Evaluation of Radar-Based Quantitative Precipitation Forecasts to Extend Flood Forecasting Lead-Time

November 28, 2012

Final

Prepared for
Urban Drainage and Flood Control District
2480 W. 26th Avenue, Suite 156-B
Denver, CO 80211

VIEUX, INC.

350 David L. Boren, Blvd. Suite 2500
Norman, Oklahoma 73072
www.vieuxinc.com
405 325-1818

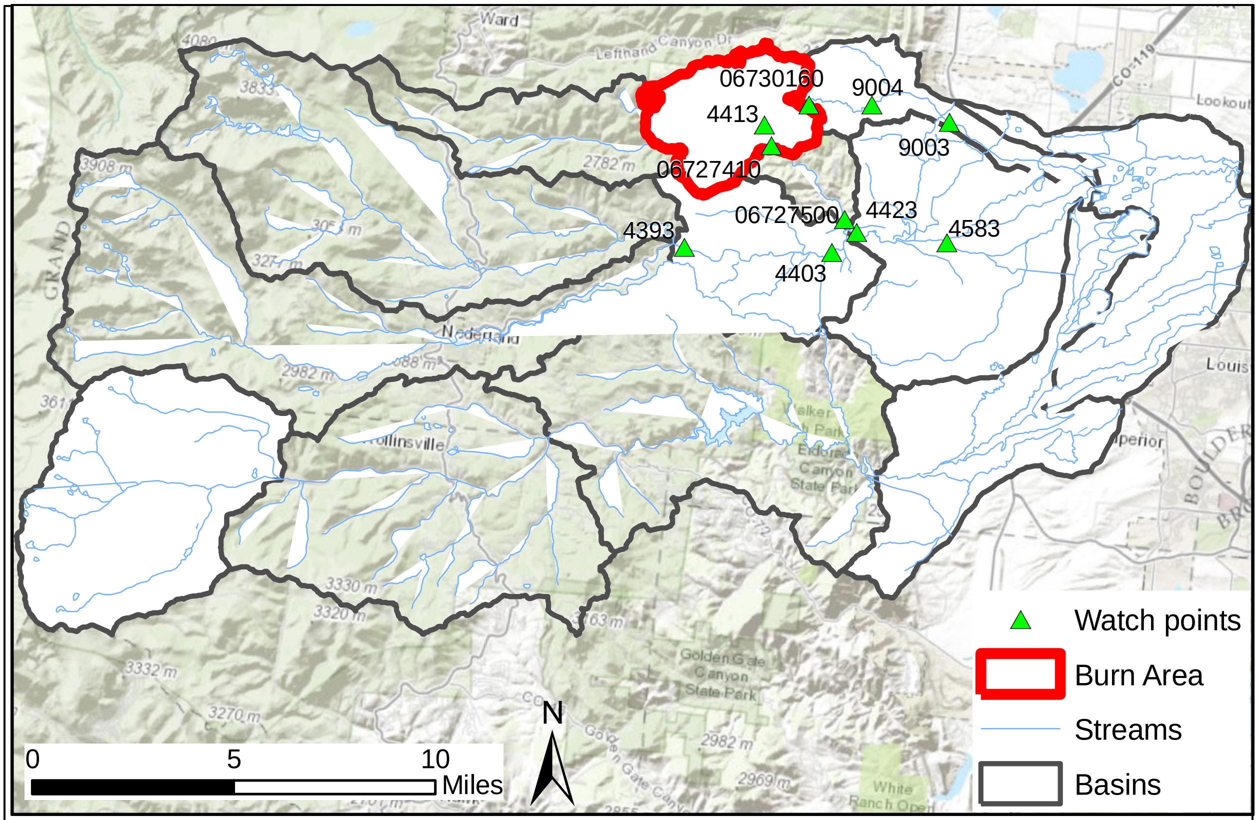
Table of Contents

Introduction

The Fourmile Canyon wildfire changed hydrologic conditions causing an increase in flood hazards downstream. Areas impacted by the burn area are along Fourmile Creek and Fourmile Canyon Creek stream channels in rural areas of Boulder County, and in the City of Boulder. The Fourmile Canyon Fire burned an area of 6,179 acres composed primarily of open ponderosa pine in the foothills of the Front Range in Colorado. Since that fire on September 6, 2010, a flood forecasting system was put into place by the Urban Drainage and Flood Control District (UDFCD). The system is composed of V*flo*™, a physics-based distributed hydrologic model, and inputs derived from a combination of radar and gauge measurements in real-time. Continuous forecasting of flood potential took place during May-August of 2011 and again in 2012, a period prone to flooding in the Boulder Creek watershed, especially since the fire altered hydrologic conditions in the burn area. The last two flood forecasting seasons, 2011-2012, were based on detected rainfall called quantitative precipitation estimates, or QPE. The purpose of this study is to evaluate the benefit of using quantitative precipitation forecasts (QPF) to extend flood forecasting lead-time.

The modeling approach integrates diverse information on the land surface, such as terrain and land use/cover, with radar-based rainfall input to simulate the hydrologic effects of the wildfire. The model was initially deployed without calibration using physically realistic model parameters and assuming zero infiltration in the burn area. After the first significant runoff event on July 13 2011, the assumed infiltration rates were increased from zero to 0.08 in/hr (on average), a rate that is still very low, but believed to be representative of the post-wildfire effects in the burn area. Predictive hydrologic information in real-time is used to generate flood threat alerts based on discharge thresholds at critical locations in downstream areas receiving streamflow from the burn area. In 2012, two events resulted in streamflow on July 7 and 30. Though flooding was minor, additional evaluation of model parameters was performed retrospectively for these two events. However, no adjustment to parameters was made in the post-2012 flood season because model performance resulted in useful and accurate results.

After the flood season passed in 2012, the model was used to test the use of QPF in addition to QPE in terms of increased forecast lead-time. Due to the short hydraulic response of these mountainous watershed areas, any increase in lead-time would be advantageous for taking emergency actions. Testing the increased lead-time was accomplished by re-running each event with QPE and then adding in QPF and evaluating the resulting hydrographs. This is done sequentially during the event where the QPF is generated from the last two radar scans, and added on to detected precipitation represented by QPE for that time interval. This study determines how much QPF extends flood forecasting lead-time for three events: July 13, 2011, July 7, 2012, and July 30, 2012. Watch points shown in Figure 1 are selected because they experienced a significant hydrograph response, and are evaluated in the following analysis.



Watch Point Description
Boulder Creek at Boulder Falls (4393)
Boulder Creek at Orodell, CO (4403)
Fourmile Creek at Salina (4413)
Boulder Creek at Bridge (4423)
Boulder Creek at Broadway (4583)
Fourmile Creek at Logan Mill Road (06727410)
Fourmile Creek at Orodell (06727500)
Fourmile Canyon Creek at Burn Area Outfall (06730160)
Fourmile Canyon Creek at Broadway (9003)
Fourmile Canyon Creek at Pinto Dr. (9004)

Figure 1 Selected watch point locations examined in this study

Methodology

The hydrologic model can use precipitation input from both quantitative precipitation estimates (QPE) and quantitative precipitation forecasts (QPF) for real time operations. QPE for the study is obtained from the operational gauge adjusted radar rainfall (GARR) system, RainVieux, developed by Vieux & Associates, Inc. It uses a statistical control approach and database to generate, display, query, and analyze GARR. QPF estimates are generated from radar reflectivity using an image segmentation technique to identify storm cells in successive radar scans, and then calculate a forecast storm motion. With these motion vectors computed for each storm cell, the projected movement and intensification or decay are projected forward at 5-min intervals into the next one hour period. A new one-hour forecast period is generated with each volume scan of the radar filtered to 5-min time steps. The testing of QPF is performed using the detected rainfall, QPE, produced for each of the three events. Archival QPE data generated during these events were used as input along with QPF that would have been used operationally. Testing the advantages of incorporating QPF to extend lead-time is evaluated in the following results section.

Results

Among the three events, the evolution of storm motion, and the resulting pattern of rainfall differs. All three events produced runoff and significant streamflow at various locations downstream of the burn area. The storm total accumulations seen in Figure 2 reveal that all three storms were spatially isolated. During the July 13, 2011 event, a storm cell initiated just to the southwest of the burn area and continued to develop and travel over the burn area giving the most lead-time of any of the events evaluated. The July 7, 2012 event developed widespread precipitation with the highest accumulation and intensities over portions of Middle and South Boulder Creek, but to a lesser extent over the burn area. During the July 30, 2012 event rainfall was also widespread, but with the highest accumulation and intensities over Fourmile Canyon Creek, but to a lesser extent over the Fourmile Creek burn area portion.

To gain an appreciation of how QPF would have aided in the forecasting of these events, the operational model was re-run with the QPE generated during each, and with the addition of QPF that would have been produced from the detected rainfall. The July 13, 2011 event is the most successful in producing increased lead-time. Initially, the QPF provides advanced warning, which then diminishes with time. Figure 3 shows rainfall detected by radar, a) at 2011-07-13 17:45 MDT, b) rainfall forecast for 18:45, c) actual rainfall at 18:45. Figure 4a shows the storm cell that developed to the southwest that later traveled over the burn area. Rainfall intensities produced by the QPF (Figure 3b) compare closely in magnitude and spatial distribution with what actually occurred at that time (Figure 3c). The testing of forecast lead-time is evaluated by generating hydrographs with the QPF generated from the same radar data used in production of QPE. Hydrographs generated with QPE (blue hydrograph), and with addition of QPF (green line) are shown in Figure 4 for the UDFCD Alert gauge 4583 located on Boulder Creek at Broadway in the City of Boulder. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55. The hydrograph generated using QPF indicated an alert at 18:05, while the hydrographs generated using QPE would not have initiated an alert until 18:55. As time progresses the difference diminishes resulting in the hydrographs generated from QPE versus QPF as being nearly identical. Hydrographs produced during the July 13, 2011 event show how QPF gives additional lead-time when a cell forms outside the burn area and then travels over it. Figure 3a shows the hydrograph generated by QPF (green hydrograph) exceeds the peak discharge predicted QPE (see blue hydrograph), and exceeds what was eventually observed by stream gauge. Even so, an advanced warning could have been generated of an impending rise in streamflow by adding QPF input. Figures A-1 thru A-7 in the Appendix show similar hydrographs for remaining watch points considered in this analysis.

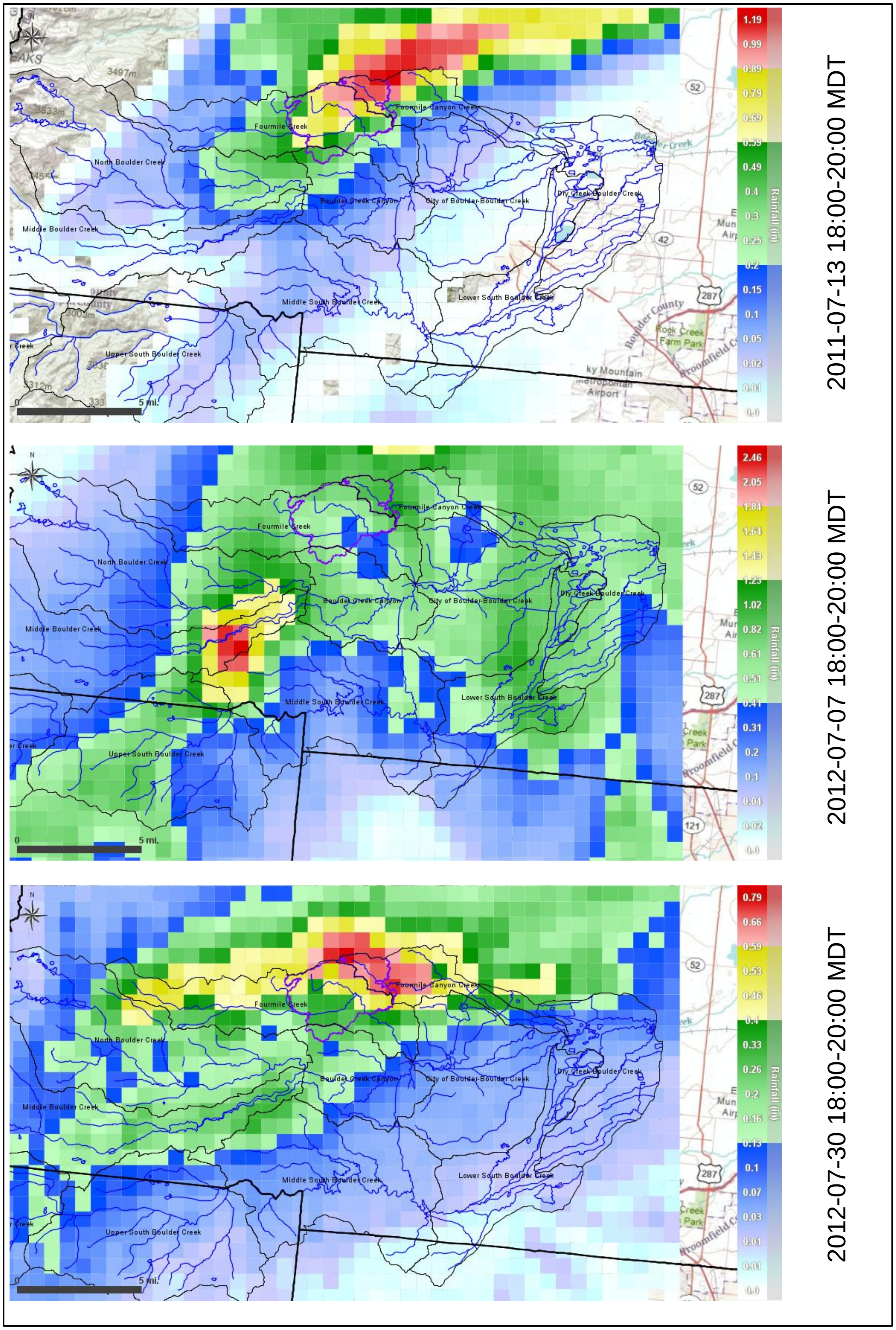
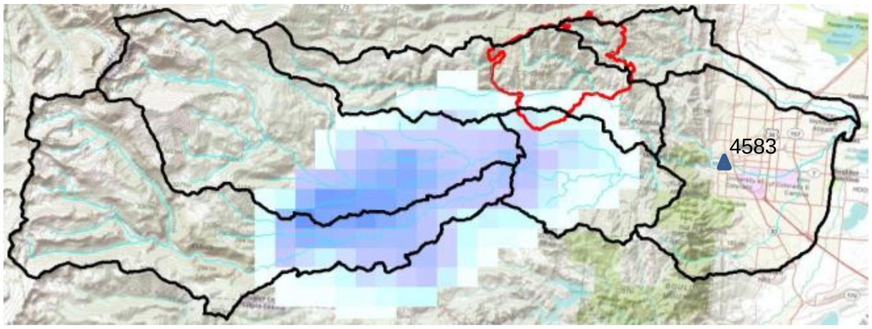
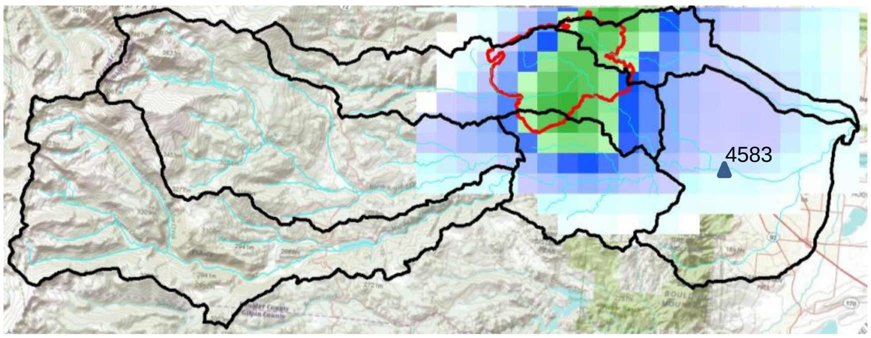


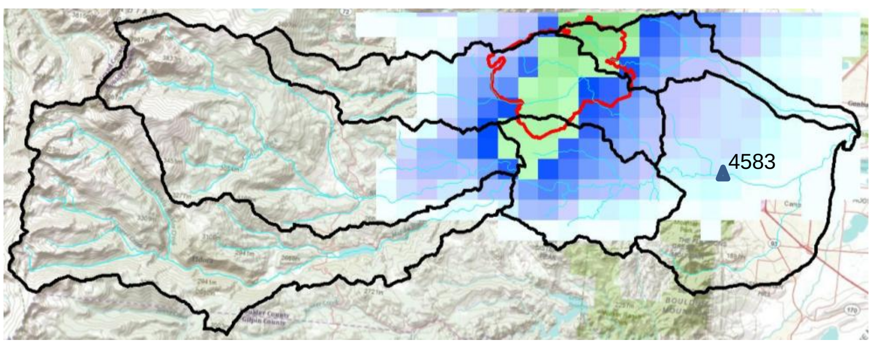
Figure 2 Rainfall totals for three events on: July 13, 2011, and July 7 and July 30, 2012



a) QPE detected by radar at 2011-07-13 17:45 MDT



b) QPF estimated for 18:45 MDT, but produced an hour earlier from the QPE at 17:45 MDT (Figure 2a above)



c) Actual QPE that occurred at 18:45 MDT comparable to Figure 2b above.

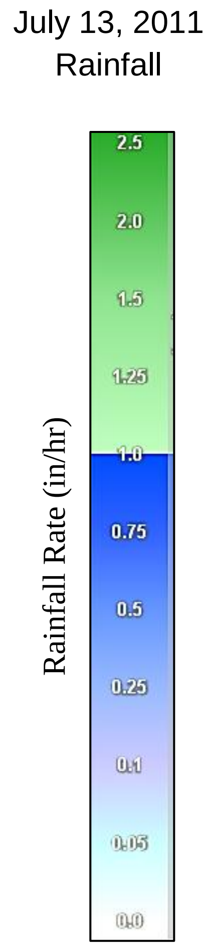


Figure 3 Rainfall detected by radar, a) at 2011-07-13 17:45 MDT, b) rainfall forecast for 18:45, c) actual rainfall at 18:45

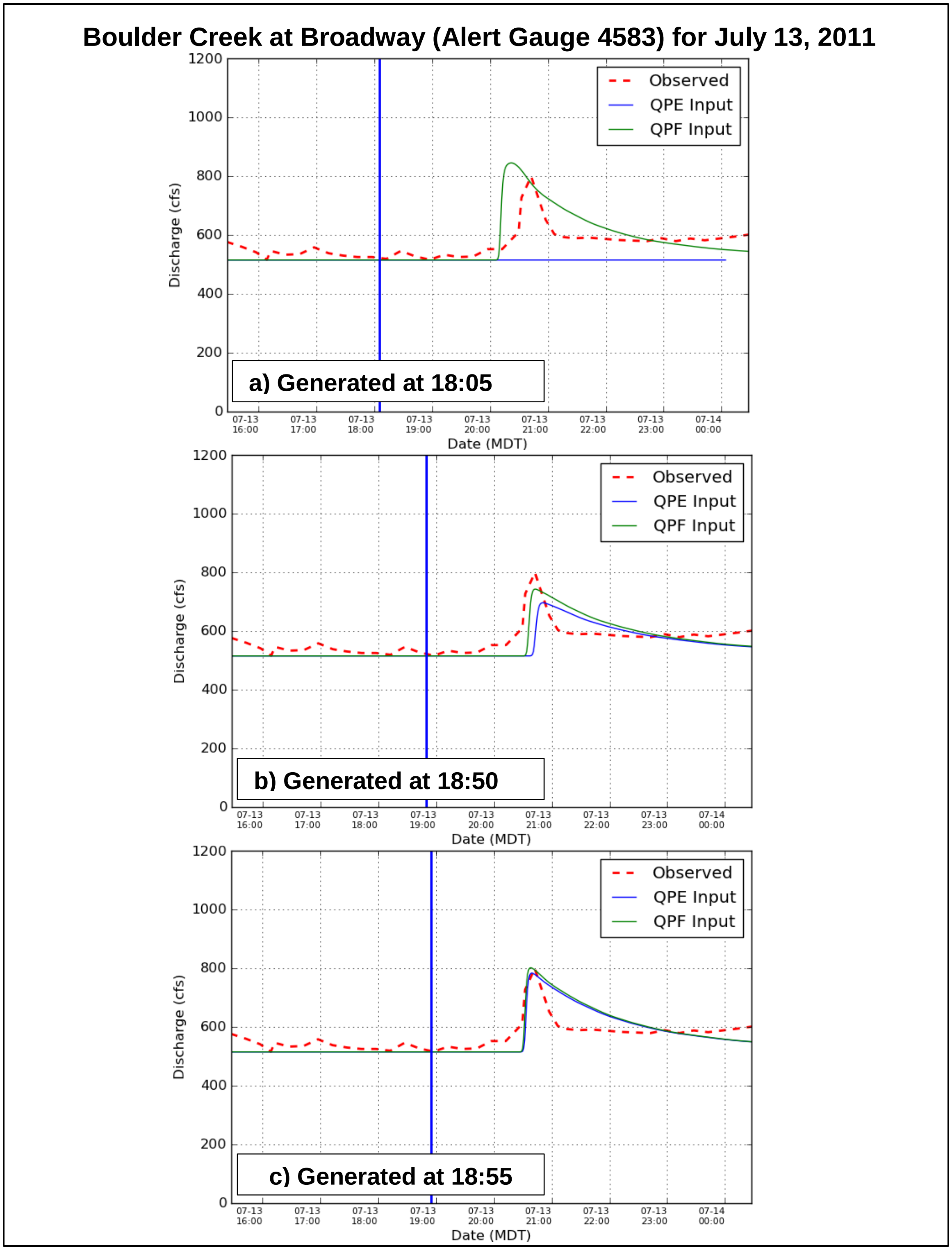


Figure 4 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for Boulder Creek at Broadway (Alert gauge 4583) in the City of Boulder. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

A summary of additional lead-times achieved by using QPE-QPF for watch points, which had a hydrologic response, are presented below in Table 1 for the three events.

Table 1 Additional lead-time for each event and selected watch points

July 13, 2011 event

Watch point	Lead-time (min)
4583	50
06730160	20
06727500	50
06727410	50
Mean	42
Maximum	50

July 7, 2012 event

Watch point	Lead-time (min)
4393	0
4403	0
4423	0
4583	0
06730160	80
06727500	120
Mean	45
Maximum	120

July 30, 2012 event

Watch point	Lead-time (min)
4413	5
4423	5
4583	0
06730160	0
06727500	5
06727410	5
Mean	3
Maximum	5

The increase in lead-time obtained with QPF presented in Table 1 above represents the difference between the hydrograph produced by QPE and QPF. For purposes of this study, an ‘alert’ is defined as when streamflow rises above a predetermined discharge rate specific to each watch point. Crossing these thresholds in operations would produce a notification to emergency personnel. The extended lead-time obtained by addition of QPF to the production of hydrographs can yield as much as 120 minutes or as little as 3-5 minutes lead-time depending on the formation and behavior of the storm activity. On average, QPF generated an additional 42 minutes of lead-time during the July 13, 2011 event and 45 minutes during the July 7, 2012 event. As expected during the July 30, 2012 event, additional lead-time would have been minimal since the storm developed directly over the burn area.

Most notably, at seven watch points, a hydrograph was generated with QPF input that preceded any detection of a hydrograph rise by QPE alone. This is evident in Figure 3 above and in the Appendix Figures A-1 through A-7 where the green line (generated from QPF at 18:05) shows a significant response is about to happen, while the QPE hydrograph (blue line) is flat with no response. These were not false alarms because the observed streamflow did eventually respond at where there were streamflow observations (at four of seven watch points). This behavior and additional lead-time is summarized in the Appendix. Figures A-1 through A-7 depict hydrographs from QPF, QPE only, along with observations available at the first four locations during the July 13, 2011 event.

Summary

This study evaluated the benefit of using quantitative precipitation forecasts to extend flood forecasting lead-time for the Fourmile Creek and Fourmile Canyon Creek watersheds, and for Boulder Creek. To gain an appreciation of how QPF would have aided in the forecasting of these events, the operational model was re-run with the QPE generated during each event, and with the addition of QPF that would have been produced from the detected rainfall.

Two of the three events tested show increased lead-time using QPF, July 13, 2011 and July 7, 2012. During the July 13, 2011 event, radar detected a thunderstorm that formed to the southwest of the burn area at 17:45. The QPF algorithm then projected the thunderstorm cell forward in time by an hour to 18:45. During this time, the hydrograph generated using QPF in addition to QPE indicated a rise in streamflow well in advance, by 50 minutes, compared to the hydrographs generated solely with QPE input. The maximum lead-time occurred when a storm grows outside of the simulated watershed, and then moves over the watershed, as was the case during the July 13, 2011 event. The addition of QPF to QPE generated an additional 42 minutes of lead-time during the July 13, 2011 event, and 45 minutes during the July 7, 2012 event on average. As expected during the July 30, 2012 event, additional lead-time would have been minimal since the storm developed directly over the burn area, where only 3 minutes of additional lead-time was realized with the addition of QPF provided by radar.

The results found in analysis of three storms showed that QPF could extend lead-time when the storms formed outside of the burn area and then pass over the watershed. During the July 13, 2011 event, a hydrograph was generated with QPF input that preceded any detection of a hydrograph rise by QPE alone at all seven watch points evaluated. In the three events tested, the range of lead-time obtained with radar-based QPF was as much as 120 min, and as little as 3-5 min lead-time, with approximately 45 min on average. Adding QPF into the V*flo*™ forecast system can increase lead-time, but depends on individual storm formation and movement over the burn area. The use of QPF could gain critical time in warning when stream levels are expected to rise, and would be a viable tool for flood forecasting in fast response watersheds.

Appendix

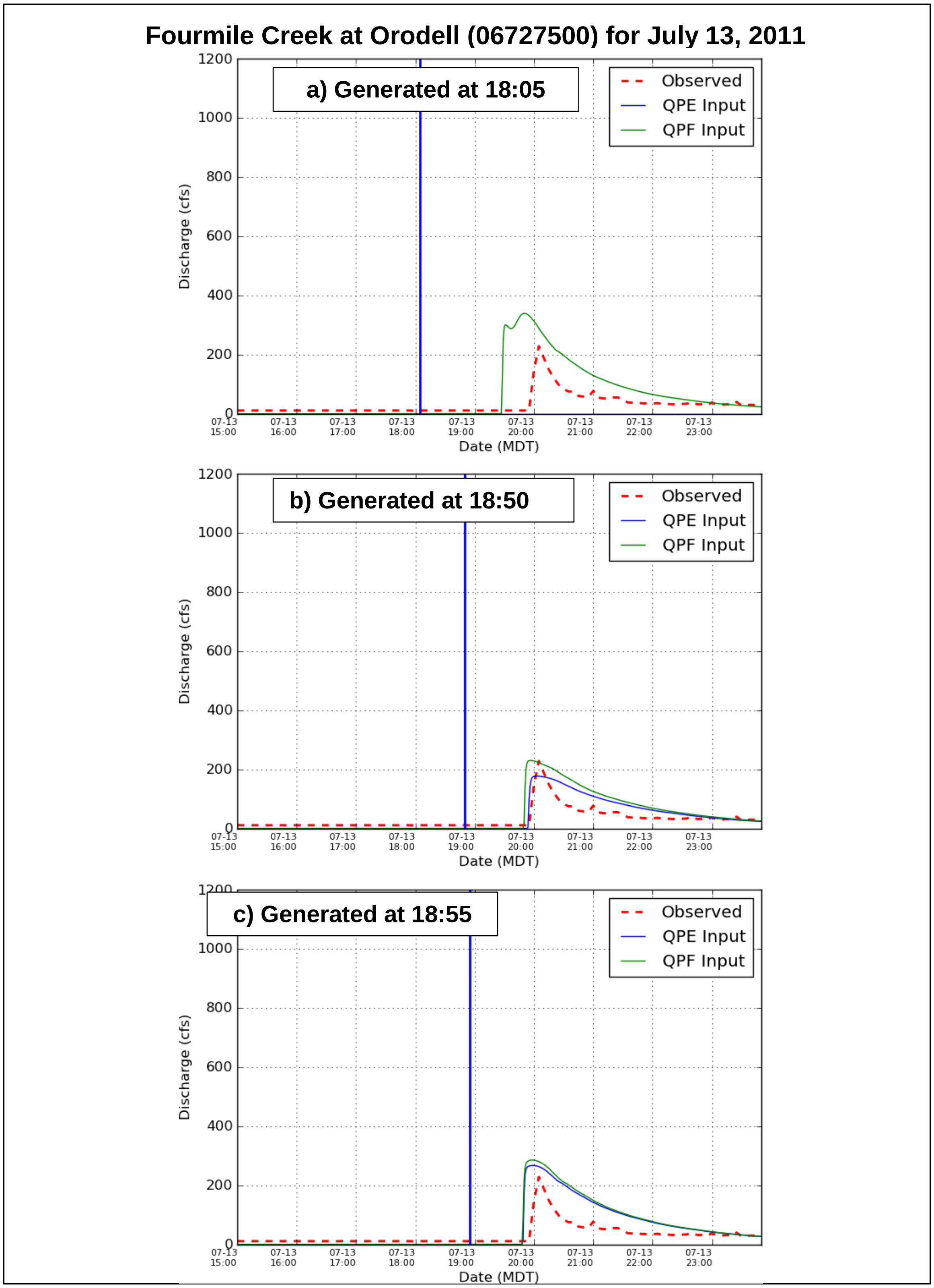


Figure A-1 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for the USGS gauge 06727500 located on Fourmile Creek at Orodell. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

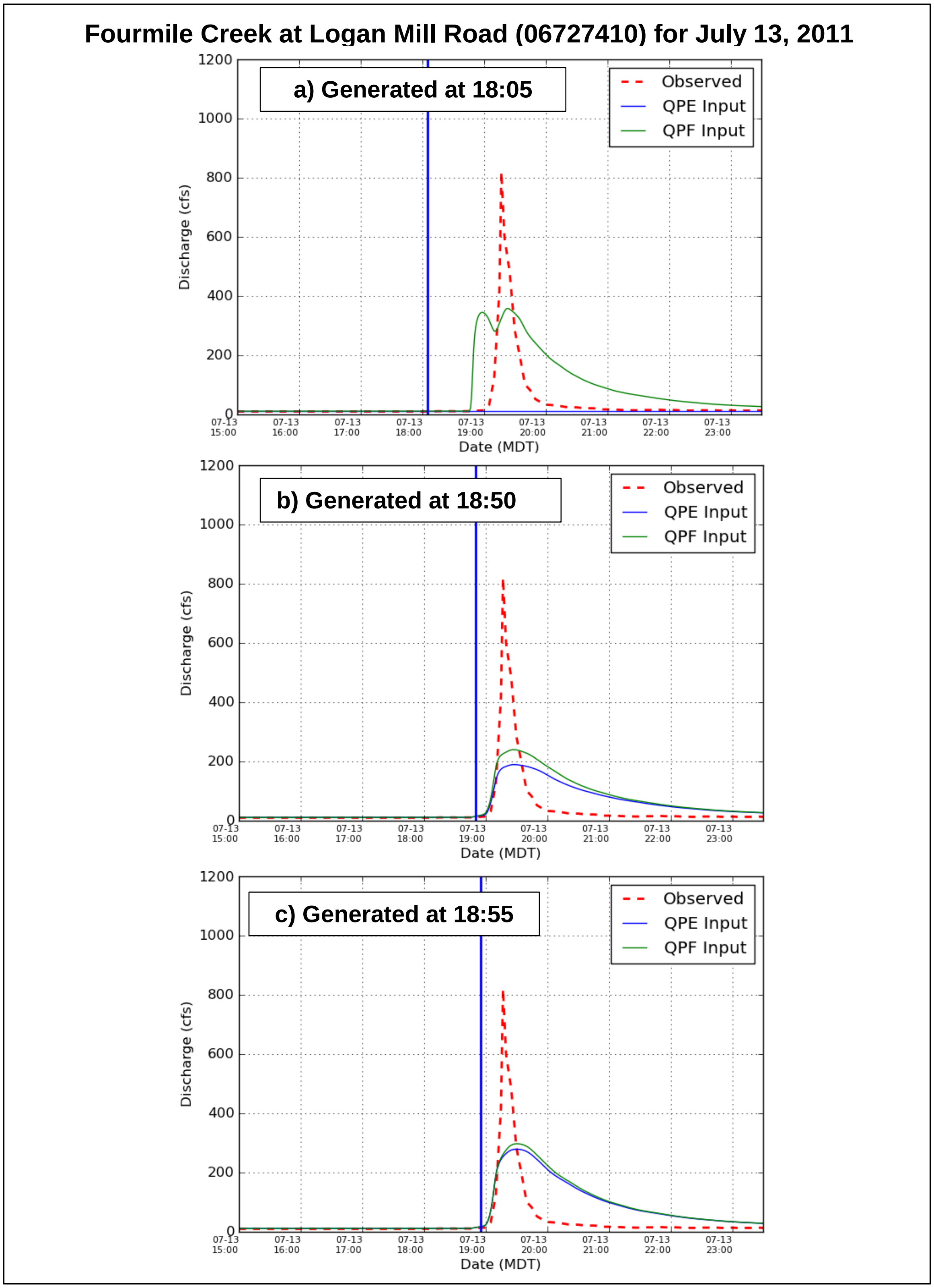


Figure A-2 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for the USGS gauge 06727410 located on Fourmile Creek at Logan Mill Road. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

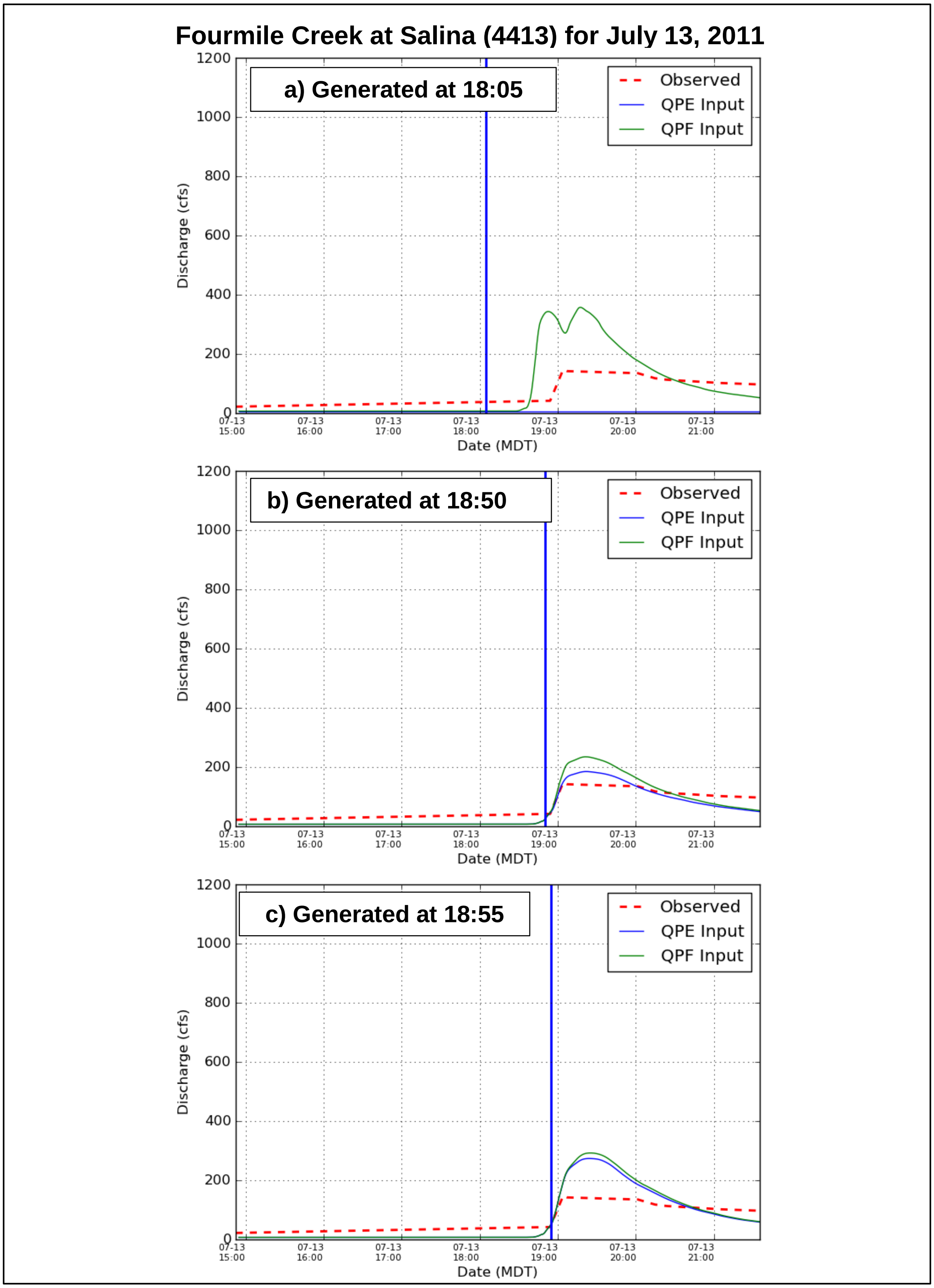


Figure A-3 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for the UDFCD gauge 4413 located on Fourmile Creek at Salina. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

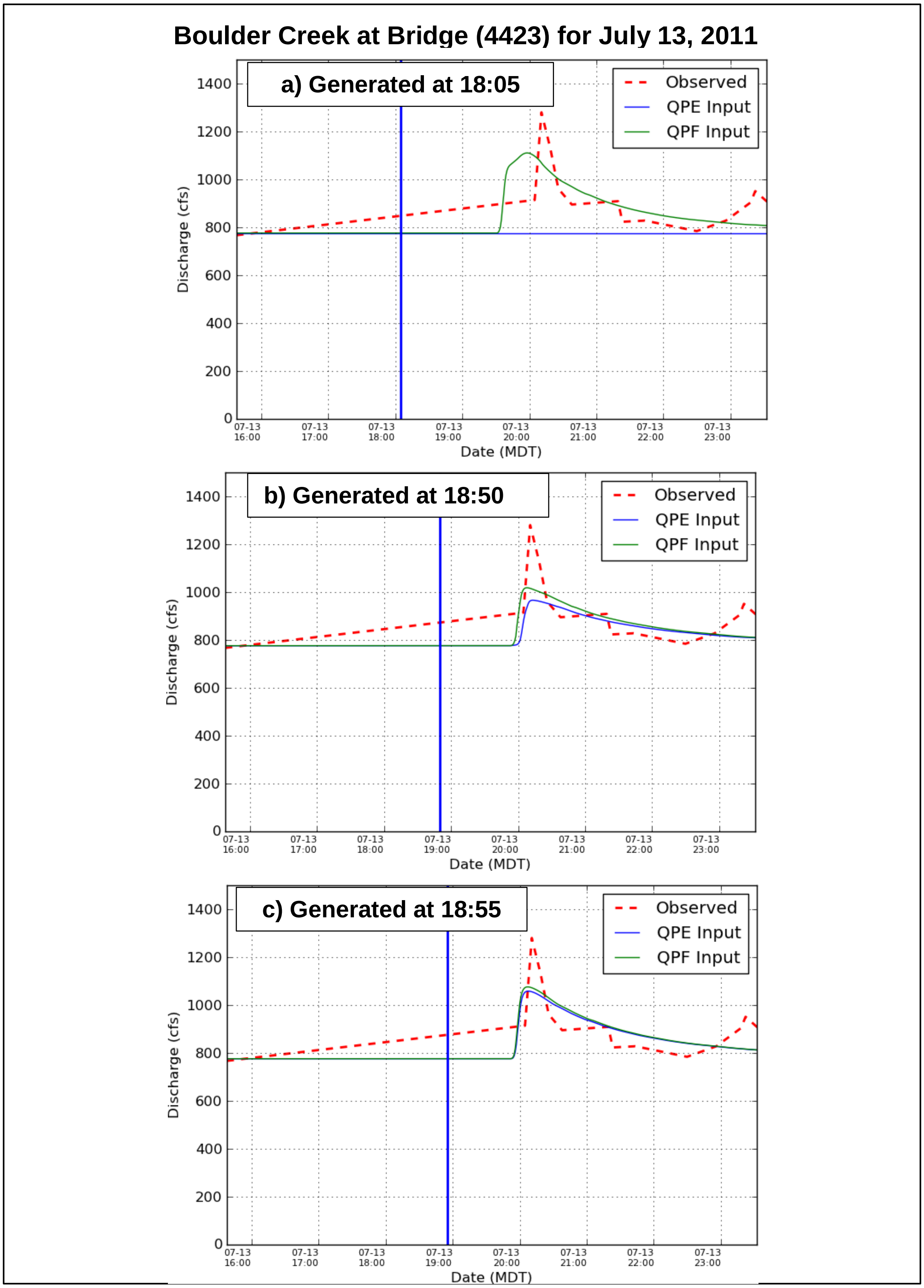


Figure A-4 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for the UDFCD gauge 4423 located on Boulder Creek at Bridge. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

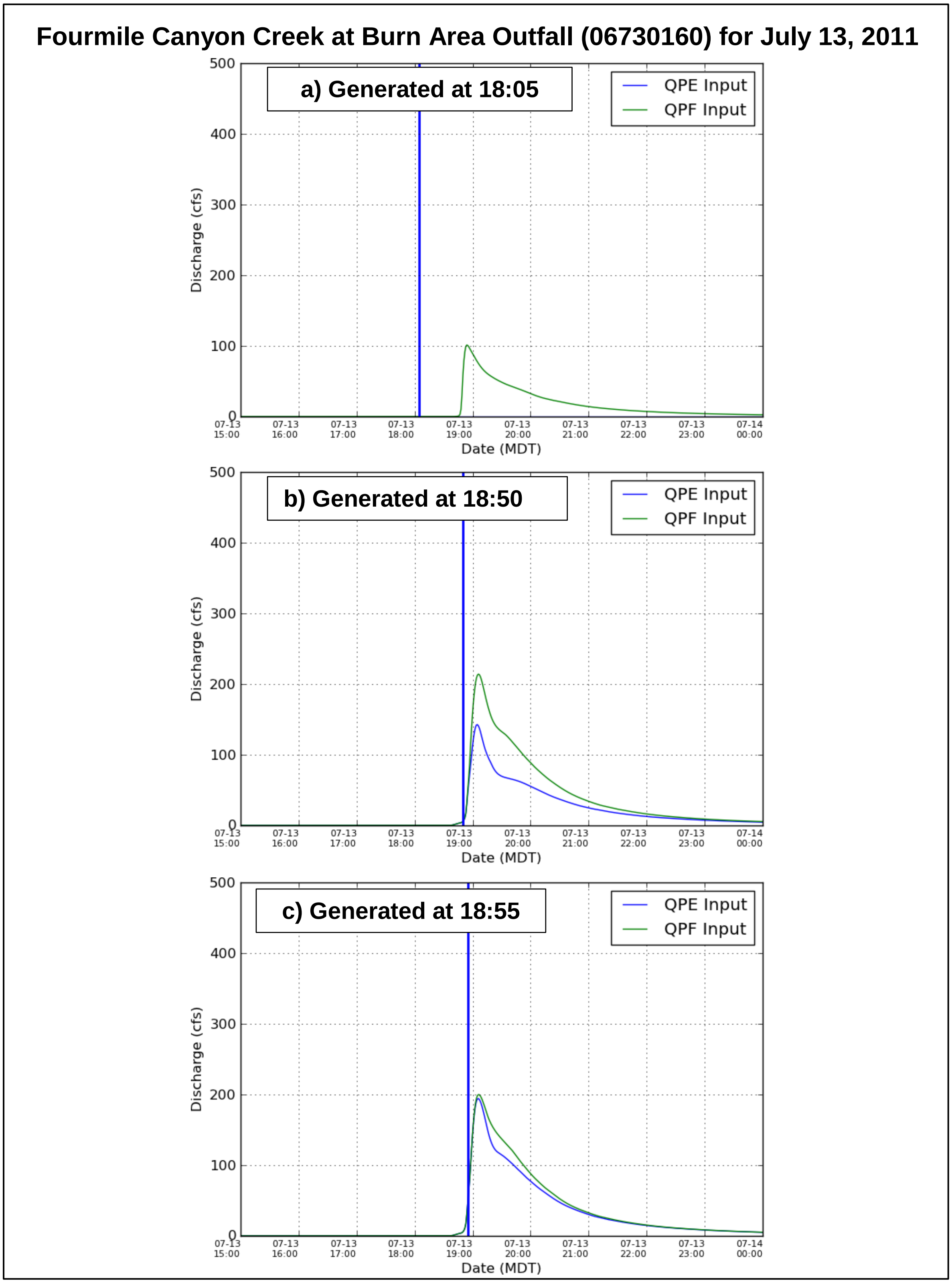


Figure A-5 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for the USGS gauge 06730160 located on Fourmile Canyon Creek at Burn Area Outfall. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

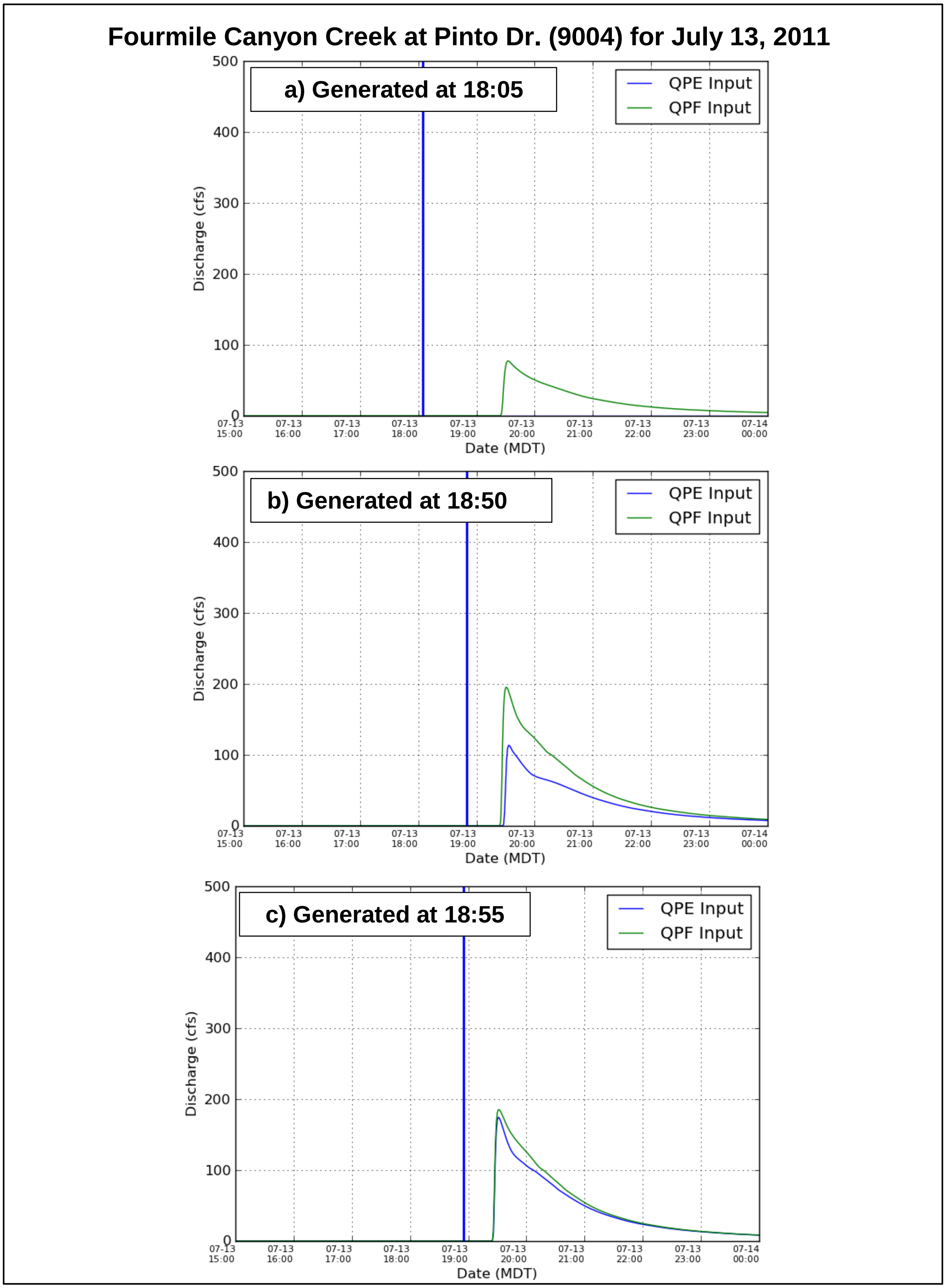


Figure A-6 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for watch point 9004 located on Fourmile Canyon Creek at Anne U. White Trailhead (Pinto Dr). Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.

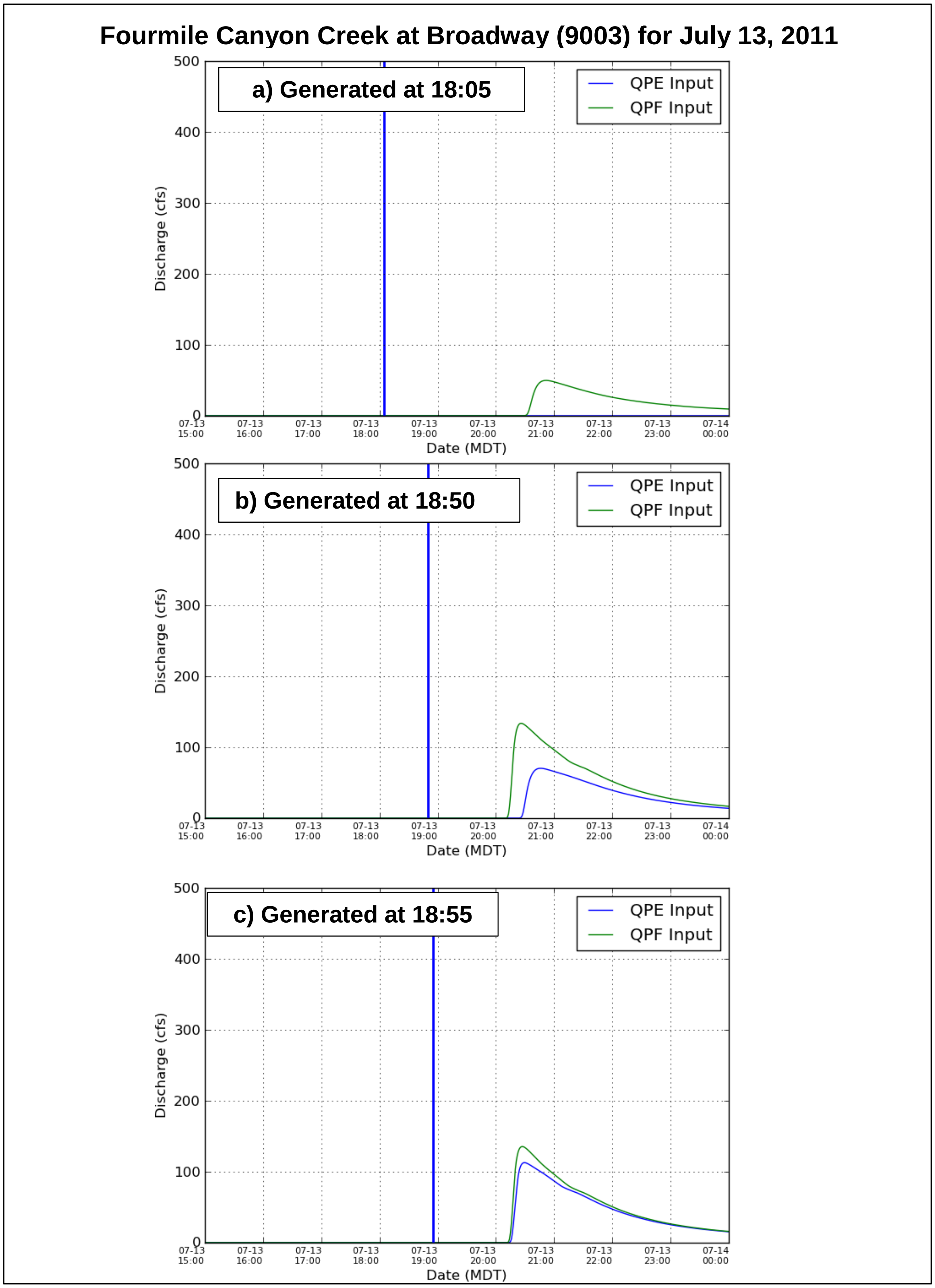


Figure A-7 Hydrographs generated using V*flo*™ with QPE input (blue hydrograph) and with addition of QPF input (green line) for watch point 9003 located on Fourmile Canyon Creek at Broadway. Successive times are shown by the vertical blue line indicating when the hydrograph was produced, a) at 18:05, b) at 18:50, and c) at 18:55.