Flood Hazard News

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Piney Creek Stream Stabilization, Bridge and Storm Sewer Project

Colorado Association of Stormwater and Floodplain Managers Grand Award Winner for 2011

By
Richard Borchardt, Senior Project Engineer

Introduction

The Piney Creek Stream Stabilization, Bridge Crossing, and Storm Sewer Outfall project is located in the City of Centennial north of Arapahoe Road and west of Liverpool Street near the intersection of Caley Drive and Euclid Drive in the Piney Creek Ranches subdivision. The project improves the safety, reduces the loss of property, stabilizes the channel, and enhances water quality. The project won the Colorado Association of Stormwater and Floodplain Managers (CASFM) Grand Award for 2011.

Piney Creek is a sand bed channel that is confined by residential development along the majority of its banks. The continuous development and loss of pervious area in the watershed keeps changing the nature of the stream. Piney Creek went from an ephemeral to a perennial stream. The result of these changes has caused an imbalance in sediment load, incising of the channel, and severe bank erosion. The residents were experiencing property loss, and adjacent structures were being threatened. An even more apparent problem in this area was the street crossing of Piney Creek to get into the residential area. This street-channel crossing was at-grade and became dangerous to cross even in more frequent rainfall and runoff events. When the creek rose from storms or iced over during the winter months it caused unsafe travel conditions.

In addition, a retention pond was located on the south side of Arapahoe Road that collected storm runoff from the Estancia development. There was a concern that the pond would overtop or breach and flow across Arapahoe Road in the next storm, since there was no drain or outfall.

Piney Creek and Caley Drive - Before

The Southeast Metro Stormwater Authority (SEMSWA), Arapahoe County (County), the City of Centennial (City), and the Urban Drainage and Flood Control District (UDFCD) teamed up and pooled resources to address these challenges through the Piney Creek Stream Stabilization, Bridge Crossing, and Storm Sewer Outfall project.

Description of the Project

The project started with the ideas and concepts developed in the Stream Stabilization and Crossing Study completed in October 1989. The project stakeholders, design team, and residents all worked together to make this a successful project. The goals of the project were to stabilize the channel, improve the water quality, improve the Caley Drive crossing of Piney Creek, and provide a storm sewer system and outfall to the Estancia Subdivision pond and local drainage basin to the south.

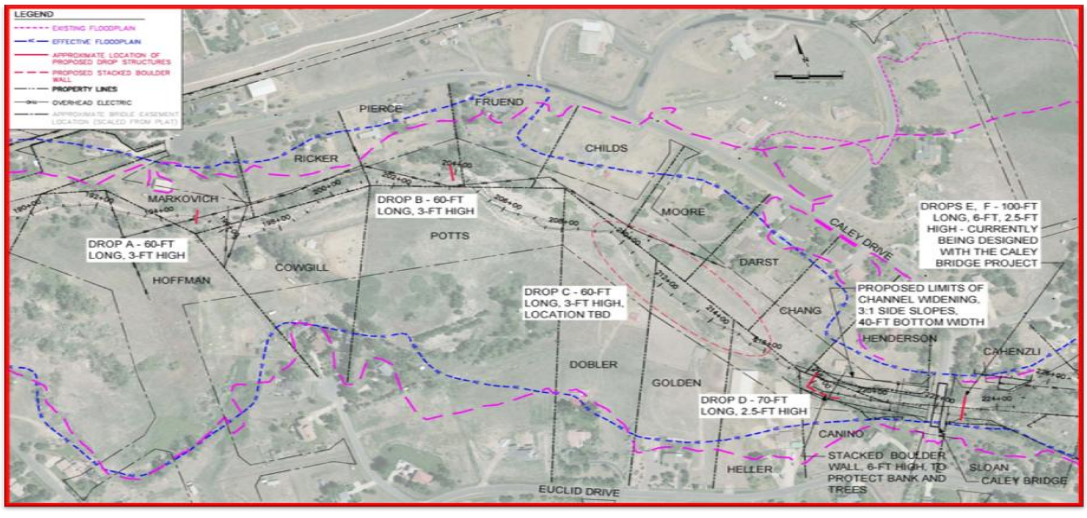
Piney Creek - Before

The UDFCD contracted with Ayres Associates for the design of the stream stabilization on Piney Creek and the Caley Drive crossing improvements. The County contracted with Stantec for the design of the storm sewer outfall project. The project successfully combined two plan sets that were designed by different engineers and awarded as one large project to a single contractor. The benefits to the public were a shortened construction schedule with a reduction of traffic detour and road closure days. The combined project's total construction cost was lower because it was larger; attracting more competition in the bidding process and avoiding duplicate items such as mobilization, water control, and traffic control.

The public relations were critical in the design of the project. A partnership approach was adopted that proved vital to being able to complete the design and build the project. The public involvement included both an educational and directional component. An overall plan was drafted that identified the problems and solutions in this stretch of Piney Creek. Each was identified and described to the residents. The residents then worked together to establish the priorities based on the benefits and funding available for the project. The result of the partnership approach was public support of the project.

The land acquisition utilized a series of negotiations in combination with property owner meetings. This approach helped to identify all of the benefits and detriments to each property owner. The project acquired all the easements needed for construction.

The stream stabilization consists of channel grade control, a low flow channel, and bank protection. Both the stream stabilization and removing vehicles from direct contact with flows improve the water quality in the creek. The old at-grade crossing of Caley Drive was improved to a bridge that safely passes flood flows under Caley Drive instead of over it. The storm sewer was added to the south and connected to the pond in the Estancia subdivision. The retention pond was converted to a detention pond with water quality capture volume. The storm sewer provides for the future expansion of Arapahoe Road and the associated increased flows.



Piney Creek – Overall Plan used in Public Relations

Construction Elements:

- Caley Drive Bridge consists of a concrete box girder 125-feet long and 27-feet wide that accommodates a 100-year flow of 8,600 cubic feet per second.
- Stream Stabilization includes an 8.5-foot tall grouted boulder drop structure, sheet pile check structure, 200 linear feet of grouted boulder bank protection, and 500 linear feet of low flow channel.
- 1800 linear feet of 36 inch to 54 inch storm sewer.

American Civil Constructors (ACC) was the successful bidder and constructed the project. The project involved multiple disciplines (channel, road, bridge, pipe, etc.) in close quarters. These disciplines converged on top of each other at the intersection of Caley Drive and Piney Creek. The construction schedule along with the diversity of disciplines in the project often required that two to three different crews work simultaneously. Coordination between trades and

Rich Borchardt, UDFCD, Molly Trujillo, SEMSWA, John Pflaum, Awards Chair, Walt Pennington, Ayres Associates

categories of work were crucial to keep the project moving along on schedule and budget.

The total project cost $2,323,000. The bid construction cost was $1,496,000 which was well under the engineer's estimate of $1,991,000. The project was constructed from January to August 2010.

Conclusion

The Piney Creek Stream Stabilization, Bridge Crossing and Storm Sewer Outfall project successfully met the project goals to stabilize channel, improve the water quality, improve the Caley Drive crossing, and provide a storm sewer system to the south. The project provides safer access for the residents and reduces the risk of damage to private property and threats to adjacent structures.

Piney Creek - After

The project successfully enhanced the public health, safety, and welfare; enhanced the surrounding environment; used unique and innovative solutions; and managed multiple-objectives. We thank all the project stakeholders and participants for their hard work, perseverance, and creativity.

District Receives Financial Reporting Certificate

For the twenty-second year in a row the District has received a *Certificate of Achievement for Excellence in Financial Reporting* from the Government Finance Officers Association of the United States and Canada. The certificate is presented to government units whose comprehensive annual financial reports achieve the highest standards in government accounting and financial reporting. The District's auditor was Johnson, Holscher & Co., P.C.

Congratulations to Frank Dobbins, Manager of Finance and Accounting, and assistant Darla Reeves for continuing this string of awards.

From left, Paul Hindman, Darla Reeves, Frank Dobbins and Board Chairman Susan Beckman

Hind' sight

By Paul A. Hindman

Timely Comment from the District's Executive Director

Last year at the District we saw a few physical changes to our office. We renegotiated our lease for another seven years at Diamond Hill and as a part of that we did some rather extensive remodeling of our offices. The main change was to the interior part of the office so that all of our student interns are now in the same place. Some may say we did this so we can keep a better eye on them but really it was to allow all of them to get the same experience while they are at the District. Before the remodel they were spread throughout the office, some were in a back office, some were in hallways, and some were in a spot where they never interacted with the entire staff and other interns. By moving all of them to the interior part of the office, all interns are now able have the same experience which will enable them to get the most out of their time at the District.

We also added a waiting room in our lobby area, a hydraulics lab for Ken, a larger office for Darren, a conference room in the Flood Warning Center on the third floor, a couple of small conference rooms known as "huddle rooms", and a larger lunch room. All of these changes have allowed us a more efficient use of our space. I hope everyone visiting our office agrees these are changes for the better.

One of the major issues we were involved with in 2011 was the aftermath of the devastating fire that happened in 2010 in the Fourmile Canyon area above Boulder. The fire stripped the hillsides of vegetation which historically has helped reduced the impact of severe rainfall which in turn reduced the flooding down the creek into Boulder County and the City of Boulder. The District contracted with several consultants to estimate the impact of the fire on runoff, and Kevin Stewart of our Flood Warning Program shared this information with Boulder County and the City of Boulder so that they could adequately predict and respond to flood threats. During the year some flooding did occur but we seemed to avoid an intense rain that could have caused major flooding issues downstream. Hopefully in 2012 we will again dodge the bullet but we will continue to keep a close eye on the area and will work closely with our local governments and consultants so that we can provide a more precise flood warning to the citizens of Boulder County and the City of Boulder.

Another issue of note is the new FasTracks rail system being designed and installed in the metro area by RTD. The West Corridor line is really shaping up and will become a great community amenity and will reshape several neighborhoods as they become connected to others. This is also true for the drainage network that the line passes over and sometimes parallels. The area around the confluence of Lakewood Gulch and the South Platte River is one of these areas that have seen some dramatic changes as a result of the RTD light rail line. Lakewood Gulch was rerouted along with the trail (or maintenance path as we like to call it) to allow a more safe passage for the flood waters, pedestrians and other trail users. This reconstruction of the area was accelerated as a result of the West Corridor schedule. The District, Denver, Lakewood, and Jefferson County all worked closely with RTD to make the new light rail line compatible with Lakewood Gulch, the South Platte River, and other drainages in the west part of the metro area. All of this could not have happened without the cooperation of all the parties, even when goals, values, and objectives were not always in line with each other.

The East Line which is now under design has also created its own unique challenges. The joke around the office is that we don't want to show RTD our Master Plans because if there is a regional detention pond planned or constructed, their rail line will hit it. That being said, when all parties work together a solution can always be found. An example of this is on First Creek just upstream of Pena Boulevard. The East Line has to cross over the creek and at the same time cross 56th avenue. This would have created a bridge spanning about 1400 feet to clear both. Also at this area, Denver and the District had planned to make major improvements to 56th along with improvements to First Creek. If each of the projects would have been done separately, rail, street and drainage, the total cost would have been over $10 million and maybe as much as $20 million. Dave Mallory of our office asked Olsson and Associates to look at a combined project which in the end was estimated at approximately $6 million. RTD's bridge was reduced to about 300 feet, the street will be improved for future planned use, and the drainage issues will be fixed which include shrinking the floodplain that will allow a major increase in developable land.

For the EAGLE P3 line and the Northern line we initiated meetings with all of the local governments to discuss issues as they come up concerning the future design and construction. As was for previous rail lines, these meetings

are extremely helpful in coming up with consistent criteria for the rail lines and allows a forum for general discussion. As we go forward I'm sure other issues will come up but as I've discovered in the past, if all the people involved get in a room together, a solution can always be found to everyone's satisfaction. You just have to stay in the room long enough. I know this goes against current technological capabilities like email and web meetings but as humans we are social creatures and as such need direct contact to solve the really tough issues. Now if only we could get Congress to understand this basic fact, we might be able to solve some of the really tough National issues.

I hope everyone has a productive and profitable year in 2012. And if you happen to visit the District's office, stop by and say hi. I'm the one in the back corner with my head buried in some kind of mindless paperwork, probably something to do with a budget.

North Sanderson Gulch wins Colorado Chapter APWA award

For Drainage and Flood Control Project in a large community

The City of Lakewood asked the District to partner with them to address a flood control need in their community. The goal of this project was to remove 21 properties from the 100-yr floodplain and enhance the natural and beneficial functions of the floodplain.

The North Sanderson Gulch project has a length of approximately 1500 feet. The drainageway flows from the west to the east with an upstream project limit at Pierce Street and W. Mexico Drive and a downstream project limit approximately 1200 feet upstream of the confluence with Sanderson Gulch. The improvements, which were completed in two phases, consist of four grouted sloping boulder drop structures, channel stabilization, three low flow culvert trail crossings of the channel, and 2000 feet of regional trail. The improvements successfully lowered the 100-year floodplain and integrated passive recreation opportunities by providing trail access through the drainageway, and preserving wildlife habitat and environment. In addition, sustainability and water quality have been improved through stabilization of the existing channel and enhanced wetland improvements. The enhanced wetland improvements consisted of aesthetic contouring, removal of sediment deposition, maintenance access, and diversification of the wetland species.

A different contracting approach was used on this project with regard to revegetation, since this was a main design component**.** Many times with a project the landscape improvements are performed by a sub to the general contractor. Should the revegetation not be successful the stakeholders are left with the challenge of working with the sub-contractor through the contractor. In many instances the leverage is limited and can be a burden to the project. As a part of this project the landscape improvements were bid under a separate contract. Not only was the revegetation incorporated into the contract, but monitoring and maintenance were also included. This will not only increase the survival rate of the original seeding and plantings but will expedite any future revegetation should areas not become established. This approach not only improves the aesthetics but also improves water quality by monitoring the vegetative cover.

Project partners included City of Lakewood, Muller Engineering Company, NRSI Services, ERO Resources Corporation, Goodland Construction, Left Hand Excavating and Arrowhead Landscaping.

North Sanderson Gulch was a cooperative effort between multiple agencies and the community that has reduced flooding risk by removing properties adjacent to the drainageway from the floodplain. The improvements provide the public with an opportunity to appreciate Lakewood open space, while preserving the existing habitat. Water quality has been improved by stabilizing the existing channel, removing deposited sediment, and diversifying the wetland species.

Winter and summer views of the project

Master Planning Program

Ken MacKenzie, Program Manager

Master Planning Projects

We completed five planning projects and five flood hazard area delineation studies in 2011, with 15 additional projects under way; and we plan to begin five new planning projects in 2012.

To date, UDFCD has completed a total of 88 major drainageway planning (MDP) studies, 83 outfall system planning (OSP) studies, and 87 flood hazard area delineation (FHAD) studies, including many updates of studies completed in the past.

Urban Storm Drainage Criteria Manual

An update of the Urban Storm Drainage Criteria Manual (USDCM), Volumes 1 and 2 is in progress. Highlights of the update will include improved areal reduction factors for the 2-year and 5-year storm rainfall depths in large watersheds, new trail criteria, detailed guidance for full spectrum detention, and new methods and equations for storm sewer inlet design.

The USDCM is one of the most respected drainage criteria manuals nationally and around the world. All three volumes of the USDCM are available in pdf format on our web page (www.udfcd.org) for download. We encourage you to check the website frequently for the latest updates.

STATUS OF PLANNING PROJECTS

Project	Sponsors	Consultant	Status
Big Dry Creek MDP & FHAD	Adams, Thornton, Westminster	Wright Water	90% Complete
Cherry Creek Stabilization Plan	Joint MP-DC&M Programs	Matrix	90% Complete
East Toll Gate Creek (Upper) MDP and FHAD	**Aurora, SEMSWA**	**J3**	**Completed in 2011**
East Toll Gate Creek (Lower) MDP and FHAD	Aurora, Buckley	J3	20% Complete
Easterly Creek OSP	Aurora	SEH	15% Complete
Globeville-Utah Junction OSP Update	Denver, Adams County	CH2M Hill	5% Complete
Happy Canyon Creek MDP & FHAD	SEMSWA, Doug. Co., Lone Tree, Parker	Not Yet Selected	2% Complete
Irondale Gulch OSP	**Commerce City**	**Moser**	**Completed in 2011**
Lafayette / Louisville Boundary OSP	**Lafayette, Louisville**	**McLaughlin**	**Completed in 2011**
Little's Creek MDP and FHAD	SEMSWA	AMEC	40% Complete
Louisville Criteria Manual Update	Louisville	WHPacific	95% Complete
Marston Lake North Drainageway MDP Update	Denver, Denver Water, Lakewood, Jefferson	None Yet	20% Complete
North Dry Gulch OSP	Lakewood	Muller	35% Complete
Park Hill (Lower) Drainage OSP	Denver, Denver Water	Enginuity	75% Complete
Pine Gulch Dam Analysis & OSP Update	**Parker, Douglas County**	**URS**	**Completed in 2011**
Piney Creek OSP & FHAD	SEMSWA, Aurora, Douglas	WRC	80% Complete
Sand Creek MDP & FHAD	Aurora, SEMSWA	Matrix	20% Complete
Second Creek MDP & FHAD	**Aurora**	**Olsson/Matrix**	**Completed in 2011**
South Boulder Creek Flood Mitigation Study	City of Boulder	CH2M Hill	70% Complete
West Toll Gate Creek MDP & FHAD	Aurora, SEMSWA	Michael Baker	25% Complete

MDP = Major Drainageway Plan, OSP = Outfall Systems Plan, FHAD = Flood Hazard Area Delineation

UDFCD Computational Tools and USDCM Support Group

You too can be a member of the UDFCD cyber-community by subscribing to this internet discussion group at: http://groups.google.com/group/UDFCD-support. Ask a question about the criteria manual, software, or spreadsheets and hear what we and other users have to say. We post messages to this group whenever a new version of the spreadsheets, software or manual is posted so this is a great way to be alerted to new releases on our website.

UDFCD Software

You may download the UDFCD unit hydrograph program *Colorado Urban Hydrograph Procedure (CUHP),* and other free software, including *UDSEWER* that includes a profile plotter, and many other free design aid workbooks from our website at www.udfcd.org. To download the CUHP companion EPA SWMM program, we have placed a hyperlink from our software site to the EPA website.

UDFCD Annual Seminar

At our 2011 annual seminar we had 318 registrants, once again the largest attendance ever. The proceedings are available at: http://udfcd.org/conferences/conferences.htm

On April 10, 2012 we will have our next annual seminar. This one-day program will be at the Stapleton Doubletree Hotel, and registration will be $60. Please mark your calendar and join us to find out what is going on regionally

and nationally in drainage, stormwater quality, and floodplain management.

A full house at the 2011 District seminar.

The District now has a Facebook page! Follow us for information of upcoming events, useful tips or information for designers, policy reminders or explanations for local governments, public service announcements, training opportunities, etc.

Check us out at:
http://www.facebook.com/pages/Urban-Drainage-and-Flood-Control-District/178014312224296

Stormwater Quality & Permitting Support Activities

Holly Piza, Senior Project Engineer and Ken MacKenzie, Manager, Master Planning Program

UDFCD continued to be active in the stormwater quality arena in 2011, with commitments to the following organizations and activities:

Best Management Practices (BMP) Advancements:

UDFCD is now making detailed reports on specific sites within the UDFCD monitoring program available to the public via the website (www.udfcd.org). New documents posted to the website include full history reports on the porous asphalt and permeable interlocking concrete pavement (PICP) sites in Denver, the pervious concrete site in Lakewood and a 2009 report for the extended detention basin (EDB) in Grant Ranch.

UDFCD BMP Monitoring Program:

UDFCD partnered with the City of Lakewood this year to construct a new rain garden as an addition to the UDFCD BMP monitoring program. UWRI, CSC, and Contech also supported this project which satisfied multiple objectives including providing stormwater quality treatment, field testing of UDFCD's new rain garden growing media, and fixing a nuisance drainage problem. The site is located within an older residential neighborhood in Lakewood. The original drainage plans consisted of a series of grass swales and driveway culverts. The swales were not protected from vehicle traffic and some culverts became buried over time. The result was nuisance flooding and muddy areas on the side of the road. The rain garden construction was finished in April, 2011. After construction, UDFCD starting monitoring water quality of the influent and effluent as well as runoff flow and volume. The rain garden is now fully vegetated with a drought tolerant seed mixture and assorted plantings. Residents provide irrigation. UDFCD plans to continue monitoring water quality and runoff peak flow and volume for the next several years. UDFCD submits all their water quality data to the International Stormwater BMP database.

The BMP monitoring program continued in 2011 with some sites collecting up to 16 rain events. We monitored a side-by-side porous asphalt and permeable interlocking concrete pavement test site at the Denver wastewater building, pervious concrete at the Lakewood Maintenance facility, an extended detention basin (EDB) in Grant Ranch, a green roof at Denver Botanic Gardens, and the rain garden described above. Both flow and pollutant data will be formatted for submittal to the International BMP Database.

New Discoveries:

We expanded our permeable pavement research with construction of a new type of permeable pavement at our BMP test site in Lakewood, CO. The site previously contained pervious concrete constructed using different aggregates. When one section of the pervious concrete started to ravel, UDFCD looked for another opportunity. The concept of the new pavement was developed by Colorado Hardscapes under the name *Hydrascapes.* Although the name is trademarked, the construction technique, which includes saw cutting of conventional concrete, remains available to the construction community. The wearing course consists of conventional concrete with a pattern of full depth cuts (perpendicular to

Rain garden in Lakewood

New permeable pavement test pad in Lakewood

flow) that extend into the aggregate below. Use of conventional concrete allows flexibility in appearance, color and pattern as well as potential for wide spread use. A skilled installer will make the full depth cuts indistinguishable from the control cuts giving the pavement the appearance of pavers. This also expands potential use of the pavement to more decorative areas at a lower cost compared to permeable interlocking concrete pavers (PICP). Colorado Hardscapes constructed this approximate 1000 square foot pad in August of 2011. UDFCD plans to conduct yearly infiltration tests and determine maintenance recommendations and promulgate design criteria dependent on performance over the next several years.

Education and Outreach:

After releasing the rewrite of the Urban Storm Drainage Criteria Manual (USDCM) - Volume 3, in November of 2010, UDFCD provided a six-hour training course for approximately 75 development review engineers. The document available at www.udfcd.org, includes updated design criteria and maintenance recommendations, new guidance on quantifying volume reduction, and has a new format designed to improve readability of the manual.

Colorado MS4 Stormwater Group:

The District continued to host quarterly luncheon meetings to discuss stormwater issues in 2010. These meetings are open to all Colorado communities affected by the Clean Water Act, which requires permits for municipal separate storm sewer system (MS4) discharges. The meetings serve as a forum to exchange ideas and experiences and to meet face-to-face with the Colorado Department of Public Health and Environment regulators.

South Platte River through Denver Selected as Urban Waters Federal Partnership Pilot Project

DENVER – The South Platte River through Denver, Colorado was selected as one of seven pilot locations for the new Urban Waters Federal Partnership (UWFP), a partnership of 11 federal agencies hoping to stimulate regional and local economies, create local jobs, improve quality of life, and protect Americans' health by revitalizing urban waterways in under-served communities across the country. The South Platte River pilot location will strive to protect one of Denver's primary sources of drinking water, while supporting ongoing on-the-ground projects, education, and research, and facilitating a growing population's connection to its urban waterways. The federal partner agencies plan to work with the City and County of Denver, The Greenway Foundation, the Urban Drainage and Flood Control District,

The confluence of Cherry Creek and the South Platte River, where Denver was born, has gone from 1970's cesspool to a vibrant ribbon of green and blue where people want to be.

Groundwork Denver, the Trust for Public Land, Colorado State agencies, local nongovernmental organizations, and businesses. The activities in the Denver metro area are also part of EPA's Green Infrastructure Initiative.

The South Platte River was chosen primarily because there already is a strong restoration effort underway. For the last thirty years, this effort has been spearheaded by the Urban Drainage and Flood Control District (UDFCD) and the Greenway Foundation, a non-profit organization founded in

Shoemaker's vision of creating a unique environmental, recreational, cultural, scientific and historical amenity has been realized.

1974 by state senator Joe Shoemaker. These two organizations have worked hand-in-hand with the seven counties and 33 incorporated towns and cities with the UDFCD jurisdictional boundary to repair, restore, beautify and make accessible the South Platte River and its major tributaries.

This re-aeration structure is a product of UDFCD's capital improvement program, matching local funds to construct infrastructure that manages river flows safely and improves water quality in the process.

The Greenway Foundation is led by executive director Jeff Shoemaker, whose mission is to advance the river and the surrounding tributaries as a unique environmental, recreational, cultural, scientific and historical amenity that uniquely links the region's past and its future.

Since its inception, the Greenway Foundation has led efforts to reclaim the South Platte River and its tributaries from a virtual cesspool to a place of environmental and recreational pride by constructing hiking and biking trails, creating parks and natural areas, building whitewater boat chutes, providing environmental education to school children, employing teenagers in youth employment programs, and helping create over $100 million of green improvements to the South Platte River and its tributaries throughout the Denver Metro area.

The UDFCD role in this effort is multi-faceted. The District invests $700,000 per year on flood hazard risk identification and master planning of tributary drainageways and watersheds for responsible release of stormwater runoff, in terms of both quantity and quality. Another $25 million is spent annually on construction projects and maintenance of existing infrastructure. The City and County of Denver and other local governments join forces with UDFCD, matching up to $12 million per year on capital improvement projects.

Over $1.2 million per year goes into routine maintenance along the river and its metropolitan tributaries. This work includes mowing, weed control, debris removal, tree thinning, and maintenance/recreation access. Hundreds of truckloads of trash, litter, and debris are removed from the river and tributary gulches and streams every year.

UDFCD joined forces with the region's first MS4 permittees and the U.S. Geological Survey in 1993 to jointly monitor water quality during wet weather stream flows in the South Platte and two of its major tributaries. This work continues today, with an expanded effort to assist all MS4 permittees in the South Platte River watershed with MS4 permit compliance. An additional significant effort is the UDFCD stormwater BMP research program, designed to better understand what BMPs work best in the high plains prairie of the Colorado Front Range.

UDFCD is looking forward to working with the new federal partnership on this exciting pilot project, and we are very aware of and grateful to the organizations and individuals that had the foresight and sense of stewardship to initiate this effort over 30 years ago - and to carry that torch to this day.

Lessons Learned from 7 Years of Monitoring Pervious Concrete

By Holly Piza, Senior Project Engineer, Master Planning Program

In 2005 Urban Drainage and Flood Control District (UDFCD) replaced a portion of the City of Lakewood maintenance office employee lot with pervious concrete. Pervious concrete is a monolithically-poured pavement that has 15 to 21% of its volume as void. The voids within the concrete are achieved by eliminating the fine sand aggregate from the concrete mix. The voids provide the flow paths for rainwater from the surface of the pavement to the base course underlying it. Pervious concrete with two different aggregates were installed side by side. The section below the pervious concrete includes an aggregate storage layer and a sand layer. The storage, consisting of aggregate, provides a volume available for storage of the runoff as well as structural reinforcement of the pavement. The sand layer is included to provide filtration of the stormwater, improving water quality prior to runoff entering an underdrain system.

The purpose of the study was to assess the long term performance of pervious concrete as a Best Management Practice (BMP) with regard to stormwater quality and volume reduction. The study included an adjacent asphalt reference site and automatic samplers programmed to collect a series of small samples through the storm hydrograph with the purpose of determining an Event Mean Concentration (EMC) for each constituent of interest.

Photograph 1. *The installation included two mixes utilizing different aggregates, AASHTO #67 (left) and AASHTO #8 (right).*

Pavement Performance

Aside from providing volume reduction and water quality, this BMP's performance is on its ability to provide an acceptable wearing course for vehicles and pedestrians over time; and also on its ability to maintain acceptable infiltration rates over time.

Wearing Course Surface

It should be noted that this site was constructed using a specification that is now outdated. In 2008 UDFCD found that a number of pervious concrete sites had areas where the pavement surface was visibly failing and began an investigation that resulted in the development of *Specifier's Guide for Pervious Concrete Pavement Design Version 1.2,* a new specification prepared by the Colorado Ready Mixed Concrete Association (CRMCA).

The Lakewood installation is considered successful compared to other installations constructed previous to the new specification. Neither the large or small aggregate sections showed any surface damage going into year four of the study. In December 2009, the small aggregate section started to ravel. Left alone, the raveling spread relatively quickly, by January 2010 a number of areas showed raveling in excess of two feet in diameter. As of December 2011, the large aggregate section remains undamaged.

Photograph 2. *In December 2009, the section with small aggregate started to ravel. It spread quickly, by January 2010 a number of areas showed raveling in excess of 2 feet in diameter.*

Pervious Concrete Infiltration

Without adequate maintenance (vacuuming one or two times per year) the pavement will clog. Once the pavement is clogged maintenance needs may change and a true vacuum truck could be required to restore infiltration, whereas a regenerative vacuum is recommended for routine maintenance. UDFCD

allowed the pavement at the Lakewood maintenances offices to clog over the course of six years. The purpose was to gain an understanding of risk when utilizing pervious concrete as a BMP. Could this pavement be restored if left unmaintained or would the pavement need to be replaced? UDFCD has not yet determined if restoration through vacuuming can be achieved at this site. One of the problems specific to the Denver area is that the maintenance industry has little knowledge of how this pavement should be maintained, and worse, lacks the right equipment. Broom sweepers are very common in this area but are ineffective at lifting sediment out of the pervious concrete. UDFCD contacted a number of sweeping companies prior to finding one that had a true vacuum (not regenerative air) truck. The first attempt at using this was unsuccessful. This may be due to wet conditions which are not ideal for vacuuming pavement. The Interlocking Concrete Pavement Institute (ICPI) recommends vacuuming without water spray. A warm, dry day is preferred. During the second attempt, the company hired to vacuum the pavement brought the wrong equipment to the site. Attempts to restore the pavement, including use of a regenerative air truck will continue in the spring of 2012. Although the pavement clogged at this location, runoff continued to make its way through the pavement section at the concrete perimeter walls.

Constituent	Data set with Higher Concentration at the Reference Site	Data Set with Higher Concentration at the BMP	CY Reference Site Median	CY BMP Site Median	Units
Alkalinity		2005, 2006, 2007, CY	85	45	mg/L
Chemical Oxygen Demand	2009, 2010, CY		18	97.5	mg/L
Chloride		2009, 2010, CY	4	50	mg/L
Conductivity		2005, 2006, 2007, CY	72.7	87	umho/cm
Hardness		2007, CY	39	55	mg/L
pH		2005, 2006, 2007, CY	6.5	9.4	
Dissolved Calcium		2009, 2010, CY	5	10	mg/L
Dissolved Iron		2009, CY	0.06	0.095	mg/L
Dissolved Magnesium		2009, 2010, CY	0.6	1	mg/L
Dissolved Sodium		2007, 2009, 2010, CY	6	57.5	mg/L
Dissolved Chromium		2007, 2009, 2010, CY	ND	2.2	µg/L
Dissolved Manganese	2005, 2007, 2009, 2010, CY		13.35	2.85	µg/L
Dissolved Nickel	2007, 2009, 2010, CY		ND	ND	µg/L
Dissolved Copper		2006, 2007, 2009, CY	5	6.2	µg/L
Dissolved Zinc	2005, 2006, 2007, 2009, 2010, CY		11.9	ND	µg/L
Dissolved Selenium		CY	ND	ND	µg/L
Total Chromium	2010		ND	ND	µg/L
Total Nickel	2009, 2010, CY		1.8	1.1	µg/L
Total Zinc	2005, 2007, 2009, 2010, CY		47.2	ND	µg/L
Total Selenium		CY	ND	ND	µg/L
Total Cadmium	CY		ND	ND	µg/L
Total Lead	2009, 2010, CY		ND	ND	µg/L
Total Manganese	2010	2006	53	42.6	mg/L
Total Copper	2010	2006, 2007	10	9.95	mg/L
Dissolved Potassium		2007, 2008, 2009, 2010, CY	2	12	mg/L
Nitrite+Nitrate		2006, 2007, 2009, 2010, CY	0.63	1.65	mg/L
Ortho-Phosphorus		CY	0.046	0.081	mg/L
Total Kjeldahl Nitrogen	2007, 2009, 2010, CY		1.8	1.1	mg/L
Total Phosphorus	2009, 2010, CY		0.155	0.1	mg/L
Total Suspended Solids	2009, 2010, CY		64	23.5	mg/L

CY = Combined Years Data, ND = Below Detection Limits

Table 1. *Data Sets Showing Significant Differences in Constituent Concentrations and Median Concentrations for All Years Combined*

Volume Reduction and Water Quality Performance

One of the biggest challenges in BMP monitoring is accurate measurement of flows and volumes. Based on the data collected this BMP may provide volume reduction between 24 to 38%; however, due to inconsistencies observed in the data, a low level of accuracy in this value is assumed.

Water quality data shows a high number of statistically significant differences between reference and BMP sites. Most of the data was highly significant, about half of the constituents were in lower concentrations for the BMP site and half were in higher concentrations. See Table 1 for data sets exhibiting significant differences in constituent concentrations and median concentrations using all data. Except for Total Copper and Total Manganese, none of the constituents that were in a significantly higher concentration in effluent from the reference site or BMP site in one year were significantly lower for another year. Total Copper data show a decrease in concentration in the BMP effluent of the 5 years of study. It is significantly high in BMP effluent in 2006 and 2007 and significantly lower in the BMP effluent in 2010. With the exception of 2005 data, Total Manganese also shows a decline in concentration over time. It is significantly higher at the BMP outlet in 2006 and significantly lower in 2010.

Based on the study, this BMP provides significant reductions in several targeted constituents including Total Suspended Solids, Total Phosphorus, Total Kjeldahl Nitrogen, Chemical Oxygen Demand, and several dissolved and total metals. The most problematic water quality issue may be the increase in pH observed in the BMP effluent, with both mean and median values for combined year data above 9.0 and no downward trend of this constituent over time.

The full report is available at www.udfcd.org.

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Floodplain Management Program

Bill DeGroot, PE, Program Manager

Bill receives ASFPM award

The Association of State Floodplain Managers (ASFPM) gave me its 2011 Meritorious Lifetime Achievement in Floodplain Management Award at its awards lunch during its annual conference in Louisville. This was a complete surprise to me, thanks at least in part to the sneakiness of David Mallory and my wife Mary. To make it even more special Mary flew our daughter Sara in from Alexandria for the occasion.

Some pretty special people have received this award before me, so I am in good company. My thanks to all of the folks at ASFPM who had a hand in this award.

Good Neighbor Policy

The Board of Directors passed a Good Neighbor Policy at its February 1, 2011, meeting. In summary the policy recognizes that many District projects are not used for their intended purpose (rare events) very often and they should therefore be designed and implemented in a way that makes them good neighbors all the time, through the incorporation of amenities like trails and the natural and beneficial functions of floodplains.

The policy has been well received nationally, and drew a front page story in ASFPM's *News and Views*. The full policy can be found on the District website home page.

LOMC delegation

We have been reviewing requests for Letters of Map Change (LOMC) for FEMA since July 1, 2001. We have had a pretty busy year again; with 31 cases received in the last nine months. As was the case last year, most of the cases we have reviewed are for government funded projects. At the end of December we had 17 cases under review and only two were private sector cases.

Expanded Appeals Procedure

Starting December 1, 2011, FEMA instituted an expanded appeals process for all Letters of Map Revision (LOMR's). The due process procedure used to only apply to new or modified Base Flood Elevations (BFE's), but will now apply to other changes to flood hazard information. The net effect will be that almost all LOMR's will have effective dates 120 days following the second newspaper publication date.

This procedure will not affect our reviews of LOMR's, nor will it change any current requirements for property owner notification. For more information see the *Changes to FEMA's Appeals Process* flyer on our website home page

LOMC database

Joanna Czarnecka and Julia Bailey are putting the final touches on a database that will allow us to easily track CLOMR and LOMR applications and maintenance eligibility projects in one place. This will help us do several things. We can assure that a LOMR has followed a CLOMR within a reasonable period of time. We can see whether a CLOMR or LOMR project has been submitted for District maintenance eligibility, or vice versa. We can sort projects by drainageway or local government. Finally, we are filing PDF's of all recent CLOMR's and LOMR's in the database for easy access.

The Beta version we have been testing has already been helpful in a number of instances. We hope to make the database available to the entire District staff in early 2012. No decision has been made on if or when to make it available to our local governments or the public.

DLOMC guidelines

We unveiled Digital Letter of Map Change (DLOMC) guidelines at the District seminar in April, 2010. So far we haven't had many submittals, which has been a bit of a disappointment. DLOMC's are voluntary, but we believe they will save both applicants and the District time and money, and we continue to encourage DLOMC submittals.

Floodplain delineation

We completed five digital flood hazard area delineation (DFHAD) studies this year; for First Creek in Denver and Aurora; Upper East Toll Gate Creek in Aurora; Piney Creek in Centennial, Arapahoe County, Aurora and Douglas County; Cottonwood Creek in Greenwood Village, Centennial, Arapahoe County, Douglas County and Lone Tree; and Second Creek above DIA in Aurora.

We have DFHAD's underway for Big Dry Creek in Adams County, Thornton and Westminster; Littles Creek in Littleton and Centennial; West Toll Gate Creek in Aurora, Centennial and Arapahoe County; Toll Gate Creek and Lower East Toll Gate Creek in Aurora; Sand Creek in Aurora and Arapahoe County; Goose Creek in Boulder; and Happy Canyon Creek in

ASFPM President Greg Main (left) and Executive Director Larry Larson (right) with Bill DeGroot at the ASFPM awards lunch.

Arapahoe County, Douglas County Lone Tree and Parker.

All of these studies are compatible with FEMA's DFIRM specifications, and will be provided to FEMA for incorporation into the appropriate DFIRMs. Terri Fead does an excellent job of assuring that the DFHAD's are done to our standards and FEMA's.

We have been talking to FEMA Region 8 about putting together a schedule of when DFHAD's will be completed so that they can be schedule by the region for Physical Map Revision (PMR) funding as they are completed. This would help get the DFHAD's into the DFIRM database and onto the National Flood Hazard Layer quicker. See Risk MAP below.

DFHAD guidelines

Our DFHAD Guidelines have been undergoing some additional modifications, with seemingly every new draft DFHAD submittal raising new issues. New guidelines will be posted on our website in early 2012.

DFIRM projects

In 2009 we received four grants from FEMA to update existing DFIRM's for the City and County of Broomfield, City and County of Denver, Douglas County and Jefferson County. At the end of 2011 Broomfield was nearing completion, with Jefferson County and Denver preliminary maps due out early in 2012. Douglas County has a way to go yet, primarily due to a large number of studies provided by Castle Rock for inclusion.

The Boulder County DFIRM conversion project, which is being managed by the Colorado Water Conservation Board, is the only one left before all of the District's local governments are covered. It will probably be late 2012 before it becomes effective.

Risk MAP moves ahead

FEMA is now well into its third year of Risk MAP. Unlike for the DFIRM projects mentioned above, which came out of FEMA's previous Map Modernization program, we have not applied for any grants to complete Risk MAP projects. As I noted in this column last year, Risk MAP is based on HUC 8 watersheds. The District is located in parts of four of these watersheds, and we decided we did not want to be the lead agency for studies extending outside the District.

This year we participated in discovery meetings for the Clear Creek and St. Vrain Creek watersheds. In 2012 the Colorado Water Conservation Board (CWCB) will take the lead for studies in these two watersheds. While we are cooperating with the CWCB on these studies, our emphasis has shifted from applying for FEMA grants to trying to get our completed DFHAD's (see above) incorporated into the DFIRM's as quickly as possible. We are also talking to FEMA about getting our master plans incorporated in some way into non-regulatory Risk MAP products.

FasTracks Coordination

FasTracks has taken a lot of our time, as David Mallory discusses below. In addition to the design and construction work David discusses, we formed a group of the local governments impacted by the Eagle P3 corridors. We meet monthly to address common issues and develop common positions for all of the communities. This has proven to be a very successful effort.

Maintenance Eligibility

Our maintenance eligibility program continues to flourish under David Mallory's direction. See David's column below.

Reinventing the NFIP

FEMA has been working on a project for some time to reinvent the NFIP in order to present their findings to Congress the next time reauthorization is on the table. At the same time there are competing versions of NFIP reauthorization bills in the Congress, and the result has been a series of short term extensions. As of now it is authorized until May 31, 2012. We will try to keep you advised of any progress toward a long term reauthorization.

Maintenance Eligibility Program

David Mallory, PE, CFM, Senior Project Engineer, Floodplain Management Program

The District has a longstanding commitment to national leadership in the areas of floodplain and stormwater management. The District generously supported my involvement in the Natural Floodplain Functions Alliance (NFFA), FEMA's Levee Analysis and Mapping Procedures (LAMP) initiative and work in the National Mitigation Framework Plan mandated by the Presidential Policy Directive 8 – National Preparedness.

This year marks the end of my tenure on the CASFM Board after seven years of service. CASFM is, in my humble opinion, the best ASFPM state chapter in the nation which speaks well of the state of Floodplain Management in Colorado. I was honored to serve and pleased that Dave Bennetts will take the reins as Chair. I encourage everyone to visit CASFM's excellent website at www.casfm.org to catch up on all the CASFM news and events.

Please join me in congratulating Joanna Czarnecka in obtaining United States citizenship this year. As most of you know, the path to citizenship requires some study, a test and a bunch of forms. While her legal status has changed, she still has the delightful accent!

The Projects

Large-scale development projects were essentially non-existent in 2011. We did spend significant effort on several public sector projects:

RTD FasTracks West Corridor Project

We have worked with RTD, the City and County of Denver, the City of Lakewood and Jefferson County on this project since the summer of 2004. Denver Transit Construction Group JV (DTCG) commenced construction in the spring of 2009. We are now winding down the third construction season and the end is in sight! Major construction activities this year have been focused on the Lakewood Gulch drop

Lakewood Gulch drop at Federal Boulevard. Photo date is September 12, 2011. This was the largest of the six drop structures built as a part of the RTD West Corridor FasTracks Project. View is looking east and downstream.

structure at Federal Boulevard and the downstream reach that interfaces with the Denver and District's South Plate River and Lakewood Gulch Project in Denver, and the Dry Gulch channel improvements at Harlan Street in Lakewood. Joanna continues to do an outstanding job of keeping this large, long and complicated project on track (pun intended) for District Maintenance Eligibility. I also want to acknowledge the contributions that Bruce Behrer and Chris Kroeger of Muller Engineering Company made relative to the Federal drop structure construction. The success of that element was a joint effort on the part of all parties involved. All major drainageway construction phases should be complete in February of 2012.

The West Corridor Project involved nearly eight years of hard work and touched most of the District staff in one way or another. Through patience, perseverance and skilled negotiations, we achieved the desired outcome. Bill DeGroot

Dry Gulch channel improvements in Lakewood. View is looking west towards Harlan Street. The Light Rail line is bounded by a park and industrial development and adjacent to the channel. The upstream headwall is the confluence of Dry Gulch and North Dry Gulch. This photo was taken on September 12, 2011.

served as the District's lead policy liaison to RTD. His leadership was important in shaping the final project. Regional cooperation among the stakeholders and local governments was also an important key to project success.

RTD FasTracks Eagle P3 Project

The Eagle P3 Project includes the East Corridor to DIA, the Gold Line to Arvada and Wheat Ridge and a starter segment of the Northwest Rail Corridor to Westminster. Eagle is an acronym for those corridors and P3 stands for public private partnership. The Eagle P3 Project is a competitive concessionaire arrangement where the selected team, Denver Transit Partners (DTP) (Fluor, HDR, PBS&J, Parsons Brinckerhoff and others) will design, build, finance, operate and maintain the project with a long-term lease back to RTD.

There are significant drainage and floodplain management issues throughout the corridors. For example, the proposed commuter rail alignment impacts every regional detention pond along Pena Boulevard. We negotiated a Memorandum of Understanding (MOU) with RTD concerning the design approach as it affects Irondale Gulch, Blue Grama Draw and the West Fork of Second Creek. Challenges also exist throughout downtown Denver, First Creek crossing, South Platte River crossing, two crossings of Clear Creek, Little Dry Creek at Federal Boulevard and Clear Creek at Federal Boulevard.

The flow of submittal packages started in late summer. We received over 40 submittals in one sixteen week period. John Pflaum was brought on board to help with the engineering review tasks in order meet RTD's schedule. Joanna does the download and cursory review in order to determine the District's interest in each submittal. She also maintains the tracking sheet to monitor progress. John follows with the detailed review and written comments that are uploaded to the RTD site.

The Eagle P3 Project has been the catalyst for several District construction projects including the Montclair Basin Outfall Project, the Westminster Little Dry Creek improvements and Baranmor Ditch in Aurora. We also identified a restoration project along First Creek. The First Creek FHAD that was completed earlier this year showed a significant overflow of 56th Avenue between Pena Boulevard and Tower Road. The problem originated with the relocation of the First Creek channel several decades ago in order to facilitate farming operations. The overflow affected RTD's East Corridor Project and Denver's 56th Avenue Widening Project as well as several adjacent landowners.

We proposed an alternate approach to partially restore the original alignment and fully utilize the existing 56th Avenue bridge capacity. RTD challenged us to quickly develop the preliminary design and gain stakeholder support. Olsson Associates was assigned the design tasks through our continuing services arrangement. They did a terrific job of meeting tight schedule and high project expectations. The stakeholders include RTD, Denver, DIA, several private landowners, two metropolitan districts and the Rocky Mountain Arsenal National Wildlife Refuge. RTD has accepted the proposed design and Denver has taken the lead on the funding arrangements. The project will move into the final design phase next year under Barbara Chongtoua's watchful eye, so stay tuned.

Parker Jordan Centennial Open Space Project

This is another interesting stream restoration project along Cherry Creek. The project limits are approximately Broncos Parkway to the 17-mile House property. The project sponsors are the Parker Jordan Metropolitan District (PJMD) and the City of Centennial. Both the District and SEMSWA are minor funding partners. As reported in last year's article the project sponsors worked through a number of difficult issues to arrive at a "balanced design". The project design is now approved; a CLOMR issued and is under construction. I believe this project will become an example of sound design, regional cooperation and environmental restoration. My congratulations to J3 Engineering and the project sponsors for successful efforts thus far.

In the Field

Joanna continues to do an outstanding job of observing the construction phase of projects that will ultimatly be eligible for District maintenance assistance. For example, Westerly Creek in and around the two flood control facilities located on the Lowry redevelopment site, Kelly Road Dam and Westerly Creek Dam. The East Lowry Open Space & Dog Park Project entails removing a section of the Westerly Creek Dam outlet pipe and replacing it with an open channel, trails, landscaping and adjacent dog park. The work is located within the emergency spillway of Westerly Creek Dam, so this means the USACE was a review agency along with the District and Denver. The companion project is the Lowry Wetlands Park Project located within the flood pool of Kelly Road Dam and includes channel and water quality improvements. Both projects are now complete.

In the Office

Terri has spent a significant part of this year reviewing various DFHADs produced by District consultants and a number of floodplain studies prepared by the Town of Castle Rock that will be included in the Douglas County DFIRM maintenance project (see Bill's article). FEMA has, through Map Mod and will continue with the introduction of Risk MAP

Joanna is seen here conducting a punch list walkthrough on December 12, 2011. This was the last in a series of RTD West Corridor substantial completion inspections for various drainage elements. Also in the photo are Ryan Espoy (left) and Barry McClung (center) with DTCG.

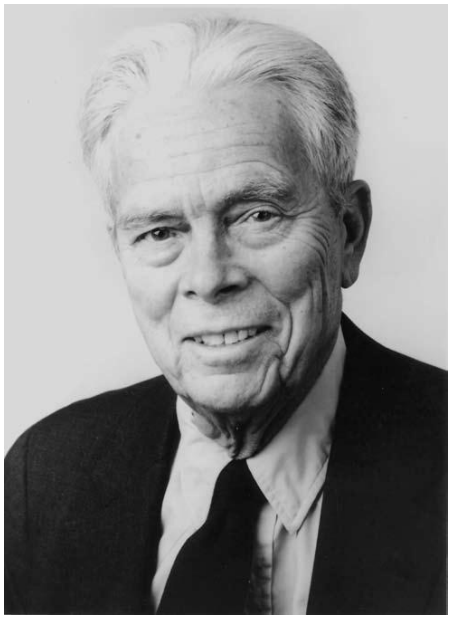
insisted on high quality data. After completing several DFIRM projects and working through the quality control reviews, we determined we had to revise our standards. The result was the publication of the DFHAD Guidelines. We now require our consultants to submit completed agreement checks with the project deliverables. More to the point, Terri is thoroughly checking all submittals in order to assure conformance with current FEMA standards.

A FITTING MEMORIAL

By Clancy Philipsborn

Now complete, the Gilbert F. White Memorial located adjacent to Boulder Creek in Central Park of downtown Boulder is a shimmering tower of respect, dedication and hard work, reflecting the same attributes that the life the "Father of Floodplain Management" revolved around.

As a student and then Professor of Geography, Gilbert's passionate thoughts regarding human ecology led to his leadership and eventual legacy in what became the profession of floodplain management --- just one of myriad accomplishments in his storied career (for more info on Dr. White's career, see: http://www.colorado.edu/hazards/gfw and http://www.rwkates.org/pdfs/a2011.01.pdf



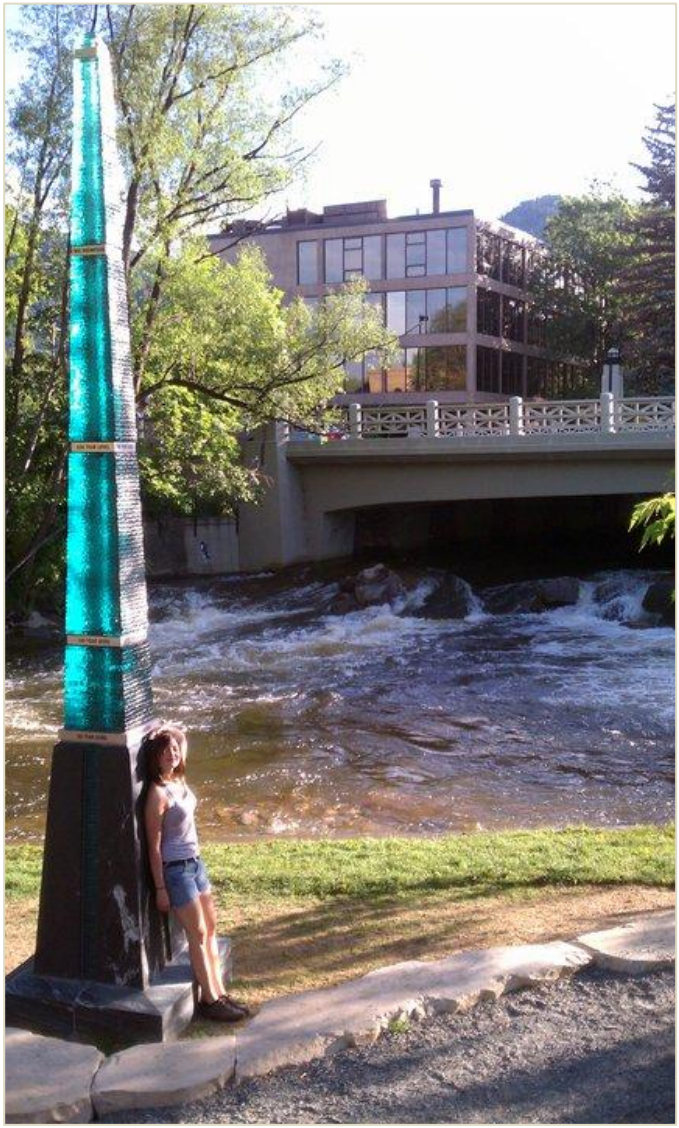
Gilbert F. White, 1911-2006

Designing a fitting memorial for Dr. White was thus a daunting task. At the request of the Boulder City Manager in 2006, a volunteer committee was formed for just that purpose. The committee was comprised of Gilbert's family, colleagues, students and friends, with guidance and support provided by the city's Parks and Recreation Department. The committee quickly agreed that any memorial honoring Gilbert should exemplify his "Life Themes," offer a practical and educational use, and contribute to the Boulder community.

While the original city concept was "something like a plaque," the final result is a dramatic, slender, 20-foot high glass obelisk with integrated markers indicating the level of the 50, 100, 500-year floods, and the 1976 Big Thompson Flood (> 500-year) at that location. The memorial, simply put, is in-your-face public education about the history, impacts and continued likelihood of flooding in Boulder. The simple magnitude of the memorial cannot be ignored --- and it's wonderful to sit on the nearby seats to contemplate its meaning, while listening to residents and visitors alike comment on its implications, while postulating what they should do during an actual flood event.

At the same time, the memorial is a wonderful piece of public art that is the ultimate combination of form and function. Constructed of 140 individually measured, cut and bored pieces of 1-inch thick glass, the spire is mounted on a black granite base, with a threaded 1" stainless steel rod running through the entire length of the structure. The rod is wrapped with two LED strands to provide internal illumination at night. The base is anchored with 3 helixical piers reaching bedrock and encased in a 50,000 pound poured concrete sub-surface foundation. It was engineered to withstand the 500-year event.

The Gilbert F. White memorial is the culmination of 3 years of coordination, collaboration, cooperation and hard work. Over 400 individuals and organizations contributed more than $120,000, and countless hours to bring this project to fruition. It is a most fitting tribute! Next time you're in Boulder, make sure to include enough time to visit the memorial in person.



The Gilbert F. White Memorial sits adjacent to Boulder Creek downstream from the Broadway Bridge

Information Services and Flood Warning Program Notes

Kevin Stewart, PE, Program Manager

Last year's *Flood Hazard News* article devoted considerable copy to evolving flood concerns resulting from the 2010 Fourmile Canyon Fire that started on Labor Day (September 6) and destroyed 169 homes in the Gold Hill area west of Boulder. Those concerns proved valid when a destructive life-threatening flash flood struck on July 13. Read on to learn how community flood preparedness efforts saved lives in the Fourmile Burn Area, and some specifics about this and other big rain events from the 2011 flood season.

When it concerns IT matters at the District, Derrick Schauer has the conn and forecasts "clear sailing" for 2012. District LAN servers were replaced in 2011, electronic records and files are secure, and our website www.udfcd.org is well-maintained. Priorities are now focused on file structure and records management as we look ahead.

Julia Bailey is the District's Information Services Engineer and gatekeeper for our Internet-accessible publications and associated data. She also oversees District GIS activities and facilitates related staff training needs. Julia is principally responsible for the EDM "Electronic Data Management" mapping interface that has become a very popular means of acquiring information from the District. The link to this valuable service is easy to find on the District homepage. Be sure to read Julia's article in this newsletter about recent changes to the EDM.

This year the IS/FWP had the pleasure of welcoming a new engineering student intern from Colorado State University, Rebecca West. Becky quickly adapted to the flood video archive project that has been underway for a number of years. She also used her talents to help us improve our online streamflow statistical summaries from over 20 years of data collection activities. Becky anticipates receiving her B.S. degree in Civil Engineering in 2012.

2011 Flood Season Recap

This past flood season had an above average number of threat days. To some extent this resulted from the elevated risk associated with the Fourmile Burn Area (FMBA). While July 7 was probably the most notable rainfall event in the District, July 13 received far more attention due to the number of lives threatened and homes damaged by flooding in the mountains of Boulder County less than three miles west of the District boundary.

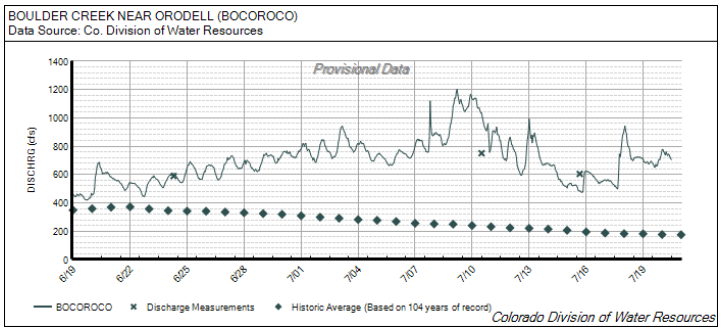
The ALERT system triggered rainfall rate alarms on 34 days between 15 April and 15 September in 2011 compared to only 17 days the previous year. Specific alarm dates are shown in red in the table below. A few alarm dates are not reflected in the table such as April 25, May 12,13&19 and September 6&7. Most of these alarms occurred from the low alarm threshold settings (¼" per hour) for rain gages in or near the FMBA. Some of the April and May alarms resulted from snow accumulating in the 12-inch diameter collector funnels and forming a frozen obstruction. When the snow melts, the "ice dams" eventually give-way causing the tipping bucket gage to falsely measure high rain rates under clear skies. The alarms on April 25 are an example of this phenomenon. On other "non-threat" days, short-duration intense storms caused a few of the FMBA gages to exceed their quarter-inch thresholds without consequence. On September 6 and 7, debris movement was reported in the FMBA without prior notice of the potential threat. This illustrates just how sensitive fresh burn areas can be to small frequently occurring rains.

Twenty-four hour precipitation totals exceeded 3" on three days in 2011 (May 11 & 18 and July 7). Nine other days (Jun19; Jul8,11,12,13&14; Aug20; Sep2&14) had rain totals ranging from 2 to 3 inches with July 13 resulting in the greatest damage from just over an inch of rain. A storm summary table and corresponding maps are available for each day listed below.

41 days with flood potential in 2011

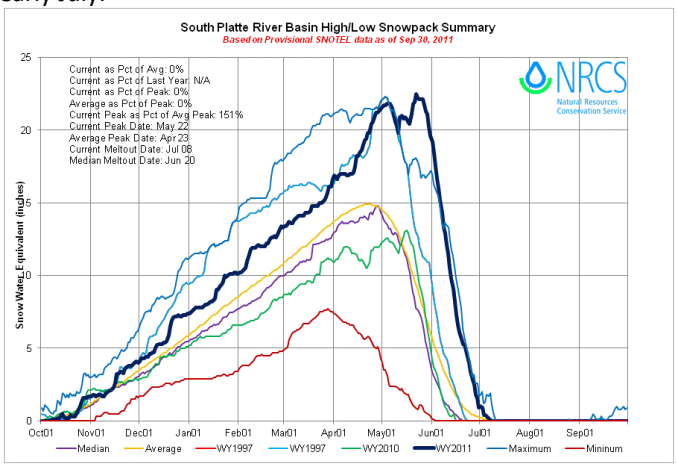
May	11, 18, 20, 23, 24	5
June	11, 13, 17, 19, 20, 30	6
July	2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 26, 27, 31	19
August	2, 3, 4, 14, 16, 20, 21, 29	8
September	2, 14, 15	3

Red dates are days when rainfall measured by automated gages exceeded alarm thresholds. Yellow highlighted dates indicate that heavy rainfall measurements only affected areas outside the District's main area of concern, i.e. Hayman Burn Area in Douglas and Jefferson Counties, and the St. Vrain Creek basin in northern Boulder County. Blue boxes designate NWS flash flood watches that affected the District and red boxes designate flash flood warnings.



The 2011 Snowpack

This was an unusually late runoff season with melting snow from the mountains affecting Colorado streamflows well into July. The plot above shows data from the Boulder Creek streamgage near Orodell with records that date back 104 years. Note the difference between the 104-year averages from mid-June to mid-July. When the Fourmile Creek flash flood occurred on July 13, the runoff from snowmelt was as least three times its normal rate. The plot below shows that the South Platte River basin held on to its snowpack through late May into early June, then the runoff became aggressive, nearly matching the maximum recorded event. Consequently, streams like Boulder Creek were flowing well above normal when the monsoon rains arrived in early July.



burn area of less than 6,200 acres could seriously threaten the City of Boulder. To help answer this question a number of hydrologic studies were quickly completed and as expected, the results differed (see table). However, all models did indicate that a short duration rainstorm of 2-inches or more over the FMBA could certainly cause problems in Boulder along Boulder Creek. It was also suggested that Fourmile Canyon Creek on the north side of Boulder may actually pose a greater threat.

To provide some context for the numbers in the table, paleoflood investigations conducted by Bob Jarrett of the USGS suggested that the Fourmile Creek minor flood events of 1995 and 2003, with estimated peaks of less than 500 cfs, were likely the largest floods experienced by this area in at least the past 75 years. The Boulder Creek flood of 1969, the largest in recent memory, resulted from four days of moderate intensity rainfall in the mountains that exceeded 9 inches at the Boulder Hydroelectric Plant and produced a peak flow on May 7 through Boulder of 2,500 to 3,000 cfs. The May 30, 1894 flood, the historic flood of record for this area, caused extensive damage along Boulder Creek and Fourmile Creek, and generated an estimated peak through Boulder of 12,000 cfs. Paleoflood studies of the 1894 event revealed that most of the rain-driven runoff came from the 25 square mile Fourmile Creek watershed and that Boulder Creek above the Fourmile Creek confluence showed little geologic evidence of high flows.

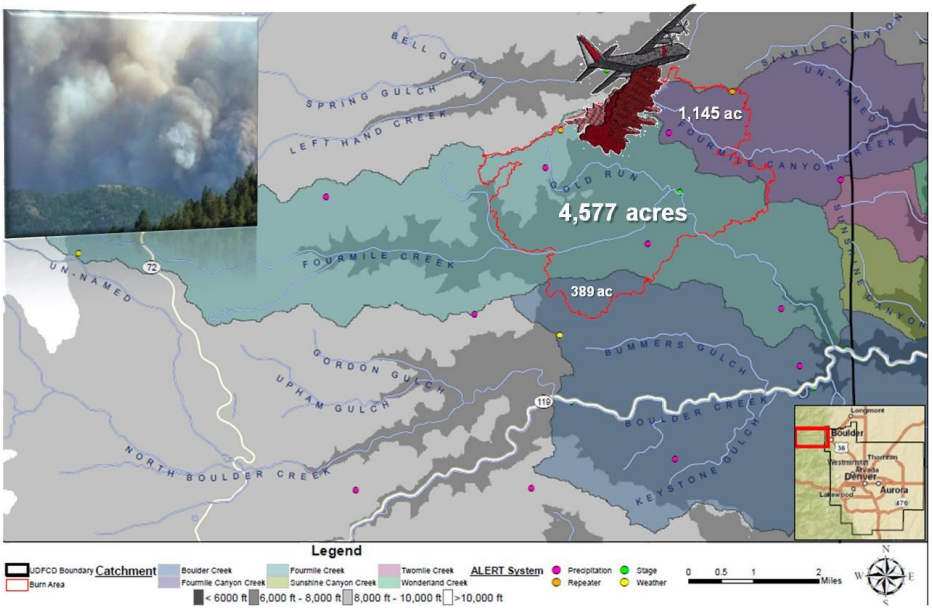
A post-fire threat assessment was conducted to evaluate potential impacts for a range of rainfall intensities. A flood hazard inventory for Fourmile Creek and Gold Run suggested that flow rates as small as 100 cfs could overtop and potentially wash-out many private drive crossings, that larger capacity road crossings like Colorado Highway 119 could handle no more than 2,000 cfs prior to overtopping, and that as many as 80 structures were at risk with approximately 20 of those—mostly private homes—potentially threatened by flow rates of less than 1,500 cfs.

Boulder County Main Events

In describing Boulder County's 2011 flood season, this recap begins in mid-January when dire predictions were being made concerning the elevated flash flood threat posed by the Fourmile Burn Area (FMBA). While there was general agreement that the risk was extremely high for those living in or traveling through the FMBA during a heavy summer downpour, opinions varied widely with respect to how such a relatively small

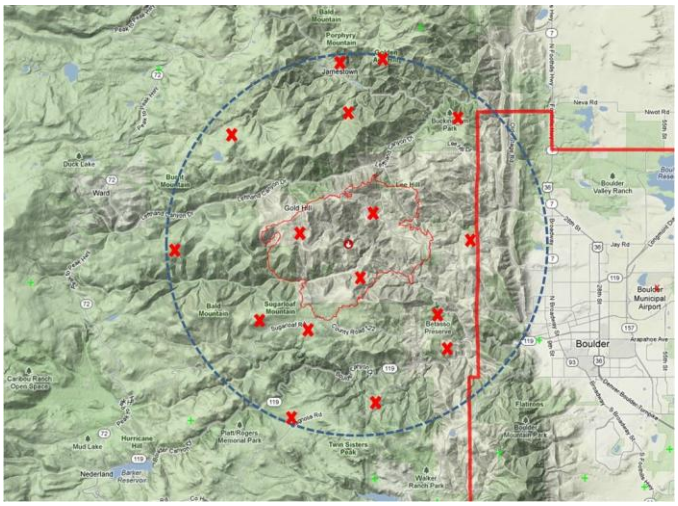
1-HR PCP	Vieux	LRE	WWE	UCD
0.5"	880	150	200	550
0.75"	1,600	460	470	900
1.0"	2,400	890	820	1,400
1.25"	3,300	1,400	1,200	1,800
1.5"	4,300	2,000	1,800	2,200
1.75"	5,300	2,600	2,800	2,700
2.0"	6,300	3,300	3,800	3,200
2.5"	8,400	4,600	5,900	4,300
3.0"	10,500	6,100	7,500	5,600

Peak discharge estimates in CFS from runoff models for the 4,577-acre burn area portion of the Fourmile Creek watershed.



The National Weather Service made use of these investigations, advice from the USGS, and their own past experience with post-wildfire Colorado floods like Hayman and Buffalo Creek to establish initial criteria for issuing public advisories, watches and warnings. With a high danger for mud, rock and debris slides, a very low ¼-inch per hour rainfall rate was established as the advisory threshold for road problems and minor flooding. The warning threshold for flash flooding in the FMBA was set for one hour rainfalls exceeding ½-inch. For the City of Boulder more rain would be required to cause a serious threat and therefore, the initial warning threshold for the City was set for an hourly amount of 1.5 inches. Prior to the fire, less than 2 inches of rain in the mountains would not likely have posed any serious flooding threat.

ALERT rainfall alarm rates were adjusted accordingly for automated gages located in and near the FMBA (see map). The District also cooperated with the USGS to reestablish two streamgage sites on Fourmile Creek near Crisman (Logan Mill Road) and at Orodell (Boulder Mountain Lodge) with satellite telemetry. The owners of the lodge also provided the utility connection that enabled installation of a live video webcam.



Map showing location of 16 automated rain gages within 5 miles of the burn area center. Alarm thresholds set at 0.25"/hr, 0.5"/hr and 0.75"/hr.

Two rainfall/runoff models for Boulder Creek were developed for real-time operations and adjusted to reflect the post-fire conditions. Both models extended their flood routing calculations to the Boulder city limits at the mouth of Boulder Canyon, but questions remained concerning their reliability because no runoff measurements existed at this point in time to calibrate the models. The Colorado Water Conservation Board provided the funding that helped make these technical accomplishments possible. The flood forecasters and response agencies were now reasonably prepared for the 2011 flood season.

With the technical resources in place and the research/study results in hand, emergency management officials, fire districts and other agencies in Boulder County undertook a major public education effort to prepare people for what might happen. These measures proved life-saving by July when the summer monsoon rains arrived. Convincing people that the threat was real was not an easy task, and many living in the FMBA still likely have some doubts about the magnitude of the threat. Doomsday predictions seldom convince people of high danger. Many public safety and public works officials, subject matter experts, and public information professionals deserve commendations for their services in 2011 as the following recaps will reveal.

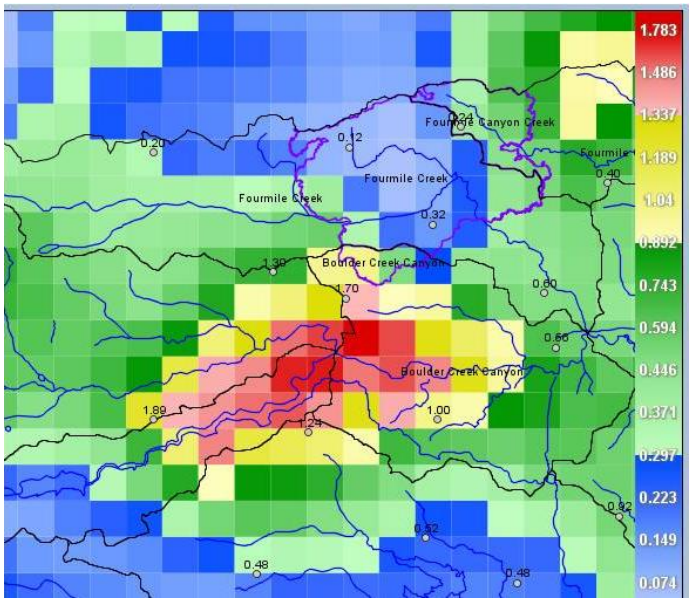
Wednesday, **May 11** was the first heavy rain threat of the 2011 flood season. Because of the reduced advisory and warning rainfall thresholds for the FMBA, the NWS issued a flash flood watch for this area. Emergency managers and response agencies were leaning forward as officials staffed the Boulder EOC preparing for the worst. At 8:58 AM, the Boulder Office of Emergency Management's director Mike Chard used their new Everbridge emergency notification system for the first time to activate weather spotters in the FMBA. Five volunteers responded immediately. The observed precipitation that day was a mixture of snow and rain with totals for the day approaching 2-inches in the lower elevations. In the FMBA most of the precipitation fell as snow, essentially eliminating the flood threat. Rainfall rate alarms from the FMBA occurred over the next two days due to melting snow that accumulated in the 12-inch diameter collector funnels.

One week later on **May 18** the NWS issued their second flash flood watch for the FMBA with similar results. This event did involve more rain than snow compared to the week prior but the rainfall intensities in the FMBA stayed below serious thresholds. Runoff from the event was observed by spotters but no damages were reported. Some heavier rain on the plains produced 24 hour totals approaching 3 inches with radar estimates exceeding 3 inches. Severe weather accompanied storm activity east of Boulder with tornado warnings being issued for northwest Adams County and eastern Broomfield.

Father's Day Sunday, **June 19**, produced a too-close-for-comfort late evening event that took aim at the FMBA and missed. The rainfall total for the Magnolia gage within the 5-mile radius was 0.94 inches. The gage also measured a peak 10-minute intensity that exceeded 3 in/hr at 10:46 PM. A small stream flood advisory was issued for the FMBA by the NWS at 11 pm, but measured rainfall totals over the burn area were only between 0.2 and 0.3-inches with no problems to report aside from a power outage.

Tuesday, **July 5** began a 15-day string of flash flood threat days for the District. The summer monsoon had officially arrived. The heavy rain potential was recognized early in the day by the NWS when they issued their 7:59 am flash flood watch for the FMBA. Later that morning the watch area was expanded to include the entire District. The day proved uneventful with 24-hour rainfall amounts not exceeding ½"

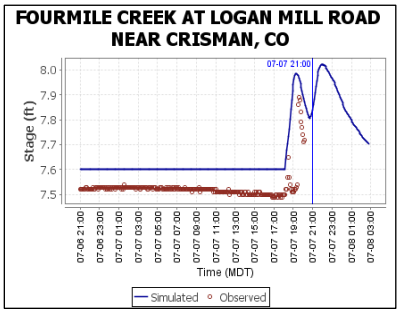
anywhere in the 7-county area served by the District. A flash flood watch was issued again for the FMBA the following day, **July 6**. Heavy rainfall was observed in northern Douglas County and northeast of DIA, but for Boulder County this day was another no show.



Radar-rainfall estimates between 5-8 pm, July 7

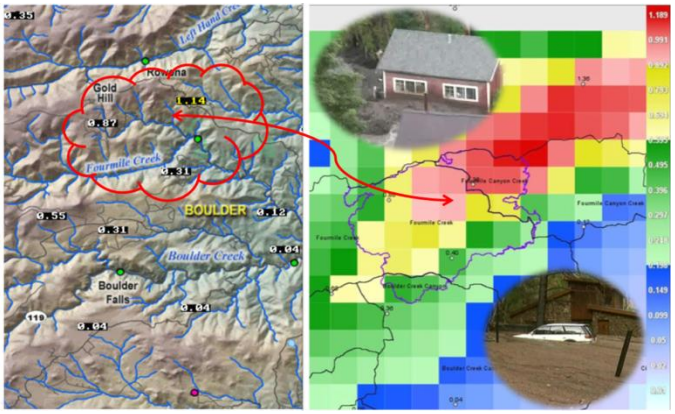
The NWS morning forecast models for Thursday, **July 7**, indicated a lower threat level than the prior two days. Therefore, a flash flood watch was not issued. By late afternoon a small amount of rain fell over the FMBA causing a 100-yard wide by 4-foot deep debris/rock/mud slide, forcing the closure of Fourmile Canyon Drive near Emerson Gulch where the 2010 fire started. The burn area rain was on the northern edge of a much larger storm cell that prompted the NWS to issue a flash flood warning for the FMBA at 6:19 pm as it approached (see above map). Fortunately the intense portion of the storm missed its target. Had the storm cell in Boulder County centered over the FMBA, the impacts in the burn area and downstream through Boulder would have been devastating. July 7 held its status as the largest heavy rainfall day of the year in the District (see later discussion).

July 7 also caused the biggest rain-related impact to the FMBA to date and it certainly drew considerable media attention. It is interesting to note just how low the rain measurements were, ranging from only 0.12 to 0.35 inches. To the south and southwest rainfall amounts in the Sugarloaf and Nederland areas totaled 1.73" and 2.01" respectively. One observer in the FMBA near Long Gulch did provide a report of 0.96" in 16-minutes. The Fourmile Creek gage at Logan Mill Road measured a rapid half-foot rise that was of little consequence. The largest rainfall measurements exceeded 3-inches in Denver and Aurora, and the ALERT system logged 117 rainfall rate alarms from 44 locations.



The first operational test of the real-time Vflo™ model showed promising results. The simulated hydrograph in the figure shows that the model predicted a 0.3-foot rise in stream level at about the right time. An observed rise of 0.4 feet was measured by the streamgage.

As of 7:50 pm, the WebEOC status board indicated no reports of any infrastructure damage other than road debris blockage in the FMBA, no homes impacted, electricity and phones working. The event summary also noted that people did evacuate to high ground with no injuries reported. Weather spotters were activated by officials at 6:13 pm. Prior to this, emergency management officials were leaning forward preparing for possible problems. The first District notification of a potential threat occurred at 12:13 pm when a Street Flood Advisory was issued indicating that strong and possible severe thunderstorms could produce 0.6" to 1.6" of rainfall in 10-30 minutes with up to 2.25" in 45-90 minutes possible. The prime time for flooding was from 2 to 7 pm. This forecast affected all 7 counties within the District.



Rainfall totals from the ALERT system and Radar estimates of rainfall that caused the flash flood of July 13, 2011

The flash flood of **July 13** will not be soon forgotten by FMBA residents, first responders, emergency managers, and many other county and city officials. A flash flood warning for the FMBA was issued at 6:17 pm. At 8:08 pm the warning was extended to include Boulder Canyon west of Boulder. Four-foot surges in water levels on Fourmile Creek were observed and publically reported. Sirens were sounded in Boulder at 8:20 pm and people reacted, some properly while others could have done better. At 8:37 pm the NWS issued a flood advisory (not a warning) that included the City of Boulder. Boulder Creek and Fourmile Canyon Creek on the north side presented concerns. Fortunately the impacts in the City of Boulder were minimal with Boulder Creek rising

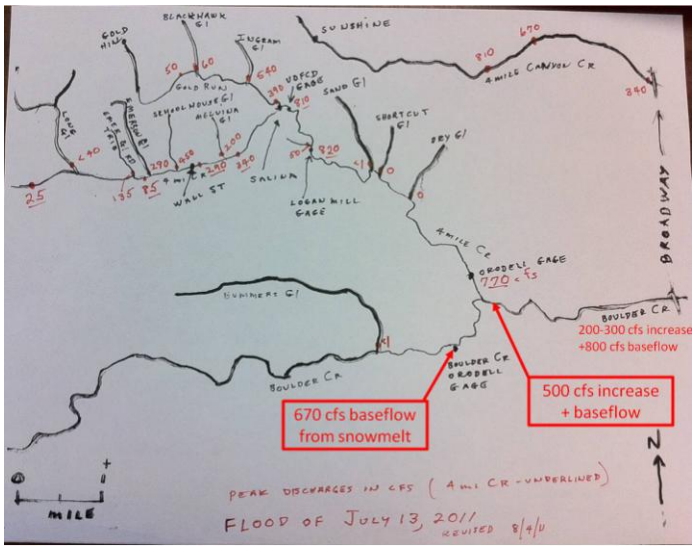
less than a foot and Fourmile Canyon Creek keeping within its flood channel for the most part with some basement damage reported.

Following are examples of some reports received from the field:

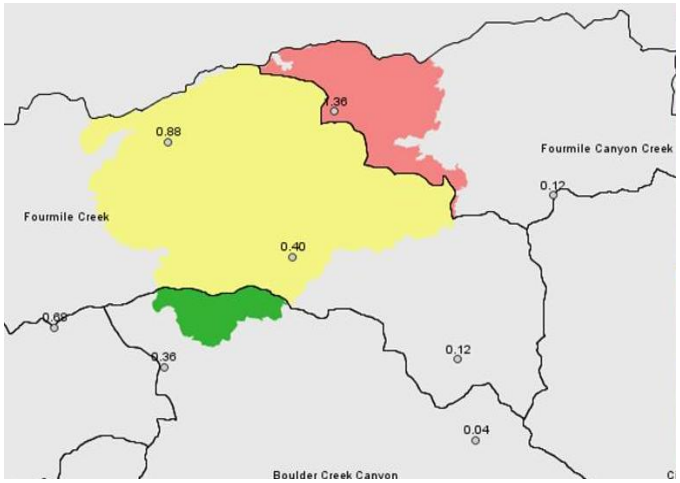
- 12 people stranded behind a washed out road were found safe.
- Lots of debris and rock on roads.
- Cars trapped between mud and trees.
- Sheriff Deputies saw debris flows and water over roads.
- Bridges and roads washed out.
- Large debris being carried by Fourmile Creek.
- At least 10 private properties, including some homes, were damaged.
- 4 people were treated for exposure and minor injuries at Gold Hill after being rescued. They were covered head-to-toe with mud.
- A fire department vehicle in route to a rescue was washing off Gold Run Road by raging floodwaters. Damages to the vehicle totaled $1,500. No one was hurt.
- Walls of water 6' to 10' high were observed by fire and Sheriff Department officials at a number of locations in both the Fourmile Creek and Fourmile Canyon Creek drainages. Ingram Gulch was one of those locations.
- Surprisingly slow movement of "walls of water" was observed.

From the perspective of an engineer or hydrologist, the following data-driven timeline for July 13 may be of interest:

5:24pm first message concerning FMBA heavy rain threat
5:53pm NWS issues small stream flood advisory for FMBA
6:06pm first ¼" rainfall rate alarm within 5 miles of FMBA
6:15pm first ¼" rain alarm in FMBA at Gold Hill
6:17pm **NWS issues flash flood warning for FMBA**
6:22pm ¼" rain alarm in FMBA at Sunshine
6:28pm first ½" rain alarm at Gold Hill
6:33pm ½" rain alarm at Sunshine
6:47pm first ¾" rain alarm at Gold Hill
6:50pm ¾" rain alarm at Sunshine
6:54pm Fourmile Creek at Salina gage detects small rise
6:55pm 1" rain alarm at Sunshine
7:05pm FM Creek at Logan Mill Road gage detects rise
7:20pm FM Creek at Logan Mill peaks showing 4' rise.
Actual peak time was later estimated to have occurred at 7:17pm and 0.8' higher than the 7:20 pm measurement.
8:00pm FM Creek at Orodell gage measures 2' increase compared to the reading 5 minutes earlier. Boulder Creek flow rate 670 cfs from snowmelt.
8:04pm Boulder Creek gage downstream of Fourmile Creek detects small rise.
8:05pm FM Creek at Orodell crests showing a total stream level rise of just under 3' in the past 10 minutes.
Rise at this location captured nicely by the live webcam.
8:11pm Boulder Creek peaks downstream of FM Creek after rising 1.2 feet in 7 minutes, corresponding to a 500 cfs increase in streamflow.
8:15pm Boulder Creek near the public library is flowing at about 800 cfs, well above average due to late mountain snowmelt runoff. At this point in time Boulder Creek levels through Boulder have not been affected by Fourmile Creek, the confluence of which is located approximately 2 miles upstream.
8:20pm **Sirens sounded in Boulder**
8:30pm Boulder Creek at Boulder measures a 0.2-foot rise from the prior 8:15pm reading.
8:45pm The Boulder Creek library gage peaks, showing only a 0.4-foot rise since 8pm and corresponding to a flow rate increase of just over 200 cfs.
Since the gage only reports every 15 minutes, it is likely that the actual increase was slightly higher. Another streamgage located a short distance downstream below Broadway measured a discharge increase of 260 cfs and a rise of 0.5 feet between 8:12 and 8:42pm.

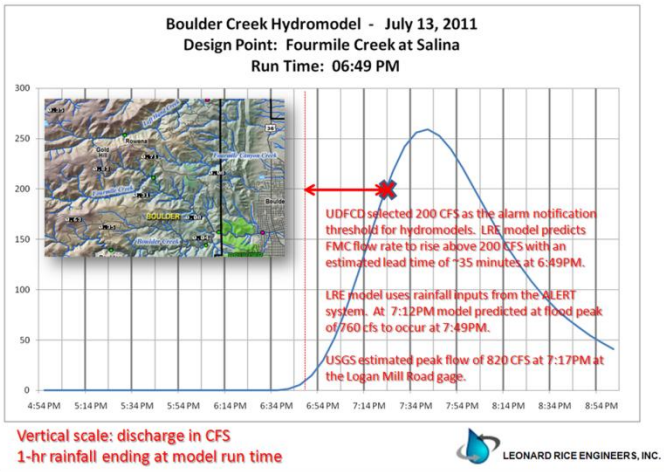


Drawing by Bob Jarrett with USGS showing peak discharge estimates for July 13 from field surveys. Additional added text pertains to Boulder Creek streamgage measurements. Note the 540 CFS estimate for Ingram Gulch, which drains ~400 acres. The Sunshine ALERT rain gage is located at the top of this drainage.



Colors represent Radar estimates of average rainfall over the FMBA by watershed thru 9PM. The yellow area (Fourmile Creek drainage) reflects an average rainfall of 0.7". The red area (Fourmile Canyon Creek drainage) reflects an average of 1.2". The green area (Bummers Gulch drainage) averaged 0.5". The numbers are ALERT rain gage totals. Sunshine measured the highest amount of 1.36".

Note that Fourmile Canyon Creek (FMC^2) and Fourmile Creek/Boulder Creek behaved similarly. Both had flood peaks of approximately 800 cfs immediately downstream of the FMBA—both streams attenuated their flood peaks by more than 50% before reaching the City—and at the Broadway crossings, both streams (Boulder Creek & FMC^2) experienced flow increases of 300 cfs, more or less. Unlike Boulder Creek, there are no historic gage records for FMC^2 but from historic accounts it is very likely that this was the largest flood seen here in many decades. The paleoflood evidence gathered by Bob Jarrett further supports this opinion.



By July 13, the jury was still out concerning how trustworthy the real-time hydrologic models would prove to be due to a lack of runoff data to validate the models. The Vflo™ model mentioned previously (see July 7) performed well at predicting the timing of the flood, but the model overestimated flood peaks on Fourmile Creek by 50%. The Vflo™ timing accuracy may have resulted from using Radar-estimated rainfall with the physics-based model. The LRE model is a unit graph-based lumped parameter model that uses rainfall inputs estimated from the ALERT rain gage data. This model did an excellent job of predicting peak flows (see above figure), but was a little slow in estimating flood arrival times. Using the data collected on July 13, both models will be recalibrated for 2012 operations. Training on the use of these models is still needed and user interface improvements are also anticipated.

Situational awareness throughout the event was good, but forecasting flood impacts was somewhat problematic. The July 13 event certainly gave everyone involved a much clearer picture about what can be expected from just over an inch of rain in one hour over the burn area. The data collected from this event provides forecasters the opportunity to refine warning decision thresholds and gives modelers valuable calibration information to make more accurate and timely flood predictions. A "hot wash" debriefing was held the following morning and action items were identified to further improve the system. During the July 14 debrief, a flash flood watch was received and EOC operations began again.

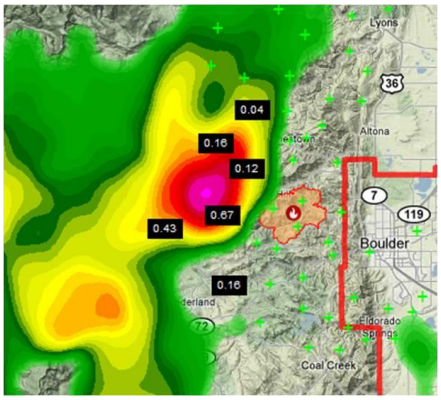
In hindsight, the siren sounding in Boulder may not have been necessary but that action did provide a unique opportunity to assess the public's response to the warning. This experience may help save lives in the future.

Many YouTube videos are available of this flood and its impacts. The District has also archived many local news broadcasts of the event. Two of these can be watched from the District's UD-Tube website.

Similar to July 7, the threat of heavy rain for July 13 was not nearly as great as the days leading up to it. There was no flash flood watch in effect, but the NWS did issue a small stream flood advisory for the FMBA concerning low impact flooding. Although the early forecast threat was considered low, emergency service personnel did not let their guard down and many can be thankful that they did not. Also, the focused and repetitive public education efforts leading up to the flood by mountain fire departments, emergency managers, public information experts, other local officials, and the news media played a huge role in saving lives. No lives were lost on July 13. Now that's a success story!

For the next 6 days Boulder officials continued leaning forward and monitoring conditions from the EOC. Heavy rainfall on Thursday, **July 14** resulted in another flash flood warning for the FMBA, this time with far less consequence as rainfall amounts over the burn area totaled less than half the prior day's rain. One storm south of the BA did measure ½" in 10 minutes around 5PM.

The next FMBA flash flood warning happened on Saturday, **July 16** at 3:46 pm, and like the 14th with nothing serious occurring.



The next day, **July 17**, produced another too-close-for-comfort storm that brushed the west side of the FMBA, resulting in a flash flood warning for Nederland and Eldora at 3:44 pm. Doppler radar estimated that up to 2" of rain had fallen in the past 30 minutes. Again, the FMBA was not impacted.

Two days later on Tuesday, **July 19**, the EOC remained staffed for the 15th consecutive day and once again heavy rains fell very near the FMBA with the ALERT gage at Twin Sisters measuring a ¾" per hour rate at 3:57 pm and accumulating 0.91" from a localized storm. The NWS issued a flash flood watch at 11:13 am for a large area in northeast Colorado above 6,000 feet. They later issued their final FMBA flash flood warning of the year in Boulder County at 3:27 pm. The burn area only received a trace of rain from this event. Another fortunate miss!

The remainder of July, August and September were relatively uneventful for Boulder County officials and most of the FMBA residents. Some debris movement in the Ingram Gulch area was observed from rain showers occurring over **September 6 and 7.** At least one home was affected by a mudslide around 3AM on the 7th. No watches or warnings were in effect for this event. It's hard to catch them all.

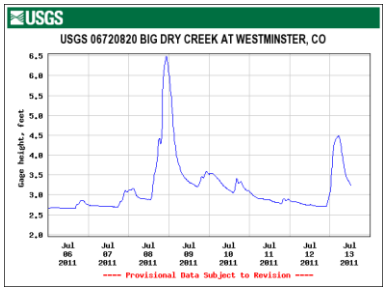
With the District's flood season operations ending on September 15, it seemed fitting that another final round of moderately intense rainfall would again occur in the FMBA. Low level ¼"/hr alarms began within the 5-mile radius at 7:17 pm on Wednesday, **September 14**, with the "adios" alarm occurring at 1:01 am on the 15th. The first email alert message from the Vflo™ hydromodel—a new procedure implemented after July 13—was received by EOC officials indicating a predicted flow of 211 cfs at 06727410 (USGS Logan Mill streamgage) at 2011/09/15 00:35:00 MDT. Fourmile Creek, however, ignored this prediction and flowed at normal levels throughout the night.

Main Events Elsewhere in the District

Arvada's biggest rainstorm of the year occurred on the afternoon of Wednesday, **May 18**. Annual high water measurements were recorded on Ralston Creek and Leyden Creek between 1PM and 2PM. Maximum rainfall totals exceeded 2-inches in Arvada and along the I-25 corridor east of Broomfield where radar estimates exceeded 3-inches.

As pointed out previously in the Boulder County recap, Thursday, **July 7** was the District's biggest rain day of 2011. This was the 3rd day of the summer monsoon season, which arrived on July 5 with the NWS issuing a flash flood watch for the entire District and nothing much happening. On July 7 the rainstorms finally did appear with many flash flood and severe thunderstorm warnings being issued, affecting Adams, Arapahoe, Boulder, Denver and Jefferson Counties. The map on the following page shows the extent of measurements made by the ALERT system and volunteer CoCoRaHS observers. The largest storm totals exceeded 3-inches in the Westerly Creek basin located in Denver and Aurora. Many other rain gages recorded amounts over 2-inches. The EMWIN-Denver Regional system delivered 81 separate NWS products to subscribers. Denver officials reported that storm sewer manholes popped their covers at over 50 locations.

Annual peak flows were recorded for Van Bibber Creek in Arvada; Westerly Creek in Denver and Aurora; Toll Gate Creek, Sable Ditch and Granby Ditch in Aurora; and Sand Creek in Commerce City where the peak flow exceeded 7,500 cfs at 8:07 pm, setting a new record for that gaging station.



Big Dry Creek in Westminster was running well above normal from yesterday's downpour when additional heavy rains fell on Friday, **July 8**, causing the creek to experience its highest flow in recent years—quickly rising over 3.5 feet and setting a new record peak, its highest since 1987. The storm that caused this was localized with maximum rainfall amounts approaching 2.5 inches. Intense rainfall was measured in Broomfield, Thornton and Westminster.

Tuesday, **July 12** was another area-wide rain day for the District. Annual peaks were measured in Denver on Cherry Creek, Lakewood Gulch, Sanderson Gulch, and the South Platte River. The Sanderson Gulch and Lakewood Gulch stream gages set new records. While the rain totals in the District were mostly under 2-inches, a large nearby storm in Elbert County had reports of rainfall exceeding 5 inches. ALERT rain alarm thresholds were exceeded at 23 stations.

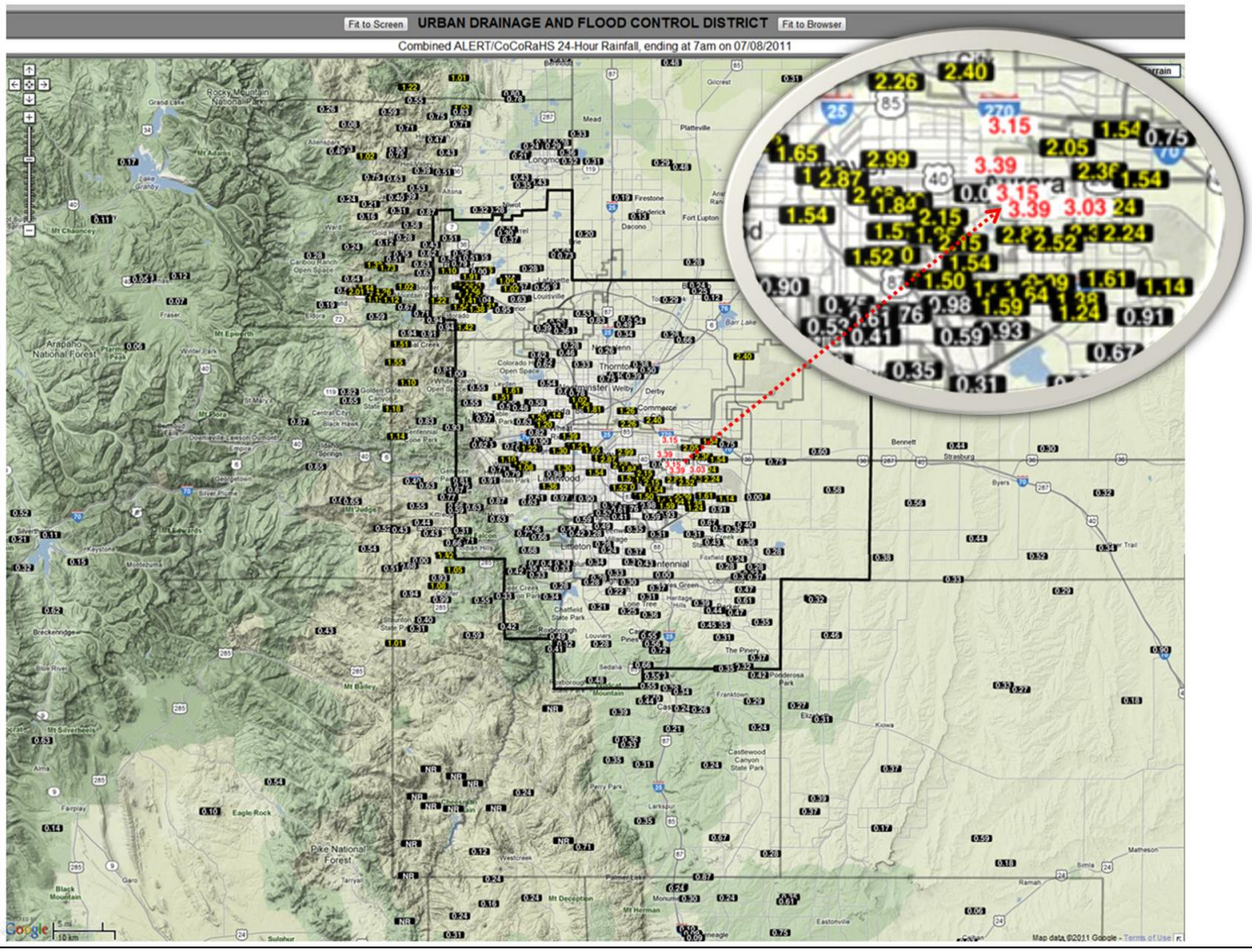
While most of the attention this day, **July 13**, was focused on the Fourmile Burn Area in Boulder County and the flash flood warning issued by the City of Boulder, a few other locations deserve honorable mention. Besides Boulder Creek and Fourmile Creek, annual streamflow peaks occurred also on Goldsmith Gulch in Denver; West Toll Gate Creek in Aurora; Lena Gulch in Jefferson County, Golden and Lakewood; the South Platte River in Adams County; and on Sulphur Gulch in Parker.

This Thursday, **July 14,** ended in tragedy when an Aurora teenager fell into Toll Gate Creek near its confluence with Sand Creek. The creek was flowing above normal but well below flood levels from rains over the past 3 days when the accident happened. The heavy rainfall this day occurred to the west in Denver and Arapahoe Counties where annual peaks were recorded for Harvard Gulch and Goldsmith Gulch at Iliff Ave. in Denver; and at Powers Parks on Slaughterhouse Gulch in Littleton between 3:00 and 3:30 pm.

Tuesday, **August 2** was the last flash flood watch day for the District, which ended without incident. The rest of the month remained very dry in the District. After what happened in July, we certainly deserved a break.

Hayman Flood Threat Nine Years Later

The Hayman Burn Area in southwest Douglas County experienced another debris-loaded flash flood on this Friday afternoon, **July 29**. The NWS issued a small stream flood advisory for this area at 3:54 pm. Trained weather spotters reported 1.2-inches of rain, consistent with Radar-estimated amounts. While flood damages were minimal, an impressive amount of debris once again accompanied the storm runoff as shown in the August 1 photo provided by the USGS. It is interesting to note that this type of impact is still occurring from such a small rainfall event so long after the 2002 fire that burned over 138,000 acres. Should those living in the Fourmile Burn Area in Boulder County expect the same?



A data-rich environment…rainfall totals for PM July 7, 2011

Early Flood Prediction and Notification Services

Meteorological support was provided by Genesis Weather Solutions in partnership with Skyview Weather for the fifth consecutive year. This program provides District local governments with early predictions of potential and imminent flood threats along with a variety of related forecast products like daily heavy precipitation outlooks, area-specific quantitative precipitation forecasts (QPF), and storm track maps. Project manager and chief meteorologist Bryan Rappolt completed his 18th year of service. Bryan's Skyview partners included lead forecaster Brad Simmons, met-techs Chris Anderson and Daryl Brynda, with Skyview's President Tim Tonge providing backup from his business location and forecast center in Castle Rock. This District program was established after the deadly 1976 Big Thompson Canyon flash flood and has served the Denver/Boulder metropolitan area for the past 33 years.

The Flash Flood Prediction Program, a.k.a. F2P2, operates from 15 April through 15 September in close partnership with the National Weather Service Forecast Office in Boulder. The F2P2 forecasts and early notifications focus primarily on heavy rain threats over approximately 3,000 square miles covering the District and watersheds upstream. During the mountain snowmelt runoff season from late spring to early summer, local governments are also kept advised concerning stream conditions and how those high flows increase the flood potential when heavy rain threatens. F2P2 notifications concerning high reservoir releases by the Tri-Lakes Office of the U.S. Army Corps of Engineers from Chatfield, Cherry Creek and Bear Creek dams are also disseminated to affected jurisdictions downstream.

F2P2 products and services were evaluated for the fifth consecutive year by Judy Peratt of JP Consulting, located in Windsor. Judy is a former emergency management director that served Jefferson County for many years. This face-to-face interview process has helped the District learn details about what works well and what could use improvement from an end-user perspective. The District greatly appreciates the valuable time taken by all the participating local officials representing emergency management, communications, public works and emergency services.

Some program changes are likely for 2012. The term "Red Flood Alert" (RFA) has long been used in the F2P2 to notify local governments when low impact flooding is likely. This product is similar to a Flash Flood Warning (F2P2 Message 3) that is used to warn of imminent threats to life and property. The once "familiar" code now confuses many users, especially

those who are new to the program. As more people gain access to this information, keeping users educated about code words becomes problematic. For example, the RFA can easily be confused with the NWS Red Flag Warning that pertains to fire weather conditions. Also, local jurisdictions commonly use colors to designate emergency status or threat levels that correspond to specific operational procedures. Using RFA as an add-on or update to a previous message is also at times misleading. One remedy suggested during Judy's interviews is to make the RFA a stand-alone message. Another good idea is to change its name to something with clear meaning, i.e. use plain language. The Boulder Office of Emergency Management has offered to assist the District with designing an acceptable alternative for 2012 by bringing together key stakeholders to share their experiences from last summer. The Fourmile Burn Area threat may be the perfect test-bed for a new F2P2 messaging procedure. If the changes can pass this test, the change should be widely accepted by others. The District is excited about this unique opportunity to greatly improve public safety communications.

Visit f2p2.udfcd.org for more information about the F2P2 products and services.

CoCoRaHS Update

Thirteen years ago this past June 17, three high school students in Fort Collins launched the first "CoCoRaHS" website. This innovative idea was a positive response to the deadly flash flood the struck that community in July of 1997. Today the Community Collaborative Rain, Hail and Snow Network is active in all 50 states and holds the distinction of being the largest provider of daily precipitation observations in the country. In December the province of Manitoba became the first Canadian community to join.

Efforts were underway this year by the CoCoRaHS team to gear-up for a school-based outreach program in 2012 for the Denver area. Their plans entail developing a special web resource page that includes lesson plans for elementary, middle school and high school teachers.

The District has been a sponsor of CoCoRaHS for over a decade and routinely makes use of this valuable data. The past 5 years of web-posted storm summary maps are a good example. Please consider becoming a CoCoRaHS observer today by signing up at www.cocorahs.org.

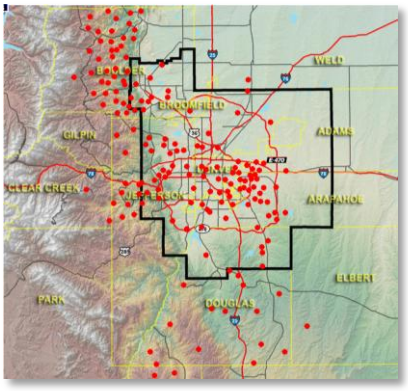
EMWIN-Denver Regional Update

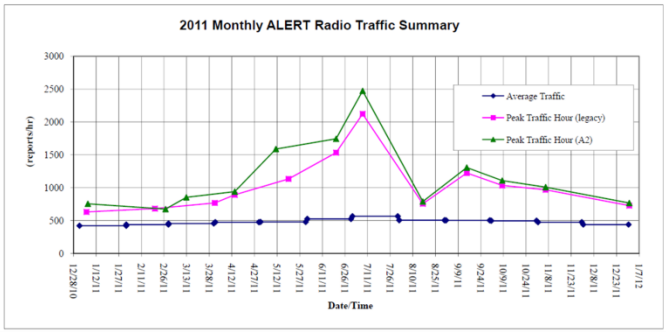
The Emergency Managers Weather Information Network continues to provide northeast Colorado communities with timely NWS weather warnings and advisories. The District currently hosts the subscription-based email service for this regional system. EMWIN-DR is guided by a steering committee chaired by Rick Newman with the Adams County Office of Emergency Management. In 2011 the web-based EAS (Emergency Alert System) activation request procedure was completed, thus providing local government officials with a simple and secure way to notify the public concerning non-weather emergencies. All EAS activation requests are verified by the NWS before alerting the public.

ALERT System News

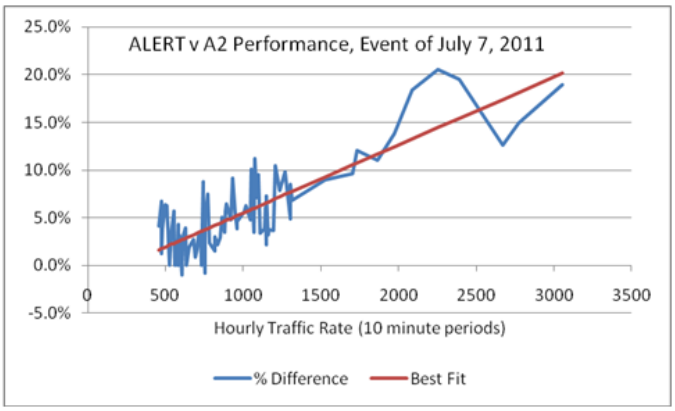
New gaging station on Happy Canyon Creek at I-25 in Douglas County.

The ALERT system currently collects data from 214 gaging stations that host 191 rain gages, 103 stream gages and 25 full weather stations. The gauging network experienced some rearrangement and growth in 2011. On the District's south side, Douglas County installed two new combination rain/steam gages on East Cherry Creek at Russellville Road and on East Plum Creek at Columbine Open Space. They also relocated eight stations from the Hayman burn area and added stream level sensors to four of those stations on Happy Canyon Creek at North Surrey Ridge, Newlin Gulch at Jordan Road in Parker, Tallman Gulch at Tallman Park near Parker, and on Big Dry Creek at Highland Heritage Regional Park near Lone Tree. One of the relocated Hayman stations at Bingham Lake Park was upgraded to full weather station status. In the northwest portion of the District a new rain/stream gage was installed on South Boulder Creek at South Boulder Road by City of Boulder Open Space and Mountain Parks.





OneRain and Water & Earth Technologies provided preventative maintenance and repair services for 2011, enabling the District to process over 4.2 million ALERT messages and more than double that amount when counting the ALERT2™ data stream. During the storm activity of July 7 the peak traffic rate briefly exceeded 3,000 reports per hour between 5:10 and 5:20 PM.



For the second consecutive year, ALERT2™ vs. ALERT legacy comparisons revealed that the newly developed A2 protocol consistently outperforms its predecessor. The legacy protocol that was first deployed in California in the mid-1970's continues to prove its value, especially for smaller gauging networks. However, when networks become as large as the District's, data collection reliability starts to degrade. Consequently, the District is prepared to take the next logical step in 2012 toward full A2 implementation by upgrading existing ALERT repeater sites to enable both receiving and rebroadcasting the enhanced protocol.

In 2011 the District began testing another new way to relay data from a radio path challenged ALERT rain gage in Douglas County—the Rampart Range Road station near Roxborough Park. The Sutron Corporation voluntarily provided the telemetry that utilizes 66 Low Earth Orbit Iridium satellites. Although the gaging station appears to perform very well, a few surface-based communication bugs still need be resolved. We are confident that systems like this offer affordable options when radio repeater networks prove inadequate.

The District has arrived at a critical crossroads in its support of existing ALERT data collection platforms commonly referred to as base stations. These base stations are comprised of radio reception and data decoding equipment that connect to aging PCs that run an operating system called QNX and proprietary software known as NovaStar. There are six locations in Denver, Douglas County, Lakewood and Boulder that currently host the QNX/NS-4 base stations and most of these sites have been operating continuously since Y2K…remember that event? These platforms also host webserver software, enabling users to access the real-time data from any desktop/notebook computer or any other smart device with Internet browsing capability. After 12 years of success using this aging technology, the time has arrived for a more sustainable approach to be implemented.

In 2012 the District will upgrade two base stations using the latest available NovaStar software and a more widely-accepted Linux operating system. Plans include developing a second receive site not at Diamond Hill (the District's office building) with failover capabilities in the event Diamond Hill somehow becomes disabled. A third site running a different software package known as Contrail Web is also being considered. With this hardened base station network design in place, the proliferation of base stations that currently exists will be much less desirable or necessary for backup data access. The new architecture will also greatly simplify database maintenance activities and reduce associated costs.

The updated equipment will provide new opportunities to consolidate useful data from other non-ALERT sources such as the satellite-monitored streamgages operated by the USGS and the Colorado Division of Water Resources (DWR). With respect to flash floods and effective use of real-time data—one stop shopping, data display familiarity, early threat recognition, longer lead times, and simplified decision support are highly desired attributes that can be difficult to achieve at times and even harder to fully satisfy every user's wishes. The District remains committed to reaching these long term goals and will do so with the help of our many partner agencies.

Speaking of partner agencies, the City of Boulder IT and Public Works departments implemented a creative way to educate the public about streamflow by linking smart phones to real-time water level measurements while observing high flows on Boulder Creek from an unusually late spring runoff. A free QR "Quick Response" Code reader app is all that's required to access the corresponding streamgage URL. B-smart signs were attached to Muni and Library footbridges over Boulder Creek near Broadway, to the flash flood area warning signs in Peach Park, and to the DWR streamgage located between 9th Street and Broadway. Credit goes to Leslie Labrecque, Jody Jacobsen, Kurt Bauer, Bob Harberg and Kip White for making this innovative idea a reality. Now if someone can just find a way to keep people from taking these nifty green signs.

Resources

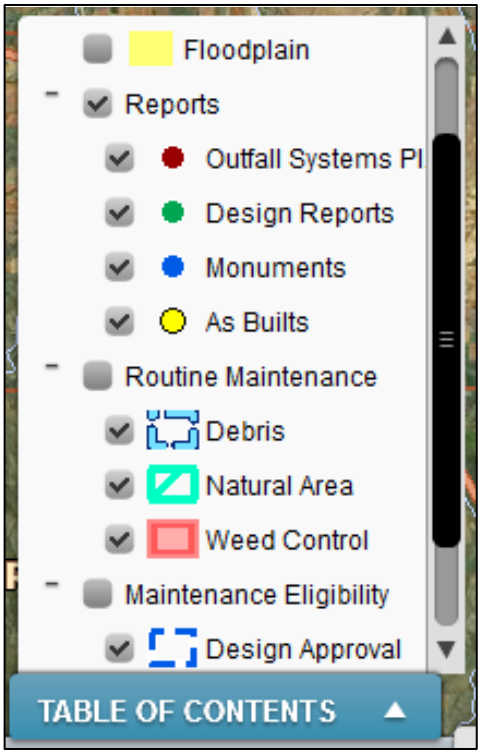
A complete archive of daily forecasts, flood threat notifications, storm track predictions, storm summary maps, and other products can be found at f2p2.udfcd.org. See www.udfcd.org/FWP/ALERT/wl/annual_peaks.xlsx for an up-to-date table of annual and record water level/streamflow peaks measured by the ALERT system. For detailed operation and maintenance reports visit:

www.udfcd.org/FWP/ALERT_Reports/ and
www.udfcd.org/FWP/F2P2_Reports/

Electronic Data Management Application Update

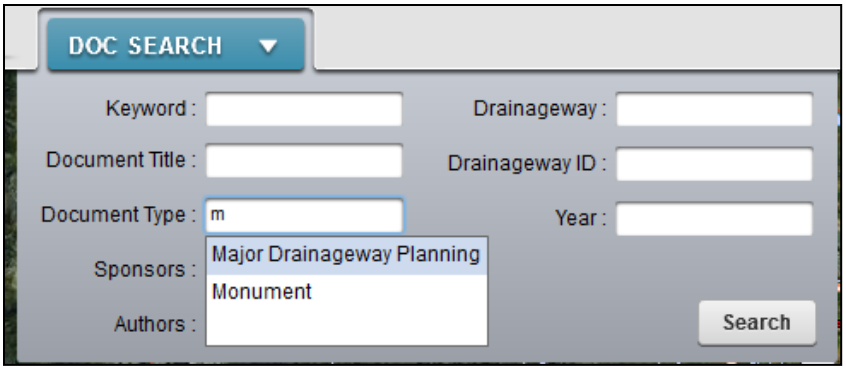
Julia Bailey, Information Services Engineer, Information Services and Flood Warning Program

The District's Electronic Data Management (EDM) web mapping interface was updated late in 2011. With the goal of making the application more user-friendly, the tabbed approach has been replaced by layer control through a Table of Contents (TOC). Users can turn layers on or off based on preference and have the flexibility to choose to see different combinations of layers. A complication in allowing the user to control layer visibility is going to be when line work doesn't match up. For example, a stream centerline showing maintenance eligibility will not be perfectly aligned with a stream centerline for routine maintenance.



The previous tabbed interface model allowed for different functionality on each tab. For the current version, GIS Workshop Inc. was tasked with linking specific functionality to the TOC layer control. For instance, the floodplain tab in the earlier version had a slider bar to control the transparency of the 100-year floodplain layer. This functionality still exists; however, the slider bar is only accessible when the 100-yr Floodplain layer is turned on from the TOC.

Also new in 2011 is a document search form. Before, the user could enter a keyword to search for documents. This keyword could be the document name, author, sponsor or related drainageway. Now, the user can enter one or many of the related document attributes: title, report type, sponsor, author, drainageway name, drainageway ID, or publication year in form fields with smart auto text selectors. The user can also enter a keyword that will return results from all attribute fields. The search results are displayed in table format with the ability to filter by report type, major basin, sponsor, and author. The filters are not cascading; however, this feature will be added in a future update. For instance, cascading filter functionality would allow the user to select an author from the filter menu and then click on the sponsor filter and see only sponsors that are related to documents filtered by the selected author. The number of documents found based on the original search criteria is shown in the top left corner of the table.



In an effort to keep the map looking as clean as possible the new graphic design utilizes pull out menus such as the document search form and the TOC. It has also minimized the map navigation zoom-to options into a single line with scrolling capability. Users can click the up and down arrows to change Zoom-To options from address (default) to stream, stream crossing, confluence, or Section-Township-Range. The address search is now using the Google geocode API.

Another positive change was to modify the disclaimer popup windows on the floodplain and maintenance eligibility tabs. There is now a single popup window when the application is first accessed that combines disclaimers and new tabs for help information, external links, contact information, and FAQ. Next year we anticipate adding short how-to videos to the help tab. Other enhancements planned in the near future include adding District activity summary polygons and historical flood information and flood videos.

Since the public release of the EDM interface in April of 2010, there has been a lot of positive feedback and suggestions from our user community. I'd like to thank those who submitted feedback that helped us debug the application and guide development towards more user-friendly functionality.

Design, Construction & Maintenance Program

Dave Bennetts, PE, CFM, Program Manager and Laura Kroeger, PE, Assistant Program Manager

CIP and Work Plan

The DCM program is funded by three different legislative authorizations; the Construction Fund, the Maintenance Fund, and the South Platte River Fund. Each year the District prepares a work plan for each of the funds. The 5-year Capital Improvement Plan (CIP) lists capital construction projects by county for the Construction and South Platte River funds. The CIP shows the District's financial participation, which will be matched by the participating local governments, for a 5 year window of time. This allows both the District and local government partners to plan funding levels into the future.

The Maintenance Work Plan lists projects for the Maintenance and South Platte River funds. Work is listed by county, category of work, the local government where the work is located, project location, description of work, and the estimated cost. Maintenance work is funded entirely by the District. Both the 5-year CIP and Maintenenace Work Plan are developed based on prioritized project requests from local governments. Copies of both of these plans are available on the District's website: http://www.udfcd.org/design_const_maint/dcm_home.html.

Routine Maintenance

Routine maintenance provides basic flood control maintenance along the major drainageways within the District. Services typically performed include mowing, trash and debris removal, weed control, and tree thinning. As part of the District's efforts to provide sustainable services, new ideas are being tried to better manage the drainageways. For example, the frequency of mowing cycles has been reduced in some areas. When this is combined with an aggressive noxious weed control program healthy vegetation can still be maintained, but with fewer site visits. In addition if more suitable vegetation is selected, like low mature plant height, this will reduce maintenance needs even further.

The success of this reduced maintenance approach depends on how the public views the changes. With fewer site visits the perception could be that the drainageways are not receiving maintenance that they need, or traditionally received. With that in mind, the District is continuing the process of developing an education brochure that will discuss the revised approach and the reasoning behind it. It will also address the benefits of a natural drainageway such has habitat and water quality benefits, as well as aesthetics. Once this information is developed, it will be available on the website to help educate the public on the efforts to provide a more sustainable routine maintenance program.

The District is currently maintaining over 300 drainageways and has spent $1,278,495 in 2010 for Routine Maintenance. Private contractors are hired each year to perform the maintenance on a unit price basis. The District's website has maps of the routine work broken down by county, major drainageway and reach.

Restoration Maintenance

Restoration work is site specific construction work to address isolated drainageway problems that are included in the Maintenance Eligibility Program. This work often mitigates the need for more costly improvements in the future. Types of restoration activities include: sediment removal, local erosion repair and bank protection, drop structure repair, and channel grading, stabilization, and revegetation. All of this work is accomplished using private contractors either through a public bidding process or a pre-qualified contractor selection process. In 2011, the District completed $ 7,741,499 of restoration work.

Design and Construction Projects

Design and construction projects implement master planned improvements. Generally, the District manages final designs prepared by consulting engineers. The local governments are involved in all aspects of the design process, and usually acquire any necessary ROW. Projects are publically bid for construction. In 2011 the District encumbered approximately $9,576,700 for construction projects. Below is a brief outline of a few capital and maintenance projects that have been recently completed:

Adams County

In the summer of 2011 the City of Thornton and the District completed channel improvements along **Grange Hall Creek** from the 108th Avenue to Riverdale Road. Grange Hall Creek and its tributaries flow east through portions of the City of Northglenn and the City of Thornton, before draining into the South Platte River north of 104th Avenue. As can be seen in the "before" photo below, the creek had become significantly down cut with eroding side slopes up to 15 feet tall and exposed utilities including a trunk sanitary sewer that had become an aerial crossing. Nearby schools make this a high traffic pedestrian area, and the vertical banks posed a safety risk to trail users.

The improvements included re-aligning the sanitary sewer to move it away from the creek, installation of grouted boulder drop structures, laying back eroded side slopes, and the installation of wrapped soil lifts. Wrapped soil lifts were used in areas of steeper side slopes up to 2-to-1. The wrapped soil lifts were planted with willow stakes harvested from an adjacent stand of willows, upland shrubs, and cottonwood poles.

In the summer of 2011 the City of Brighton and the District partnered to install Phase I of the **North Outfall**

Grange Hall Creek before and after

Storm Sewer improvement project. This project will provide much needed storm sewer improvements for the greater part of downtown Brighton.

Phase I completed the downstream portion of the new storm sewer from the South Platte River, across Highway 85, and along Denver Street to just west of Main Street. The first phase included construction of a new channel outfall, re-alignment of several existing sanitary trunk sewers up to 24-inch diameter, and installation of approximately 2,000 linear feet of storm sewer up to 78-inch diameter. The storm sewer reached depths of up to 25 feet, and the project included a carefully planned detour along Highway 85 that lasted several months and allowed for phased open cut construction of the storm sewer and sanitary sewer improvements. The future second phase of the project will extend the storm sewer through an existing rail yard and past the Fulton Ditch, to a connection with the existing storm sewer system in Midland Street.

In the summer of 2011 Adams County and the District partnered to construct phases III and IV of the **Dahlia Pond/Kenwood Outfall** storm sewer. The Dahlia Pond portion of the project included formalizing the pond outfall and constructing a 54-inch diameter outfall pipe across Interstate 76. The outfall pipe construction used micro tunneling trenchless technology, as I-76 could not be detoured to accommodate open cut construction. Micro tunneling technology was necessary because of the presence of high groundwater and highly flow able soils, which would prove problematic for conventional tunneling methods. The 200-foot long 54-inch diameter tunnel was completed without any inconveniences to the traveling public.

The Kenwood Outfall storm sewer discharges to the Dahlia Pond. The outfall construction included tunneling underneath the O'Brian Canal. A previous attempt to tunnel under the O'Brian Canal had failed, with sinkholes forming along the canal bottom and construction subsequently halted. The first tunnel drive stopped just south of the upper bank of the canal, but did not extend past a major sanitary sewer that had to be avoided. The second tunneling effort came from the opposite direction using conventional hand tunneling, and successfully connected with the original tunnel drive underground while completely avoiding disruptions to the sanitary sewer and the canal. Future phases of the project will extend the Kenwood Outfall storm sewer further south and east across Highway 85 and across the Union Pacific Railroad tracks.

In the summer of 2011 the City of Westminster, Adams County, and the District partnered to construct the **Shaw Heights Tributary** Drainage Improvements. The Shaw Heights project provided much needed improvements to the existing storm sewer system in an older residential neighborhood. Runoff from an area of approximately 270 acres drains down Shaw Boulevard to a sump located in a "T" intersection at Circle Drive where a single Type R Inlet captured runoff and conveyed it in a 24-inch storm sewer pipe to the Allen Ditch. A single family residence at this intersection experienced frequent flooding as the inlet would be overwhelmed by runoff and occasionally become clogged due to sediment

North Outfall pipeline construction and finished outfall channel

Shaw Heights Tributary completed 45-foot special curb inlet

loading from an upstream agricultural area.

This project installed a special 45-foot long open throat sump inlet that will capture the 10-year storm and convey it to a new storm sewer along Circle Drive. An overflow was constructed to convey runoff in excess of the 10-year storm from the inlet to the Allen Ditch. The new storm sewer along Circle Drive drains to an enlarged storm sewer system along Wagner Drive that replaced an older undersized system. The Wagner Drive storm sewer outfall flows into the detention pond at Rotary Park, which was built in 1990 as a previous District project. Improvements were made to the Allen Ditch to provide a controlled spill location so that single family residences along the ditch can be protected from storm runoff intercepted and conveyed by the ditch.

Arapahoe County

The District and the City of Greenwood Village (Greenwood Village) completed a capital project on **Little Dry Creek at Platte Avenue (extended),** located northeast of Long Road and Steele Street. The stream had cut down to claystone bedrock and eroded vertical banks up to 18 feet tall. The project used grouted boulder drop structures for grade control and grouted boulder edging, soil riprap, willow fascines, and soil wraps (reinforced with geo-synthetics, riprap, and vegetation) for bank protection. An equestrian crossing was incorporated into one of the grouted boulder drop structures. In several areas, the low flow channel was flipped from one side of a cottonwood gallery to the other. This approach allowed the eroded bank to be repaired and the cottonwood gallery to be saved.

The District, City of Littleton and South Suburban Parks and Recreation District completed a maintenance project on **Lee Gulch at the Highline Canal,** located southwest of Broadway and Dry Creek Road. The existing undersized culverts would over top in storm events effectively closing the trail. Constant erosion of the channel was another problem. The project provided grade control with the construction of a boulder drop structure. The banks were protected with boulder edging and soil riprap. The old corrugated metal pipes were replaced with a concrete box culvert. The new crossing allows year round use of the trail and improved maintenance access. Willows and native grasses were planted in the disturbed areas. The project was put to the test right away with high flows from the storm season and the flushing of the Highline Canal. The project held up well with no damage observed.

Lee Gulch at the High Line Canal after construction

Little Dry Creek before and after

Boulder County

Rock Creek was experiencing vertical and lateral channel erosion in the project reach. Low flow channel erosion had caused large cottonwood trees to fall, and there were additional large cottonwood trees at risk of falling. Throughout the project reach, Rock Creek varied from a few feet wide to approximately 15 feet wide. The base flow in the creek was on average one to two feet deep. The side slopes varied from vertical eroding banks to relatively flat and vegetated banks. Relatively few low overbank areas existed, as most of the channel had degraded and was contained in a deep, trapezoidal-shaped cross section. In general, the low flow vegetation consisted of grass, brush, and trees, while the overbanks were primarily covered with short native grasses and some trees. The bottom of the channel varied from earthen material to gravel-sized rock and cobbles.

The Town of Superior partnered with the District to design and construct maintenance improvements along Rock Creek during the fall of 2011. The goal of the project was to re-establish the channel bottom by installing grade control structures along the project reach. In addition, overbank areas were excavated to allow for more frequent inundation of the overall floodplain. A unique aspect of the project is that various timber drop structures were used. Four different types of timber drop structures were installed. Two were constructed of concrete made to look like faux logs, three were constructed of imported cedar logs, one used a pine log, and the last structure utilized a downed cottonwood tree from the site. The site was bounded by the two concrete structures, which were attached to sheet piling, and the log drop structures were dispersed throughout the center of the project. Each drop was approximately one to 1.5-feet tall. The use of logs on this project is considered experimental, and will be monitored over time to determine how the various timbers hold up.

Another unique aspect of the project was the use of pre-vegetated materials in lieu of buried riprap along the low flow channel and around channel bends. Pre-vegetated material was ordered in the spring so it would be fully grown and ready for installation. Pre-vegetated materials included wetland sod and bio-logs planted with willows and wetland grasses, with the bio-logs being planted along the edges of the creek.

Drainageway G is tributary to Rock Creek, and drains portions of Louisville and Lafayette. The project reach from U.S. Highway 287 to 104th Street developed a head-cut several feet tall near Highway 287. The City of Lafayette and the District partnered to construct a pair of grouted boulder drop structures to stabilize the channel at the head-cut. The project also included formalizing the City's trail along Drainageway G, and the installation of a pair of pedestrian bridges to provide proper trail and maintenance access across the drainageway.

In the winter of 2011 Boulder County and the District completed maintenance improvements along **Rock Creek at the Carolyn Holmberg Preserve**. Agricultural and ranching activities had impacted a section of Rock Creek, resulting in a severely incised channel with 5- to 8-foot tall eroded vertical banks. Based on field observation and review of historical

Rock Creek pre-construction conditions

Completed timber drop

Concrete log drop during construction

Post-construction view of concrete log drop and bio-logs

Concrete log drop close-up

Before and after views of Rock Creek at the Carolyn Holmberg Preserve

aerial photographs, it appeared that the alignment of the channel had moved significantly from its historic course, which contributed to the bank and bed erosion. If left alone, the channel would continue to erode and cut a deep channel upstream further degrading more reaches of Rock Creek. The purpose of the project was to repair the stream bank and bottom erosion and restore aquatic and riparian habitat to Rock Creek.

Restoration objectives included reconnecting the channel to the floodplain to restore hydraulic and habitat functions, provide channel stability, minimize cut and fill, and enhance riparian vegetation for habitat and erosion control. A natural channel design approach was utilized to restore the channel.

The natural channel design approach utilizes data collected from a stable and high quality "reference reach" within the same stream system to develop the design criteria for the section of channel to be restored. A reference reach along Rock Creek upstream of the Town of Superior and a reference reach downstream along Coal Creek were used. The data collected from the reference reaches primarily identifies the physical character of the stream including the width and depth dimensions, sinuosity pattern, channel bed profile and channel bed material (size and type of soil/rocks). During the data collection phase, cross section dimensions were obtained at several riffle and pool sections, which helps identify the vertical stability parameters. The channel bank full profile was measured to ascertain lateral stability. Bed material from the stream channels was collected and evaluated to determine the bed material size-frequency distribution. Observations of the existing vegetation communities were recorded for re-vegetation recommendations and to maintain thriving wildlife habitat.

A similar project along Rock Creek at the Zaharias Open Space was constructed in 2010. The Zaharias project has very little development upstream of it, whereas this project is downstream of the Town of Superior. The two projects will be monitored over time to determine the effectiveness of the design approach for developed and undeveloped watersheds, and as a comparison of the use of different reference reaches along the same stream system.

Broomfield County

Alexx and Michael's Pond, located at 132nd Avenue and Zuni Street, is a former privately owned water storage and regional detention pond built in the late 1970's to serve the surrounding farming communities. Due to the desire to store much needed water for irrigation, it is believed the pond was clay-lined with an emergency outlet constructed at a high elevation to store as much water as possible without overtopping Zuni Street during large storm events. As the tributary areas quickly developed, a considerable amount of sediment entered the pond from at least seven stormwater discharge points. It was suspected that this amount of sediment could endanger the pond's ability to effectively detain 100-year storm flows.

In 1986 the pond was dedicated to the City and County of Broomfield. Since then it appears that water rights are no longer exercised due to the development of the surrounding farmlands once served by the pond. Unfortunately this meant the pond was essentially stagnant, as the only release of water would occur from evaporation and minimal infiltration. Also in wet years the high water levels have inundated a large grove of mature trees and other dense vegetation that have thrived below the emergency outlet. Without the ability to drain the pond, control fluctuations, or release high water this vegetation has experienced sustained inundation, resulting in decay, rot, high algae growth and a high level of mosquito infestation, all contributing to the poor water quality and unpleasant odors commonly reported by neighborhood residents.

The District and Broomfield explored options to stabilize the fluctuating water surface and improve the environmental habitat of the pond. A pump system with the ability to vary the pond elevation and re-circulate water throughout the permanent pond was selected as the preferred alternative since it's cost was estimated to be half that of a gravity outfall to Big Dry Creek. An environmental evaluation completed by ERO Resources will help set the desirable water level to

preserve trees and improve water quality. In addition the pump system will allow pumping down the pond for future sediment removal and ease of maintenance. Construction is expected to begin in January 2012 and should be completed before the high flow season.

Jefferson County

Early 2010 saw the completion of the **Richey Park Detention Expansion** project, located at 14th Avenue and Carr Street, in conjunction with the Regional Transportation District (RTD) West Corridor Light Rail project in the City of Lakewood. The District and Lakewood equally funded the design and construction while Muller Engineering, under contract with the District, designed improvements to provide additional regional detention. Just downstream of the park, RTD was responsible for a new 100-year capacity storm sewer sized to carry Dry Gulch and local flow along the light rail corridor from Carr Street east to Zephyr Street, just west of Wadsworth Boulevard.

This project consisted of widening and lengthening the existing low flow channel and the adjacent overbank area through the park to provide full 100-year regional detention. This additional detention helped limit the required size of the new downstream storm sewer to a 10-foot by 6-foot concrete box located within the limited 13th Avenue/light rail corridor right-of-way. At the upper end of the storm sewer a new sloped-drop, improved inlet was constructed within the park. This new outfall replaced the existing undersized 48-inch outfall under Carr Street which was consistently being plugged by trash and debris. In addition, the existing emergency spillway along Carr Street was slightly raised to add storage capacity. As a result of the increased detention several of the homes along Dry Gulch from the park to Zephyr Street were removed from the 100-year floodplain.

Prior to this project it was observed that much sediment had been deposited in the park area, severely limiting the existing channel capacity. Therefore it was recommended to construct a concrete forebay at the upper end of the park to provide a convenient access point to remove accumulated sediment before it entered the downstream channel/ detention area and subsequently the downstream storm sewer. Unfortunately a park user has remarked about the new odors coming from the forebay at times, but this must mean it's working well. It may be a challenge to keep up with routine sediment removals.

Additional park improvements included new sidewalks, new trees, wetlands enhancement, upgraded irrigation system, and better maintenance access. Construction was completed by 53 Corporation, Inc. The new and improved Richey Park will provide a nice amenity to the neighborhood while decreasing flood risks downstream. West Corridor Light Rail should be running in 2013.

South Platte River

In February of 2010, a large meeting was held that included all the stakeholders related to the regional trail over **Marcy Gulch** just upstream of the confluence with the South Platte River. The trail system is used by numerous hikers and bikers and provides access for fishermen and other water enthusiasts. Given that this is a high use area, access over Marcy Gulch is extremely important and it was at risk of failure. The existing crossing of twin 48" CMP's was being undercut and there was severe erosion along the banks, leaving the trail crossing in jeopardy. A sanitary sewer line running parallel to the South Platte River was close to being exposed and in danger of failing. Obviously a multi faceted approach was needed to deal with the numerous issues existing at the confluence.

Richey Park detention after construction, looking downstream at the pond outlet and upstream at the forebay

Fortunately, the February meeting brought together an outstanding group of partners that made this project happen under a quick time frame. Many thanks goes out to Centennial Water and Sanitation District, Highlands Ranch Metro District, Littleton, Colorado Water Conservation Board, South Suburban Park and Recreation, Colorado State Parks, Southwest Metro Water and Sanitation District, Douglas County, and Army Corps of Engineers.

Muller Engineering was hired to design the project drop structure and bridge that would handle the drainage

challenges while also matching into the park setting. It was determined that a grouted boulder drop structure would best suit the existing topography, while allowing for flexibility during construction. Grouted boulders could be placed in such a way as to provide excellent grade control, while tying into existing banks and subsequent riprap bank protection. A single span steel bridge was then designed to connect the trail on either side of Marcy Gulch, providing both pedestrian and maintenance access to the area.

For construction, Naranjo Civil Constructors was awarded the project. Since this is a high usage area, pedestrian access had to be maintained throughout the project. A "clean water bypass" was established to convey the flow in conjunction with the temporary pedestrian trail. The construction of the grade control was started at the upper end of the project, which included the abutments for the pedestrian bridge. The grade control was comprised of a short upper drop into a gently sloping elongated section under the bridge to the longer drop to the South Platte River elevation. The elongated section allows for flows to pass under the bridge as well as allowing enough length to span the encasement of the sanitary sewer line. Once construction of the upper drop and abutments was complete, the bridge was set. The temporary pedestrian crossing was then re-aligned to allow work on the lower portion of the drop structure.

Finished drop structure looking upstream at Marcy Gulch. (Inset) Trout caught in Marcy Gulch

Concurrent to the work on the drop structure, channel work along the South Platte River was also underway. The banks of the South Platte River, both upstream and downstream of the confluence were highly unstable and large scour areas had developed. Both Type M and L riprap were installed to protect the banks. Type M was placed along the top of bank downstream of the confluence to provide additional protection for overflow of Marcy Gulch into the South Platte River. While providing a means of dealing with high flows in Marcy Gulch and protecting the upper bank of the South Platte River, this enhanced riprap protection was also designed to help protect an adjacent downstream pedestrian bridge, which spans the South Platte River. Completion of the lower section of the Marcy Gulch grade control structure was accomplished with boulders tying into both the banks of Marcy Gulch as well as boulders being toed into the channel of the South Platte River. This allows for protection from flows in Marcy Gulch as well as any potential channel degradation in the South Platte River.

Once the drop structure was complete, a final cleaning of the structure was done. New concrete trail was placed on both sides of the bridge to tie in the new work with the existing trail system. At this point, flows were placed back in the main channel and the "clean water by pass" was taken out. After the flow was back in the main channel, there was still standing water in the "clean water by pass". As the bypass was being taken out, we noted that a good number of fish were trapped in the bypass. The contractor's crew was able to use buckets to capture these fish and return them to South Platte River. The trout that were caught ranged from 6" to one Rainbow Trout that was approximately 16" in length. It was interesting to note that these fish were trying to move upstream into Marcy Gulch. While the grade control structure was not designed with fish passage in mind, the gentle slope of both the upper and lower drops will likely provide passage for fish moving upstream, thereby helping to enhance the bio diversity of the system.

In 2011 several restoration maintenance projects were completed along the South Platte River. One such project was the safety improvements of the Union Avenue Boat Chutes in Sheridan. The boat chutes, located approximately 250 ft downstream of Union Avenue, were originally constructed in 1992 replacing a low-head dam, built in 1984. The chutes have undergone several expansions and improvements throughout the years. Unfortunately, even with these improvements there were still some safety concerns. Following a drowning accident, the District partnered with McLaughlin Whitewater Design Group, Colorado Water Conservation Board, the City of Sheridan, and the City of

Englewood to mitigate these issues. The purpose of the project was to improve egress from the pool at the base of the furthest upstream drop, improve the line of sight to the pool and reduce eddy velocities. All was achieved by saw cutting and removing material from the existing concrete structure to change the angles of the walls. This change in height and position of the wall changes the direction of the local currents, thereby decreasing and/or eliminating eddies in this area. To assist in redirecting the current near the structure several stacks of riprap and boulders were placed in the channel as well as some re-shaping of the gravel bars. To draw the project to completion, a new USGS gauge was installed to maintain accurate flow readings.

Denver County

The channel stabilization project along the **Southmoor Tributary** is located at South Tamarac Drive and Eastman Ave, in the City and County of Denver (City). Southmoor is a tributary to Goldsmith Gulch with the confluences of the two gulches immediately downstream of the project area. The perennial tributary parallels Goldsmith Gulch north of Eastman Avenue and lies within its floodplain affording the neighboring residences an open space of lush wetlands and native cottonwood trees.

Channel degradation, however, has compromised much of the Southmoor Tributary north of the project reach resulting in an incised channel which has negatively altered the riparian belt. The degradation is migrating upstream threatening the stability and ecology of the channel. Aggradation has compromised much of the low flow channel within the project reach resulting in unconfined storm flow conditions. This condition has encouraged bypass flows to Goldsmith Gulch during even the smallest storm. SEH was contracted to assist the District and the City with the design of an improvement plan that would arrest the existing instability while preserving the natural character of the corridor.

Looking south at the existing channel, erosion threatens community of wetlands and overall corridor.

Looking north at improved corridor, partially grouted drop structure stabilizes the channel and protects upstream wetlands

Looking upstream, newly constructed low flow channel directs more frequent storm flows toward the drop structure

The vision was to manage the degradation while restoring the Southmoor Tributary low flow channel. The challenge during design and construction was deriving a practical and constructible low flow edge since it was key to the sustainability of the low flow channel. Soil lifts were constructed to form a rigid boundary that would prevent the migration of cattails into the low flow channel. Planted with bull rushes and a variety of wetlands grasses, the low flow channel will not only reconnect the upper and lower reaches of the tributary but also diversify the wetland community. Naranjo Civil Constructors was instrumental in implementing the vision with completion achieved in the December 2011. Wetland plugs for the soil lifts and channel bottom is scheduled for the spring 2012. Thank you to the City Public Works and Parks for their collaboration on the project.

Douglas County

The District and the Town of Parker have been working together, for the last few decades, to rehabilitate **Sulphur Gulch**. In the spring of 2011, the District and the Town again

collaborated on the construction of drainage improvements along Sulphur Gulch from Parker Road east 3,000 feet approximately to the Town Hall.

As a result of increased flows resulting from development and channel improvements upstream of the project area, this reach of Sulphur Gulch is experiencing severe channel incision and stream bank instability. The town has been monitoring this reach for years and has observed accelerated severe down cutting and bank erosion in the recent years. Improvements to Sulphur Gulch were necessary as channel bed instability threatened utility crossings, recreational and maintenance trails, and existing check structures.

The channel improvements included the retrofit of three existing drop structures, the installation of two new sculpted concrete drop structures, a wider low-flow channel, and the implementation of various types of bank protection treatments. The project reshaped the channel, lessened the overall channel slope to reduce velocities and erosive properties of the gulch, and increased the flood conveyance capacity through the project reach. A series of before and after photos capture the essence of the project and memorialize its achievement. Thank you to Muller Engineering and Naranjo Civil Constructors for their engineering and construction services.

The following DCM staff members contributed to this column: Bryan Kohlenberg, P.E., Senior Project Engineer; David Skuodas, P.E., CFM, LEED AP, Senior Project Engineer; Richard Borchardt, P.E., CFM, Senior Project Engineer; Barbara Chongtoua, P.E., CFM, Senior Project Engineer; Steve Materkowski, E.I., Senior Construction Manager; Jessica Barr, E.I., Engineering Student Intern

Check structures (left) had been installed to keep potential degradation to a manageable level (center and right)

The check structures were turned into drop structures (left) and the channel was reshaped (center and right)

Two sculpted drop structures were also constructed

Marcy Gulch Timeline

Facts

- Location: southwest portion of Highlands Ranch, confluence with South Platte River just south of C-470 and west of Santa Fe Drive
- Watershed: 4.2 square miles, 5 miles of channel length and 500 feet of vertical drop
- Steep, sandy channel
- Master planning efforts preserved the natural function of the drainageway corridor, which doubled as valuable open space
- Predevelopment = ephemeral stream
- Post development = perennial stream

The channel experiencing instability, degradation, lateral migration and high sediment transport, resulting in damage to infrastructure, residential property and overall quality and safety of open space.

Phase 2 completed based on success of the soil cement drops and bank protection in the first phase. Total Phase 1 and 2 improvements constructed in upstream reaches: 18 soil cement drops constructed along with 400 ft of soil cement bank protection, 3000 ft of bioengineering bank protection and 6 trail crossings. Utilizing soil cement drops saved project approximately 15% of standard method costs.

1981

Highlands Ranch founded

HIGHLANDS RANCH Metro District

1994

Development starting to occur in the basin

1999

Downstream reaches (Highlands Ranch Golf Club) experiencing heavy aggradation due to upstream channel instability.

2000

Highlands Ranch completed a channel stabilization study, identifying location of drop structures, grading, bank protection and crossings for upstream reaches

2001

First major implementation (Phase IA) of stabilization improvements in upstream reaches included a pilot project for soil cement drops and soil cement bank protection.

2002

Phase 1B implemented, including trail crossings, grouted boulder drop and regional detention pond modifications.

Marcy Gulch Timeline

2004

New approach tried in a very steep reach towards upstream end of watershed. Instead of traditional drop structures with a flat slope in between, a low flow void-filled riprap channel lining at a steeper slope was used to minimize disturbance and number of drops. Results were a cost effective solution that introduced the District to a new material that provided structural protection with a good growing medium.

2007

Completed a second stabilization study for downstream reach from confluence to Town Center Drive

2008

In the spring, Highland Ranch Golf Club loses cart crossing and in summer a second trail crossing is washed out leaving the Highline Canal flume in jeopardy, due to a 14’ head cut 20 feet from the abutments.

2010

Project completed in reach upstream of Town Center Drive to stabilize the active channel using a combination of smaller sculpted concrete drops and low flow void-filled riprap lining, thus letting larger flows go outside of the banks and spread across the riparian corridor.

Highlands Ranch Golf Club, in downstream reach is now experiencing major degradation in the channel and losing large cottonwood trees along the banks.

Emergency repair (void-filled riprap rundown) to temporarily stabilize head cut and protect Highline Canal, installed within 1 month of failure. Offered 10-yr protection and material was reused in final design.

Marcy Gulch Timeline

New dual cart and trail crossing constructed at Highlands Ranch Golf Club

Within the golf course reach, final design through construction was done in a total of 10 months. This was accomplished by bidding 90% design drawings among District drainageway contractors and breaking project into two phases. Design included improvements along 3,000 lf of channel, raising invert back up to predevelopment elevations (about 7-8 feet in upper reach and 4-5 feet in middle reach), building a total of 45 vertical feet of drop structures, and placing 36,000 cy of fill.

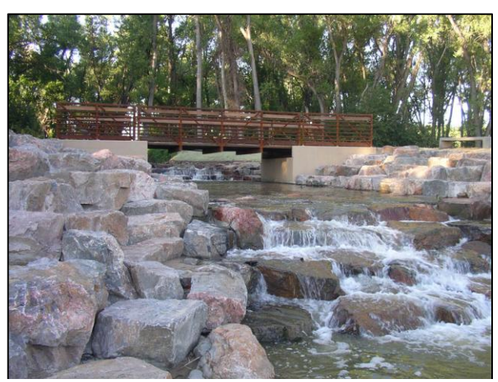
Not done yet, large sediment loads still going into River. Next phase in process…

2011

Next

In middle reach of golf course, a new type of drop structure used: cascading loose boulder drop. Tested during high flow shortly after construction and performed as designed.

More severe damage also occurred near the confluence with the South Platte River. The regional trail crossing over Marcy was about to be washed out. An unprecedented group of local sponsors each contributed to the cost of this repair: Centennial Water and Sanitation District, Highlands Ranch Metro District, Littleton, Colorado Water Conservation Board, South Suburban Park and Recreation District, Colorado State Parks, Southwest Metro Water and Sanitation District and Douglas County, with cooperation from Army Corp of Engineers. Thank you.



Lessons Learned

- Sandy channels are very dynamic and the gulch's response to each project was very quick!
- Stabilization studies were essential in budgeting and also helped get final design underway quicker once the crossing failed.
- Plan to fund continuous projects until entire reach is stabilized.
- Check structures installed during development would have slowed gulch's response time and prevented such a large migration of sediment.

2-D or Not 2-D?: New UDFCD Guidelines

By Shea Thomas, Master Planning Program; Alan Turner and Cory Hooper, CH2M Hill

Just like “sustainability” and “green infrastructure” are the current buzzwords in the stormwater community, “2-D modeling” seems to be the equivalent in the floodplain modeling world. While technological advances in modeling software allow the user to venture into new territories beyond the limitations of a one-dimensional model like HEC-RAS, one must step back and look at the policies and goals behind floodplain modeling before jumping on the bandwagon.

Numerous consultants and local governments have asked about the potential of utilizing 2-D modeling for UDFCD master planning studies. Before using the software, an analysis should be performed to understand how the results produced from a 2-D model compare to results from a traditional HEC-RAS model, what the reasons are for any differences between results and which modeling alternative is the better route to take from a policy standpoint. The results of this analysis compare and contrast the two modeling techniques for a variety of flood inundation scenarios and are used to develop a guidance to help modelers know when and how to use a two-dimensional model for floodplain management. This article is a summarized preview of what will soon be published as “Guidance for 2-Dimensional Model Development in Riverine Systems“, which will gather and analyze data from three case studies and develop guidelines for future models. The purpose of the paper is to provide guidance on when 2-D models should be utilized and how to correctly develop a 2-D model for riverine systems. In addition, and perhaps most importantly, this paper will develop guidelines on how the results of 2-D hydraulic model can be used to quickly and efficiently develop 1-D models acceptable to regulatory agencies and municipalities on riverine systems.

Background

With the increased computational power, including processing speed and memory capacity, that is now available, 2-D hydraulic models can be quickly created and run to represent complex flow situations. Current regulations for floodplain management are generally geared toward 1-D modeling with kinematic wave routing assumptions. Many flooding scenarios are better represented by 2-D models including areas of split flows caused by hydraulic structures, urban flooding areas, and alluvial fan analysis.

The regulatory environment that exists today for floodplains and flood studies is currently built around the use of 1-D models. There have been recent flood studies performed utilizing 2-D models that have been incorporated as regulatory models into the Federal Emergency Management Agency’s (FEMA's) Digital Flood Insurance Rate Map (DFIRM) products. The challenges that have been observed from these projects include reconciling flow rates computed in a dynamic wave analysis with surrounding models developed with kinematic wave routing and the traditional steady state flow condition employed in 1-D modeling. There are also challenges associated with the availability of the data, software, and computational power to efficiently and cost-effectively share and update 2-D models as compared to 1-D models when development or changes occur or are proposed within a floodplain. It is because of these challenges that this study developed an approach for utilizing the accuracy from a 2-D model to create and validate a 1-D model to achieve a superior hydraulic analysis while creating a hydraulic model that can be utilized by the engineering and regulatory communities.

Modeling Overview and Comparison to 1-D Modeling

1-D steady state models and 2-D models compute water surface elevations, velocities, and floodplain extents by making different assumptions about how flow propagates. In general, both 1-D and 2-D models solve the Saint-Venant equations with some underlying assumptions to simplify the equations. In 1-D flow programs such as HEC-RAS or EPA-SWMM, the flow direction is assumed to be in the downstream direction (Figure 1) and is not explicitly computed; while in 2-D models, the flow directions are explicitly computed in any of eight separate directions (Figure 2). In addition to flow direction, 2-D models compute flow velocity and flow rate in any of the eight directions.

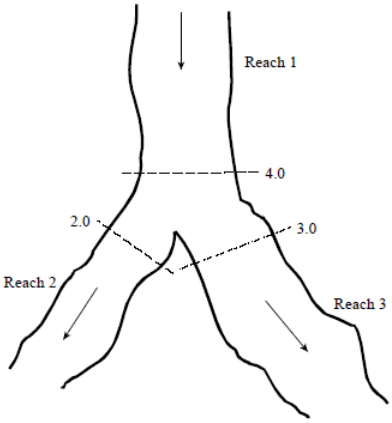


Figure 1
Assumed Flow Direction for 1-D Models

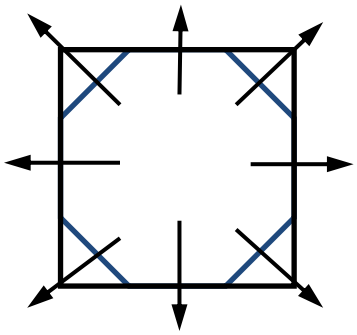


Figure 2
Computed Flow Direction for 2-D Models

For a 1-D model, geometric data and the physical properties of the stream system are computed utilizing cross sections and channel profiles, while a 2-D model represents the ground surface elevation for the study area utilizing grid cells with elevation and roughness information. To develop the grid for a 2-D model, terrain data is required to be rasterized. This interpolation method aggregates multiple elevation points into a single elevation point that becomes the assigned elevation for the entire grid cell. The rasterization process can subtly change the shape of a cross section based on the assimilation of multiple elevation points into one grid cell. Figure 3 depicts the differences between a cross section cut on a grid and one cut for a 1-D model on a set of contour data.

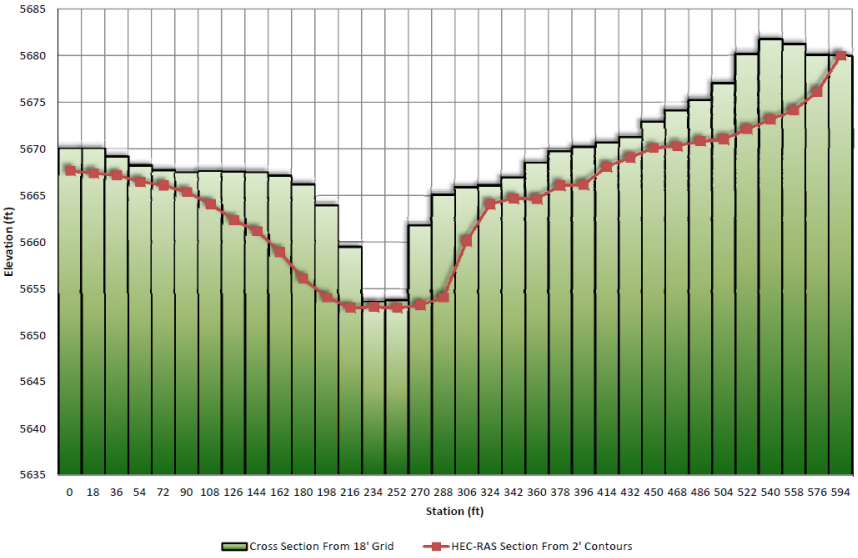


Figure 3 – Comparison of Cross section from HEC-RAS vs. from FLO-2D 18' Grid

In a 2-D model, flow direction may change with each time step in any direction, requiring the program to come up with a numerical solution to the Saint-Venant equations at each grid cell and for each time step. This results in 2-D models completing a large number of calculations, which can result in excessively long model run times for riverine or floodplain analysis. This can also result in model instability. There are some recommended approaches to developing a stable 2-D model to reduce run time while maintaining meaningful results. These will be discussed in detail in the final paper.

In addition to the differences in the assumptions regarding flow directions, there are other major differences in the computations of the two models. Transverse velocity and momentum and transverse variations in water surface depths are handled differently in 1-D and 2-D models. In 1-D models transverse velocity, momentum and water surfaces depths are not calculated and are assumed constant across the cross section. For 2-D models, these

variables are explicitly calculated and provide additional in-depth information about the behavior of a flooding source.

Comparison of Kinematic and Dynamic Hydrograph Routing

One of the major differences between 1-D steady state models and 2-D models is the methodology by which they route the flow hydrographs through the model domain. For 1-D steady state models, kinematic wave routing theory is employed to route flows downstream. This changes for unsteady 1-D models, which utilize dynamic wave routing theory. 2-D models also apply dynamic flood routing.

Kinematic routing assumes that inertial and pressure forces are negligible in the Saint-Venant equations. The theory assumes that the weight of the water flowing downstream is approximately balanced by the resistive forces of the channel bed friction. Those assumptions then dictate that flood flows moving in the downstream direction will not accelerate appreciably and the flow will remain relatively uniform, defining the kinematic wave propagation. Backwater effects and floodplain storage are generally considered negligible as well. In contrast, dynamic wave routing assumes that inertial and pressure forces are not negligible and that backwater effects and floodplain storage can affect the wave propagation. This results in dynamic wave propagation controlling the propagation of long waves in shallow water.

Studies reviewed by the USACE have drawn the conclusion that kinematic waves will ultimately dominate the flow regimes occurring for overland flows and small watershed channel flows when the Froude number is less than 2. As a result, flood flows for small watershed systems, like those within the Denver metro area, are generally dominated by kinematic waves because the passage of the flood wave appears as a uniform rise and fall in the water surface elevation over a relatively long period. This is the reason why flood studies are completed with kinematic wave routing. A secondary reason for utilizing kinematic wave routing includes the consideration of backwater and storage effects. Many regulations require that areas of storage be owned and maintained by local governments. Because backwater effects behind roads and overbank storage in the floodplain is not explicitly defined or protected by regulation, removing these effects from routing equations provides a conservative estimate of peak flow rates that can be used to plan for infrastructure improvements in the absence of dedicated storage.

2-D Modeling Additional Data Requirements

2-D modeling requires additional information to complete a model run. Although the information to develop a 2-D model is closely related to the data required for 1-D modeling, the amount of data is more extensive. Terrain data for 1-D models can be as simple as survey only for cross sections. For 2-D modeling, a continuous terrain model is required for the entire modeling domain. The terrain data needs to be surveyed in sufficient detail and the grid size selected to be sure that adequate detail and flow resolution can be obtained. An example of a 14-foot grid cell 2-D bathymetric grid is represented in Figure 4.

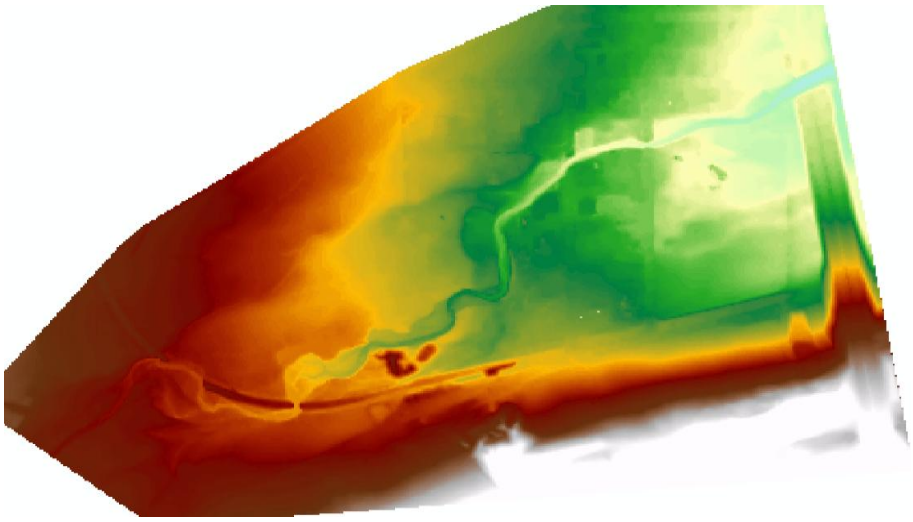


Figure 4 – Example Bathymetric Terrain Data

In addition to known elevation data throughout the modeling domain, Manning's roughness (n) values need to be determined for the entire modeling domain. This is a departure from 1-D modeling which requires a minimum of three Manning's n values to define the roughness across a cross section. To determine Manning's n values for the entire modeling domain, aerial photographs, zoning maps and land use maps can be employed to spatially represent land use conditions that can be related to Manning's n values for the entire modeling domain

Once the Manning's n values and elevation grid have been finalized, the final set of data required for a 2-D model is inflow hydrographs. Generally, with 1-D steady state regulatory models, steady state peak flows are input into the models. These models do not have time variable hydrographs to input into the 2-D modeling domain. UDFCD, and on occasion FEMA, will have Colorado Urban Hydrograph Procedure or other hydrologic models, SWMM models or HEC-HMS models that define hydrographs throughout the modeling domain, which can be input directly into the 2-D model. However, in the absence of a hydrograph, unit hydrograph methodologies can be employed to create approximate hydrographs based on peak flow assumptions. It should be noted that if approximate methodologies are used to determine hydrographs, the volume of flow in the system will not match closely with the original hydrology and can lead to differing flooding analysis from 1-D models.

Grid Cell Sizing Effects on Run Time

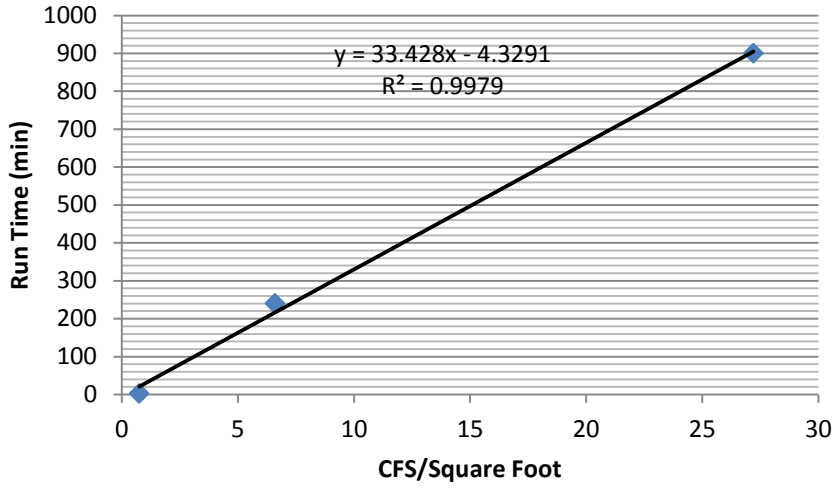
The bathymetric terrain file has a *dramatic* effect on the run time of 2-D models, the resolution and relative accuracy of the floodplain delineations and the general stability of model runs. The grid cell sizing effects on model run times as well as the accuracy of the floodplain delineations and the relative effects on model stability will be discussed extensively in the final paper.

To begin the selection of a grid cell size for the development of a 2-D model bathymetric file, model literature recommends that a grid cell size be selected so that the estimated peak discharge divided by the area of a single grid cell falls between (FLO-2D Pocket Guide, 2011):

$$0.1\text{cfs/sq-ft} < Q_{Peak}/A_{surf} < 1\ \text{cfs/sq-ft} \qquad \text{[EQ 1]}$$

As an example, for a 10'x10' grid cell there should be no more than 100 cfs loaded on any particular grid cell. This relationship will help optimize run times and help with the stability of the 2-D model calculations, but following these recommendations can often impact the resolution of the floodplain by not providing the level of detail needed to correctly determine floodplain boundaries and flow splits.

The final paper will provide additional guidance on the selection of a grid cell size and the impact on 2-D model run times based on experimentation with case study models. The graph in Figure 5 is a result of that experimentation which indicates there is almost a linear relationship between the Q_{Peak}/A_{surf} and model runtime.



Grid Cell Sizing Effects on Resolution

A comparison of different grid cell sizing was created for the three case studies and will be presented in detail in the final paper. In summary, there is a significant difference between the resolution and flooding impact between model runs with varying grid cell sizes. Large coarse grid models are an effective and quick tool for identifying regional tendencies with respect to inundation areas and major split flow paths. However, for the purposes of converting 2-D models to 1-D regulatory models, additional detail is needed to help define flow paths.

Grid cell sizing has a profound effect on model set up, run times and resolution. Often these three interests are in conflict. As such, working with project sponsors to define the requirements of a study prior to developing a 2-D model, so they understand the implications in project schedules and resolution of mapping is imperative. As a rule of thumb, attempting to size grid cells so there is a minimum of 2-grid cells for a street feature or channel feature has been found to provide adequate resolution while maintaining reasonable runtimes.

Modeling Structures

There are three ways to incorporate culverts and other hydraulic control structures into the 2-D modeling domain.

1. Include a short 1-D coupled model in the model domain that models the structure as a 1-D hydraulic structure that accepts flow from the 2-D domain and passes the flow back to the 2-D modeling domain.
2. Rating curves developed from HEC-RAS, Culvert Master or another external hydraulic model that relate head to discharge.
3. The modification of the model bathymetric grid to "burn" the culvert into the elevation grid and manipulation of Manning's n values and area reduction factors to mimic the hydraulic performance of a culvert.

The three methods have different levels of complexity. Incorporating a 1-D coupled model requires the construction of inlet and outlet points as well as the creation of 1-D cross sections to embed into the 2-D modeling domain. Depending on the number of hydraulic structures, this can be a labor-intensive process and can be the source of instabilities when running the 2-D models. The final paper will show the different effects hydraulic structures can have on floodplain mapping in 1-D and 2-D models.

Conclusions

The results of this study have shown that for channelized systems that do not generally have multiple flow paths, it is recommended to continue to utilize the 1-D channel modeling approach. For those channelized riverine systems, the 1-D model development and run time is less cumbersome and creates results that are consistent with the current regulatory requirements. The results for those channelized systems also show that the floodplain determined with the 2-D model for a channelized system is very similar to the 1-D floodplain.

However, for systems with the data available to create a 2-D model for complex flooding situations, a 2-D model can be quickly built and can provide extremely strong information for creation of a refined 1-D model that provides much more accurate data. By utilizing the flow vector results and flow split percentages, a highly accurate 1-D model can be created that can be regulated, shared, and used for floodplain management.

2011 Professional Activities of District Staff

Paul Hindman, Executive Director

*Co-Chair of Cherry Creek Stewardship Partners annual "Run for the Watershed"
*Chair of the 2011 Denver Site Committee for the American Public Works Association (APWA) International Public Works Congress and Exposition
*Chapter Delegate, APWA Colorado Chapter
*Chair of National APWA House of Delegates
*Member, APWA National Water Resource Committee
*Elected as Board Member to Colorado Counties Officials and Employee Association

Bill DeGroot, Manager, Floodplain Management Program

*Board Member of the National Association of Flood and Stormwater Management Agencies (NAFSMA).
*Attended the ASFPM annual conference in Louisville in May, where I received its Meritorious Lifetime Achievement In Floodplain Management Award
*Attended the CASFM Annual Conference in Snowmass Colorado in September.
*Attended NAFSMA's annual meeting in St. Pete Beach in November, and presented *Communicating Floodplain Preservation Values in Land Use Decisions*
*Represented NAFSMA as a member of FEMA's Operating Partners Focus Group, which meets quarterly with representatives from FEMA, their Risk MAP contractors, NAFSMA and ASFPM to discuss Risk MAP and other mapping issues.
*Represented NAFSMA as a member of the Intergovernmental Flood Risk Management Committee (IFRMC), meeting quarterly with NAFSMA, ASFPM, FEMA and the Corps of Engineers.
*Participated in a panel discussion on "Sustaining Resilience Over Time" at the Natural Hazards Conference in Broomfield in July.
*Presented *The History of the Urban Drainage and Flood Control District* at the District's annual seminar in April.
*Presented *Regional Approach to Floodplain and Stormwater Management* at the Public Works Stormwater Summit at the APWA Congress in Denver in September
*Co-authored *Ode to Riparian Floodplains, Protect and Be Protected* with David Mallory and Julie Ash, who presented it at the CASFM Annual Conference held in Snowmass in September and the Sustaining Colorado Watersheds Conference held in Avon in October.
*Member of Association of State Floodplain Managers (ASFPM), American Society of Civil Engineers (ASCE), Colorado Association of Stormwater and Floodplain Managers (CASFM), Natural Hazard Mitigation Association (NHMA) and American Public Works Association (APWA)

Kevin Stewart, Manager, Information Services and Flood Warning Program

*National Hydrologic Warning Council (NHWC) President
*National Hydrologic Warning Council (NHWC) Board Member and Past President
*U.S. Department of the Interior Advisory Committee on Water Information, Subcommittee on Hydrology
*American Meteorological Society (AMS) Weather and Climate Enterprise Commission Steering Committee
*Member: ASCE, ASFPM, CASFM, AMS, APWA and Colorado Emergency Management Association
*Attended 91st AMS Annual Meeting in Seattle, WA in January.
*Attended Governor's Conference on Emergency Management in Fort Collins in March.
*Presided at 9th Biennial NHWC Conference & Exposition in San Diego, CA in May.
*Invited participant at FEMA National Flood Insurance Program Community Rating System Weighting Forum in Philadelphia in June.
*Planning committee member and speaker at AMS Summer Meeting at NCAR in Boulder in August.
*Speaker at APWA International Public Works Congress & Exposition Stormwater Summit in Denver in September.
*Keynote speaker at 22nd Annual CASFM Conference in Snowmass, CO in September.

Ken MacKenzie, Manager, Master Planning Program

*Moderator of the UDFCD Annual Seminar in April; presented "*Stream Stabilization: the Best Management Practice*" with Laura Kroeger.
*Presented "*Evolution and Implementation of the Urban Storm Drainage Criteria Manual Volume 3: Best Management Practices*" at the Nebraska Stormwater and Floodplain Manager's Conference in April.
*Presented "*How did the Clean Water Act Become an Obstacle to Addressing Water Quality?*" with Laura Kroeger at the National Association of Stormwater and Floodplain Managers Association Annual Meeting in November.

*Served on the board of directors of the Urban Watershed Research Institute (UWRI).
*Served on the Urban Water Resources Research Council and Low Impact Development Committee of the ASCE Environmental & Water Resources Institute.
*Served on Water & Environment Research Foundation (WERF) committee creating a model to link stormwater BMP systems performance to receiving stream protection.
*Served on the NAFSMA Stormwater Committee.
*Served on the CASFM Outreach Committee.
*Served on CCBWQA Technical Advisory Committee.
*Member of ASCE, ASFPM, CASFM, & NAFSMA.
*Co-authored "*The Case for Water Quality Capture Volume*" article in *Stormwater* magazine, October.
*Co-instructor for training course on *Street Hydraulics, Storm Sewer Inlet Sizing, and Storm Sewer Design* in October.
*Co-instructor for S*tormwater Best Management Practices* training course in October.

David Bennetts, Manager, Design, Construction & Maintenance Program
*Presenter at UDFCD's Annual Seminar in April in Denver
*Presenter at ASFPM's State Flood Risk Symposium in April in Boulder
*Presentation to Australian Delegation in September at District
*Presenter at APWA's Annual Congress, Stormwater Summit in August in Denver
*Moderator at CASFM's Annual Conference in September in Snowmass
*Attended CML's Annual Legislative Workshop in February in Denver
*Attended ASFPM's Annual Conference in May in Louisville
*Council Member, CU Denver Engineering Leadership Council
*Served as Vice Chair, CASFM Board of Directors
*Member of ASCE, APWA, ASFPM, and CASFM

Laura A. Kroeger, Assistant Manager, Design, Construction & Maintenance Program
*Presented "*Stream Stabilization: the Best Management Practice*" with Ken MacKenzie at the UDFCD Annual Seminar in April
*Presented "*How did the Clean Water Act Become an Obstacle to Addressing Water Quality?*" with Ken MacKenzie at the National Association of Stormwater and Floodplain Managers Association Annual Meeting in November
*Colorado Chapter APWA At-Large Board Member
*Colorado Chapter APWA Education Chair
*ACEC Scholarship Committee
*National APWA Co-Chair of Bridging Generations Sub Committee to Diversity Committee
*National APWA Membership Committee Member
*National APWA By-Laws Committee Member
*Panel Speaker at APWA Congress on Generational Diversity

Bryan Kohlenberg, Senior Project Engineer, Design, Construction & Maintenance Program
*Continued as National Society of Professional Engineers' (NSPE) scoring coordinator for the Jefferson County, North Metro and Colorado State MATHCOUNTS competitions for 6th, 7th and 8th graders
*Member of American Society of Civil Engineers (ASCE), Chi Epsilon, Colorado Association of Stormwater and Floodplain Managers (CASFM) and American Public Works Association (APWA)
*Volunteered at the APWA Public Works Congress & Exposition in September
*Presented and co-led tours of South Platte River - Zuni/Sun Valley Reach Project for APWA Public Works Congress & Exposition in September
*Attended the CASFM Annual Conference in Snowmass Colorado in September

David Mallory, Senior Project Engineer, Floodplain Management Program
*Chair of the Colorado Association of Stormwater and Floodplain Managers (CASFM).
*Co-chair of the Floodplain Management Committee of the National Association of Flood and Stormwater Management Agencies (NAFSMA).
*Board Member of the Natural Hazard Mitigation Association (NHMA).
*Additional Memberships in the Association of State Floodplain Managers (ASFPM), and the American Public Works Association (APWA).
*Member of the Core Writing Team for the National Mitigation Framework Plan pursuant to Presidential Policy Directive 8, National Preparedness signed by President Obama on March 8, 2011.
*Presented *Digital Letter of Map Change Guidelines* at the FHWA Floodplain Workshop held in Lakewood in February.

*Attended the CASFM-sponsored CRS Workshop in Longmont in March.
*Co-hosted the Colorado Flood Risk Symposium sponsored by CASFM & ASFPM at the Natural Hazards Center at CU in April.
*Attended the UDFCD Seminar held in Denver in April.
*Presented *Communicating Floodplain Preservation Values in Land Use Decisions* at the Arkansas River Basin Water Forum held in Colorado Springs in April.
*Co-presented the *Negations for Floodplain Managers* workshop at the ASFPM Annual Conference in Louisville Kentucky in May.
*Attended the Natural Hazards Workshop held in Broomfield in July.
*Attended FEMA's Levee Analysis and Mapping Procedures (LAMP) Roundtable Workshop held in Washington DC in July.
*Presented *Communicating Floodplain Preservation Values in Land Use Decisions* at the APWA Western Water Summit held in Denver in September.
*Co-Presented, with Julie Ash, *Ode to Riparian Floodplains, Protect and Be Protected* at the CASFM Annual Conference held in Snowmass in September and the Sustaining Colorado Watersheds Conference held in Avon in October.
*Presented *Communicating Floodplain Preservation Values in Land Use Decisions* at the Natural Floodplains Function Alliance Workshop held in Washington DC in October.
*Attended the NAFSMA Annual Meeting held in St. Petersburg in November.

Rich Borchardt, Senior Project Engineer, Design, Construction & Maintenance Program
*Chair of the Water Resource Committee for the Colorado Chapter of the American Public *Works Association (APWA)
*Attended Project Management Boot Camp by PMSJ Resources in Denver
*Attended District Annual Seminar in April in Denver
*Attended APWA International Public Works Congress and Exposition in Denver
*Presented at Colorado Association of Floodplain Manager (CASFM) Annual Conference in Snowmass
*Attended Cherry Creek Stewardship Partners Conference in Denver

Shea Thomas, Senior Project Engineer, Master Planning Program
*Presented "*Why You Need an iPad*" at the annual UDFCD seminar in Aurora in April.
*Presented "*Big Dry Creek Study: An Urban Watershed*" at the 2011 CASFM Conference in Snowmass Village in September.
*Presented "*Two Dimensional Modeling as a Calibration Tool for Riverine Floodplain Analysis in the Front Range of Colorado*" at the 2011 CASFM Conference in Snowmass Village in September.
*Presented "*Plains, Rain and Automobiles – Anticipating Future Development in Storm Drainage Master Plans*" at the 2011 Cherry Creek Conference in Parker in November.
*Elected Secretary of CASFM in September.
*Served as the Scholarship Committee Chair and Conference Program Chair for CASFM.
*Served on the Stormwater Management and Floodplain Management Committees for NAFSMA.
*Served on the Floodplain Management Degree and Continuing Education Steering Committee for the Community College of Aurora

Barbara Chongtoua, Senior Project Engineer, Design, Construction and Maintenance Program
*Successfully Delivered Project on time and schedule, Prissana Lanessa Chongtoua born exactly 11 hours after projected due date.
*Chaired the APWA Futures Program at APWA 2011 Congress in Denver, Colorado.
*Member of ASCE Urban Water Resources Research Council and National Safety Standards for Storm Water Facilities Sub-committee.
*Member of ASCE, APWA, Chi Epsilon, and CASFM.

Holly Piza, Senior Project Engineer, Master Planning Program
*Conducted a USDCM Volume 3 six-hour training course for approximately 75 development review engineers (April through July)
*Presented Integrating Landscaping with Urban Stormwater Management Practices at the ASLA Learning Lunch in Denver (March) and in Colorado Springs (October)
*Presented at the USGBC Conference in April as part of the LEED Sustainable Sites Implementation Panel
*Presented Rain Garden Design and Construction Considerations at the UDFCD Annual Seminar in April
*Presented The USDCM Volume 3 Rewrite at the Denver Stormwater Technology Workshop (May)
*Presented UDFCD Green Roof Research and Resources at the Green Roof Symposium (June)
*Presented Rain Garden Design and Construction: a Case Study as part of a green infrastructure workshop in connection with the Green Roof Symposium (June)
*Presented Tools for Implementation for the Water Quality Forum retreat (August)
*Presented Working in Waterways and Rain Garden Design and Construction Considerations at the CSC Conference (August)
*Presented A New Tool for Quantifying Volume Reduction for Site Level Designs at StormCon (August) as well as at the ASCE – LID Symposium (September), and at CASFM (September)

*Presented Green Roof Design and Maintenance in the Semi-Arid West and also LID 101 at APWA Congress (September)
*Presented at the ASLA Learning Lunch (student chapter) in October as part of a panel on water use in Colorado
*Co-authored Green Roofs in the Semi-Arid and Arid West for the September issue of the APWA Reporter
*Served as the CASFM Water Quality Committee Chair
*Also a member of ASCE, CASFM, and CSC

Dave Skoudas, Project Engineer, Design, Construction & Maintenance Program
*Co-Chair of the ASCE Water Resources & Environmental Sciences Technical Group
*Member of ASCE, CASFM, APWA, and ASFPM
*Attended the Annual CASFM Conference in Snowmass
*Attended the APWA International Congress and Exposition
*Co-presenter of "Adventures in Tunneling" and "Converting Natural Channels into Dimensionless Ratios (and then Back)" at the Annual CASFM Conference
*Participated in a Senior Design Project for the CU-Boulder Senior Design Class
*Contributed a Pilot Project to the Institute for Sustainable Infrastructure's envision™ Rating System
*Attended the Flood Risk Symposium at the Natural Hazards Center in Boulder

Terri L. Fead, P.E., CFM, Project Engineer, Floodplain Management Program
*Member of the Colorado Association of Stormwater and Floodplain Managers (CASFM), Association of State Floodplain Managers (ASFPM), American Society of Civil Engineers (ASCE) and the National Society of Professional Engineers (NSPE).
*Attended the UDFCD Seminar held in Denver in April.
*Attended the Colorado Flood Risk Symposium sponsored by CASFM & ASFPM and held at the Natural Hazards Center at CU Boulder in April.
*Attended the FEMA and FHWA LOMR/CLOMR Preparation Training in Lakewood in February.
*Attended the CASFM-sponsored Emergency Management Institute field deployed Community Rating System Course in Longmont in October.
*Attended the UWRI training for Finding Water Quality Capture Volume Using Continuous Runoff Simulation held in Denver in August.
*Attended webinars on Advanced Bridge Hydraulics with HEC-RAS and Advanced Culvert Hydraulics with HEC-RAS (ASCE, August 2011)
* Member of Cherry Creek High School Engineering Physics Advisory Committee

Julia Bailey, Information Services Engineer, Information Services and Flood Warning Program
*Attended the ESRI Annual International Users Conference in San Diego, CA in July.
*Drainage Subcommittee member for DRCOG Denver Regional Data Consortium.
*Steering Committee member for EMWIN-Denver (Emergency Managers Weather Information Network).
*Member of GITA (Geospatial Information & Technology Association).

Mike Sarmento, Senior Construction Manager, Design, Construction & Maintenance Program
*Attended APWA Construction Inspector's conference in February
*Attended HAZWOPER Site Safety Training in March.
*Attended Colorado Weed Network Presentation Co-presented at District's Annual Seminar in April in Denver

Steve Materkowski, Senior Construction Manager, Design, Construction & Maintenance Program
*Appointed as CO APWA Representative to State All Hazards Committee
*Appointed to APWA National Emergency Management Sub-committee
*Attended/Volunteer APWA National Congress
*Attended APWA Construction Inspection Conference
*Attended IECA Annual Conference
*Completed UWRI Course on BMP Selection
*Completed HAZWHOPER Recertification Course
*Completed FEMA IS-00552 Course

Jeff Fisher Senior Construction Manager, Design, Construction & Maintenance Program
*Attended FEMA Debris Management for Tribal and Local Officials in May
*Member of APWA
*Volunteered for APWA Public Works Congress

Joe Williams, Senior Construction Manager, Design, Construction & Maintenance Program

*Attended the UDFCD Annual Seminar in April
*Attended and Completed the FEMA Debris Management Planning for State Tribal and Local Officials training in May
*Volunteered for 2011 APWA International Public Works Congress and Exposition held in Denver in September

Darren Bradshaw, Construction Manager, Jefferson and Broomfield County – Design, Construction & Maintenance Program

*Continued membership in Association of State Floodplain Managers (ASFPM)
*Continued membership in American Public Works Association (APWA)
*Continued certification for the ASFPM Certified Floodplain Manager (CFM)
*Attended the APWA Construction Inspection Conference in February
*Attended the UDFCD annual Stormwater & Floodplain Management Seminar in April
*Attended the FEMA Debris Management Planning for State Tribal and Local Official in May
*Volunteered at the APWA Public Works Congress & Exposition in September
*Attended the Mountain States Chapter of IECA Winter Conference in December

Joanna Czarnecka, Construction Manager, Floodplain Management Program

*Member of the Colorado Association of Stormwater and Floodplain Managers (CASFM), Association of State Floodplain Managers (ASFPM) and the American Public Works Association (APWA).
*Attended the FEMA and FHWA LOMR/CLOMR Preparation Training in Lakewood in February.
*Attended the Colorado Flood Risk Symposium sponsored by CASFM & ASFPM and held at the Natural Hazards Center at CU Boulder in April.
*Attended the UDFCD Seminar held in Denver in April.
*Attended the CASFM Annual Conference held in Snowmass in September.
*Attended the CASFM-sponsored Emergency Management Institute field deployed Community Rating System Course in Longmont in October.
*Attended the UWRI LID training held in Denver in December.
*Attended two CU Denver classes: Open Channel Hydraulics and PE Examination Refresher class.