Appendix E

Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986-2021

TECHNICAL MEMORANDUM

2171 E. Francisco Blvd., Suite K • San Rafael, California • 94901
TEL: (415) 457-0701 FAX: (415) 457-1638 e-mail:
sr@stetsonengineers.com

TO:	U.S. Bureau of Reclamation	DATE:	December 13, 2022 (Finalized 4-19-23 with no changes from 12-13-22)
FROM:	Curtis Lawler	JOB NO:	1336

RE: Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986-2021

1.0 Introduction and Objective

The purpose of this draft technical memorandum is to document the procedures used to compile the hourly hydrologic data for use in the Truckee-Carson RiverWare™ models as used for the Truckee Basin Water Management Options Pilot (WMOP) study. The WMOP study is evaluating changes to flood control reservoir operations to allow more storage but at the same time not increase risks from flood damages including dam overtopping.

This hourly dataset is intended to augment the RiverWare daily dataset methodologies (Precision, 2022a). This hourly dataset is intended to run in an hourly version of the Truckee-Carson RiverWare models and in tandem with the daily timestep RiverWare operations model. The objective of this technical memorandum is to provide a summary of the methodologies and provide notes to file for this hourly dataset developed for historical flooding periods used in the WMOP study, 1986-2021.

Operations and accounting of water in the Truckee system occur on a daily timestep. However, the flood target per the Water Control Manual is set based on an instantaneous flow rate (6,000 cfs). Therefore, hourly data was developed for historic flooding periods to simulate conditions when the instantaneous flow rate at or above the flood threshold as defined by the Water Control Manual. For all other periods, the system is operated at a daily timestep to allow for the complications of TROA operations which would not be feasible at an hourly timestep, thus derivation of hourly data for periods outside of the major runoff events is unnecessary.

2.0 Identification of Hourly Datasets for WMOP Study

The hourly dataset for the WMOP study focuses only on the major runoff events in the period of water years 1986 through 2021. A major runoff event is classified (Reclamation, 2 021) as any period within two weeks of either:

1. Hourly observed flows at the Truckee River at Reno, NV Gage (United States Geological Survey (USGS) gage number 10348000) exceeding 5,000 cfs,
2. Daily Farad Natural Flow exceeding 5,000 cfs, or
3. RFC hindcasts showing the flow at Reno exceeding 6,000 cfs.

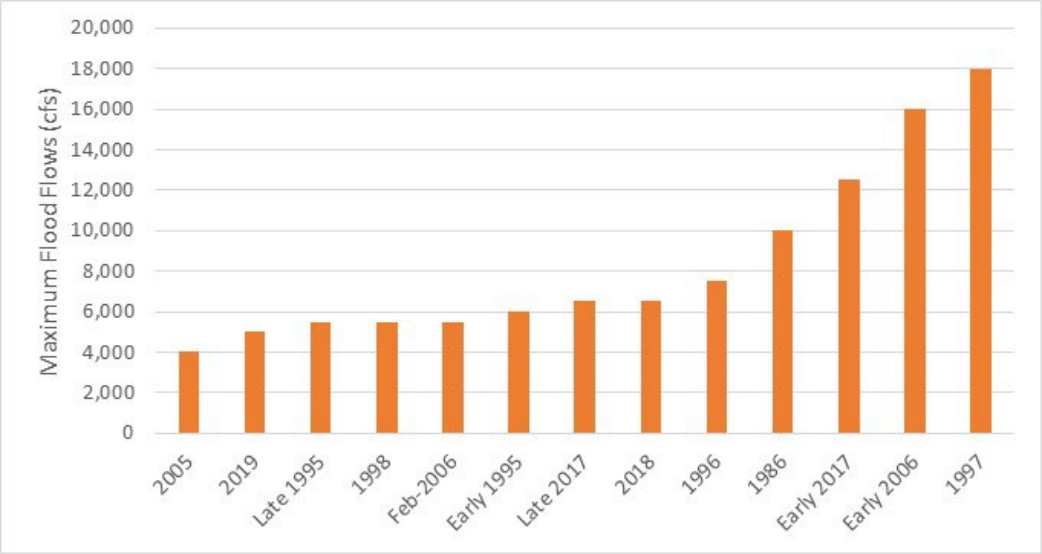
Table 1 shows a summary of the period of record for the 15 historical events that hourly data was developed. Some years had multiple events and would need to be identified with the month as well as year (i.e., March 1995, May 1995, December-January 2006, February 2006, December 2016, January2017, February 2017, April-May 2017). Other seven years only had 1 event or multiple storms close to the one event (water years 1986, 1996, 1997, 1998, 2005, 2018, 2019). Out of the total 36 years in the period 1986-2021, 10 years, or about 25-30%, had hydrologic events that came close to or exceeded flood control operational criteria. Note that the 5,000 cfs main criterion used is conservative in that the majority of flood impacts may actually occur at higher criteria levels (i.e., 6,000 – 10,000 cfs). The largest events occurred in water years 1997, 2006, 2017, 1986, and 1996. Figure 1 shows the maximum flood flows for the Truckee River at Reno gage (USGS 10348000).[1]

Table 1: Summary of Period of Record of Hourly Data that was Developed for the WMOP Study.

	Farad Nat or Reno > 5000 cfs?		**2-week leadtime for model analysis**	
Flood Event ID	**Date Begin**	**Date end**	**Model Date Begin**	**Model Date End**
1	2/15/1986	3/14/1986	2/1/1986	3/28/1986
2	3/9/1995	3/11/1995	2/23/1995	3/25/1995
3	5/1/1995	5/25/1995	4/17/1995	6/8/1995
4	5/16/1996	5/20/1996	5/2/1996	6/3/1996
5	12/24/1996	1/29/1997	12/10/1996	2/12/1997
6	3/24/1998	3/24/1998	3/10/1998	4/7/1998
7	5/19/2005	5/20/2005	5/5/2005	6/3/2005
8	12/30/2005	1/2/2006	12/16/2005	1/16/2006
9	2/28/2006	2/28/2006	2/14/2006	3/14/2006
10a	12/11/2016	12/17/2016	11/27/2016	See 10 c
10b	1/8/2017	1/11/2017	See 10a	See 10 c
10c	2/8/2017	2/12/2017	See 10a	2/26/2017
11	3/21/2017	5/31/2017	3/7/2017	6/14/2017
12	4/7/2018	4/11/2018	3/24/2018	4/25/2018
13	4/9/2019	4/9/2019	3/26/2019	4/23/2019

[1] Note that Water Year 2005 had a flood flow less than 5,000 cfs at Reno but met the other criteria for identifying flood flows with a daily Farad Natural Flow exceeding 5,000 cfs.

Figure 1: Summary of Flood Flows at Reno Gage by Event, Ranked for WY1986-WY2021, rounded to nearest 500 cfs.



3.0 Procedures Summary

The procedures for developing the WMOP study historical inflow data can be summarized in the following five steps with the section in this technical memorandum that discusses them in parentheses:

1. Gaged data collection (Section 4.0),
2. Data estimation for missing data (Section 4.0),
3. RiverWare processing (Section 4.0),
4. Manual review of RiverWare output (Section 5.0), and
5. Additional edits for WMOP study (Section 5.0).

Precision Water Resources Engineering created a preliminary summary and instructions on how to utilize tools that were used for the development of hourly data for the WMOP study (Precision, 2022b). These instructions and RiverWare model are included as **Attachment 1**. The key files that were utilized are listed, including: "HourlyModelCalibrationData-Inputs.xlsx" (used in Steps 1 and 2 above) and "LocalHourlyInflows.xlsx" (final product after Step 5 above). Final versions are these files are enumerated as attachments to this technical memorandum (**Attachment 2**).

In general, mass balance equations for reservoir and reaches were used to compute local inflows (Change in Storage = Inflows minus Outflows). Please refer to "Truckee River Basin Historical Data Development Methodologies: Water Years 2001-2016" (Precision, 2022a) for more details on mass balance methodologies. The main difference between the methodologies for the daily and hourly datasets are important to note and include:

- Daily dataset is continuous for period 1986-2021; Hourly dataset only for periods listed in Table 1.
- The reaches below Farad have been simplified in the hourly RiverWare model to include three reaches (Farad-Reno, Reno-Vista, and Vista-Wadsworth). Whereas, the daily model has eight reaches below Farad and extends further to Nixon. Also, the sidewater reaches above Farad are simplified into two reaches (Tahoe-Truckee and Truckee-Farad, instead of three reaches).[2]
- Inflows for hourly dataset are all "Net" inflows.
    - For reservoirs' inflows, evaporation and precipitation on all reservoir surfaces are implicit in the hourly dataset already; whereas, the daily datasets have separated evaporation and precipitation out. Note the daily dataset for Lake Tahoe inflow is also a "Net" inflow parameter with evaporation and precipitation already accounted in the inflow determination.
    - All diversions are part of the "Net" inflow. This does not include outflows from reservoirs, but rather diversions from the river. So, all diversions below Farad are part of the "Net" inflow for any reach. The Sierra Valley diversions above Stampede Reservoir are also part the "Net" inflow. The Truckee Canal diversions would also be part of the "Net" inflow for the Vista-Wadsworth reach.
    - Tributaries including Hunter Creek and Steamboat Creek and TMWRF return flows are also part of the "Net" inflow in their respective reaches (Hunter Creek in Farad-Reno and Steamboat in Reno-Vista).

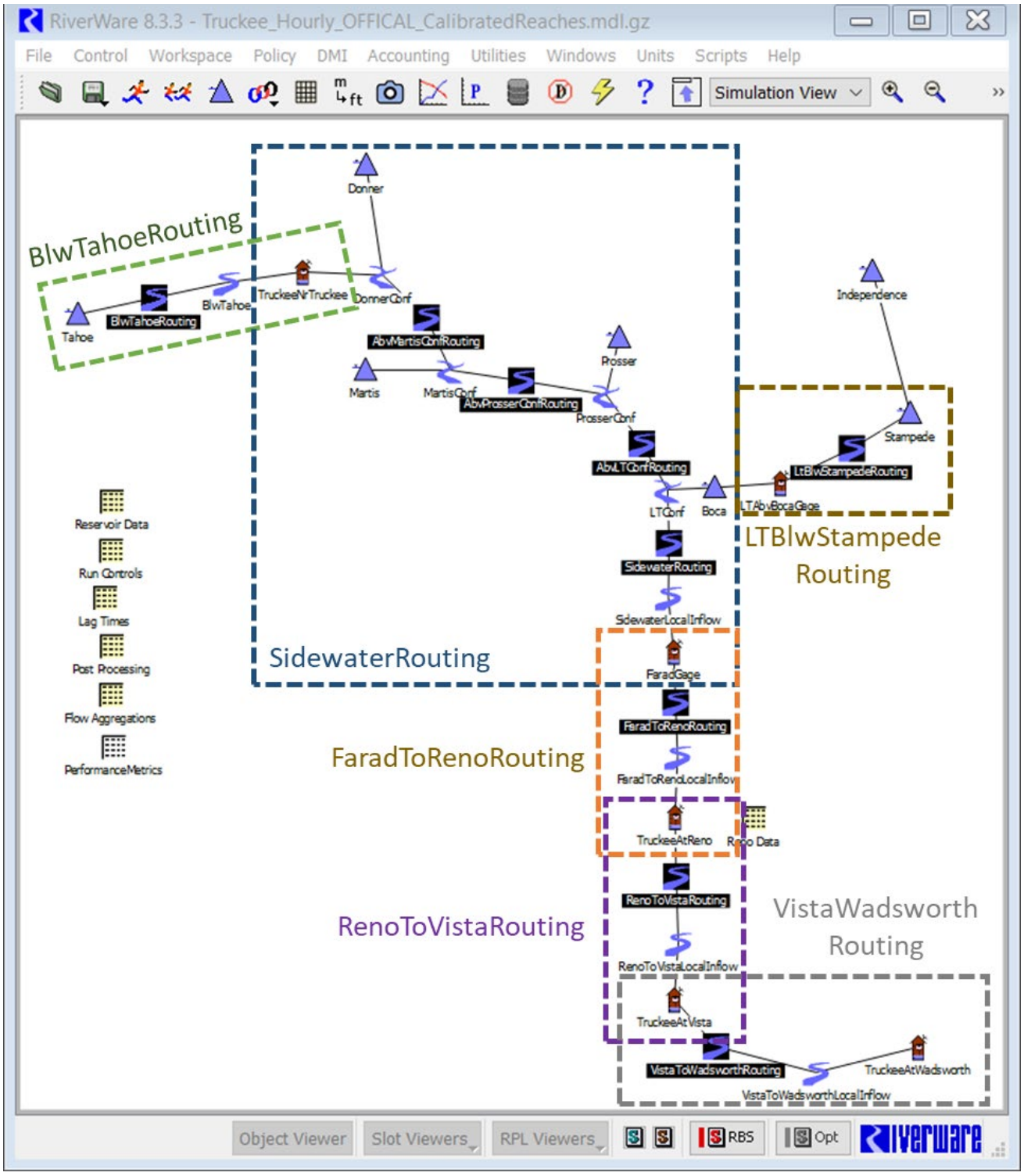
[2] The hourly model reaches were simplified to be consistent with the subbasins and water balance assumptions (i.e. net inflow) from the pre-existing HEC-ResSim model and what is forecasted by RFC. The more detailed water balance in the Daily timestep model is necessary to accurately model TROA.

The output for the RiverWare reaches in the hourly model are shown in Figure 2 (Precision, 2022c) and include the following twelve inputs:

1. Tahoe.Hydrologic Inflow
2. BlwTahoe.Local Inflow
3. Donner.Hydrologic Inflow
4. Martis.Hydrologic Inflow
5. Prosser.Hydrologic Inflow
6. Independence.Hydrologic Inflow
7. Stampede.Hydrologic Inflow
8. Boca.Hydrologic Inflow
9. SidewaterLocalInflow.Local Inflow
10. FaradToRenoLocalInflow.Local Inflow
11. RenoToVistaLocalInflow.Local Inflow
12. VistaToWadsworthLocalInflow.Local Inflow

Below are notes to file that are specific to the hourly dataset development. Section 4 discusses data inputs needed to calculate inflows using the hourly RiverWare model. Section 5 discusses manual review and additional edits needed for the WMOP study after RiverWare calculated the hourly inflows. The final hourly dataset from this study 1986-2021 were compiled into one spreadsheet "LocalHourlyInflows.xlsx" (Attachment 2).

Figure 2: TR Hourly River Model Schematic with routing reach highlighted and calibration subbasins emphasized (from Figure 1, "WMOP Truckee River Hourly River Model Time Lag Routing", Precision, 2022c).



4.0 Gaged Data Collection and Estimation of Missing Data

Once the flood events were selected, raw streamflow and elevation data was gathered from primarily the USGS database (Martis Creek Reservoir also includes data from the TROA Information System (TIS) database). This includes collecting data for nineteen gages including:

	Model Input Needed to Generate Hourly Inflows	Source	ID
1.	Tahoe Outflow (Truckee River at Tahoe City)	USGS	10337500
2.	Donner Creek at Donner Lake	USGS	10338500
3.	Martis Creek Reservoir Outflow	USGS, TIS	10339400
4.	Prosser Creek below Prosser	USGS	10340500
5.	Independence Creek near Truckee	USGS	10343000
6.	Little Truckee River above Boca	USGS	10344400
7.	Little Truckee River below Boca Dam	USGS	10344500
8.	Truckee River near Truckee	USGS	10338000
9.	Truckee River at Farad	USGS	10346000
10.	Truckee River at Reno	USGS	10348000
11.	Truckee River at Vista	USGS	10350000
12.	Truckee River at Wadsworth	USGS	10351650
13.	Lake Tahoe Elevation	USGS	10337000
14.	Donner Lake Elevation	USGS	10338400
15.	Martis Elevation	USGS, TIS	10339380
16.	Prosser Creek Reservoir Elevation	USGS	10340300
17.	Independence Lake Elevation	USGS	10342900
18.	Stampede Reservoir Elevation	USGS	10344300
19.	Boca Reservoir Elevation	USGS	10344490

For flow data (items 1 through 12 above), instantaneous data was averaged over one hour to match the timestep of the hourly RiverWare model. For elevation data (items 13 through 19 above), the end of the hour elevation was compiled. This data was compiled and formatted in Excel workbooks which are then used in the RiverWare Input DMI. If hourly reservoir storage data was available, but hourly reservoir elevation data was not available, then the reservoir storage data was converted to elevation data using the reservoir's elevation-volume table. Table 2 summarizes raw data that was not available hourly for the selected flood events. Any missing data points were estimated from available daily data and nearby gage stations.

Table 2. Summary of Unavailable Hourly Data for WMOP Study, 1986-2000

Flood ID	Period of Record (POR)		# of Gages with Missing Values (>4% of POR)		Comments on Missing Data
			Elevation	Flow	
1	2/1/1986	3/28/1986	7	1	All pre-2000 elevation estimated from daily; Truckee River near Truckee estimated from nearby gages
2	2/23/1995	3/25/1995	7	0	All pre-2000 elevation estimated from daily
3	4/17/1995	6/8/1995	7	0	All pre-2000 elevation estimated from daily
4	5/2/1996	6/3/1996	7	0	All pre-2000 elevation estimated from daily
5	12/10/1996	2/12/1997	7	0	All pre-2000 elevation estimated from daily
6	3/10/1998	4/7/1998	7	0	All pre-2000 elevation estimated from daily
7	5/5/2005	6/3/2005	1	2	Martis elevation estimated from daily; Independence outflow and Truckee near Wadsworth estimated from nearby gages.
8	12/16/2005	1/16/2006	6	0	All elevations, except Tahoe, estimated from daily
9	2/14/2006	3/14/2006	3	1	Stampede, Independence, and Prosser elevations estimated from daily; Farad estimated from nearby gages
10a	11/27/2016	12/31/2016	0	1	Truckee River near Truckee estimated from nearby gages
10b	12/25/2016	1/25/2017	0	1	Truckee River near Truckee estimated from nearby gages
10c	1/25/2017	2/26/2017	1	0	Independence Elevation estimated from daily
11	3/7/2017	6/14/2017	0	1	Independence Outflow estimated from daily
12	3/24/2018	4/25/2018	0	0	
13	3/26/2019	4/23/2019	0	0	

The input data needed to calculate the hourly hydrologic inflows (reservoir elevations and outflows, and flow data) are compiled into the spreadsheet "HourlyModelCalibrationData-Inputs.xlsx" (Attachment 2). This is the input file used in the "Compute Local Inflow" script (see Attachment 1). Due to noise in the hourly reservoir elevation data, all hourly reservoir elevation data is smoothed out using 5-hour averages (current hour plus the 2 hours before and after). This data is then run through the hourly RiverWare model which has the latest routing parameters (Precision, 2022c). The inflows are calculated based on mass balance (Local Inflow = Change in Storage (Reservoirs Only) + Gage Outflow – Upstream Inflows if any) for each of the twelve hydrologic inflow slots. The script and DMI then outputs the calculated hydrologic inflows for the twelve slots which are manually reviewed as discussed below. This initial hydrologic inflows from the gaged and estimated data as run through the calibrated hourly RiverWare model is compiled into the spreadsheet "RawOutputofHydrologicInflows.xlsx" (Attachment 2). This hourly inflow dataset is referred to as the "Raw" data and includes anomalies caused primarily by gaging errors. Although not perfect, this dataset is important because it is based on measured data. Also, the "Raw" dataset is important as the benchmark for total annual volumes that need to be conserved in the next steps.

5.0 Additional Edits of RiverWare Hydrologic Inflows for WMOP Study

The hourly data compilation for 1986-2021 flood events includes two additional steps after calculating the "Raw" inflow data: 1) initial smoothing of inflow data; and 2) disaggregation of hourly inflow data for the pre-2000 data and for consistency with daily data set. The spreadsheets for each of these two sets of edits are included as auxiliary files in Attachment 2.

The edits of initial smoothing of the hourly data are logged in the spreadsheet "InflowSmoothing Edits.xls" (Attachment 2). Review of the roughly 200,000 records of hourly inflow data was performed and manually smoothed out by averaging flows using criteria of negative hydrologic inflows and unusual patterns of standard deviation not associated with rainfall. The raw data that is edited is highlighted in yellow in this smoothing spreadsheet.

After this initial smoothing, all of the hourly data (Table 1) was disaggregated or redistributed using hourly reference events post-2000 for one of two reasons:

1. The pre-2000 data relies on daily reservoir elevation data, so the resulting hourly inflow calculations had a stair-step quality. The disaggregation process matched the same volume of the original pre-2000 data but redistributed the flows to look more natural.

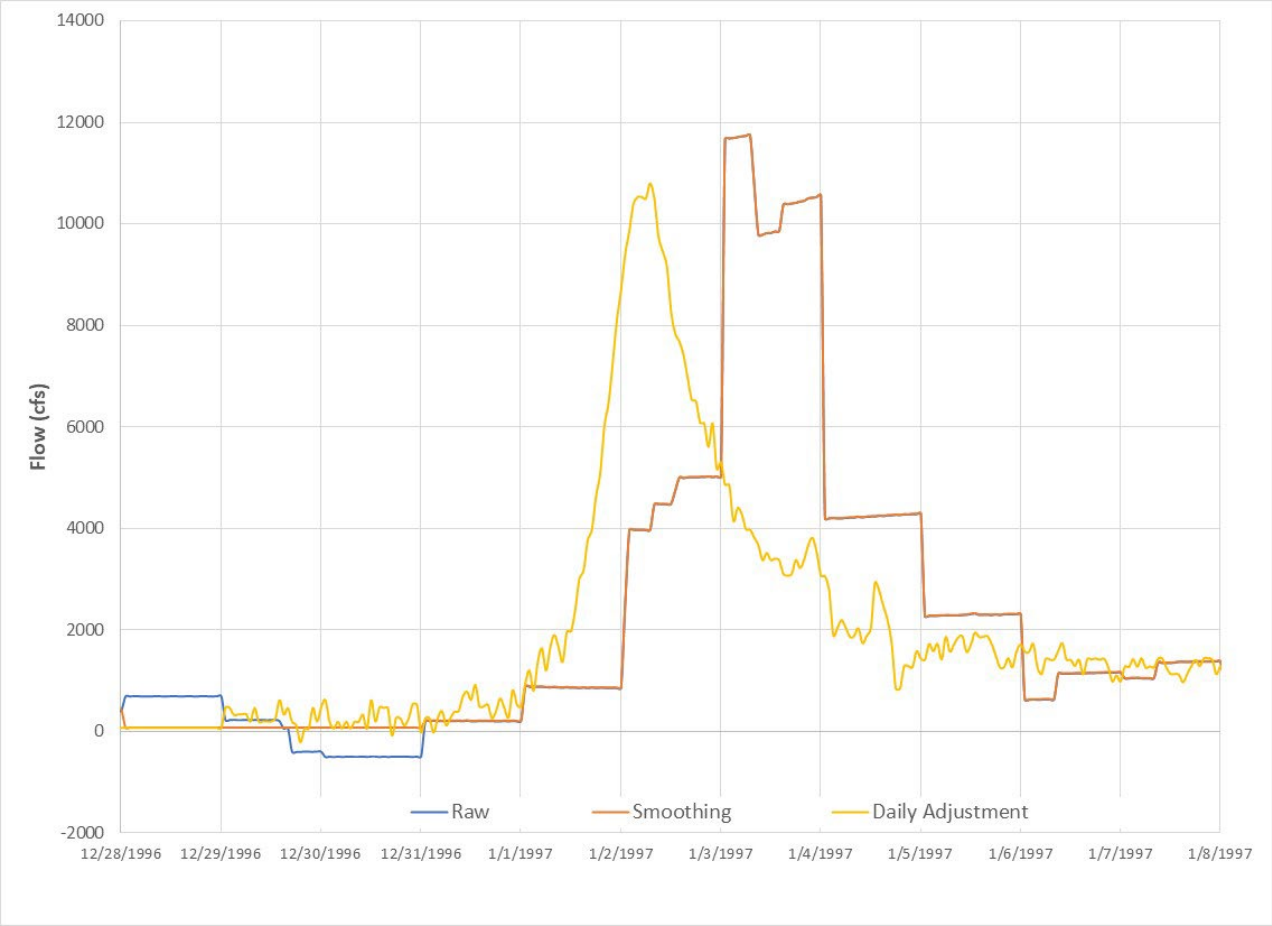
2. As used in the WMOP study, the hourly data and the daily dataset have to be consistent in order to test the different flood control operations. The timing and volume of the peak flows from the daily data did not match the peak timing the from the hourly data. Since the hourly model sets the releases for the daily model during flood event periods, the inflows need to match for consistency. The disaggregation process adjusted the hourly data set to match the timing and volume of inflows in the daily data set.

The edits for the disaggregation of the hourly data are logged in the spreadsheet "FloodEvent_HourlyInputs_DailyCorrection_FullEvents_StpCorrection" (Attachment 2). This spreadsheet tool was developed by Precision Water Resources Engineering in conjunction with the WMOP study. The steps for hourly data disaggregation within this spreadsheet are summarized as:

a. A post-2000 hourly event that was similar in season and peak flow is chosen (the Reference Event).
b. Through trial and error (which was automated), the relative timing of the Reference event was determined that lined up best with the timing of the event in question. This was done by choosing the Reference Event Start (Reference Start) timing with the best R2 compared to the event in question for pre-2000 data and to the best R2 compared to the Daily data. In this case R-squared is desirable because the magnitude of the flows in the reference event are known to not match the magnitude of the flows in the historical event and the objective is to determine the relative timing of the reference event to the historical event where the events are in phase. The Shifts used are recorded in columns AI-AO of the _Disagg sheet and column AP of the _DailyAdj sheet. The final shift adjustment is in the "DailyAdj" sheet.
c. The scale factor was computed to scale the reference event to give the same volume as the event in question for pre-2000 data and to match the same event in the daily dataset. The scale factors used are summarized in columns AN of the _Disagg sheet for the event for pre-2000 data and in column AN of each event _DailyAdj sheet. The final adjustment to the hourly dataset is in the "DailyAdj" sheet.
d. This was repeated for each of the twelve parameters and fifteen flood events (180 series).

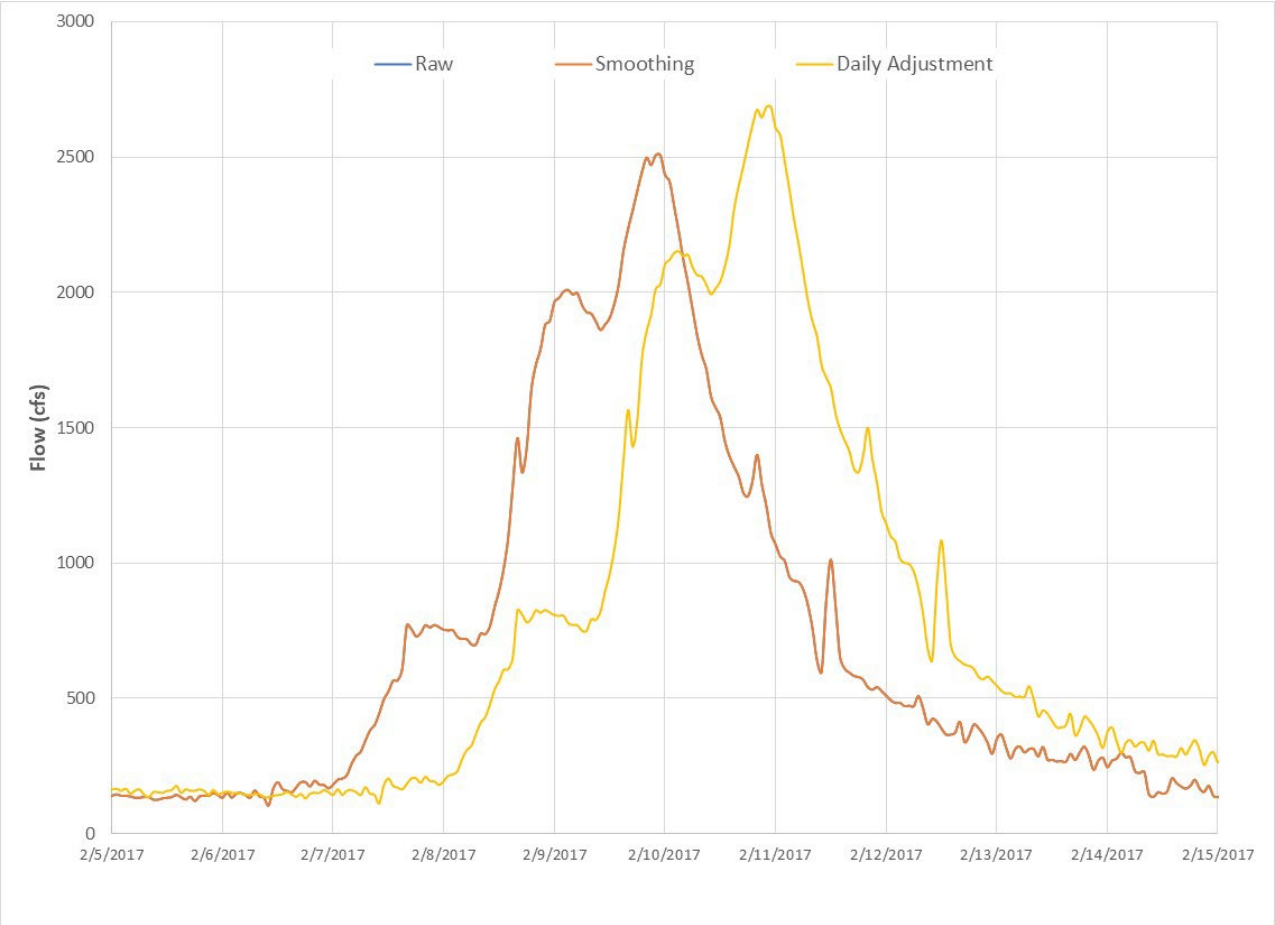
An example of the manual edits of the hourly data are shown in Figure 3 for Stampede Reservoir Hydrologic Inflow during the January 1997 flood event. Initially, the "Raw" data was smoothed out to avoid negative inflows as shown in the "Smoothing" dataset. Note that the pre-2000 inflow has a stairstep between days due to lack of hourly reservoir elevation data. To match the daily inflow input for Stampede Reservoir, the timing and magnitude of the peak flows were further adjusted. Overall, the hourly peak flows are similar (~11,000 cfs) and higher than the maximum daily flow of about 8,000 cfs for this event.

Figure 3: Stampede Reservoir Hydrologic Inflow during the January 1997 flood event.



Another example of the manual edits of the hourly data are shown in Figure 4 for Prosser Creek Reservoir Hydrologic Inflow during the February 2017 flood event. There was no smoothing of the raw data in this example. To match the daily inflow input for Prosser Creek Reservoir, the timing of the peak was shifted by about a day forward and the magnitude of the peak flows was increased. Overall, the hourly peak flows are similar (~2,500 to 2,600 cfs).

Figure 4: Prosser Creek Reservoir Hydrologic Inflow during the February 2017 flood event.



6.0 Summary

The Truckee River Hourly RiverWare Model will aid the TROA Planning Model in determining the necessary hourly releases for rapidly changing downstream inflows during major runoff events. For the purposes of the WMOP study, hourly inflow data was generated for twelve inputs in the hourly RiverWare model using all available gaged data during all major flood events in the last 35 years (1986-2021). This data was then adjusted to match the timing and volume of the daily inflow input parameters. The final hourly dataset used in the October 2022 WMOP study is included in Attachment 2, "LocalHourlyInflows.xlsx".

7.0 References

Precision Water Resources Engineering (a). Truckee River Basin Historical Data Development Methodologies: Water Years 2001-2016. August 19, 2022.

Precision Water Resources Engineering (b). Readme. Instructions to Develop Hourly Datasets. January 2022.

Precision Water Resources Engineering (c). WMOP Truckee River Hourly River Model Time Lag Routing. November 2021.

Reclamation. 2021 Hydrologic Engineering Analysis Tasks Report. Truckee Basin Water Management Options Pilot, Nevada, California-Great Basin Region. July 2021.

Attachment 1 Instructions

ReadMe.doc
Truckee_Hourly_CalibratedReaches_CorrectParameters.mdl.gz

Attachment 2 Spreadsheets

HourlyModelCalibrationDataSheets.xlsx
LocalHourlyInflows.xlsx
RawOutputofHydrologicInflows.xlsx
InflowSmoothingEdits.xlsx
FloodEvent_HourlyInputs_DailyCorrection_FullEvents_StpCorrection.xlsx