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Appendix F

Modelling

Appendix F - Hydrologic and Hydraulic Modelling

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F.1 Introduction

The latest SWMM software engine was used for developing the City of Courtenay (City) hydraulic and hydrologic watershed model. The final SWMM model is available as an InfoSWMM software model as requested by the City. The drainage system, as shown on Figure 1 in the main body of the report, includes:

- 30.3 km of trunk storm sewers;
- 125.6 km of non-trunk storm sewers;
- 2,022 storm manholes;
- 92 drainage culverts;
- 1 bridge crossing (MoTI); and,
- 3 storm detention ponds/facilities.

This appendix outlines the development of the detailed hydrologic and hydraulic model of the City watersheds. The section includes:

- descriptions of the detailed hydrologic and hydraulic model development using the GIS data received from the City and supplemented with the survey as a base; and,
- calibration and verification of the hydrologic model to ensure accurate predictions of watershed rainfall-runoff response.

The completed hydrologic/hydraulic model was used to assess the drainage system under different design event conditions. The results of these analyses are presented in Appendix D.

F.2 Stormwater System Model Development

Model Drainage Sub-catchments

The City drainage sub-catchments were modelled by individual land parcels in urban and suburban areas based on cadastral data from the City and with large manually delineated catchments in undeveloped areas.

Usually, to assign parcel sub-catchments to the drainage network an automated process in the modelling software links sub-catchments to the nearest downstream node. To assign sub-catchments to their proper nodes and preserve proper drainage areas, sub-catchment-node connections were manually assigned where needed by reviewing mapping and as-builts across the City drainage network.

The right-of-way (ROW) sub-catchments were split up using the Thiessen polygons method and using the storm manholes included in the model. The split ROW sub-catchments were assigned outlet nodes in a similar fashion as the parcel sub-catchment assignment described above.

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In total the model includes 11,600 sub-catchments, which includes 2,586 small right-of-way sub-catchments. Sub-catchments were assigned the following attributes:

- slopes, using digital elevation mapping (DEM) information,
- existing land use impervious area percentages, by using a combination of the BC Assessment land use information for legal catchments and 2020 orthophotos received from the City,
- impervious area percentages for future land use scenarios, using the City's Official Community Plan (OCP) information, and
- infiltration and groundwater parameters based on soils mapping.

The stormwater management model (SWMM) drainage sub-catchments are shown on Figure 2 in the main body of the report.

Design Storms

The drainage system analysis was performed using intensity-duration-frequency (IDF) data from the City of Courtenay Subdivision and Development Servicing Bylaw No. 2919 – 2018. The IDF data was developed from the Courtenay Puntledge BCHP station ID 1021990 using 1964-1995 (35 Years) recorded data and include a 15% increase for future climate change to Year 2050. Existing condition IDF data was estimated by removing the 15% increase built into the City's IDFs. The design storm data in the City Bylaw 2919 – 2018 uses a Modified Chicago Storm Distribution with 24-hour duration. The following design storms were simulated in the modelling:

- the existing climate conditions 2-year, 10-year, and 100-year return period events using the Modified Chicago Storm Distribution with 24-hour duration; and,
- the future climate (Year 2050) conditions 2-year, 10-year, and 100-year return period events using the Modified Chicago Storm Distribution with 24-hour duration.

The rainfall intensities for the existing and climate change IDFs are presented in Table F-1.

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Table F-1: IDF Data for Drainage System Analysis

Duration	2-year Total Rainfall (mm/hr)	10-year Total Rainfall (mm/hr)	100-year Total Rainfall (mm/hr)
Existing Climate Conditions			
1-hour	10.9	21.0	33.6
2-hour	8.3	15.8	25.3
6-hour	5.9	10.1	15.2
12-hour	4.4	6.8	9.7
24-hour	3.0	4.5	6.4
Future Climate Conditions (Year 2050)			
1-hour	12.5	24.1	44.4
2-hour	9.5	18.2	33.5
6-hour	6.8	11.6	20.1
12-hour	5.1	7.8	12.8
24-hour	3.5	5.2	8.5

Groundwater and Soil Parameters

The groundwater routine in SWMM was used to better estimate the groundwater and interflow portions of the runoff hydrograph. Infiltration rates, soil depths, and soil hydraulic conductivity values were all input based on typical values. All events for the storm system capacity assessment scenarios were modelled using saturated soil conditions typical of winter conditions. Figure 3 in the main body of the report shows the surficial geology (Geological Survey of Canada, 1976) of the City study area that was used to determine soil parameters. Soil types within the Anthropogenic soil zones shown on Figure 3 were referenced from the Hydrogeological Assessment Report (by Waterline Resources Inc. dated November 20, 2020) contained within Appendix B of the Courtenay IRMP Phase 2 Report.

Percentage Impervious

As a starting point for calibration, impervious percentages were assigned based on typical values, as shown in Table F-2.

Table F-2: Base Land Use Impervious Percentage Values

Land Use	Base % Impervious
Rural Residential	**10%**
Single Family Residential	**50%**
Master Planned Residential	**50%**
High Density (i.e., Multi-Family) Residential	**80%**
Mobile Home Park	**40%**
Commercial	**90%**

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Land Use	Base % Impervious
Commercial Shopping Centers	**90%**
Industrial	**75%**
Institutional/Public	**70%**
Parks and Open Space	**1%**
Agricultural, Agricultural Land Reserve (ALR) and Cultivated Fields	**5%**
Woodlands / Forested	**1%**
Right-of-Way (ROW)	**80%**

Existing Land Use

The existing land use impervious percentage for all land parcels was determined from the BC Assessment data received from the City, and then applying the typical impervious values as a base. Percent impervious values were then checked for accuracy by overlaying the 2020 orthophoto provided by the City, and if needed the impervious percentages were manually adjusted in areas with a large mismatch. Low density (i.e., rural) residential lots were commonly adjusted because of varying size of lot and existing impervious coverage.

Future Land Use

The future land use impervious percentage for all land parcels was determined from the City of Courtenay Official Community Plan (OCP) Bylaw No. 3070 – 2022 data received from the City, and then applying the typical impervious values as a base.

Model Network

The stormwater system model network includes:

- 30.3 km of trunk storm sewers;
- 125.6 km of non-trunk storm sewers;
- 2,022 storm manholes;
- 92 drainage culverts;
- 1 bridge crossing (MoTI); and,
- 3 stormwater detention ponds/facilities.

Nodes in the model consist of storm manholes, outfalls, and culvert ends. Missing or inaccurate information in the database was corrected with the use of available as-built drawings and field inspection notes. Figure 1 in the main body of the report shows the City's drainage system.

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Stormwater Detention Ponds/Facilities

Given the project requirements and budget restrictions, a total of 3 important existing stormwater detention ponds/facilities were included in the modelling for the following sites:

1. North Island College (stormwater detention pond) located at 2300 Ryan Road;
2. North Island Hospital Comox Valley (underground detention) located at 101 Lerwick Road; and,
3. Costco Retail Store (underground detention) located at 588 Crown Isle Boulevard.

To determine detention pond/facility volumes, storage curves were developed for the SWMM model based on the as-built drawings received from the City.

Assumptions

Data received from the City was checked for any missing elements and for quality. The City filled nearly all the data gaps following the IRMP Phase 1 and 2 work, therefore there was very little missing data for the storm system network. Missing data was compiled and given to the KWL survey team who filled in as much of the missing data as they could in the field within the confines of the project budget. Any further missing data was assumed in both the SWMM model and GIS.

Storm Manhole Data

Storm manhole invert data was assumed in two ways:

1) If a manhole with missing invert data was between upstream and downstream manholes with known inverts, the SWMM model could calculate the missing invert based on a slope calculation between the two known inverts.
2) If there were 2 or more manholes connected in series with missing invert data, inverts were set so the slope of the furthest upstream conduit was preserved.

Missing manhole rim elevations were assumed using a digital elevation model (DEM) that KWL developed from the elevation contour data provided by the City (which the City developed from the 2012 LiDAR information). All assumptions and interpolations are recorded in the model.

Storm Sewer & Culvert Inverts

Any storm sewers with missing inlet or outlet invert data were assumed to have the same invert as the manhole or node they were connected to.

Culvert inverts that were not able to be surveyed due to safety, access, or project budget reasons were assumed with the DEM described above and further interpolation if needed. All assumptions and interpolation is recorded in the modelling.

Watercourses and Channels

Cross-sections for the major watercourses and channels in the City were created from the DEM described above. Cross-sections for man-made drainage channels were also derived from the DEM. Cross-sections for minor channels and small roadside ditches were modelled as trapezoidal channels using typical minor channel and roadside ditch geometries.

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Conduit Roughness

Storm sewers and culverts roughness values were assigned based on typical values associated with the conduit material. Natural and man-made channel roughness values were assigned based on typical values associated with the channels.

Boundary Conditions

The hydrologic and hydraulic model was developed specifically for the purpose of assessing storm sewer and culvert conveyance capacities, therefore a free outlet boundary condition was applied in the assessment and design scenarios. This prevented backwatering and flooding from the downstream watercourses, allowing the pipe capacity to be evaluated.

F.3 Weather Station Rainfall and Flow Monitoring Data Collection

Weather Station Rainfall Data

Rainfall data for calibration was collected from 3 rain gauge locations as provided by the City:

1. "Majestic LS" - Lift Station located in the Crown Isle Subdivision.
   Coordinates – Latitude: 49.71414 W, Longitude: 124.94903 W
2. "VMP" – Located at Veterans Memorial Pkwy & Caledon Crescent.
   Coordinates – Latitude: 49.71568 N, Longitude: 124.98783 W
3. City Hall – Located at 830 Cliffe Ave, Courtenay, BC V9N 2J7.
   Coordinates – Latitude: -124.99539 N, Longitude: 49.68963 W

The period of record available for the above rain gauge locations was November 2021 to March 2022. See **Error! Reference source not found.**1 in the main body of the report for the rain gauge station locations.

Flow Monitoring Data

Flow monitoring gauges marked on Figure 1 in the main body of the report were used to calibrate and validate the storm system model using the recorded flow values. Calibration and validation rainfall events were chosen by selecting the largest rainfall events with fewest data gaps that also occurred within the recording period of the installed flow monitoring gauges. Selected rainfall events were modelled in the SWMM model, and the resulting flows were compared to the recorded data at the flow monitoring gauges.

City Flow Monitoring Data Collection

KWL received instructions from the City to obtain the flow monitoring data collected by BotCorp.

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Table F-3: Flow Monitoring Gauges Summary

Monitoring Station	Location	Active Period
Flow Monitoring Site # 36-0005 – Muir Road	49.71299 N, -124.98149 W	November 2021 to March 2022
Flow Monitoring Site # 37-2033 – Crown Isle Blvd.	49.71557 N, -124.96335W	November 2021 to March 2022
Flow Monitoring Site # 15-0002 – Woods Ave.	49.68631 N, -125.01404W	November 2021 to March 2022

F.4 Total Impervious Area Estimates

The existing conditions impervious coverages for the total impervious area (TIA) at the flow monitoring gauges are shown in **Error! Reference source not found.**.

Table F-4: Existing Conditions TIA Estimates for Catchment at Gauge Location

Location	TIA[1]
Flow Monitoring Site # 36-0005 – Muir Road (BotCorp)	42%
Flow Monitoring Site # 37-2033 – Crown Isle Blvd. (BotCorp)	85%
Flow Monitoring Site # 15-0002 – Woods Ave. (BotCorp)	56%

1. The total impervious area (TIA) for the existing conditions was estimated using assigned percent impervious in the model based on BC Assessment and air photo information.

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F.5 Modelling Calibration and Validation

Ideally, the calibration/validation process includes two calibration storms, one dry initial condition to calibrate the imperviousness of the watershed and one wet initial condition to calibrate the groundwater response and a third independent validation storm. Unfortunately, the recorded flow data did not include a dry initial condition period and therefore the wet initial condition storm was used for calibration of both imperviousness and groundwater. Once calibrated, it is important to validate the hydrologic/hydraulic model against events that were not used in the calibration process. This serves as an independent check on the assumptions made during the calibration.

The initial calibration step for the model was refining the sub-catchments tributary area to each flow monitoring station. As-builts for various existing developments provided by the City were used to review and confirm tributary drainage areas.

The sub-catchments on the west side of the Courtenay River were calibrated to have their subarea routing value set to pervious. The sub-catchments on the east side of the Courtenay River were calibrated to have their subarea routing value set to outlet.

Additionally, the model groundwater parameters for all sub-catchments were calibrated to have the following values:

- A1 coefficient set to 1;
- B1 exponent set to 1;
- A2 coefficient set to 0;
- B2 exponent set to 0; and,
- A3 coefficient set to 0.

Calibrated parameters were applied to the flow monitoring stations respective watershed. Sub-catchments in other City lands, outside of the tributary watershed areas to the above noted flow monitoring gauges, were assigned appropriate calibrated parameters from adjacent land with similar characteristics. The calibration at the three flow monitoring stations is further described below.

Flow Monitoring Station: Storm Manhole # 36-0005 – Muir Road

Figure F-1 shows the model calibration graph for the watershed tributary to Storm Manhole # 36-0005. Figure F-2 shows the model validation graph for the watershed tributary to Storm Manhole # 36-0005.

The continuous simulation of the period from December 10 to December 14, 2021, was used to calibrate the model upstream of the Storm Manhole # 36-0005 gauge. The continuous simulation of the period from November 25 to December 1, 2021, was used to validate the model upstream of the Storm Manhole # 36-0005 gauge. The validated peak flows and volumes are summarized in Table C-5 below.

Flow Monitoring Station: Storm Manhole # 37-2033 – Crown Isle Boulevard

Figure F-3 shows the model calibration graph for the watershed tributary to Storm Manhole # 37-2033. Figure F-4 shows the model validation graph for the watershed tributary to Storm Manhole # 37-2033.

The continuous simulation of the period from December 10 to December 14, 2021, was used to calibrate the model upstream of the Storm Manhole # 37-2033 gauge. The continuous simulation of the period from January 10 to January 13, 2022, was used to validate the model upstream of the Storm Manhole # 37-2033 gauge. The validated peak flows and volumes can be seen in Table C-5 below.

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Flow Monitoring Station: Storm Manhole # 15-0002 – Woods Avenue

Figure F-5shows the model calibration graph for the watershed tributary to Storm Manhole # 15-0002. Figure F-6 shows the model validation graph for the watershed tributary to Storm Manhole # 15-0002.

The continuous simulation of the period from December 10 to December 14, 2021, was used to calibrate the model upstream of the Storm Manhole # 15-0002 gauge. The continuous simulation of the period from November 25 to December 1, 2021, was used to validate the model upstream of the Storm Manhole # 15-0002 gauge. The validated peak flows and volumes can be seen in Table F-5 below.

The above flow monitoring stations recorded volumes and peak flows may not exactly match the rainfall stations volume and peak flows because the rain gauges used were outside of the sub-catchment areas tributary to the flow monitoring gauges and the three rainfall gauges recorded significantly different amounts of rainfall during the calibration/validation periods and in the period of record overall. However, as a model primarily used for sizing storm sewers and culverts, the validated model flows are conservative and acceptable.

Table F-5: Modelling Validation Summary

Flow Monitoring Gauge Station	Peak Flow (m^3/s)		Peak Flow Difference	Volume (m^3)		Volume Difference
	Recorded	Validated		Recorded	Validated	
Manhole # 36-0005 – Muir Road	0.140	0.160	+14 %	11,880	11,620	-2 %
Manhole # 37-2033 – Crown Isle Blvd.	0.070	0.078	+11 %	4,084	4,337	+6 %
Manhole # 15-0002 – Woods Ave.	0.390	0.410	+5 %	43,700	39,580	-9 %

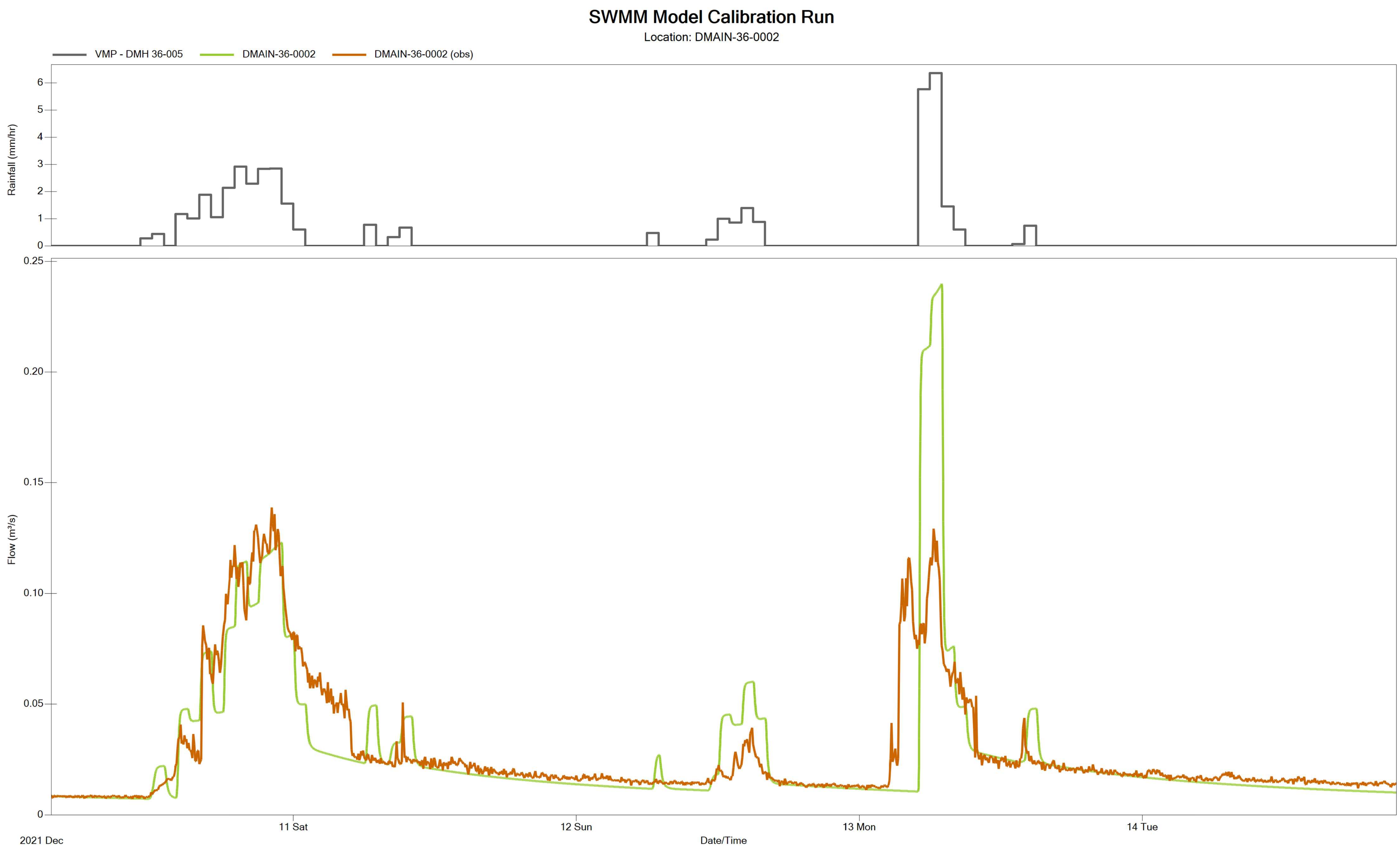

SWMM Model Calibration Run
Location: DMAIN-36-0002
VMP - DMH 36-005
DMAIN-36-0002
DMAIN-36-0002 (obs)
Rainfall (mm/hr)
6
5
4
3
2
1
0
Flow (m³/s)
0.25
0.20
0.15
0.10
0.05
0
11 Sat
12 Sun
13 Mon
14 Tue
2021 Dec
Date/Time

Figure F-1

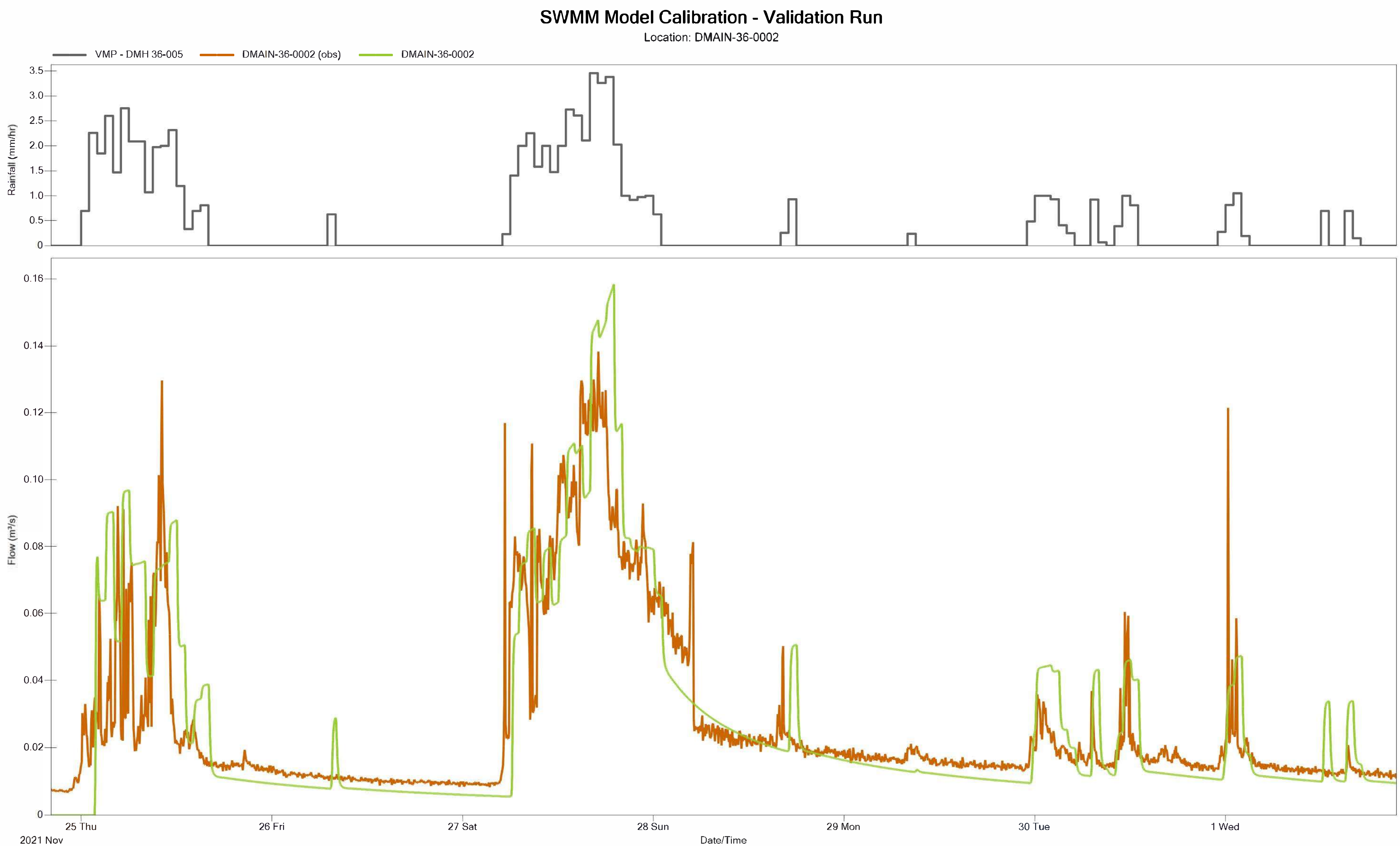

SWMM Model Calibration - Validation Run
Location: DMAIN-36-0002
VMP - DMH 36-005
DMAIN-36-0002 (obs)
DMAIN-36-0002
Rainfall (mm/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Flow (m³/s)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
25 Thu
26 Fri
27 Sat
28 Sun
29 Mon
30 Tue
1 Wed
2021 Nov
Date/Time

Figure F-2

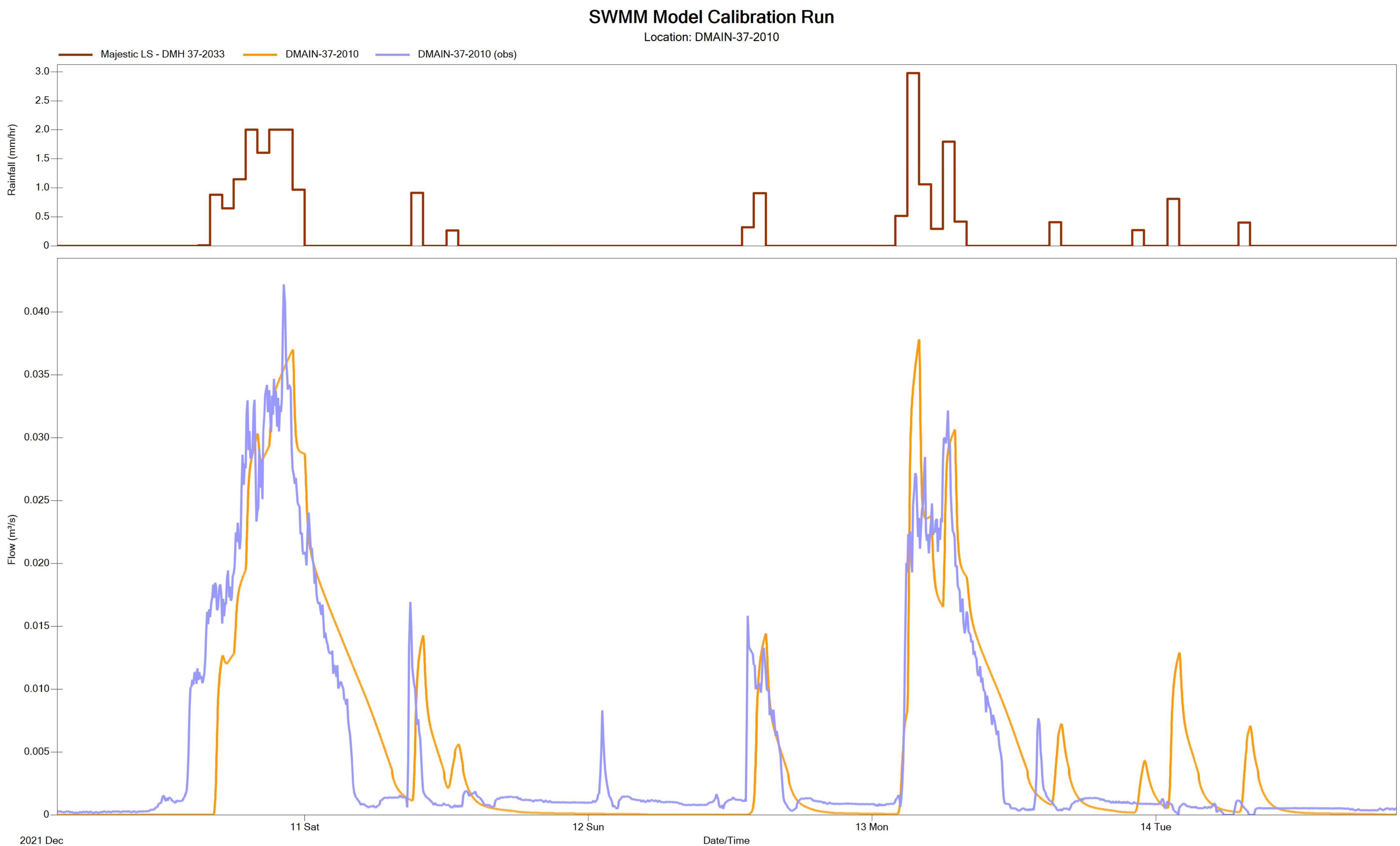

SWMM Model Calibration Run
Location: DMAIN-37-2010
Majestic LS - DMH 37-2033
DMAIN-37-2010
DMAIN-37-2010 (obs)
Rainfall (mm/hr)
3.0
2.5
2.0
1.5
1.0
0.5
0
Flow (m³/s)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0
11 Sat
12 Sun
13 Mon
14 Tue
2021 Dec
Date/Time

Figure F-3

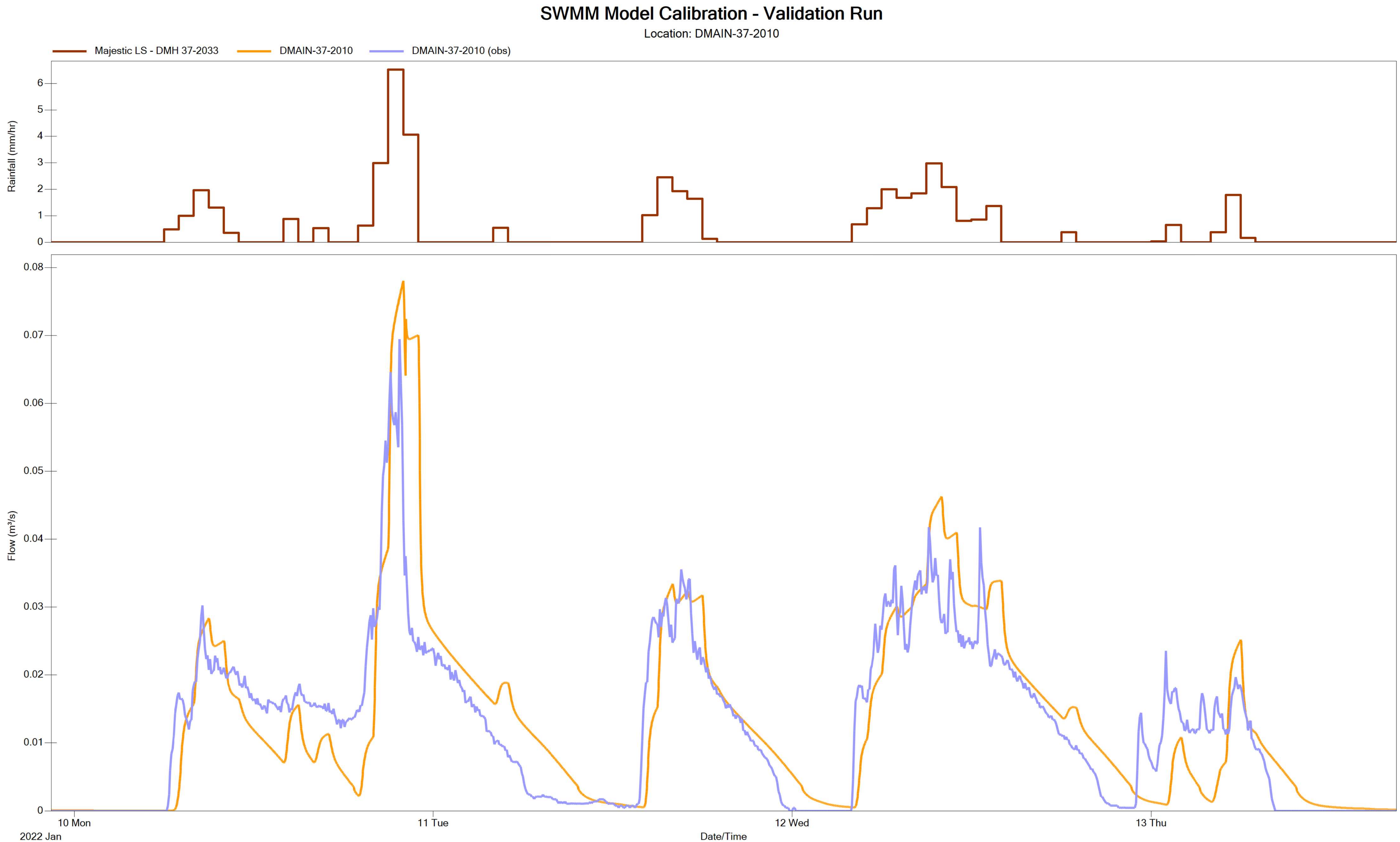

SWMM Model Calibration - Validation Run
Location: DMAIN-37-2010
Majestic LS - DMH 37-2033
DMAIN-37-2010
DMAIN-37-2010 (obs)
Rainfall (mm/hr)
6
5
4
3
2
1
0
Flow (m³/s)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10 Mon
2022 Jan
11 Tue
12 Wed
13 Thu
Date/Time

Figure F-4

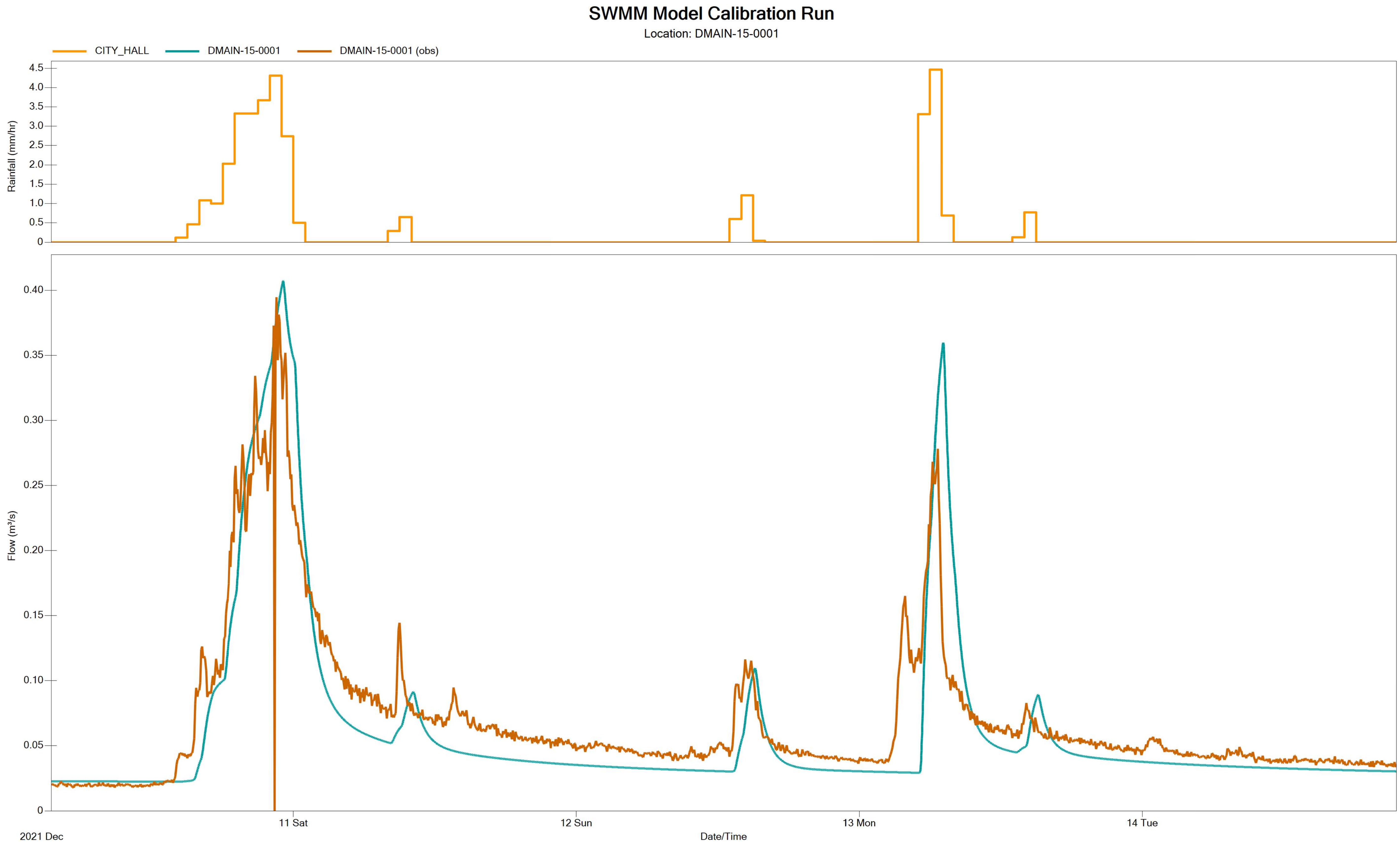
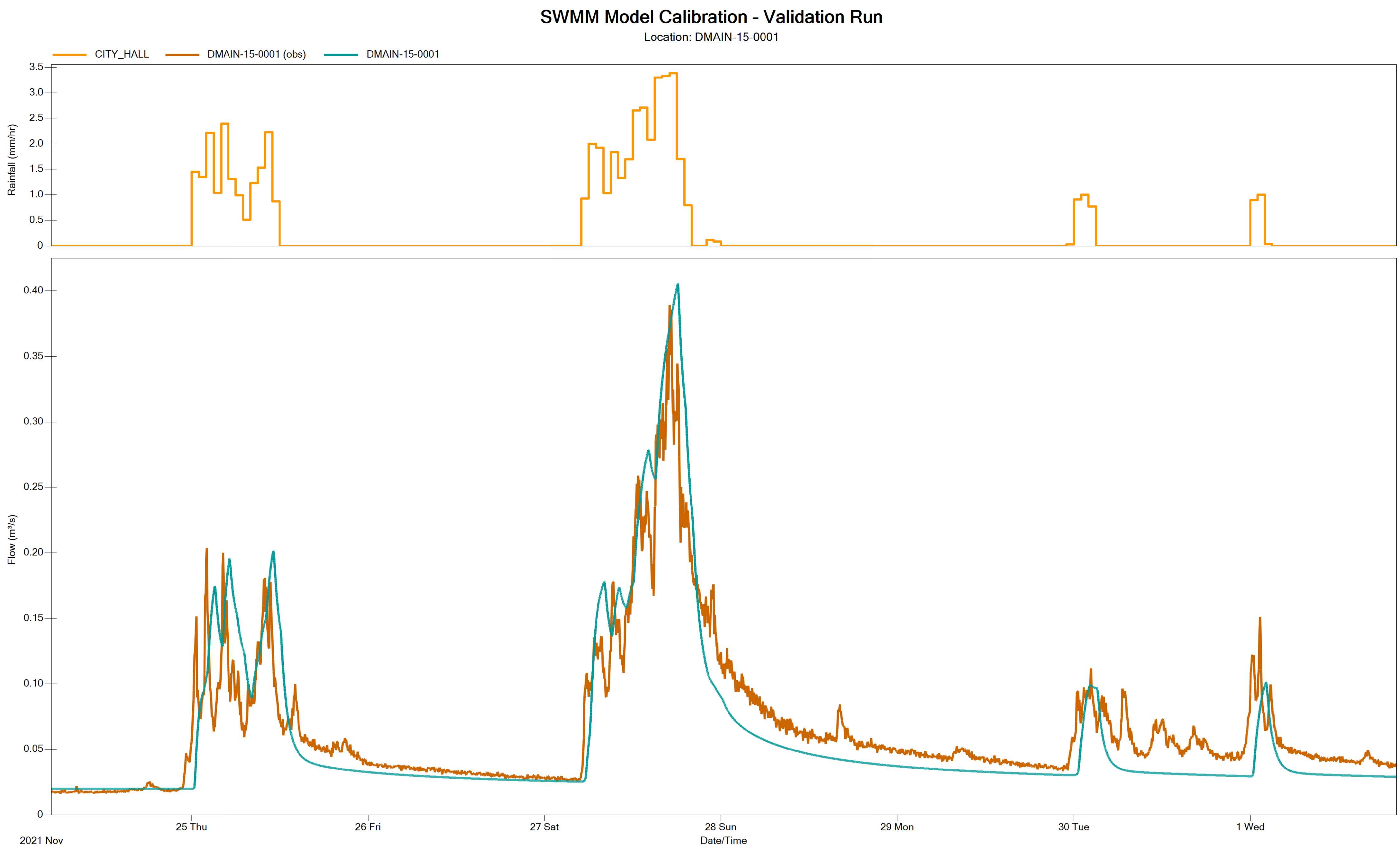

SWMM Model Calibration Run
Location: DMAIN-15-0001
CITY_HALL
DMAIN-15-0001
DMAIN-15-0001 (obs)
Rainfall (mm/hr)
Flow (m³/s)
11 Sat
12 Sun
13 Mon
14 Tue
2021 Dec
Date/Time

Figure F-5



SWMM Model Calibration - Validation Run
Location: DMAIN-15-0001
CITY_HALL
DMAIN-15-0001 (obs)
DMAIN-15-0001
Rainfall (mm/hr)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Flow (m³/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
25 Thu
26 Fri
27 Sat
28 Sun
29 Mon
30 Tue
1 Wed
2021 Nov
Date/Time

Figure F-6