MEMORANDUM

To: Kurt Bauer, P.E. and Bob Harberg, P.E.
City of Boulder
Via Email

From: Wright Water Engineers, Inc.
Andrew Earles, Ph.D. P.E.

Date: June 27, 2014

Re: Upper Twomile Creek Watershed Analysis

Wright Water Engineers, Inc. (WWE) has prepared this memorandum to provide a summary of recent discussions and analyses related to the upper portion of the Twomile Creek watershed in Boulder. We have had multiple discussions with ICON Engineering (ICON) and we have consulted with Bob Jarrett (formerly United States Geological Survey, working on behalf of Urban Drainage and Flood Control District). The following sections summarize this recent work.

Rainfall Depth-Duration-Frequency

Table 1 shows specific recurrence intervals (RIs) calculated for various rainfall durations in the upper Twomile watershed (above Spring Valley Road). To calculate these RIs, WWE used gage-corrected radar data and calculated "worst case" rainfall depths for each of the durations in the table. These depths were compared with NOAA Atlas 14 depth-duration-frequency data to assign RIs to the data[1]. In reviewing the data in Table 1, it is noteworthy that the "worst case" depths from durations in the table all came from the same general period in the overall storm (evening of September 11 and September 12, 2013).

The 2-hour duration RI of approximately 50-years is the most direct comparison to the UDFCD rainfall distribution used for design storms, which would use a 2-hour storm for a watershed of this size. In addition, WWE performed a conceptual time of concentration calculation using methods in the UDFCD Urban Storm Drainage Criteria Manual and estimated a time of concentration for watershed on order of 1-hour. Accounting for Pine Brook Hills Reservoir storage and the associated delay in runoff, the actual time of concentration could be longer. Based on these observations and calculations, using a 1- to 2-hour duration for the basis of evaluating rainfall/runoff relationships is reasonable. As shown in the table, the estimated RIs are approximately 17 years and 50 years for the "worst case" 1- and 2-hour durations, respectively[2].

[1] The NOAA Atlas 14 provides precipitation frequency estimates at lower and upper bounds of the 90% confidence interval. Note that the RIs in the table were calculated based on the reported NOAA Atlas 14 average recurrence intervals, not the 90% confidence intervals.

[2] It is notable that the Rational Method, which relates peak flow rates to the rainfall intensity at the time of concentration

Table 1. Summary of Duration, Depth, Frequency and Antecedent Precipitation for Upper Twomile Watershed

Duration	Depth (in)	Return Frequency (year)	Date & Time of "Worst Case" Rainfall	7-day Antecedent Rainfall (in) *
5-minute	0.24	2	9/12 @ 12:00 – 12:05 am	5.31
10-minute	0.39	3	9/11 @ 11:55 pm – 9/12 @ 12:05 am	5.24
15-minute	0.54	4	9/11 @ 11:50 pm – 9/12 @ 12:05 am	5.12
30-minute	0.84	5	9/11 @ 11:40 pm – 9/12 @ 12:10 am	4.88
1-hour	1.47	17	9/11 @ 11: 10 pm – 9/12 @ 12:10 am	4.49
2-hour	2.39	49	9/11 @ 10:25 pm – 9/12 @ 12:25 am	4.13
6-hour	4.45	292	9/11 @ 6:45 pm – 9/12 @ 12:45 am	3.07
12-hour	4.92	172	9/11 @ 6:30 pm – 9/12 @ 6:30 am	3.07
24-hour	8.35	1516	9/11 @ 9:25 pm – 9/12 @ 9:25 pm	3.70

*Note: Radar rainfall data provided from 9/11/13 6:00 pm on September 11 to 6:00 am on September 13, 2013. 7-day antecedent precipitation based on nearest ALERT station.

Effects of Saturated Conditions at Time of "Worst Case" Rainfall

Observations by Bob Jarrett and ICON modeling results indicate that runoff easily surpassed 50-year levels and was likely comparable to or greater than the regulatory 100-year peak runoff rate of 710 cfs in the vicinity of Spring Valley Road. While this may seem like a disconnect between rainfall frequency and runoff frequency given a cursory review, when antecedent precipitation is taken into account, the relationships are much more reasonable and in line with observed and modeled flow rates. The 1-hour "worst case" rainfall depth was approximately 1.5 inches; however, this "worst case" period occurred after approximately 4.5 inches of rain had fallen in the past week. Similarly, for the 2-hour duration, the "worst case" precipitation was approximately 2.4 inches but occurred after more than 4 inches of rain had fallen in the past week. With this magnitude of preceding rainfall, soils in the watershed would have been saturated at the start of the "worst case" periods, and the runoff response would have been significantly magnified.

One way to conceptualize the effects of the antecedent precipitation in terms of RIs is to adjust the "worst case" rainfall to account for the absence of significant infiltration potential, depression storage and other losses that have already been filled by the antecedent precipitation. In other words, how much rainfall would be required to cause the same runoff response if antecedent conditions were typical (NRCS AMC II) versus saturated? Another significant factor in the foothills is the relatively thin soil mantle over bedrock. Once this layer becomes saturated, there is virtually no additional infiltration and the land surface rainfall/runoff response would be similar to a impervious cover.

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for a given watershed, would not typically be applied to a watershed of this size and complexity; however, evaluating rainfall intensity over the approximate time-scale of the time of concentration is useful for comparative purposes. In terms of a runoff coefficient at the times that the "worst case" rainfall occurred, the antecedent precipitation would have produced saturated conditions that would have resulted in a runoff coefficient of almost 1.0 (all rainfall becomes runoff).

To evaluate this in terms of RI, consider the 1-hour "worst case" depth of approximately 1.5 inches. Given initial losses in the watershed on the order or 0.5 to 1.0 inches[3] and the saturated conditions at the time the 1-hour "worst case" rainfall occurred, an event occurring with typical antecedent conditions would need to have 1-hour depths on the order of 2.0 to 2.5 inches for a similar runoff response. One-hour rainfall depths of 2.0 and 2.5 inches have RIs of approximately 50- to greater than 100-years, respectively.

Similarly, if the 2-hour "worst case" depth of approximately 2.4 inches is adjusted to account for saturated conditions, a depth of 2.9 to 3.4 inches over a 2-hour period would be required to produce a similar runoff response under typical antecedent conditions, corresponding to RIs in excess of 100-years and 200-years, respectively.

Based on this analysis, a runoff response on the order of a 100-year event or more would be expected from the "worst case" rainfall in the Twomile watershed due to saturation of the watershed prior to the "worst case" rainfall period.

Runoff Measurements and Modeling

Runoff measurements by Bob Jarrett indicate a peak flow rate at North Cedar Brook Road (upstream of Spring Valley Road) of approximately 1200 cfs, and ICON modeling analysis of the watershed above Spring Valley Road has produced peak flow rates in the range of 800 to 1000 cfs. As noted above, the regulatory 100-year discharge in the vicinity of Spring Valley Road is 710 cfs.

WWE and ICON met with Bob Jarrett to discuss his flow measurement and rainfall/runoff relationships for the watershed. Jarrett indicated measurement accuracy on the order of 20% +/- and also confirmed that his measurement would have reflected bulking effects due to entrained mud and debris. These bulking effects would have been most significant in the upper portions of the watershed where landslides occurred on slopes that fed into the steep channel. Jarrett indicated that bulking effects were likely on the order of 20% in the area where he made his flow estimate measurements. Since the modeling conducted by ICON assumes "clearwater" flows (e.g. no bulking), the ICON modeled flows would need to be increased on the order of 20% for a direct comparison with Jarrett's number. When this adjustment is considered, the ICON's modeled flow rates and Jarrett's measurements agree fairly well.

It is important to realize that there is uncertainty associated with field estimates of flows, modeled flow rates and the underlying rainfall data to a degree. Given this uncertainty, differences between the peak flow rates modeled by ICON and Jarrett's field measurements are to be expected. Even given this uncertainty and difference in model versus field observations, the field measurements, model results and rainfall data support the conclusion that the runoff response for this watershed was on the order of a 100-year event or greater.

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[3] WWE performed calculations using typical NRCS Curve Numbers (CNs) to evaluate initial abstractions and calculated initial abstractions ranging from 0.6 to 0.8 inches, which is in general agreement with the rule of thumb of initial losses on the order of ½ to 1 inch for the Twomile watershed.

Conclusion

Given uncertainty in runoff measurements (+/- 20%), modeling assumptions, differences between clearwater and mud-floods and saturated conditions at the time of "worst case" rainfall, the rainfall and runoff frequency relationships for the upper Twomile watershed generally make sense. The rainfall data analysis and modeling support observations in the field that the rainfall on September 11 and 12, the most intense of which occurred after the watershed had reached saturation, produced peak runoff flow rates comparable to or greater than the regulatory 100-year flood discharge.

We hope this information is helpful. Please let us know if you would like to set up a call to discuss.

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