Appendix K

Revised Guide Curve Modeling
Improving Current Guide Curves with dSRD Approach

REVISED GUIDE CURVE MODELING

Improving Current Guide Curves with dSRD Approach

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1 CONTENTS

2 INTRODUCTION

The Truckee Basin Water Management Options Pilot Study (WMOP) is a cost share study being performed by the U.S. Bureau of Reclamation (Reclamation), Truckee Meadows Water Authority (TMWA), the Federal Water Master/Truckee River Operating Agreement (TROA) Administrator, Pyramid Lake Paiute Tribe, and California Department of Water Resources (the Technical Team). The study will evaluate a range of alternatives including Forecast Informed Reservoir Operations, flexible guide curves, and changes to downstream regulation goals. This study will then be documented in a Viability Assessment and provided to the United States Army Corps of Engineers (USACE) for a potential update to the Water Control Manual. One of the Alternatives discussed in the WMOP Plan Formulation and further refined by the Technical Team is to update the guide curves contained within the current Truckee River Basin Water Control Manual (WCM) to utilize the latest data and runoff forecasts. This report discusses the methodology utilized to update the WCM guide curves for a range of potential Reno flood target flows between 6000 cubic feet per second (cfs) and 8000 cfs, as measured at the Truckee River at Reno gage (Reclamation, 2021).

Guide curves diagrams, also referred to as guide curves diagrams, prescribe flood space requirements in a reservoir for a given day. These guide curves are based on the amount that the historical unregulated Reno runoff exceeded specified flood target flows for a location. These data are employed to determine flood space requirements as a function of forecasted remaining water year Farad Natural Flow runoff. Specifically, they allow determination of flood space storage volume requirement for a specified date of the water year and forecasted runoff volume.

Current guide curves contained within the current Truckee River Basin Water Control Manual (WCM) were last updated in July of 1985 (USACE, Truckee River Basin Reservoirs, Truckee River, Nevada and California Water Control Manual, 1985). These guide curves are based off Reno flood flows over a specified target (USACE, Truckee River Basin Reservoirs, Truckee River, Nevada and California Water Control Manual, 1985). There are opportunities for improving the current guide curves considering guidelines set forth by the Natural Resources Conservation Service (NRCS, Technical Release No. 75, 1991) and the US Army Corps of Engineers (USACE, Hydrologic Engineering Requirements for Reservoirs EM 1110-2-1420, 2018) . Generally, these improvements include (1) flood targets informed by the latest available data and improvements in forecast availability, and (2) potential water supply benefits resulting from encroachment all the while ensuring conservative flood space requirements throughout a given water year. These improvements can be realized by updating the WCM's guide curves according to USACE and NRCS guidance with the latest data.

To implement a guide curve in operational practice, a few simple steps are necessary to arrive at a flood space requirement on a given day. Firstly, an operator must identify the appropriate curve based on the remaining Farad April through July runoff forecast on the diagram. Secondly, the operator must identify the current date on the diagram. Thirdly, after locating the intersection of the current date and inflow forecast series, the operator must determine the flood space requirement for that day from the y-axis of the diagram. An example of Prosser Reservoir's current guide curve is shown in Figure 1.

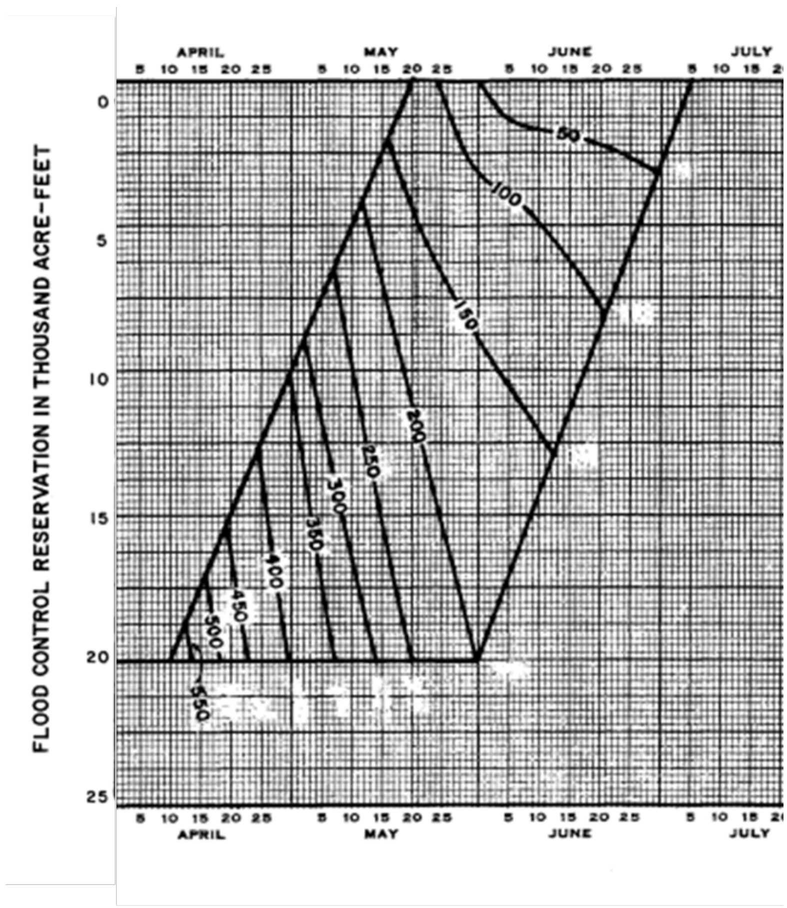


Figure 1: Curent Prosser Reservoir Guide Curve

In this report, the need for, advantages of, and methods pertaining to revised guide curves are discussed. The USACE method for determining guide curves results in a Dynamic Storage Reservation Diagram (dSRD). This terminology will carry throughout the report.

3 DATA

Data used for the revised guide curves was the same data compiled for the rain flood and snowmelt flood frequency curve update (Hunter, et al., 2022). This data source was approved for use in the guide curve update by the WMOP Technical Team in November 2021. Specifically, the data utilized in this analysis includes daily unregulated, natural flow at Reno and Farad from January 1909 through October 2021, ranging 112 years. Specific water balance equations employed for the Farad and Reno daily flow data are specified in Figure 2 and Figure 3. Note that the Farad unregulated flow data does not include Tahoe City flows, whereas the Reno unregulated flow does include Tahoe City flows.

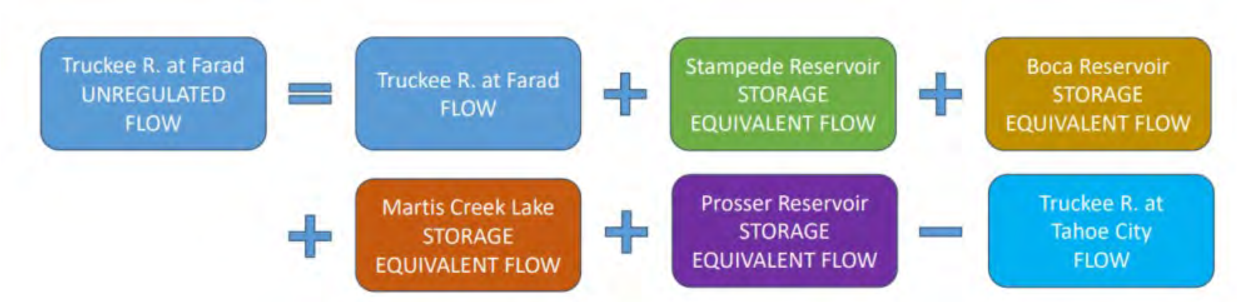


Figure 2: Farad Unregulated Flow Water Balance

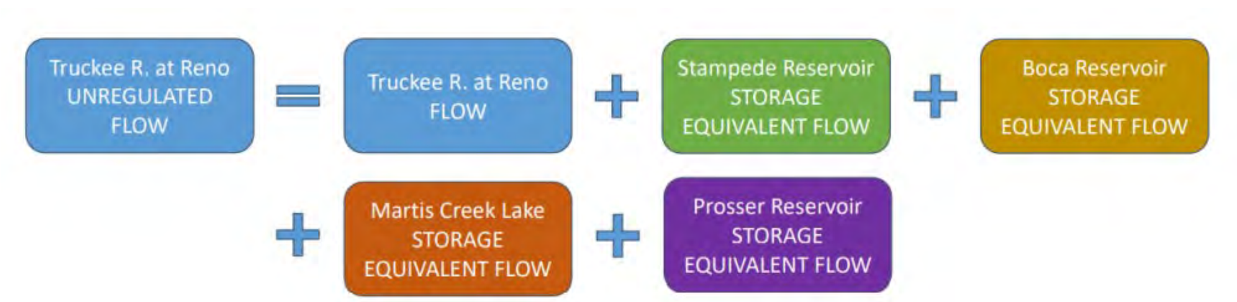


Figure 3: Reno Unregulated Flow Water Balance

This exclusive data source used to derive the guide curves is justified by USACE and NRCS documentation. According to Section 3.3.6 of Engineering Manual (EM) 1110-2-3600, the manual detailing water control system management,

> "To develop a water control plan to provide flood risk management, a study should be made of water management operating criteria alternatives applied to

past record floods and selected hypothetical floods. The historical flood record is the principal source of data to derive and test operating events even if it is too basic or short for a comprehensive investigation" (USACE, Management of Water Control Systems EM 1110-2-3600, 2017).

According to NRCS, data requirements for guide curves require a minimum number of data points which meet specific requirements. In their words,

> "The first step is to obtain a minimum of 10 years of daily reservoir inflow data. This data set should include high and low runoff conditions and should not be overly biased toward the maximum or minimum. Daily streamflow observations for the snowmelt period will satisfy the minimum data requirements. However, complete annual records are desirable to detect unusual runoff events that affect reservoir operation but are unrelated to snowmelt runoff. (NRCS, Technical Release No. 75, 1991)"

In other words, both the USACE and NRCS documentation clarify that the guide curves can be based solely on historical flood data, allowing for flexibility with the inclusion of "selected hypothetical floods." Given that the dataset employed in this analysis involves 112 years of complete annual records of daily flows, this data source is justified.

4 Current Guide Curve, Problems, and Opportunities

The purpose of the WMOP is to develop flexible flood risk reduction criteria without increasing downstream flood risk. One of the alternatives evaluated within this study is flexible guide curves. The WMOP Technical Team has identified problems and opportunities for improved flexibility with the current guide curves from a water supply perspective. These problems were identified in the Plan Formulation phase of the WMOP via a series of virtual workshops and documented in the Alternative Operational Scenarios Development Report (Reclamation, 2021). Those problems are summarized and discussed in this section.

Current guide curves miss opportunities for storing inflow. Members of the WMOP Technical Team first identified an example of missed opportunity that can occur during large runoff years,

> "Even in large runoff years in the Basin, the governing flood control diagrams (i.e., rule curves) and snowmelt parameters [forecasted remaining natural runoff

> volume through July 31st] that dictate when and how reservoirs can be filled can require Reclamation and other water managers to maintain empty flood space in reservoirs until it is too late in the season to fill them. Even during years with significant snowpack, by the time filling is finally allowed into the flood storage space (based on the high snowmelt parameters) the runoff has often receded to a level that some reservoirs aren't always able to be filled to capacity" (Reclamation, 2021).

For example, during the spring refill period, especially during dry years, reservoir inflows may need to be passed to maintain flood space when there is little risk of flooding. This passed inflow could have been stored in the reservoir for later use. Updating the guide curves could benefit water supply objectives of the WMOP.

Another issue pertaining to current guide curves, as identified by the Technical Team, is that the timing of drawdown is "overly restrictive" and "hindering reservoir management" (Reclamation, 2021). During the fall drawdown period, current rules dictate that reservoir storages be fully drawn down by November 1st, which can require water to be released faster than the demand would dictate below the reservoirs and the lower Truckee River. This water could be conserved for demands in the future. This drawdown requirement often necessitates that higher reservoir releases occur out of phase and with larger fluctuations than what is desirable to meet instream objectives for threatened and endangered species and other basin instream concerns. Updating the fall drawdown detailed by the revised guide curves could result in improved water conservation and more efficient management.

A third issue was identified during the planning phase of the workshops. Participants agreed that downstream flood thresholds are too restrictive and do not account for recent and future flood mitigation projects (Reclamation, 2021). Further, the flood operations target flow at the Truckee at Reno gage of 6,000 cfs may no longer be a reasonable threshold to constrain flood operations by. Should this flood flow target change, so will the guide curves and their resulting flood space requirements. For instance, if the flood flow target increases, the dataset will demonstrate fewer instances of flows over that target. Thus, less flood space may be required at certain forecasts. To address this concern, this report developed the guide curve based on operational flood targets at the Truckee River at Reno gage between 6,000 cfs and 8,000 cfs at 500 cfs intervals thus allowing flexibility to adapt to the current conditions and potential future updates to the flood target.

5 MODEL GUIDE CURVE: NAVAJO RESERVOIR

Navajo reservoir, located on the border between New Mexico and Colorado, is operated according to a guide curve created in 2010 (USACE, 2011 Revised Water Control Manual, Navajo Dam and Reservoir, San Juan Rive Basin, Colorado and New Mexico, 2011) . This curve has a few advantages to the current Truckee Basin guide curve structure. These advantages, pointed out in this section, make it an appropriate model curve around which to base the Truckee River Basin's revised guide curves.

Figure 4 provides the current guide curve for Navajo Reservoir. On the x-axis, is the day of the year. On the y-axis, is "live storage", which is the difference between the reservoir's capacity and the required flood space on that day. The various series on this plot represent the adjusted inflow/runoff forecast. Specifically, these "modified" forecasts are defined as the modified unregulated 50% exceedance inflow forecasts between a given date and July 15th.

The Navajo guide curve offers some advantages over the current Truckee Basin guide curves. Primarily, it was created in 2010 and thus is based on more recent forecasting technology (USACE, 2011 Revised Water Control Manual, Navajo Dam and Reservoir, San Juan Rive Basin, Colorado and New Mexico, 2011). Current guide curves in the Truckee River Basin were published in the Water Control Manual in 1985 (USACE, Truckee River Basin Reservoirs, Truckee River, Nevada and California Water Control Manual, 1985). Secondly, the Navajo guide curve encapsulates the remaining water year (WY, October 1st through September 30th) runoff within each series. Specifically, the parameters for the operation using this diagram include modified unregulated 50% exceedance inflow forecasts between a given date and July 15th. The Truckee River Basin's current guide curves do not yet leverage recent improvements in forecast technology, wherein a runoff forecast for the water year is now available every day. The earliest begin fill date associated with the current Truckee guide curves is April 10th. Although reasoning for this was not directly identified, it was postulated by the Technical Team that April 10th was approximately the earliest date when a runoff forecast would have been available when the WCM was derived in 1985. Thirdly, the Navajo diagram demonstrates that encroachment is allowed as early as January 1st with a sufficiently low remaining WY runoff forecast. Lastly, the Navajo diagram captures short term forecast storms that are included within the River Forecast Center remaining volume forecast.

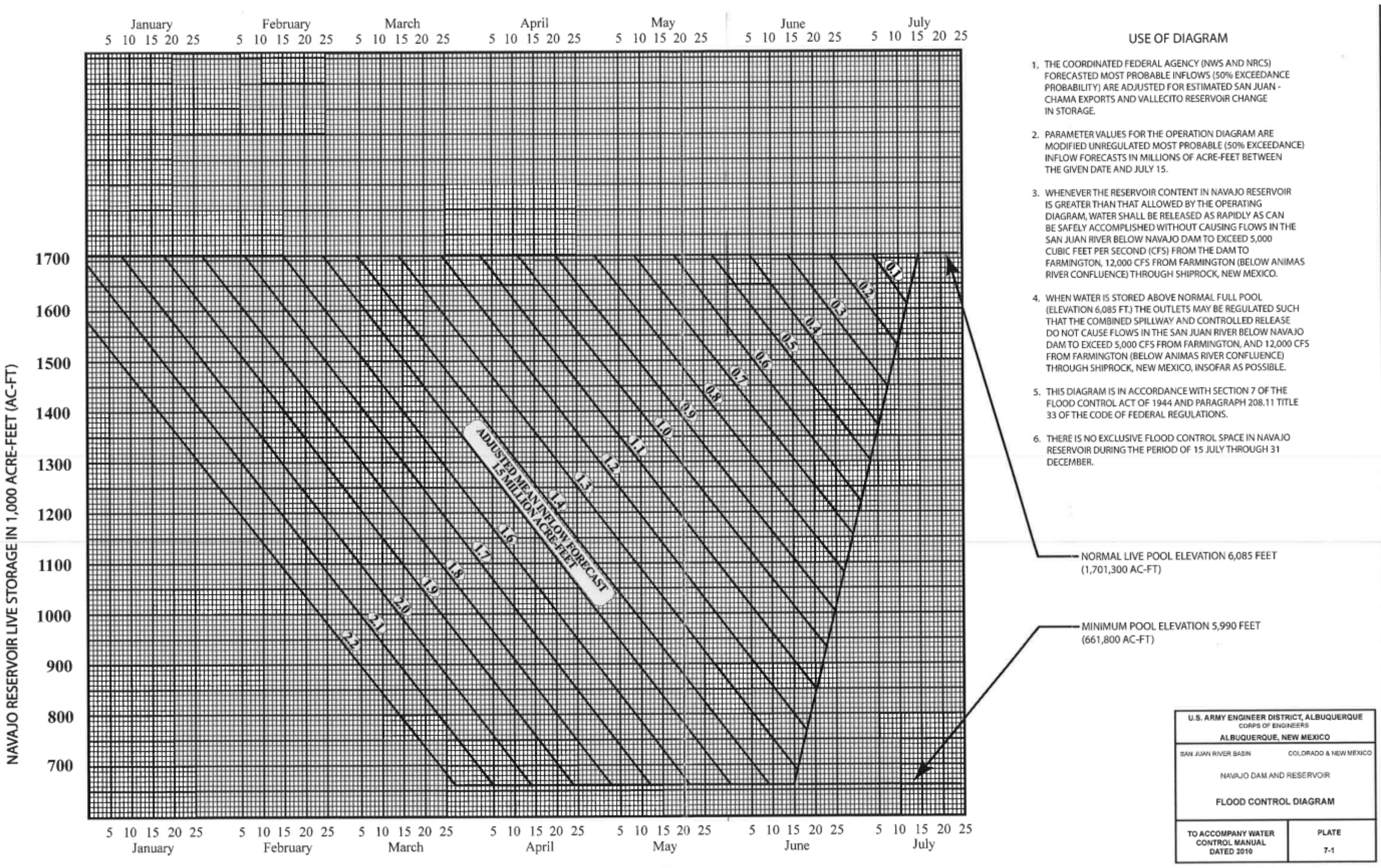


Figure 4: Navajo Reservoir Guide Curve *(USACE, 2011 Revised Water Control Manual, Navajo Dam and Reservoir, San Juan Rive Basin, Colorado and New Mexico, 2011))*

It is important to note that although the Navajo guide curve is employed as a reference, the final guide curves will be plotted in terms of flood space requirements instead of live storage, since current guide curves plot flood space requirements. This ensures consistency with the current Truckee Basin WCM.

6 METHODS

There are four key steps necessary to develop a dSRD--the USACE methodology of updating the guide curves:

1. Process the data to populate the curve.
2. Generate storage envelopes.
3. Develop the fall drawdown components of the curve.
4. Superimpose the same developed fall drawdown and storage envelope curves on the same dSRD.

Each of these steps is explained in detail below.

6.1 VOLUMES OVER THE TARGET AND REMAINING WY VOLUME FORECAST

The first step involves three calculations to prepare data for the dSRD. The first of these calculations is the remaining WY volume over the target. This remaining WY volume over the target is measured in units of thousands of acre-ft (kAF). This calculation helps to inform the curvature of each series on the dSRD. See Equation 1 below.

$$Required\ Floodspace\ (kAF) = \sum_{t}^{t_f} max\left(I_t - T_{Reno\ target\ flow}, 0\right)_{high\ flows} * \frac{1.983}{1000}\frac{kAF}{cfs - day}$$

Equation 1: Flow Volumes Over Target

In this equation, I represents the daily unregulated Reno natural flow at time t, T represents the Reno Flood Flow Target, time t represents a given date within the dataset, and t_f represents the end of the water year associated with time t. The coefficient of 1.983/1000 represents the conversion factor between cfs-days and kAF.

According to NRCS, the use of equation 1 is justified:

> "Storage volumes are the sum of all daily flows greater than or equal to the selected outflow. This prevents a loss of storage and implies that the outflow is set equal to the inflow when the outflow is higher than the inflow" (NRCS, Technical Release No. 75, 1991).

In this application, storage volumes (synonymous with required flood space) greater than the selected outflow (the Reno flood flow target) are summed to the end of the water year, and any negative flood space requirements are set to zero.

A visual demonstration of Equation 1 is pictured in both Figure 5 and Figure 6 below. In Figure 5, the dashed line represents the Reno Target of 6,000 cfs. The light blue bars demonstrate inflow below the target, and the dark blue represents the inflow above the target. The orange bars demonstrate flood space evacuation after the event. Finally, the maximum point on the gold, cumulative storage curve demonstrates the storage requirement for a single day. In other words, this point represents the solution to Equation 1. An example of a tabular view of Equation 1, calculating inflows (I) over a Reno flood flow target (T), is demonstrated in Figure 6.

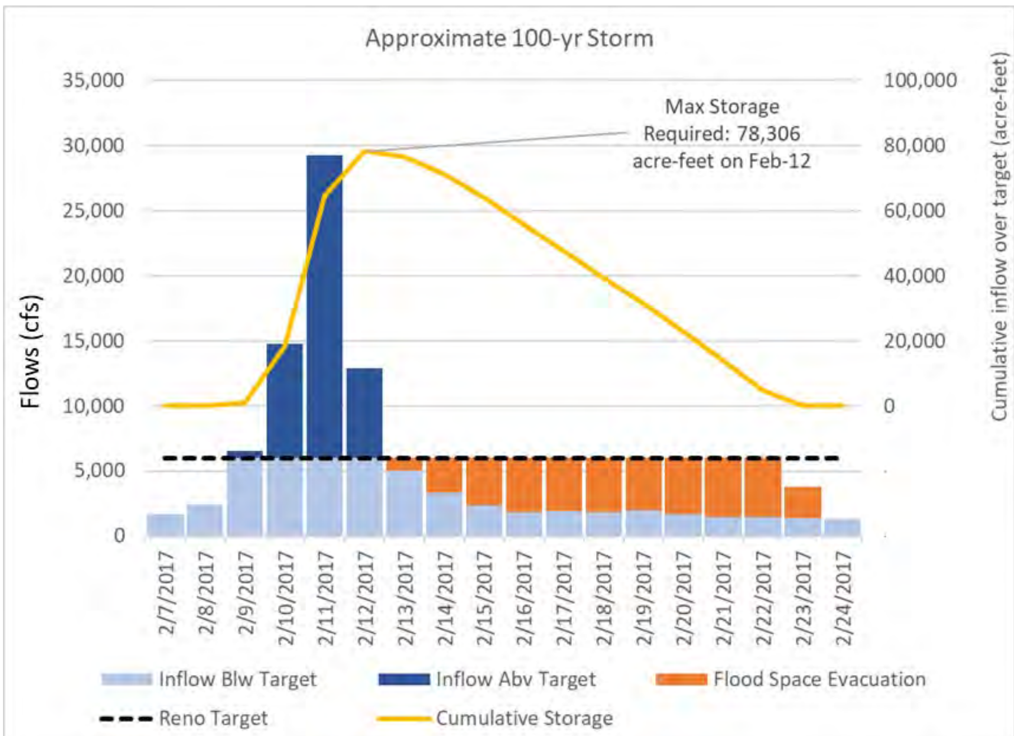


Figure 5: Required Flood Space Demonstration (a)

	I	T	Inflow Over Target	Volume Over Target
	cfs	cfs	cfs	AF
2/7/2017	1200	6,000	0	0
2/8/2017	1400	6,000	0	0
2/9/2017	6,200	6,000	200	397
2/10/2017	15,000	6,000	9,000	17,851
2/11/2017	29,000	6,000	23,000	45,620
2/12/2017	13,000	6,000	7,000	13,884
2/13/2017	5,000	6,000	0	0
2/14/2017	3,000	6,000	0	0
2/15/2017	2,500	6,000	0	0
2/16/2017	2,000	6,000	0	0
2/17/2017	2,100	6,000	0	0
2/18/2018	2,100	6,000	0	0
2/19/2018	2,100	6,000	0	0
2/20/2018	2,100	6,000	0	0
2/21/2018	1,900	6,000	0	0
2/22/2018	1,900	6,000	0	0
2/23/2018	1,800	6,000	0	0
2/24/2018	1,700	6,000	0	0
		Basin Flood Space:		**77,752**

Figure 6: Required Flood Space Demonstration (b)

The second calculation determines the remaining water year forecast. This calculation dictates the series on the final dSRD, representing the forecasted remaining Farad Natural Flow water year volume. This calculation is defined in Equation 2 below. Note that this calculation disregards the flood flow target and is based on the Farad unregulated flow instead of the Reno unregulated flow because Farad unregulated flow forecasts are more commonly available and discussed within the Truckee Basin. I represents the daily unregulated Farad natural flow at time t, time t represents a given date within the dataset, and t_f represents the end of the water year associated with time t. The coefficient of 1.983/1000 represents the conversion factor between cfs-days and kAF.

$$Remaining\ WY\ Forecast\ (kAF) = \sum_{t}^{t_f}(I_t) * \frac{1.983}{1000}\frac{kAF}{cfs - day}$$

Equation 2: Remaining WY Volume Forecast

The third calculation determines the WY to date flows over the flood flow target. This calculation is employed to determine the storage required early in the WY (i.e., the fall drawdown portion of the guide curve). This calculation is defined in Equation 3.

$$WY\ to\ Date\ Flows\ Over\ Target\ (kAF) = \sum_{t}^{t_f} max(I_t - T_{Reno\ target\ flow}, 0)_{high\ flows} * \frac{1.983}{1000} \frac{kAF}{cfs - day}$$

Equation 3: WY to Date Volume Forecast

In this equation, t is the first day of the water year associated with t_f, the date of interest within the dataset. All other variables have the same significance as Equation 1.

After calculations for Equation 1 through Equation 3 are computed for each day where historical daily Reno and Farad Natural Flows are available, the data can be refined. Date information associated with results of Equation 1 through Equation 3 are then summarized based on the day of the water year to determine which seasons floods have occurred in historically. Then, results of Equation 1 are first parsed down to each unique volumes over the target. Then, for each result of Equation 1, the latest date within the normalized water year corresponding with that unique value is identified. Finally, the smallest remaining WY volume corresponding with each unique result of Equation 1 is identified. This ensures that the largest flow volumes over the target are associated with their smallest historically observed WY remaining volume bin. This data refinement process allows for synthesis of storage envelope curves described in the following section.

6.2 Generate Storage Envelope Curves

In this step, values calculated in Section 6.1 are utilized to generate storage envelope curves.

According to EM 1110-2-3600, guide curves are composed of "storage space required for the management of historical floods as a function of time of the year" (USACE, Management of Water Control Systems EM 1110-2-3600, 2017). These guide curves are informed by the storage envelope curves developed via the steps explained in this section.

To generate these envelope curves, The results of Equation 1 must be grouped by corresponding results of Equation 2. Then, data can be plotted. The day of the water year must be plotted on the x-axis. Results of Equation 1 must be plotted on the y-axis according to their grouping, which is dictated by their corresponding results of Equation 2. See Figure 7 for an example of a storage envelope plot with all remaining WY volume bins plotted.

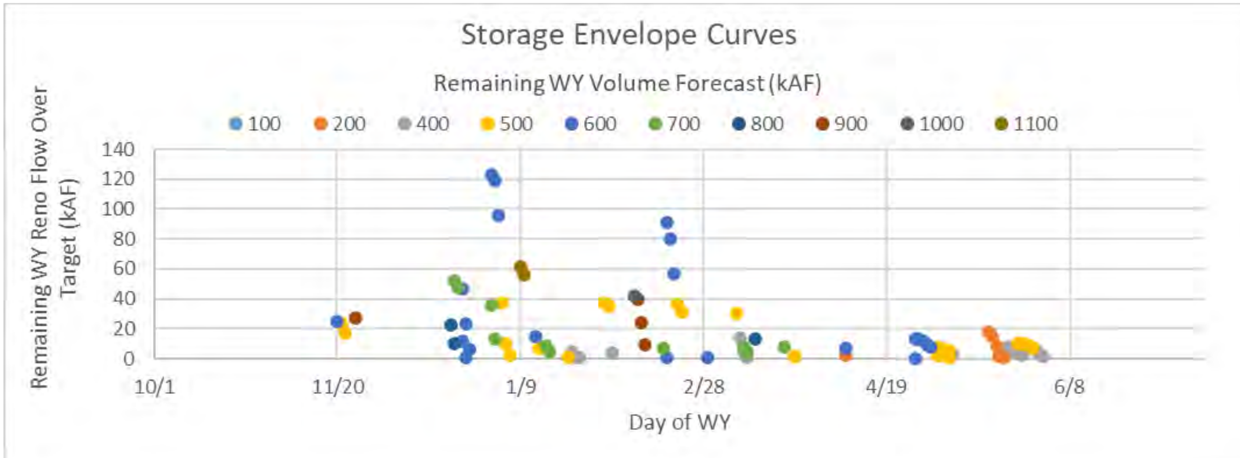


Figure 7: Overall Storage Envelope Curve 6,000 cfs Flood Flow Target

After plotting the overall storage envelope plot as demonstrated in Figure 7, storage envelope regression equations can be derived. An envelope curve identifies the latest days of the water year in which the largest flow volumes over the target occurred for a given remaining water year runoff. This envelope curve must capture the largest flow volume over target across all points within the water year. See Equation 4 and Figure 8 below.

$$Floodspace\ Required = MIN(MAX(mx + b, 0), total\ basin\ floodspace)$$

Where

m= slope of storage envelope curve

x = day of WY

b = y intercept of envelope curve

Equation 4: Storage Envelope Regression Equations

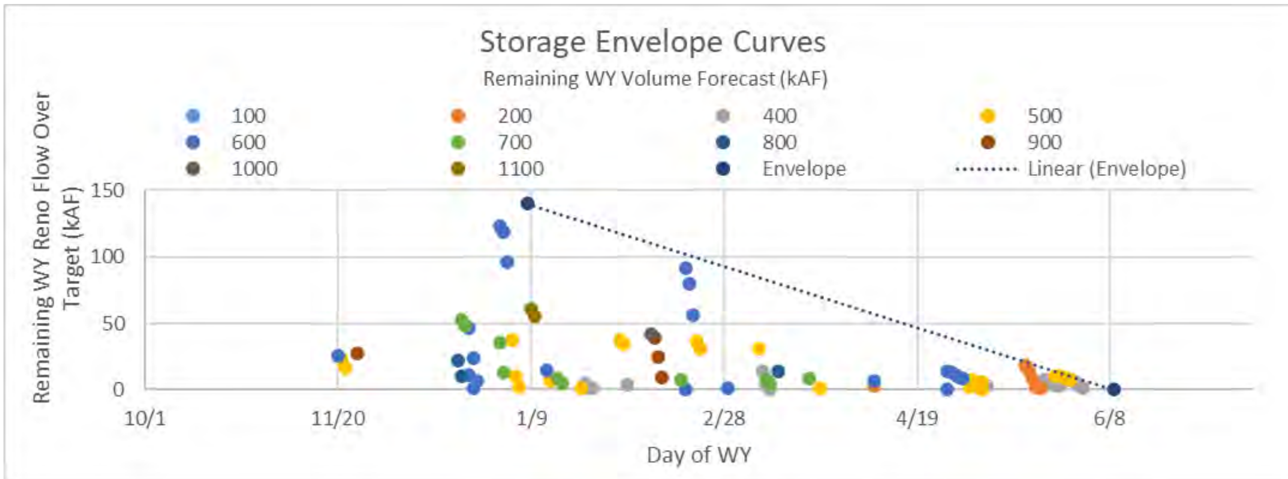


Figure 8: Overall Storage Envelope 6,000 cfs Reno Flow Target

After the overall envelope curve is developed, an envelope curve for each remaining WY volume bin must be established. The process to achieve this is to first remove the largest remaining WY volume bin from the storage envelope chart and generate a new linear regression equation capturing the largest flow volumes over the target each day in the WY. This new regression relationship defines the envelope regression equation for the largest remaining WY volume bin still visible on the chart. This process of removing the next largest WY volume bin series from the chart and developing a new envelope regression equation must be repeated until no remaining WY volume bins remain on the chart.

It is important to note that a few of the smallest WY volume remaining bins, in this case Less than 200 kAF, do not show any points in the normalized WY with flow volumes over the 6,000 cfs flood flow target. Given that there is a relatively small data record, the regressions for these bins are estimated as described in later steps.

At this time, it is also necessary to develop the storage envelope curve representing the fall drawdown portion of the dSRD, which influences the flood space required early in the WY. This step involves plotting the day of the WY on the x-axis and the results of Equation 3 on the y-axis, before prescribing a linear regression relationship demonstrating the largest WY to date flow volumes over the target required at the earliest dates within the WY. An example of this fall drawdown envelope regression is visualized below in Figure 9.

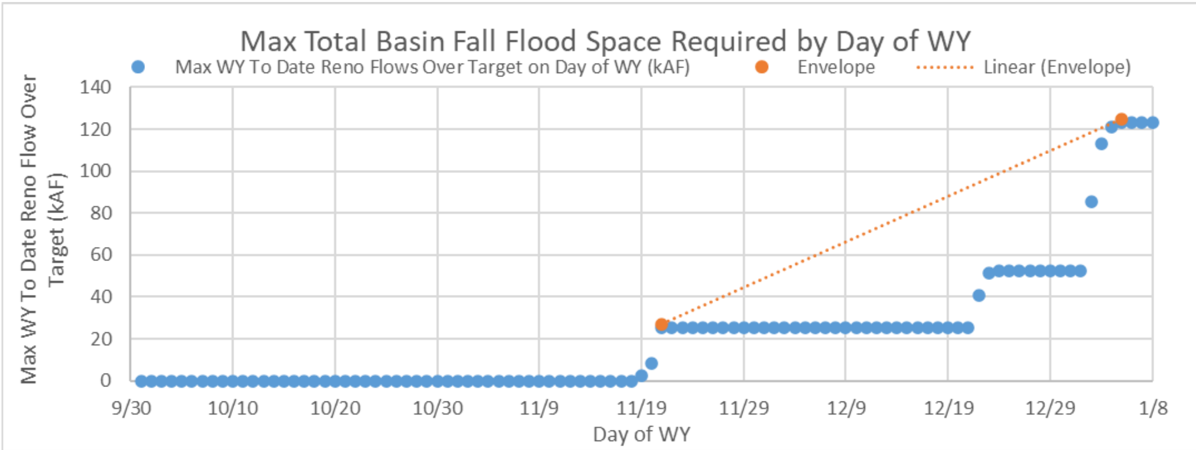


Figure 9: Fall Drawdown Envelope 6,000 cfs Reno Flow Target

Note that this fall drawdown component of the dSRD does not include the remaining WY forecast as a parameter, since available forecasts during this period are, as a general statement, not viewed as useful until the following January, corresponding to the earliest NRCS statistical volume forecast. Water supply forecasts issued by NRCS are available between January and June of each year (NRCS, Nevada & Eastern Sierra Streamflow Forecasts, n.d.).

At this point, the dSRD can be configured with the storage envelope curves generated via methods described in this section.

6.3 Generate dSRD

The final dSRD can be generated by the following steps described in this section. Firstly, the storage envelope regression equations configured in the previous section must be employed to calculate flows over the target at each day of the water year, for each remaining water year volume bin. Additionally, the fall drawdown regression equation must be superimposed to this diagram to prescribe the appropriate flood space required during the fall months.

Figure 10 demonstrates an example of a total basin dSRD configured for a Reno flood flow target of 6,000 cfs. This figure assumes Martis is non-operational, resulting in a total basin flood space volume of 50 kAF (Table 1). The series on this chart demonstrate the remaining WY forecasts less than or equal to the magnitude specified, except for the 600 kAF WY forecast, which demonstrates flood space requirements for all forecasted remaining WY volumes greater than or equal to 600 kAF.

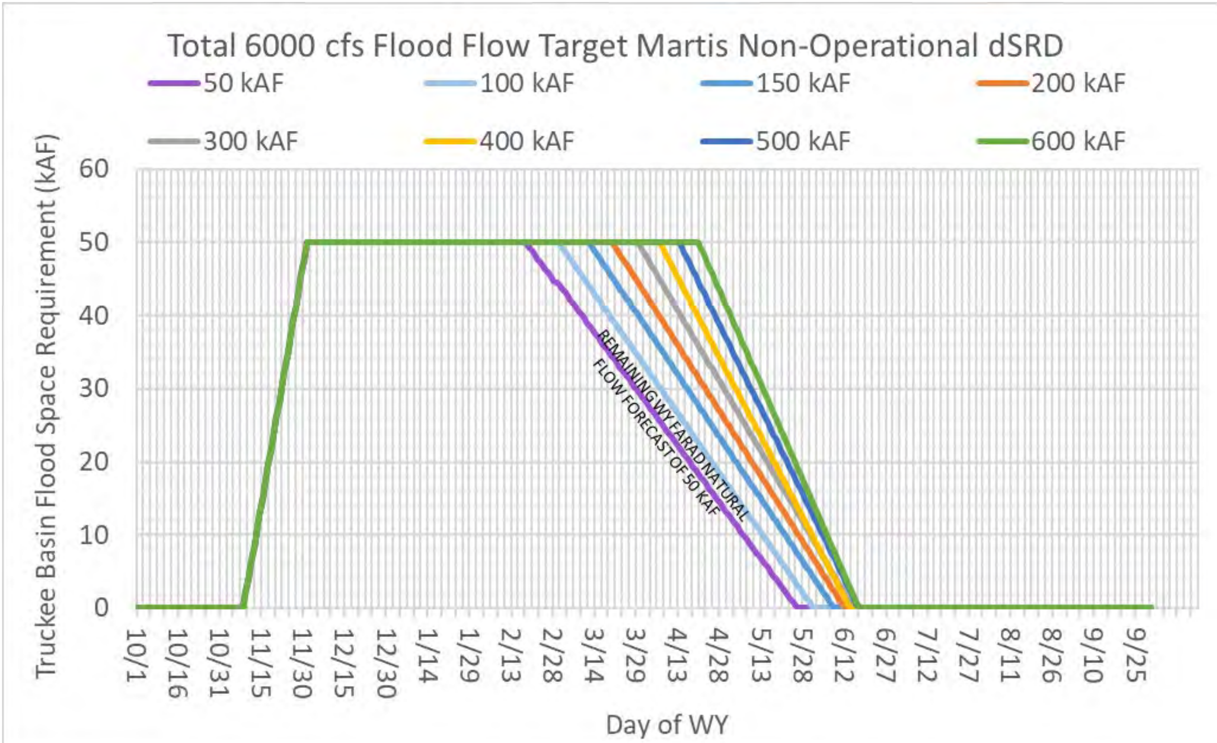


Figure 10: Total Basin dSRD 6,000 cfs Flood Flow Target, Martis assumed non-operational

On the x-axis of this diagram, plotted is the day of the WY. On the y-axis, similarly to the current guide curves, plotted is the Truckee Basin Flood Space Requirement in units of thousands of acre-ft. Numerically, the y-axis represents the cumulative remaining WY volume over the target (Equation 1). The various series of this diagram represent the remaining WY Farad natural flow forecast in units of thousands of acre-ft (Equation 2). The diagram takes on a trapezoidal shape, given that the dSRD is bounded by the largest unique remaining WY volume forecast's curve (600 kAF) and the fall drawdown curve prescribed by Equation 3. Note that the maximum flood space required cannot be any larger than the maximum flood space available. In this case, where the dSRD is configured for the total basin, no more than 50 kAF can be required on a given day of the WY based on the reservoir flood space allocations shown in Table 1. Further, note that in Figure 10 above, curves for remaining WY volume forecasts of 50 kAF, 100 kAF, 150 kAF, and 300 kAF have been added. No flows exceeding the flood target have been observed when the remaining WY volume was less than 200 kAF. Thus, these curves were generated by utilizing approximately the same change in slope as the smallest three WY volume remaining bin's storage envelope curve and translating the x-intercept of that same bin's storage envelope curve a similar number of days to the left relative to neighboring envelope curves. All total basin dSRD curves are available in Section 8 and Section 9.

EM 1110-2-3600 supports the methodologies described in this section. In its words,

> "These guide curves are drawn as enveloping lines of storage space required for the management of historical floods as a function of the time of year. They are usually drawn as straight lines on a monthly or seasonal basis… For those rivers that may have a significant contribution of runoff from snowmelt, a family of guide curves representing the flood storage reservation requirements may be derived based on anticipated seasonal runoff volume" (USACE, Management of Water Control Systems EM 1110-2-3600, 2017).

This reference specifies that snowmelt-driven systems permit curves based on seasonal runoff as conducted in this analysis, and that envelope curves may be drawn as straight lines.

In practice, this dSRD can be employed similarly to the current WCM's guide curves. Firstly, an operator must identify the remaining Farad natural flow remaining water year forecast on the diagram. Secondly, the operator must identify the current date on the diagram. Thirdly, after locating the intersection of the current date and inflow forecast series, the operator must determine the flood space requirement for that day from the y-axis of the diagram. Figure 10 displays the total basin flood space. In practice, the operator will employ the appropriate subbasin dSRD to ensure appropriate flood space is available within a given reservoir. The following section explains how subbasin dSRDs are derived.

6.4 Configuring Subbasin dSRDs

Current guide curves show flood space required for each subbasin and day of the WY. Thus, it is necessary to adapt the total basin dSRD pictured in Figure 10 to each subbasin. Unchanged storage envelope regression relationships developed in previous sections still apply to subbasin dSRDs. However, the total flood space requirement must be split up proportionally based on each reservoir's portion of the total basin flood space. Table 1 below describes the total flood space available for each subbasin. Note that the percent allocation of storage for each of these subbasins will not change because of the WMOP.

It is also important to note that in the process of developing the dSRDs, two sets of curves were generated: one set of dSRDs with Martis assumed operational for flood control and another set with Martis assumed non-operational for flood control. As shown in Table 1 and in all dSRDs included in the main body of this report (unless otherwise clearly stated), Martis is assumed to be non-operational.[1] Thus, the total basin maximum flood space allocation is 50 kAF. The suite of curves assuming Martis is non-operational are available in **Appendix A: Total Basin (Martis Non-Operational) dSRDs at Potential Flood Flow Targets** and **Appendix C: Subbasin dSRDs at Potential Flood Flow Targets (Martis Not Operational)**. The suite of curves that assumes Martis is operational with 20 kAF of subbasin flood space and, therefore, a total basin flood space of 70 kAF, are included in **Appendix B: Total Basin (Martis Operational) dSRDs at Potential Flood Flow Targets** and **Appendix D: Subbasin dSRDs at Potential Flood Flow Targets (Martis Operational)**.

Table 1: Subbasin Flood Space

Subbasin	Maximum Flood Space Allocated (kAF)	Portion of Basin Flood Space (%)
Boca & Stampede	30	60%
Prosser	20	40%
Total	**50**	**100%**

The subbasin dSRD's envelope regression equations are informed by the following equation.

Equation 5: Subbasin Envelope Regression Equation

$$Floodspace = MIN(MAX(mx + b, 0), total\ basin\ floodspace) * Subbasin\ Floodspace\ Percentage\ of\ total\ basin\ floodspace$$

Where

[1] Several issues have been discovered with Martis Creek Dam regarding dam safety. In 2008, a risk-screening was conducted on Martis Creek Reservoir that ultimately led to changes in the reservoir's regulation criteria that same year, and Martis Creek Reservoir is not currently operated to the regulation criteria specified in the Water Control Manual (Moen, 2023). Rather, Martis Creek Dam's gates are left open, and the reservoir only provides incidental flood protection when inflows to the reservoir exceed its release capacity (US Army Corps of Engineers, 2022).

m= slope of storage envelope curve

x = day of WY

b = y intercept of envelope curve

Two example dSRDs are provided in Figure 11 and Figure 12, each representing a different status of Martis reservoir. Martis's status of operational or non-operational affects the total basin flood space and therefore the portion of flood space required in each flood control reservoir. When Martis is non-operational, Prosser accounts for 40% of the Basin's flood space in contrast to 28.5% of the total basin flood space when Martis is operational. As shown in Figure 11, with Martis operational, the first day all Prosser's flood space is required is December 10th. With Martis non-operational (Figure 12), the first day all Prosser's flood space is required occurs on December 1st. In other words, when Martis is operational, Prosser's total flood space allocation is not required until ten days later than would be required with Martis non-operational.

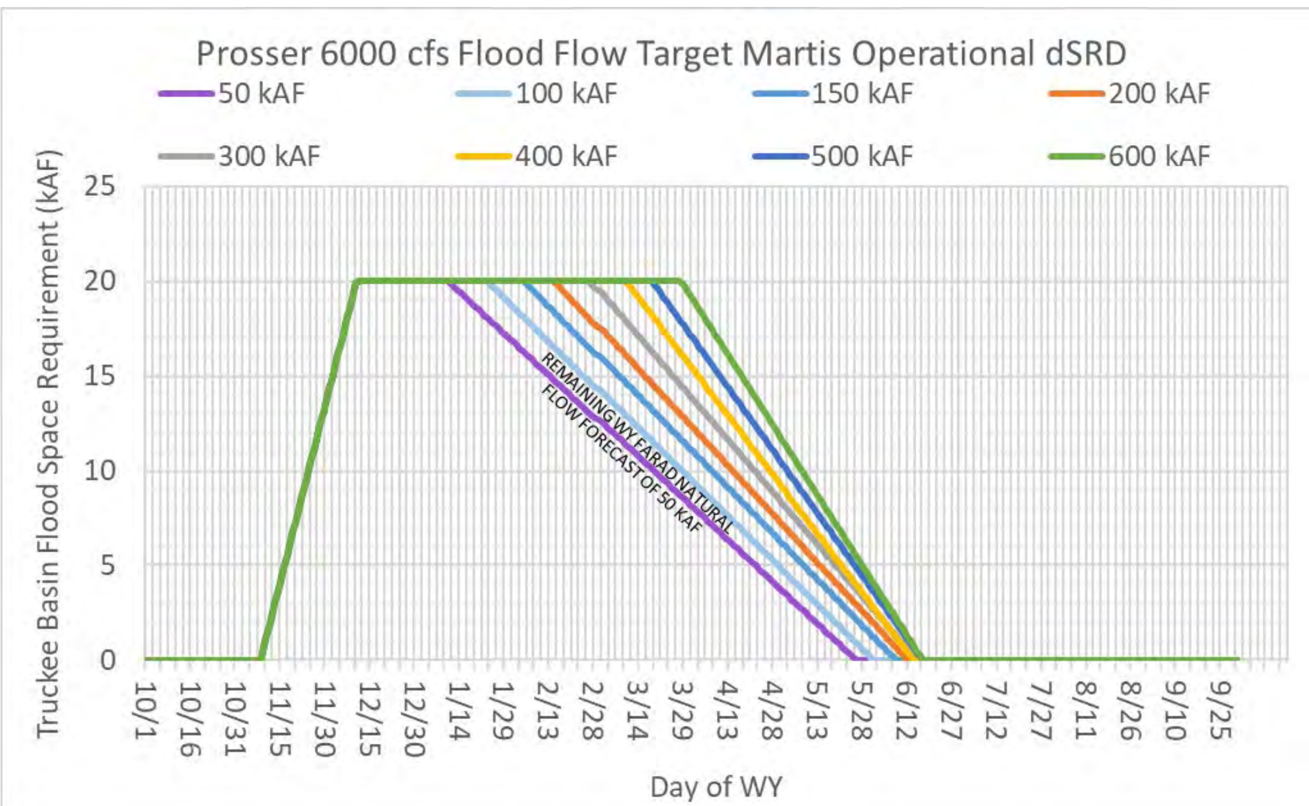


Figure 11: Prosser Subbasin dSRD 6,000 cfs Flood Flow Target, Martis assumed operational

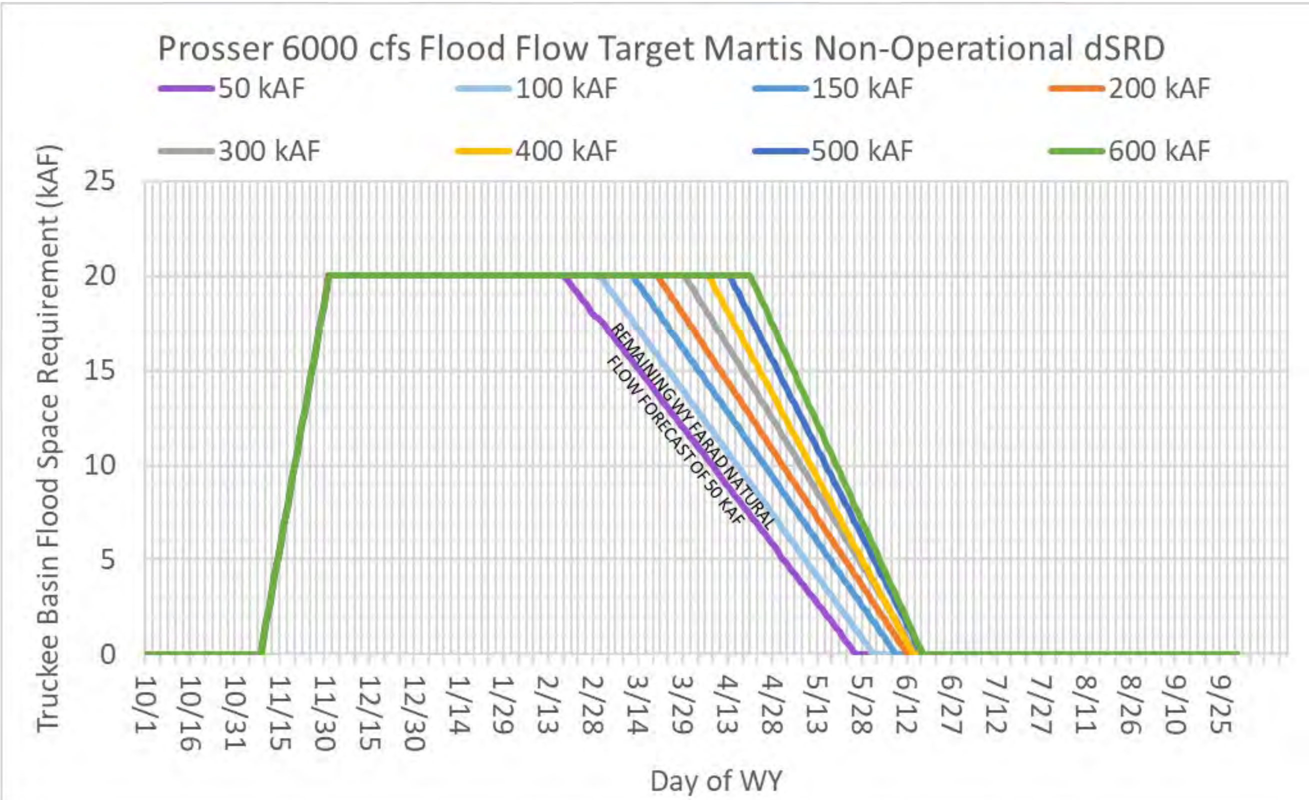


Figure 12: Prosser Subbasin dSRD 6,000 cfs Flood Flow Target, Martis assumed non-operational

6.5 Configuring dSRDs for Different Reno Flood Flow Targets

One of the action alternatives of the WMOP involves investigating a potential increase in the Reno flood flow target. Thus, dSRD diagrams have been prepared to investigate the impacts of an increased flood flow target on flood space requirements throughout the WY prescribed by this approach. This will allow for updating the dSRD diagrams should the Reno flow target be changed based on future flood improvement projects (one of the objectives on the WMOP project).

To generate a dSRD for a different flood flow target, the same methods described in previous sections are to be applied with the unique exception of applying the proposed Reno Flood Flow Target to Equation 1. Total basin and subbasin diagrams have been compiled for future Reno flood flow targets of 6,500, 7,000, 7,500, and 8,000 cfs in addition to the current target of 6,000 cfs.

7 RESULTS & CONCLUSIONS

While in line with requirements set forth in the literature, the revised guide curves demonstrate some water supply benefits. Table 2 contrasts Prosser Reservoir's flood space requirements outlined by the current guide curves with those of the revised guide curves. This section also provides insight into potential water supply benefits resulting from the revised guide curves.

It is important to note that the current WCM's guide curves for Prosser and Stampede and Boca reservoirs share the same earliest begin fill, earliest full, and latest full dates. Similarly, since each subbasin dSRD results from scaling of the Total Basin dSRD's daily flood space requirements according to the subbasin's portion of total basin flood space (Table 1), the dates provided in Table 2 are demonstrative of all subbasin dSRDs constructed in this study. A comparison of April 10th storage requirements necessitated by each potential Reno Flood Flow Target's corresponding subbasin dSRD is provided in Table 4. All dSRD diagrams can be replicated in the accompanying Excel workbook titled "dSRD All Flood Flow Targets Report_xlsx".

Table 2: Comparison between current WCM and 6,000 cfs Prosser Reservoir dSRD

Prosser dSRD Comparison to Current WCM, Martis Non-Operational						
Parameter	**Current WCM**	**6,000 cfs Flood Flow Target dSRD**	**6,500 cfs Flood Flow Target dSRD**	**7,000 cfs Flood Flow Target dSRD**	**7,500 cfs Flood Flow Target dSRD**	**8,000 cfs Flood Flow Target dSRD**
Earliest Begin Fill	4/10	Not Applicable				
Earliest Full (i.e., no flood space required)	5/20	5/24	5/16	5/15	5/3	4/26
Latest Full (i.e., no flood space required)	7/5	6/16	6/23	6/26	6/12	5/27
April 1st Flood Space Required (kAF) for Median Farad RFC Seasonal Forecast of 300 kAF	20	19	20	20	14	13

Firstly, the current guide curve requires that all of Prosser Reservoir's flood space be available for use until April 10th, unless regulating a flood event. During a review of the literature, no evidence of a rationale for this was discovered nor where are there any flood events in the historical record to justify this date. After discussion with the WMOP Technical Team on this subject, it was decided that it would not be enforced within the approach to the revised guide curve. Within the revised guide curve, this constraint on the latest date that all flood space within Prosser reservoir must be reserved has been based on the historical flood record for a given remaining runoff volume (USACE, Management of Water Control Systems EM 1110-2-3600, 2017). Thus, the dSRDs offers more flexibility for partial flood space allocation prior to April 10th than the current curves. This result applies to all total basin and subbasin revised guide curves.

Secondly, for dSRDs corresponding with flood flow targets greater than 6,000 cfs, the earliest full date occurs earlier the current guide curve. This means that, for some of the flood flow target dSRDs, there is an earlier opportunity to fill the reservoir's flood space with storage earlier during the water year than allowed by the current WCM. This would result in greater water supply earlier in the water year should the revised guide curves be accepted.

Thirdly, the latest date that flood space is required in Prosser reservoir is reduced by at least 9 days between the current and revised guide curves. This means that maximum encroachment is allowed earlier in the year in Prosser reservoir, should the revised guide curve be accepted. This would also result in increased water supply. This reduction in latest full date remains true for all revised guide curves, since the largest remaining water year volume forecast is informed by all, or fewer data points associated with the 6,000 cfs total basin revised guide curve.

Finally, three of the five revised guide curves allow some encroachment into flood space by April 1 for all downstream flow targets with a median RFC seasonal forecast of 300 kAF. According to NRCS, "Managers are required to balance storage and releases with expected inflow volume. Seasonal streamflow volume forecasts are issued by the Soil Conservation Service (SCS) and/or the National Weather Service (NWS)" (NRCS, Technical Release No. 75, 1991). Should these curves be accepted, the RFC seasonal forecasts will be used to estimate the remaining WY runoff forecast necessary to utilize the dSRD in practice. With the current 6,000 cfs flow target, the revised guide curve would allow 1 kAF encroachment into flood space on April 1 with a median runoff forecast of 300 kAF that is not allowed by the current guide curves. Should the flow threshold downstream be increased, incremental increases in the allowed encroachment would occur with only 13 kAF of flood space being required on April 1 if the flood target were increased to 8,000 cfs at Reno. A comparison of the April 1st flood space requirements set forth by the Martis non-operational revised guide curves for each subbasin and potential Reno Flood Flow Target is offered in Table 3. Table 4 compares April 1st flood space requirements for guide curves assuming Martis is operational.

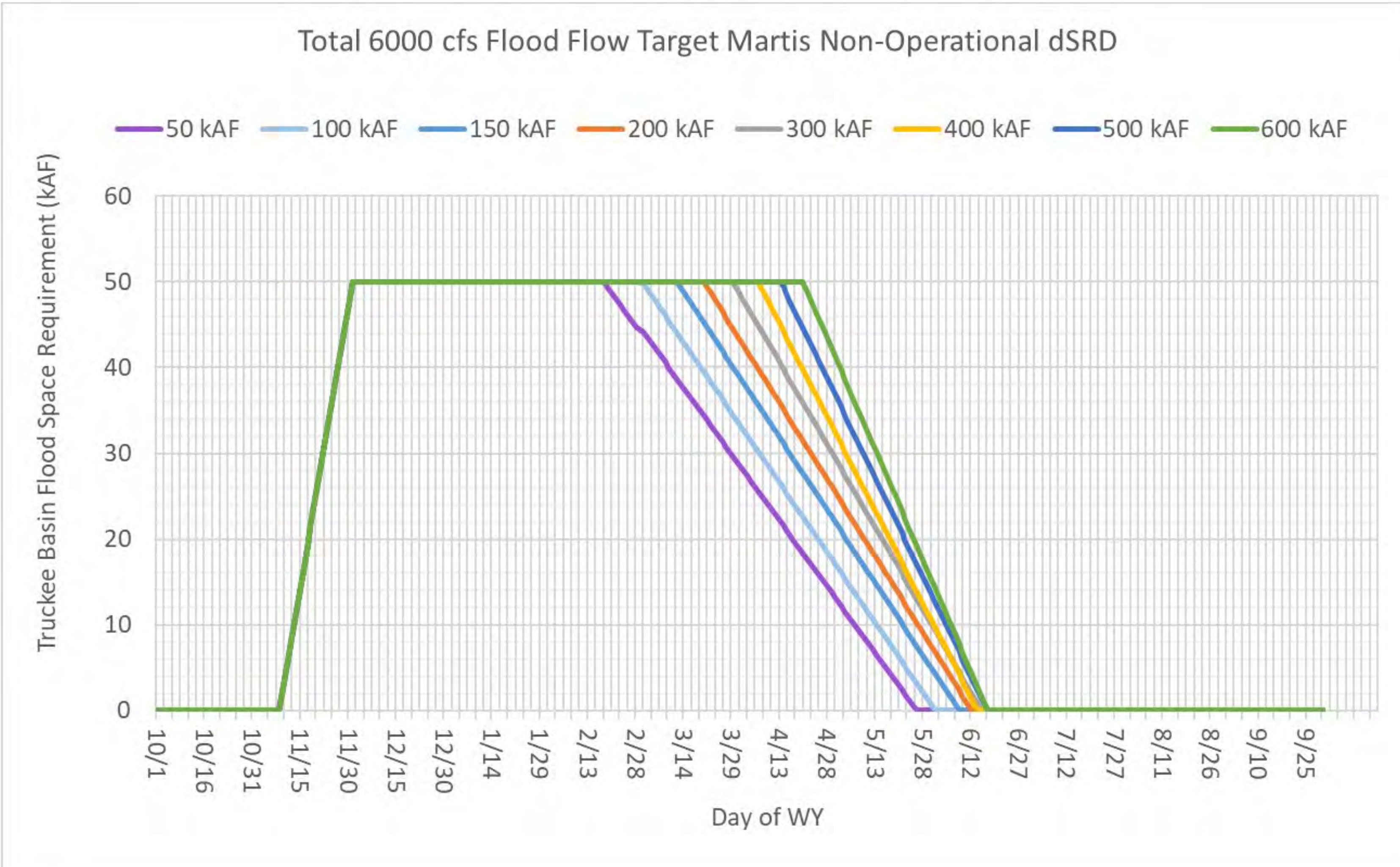
Table 3: April 10th Flood Space Requirements by Subbasin and dSRD Flood Flow Target, Martis assumed non-operational

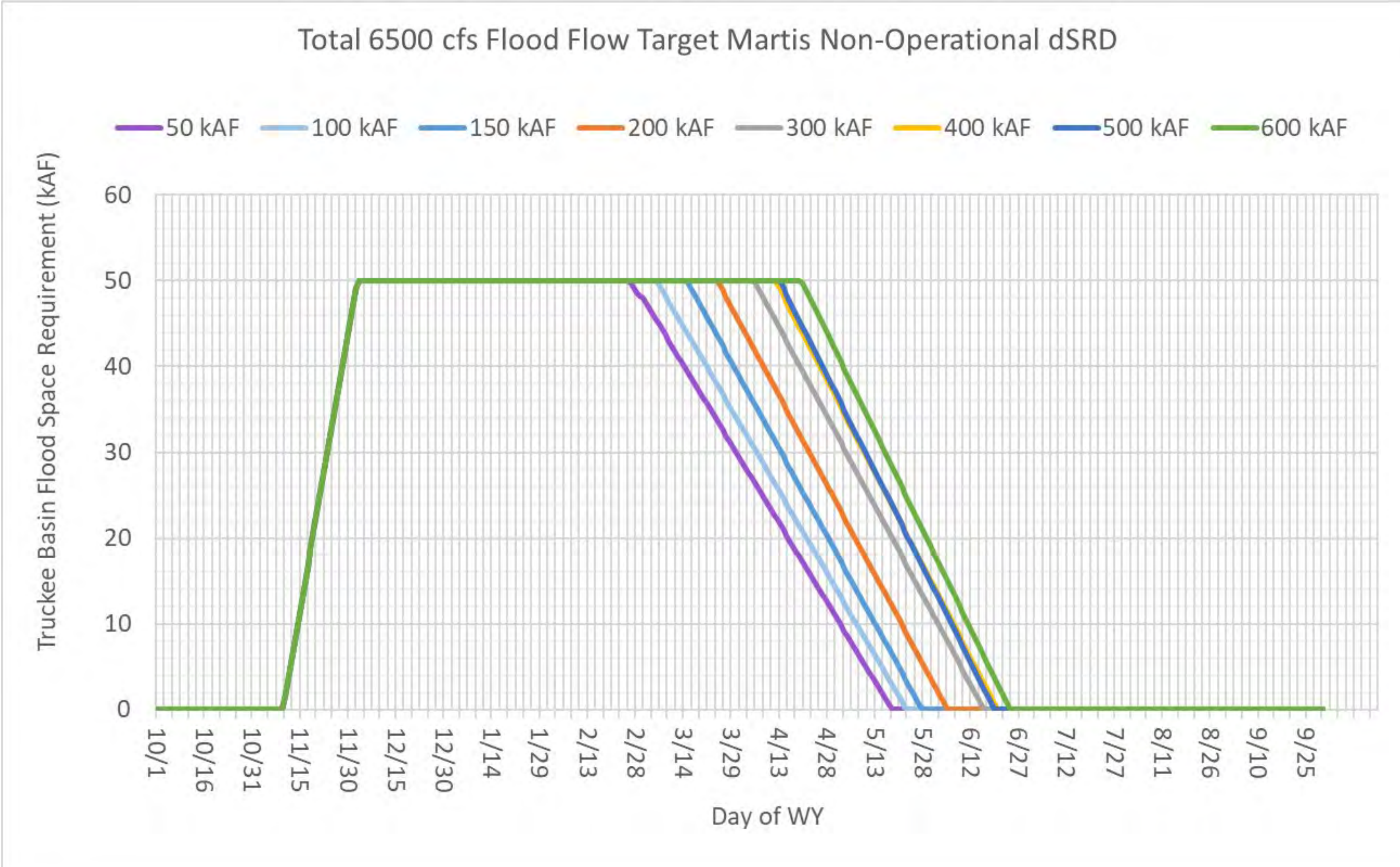
April 10th Flood Space Requirement Comparison By Subbasin Martis Non-Operational		
Subbasin	Flood Flow Target (cfs)	April 1st Flood Space Required (kAF) for Median Farad RFC Seasonal Forecast of 300 kAF
Prosser	Current WCM	20
Prosser	6000	19
Prosser	6500	20
Prosser	7000	20
Prosser	7500	14
Prosser	8000	13
Stampede & Boca	Current WCM	30
Stampede & Boca	6000	29
Stampede & Boca	6500	30
Stampede & Boca	7000	30
Stampede & Boca	7500	21
Stampede & Boca	8000	19

Table 4: April 10th Flood Space Requirements by Subbasin and dSRD Flood Flow Target, Martis assumed operational

April 10th Flood Space Requirement Comparison By Subbasin Martis Operational		
Subbasin	Flood Flow Target (cfs)	April 1st Flood Space Required (kAF) for Median Farad RFC Seasonal Forecast of 300 kAF
Prosser	Current WCM	20
Prosser	6000	14
Prosser	6500	15
Prosser	7000	14
Prosser	7500	10
Prosser	8000	9
Stampede & Boca	Current WCM	30
Stampede & Boca	6000	21
Stampede & Boca	6500	23
Stampede & Boca	7000	21
Stampede & Boca	7500	15
Stampede & Boca	8000	13
Martis	Current WCM	20
Martis	6000	14
Martis	6500	15
Martis	7000	14
Martis	7500	10
Martis	8000	9

8 APPENDIX A: TOTAL BASIN (MARTIS NON-OPERATIONAL) DSRDS AT POTENTIAL FLOOD FLOW TARGETS





Total 6500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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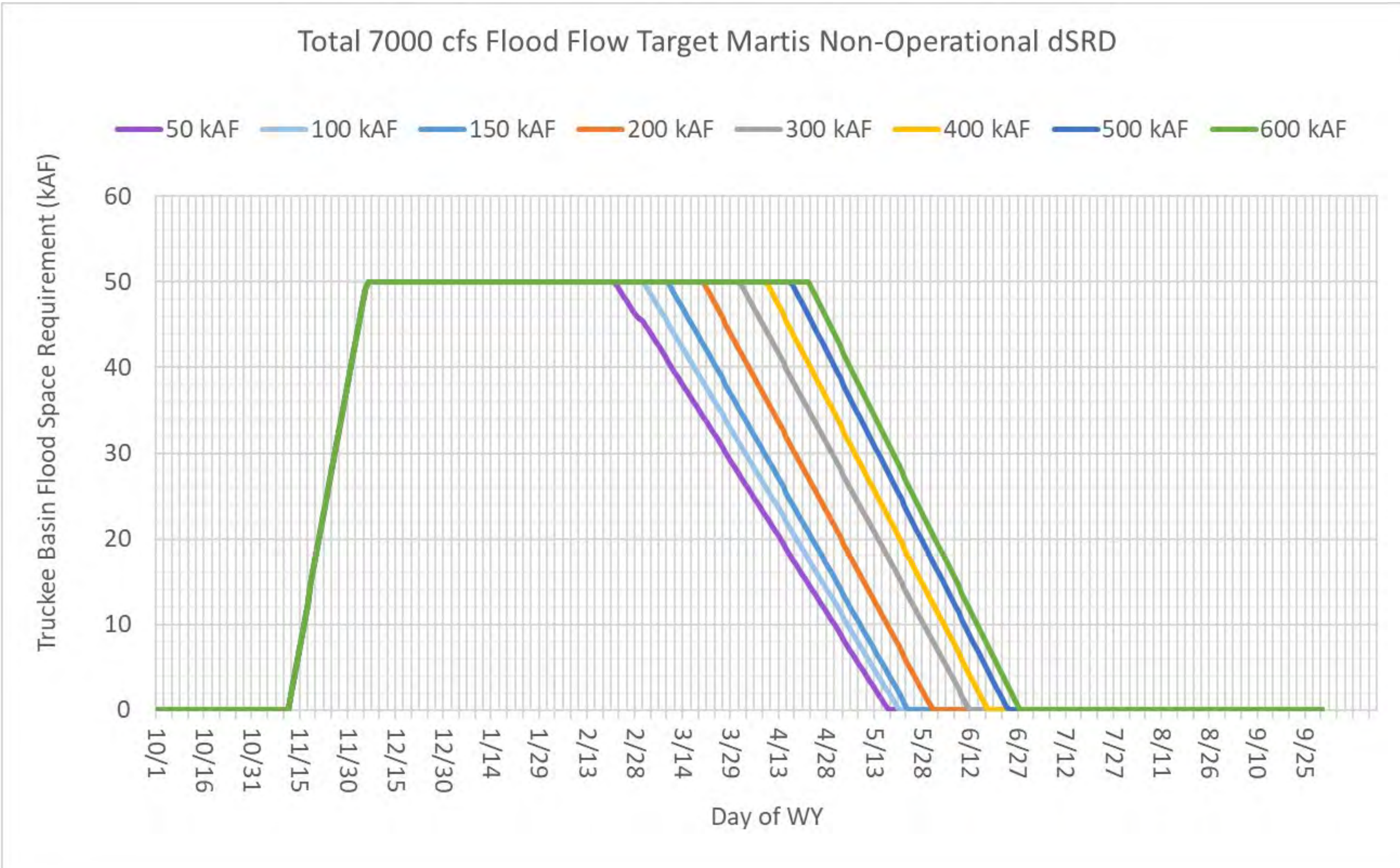
8/11
8/26
9/10
9/25
Day of WY


Total 7000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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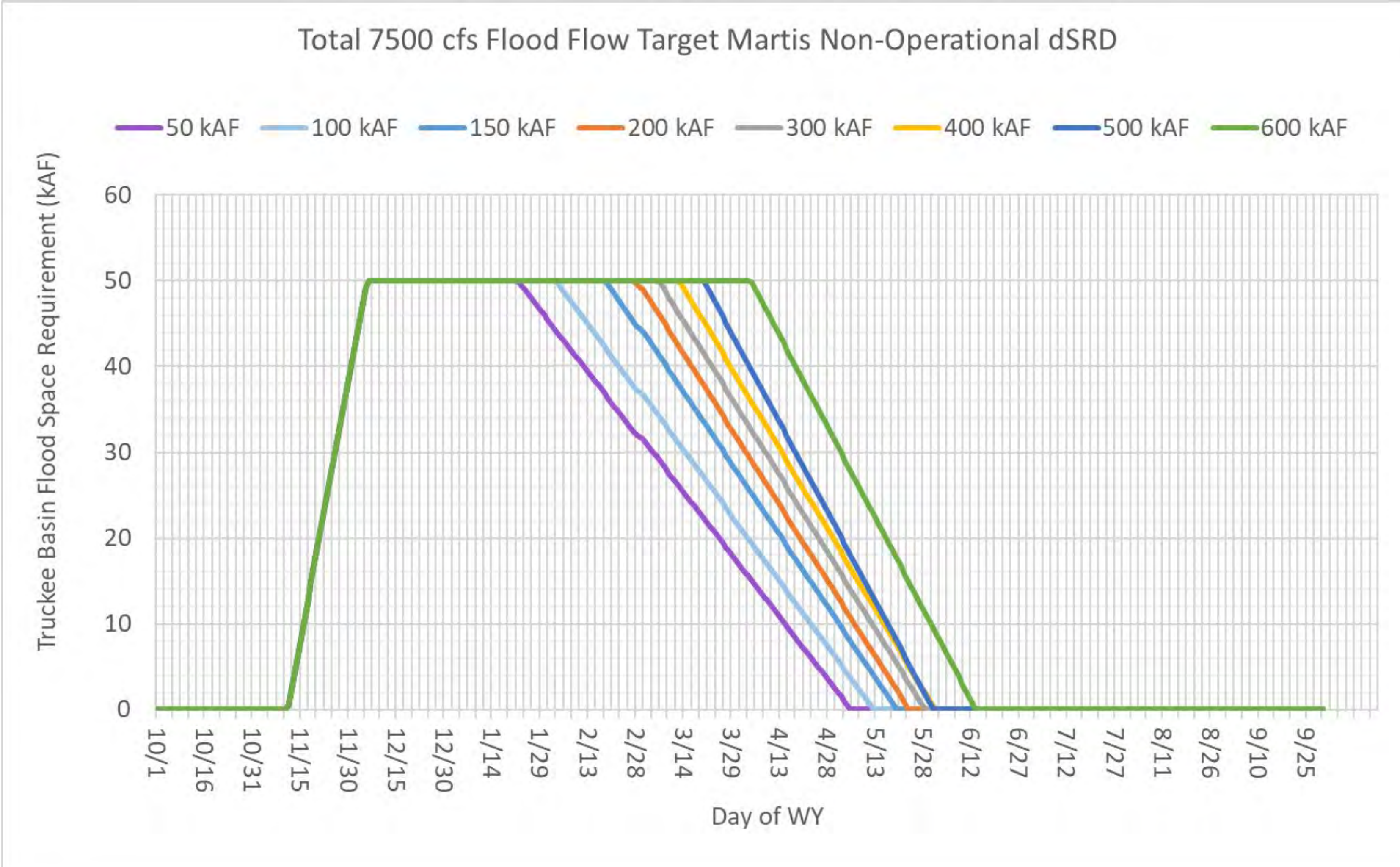
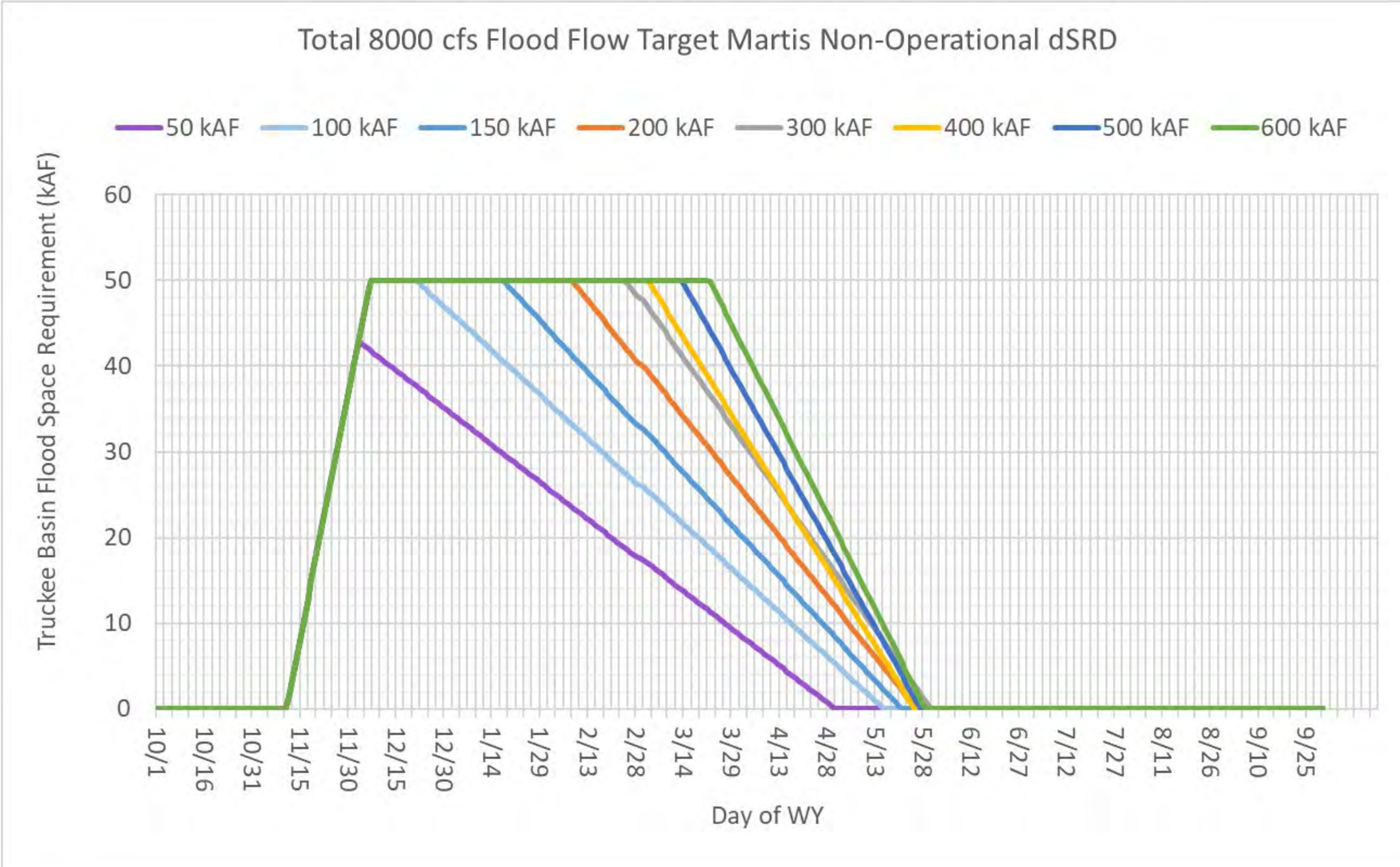
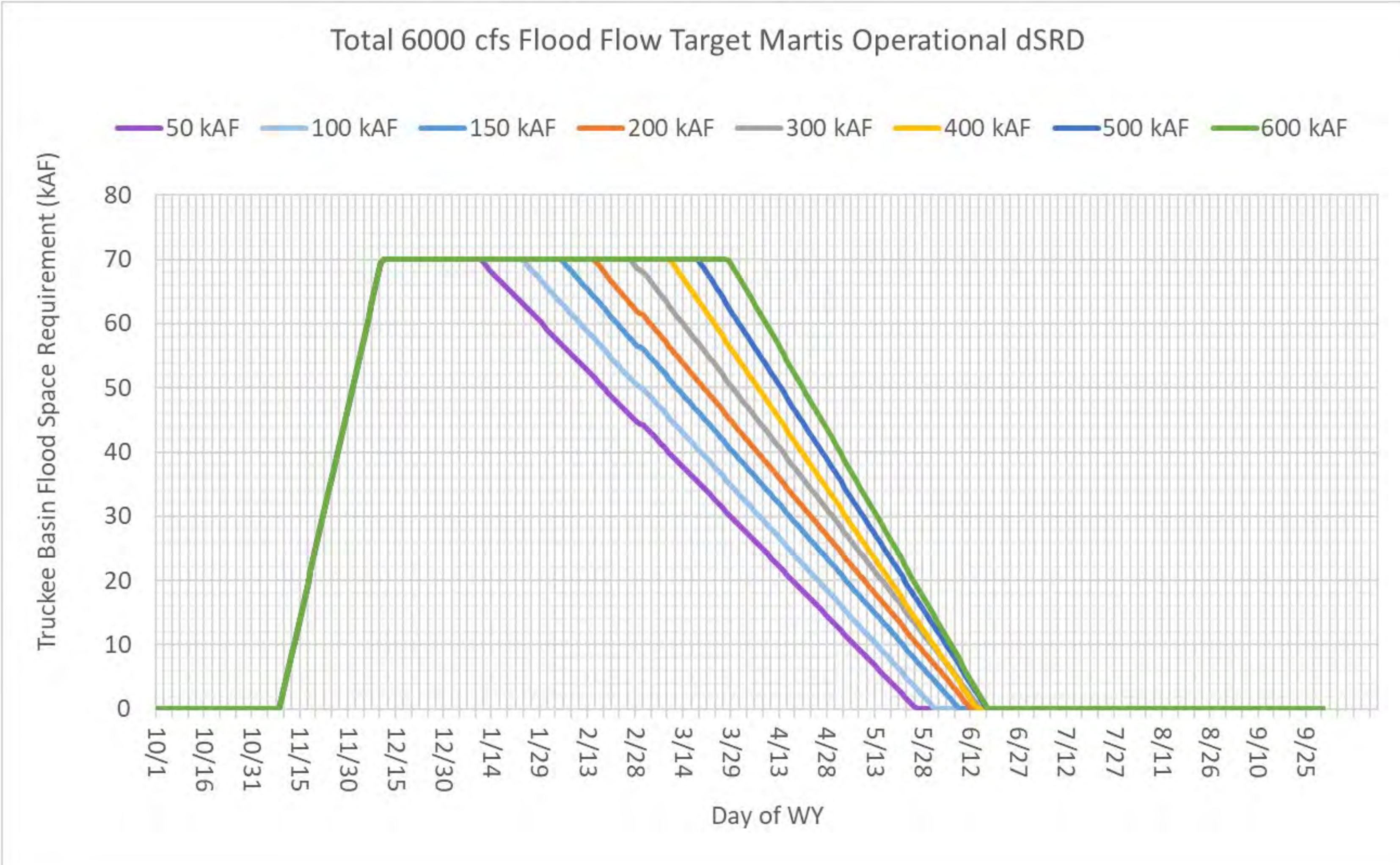
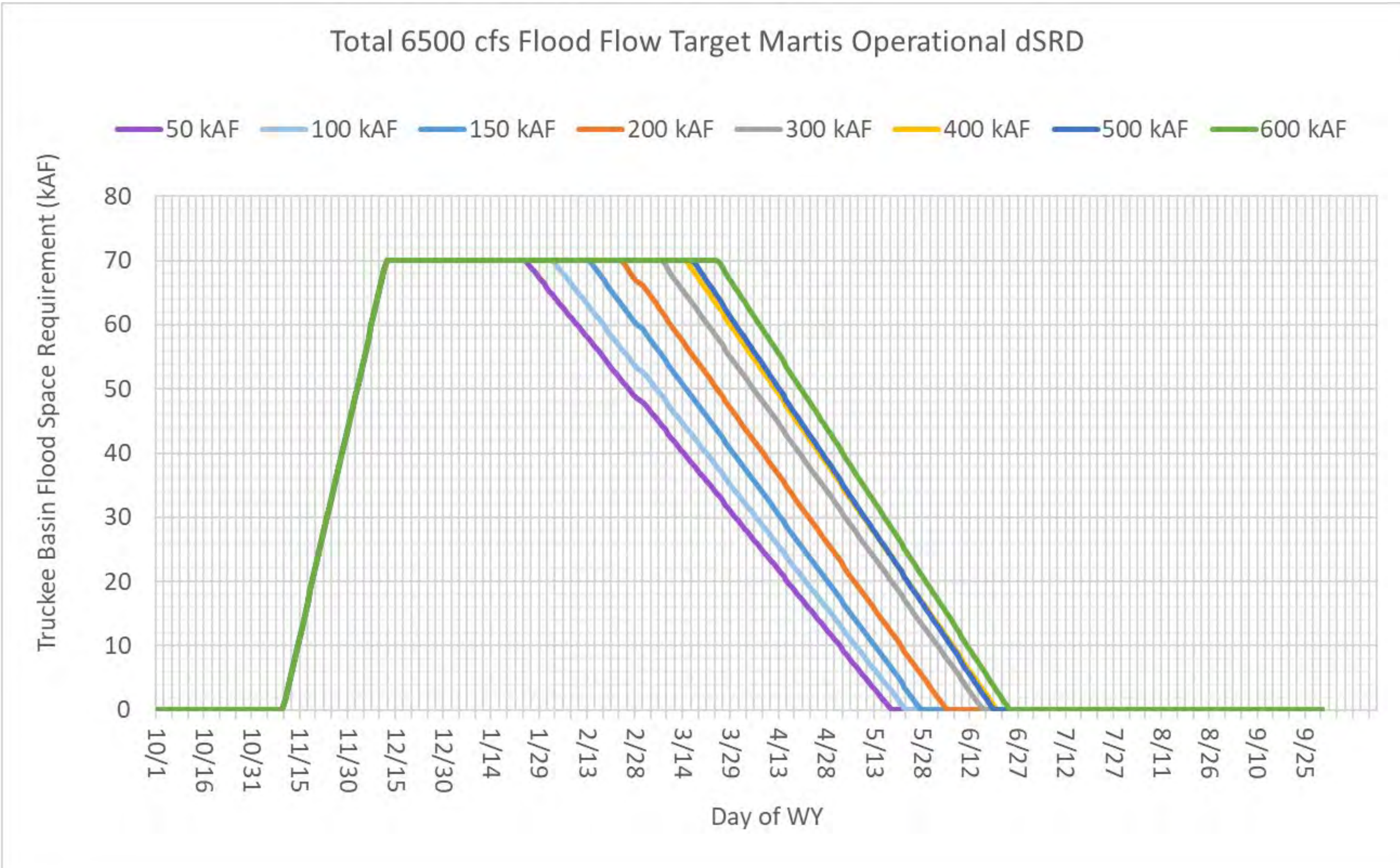
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

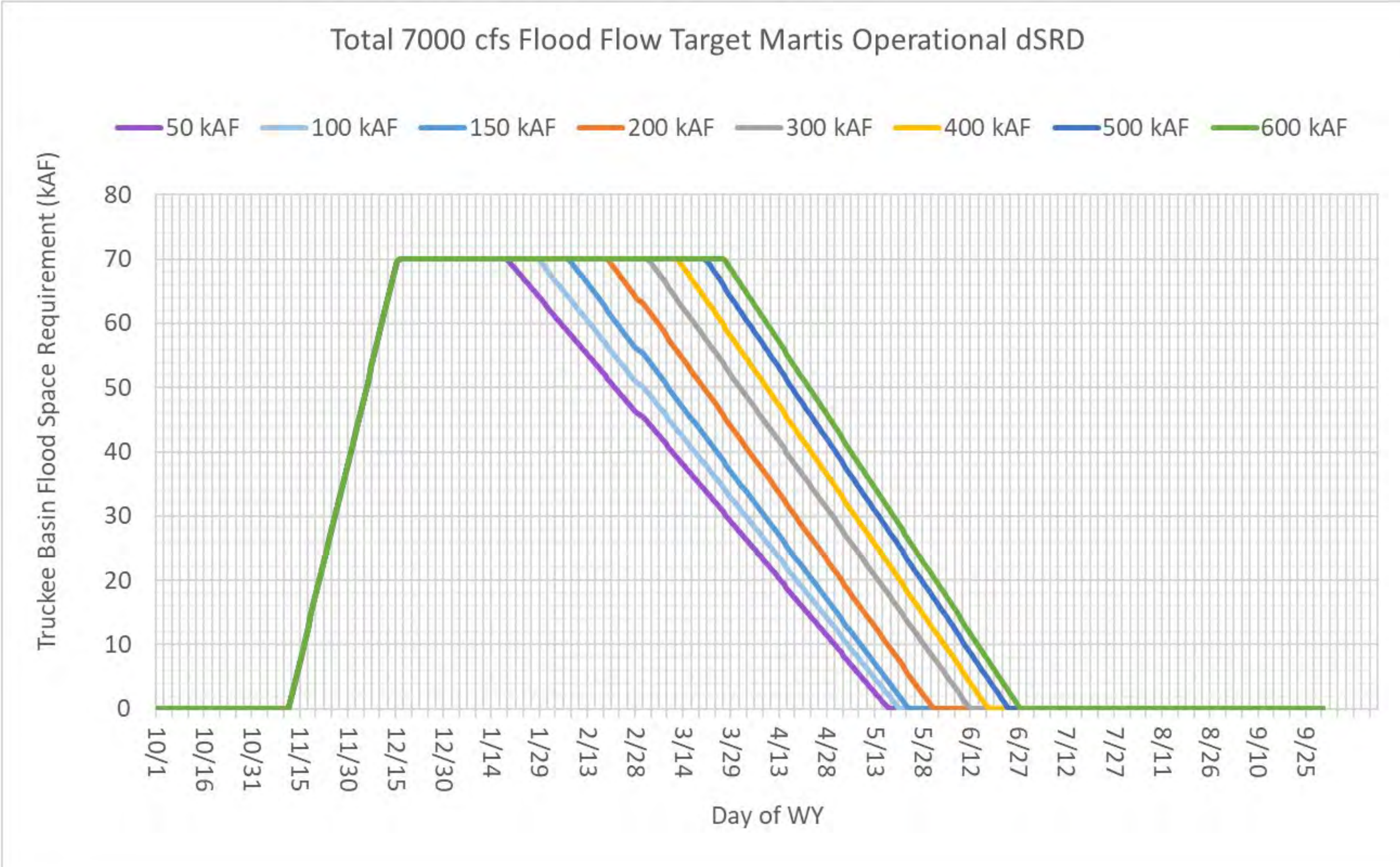

Total 7500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY


Total 8000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
0
10
20
30
40
50
60
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

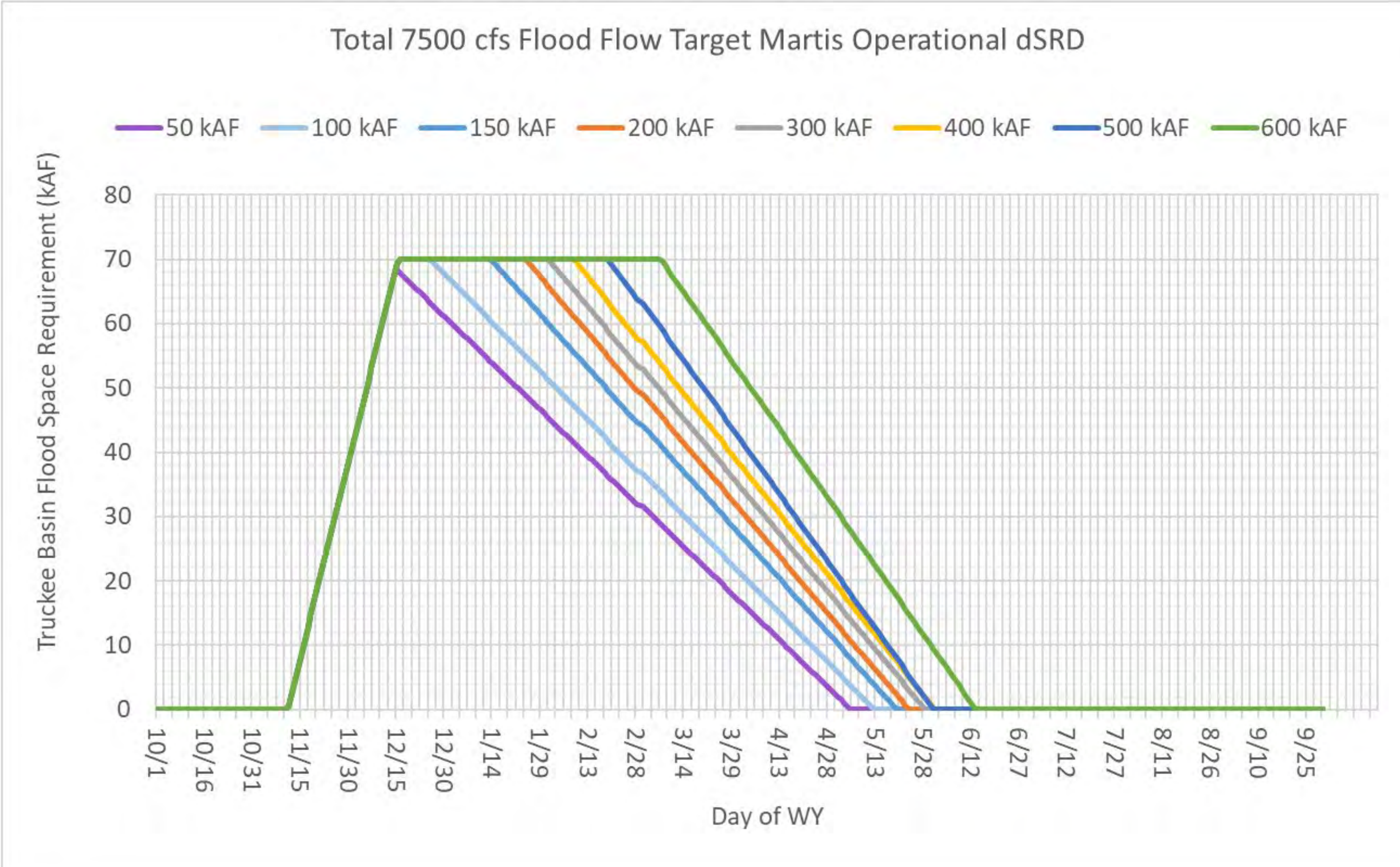
9 APPENDIX B: TOTAL BASIN (MARTIS OPERATIONAL) dSRDS AT POTENTIAL FLOOD FLOW TARGETS

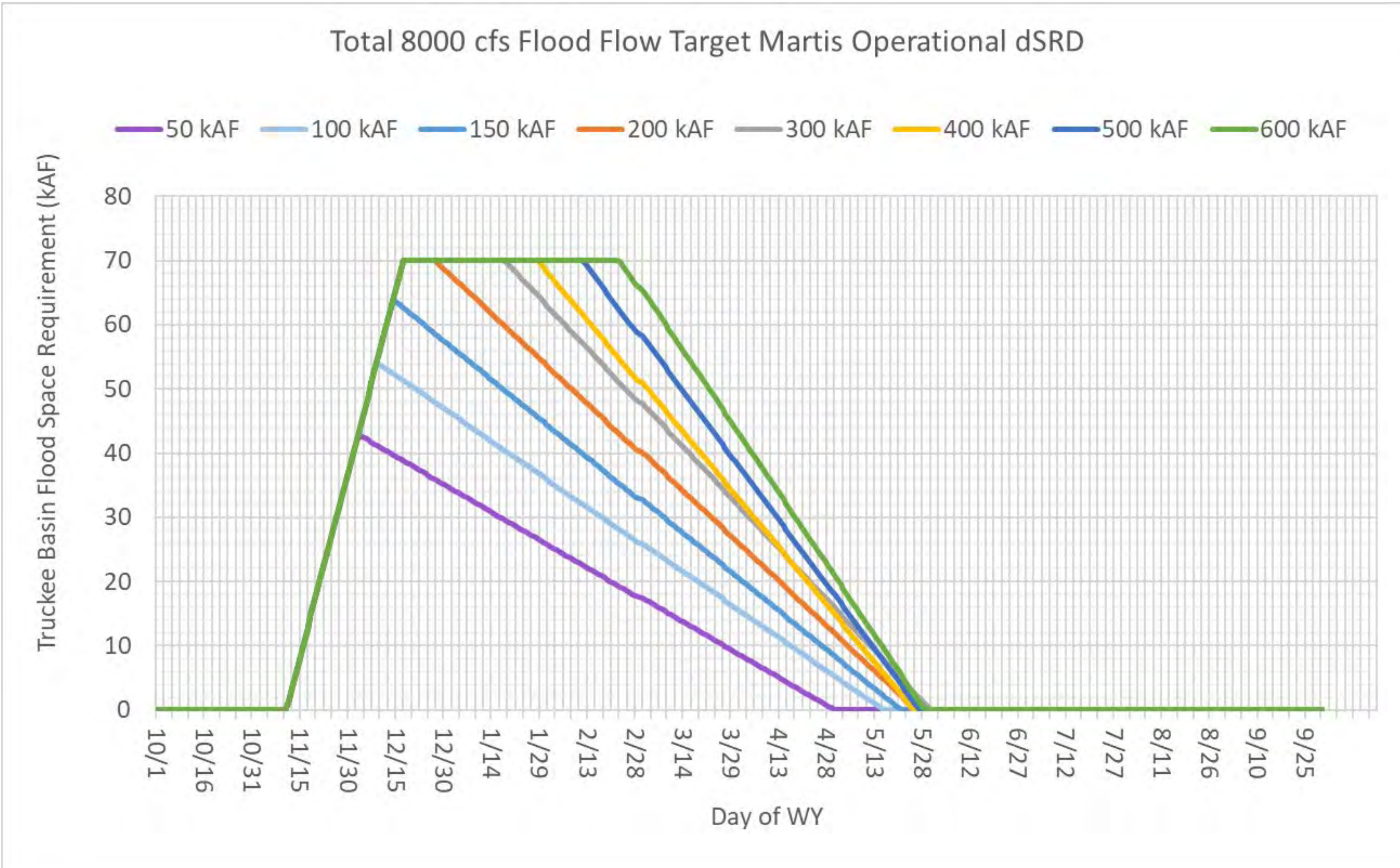



Total 6500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
80
70
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY



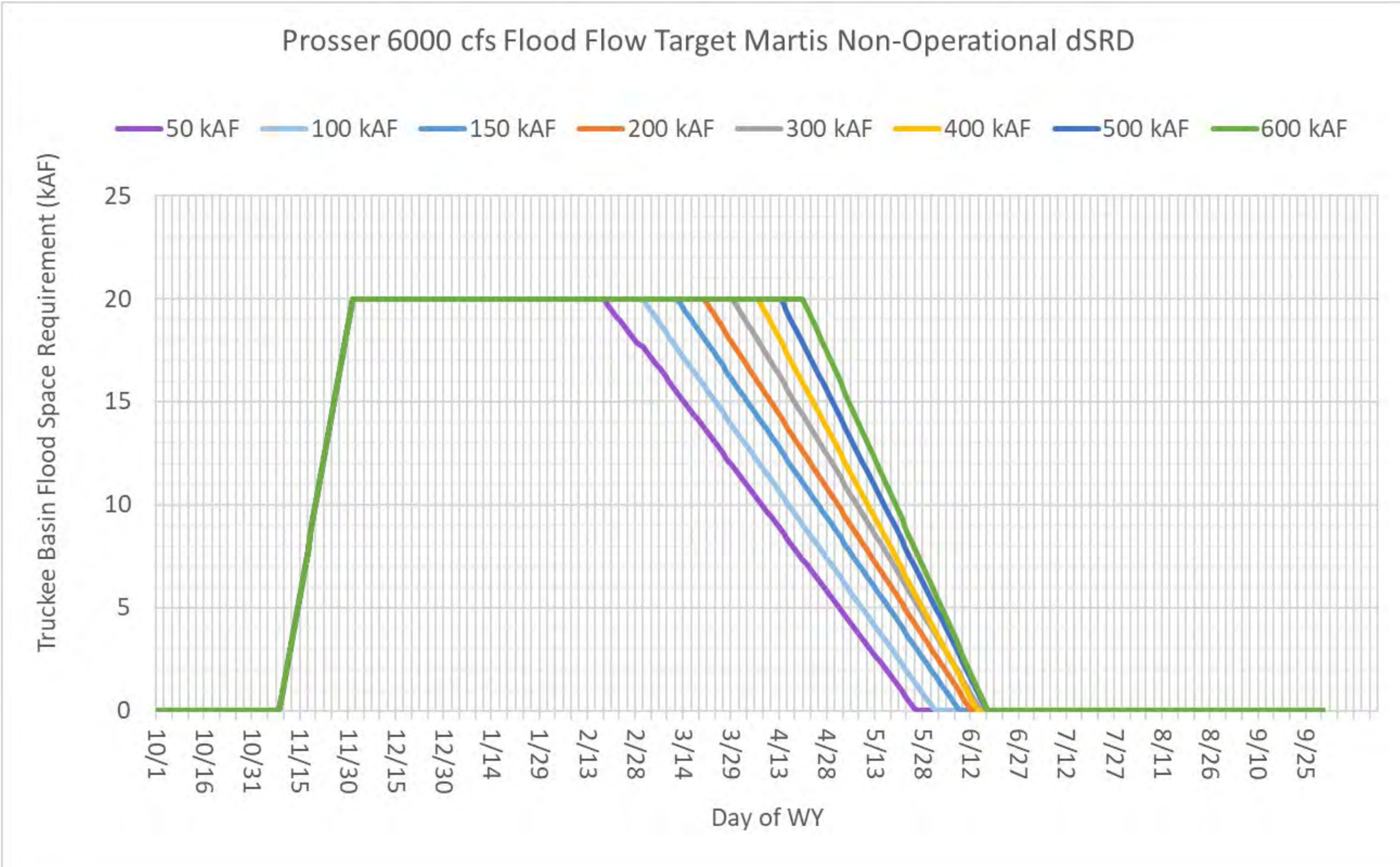
Total 7000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
80
70
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

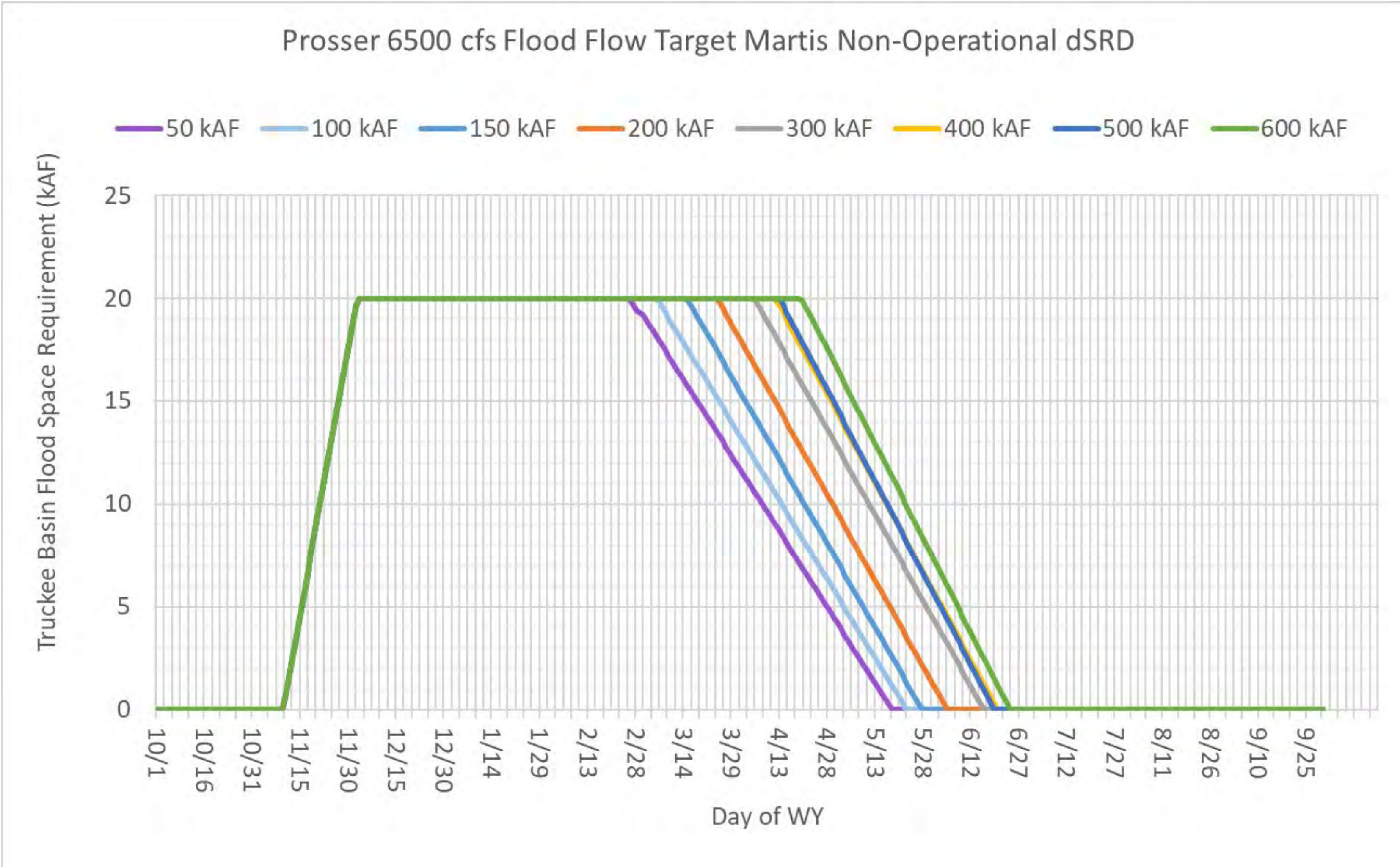

Total 7500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
80
70
60
50
40
30
20
10
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY


Total 8000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
0
10
20
30
40
50
60
70
80
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

10 Appendix C: Subbasin dSRDs at Potential Flood Flow Targets (Martis Not Operational)

10.1 Prosser Subbasin dSRDs




Prosser 6500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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6/12
6/27
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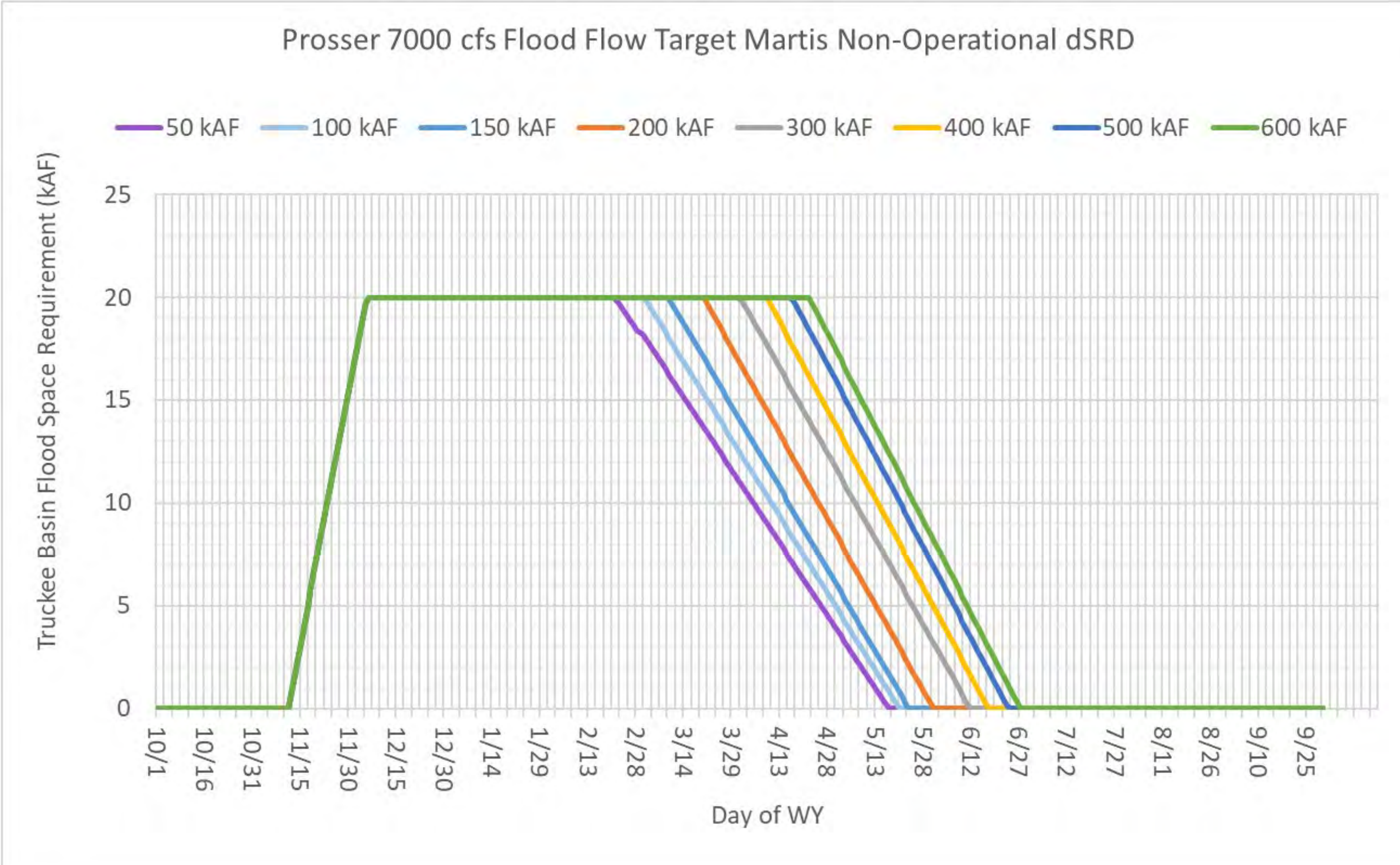
7/27
8/11
8/26
9/10
9/25
Day of WY


Prosser 7000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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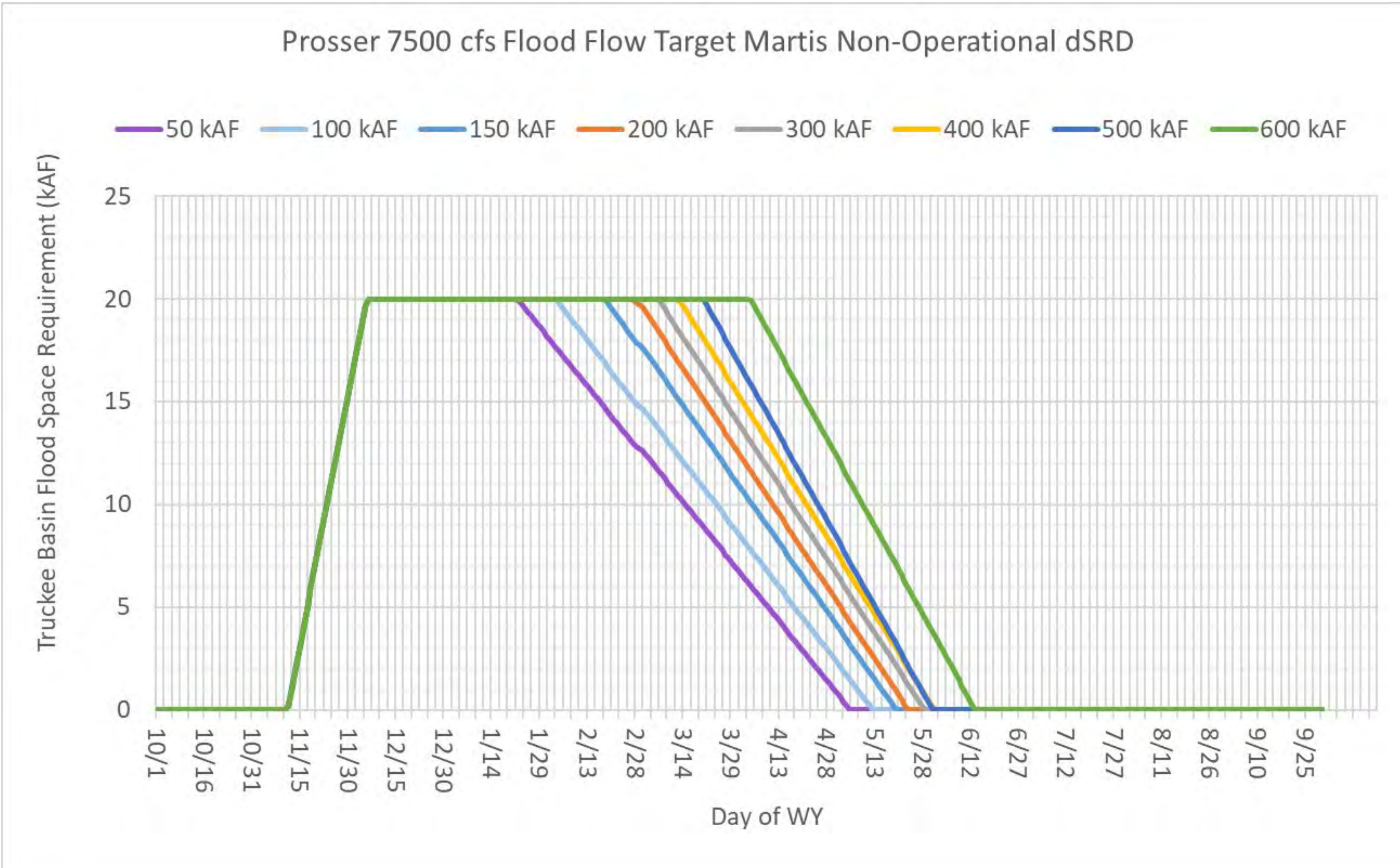
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY



Prosser 7500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
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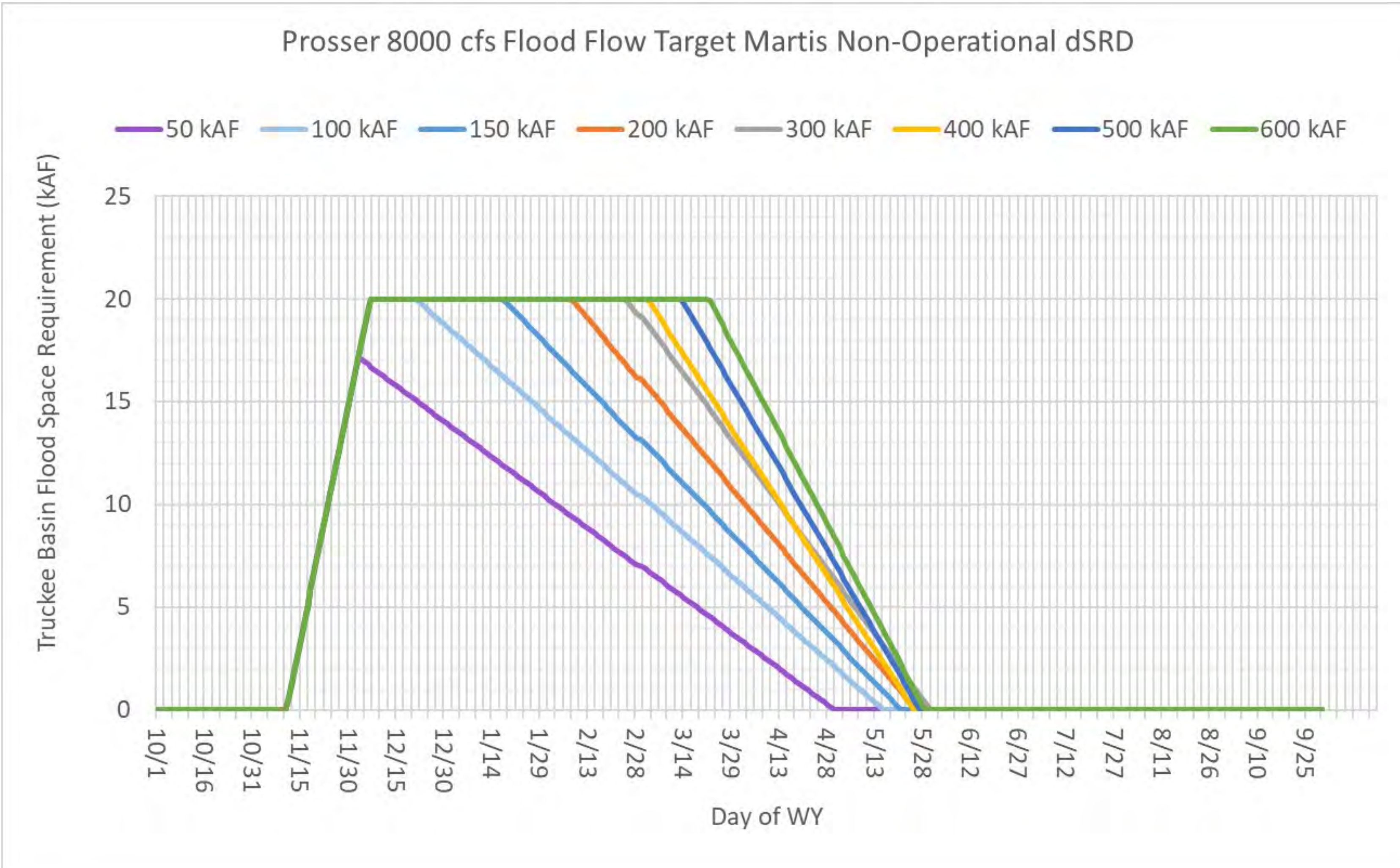
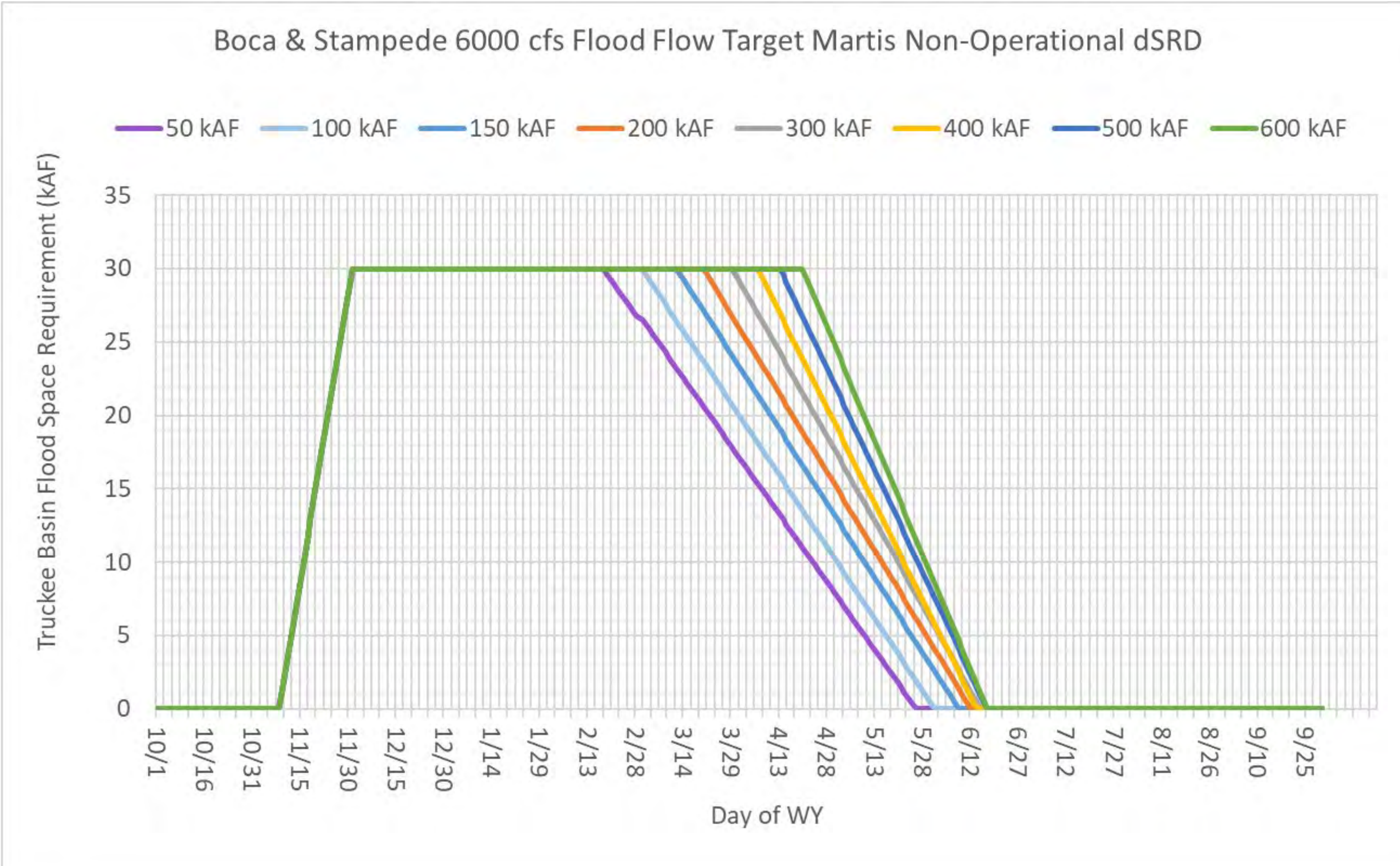
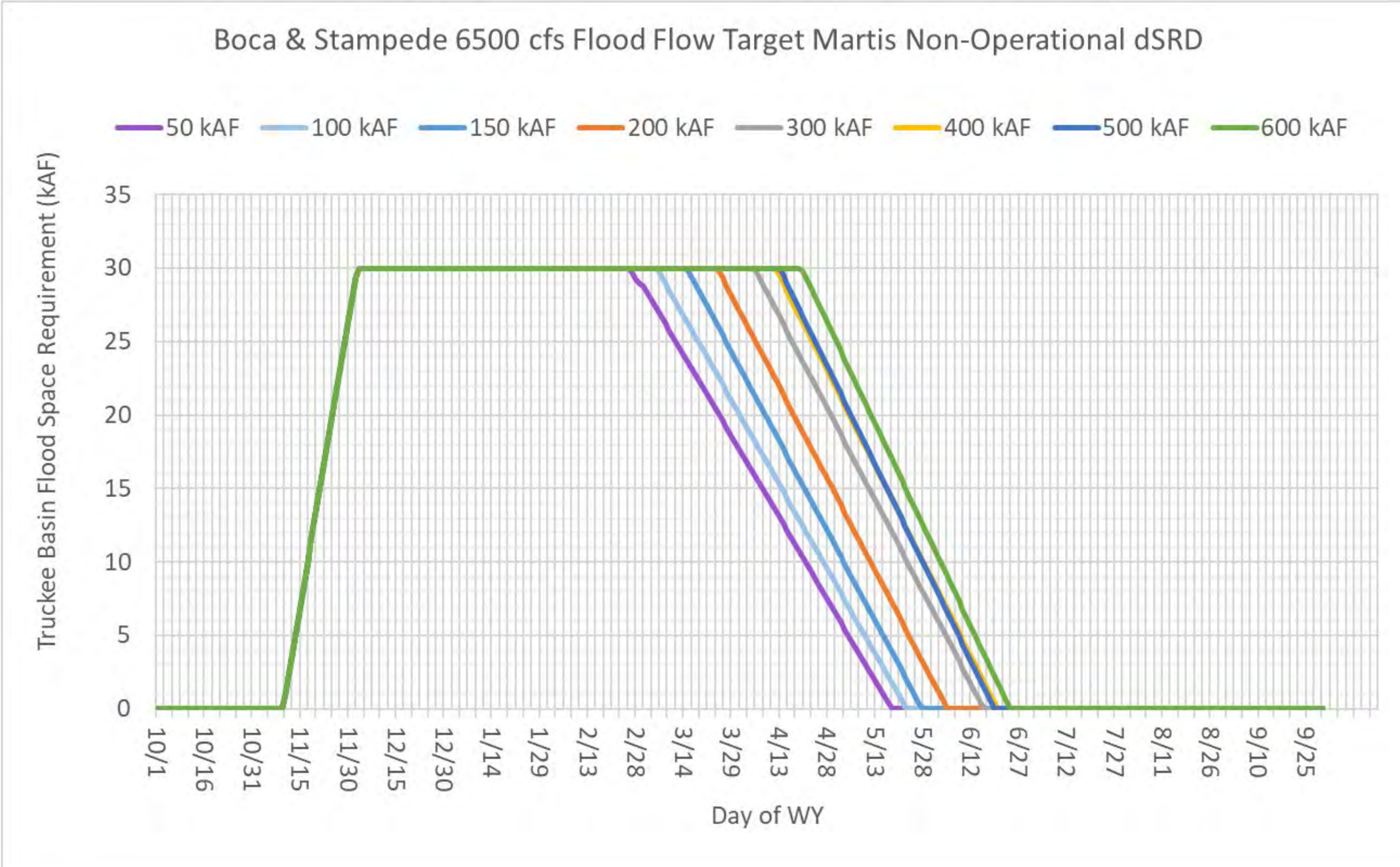
8/26
9/10
9/25
Day of WY


Prosser 8000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

10.2 Boca & Stampede Subbasin dSRDs




Boca & Stampede 6500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
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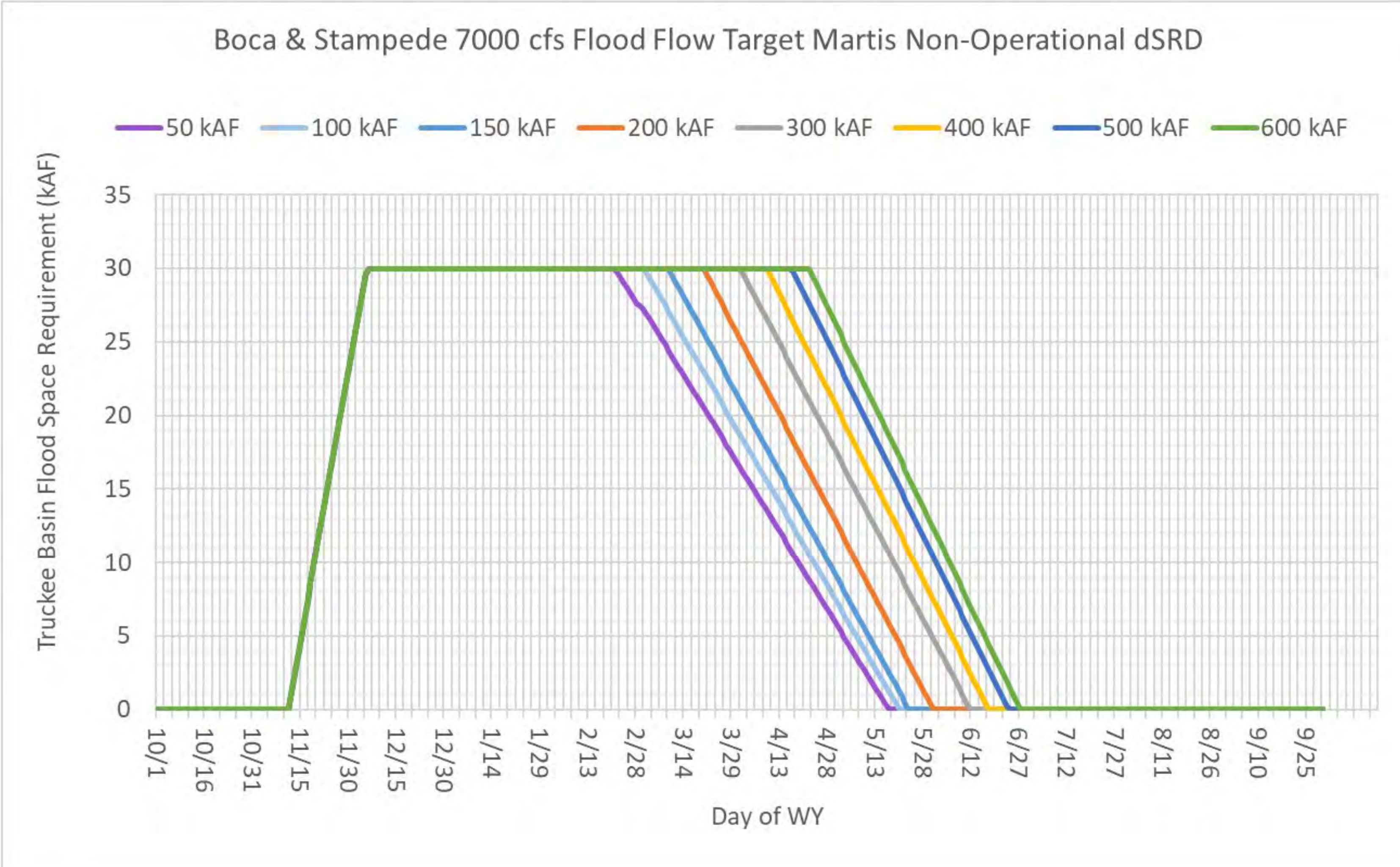
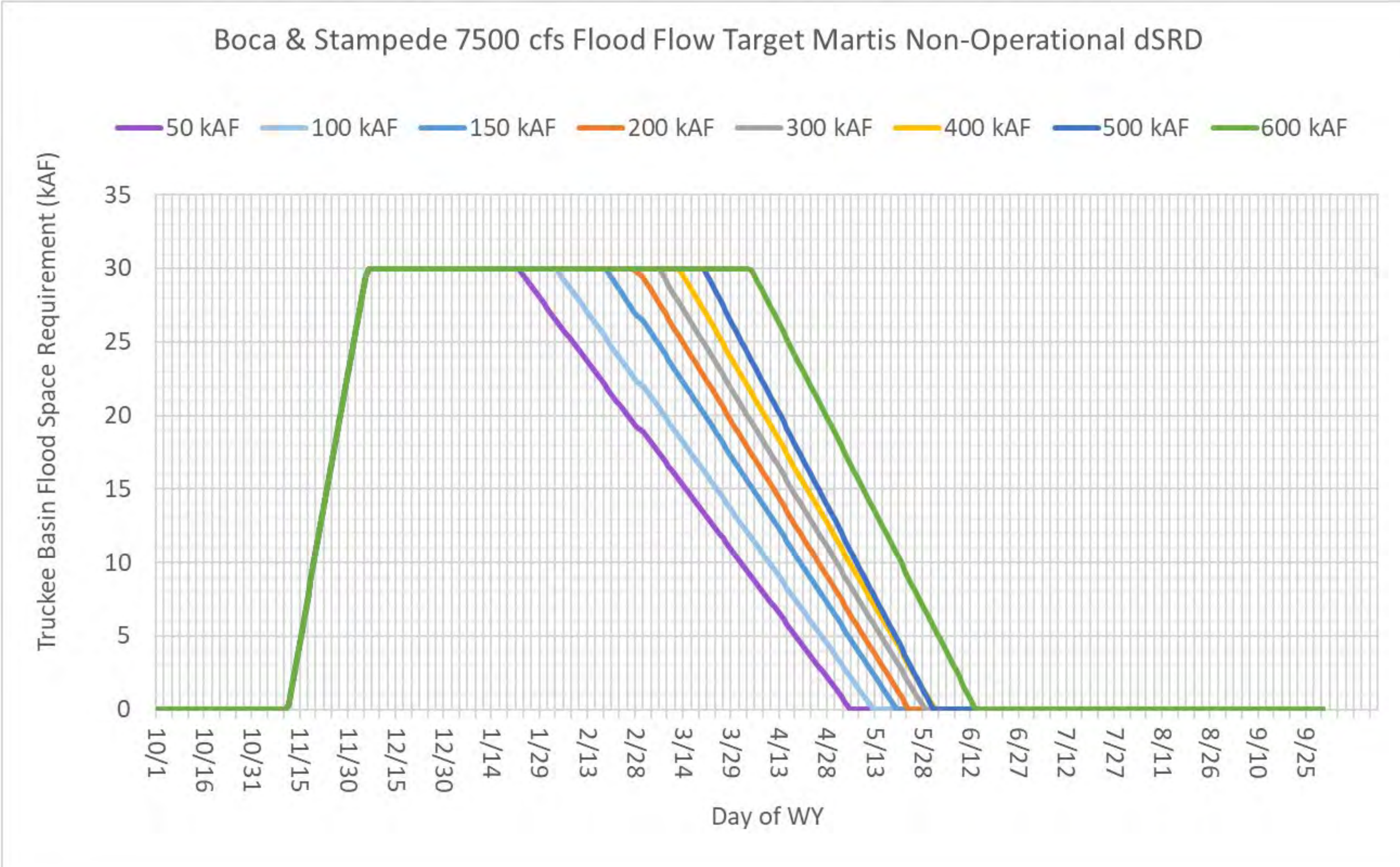
9/10
9/25
Day of WY


Boca & Stampede 7000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY



Boca & Stampede 7500 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
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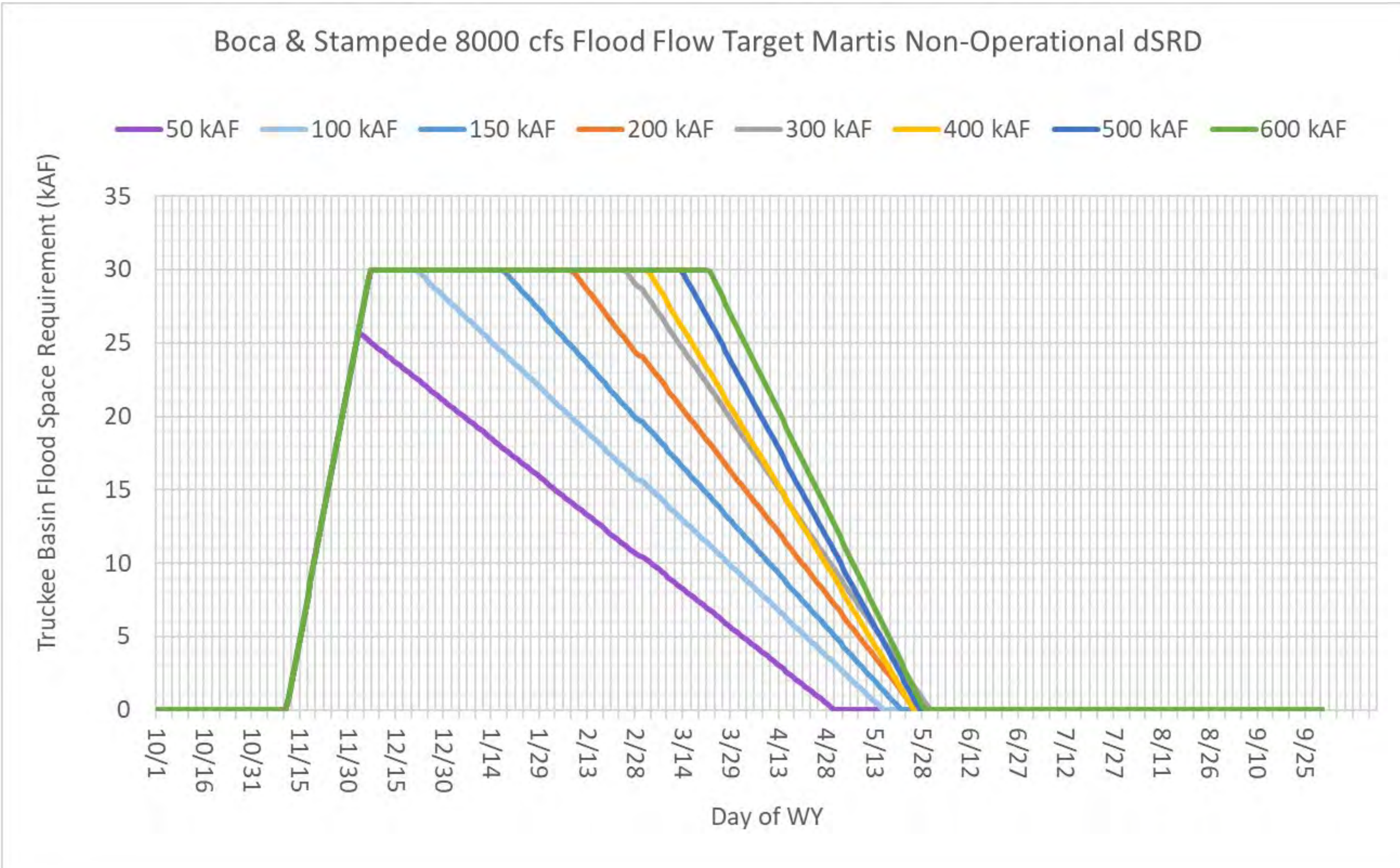
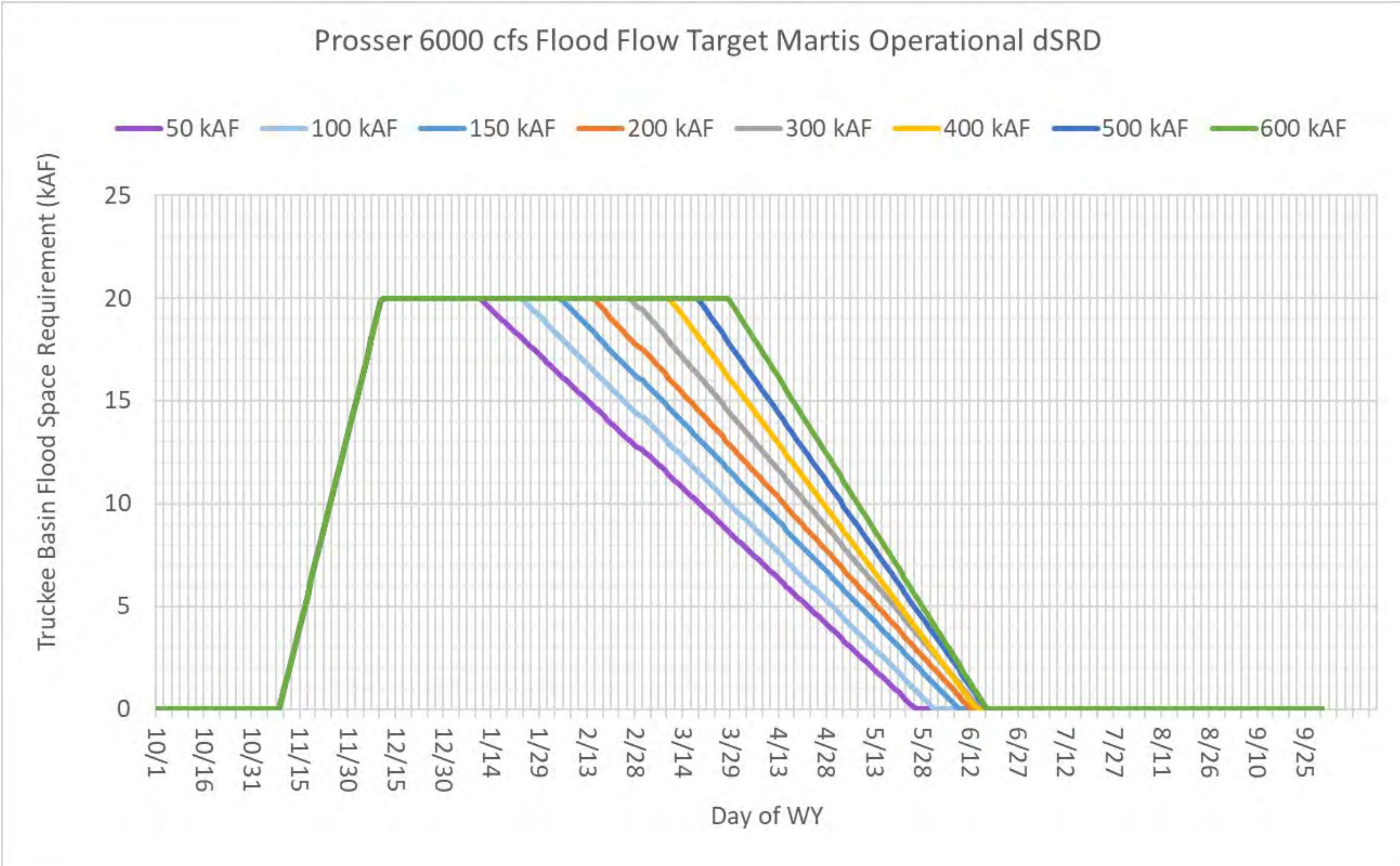
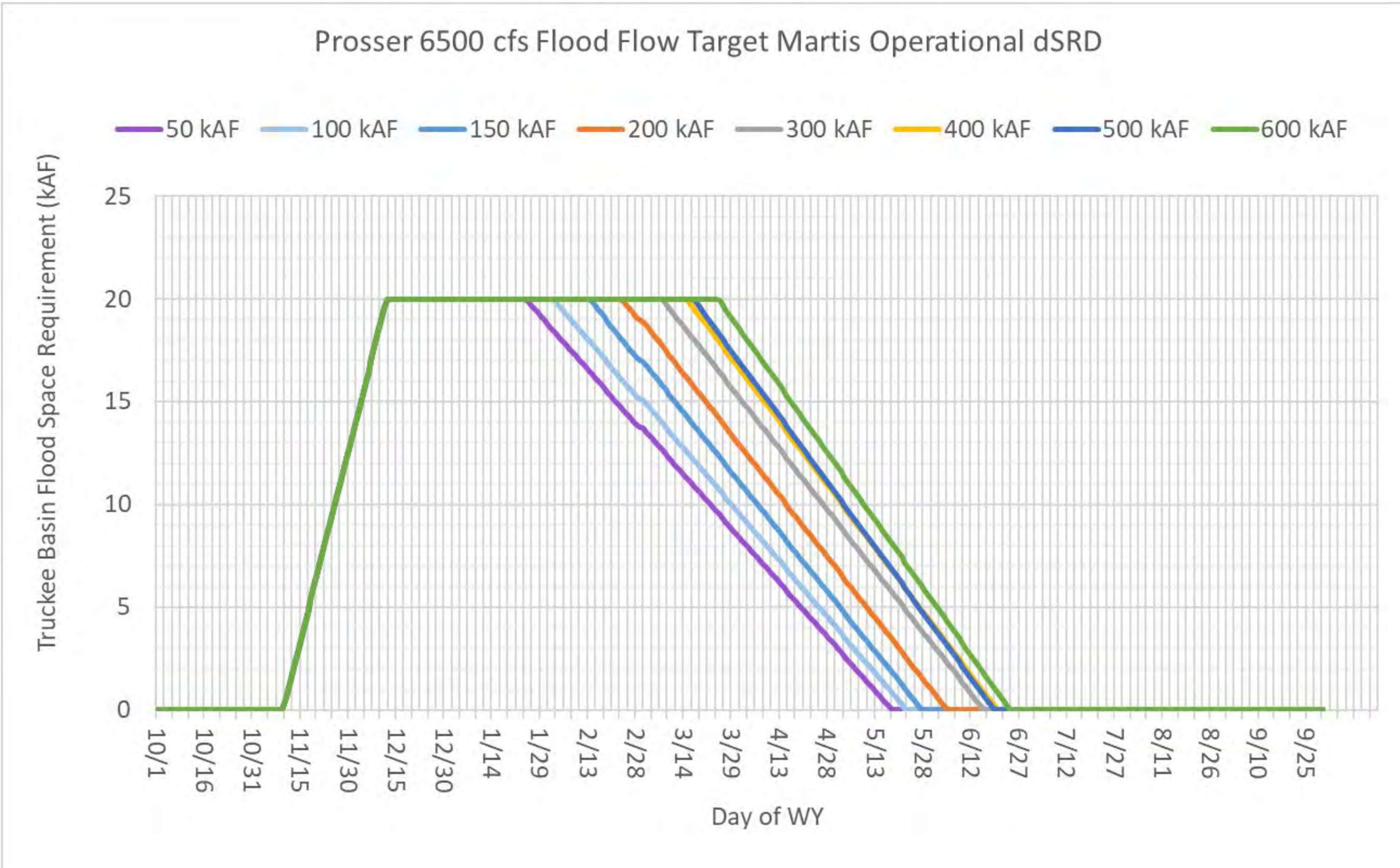
8/26
9/10
9/25
Day of WY


Boca & Stampede 8000 cfs Flood Flow Target Martis Non-Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
5/13
5/28
6/12
6/27
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY

11 Appendix D: Subbasin dSRDs at Potential Flood Flow Targets (Martis Operational)

11.1 Prosser Subbasin dSRDs





Prosser 6500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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5/28
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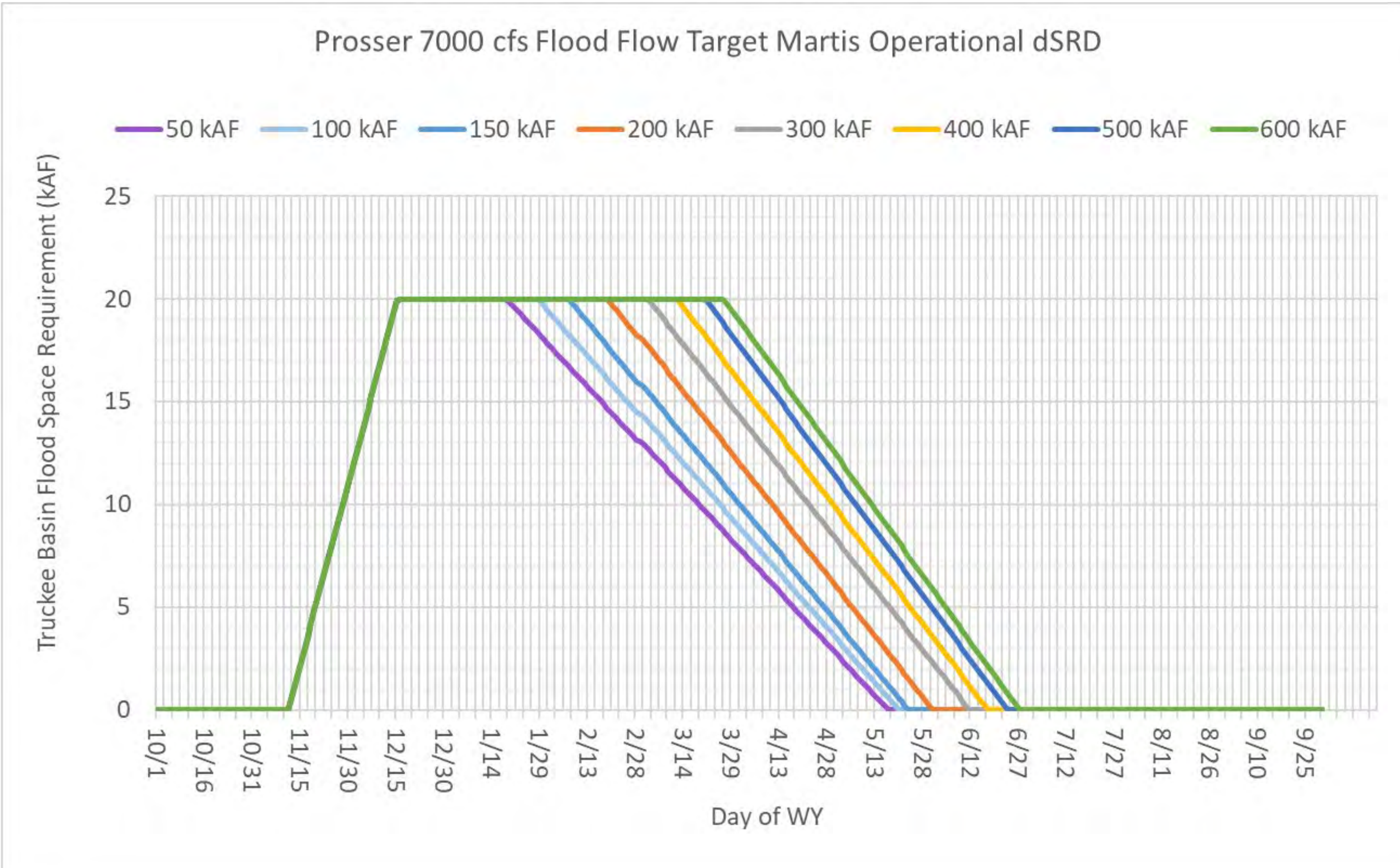
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY


Prosser 7000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
0
5
10
15
20
25
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
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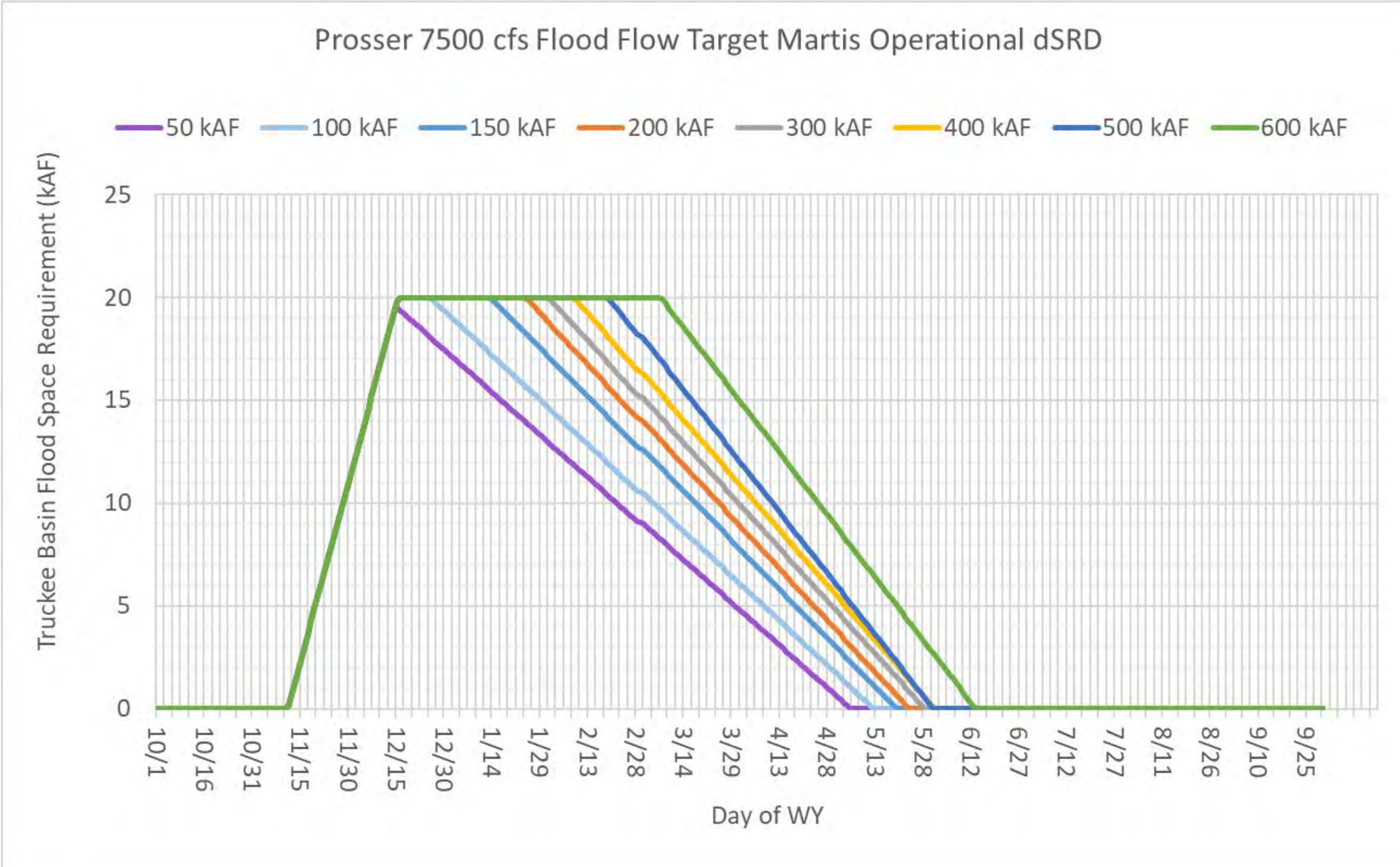
8/26
9/10
9/25
Day of WY


Prosser 7500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
3/29
4/13
4/28
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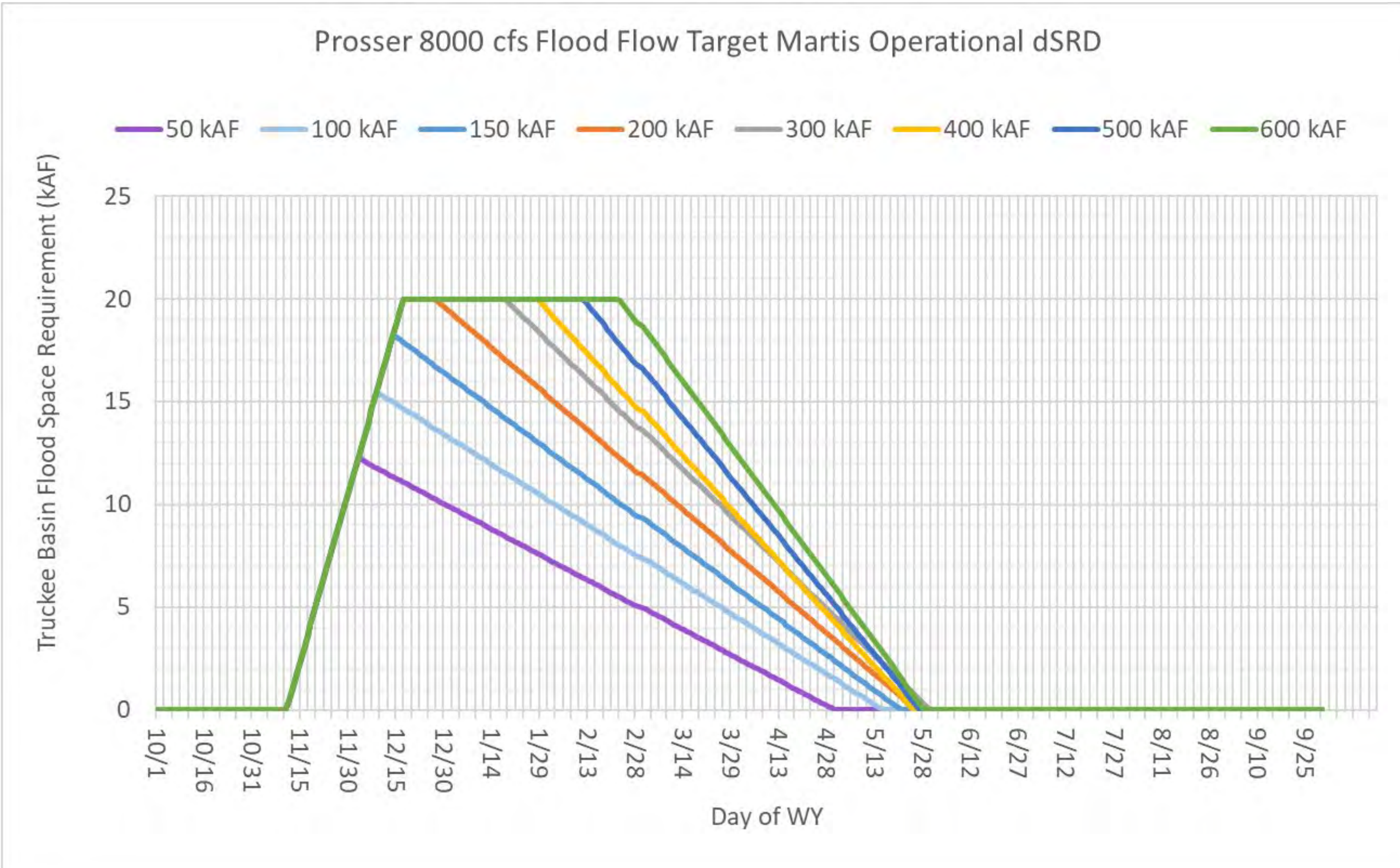
7/12
7/27
8/11
8/26
9/10
9/25
Day of WY



Prosser 8000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
3/14
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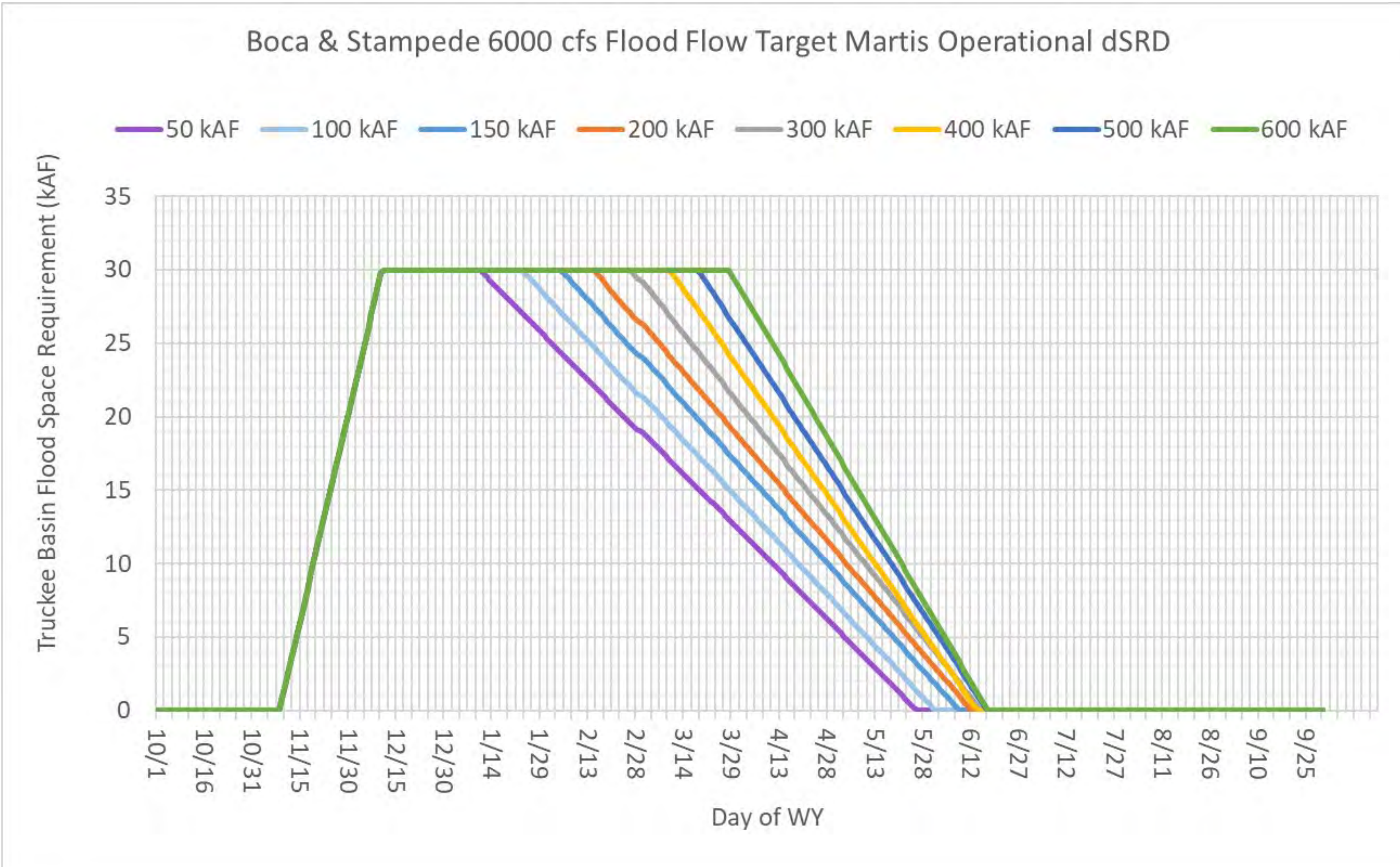
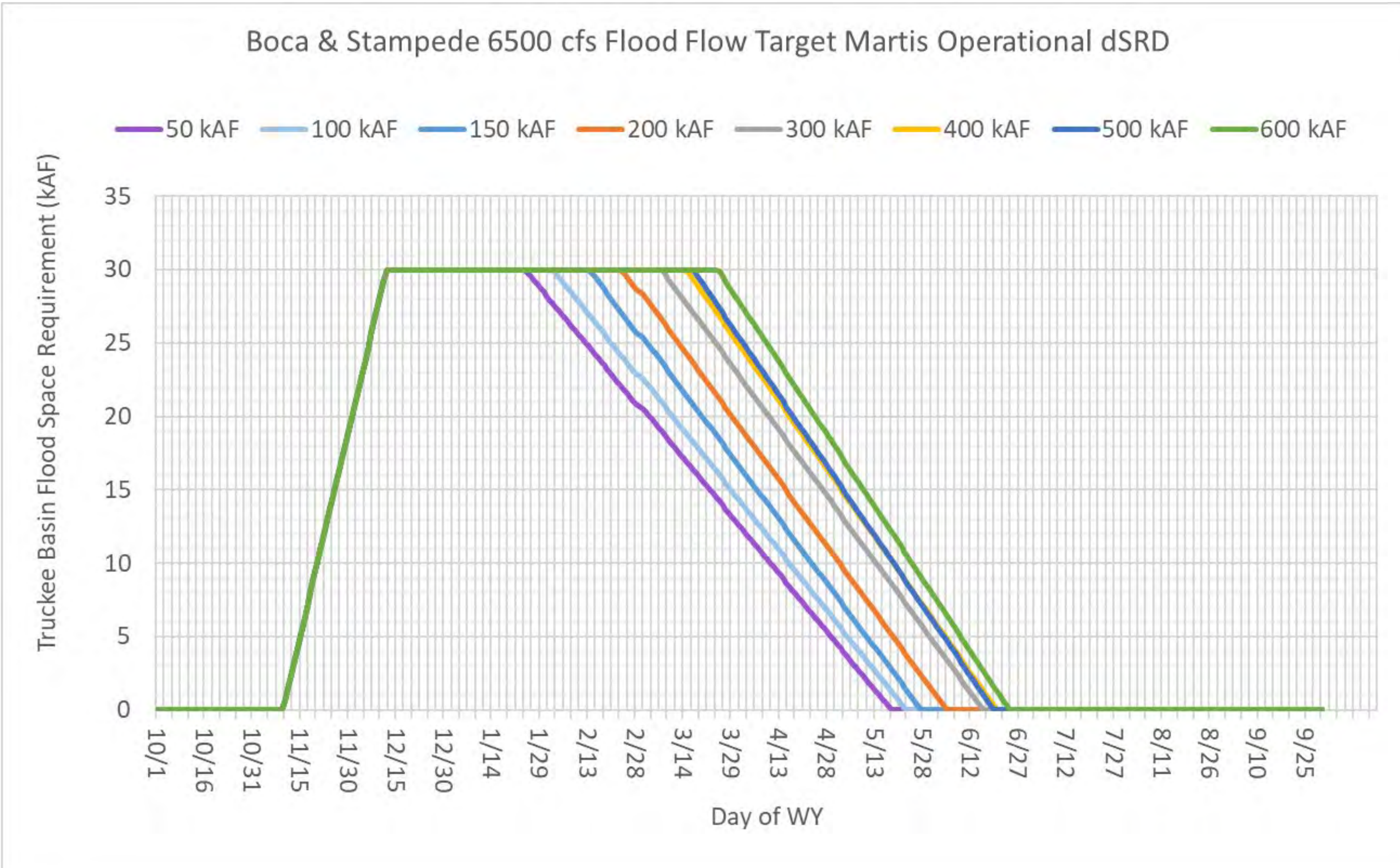
8/26
9/10
9/25
Day of WY

11.2 Boca & Stampede Subbasin dSRDs





Boca & Stampede 6500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
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3/14
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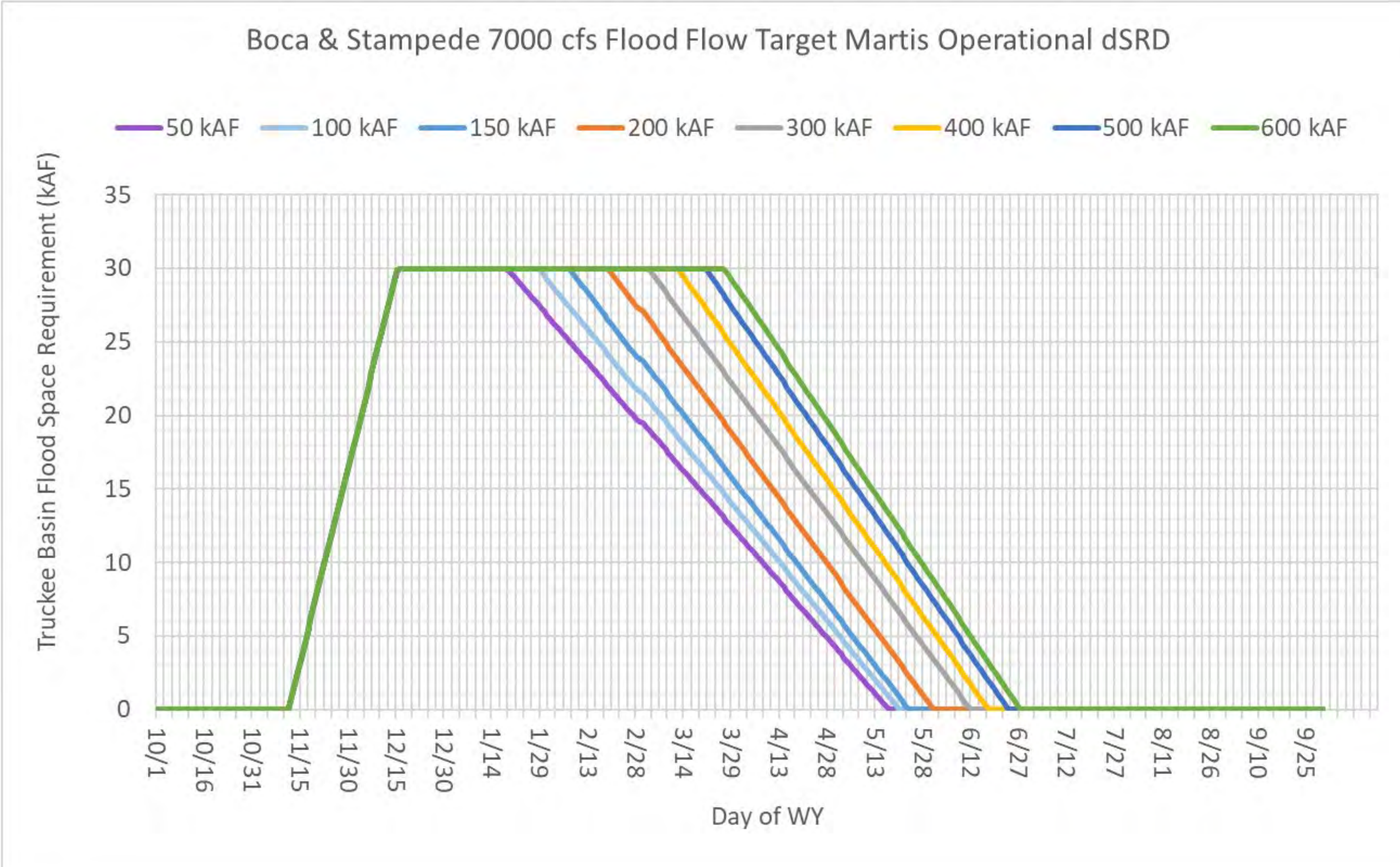
9/10
9/25
Day of WY


Boca & Stampede 7000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
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3/14
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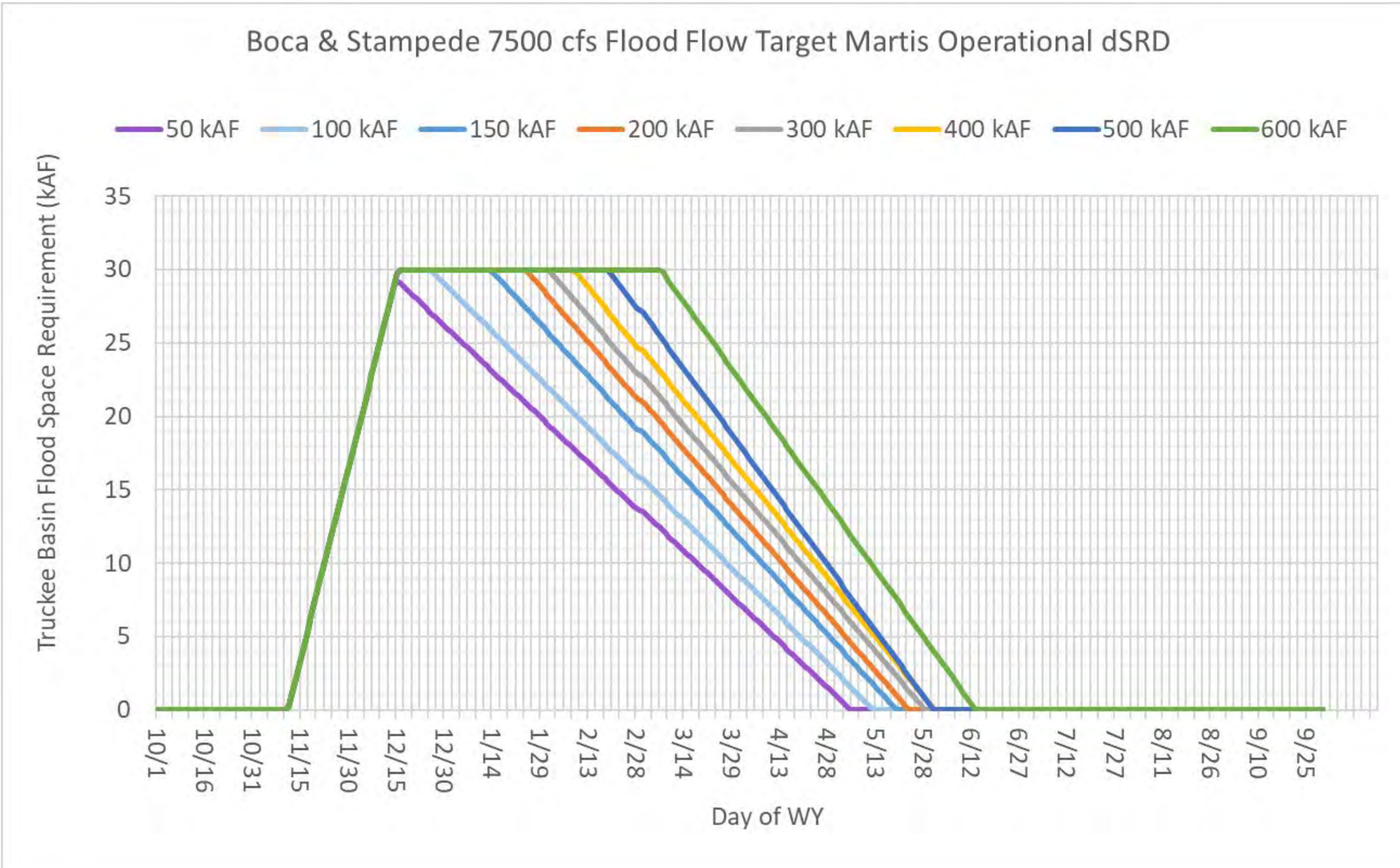
9/25
Day of WY



Boca & Stampede 7500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
15
10
5
0
10/1
10/16
10/31
11/15
11/30
12/15
12/30
1/14
1/29
2/13
2/28
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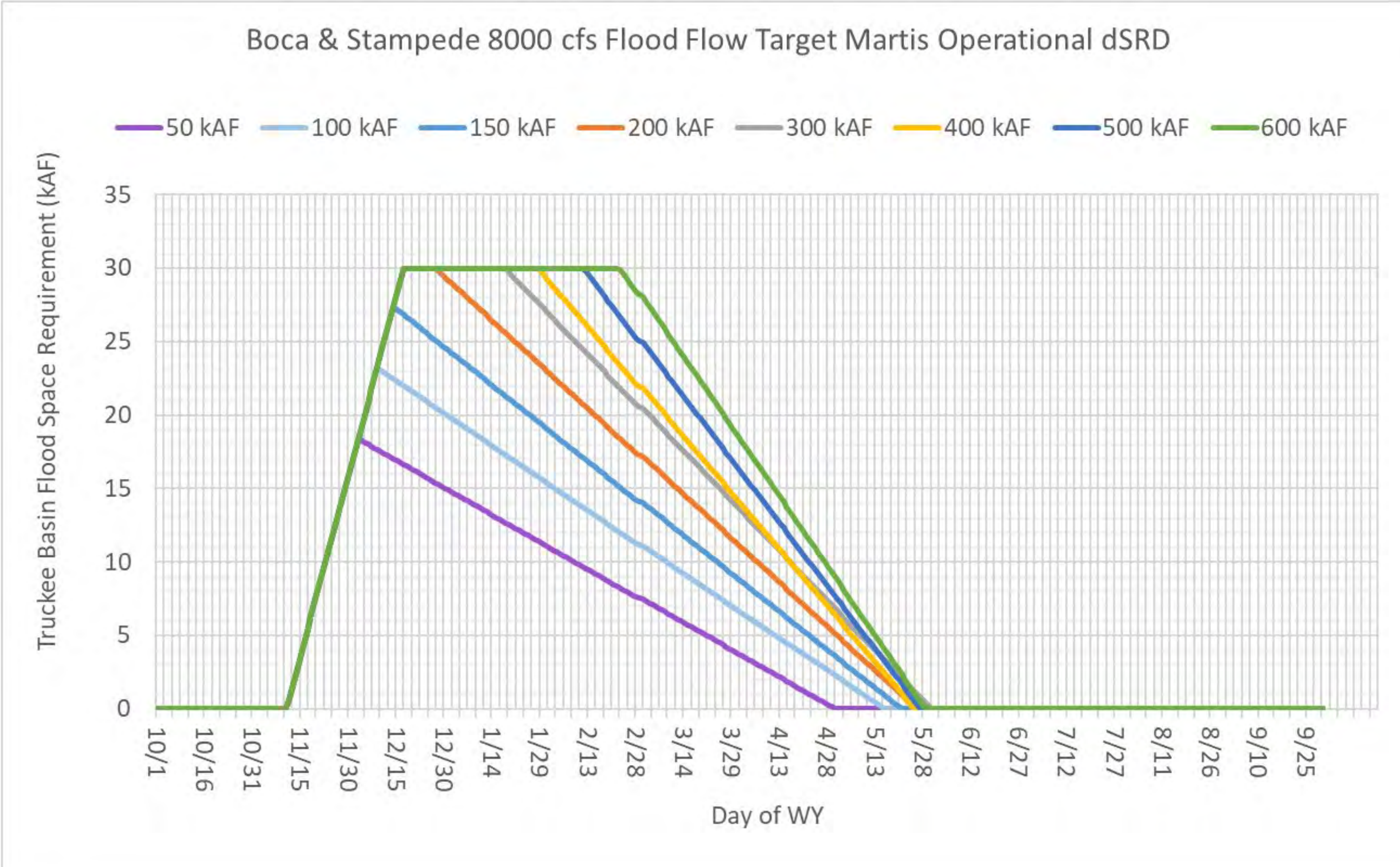
9/25
Day of WY


Boca & Stampede 8000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
35
30
25
20
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10
5
0
10/1
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11/15
11/30
12/15
12/30
1/14
1/29
2/13
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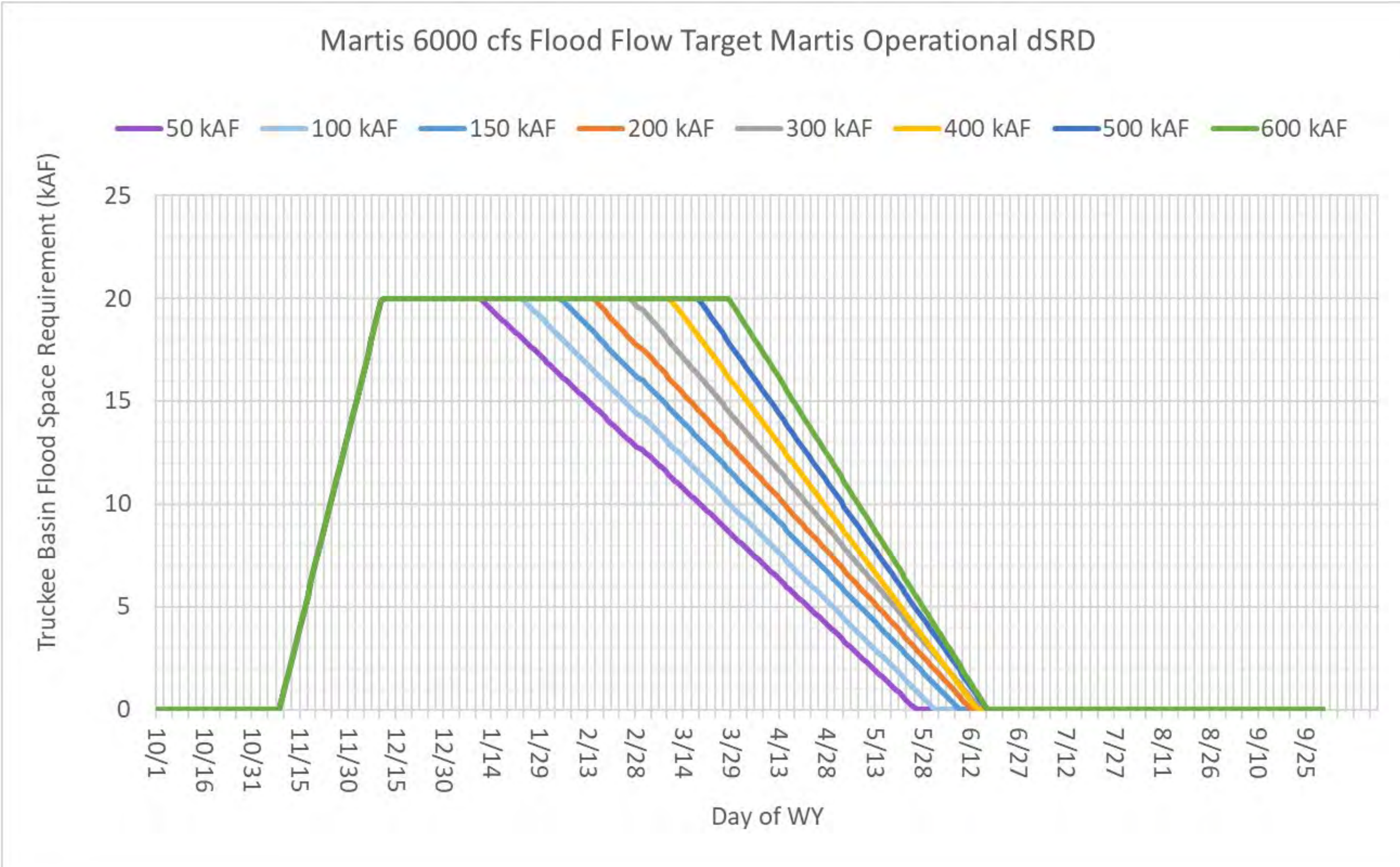
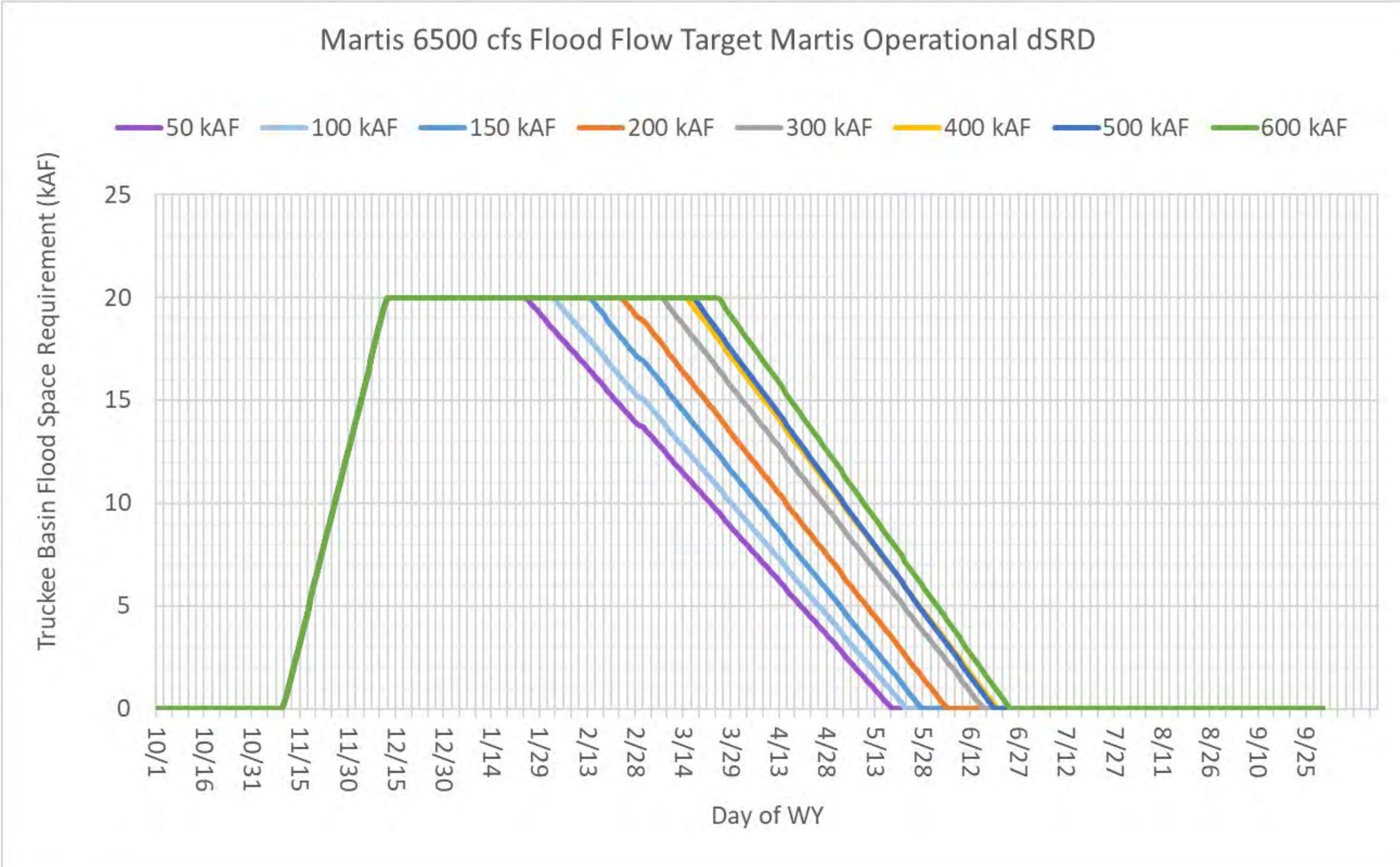
9/25
Day of WY

11.3 Martis Subbasin dSRDs





Martis 6500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
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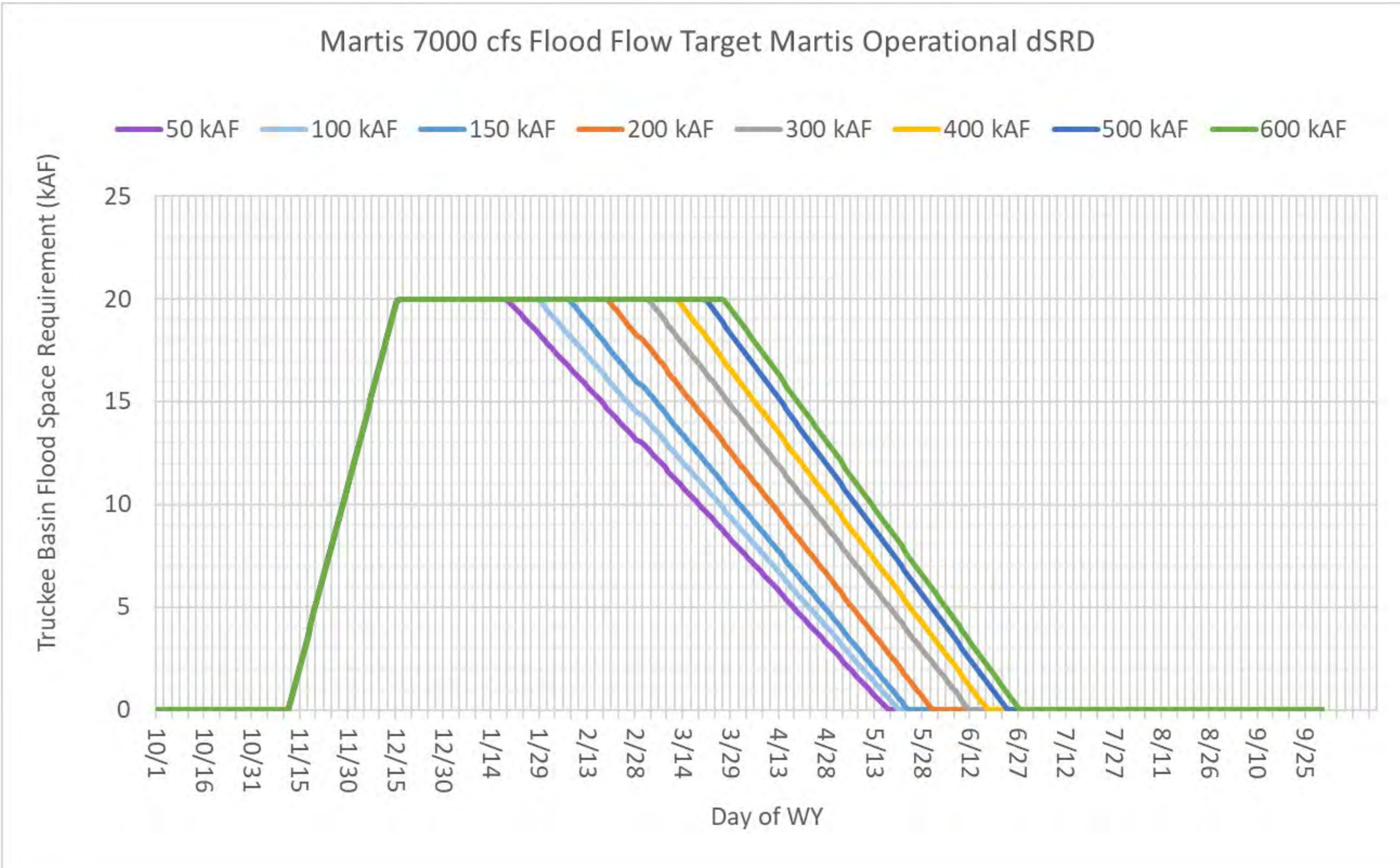
9/10
9/25
Day of WY


Martis 7000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
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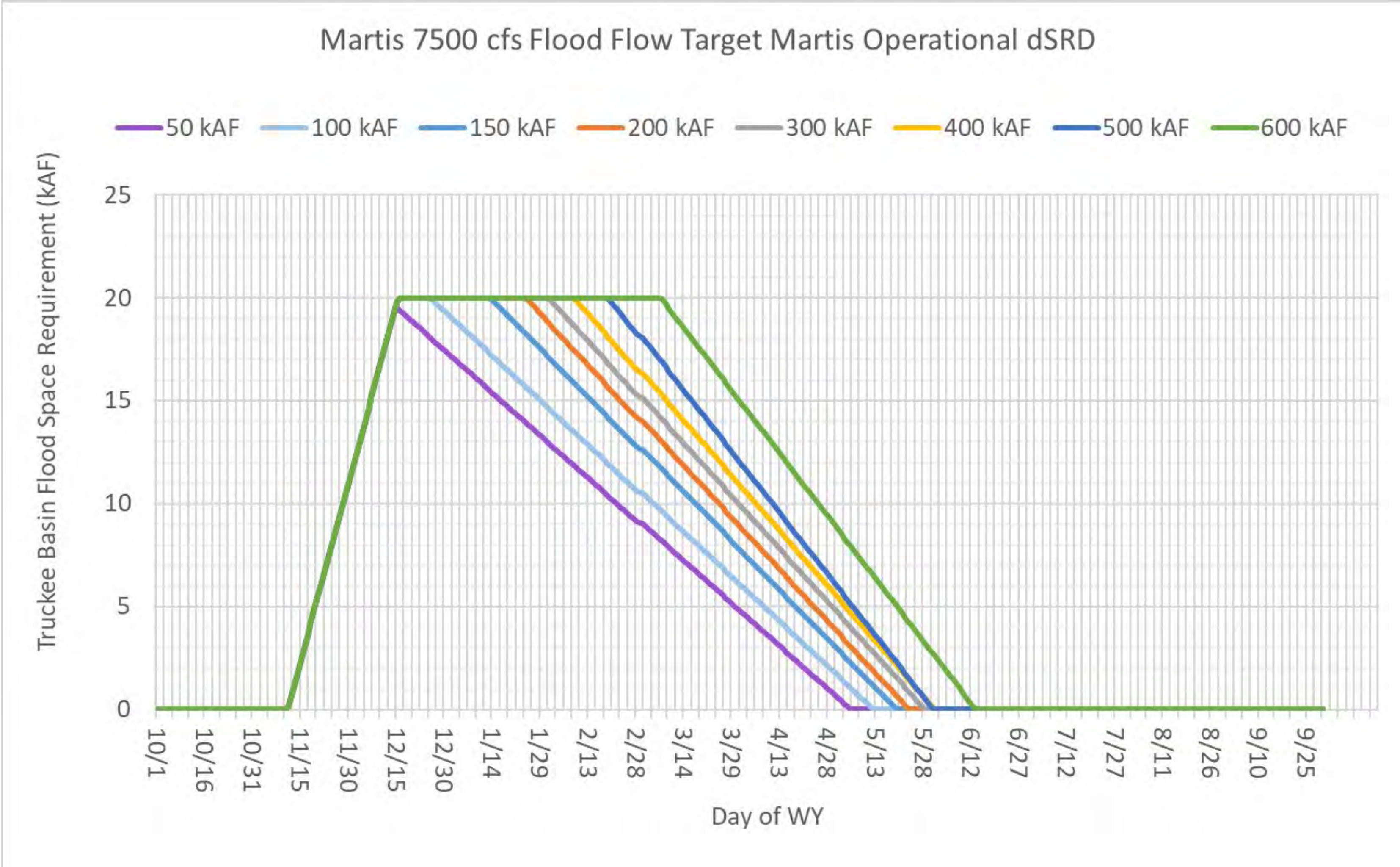
Day of WY


Martis 7500 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
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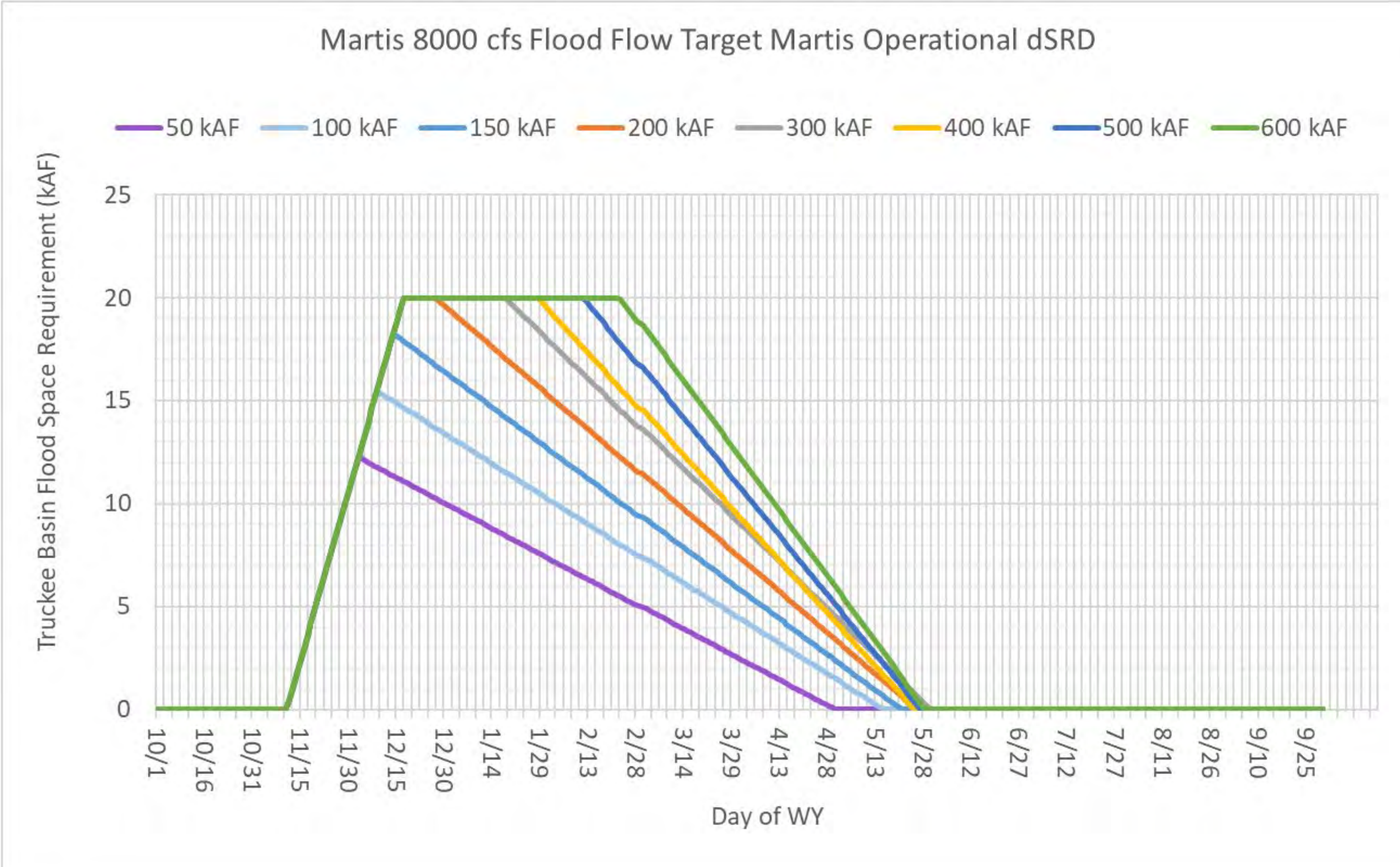
9/25
Day of WY



Martis 8000 cfs Flood Flow Target Martis Operational dSRD
50 kAF
100 kAF
150 kAF
200 kAF
300 kAF
400 kAF
500 kAF
600 kAF
Truckee Basin Flood Space Requirement (kAF)
25
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10/16
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12/30
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9/25
Day of WY

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