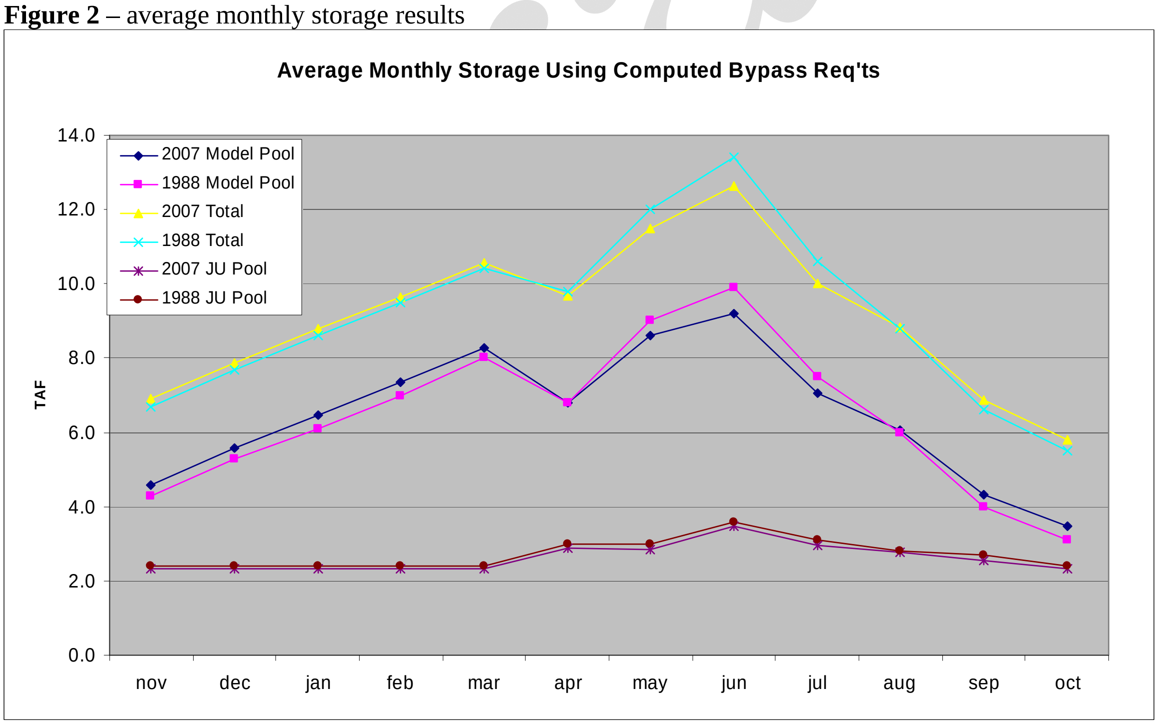
The principal goal of the new modeling effort was to reverse-engineer logic that would allow the reproduction of 1988 and 1964 results. This has been accomplished; results of the 2007 Model closely match the monthly 1988 model results. Most differences are small, and significant figures, the evaporation estimate effect, and slight discrepancies in the return flow values are the causes.

Table 3 shows average monthly results for key outputs for both the 1988 model and the 2007 model. Figure 2 is a plot comparing the average monthly storage results.

Table 3 – average monthly results comparison for 1988 and 2007 models

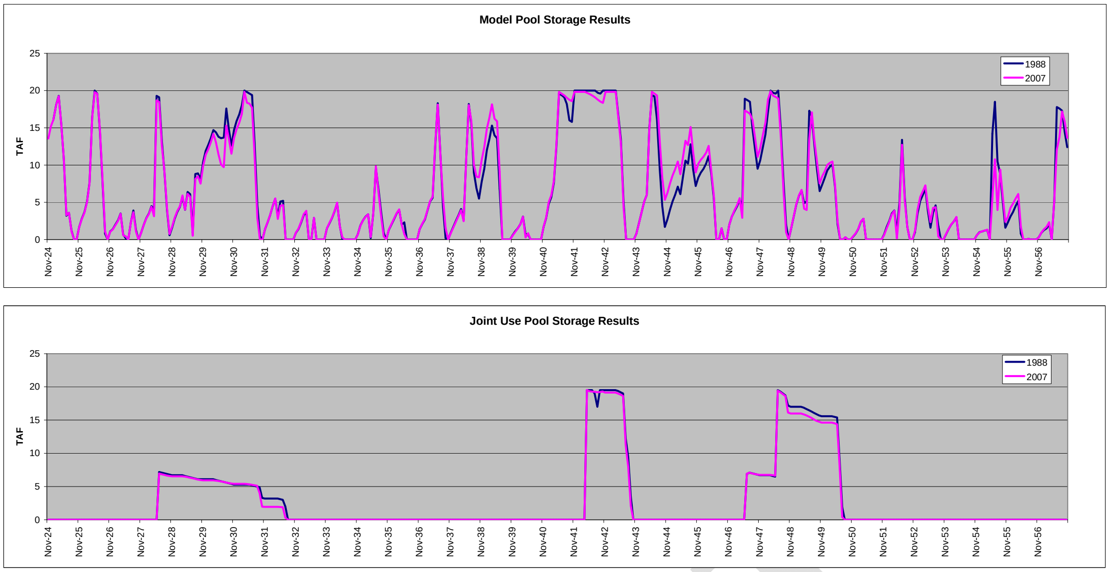
	Total HG Req't		Total Project Delivery		Total Project Shortage		RF Used for Irrigation		Total Evap		Model Pool Storage		Joint Use Storage		Total Storage	
	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model	1988 Results	2007 Model
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	4.30	4.59	2.40	2.31	6.70	6.91
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.30	5.57	2.40	2.31	7.70	7.88
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.10	6.46	2.40	2.31	8.60	8.77
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	7.34	2.40	2.31	9.50	9.65
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00	8.27	2.40	2.31	10.40	10.58
Apr	4.30	4.28	4.20	4.12	0.10	0.15	0.40	0.37	0.07	0.07	6.80	6.80	3.00	2.89	9.80	9.69
May	6.70	6.73	6.10	5.97	0.60	0.76	0.60	0.65	0.10	0.10	9.00	8.63	3.00	2.86	12.00	11.49
Jun	11.00	11.03	9.60	9.62	1.40	1.41	0.90	0.91	0.15	0.14	9.90	9.18	3.60	3.46	13.40	12.64
Jul	13.50	13.47	10.80	10.62	2.70	2.85	1.10	1.18	0.19	0.17	7.50	7.07	3.10	2.94	10.60	10.01
Aug	12.20	12.24	9.80	9.41	2.40	2.83	1.10	1.14	0.17	0.16	6.00	6.06	2.80	2.78	8.80	8.84
Sep	8.00	7.95	5.80	5.69	2.20	2.27	0.80	0.92	0.14	0.13	4.00	4.33	2.70	2.55	6.60	6.87
Oct	5.50	5.50	3.50	3.50	2.00	2.00	0.60	0.67	0.07	0.07	3.10	3.46	2.40	2.34	5.50	5.79
Total	61.20	61.21	49.80	48.94	11.40	12.27	5.50	5.84	0.94	0.89						

Figure 2 – average monthly storage results



Time series monthly results of the 1988 and 2007 models for storage in the Model Pool and Joint Use Pool are compared in Figure 3.

Figure 3 – monthly results for storage in Model Pool and Joint Use Pool



An investigation of each of the larger differences found most of them attributable to a single issue. 1988 model results tables show output for the Ninemile and Highland Canal bypasses on rows 5 & 6 and also on rows 52 & 53. Documentation states that the values on rows 5 & 6 are the same as on 52 & 53, unless Flow at Trinidad is not sufficient to provide the required bypass, but this is not always the case. Rows 5 & 6 are on numerous occasions lower than rows 52 & 53, despite the fact that there is only one month of the simulation when inflow is not sufficient to satisfy the bypass requirement. The months when this is the case are all months with 1988 vs. 2007 model results discrepancies. The 2007 model calculations typically result in values that match rows 52 and 53, but the 1988 model uses the bypass values from rows 5 and 6 in implementing the operations for each month. Where these values are different, the results for storage in the 1988 and 2007 models change by an equal amount.

The other contributor to the larger differences in monthly storage results seen in Figure 3 are the different values for high inflow bypass (see Table 1). Where the difference between the bypass calculated from USGS data and the value reported in the 1988 model was substantial, this could cause a commensurate change in the water available for storage and thus the end of month storage result.

The use of regression relationships to define evaporation was discussed earlier with model input data. The effects of using this approach can be seen in Figure 4, a plot of the annual total evaporation from the 1988 model and the 2007 model. While the average monthly evaporation matches quite closely, the regression functions in the 2007 calculate individual monthly evaporation values that are either over or under the results from the 1988 study. On a monthly and often annual basis, this causes running differences in storage that persist until the reservoir either fills or drains. These differences are typically small, averaging less than 60 acre-feet, and never exceeding 270 acre-feet.

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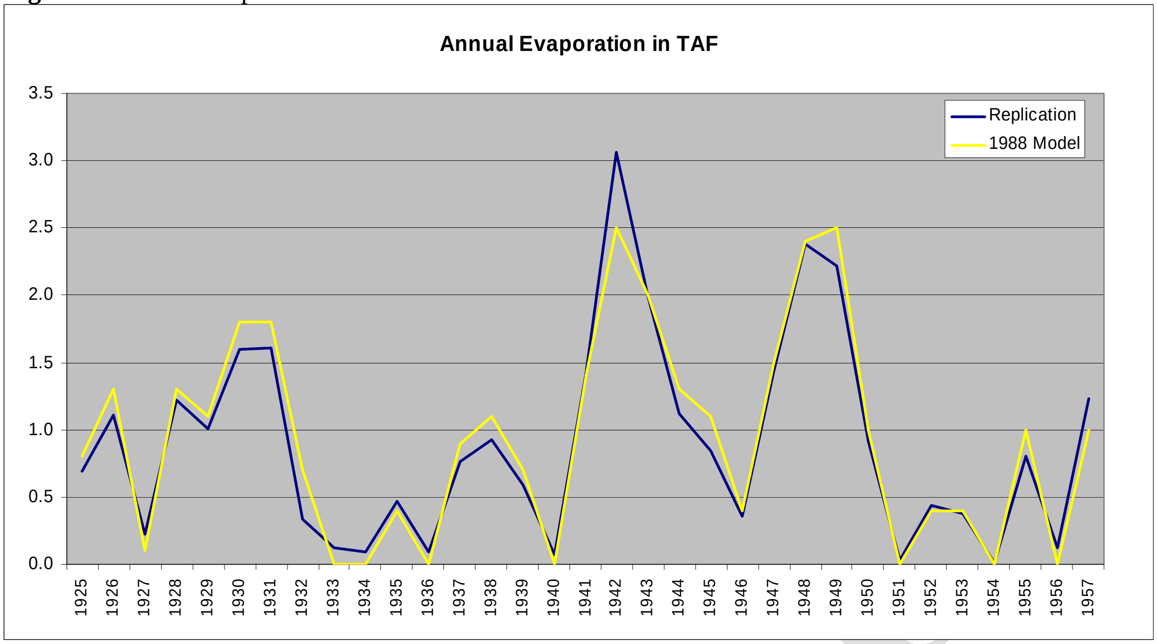
Figure 4 – annual evaporation from Trinidad Reservoir



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