September 11-13, 2013 Arvada Flood Event

Reconstruction and Documentation

Prepared for:

City of Arvada Public Works Department

Engineering Division

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Table of Contents

Table of Tables

Table of Figures

List of Acronyms

AAC	Arvada Area Command
Acre-ft	Volume Equal to One Foot of Depth over One Acre
AFPD	Arvada Fire Protection District
ALERT	Automated Local Evaluation in Real Tine
cfs	Cubic Feet per Second; discharge measurement
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network
CRS	Community Rating System (through FEMA)
EDM	Electronic Data Mapping (UDFCD Service)
EOC	Emergency Operations Center
FEMA	Federal Emergency Management Agency
FHAD	Flood Hazard Area Delineation
FRICO	Farmer's Reservoir and Irrigation Company
HIG	Hazardous Information Group
NFIP	National Flood Insurance Program (through FEMA)
NWIS	USGS National Water Information System
NWS	National Weather Service
UDFCD	Urban Drainage and Flood Control District
USGS	United States Geological Survey

1. Executive Summary

Record-breaking rains from September 9th to 13th, 2013 caused serious flooding in Arvada, Colorado. Unlike a typical summer thunderstorm and flash flood, the September 11th – 13th, 2013 Arvada Flood Event was the result of widespread long-duration rainfall. The heaviest rain fell on the headwaters of Leyden Creek, a tributary to Ralston Creek. Rainfall totals for gages located in the Leyden Creek watershed exceeded design rainfall totals for the 100-year precipitation event. In addition, storm runoff was routed into Leyden Creek from drainage basins lying to the south by canals that intercepted runoff where they crossed swollen creeks, including Van Bibber Creek, Ralston Creek and Moon Gulch.

- At Van Bibber Creek, the interception of stormwater by the Croke Canal occurred when the capacity of the siphon conveying the creek beneath the canal was exceeded, and the canal embankment was overtopped. This interception likely occurs frequently.
- At Ralston Creek and Moon Gulch, the interception of stormwater by the Croke Canal was the result of a breach of the canal embankment.

A water main break where Leyden Creek overtopped Quaker Street depleted stored water supplies late on Wednesday, September 12. Subsequent heavy rains in the headwaters of Ralston Creek caused damage to infrastructure at two on-channel water supply reservoirs located in series: Ralston Reservoir and just downstream, Arvada/Blunn Reservoir. Both reservoirs filled and made spillway releases but did not exceed 100-year design discharges. Water supply monitoring equipment at both reservoirs was destroyed. Ralston Reservoir's spillway and Arvada/Blunn's inflow channel were both seriously eroded. Turbid water caused problems at the City's two water treatment plants, and the City relied for a time on stored treated water, coming within a 90-minute supply of depleting treated water. Water was safe to drink throughout the flood.

More severe flood damage occurred on Leyden Creek than on the Ralston Creek main stem. Damages were the result of heavy rains September 11th and 12th. Damages upstream of the Leyden Detention Facility included:

- Blue Mountain Estates. A clogged culvert beneath Blue Mountain Road caused flow to proceed along the road. The diverted flow eroded a gulley up to 10 feet deep in the shoulder of the road and ultimately reached Leyden Creek, instead of proceeding downstream in Coal Creek.
- Leyden Road was overtopped by as much as three feet at its crossing with Leyden Creek.
- Quaker Street was overtopped at its crossing with Leyden Creek. The road was damaged and erosion of the downstream shoulder of the road exposed and broke a 12-inch water main.
- Homes in Leyden Township suffered flood damage.
- The Church Ditch embankment was breached at its crossing with Leyden Creek. Flow in the Church Ditch after the breach was diverted into the Leyden Detention Facility.

The Leyden Detention Facility filled on the evening of Thursday, September 12th and began releasing discharge over its service spillway. The estimated peak discharge over the spillway of 1,351 cfs exceeds the design discharge for the 3-hour, 100-year storm of 373 cfs. This discharge created damages downstream of the Leyden Detention Facility as follows:

- Indiana Street was substantially overtopped at its crossing of Leyden Creek. The downstream shoulder of the road eroded, exposing an 18" water main encased in a 36" concrete pipe. Concrete jersey barriers were placed downstream of the main to stabilize it and prevent it from rupturing.
- Leyden Creek overtopped the upstream embankment of the Croke Canal at their crossing, and a section of the downstream embankment nearby was also overtopped. Flows returned to Leyden Creek through private property.
- Homes and businesses along Leyden Creek experienced creek flooding. Sewer surcharges also impacted some homes.
- Due to the commingled stormwater inflows at Van Bibber Creek, Ralston Creek, Moon Gulch and Leyden Creek, the Croke Canal's capacity was exceeded. Its downstream embankment was overtopped at a bend near Eldridge St. and W. 78th Place, where the invert of the Canal sits high above the ground surface and adjacent homes in Cameo Estates. The overtopping eroded the embankment significantly. To avert a full breach, City of Arvada personnel, with the consent and cooperation of FRICO personnel, made an intentional opening in the downstream embankment of the Croke Canal at its Leyden Creek crossing, just downstream of Indiana St. The intentional release lowered the water surface in the Croke Canal and relieved the overtopping that was threatening to create a breach at Eldridge and 78th. The intentional release created a second, lower flood peak on Leyden Creek on the morning of Friday, September 13th that impacted areas that had been flooded the night before as a result of the Leyden Detention Facility's spillway release.
- Alkire Street was overtopped at Leyden Creek and was closed.

As a result of the analysis described in this report, the following recommendations are provided:

1. For precipitation gages in the Van Bibber, Ralston and Leyden Creek watersheds, the 6-hour alarm criterion should be lowered to better detect flood potential from longer duration events like this one.
2. Arvada/Blunn reservoir should be equipped with a real-time ALERT flood detection gage. Releases from Arvada/Blunn immediately impact urban Arvada, and access to data measured there directly would have relieved uncertainty and supported decision-making during this event. Current hydrometrics could not even allow Arvada to determine if the reservoir level was stable, rising or receding with any confidence. Data collected at Arvada/Blunn would also have been useful to characterize hydraulic response in the urban portion of the Ralston Creek downstream of the dam, had it been available for this analysis.
3. Given the peak discharge estimate at Ward Road, it is recommended that the rating at Simms St. be evaluated to determine if it is overestimating discharges for measured stages.
4. The current rating for Gage 213 Leyden Confluence seriously overestimates flows for stages measured by the gage. A full reach and cross-section survey should be undertaken to support the development of an updated hydraulic stage/discharge rating for the gage.

2. Introduction and Background

Between September 9th and September 13th, 2013, record-setting rainfall over much of the Front Range of Colorado impacted many communities, including those in northern Jefferson County. Arvada, Colorado, experienced both localized flooding and creek flooding, particularly on Ralston and Leyden Creeks.

This document has been developed for the City of Arvada Public Works Department, Engineering Division to document and quantify the flood event and to describe responses to flooding. This report is intended to provide a coherent reference for information about the flood event as well as to support future planning and response to the extent possible. The introduction describes the hydrologic setting relevant to the events of the September flooding, and brief description of flood vulnerability and flood history in Arvada. Then, the precipitation and discharge data sources that are used in the remainder of the report are discussed. In some cases, flows that were not measured could be estimated from reconstructions using existing data with some assumptions. In some cases, independent estimates of peak discharge at both locations with gages and other locations were made. Supporting documentation for these peak discharge estimates are provided in Appendix A. The September flood is described generally and then in more detail for each of the relevant drainage basins, with the discussion organized from southern basins to northern basins and from upstream to downstream. Because the event included several periods of heavy rain that produced impacts in these basins, this organization is not always chronological, but the timing of events is addressed as needed. The Arvada Police Activity Log provides a chronological accounting of events and is included as Appendix B. Finally, recommendations based upon the events of this flood are provided.

2.1. Hydrologic Setting

Ralston Creek is a left-bank tributary to Clear Creek encompassing a watershed of over 90 square miles (Boyle Engineering Corporation, 2003) in both Gilpin and Jefferson Counties. The watershed extends from headwaters in the foothills west of Arvada, including Golden Gate Canyon State Park, to the confluence with Clear Creek near Sheridan Boulevard, also in Arvada. Ralston Creek's major tributaries are Van Bibber Creek (draining 17.7 square miles) to the south and Leyden Creek (draining 11.9 square miles) to the North. In this report references to the Ralston Creek watershed include both the Leyden Creek and Van Bibber Creek watersheds unless specifically noted. All three creeks- Van Bibber Creek, Ralston Creek and Leyden Creek- cross areas of Arvada, Colorado in meandering flow paths with an overall west-to-east orientation (Figure 1).

In addition to the three major watercourses, several canals flow through Arvada, including the 26-mile long Church ditch, built in the early 1870's, the Farmers' High Line Canal, built in the 1860's and expanded in the 1870's, and the Croke Canal, begun in 1902. All these canals (and additional smaller conveyances) move decreed water from Clear Creek near Golden to irrigation and water supply infrastructure to the north and east, crossing the natural drainages in their meandering courses. Farmers Reservoir and Irrigation Company (FRICO) owns and operates the Croke Canal. The Farmers High Line Canal is owned by The Farmers' High Line Canal and Reservoir Company, while the Church Ditch is operated by the Church Ditch Water Authority/City of Northglenn.

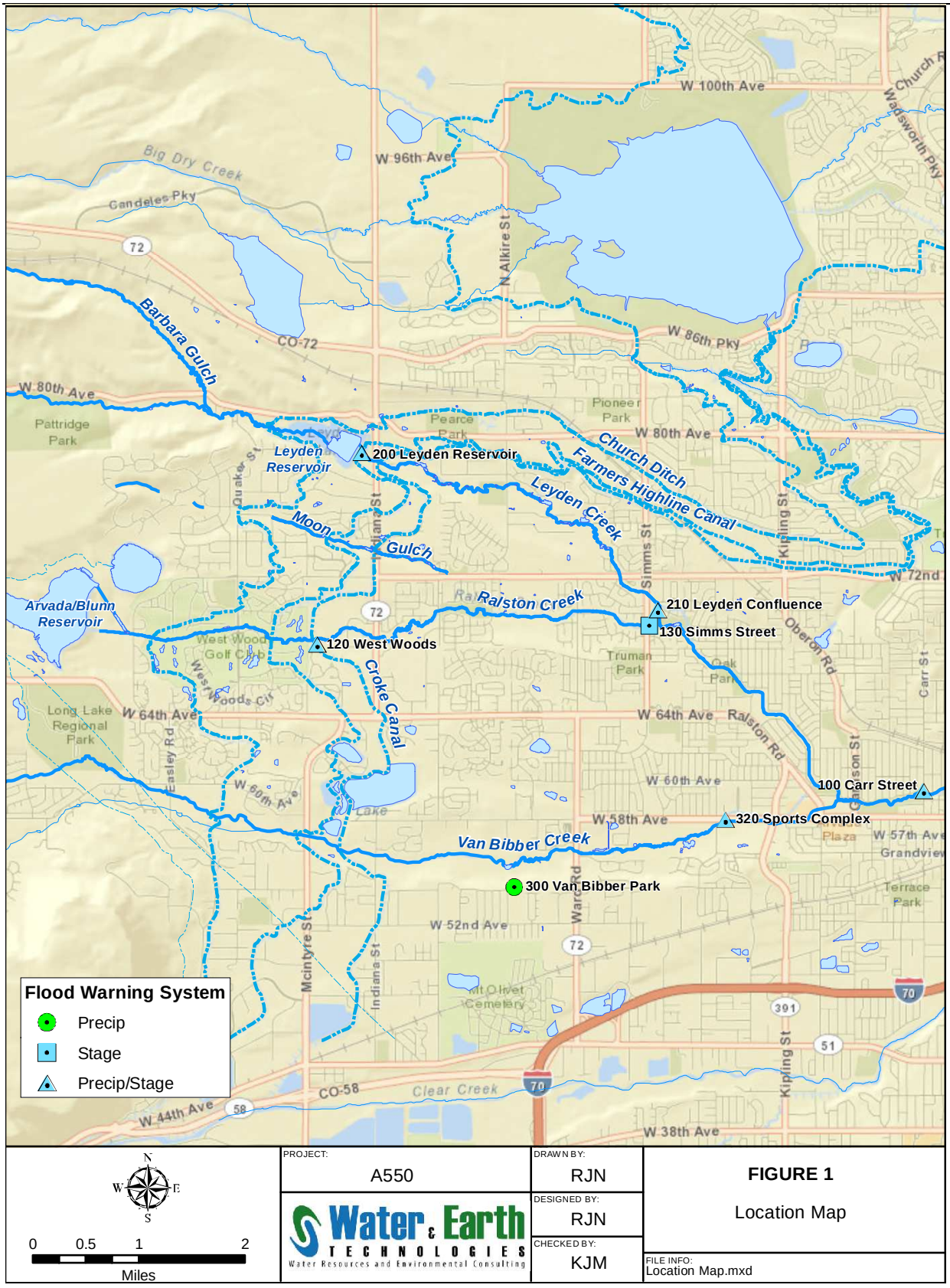

Figure 1. Location Map.

The canals were constructed at a time when water management practices were different than they are today, and some vestiges of that legacy remain. Historically the canals accepted stormwater inflow, but as the urbanization of surrounding areas impacted the water quality of stormwater runoff, efforts were made to segregate the decreed waters from storm runoff. That segregation is not yet perfect for any of the canals, especially during high flow events. Flow limiters on the canals route excess flow in the canals into the natural drainages, and there are also still scattered locations where storm runoff is routed directly into canals. Typically, where canals intersect natural drainages, hydraulic structures sized to convey the 100-year flood carry the natural drainage across the canal. However, at some of the intersections between canal and natural watercourse (where Van Bibber Creek crosses the Croke Canal, for example), the stream conveyance (typically a siphon conveying the stream beneath the canal) has limited capacity and/or is designed to allow stormwater runoff in excess of capacity to enter the canal.

The interception of stormwater by the canals and the potential for them to be overtopped during storm events is acknowledged by the 2003 *Ralston/Leyden Creeks Hydrology Report*, which states that, "Numerous irrigation canals exist in the City of Arvada and many of the canals intercept stormwater flows from frequent storm events. Larger flows fill and overtop the canals. For modeling purposes, it was assumed that flows from all storm events bypass the canals with no interception" (Boyle Engineering Corporation, 2003). Theoretical hydrologic modeling that considers the range of potential interactions between the canals and storm runoff is not feasible due to the large number of spatial and temporal unknowns. However, the overall impact of the canals is to move flows across the natural drainage basin boundaries from more southerly drainage basins to basins lying to the north. They were constructed to divert flow from the Clear Creek basin to the north, and during storm events they remain capable of diverting flows northward and either relieving or exacerbating flooding.

2.2. Flood Vulnerability and Flood History in Arvada

The City of Arvada Public Works Department's Engineering Division is responsible for floodplain management within the City, with FEMA-identified 100-year floodplains on Big Dry Creek, Little Dry Creek and Clear Creek as well as Van Bibber, Ralston and Leyden Creeks. Arvada's regulatory floodplain is based upon the June, 2004 *Flood Hazard Area Delineation (FHAD): Ralston Creek – Leyden Creek* (Boyle Engineering Corporation, June 2004). The FHAD provides information on the regulatory (100-year) flood elevations as well as on 10-year, 50-year and 500-year flows, and is the source for design flood discharges cited in this report unless specifically noted. The hydraulic modeling for the 2004 FHAD used the hydrology results from the 2003 *Ralston/Leyden Creeks Hydrology Report* previously cited. Arvada's Flooding Information and History web page indicates that, "the City joined the federal National Flood Insurance Program (NFIP) in 1972 and has participated in the Community Rating System (CRS) since 1991." Arvada is a Class 5 community in the CRS, in recognition of its efforts to manage ongoing development in ways that are consistent with reducing flood hazards, and to promote flood awareness and flood insurance among residents of areas that lie within the regulatory (100-year) floodplain. The Class 5 designation confers a discount of 25% on premiums for Arvada citizens purchasing flood insurance. Very few communities in the U.S. achieve better than Class 5 designation, especially cities like Arvada that developed substantially before the era of modern floodplain management. Arvada includes developed areas that are within the 100-year floodplains for the creeks.

In addition to those areas that are vulnerable to creek flooding, there are areas within Arvada with more localized drainage issues that create nuisance flooding regularly as a result of typical thunderstorms. The City of Arvada Stormwater Utility has levied a stormwater utility fee on properties within Arvada since January, 2002. Each property's fee is based upon its impervious area. Many minor drainage improvements projects have been undertaken to reduce flood vulnerability in Arvada. In addition, major capital projects with a flood control component, including improvements to both Leyden Lake and the Arvada/Blunn reservoir, have been completed.

There is surprisingly little documentation of past flooding in Arvada. The June, 2004 FHAD includes, as FHADs typically do, a section on Flood History, which states, "Although the potential exists for severe flooding, there is little information regarding past floods on the study streams. Records of past flooding could not be identified during the reconnaissance and library searches. It is likely that severe flooding has occurred on the study streams, which were not recorded…" Arvada's Flooding Information and History web page briefly cites an instance of flooding in June of 1989, described as a 50-year storm event that impacted Arvada Plaza on Ralston Road. However, no 1989 flood is included in the Flood History provided in the Ralston Creek Flood Warning Plan (UDFCD, 2009), which instead lists the following flood events:

- On Van Bibber Creek: July 29, 2003.
- On Ralston Creek: July 22, 1991; May 18 and June 4, 1995; July 10, 2009.
- On Leyden Creek: none.
- County-Wide or north-east Jefferson County: August 4, 1999; June 8, 2004; June 27, 2004.
- At "several intersections in Arvada": August 4, 1997.

Anecdotally, Arvada Public Works employees indicate that flooding issues in the past have been almost exclusively on Van Bibber and Ralston Creeks, rather than on Leyden Creek.

3. The Rainfall Event of September 11th – September 13th, 2013

Rainfall along the Front Range of northern Colorado in the period from September 9th through September 15th was the result of an unusual weather pattern. Stationary low pressure cells parked over adjacent states directed moist air from both the Pacific Ocean and the Gulf of Mexico towards the Front Range. Upslope flow pinned the moisture against the foothills, where a strong lift produced an unusually long period of unusually widespread and intermittently heavy rain in a typically arid region. Flooding in the Front Range is more typically flash flooding as a result of extremely intense rainfall with a much smaller aerial extent and duration (CIRES WWA, 2013).

Compared to detecting a flash flood threat, the developing flood risk due to wide-spread, recurring heavy precipitation during the September event was not difficult to detect. During the event there were numerous alarms from the remote stream monitoring network indicating both heavy precipitation and high runoff. In addition, Arvada received National Weather Service (NWS) and UDFCD warnings developed from radar precipitation estimates.

The heaviest rainfall was in the day-and-a-half long period from the afternoon of Wednesday, September 11th through the early morning hours on Friday, September 13th. However, flooding

from rain in that period was exacerbated by the saturated conditions and continuing runoff from rains earlier in the week.

3.1. September 9 through September 13 Precipitation Data for Arvada

In cooperation with the Urban Drainage and Flood Control District (UDFCD), precipitation in the headwaters of Van Bibber, Ralston and Leyden Creeks as well as along these watercourses in Arvada is monitored (Figure 2).

- Data from four gages are relevant to **Van Bibber Creek** (from most upstream to downstream: Station ***310 Guy Hill*** in the headwaters above Horseradish Gulch lies less than a half mile south of the Van Bibber watershed boundary; Station ***330 Van Bibber @ HWY 93***, *Station* ***300 Van Bibber Park***, and Station ***320 Sports Complex***). Data for the September event at Station ***320 Sports Complex*** are not available because a clogged funnel impeded the rain gage there.
- **Ralston Creek** precipitation is monitored at four locations (from most upstream to downstream: Station ***150 Nott Creek***, Station ***110 Ralston Reservoir***, Station ***120 Ralston @ West Woods***, and Station ***100 Ralston @ Carr Street***). Gage ***130 Ralston @ Simms St.*** provides only discharge data.
- **Leyden Creek** is monitored at four locations (from most upstream to downstream: Station ***140 Blue Mountain***, Station ***220 Upper Leyden***, Station ***200 Leyden Reservoir*** and Station ***210 Leyden Confluence***).

Cumulative precipitation for the period beginning at 9/9/2013 at 00:00 and ending at 9/15/2013 at 24:00 at each of the stations for which data are available is shown in Figure 3, along with total rainfall for the period. Periods without rain plot as horizontal lines, while the slope of rising portions of the plot indicates the intensity of rainfall in that period. The data demonstrate aspects of the rainfall event that are also anecdotally accepted:

- Heavy rainfall on September 11th and again on the 12th fell on ground that had been saturated by less intense but sustained rainfall earlier in the week. Rainfall on Tuesday, September 10th was heavy enough to cause some localized flooding in Arvada.
- The heaviest rainfall responsible for subsequent Arvada stream flows occurred in the mountainous headwaters west of town. All six of the gages that recorded precipitation totals over 7 inches are headwaters gages, located at or west of Highway 93.
- In the headwaters where the precipitation was most intense, precipitation totals are highest for the northernmost gages and lowest for the southernmost gages; i.e., precipitation was heavier on the Leyden Creek headwaters than on the Ralston Creek main stem headwaters, and precipitation totals on the Van Bibber Creek headwaters were lower yet. Rainfall totals even higher than those reported by the Leyden Creek gages were recorded in areas yet farther north, impacting Coal Creek, St. Vrain Creek, Boulder Creek and the Big Thompson River.

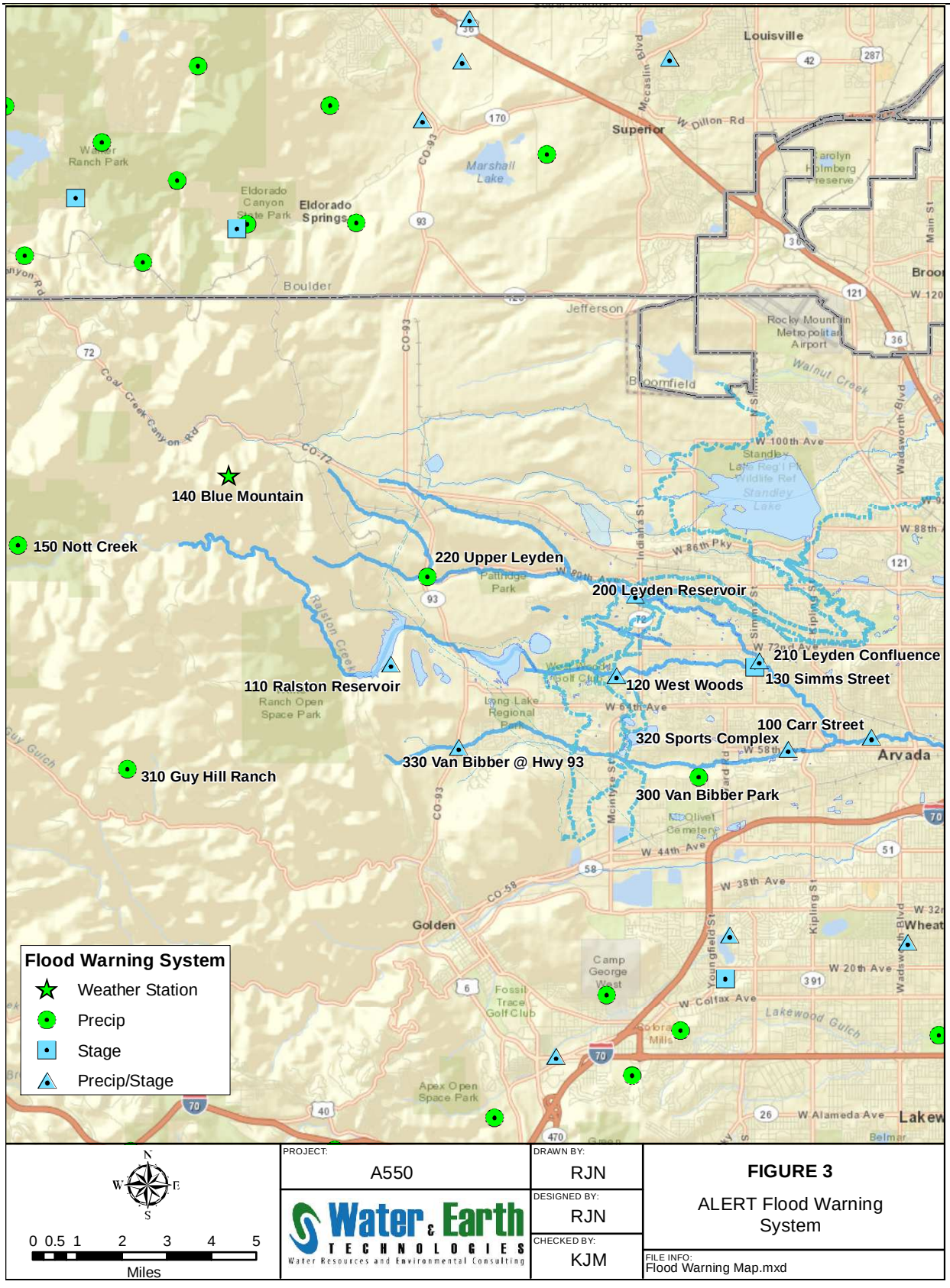

Figure 2. Precipitation Monitoring Stations for Leyden, Ralston and Van Bibber Creeks

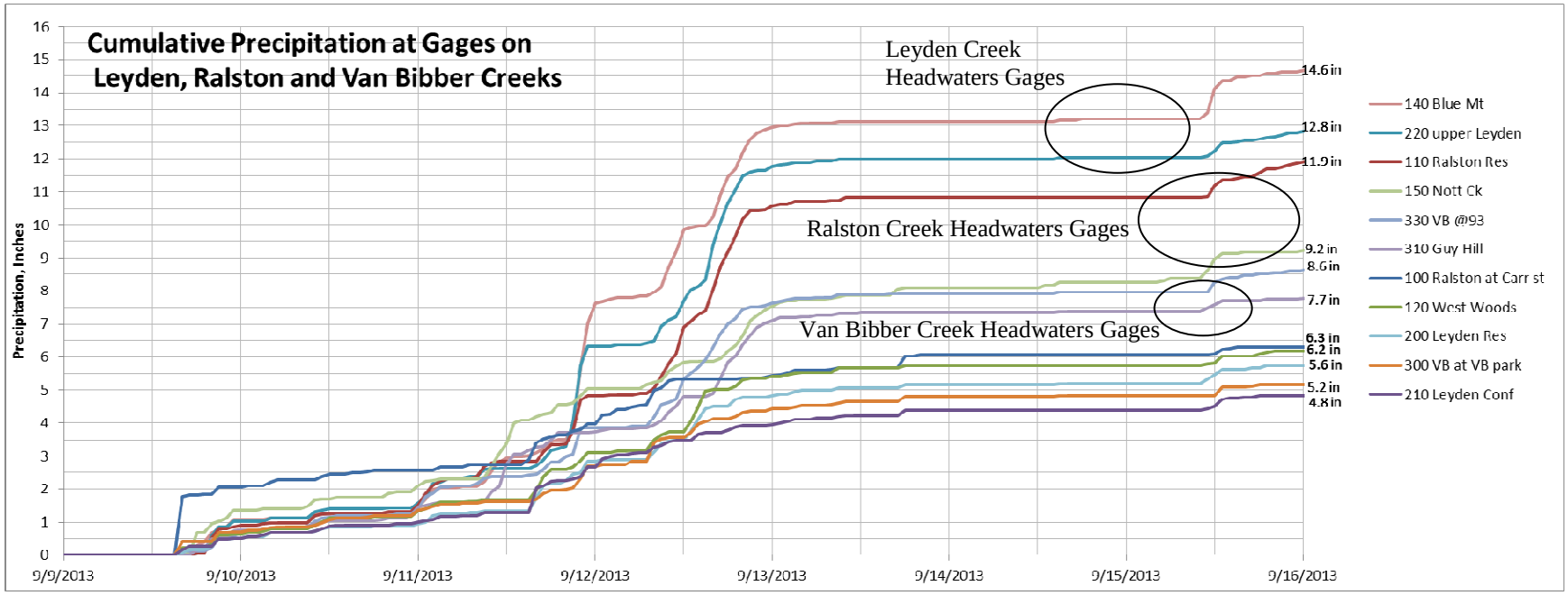

Figure 3. Cumulative Precipitation at Gages on Leyden, Ralston and Van Bibber Creeks

- The generalization that precipitation was heaviest in the north and lightest in the south does not apply to the urban gages farther to the east. Those five gages reported relatively consistent precipitation totals for the period plotted, ranging from 4.8 inches at the mouth of Leyden Creek to just over 6 inches at the two gages on the main stem of Ralston Creek.

A spatial comparison of rainfall totals from RADAR and ground-based ALERT and CoCoRaHS gages for September 13, 2013 is shown in Figure 4. This figure shows 24-hour rainfall totals ending at 7 a.m. on the 13th, which includes a period of intense rainfall in the mountainous areas west and north of Arvada. CoCoRaHS observation values are highlighted in white, and ALERT gage total values are highlighted in yellow. The two red circles are the 24-hour precipitation maximums measured by CoCoRaHS and ALERT gages. An annotated excerpt from the message map is also provided, labeled to show the 24-hour precipitation totals on Van Bibber, Ralston and Leyden Creeks.

The ALERT gages are currently set to alarm for rainfall exceeding:

- ½ inch in 10 minutes (exceeded at ***100 Ralston @ Carr*** and ***220 Upper Leyden***)
- 1 inch in 1 hour (exceeded at ***100 Ralston @ Carr***, ***140 Blue Mtn.*** and ***220 Upper Leyden***)
- 3 inches in 2 hours (exceeded at gage ***140 Blue Mtn.***)
- 5 inches in 6 hours (never exceeded during this event…the maximum 6 hour rain intensity was recorded at gage ***140 Blue Mtn*** and was 4.29 inches)

Arvada and the UDFCD may wish to consider making changes to the 6-hour precipitation alarm criteria to better reflect the flooding potential from longer-duration events like this event, based both on the hydrologic analysis described in the 2003 *Ralston/Leyden Creeks Hydrology Report* and used as the basis for the delineation of the regulatory floodplain in Arvada, and on the data from this event.

The 2003 *Ralston/Leyden Creeks Hydrology Report* provides 1-hour and 6-hour design rainfall depths for four design frequencies and for three rainfall regions (Boyle Engineering Corporation, 2003). Table 1 shows the rainfall depths for each of the three rainfall regions represented as a min-max range (the maximum values in the table correspond to the eastern region of all three stream courses; the Hydrology Report indicates that the western region is only applicable to the headwater reaches of Ralston Creek, the headwaters of Van Bibber Creek and the mid portion of Ralston Creek lie within the Central region. The urban portions of all three creeks and Leyden Creek in its entirety lie within the Eastern region). The current alarm for rainfall exceeding 1 inch in 1 hour is lower than the minimum depth (of 1.30 inches) cited for a design frequency of one occurrence in 10 years in the Hydrology Report. That alarm threshold should be retained if it is not producing frequent nuisance alarms during typical thunderstorms. However, the current alarm criterion of 5 inches in 6 hours is higher than the 6-hour 500-year rainfall depths from the Hydrology Report, which range from 3.45 to 4.70 inches.

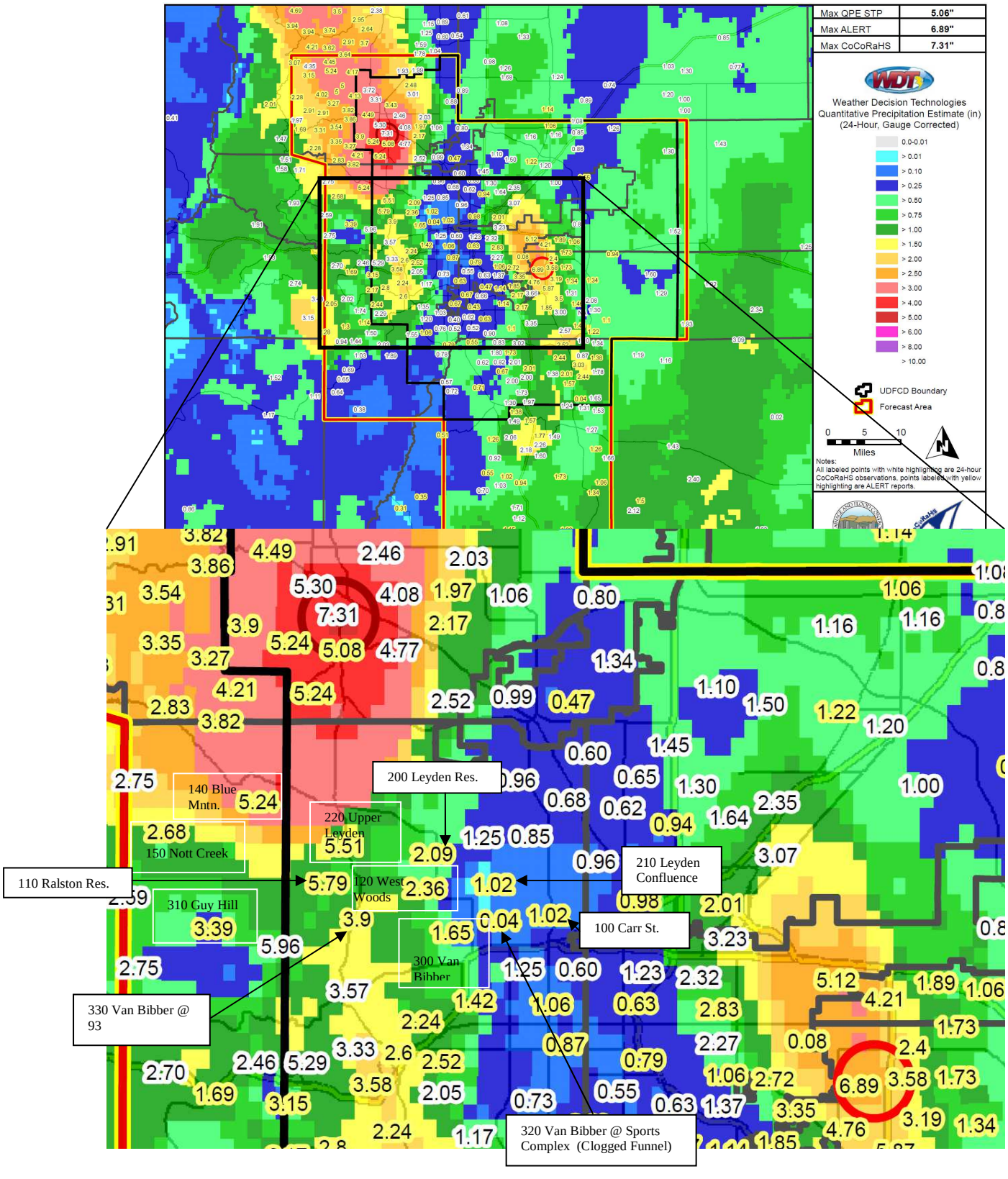

Figure 4. Precipitation Data Comparison.

Table 1. Design Rainfall Depth Ranges from the Hydrology Report.

	Design Rainfall Depth for Design Frequency (inches)			
Rainfall Duration	**10-year**	**50-year**	**100-year**	**500-year**
1-hour	1.30 – 1.75	2.00 – 2.40	2.20 – 2.65	2.80 – 3.25
6-hour	1.85 – 2.45	2.60 – 2.90	2.80 – 3.75	3.45 – 4.70

The 5-inches in 6-hours alarm criterion also exceeds any of the 6-hour rainfall totals recorded during the September 11th-13th, 2013 event. Incremental rainfall in both 1-hour and 6-hour time periods was computed from the rain data for each of the relevant gages, and the maximum value for each gage is shown in Table 2. The highest 6-hour maximum rainfall totals recorded, of 4.29 inches and 3.54 inches, were at ***140 Blue Mountain*** and ***220 Upper Leyden***, respectively. These peak 6-hour rainfall totals exceed the rainfall depth (3.75 inches) cited in the Hydrology Report as the 100-year design frequency rainfall for the Leyden Creek watershed.

Table 2. One-hour and 6-hour Incremental Rainfall Totals.

Gage	1-hr Max Rainfall (inches) Date and Time of Peak Intensity	6-hour Max Rainfall (inches)
140 Blue Mt.	2.05 9/11 10:09 p.m.	4.29 9/11 11:33 p.m.
220 Upper Leyden	2.17 9/11 10:16 p.m.	3.54 9/11 10:41 p.m.
200 Leyden Reservoir	0.59 09/11 4:36 p.m.	1.14 9/11 8:37 p.m.
210 Leyden Confluence	0.75 09/11 4:00 p.m.	1.06 9/11 9:11 p.m.
110 Ralston Reservoir	0.98 9/11 10:00 p.m.	3.03 9/12 8:23 p.m.
120 West Woods	0.59 9/12 1:39 p.m.	1.29 9/12 1:39 p.m.
100 Ralston @ Carr St.	1.81 09/09 4:14 p.m.	2.05 9/9 8:36 p.m.
150 Nott Creek	0.67 9/11 12:54 p.m.	1.77 9/11 1:13 p.m.
310 Guy Hill	0.71 9/11 12:02 p.m.	2.00 9/12 9:55 p.m.
330 VB @ Highway 93	0.79 9/11 10:00 p.m.	2.17 9/12 5:29 p.m.
300 VB Park	0.63 9/11 10:29 p.m.	1.06 9/12 1:32 p.m.

A "100-year" hydrologic event has a 1 in 100 or 1% chance of occurrence in any year. Measuring a "100-year" rainfall event at precipitation gages does not guarantee that a "100-year" flood event occurred at any given location downstream. Predicting watershed response to precipitation is the most difficult part of both flood warning and flood planning. For flood planning and floodplain management purposes (i.e., the development of the "100-year floodplain"), mathematical models use idealized rainstorms, with characteristics that are determined by statistical analyses of rainfall data from many different storms. Any actual storm event is characterized by both temporal and spatial variability in rainfall intensity. The watershed response for a particular storm event is a unique creation of that storm event and its interaction with the landscape, both natural and manmade, that impacts how and where runoff occurs. Because this is hard for the public to understand, it is one of the frequently asked

questions included in the "2013 Flood FAQs" compiled by the UDFCD at: http://www.udfcd.org/2013flood/faq.html. *Severe Flooding on the Colorado Front Range, September 2013: A Preliminary Assessment (CIRES WWA, 2013)* is one of the resources linked to the UDFCD FAQ page that provides useful information about this issue. It provides information about the September 2013 flood event in particular, and about past and future flood potential for the Front Range, and is included here as Appendix C.

The September 11-13th 2013 rain event did produce flows in excess of one-hundred year design flows on Leyden Creek downstream of the Leyden Detention Facility. Specifically, the design capacity of the Leyden Detention Facility was based upon a three-hour, 100-year runoff volume of 753 acre-ft., which would be accommodated with a water surface elevation at the spillway crest (El. 4,508 ft.) and a discharge of 373 cfs through the outlet works (not over the spillway). During the September 11-13th event, the spillway was active and the estimated peak discharge (based upon gage ***200 Leyden Reservoir*** data) was 1,351 cfs. During this event, however, the peak discharge attenuated in the reach of Leyden Creek immediately downstream of the Leyden Dam release. The areas within Arvada where the most significant flooding occurred provided inadvertent detention, and reaches farther downstream did not experience 100-year flows. Additional discussion about flows on Leyden Creek during this event is provided in subsequent sections of this report.

The estimated peak discharges from Ralston Reservoir (865 cfs based upon gage ***110 Ralston Reservoir*** data) and Arvada Blunn Reservoir (1,783 cfs, based upon an analysis described elsewhere in this report, since Arvada/Blunn Reservoir is not gaged) were well below the 100-year design values as shown in Table 3 of the Hydrology Report (Boyle, 2003), reproduced below:

Table 3. Design Reservoir Inflow and Outflow for Design Frequency.

	Design Reservoir Inflow and Outflow for Design Frequency			
Reservoir	**10-year**	**50-year**	**100-year**	**500-year**
Ralston Reservoir	Inflow 879 cfs Outflow 283 cfs	Inflow 5,462 cfs Outflow 3,608 cfs	Inflow 7,228 cfs Outflow 5,262 cfs	Inflow 11,486 cfs Outflow 9,603 cfs
Arvada/Blunn Reservoir	Inflow 282 cfs Outflow 272 cfs*	Inflow 3,499 cfs Outflow 3,052 cfs	Inflow 5,069 cfs Outflow 4,440 cfs	Inflow 9,321 cfs Outflow 8,272 cfs
Leyden Lake	Inflow 1569 cfs Outflow 134 cfs	Inflow 3,269 cfs Outflow 148 cfs	Inflow 4,081 cfs Outflow 373 cfs	Inflow 5,577 cfs Outflow 2,247 cfs

*Outflow from Arvada/Blunn Reservoir is cited as 314 cfs in the FHAD.

3.2. Stage/Discharge Data for Arvada

Most of the precipitation monitoring stations previously described (except those located in the extreme headwaters) also provide remote monitoring of stream stage to assist in flood detection. Pressure transducers (PTs) installed in the stream channels convert the pressure on a membrane to a measured voltage, and then into a depth of flow above the PT. The result is a measurement of river stage, or depth above the measuring device, in feet. If the PT was installed such that it measured exactly from the channel invert, measured stage would equal stream depth. At some gages, the PT sits below the channel invert. Where the PT sits above the channel invert, the device cannot distinguish amongst flows beneath a minimum value of stage. Measurements of stage are sufficient for flood detection, and alarm thresholds for the ALERT stream monitoring

gages are set based upon measurements of high stage as well as change in stage within an interval of time (to detect rapidly rising stage). To assess the quality of stage data, the stage recorded during the event by the device can be compared to measurements of high water marks left after the event.

The peak flow (and the associated stream stage) at any location determines flooding extent, but depending upon channel capacity, the stage associated with a given discharge can vary greatly between different gages on the same watercourse. While measuring stage is important for flood detection, estimates of discharge are more useful for analyzing watershed response, determining travel times for flood flows and providing insight into the relationship between events. Therefore for planning, analysis and design purposes, measurements of stage are converted into estimated discharges through the use of hydraulic ratings. It is important to recognize the limitations of these ratings. Discharge estimates for flood detection gages are generally based upon theoretical, mathematical relationships between stage and discharge (rather than pairs of measured stage with a measured discharge). Mathematical modeling methods are employed to simulate a wide range of conditions because of both the expense of multiple discharge measurements and the impracticality of measuring a wide range of discharges. The accuracy of the rating relationship varies from station to station and can also vary over the range of discharges, especially where the hydraulic conditions in the reach are variable. Ratings for stream gages located in natural channel reaches become less accurate over time if channel conditions change over time, due to scour, deposition, vegetation growth, etc. Channel conditions can also change suddenly, especially during flood events, due to scour, deposition, debris dams, etc. To assess the quality of ratings, measurements of discharge can be made at known values of stage, or theoretical peak discharge estimates can be made using high water marks and measurements of the channel slope and geometry characteristics. The discharge estimates described here are the best available, and when appropriate limitations specific to each site are discussed.

Measured stage and calculated discharge data are available for locations on Van Bibber, Ralston and Leyden Creeks as follows:

- Stage/flow data from two gages are relevant to **Van Bibber Creek** (from most upstream to downstream: Station ***330 Van Bibber @ HWY 93*** and Station ***320 Sports Complex***). Station ***300 @ Van Bibber Park*** measures only precipitation, not stage. The channel at Station ***330 Van Bibber @ HWY 93*** is prone to cross section geometry changes (both aggradation and scour), which makes it difficult to provide a stable rating at this location that produces good estimates of discharge over the full range of flows. In addition, the PT is installed several feet above the invert of the culvert, so that data are only collected at that location when the flows are substantial.
- **Ralston Creek** is monitored at four locations (from most upstream to downstream: Station ***110 Ralston Reservoir*** measures stage in the reservoir and provides estimates of discharge from the reservoir, Station ***120 West Woods***, Station ***130 @ Simms St.***, and Station ***100 Carr Street***). The park in the vicinity of Station ***100 Carr Street*** was in the middle of a redevelopment project when this event occurred, and the rating that was in place at the time of the flood event had not been updated to reflect the reconstructed channel geometry. Therefore flows calculated during the event at this station are possibly incorrect. A new rating for this gage was developed after the flood and discharges during the flood were back-calculated.

- **Leyden Creek** is monitored at two locations (from most upstream to downstream: Station ***200 Leyden Reservoir***, which measures the water surface elevation in the reservoir and provides estimates of discharge based upon the outlet works and spillway rating, and Station ***210 Leyden Confluence***). At ***200 Leyden Reservoir***, the rating relies upon theoretical calculation of discharge over the spillway. The peak discharge of 1,351 cfs was calculated for a single measurement of stage. At ***210 Leyden Confluence***, the validity of the rating was challenged by the estimation of a peak discharge for the September 11th-13th event and a new rating is recommended. Peak discharge at this location is likely less than the current rating calculates.

4. The Flood Event of September 11th – September 13th, 2013

The September 11-13, 2013 flood event in Arvada damaged City streets, sewer and water infrastructure, stream channels and canals and private homes and businesses. Reservoirs that had never before become filled reached their capacity and discharged from their service spillways, causing concern and even alarm. Localized drainage issues or short-lived flooding concerns were reported at scattered locations around Arvada, particularly in construction zones where incomplete work and bare ground exacerbated problems with runoff. Creek flooding was generally restricted to the area west of Simms Street, with few problems reported on Van Bibber Creek. More flooding was apparent on the Ralston Creek main stem, and the most significant problems occurred along Leyden Creek.

Although analyzing flooding for any specific event cannot predict flooding in a future storm event with its different characteristics, documenting the September 2013 flood is important, both to allow Arvada to both explain and assess response to this event as well as to identify flood vulnerabilities that can inform future flood planning and response. The description of flooding events is organized geographically (roughly from south to north and from upstream to downstream).

4.1. Van Bibber Creek

Figure 5 shows the Van Bibber Creek drainage basin and its unofficial 100-year floodplain, as it appears on the UDFCD Electronic Data Mapping (EDM) webpage. The official 100-year floodplain map is available from FEMA or from Arvada. Figure 6 shows cumulative precipitation at the Van Bibber gages superimposed on the discharge plots for Gage ***330 Van Bibber @ Highway 93*** and Gage ***320 Sports Complex***. The plot for gage ***330 Van Bibber @ 93 s***hows zero discharges abruptly transitioning to large flow values because the gage there is installed several feet above the stream invert.

Peaks apparent in the discharge data for Gage ***333 Van Bibber @ 93*** do not appear, even in an attenuated form, in the data for the downstream gage, ***323 Sports Complex***. The apparent reason for this independence is that the 4X4 siphon which conveys Van Bibber Creek beneath the Croke Canal (Figure 7) has limited capacity, and flows exceeding that capacity are captured by the Croke Canal and conveyed northward rather than continuing eastward in Van Bibber Creek. The peak stages recorded over the entire period of record at ***323 Sports Complex*** lie in a very narrow range (Table 4), which implies that the capacity of this crossing is frequently exceeded, with weir flow of variable depth over the ditch road and into the Croke Canal occurring during most years.

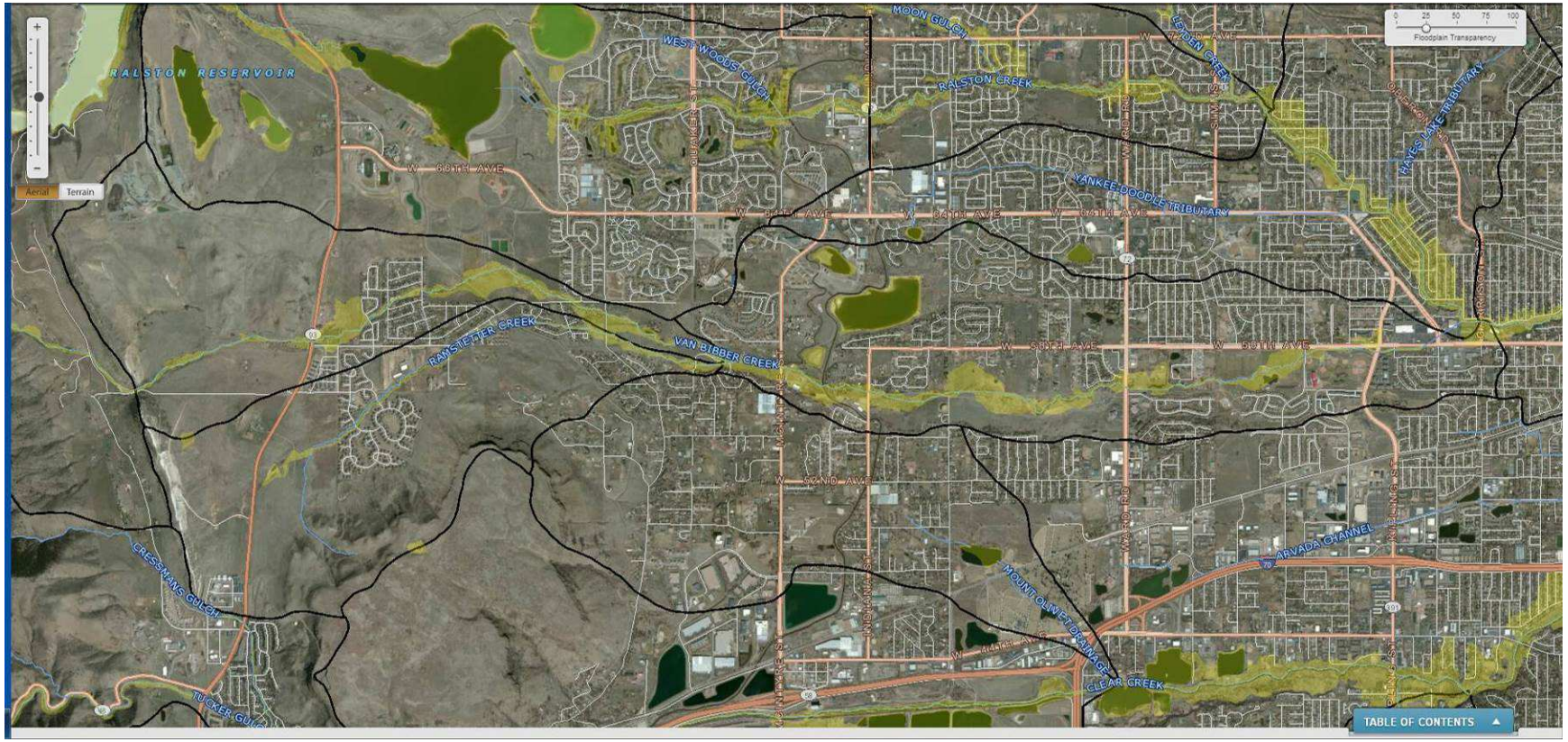

Figure 5. The Van Bibber Creek Watershed.

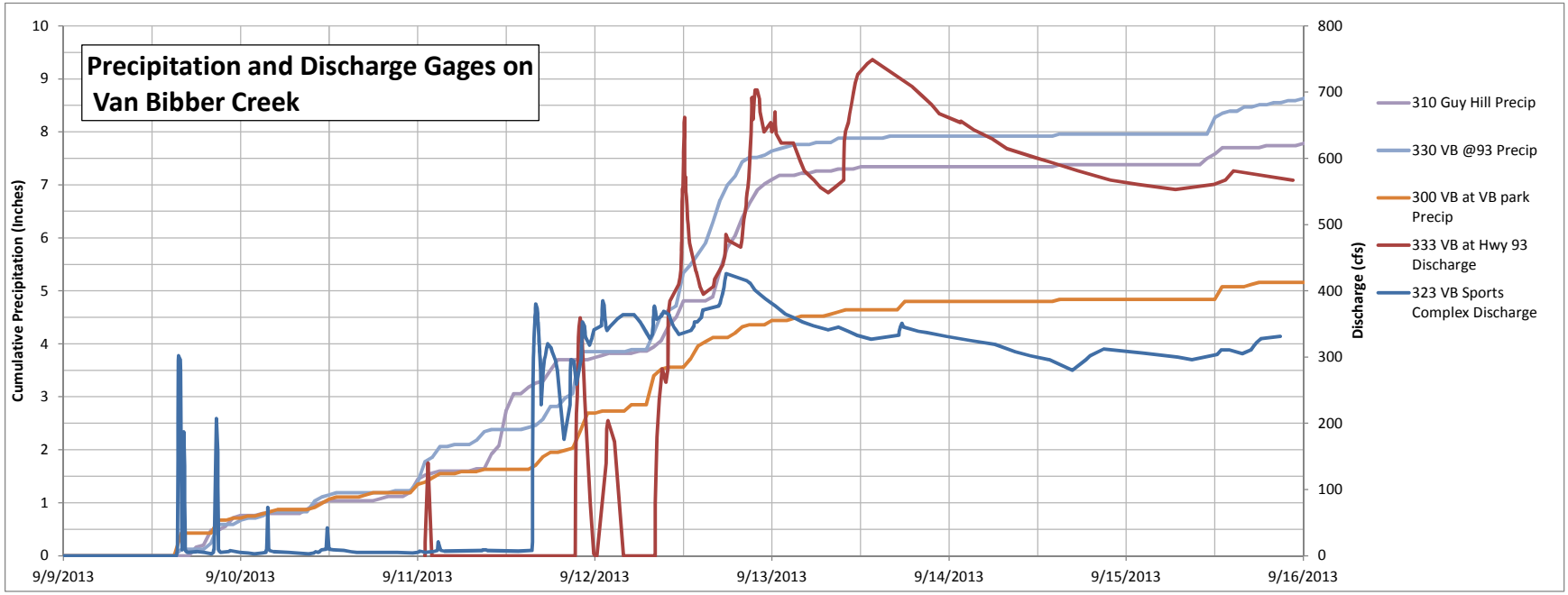

Figure 6. Precipitation and Discharge Data for Van Bibber Creek.

Figure 7. Entrance to Siphon Conveying Van Bibber Creek beneath the Croke Canal.

It is most likely that flows began entering the Croke Canal at the Van Bibber Creek crossing some time on the afternoon or evening of Thursday, September 12th. High water marks showing the limits of the upstream embankment's overtopping were apparent during a field inspection of the crossing, although the embankment was not damaged during the event. An estimate of inflow to the Croke Canal at Van Bibber Creek was not made, however, because the Croke Canal also received inflow from Moon Gulch (probably Thursday afternoon as well) and Ralston Creek (probably late Thursday night or early Friday morning) as described in the next section.

Table 4. Historic Annual Peak Flows on Van Bibber Creek.

Year	Van Bibber Creek at Gage *333* *Highway 93*		Van Bibber Creek at Gage *323* *Sports Complex*	
	Peak Stage (ft)	Peak Discharge (cfs)	Peak Stage (ft)	Peak Discharge (cfs)
2013	2.58	750	3.64	426
2012	2.54	396	3.07	353
2011	2.25	349	3.53	404
2010	2.68	417	3.00	350
2009	2.46	383	3.1	352
2008	--	--	2.53	296
2007	2.60	402	2.92	337
2006	--	--	1.70	--
2005	--	--	2.40	157
2004	2.50	387	3.30	375
2003	4.30	665	2.66	309
2002	2.60	402	2.86	331
2001	--	--	3.40	387
2000	--	--	3.50	406
1999	4.21	652	3.34	382
1998	--	--	2.94	339
1997	3.67	571	2.81	325
1996	--	--	2.72	315
1995	3.60	560	2.80	324
1994	2.75	428	2.50	292
1993	2.84	442	2.80	324
1992	2.75	428	2.80	324
1991	2.93	456	3.70	440
1990	--	--	2.50	292

4.2. The Croke Canal

The Croke Canal diverts water from Clear Creek for agriculture and municipal water supply. The decreed water right for the Croke Canal is 950 cfs, but its maximum capacity is significantly lower. Arvada Public Works personnel estimated that the canal is maxed out at 450-500 cfs. A maximum capacity less than 400 cfs is cited by GEI Consultants in materials describing a project undertaken on behalf of FRICO to determine alternatives for increasing capacity (GEI Consultants, undated).

The Croke Canal was conveying approximately 300 cfs during the early part of the storm event, based upon FRICO discharge data. (No information is available about the method FRICO uses to estimate discharges, but they are presently working to upgrade their monitoring network). FRICO stopped diverting water into the Croke Canal on Thursday evening September 12, 2013 at 8 p.m. According to data from FRICO's flow monitoring network, flows at the head gate on Clear Creek then fell to a scant 19 cfs. The canal was observed without flow at a location (near 52nd Avenue and McIntyre St.) within the Mount Olivet drainage (upstream in the canal from the Van Bibber Crossing) by Arvada Public Works personnel. Arvada Public Works personnel also

found the head gates just upstream of the Van Bibber crossing closed during an inspection on Saturday morning.

After the head gates were closed, FRICO flow data show that outflow from the Croke Canal at Standley Lake (at the northern terminus of the canal) fell to zero cfs until about midnight on Thursday the 12th, when a flow of 315 cfs was recorded. This inflow at Standley Lake marks the arrival there of intercepted stormwater (from Van Bibber Creek, Moon Gulch and Ralston Creek) rather than of flows diverted from Clear Creek. The flow rose to a peak of 370 cfs a short time later and remained at that flow until mid-morning on Friday the 13th, when the rate of flow began to fall again.

Flows diverted into the Croke Canal ultimately exceeded its capacity and its embankment began to be overtopped in locations with low capacity. The most problematic overtopping location was at Eldridge St. and W. 78th Place, where the overtopping eroded and threatened to breach the downstream embankment of the Croke Canal (see Section 3.3.1). The Croke Canal also certainly overtopped at its crossing with Leyden Creek, just downstream of Indiana Street. The creek overtopped the upstream embankment of the Croke Canal in this location and the commingled flows overtopped the downstream embankment. City of Arvada Public Works Department personnel estimate that the Croke was probably overtopped in this location beginning Thursday afternoon (and certainly after the Moon Gulch breach described below) and continuing through Saturday.

Because it is useful to know locations of low capacity on the Canal, the Activity Log maintained by the Arvada Police during the flood event was scrutinized to find reports and road closures that coincide with Canal crossing locations. These are locations at which the Croke Canal potentially was overtopped during the September 11th-13th, 2013 event, based on reported problems at locations proximate to the canal:

- The roadway at W. 74th Avenue and Carr St. was reported "washed out" with a car stuck in mud at 05:08 a.m. on Thursday, 9/12/2013, prior to the closing of the head gates and possibly before any of the breaches. The proximity of this location to the Croke Canal crossing of W 74th Avenue suggests that it may have been a factor in flooding observed there, but that is not documented.
- West 64th Avenue at Indiana St. was described as a street closure location in the police logbook at 07:30 a.m. on Thursday, September 12th, prior to the closing of the head gates and possibly before any of the breaches. Both the Croke and the Farmers' High Line Canals cross W. 64th Avenue near Indiana St.
- West 80th Avenue between Kipling St. and Hoyt Way (both the Farmers' High Line and Croke Canals cross W 80th Ave. here. The Croke canal overtopped, sending flows down the street at this location. The Farmers High Line did not overtop.) Flooding here occurred both late Thursday night (22:44 in the police logs) and Friday morning (00:18, 03:12 and 08:19 in the police logs), and a business in that area reported driveway flooding.

In addition to the known or suspected problems at locations where the Croke Canal has low capacity, events during the September 11th-13th flood event suggest areas at which low ditch and canal capacity caused overtopping of the Church Ditch, The Farmers' High Line Canal and the Juchem Ditch. These are provided in Appendix D.

4.2.1. Ralston Creek's Breach into the Croke Canal

The Croke Canal crosses Ralston Creek at the location of the Arvada/Blunn reservoir pumping station in the West Woods golf course (gage ***120 Ralston Creek @ West Woods*** is located there as well). A flow limiter at their confluence is designed to divert flows in excess of the Croke's capacity into Ralston Creek. A flow separation structure constructed in 1994 and designed to convey the 100-year flow routes Ralston Creek over the Croke Canal. Flows in Ralston Creek in excess of the structure's capacity are directed into the Croke.

During the September 11-13th flood event, Arvada Public Works personnel were monitoring Ralston Creek at its crossing with the Croke. Very minor discharge into the Croke at the flow separation structure's spillway was eventually observed, but even that minor release had stopped by Friday at noon, although the water levels remained high in both creek and canal. However, after the waters had receded and access to creek-side natural areas to the north of the flow separation structure was re-established, it became clear that Ralston Creek flows had become rerouted into the Croke canal during the flood at another location. Ralston Creek had backed up behind a pedestrian bridge blocked by a debris dam (Figure 8) and had overflowed to the north, where flows imped upon the upstream embankment of the Croke canal and eventually breached it (Figure 9).

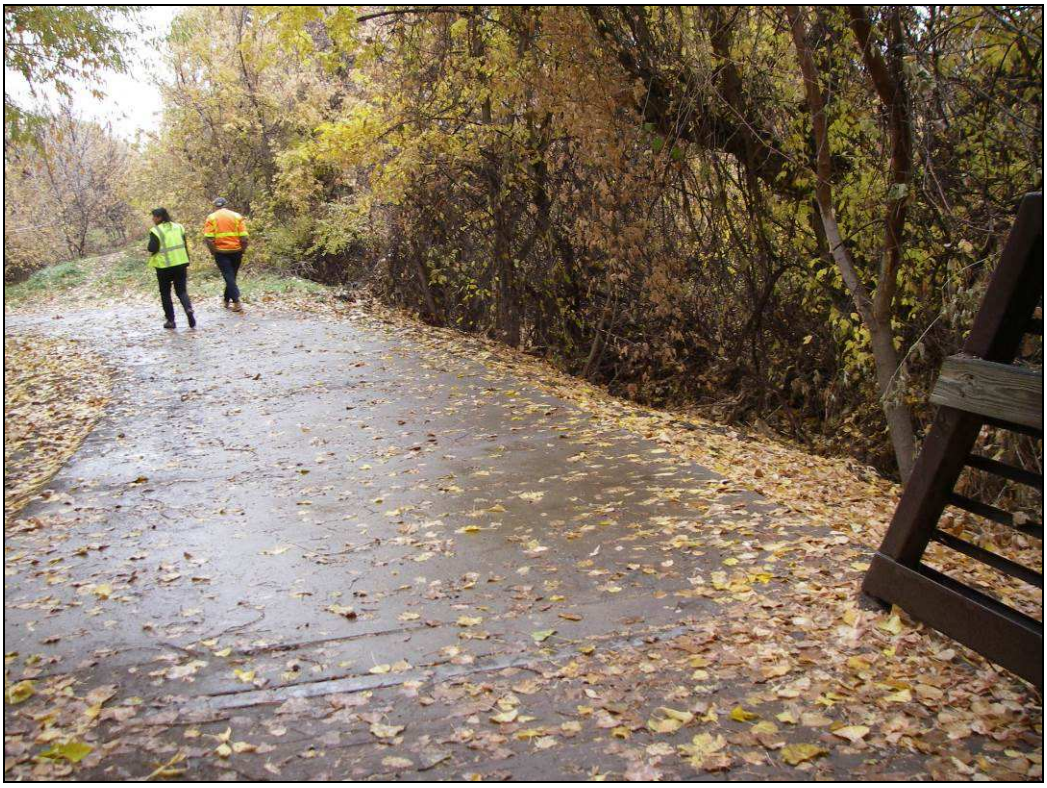

Figure 8. Ralston Creek Pedestrian Bridge at West Woods

Figure 9. Ralston Creek Breach into the Croke Canal at West Woods.

The breach likely occurred late Thursday night or early Friday morning. Arvada/Blunn Reservoir began releasing water over its service spillway just after midnight (See Section 3.2.1). Given the significant flows on Ralston Creek, the Croke Canal can be assumed to have been flowing northward at its full capacity after this breach.

4.2.2. Moon Gulch's Breach into the Croke Canal

Moon Gulch is an ungaged left bank (north) tributary to Ralston Creek. Moon Gulch exits the Saddlebrook detention pond through a 54" RCP beneath the Farmers' High Line Canal and flows continue to an area of inadvertent detention created by the embankment for the Croke Canal and adjacent Indiana St. Outflow for runoff detained in this area is through an 18-inch pipe. During

the September 11-13th storm event, the upstream embankment for the Croke Canal was overtopped and eroded away at this location, draining the majority of the detained volume of flow from Moon Gulch into the Croke (Figure 10). Arvada Public Works personnel have estimated that this breach occurred between 6:00 and 6:30 p.m. on Thursday.

Figure 10. Moon Gulch Breach into Croke Canal.

4.3. Ralston Creek

Flooding and flood damages were more apparent on Ralston Creek, where more intense rainfall occurred, than on Van Bibber Creek. The Ralston Creek watershed is large, and the lower, eastern portion is separated hydraulically from the western headwaters portion by two main stem water supply reservoirs in close proximity: Ralston Reservoir and Arvada/Blunn Reservoir. Most of the flood damages for the September 11-13th event were in the upper reaches of Ralston Creek above Arvada/Blunn reservoir and at the previously described breach of the Croke Canal at its intersection with Ralston Creek. However, high, fast water and out-of-bank flow occurred intermittently in the eastern, urban channel reaches of Ralston Creek as well. Figure 11shows the Ralston Creek drainage basin and its unofficial 100-year floodplain, as it appears on the UDFCD Electronic Data Mapping (EDM) webpage. (The official 100-year floodplain map is available from FEMA or from Arvada). Figure 12 shows cumulative precipitation at the Ralston Creek gages, superimposed on the discharge plots for Gages 110 Ralston Reservoir, 120 West Woods, and 100 Carr St. The figure will be referred to during discussions of flood impacts along Ralston Creek.

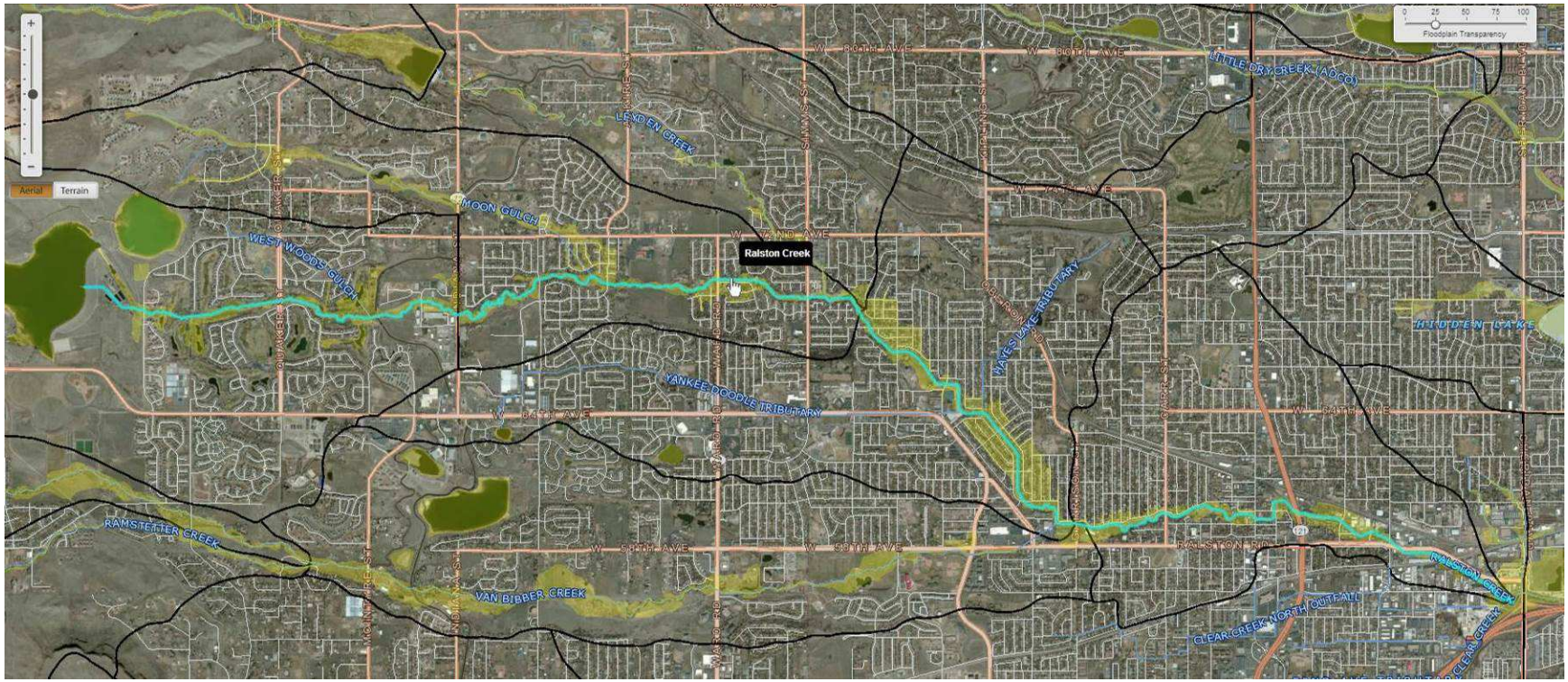

Figure 11. Ralston Creek Below Arvada/Blunn Reservoir.

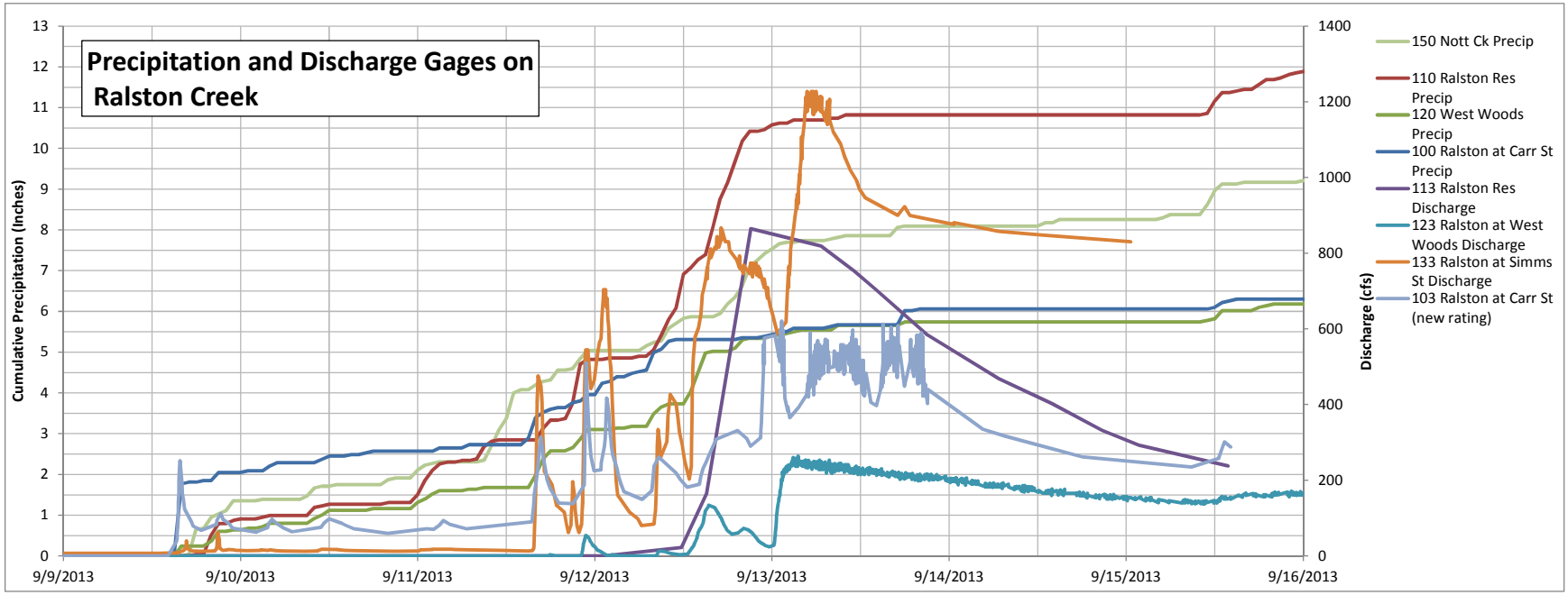

Figure 12. Precipitation and Discharge Data for Ralston Creek.

Table 5 shows historic annual peaks for each of the gages on Ralston Creek. The 2013 peak stages and discharges are the new historic peak at each gage except at the new gage installation at ***103 Ralston Creek @ Carr St***.

Table 5. Historic Annual Peak Flows on Ralston Creek.

Year	Ralston Reservoir Release at Gage *113*		Ralston Creek at Gage *123 West Woods*		Ralston Creek at Gage *133 Simms St.*		Ralston Creek at Gage *103 Carr St.*	
	Peak Stage (ft)	Peak Discharge (cfs)	Peak Stage (ft)	Peak Discharge (cfs)	Peak Stage (ft)	Peak Discharge (cfs)	Peak Stage (ft)	Peak Discharge (cfs)
2013	49.87	865	3.92	264	3.68	1,227	23.71	621*
2012	--	--	1.09	15	1.74	300	--	--
2011	46.12	12	2.39	105	2.09	486	24.94	1,340
2010	46.74	74	2.74	136	2.23	544	24.26	934
2009	--	--	2.80	147	1.80	341	24.22	918
2008	--	--	2.37	103	1.72	286	23.42	581
2007	47.30	190	3.10	175	2.10	500	23.70	677
2006	46.60	57	0.50	0	2.10	500	24.36	976
2005	47.20	160	2.30	101	1.90	374	22.60	298
2004	--	--	1.80	56	1.70	262	24.40	979
2003	47.80	334	2.07	78	1.40	120	23.20	490
2002	47.78	334	1.87	63	2.91	836	23.10	460
2001	48.00	393	1.80	56	2.70	749	24.40	1,020
2000	46.90	88	2.50	115	2.60	708	25.20	1,539
1999	47.40	214	3.23	186	2.18	522	26.40	2,300
1998	46.98	98	2.16	85	2.08	481	24.70	1,167
1997	45.49	0	2.03	75	1.90	400	24.86	1,291
1996	46.49	49	2.25	93	2.37	606	25.24	1,536
1995	46.70	70	3.40	200	3.00	890	24.90	1,315
1994	44.70	0	2.60	123	2.03	458	24.10	882
1993	47.10	130	1.80	58	1.50	147	23.80	756
1992	45.50	0	--	--	1.58	200	23.40	588
1991	46.20	20	3.30	194	2.16	513	27.20	3,010
1990	47.00	100	1.40	32	--	--	24.80	1,249
1989	44.80	0	--	--	--	--	24.41	996
1988	--	--	--	--	--	--	24.11	870

*Updated rating used to reflect channel and gage reconstruction

4.3.1. Ralston and Arvada/Blunn Reservoirs

By Wednesday night September 11th, both Ralston Reservoir and Arvada/Blunn Reservoir were full and releases became inevitable when additional heavy rain fell in the early hours of Thursday, September 12. The two reservoirs are on-channel water supply reservoirs located on Ralston Creek, with Arvada/Blunn located about 1 mile downstream of Ralston Reservoir.

Ralston Reservoir has a 40.4 square mile drainage area. In addition to capturing flows from Ralston Creek, Denver Water is able to divert water from Gross Reservoir to Ralston Reservoir through the South Boulder Diversion Canal. Arvada's Ralston Water Treatment Plant (RWTP) receives its Moffat Tunnel System water this way, and was taking water directly from Ralston

Reservoir when extremely turbid runoff entered the reservoir at around 3:00 a.m. on Thursday morning, September 12th. Mud washed into the pretreatment building. Typical values of measured turbidity are 2 to 4 ppm, but during this event the treatment plant received inflows with as much as 2,200 ppm of turbidity, creating challenges for water treatment. Operators shut down the RWTP and began treating water at the Arvada Water Treatment Plant (AWTP), which withdraws from Arvada/Blunn reservoir and is typically used as a peaking plant. The AWTP was also shut down at around 5:30 a.m. on Friday, September 13, when measured turbidity there exceeded about 30 ppm. By that time, cleanup at the RWTP was proceeding well. Operations at RWTP were reconfigured to release treated water back to the reservoir until state regulators could test water quality. Although the police report indicates: "Ralston Plant open. Water checked by state and is safe." at 9?32-9:35 a.m. on Friday, September 13th, the RWTP was actually brought back on line at around 4:30 p.m. that afternoon. The water supply in Arvada remained completely safe to drink throughout the event. However, a water main break where Leyden Creek had damaged Quaker Street (see Section 3.3.2) had caused a significant depletion of stored water Wednesday night, and Arvada residents were asked to conserve water Friday morning. Arvada came to within about 1 foot of stored depth (a 90-minute supply) of depleting stored water supplies and being forced to issue a boil water order.

For the first time in its 76-year history, Ralston Reservoir began releasing water over its emergency spillway, just before noon on Thursday, September 12th. ALERT stage gage ***110 @ Ralston Reservoir*** recorded a peak stage of 49.87 ft at 21:08 pm on Thursday night, 9/12/13, corresponding to a peak discharge of 865 cfs. Design outflows from Ralston Reservoir were provided in Table 3. This peak discharge corresponds to a frequency of once in 10 to 50 years. The spillway outflow eroded a deep gulley on the steep hillside that will require repairs by Denver Water (Figure 13).

Outflow from Ralston Reservoir and runoff from the intervening tributary area enters Arvada/Blunn Reservoir through an 8-foot wide inlet channel, which suffered serious damage from erosion (Figure 14). Up to 7 feet of material was removed from reaches of the channel vertically, and bank erosion extended over a width of up to 200 ft. In addition, a water main crossing the inflow channel was exposed by the degradation.

Figure 13. Outflow from Ralston Reservoir. Denver Water.

Figure 14. Ralston Creek at the Inflow Channel for Arvada/Blunn Reservoir.

Neither inflow nor outflow data for Arvada/Blunn Reservoir are available for the flood period. No ALERT gage is installed at Arvada/ Blunn Reservoir. Prior to the flood event, a water supply monitoring station was visited weekly to download inflow data, typically on the order of 1 to 2 cfs. However, the station was not equipped to provide real-time access to inflow data during the flood event and the station (as well as similar inflow and outflow gages at Ralston Reservoir) was destroyed by the flood.

Arvada Public Works Department personnel estimated that the peak inflow to Arvada/Blunn Reservoir was 1,200-1,400 cfs. However, the estimate of peak inflow resulting from a mass balance reconstruction of the reservoir stage, storage, inflows and releases for Ralston and Arvada Blunn reservoirs suggests a slightly higher peak inflow, of just over 1,800 cfs. The results of the reconstruction are presented in Table 6. This table represents estimates of the conditions at 11:59 pm on each day. Data points at noon and 5pm on Friday 9/13 are also included in the table. UDFCD ALERT data were used where available. Reservoir storage data were calculated based on reservoir stage, using piecewise linear interpolation. The stage discharge tables were used to equate reservoir stage/storage and discharge over the spillways, using piecewise linear interpolation. There is no stage measurement device on Arvada Blunn reservoir, however there was a high water measurement performed in the field that marked the reservoir peak during the flood at noon on Friday. It was also assumed that Ralston Reservoir outflows plus some additional tributary inflow equaled Arvada Blunn inflows. Other flows and

storage were calculated using water mass balance for the reservoir (daily total inflow – daily total outflow = change in storage over the day), where flows presented are assumed to be constant between times presented in the table.

Table 6. Reconstructed Ralston and Arvada/Blunn Reservoir Conditions During Flood

Date	Day of the week	Ralston Reservoir				Arvada/Blunn Reservoir			
		Reservoir Elevation (ft)	Reservoir Volume Stored (AF)	Inflows (cfs)	Releases (cfs)	Reservoir Elevation (ft)	Reservoir Volume Stored (AF)	Inflows (cfs)	Releases (cfs)
9/11/2013	Wed	6046.0	10750.0	0	0	5763.0	6361.0	0.0	0
9/12/2013	Thurs	6046.0	10750.0	0	0	5763.0	6361.0	0.0	0
9/13/2013	Fri just after midnight	6049.9	11427.3	1216	875	5763.6	6489.3	875	810
9/13/2013	Fri noon	6049.4	11355.5	694	730	5764.0	6562.0	1856	1783
9/13/2013	Fri 5pm	6049.3	11327.5	626	640	5763.5	6466.5	640	871
9/13/2013	Fri midnight	6049.1	11285.5	509	530	5763.5	6453.8	530	552
9/14/2013	Sat	6048.6	11201.5	250	292	5763.3	6422.8	292	308
9/15/2013	Sun	6047.6	11037.0	184	267	5763.3	6419.6	267	269
9/16/2013	Mon	6047.6	11023.0	177	184	5763.2	6406.5	184	191
9/17/2013	Tues	6047.3	10974.0	41	66	5763.1	6377.6	67	82
9/18/2013	Wed	6046.7	10865.5	0	55	5763.0	6367.4	26	31
9/19/2013	Thu	6046.3	10795.5	0	35	5762.5	6268.3	0	50
9/20/2013	Fri	6046.0	10745.0	0	25	5762.0	6169.1	0	50
9/21/2013	Sat	6045.7	10700.0	0	23	5761.5	6069.9	0	50
9/22/2013	Sun	6045.4	10645.0	0	28	5761.0	5970.7	0	50
9/23/2013	Mon	6045.0	10581.7	0	32	5760.5	5871.6	0	50
9/24/2013	Tue	6044.6	10520.0	0	31	5759.9	5772.4	0	50
9/25/2013	Wed	6044.7	10525.0	3	0	5759.4	5673.2	0	50

Arvada/Blunn Reservoir began releasing water over its service spillway just after midnight on Friday, September 13, 2013 (Figure 15). Arvada/Blunn Reservoir was retrofitted with a labyrinth weir spillway in late 2004, raising the crest elevation by 5 feet and increasing the 100-year discharge over the previous spillway configuration. (Design outflows from Arvada/Blunn Reservoir were provided in Table 3.) The new spillway configuration had not been activated prior to this event and there was some confusion amongst the public and the media about the meaning of the release. It was reported Friday morning that the dam had breached.

Figure 15. Release from the Arvada/Blunn Reservoir Service Spillway.

During the flood event the staff gage on the outlet works, with its 1-foot graduations, was inadequate to determine if the water surface was still rising and how fast. In lieu of remote stage sensing, Arvada Stormwater personnel made manual stage measurements from a handicapped dock in the reservoir. The flume upstream of Virgil Way only measures low flow and was quickly inundated during the event, so outflow data was also unavailable. To aid in decision support during flood events, the installation of a remote monitor for stage at Arvada/Blunn Reservoir is recommended. Due to concern that the emergency spillway's gravel fuse plugs would be activated and uncertainty about whether or not the reservoir water surface elevation had peaked, it was decided to begin making releases through the outlet works in addition to the outflow over the service spillway. By Friday morning, releases in the 50-70 cfs range were occurring through the outlet works. Ultimately the reservoir surface came within about 2 feet of activating the emergency spillway.

4.3.2. Damages in Urban Arvada on Ralston Creek

The majority of the flooding in urban Arvada occurred on Leyden Creek, rather than on Ralston Creek. Due to development constricting the floodplain, it is not that uncommon to have bankful flow in Ralston Creek through urban Arvada, as was typical of this event. Serious damage was limited to the previously described re-channelization of Ralston Creek at West Woods, which caused the upstream embankment of the Croke Canal to be breached. This occurrence may have relieved flooding farther downstream on Ralston Creek but may have exacerbated flooding on Leyden Creek during this event. A period of rapid increase in stage at gage ***123 Ralston Creek @ West Woods*** began after midnight, when the Arvada/Blunn service spillway began making releases, and the peak discharge at West Woods of 264 cfs occurred at 3:33 a.m. on Friday 9/13/2013. However, the measured discharge at ***123 Ralston Creek @ West Woods*** tapered off

even as outflow from Arvada/Blunn continued to rise through noon on Friday, most likely caused by Ralston Creek overflowing its banks upstream of the gage and scouring a channel into the Croke Canal. Ralston Creek also crosses the Church Ditch and the Farmers' High Line Canal in the West Woods area and may have also contributed flow to those conveyances. The Church Ditch is designed to accept 200 cfs from Ralston Creek at this location during high flows.

Downstream of the West Woods area, the Ward Road Bridge over Ralston Creek did not overtop but the discharge was very close to the maximum for that structure. A high water photograph was taken by City of Arvada staff (Figure 16).

Figure 16. Ward Road at Ralston Creek Peak Stage During the Flood.

The single span bridge at Ward Road has the lowest capacity of any of the Ralston Creek conveyances investigated (Figure 17, looking at the downstream face of the bridge). To estimate peak flow at this crossing, the bridge opening and channel slope were surveyed as well as high water marks from the event. The discharge was modeled with the Army Corps of Engineers model HEC-RAS and the peak discharge was estimated at 650 cfs, which is likely a better estimate of flow in the reach between West Woods and Simms St. than the 264 cfs peak from ***123 Ralston Creek @ West Woods***. At the intersection of W 69th Avenue and Ward Rd, some street flooding provided unintentional detention for flows just upstream of the Ward Road crossing.

Much higher peak discharge was estimated by the rating for gage ***133 Ralston @ Simms St.***, located a little more than a half mile river distance downstream from the Ward Road crossing, but still upstream of the confluence with Leyden Creek. The peak discharge at Simms St., of 1,227 cfs, occurred Friday afternoon at 4:47 p.m., just less than five hours after the peak release from Arvada/Blunn Reservoir. Given the peak discharge estimate at Ward Road, it is recommended that the rating at Simms St. be evaluated to determine if it is overestimating discharges for measured stages.

Figure 17. Ward Road at Ralston Creek After the Flood, Showing Low Capacity

No major creek flooding was reported east of Simms St. in spite of the confluence between Ralston Creek and Leyden Creek just downstream of there in Davis Lane Park. In Davis Lane Park, out-of-bank flow is common during typical summer thunderstorms. This storm event caused out-of-bank flow and some areas of damage that will require remediation. Just downstream of the Leyden Creek – Ralston Creek confluence, the small on-channel pond will need to be dredged due to heavy deposition during the flooding, possibly related to sediment from construction activity to the west. This pond has required dredging before. Farther downstream, an area of rip rap work at a steep bank on an outside curve was weakened and will require repair, as will some intermittent creek bank erosion.

At 68th Avenue, Ralston Creek impinged upon the street, with water up to 6 inches over the bridge. This is a concrete double box culvert with significant deposition at its downstream end. Oak Park experienced some flooding, but houses on the south side were not impacted.

Deposition was the major issue in this area, with gravel, cobble and debris deposition both in overbank areas and in the channel. The invert of the channel was raised by this deposition and Arvada may need to remove some material to maintain capacity. Four to six homes in the area of 64th and Miller had trouble with sewer surcharge, but homes in the "narrows" area were not flooded. Nor were streets inundated at bridges at concrete double box culverts in the area, for example at Rensselaer Dr. and at 61st Ave., but these conveyances were very nearly at capacity and their capacities (approximately 1,300 and 1,400 cfs, respectively) constitute a bounding estimate of discharge at these locations. Ralston Cove Park was under water and Arvada Streets personnel were required to remove debris at W. 59th Ave and Brooks Drive to prevent flows from impinging on adjacent streets.

The most downstream gage location on Ralston Creek is at Carr Street. The peak flow there (621 cfs at 1:19 on Friday afternoon) was estimated using the new rating for ***103 Ralston @ Carr St*** (which is based upon a model of the as-built channel geometry since the redevelopment of the park). This peak is significantly lower than the peak at Simms St.

The data suggest three discrete peaks with relatively similar peak flows, but the extreme variability of the data in the final two "peaks" suggests that the gage was reading a lot of noise (due to turbulence, equipment movement due to the interim status of the installation there during re-construction, or hydraulic transience) during those peak periods. The PT for ***103 Ralston @ Carr St*** is installed at the base of a drop structure which could experience turbulence and entrained bubbles capable of creating pressure fluctuations at the PT (Figure 18). However, the stage associated with measured high water marks at the gage site corresponds well with the peak stage measured by the PT. The multiple peaks in the data likely reflect the offset arrival of attenuated peaks from upstream sources in the period from Thursday night to Friday morning. If those peaks had coincided, flooding in the lower reaches of Ralston Creek could have been more significant.

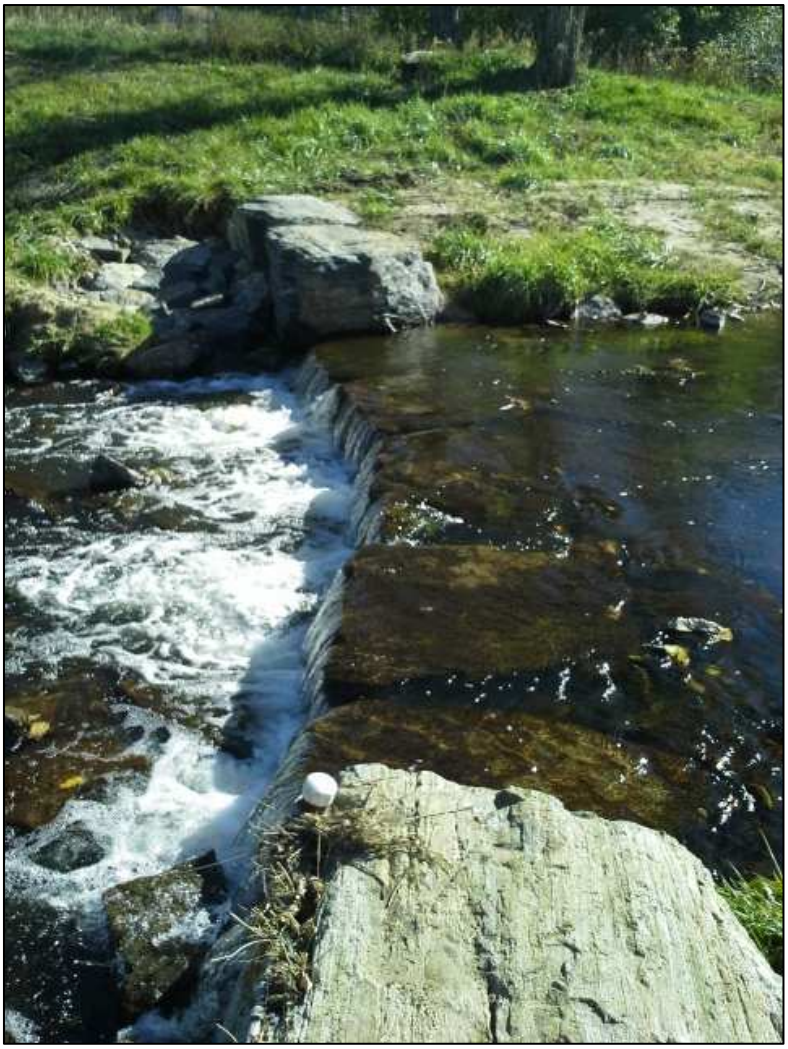

Figure 18. Ralston Creek at Carr Street PT Installation: Intake below Drop

High water in Memorial Park (downstream of the Carr St. gage) is pictured in Figure 19. High water also caused concern father downstream, for residents of apartments on Pierce St. near Creekside Park. The eastern-most issue recorded during the event was the closure of Sheridan Blvd. between Ralston Road and I-76 at around 10 p.m. on Thursday the 12th. The confluence of Ralston Creek with Clear Creek occurs near this street location, but localized flooding related to ongoing construction activity there was given as the cause of the problem, and Arvada Streets personnel were dispatched to clear debris in this location as well.

Figure 19. Ralston Creek near Memorial Park

4.4. Leyden Creek

Figure 20 shows cumulative precipitation at the Leyden Creek gages, superimposed on the discharge plots for Gages ***203 Leyden Reservoir*** and ***213 Leyden Confluence***. The figure will be referred to during discussions of flood impacts in the Leyden Creek watershed. Table 7 shows historic annual peaks for the two discharge gages on Leyden Creek, ***203 Leyden Reservoir*** and ***213 Leyden Confluence***. The 2013 peak value is a new historical peak for gage ***203 Leyden Reservoir***, but the September 2013 value was exceeded in 1995 at ***213 Leyden Confluence.***

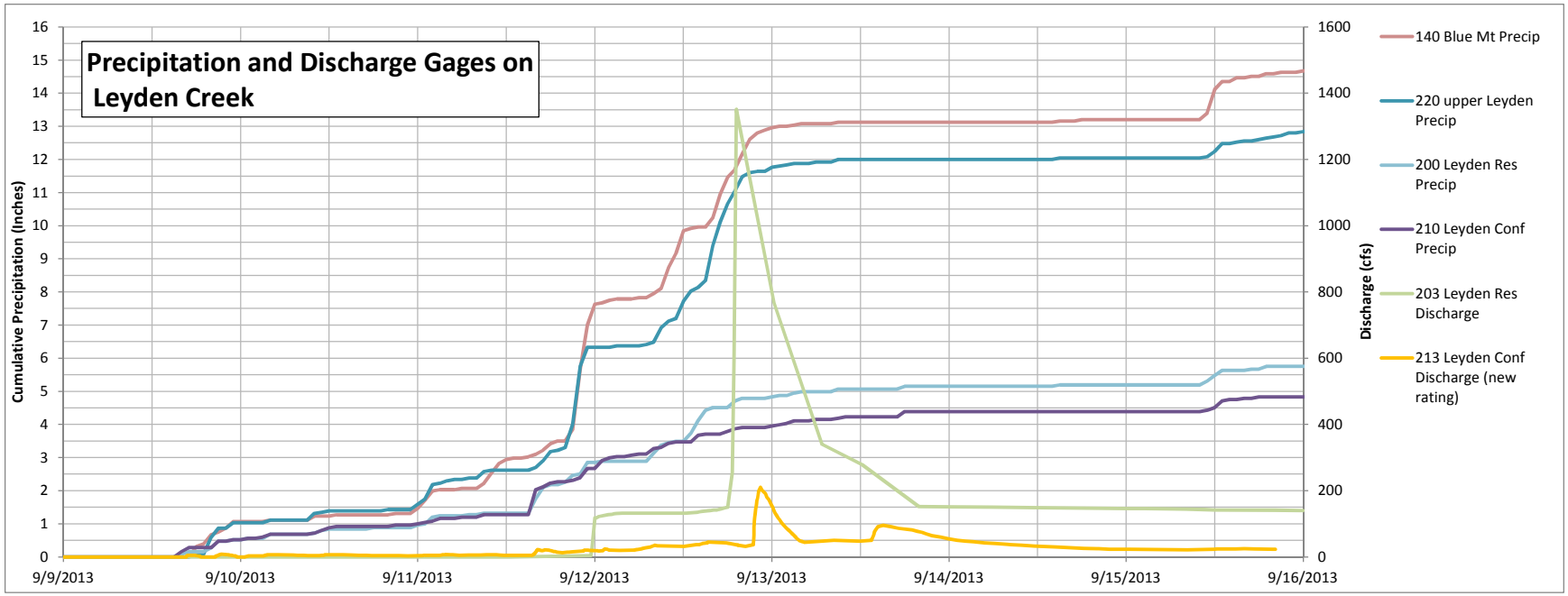

Figure 20. Precipitation and Discharge Data for Leyden Creek. The Leyden Confluence Discharges are Calculated with a Provisional (Based upon the Peak Flow Estimate Survey Conducted after the September Flood Event).

Table 7. Historic Annual Peak Flows on Leyden Creek.

Year	Leyden Reservoir Release at Gage *203*		Leyden Creek at Gage *213 Leyden Confluence*	
	Peak Stage (ft)	Peak Discharge (cfs)	Peak Stage (ft)	Peak Discharge (cfs)
2013	108.92	1,351	3.82	2,903*
2012	15.39	0	1.76	405*
2011	15.60	0	2.49	1,097*
2010	16.02	0	2.27	871*
2009	16.41	0	2.30	932*
2008	--	--	1.89	496*
2007	89.80	71	--	--
2006	17.00	0	--	--
2005	16.10	0	0.90	9*
2004	16.00	0	1.10	26*
2003	15.66	0	1.15	56*
2002	--	--	0.86	7*
2001	--	--	1.62	299*
2000	--	--	1.10	46*
1999	--	--	1.44	176*
1998	--	--	1.33	126*
1997	--	--	1.42	164*
1996	--	--	1.14	51*
1995	--	--	4.20	3,520*
1994	--	--	1.00	10*
1993	--	--	1.50	200*
1992	--	--	1.40	157*
1991	--	--	3.00	1,720*
1990	--	--	2.60	1,227*

*Computed Using Existing Rating. Rating revision recommended due to overestimates of discharge

The Leyden Creek drainage basin is separated hydraulically into an upper and a lower basin by the Leyden Detention Reservoir. Given that the highest rainfall totals were in the headwaters of Leyden Creek, it is not surprising that issues and damages related to the rainfall were experienced there, many of them related to the period of intense rainfall around 10:00 p.m. on Wednesday, September 11th. By midnight, Highway 72 had been closed at Highway 93 because portions of the road in Coal Creek Canyon were washed away and impassable. Miscellaneous damages were reported to Arvada police, including the collapse of a retaining wall on Westridge Road, a train derailment at Pinecliff and damage to the parking lot for the NE trailhead at Pattridge Park. Near the intersection of Highways 72 & 93, six to seven feet of fill material was scoured from a buried water transmission line belonging to Consolidated Mutual, and the Welton Reservoir had a reported rise of 8" due to the heavy rainfall. At the intersection of W. 87th Avenue and Indiana Street (in unincorporated Jefferson County), a low section of road was covered with standing water but the road remained passable. Flooding issues of importance for the Arvada Department of Public Works are described in the following sections, working from upstream to downstream in the Leyden Creek watershed.

4.4.1. Runoff from Blue Mountain Estates Area Captured by Leyden Creek

The uppermost headwaters portion of the Leyden Creek drainage basin (highlighted in blue) is shown on Figure 21 as it appears on the UDFCD Electronic Data Mapping (EDM) webpage, with its unofficial 100-year floodplain highlighted in pale yellow (The official 100-year floodplain map is available from FEMA or from Arvada). The EDM map shows basin delineations for the headwaters of a large number of creeks (Rock Creek, Walnut Creek, Woman Creek, Big Dry Creek, Barbara Gulch, Leyden Gulch) converging on a relatively flat plateau at the mouth of Coal Creek Canyon (circled in Figure 21). Basin delineations in this area are difficult due to the topography, and during the September 11-13 event, a clogged culvert caused runoff that theoretically should drain to Coal Creek to be captured by Leyden Gulch. The most upstream extent of Barbara Gulch's drainage basin may also be underestimated.

Runoff from most of Blue Mountain Estates, an area of about 1.32 square miles, is intended to pass beneath a railroad embankment and then beneath Blue Mountain Road in CMP culverts that direct flow towards Coal Creek. During the September 2013 event, however, the culvert beneath Blue Mountain Road became clogged with debris and flow began to travel along the East side of Blue Mountain Road, eventually scouring the shoulder of the road. The channel eroded by this flow was up to 10 feet deep and was repaired over the course of the week following the flooding with 2,000 tons of fill material. Flows exposed but did not damage a gas line.

A peak flow estimated at 280 cfs passing under the railroad embankment in a 6 foot diameter CMP culvert was diverted into Leyden Gulch. Supporting documentation for the estimate is provided in Appendix A. The total extra volume entering Leyden Detention Reservoir from this inter basin transfer is unknown, but the additional 1.32 square miles of drainage area increases the watershed area tributary to Leyden Detention Reservoir (8.83 square miles without the Blue Mountain Estates area) by about 15%.

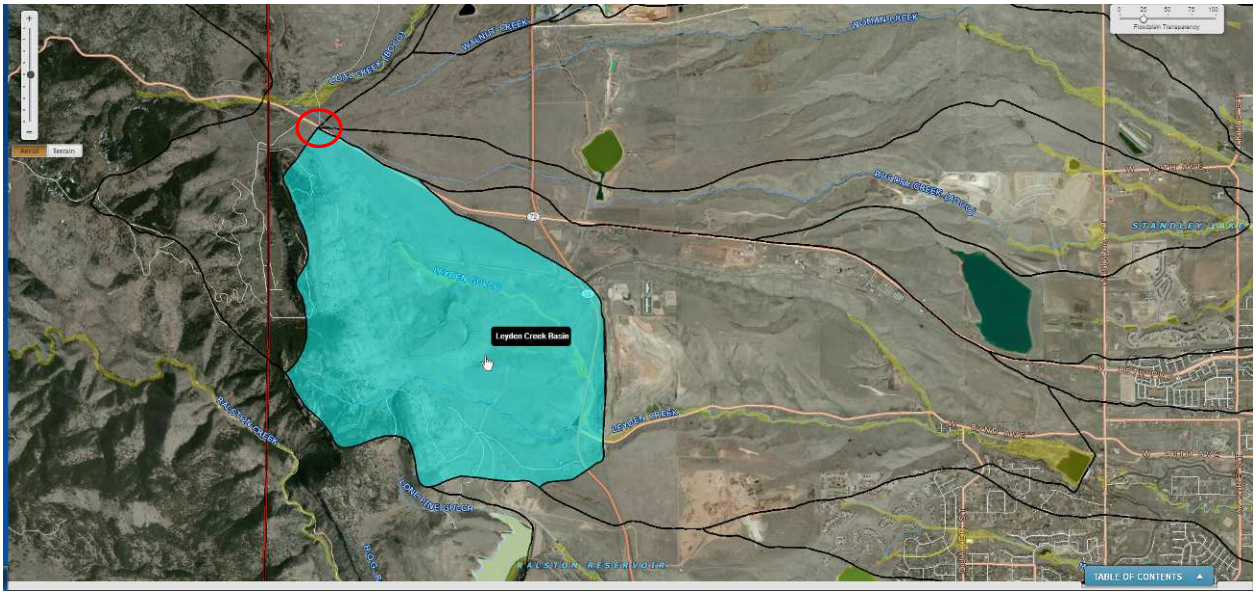

Figure 21. The Upper Leyden Creek Watershed.

4.4.2. Leyden Road Closure

Leyden Road (West 82nd Avenue where it runs west of Indiana St.) was impacted by runoff at intermittent locations in the late evening and early morning hours of September 11th and 12th. The road was overtopped by as much as three feet at its crossing with Leyden Creek just less than a mile east of Highway 92. High water marks on the road and debris in fencing adjacent to the road are visible in Figure 22. Normally a trickle, Leyden Creek was running about 300 ft wide. Leyden Road was closed by 11:40 p.m. on September 11th between Quaker and Indiana because water and mud from adjacent construction at Leyden Rock were covering the roadway. At 5:31 a.m. the next morning, the road was closed from Indiana to Highway 93.

Figure 22. Leyden Road at Leyden Creek High Water Marks.

4.4.3. Quaker Street Overtopping and Water Main Break

Arvada Public Works Department personnel found Quaker Street passable at Leyden Creek at 10:15 p.m. on Wednesday, September 11th, but it was overtopped shortly thereafter, and not long after that the 12-inch water main running on the east side of the road broke due to the erosion of the shoulder of the road. There was a report that Leyden Rock subdivision was without water briefly, and the water supply storage tanks dropped from about 16 feet to under 5 feet in less than an hour, but the break was isolated by 1:00 or 1:30 a.m. By reconfiguring the water supply, service to the Leyden Rock and Candella subdivisions was maintained without a sustained interruption in the provision of drinking water. To best conserve the remaining water in storage, it was decided not to flush the lines. It is possible that some customers experienced air in the water lines. Figure 23 shows Quaker St. in the aftermath of the flooding.

Arvada Public Works Department personnel indicated that the first flood in the early hours of Thursday morning was followed by a second, higher peak on Thursday morning that interrupted crews working to repair the damage. In addition to the road and water infrastructure damage, two homes in the Township of Leyden suffered flood damage. Arvada police assisted Jefferson County with the evacuation of Leyden on the afternoon of 9/12/2013.

The culvert conveying Leyden Creek beneath Quaker St. and high water debris mark (indicated with an orange arrow on Figure 23) were surveyed to allow the peak discharge at this location to be estimated. The standard UDFCD inlet-controlled culvert nomograph and broad-crested weir equation were used to estimate the total discharge through the culvert and over the road. This peak discharge was estimated at 1,700 – 2,030 cfs. Estimates by the City of Arvada Public Works Division were slightly lower, 1,300 to 1,500 cfs. Since there is no inflow monitoring at Leyden Lake, this is a lower bounding estimate of peak inflow to the Leyden Detention Facility. The facility's design capacity was based upon a three-hour, 100-year volume of 753 acre-ft, and the design inflows were provided in Table 3. The calculated inflow exceeds the 10-year design inflow of 1,569 cfs but not the 50-year design inflow of 3,269 cfs.

Quaker Street was repaired and reopened by September 18, 2013.

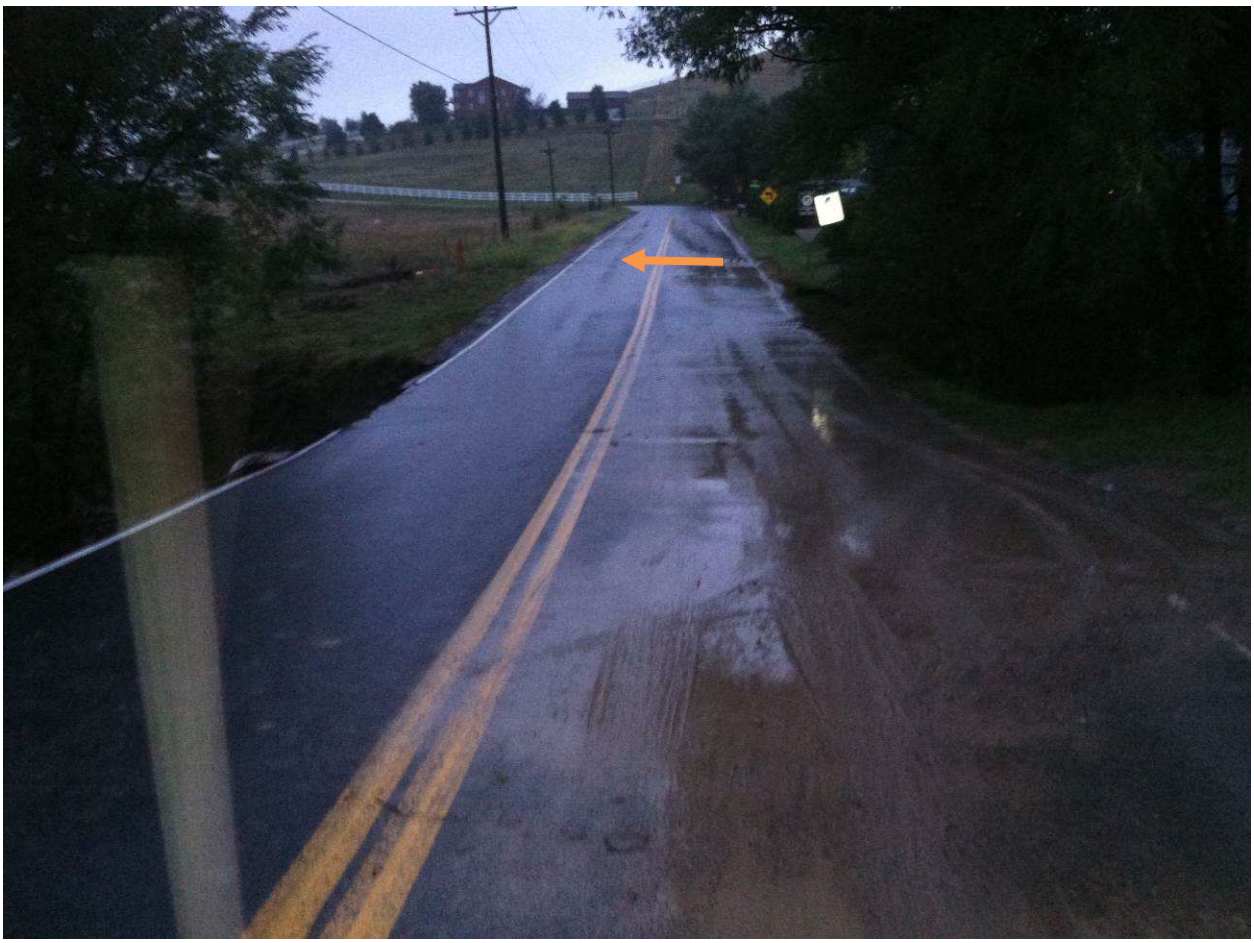

Figure 23. Quaker Street at Leyden Creek.

4.4.4. Breach of the Church Ditch at Leyden Creek

The Church Ditch crosses Leyden Creek downstream of the Quaker Street crossing and just upstream of the Leyden Lake. At some point during the September 11th-13th event the ditch embankment at the crossing was breached (Figure 24), diverting flows in the Church Ditch into the Leyden Detention facility. The capacity of the Church Ditch exceeds its decree for 113 cfs and was estimated at 200 cfs by Arvada Public Works personnel.

Figure 24. Leyden Creek Breach of the Church Ditch Upstream of Leyden Reservoir.

4.4.5. Spillway Release from Leyden Detention Facility

The lower Leyden Creek watershed, below Leyden Detention Facility, is shown highlighted in blue in Figure 25. Unlike Ralston and Arvada/Blunn Reservoirs, the Leyden Detention Facility primarily serves a flood control purpose. Originally built in 1902, Leyden Reservoir stored irrigation and municipal water for the Farmers' High Line Canal and Reservoir Company. The water surface elevation was lowered and improvements to the dam were required for its conversion to a detention facility, in 2001. Improvements including a new spillway were constructed as a joint project between Arvada and the UDFCD. In addition, the outlet works were reconstructed to route discharges into Leyden Creek (instead of into the Farmers' High Line Canal). The discharge through the uncontrolled 36" pipe serving the outlet works depends upon the head, but approaches a maximum discharge just above 150 cfs. Releases from the spillway are still routed into the Farmers' High Line Canal, which has a capacity of about 350

cfs. The reservoir at the emergency spillway crest provides sufficient capacity to store the three-hour, 100-year volume of 753 acre-ft. Elevation 5,608 ft (NGS Datum, per the as-builts) is the maximum water surface during the 100-year design event and also the elevation of the spillway crest (URS, 2002). Design discharge during a 100-year flow is 373 cfs (Boyle Engineering Corporation, 2003 and UDFCD, 2009).

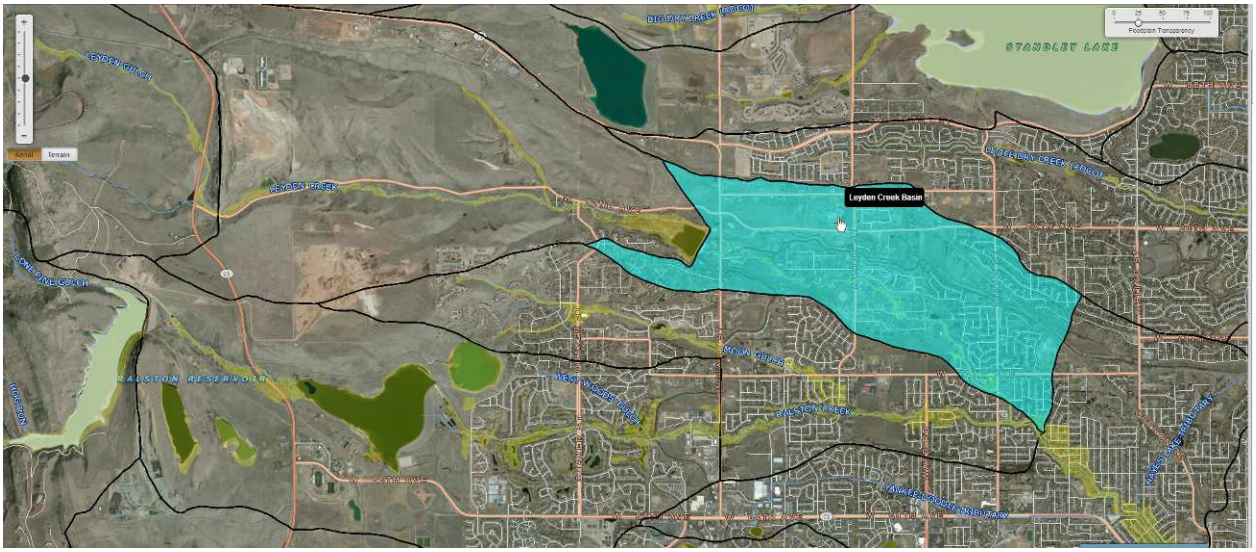

Figure 25. The Lower Leyden Creek Watershed.

By 7 p.m. on Thursday, 9/12/2013, Leyden Reservoir had reached its capacity and spillway release was imminent. The Farmers' High Line Canal was observed to be dry prior to the release. Head gates on the Farmers' at Clear Creek had been closed Wednesday morning. The ALERT data from gage 203 Leyden Reservoir, plotted in Figure 20, shows maximum discharge through the outlet works of about 150 cfs and sharp spike in discharge during the period of spillway release. The peak outflow estimated by the gage rating of 1,351 cfs was recorded at 19:12 on Thursday, September 12th. The peak exceeds the 100-year outflow of 373 cfs. The peak is defined by a single data point with steep rising and receding limbs. Receding water was reported around 4 a.m. on Friday, 9/13/2013 both upstream of the Leyden Detention Facility, and Quarter St., and downstream, at Indiana. By 7 a.m. Friday morning the spillway release had receded to 340 cfs, below the capacity of the receiving Farmers' High Line Canal.

Reconstruction of the reservoir stage, storage, average inflows and average releases for Leyden reservoir from September 11th -25th is presented in Table 8. This table represents estimates of the conditions at 11:59 pm on each day. Data points at noon and 5pm on Friday 9/13 are also included in the table. UDFCD ALERT data for reservoir stage and discharge were used where available. Reservoir storage data were calculated based on reservoir stage, using piecewise linear interpolation. Total inflow was calculated using water mass balance for the reservoir (daily total inflow – daily total outflow = change in storage over the day), where flows presented are assumed constant between times presented in the table.

Table 8. Reconstructed Leyden Reservoir Conditions During Flood

Date	Day of the week	Leyden Reservoir			
		Reservoir Elevation (ft)	Reservoir Volume Stored (AF)	Inflows (cfs)	Releases (cfs)
9/11/2013	Wed	5590.2	124.6	123	108
9/12/2013	Thurs	5608.6	853.3	1134	767
9/13/2013	Fri just after midnight	5608.6	853.3	1134	767
9/13/2013	Fri noon	5608.0	826.6	265	278
9/13/2013	Fri 5pm	5607.6	805.6	141	152
9/13/2013	Fri midnight	5607.3	790.3	119	151
9/14/2013	Sat	5605.2	692.5	97	146
9/15/2013	Sun	5602.1	541.9	64	140
9/16/2013	Mon	5596.0	288.9	0.4	128
9/17/2013	Tues	5592.0	170.3	60	120
9/18/2013	Wed	5590.9	141.2	103	118
9/19/2013	Thu	5590.3	125.7	104	112
9/20/2013	Fri	5590.1	123.0	99	100
9/21/2013	Sat	5590.0	121.0	88	89
9/22/2013	Sun	5589.8	118.3	71	72
9/23/2013	Mon	5590.0	121.6	94	92
9/24/2013	Tue	5589.9	118.9	75	76
9/25/2013	Wed	5589.7	116.2	59	60

The spillway release caused significant inundation in areas downstream described in following sections. An aerial view of Leyden Reservoir during the spillway release and showing areas of flooding downstream, shot Friday, September 13, 2013, is provided (Figure 26) (video of the flyover is available online at:

https://www.youtube.com/watch?v=tAax9CpibdE).

In the hour between 18:50 and 19:50, evacuation and reverse 911 notifications were provided to residents of areas east of the dam in unincorporated Jefferson County and in Arvada in anticipation of imminent or active flooding. Alkire Estates residents received a reverse 911 call warning of potential flooding from the Croke Canal (not the Church Canal, as indicated in the police report), and the Double E Ranch neighborhood was warned of flooding from the Farmers' High Line Canal as spillway releases were expected to exceed the capacity of that conveyance.

4.4.6. Overtopping of Indiana Street and Threatened Water Main

The conveyance for Leyden Creek beneath Indiana during the event (a 36" and an 18" pipe) was known to have inadequate capacity prior to the September flooding. The overtopping of Indiana St. by flows in Leyden Creek is a relatively frequent event, according to Arvada Public Works Department personnel. Its overtopping during the September 11th-13th flood event preceded the release from the Leyden Detention spillway and may have been exacerbated by debris clogging the culverts. By 11:00 or 11:30 p.m. on Wednesday night it had been reported that 3 inches of

Figure 26. Aerial View of Leyden Reservoir, Leyden Creek at Indiana Street and Croke Canal During Flood.

flow was passing over Indiana Street and ultimately the roadway was inundated by flows up to a foot deep (Figure 27). The east shoulder of Indiana St. was eroded, exposing an 18" water main encased in a 36" concrete pipe (Figure 28). Arvada was able to quickly mobilize a contractor to place a line of concrete jersey barriers to stabilize the water main and it did not break during the event. Repairs to the road after the September 11th – 13th event included upgrading the conveyance for Leyden Creek beneath Indiana St. to triple 36" CMPs. Additional improvements are planned by CDOT but awaiting the completion of the Northwest Bypass. Indiana Street was the last street to reopen after the September flooding, on Wednesday, October 16.

Figure 27. Overtopping of Indiana Street (Looking Northeast).

4.4.7. Flooding on Leyden Creek downstream of Indiana

Flow over the spillway at Leyden Dam caused significant flooding in areas east of Indiana St., extending to Alkire Street and scattered locations beyond during the evening of Thursday, September 12, 2013. Immediately east of Indiana St., Leyden Creek passes beneath the Croke Canal in a siphon. The capacity of that conveyance was exceeded Thursday night and backwater behind the siphon overtopped the Croke Canal's upstream and downstream embankments, with flow returning to Leyden Creek through corrals and pastures adjacent to the canal. Leyden Creek flows through an unplatted County area occupied by large rural lots of 20-40 acres in the reach between Indiana and Eldridge Streets.

Figure 28. Water Main Damage at Indiana Street (Looking South East).

The portion of the Cameo Estates neighborhood lying between Eldridge St. and Alkire St. was hard hit (Figure 29 - Figure 32), with widespread flooding in pastures, yards, and streets, as well as damage to several homes. At the time of the flood, this western portion of Cameo Estates had been annexed into the City and had received City water and sewer service. However, this neighborhood retained stormwater conveyance infrastructure typical of County development, with driveways served by small culverts placed in inconsistent drainage ditches along streets, rather than curb, gutter and storm sewers. In several places along this reach, residents of these 1 to 2-acres lots had created small ponds by building small structures in the Creek.

Alkire St. at Leyden Creek was overtopped and closed with barricades from W 78th Ave. to W. 74th Drive. Inundation at Leyden Creek reached nearly to 75th Place. Significant inundation of Youth Memorial Park/Sports Complex (extending almost to Van Arsdale Elementary School) provided some unintentional detention. (Alkire St. also had flooding issues at its crossing with the Church Ditch near W. 81st Ave. and at its crossing with Big Dry Creek 88th and 96th).

East of Alkire St. Leyden Creek flows through an enclave of unincorporated Jefferson County, with the eastern (not annexed) portion of Cameo Estates to the north and residential and commercial developments on larger parcels to the south. In some places this development has seriously encroached upon the creek and left it with little capacity. Some flooding on 75th Place and 75th Ave. was reported. Overbank flow in this reach may have provided unintentional detention and contributed to significant attenuation of peak flows reaching the bridge conveying Leyden Creek under West 72nd Ave. That bridge (on West 72nd Avenue between Ward Rd. and Simms St.) was monitored closely and West 72nd Avenue was closed for a period, but although the water began to impinge upon the road, it was never overtopped.

Figure 29 Cameo Estates Flooding.

Figure 30 Cameo Estates Flooding.

Figure 31 Cameo Estates Flooding.

Figure 32 Cameo Estates Flooding.

Although flows were high as Leyden Creek continued through urban Arvada, flood damages tapered off with distance downstream. The bridge over Leyden Creek at Simms St. is sized for the 100-year design flow there, and was not overtopped. The peak flow released from Leyden Dam was significantly attenuated by flooding along the Leyden Creek course, and neither the lower reaches of Leyden Creek nor Ralston Creek below their confluence suffered damaging flooding. Additional information about flood peaks in the lower reaches of Leyden Creek is provided in the next section.

4.4.8. Intentional Release from the Croke Canal

Although releases from Leyden Dam were receding by early Friday morning, the Croke Canal continued to be overtopped at scattered locations. At Eldridge and 78th (Figure 33), flows over the downstream embankment of the Croke Canal had seriously eroded the embankment by Friday morning. The width of the top of the embankment had been reduced to about 5 feet from about 30 feet, and complete breach of the canal appeared imminent unless mitigation efforts were employed immediately. A breach in this location would have caused dangerous and serious flooding to adjacent properties. City crews were dispatched to place material to reinforce the embankment. In addition it was decided to open the Croke Canal at a location not far upstream (just east of Indiana St., where the upstream edge of the canal was also being overtopped at its intersection with Leyden Creek, see Figure 33) to relieve pressure on the vulnerable embankment at Eldridge and 78th.

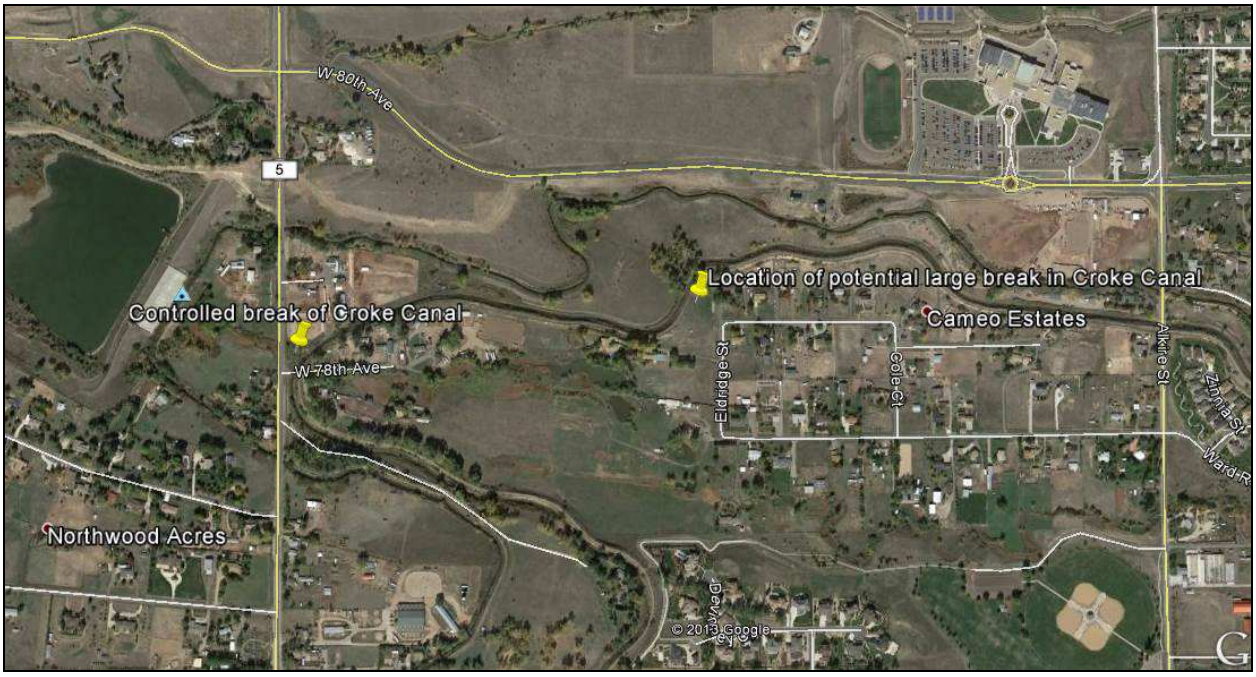

Figure 33. Location Map of Croke Canal Break Area.

At Eldridge and 78th, the embankment that contains the Croke Canal is built above the natural ground surface, and Arvada Public Works personnel feared that a breach there would release more of the flow in the Canal than a controlled opening at Indiana St. A survey conducted on November 1st confirms this assumption. Figure 34 shows a rodman holding a 16-foot survey rod at the native ground surface beneath the repaired embankment that was overtopping at Eldridge and 78th. The disturbed foreground area is due to the repair of the embankment. The invert of

the Croke Canal on the other side of the embankment was found to be 5.51 feet higher than the native ground where the rod is shown in Figure 34. An uncontrolled breach at this location would have emptied the entire contents of the Croke Canal, from both the upstream and downstream sides, into the Cameo Estates subdivision. In contrast, the invert of the Croke Canal at the site of the intentional opening near Indiana Street (Figure 35) lies 2.12 ft lower than the invert of Leyden Creek on the downstream side of the embankment there (Figure 36).

Figure 34. Location of Averted Breach of the Croke Canal Embankment.

Digging began shortly after 11:00 a.m. at the intentional release location and the release of water was reported at 11:18 a.m. The release lowered the water level in the Croke Canal by 4-5 inches in the first 22 minutes, by 15 inches in an hour and by 18 inches after 3 hours and 40 minutes, based upon reports to the City of Arvada Police (Appendix B). City of Arvada personnel were cognizant that the release could create a second flood peak in areas that had already been flooded the previous night. Downstream areas were monitored throughout the release and ultimately the flood peak created by the intentional release at Indiana St. caused a flood peak estimated at 0.5 feet below the peak from the previous evening. Flow from the controlled release was monitored during the release at Alkire St. and 75th Avenue.

Figure 35. Flooding Into The Croke Canal Below Indiana St. (Background) and the Location of the Controlled Release From The Croke Canal (Foreground).

Figure 36. Conveyance for Leyden Creek Beneath the Croke Canal (After Repairs)

At the mouth of Leyden Creek, gage ***213 Leyden Confluence*** registered two distinct peaks, as shown on Figure 20. A peak stage of 3.82 ft. was measured at 22:26 on Thursday night September 12th, 3 hours and 14 minutes after the peak release at Leyden Dam. A second much smaller peak, with a maximum measured stage of 3.0 ft, occurred at 3:04 on Friday afternoon, 3 hours and 45 minutes after the beginning of the controlled release through the opening of the Croke Canal (which was reported in the Arvada police logs to have begun sometime between 11:13 and 11:18 a.m.). These peaks do suggest a consistent but long travel time for (attenuated) peak flows between these two locations.

At the time of the flood event, the rating for gage ***213 Leyden Confluence*** estimated the first, larger peak flow at 2,903 cfs. This discharge is well in excess of the peak discharge estimated by the Leyden Dam gage. To field-truth this discharge value, a peak flow estimate was made using high water marks and channel geometry surveyed on November 1st, 2013. The surveyed high water marks were lower than the peak stage measured by the PT by 0.33 ft. However, the modest capacity of the low flow channel in the monitored reach, the mild channel slope and the significant growth of vegetation including cattails and willows (Figure 37) suggested that the rating was seriously overestimating flows for the gage. The reach is not capable of passing the very large discharge predicted by the rating without a substantially higher water surface elevation.

Figure 37. Leyden Creek at Its Mouth.

The peak discharge estimate was made using a simplified HEC-RAS model of reach hydraulics. The resulting peak discharge estimate is 160 to 300 cfs. It is strongly recommended that a new rating be developed for gage ***213 Leyden Confluence***. The flow data shown on Figure 20 were re-calculated using the output from the simplified HEC-RAS model used to estimate the peak flow, but should be considered provisional and updated after rating development using a full reach and cross-section survey.

5. Summary

During the September 11th-13th Arvada flood event, a rainfall pattern marked by record-breaking rainfall on the headwaters of Leyden Creek was coupled with the interception of flows from the Van Bibber and Ralston Creek watersheds by the Croke Canal (and to a lesser extent the Farmers' High Line Canal and the Church Ditch), which moved storm runoff across basin boundaries and into Leyden Creek. A smaller trans basin diversion occurred from Coal Creek, as flow from the Blue Mountain Estates area entered Leyden Creek through a gully eroded along the shoulder of Blue Mountain Road.

Damage to water supply infrastructure included a water main break at Quaker Street and Leyden Creek, damage to the Ralston Reservoir spillway and the Arvada/Blunn inflow channel, destroyed remote monitoring equipment at both reservoirs, and exposed water mains at scattered locations including at Indiana St. and Leyden Creek. Both of the City's two water treatment plants had to be closed for water testing and the City relied for a time on stored treated water supplies, but safe water was maintained throughout the flood. Both Ralston and Arvada/Blunn Reservoirs filled and made spillway releases that did not exceed 100-year design discharges.

More severe flood damage in Arvada occurred on Leyden Creek than on the Ralston Creek main stem. The Leyden Detention Facility filled on the evening of Thursday, September 12th and began releasing discharge over its service spillway. The estimated peak flow on Leyden Creek downstream of the dam exceeded the 100-year storm and caused serious creek flooding of homes, businesses and streets including Indiana Street and Alkire Street. Overtopping of the Croke Canal threatened to breach its embankment at Eldridge St. and W. 78th Place. To avoid a breach at that location, and opening in the Croke was made by Arvada Public Works personnel with the consent and cooperation of FRICO personnel at a more advantageous location, just downstream of Indiana St. The intentional release created a second flow peak on Leyden Creek around mid-day on Friday September 13th that did not exceed the flood peak released over the Leyden Dam spillway the night before.

6. Recommendations

Recommending design improvements for flood-prone areas of Arvada is beyond the scope of this effort. However, the following items are recommended to improve flood detection, data collection and response, based upon the events of September 11th -13th:

1. For precipitation gages in the Van Bibber, Ralston and Leyden Creek watersheds, the 6-hour alarm criterion should be lowered to better detect flood potential from longer duration events like this one.
2. Arvada/Blunn reservoir should be equipped with a real-time ALERT flood detection gage. Releases from Arvada/Blunn immediately impact urban Arvada, and access to data measured there directly would have relieved uncertainty and supported decision-making during this event. Current hydrometrics could not even allow Arvada to determine if the reservoir level was stable, rising or receding with any confidence. Data collected at Arvada/Blunn would also have been useful to characterize hydraulic response in the urban portion of the Ralston Creek downstream of the dam, had it been available for this analysis.
3. Given the peak discharge estimate at Ward Road, it is recommended that the rating at Simms St. be evaluated to determine if it is overestimating discharges for measured stages.
4. The current rating for Gage 213 Leyden Confluence seriously overestimates flows for stages measured by the gage. A full reach and cross-section survey should be undertaken to support the development of an updated hydraulic stage/discharge rating for the gage.

7. References

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Appendix A

Ralston Creek at Ward St. Peak Q Estimate

Ralston Creek at Ward St Bridge
September Flood Peak Q estimate
Field survey
11/1/2013 Kate Malers, Blair Hanna, Water and Earth Technologies, Inc.
Sunny, warm

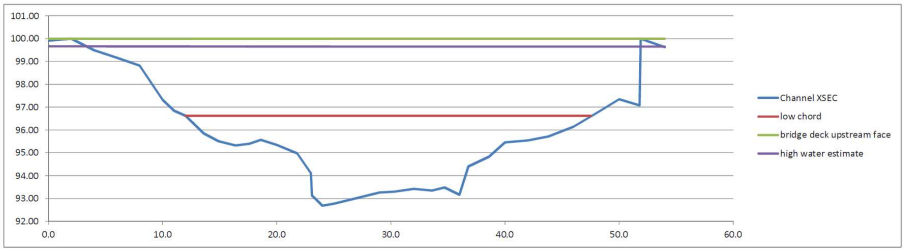
Peak Q	
650	cfs

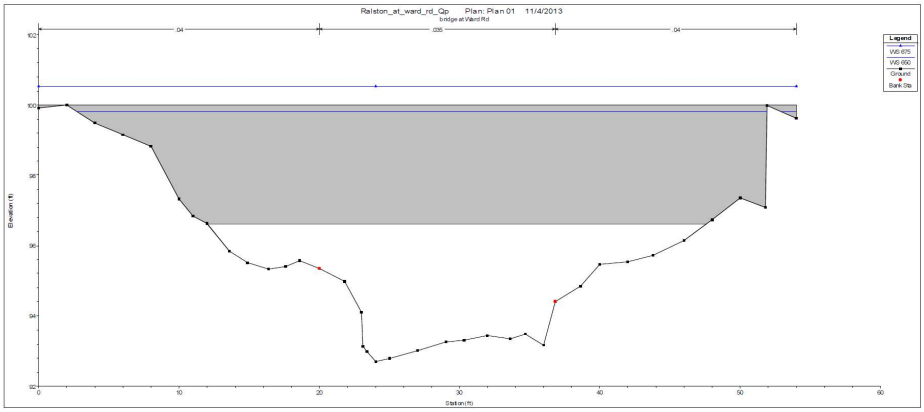
bridge did not overtop during September Flood
opening is partially blocked by debris
bridge is single span concrete bridge, not concrete box
78.3 length of bridge opening (from google earth, too much traffic to measure with tape)

9.32	94.98	upstream WS 2 (133 ft upstream)		channel slope	
10.2	94.10	WS at sta 27 (0 ft upstream)		0.006616541	
11.82	92.48	upstream invert2 (133 ft upstream)	adverse slope		
11.68	92.62	upstream invert1 (115 ft upstream)	adverse slope		
11.61	92.69	channel invert at upstream face of bridge			
11.57	92.73	d/s invert	adverse slope		
	104.30	HI1		low chord	
	99.99	top of deck at station 27		12	96.62
	96.62	low chord of bridge		47.5	96.62

XSEC upstream of bridge opening

HI1 Station	Rod	Elevation		bridge deck	
0.0	4.39	99.91	LPIN	0	100.00 arbitrary datum
2.0	4.30	100.00	on concrete, arbitrary datum of 100.00 ft	27	99.99
4.0	4.81	99.49		54	99.99
6.0	5.14	99.16			
8.0	5.48	98.82		high water estimated	
10.0	6.98	97.32		0	99.66667
11.0	7.46	96.84		27	99.65667
12.0	7.67	96.63		54	99.65667
13.6	8.45	95.85			
14.9	8.79	95.51			
16.4	8.97	95.33			
17.6	8.90	95.40			
18.6	8.73	95.57			
20.0	8.95	95.35	LTOB		
21.8	9.32	94.98	LEW		
23.0	10.19	94.11	LBOB		
23.1	11.17	93.13			
23.4	11.32	92.98			
24.0	11.61	92.69	INVERT		
25.0	11.52	92.78			
27.0	11.28	93.02	CL		
29.0	11.04	93.26			
30.3	11.00	93.30			
32.0	10.87	93.43			
33.6	10.95	93.35			
34.7	10.81	93.49			
36.0	11.13	93.17	RBOB		
36.8	9.89	94.41	RTOB		
38.6	9.46	94.84			
40.0	8.84	95.46			
42.0	8.76	95.54			
43.8	8.58	95.72			
46.0	8.15	96.15			
48.0	7.56	96.74			
50.0	6.95	97.35			
51.8	7.22	97.08			
51.9	4.31	99.99	Adjusted		
54.0	4.67	99.63	RPIN		





Appendix A

Blue Mountain Transfer Peak Q Estimate

Blue Mountain Transfer Peak Q estimate

CMP culvert under RR Tracks at Blue Mt Road
Survey date: 10/29/2013
Water and Earth Technologies, Inc.
Blair Hanna
Kate Malers

Sept 2013 Flood
Qp ESTIMATE culvert
280

Weather: cloudy and cold

Culvert and entrance clear of debris upon inspection. Post-flood reconstruction of gravel road above culvert entrance had already been completed prior to inspection.

93.7 length of culvert in ft

	ft	inches
diameter	5.9	70.8

very inefficiant entrance
High water mark based on physical observation of clear debris line

height above CMP crown (ft)	2.5
HW (ft)	8.4

HW/D
1.42

from inlet control nomograph, see blue line on nomograph
280 cfs through culvert

Appendix A

Blue Mountain Transfer Peak Q Estimate Nomograph

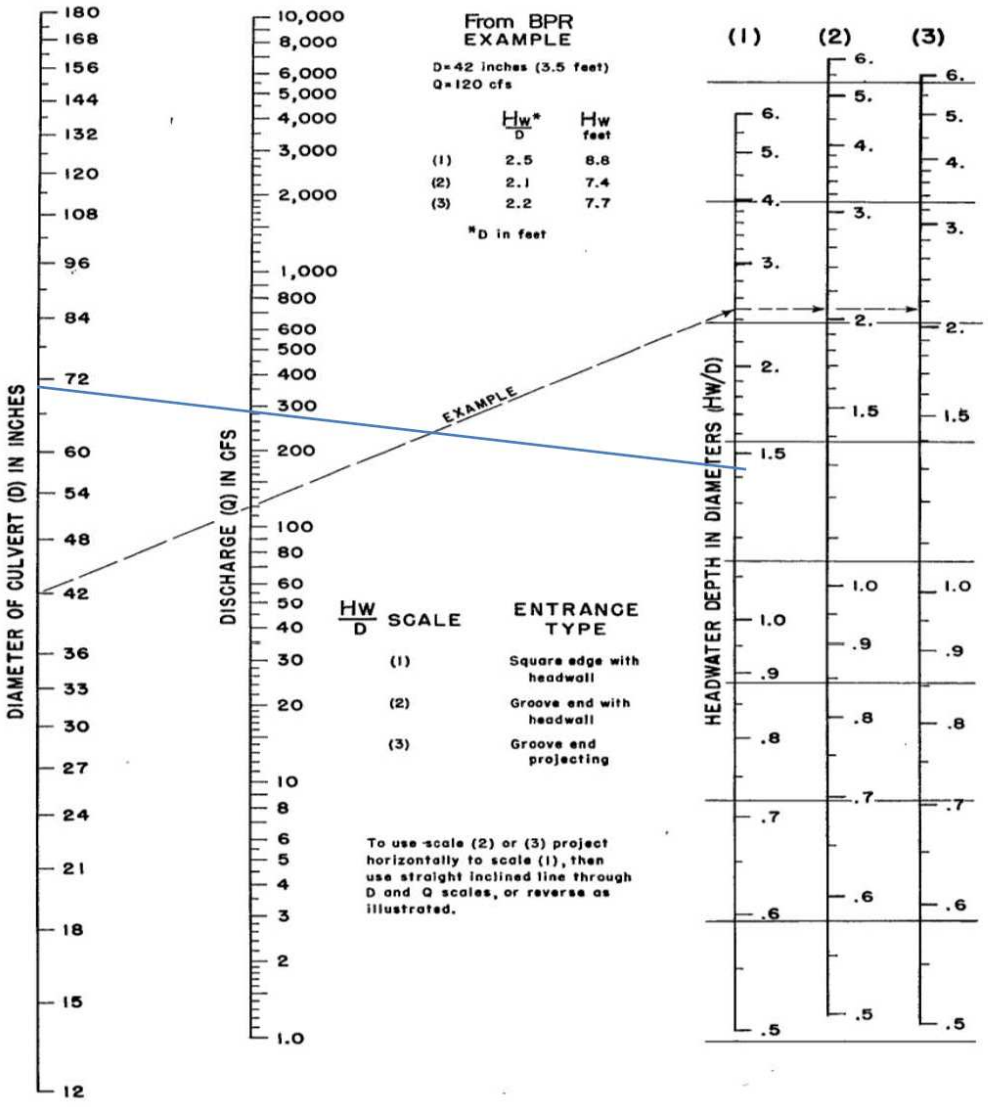


Figure CU-9—Inlet Control Nomograph—Example

Appendix A

Blue Mountain Transfer Peak Q Estimate

Above culvert looking upstream

Gravel road upstream of culvert

Appendix A

Blue Mountain Transfer Peak Q Estimate

Upstream entrance to culvert under RR tracks, just downstream of gravel road

Looking downstream through culvert

Appendix A

Blue Mountain Transfer Peak Q Estimate

Upstream entrance and high water debris line

Appendix A

Leyden Creek at Quaker St. Peak Q Estimate

Leyden Creek overflow of Quaker Street
Peak Q estimate
Survey date: 10/29/2013
Water and Earth Technologies, Inc.
Blair Hanna
Kate Malers
Weather: cloudy and cold

Qp ESTIMATE culvert plus weir
1694
2031
Range of discharge using range of weir coefficients

from UDFCD inlet control nomograph
410 cfs in culvert

Broad-Crested Weir
Roadway not horizontal, as assumed by equation
Q=CbH^(3/2)
b= weir length (ft) 140 width of flow
H =measured head (ft) 2.3
breadth (ft) 26.5 length of flow

C 2.63 3.32 - 2.63 for breadth 0.5 ft to 15 ft
3.32

Q over roadway (cfs)
1284 low end
1621 high end

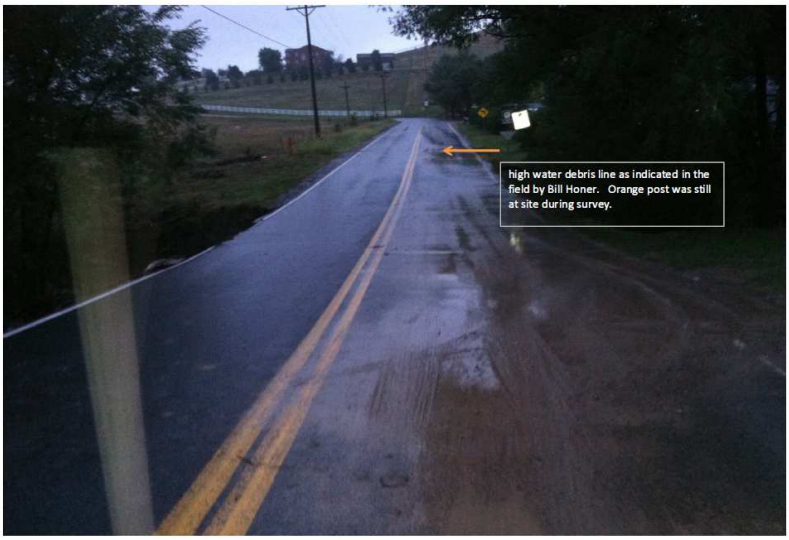
12.79 HW
2.13 HW/D
6-ft CMP 72 inches diameter
39.4 length of culvert in ft

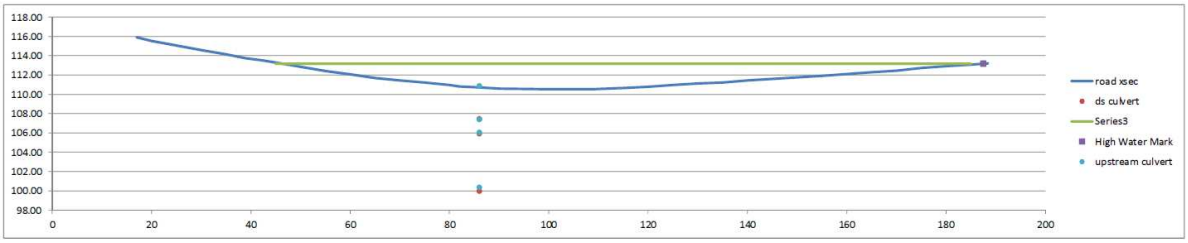
187.5	3.94	113.155	High water mark based on Bill Honer location during field visit (see photo)
86	9.61	107.485	downstream culvert
86	11.16	105.935	downstream top of pipe
86	17.095	100	downstream pipe invert
86	6.24	110.855	top of new pavement on upstream side of road
86	11.02	106.075	upstream top of pipe
86	9.67	107.425	upstream headwall top
86	16.73	100.365	upstream pipe invert

culvert slope 0.009263959

		High water mark	
100	downstream pipe invert arbitrary datum	45	113.155
117.095	HI	185	113.155

HI1 Station	Rod	Elevation	Comments
17	1.19	115.91	
20	1.57	115.53	
25	2.04	115.06	
30	2.51	114.59	
35	2.95	114.15	
39	3.36	113.74	end of old pavement
42	3.55	113.55	on new pavement
45	3.82	113.28	
50	4.24	112.86	
55	4.68	112.42	
60	5.03	112.07	
65	5.41	111.69	
70	5.68	111.42	
75	5.90	111.20	
80	6.15	110.95	
82	6.28	110.82	
86	6.4	110.70	
90	6.51	110.59	
95	6.55	110.55	
100	6.58	110.52	
109	6.59	110.51	
110	6.55	110.55	
115	6.46	110.64	
120	6.34	110.76	
125	6.15	110.95	
130	5.99	111.11	
135	5.87	111.23	
140	5.66	111.44	
145	5.5	111.60	
150	5.34	111.76	
155	5.19	111.91	
160	5.01	112.09	
165	4.8	112.30	
170	4.66	112.44	
175	4.36	112.74	
180	4.19	112.91	
185	4.02	113.08	
188.4	3.89	113.21	





Appendix A

Leyden Creek at Leyden Confluence Peak Q Estimate

Leyden Confluence Peak Q Survey Station 213

11/1/2013 Kate Malers, Blair Hanna, Water and Earth Technologies, Inc.

Sunny, warm

Peak Q	
PT stage	Discharge (cfs)
3.82	160-210
4.15	210-300

Benchmarks

	2.5625	102.56	top of riser w/o cap to stop bolt
		100.00	PT elevation arb BM
		111.86	HI1
		106.83	HI2
		103.82	in-field High Water mark
		104.15	peak PT reading (before base value applied)

stage based on high water mark surv
stage based on peak PT reading
INCLUDING REFERENCE LEVEL

channel slope 0.000606

0.035 n in channel
0.06 n L overbank
0.05 n R overbank

0.001

0.035 n in channel
0.045 n overbank

PT Cross Section XS 2.0 99.90 channel invert in PT XSEC d/s translated cross section XS 1.0

	Station	Rod	Elevation	Comments	Station	Elevation
HI1		5.07	106.79	base of standpipe, no enclosure door		
HI1		9.3	102.56	top of riser without cap		
HI2		4.27	102.56	top of riser without cap		
HI2		6.93	99.90	d/s channel invert, downstream 99 ft		
HI1	151.0	4.37	107.49	Rpin at apt grass edging	151.0	107.43
HI1	148.0	4.43	107.43		148.0	107.37
HI1	145.0	4.71	107.15		145.0	107.09
HI1	142.0	4.87	106.99		142.0	106.93
HI1	139.0	4.98	106.88		139.0	106.82
HI1	136.0	4.97	106.89		136.0	106.83
HI1	133.0	5.26	106.60		133.0	106.54
HI1	129.0	5.97	105.89		129.0	105.83
HI1	126.0	6.75	105.11		126.0	105.05
HI1	123.0	7.46	104.40		123.0	104.34
HI1	122.0	7.75	104.11		122.0	104.05
HI1	119.5	7.78	104.08		119.5	104.02
HI1	116.5	7.45	104.41		116.5	104.35
HI1	113.3	7	104.86	R edge bikepath on grnd	113.3	104.80
HI1	113.2	6.83	105.03	R edge bikepath on path	113.2	104.97
HI1	102.0	6.93	104.93	L edge bikepath on path	102.0	104.87
HI1	101.9	7.13	104.73	L edge bikepath on grnd	101.9	104.67
HI1	98.0	8.48	103.38		98.0	103.32
HI1	95.0	9.04	102.82		95.0	102.76
HI1	92.0	9.43	102.43		92.0	102.37
HI1	90.7	9.63	102.23		90.7	102.17
HI1	89.0	9.54	102.32		89.0	102.26
HI1	86.0	9.66	102.20		86.0	102.14
HI1	83.0	9.73	102.13		83.0	102.07
HI1	81.0	9.58	102.28		81.0	102.22
HI1	78.0	9.66	102.20		78.0	102.14
HI1	76.2	9.37	102.49		76.2	102.43
HI1	73.0	9.39	102.47		73.0	102.41
HI1	70.0	9.7	102.16		70.0	102.10
HI1	68.8	9.88	101.98	RTOB	68.8	101.92
HI1	68.6	11.13	100.73	RBOB	68.6	100.67
HI1	67.9	11.46	100.40		67.9	100.34
HI1	67.0	11.65	100.21		67.0	100.15
HI1	65.7	11.88	99.98		65.7	99.92
HI1	64.4	11.8	100.06		64.4	100.00
HI1	63.2	11.9	99.96	CL	63.2	99.90
HI1	62.5	11.81	100.05		62.5	99.99
HI1	61.5	11.71	100.15		61.5	100.09
HI1	60.9	11.54	100.32	LBOB	60.9	100.26
HI1	60.5	10.9	100.96	LEW	60.5	100.90
HI1	60.4	10.2	101.66	LTOB	60.4	101.60
HI1	59.1	9.98	101.88		59.1	101.82
HI1	58.3	9.86	102.00		58.3	101.94
HI1	56.8	9.65	102.21		56.8	102.15
HI1	54.4	9.5	102.36		54.4	102.30
HI1	52.0	9.58	102.28		52.0	102.22
HI1	50.0	9.6	102.26		50.0	102.20
HI1	48.0	9.54	102.32		48.0	102.26
HI1	46.0	9.48	102.38		46.0	102.32
HI1	44.0	9.52	102.34		44.0	102.28
HI1	42.0	9.37	102.49		42.0	102.43
HI1	41.5	9.47	102.39		41.5	102.33
HI1	39.0	9.45	102.41		39.0	102.35
HI2	36.6	4.29	102.54		36.6	102.48
HI2	33.5	4.11	102.72		33.5	102.66
HI2	29.9	3.97	102.86		29.9	102.80
HI2	26.0	4.18	102.65		26.0	102.59
HI2	25.5	4	102.83		25.5	102.77
HI2	22.2	4.02	102.81		22.2	102.75
HI2	19.0	3.81	103.02		19.0	102.96
HI2	16.0	3.58	103.25		16.0	103.19
HI2	13.0	3.35	103.48		13.0	103.42
HI2	10.0	2.97	103.86		10.0	103.80
HI2	11.1	3.01	103.82	High water mark	11.1	103.76
HI2	7.0	2.44	104.39		7.0	104.33
HI2	4.0	1.94	104.89		4.0	104.83
HI2	2.0	1.53	105.30		2.0	105.24
HI2	0.0	0.98	105.85	LPIN	0.0	105.79
HI2	-4.9	0.39	106.44	near but not at fence	-4.9	106.38

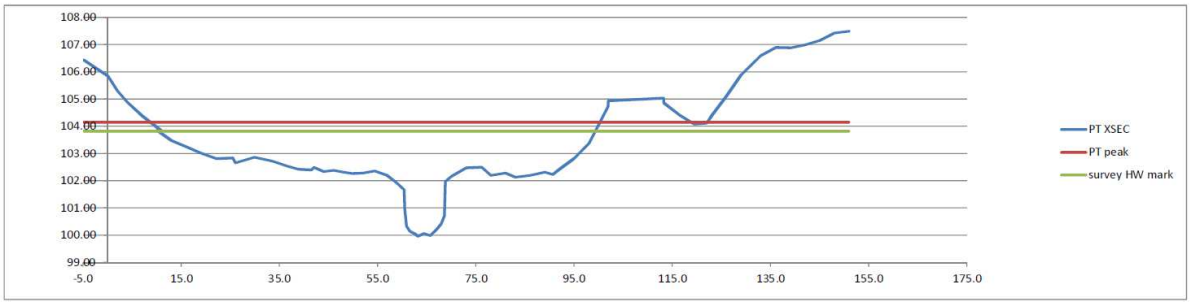
Appendix A

Leyden Creek at Leyden Confluence Peak Q Estimate

Leyden Confluence Peak Q HEC-RAS model Results

overbank n=0.06, 0.05 at PT, overbank n=0.045 downstream

Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	
10	99.96	101.35		101.36	0.000606	1.04	9.59		8.25	0.17
25	99.96	102.24		102.27	0.000611	1.44	18.73		21.85	0.18
50	99.96	102.82		102.85	0.000665	1.78	48.18		67.95	0.19
100	99.96	103.38		103.42	0.000729	2.12	91.97		83.57	0.21
110	99.96	103.46		103.5	0.000737	2.17	99.21		84.96	0.21
120	99.96	103.54		103.59	0.000744	2.21	106.1		85.8	0.21
130	99.96	103.62		103.66	0.00075	2.26	112.68		86.44	0.22
140	99.96	103.69		103.74	0.000755	2.3	119.06		87.07	0.22
150	99.96	103.76		103.81	0.00076	2.34	125.25		87.67	0.22
155	99.96	103.8		103.84	0.000763	2.36	128.25		87.96	0.22
160	99.96	103.83		103.88	0.000766	2.38	131.27		88.45	0.22
165	99.96	103.87		103.92	0.000767	2.39	134.6		89.44	0.22
170	99.96	103.9		103.95	0.000769	2.41	137.51		89.72	0.22
175	99.96	103.93		103.98	0.000771	2.43	140.42		90	0.22
180	99.96	103.97		104.01	0.000773	2.44	143.29		90.27	0.22
185	99.96	104		104.05	0.000774	2.46	146.14		90.54	0.22
190	99.96	104.03		104.08	0.000776	2.48	148.94		90.8	0.22
195	99.96	104.06		104.11	0.000778	2.49	151.73		91.07	0.22
200	99.96	104.09		104.14	0.000779	2.51	154.49		91.93	0.22
205	99.96	104.12		104.17	0.000782	2.53	157.21		94.42	0.23
210	99.96	104.15		104.2	0.000783	2.54	160.04		95.05	0.23
215	99.96	104.18		104.23	0.000785	2.56	162.79		95.65	0.23
220	99.96	104.21		104.26	0.000786	2.57	165.53		96.26	0.23
225	99.96	104.23		104.28	0.000788	2.58	168.26		96.85	0.23
230	99.96	104.26		104.31	0.000789	2.6	170.98		97.44	0.23
235	99.96	104.29		104.34	0.00079	2.61	173.68		98.03	0.23
240	99.96	104.32		104.37	0.000791	2.63	176.37		98.6	0.23
245	99.96	104.34		104.4	0.000793	2.64	179.05		99.17	0.23
250	99.96	104.37		104.42	0.000794	2.65	181.71		99.74	0.23
300	99.96	104.63		104.68	0.000802	2.78	207.81		104.95	0.23



Appendix B Arvada Police Activity Log for the Arvada Flooding Incident

ACTIVITY LOG (ICS 214)

1. Incident Name: Arvada Flooding	2. Operational Period: Date From: 9/12/2013 Time From: 0100	Date To: Date Time To: HHMM
3. Name: Cmdr. Kathy foos	4. ICS Position: Incident Commander	5. Home Agency (and Unit): Arvada Police

6. Resources Assigned:

Name	ICS Position	Home Agency (and Unit)
Cmdr. Kathy Foos	Incident Commander	Arvada Police
Sgt. Petersen	Operation Chief	Arvada Police
Commander Moriarty	IC	Arvada Police
Sgt. Thome	Street Supervisor	Arvada Police
Jim Lancy		Arvada Police
DC Creager		Arvada Police

7. Activity Log:

Date/Time	Notable Activities
9/11/13 2340	Foos called by Sgt. Petersen and briefed on 3 separate incidents caused by flooding. Situation 1 was road closure at HW 72 & 93 for flooding. Portions of 72 in Jeffco have washed away the road, there was a train derailment at Pinecliff and a retention wall washed out on Westridge road. Situation 2 was the closure of Leyden Road between Quaker and Indiana from flooding and mud from construction site. Sitatution 3 was the closure of 64 Ave between Lamar and Otis from washed away of a temporary roadway covering utitlity work.
9/12/13 0100	Initiated a command post in “Charlie” office at police HQ. Briefed by dispatch – they left a message with PIO McGranahan to work with Jeffco’s PIO on road closures.
9/12/13 0105	Contacted DC Creager to advise of the situation.
9/12/13 0005	Received flash flood warning message mostly for northwestern Arvada per urban flood/drainage until 0415
9/12/13 0115	All Arvada Units cleared from traffic control
9/12/13 0120	Started a list with dispatch of drainage concerns needed addressed in the morning: 1. Miller at Ralston Creek by Begdohl Building (clogged by debris) 2. NE trailhead at Patridge Park, millings washed out
9/12/13 0208	Officer dispatched to 87 & Indiana for flooding. There is a low section with standing water but it is in unincooperated Jeffco.
9/12/13 0226	I sent out a HIG message updating city personnel. Cliff Deeds advised there was a watermain break at Leyden Rd & Quaker. The break was isolated and no one is without water. His crew is going home and will be back at 0600.
9/12/13 0236	Cliff Deeds: We found that the flooding had washed out this 12 inch water main under the Creek. Our storage tanks dropped from about 16 feet to under 5 feet in less than an hour. We isolated the main and everybody is back in water but our customers will experience some minor water quality issues, just air in the lines. I made the decision not to flush the subdivision because the tanks are so low I did not want to take a chance if there were further problems of people being completely out of water.
9/12/13 0508	74 & Carr Roadway partially washed out. Car stuck in the mud. Officer Brown asking for streets to respond to deal with the hazard. Connelly’s request to tow car.
9/12/13 0531	Leyden Road closed from Indiana to HW 93 per Officer Giddon.

1. Incident Name: Arvada Flooding	**2. Operational Period:**	Date From: 9/12/2013 Date To: Date Time From: 0100 Time To: HHMM
9/12/13 0608	Command post handed over to DC Creager. Sgt. DeAndrea unable to respond for work due to road closures near his home.	
9/12/13 0700	Command Post handed over to Commander Hutchcraft. Sergeant Thome in at 0800 to assume street supervision	
09/12/13 0730 – 0930	Cmdr Hutchcraft and DC Creager drove affected street closures at 64th and Quay, 74th and Carr Dr., 64th and Indiana, Leyden Rd., etc. Streets passable with some flooding.	
09/12/13 1400	Update briefing held with Pat Doughert (City Engineering), Mike Piper (AFPD), DC Creager, DC Johnson and Cmdr. Hutchcraft decision made to leave AAC closed.	
09/12/13 1435	Assisted with the evacuation of the town of Leyden per the request of Jefferson County EOC.	
09/12/13 1700	Cmdr. Hutchcraft and DC Creager met Cliff Deeds (Water Operations) at area of 80th Ave and Indiana to discuss the potential of the Leyden Dam failing. Recommended a warning be issued to county residents in the area.	
09/12/13 1710	Contacted Jefferson County EOC with the recommendation of an issued warning to Leyden Dam neighborhood.	
09/12/13 1750	Notified by Cliff Deeds that the Leyden Lake level was receeding.	
09/12/13 1820	Notified Jefferson County EOC of Leyden Lake situation.	
09/12/13 1850 09/12/13 1915 09/12/13 1945 09/12/13 1950	Re-contacted by Cliff Deeds who advised Leyden Dam had risen to the point of overflowing, recommended the Jefferson County neighborhood to the east be evacuated. Immediately notified Jefferson County EOC of this information; advised they would send a Code Red to the neighborhood. Cmdr Hutchcraft and DC Creager responded to 81st and Alkire St reference a CFS regarding flooding. Authorized a reverse 911 to Alkire Estates to expect flooding from the Church Canal. Authorized a reverse 911 to the Double E Ranch neighborhood to expect flooding from the Farmers Highline Canal. Notified Cmdr. Foos to respond to the Police Department to open the AAC. Cmdr. Foos responded and opened the AAC at 2043 hours.	
2152 2220	Sheridan from Ralston Rd to I-76 closed Water rescue 78 & Alkire – flooding around Van Arsdale Elem. Flooding at Cameo Estates. 74 – 78 Alkire closed by barricades	

1. Incident Name: Arvada Flooding	2. Operational Period:	Date From: 9/12/2013 Time From: 0100	Date To: Date Time To: HHMM

2043	Ralston Creek @ 70 & Ward Denny Kendrick Park Good
2244	80th between Kipling & Hoyt flooding
2247	10935 W 68 Ave creek flooding
	Code Red sent out from Ward to Independence 80 to 64th
2258	Confusion w/Red Cross & Arvada High School – it is confirmed at Arvada High Main Entrance
2258	All 3 Sgts asked to respond to AAC
2334	Barricades taken to 72 Simms & Ward Rd
2336	People evacuated from 7280 Urban Drive & 7300 Urban Ct
2344	Flooding at 59 & Brooks from debri – Streets sent to unplug
2348	Jason calling out Sargent McDonald GIS to assist with mapping; he will be here in 10 minutes
2357	Brooks & Dover Construction Equipment flooded
09/13/ 0010	Flash Food Warning for western Arvada
0016	R1 Schools closing Ralston Valley HS, Van Arsdale and Oberon Sept. 13.
	Union Pacific RR has shut down all service to West Arvada due to flooding
0018	2 Ponds Boarding 9530 W 80 flooding in driveway. Owner contacting via dispatch
0021	Blunn Res maybe breeched which could cause Ralston Creek to flood; officers monitoring
0021	75 Simms Highland Canal slowing down (Per Petersen)
0029	5887 Pierce St – Ralston Creek is overflowing and is almost to the apartments – requested officer response.
0035	Confirmed Blunn Res spilling
	60 & Vance Ralston Creek close to home
	76 & Sheridan needs debris cleared – Arvada dispatch notifying Westy
0039	69 & Beech Code 4 (Per Sgt. Strasheim)
	70 & Ward Rd Code 4
0110	4th Code Red for flooding warning – from Virgil to Sheridan to 58 to 72 Ave. Sent out 23,000 messages.
0045	Officer re-checking Waste Water building – ped walkway flooding. No flooding on street or into building.
0111	Ralston Creek at 69 Ave and Virgil Way running fast but not flooding.
	Ralston Creek at 72 & Urban code 4
0125	Ralston Creek from Indiana to Simms code 4
	Flood warning remains in effect until 0730 . Dams and retention ponds have been weakened and filled by the saturating rainfall. Arvada will experience flooding.
0137	Sheridan from Ralston to I76 re-opened.
0140	Officer taking 3 citizens from HQ to Arvada High Red Cross (1 person spent the night)
0152	72 Ave opened between Ward and Simms
0214	Yankie Doodle Park/Springwood Retirement area check. Everything fine per officers. RP was contacted.
0219	Teletype from Westy concerned with road erosion at 96 and Indiana. City Street Dpt was sent there.
0239	Officers doing an area check of Campbell Elem, Fitzmorris, Little and Xcel Acdmy. Campbell showed some water at North corner by gazebo but school appeared Code 4. Little has 2 inches of water in the north parking area. All other schools were Code 4.
0310	80 and Hoyt still flooded.
0312	Parr Elem has some standing water on North side but Code 4 for school.
0340	Water recessing at 72 & Urban
0406	Water recessing at Leyden Creek at Quaker; water is under the road, what is left of it. Leyden Creek at Indiana has also recessed but CDOT is concerned the road is seriously damaged. CDOT will assess during the day but Indiana could be closed for a few days.
0428	
09/13/13 0445	Cmdr. Moriarty taking over AAC.

1. Incident Name: Arvada Flooding	2. Operational Period:	Date From: 9/12/2013 Time From: 0100	Date To: Date Time To: HHMM

09/13/13 0525	Checked the road at Alkire between 74-78 Sergeant Petersen advised the road should remain closed.
09/13/13 0556	Jason advised water seems to be flowing well in the creeks.
	Both water plants are shut down/City is on stored water now
09/13/13 0626	13650 W 69 Pl. Call of a Large tree down in the creek
09/13/13 0640	Aravda HS is no longer a Shelter….Red Cross phone number 303-722-7474
09/13/13 0710	Contacting Jeffco EOC to check on Alkire between 88-96 to allow traffic to open again to let the neiborhoods out.
09/13/13 0725	Trying to open the Ralston Plant. State has to come in and test the water quality.
09/13/13 0746	Road Closures checked and Sergeant Thome advised they all need to remained closed.
09/13/13 0747	Wendy sending message out to Arvada Citizens to conserve water. Checked Ralston Dam checked okay
09/13/13 0800	70/Ward Rd. checked for flooding. Officer advised the water flowing under the bridge at this time no problems.
09/13/13 0819	Rain started heavy out west.
	Checked 80th between Hoyt and Kipling starting to flood (Farmers). Cars are still able to get through. Will continue to watch the area.
09/13/13 0850	Both Dam have been assessed and are working correctly
09/13/13 0900	Advised of Croke Canal. Sgt Thome is out with Cliff Deeds
09/13/13 0919	Checking the creek near Ralston Treament Plant. Advised it is flowing heavy near the bike path. Is not in the roadway.
09/13/13 0932	PD Dispatch calls about flooding in homes will be sent to fire dispatch to triage calls. Ralston Plant
09/13/13 0935	open. Water checked by state and is safe.
	City crews are moving dirt into the area of Cameo Estates.
09/13/13 1000	Code Red going out about Croke Canal release of water (Bill Ray). Officers have been move into postions and Alkire has been shut down. Officers have been placed at 70/Swadley and 72/Simms.
	Jeffco EOC advised
09/13/13 1025	Declared a State of Emergency
09/13/13 1035	Water release taking place. Working on the wall. Sergeant Thome on scene with crews. Need to get more equipment.
09/13/13 1113	Digging now.
09/13/13 1118	Breach started. Water flowing out without problems. Officers around the area advising Code 4 so far. Minimal call to APD dispatch center after breach.
09/13/13 1135	Breach has helped the water levels go down 4-5 in. @ Croke Canal (also helped other ares).
	Fire Rescue with Kid in water (6949 Torrey)
09/13/13 1154	Clearing all units east of Alkire.
09/13/13 1200	Officer comfirmed street closures need to stay in place.
09/13/13 1215	Arvada Reservoir water needs to be release. We are setting up officers, fire and Waste Water to Ralston Creek areas: Westwoods/Quaker-Fire 69/Indiana-Traffic Unit 68/Beech-Traffic Unit 70/Ward-Waste Water 66/Oak-Fire PD near park-Hutchcraft 58/Pierce-Waste Water Waste Water-Waste Water
09/13/13	Rescue is complete kid and fire crews out of water.

ACTIVITY LOG (ICS 214)

1. Incident Name: Arvada Flooding	2. Operational Period:	Date From: 9/12/2013 Date To: 9/13/2013 Time From: HHMM Time To: HHMM

7. Activity Log (continuation):

Date/Time	Notable Activities
09/13/13 1306	Moving a Patrol unit to 68/Oak two block west checking street flooding.
09/13/13 1316	Croke Creek update: Water is down 15in.
09/13/13 1328	Units were pulled from watching Ralston Creek. Advised to have officers check on the creek over the next few hours.
09/13/13 1342	PD checked on city road closures and advised we should have roads stay closed for now.
09/13/13 1400	Contacted Jeffco EOC about Alkire between 88-96 about citizen moving the barricades. Updated on West Water Plant: Right now we have one tank with good water and one with unkown quality water. We have enough for 2-3 hour. Waiting on a water quality check. We have asked street's department to put bigger barricades on Alkire between 7400-7800
09/13/13 1451	Water update: Public Water is safe and the West Water Plant open and producting water. Public Works is continuing to work on Croke in Cameo Estates and will work until dusk. Croke's water level is down 18 in now.
09/13/13 1550	Hwy 93 and Hwy 72 are now open.
09/13/13 1620	Cmdr. Moriarty relieved by Cmdr. Hutchcraft
09/13/13 1631	W. 72nd Ave backed up to Beech from Simms. WB moving with some flooding in EB lanes, per patrol.
09/13/13 1750	Advised by patrol the work on the Croke Canal is continuing. Requested larger barricades for 7400 and 7800 Alkire St.
09/13/13 1658	Advised that it is starting to rain at City Hall, heavy; light rain at 74th and Alkire.
09/13/13 1700	Personnel to remain at the traffic direction points on Alkire. No need for the larger barricades.
09/13/13 1730	Report from Denver water authority CFS is at the same rate from Ralston reservoir into Arvada reservoir as 1530 hours assessment. Will assess again at 1900 hours.
09/13/13 1732	Ralston Creek within it's banks at Memorial Park and 58th Ave. and Pierce St. Report of children playing in the creek at Brooks Dr. and Hoyt St.
09/13/13 1755	Citizen complaint on placement of barricades at 77th and Indiana. No barricades located at 72nd and Indiana. Request to CDOT to place a Local Traffic Only sign at 72nd.
09/13/13 1810	City Streets Dept. employees EOW with the exception of those (8) working on Croke Canal in Cameo Estates.
09/13/13 1830	One officer remaining at 7400 Alkire St. Will monitor for approx. 30 mins. and clear leaving barricades for traffic control.
09/13/13 1843	Residential water flow in Sunrise Ridge, 17100 blk of 61st Pl is very minimal. Public Works dispatching a crew to check for a water main break.
09/13/13 1845	CDOT on scene on Indiana St. monitoring/directing traffic at that location.
09/13/13 1905	Denver Water advises the CFS rate is less than it was at 1730 hours between Ralston and Arvada Reservoir.
09/13/13 1910	Arvada AAC shut down.

Appendix C UDFCD Public Outreach Materials Explaining Precipitation and Flood Frequencies

http://www.udfcd.org/2013flood/faq.html

Frequently Asked Questions

2013 Storm FAQs

How much rain fell?
This was an unprecedented 7-day rainfall event that began on September 9th and ended on the 15th. Rain totals exceeded 10 inches at many locations–in Boulder County, Northern Jefferson County, Eastern Denver and Western Aurora. Portions of Larimer and Weld Counties also experienced double-digit rainfall totals. Some locations measured nearly 18 inches– significantly more precipitation than this region normally experiences over an entire year (including snowfall). This is a lot of rainfall in any part of the country, but far less likely for the semi-arid west where we live. For more information about this storm, read the recent report prepared by the Western Water Assessment team (http://wwa.colorado.edu/resources/front-range-floods/).

How do you know if it was a 100-year flood?
The labels we give floods are dependant on the chance of that flood happening. For example, a 100-year flood has a 1-percent chance of happening every year, a 50-year flood has a 2-percent chance, a 500-year flood has a 0.2-percent chance, and so on. This is quite different from the common belief that a 100-year event will ***only*** happen every 100 years. If it happened this year, it could just as easily happen next year. For more information on flood frequency see http://cwcb.state.co.us/technical-resources/floodplain-stormwater-criteria-manual/Documents/Chapter%209/Chapter%209%20Section%202.pdf.

Why was flooding worse in some areas?
Even though the storm was experienced along the entire Front Range, there were areas where the rain fell harder and longer than in others. This can be seen on UDFCD's maps of the 7-county Denver-Boulder area that show where the largest amounts of rain fell. If the drainage systems were not able to contain the large streamflow, floodwaters spread to adjacent areas and resulted in a lot of damage.

Does a 100-year rainfall result in a 100-year flood?
No. Flooding is caused by the ***portion*** of rainfall that actually runs off the land into the stream. Several factors influence how much of the rainfall will end up as streamflow. Flooding happens when too much rain falls too quickly, causing drainage systems to overflow. One preliminary article on why a 100-year rainfall may not result in a corresponding 100-year flood event can be found at: http://wwa.colorado.edu/resources/front-range-floods/.

What does "a dam has been breached" mean?
When a dam breach occurs, the dam has failed. The impact of a failure can often be catastrophic, usually resulting in a very large amount of water suddenly released into the area downstream. The term "breach" is often misused and/or confused when water is safely being released from a dam, and it is working properly. Most dams are designed to have a path for excess water to follow (a spillway) to protect the dam and avoid the danger of an actual failure. A spillway that is operating safely is not a "breach, it is spilling."

My home/business is not in the 100-year floodplain, but got damaged. Why wasn't I required to buy flood insurance?
The mandate to buy flood insurance in a 100-year floodplain is for property subject to a federally-backed government loan. Flood damage can and does happen outside the 100-year floodplain for a number of reasons. Events larger than the 100-year flood can and do occur Many owners outside the 100-year floodplain voluntarily choose to purchase flood insurance available at lower rates (see Flood Map/Insurance FAQs below for more information).

I received some flood damage, but don't have flood insurance. Are there any other resources to assist me?
The best resources for information on recovery and rebuilding are your local Disaster Assistance Center/Disaster Recovery Centers.

Links to information for specific counties are:

Counties in UDFCD	Other Counties
Adams	Clear Creek
Arapahoe	El Paso
Boulder	Fremont
Broomfield	Larimer
Denver	Logan
Douglas	Morgan
Jefferson	Pueblo
	Washington
	Weld

Flood Map/Insurance FAQs

Great information on all aspects of preparedness, resources and more FAQs can be found at http://www.ready.gov/floods and http://www.floodsmart.gov/floodsmart/pages/faqs/faqs_considering.jsp

My home/business is located in the 100-year floodplain, but did not receive damage. Why am I still required to purchase flood insurance?

The mandate to buy flood insurance in a 100-year floodplain is for property subject to a federally-backed government loan. Being in a 100-year floodplain does not mean you will sustain flood damage every time it rains, but had conditions for this storm been different, it is possible that your property would have been subjected to the floodwaters, and corresponding damages seen in other communities along the Front Range.

Where can I find information on flood insurance?

Please visit http://www.floodsmart.gov/floodsmart/

Where can I find information on floodplain maps and elevation certificates?

Please visit http://www.fema.gov/frequently-asked-questions-0/homeowners-frequently-asked-questions

Appendix D Potential Canal/Ditch Overtopping Locations

Locations where issues during the September 11th -13th flood event suggest that ditch/canal infrastructure may have low capacity, organized by ditch or canal:

CHURCH DITCH

- 81st and Alkire East of the High School; Alkire Estates Area

FARMERS' HIGH LINE CANAL

- Double E Ranch Neighborhood East of Alkire
- 80th Ave. from Kipling to Hoyt was overtopped intermittently (Thursday night 22:44 in the police logs, and Friday morning 00:18, 03:12 and 08:19 in the police logs). The Croke Canal also crosses W 80th Ave. here and the reporting parties may have used the more familiar name.

JUCHEM DITCH

- 64th Avenue was closed between Lamar and Otis, where a temporary roadway at a utility construction location was washed away. The Juchem ditch as the only watercourse in this area; crossing W. 64th Avenue between Lamar Pl. and Marshall St. It is not known if the damage resulted from localized drainage issues at the construction site or if the problem was related ditch infrastructure.
- 64th and Quay