TAPER - A REAL-TIME DECISION SUPPORT TOOL FOR BALANCED FLOOD OPERATION OF THE ARKANSAS RIVER IN TULSA DISTRICT

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Abstract: The U.S. Corps of Engineers Tulsa district is responsible for water management of the Arkansas River as it flows through Kansas and Oklahoma including the operation of numerous flood storage reservoirs and five navigation locks. The goal is to minimize flooding throughout the network with the key regulation control location at Van Buren, Arkansas. Upstream of Van Buren are 13 major flood storage reservoirs (7.6 million acre-feet) with 7,200 sq miles of uncontrolled local runoff that are managed to minimize flooding. The system flood evacuation plan calls for releases that evacuate the flood storage as quickly as possible without causing flooding, while still balancing the system storage and tapering down the flow at Van Buren.

During flood operations, Corp staff use a real-time decision support system named TAPER, implemented in RiverWare, which simulates the river and reservoir network, including all of the reservoir operations. The RiverWare model imports observed and forecasted inflows and local runoff and then uses rulebased simulation to model mandatory surcharge releases, allowable flow at various control locations, and the releases to meet the allowable flow in a balanced manner. The regulation discharge at Van Buren is computed based on a seasonally varying guide curves representing the equivalent percent of basin storage utilized. This algorithm allows higher flows during flooding seasons and when the system is full to recover the flood storage space in the upstream projects. The targets also include a smooth tapered recession to bring the system down to normal operations while allowing for scouring and dredging for navigation.

Given this regulation discharge, the RiverWare model computes a set of proposed release to balance the relative reservoir storages while not exceeding the downstream flow targets. Routing is modeled using the step response routing algorithm. Water managers collectively review the proposed releases and river flows and modify releases based on event specific conditions. RiverWare System Control Tables, plots, and output tools provide a friendly user interface focusing on the key variables in the system. As water managers modify releases, the model is re-run to compute downstream flows and reservoir levels. This process repeats until the managers are satisfied. The final release schedule and other reports are sent to dam operators, other federal agencies, local water managers, power authorities and other interested stakeholders.

RiverWare is a river and reservoir modeling tool developed by the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) with sponsorship of the Tennessee Valley Authority, the Bureau of Reclamation and the U.S. Army Corp of Engineers.

INTRODUCTION

The Arkansas River originates in central Colorado and flows through Kansas, Oklahoma, and Arkansas to its confluence with the Mississippi River. The U.S. Army Corps of Engineers (USACE) Tulsa District is responsible for water management of the river through Kansas and Oklahoma (Figure 1). During flood events, the system is operated to reduce downstream flooding and then evacuate the flood pool storage as quickly as possible in a balanced manner while still meeting navigation objectives. The Tulsa District has developed a RiverWare operations model called TAPER which helps the District perform this operation on a day-to-day basis as needed. This paper describes the basin and its operations during these flood pool evacuation operations and presents information on the TAPER model.

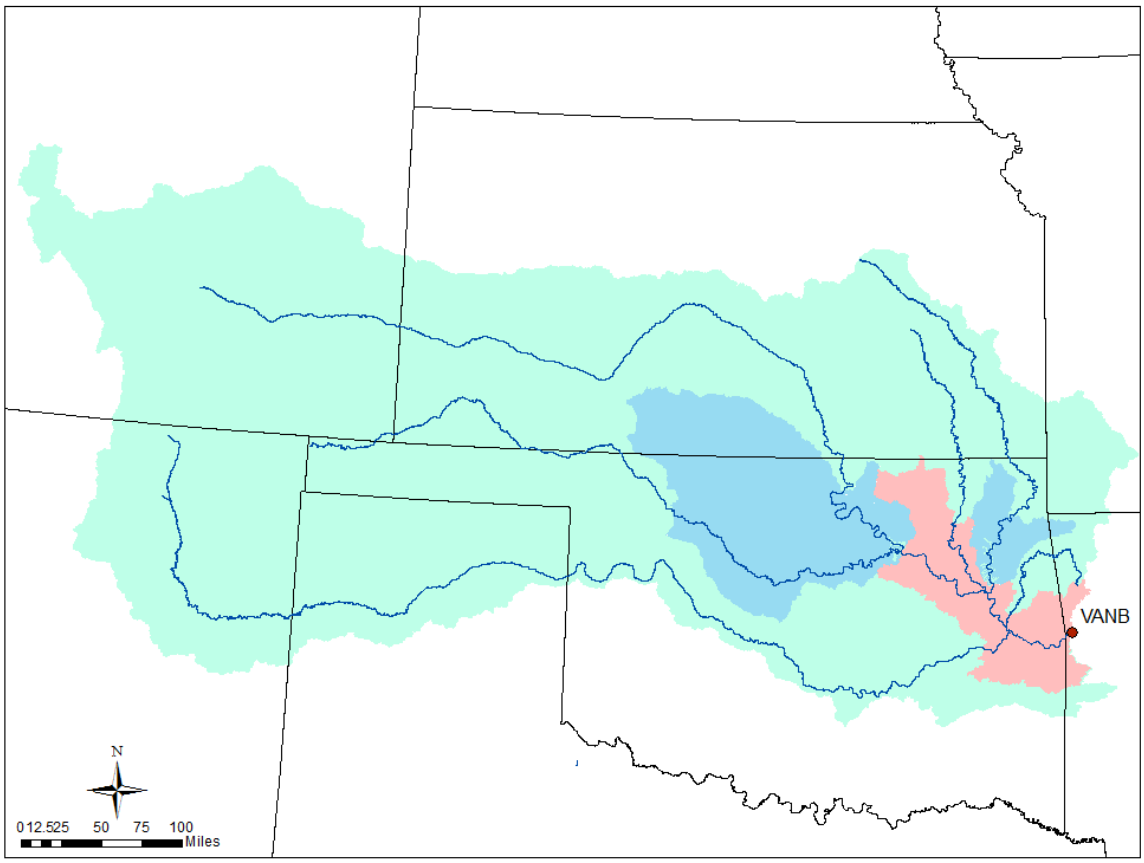


Figure 1 Drainage area (green) for the Arkansas River to Van Buren including locals (above reservoirs (blue), uncontrolled (pink)).

Basin Background: Thirty flood storage reservoirs exist on the Arkansas River and tributary system in Kansas and Oklahoma, including five navigation lock and dams. These reservoirs contribute to a common downstream control point for system regulation at Van Buren, Arkansas (VANB). Thirteen of these reservoirs (Copan, Hulah, Oologah, Birch, Skiatook, Kaw, Keystone, Pensacola, Hudson, Fort Gibson, Tenkiller, Eufaula, and Wister) are all in close proximity to VANB.

The Tulsa District manages the Arkansas River to VANB near Van Buren, Arkansas, and water management policies are specified in the Arkansas River Basin: Water Control Master Manual (USACE Tulsa and Little Rock District). The Arkansas River is managed to keep flows below regulation stage, evacuate flood storage in a timely manner, meet navigation needs, slowly taper flows down to allow for scouring, dredging of navigation channels, and provide for miscellaneous stakeholders needs. When upstream reservoirs are in the flood pools, the Corps is responsible for evacuating this pool. The combined flood pool storage of these lakes is 7.6 million acre-ft and the releases from all 13 reservoirs must be managed along with 7,200 sq miles of uncontrolled local runoff (Figure 2), to meet these multiple objectives, with a max regulation discharge of 150,000 cfs. Based on the percent of flood storage utilized, each reservoir is given an allocation and priority that guides in its releases to meet the flow hydrograph at VANB.

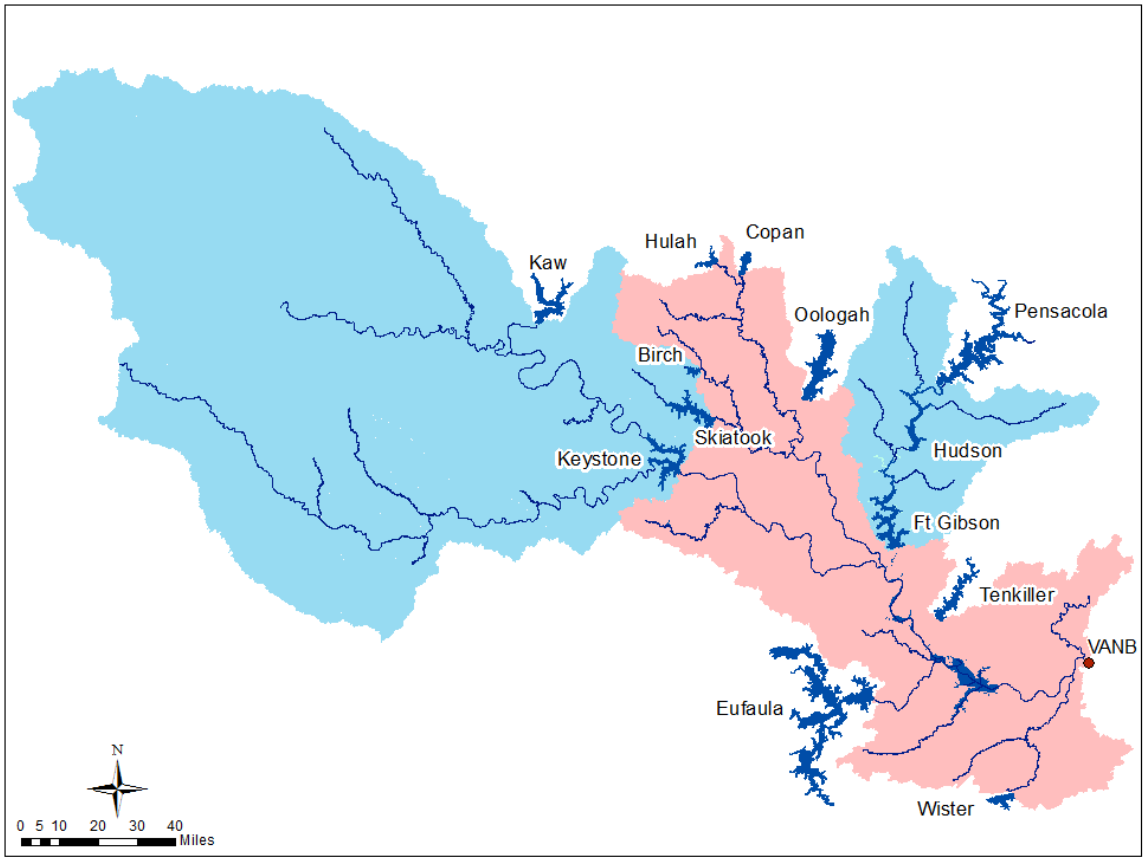


Figure 2 Thirteen reservoirs along Arkansas River and local areas (uncontrolled (pink), above reservoirs (blue))

Taper Operations: Tulsa District uses a procedure called TAPER to balance releases through the Arkansas River to Van Buren. The goal of TAPER is to determine releases using the system flood storage evacuation plan, which correlates system percent full with target flow. The target flow allowed at Van Buren consists of a series of stepped down benches set by a guide curve, which is based on the equivalent percent of basin storage utilized. The benches vary seasonally based on historical flood patterns. Flood water is released quicker during flooding seasons to

increase available flood storage in the upstream projects, and includes a tapered recession for navigation to allow for scour and dredging. A typical evacuation operation period is twenty-one days. To assist with the TAPER operations, Tulsa district uses simulation models to represent the system. The original TAPER program was a daily timestep model, with daily average releases and flows. This caused issues with high and low flow fluctuations in the navigation system. These fluctuations contribute to bank caving and shoaling issues in the system. In order to reduce fluctuations with the old TAPER program the gate changes are entered into a HEC-1 forecast model to route the flows through the Arkansas River. Then gate changes are manipulated to try and reduce fluctuations. This method of operating the system was very time consuming, and was not efficient. A new model was needed with 6-hr timesteps, better routing, and the ability to make a better initial suggestion at the release schedule. RiverWare was selected as the modeling tool in which to implement a new version of TAPER.

The RiverWare TAPER model is a real-time flood management model that imports forecast inflows and local runoff from forecast models. It then uses rulebased simulation to model water management strategies used by the USACE Southwest Division. These rules balance the system by allowing reservoirs to set releases based on priority curves and reservoir fullness, but also by allowing for a smooth flow transitions through reaches, and to not allow rivers to rise above flood stage. RiverWare TAPER produces a set of proposed releases for all reservoirs in the system. Water managers collectively look over proposed releases and modify based on event specific conditions. The final release schedule is sent to stakeholders who have an interest in the reservoirs and river system.

RIVERWARE TAPER MODEL

RiverWare is a river and reservoir modeling tool developed by the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) with sponsorship of the Tennessee Valley Authority, the Bureau of Reclamation and the U.S. Army Corp of Engineers. RiverWare models operations of the reservoirs and routes releases through routing reaches (CADSWES, 2014). The models consist of reservoirs, control points, confluence objects, routing reaches, and data objects (Figure 3).

Initial Conditions and Inflow Forecasts: To provide an effective evaluation of the river, 30 days of observed pre-simulation release and local inflows are provided to accurately prime the system. For the simulation period, initial elevations, reservoir inflows, and local uncontrolled runoff come from HEC-1 forecast models. HEC-1 is a rainfall runoff model developed by HEC (USACE Hydrologic Engineering Center, 1998). Forecast models are developed for each of the reservoirs and for the local areas. During flood operations, forecast models are calibrated for the specific storm events, using initial and constant loss, Snyder unit hydrograph, and baseflow recession. The corresponding reservoir inflows and local runoffs are imported into RiverWare using RiverWare's Data Management Interface (DMI) tool.

Rules: TAPER uses rules to determine releases that evacuate the flood pool in an efficient manner while not causing flooding downstream and limiting downstream flow for system benches. The goals of the rules are to keep flows at Van Buren below regulation levels determined using system evacuation guide curves, keep all control points below regulation

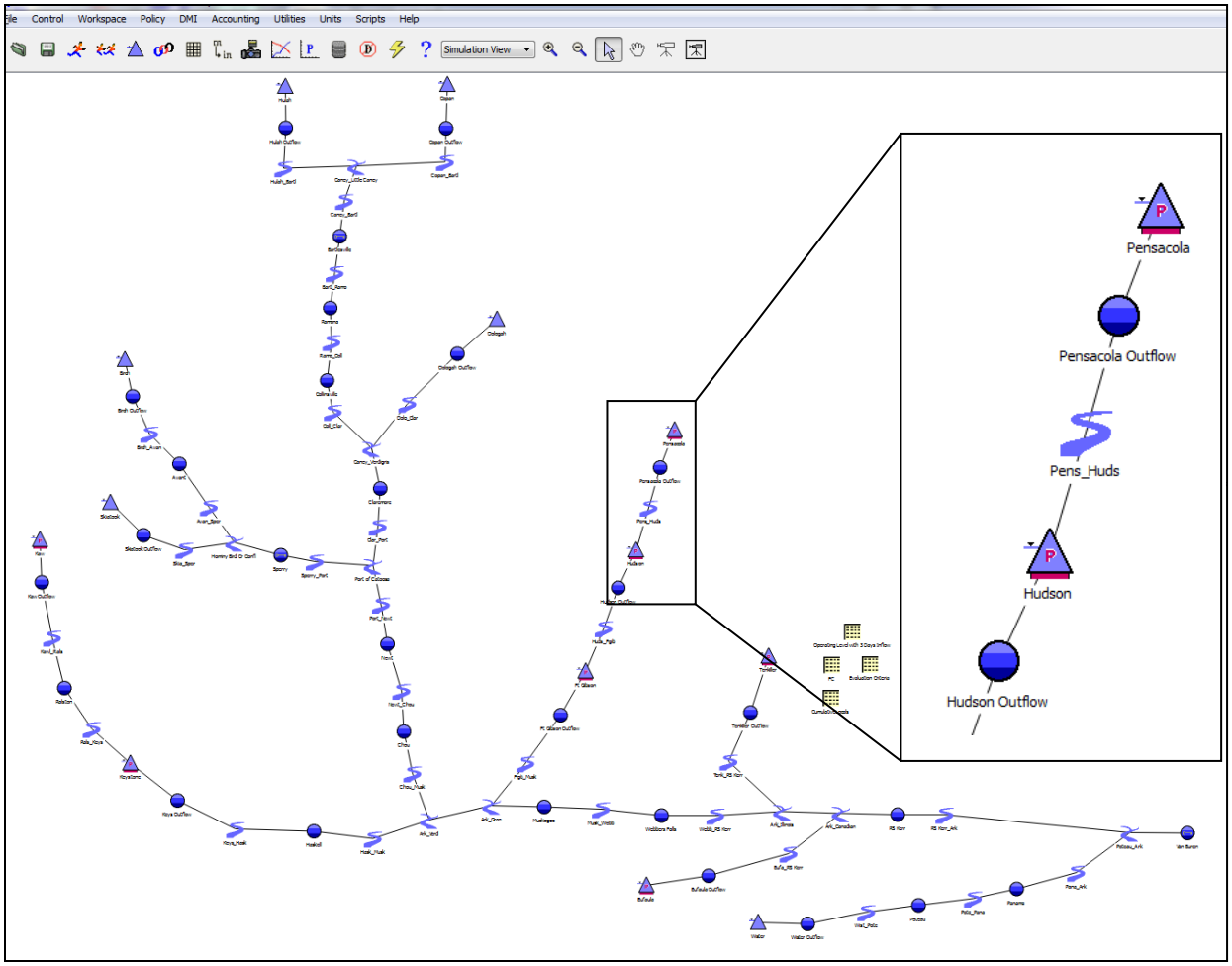


Figure 3 Schematic of RiverWare workspace

limits, and balance the system. The releases are determined using the surcharge, regulation discharge, and flood control rules developed for the USACE Southwest Division, based on the operating policies.

Surcharge: Surcharge occurs when flood water in the lake is above the flood pool and water must be released, regardless of downstream conditions. The surcharge releases are calculated for each reservoir one at a time starting with the most upstream reservoir. In the case where surcharge releases are necessary, they are routed through the system. If the upstream reservoir is above another reservoir, the releases are routed downstream to become inflows to the next reservoir. This reservoir then calculates its surcharge releases. This process continues until surcharge releases have been calculated for every reservoir.

Regulation Discharge: The regulation discharge, which is the maximum flow allowed at Van Buren, varies seasonally and with regard to the percent of basin storage utilized, summarized in the Van Buren Guide Curve (Figure 4).

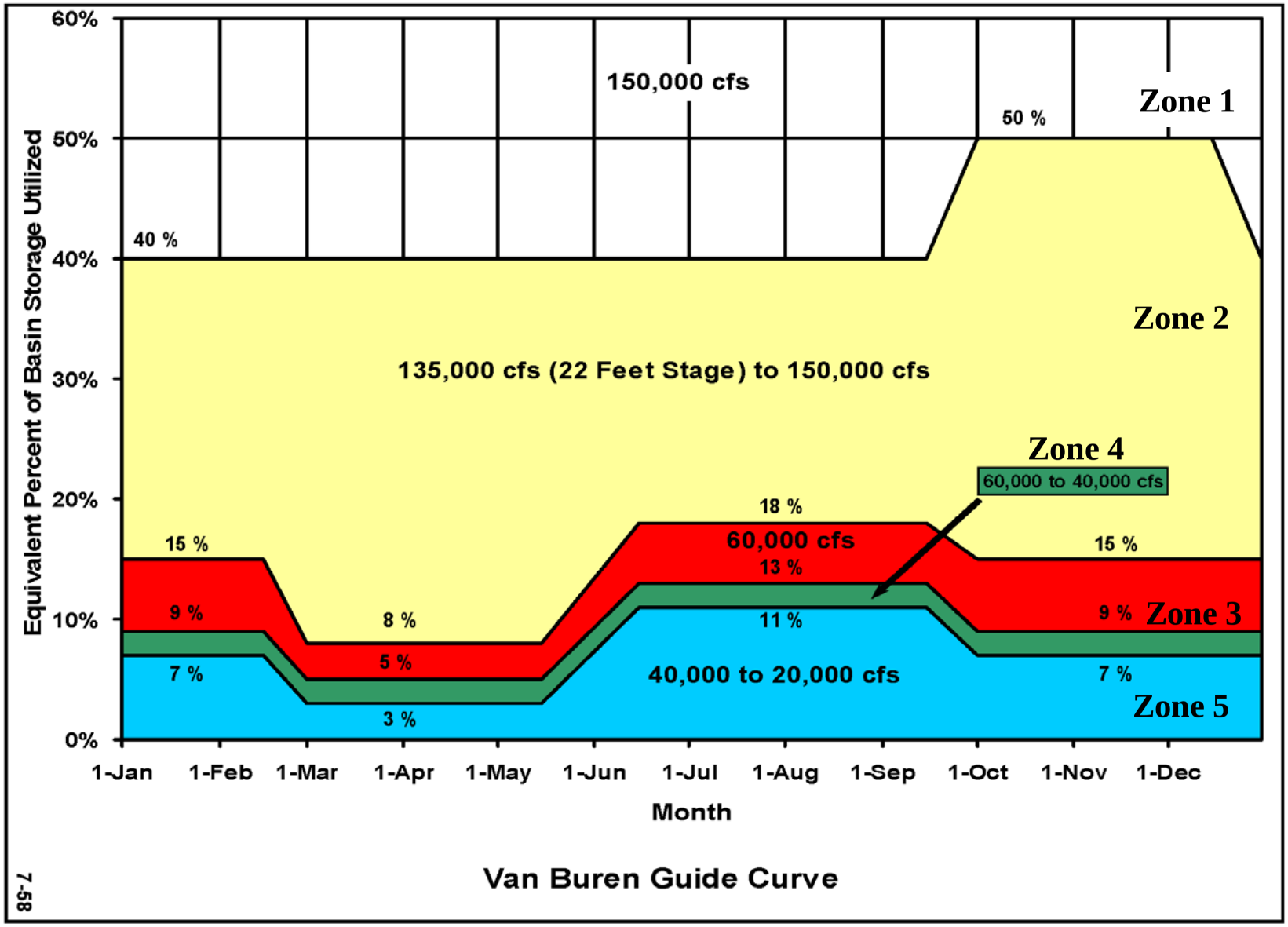


Figure 4 Van Buren Guide Curve with specified regulation discharge flows for five zones.

The Equivalent Percent of Basin Storage Utilized is calculated as

$$\frac{\sum_{@\,t} S + \left(\sum_{t}^{t+3} I - \sum_{t}^{t+3} O\right)}{\sum_{@t} S_{Total}} * 100 \qquad (1)$$

where S is reservoir's flood pool storage utilized, I is reservoir inflow, O is reservoir releases, S_{Total} is the reservoir's total flood pool storage, and t is the current time in days. Depending on the time of year the equivalent percent of basin storage utilized correlates to a regulation discharge at Van Buren, ranging from a high of 150,000 cfs to a low range of 40,000 to 20,000 cfs. There are five zones and each has additional criteria that determines the flow and time period for the range of flows (Figure 4). Some of the zones represent maximum regulation discharge values, while others show a range of flows to transition between. For example Zone 5 requires a tapered recession from 40,000 to 20,000 cfs in 21 days (USACE Tulsa and Little Rock District, Chapter 7). There are also other regulation points in the system such as Bartlesville, Ramona, Collinsville, Claremore, and Muskogee. Each regulation point has a site specific regulation discharge.

Flood Control: The SWD Flood Control rules try to balance the system by reducing each lake to the same balance level/operating level. Tulsa District developed a correlation between percent flood pool storage with a balance level. This allows for a priority assignment for reservoir releases that are competing for downstream channel space. The balance level is based on the system flood storage balance level vs. storage curves (Figure 5). Curve C is the highest priority until the percent of flood storage utilized reaches thirty percent than all lakes have the same priority. Curve B is next in priority followed by Curve A. Each reservoir is assigned a release schedule that will bring all reservoirs to the same operating (balance) level without causing downstream flooding. This process is repeated for each timestep in the forecast time period. The RiverWare rules execute this logic through the use of the predefined Flood Control function which executes the system wide solution. The results are the outflows from each reservoir which are then routed through the system.

Iterative MRM: Since the equivalent percent full equation (1), uses the outflow from the reservoirs, this value will change based on the releases computed in the Flood Control rules. To perform this iteration, RiverWare's Iterative Multiple Run Manager (MRM) is used. This utility allows an entire simulation run to be made and then logic is executed to decide if another simulation is necessary. The logic sets values in the system and another run is executed. For the first pass, the Iterative MRM sets the outflow values in equation (1) to 180,000 acre-ft. For every other run it is set to the computed outflow from the reservoirs. The model runs through three different runs, until the results converge to a solution.

RESULTS

After three iterative runs are made the results are shown in RiverWare's System Control Table (SCT). For each reservoir, the inflow sum, outflow, operating level, pool elevation, percent of flood control pool, and operating level with three days inflow are summarized in a the table (Figure 6). The water managers then look at the model's suggested release schedule and make changes based on engineering experience not captured by the rules and special circumstances.

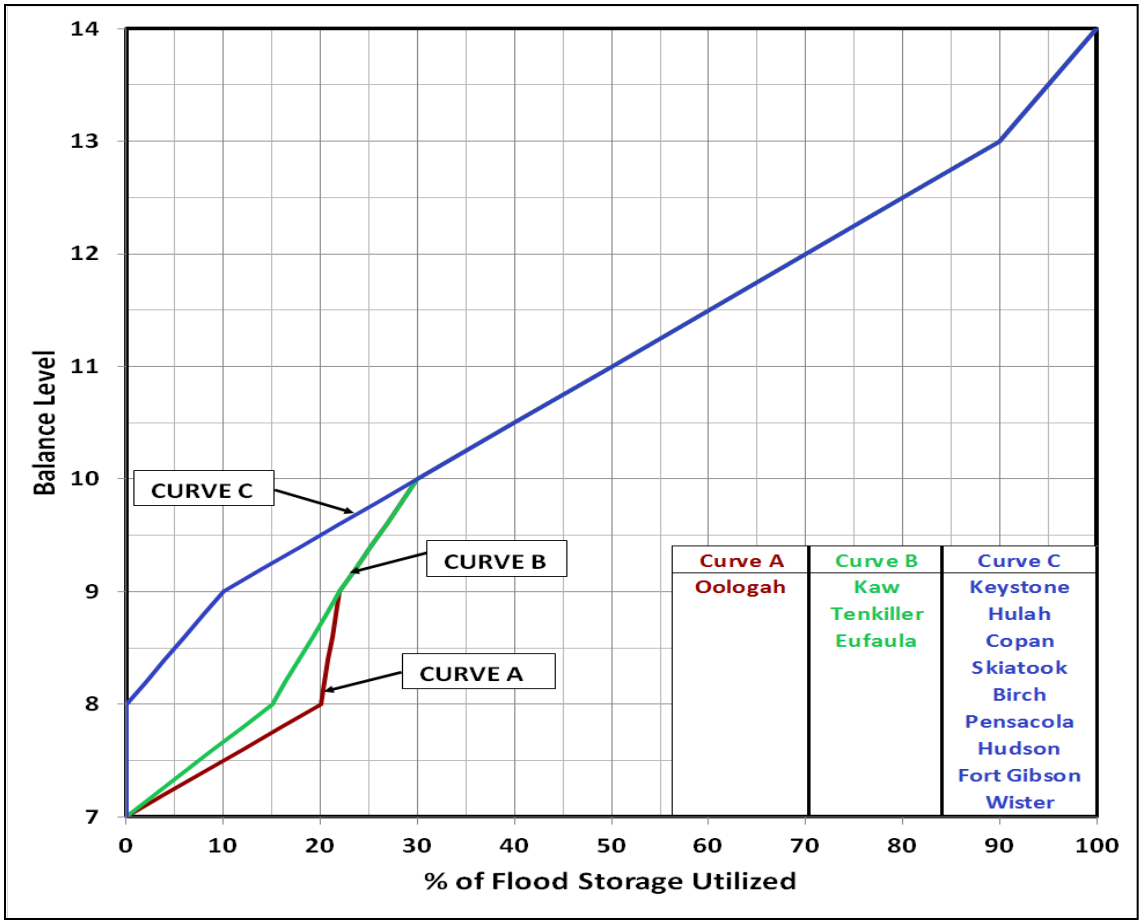
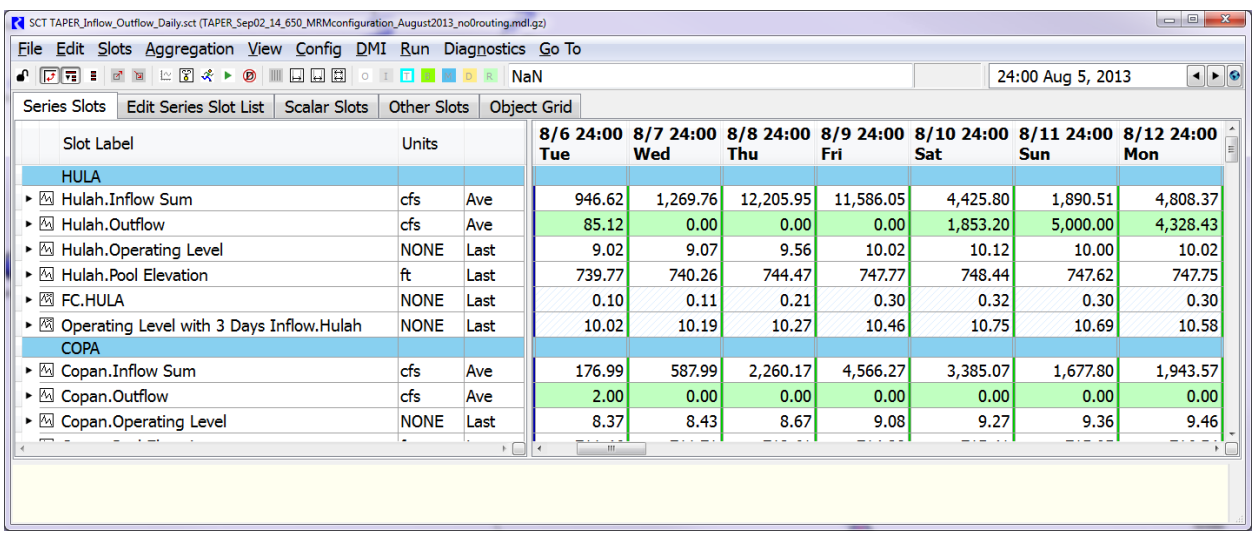


Figure 5 Balance level vs. percent of flood storage utilized curves.



SCT TAPER_Inflow_Outflow_Daily.sct (TAPER_Sep02_14_650_MRMconfiguration_August2013_no0routing.mdl.gz)

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Series Slots | Edit Series Slot List | Scalar Slots | Other Slots | Object Grid

Slot Label	Units		8/6 24:00 Tue	8/7 24:00 Wed	8/8 24:00 Thu	8/9 24:00 Fri	8/10 24:00 Sat	8/11 24:00 Sun	8/12 24:00 Mon
HULA									
Hulah.Inflow Sum	cfs	Ave	946.62	1,269.76	12,205.95	11,586.05	4,425.80	1,890.51	4,808.37
Hulah.Outflow	cfs	Ave	85.12	0.00	0.00	0.00	1,853.20	5,000.00	4,328.43
Hulah.Operating Level	NONE	Last	9.02	9.07	9.56	10.02	10.12	10.00	10.02
Hulah.Pool Elevation	ft	Last	739.77	740.26	744.47	747.77	748.44	747.62	747.75
FC.HULA	NONE	Last	0.10	0.11	0.21	0.30	0.32	0.30	0.30
Operating Level with 3 Days Inflow.Hulah	NONE	Last	10.02	10.19	10.27	10.46	10.75	10.69	10.58
COPA									
Copan.Inflow Sum	cfs	Ave	176.99	587.99	2,260.17	4,566.27	3,385.07	1,677.80	1,943.57
Copan.Outflow	cfs	Ave	2.00	0.00	0.00	0.00	0.00	0.00	0.00
Copan.Operating Level	NONE	Last	8.37	8.43	8.67	9.08	9.27	9.36	9.46

Figure 6 System Control Table summarizing daily results for 6-hr timestep model

Once the water managers have set their releases, they are locked in as input values for a few days and the model is rerun for the rest of the simulation period. The model determines any unspecified release based on the modified release scenario. The water managers check that gages downstream stay below regulation discharge, and lock in several more days of releases. This process continues until the water managers are satisfied with the final release scenario. Once water managers are satisfied with the results, then html reports, plots (Figure 7), DSS files, and text files are developed for stakeholders. Water managers use the releases plan to make requested gate changes from the dam operators, and coordinate hydropower releases.

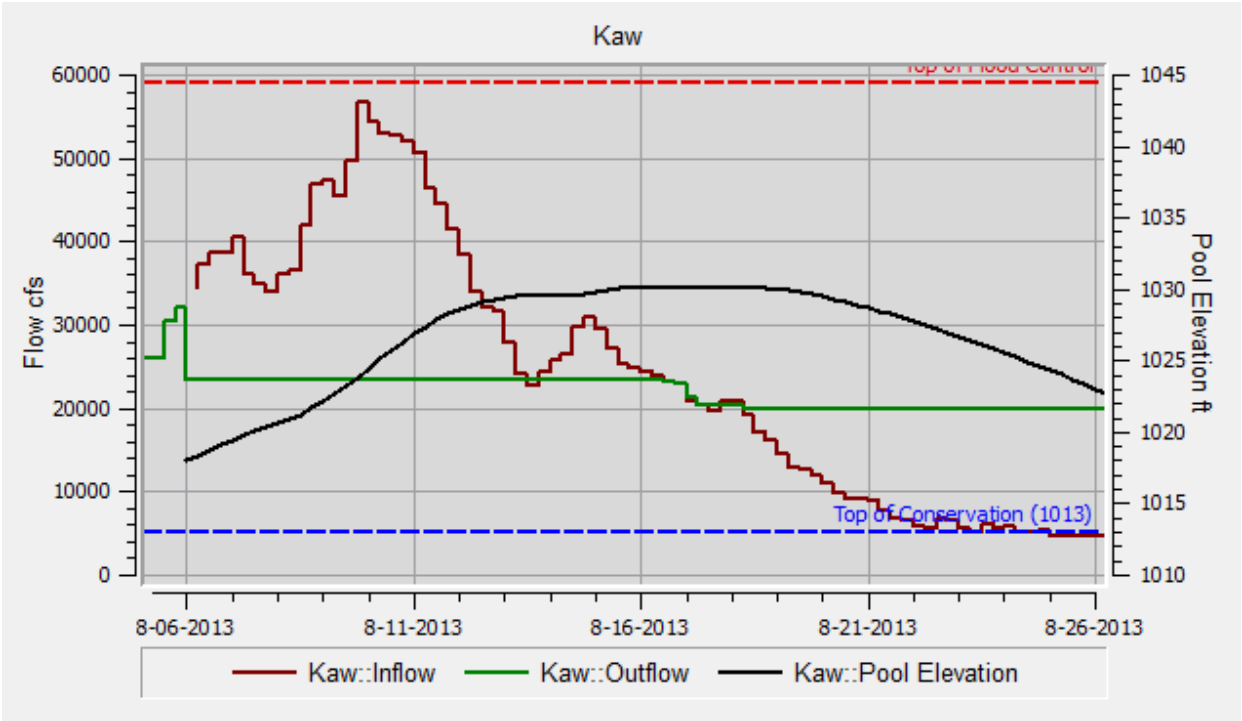

Figure 7 Example of plot sent to stakeholders

CONCLUSION

The U.S. Army Corps of Engineers, Tulsa District manages flows to Van Buren, Arkansas, using a RiverWare model to help with TAPER operations. The model uses operating curves and model constraints to create a recommended release plan that evacuates the flood pool in an efficient manner, while maintaining many stakeholder and navigation needs. The RiverWare model and user interface tools will save water managers time and create a more efficient process to create release plans. The 6-hr model will help to reduce flow fluctuations at the Arkansas River lock and dams, and will allow for one model to create and edit release plans reducing the amount of time spent by water managers.

REFERENCES

Center for Advanced Decision Support for Water and Environmental Systems (CADSWES). (2014) RiverWare User's Guides. http://www.riverware.org/PDF/RiverWare/documentation.

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U.S. Army Corps of Engineers Hydrologic Engineering Center. (1998) HEC-1 Flood Hydrograph Package User's Manual.