APPENDIX IR2-1 PROBABLE MAXIMUM FLOOD ANALYSIS

Stantec

Appendix IR2-1 Probable Maximum Flood Analysis

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Springbank Off-Stream Reservoir Project

Probable Maximum Flood Analysis

DRAFT REPORT

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1.0 INTRODUCTION

1.1 SCOPE

This report presents the analyses and results for the estimation of the Probable Maximum Flood (PMF) for the Springbank Off-Stream Reservoir (SR1); specifically, the PMF for the design of the Elbow River Diversion Dam and the SR1 Off-Stream Flood Storage Dam. The PMF was estimated by development and calibration of a Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) model. The model development included a comprehensive evaluation of appropriate methodologies and relevant recorded data pertaining to the meteorological, hydrometric, and physical characteristics of the Elbow River Basin. The initial calibration determined model parameters to simulate the 2005 and 2013 floods. The model was further refined based on flood frequency simulation. The calibrated model was applied to estimate the PMF by using Probable Maximum Precipitation (PMP) data. PMP data was developed for four scenarios: general storm (48-hour) and local storm (6-hour) for the 863 km^2 watershed upstream of the SR1 Diversion Site; general storm for the 1,212 km^2 watershed upstream of Glenmore Reservoir; and local storm for the 31 km^2 watershed upstream of the SR1 Off-Stream Dam.

2.0 HYDROLOGIC MODEL SETUP

A basin wide watershed model for the Elbow River Basin upstream of Glenmore Reservoir was developed using HEC-HMS. The drainage area was systematically partitioned based on a sub-basin approach where each sub-basin is represented by hydrologic parameters.

HEC-HMS was selected for the development of the Elbow River Basin hydrologic model. The model is available in the public domain and is widely applied to different hydrological studies in Canada and the United States.

2.1 SUB-BASIN DELINEATION

Topographic data for the study area are derived from a 1:50,000 (approximately 20 m x 20 m grid cells) digital elevation model (DEM) that covers the entire Elbow River Basin (GeoGratis 2015). The outer boundary of the basin consists of elevations varying between 1,058 m and 3,164 m and was delineated using the DEM. A map showing the variation in topography across the Elbow River Basin is included in Appendix A.

The Elbow River Basin was partitioned into eleven sub-basins based primarily on the topographic characteristics of the area with consideration of vegetation, surficial geology, and land use. Several hydrologic parameters were derived for each sub-basin including length and slope of watercourses, area, elevation at centroid of the sub-basins, and upstream and downstream elevations. Individual sub-basins ranged in size from 3,120 ha to 35,300 ha. Some of the basic model parameters generated for each sub-basin are shown in Table 1. See Figure 1 for a map of the delineated sub-basins and the boundary of the Elbow River Basin.

Table 1: Main Attributes of Sub-Basins

Sub-Basin Name	Area (ha)	Watercourse Name	Sub-basin Length (m)	Sub-basin Slope (m/m)
W100	27,800	-	-	-
W150	5,830	R240	7,050	0.0070
W200	12,100	R190	3,480	0.013
W250	3,360	R160	2,680	0.015
W300	8,150	R180	8,900	0.0090
W350	5,040	R130	10,300	0.0076
W400	35,300	R750	12,300	0.0073
W450	8,900	R100	7,400	0.0065
W500	7,690	R10	1,930	0.012
W550	3,120	R20	19,800	0.0045
W600	3,980	R120	8,140	0.00010

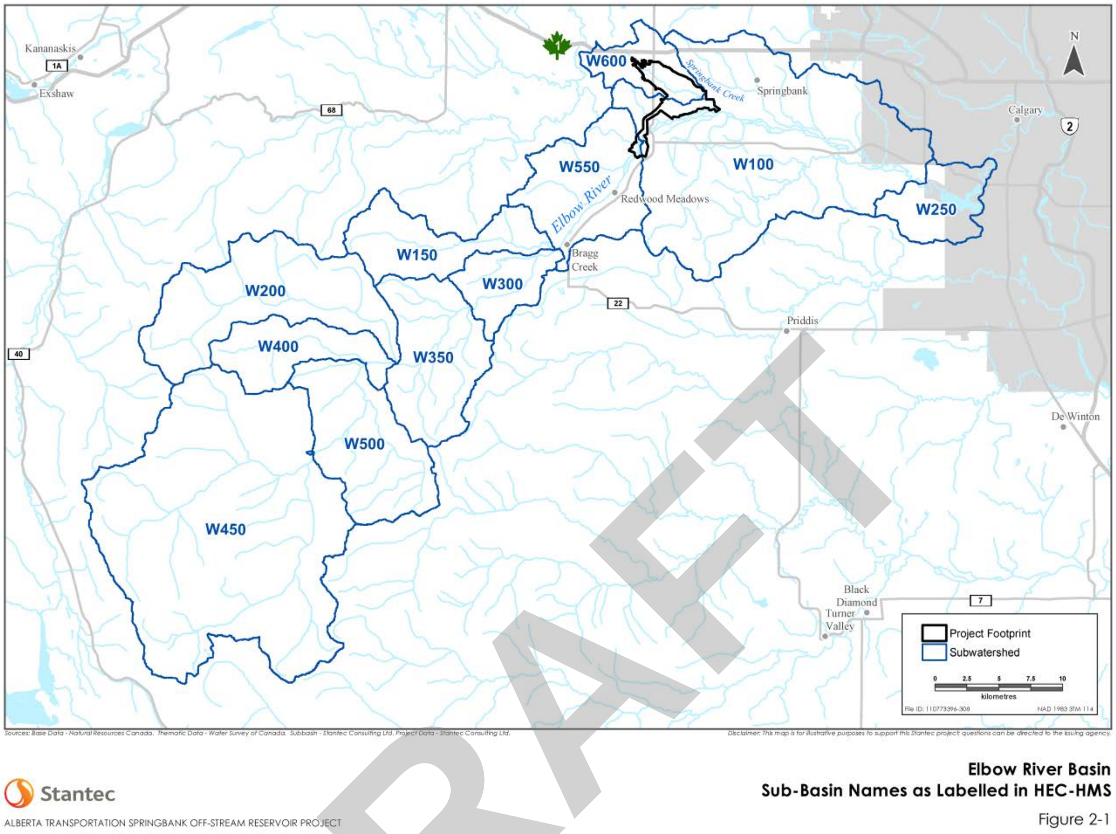

Figure 1: Sub-Basin Names as Labelled in HEC-HMS

2.2 RAINFALL LOSS PARAMETERS

HEC-HMS computes runoff volume by estimating the depth of rainfall loss and subtracting it from precipitation. It is computed using an initial and constant loss rate method. Initial loss represents interception, depression storage, and some portion of the initial soil infiltration. The constant loss rate represents the saturated soil hydraulic conductivity. Soils throughout the watershed are comprised primarily of loam. Using typical values from Tables 8 and 10 of the State of Colorado *Hydrologic Basin Response Parameter Estimation Guidelines* (Sabol 2008), an initial loss of 20 mm was assigned to all sub-basins. Using typical values from Table 12 of the same State of Colorado guidance document, a constant loss rate of 6 mm/hour was assigned to each sub-basin. The initial estimate for the rainfall loss parameters of each sub-basin is presented in Table 2.

The surficial geology of the Elbow River Basin was obtained from Alberta Geological Survey's digital data for the surficial geology of Alberta un-generalized digital mosaic. This GIS dataset is an organization of existing surficial map information for Alberta tiled into one layer (AGS 2013). A map of the different types of surficial geology within the Elbow River Basin is included in Appendix A.

Surficial geology data together with land use data was used to estimate the impervious area of each sub-basin by calculating the area of exposed bedrock and assuming it to be effectively impervious. The estimate of the impervious percent of each sub-basin is presented in Table 2.

Table 2: Summary of Initial Rainfall Loss Parameters

Sub-Basin	Drainage Area (ha)	Initial Loss (mm)	Constant Loss Rate (mm/hour)	Percent Impervious (%)
W100	27,800	20	6	0
W150	5,830	20	6	5
W200	12,100	20	6	33
W250	3,360	20	6	13
W300	8,150	20	6	0
W350	5,040	20	6	13
W400	35,300	20	6	23
W450	8,900	20	6	53
W500	7,690	20	6	19
W550	3,120	20	6	0
W600	3,980	20	6	0

2.3 RUNOFF TRANSFORMATION (UNIT HYDROGRAPH METHOD)

Runoff transformation is a process by which precipitation excess is converted into a volumetric time sequence of surface runoff or hydrograph. The unit hydrograph is one such transformation method whereby precipitation excess is converted into runoff hydrographs based on physiographic characteristics. In this work, unit hydrographs were developed for each sub-basin using the method described in the State of Colorado, *Hydrologic Basin Response Parameter Estimation Guidelines* (Sabol 2008). Based on this method, the US Bureau of Reclamation (USBR) synthetic unit hydrograph for the Rocky Mountain general storm was used for all sub-basins during initial model development.

The coordinates of each unit hydrograph are a function of the basin lag time (L_g) parameter. Lag time is estimated from topographic characteristics of each sub-basin. A lumped parameter representing resistance to overland flow (K_n) was estimated for each sub-basin in order to estimate lag time. The length of the longest watercourse (L), basin slope (S), and distance to the sub-basin centroid (L_{ca}) were estimated in HEC-GeoHMS using the 20 m resolution topographic data. A K_n value of 0.15 was initially selected for all sub-basins based on Table 7 from the State of Colorado guidance document. Parameters used to develop the unit hydrographs are presented in Table 3. These input parameters are presented in Imperial Units as used in the guidance document. The resulting unit hydrographs were converted to SI units after calculations were completed. Full unit hydrographs for each sub-basin are presented in Figure 2.

Table 3: Summary of Initial Sub-Basin Unit Hydrograph Input Parameters

Sub-Basin	Drainage Area (mi^2)	Basin Slope (ft/mi)	L (mi)	L_{ca} (mi)	K_n	Computed L_g (hr)	Unit Duration, D (min)
W100	107	51.7	21.7	9.37	0.15	11.8	60
W150	22.5	168	13.3	7.48	0.15	7.65	60
W200	46.7	205	18.1	9.35	0.15	8.81	60
W250	15.4	47.0	9.81	6.65	0.15	8.20	60
W300	13.0	161	7.76	4.27	0.15	5.35	60
W350	31.5	125	9.23	3.52	0.15	5.54	60
W400	19.4	300	11.2	6.40	0.15	6.22	60
W450	136	229	19.1	5.74	0.15	7.50	60
W500	34.4	206	12.9	4.40	0.15	6.14	60
W550	29.7	83.4	10.4	5.90	0.15	7.32	60
W600	12.0	34.9	8.04	3.64	0.15	6.61	60

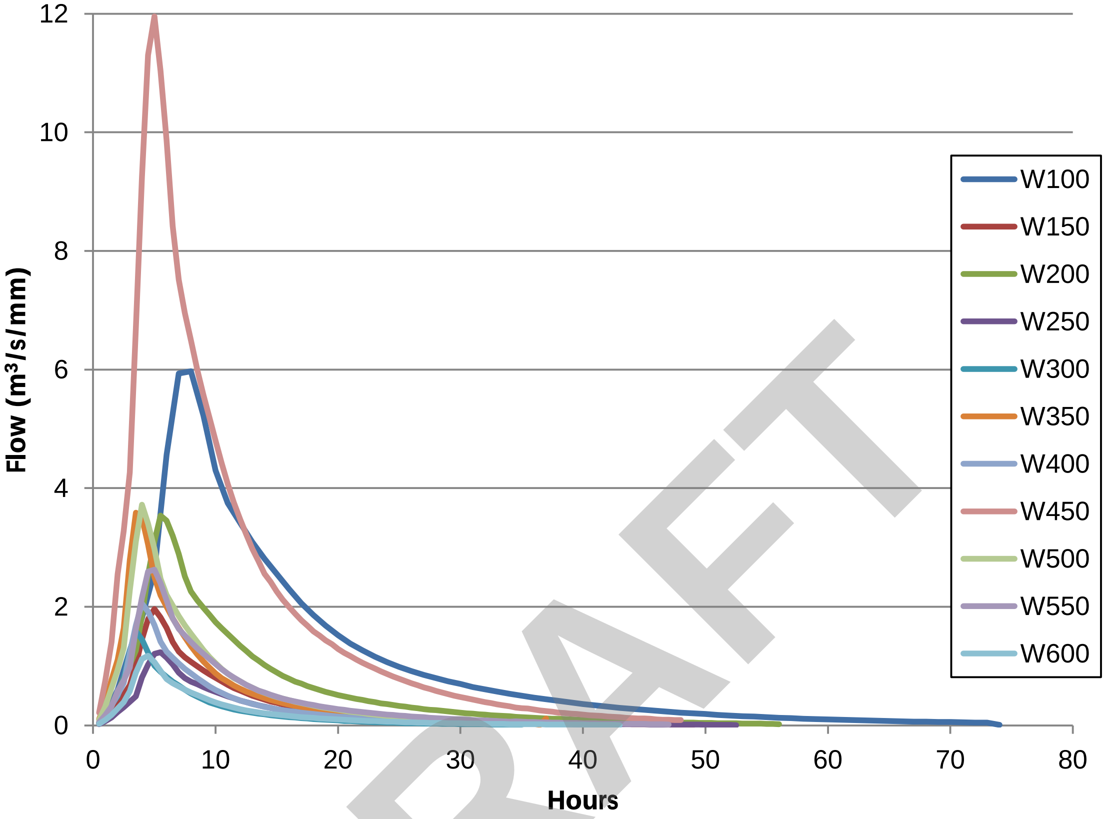

Figure 2: Sub-Basin Unit Hydrographs Used in the Initial Modeling

2.4 CHANNEL ROUTING

River routing within the model represents the travel time and attenuation that occurs within the Elbow River and its tributaries between modeling concentration points. Two methods were employed in the model to represent channel routing. For small tributaries and the upstream reaches of the Elbow River, the kinematic wave routing method was used. The river length, slope, and approximate width were estimated from the 20 m by 20 m topographic data and aerial imagery. The Muskingum routing method was used for the portion of Elbow River between Bragg Creek and the Glenmore Reservoir. This routing method requires the specification of travel time, K, and a parameter defining attenuation, X. The travel times were selected based on observed historic flood peaks at Bragg Creek and Sarcee Bridge hydrometric stations. An X value of 0.4 was initially assumed for all Muskingum routing reaches which results in low attenuation. Table 4 summarizes routing parameters used in the model.

Table 4: Summary of Initial Reach Routing Parameters

***Kinematic Wave* Reach Routing Methodology**

Sub-Basin	Length (m)	Slope (m/m)	Manning's n	Sub-Reaches	Shape	Width (m)
R160	2,680	0.015	0.02	2	Rectangular	75
R240	7,050	0.0071	0.02	2	Rectangular	40
R190	3,480	0.013	0.02	2	Rectangular	40
R180	8,900	0.0091	0.03	2	Rectangular	100
R10	1,930	0.012	0.03	2	Rectangular	20

***Muskingum* Reach Routing Methodology**

Sub-Basin	K (hour)	X
R750	4.0	0.4
R130	1.2	0.4
R100	2.0	0.4
R20	6.0	0.4
R120	2.0	0.4

2.5 BASEFLOW

2.5.1 Baseflow Method

Baseflow was initially assumed to be a constant value. As such, all sub-basins were assigned a fixed baseflow of 1 m^3/s, except for the largest upstream sub-basin, W450, which was adjusted so that the flow at the beginning of the simulation matched the observed flow. The initial estimate for the baseflow for each sub-basin is presented in Table 5.

Table 5: Summary of Initial Sub-Basin Baseflow

Sub-Basin	Baseflow Methodology	2005 Event Baseflow (m^3/s)	2013 Event Baseflow (m^3/s)
W100	Constant	1	1
W150	Constant	1	1
W200	Constant	1	1
W250	Constant	1	1
W300	Constant	1	1
W350	Constant	1	1
W400	Constant	1	1
W450	Constant	27	21
W500	Constant	1	1
W550	Constant	1	1
W600	Constant	1	1

3.0 HYDROLOGIC MODEL CALIBRATION

3.1 CALIBRATION EVENTS

The HEC-HMS model was calibrated for two flood events: June 4, 2005 to June 16, 2005 and June 19, 2013 to June 28, 2013.

3.1.1 Precipitation Data

Gridded precipitation data was developed by Applied Weather Associates (AWA); a sub-consultant to Stantec for this project (see Table 6). Appendix B provides cumulative precipitation maps for the 2005 and 2013 flood events.

Table 6: Summary of Precipitation Data Provided by AWA

Precipitation Data	Time Period
2005 Flood Event	June 1, 2005 at 8:00 to June 9, 2005 at 7:00
2013 Flood Event	June 19, 2013 at 8:00 to June 22, 2013 at 7:00

3.1.2 Hydrometric Data

Available hydrometric data was obtained and analyzed from four sources: City of Calgary; Alberta Environment and Sustainable Resource Development (ESRD); Alberta Environment Monitoring Branch, now part of Alberta Environmental Monitoring and Reporting Agency (AEMERA); and Water Survey of Canada (WSC). ESRD takes raw gauged data and develops real-time flow rates for use in flood forecasting and real time water management. Since data from ESRD is intended for real-time use and as ESRD generally does not back correct data after the event has passed, their data can be prone to some data errors. AEMERA reviews and adjusts data from their own gauges prior to submission to WSC. WSC does not issue preliminary hydrograph data until it has undergone an extensive review process which can take months or years prior to the releasing official streamflow data. It is generally accepted that WSC data is preferred when available for calibration. Therefore, WSC was taken as a reference for comparison because it is generally known to be the “official” and most reliable source for streamflow data.

The gauging stations used in model calibration were Elbow River at Bragg Creek (05BJ004) and Elbow River at Sarcee Bridge (05BJ010). The Bragg Creek Station is located upstream of the proposed SR1 Diversion Structure, while the Sarcee Bridge Station is situated downstream of the Diversion Structure, upstream of Glenmore Reservoir.

The contributing drainage area to the Bragg Creek Station is 790.8 km^2 and includes the mountainous portions of the basin where both the 2005 and 2013 rainfalls were the heaviest. The contributing drainage area to the Sarcee Bridge Station is 1189.3 km^2 and represents nearly the full study area. To the end of 2005, the Sarcee Bridge station was operated by AEMERA. The station was taken over by WSC in 2006.

See Table 7 for a summary and refer to Appendix A for a map of the relevant hydrometric stations.

Table 7: Relevant Hydrometric Station Summary

Station ID	Station Name	Drainage Area (km²)	Period of Record		Type of Flow	Operation Schedule
			From	To		
05BJ004	Elbow River at Bragg Creek	790.8	1934	2012	Natural	Continuous
05BJ010	Elbow River at Sarcee Bridge	1189.3	1979	2012	Natural	Continuous

3.1.2.1 2005 Hydrometric Data for Model Calibration

There were three closely spaced storms in June of 2005 resulting in flood discharges. The first of the three storms and floods took place between June 1, 2005 and June 16, 2005 and was selected for model calibration. Hydrograph data was obtained from WSC for the Bragg Creek station and is presented in Figure 3.

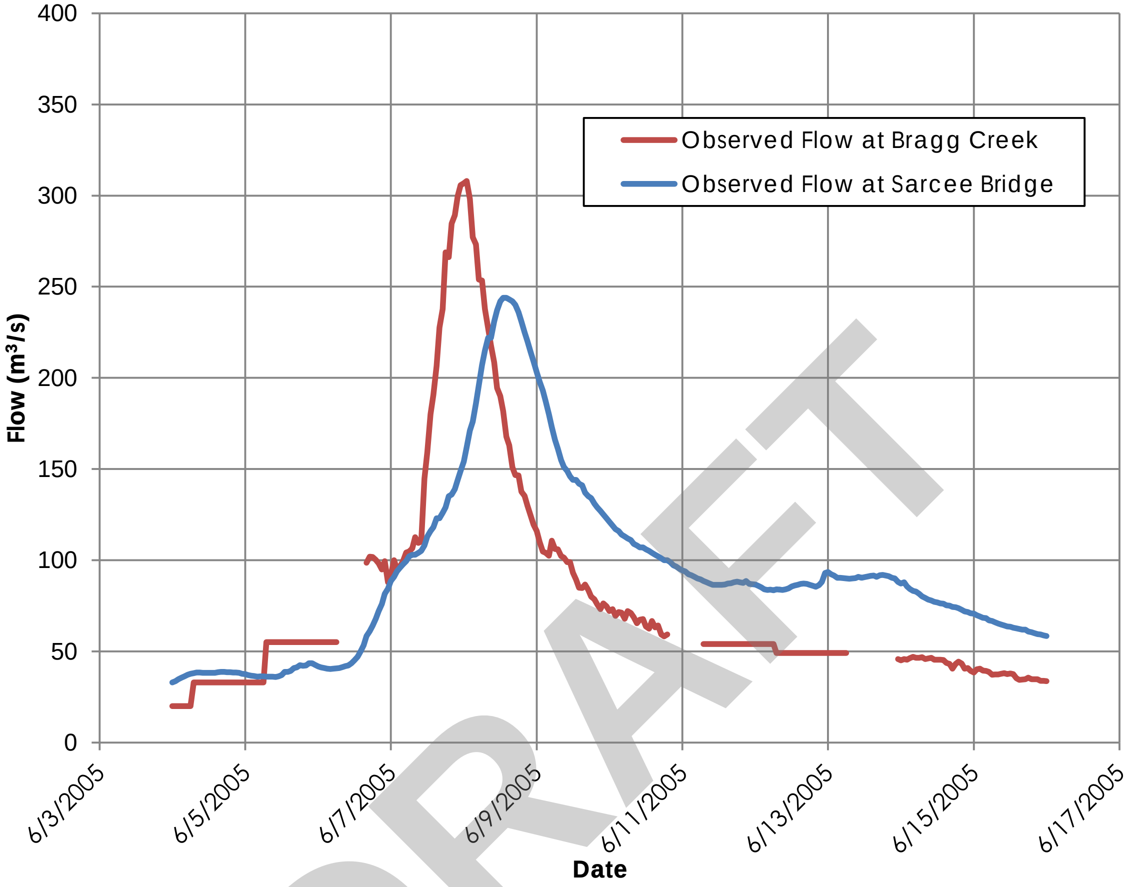

Figure 3: Observed Flood Hydrographs for the 2005 Flood Event

Hydrograph data was obtained from AEMERA for the Sarcee Bridge station and is also presented in Figure 3. This is hourly data which was not previously submitted to WSC. The peak is significantly lower than the peak flow at Bragg Creek and according to the field notes of Jay Parsons, a field technician for the Alberta Environment – Water Survey Branch (AE-WSB) responsible for this site in 2005, the peak of the hydrograph at Sarcee Bridge is likely underestimated (Mahler pers. comm. 2015).

3.1.2.2 2013 Hydrometric Data for Model Calibration

The SR1 hydrological model was also calibrated to the 2013 flood event, which took place between June 19, 2013 and June 24, 2013. WSC has not yet issued an official hydrograph for the 2013 event at Bragg Creek but has estimated a peak instantaneous flow for the site of 1150 m^3/s (Lazowski pers. comm. 2015). Stantec developed an estimated hydrograph at this location using

WSC's estimated peak flow and WSC real time preliminary water level data together with stage-discharge rating curves (See the separate Springbank Off-Stream Reservoir Project Hydrology Flood Frequency Analysis Report). The hydrograph developed by Stantec was used for calibration purposes and is presented in Figure 4.

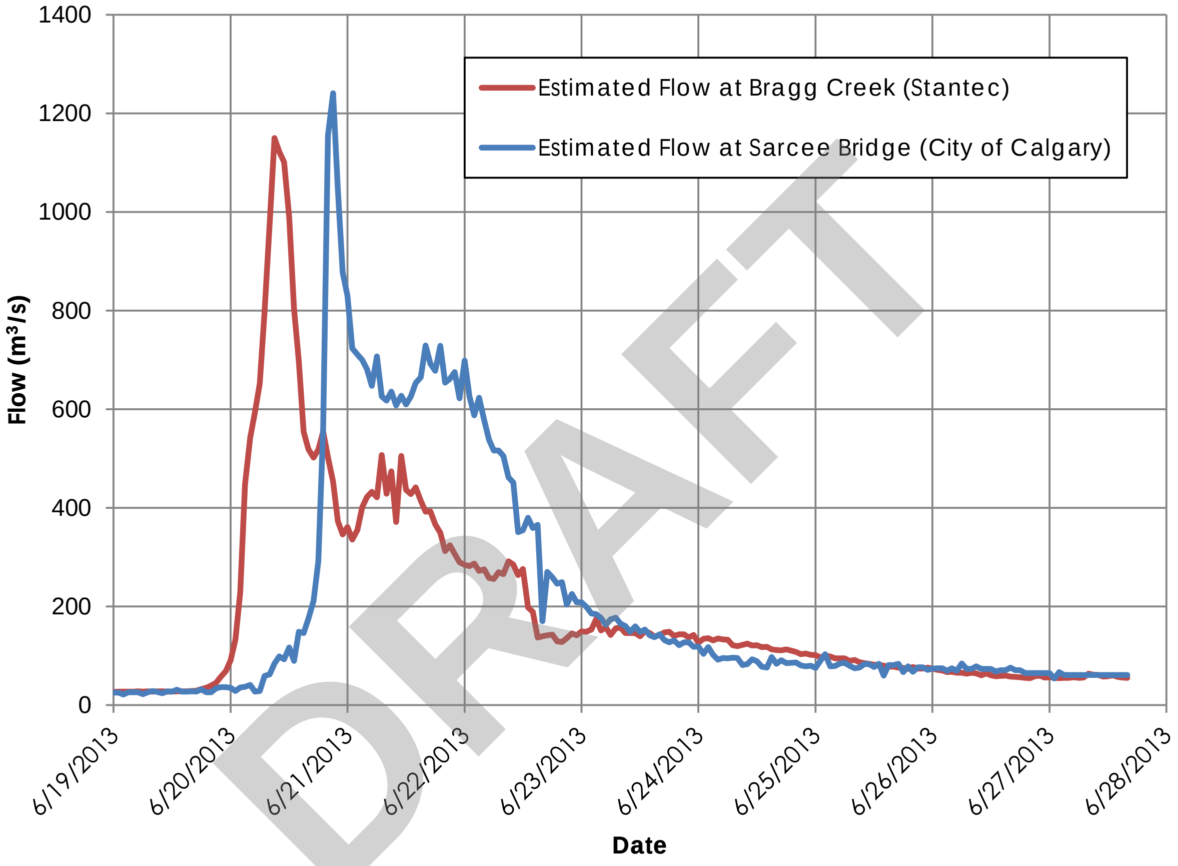

Figure 4: Flood Hydrographs for 2013 Event

The City of Calgary provided an estimated inflow hydrograph into the Glenmore Reservoir for the June 2013 event. This estimate was based on back calculations using reservoir level (change in storage) and outflow. That hydrograph is referred to herein as the estimated flow at Sarcee Bridge as shown in Figure 4. No official WSC streamflow data is available for the 2013 flood at Sarcee Bridge or into Glenmore Reservoir. However, WSC did supply a preliminary 2013 peak instantaneous flow of 1240 m^3/s (Lazowski pers. comm. 2015). Because there is no official hydrograph as of yet for 2013 from WSC, the City of Calgary 2013 estimate represents the best information available for calibration at this time.

3.2 GENERAL APPROACH

Calibration was carried out by attempting to match model simulation to the 2005 and 2013 flood hydrographs in terms of peak flow, hydrograph shape, and runoff volume. The 2005 flood hydrograph at Bragg Creek is considered to be generally reliable. Therefore emphasis was placed on matching the model result to the peak flow, hydrograph shape, and runoff volume of this event. Since the 2005 hydrograph at Sarcee Bridge has an unreliable peak, emphasis was placed on matching the rising and falling limbs of this hydrograph rather than matching the magnitude of the peak. As the entire 2013 flood hydrograph at Bragg Creek and Sarcee Bridge are estimated based on preliminary peak values from WSC, emphasis was placed on matching the magnitude of the peak.

The primary parameters used for calibration include impervious area and constant loss rate of each sub-basin, as well as baseflow methodology. Attenuation in river reaches and surface storage were used for additional fine tuning of the HEC-HMS model. Calibration of parameters was performed manually in an attempt to match the simulated flow with the observed flow.

3.3 CALIBRATED PARAMETERS

The initial parameters presented in Section 2.0, were adjusted to produce the calibrated model. The calibrated parameters are presented in Table 8 through Table 10.

Notable changes from the initial parameter estimates include:

- Reduction of impervious areas by 25% for all sub-basins.
- Additional impervious area to the downstream sub-basins to account for urbanization.
- Reduction of the constant loss rate to 2.5 mm/hour upstream of Bragg Creek and to 3 mm/hour downstream of Bragg Creek.
- Incorporation of 10 mm surface storage in the sub-basins upstream of Bragg Creek.
- Reduction of attenuation in the Muskingum routing reaches by an increase of the Muskingum *X* value to 0.5.
- Alteration of the baseflow methodology for the mountainous sub-basins upstream of Bragg Creek from the constant baseflow to linear reservoir routing method (the linear reservoir routing method generates baseflow based on previous rainfall infiltration within each respective sub-basin).

Table 8: Summary of Calibrated Sub-Basin Loss Parameters

Sub-Basin	Drainage Area (ha)	Initial Loss (mm)	Constant Loss Rate (mm/hour)	Percent Impervious (%)
W100	27,800	20	3	4.0
W150	5,830	20	2.5	4.0
W200	12,100	20	2.5	24.0
W250	3,980	20	3	25.0
W300	3,360	20	3	1.0
W350	8,150	20	2.5	10.0
W400	5,040	20	2.5	17.0
W450	35,300	20	2.5	39.0
W500	8,900	20	2.5	14.0
W550	7,690	20	3	1.0
W600	3,120	20	3	1.0

Table 9: Summary of Calibrated Reach Routing Parameters

Calibrated Parameters for *Kinematic Wave* Reach Routing Method						
Reach	**Length (m)**	**Slope (m/m)**	**Manning's *n***	**Sub-reaches**	**Shape**	**Width (m)**
R160	2,680	0.015	0.02	2	Rectangular	75
R240	7,050	0.007	0.02	2	Rectangular	40
R190	3,480	0.013	0.02	2	Rectangular	40
R180	8,900	0.009	0.03	2	Rectangular	100
R10	1932.9	0.012	0.03	2	Rectangular	20

Calibrated Parameters for *Muskingum* Reach Routing Method		
Reach	**K (hour)**	**Muskingum *X***
R750	4	0.5
R130	2	0.5
R100	2	0.5
R20	6	0.5
R120	2	0.5

Table 10: Summary of Calibrated Sub-Basin Baseflow Parameters

Sub-Basin	Baseflow Methodology	2005 Event Initial / Constant Baseflow (m^3/s)	2013 Event Initial / Constant Baseflow (m^3/s)	GW 1 Coefficient	GW 1 Reservoirs
W100	Constant	3	1	-	-
W150	Linear Reservoir	2	1	200	1
W200	Linear Reservoir	3	5	75	2
W250	Constant	3	1	-	-
W300	Constant	2	1	-	-
W350	Linear Reservoir	2	1	200	1
W400	Linear Reservoir	2	2	75	2
W450	Linear Reservoir	9	14	75	2
W500	Linear Reservoir	2	4	75	2
W550	Constant	3	1	-	-
W600	Constant	3	1	-	-

3.3.1 Snowmelt

The contribution of snowmelt to the 2005 and 2013 floods was considered in regard to model calibration. For that purpose the volume of snowmelt for each of those floods was estimated. The data available for evaluating snowmelt contribution in 2013 is based on remotely sensed data. The satellite data for snow water equivalent maps was obtained from the National Operational Hydrologic Remote Sensing Center (NOHRSC) under the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2015).

Remote sensing data is not available for the 2005 flood. However, a map showing spatial extent of snow cover on June 4, 2005 was obtained from NOHRSC (NOAA 2015). At that time, snow cover was only present on a small fraction of sub-basin W450. Therefore it is assumed that snowmelt contribution to the 2005 flood is negligible in regard to both flood peak and runoff volume.

Remote sensing data showing the spatial distribution and depth of snowpack were extracted before and after the 2013 flood on June 19, 2013 and June 24, 2013. These figures are provided in Appendix A.

In 2013, snowpack was observed only in the mountainous portion of the watershed within the extent of four model sub-basins. The data was processed to estimate the snowpack before and after the storm to determine the volume that would have contributed during the 2013 flood. A summary of the snowmelt contribution by sub-basin is presented in Table 11.

Table 11: Summary of 2013 Snowpack Volume by Sub-Basin

	June 19, 2013		June 24, 2013	
Sub-Basin	**SWE (mm)**	**SWE (dam³)**	**SWE (mm)**	**SWE (dam³)**
W200	29	3,557	18	2,216
W400	52	2,606	24	1,188
W450	188	66,312	148	52,055
W500	10	885	5	343
Total	-	73,360	-	55,802

Based on the remote sensing data for June 2013, snowmelt contributed approximately 17,558 dam^3 to the total flood volume of 157,308 dam^3, or approximately 12% of the total flood hydrograph. This is an estimated snowmelt moisture input and may not translate into flow. However, considering the accuracy and uncertainty of the 2013 flood hydrographs, any attempt to calibrate to those hydrographs exceeds the reliability of the available data. Therefore, snowmelt was not incorporated in the 2013 model calibration effort. Furthermore, snowmelt for the PMF model was calculated external from the HEC-HMS and entered as a baseflow hydrograph. No calibration of snowmelt processes was required.

3.4 CALIBRATION RESULTS

3.4.1 2005 Flood Calibration Results

Comparisons of the simulated and observed hydrographs at Bragg Creek and Sarcee Bridge for the 2005 flood are presented in Figure 5 and Figure 6. Table 12 summarizes the accuracy of the match in terms of hydrograph peak, timing, and flood volume at Bragg Creek. Similarly, Table 13 summarizes the accuracy of the match in terms of hydrograph peak, timing, and flood volume at Sarcee Bridge.

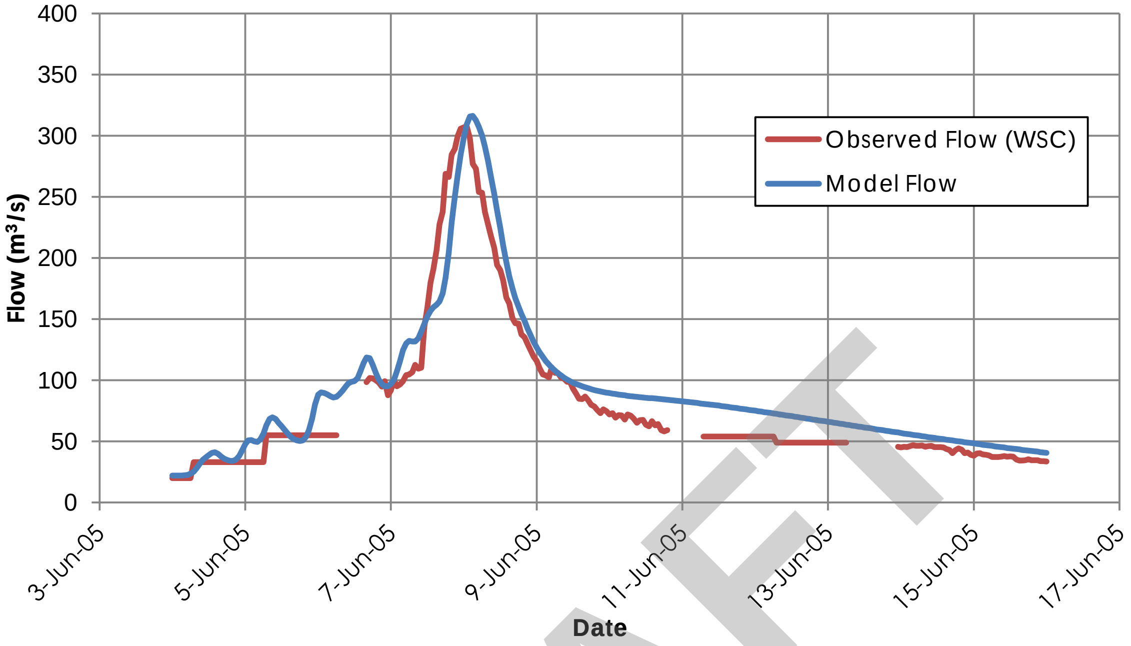

Figure 5: Observed and Calibrated Hydrographs at Bragg Creek for the 2005 Flood

Table 12: Calibration Accuracy for the 2005 Flood at Bragg Creek

Name	Peak Discharge (m^3/s)	Time of Peak	Volume (dam^3)[1]
Observed (WSC)	308.0	June 8, 2005 at 1:00	79,905
Calibrated Model	316.3	June 8, 2005 at 3:00	93,070
Percent Difference	+2.7%	-	+16.5%

[1] - Volume was calculated for the duration of simulation (June 4, 2005 at 00:00 to June 16, 2005 at 00:00).

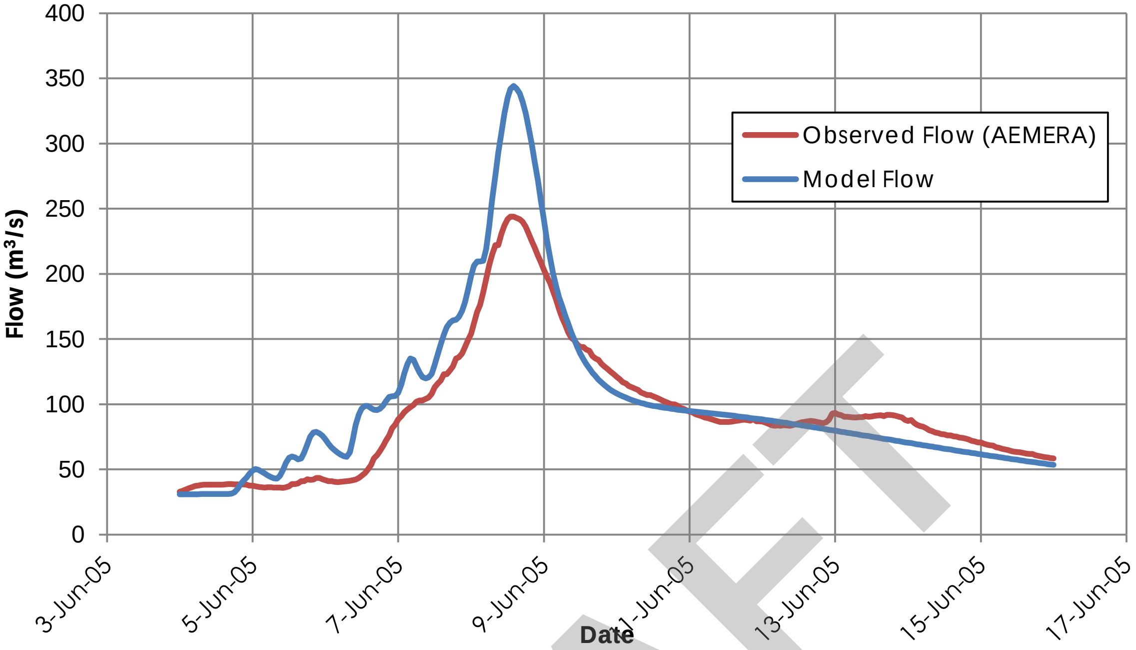

Figure 6: Observed and Calibrated Hydrographs at Sarcee Bridge for the 2005 Flood

Table 13: Calibration Accuracy for 2005 Flood at Sarcee Bridge

Name	Peak Discharge (m^3/s)	Time of Peak (UTC)	Volume (dam^3)[1]
Observed (AEMERA)	244.0	June 8, 2005 at 13:00	97,260
Calibrated Model	344.1	June 8, 2005 at 14:00	105,929
Percent Difference	+41.0%	-	+8.9%

[1] - Volume was calculated for the duration of simulation (June 4, 2005 at 00:00 to June 16, 2005 at 00:00).

3.4.1.1 Calibration Results per Sub-Basin

For each sub-basin, a graph is provided in Appendix C that illustrates the hourly temporal distribution of rainfall, the corresponding amount of rainfall loss and rainfall excess, and the resulting sub-basin runoff hydrograph. Those figures illustrate well the modeled hydrologic process and model results at the sub-basin level. See Table 14 for a summary of the 2005 model calibration outputs.

Table 14: Water Balance Summary for the 2005 Flood Calibration (June 4 to 16, 2005)

Sub-Basin	Rainfall (dam^3)	Baseflow (dam^3)	Direct Runoff (dam^3)	Total Inflow (dam^3)	Total Inflow-Rainfall Ratio	Direct Runoff-Rainfall Ratio	Baseflow-Total Inflow Ratio
W100	29,091	3,110	2,920	6,031	0.21	0.10	0.52
W150	10,296	6,633	1,557	8,189	0.80	0.15	0.81
W200	20,379	10,405	5,553	15,959	0.78	0.27	0.65
W250	4,384	3,110	1,217	4,327	0.99	0.28	0.72
W300	6,033	2,074	694	2,767	0.46	0.11	0.75
W350	14,922	8,026	3,272	11,298	0.76	0.22	0.71
W400	8,740	5,553	1,808	7,361	0.84	0.21	0.75
W450	46,908	18,221	18,280	36,500	0.78	0.39	0.50
W500	14,056	9,223	1,972	11,195	0.80	0.14	0.82
W550	10,785	3,110	1,274	4,384	0.41	0.12	0.71
W600	3,097	3,110	223	3,333	1.08	0.07	0.93
Sum[1]	164,306	69,466	37,552	107,017	0.65	0.23	0.65

[1] - Represents the sum at Sarcee Bridge i.e. not including W250.

As can be seen in Table 14, most of the 2005 runoff in the Elbow River Basin was generated from the mountainous part of the watershed (W200, W350, W400, W450 and W500) upstream of Bragg Creek. The sub-basins downstream of Bragg Creek contributed less runoff in comparison. This is attributed to two factors; first, the heaviest rainfall in 2005 occurred in the upper watershed and second, the rainfall losses are less in that portion of the watershed due to the high percent of rock outcrop.

3.4.2 2013 Flood Calibration Results

Comparisons of the modeled and estimated hydrographs at Bragg Creek and Sarcee Bridge for the 2013 flood are presented in Figure 7 and Figure 8. Table 15 summarizes the accuracy of the match in terms of hydrograph peak, timing, and flood volume at Bragg Creek. Similarly, Table 16 summarizes the accuracy of the match in terms of hydrograph peak, timing, and flood volume at Sarcee Bridge.

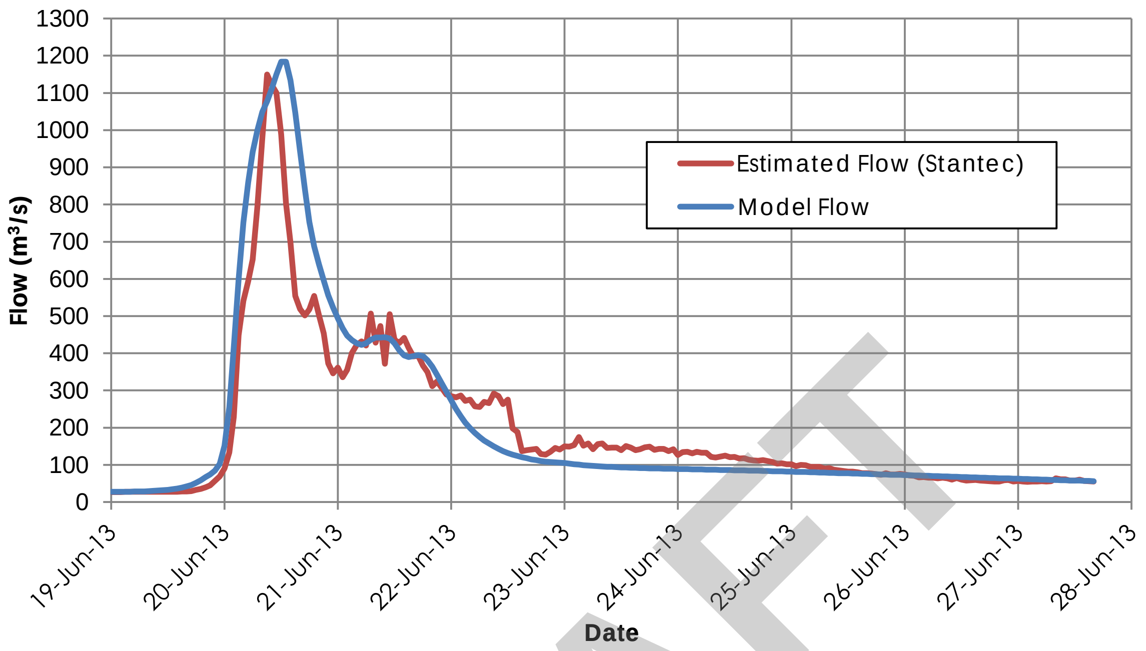

Figure 7: Estimated and Calibrated Hydrographs at Bragg Creek for the 2013 Flood

Table 15: Calibration Accuracy for the 2013 Flood at Bragg Creek

Name	Peak Discharge (m^3/s)	Time of Peak	Volume (dam^3)[1]
Estimated (Stantec)	1150	June 20, 2013 at 17:00	147,446
Calibrated Model	1184	June 20, 2013 at 21:00	153,827
Percent Difference	+3.0%	-	+4.3%

[1] - Volume was calculated for the duration of simulation (June 19, 2013 at 08:00 to June 28, 2013 at 00:00).

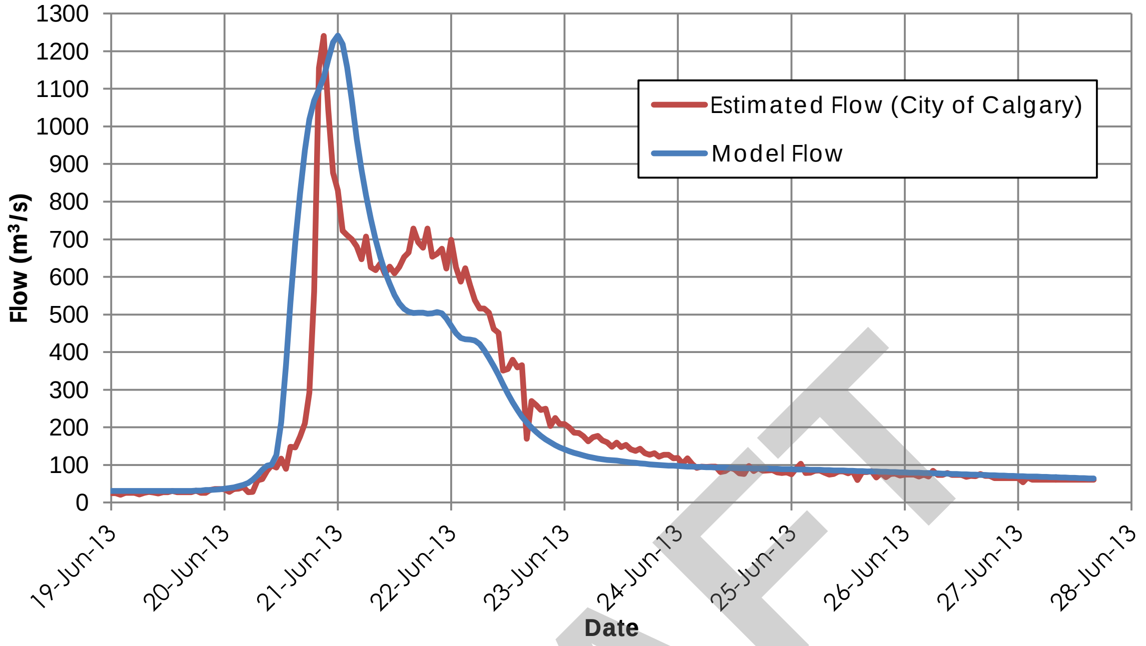

Figure 8: Estimated and Calibrated Hydrographs at Sarcee Bridge for the 2013 Flood

Table 16: Calibration Accuracy for the 2013 Flood Event at Sarcee Bridge

Name	Peak Discharge (m^3/s)	Time of Peak (UTC)	Volume (dam^3)[1]
Estimated (City of Calgary)	1240.4	June 21, 2013 at 5:00	157,308
Calibrated Model	1241.3	June 21, 2013 at 8:00	164,896
Percent Difference	+0.1%	-	+4.8%

[1] - Volume was calculated for the duration of simulation (June 19, 2013 at 08:00 to June 28, 2013 at 00:00).

3.4.2.1 Calibration Results per Sub-Basin

For each sub-basin, a graph is provided in Appendix C that illustrates the hourly temporal distribution of rainfall, the corresponding amount of rainfall loss and rainfall excess, and the resulting sub-basin runoff hydrograph. Those are very instructive in illustrating the modeled hydrologic process and model results at the sub-basin level. See Table 17 for a breakdown of the 2013 model calibration outputs on a sub-basin level.

Table 17: Water Balance Summary for the 2013 Flood Event (June 19, 2013 at 8:00 to June 28, 2013 at 00:00)

Sub-Basin	Rainfall (dam³)	Baseflow (dam³)	Direct Runoff (dam³)	Total Inflow (dam³)	Total Inflow-Rainfall Ratio	Direct Runoff-Rainfall Ratio	Baseflow-Total Inflow Ratio
W100	25,662	749	6,186	6,934	0.27	0.24	0.11
W150	10,629	4,630	3,014	7,644	0.72	0.28	0.61
W200	28,446	8,920	15,255	24,175	0.85	0.54	0.37
W250	3,509	749	1,478	2,227	0.63	0.42	0.34
W300	5,896	749	1,144	1,893	0.32	0.19	0.40
W350	15,187	5,686	5,025	10,710	0.71	0.33	0.53
W400	11,632	4,208	5,623	9,831	0.85	0.48	0.43
W450	93,997	19,083	62,738	81,820	0.87	0.67	0.23
W500	20,815	8,003	9,998	18,000	0.86	0.48	0.44
W550	11,611	749	3,275	4,024	0.35	0.28	0.19
W600	3,376	749	678	1,427	0.42	0.20	0.52
Sum[1]	227,250	53,524	112,933	166,457	0.73	0.50	0.32

[1] - Represents the sum at Sarcee Bridge i.e. not including W250.

As can be seen in Table 17, most of the 2013 runoff in the Elbow River Basin was generated from the mountainous part of the watershed (W200, W350, W400, W450 and W500) upstream of Bragg Creek. The sub-basins downstream of Bragg Creek contributed less runoff in comparison. As with the 2005 calibration, this is attributed to two factors; first, the heaviest rainfall in 2013 occurred in the upper watershed, and, second, the rainfall losses are less in that portion of the watershed due to the high percent of rock outcrop. As opposed to the 2005 storm, the 2013 storm was centered further to the west and sub-basin W450 provided an even greater portion of the watershed runoff.

3.5 CALIBRATION SUMMARY

Calibration of the HEC-HMS model had limited success, which was due to the uncertainty of the hydrometric data at the Bragg Creek and Sarcee Bridge gauging stations. The partial areal coverage and non-uniformity of rainfall used in calibration also played a role in the calibration process. Calibration was successful in adequately establishing the sub-basin rainfall loss parameters, in refining the channel routing parameters, and in developing reasonable baseflow simulation methodology. However, actual rainfall for the 2005 and 2013 storms were highly variable in spatial distribution resulting in some sub-basins receiving little rainfall and other sub-basins receiving highly non-uniform rainfall. The consequences are that calibration of the unit hydrograph for the sub-basins was tenuous since the basic unit hydrograph requirement of uniform rainfall over the sub-basins is not achieved. Therefore, the model was recalibrated during the PMF simulation. That calibration was performed by adjusting the unit hydrograph parameters so that the simulated 100-year peak discharge and runoff volume for the input of the 100-year rainfall represented the calculated 100-year frequency flood peak and 7-day flood volume (see Section 4.5).

4.0 PROBABLE MAXIMUM FLOOD (PMF) ESTIMATION

The PMF can be defined as theoretically the largest flood resulting from a combination of the most severe meteorological and hydrologic conditions that could reasonably be expected to occur in a given area. The PMF is generally viewed as the flood resulting from a PMP, plus snowmelt where appropriate, applied to reasonable severe antecedent watershed conditions.

4.1 GENERAL APPROACH

The calibrated hydrologic model was applied to estimate the PMF for several viable PMP scenarios. A 100-year frequency rainfall as an antecedent condition and, in some cases, snowmelt were applied in the PMF simulations.

4.2 PROBABLE MAXIMUM PRECIPITATION (PMP) SCENARIOS

PMP is defined by the World Meteorological Organization (WMO 1986) as "*theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of year.*" The PMP data was developed by sub-consultant AWA for multiple spatial distributions in the Elbow River Basin. AWA provided Stantec with average sub-basin and gridded PMP data for general and local storms, centered on various spatial distributions. Gridded local storm PMP values were calculated for 6-hour durations, while general storm PMP values were calculated for 48-hour durations. The local storms were assessed for the area upstream of the SR1 Diversion (863 km^2) and sub-basin W600, which is the drainage area for the SR1 Off-Stream Dam (31 km^2). The general storms were assessed for the entire watershed upstream of Glenmore Dam (1,212 km^2), as well as the area upstream of the SR1 Diversion (863 km^2).

In regards to spatial distribution, the local storm PMP for the SR1 Off-Stream Dam was centered over the W600 sub-basin. The PMP for the local storm upstream of the proposed SR1 Diversion was spatially distributed using a representative severe local storm from the PMP database. The general storm PMP spatial pattern is based on orographic and moisture transposition factors of controlling storms (hereafter referred to as the orographic distribution). Therefore, a total of four different PMP scenarios were developed by AWA (see Table 18).

Table 18: Summary of PMP Scenarios

Scenario	Description
1	General storm PMP (48 hour) with orographic pattern over watershed upstream of proposed SR1 Diversion (863 km^2)
2	General storm PMP (48 hour) with orographic pattern over watershed upstream of Glenmore Dam (1,212 km^2)
3	Local storm PMP (6 hour) with maximum 1 hour spatial distribution centered over the watershed upstream of the proposed SR1 Diversion (863 km^2)
4	Local storm PMP (6 hour) centered over sub-basin W600 upstream of proposed SR1 Dam (31 km^2)

For the local storm, the cumulative 1- to 6-hour basin average PMP values were provided for each sub-basin for the various spatial scenarios. For the general storms, the cumulative 1-, 6-, 12-, 24-, and 48-hour basin average PMP values were provided for each sub-basin for the various spatial scenarios. For the general storm, the basin average PMP for durations other than 1-, 6- 12-, 24-, and 48-hour were estimated by interpolating from the durations for which PMP was provided. See Appendix D for the storm PMP averaged by sub-basin for each scenario.

4.2.1 Summary of Spatial Distribution of Gridded PMP

The PMP spatial distribution for the general storm was shaped by the orographic factors while the spatial distribution of the local storm was shaped by a representative severe local storm. However, both the general and local storms showed the highest values to be concentrated in the mountainous region of the watershed. The PMP values then decreased to the east or the low lying reaches of the Elbow River Basin. See Table 19 for a summary of the spatial distribution of each PMP scenario.

Table 19: Summary of Spatial Distribution of Gridded PMP Scenarios

Scenario	Average PMP Grid Value (mm)	Highest Average PMP Value by Sub-Basin	Grid Value Range
1	402	442 mm in W450	333 mm in W150 to 465 mm in W450
2	378	427 mm in W450	322 mm in W150 to 449 mm in W450
3	201	307 mm in W400	53 mm in W450 to 502 mm in W450
4	N/A	286 mm in W600	N/A

4.2.2 Summary of Temporal Distribution of Gridded PMP

The temporal distribution of the PMP for the local storms was determined by first calculating the incremental hourly rainfall depths from the cumulative PMP's provided by AWA (i.e. 2-hr PMP minus 1-hour PMP, 3-hour PMP minus 2-hour PMP, etc.) and by then distributing the hourly values according to the "alternating block" method (i.e. the highest 1-hour rainfall was placed in the 3rd hour, the second highest hourly rainfall was placed in the 4th hour, the third highest was placed in the 2nd hour, etc.). This was done for each sub-basin and spatial distribution.

The temporally distributed hourly incremental values for the local storm were calculated as a percentage of the 6-hour PMP and plotted against time. See Figure 9 for the average temporal distribution, as a percentage of 6-hour PMP, for the area upstream of the SR1 Diversion. See Figure 10 for the temporal distribution, represented as a percentage of 6-hour PMP, for the area of the SR1 Off-Stream Dam.

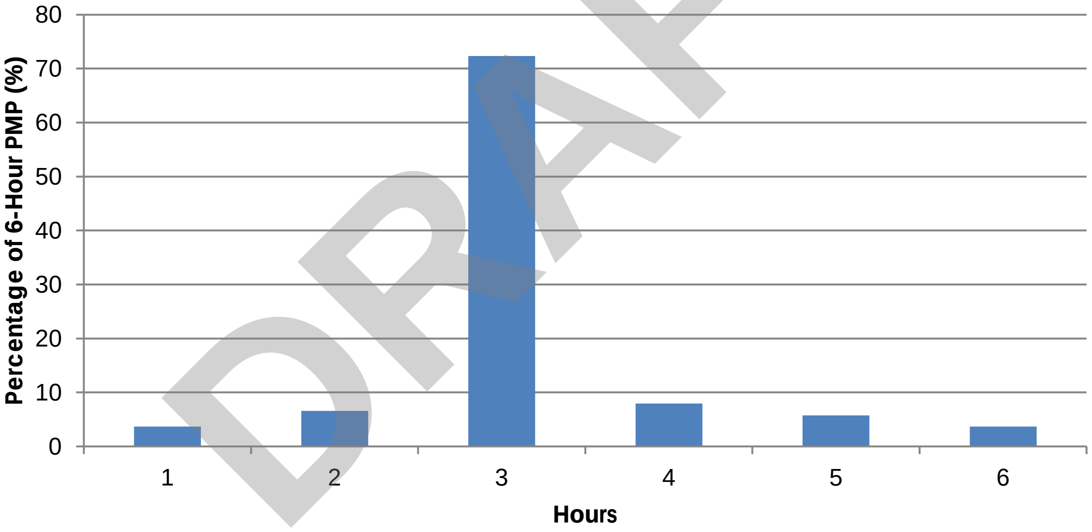

Figure 9: Average Temporal Distribution of Local Storm as a Percentage of 6-hour PMP for the Area Upstream of the SR1 Diversion (863 km²)

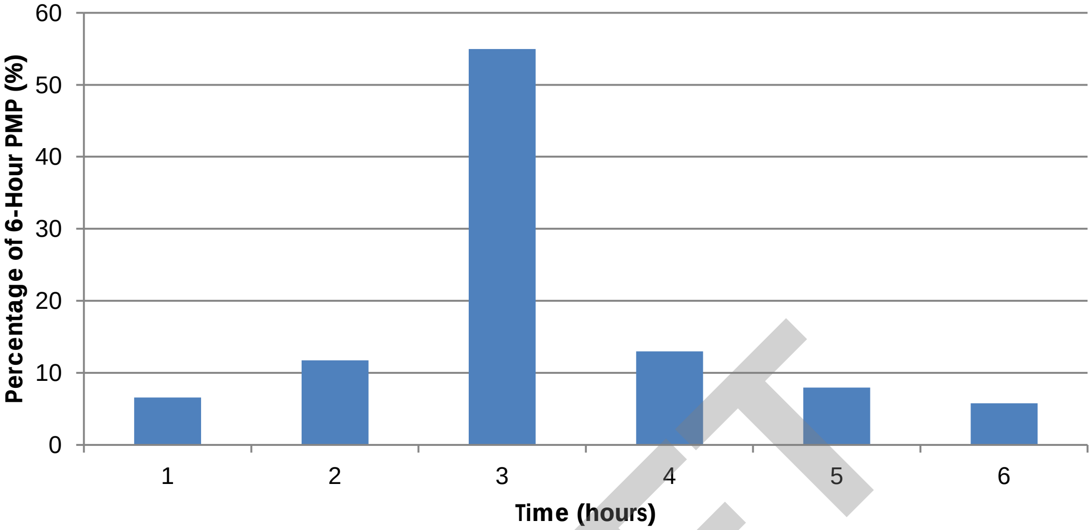

Figure 10: Temporal Distribution of Local Storm as Percentage of 6-hour PMP for the Area of the SR1 Off-Stream Dam (31 km²)

Temporal distribution of the PMP for the general storm was determined by first plotting the 1-, 6-, 12-, 24-, and 48-hour PMP values as a percentage of the 48-hour PMP against time. A third order polynomial relationship was fitted to this data to determine the PMP for all hours in the 48-hour duration. The incremental difference in rainfall depth between subsequent hours was determined throughout the entire storm duration. The hourly incremental values were then temporally distributed using the “alternating block” method. The center of the storm occurred 24-hours into the PMP.

See Figure 11 for the average temporal distribution of the general storm represented as a percentage of 48-hour PMP for the watershed upstream of Glenmore Dam. See Figure 12 for the average temporal distribution of the general storm represented as a percentage of 48-hour PMP for the area upstream of the SR1 Diversion.

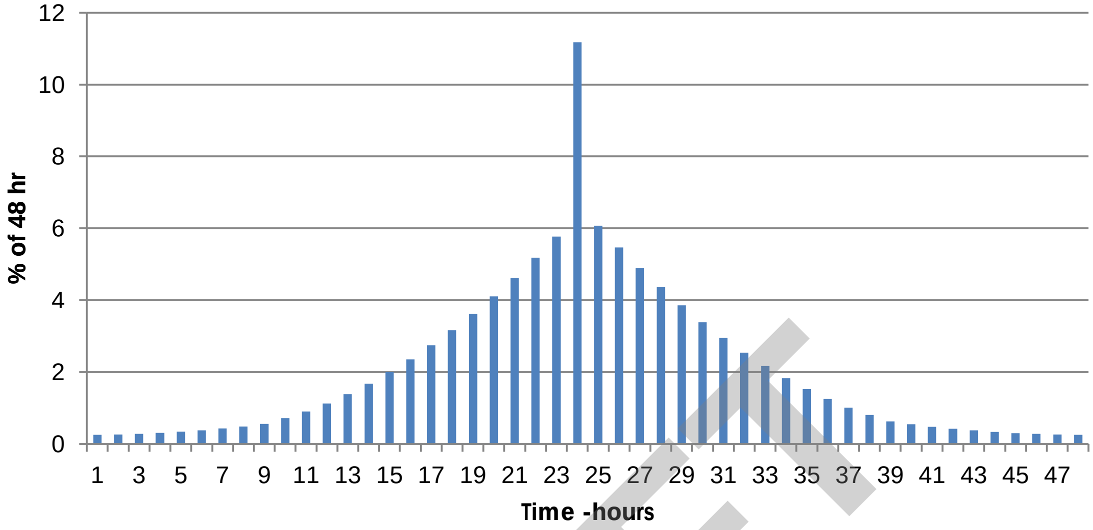

Figure 11: Average Temporal Distribution of General Storm as Percentage of 48-hour PMP for the Full Basin (1,212 km²)

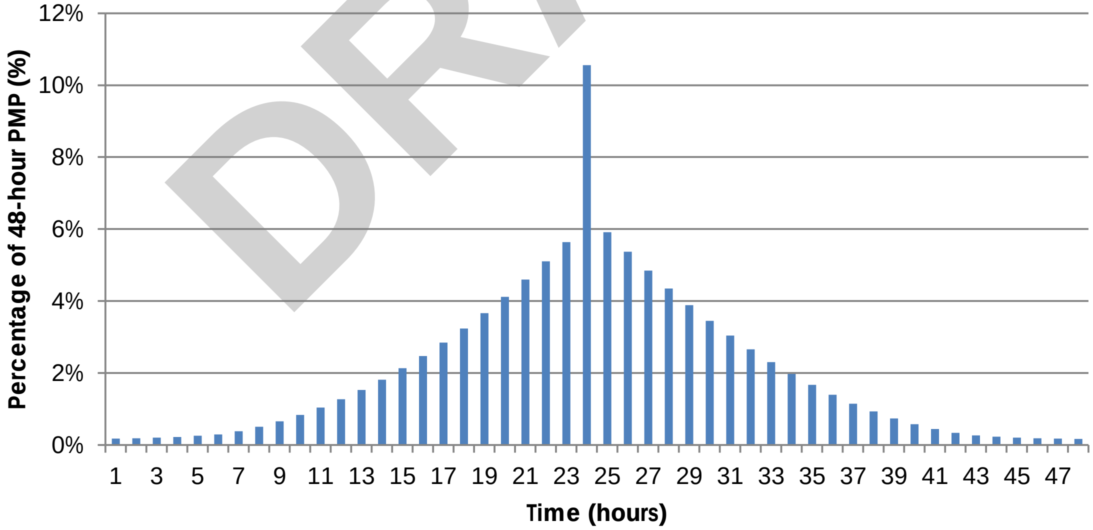

Figure 12: Average Temporal Distribution of General Storm Distribution as Percentage of 48-hour PMP for the Area Upstream of the SR1 Diversion (863 km²)

4.3 ANTECEDENT RAINFALL

4.3.1 Estimation of 100-Year, 24-Hour Antecedent Rainfall

The procedures for selecting antecedent basin conditions vary among different agencies and hydrologists. A common practice in British Columbia (BC) and Alberta is *"… to precede the PMP with a 100-year 24-hour rainfall leaving a period of three days between the storms"*(Alberta Transportation 2004). While the shortest observed time interval between two severe rainfall events in the mountain and foothill areas of Alberta is on the order of 5-7 days, studies suggest that a time interval as short as three days is possible (Gerhard 2000). Based on the aforementioned, a decision was made to establish the basin antecedent conditions for the Elbow River prior to the PMP by introducing an antecedent storm, having a 100-year 24-hour rainfall, three days prior to the start of PMP, as has been the common practice in BC and Alberta.

Short duration (up to 24-hours) "point" (single station) rainfall amounts for various return periods are computed and published by Environment Canada, Meteorological Services Canada (MSC) for most airports and key meteorological sites across Canada. Currently there are no estimates of the 100-year, 24-hour rainfall amounts for larger area sizes. As such, it was decided that the estimation of the 100-year, 24-hour rainfall for the Elbow River Basin would be carried out by applying an area reduction factor (ARF) to the 100-year point rainfall values. For this project the ARF was based on the ratio of the 1,000 km^2 (approximately the drainage area of the Elbow River Basin) rainfall to 10 km^2 rainfall observed for major storms in Alberta. Point rainfalls are generally considered as representative of rainfall for a 10 km^2 area. It was further decided that the 100-year, short-duration point rainfall amounts to be used would be based on the rainfall amounts for Pincher Creek Airport. This Environment Canada meteorological station is the closest in proximity and physiographic characteristics to the Elbow River Basin. It also has a relatively long period of record.

The "*n*"-year, including 100-year, rainfall amounts for durations of 1-, 2-, 6-, 12-, and 24-hour at Pincher Creek Airport were computed and published by MSC in 2014. The 100-year rainfall amounts for other durations were computed by plotting the 1-, 2-, 6-, 12-, and 24-hr accumulations against time and fitting a curve through the values published by MSC (Figure 13).

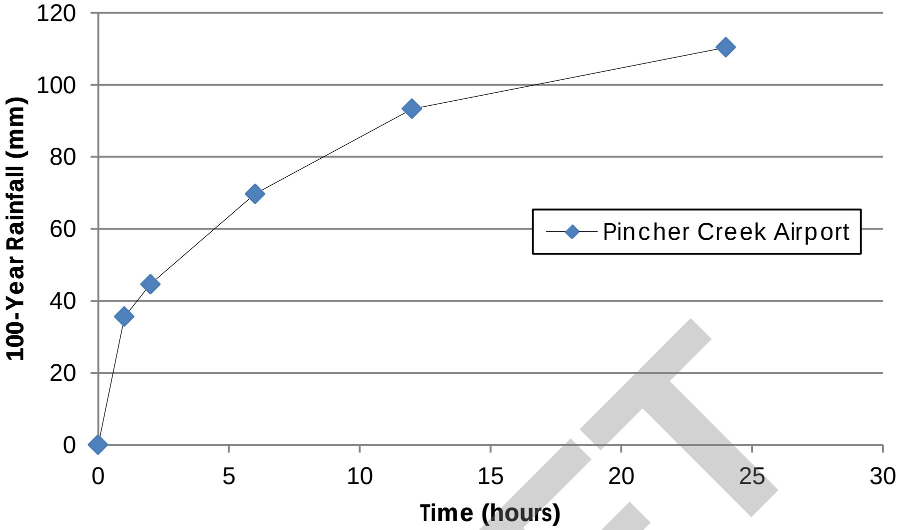

Figure 13: Pincher Creek Airport Station 100-Year Rainfall as a Function of Time

The incremental rainfall values were subsequently computed by disaggregating the cumulative “n”-hour 100-year rainfall into hourly values. These hourly values were divided by the 100-year, 24-hour rainfall total to determine the percentage of incremental rainfall per 100-year, 24-hour rainfall. These percentages were then temporally distributed according to the “alternating block” method, with maximum intensity at the center of the storm period (Alberta Transportation 2004). This method is commonly termed the "Chicago" or "Theoretical" hyetograph method. In this method the highest hourly value is placed at the center of the storm (in this case, at 12 hours), the second highest hourly value is placed after and next to the highest value (in this case at 13 hours), the third highest value is placed next to and in front of the highest hourly value (in this case at 11 hours), the fourth highest hourly value is placed next to and after the second highest hourly value etc. See Figure 14 and the last column of Table 20 for the temporal distribution of the antecedent rainfall as a percentage of the 24-hour rainfall.

Table 20: Computation of Antecedent 100-Year, 24-hour Rainfall to Precede PMP

Duration (hours)	100-Year Short Duration Point Rainfall Amounts (mm)	Incremental Point Rainfall (mm)	Incremental Rainfall as a Percentage of 24-Hour Rainfall (%)	Temporal Distribution of 100-Year, 24-Hour Rainfall as Antecedent Rainfall (%)
1	***35.6***	35.6	32.25	1.11
2	***44.6***	9.0	8.15	1.17
3	52.6	8.0	7.23	1.25
4	59.1	6.5	5.91	1.33
5	64.7	5.6	5.09	1.44
6	***69.7***	5.0	4.52	1.57
7	74.4	4.7	4.24	3.20
8	78.7	4.3	3.90	3.62
9	82.7	4.0	3.62	4.24
10	86.4	3.7	3.39	5.09
11	90.0	3.5	3.20	7.23
12	***93.3***	3.3	3.03	32.25
13	95.0	1.7	1.57	8.15
14	96.7	1.7	1.50	5.91
15	98.3	1.6	1.44	4.52
16	99.8	1.5	1.38	3.90
17	101.3	1.5	1.33	3.39
18	102.7	1.4	1.29	3.03
19	104.1	1.4	1.25	1.50
20	105.4	1.3	1.21	1.38
21	106.7	1.3	1.17	1.29
22	108.0	1.3	1.14	1.21
23	109.2	1.2	1.11	1.14
24	***110.4***	1.2	1.08	1.08

__Bold and italicized__ rainfall values obtained from Environment Canada's IDF curve for Pincher Creek Airport.

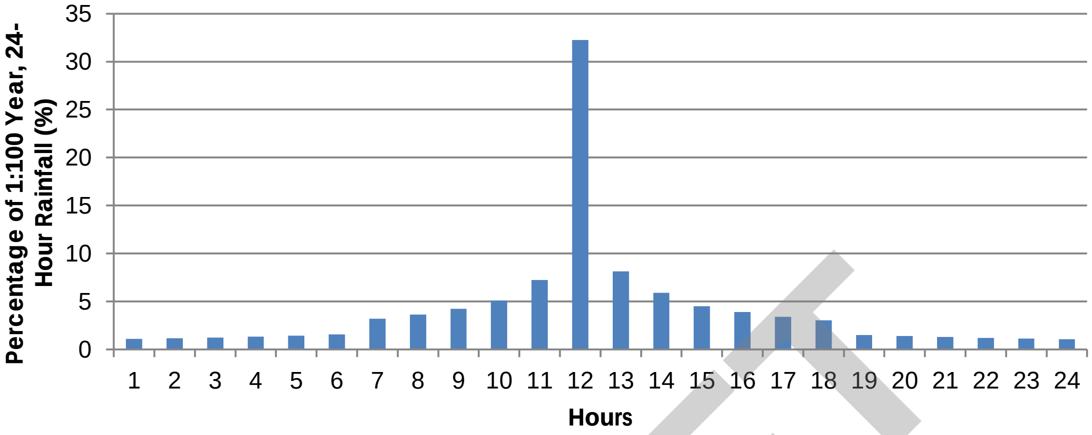

Figure 14: Temporal Distribution of Antecedent Rainfall as Percentage of 100-Year Rainfall

AWA provided the gridded precipitation data for the 100-year, 24-hour rainfall. Stantec used that data to calculate the average 100-year, 24-hour rainfall per sub-basin using ArcGIS. The hourly values as a percentage of the 100-year, 24-hour rainfall calculated from the Pincher Creek Airport station were then multiplied by the average 100-year, 24-hour rainfall volume for each sub-basin. This was chosen as the antecedent rainstorm for the local storm of the SR1 Off-Stream Dam area. For all other PMP scenarios studied, the previously computed antecedent point rainfall was multiplied by an ARF.

Alberta Transportation has analyzed depth-area-duration (DAD) curves of large storms in Alberta and has computed the mean DAD curve for the top 10, 20, and 50 storms (Figure 15). The ARF applied to adjust the previously computed antecedent point rainfall to a 100-year, 24-hour rainfall was estimated at 0.85 based on the ratio of the 1,000 km^2 to 10 km^2 rainfall for the top 20 large storms (195 mm/225 mm = 0.85). This antecedent storm was applied three days prior to the local and general PMP for the full basin and area upstream of the SR1 Diversion scenarios.

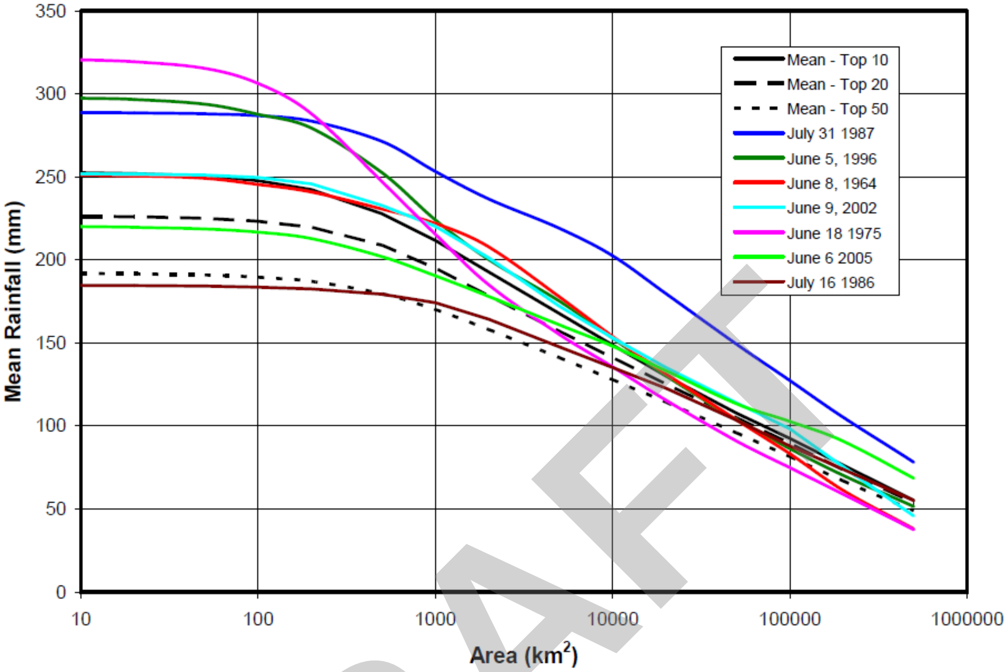

Figure 15: Depth-area-duration curves for large storms in Alberta (Alberta Transportation 2007)

4.4 SNOWMELT HYDROGRAPH

4.4.1 Antecedent Snow Water Equivalent

The moisture input from snowmelt during PMP is governed primarily by two factors: the snow-covered-area and the rate of melt. The snowmelt contribution to PMF then becomes simply the product of the snowmelt volume times the runoff coefficient. Snowmelt was applied to the general storms, not the local storms since severe convective storms cannot develop over large snowpack areas.

The procedures for computing snowmelt contribution to PMF for mountain and foothill areas where floods are dominated by rain on snow vary significantly among different agencies and hydrologists. Two of the three specifications used by BC Hydro for areas in the interior are (Alberta Transportation 2004):

- To apply "*a 100-year snowpack followed by a 100-year high temperature melt sequence then the PMP (the return period of the melt sequence can be reduced or the melt sequence can be eliminated entirely if it [the melt sequence] results in a worse flood [than applying PMP]*".

- To apply "*average snowpack and average melt conditions followed by a pre-storm and then PMP*".

In their report "Guidelines on Extreme Flood Analysis", Alberta Transportation (2004) recommends:

> "*For a PMP on snowpack ... the initial snow water equivalent and snow-covered area at the start of the antecedent rainfall event should be representative of 10-year conditions. Estimates of snow water equivalent should be based on analysis of historic snowpack or snow-on-ground data over a period extending two weeks either side of the date of the PMP.*"

However, the above noted recommendation appears to be driven primarily by the concern that combining too many extreme conditions may lead to over maximization of PMF rather than any scientific reasoning.

Since 1978, AEMERA has operated five snow pillow stations, and eight snow courses that are within or in close proximity of the Elbow River Basin (see Figure 16). The snow pillows have hourly readings of SWE for most years and the snow courses have SWE observations on the first (plus or minus 3 days) of each month during the December to June period. Therefore, it was felt that a more reliable estimate of snowmelt moisture input to PMP (the product of snow covered area and melt rates) and contribution to PMF could be obtained based on the maximum observed snow covered area and melt rates during the four largest rainfall events in this period. This decision was supported by a review of June 1 SWE for snow pillow and snow course sites in the vicinity of the Elbow River Basin which indicate that the June 1, 1995 SWE (shortly prior to one of the four largest rainfall events that occurred during the 1978 to 2015 period) had a return period of about 5-years; relatively similar to the 10-year SWE recommended by Alberta Transportation.

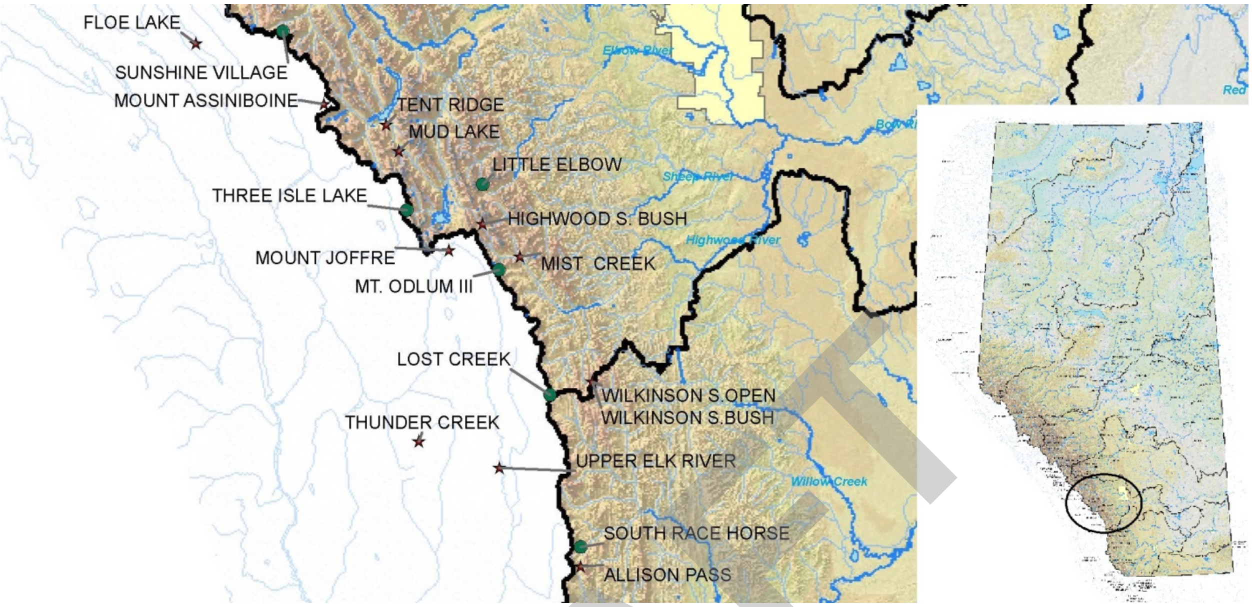

Figure 16: Location of Snow Pillow and Snow Course Sites within the Bow/Elbow Basins (Government of Alberta 2011)

4.4.1.1 Estimation of Maximum Snowmelt Rates during Antecedent Storm and PMP

Table 21 shows the observed SWE at five snow pillow sites within, or in close proximity to the Elbow River Basin for the day prior to and during the four largest rainfall events during the 1978 to 2014 period (June 6 – 7, 1995; June 5 – 7, 2005; June 17 – 18, 2005; and June 19 – 21, 2013). This data was obtained from Alberta Environment and Parks WISKI database.

Table 21: Snow Water Equivalent (SWE) during Large Rainfalls in the Elbow River Basin

Snow Pillow Location	Lost Creek South	Sunshine Village	Three Isle Lake	Little Elbow Summit	Mount Odlum
Elevation (m)	**2130**	**2230**	**2160**	**2120**	**2060**
Date	**Snow Water Equivalents (mm)**				
June 6-7, 1995 Event					
5-Jun-95	507	445	446	367	279
6-Jun-95	478	431	439	246	258
7-Jun-95	460	411	422	332	243
8-Jun-95	458	395	409	329	227
June 5-7, 2005 Event					
4-Jun-05	48	157	243	17	-

Snow Pillow Location	Lost Creek South	Sunshine Village	Three Isle Lake	Little Elbow Summit	Mount Odlum
5-Jun-05	34	132	223	8	-
6-Jun-05	41	130	227	30	-
7-Jun-05	124	127	246	88	-
8-Jun-05	160	114	250	94	-
June 17-18, 2005 Event					
16-Jun-05	87	12	160	20	-
17-Jun-05	64	20	149	35	-
18-Jun-05	52	64	149	34	-
19-Jun-05	38	50	130	16	-
June 19-21, 2013 Event					
18-Jun-13	256	182	274	199	53
19-Jun-13	229	151	266	178	38
20-Jun-13	204	105	233	148	10
21-Jun-13	192	75	252	186	0
22-Jun-13	167	43	246	179	0

Note: 1995 and Lost Creek SWE were based on daily average, all other values were based on 12:00 AM values

The maximum snowmelt during the 100-year, 24-hour antecedent storm and PMP was estimated by calculating the daily change in SWE (snow accumulation or depletion), during the four largest rainfall events (see Table 22).

Table 22: Daily Accumulation and Depletion in SWE during Large Rainfalls

Snow Pillow Location	Lost Creek South	Sunshine Village	Three Isle Lake	Little Elbow Summit	Mount Odlum	Average daily accumulation and depletion for pillows not limited by low SWE
Elevation (m)	**2130**	**2230**	**2160**	**2120**	**2060**	
Date	**Snow Water Equivalents (mm)**					
June 6-7, 1995 Event						
5-Jun-95	-	-	-	-	-	-
6-Jun-95	-29	-14	-7	-21	-21	-18
7-Jun-95	-18	-20	-17	-14	-15	-17
8-Jun-95	-2	-16	-13	-3	-16	-10
Total	-49	-50	-37	-38	-52	-45

Snow Pillow Location	**Lost Creek South**	**Sunshine Village**	**Three Isle Lake**	**Little Elbow Summit**	**Mount Odlum**	**Average daily accumulation and depletion for pillows not**
June 5-7, 2005 Event						
4-Jun-05	-	-	-	-	-	-
5-Jun-05	-14	-25	-20	-9	-	-17
6-Jun-05	7	-2	4	22	-	8
7-Jun-05	83	-3	19	58	-	39
8-Jun-05	36	-13	4	6	-	8
Total	112	-43	7	77	0	38
June 17-18, 2005 Event						
16-Jun-05	-	-	-	-	-	-
17-Jun-05	-23	8	-11	5	-	-5
18-Jun-05	-12	44	0	5	-	9
19-Jun-05	-14	-14	-19	-18		-16
Total	-49	38	-30	-8	0	-12
June 19-21, 2013 Event						
18-Jun-13	-	-	-	-	-	-
19-Jun-13	-27	-31	-8	-21	-15	-20
20-Jun-13	-25	-46	-33	-30	-28	-32
21-Jun-13	-12	-30	19	38	-10	1
22-Jun-13	-25	-32	-6	-7	-	-18
Total	-89	-139	-28	-20	-53	-69

Notes:

- Highlighted dates indicate period when snowmelt would have been influenced by heavy rainfall.
- Positive values indicated accumulation and negative values indicate depletion of SWE.

Table 22 shows the largest observed snow depletion or melt was 69 mm and occurred during the four days surrounding the June 19 – 21, 2013 rainfall event. The largest single day melt was 32 mm on June 20th, 2013. In general, the rate of melt, or results in snow accumulations, seems to be greatly reduced during the latter part of rainfall event as the cold front begins to move into the area. Based on these assessments, and in consideration of the temporal distribution of the PMP, it was felt that the snowmelt rates given in Table 23 were appropriate for use in the estimation of snowmelt during the antecedent rainfall, PMP, and for days following the two.

Table 23: Snowmelt Rates for Entire PMP Duration

Time Period of Entire PMP	SWE (mm)
1:100-year, 24-hr antecedent rainfall event	30
Day 1 following antecedent rainfall event	20
Day 2 following antecedent rainfall event	15
Day 3 following antecedent rainfall event	10
First 24-hrs of PMP	30
Second 24-hrs of PMP	30
Day 1 following PMP	20
Day 2 following PMP	15
Day 3 following PMP	10

Further, as a review of hourly snow accumulations and depletions during the June 19 – 21, 2013 event do not show any significant degree of diurnal variability (see Table 24); the daily melt rates were assumed to be uniformly distributed throughout each day.

Table 24: Hourly Distribution of Daily Melt Rates

Time (hour)	Hourly Snowmelt Rate (mm)			Average Melt (mm)
	18-Jun-15	19-Jun-15	20-Jun-15	
1:00	0.5	0.8	2.3	1.2
2:00	0.8	1.3	2	1.4
3:00	0.5	0.5	1.8	0.9
4:00	0.3	0.8	1.8	1.0
5:00	0	0.5	1.3	0.6
6:00	0	0.3	1.5	0.6
7:00	0	0	1.8	0.6
8:00	0.3	-0.5	1.5	0.4
9:00	-0.5	0.5	2	0.7
10:00	-0.5	0.8	2.3	0.9
11:00	0.5	1.3	2.3	1.4
12:00	1.3	1.5	2.8	1.9
13:00	1	1.3	1.8	1.4
14:00	1.8	1.3	1.3	1.5
15:00	2	1	1.5	1.5
16:00	1.8	1.5	1.8	1.7

Time (hour)	Hourly Snowmelt Rate (mm)			Average Melt (mm)
	18-Jun-15	19-Jun-15	20-Jun-15	
17:00	1.8	0.5	1.8	1.4
18:00	1.5	0.8	1	1.1
19:00	1.5	0.5	0.8	0.9
20:00	1.5	0	1	0.8
21:00	1.5	1.3	0.5	1.1
22:00	1.8	1	-0.3	0.8
23:00	1	0.8	0.3	0.7
24:00	0.8	1.5	0	0.8

4.4.1.2 Estimation of Snow Covered Area during Antecedent Storm and PMP

Table 25 shows the observed SWE at five snow pillow sites within or in close proximity to the Elbow River Basin on the day prior to and during the four largest rainfall events that occurred during the 1978 to 2014 period, as well as the June 1 (+/- 3 days) snow surveys for the two large storm events that occurred within one week of June 1 (June 6 – 7, 1995 storm and June 5 – 7, 2005 storm).

Table 25: SWE for Snow Pillow and Survey Locations near Elbow River Basin prior to Large Rainfall Events

Snow Pillows/Survey Sites		Elevation (m)	June 5, 1995 SWE (mm)	June 4, 2005 SWE (mm)	June 16, 2005 SWE (mm)	June 18, 2013 SWE (mm)
Snow Pillow Site	Lost Creek South	2130	507	48	87	256
	Sunshine Village	2230	445	157	12	182
	Three Isle Lake	2160	446	243	160	274
	Little Elbow Summit	2120	367	17	20	199
	Mount Odlum	2060	279	-	-	53
Snow Survey Site (based on measurements between May 27 and June 3)	Highwood Summit - Bush	2210	478	140	-	-
	Little Elbow Summit	2120	419	50	-	-
	Lost Creek South	2130	658	215	-	-
	Mount Odlum	2060	328	0	-	-
	Mud Lake	1910	213	0	-	-
	Tent Ridge	2025	257	0	-	-
	Three Isle Lake	2160	511	345	-	-
	Wilkinson Summit - Open	1980	-	0	-	-

The snowline elevation and the associated snow covered area for each sub-basin of the Elbow River was calculated by plotting the SWE's prior to each large rainfall event (Table 25) against the snow pillow and snow course elevations (Figure 17) so as to determine the lowest snowline elevation prior to each of the four large rainfall events.

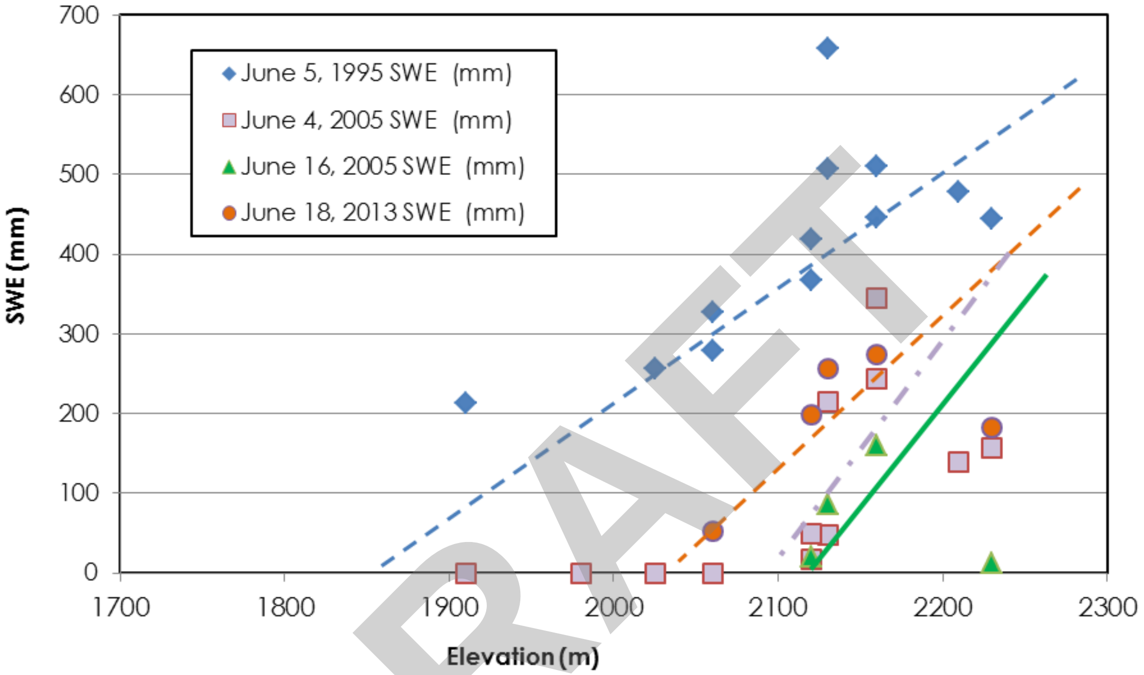

Figure 17: Relationship between SWE and Elevation Prior to Large Storms

Figure 17 shows that the lowest snowline elevation prior to the four largest rainfall events was approximately 1,800 m (5,900 ft). The maximum snow covered area during the antecedent storm and PMP was computed for each of the sub-basins based on the snowline elevation of 1,800 m, determined from the Figure 17 (see Table 26).

Table 26: Area above 1,800 m per Sub-Basin

Sub-Basin	Area above 1,800 m (km^2)
W150	4.50
W200	93.60
W350	2.40
W400	30.80
W450	320.30
W500	31.20
TOTAL (Area upstream of Bragg Creek above 1,800 m)	482.80

4.4.1.3 Estimation of Snowmelt Moisture Input during the Antecedent Storm and PMP, and Flow Contribution to PMF

The snowmelt moisture input for each day of the antecedent storm and PMP were computed by multiplying the snow covered area of each sub-basin (area above 1,800 m) by the melt rates computed in Section 4.4.1.1. The resulting snowmelt moisture input was subsequently converted to a snowmelt runoff contribution to PMF by applying a runoff coefficient of 0.7 to the previously computed snowmelt moisture inputs. Detailed computations of the snowmelt contribution to PMF are presented in Table 27.

Table 27: Snowmelt Moisture Input to Antecedent Storm, PMP, and Flow Contribution to PMF

Sub-Basin	Area Above 1,800 m (km^2)	Ant. Storm	Day 1 after Ant. Storm	Day 2 after Ant. Storm	Day 3 after Ant. Storm	PMP	PMP	Day 1 after PMP	Day 2 after PMP	Day 3 after PMP	Totals
		Snow Melt Rate (mm/day)									
		30	20	15	10	30	30	20	15	10	180
		Moisture Input due to Snowmelt (dam^3)									
W150	4.5	135	90	68	45	135	135	90	68	45	811
W200	93.6	2,808	1,872	1,404	936	2,808	2,808	1,872	1,404	936	16,848
W350	2.4	72	48	36	24	72	72	48	36	24	432
W400	30.8	924	616	462	308	924	924	616	462	308	5,544
W450	320.3	9,609	6,406	4,805	3,203	9,609	9,609	6,406	4,805	3,203	57,655
W500	31.2	936	624	468	312	936	936	624	468	312	5,616

Calculated Values	Ant. Storm	Day 1 after Ant. Storm	Day 2 after Ant. Storm	Day 3 after Ant. Storm	PMP	PMP	Day 1 after PMP	Day 2 after PMP	Day 3 after PMP	Totals
Total snow moisture input upstream of Bragg Creek during antecedent storm and PMP (dam^3)	14,484	9,656	7,242	4,828	14,484	14,484	9,656	7,242	4,828	86,904
Runoff Coefficient	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Snowmelt Runoff Contribution to PMF (dam^3)	10,139	6,759	5,069	3,380	10,139	10,139	6,759	5,069	3,380	60,833
Snowmelt Runoff Contribution to PMF (m^3/sec)	117	78	59	39	117	117	78	59	39	

Note: Ant. refers to Antecedent

4.5 REFINEMENT OF HYDROLOGIC MODEL TO 100-YEAR FLOOD FOR PMF ANALYSIS

The initial model run for PMF analysis was carried out using the hydrologic model calibrated to the 2005 and 2013 floods. That model produced a peak flow of 1,215 m^3/s at the SR1 Diversion Site for the 100-year 24-hour antecedent rainfall. However, the flood frequency analysis performed by Stantec as part of the SR1 Project showed the estimated peak flow for a 100-year event at the proposed SR1 Diversion to be 760 m^3/s (Stantec 2015). Therefore, the model calibrated for the 2005 and 2013 floods overestimated the 100-year flood event by approximately 60%.

In order to match the modeled peak flow using the 100-year, 24-hour antecedent rainfall with the flood peak derived for the 100-year flood frequency value, the model was refined to simulate the 100-year flood peak. This was performed by adjusting the K_n value within the recommended parameter range of 0.15 to 0.3. A K_n value of 0.3 resulted in a peak flow of 813 m^3/s. The 7-day flood volume for the simulation using a K_n value of 0.3 was estimated at 108,000 dam^3, which is approximately equal to the 100-year 7-day volume estimated by the flood frequency analysis. Results are summarized in Table 28 below.

Table 28: Peak Discharge and 7-Day Volumes at Proposed SR1 Diversion for the 100-Year Flood

Scenario	K_n	Peak Discharge (m^3/s)	7-Day Volume (dam^3)
100-year flood by flood frequency analysis	N/A	760	97,600
100-year 24-hour antecedent rainfall	0.30	813	108,000

4.6 UNIT HYDROGRAPHS

The Rocky Mountain general storm unit hydrograph was used for sub-basins upstream of Bragg Creek (W150, W200, W300, W350, W400, W450, and W500) for the general and local storm PMF simulations (Scenarios 1, 2, and 3). The Great Plains unit hydrograph was used in all PMF simulations for sub-basins downstream of Bragg Creek (W100, W250, W550, and W600). In general the Great Plains unit hydrograph has a lower peak and a milder receding limb than the Rocky Mountain unit hydrograph (see Figure 18).

A K_n of 0.07 was used for the Great Plains unit hydrograph for sub-basins W100 and W550. A K_n of 0.045 was used for sub-basin W250 due to partial urbanization and W600 due to its physiographic characteristics.

Figure 18 shows the shape of the Rocky Mountain general storm unit hydrograph applied in Scenarios 1, 2, and 3 using sub-basin W450 as an example; the Great Plains unit hydrograph applied in Scenarios 1, 2, and 3 using sub-basin W100 as an example; and the Great Plains unit hydrograph applied in Scenarios 1 to 4 at sub-basin W600.

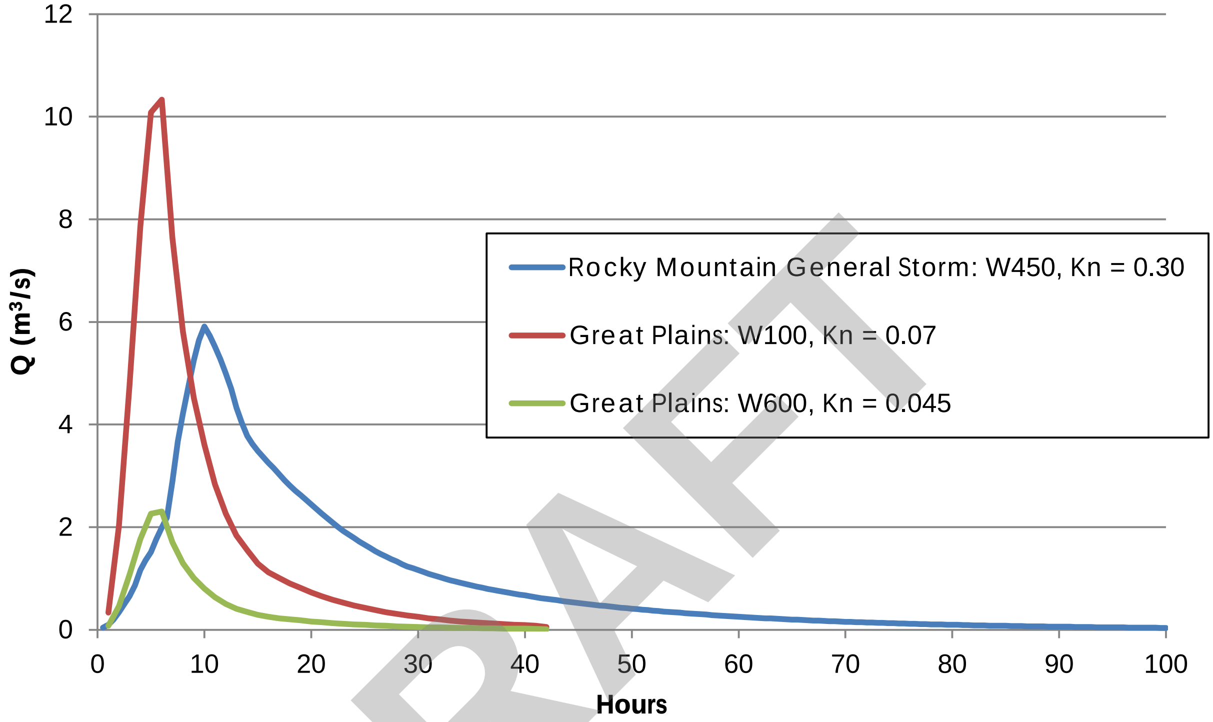

Figure 18: Unit Hydrograph Comparison

4.7 PMF SIMULATION RESULTS

PMF simulations were run for all four scenarios described in the previous sections. The four scenarios differed primarily based on the PMP data but also on the antecedent rainfall, snowmelt, and unit hydrographs used in the models. See Table 29 for a detailed outline of each PMF simulation. See Appendix E for figures representing the model output per sub-basin for each PMF scenario.

Table 29: Summary of Input Data for PMF Simulations

Scenario	Antecedent Rainfall	PMP	Unit Hydrograph	Snowmelt
1	100-year 24-hour precipitation with ARF	General storm PMP with orographic pattern over watershed upstream of proposed SR1 Diversion (863 km²)	Rocky Mountain (applied to sub-basins upstream of Bragg Creek) and Great Plains (applied to sub-basins downstream of Bragg Creek)	Snowmelt contribution (Table 27) applied at Bragg Creek
2	100-year 24-hour precipitation with ARF	General storm PMP with orographic pattern over watershed upstream of Glenmore Dam (1,212 km²)	Rocky Mountain (applied to sub-basins upstream of Bragg Creek) and Great Plains (applied to sub-basins downstream of Bragg Creek)	Snowmelt contribution (Table 27) applied at Bragg Creek
3	100-year 24-hour precipitation with ARF	Local storm PMP with a representative severe local storm spatial distribution centered over watershed upstream of proposed SR1 Diversion (863 km²)	Rocky Mountain (applied to sub-basins upstream of Bragg Creek) and Great Plains (applied to sub-basins downstream of Bragg Creek)	N/A
4	100-year 24-hour precipitation	Local storm PMP centered over sub-basin upstream of proposed SR1 dam (W600) (31 km²)	Great Plains	N/A

For Scenarios 1, 2, and 3 peak flood and 7-day volume PMF results were reported at the proposed SR1 Diversion Site as well as at the Glenmore Dam. For Scenario 4, PMF results are reported at the proposed SR1Off-Stream Dam.

4.7.1 General Storm PMF Scenarios (Scenarios 1 and 2)

Hydrographs representing the PMF for Scenarios 1 and 2 were generated at the proposed SR1 Diversion Site and Glenmore Dam (see Figure 19 and Figure 20). A detailed summary of the peak flow and 7-day volume for the PMF scenarios is given in Table 30.

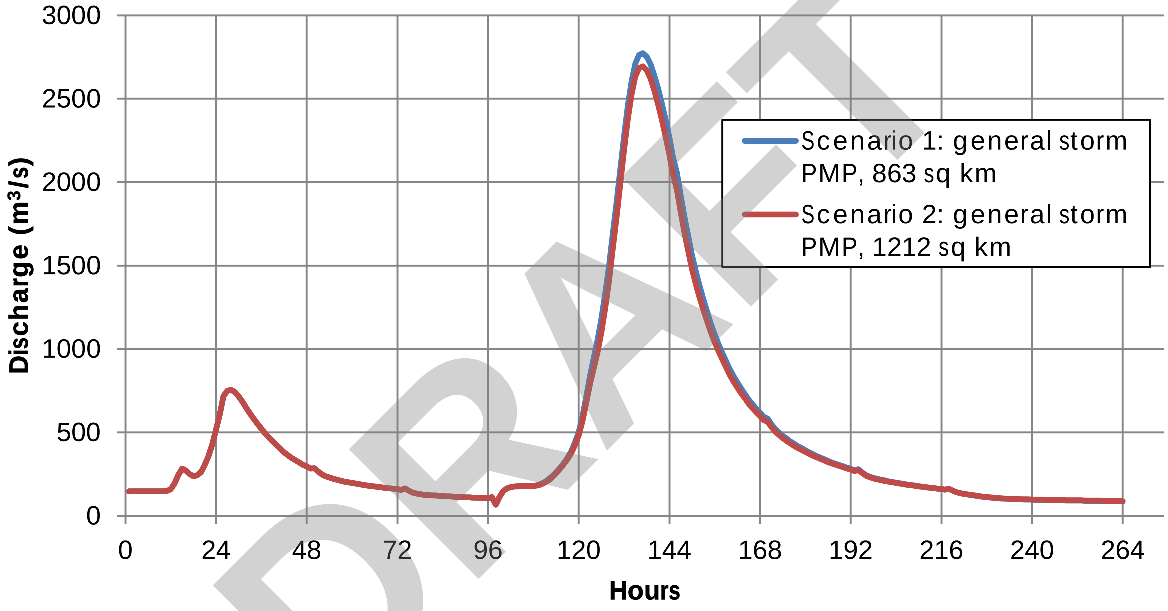

Figure 19: General Strom PMF Simulation Hydrographs for Scenarios 1 and 2 at the Proposed SR1 Diversion Site

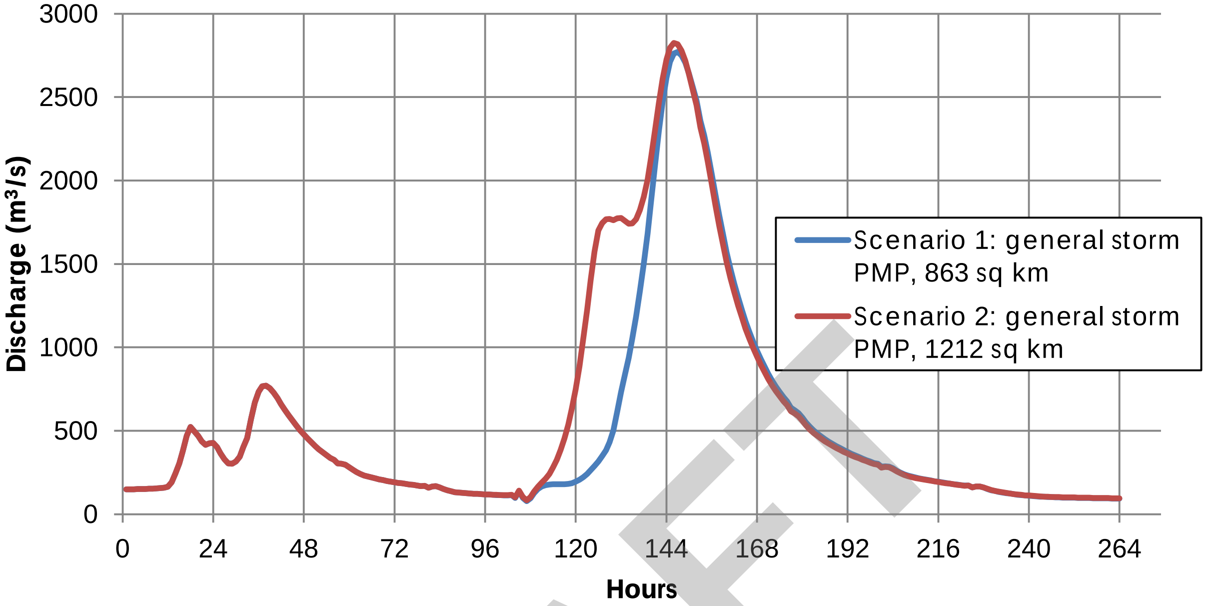

Figure 20: General Storm PMF Simulation Hydrographs for Scenarios 1 and 2 at Glenmore Dam

Table 30: General Strom PMF Results for Scenarios 1 and 2

Scenario	SR1 Diversion Site		Glenmore Dam	
	Peak Flow (m³/s)	7-Day Volume (dam³)	Peak Flow (m³/s)	7-Day Volume (dam³)
1	2,770	362,000	2,770	364,000
2	2,690	349,000	2,830	437,000

4.7.2 Local Storm PMF Scenario for area upstream of SR1 Diversion (Scenario 3)

A hydrograph representing the local storm PMF was generated at the proposed SR1 Diversion Site and Glenmore Dam (see Figure 21 and Figure 22). A detailed summary of the peak flow and 7-day volume for the local storm PMF Scenario 3 is given in Table 31.

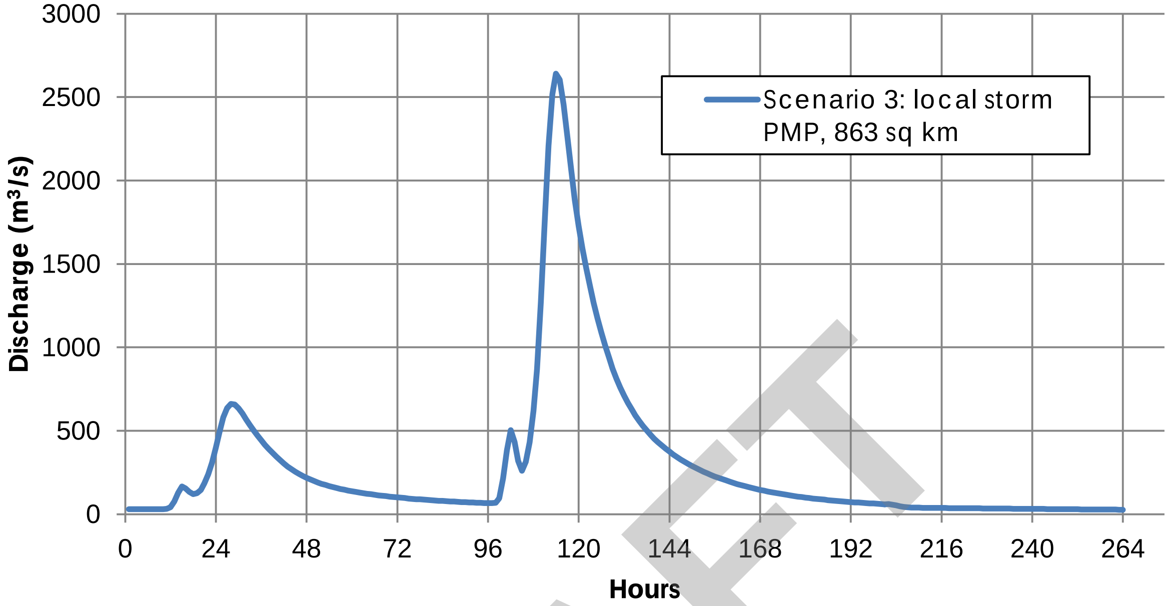

Figure 21: Local Storm PMF Simulation Hydrographs for Scenarios 3 at the Proposed SR1 Diversion Site

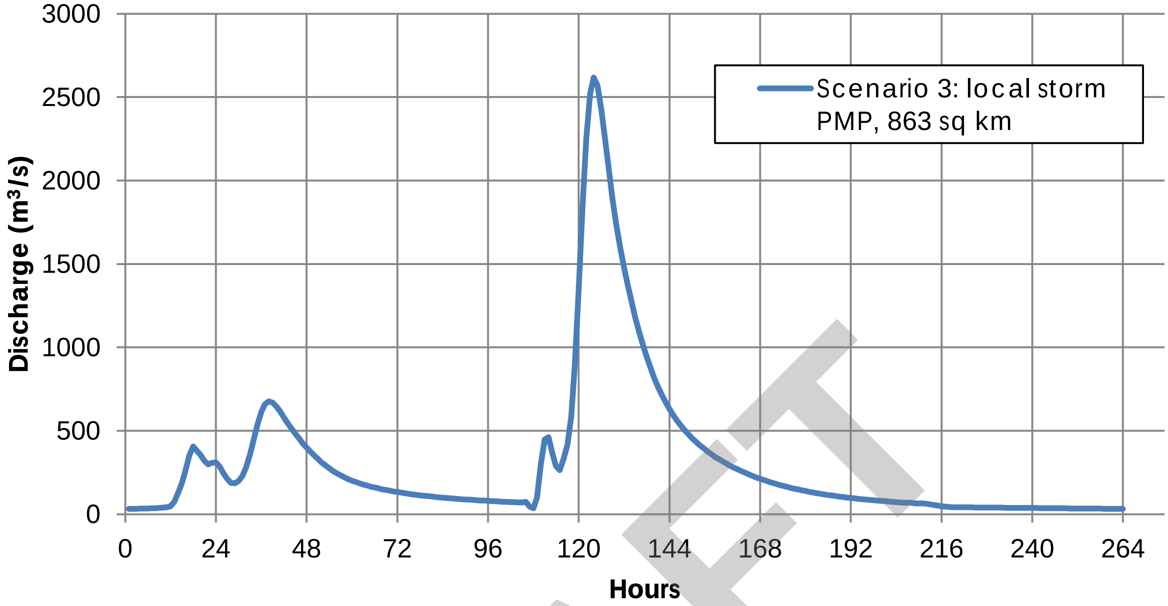

Figure 22: Local Storm PMF Simulation Hydrographs for Scenarios 3 at Glenmore Dam

Table 31: Local Storm PMF Results for Scenario 3

Scenario	SR1 Diversion		Glenmore Dam	
	Peak Flow (m³/s)	7-Day Volume (dam³)	Peak Flow (m³/s)	7-Day Volume (dam³)
3	2,640	208,000	2,620	211,000

4.7.3 Local Storm PMF Scenario for Area Upstream of Proposed SR1 Dam (Scenario 4)

Figure 23 shows the generated PMF hydrograph for Scenario 4 at the proposed SR1 Off-Stream Dam. The results are summarized in Table 32.

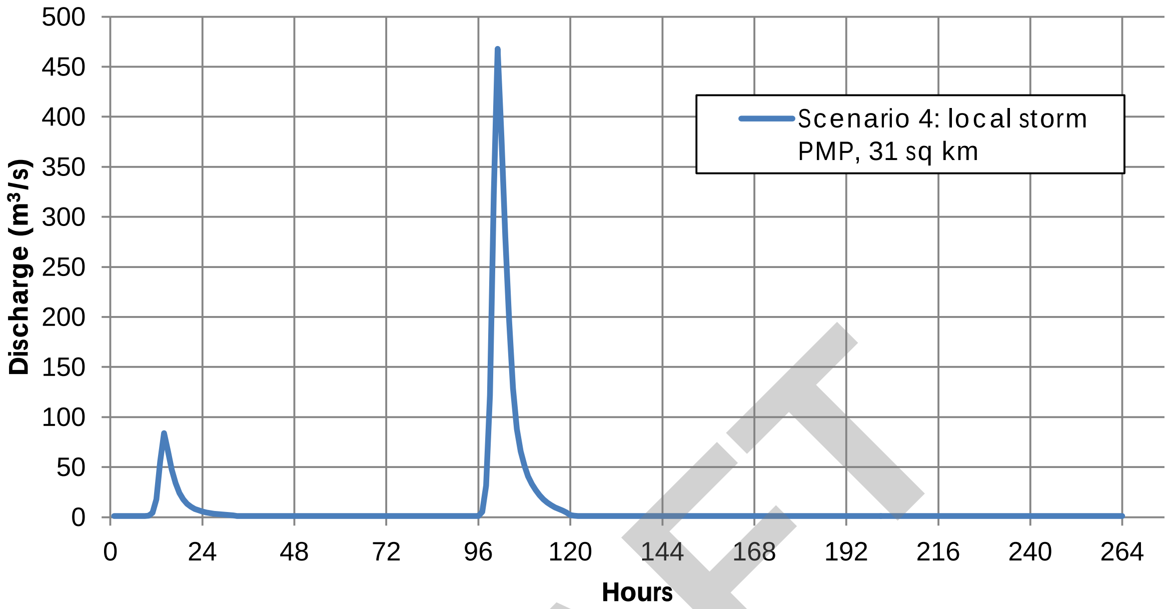

Figure 23: Local Storm PMF Simulation Hydrograph for Scenario 4 at Proposed SR1 Off-Stream Dam

Table 32: Local Storm PMF Results for Scenario 4

Scenario	SR1 Dam	
	Peak Flow (m³/s)	7-Day Volume (dam³)
4	468	8,930

5.0 PMF SUMMARY AND CONCLUSION

The PMF for the Elbow River Basin was estimated for design purposes of the proposed SR1 Diversion Structure on the Elbow River and the proposed SR1 Off-Stream Dam. A major component of the PMF estimation was the development of the PMP. The PMP analysis and delivery of the PMP values were provided by AWA of Monument, Colorado, a sub consultant to Stantec. Four PMP scenarios were deemed necessary to assess the possible design floods of interest for the project (see Table 18). The PMF analyses were performed by setting up and calibrating HEC-HMS models of the watershed forced by various PMP data. The HEC-HMS models incorporate:

- 11 sub-basins each representing hydrologically homogeneous characteristics.
- Rainfall loss estimation using the Initial Loss plus Uniform Loss Rate method. Input parameters include the initial loss represented by a rainfall depth, the saturated soil hydraulic conductivity, and the effective impervious area as a percent.
- Unit hydrograph method based on published guidelines for similar Rocky Mountain watershed physiography.
- Channel routing methodology to translate runoff hydrographs at concentration points internal to the model to downstream concentration points.
- Baseflow estimates based on return flow from watershed infiltration to the receiving watercourses.
- Snowmelt contribution to represent seasonal snowmelt that could reasonably be expected to occur with each PMF scenario.
- An antecedent storm was included in the model to represent the 100-year, 24-hour rainfall occurring three days prior to the onset of the PMP storm.

The HEC-HMS model was initially calibrated to the June 2005 and the June 2013 floods. For that purpose, AWA analyzed those storms and provided digital data for each sub-basin that is representative of the actual temporal and spatial distributions of each of those storms. Due to limitations of the aerial extent of those storms and uncertainties in the streamflow data, the model calibration yielded preliminary conclusions. That calibration process was successful in developing appropriate rainfall loss parameter values, and in the development of appropriate watershed channel routing and baseflow methodologies. However, the calibration of the unit hydrograph methodology and parameter estimation could not be relied upon because the historic rainfalls did not fully cover all of the model sub-basins and rainfall intensities were not sufficiently uniform over the watershed and sub-basins to meet the requirements of unit hydrograph theory.

When the initially calibrated HEC-HMS model was used with the PMP scenarios including the antecedent 100-year storm, the runoff for the 100-year rainfall resulted in peak discharges greatly in excess of the 100-year peak discharge that was previously estimated by flood frequency analysis. Inspection of the HEC-HMS model indicated that the unit hydrographs were producing too rapid response for such a uniformly applied PMP rainfall. Subsequently, the unit hydrograph parameters for the sub-basins were adjusted such that the HEC-HMS model satisfactorily reproduced 100-year flood runoff response to a simulated 100-year rainfall over the watershed.

A snowmelt hydrograph was developed based on snowpack and snowmelt data during severe rainstorms on the watershed. That snowmelt hydrograph was applied at the start of the 100-year storm for Scenario 1 and 2 with subsequent recession followed by a rise in snowmelt contribution during the PMP.

The final calibrated HEC-HMS model with PMP input for each of the four scenarios resulted in design PMF estimates at the SR1 Diversion Structure on the Elbow River and the SR1 Off-Stream Dam. Although not a design requirement for the SR1 Project, the PMF for Glenmore Dam was estimated as well.

A summary of the PMF results for each scenario are provided in Table 33 below. The recommended PMF hydrographs are based on the PMF scenario with the largest peak flow and 7-day volume. PMF Scenarios 1, 2, and 4 represent the maximum discharge and volume at the SR1 Diversion Structure, Glenmore Dam, and SR1 Off-Stream Dam, respectively. A summary of the recommended PMF hydrographs at the SR1 Diversion Structure, Glenmore Dam, and SR1 Off-Stream Dam are shown in Table 34.

Table 33: Summary of PMF Results per Scenario

Scenario	Peak Flow (m^3/s)			7-Day Volume (dam^3)		
	SR1 Diversion Structure	Glenmore Dam	SR1 Off-Stream Dam	SR1 Diversion Structure	Glenmore Dam	SR1 Off-Stream Dam
1	2,770	2,770	-	362,000	364,000	-
2	2,690	2,830	-	349,000	437,000	-
3	2,640	2,620	-	208,000	211,000	-
4	-	-	470	-	-	9,000

Table 34: Summary of PMF Results

	SR1 Diversion Structure	Glenmore Dam	SR1 Off-Stream Dam
Peak discharge (m^3/s)	2,770	2,830	470
7-Day Volume (dam^3)	362,000	437,000	9,000
Reference	Figure 19	Figure 20	Figure 23

6.0 REFERENCES

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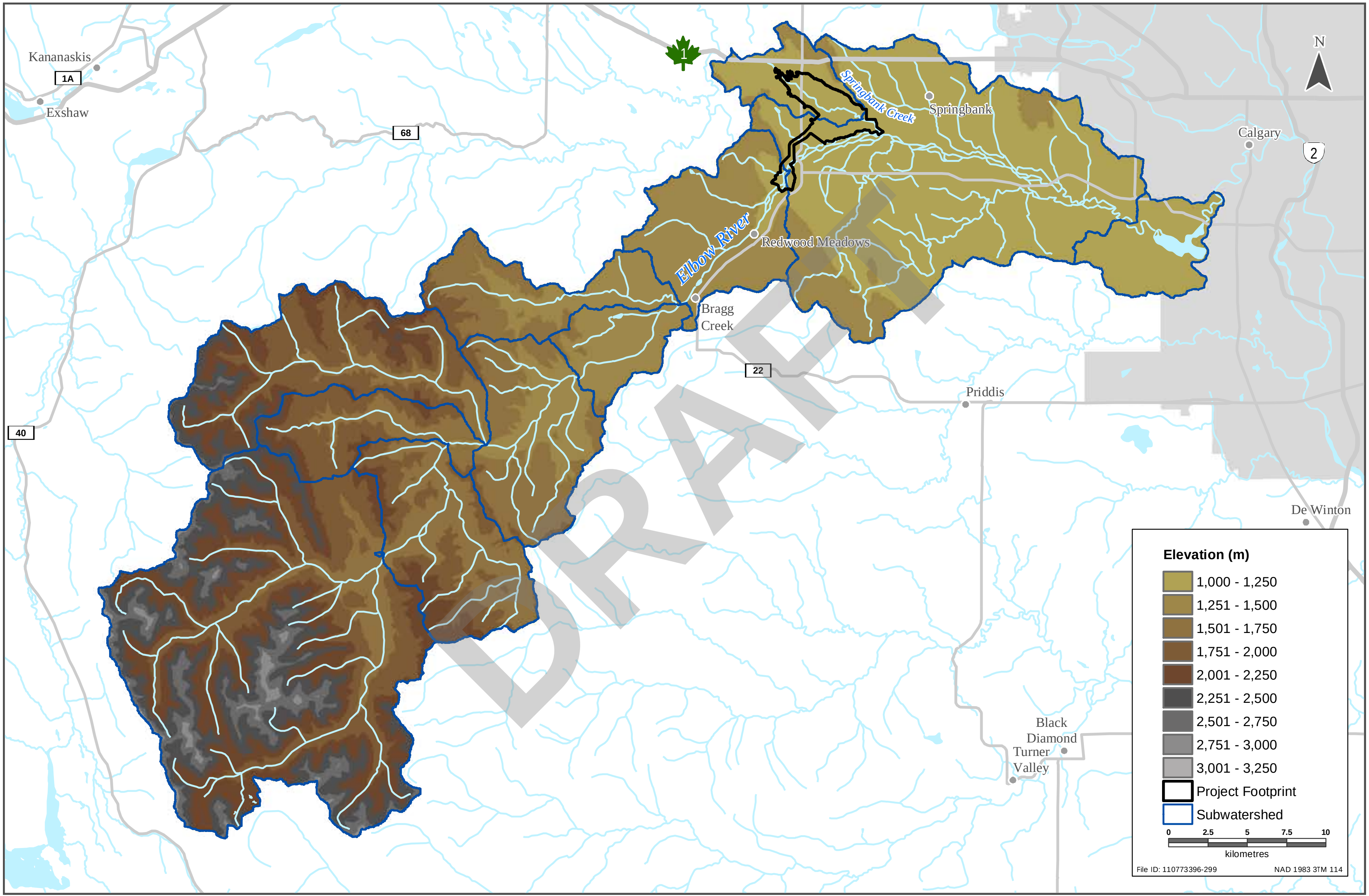
APPENDIX A

WATERSHED CHARACTERISTICS FIGURES



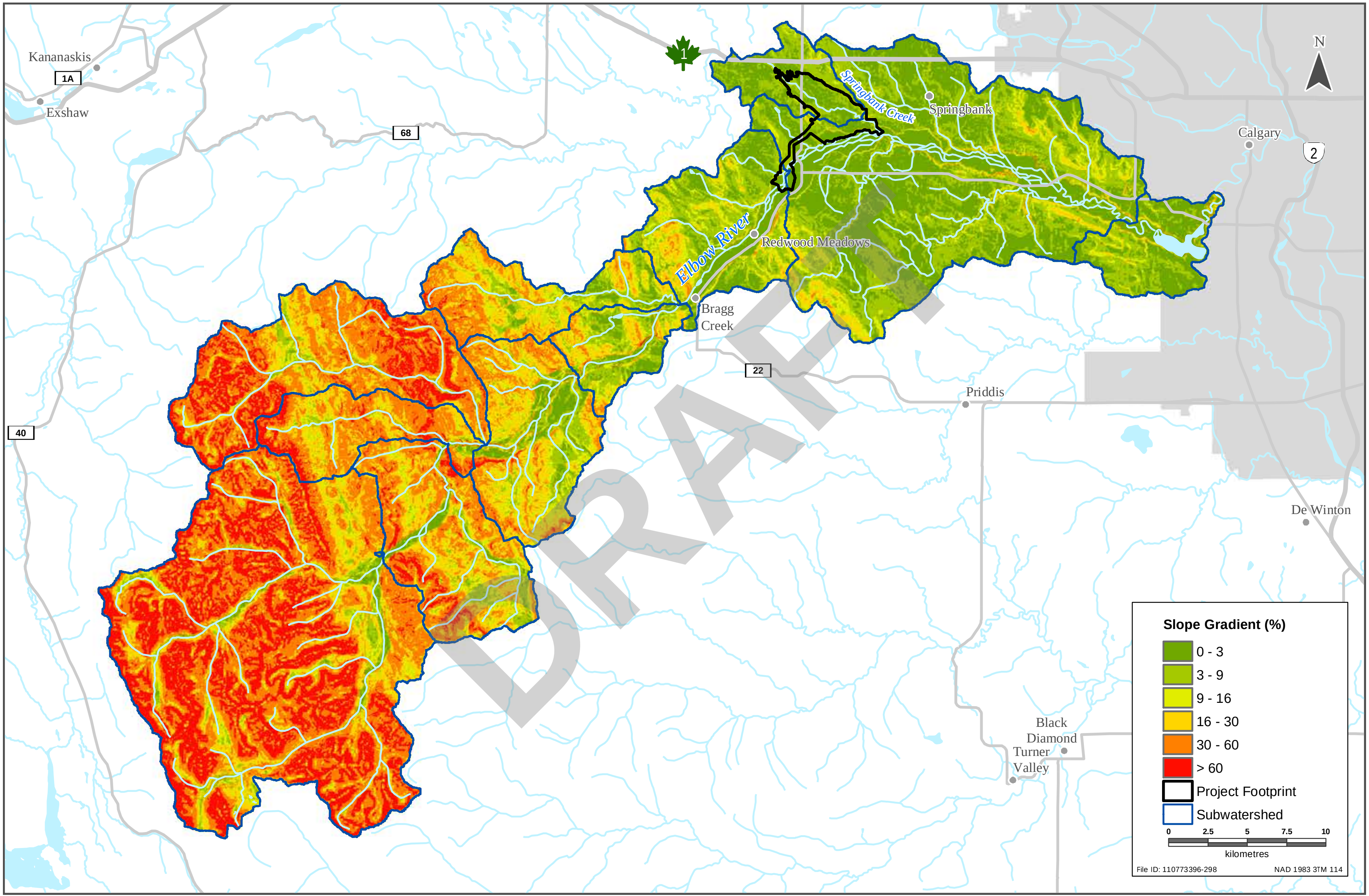
Sources: Base Data - Natural Resources Canada. Thematic Data - (1:20,000 DEM) Stantec Consulting Ltd. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Elbow River Basin
Ground Elevation

Figure A.1

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT



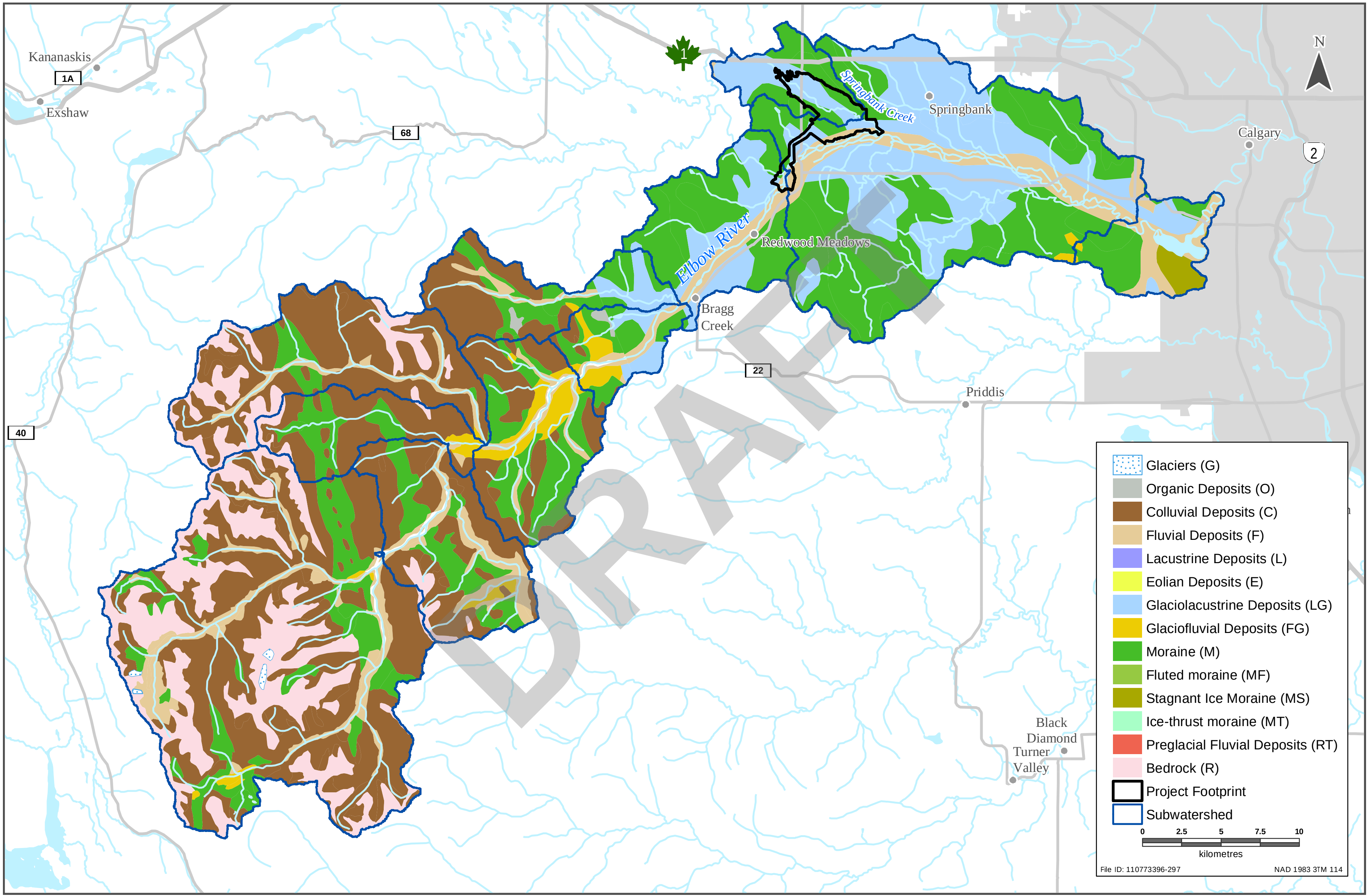
Sources: Base Data - Natural Resources Canada. Thematic Data - (1:20,000 DEM) Stantec Consulting Ltd. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT

Elbow River Basin
Slope Gradient

Figure A.2

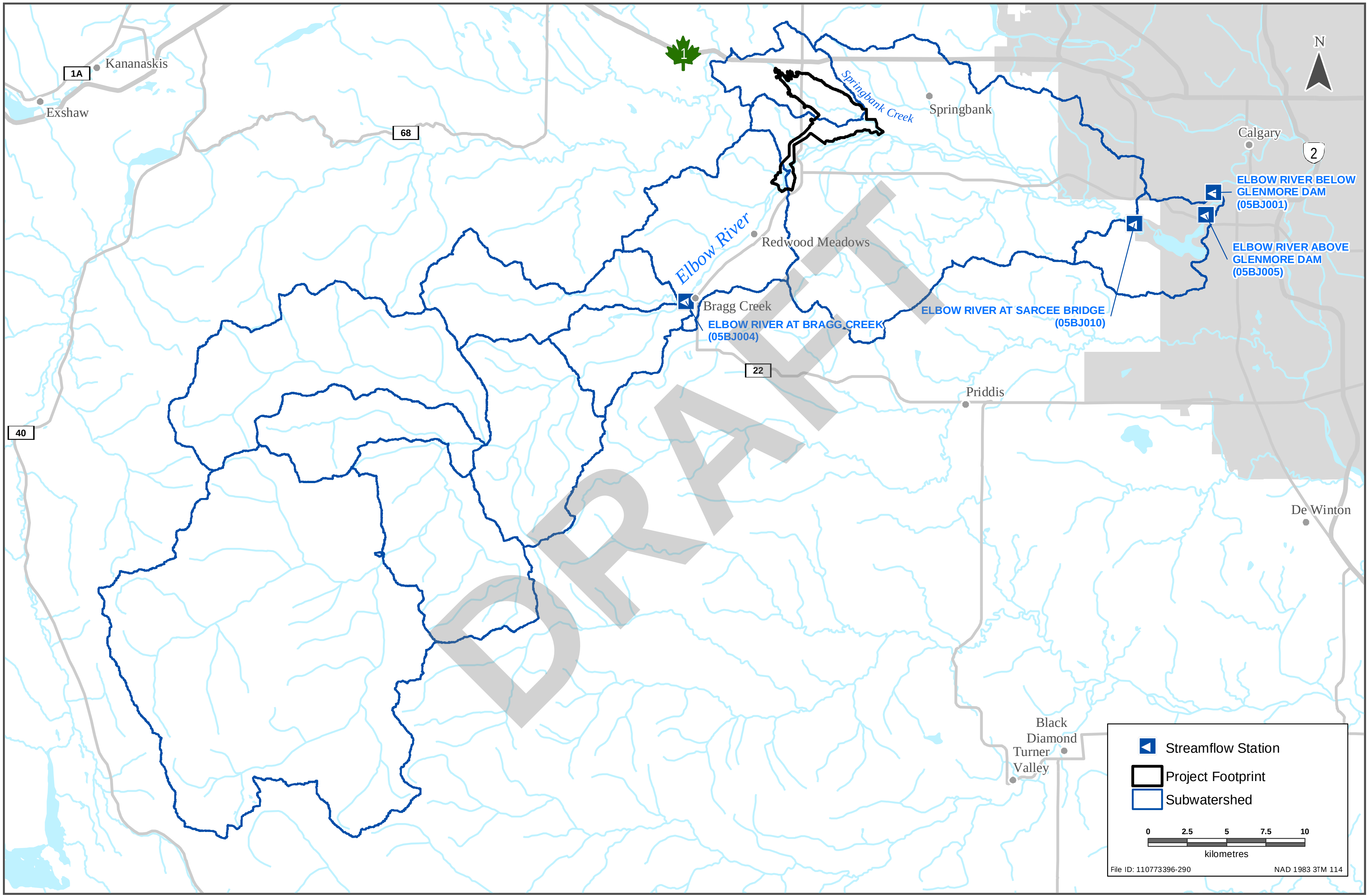


Sources: Base Data - Natural Resources Canada. Thematic Data - Alberta Energy Regulator/Alberta Geological Survey. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Elbow River Basin Surficial Geology

Figure A.3

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT



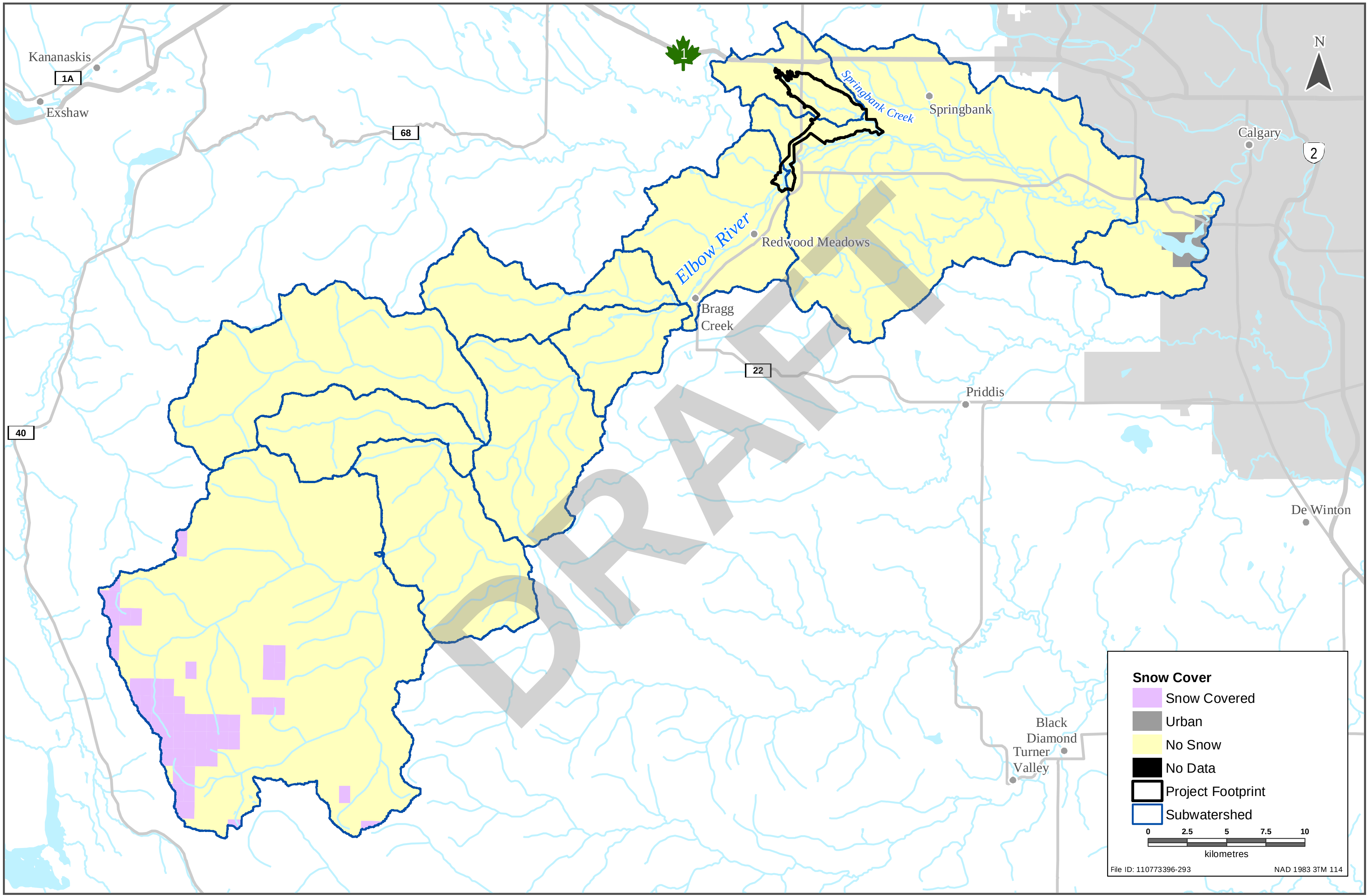
Sources: Base Data - Natural Resources Canada. Thematic Data - Water Survey of Canada. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT

Elbow River Basin
Streamflow Station Locations

Figure A.4



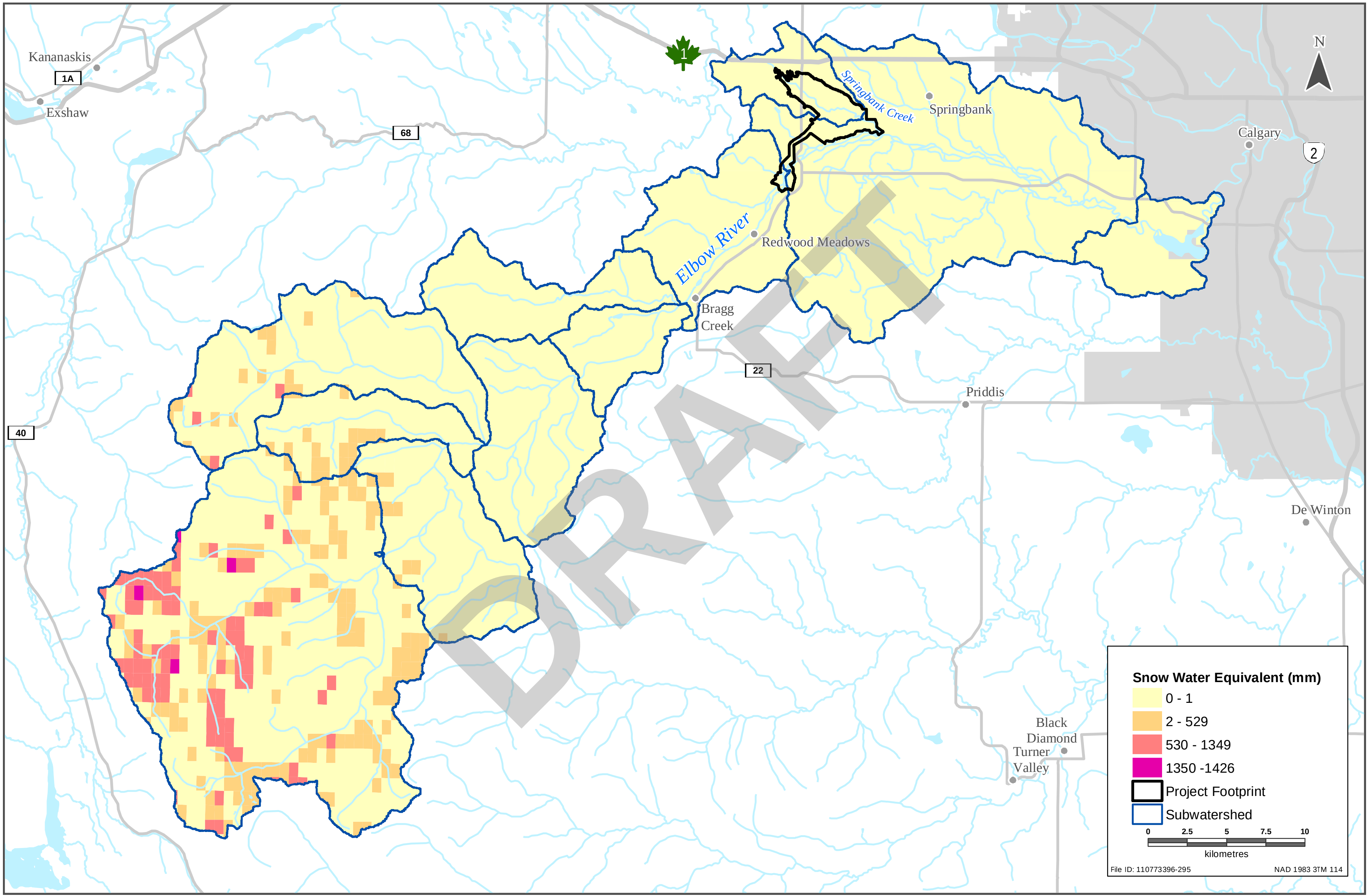
Sources: Base Data - Natural Resources Canada. Thematic Data - Environment Canada. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT

Elbow River Basin
Snow Cover (June 4, 2005)

Figure A.5



Sources: Base Data - Natural Resources Canada. Thematic Data - ABMI Remote Sensing Group 2012. Subbasin - Stantec Consulting Ltd. Project Data - Stantec Consulting Ltd.

Stantec

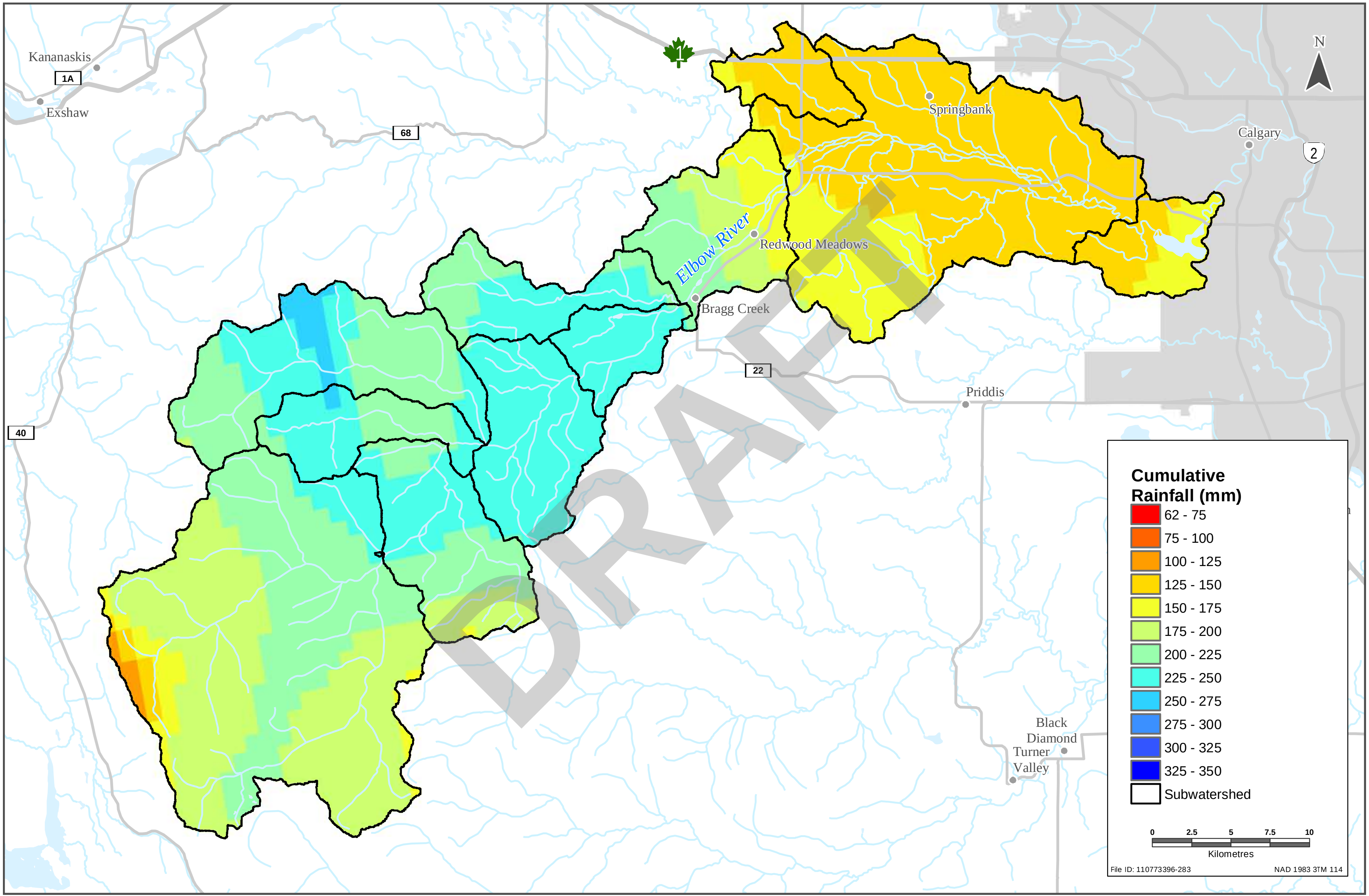
ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT

Elbow River Basin
Snow Water Equivalent (June 24, 2013)

Figure A.6

APPENDIX B

CUMULATIVE PRECIPITATION FIGURES

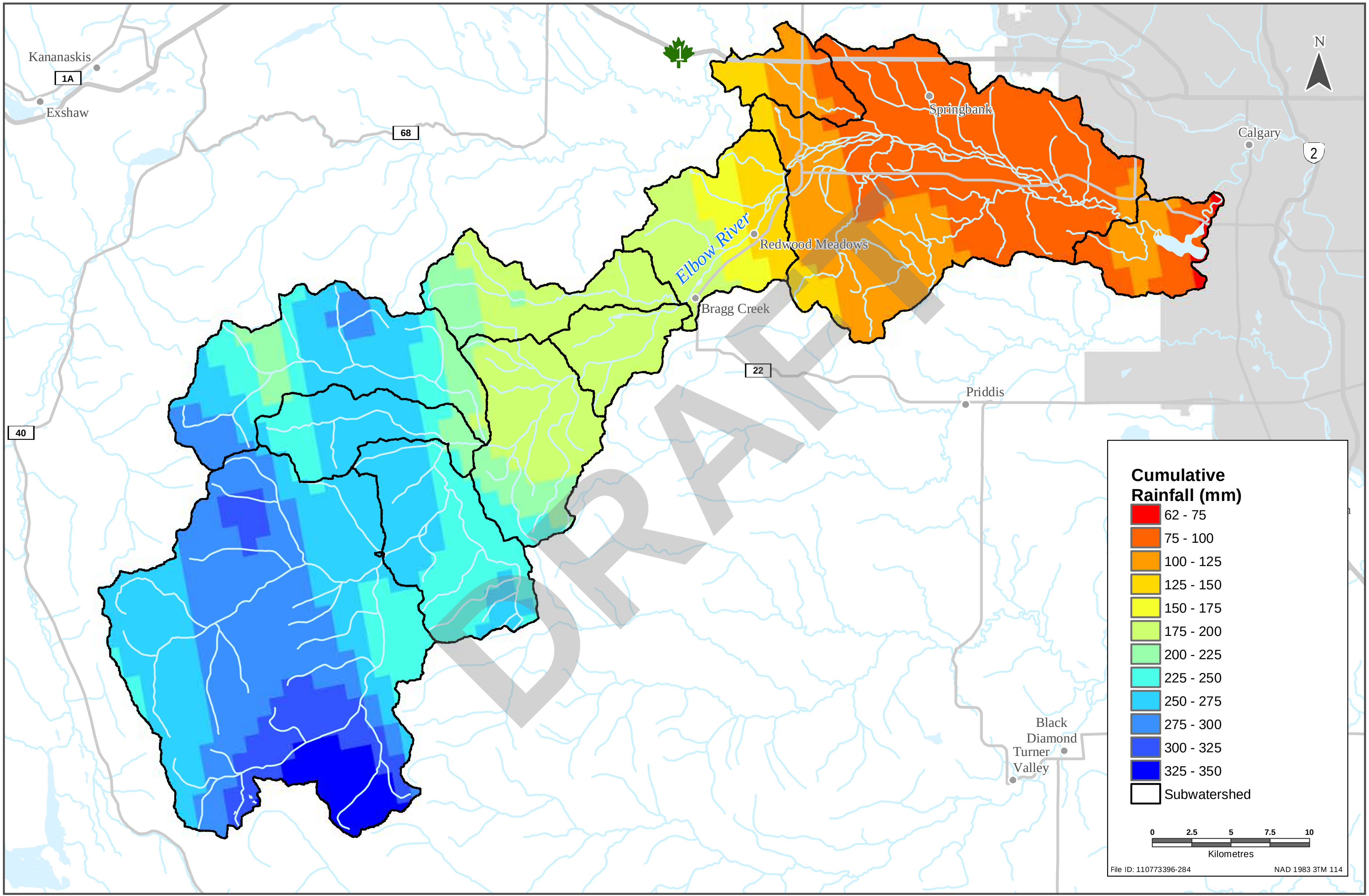


Sources: Base Data - Natural Resources Canada. Weather Data - Environment Canada/Applied Weather Associates. Subbasin - Stantec Consulting Ltd.

Cumulative Precipitation (mm) for the Elbow River Basin
8:00 a.m. June 01, 2005 to 7:00 a.m. June 09, 2005

Figure B.1

Stantec



Sources: Base Data - Natural Resources Canada. Weather Data - Environment Canada/Applied Weather Associates. Subbasin - Stantec Consulting Ltd.

Cumulative Precipitation (mm) for the Elbow River Basin
8:00 a.m. June 19, 2013 to 7:00 a.m. June 22, 2013

Figure B.2

Stantec

ALBERTA TRANSPORTATION SPRINGBANK OFF-STREAM RESERVOIR PROJECT

APPENDIX C

CALIBRATION WATER BALANCE FIGURES PER SUB-BASIN

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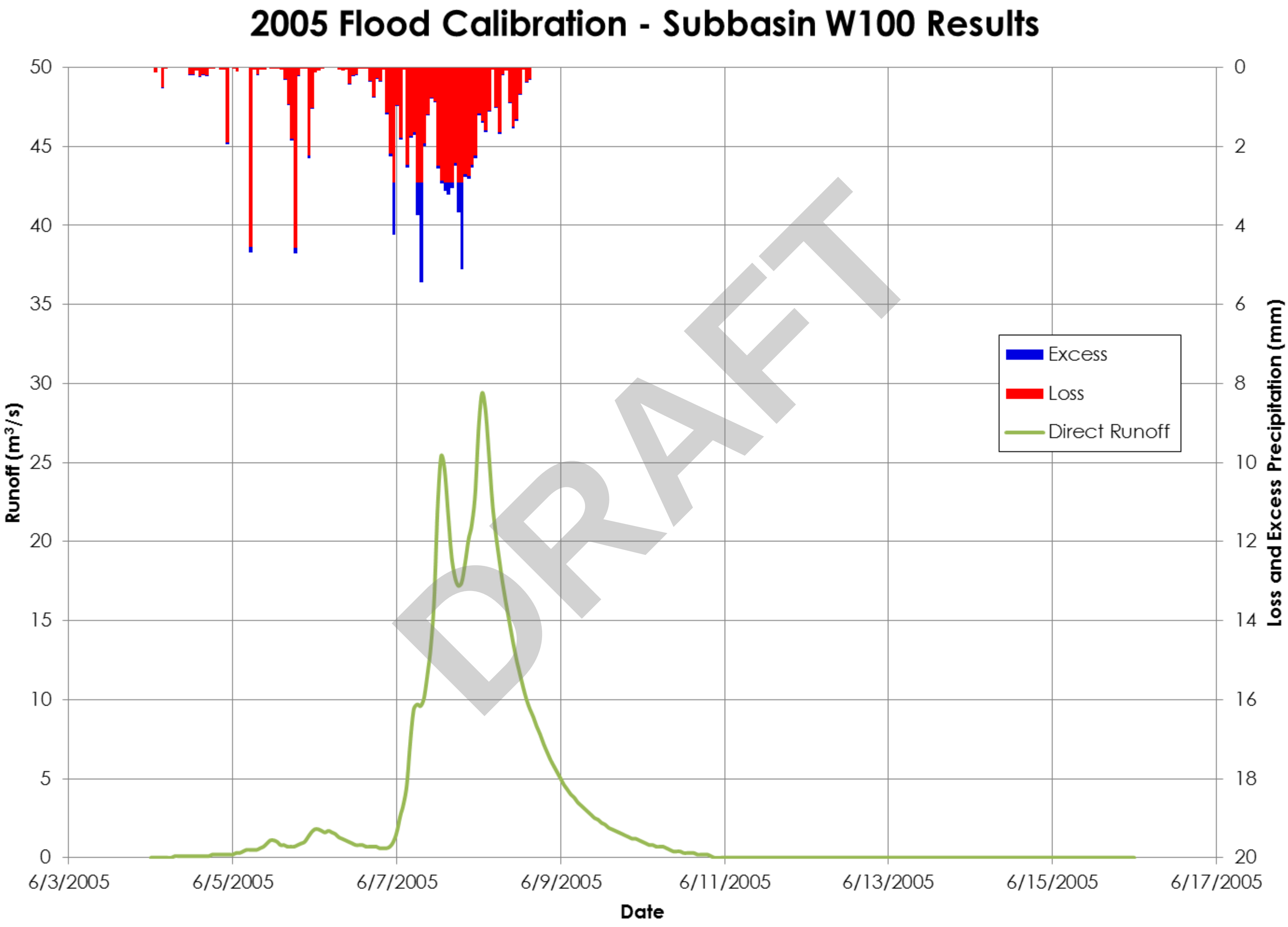
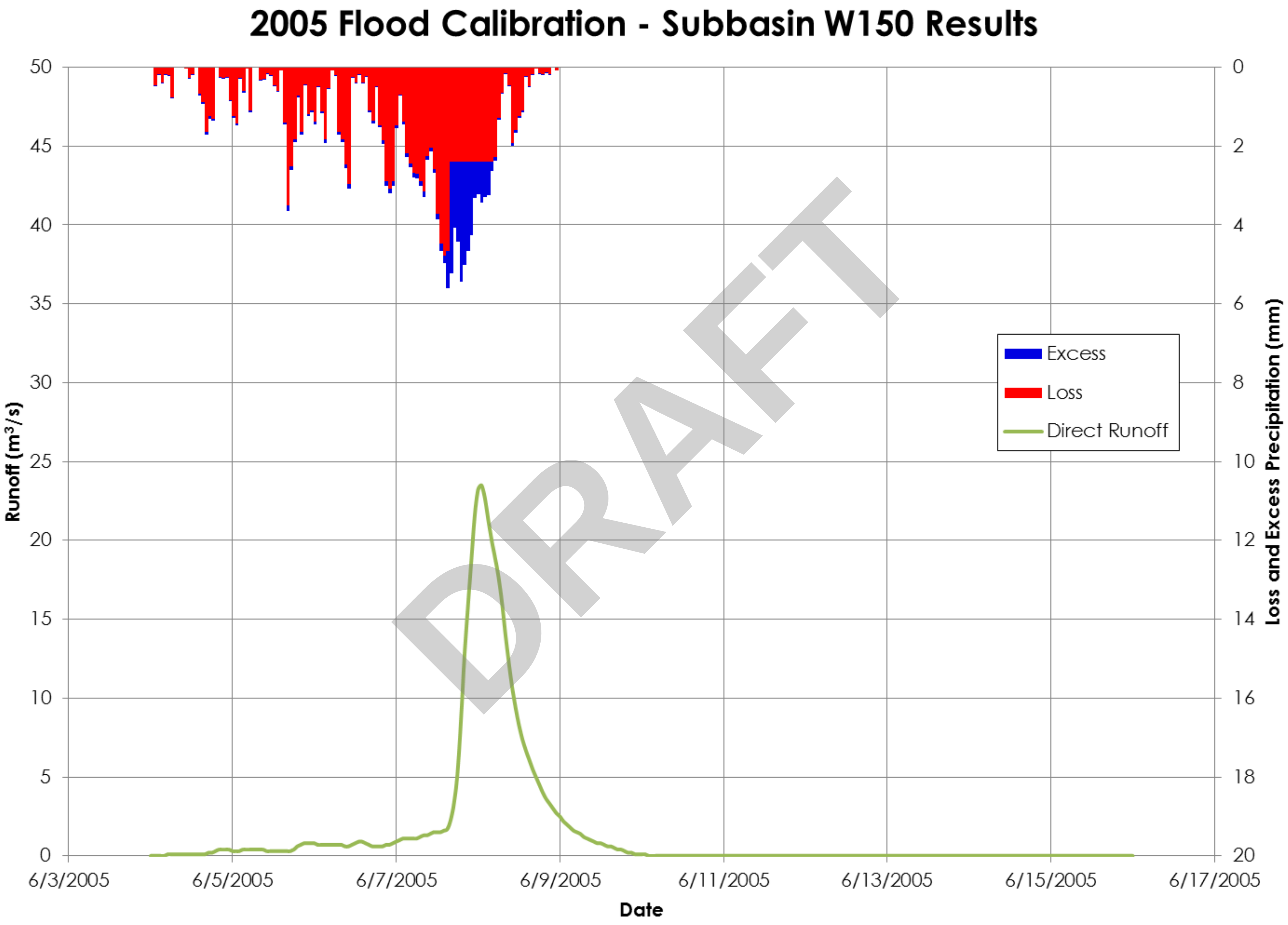

2005 Flood Calibration - Subbasin W100 Results
Runoff (m³/s)
50
45
40
35
30
25
20
15
10
5
0
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Excess
Loss
Direct Runoff
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date

Figure C.1



2005 Flood Calibration - Subbasin W150 Results
Runoff (m³/s)
50
45
40
35
30
25
20
15
10
5
0
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Excess
Loss
Direct Runoff
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date

Figure C.2

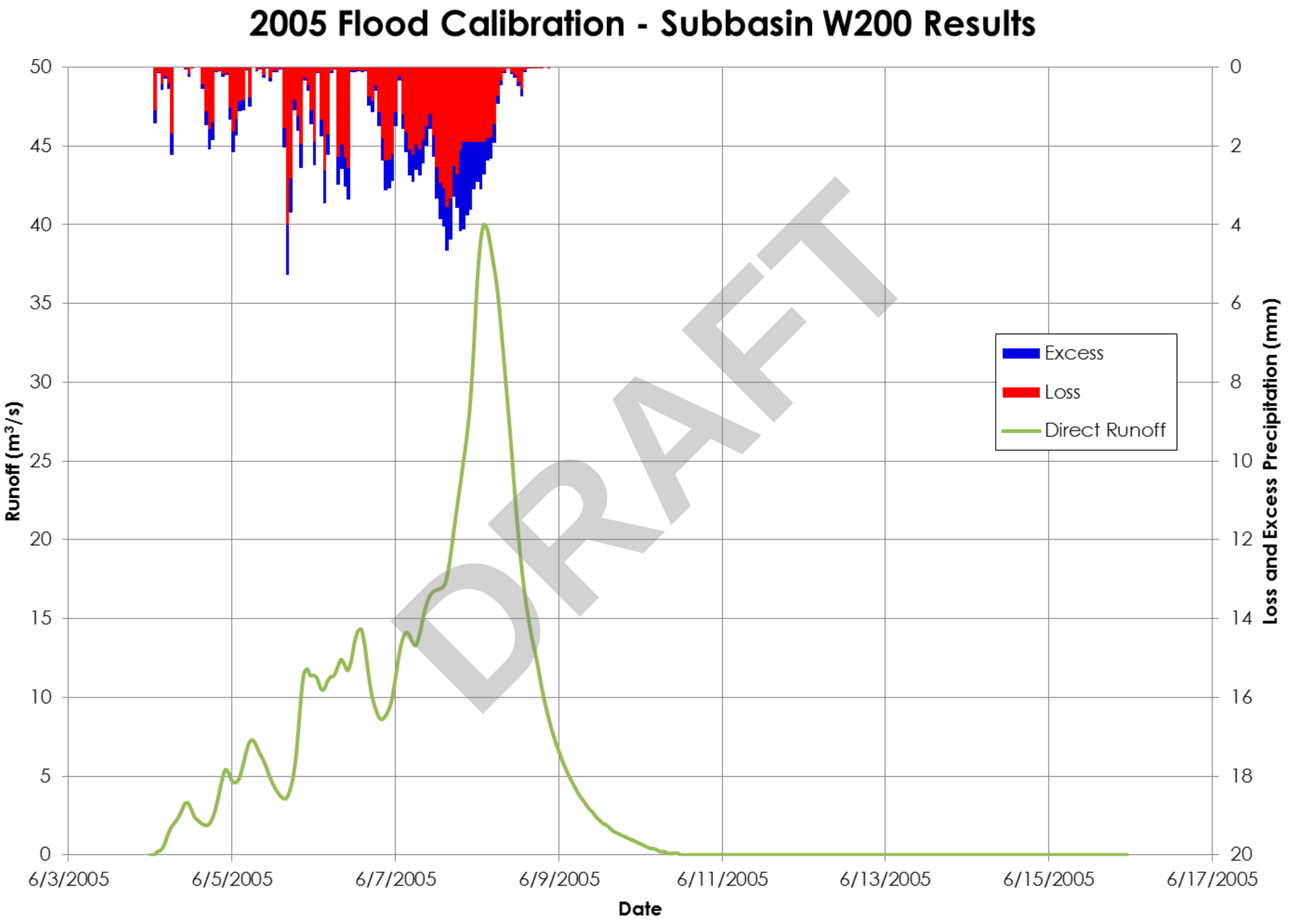

2005 Flood Calibration - Subbasin W200 Results
Runoff (m³/s)
0
5
10
15
20
25
30
35
40
45
50
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date
Excess
Loss
Direct Runoff

Figure C.3

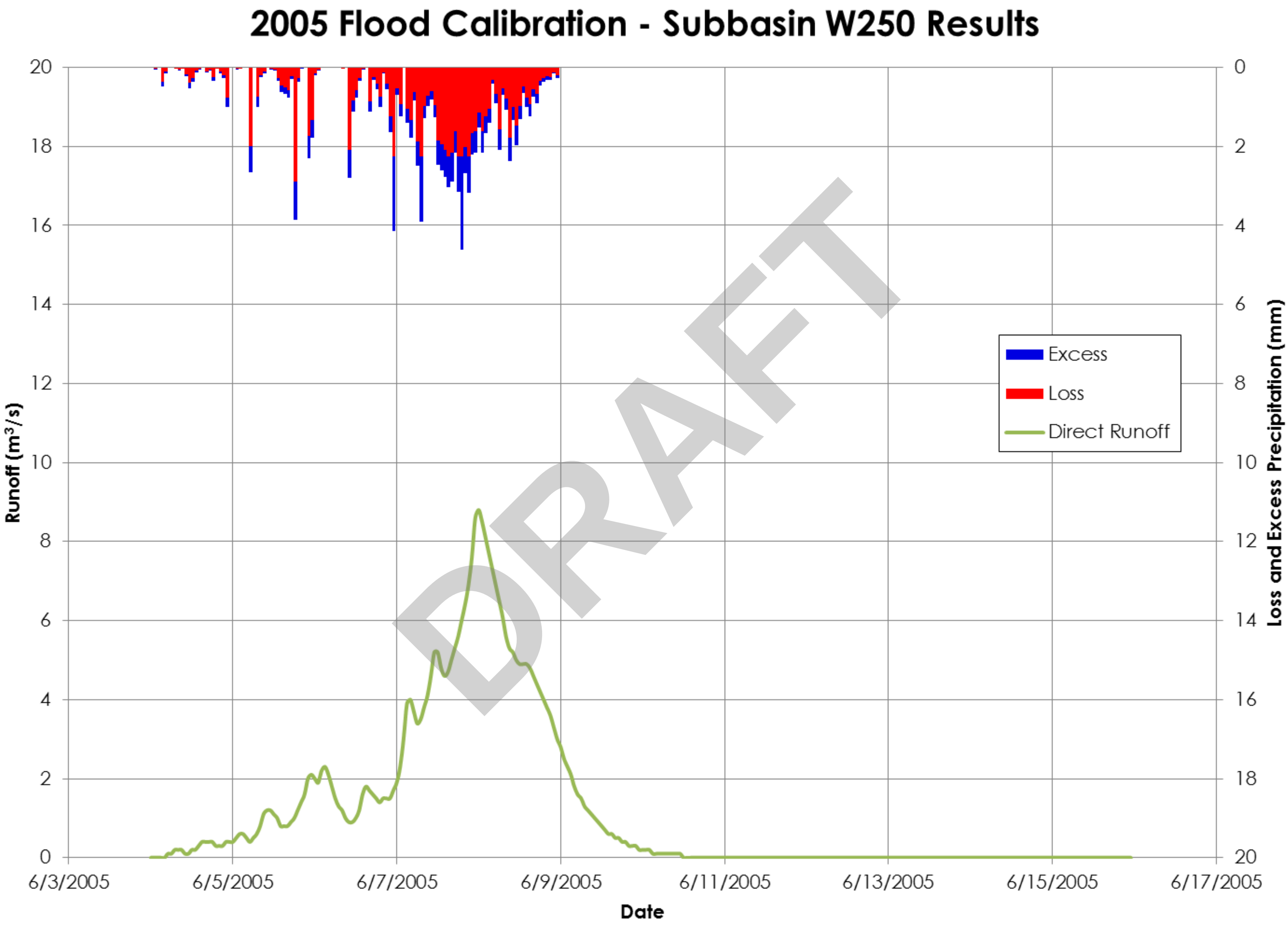

2005 Flood Calibration - Subbasin W250 Results
Runoff (m³/s)
0
2
4
6
8
10
12
14
16
18
20
Loss and Excess Precipitation (mm)
Excess
Loss
Direct Runoff
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date

Figure C.4

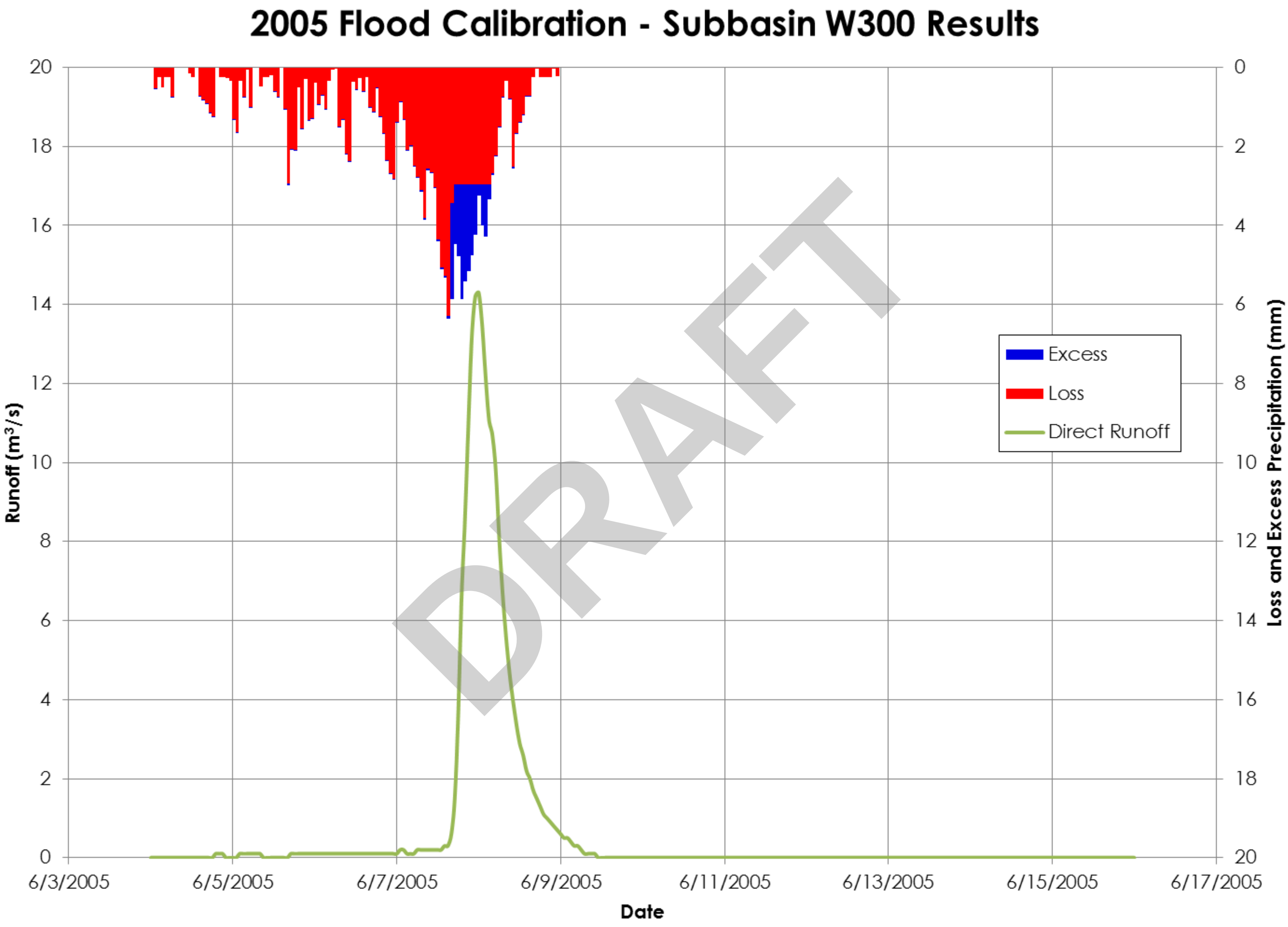

2005 Flood Calibration - Subbasin W300 Results
Runoff (m³/s)
20
18
16
14
12
10
8
6
4
2
0
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Date
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Excess
Loss
Direct Runoff

Figure C.5

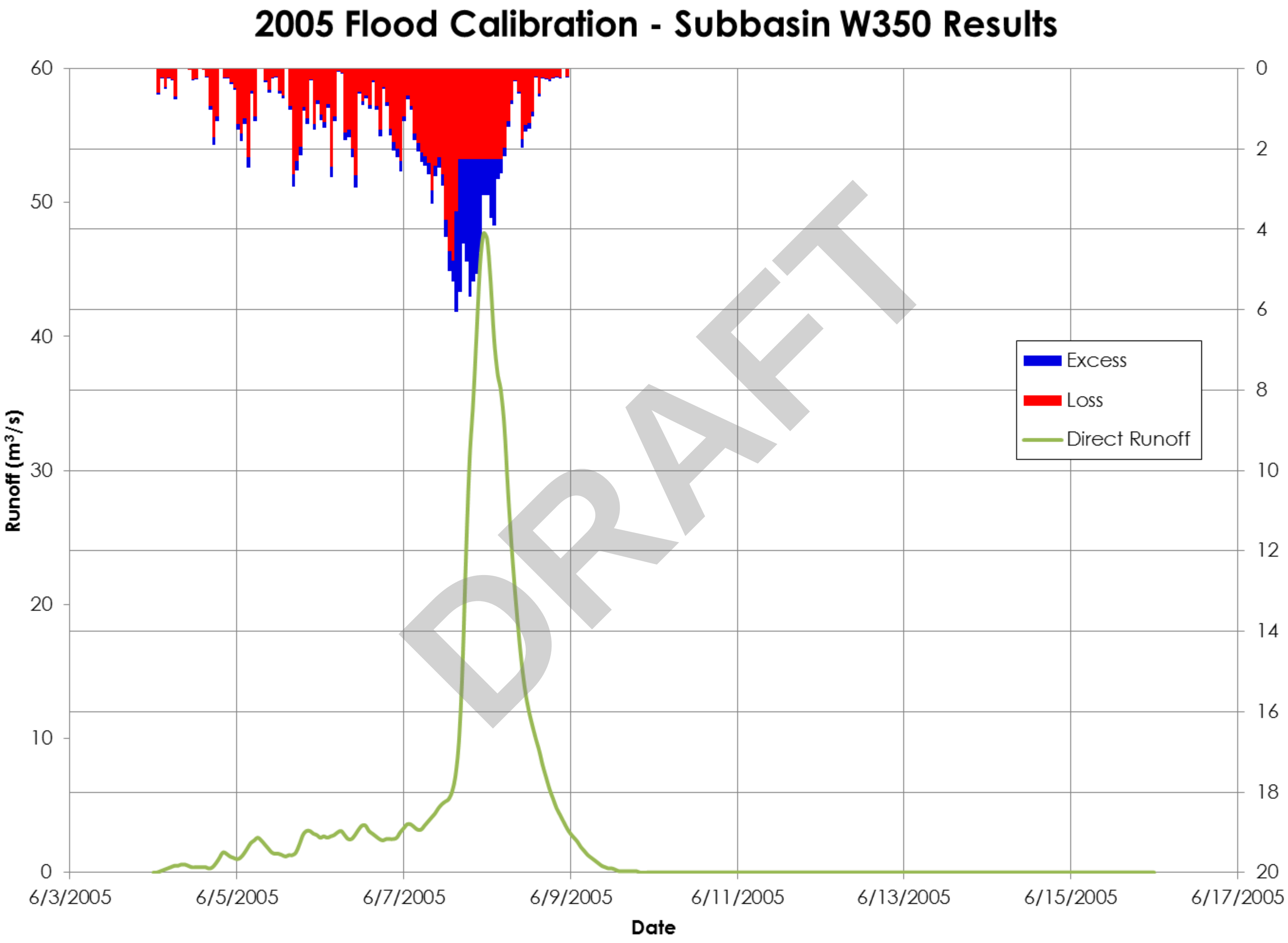

2005 Flood Calibration - Subbasin W350 Results
Runoff (m³/s)
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Date
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Excess
Loss
Direct Runoff

Figure C.6

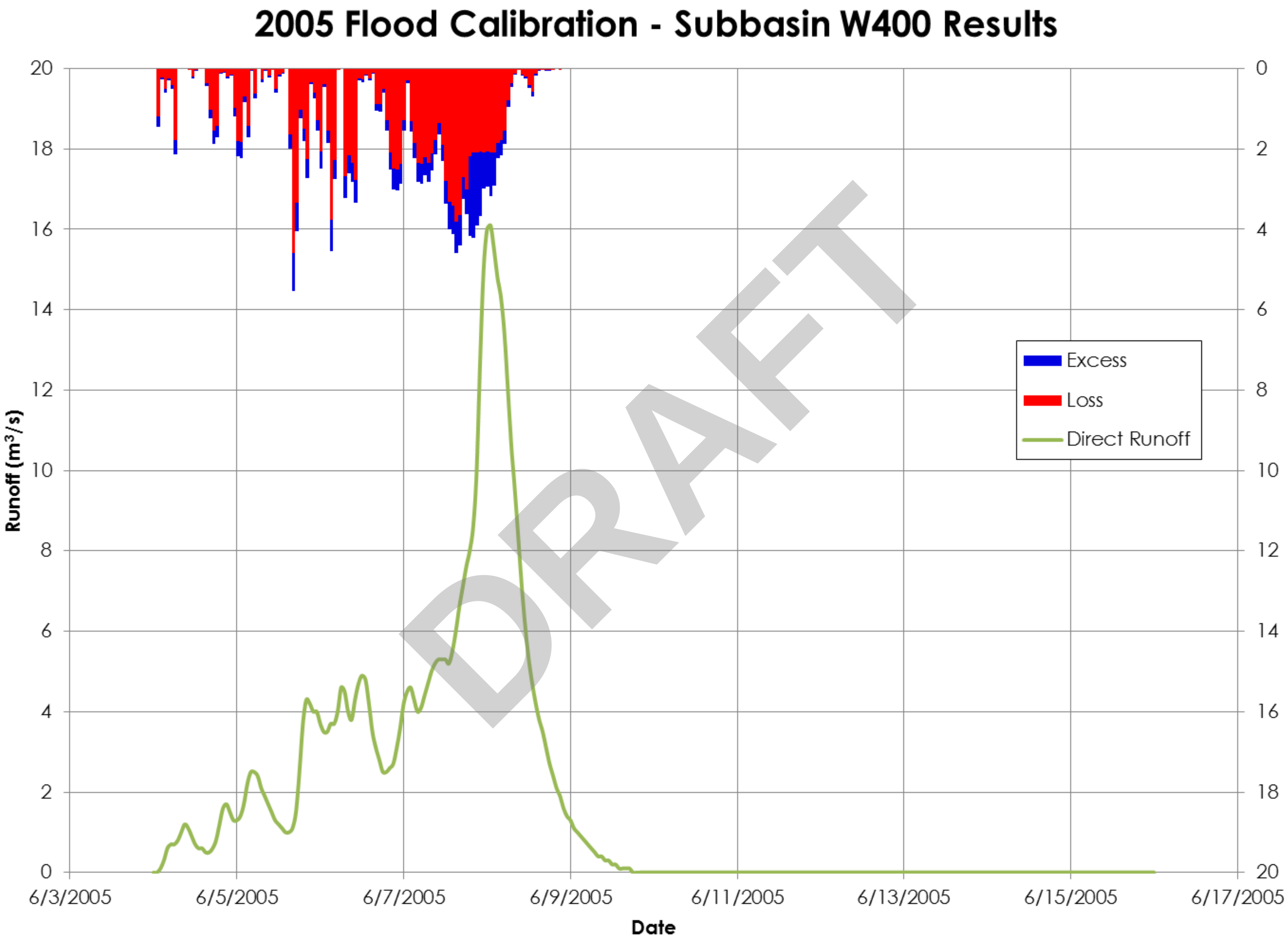
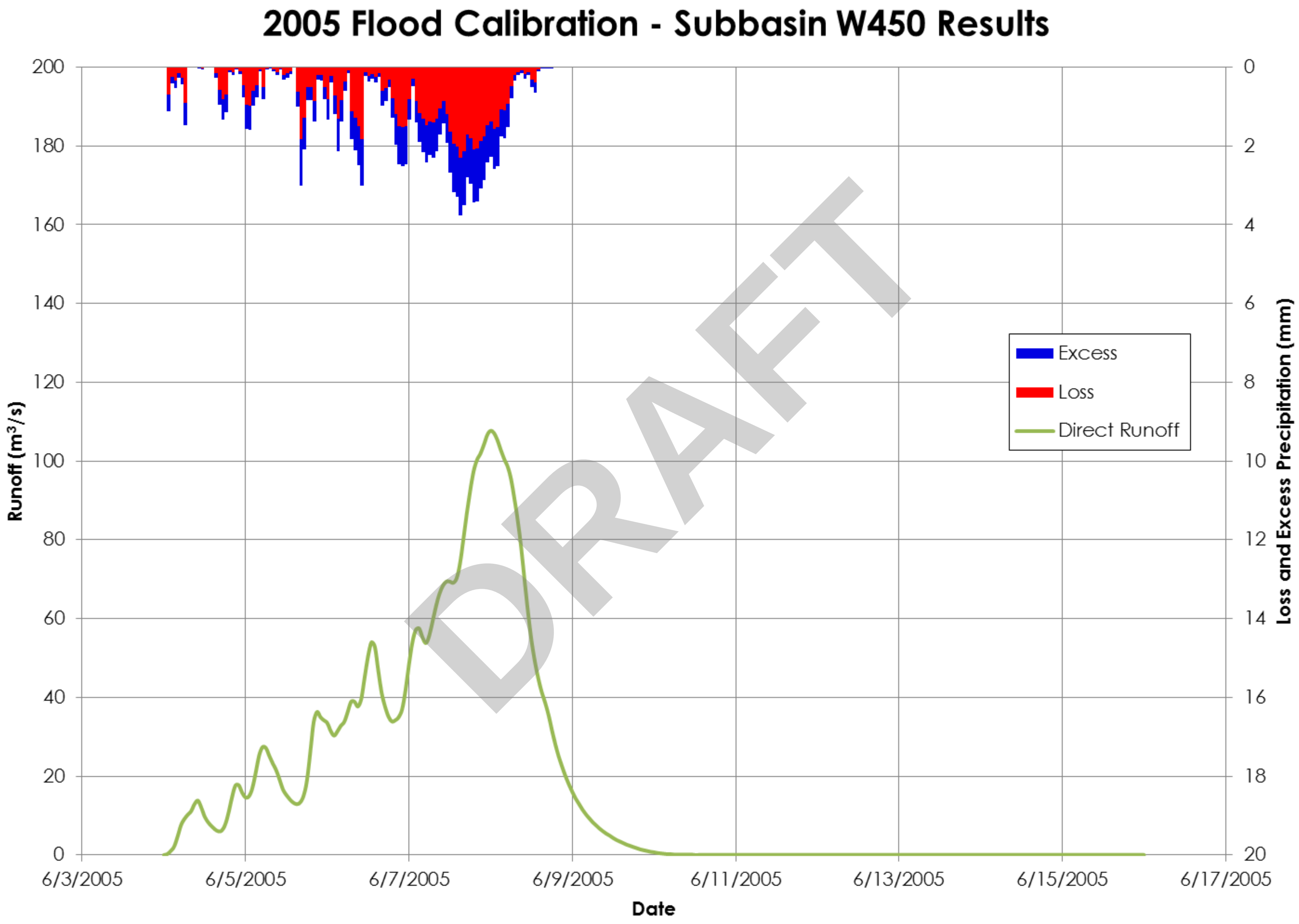

2005 Flood Calibration - Subbasin W400 Results
Runoff (m³/s)
0
2
4
6
8
10
12
14
16
18
20
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Excess
Loss
Direct Runoff
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date

Figure C.7



2005 Flood Calibration - Subbasin W450 Results
Runoff (m³/s)
0
20
40
60
80
100
120
140
160
180
200
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Date
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Excess
Loss
Direct Runoff

Figure C.8

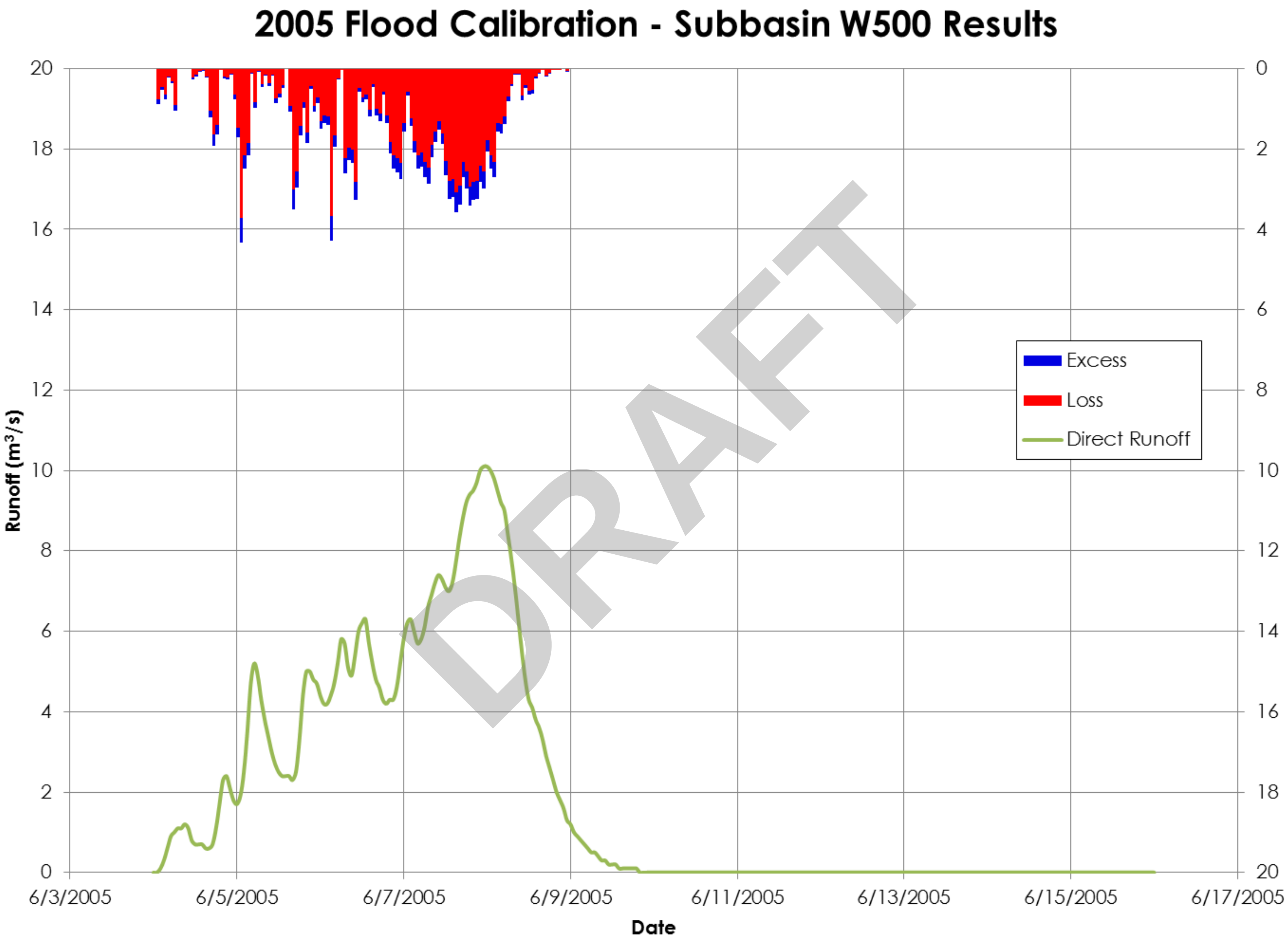

2005 Flood Calibration - Subbasin W500 Results
Runoff (m³/s)
0
2
4
6
8
10
12
14
16
18
20
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date
Excess
Loss
Direct Runoff

Figure C.9

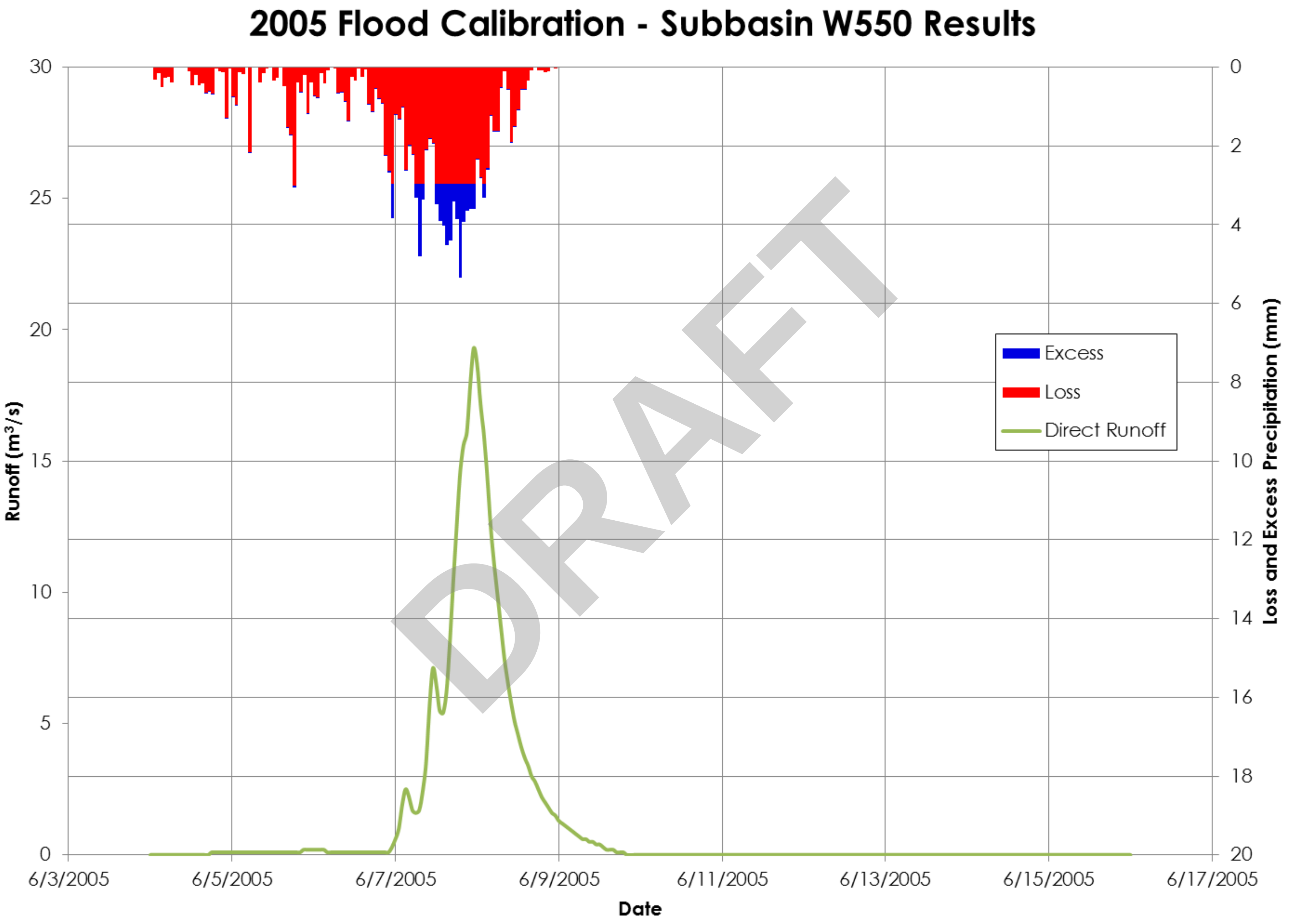

2005 Flood Calibration - Subbasin W550 Results
Runoff (m³/s)
30
25
20
15
10
5
0
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date
Excess
Loss
Direct Runoff

Figure C.10

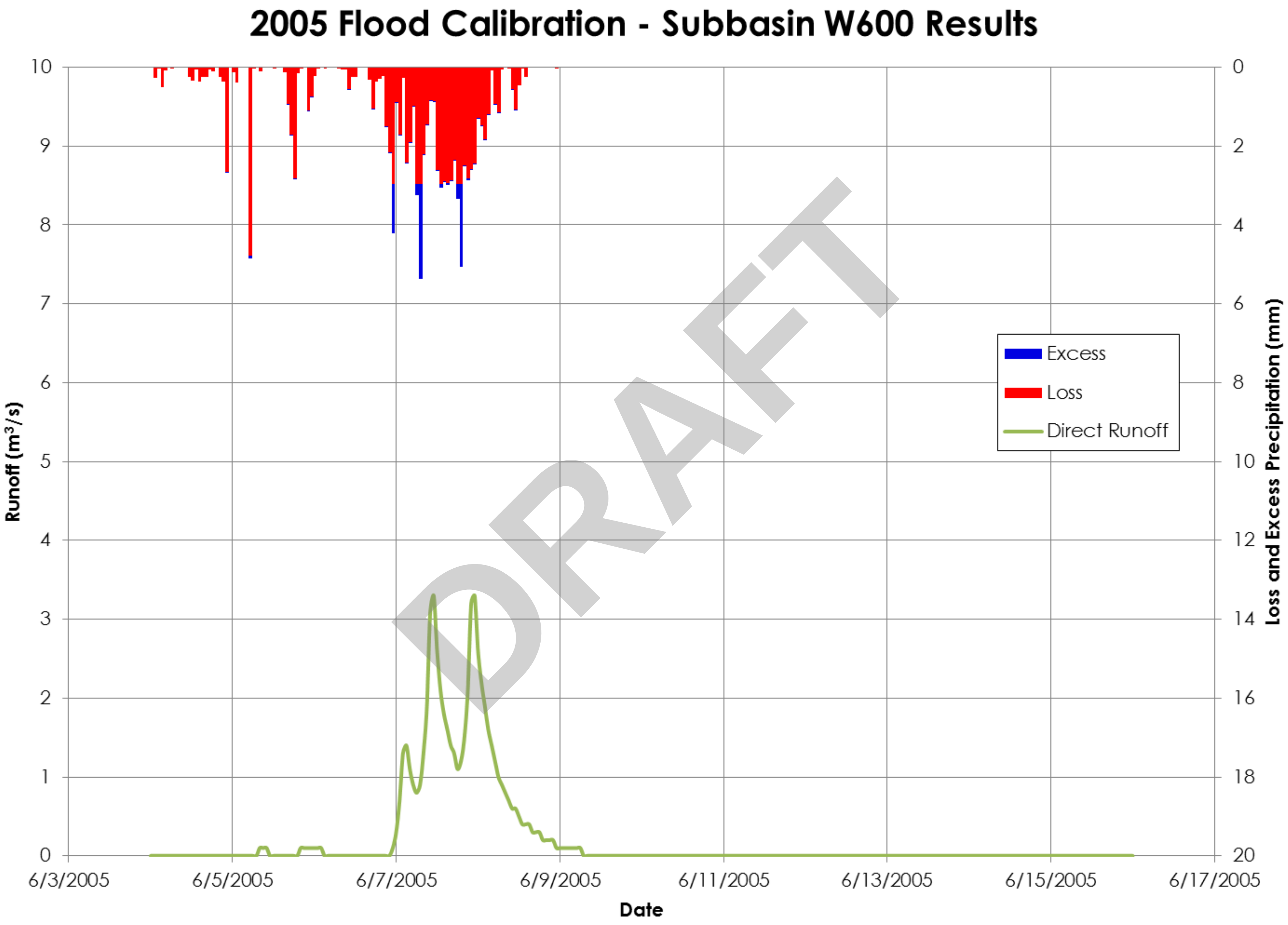

2005 Flood Calibration - Subbasin W600 Results
Runoff (m³/s)
0
1
2
3
4
5
6
7
8
9
10
Loss and Excess Precipitation (mm)
0
2
4
6
8
10
12
14
16
18
20
Excess
Loss
Direct Runoff
6/3/2005
6/5/2005
6/7/2005
6/9/2005
6/11/2005
6/13/2005
6/15/2005
6/17/2005
Date

Figure C.11

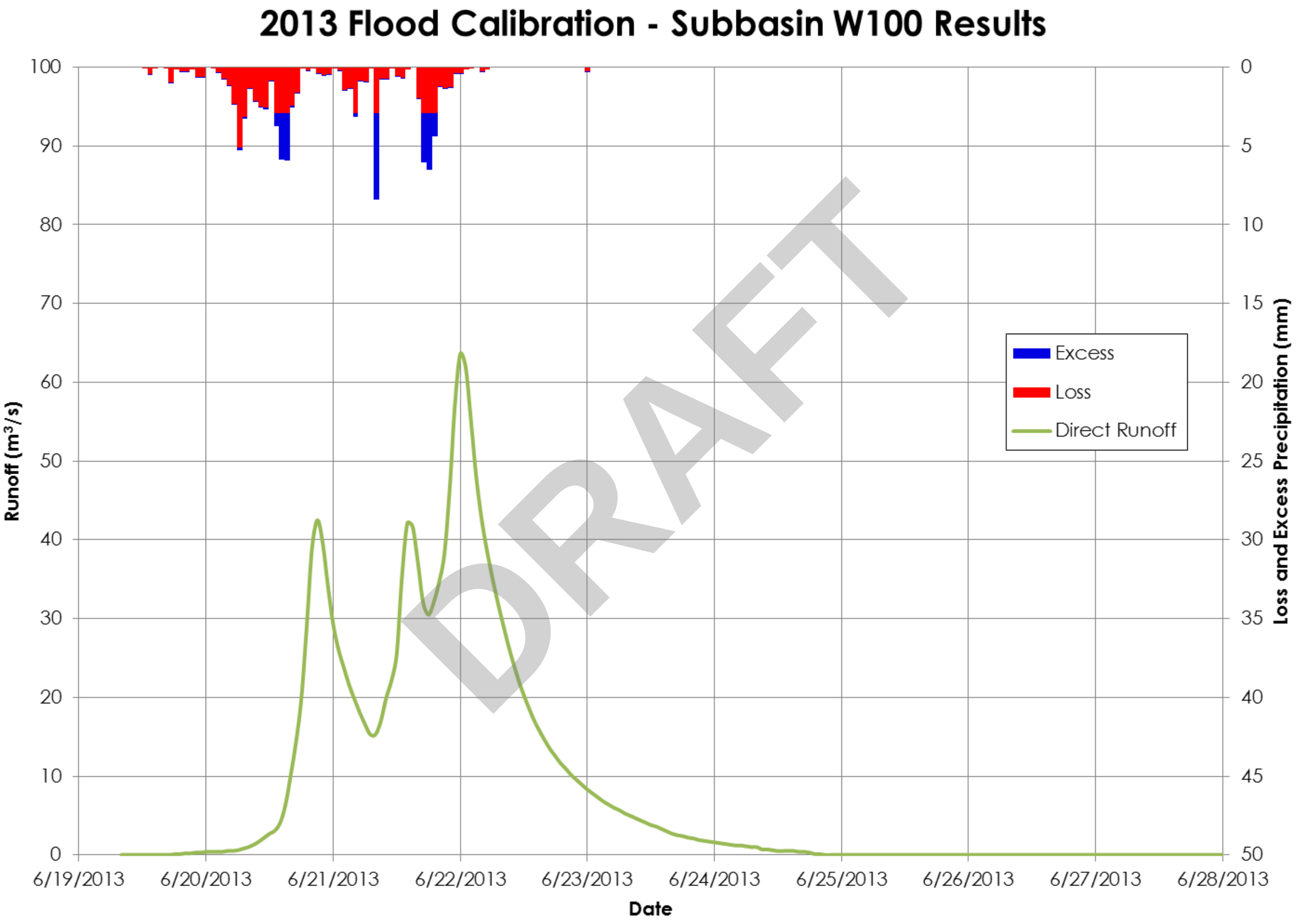

2013 Flood Calibration - Subbasin W100 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.12

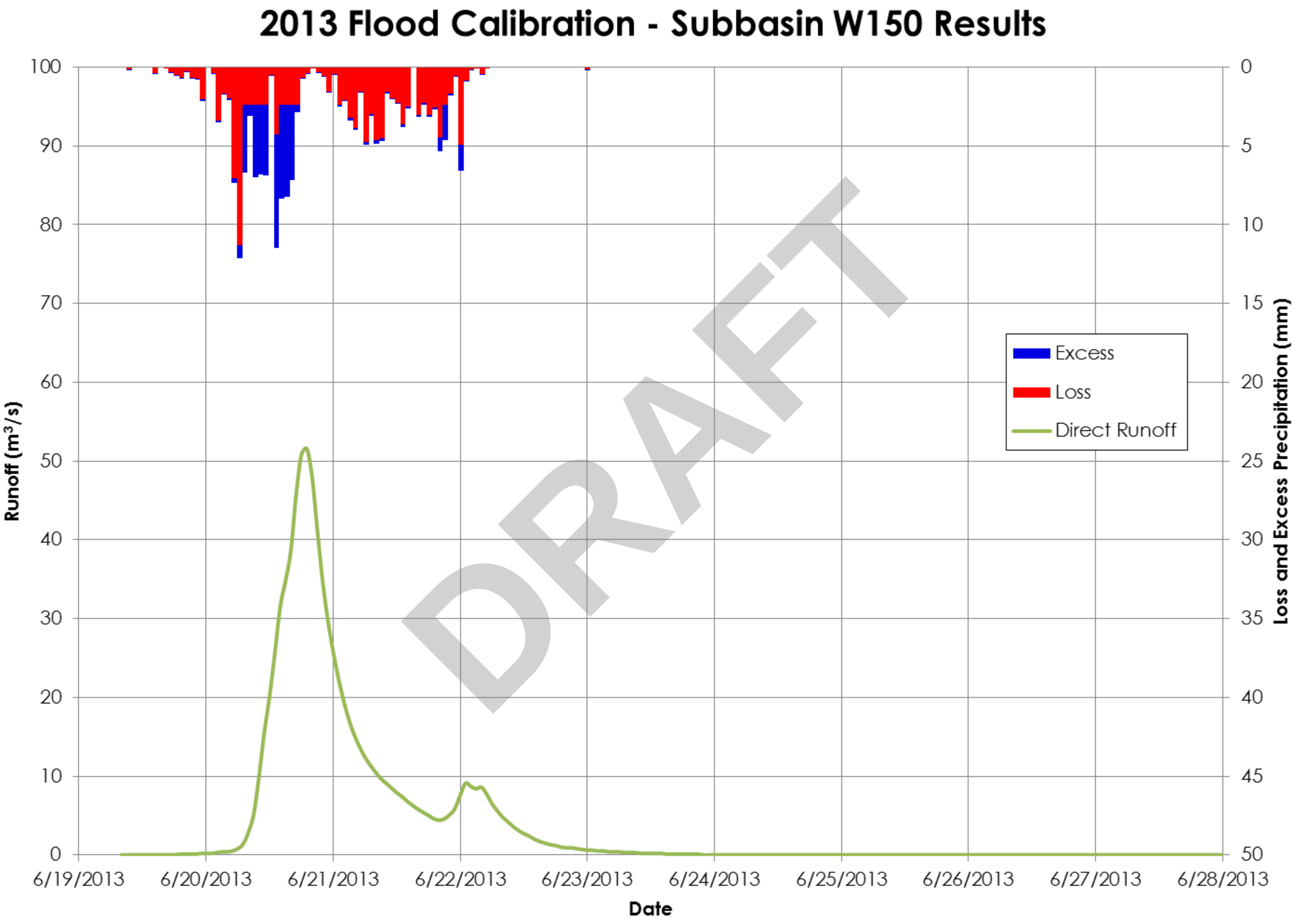

2013 Flood Calibration - Subbasin W150 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.13

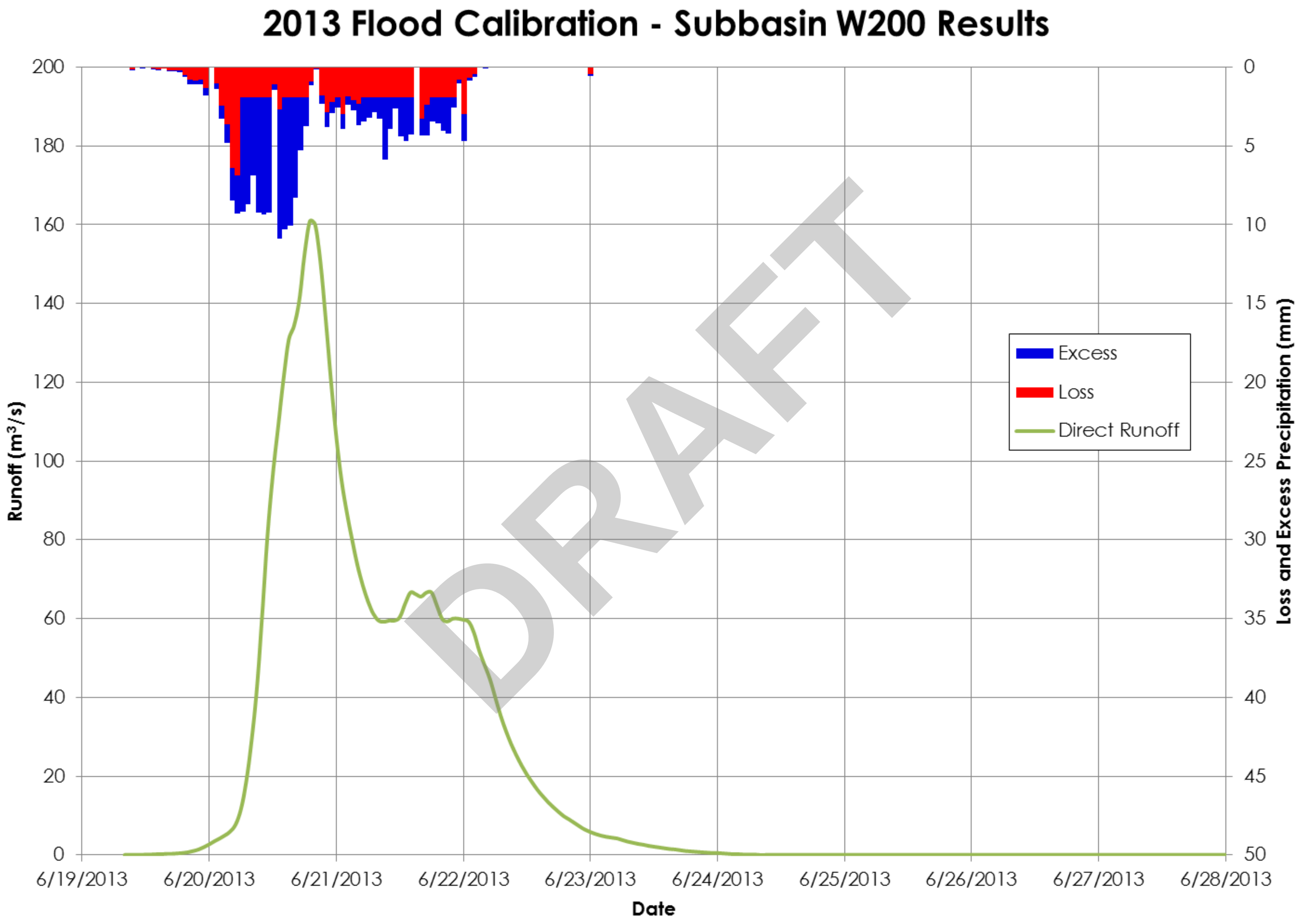

2013 Flood Calibration - Subbasin W200 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.14

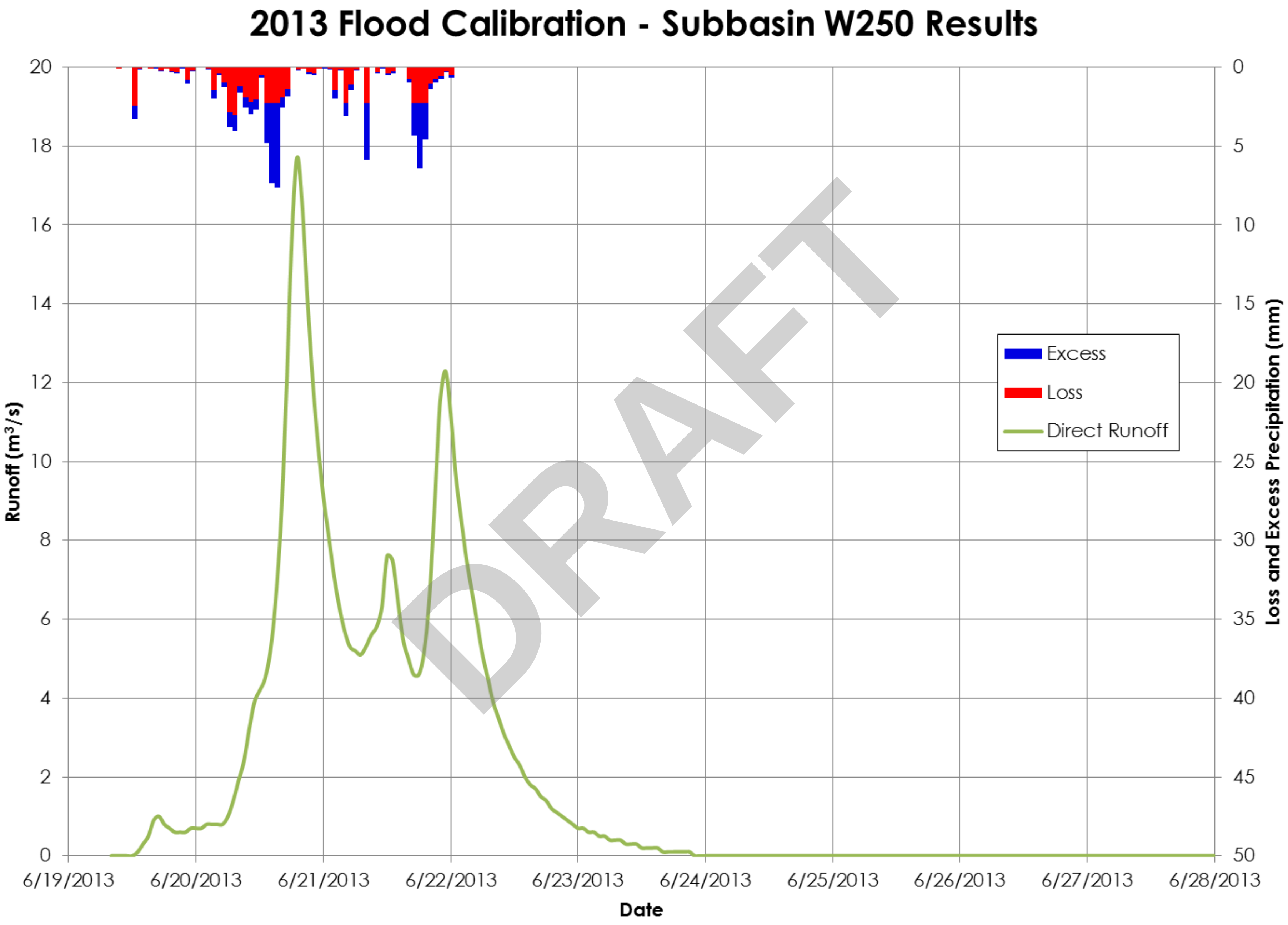

2013 Flood Calibration - Subbasin W250 Results
Runoff (m³/s)
20
18
16
14
12
10
8
6
4
2
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.15

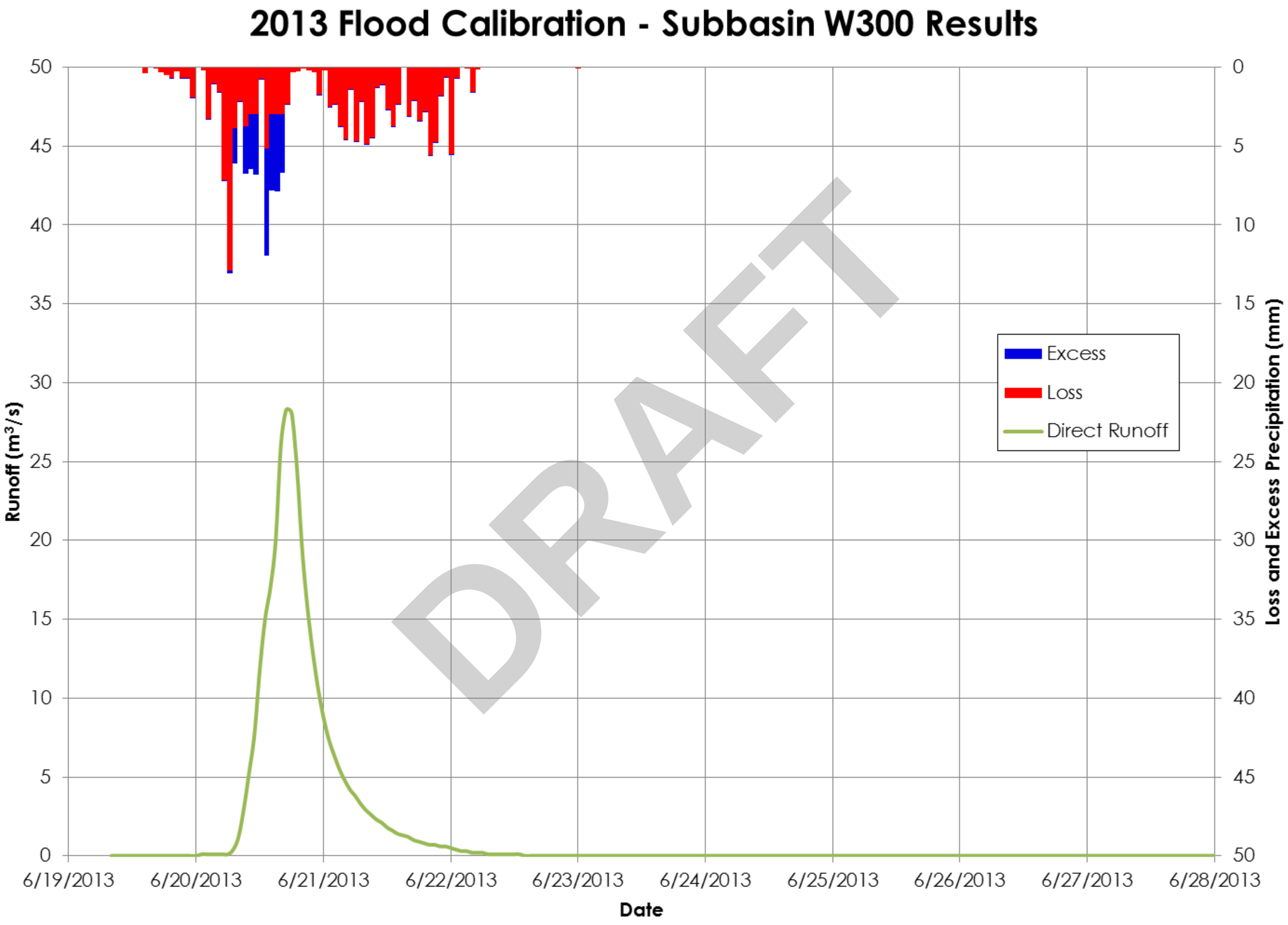

2013 Flood Calibration - Subbasin W300 Results
Runoff (m³/s)
50
45
40
35
30
25
20
15
10
5
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date
Excess
Loss
Direct Runoff

Figure C.16

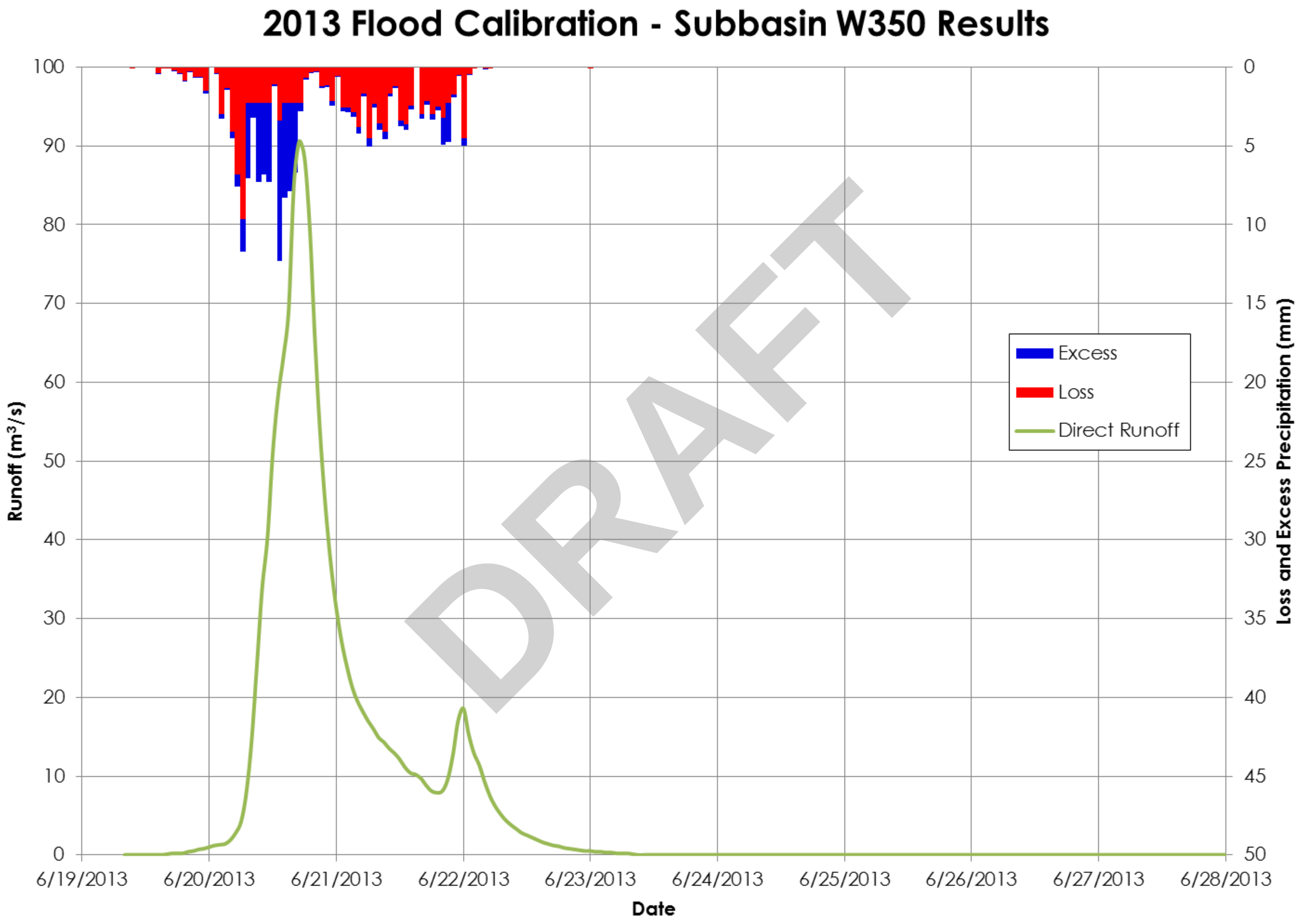

2013 Flood Calibration - Subbasin W350 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Date
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Excess
Loss
Direct Runoff

Figure C.17

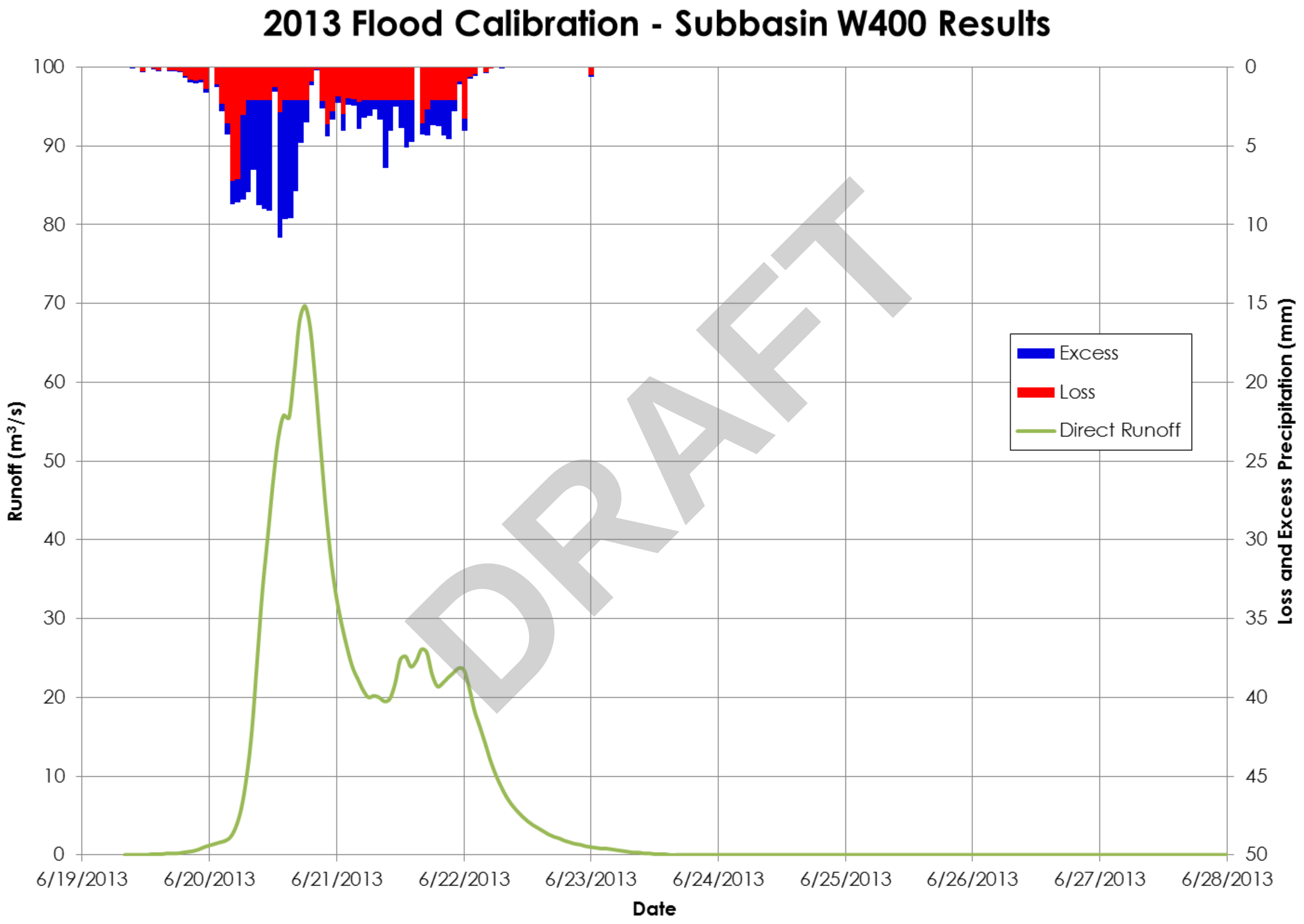

2013 Flood Calibration - Subbasin W400 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.18

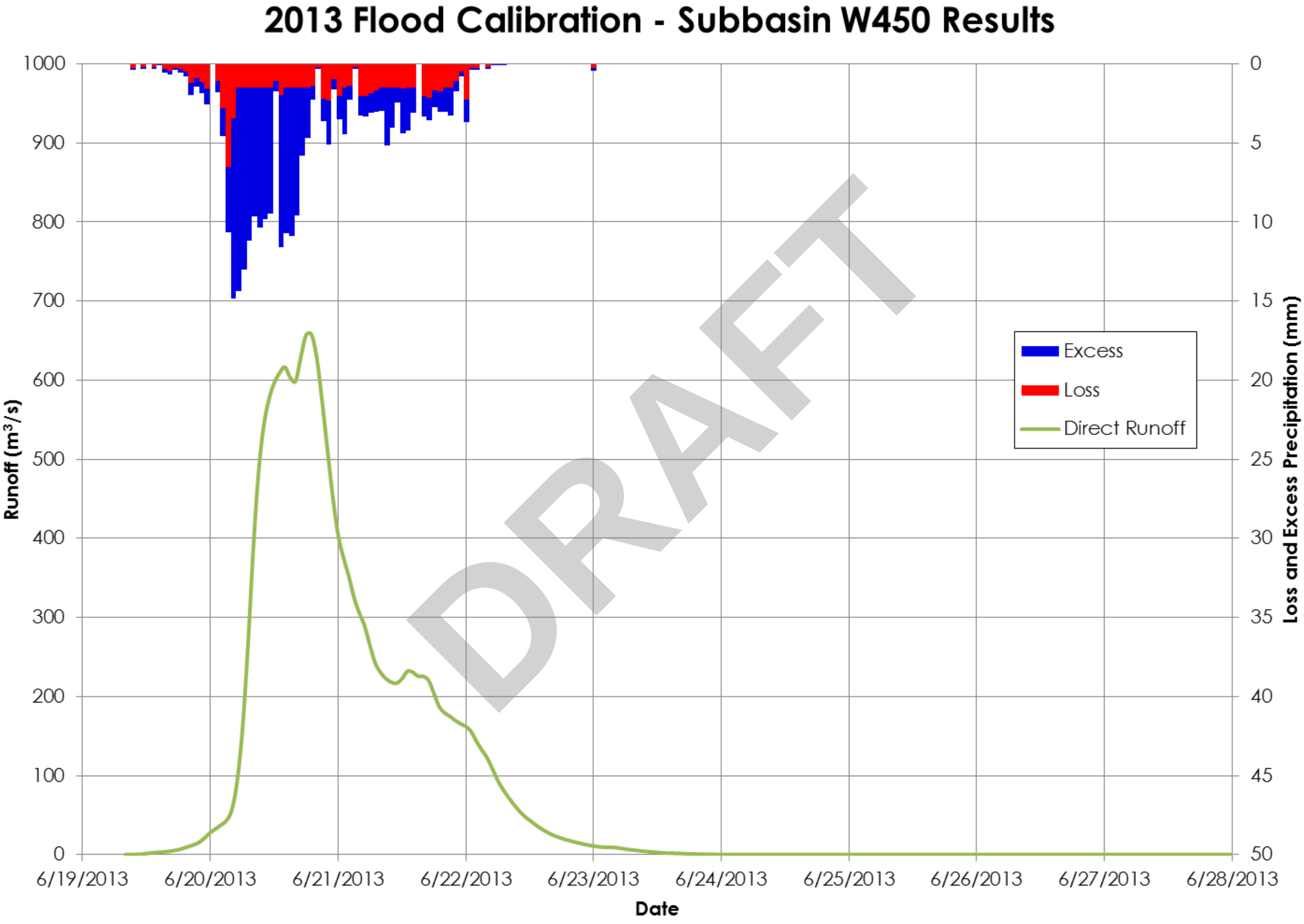

2013 Flood Calibration - Subbasin W450 Results
Runoff (m³/s)
1000
900
800
700
600
500
400
300
200
100
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.19

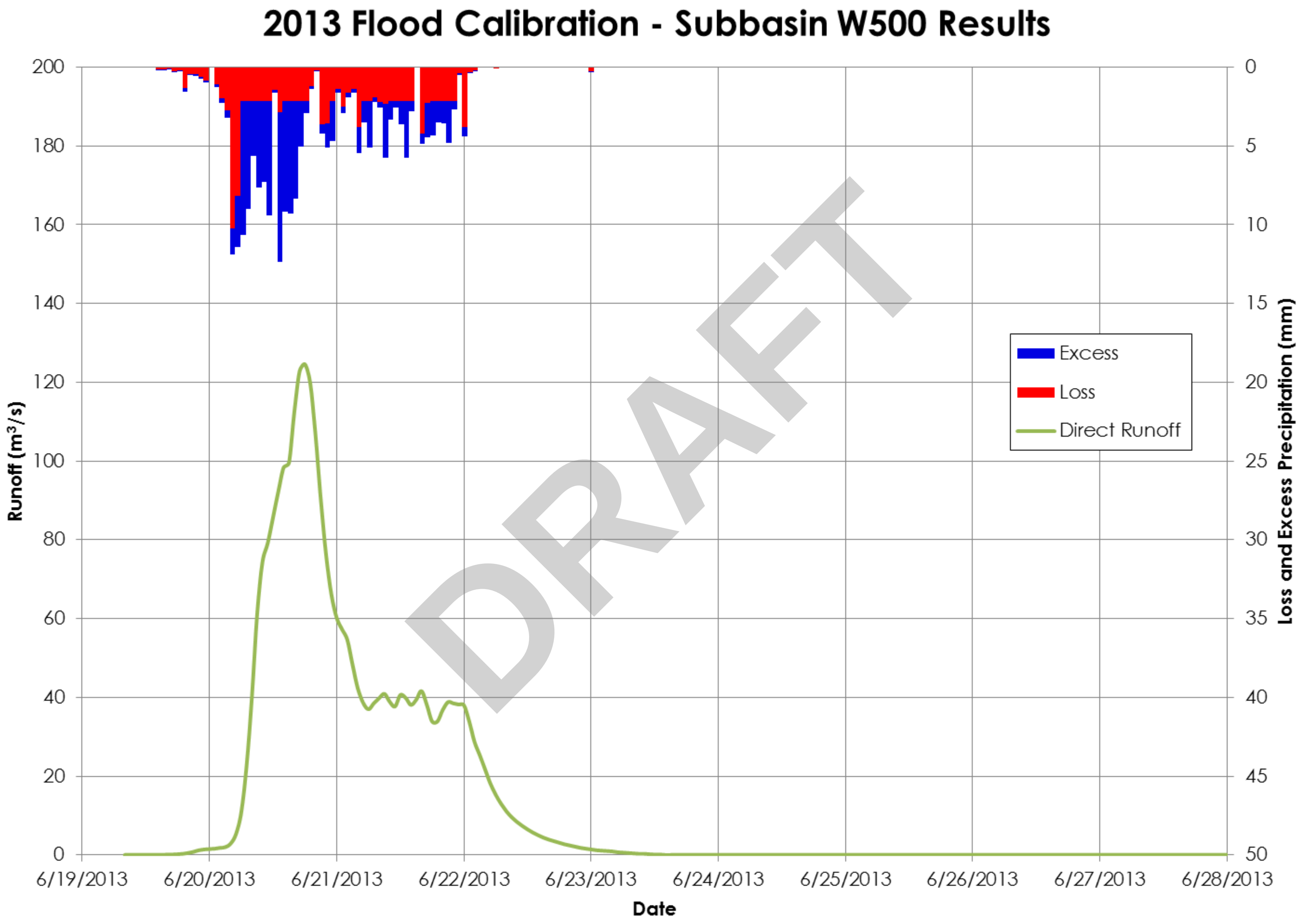

2013 Flood Calibration - Subbasin W500 Results
Runoff (m³/s)
Loss and Excess Precipitation (mm)
Date
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Excess
Loss
Direct Runoff

Figure C.20

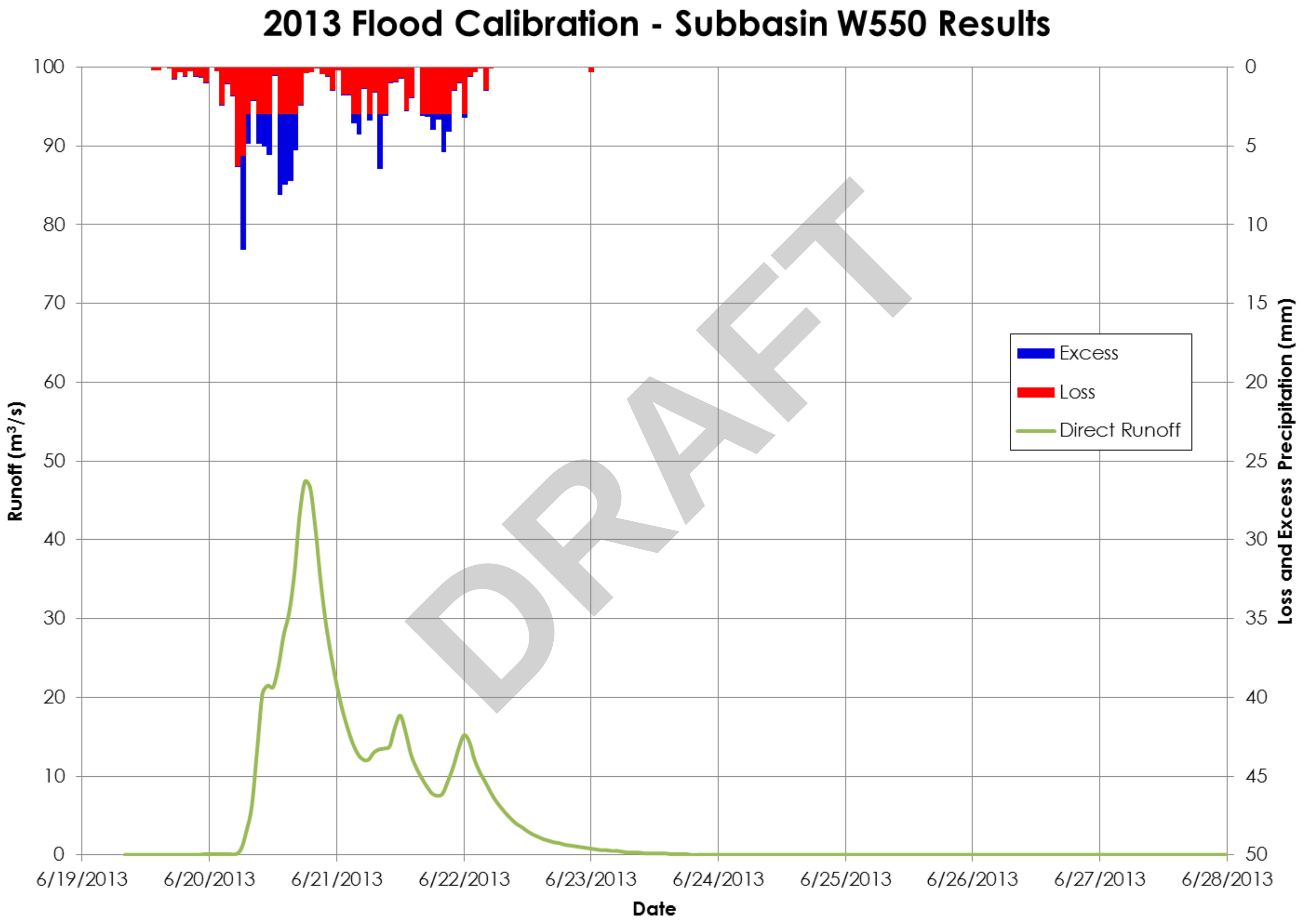

2013 Flood Calibration - Subbasin W550 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.21

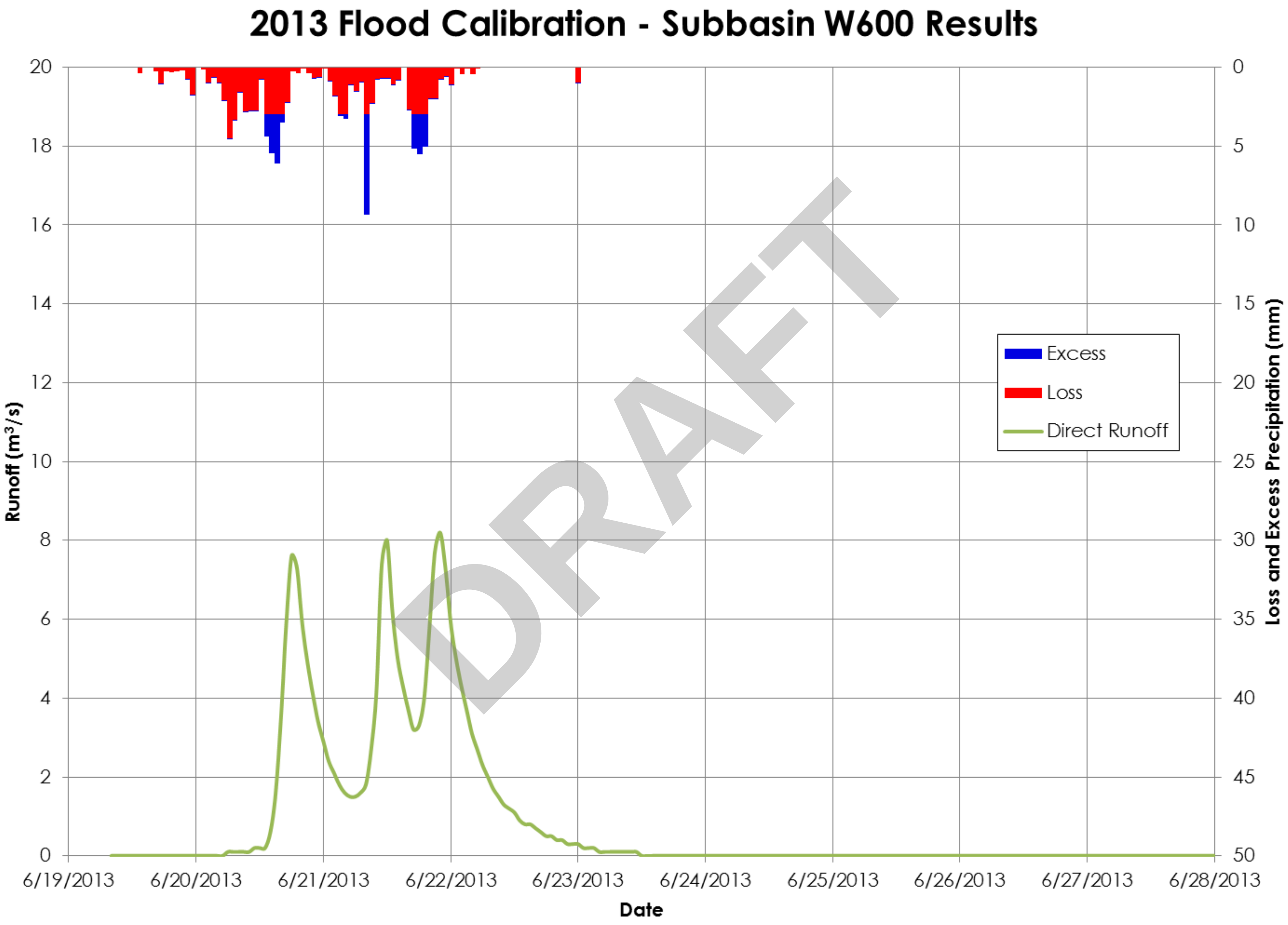

2013 Flood Calibration - Subbasin W600 Results
Runoff (m³/s)
20
18
16
14
12
10
8
6
4
2
0
Loss and Excess Precipitation (mm)
0
5
10
15
20
25
30
35
40
45
50
Excess
Loss
Direct Runoff
6/19/2013
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
Date

Figure C.22

APPENDIX D

PROBABLE MAXIMUM PRECIPIATION FIGURES

863 km^2 general storm PMP averaged by sub-basin for the region upstream of SR1 diversion. The gridded PMP follows the spatial pattern of the orographic and moisture transposition factors of the conrtolling storms and has not been re-distributed. Grid cells along the basin boundary with their centroids outside the basin are not included in the averages.

Sub-basin Name	Sub-basin ID	Sub-basin Area	1-hr PMP (mm)	6-hr PMP (mm)	12-hr PMP (mm)	24-hr PMP (mm)	48-hr PMP (mm)
W150	46	58 km^2	39	137	220	311	351
W200	47	121 km^2	40	134	238	350	395
W300	49	34 km^2	40	143	225	316	357
W350	52	81 km^2	36	123	220	323	365
W400	53	50 km^2	40	134	238	350	395
W450	55	353 km^2	44	149	267	391	442
W500	56	89 km^2	39	133	238	349	394
W550	73	77 km^2	49	176	243	320	363

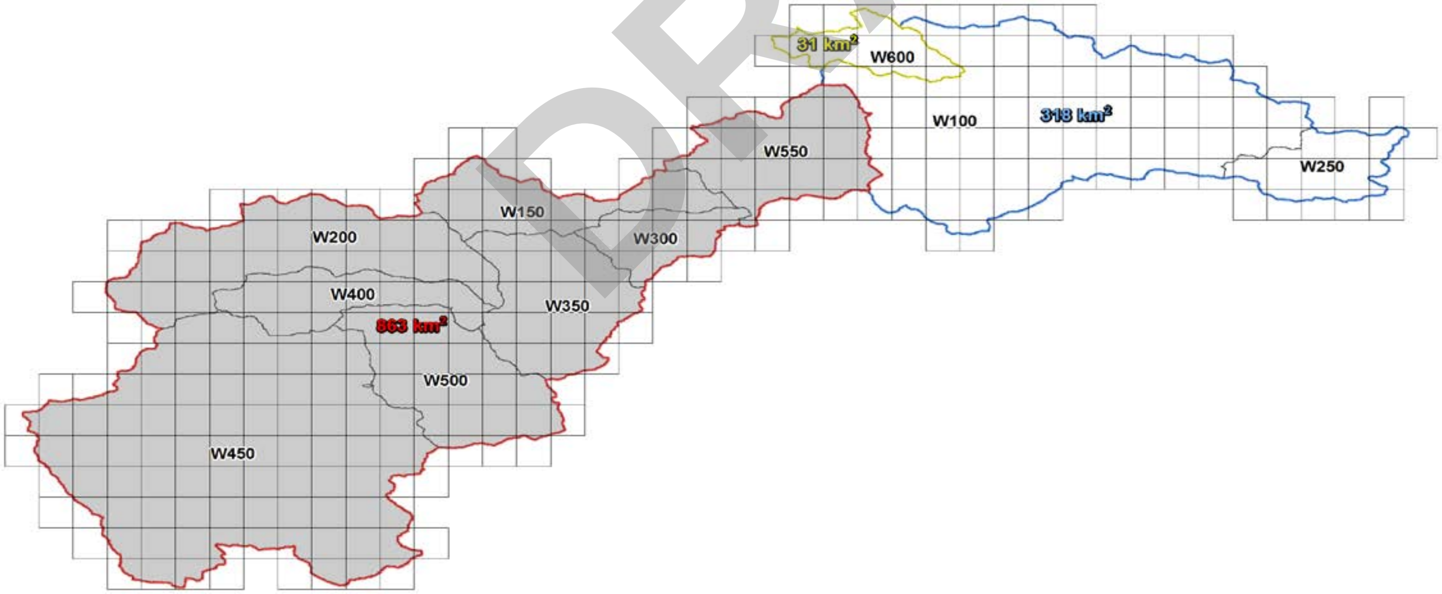


Figure E.1

1,212 km^2 general storm PMP averaged by sub-basin. The gridded PMP follows the spatial pattern of the orographic and moisture transposition factors of the conrtolling storms and has not been re-distributed. Grid cells along the basin boundary with their centroids outside the basin are not included in the averages.

Sub-basin Name	Sub-basin ID	Sub-basin Area	1-hr PMP (mm)	6-hr PMP (mm)	12-hr PMP (mm)	24-hr PMP (mm)	48-hr PMP (mm)
W100	45	278 km^2	47	170	235	312	353
W150	46	58 km^2	38	130	212	301	341
W200	47	121 km^2	37	126	229	336	382
W250	82	40 km^2	45	161	222	294	333
W300	49	34 km^2	39	136	217	306	347
W350	52	81 km^2	34	116	212	311	353
W400	53	50 km^2	38	126	229	337	382
W450	55	353 km^2	42	141	256	376	427
W500	56	89 km^2	37	126	229	336	381
W550	73	77 km^2	48	171	236	313	354
W600	78	31 km^2	46	166	229	304	344

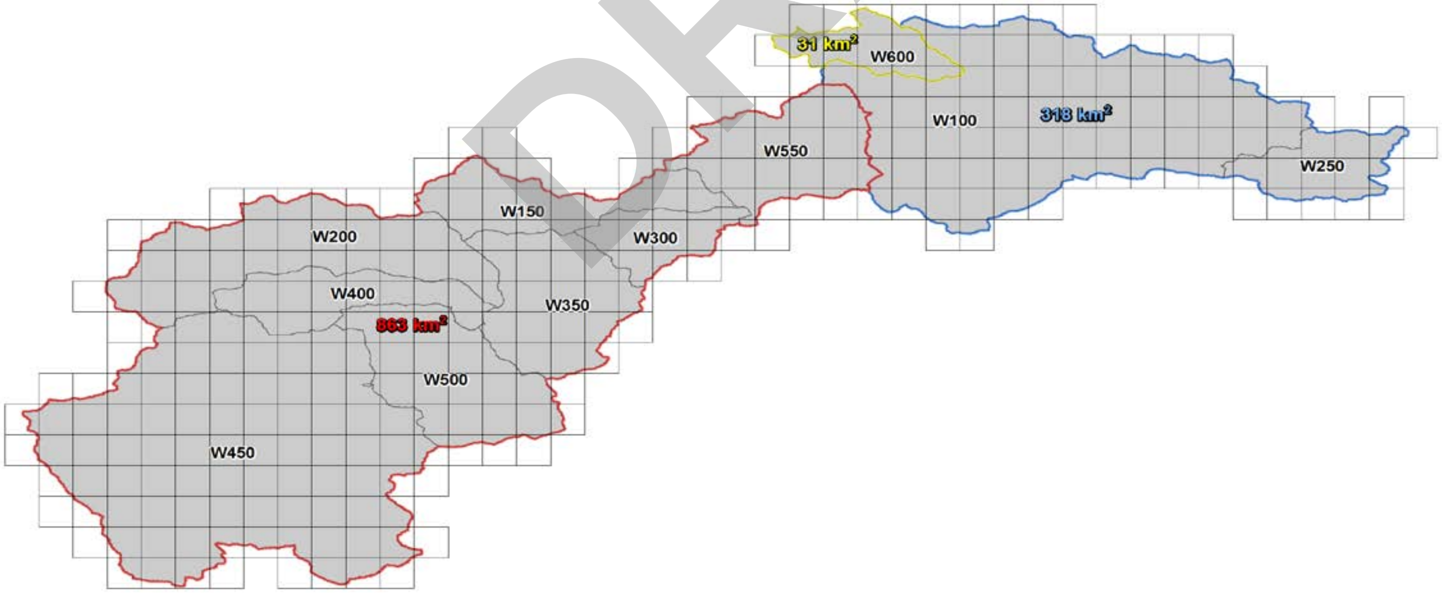


Figure E.2

Local storm point PMP averaged by sub-basin for the region upstream of SR1 diversion. The gridded maximum PMP is spatially re-distributed using the June 1966, Glen Ullin, ND (SPAS 1324) maximum 1-hour rainfall pattern centered over the basin. Grid cells along the basin boundary with their centroids outside the basin are not included in the averages.

Sub-basin Name	Sub-basin ID	Sub-basin Area	1-hr PMP (mm)	2-hr PMP (mm)	3-hr PMP (mm)	4-hr PMP (mm)	5-hr PMP (mm)	6-hr PMP (mm)
W150	46	58 km²	116	122	128	141	150	160
W200	47	121 km²	112	118	124	136	145	155
W300	49	34 km²	134	141	148	163	173	186
W350	52	81 km²	153	161	169	186	198	212
W400	53	50 km²	222	233	244	269	286	307
W450	55	353 km²	191	201	211	232	247	264
W500	56	89 km²	214	225	236	259	276	296
W550	73	77 km²	97	102	107	118	126	135

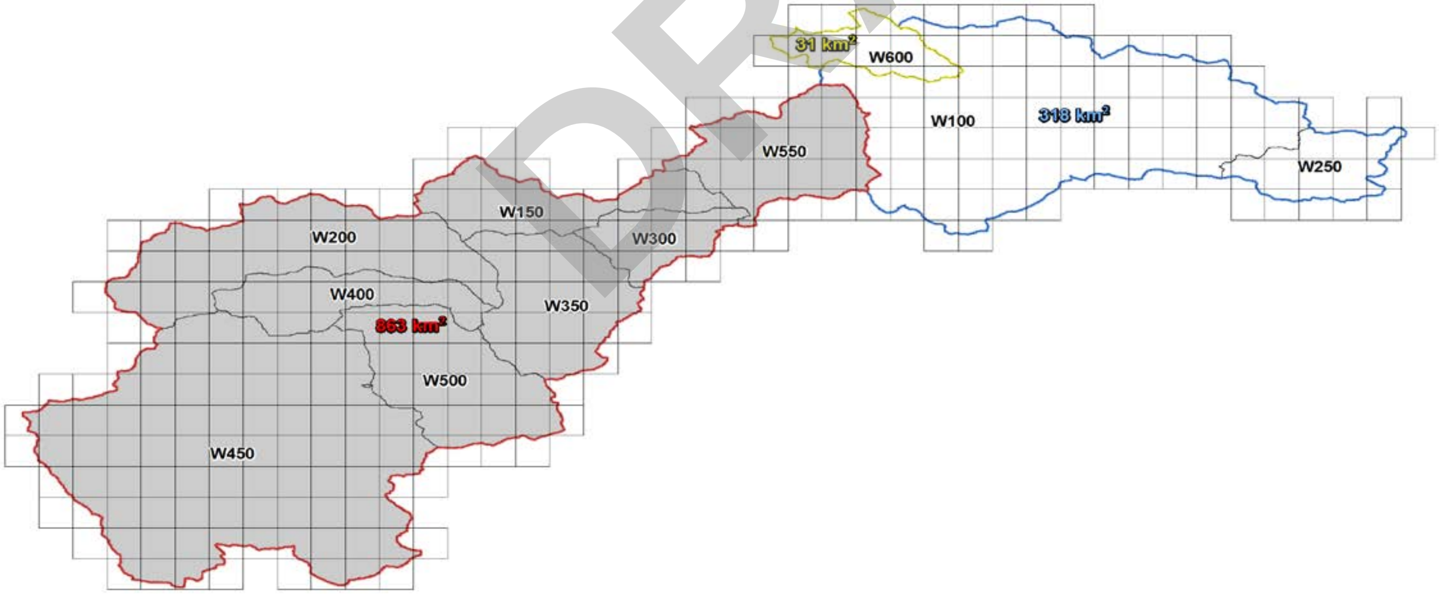


Figure E.3

31 km² local storm PMP averaged over the sub-basin region upstream of SR1 dam. Grid cells along the basin boundary with their centroids outside the basin are not included in the averages.

Sub-basin Name	Sub-basin ID	Sub-basin Area	1-hr PMP (mm)	2-hr PMP (mm)	3-hr PMP (mm)	4-hr PMP (mm)	5-hr PMP (mm)	6-hr PMP (mm)
W600	78	31 km²	157	195	228	245	264	286

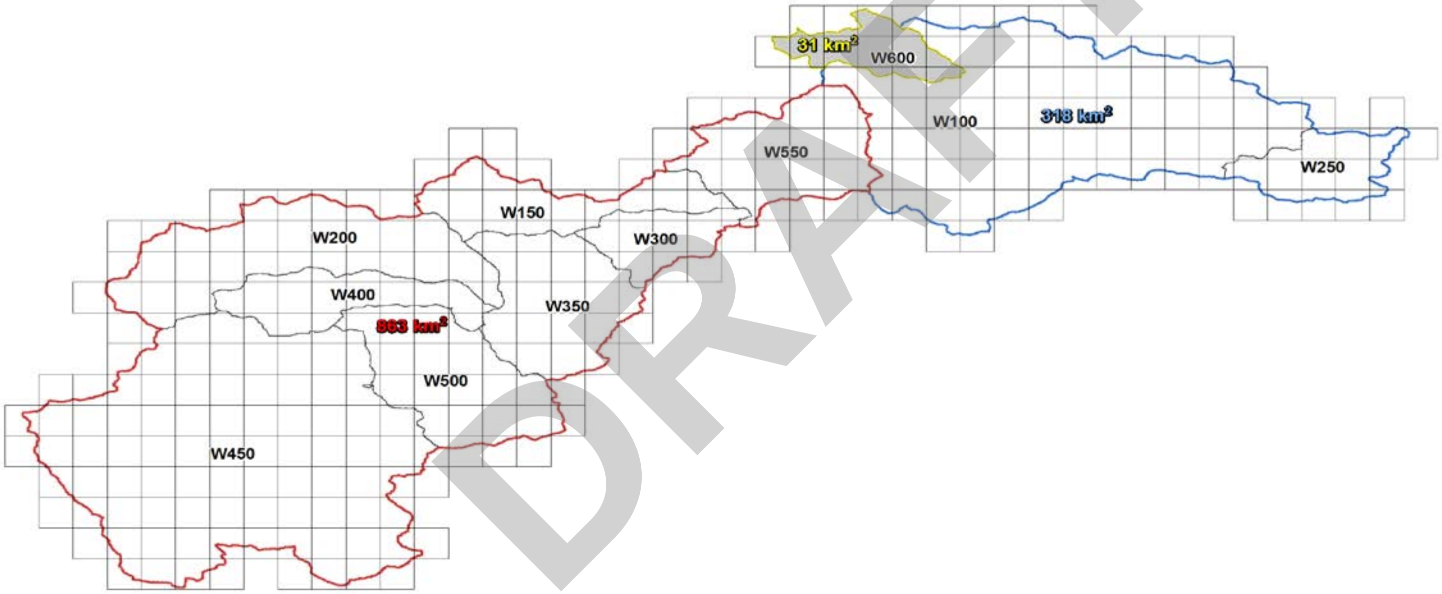


Figure E.4

APPENDIX E

PROBABLE MAXIMUM FLOOD WATER BALANCE FIGURES PER SUB-BASIN

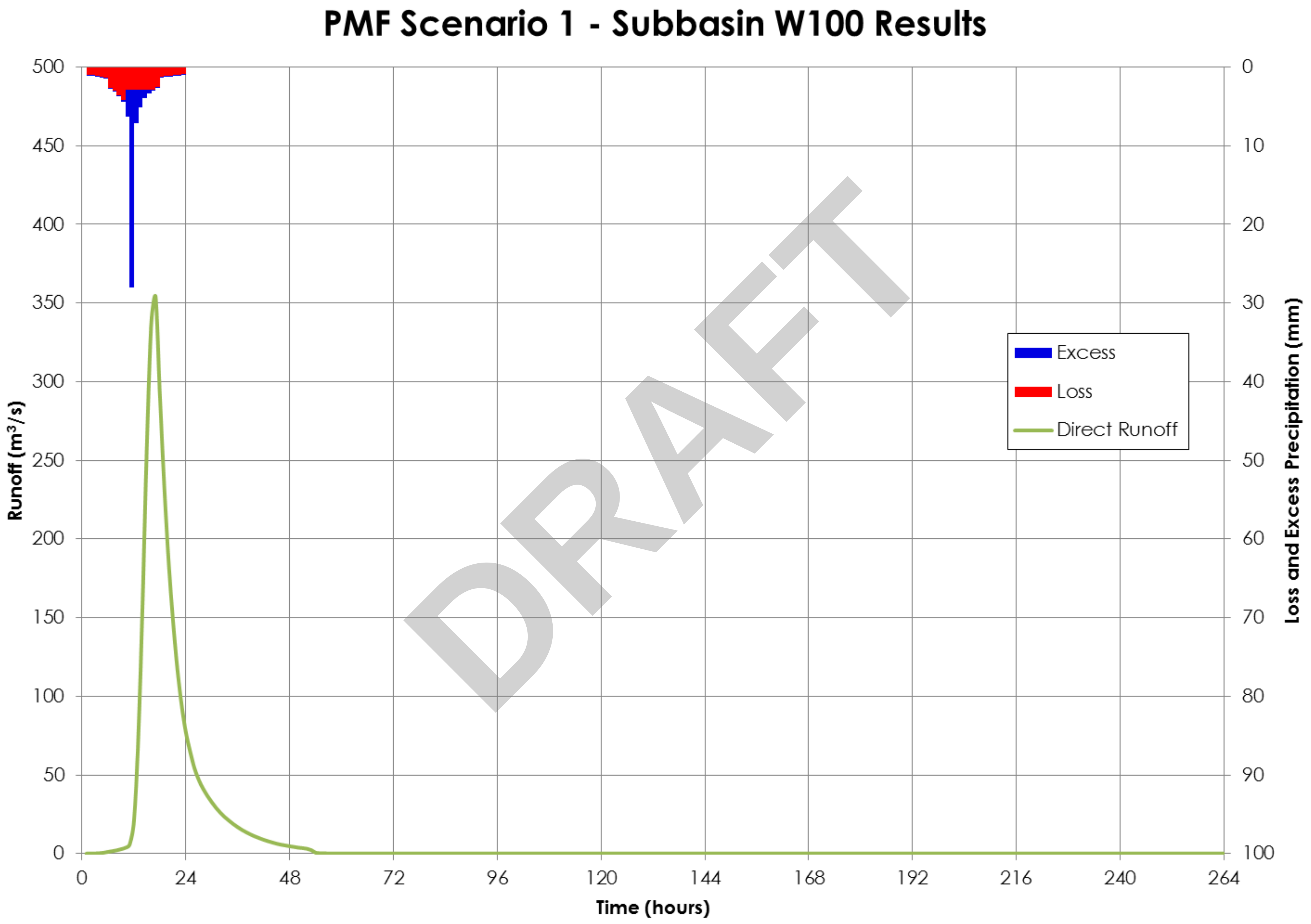

PMF Scenario 1 - Subbasin W100 Results
Runoff (m³/s)
500
450
400
350
300
250
200
150
100
50
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.1

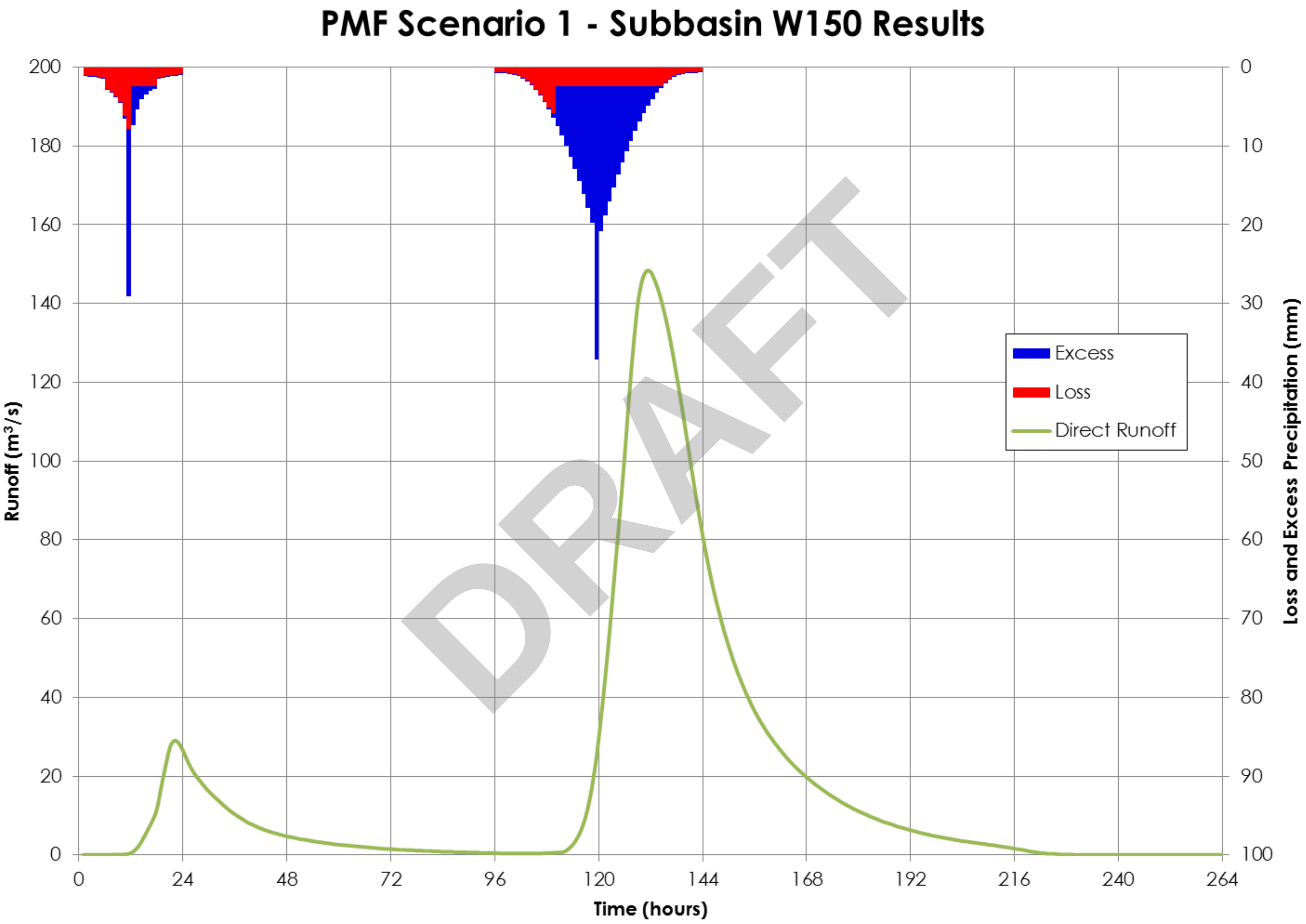

PMF Scenario 1 - Subbasin W150 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.2

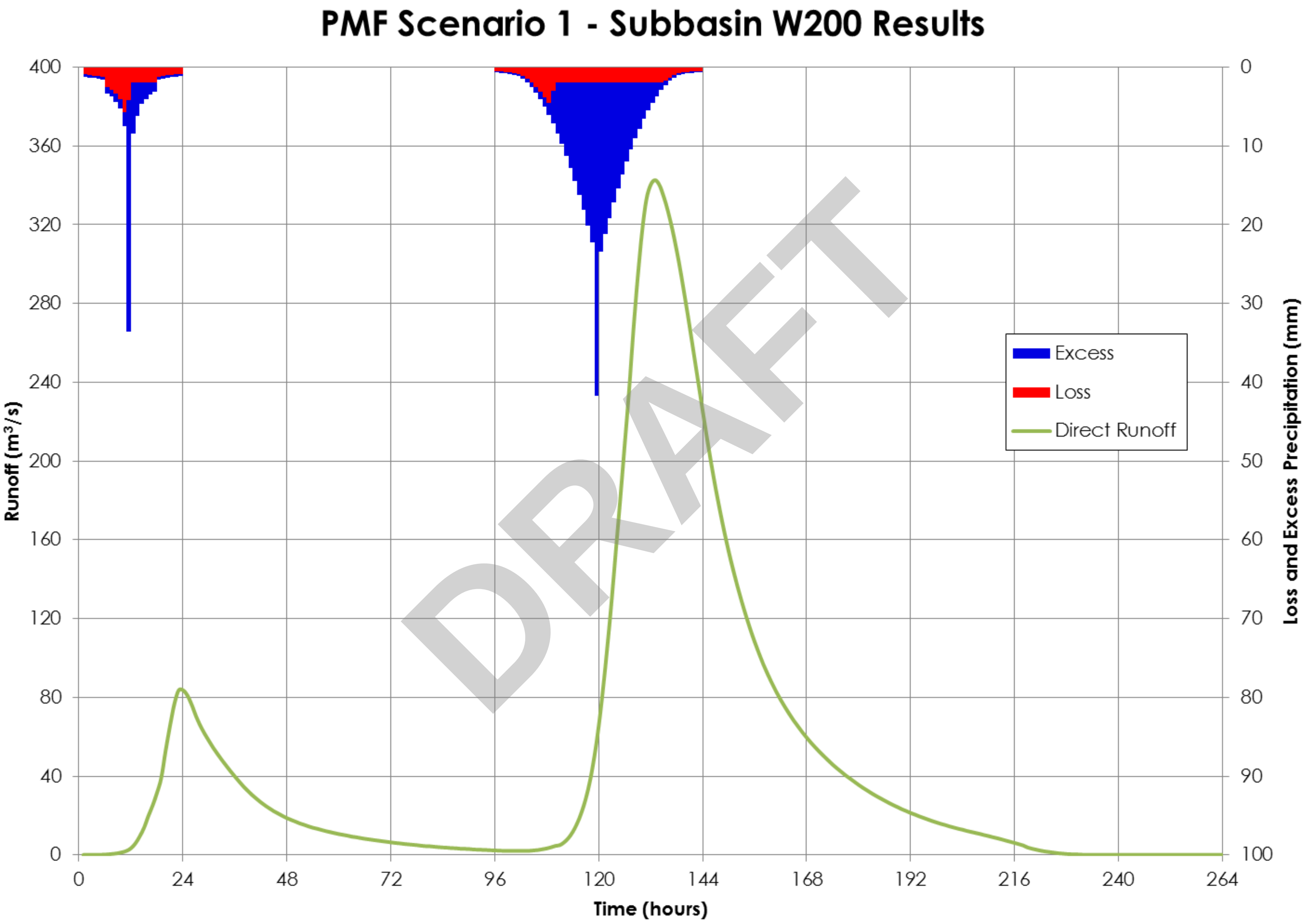

PMF Scenario 1 - Subbasin W200 Results
Runoff (m^3/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.3

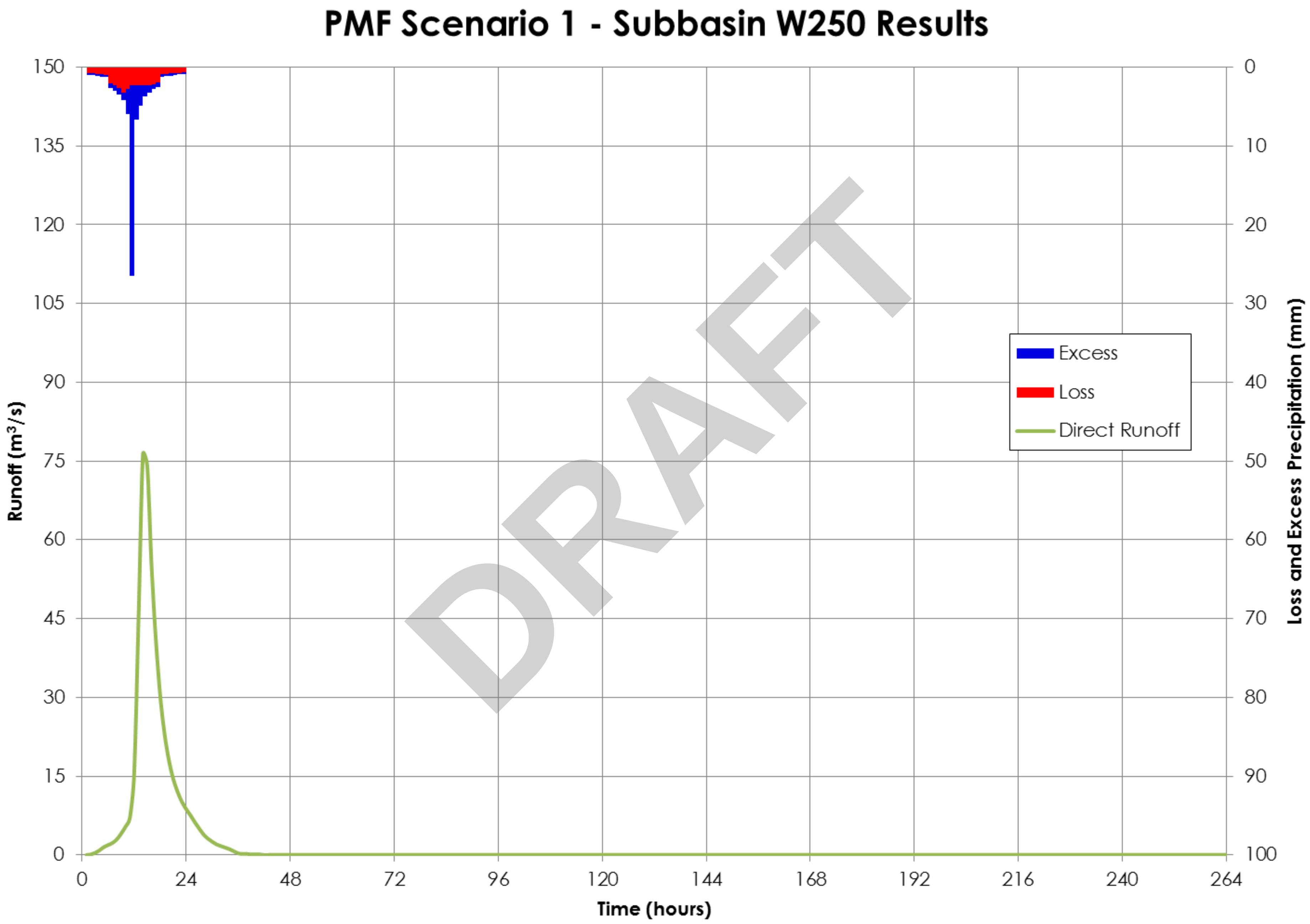

PMF Scenario 1 - Subbasin W250 Results
Runoff (m³/s)
150
135
120
105
90
75
60
45
30
15
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.4

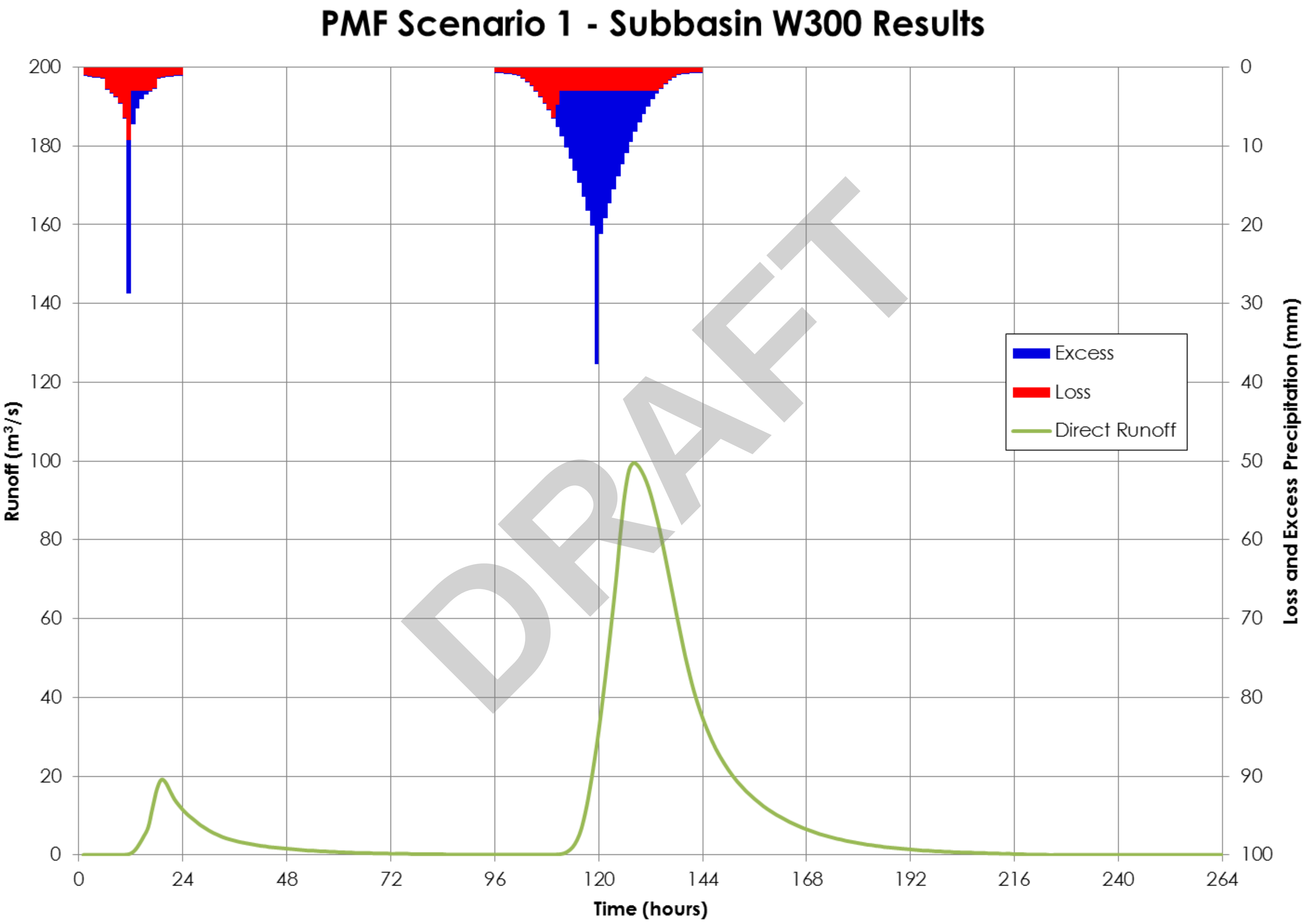

PMF Scenario 1 - Subbasin W300 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.5

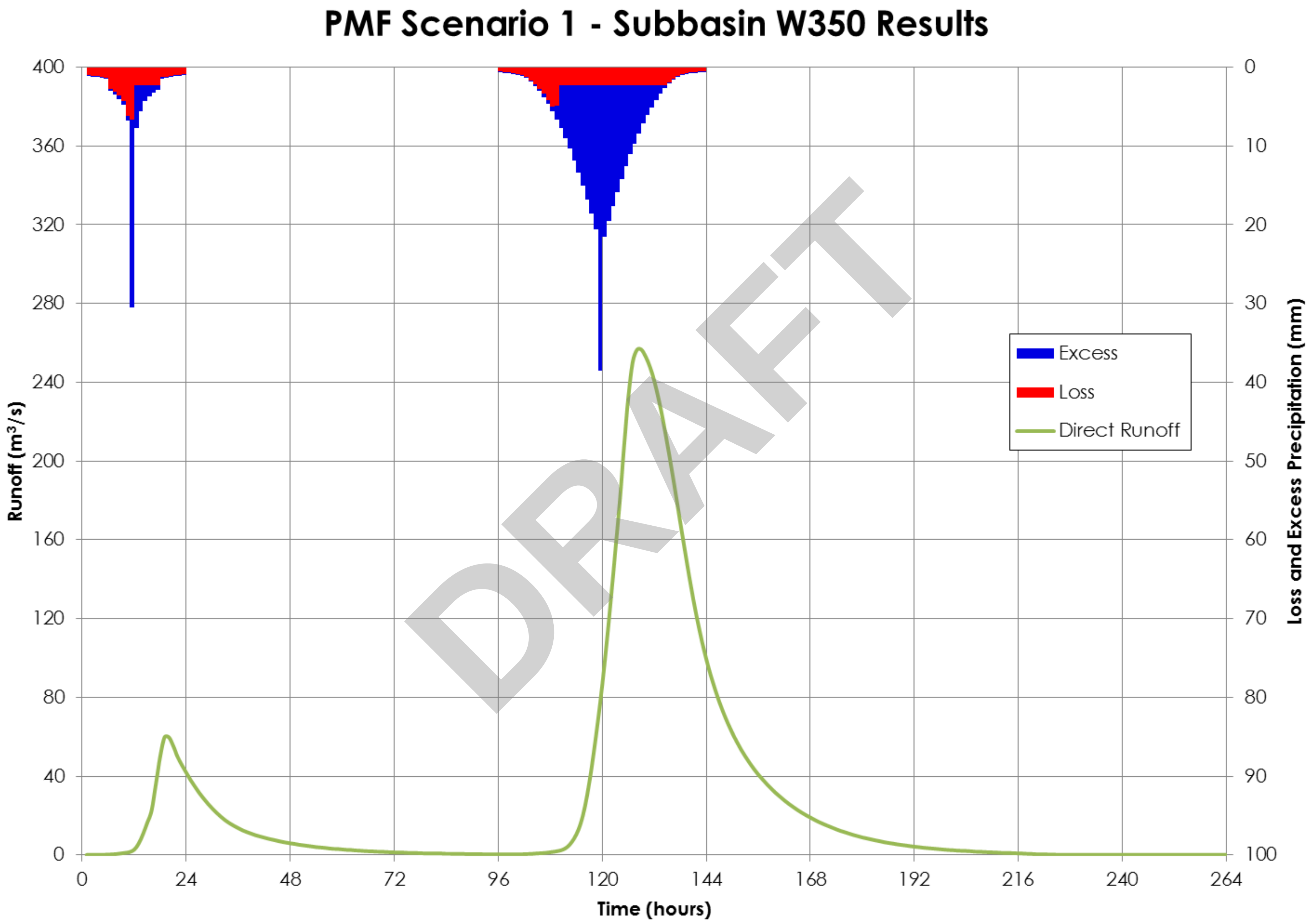

PMF Scenario 1 - Subbasin W350 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff
DRAFT

Figure F.6

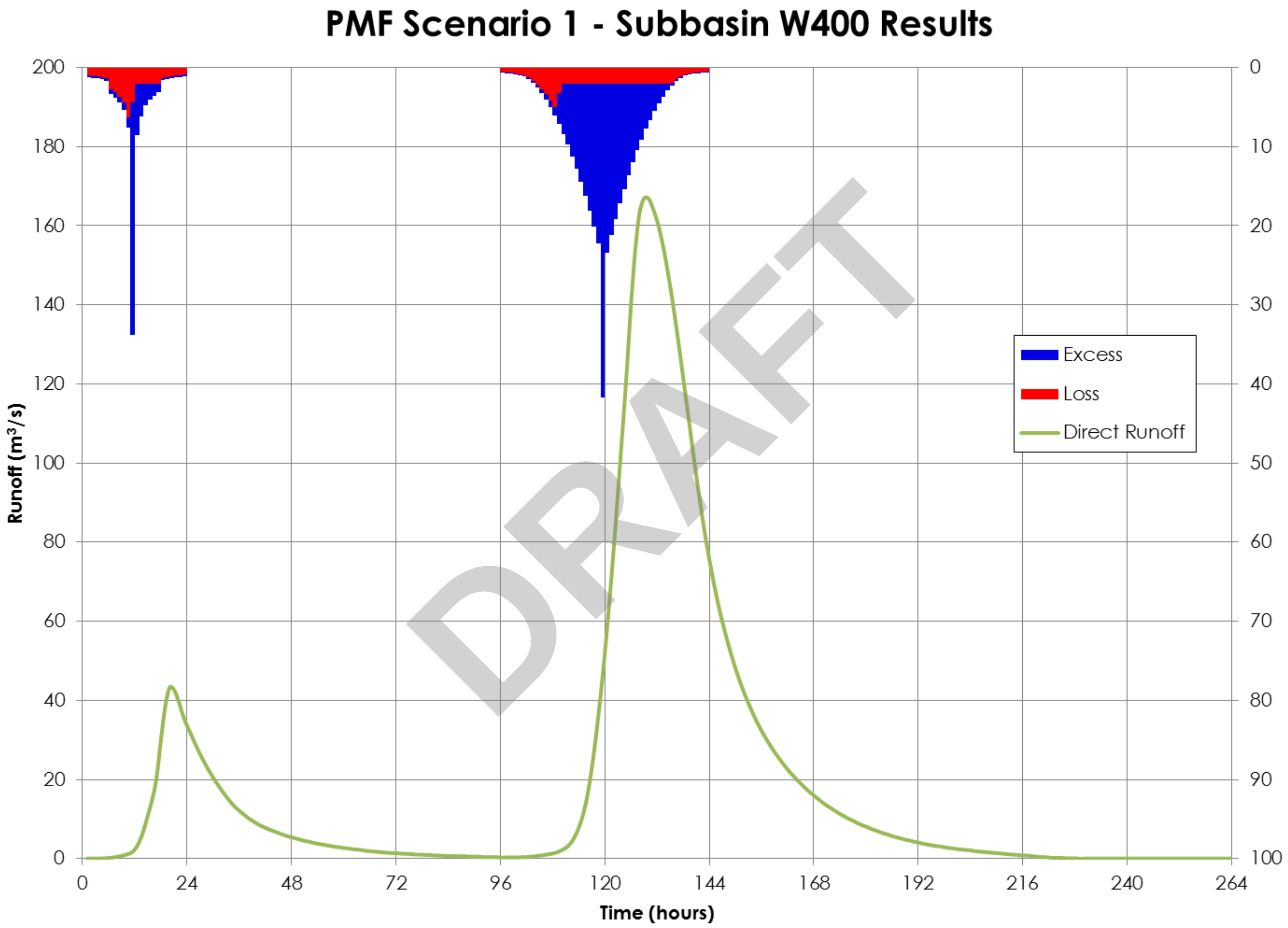

PMF Scenario 1 - Subbasin W400 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.7

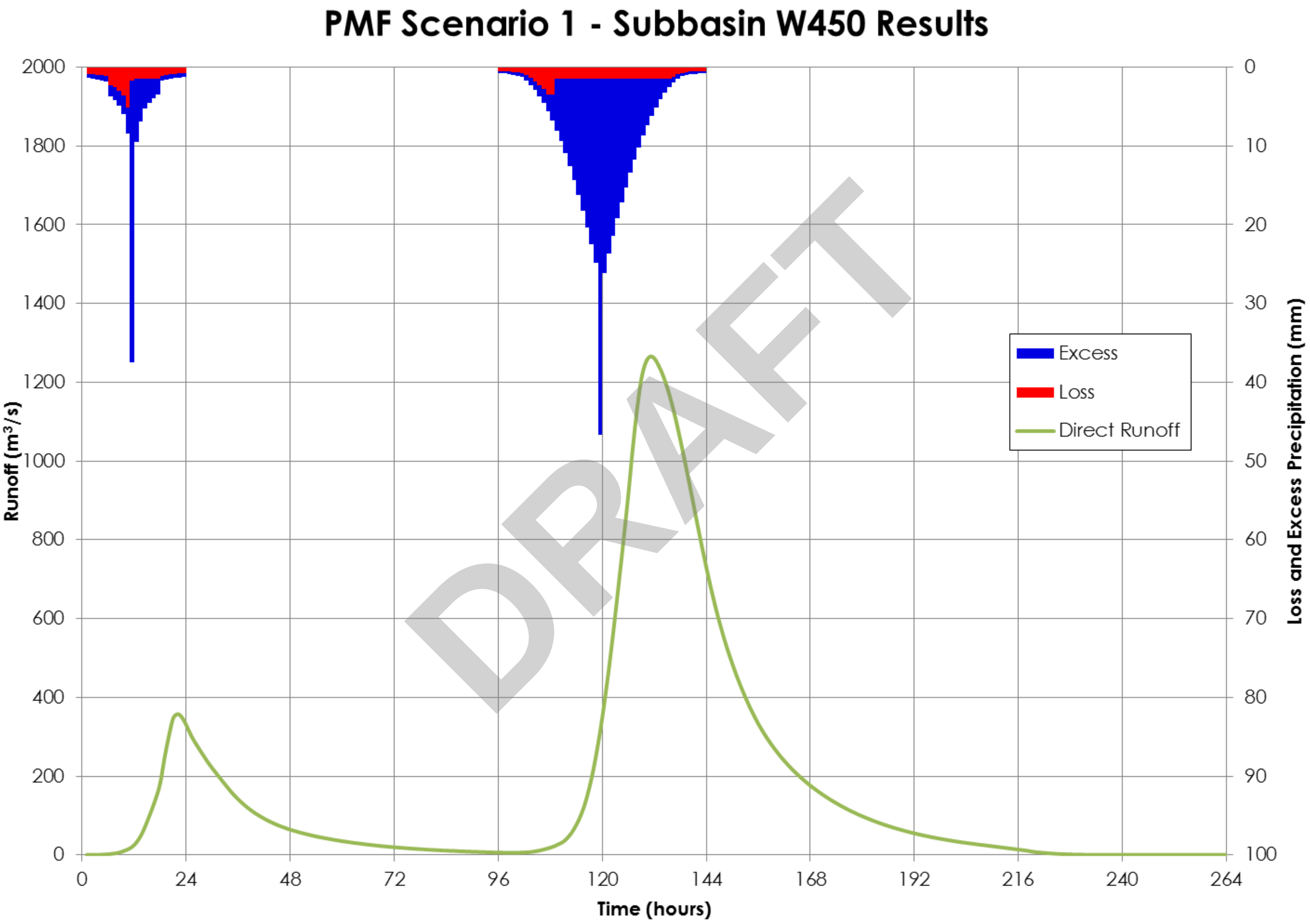

PMF Scenario 1 - Subbasin W450 Results
Runoff (m³/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.8

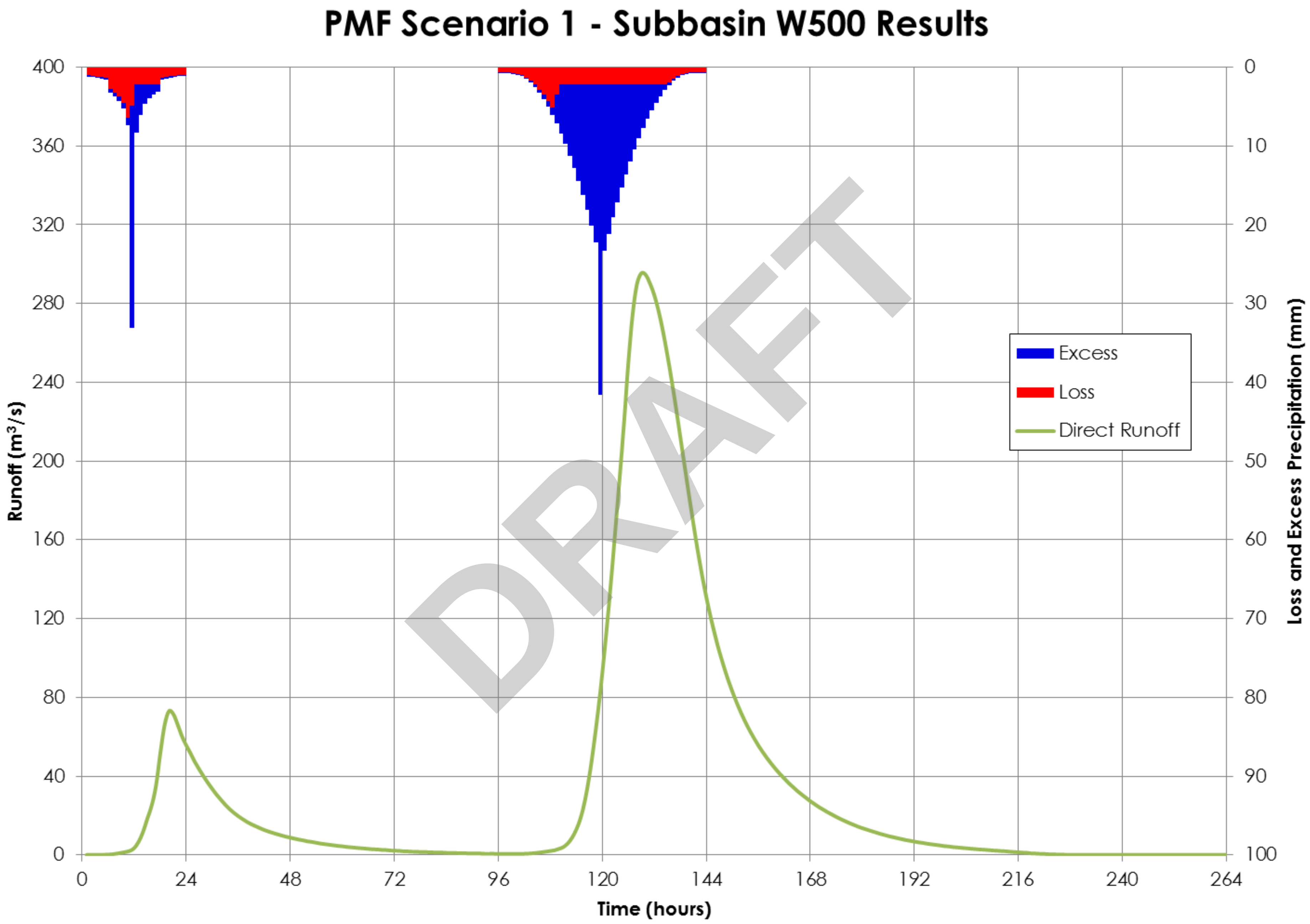
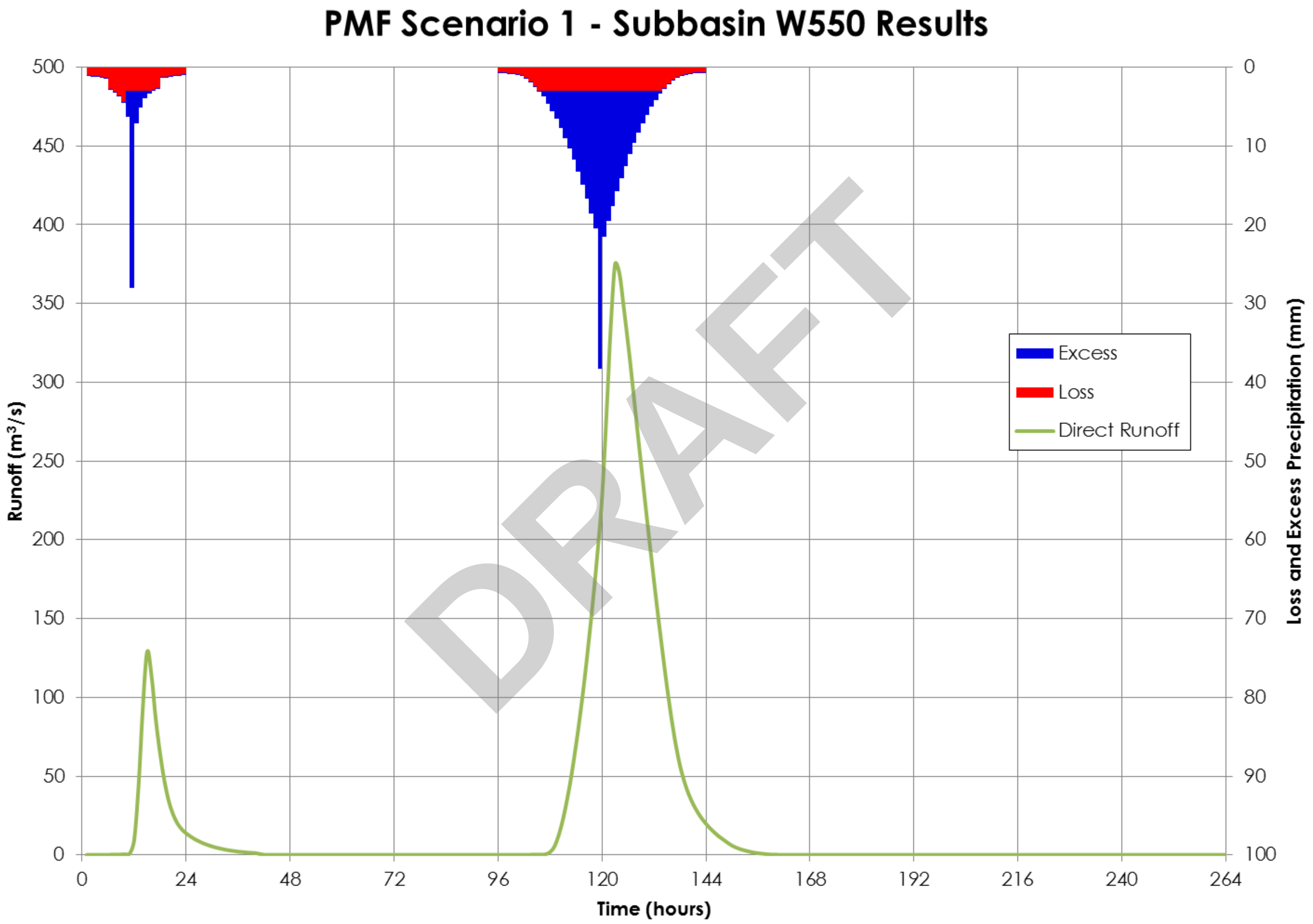

PMF Scenario 1 - Subbasin W500 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.9



PMF Scenario 1 - Subbasin W550 Results
Runoff (m³/s)
Loss and Excess Precipitation (mm)
Time (hours)
500
450
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.10

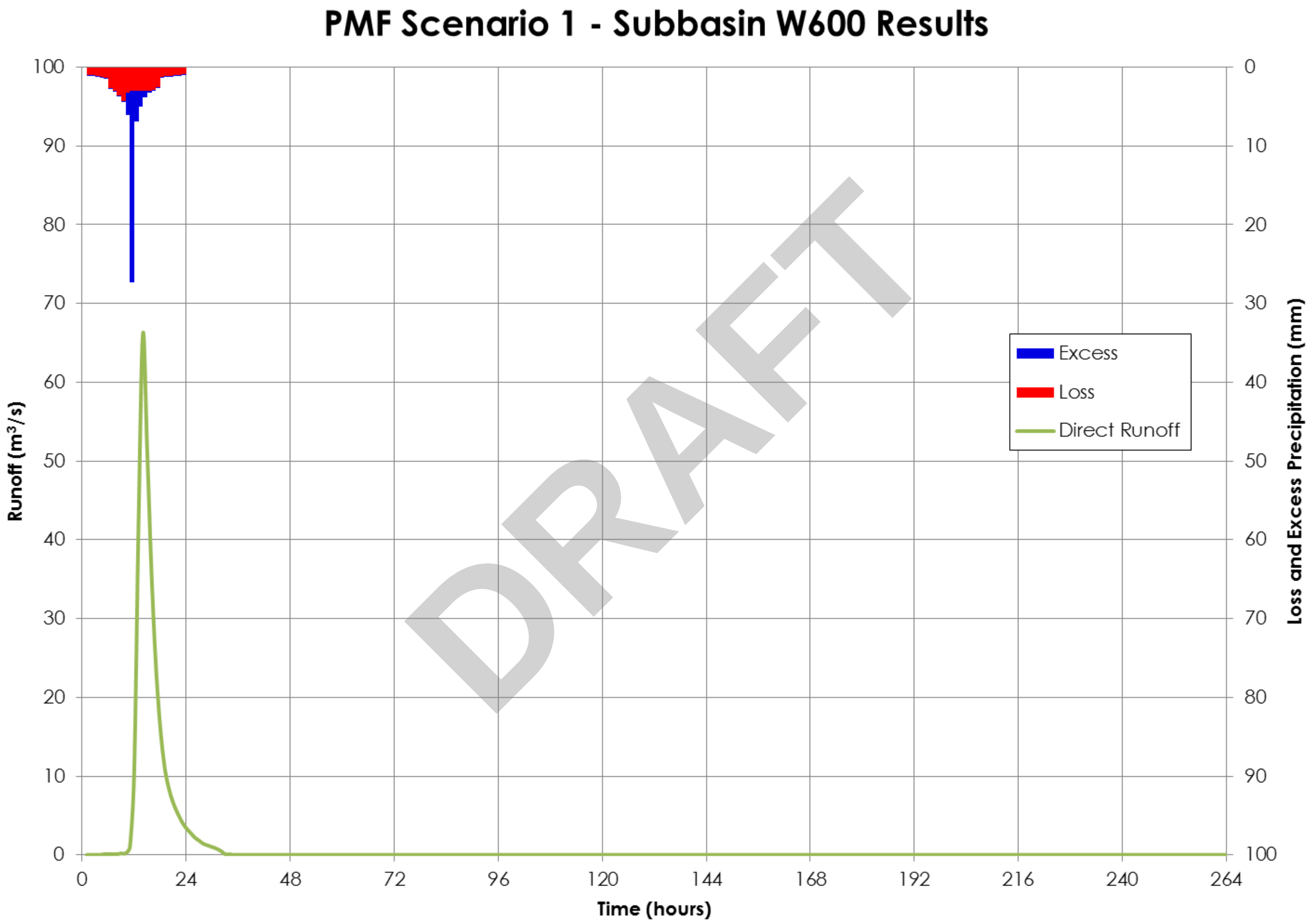

PMF Scenario 1 - Subbasin W600 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.11

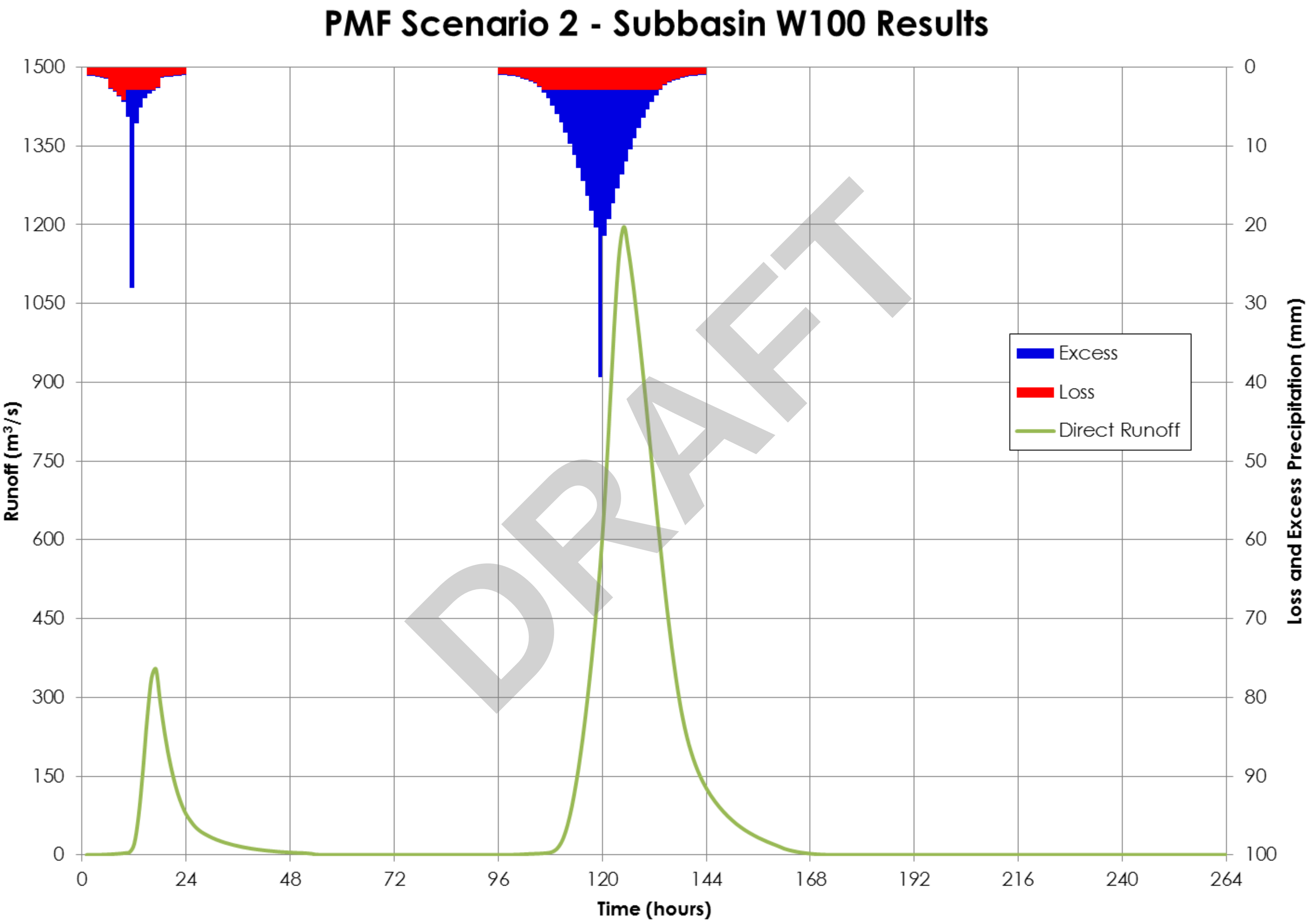

PMF Scenario 2 - Subbasin W100 Results
Runoff (m³/s)
1500
1350
1200
1050
900
750
600
450
300
150
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
0
24
48
72
96
120
144
168
192
216
240
264
Time (hours)
Excess
Loss
Direct Runoff

Figure F.12

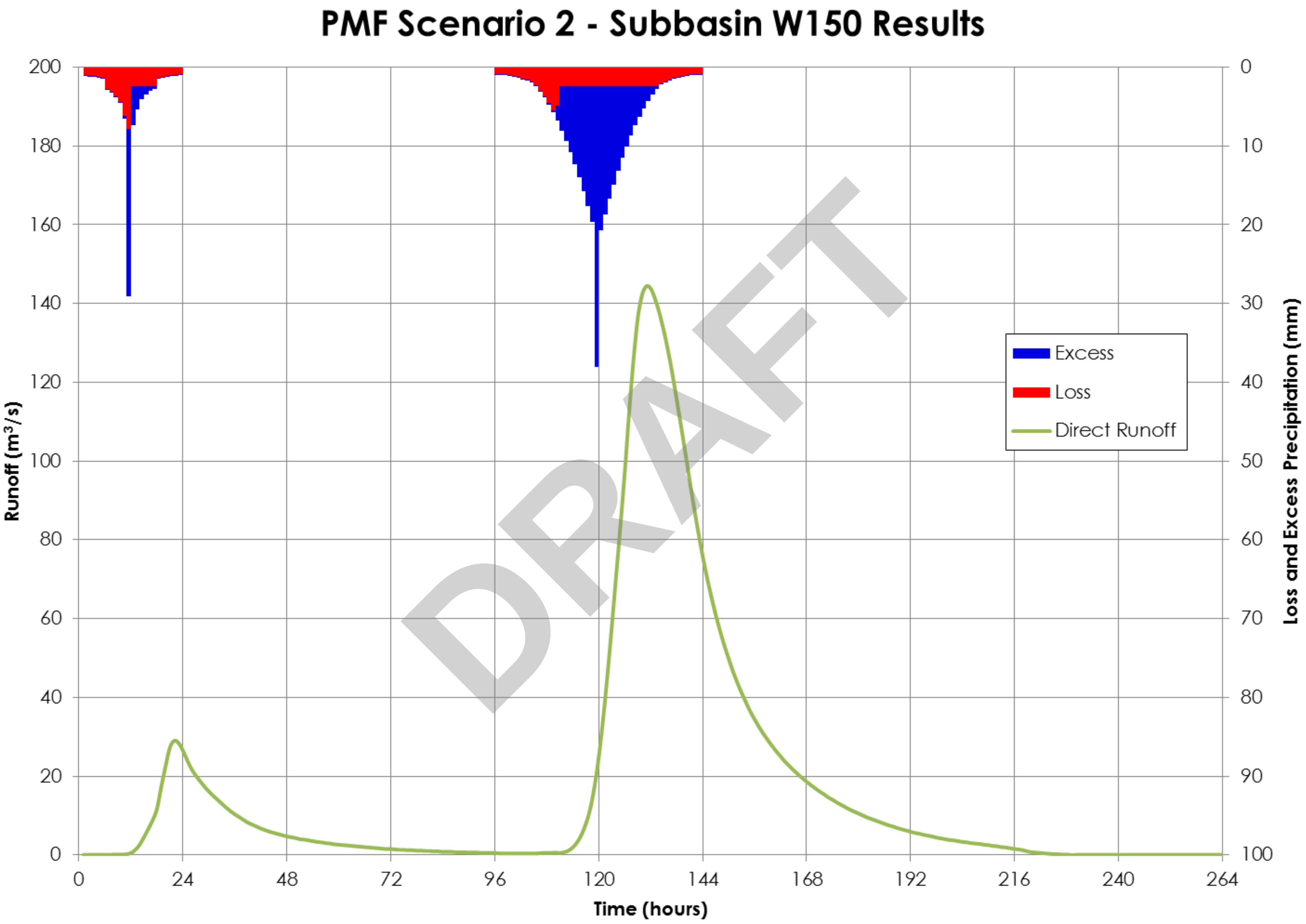

PMF Scenario 2 - Subbasin W150 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.13

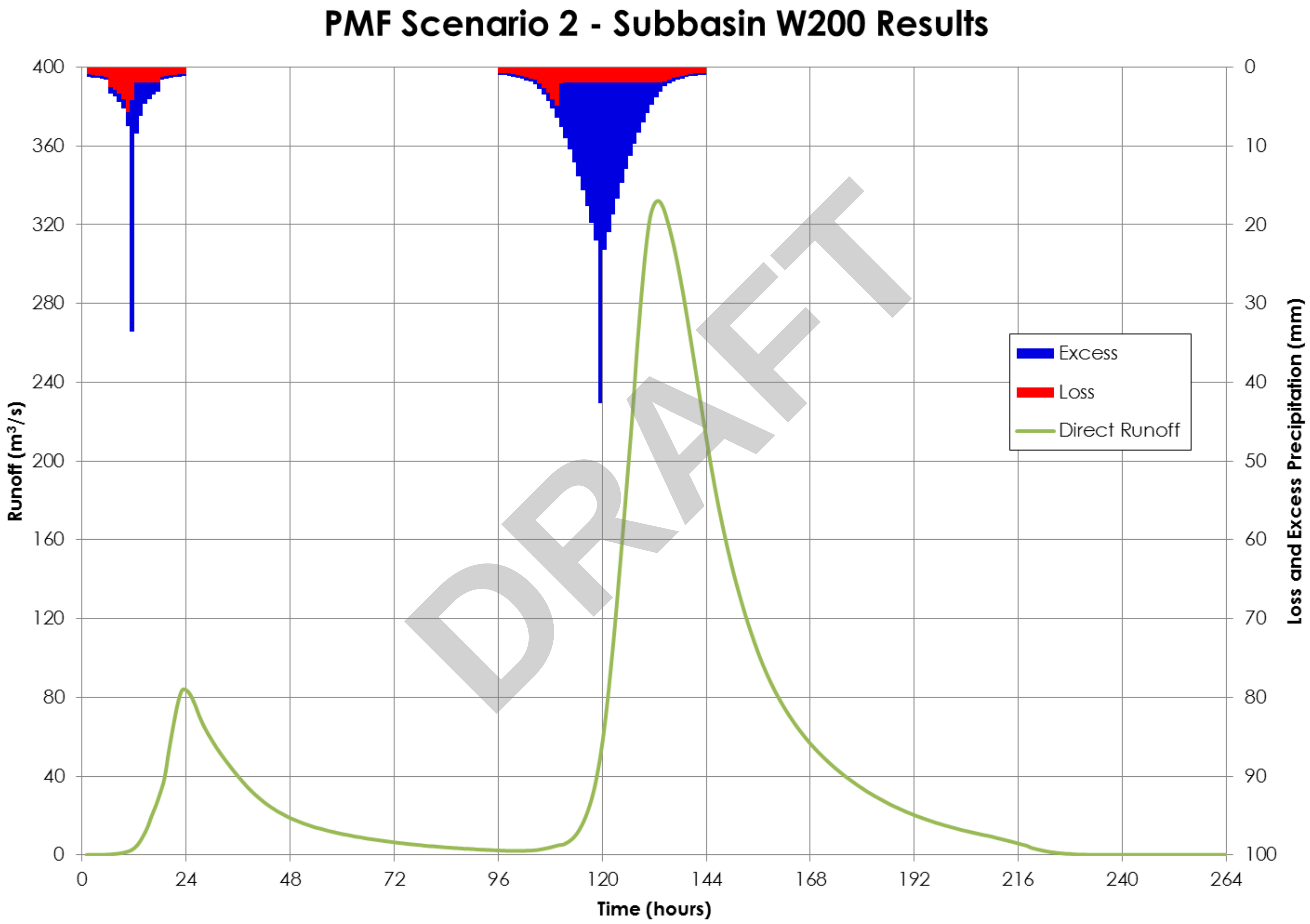

PMF Scenario 2 - Subbasin W200 Results
Runoff (m³/s)
Loss and Excess Precipitation (mm)
Time (hours)
Excess
Loss
Direct Runoff
400
360
320
280
240
200
160
120
80
40
0
0
10
20
30
40
50
60
70
80
90
100
0
24
48
72
96
120
144
168
192
216
240
264

Figure F.14

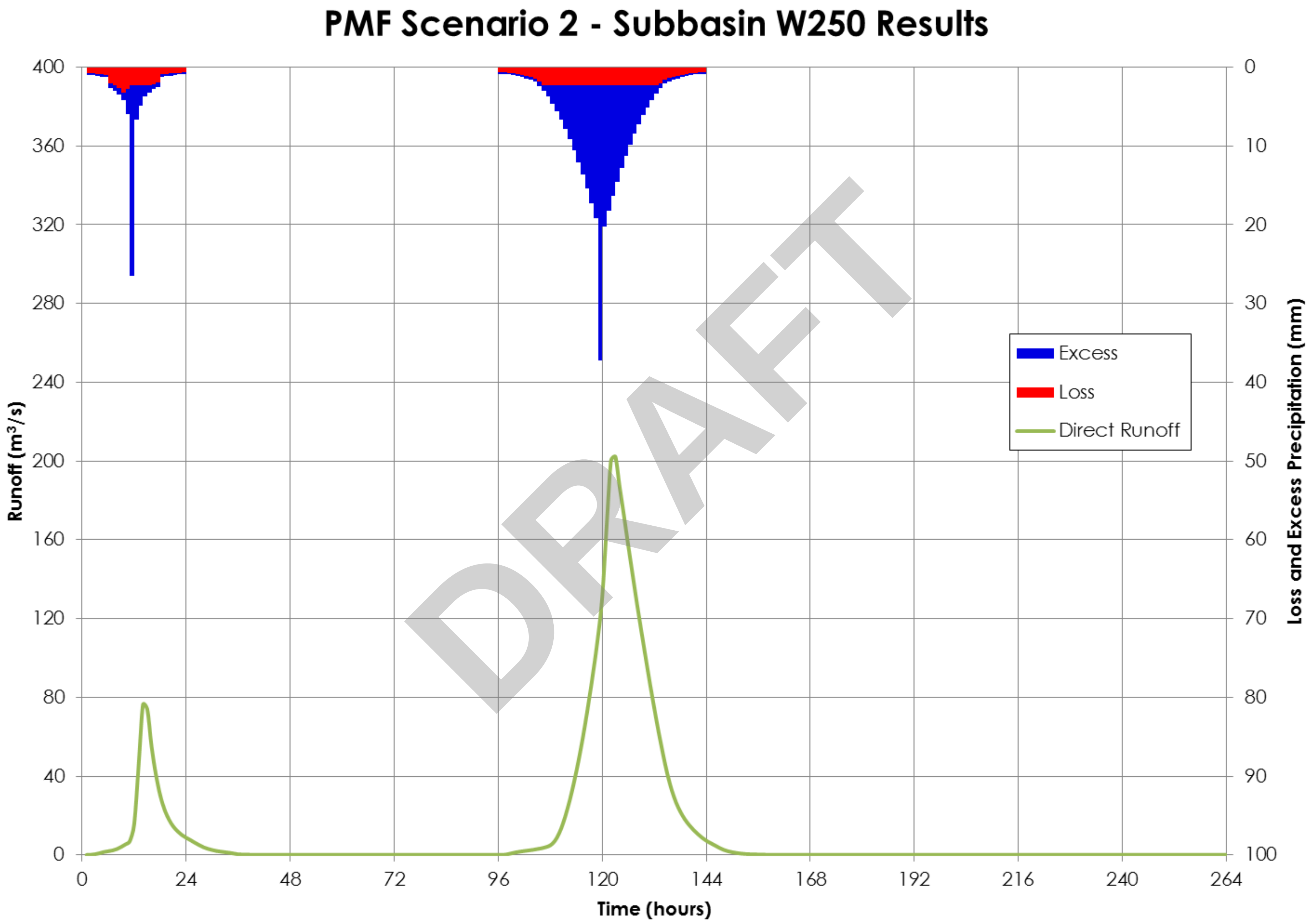

PMF Scenario 2 - Subbasin W250 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.15

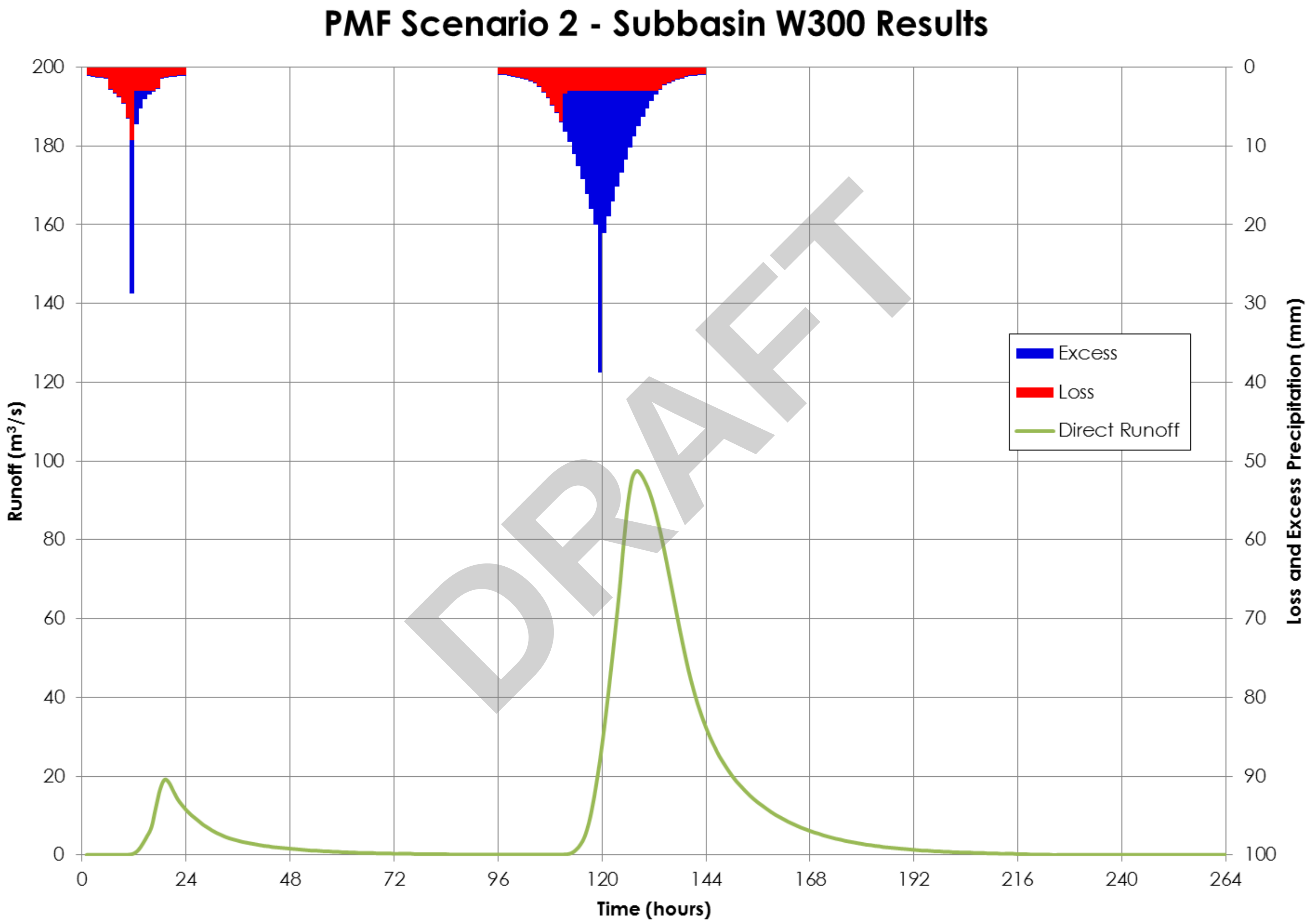

PMF Scenario 2 - Subbasin W300 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.16

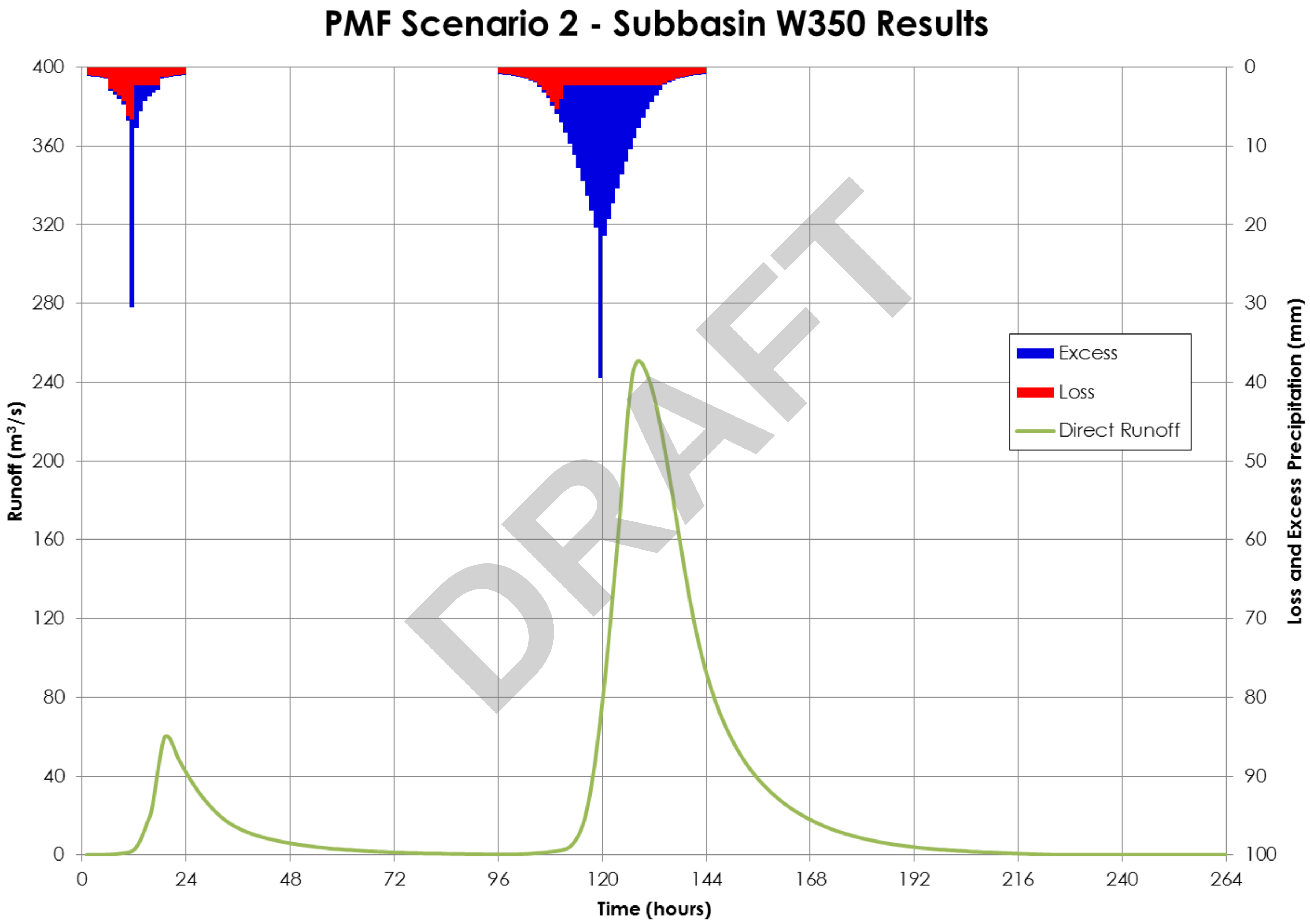

PMF Scenario 2 - Subbasin W350 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.17

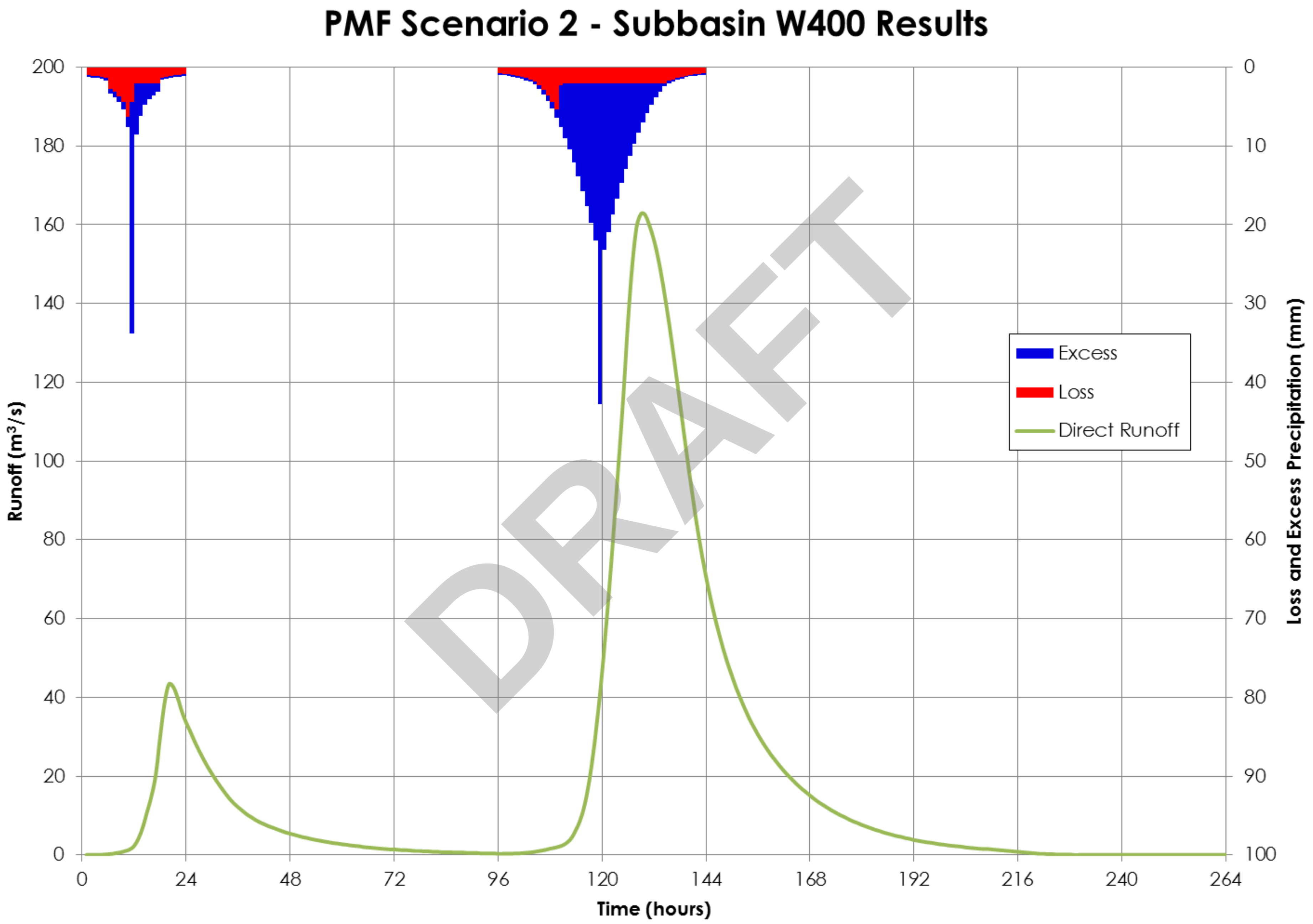

PMF Scenario 2 - Subbasin W400 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.18

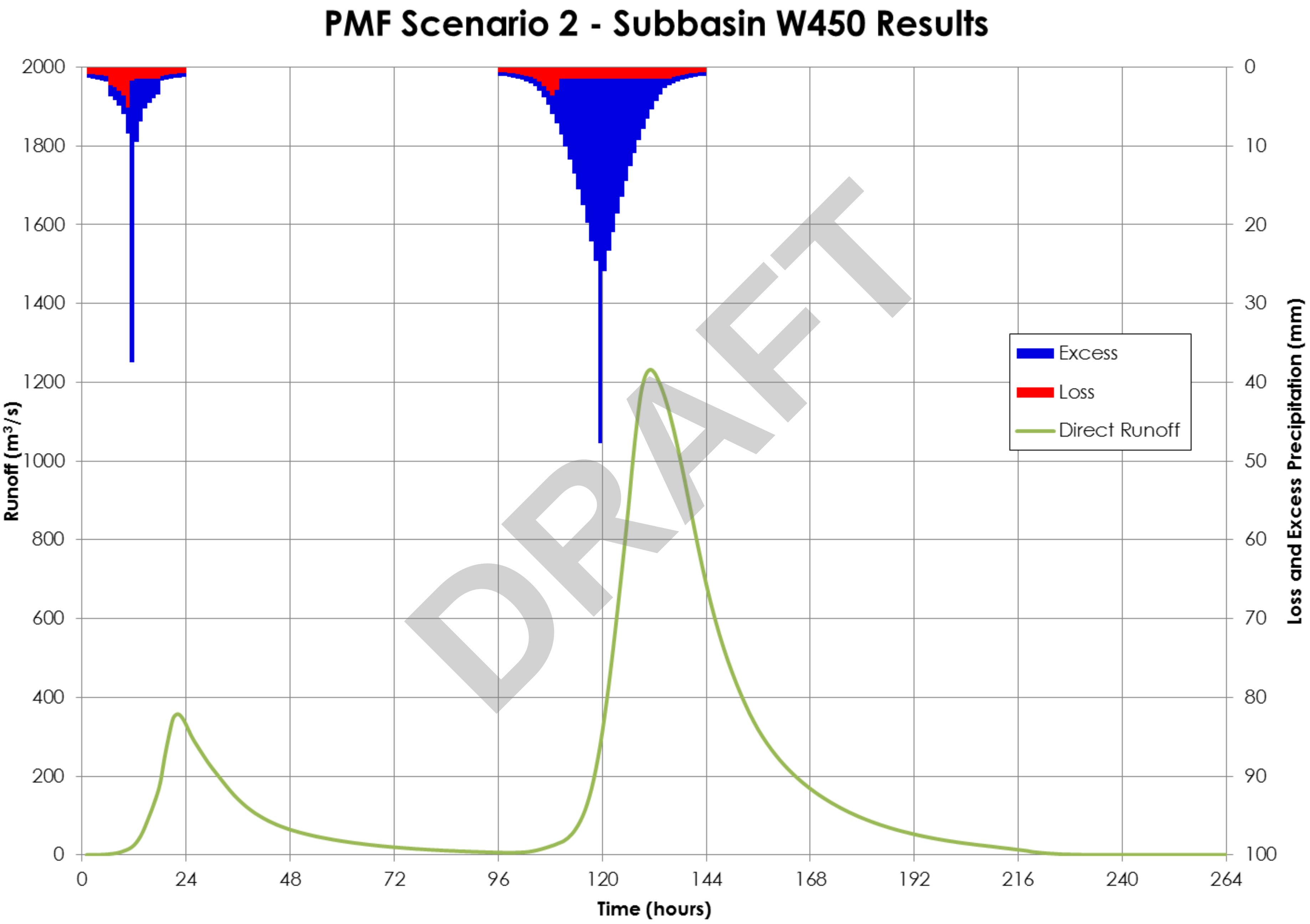

PMF Scenario 2 - Subbasin W450 Results
Runoff (m³/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.19

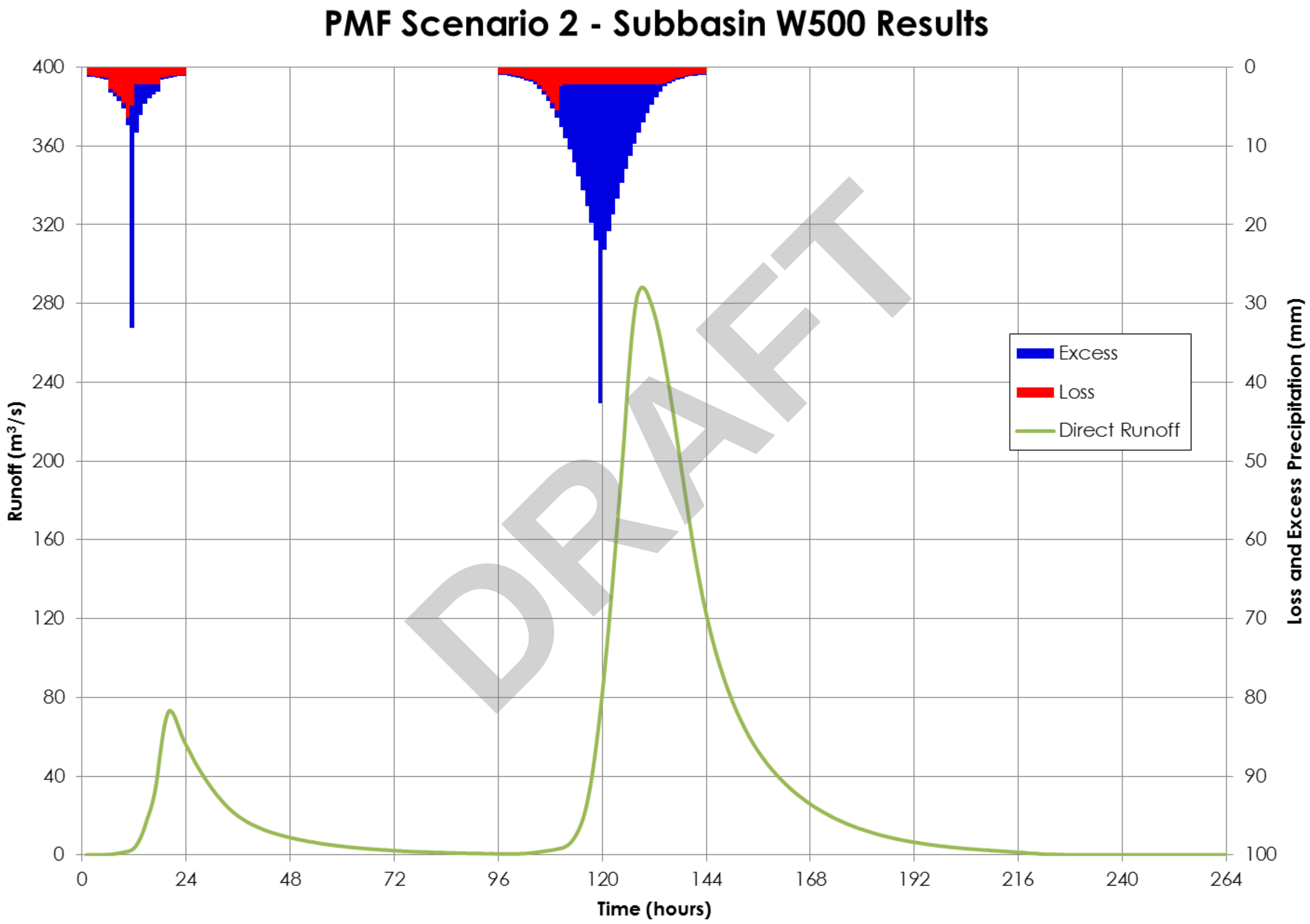
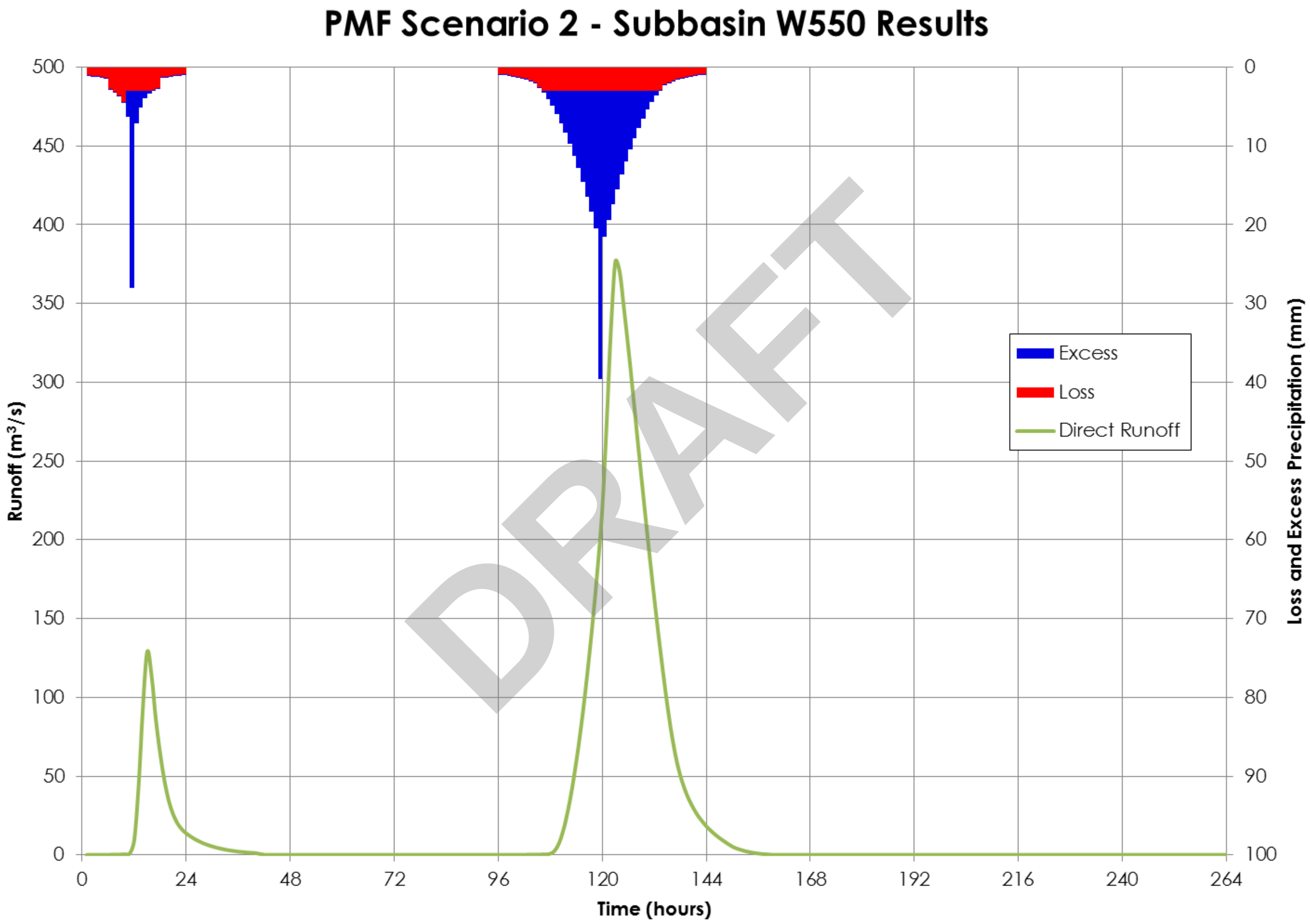

PMF Scenario 2 - Subbasin W500 Results
Runoff (m³/s)
0
40
80
120
160
200
240
280
320
360
400
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.20



PMF Scenario 2 - Subbasin W550 Results
Runoff (m³/s)
500
450
400
350
300
250
200
150
100
50
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.21

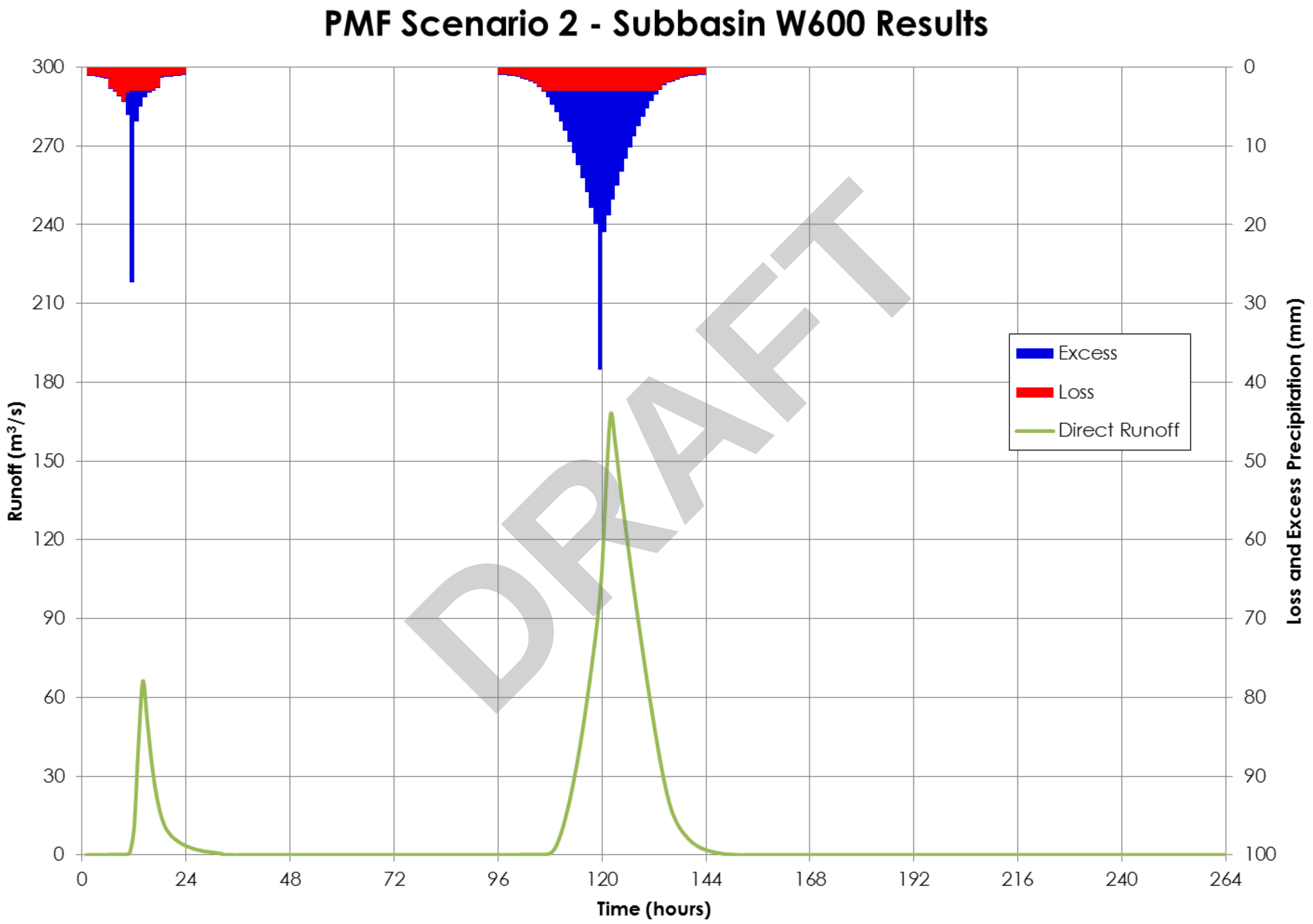

PMF Scenario 2 - Subbasin W600 Results
Runoff (m³/s)
300
270
240
210
180
150
120
90
60
30
0
Loss and Excess Precipitation (mm)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.22

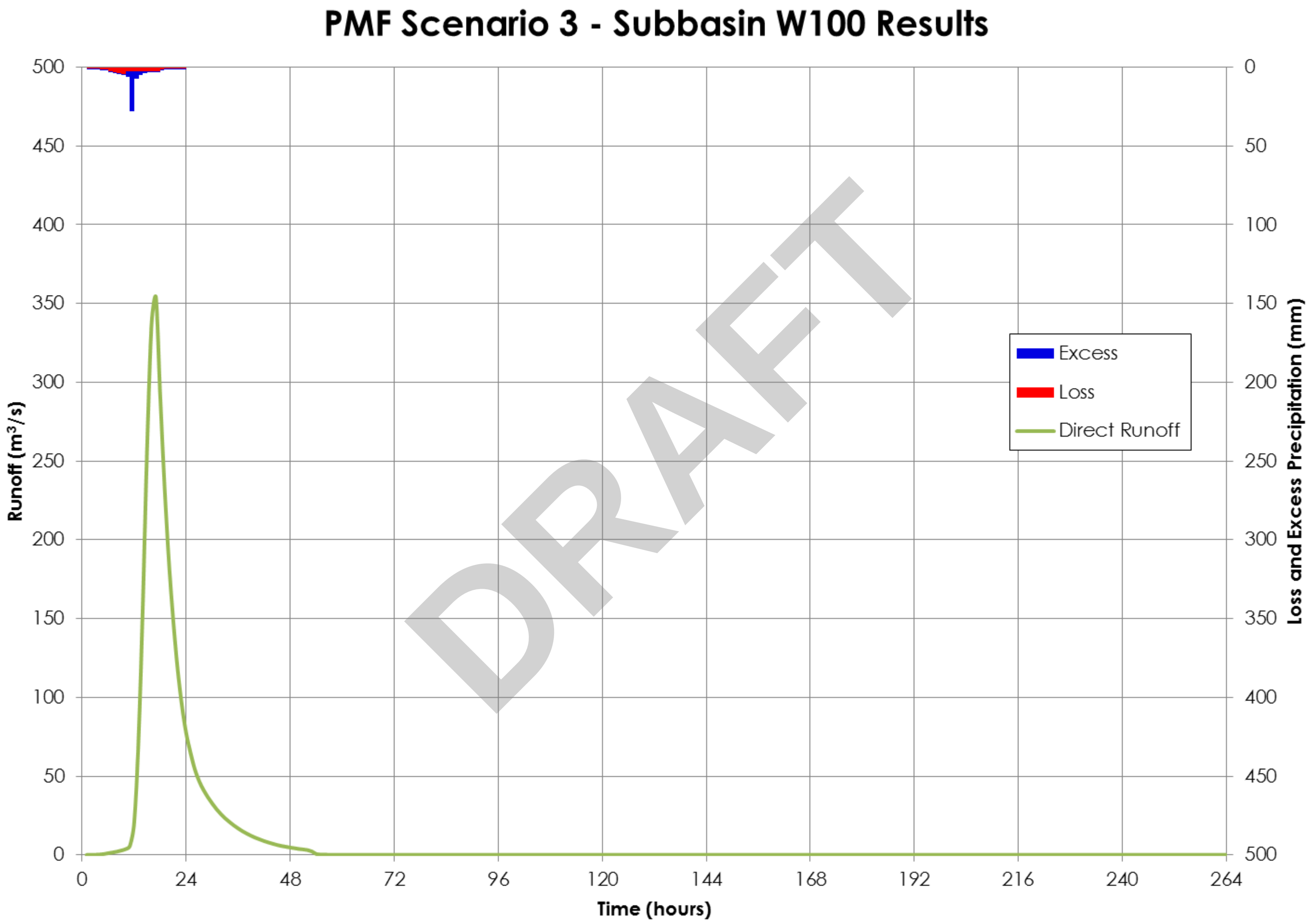

PMF Scenario 3 - Subbasin W100 Results
Runoff (m³/s)
500
450
400
350
300
250
200
150
100
50
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.23

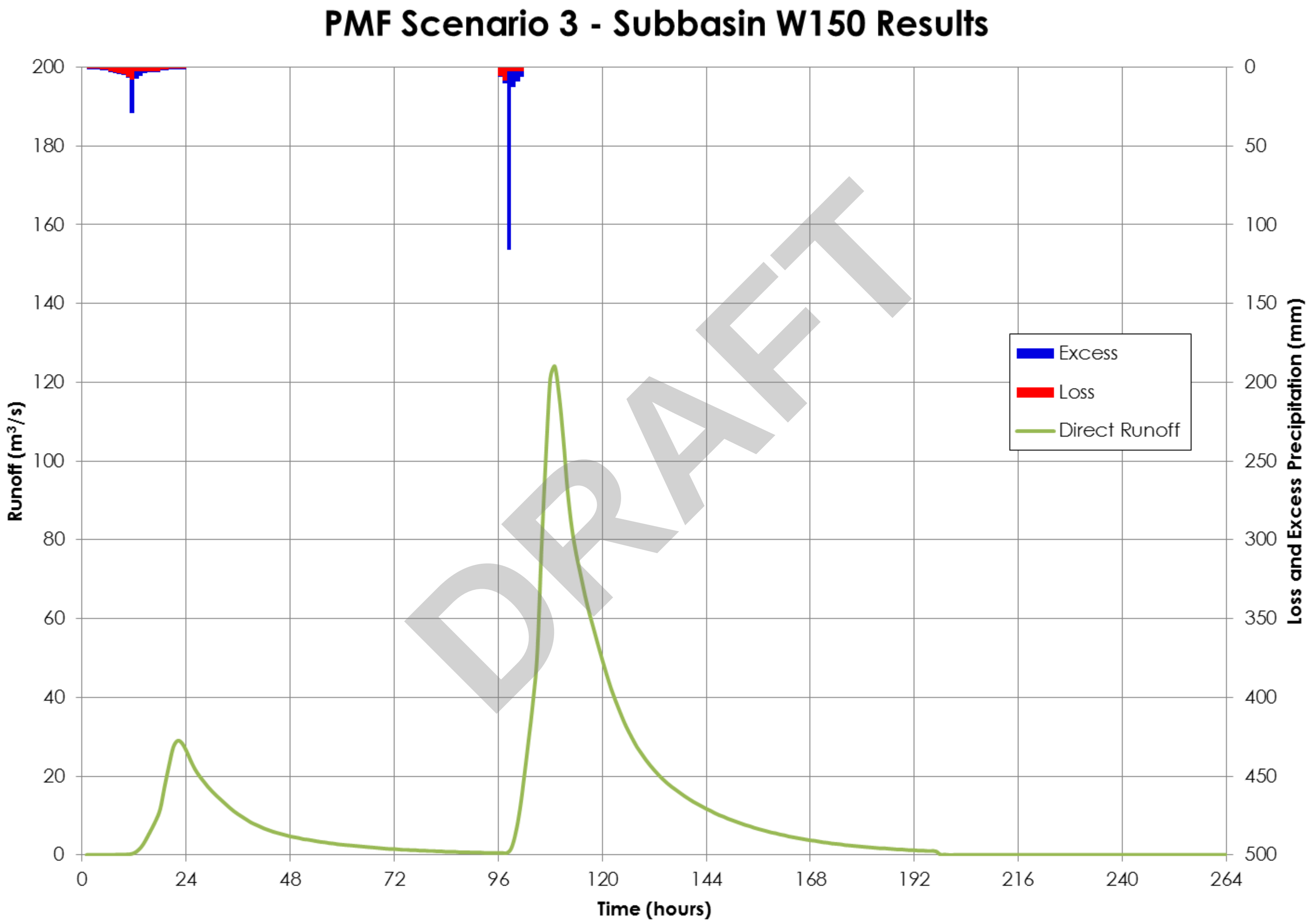

PMF Scenario 3 - Subbasin W150 Results
Runoff (m³/s)
Loss and Excess Precipitation (mm)
Time (hours)
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.24

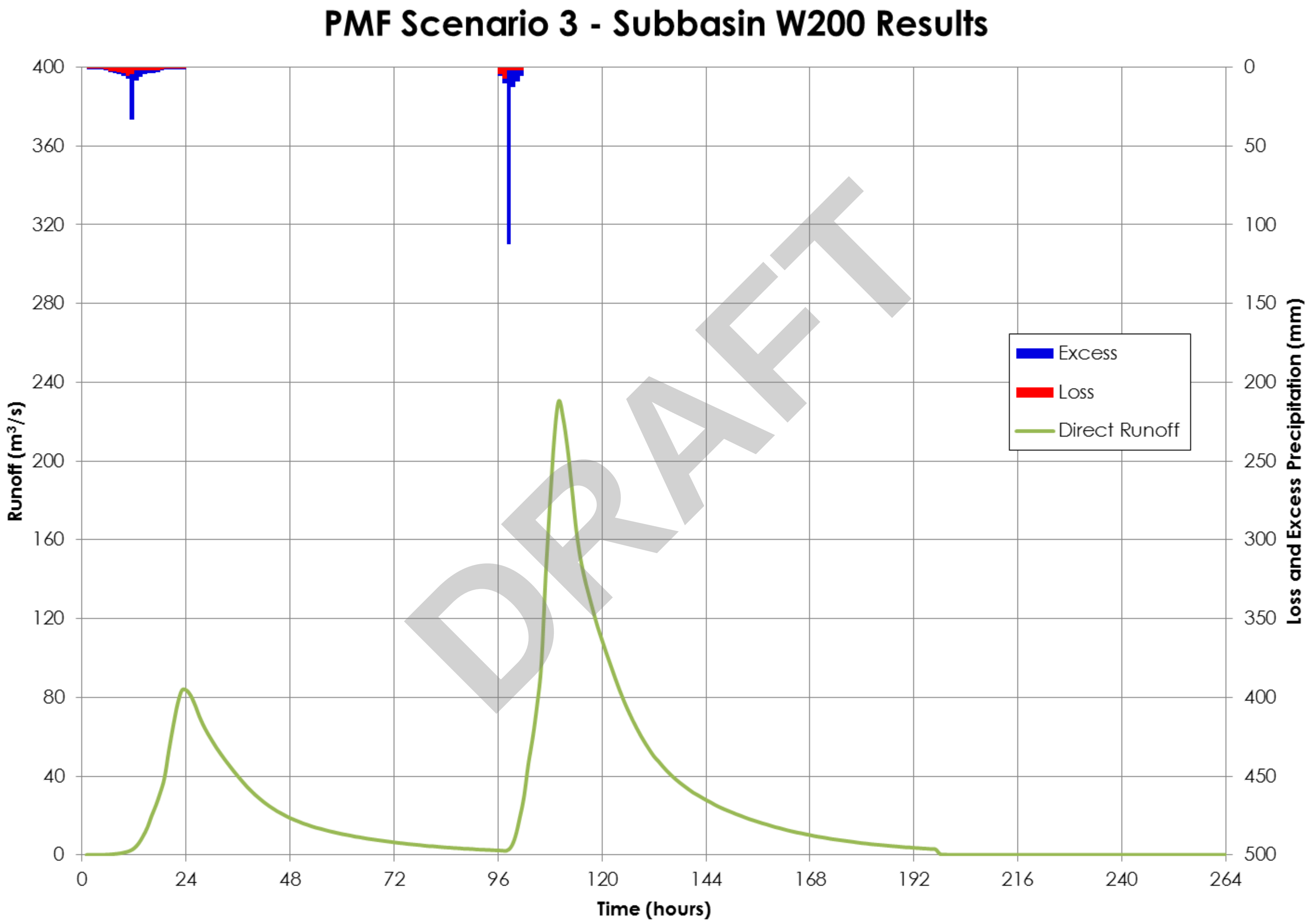

PMF Scenario 3 - Subbasin W200 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.25

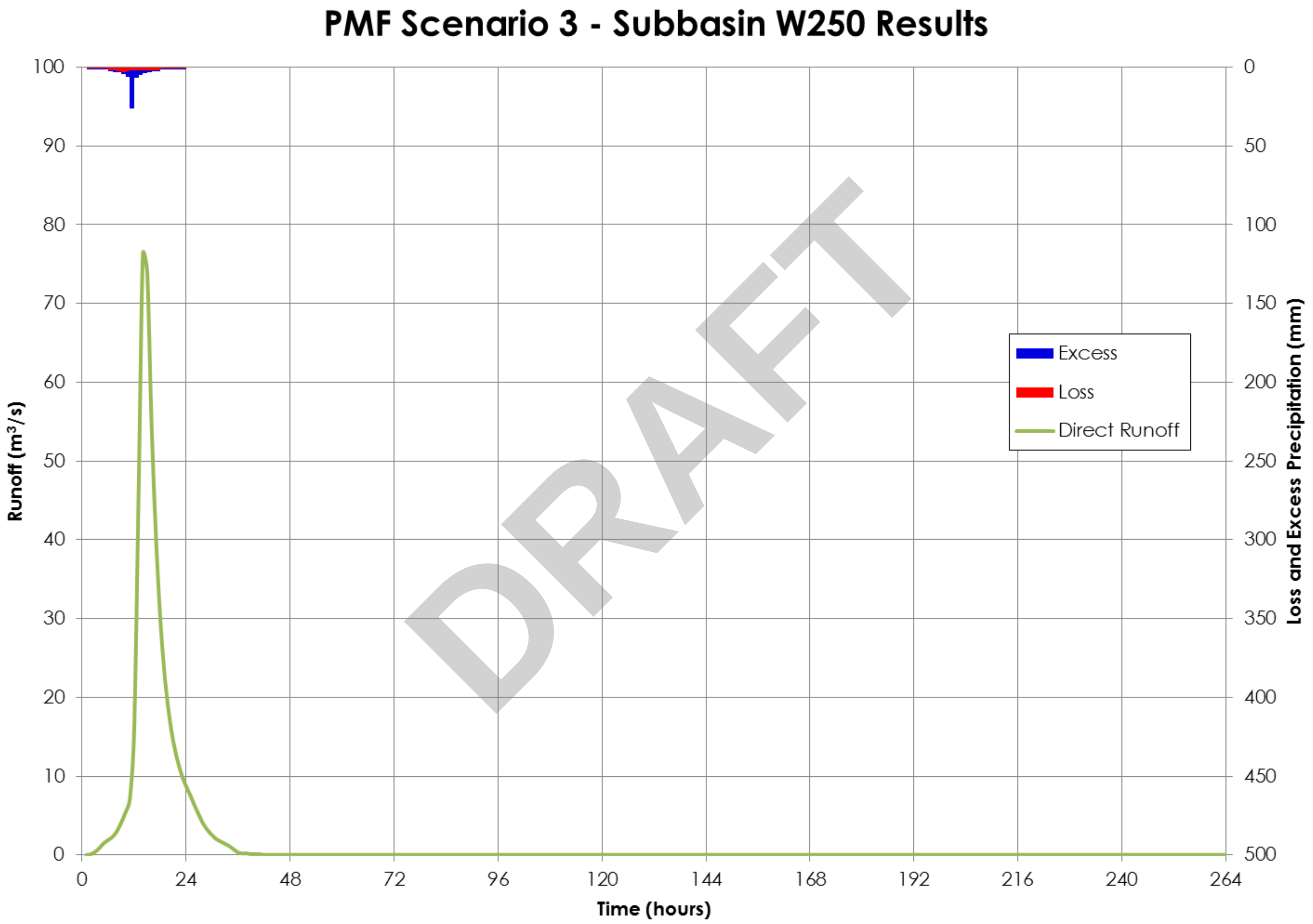
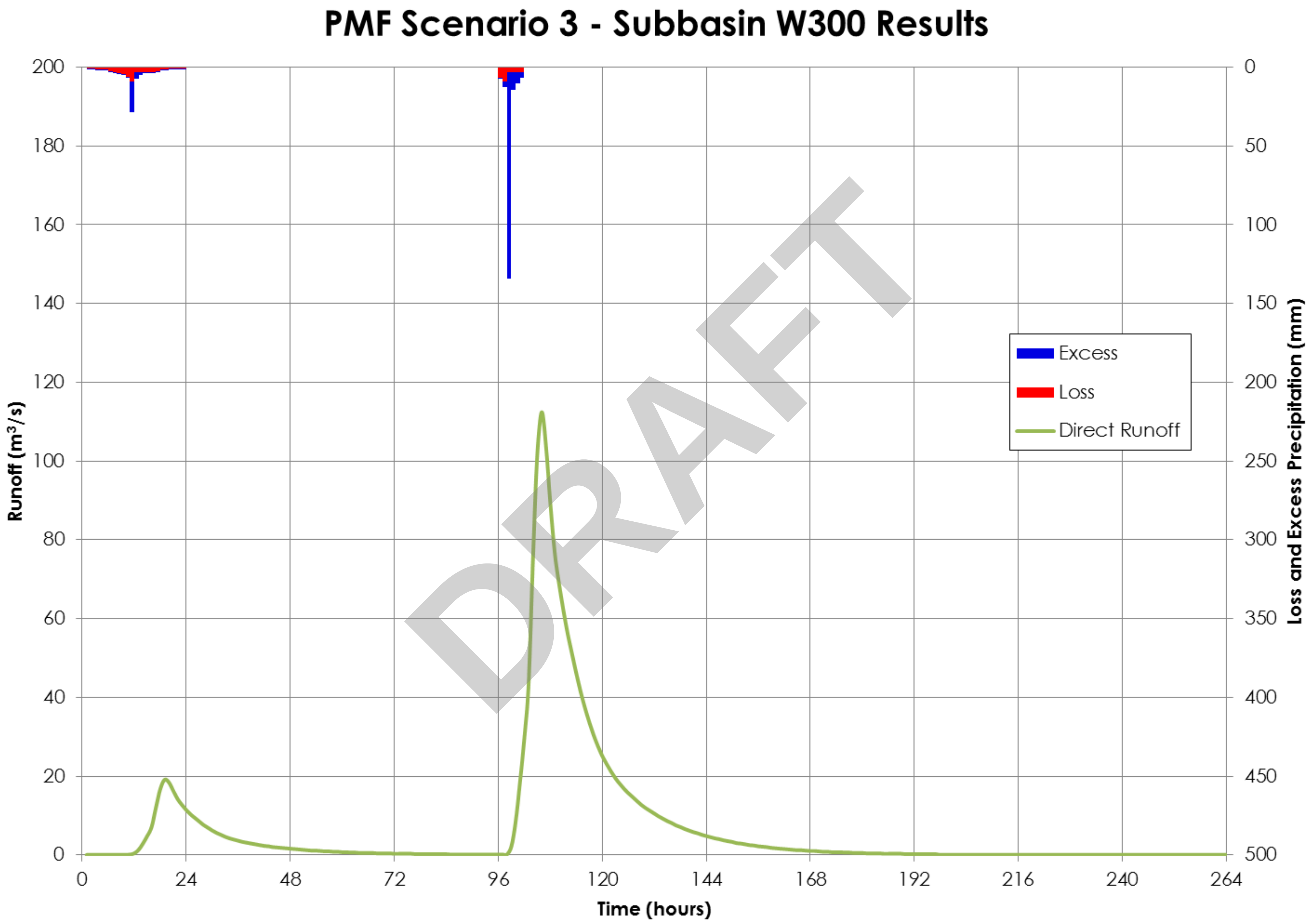

PMF Scenario 3 - Subbasin W250 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.26



PMF Scenario 3 - Subbasin W300 Results
Runoff (m³/s)
200
180
160
140
120
100
80
60
40
20
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.27

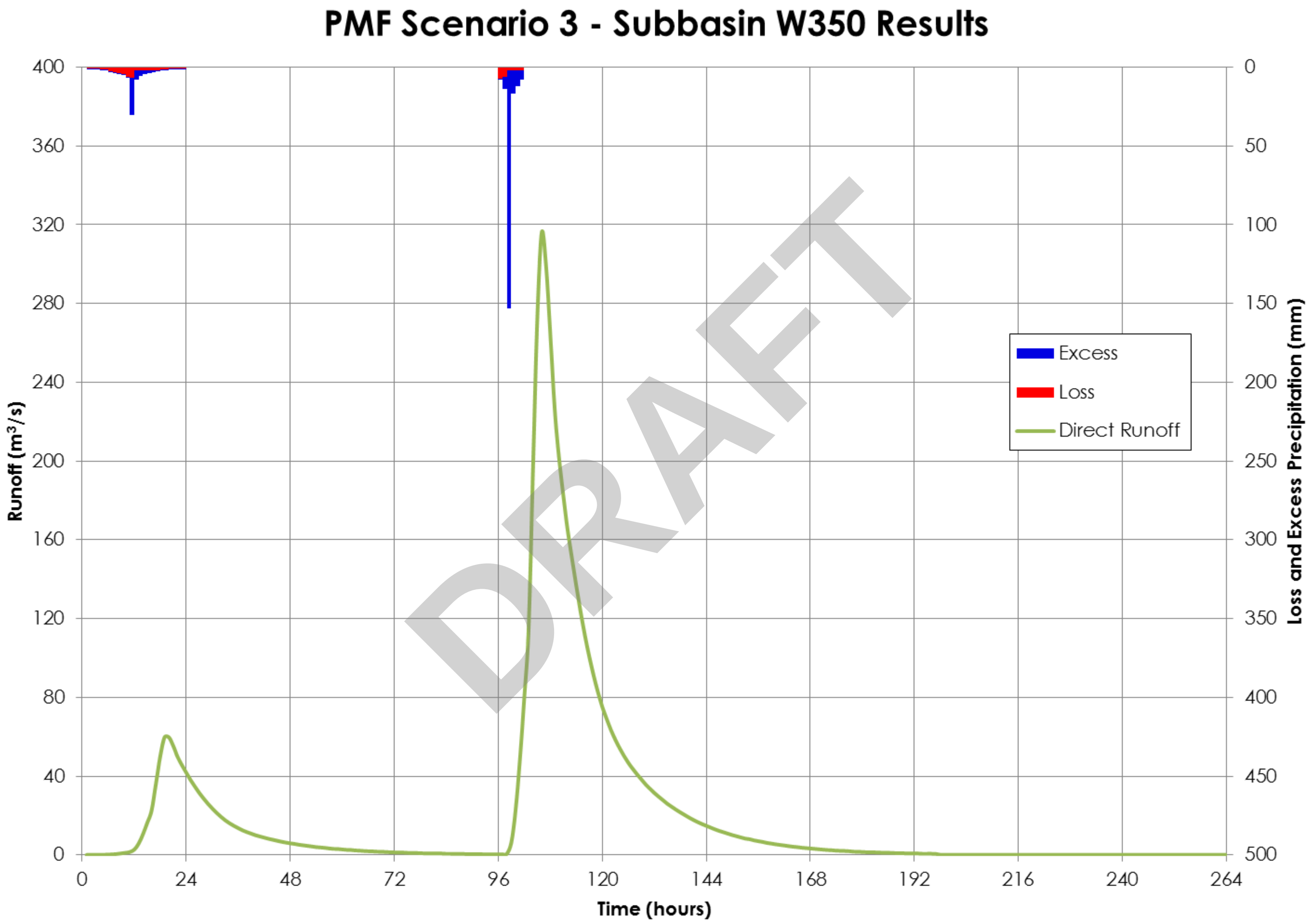

PMF Scenario 3 - Subbasin W350 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.28

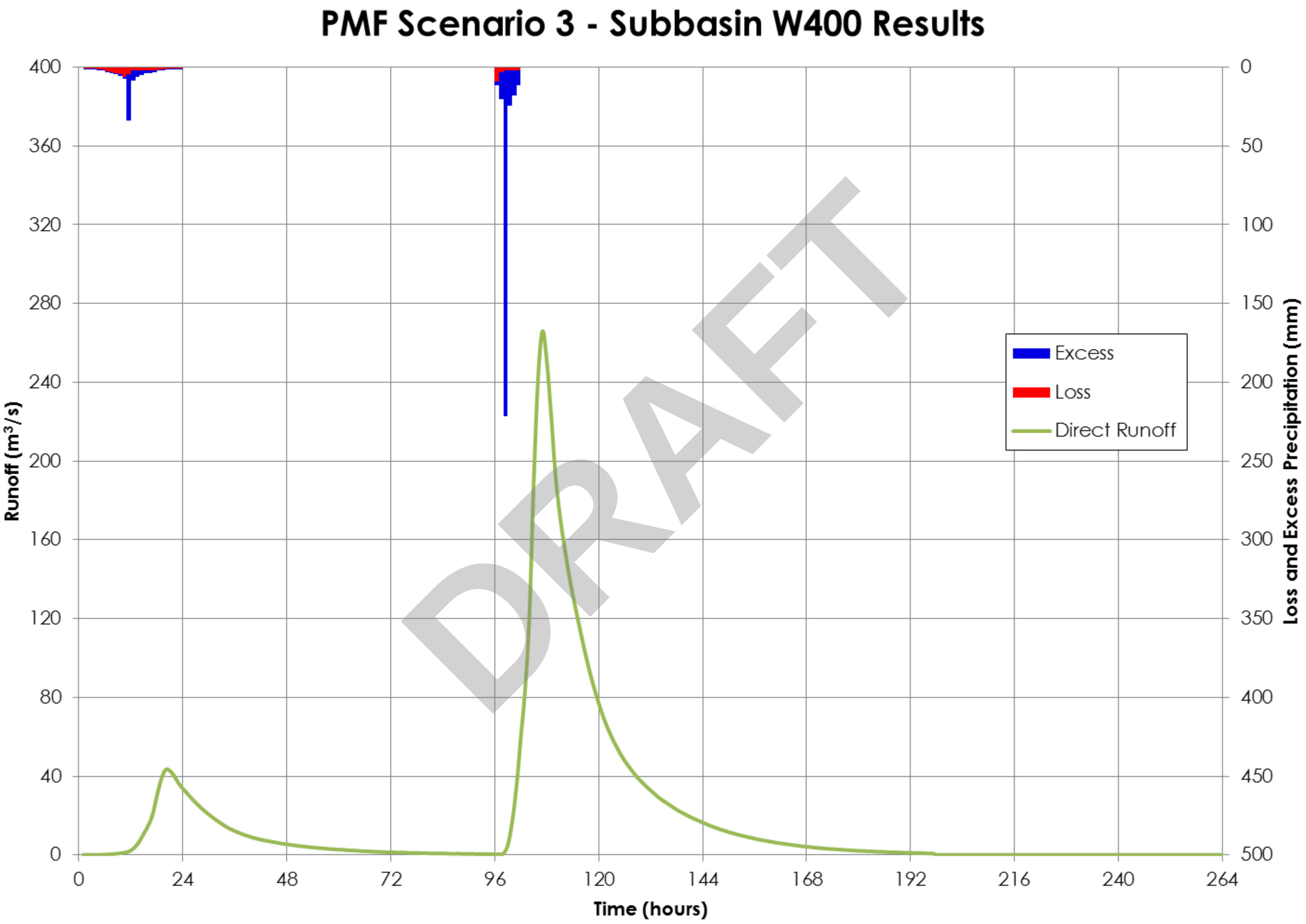

PMF Scenario 3 - Subbasin W400 Results
Runoff (m³/s)
400
360
320
280
240
200
160
120
80
40
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.29

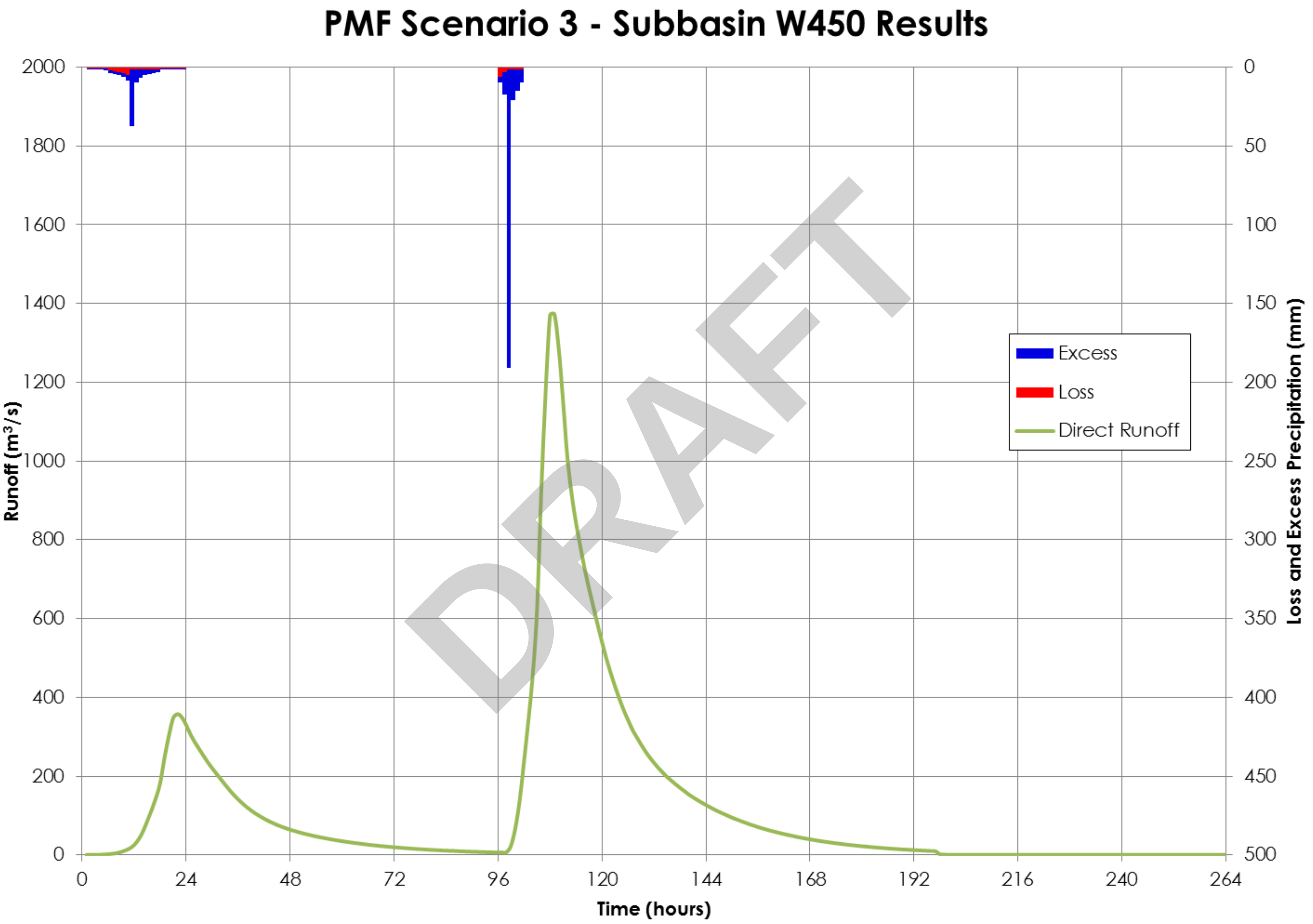

PMF Scenario 3 - Subbasin W450 Results
Runoff (m³/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.30

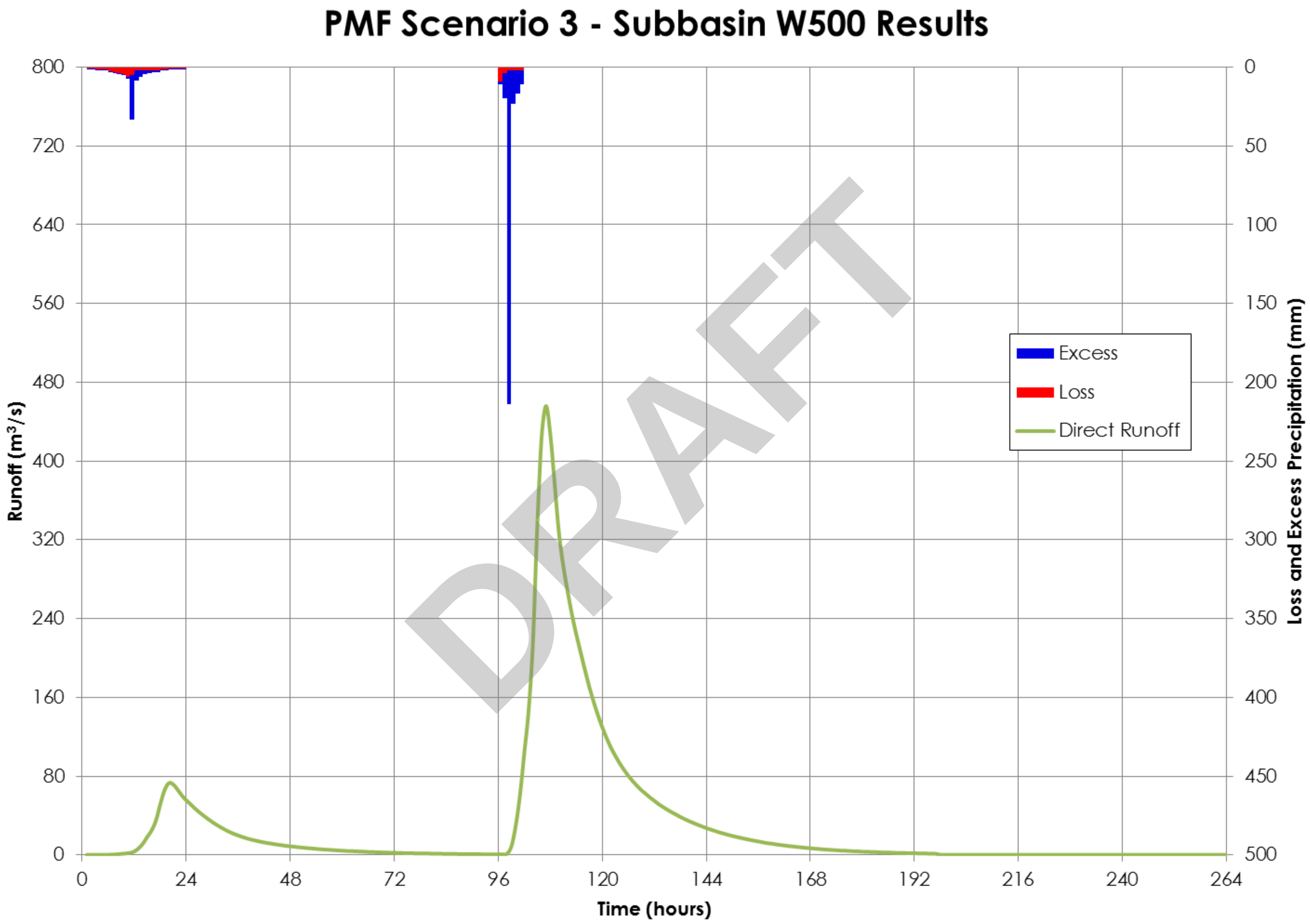

PMF Scenario 3 - Subbasin W500 Results
800
720
640
560
480
400
320
240
160
80
0
Runoff (m^3/s)
0
50
100
150
200
250
300
350
400
450
500
Loss and Excess Precipitation (mm)
0
24
48
72
96
120
144
168
192
216
240
264
Time (hours)
Excess
Loss
Direct Runoff

Figure F.31

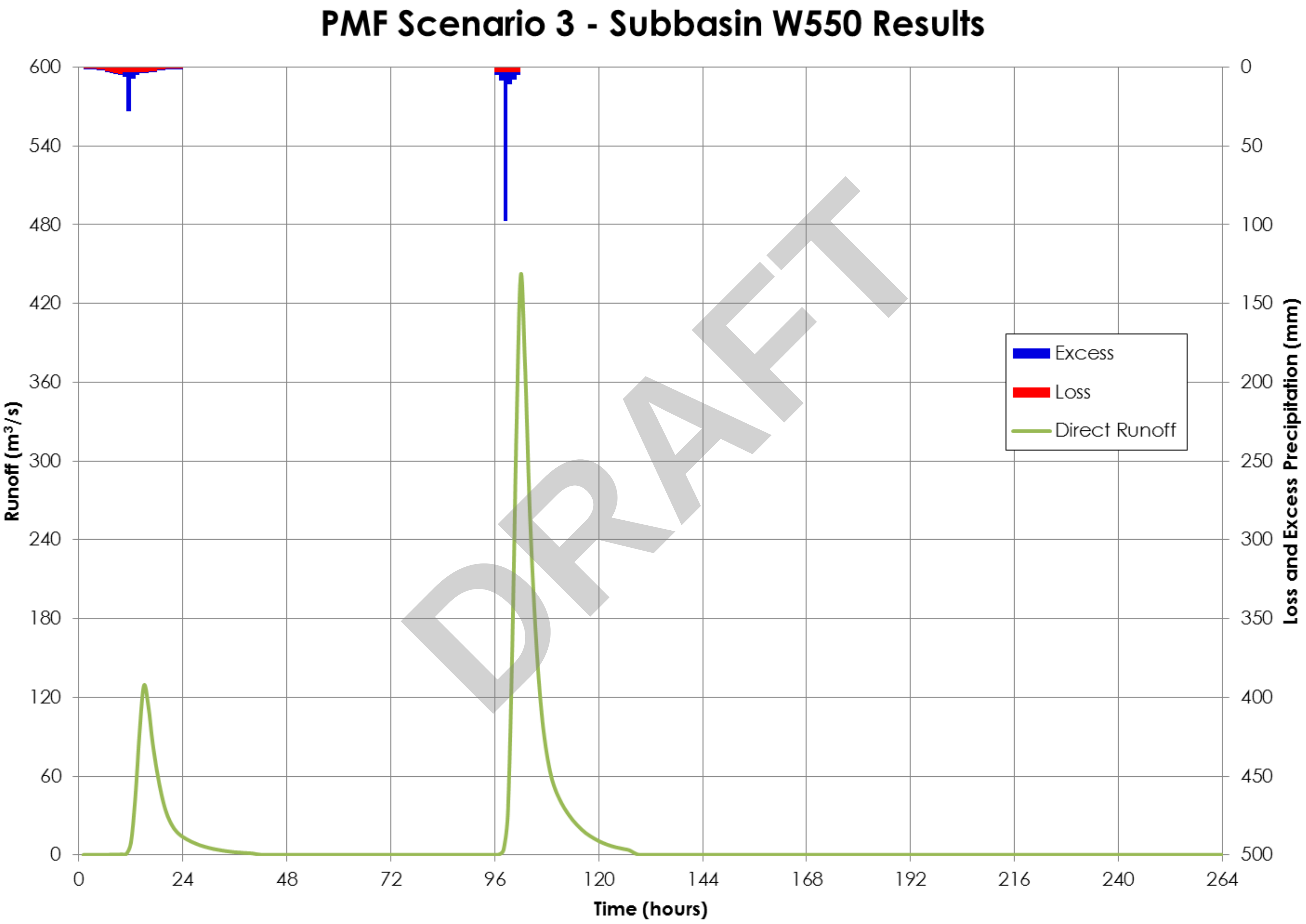

PMF Scenario 3 - Subbasin W550 Results
Runoff (m³/s)
600
540
480
420
360
300
240
180
120
60
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.32

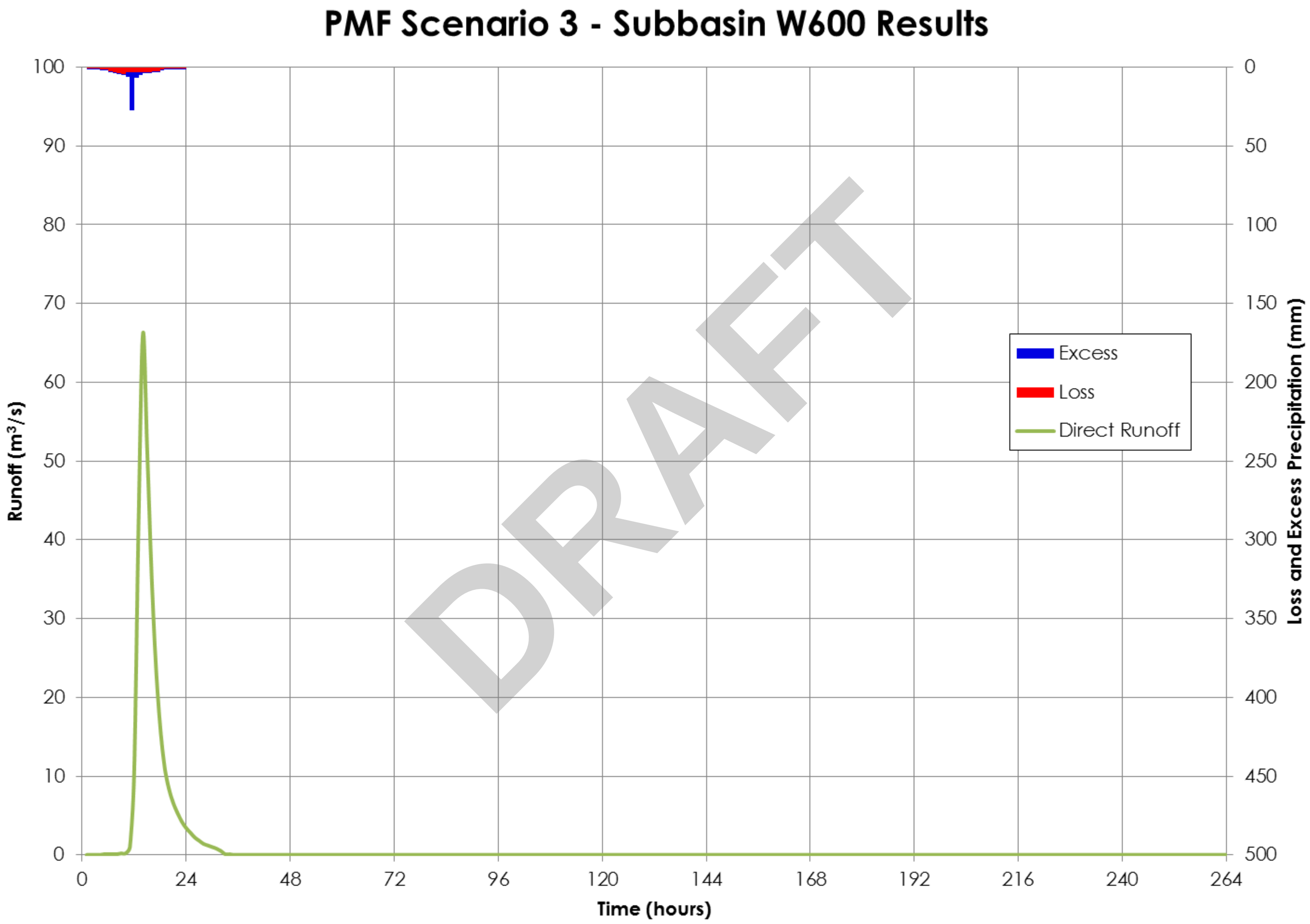

PMF Scenario 3 - Subbasin W600 Results
Runoff (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.33

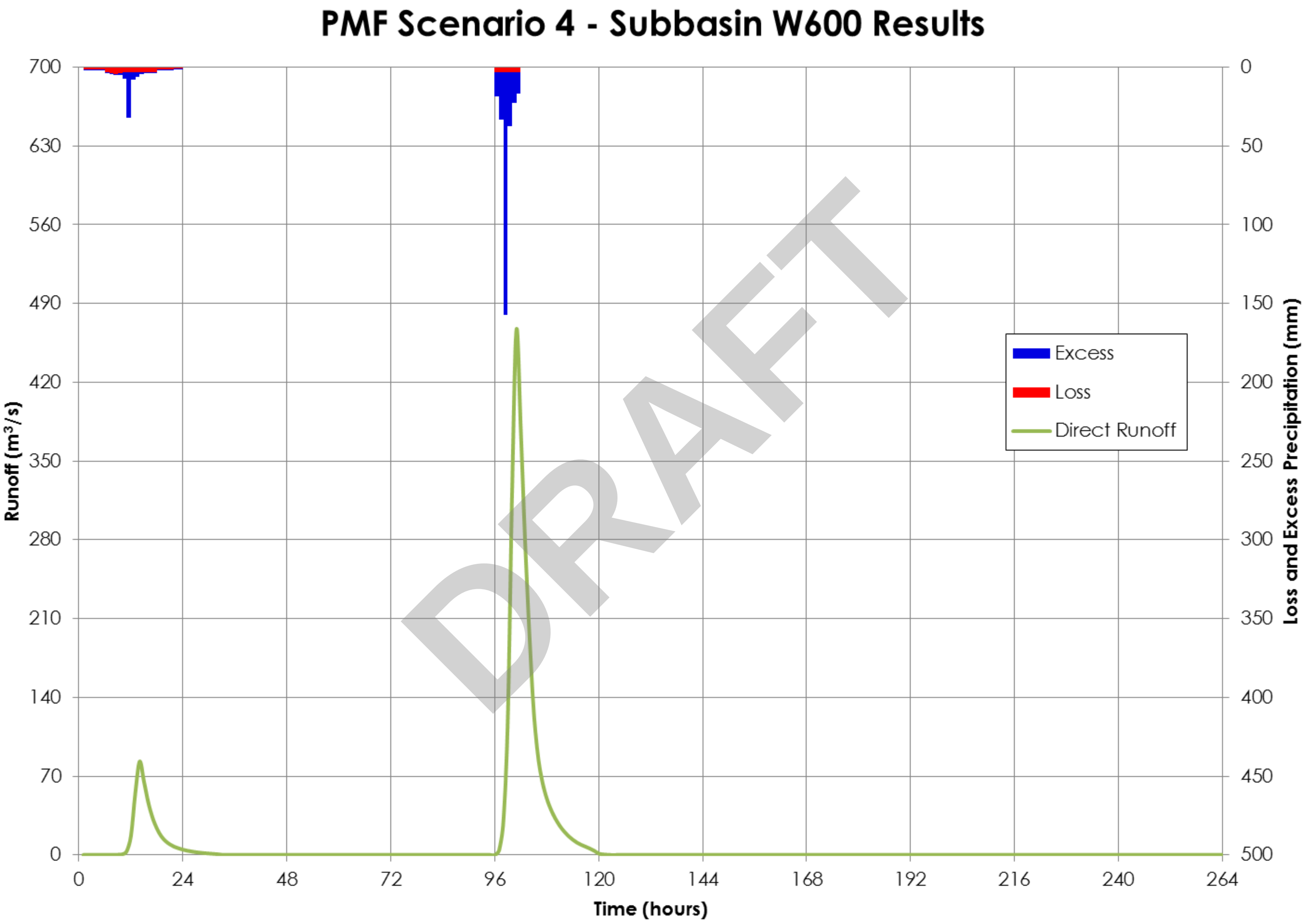

PMF Scenario 4 - Subbasin W600 Results
Runoff (m³/s)
700
630
560
490
420
350
280
210
140
70
0
Loss and Excess Precipitation (mm)
0
50
100
150
200
250
300
350
400
450
500
Time (hours)
0
24
48
72
96
120
144
168
192
216
240
264
Excess
Loss
Direct Runoff

Figure F.34