Memorandum

To: Kevin Stewart, P.E., Information Systems & Flood Warning Program Manager
From: Mark Mitisek, H.I.T.
Reviewed by: Kelly Close, P.E.
Date: 04/22/2013
Project: Boulder Creek Hydromodel
Subject: Precipitation Input Evaluation

The purpose of this memorandum is to document and evaluate the use of gauge adjusted radar rainfall (GARR) for the Boulder Creek hydromodel. Currently, Thiessen weights are used to distribute real-time five minute rainfall totals from UDFCD ALERT stations to each of the models 24 sub-basins. Although effective, the use of ALERT real-time rainfall directly does not allow for the ability to integrate reliable forecasts of future rainfall events. The use of GARR for actual events will allow for the evaluation, proof of concept, and demonstration of how GARR totals can be incorporated into the existing Boulder Creek hydromodel. To evaluate the use of GARR in the Boulder Creek hydromodel the following tasks have been completed:

- Compiled quantitative precipitation estimate (QPE) GARR products from Vieux, Inc. and reconstructed rainfall time series data for the July 13, 2011 and July 30, 2012 storm events.
- Revised the Boulder Creek hydromodel to ingest basin total rainfall time series from GARR QPE products.
- Completed model simulations for all precipitation inputs and documented results at specified model design points.
- Compared observed precipitation and flow data to simulated precipitation and flow data and summarized modeled results for the July 13, 2011 and July 30, 2012 for all precipitation inputs.

QPE Basin Totals

QPE Basin totals were characterized using the same basin boundaries to understand and compare rainfall distributions for Thiessen and GARR methods for two storm events in the Boulder Creek watershed.

Thiessen QPE Basin Totals

Thiessen QPE basin totals were compiled for each basin by simulating the model and recording the 5-minute basin rainfall totals for each storm event. Note that the Thiessen Weights are pre-determined fixed weights that assign ALERT stations that contribute to each basin. **Figure 1** shows the location of Boulder Creek basins and ALERT stations used to characterize QPE basin totals for each storm event.

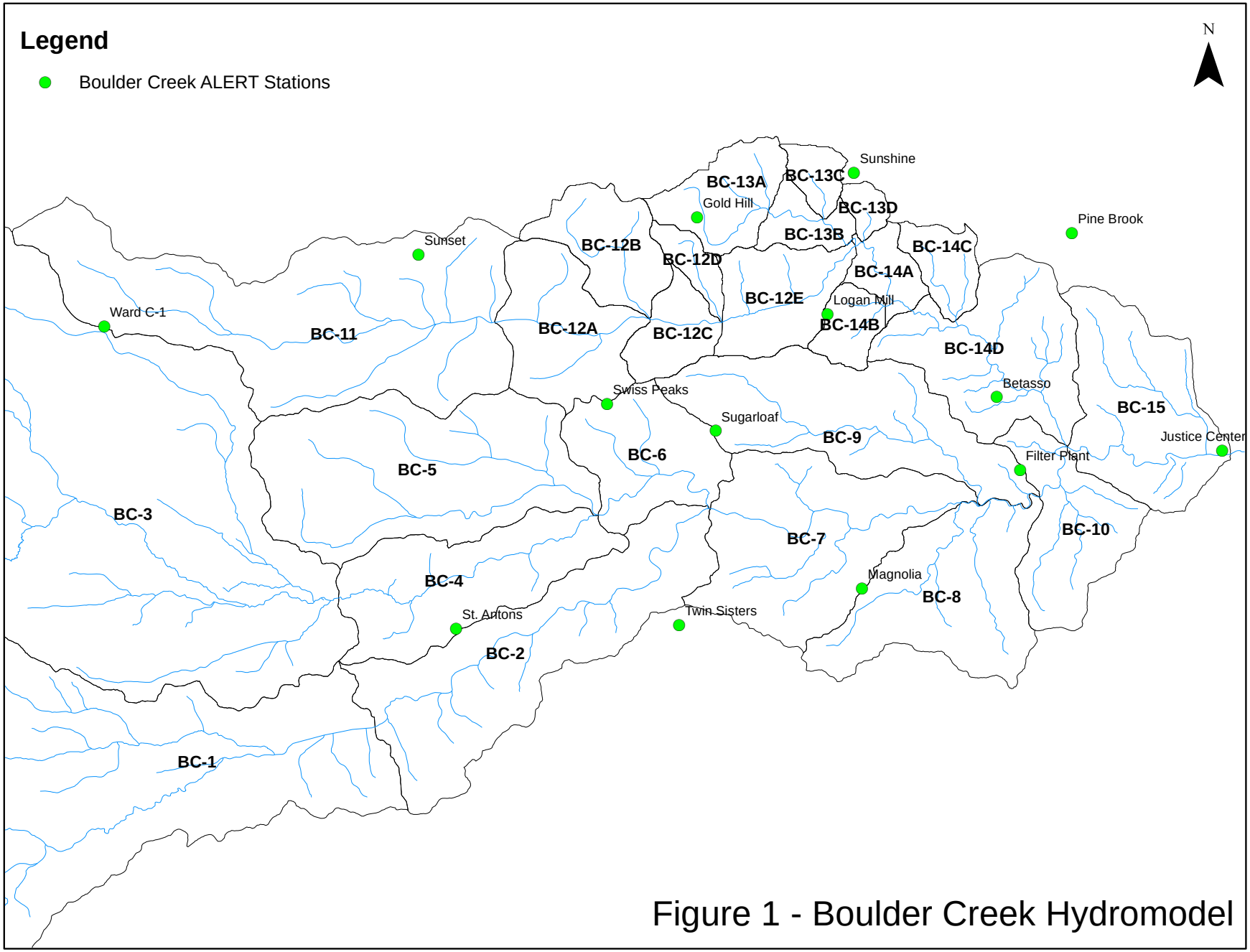


Figure 1 - Boulder Creek Hydromodel

GARR QPE Basin Totals

GARR data for the July 13, 2011 and July 30, 2012 storm events were compiled by Vieux, Inc. for use in the Boulder Creek Vflo model. 5-minute QPE totals were then summarized for each storm event for each basin using the Boulder Creek basin boundaries.

Precipitation Input Evaluation

The following section documents and compares the Thiessen and GARR basin rainfall inputs for the July 13, 2011 and July 30, 2012 storm events. There are three components of each rainfall method that were examined for each storm event:

1. Spatial Distribution
2. Rainfall Total Distribution
3. Temporal Distribution

Spatial Distribution

Figure 2 and **Figure 3** illustrate the spatial distribution of each of the storm events showing the percent of total rainfall in each basin compared to the watershed total rainfall for each method. In general, the plots show a similar spatial distribution with the exception of basin BC-3. Basin BC-3 has a significant amount of area assigned to one ALERT station resulting in a disproportionate rainfall total in that basin. This comparison confirms both methods provide valid spatial distributions of rainfall totals.

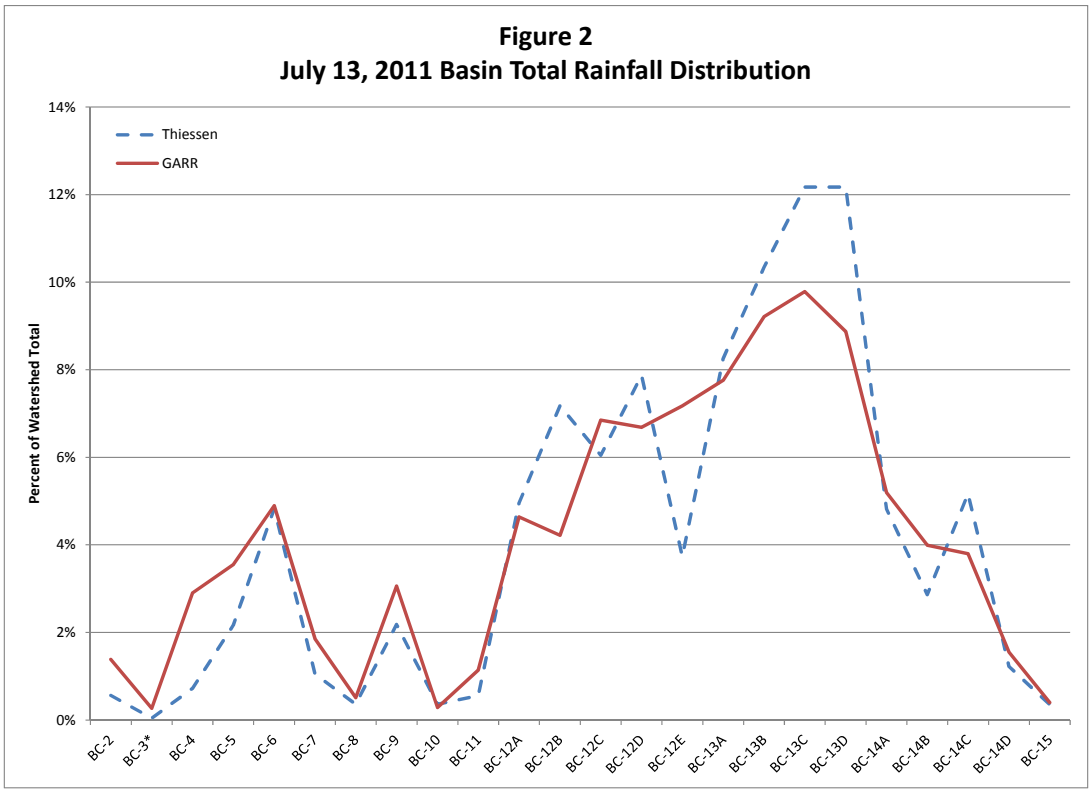
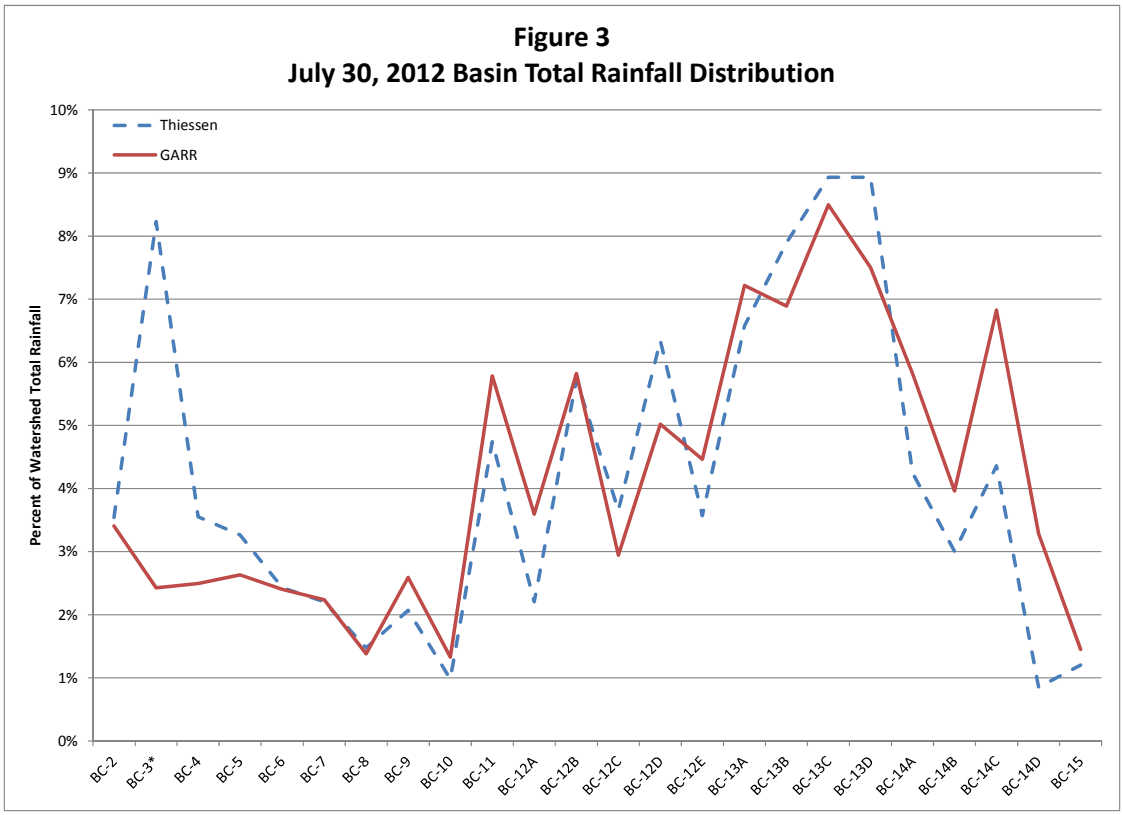


Figure 3
July 30, 2012 Basin Total Rainfall Distribution



Rainfall Total Distribution

Table 1 summarizes the total rainfall for each basin in the Boulder Creek model for each of the methods for each of the storms. The table also summarizes the percent difference between the two methods. Here are some key observations about rainfall total distributions for each method:

- GARR basin totals are approximately 26% less than Thiessen basin totals.
- The July 13, 2011 event was more evenly distributed across the watershed. For this storm the Thiessen average basin total rainfall is 0.47 inches, and the GARR average basin total rainfall was 0.41 (13% difference).
- The July 30, 2012 event was not evenly distributed across the watershed. For this storm the average total Thiessen basin rainfall is 0.50 inches, and the average total GARR basin rainfall was 0.31 (38% difference).
- The largest difference between the two rainfall distribution methods are seen in storms that total less than 0.10 inches.
- GARR and Thiessen totals are more comparable in basins where there is a higher density of precipitation stations.

Table 1 – Boulder Creek Basin Total Rainfall for July 13, 2011 and July 30, 2012 Storm Events

Basin	Name	Acres	Station Count	7/13/2011			7/30/2012			% Ave
				Thiessen	GARR	% Diff	Thiessen	GARR	% Diff	
BC-2	Upper Boulder Creek	3676.3	3	0.06	0.14	115%	0.42	0.25	-41%	37%
BC-3*	Upper Boulder Creek	21033.9	2	0.00	0.03	442%	0.99	0.18	-82%	180%
BC-4	Boulder Creek	2248.8	3	0.08	0.28	250%	0.43	0.18	-57%	97%
BC-5	Boulder Creek	3972.9	4	0.24	0.35	43%	0.39	0.19	-50%	-4%
BC-6	Boulder Creek	1499.8	3	0.54	0.48	-12%	0.29	0.18	-39%	-25%
BC-7	Boulder Creek	3006.3	4	0.12	0.18	54%	0.26	0.17	-38%	8%
BC-8	Boulder Creek	2406.7	2	0.04	0.05	25%	0.18	0.10	-42%	-9%
BC-9	Boulder Creek	2837.8	5	0.24	0.30	22%	0.25	0.19	-23%	0%
BC-10	Boulder Creek	1501.3	3	0.04	0.03	-30%	0.12	0.10	-17%	-23%
BC-11	Upper Fourmile Creek	5650.4	3	0.06	0.11	78%	0.57	0.43	-25%	26%
BC-12A	Upper Fourmile Creek	1556.3	3	0.55	0.45	-18%	0.26	0.27	0%	-9%
BC-12B	Long Gulch	1010.7	3	0.80	0.41	-49%	0.69	0.43	-37%	-43%
BC-12C	Fourmile Creek	606.2	3	0.68	0.67	-1%	0.44	0.22	-50%	-26%
BC-12D	Emerson Gulch	287.5	1	0.88	0.65	-26%	0.76	0.37	-51%	-39%
BC-12E	Fourmile Creek	1093.7	3	0.42	0.70	67%	0.43	0.33	-23%	22%
BC-13A	Upper Gold Run	902.5	2	0.92	0.76	-18%	0.79	0.53	-32%	-25%
BC-13B	Lower Gold Run	402.9	4	1.16	0.90	-22%	0.95	0.51	-46%	-34%
BC-13C	Ingram Gulch	286.5	1	1.36	0.95	-30%	1.07	0.63	-41%	-36%
BC-13D	Sweet Home Gulch	174.5	1	1.36	0.86	-36%	1.07	0.55	-48%	-42%
BC-14A	Fourmile Creek	422.7	2	0.54	0.51	-6%	0.51	0.43	-16%	-11%
BC-14B	Sunbeam Gulch	400.3	1	0.32	0.39	22%	0.36	0.29	-19%	1%
BC-14C	Sand Gulch	482.9	4	0.58	0.37	-36%	0.52	0.50	-4%	-20%
BC-14D	Lower Fourmile Creek	2241.2	4	0.14	0.15	10%	0.10	0.24	137%	74%
BC-15	Boulder Creek	2203.4	4	0.04	0.04	-1%	0.14	0.11	-26%	-13%
Basin Total		**59905.4**	-	**11.17**	**9.74**	**-13%**	**11.98**	**7.37**	**-38%**	**-26%**

*BC-3 has a significant area represented by a single precipitation station.

Temporal Distribution

The major difference between Thiessen and GARR precipitation inputs is the temporal distribution of rainfall. **Appendix A** and **Appendix B** summarize the hyetographs and cumulative rainfall distributions for each method for each basin for each storm event. Here are some key observations about temporal distributions for each method:

- The Thiessen temporal distributions vary basin to basin depending on precipitation station densities and edge effects compared to GARR.
- For the July 13, 2011 storm event; Thiessen basin wide modeled rainfall began at 17:50 and continued until 19:15 (90 minutes); GARR basin wide modeled rainfall began at 17:35 and continued until 19:10 (100 minutes).
- For the July 30, 2012 storm event; Thiessen basin wide modeled rainfall began at 14:30 and continued until 15:50 (85 minutes); GARR basin wide modeled rainfall began at 14:40 and continued until 15:45 (70 minutes).
- In most basins GARR shows rainfall occurring approximately 5-10 minutes sooner than Thiessen.
- Generally, the timing of rainfall for each basin between the two methods is similar, but GARR is more equally distributed than Thiessen (i.e. longer storms).
- Higher rainfall amounts occurred during a shorter periods of time using Thiessen.

Hydromodel Performance

The following section documents the simulation streamflow of the model from the July 13, 2011 and July 30, 2012 storm events using Thiessen and GARR precipitation inputs.

Evaluation of the July 13, 2011 Storm Event

The July 13, 2011 flood event was well documented by UDFCD and USGS, including peak discharge and the timing of peak flows at different design points throughout the basin. The summaries below show the observed and simulated peak discharge and timing of peaks for Thiessen and GARR rainfall distributions. **Appendix C** shows the simulated hydrographs modeled for the Fourmile Creek design points.

Peak Discharge

Table 4 below is a summary of the observed and simulated peak discharge corresponding modeled design points for the storm event:

Table 2 – July 13, 2011 Observed and Simulated Peak Discharges (cfs)

Design Point	Observed Peak	Thiessen Peak	GARR Peak
Fourmile Creek at Salinas	810	811	492
Fourmile Creek at Logan Mill Road	820	824	509
Fourmile Creek at Orodell	770	720	451
Boulder Creek At Orodell	674	674	674
Boulder Creek At Bridge	1,280	1,374	1,116
Boulder Creek At Canyon Mouth	1,020	1,283	1,065

Time of Peak

Table 5 below is a summary of the observed and simulated time of peak corresponding modeled design points for the storm event:

Table 3 – July 13, 2011 Observed and Simulated Time of Peak Discharge

Design Point	Observed Time of Peak	Thiessen Time of Peak	GARR Time of Peak
Fourmile Creek at Salinas	N/A	7:20 PM	7:20 PM
Fourmile Creek at Logan Mill Road	7:17 PM	7:25 PM	7:25 PM
Fourmile Creek at Orodell	8:06 PM	8:05 PM	8:05 PM
Boulder Creek At Orodell	8:00 PM	7:06 PM	7:06 PM
Boulder Creek At Bridge	8:10 PM	8:15 PM	8:20 PM
Boulder Creek At Canyon Mouth	8:45 PM	9:05 PM	9:05 PM

Model Evaluation of the July 30, 2012 Storm Event

The July 30, 2012 flood event was well documented by UDFCD and USGS, including peak discharge and the timing of peak flows at different design points throughout the basin. The summaries below show the observed and simulated peak discharge and timing of peaks for Thiessen and GARR rainfall distributions. **Appendix C** shows the simulated hydrographs modeled for the Fourmile Creek design points.

Peak Discharge

Table 4 below is a summary of the observed and simulated peak discharge corresponding modeled design points for the storm event:

Table 4 – July 30, 2012 Observed and Simulated Peak Discharges (cfs)

Design Point	Observed Peak	Thiessen Peak	GARR Peak
Fourmile Creek at Salinas	140	575	178
Fourmile Creek at Logan Mill Road	108	600	189
Fourmile Creek at Orodell	131	520	171
Boulder Creek near Orodell	145	144	133
Boulder Creek At Bridge	251	634	296
Boulder Creek At Canyon Mouth	221	596	273

*Note the observed peak flow from Fourmile Creek at Salinas is questionable.

Time of Peak

Table 5 below is a summary of the observed and simulated time of peak corresponding modeled design points for the storm event:

Table 5 – July 30, 2012 Observed and Simulated Time of Peak Discharge

Design Point	Observed Time of Peak	Thiessen Time of Peak	GARR Time of Peak
Fourmile Creek at Salinas	4:02 PM	3:55 PM	3:55 PM
Fourmile Creek at Logan Mill Road	4:05 PM	4:00 PM	4:00 PM
Fourmile Creek at Orodell	4:45 PM	4:35 PM	4:40 PM
Boulder Creek near Orodell	11:00 PM	7:06 PM	7:06 PM
Boulder Creek At Bridge	4:52 PM	4:45 PM	4:50 PM
Boulder Creek At Canyon Mouth	5:45 PM	5:20 PM	5:40 PM

The use of GARR as a precipitation input simulates valid results. It is important to note that the differences seen between the two simulations is partially the result of the hydromodel being calibrated to Thiessen precipitation inputs for specific storms. Rainfall is by far the most important parameter of the model and any improved accuracy will help to enhance calibration and representation of future events.

Conclusion

The use of GARR as an input to the Boulder Creek hydromodel is highly recommended. The current Thiessen method reasonably quantifies total precipitation for long duration storms that are equally distributed across the watershed. However, there are some basins that are poorly represented using the Thiessen method due to station densities, orographic effects, or other effects. GARR more consistently represents basin temporal and total rainfall distributions.

The simulation of rainfall runoff for the July 13, 2011 and July 30, 2012 storm events reflects the volumetric differences between the two inputs. The timing of rainfall runoff was relatively unaffected by GARR precipitation inputs. However, GARR basin totals are approximately 26% less Thiessen basin totals and are more evenly distributed temporally with reduced rainfall intensities. The result is GARR rainfall runoff is much less than Thiessen rainfall runoff. Interestingly, Thiessen peak discharges were closer to observed for the July 13, 2011 event, and GARR peak discharges were closer to observed for the July 30, 2012 event.

In summary, the use of refined grid based precipitation data in a lumped parameter model does produce valid results with increased the accuracy, but recalibration of the model would be necessary.

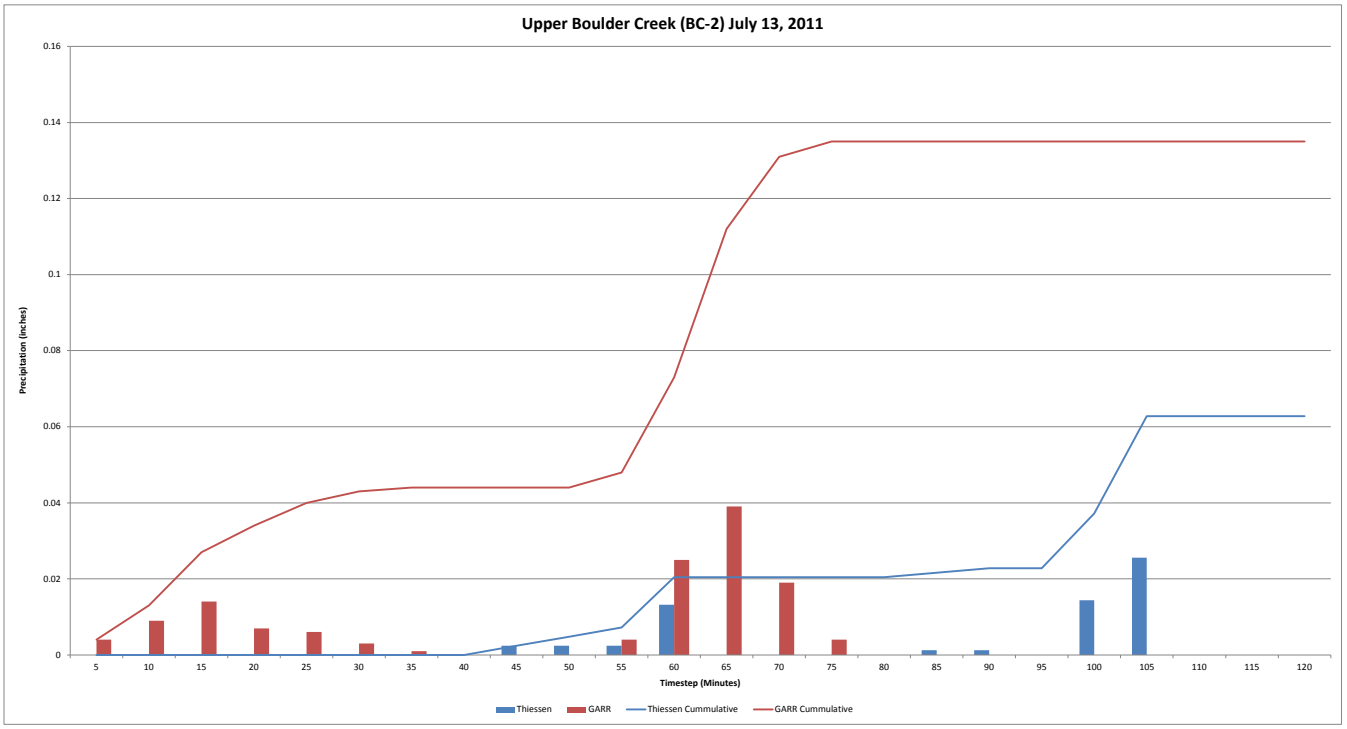
Cost Estimate for Real-time Implementation of GARR Inputs

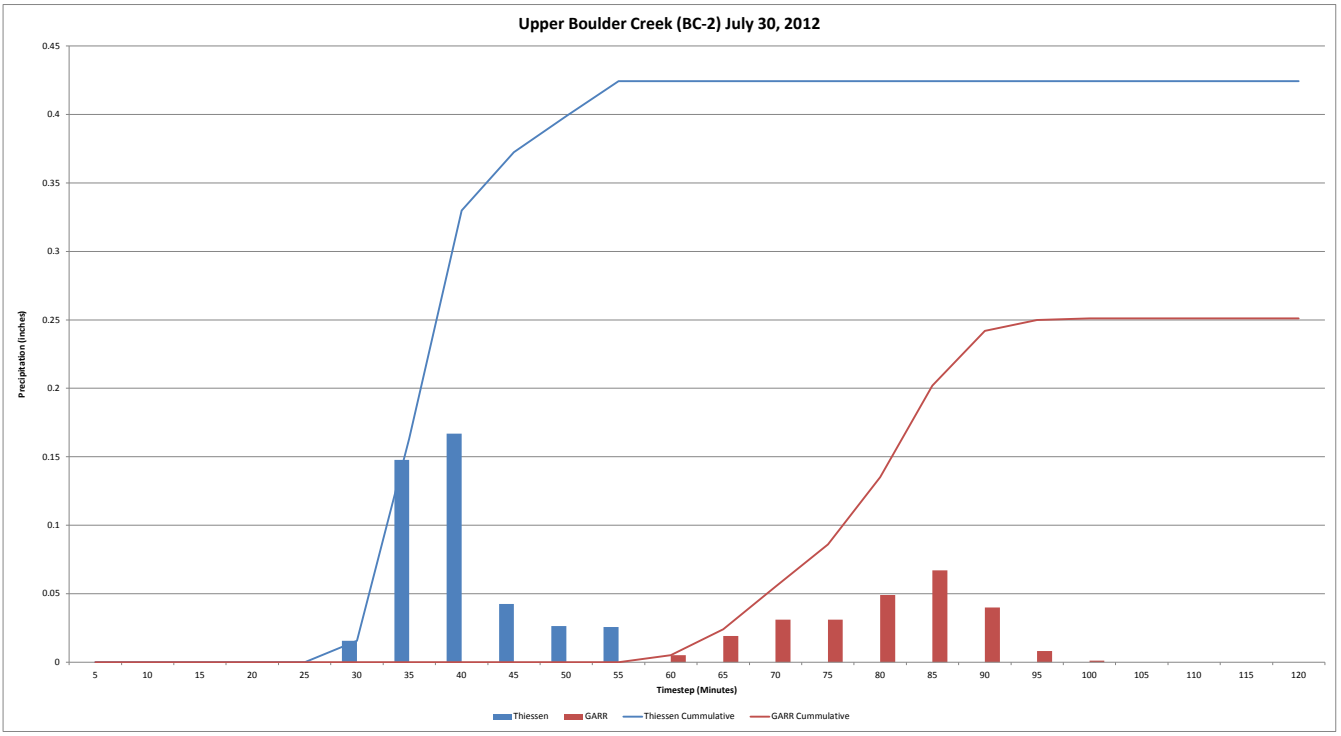
This memorandum documents the results of GARR precipitation inputs and provides proof of concept that the implementation of GARR is not only feasible, but effective. Implementation of GARR real-time will allow for not only for QPE, but QPF rainfall runoff estimates, which ultimately leads to enhanced flood warning systems. The cost summary below represents the estimated cost to implement GARR real-time.

Task	**Cost**
QPE/QPF GARR Processing (Viuex or WDT) -	$12,000/all models
PostgreSQL processing -	$3,000/all models
Hydromodel QPE GARR Integration -	$3,000/model
Hydromodel Calibration -	$1,500/model
Hydromodel QPF GARR Integration -	$2,000 (2 QPF inputs)/model
Coordination/Scoping/Project Management -	$500/model
Total -	**$15,000 + $7,000/model**

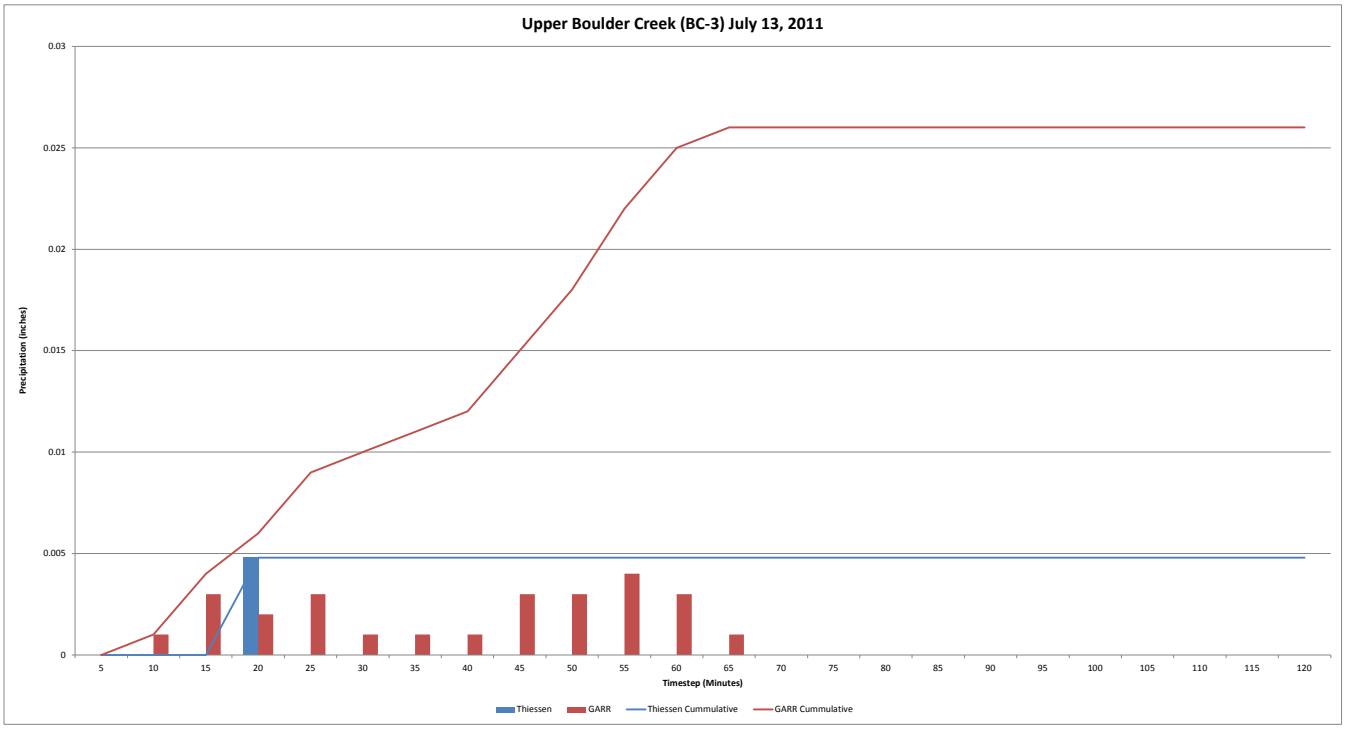
Appendix A - Precipitation Comparison Graphs

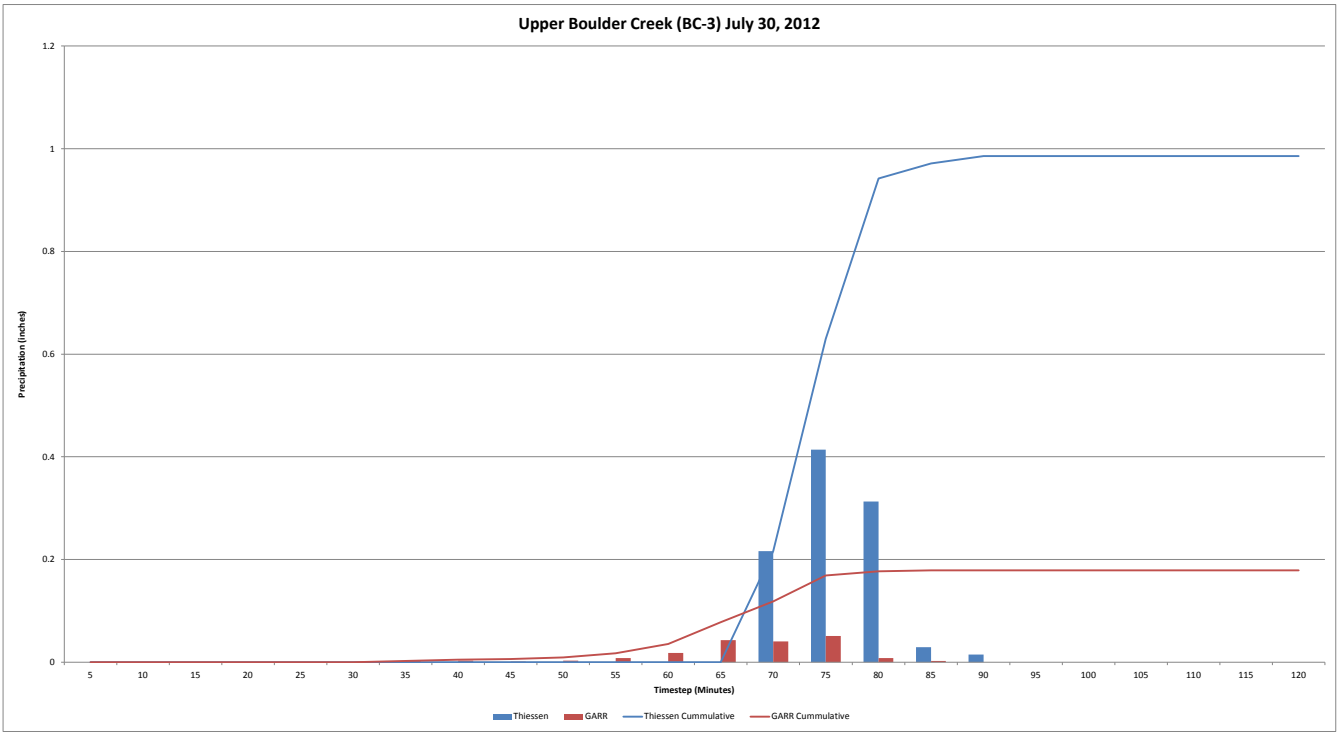
Appendix A1 Hyetograph (BC-2)



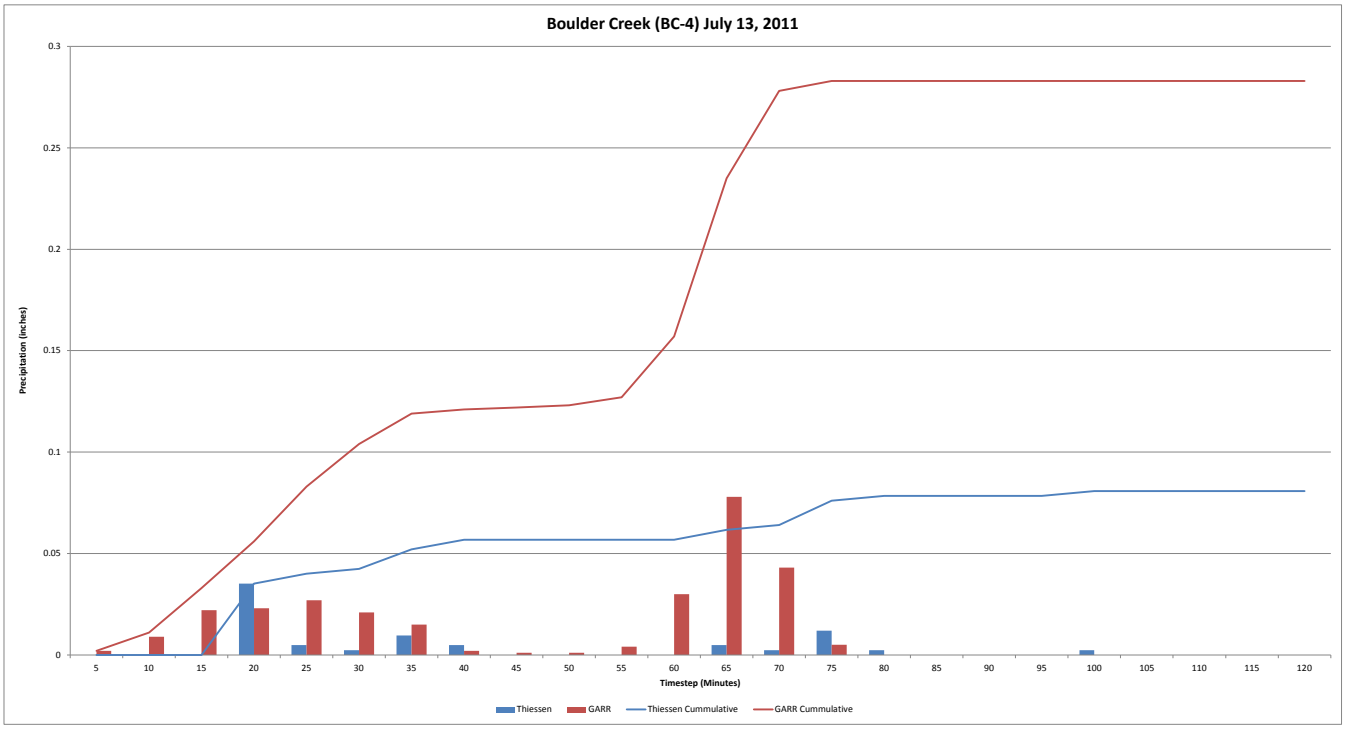


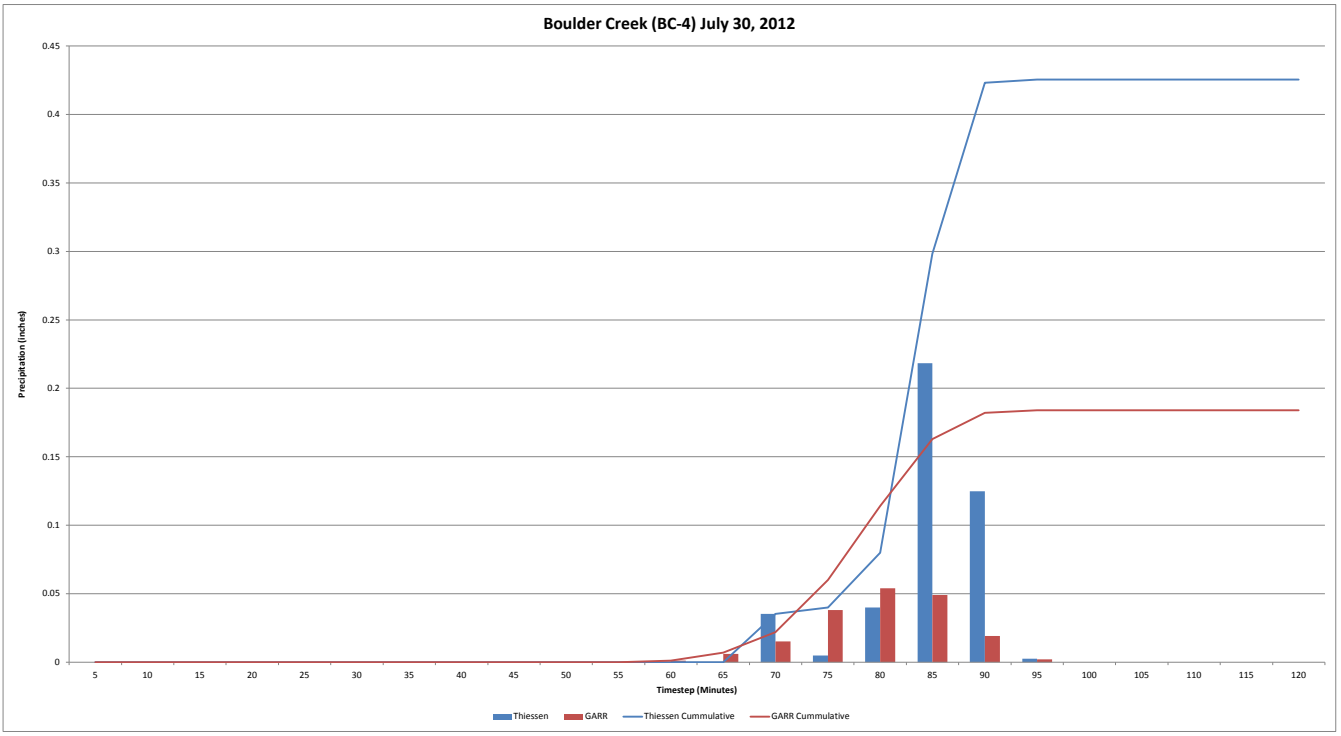
Appendix A2 Hyetograph (BC-3)



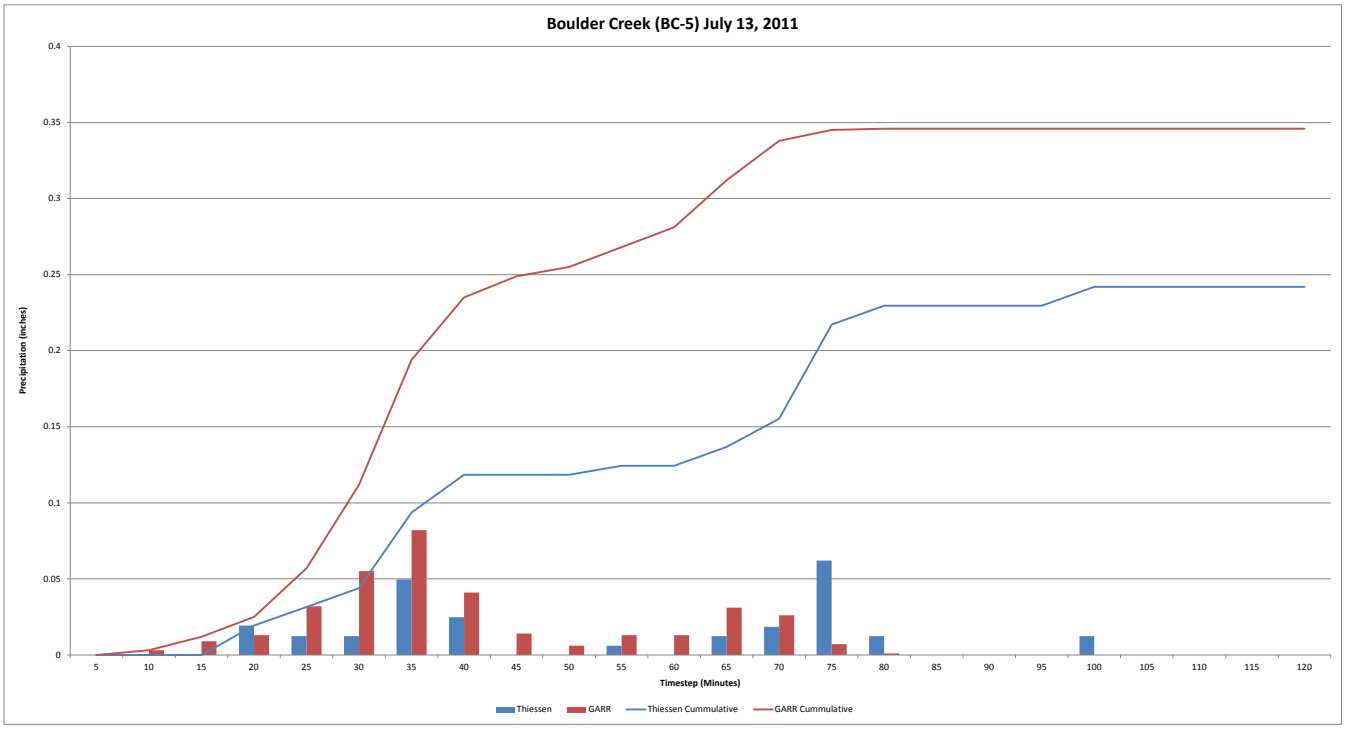


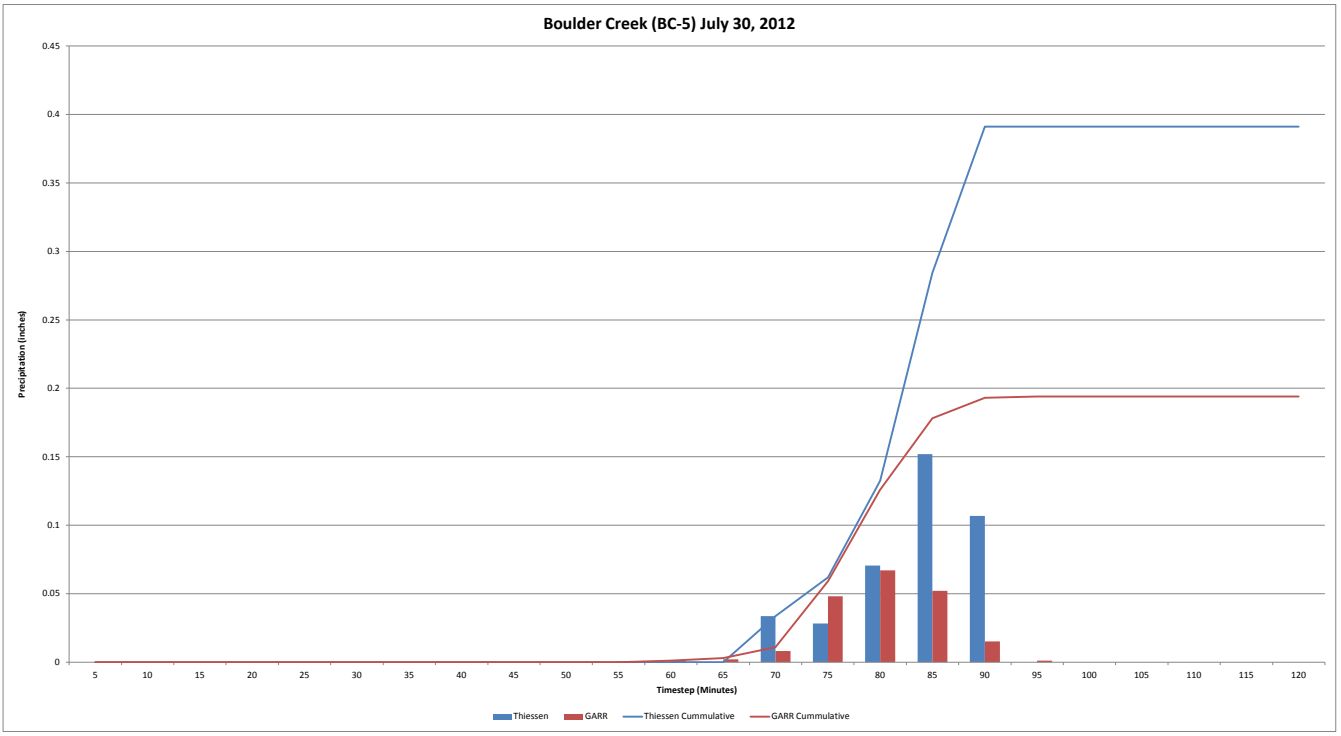
Appendix A3 Hyetograph (BC-4)



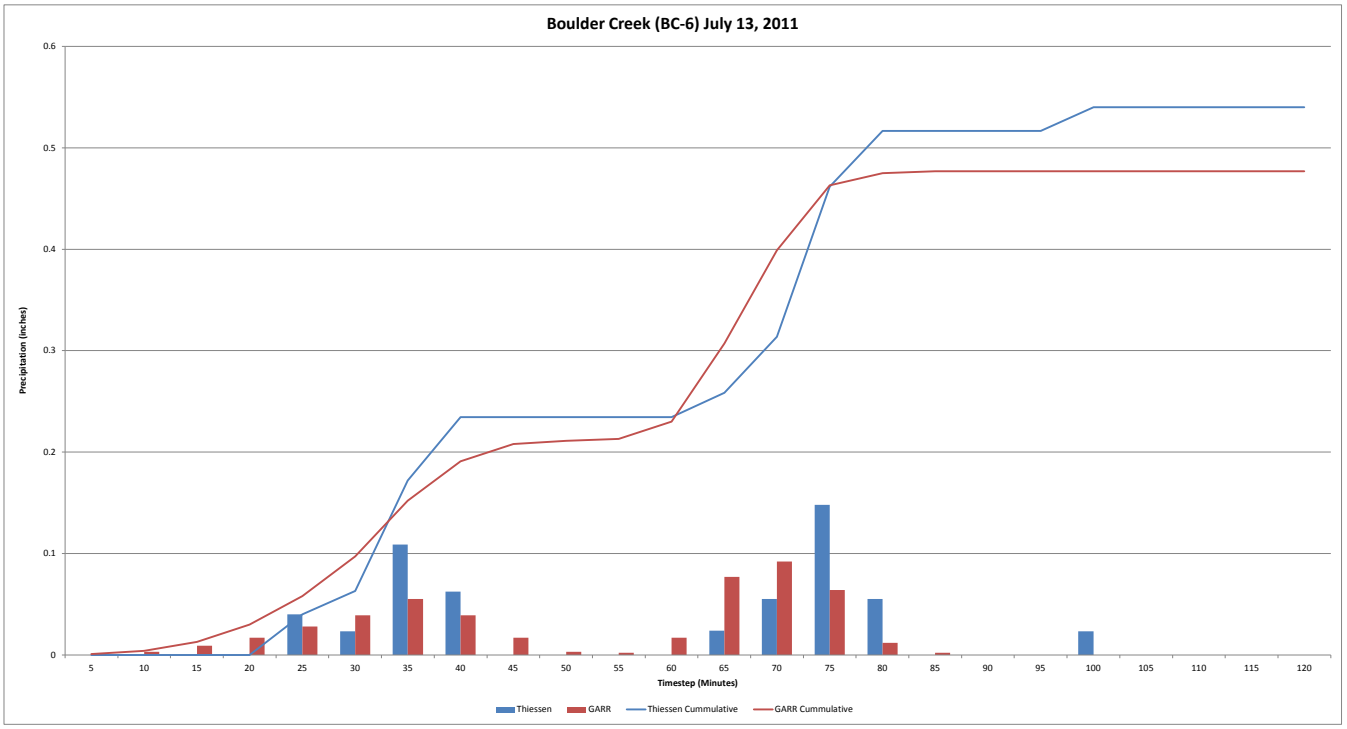


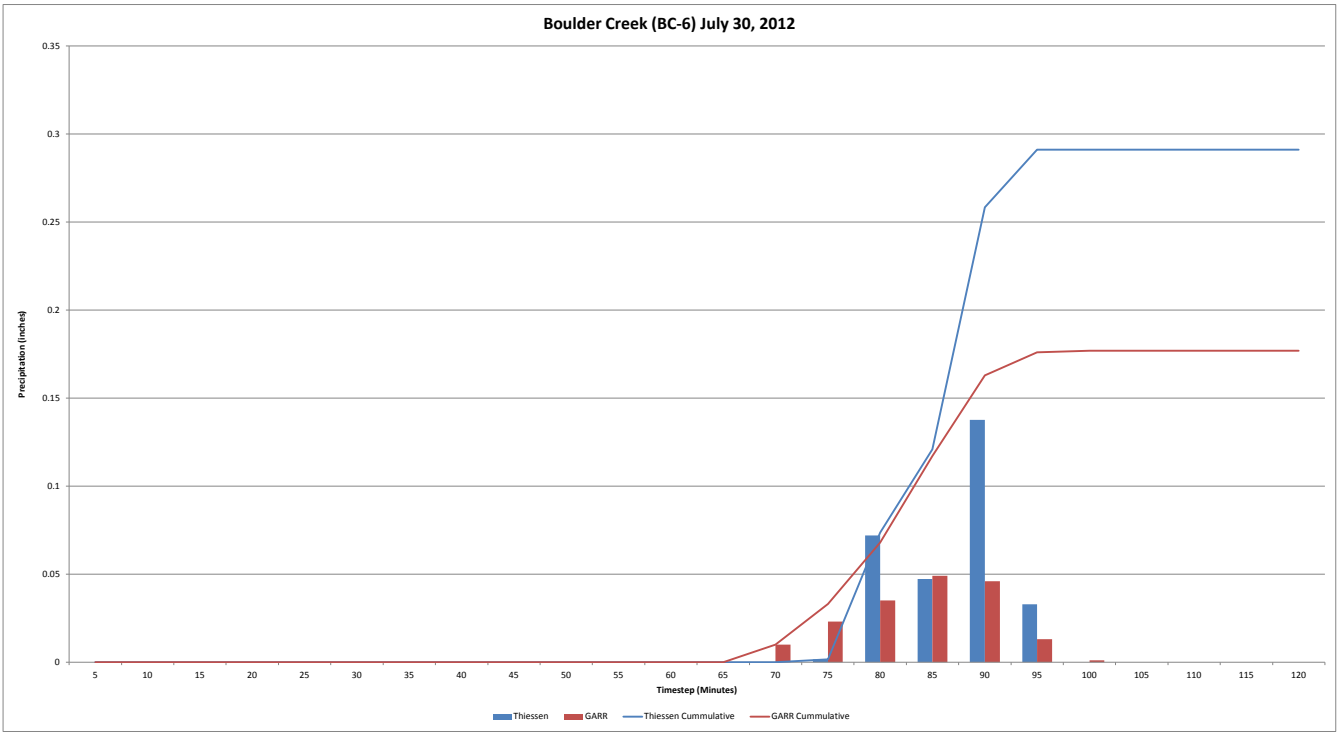
Appendix A4 Hyetograph (BC-5)



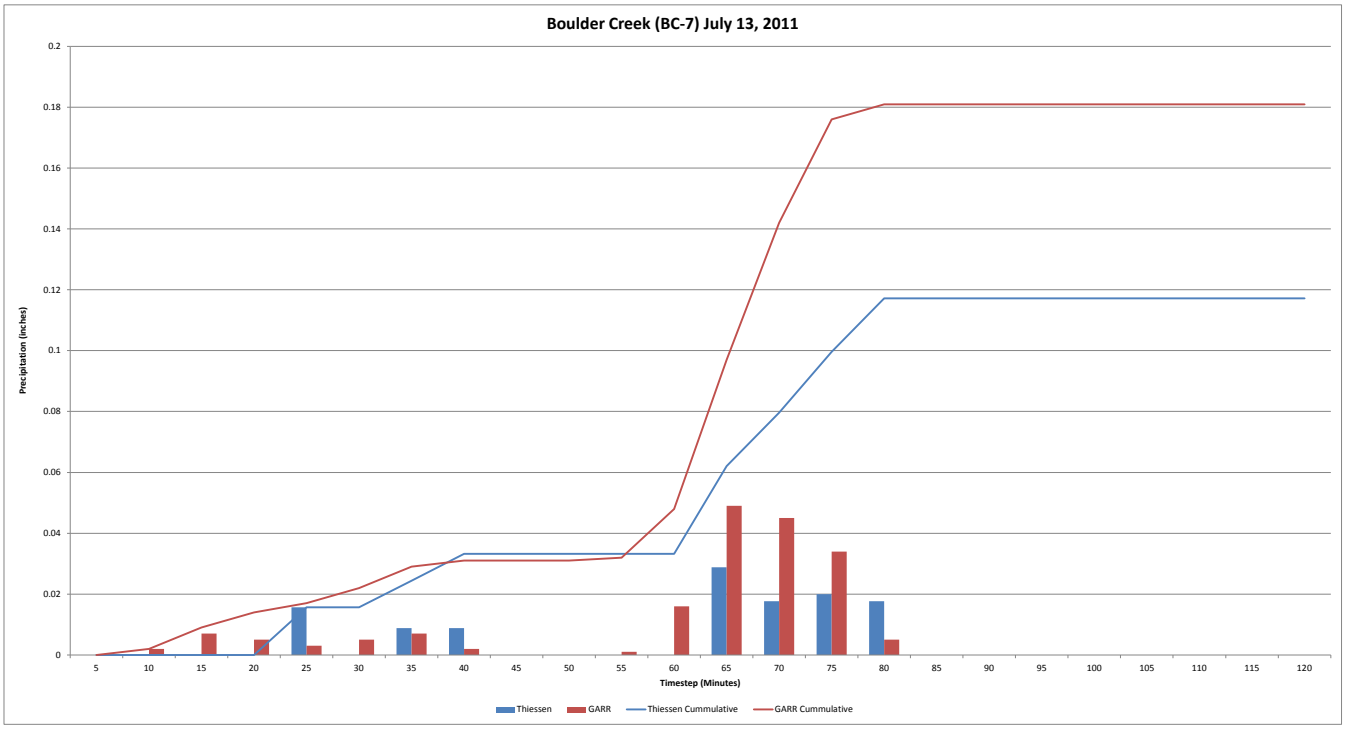


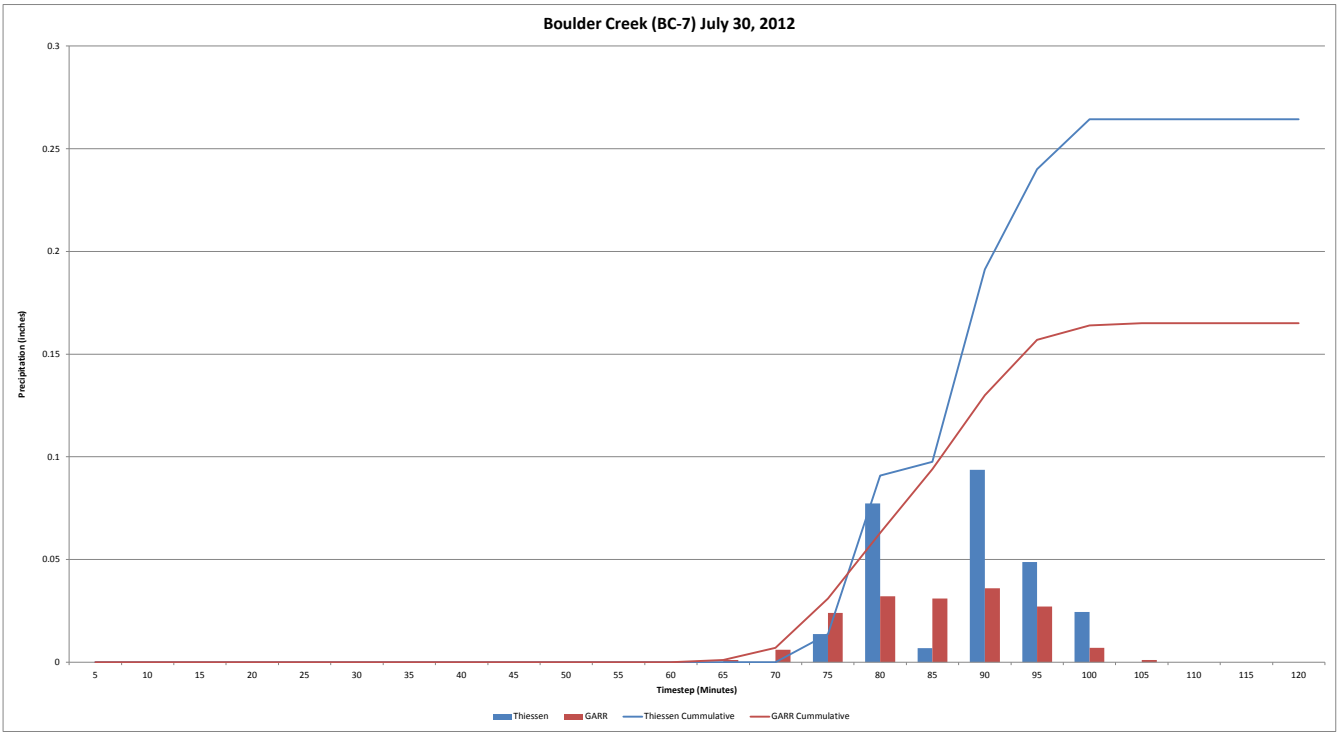
Appendix A5 Hyetograph (BC-6)



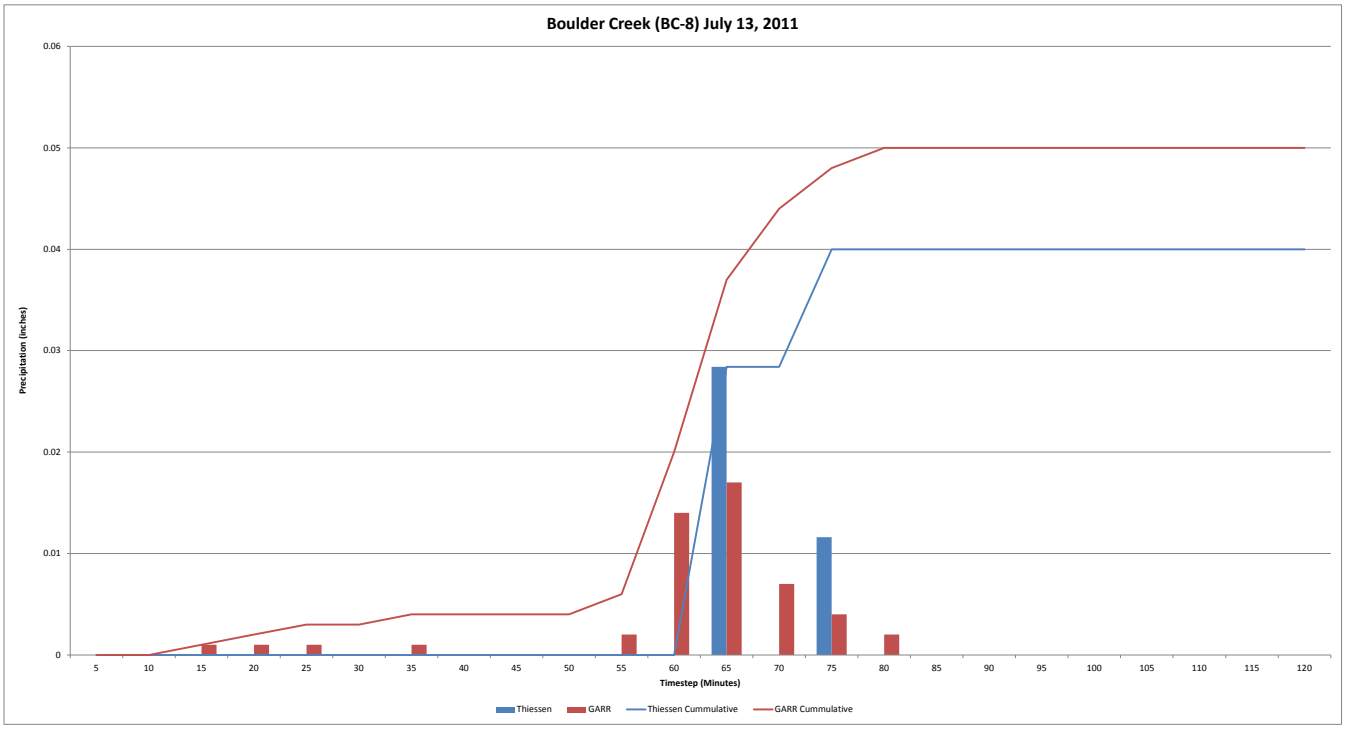


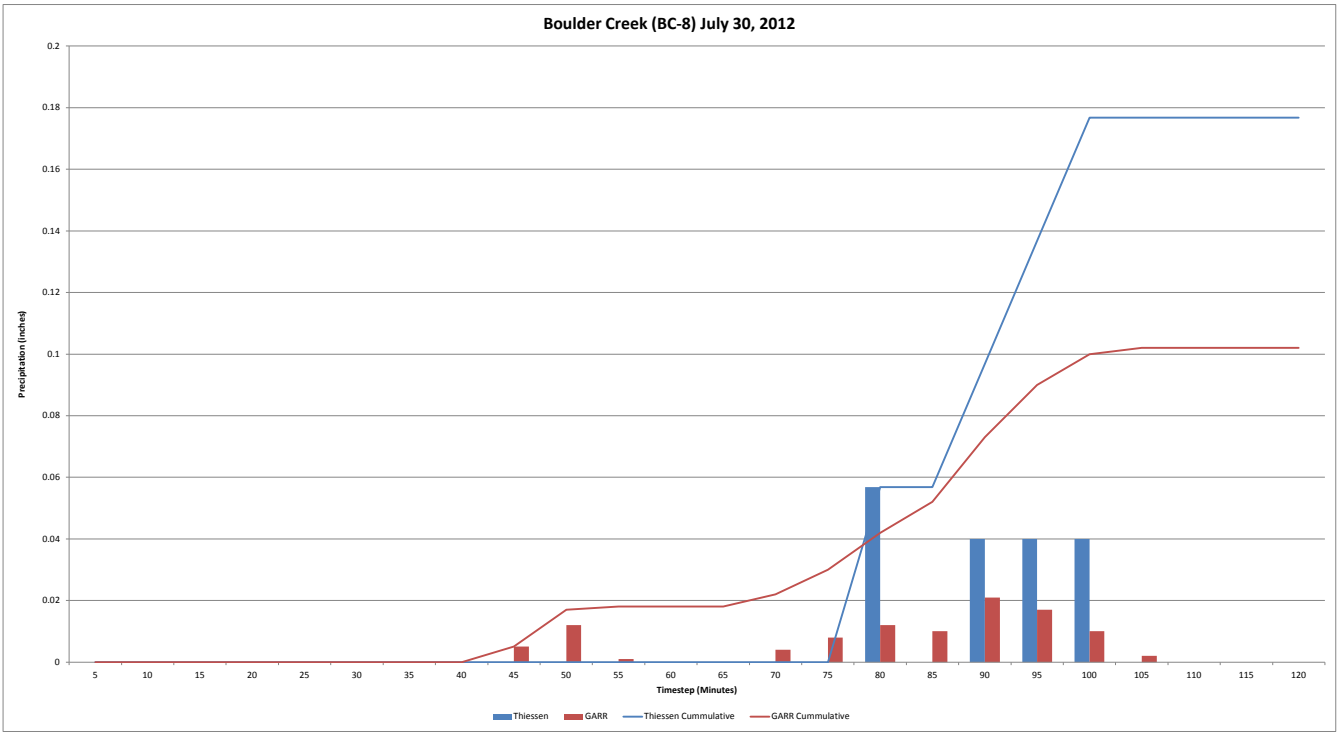
Appendix A6 Hyetograph (BC-7)



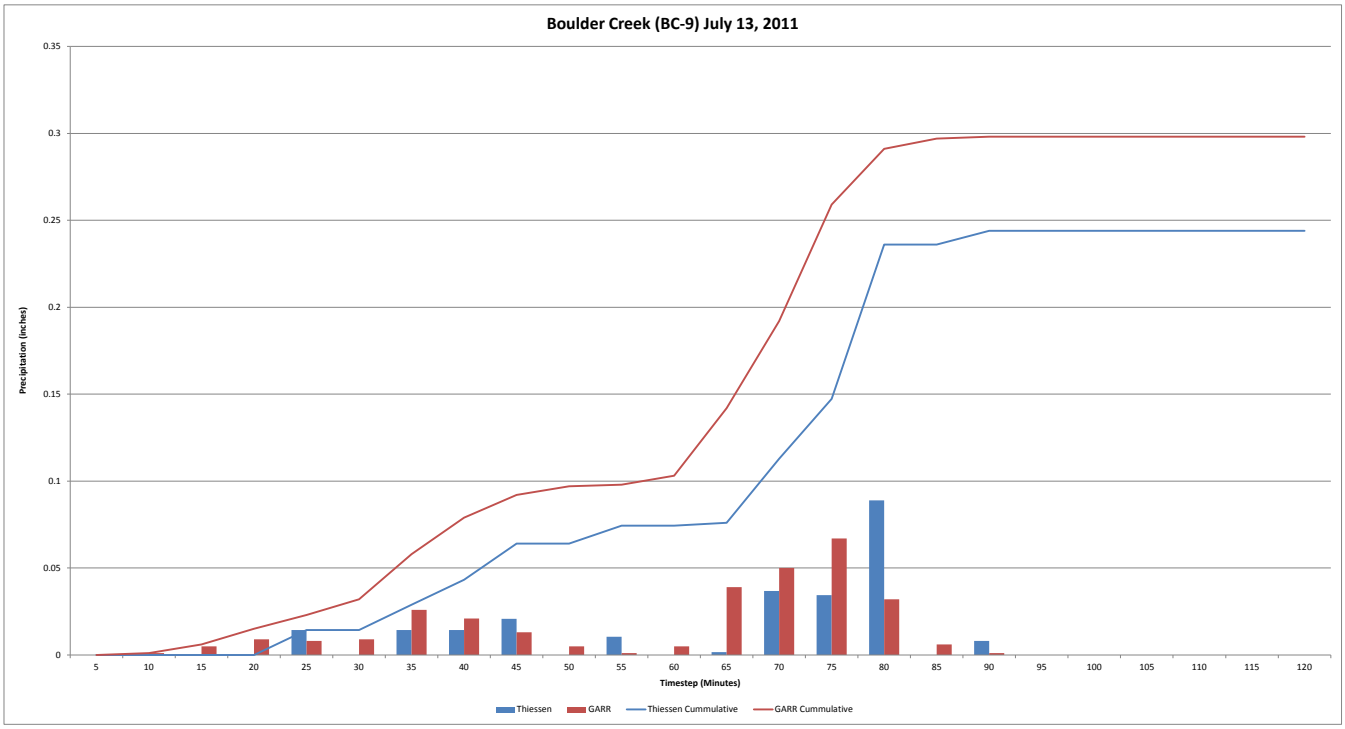


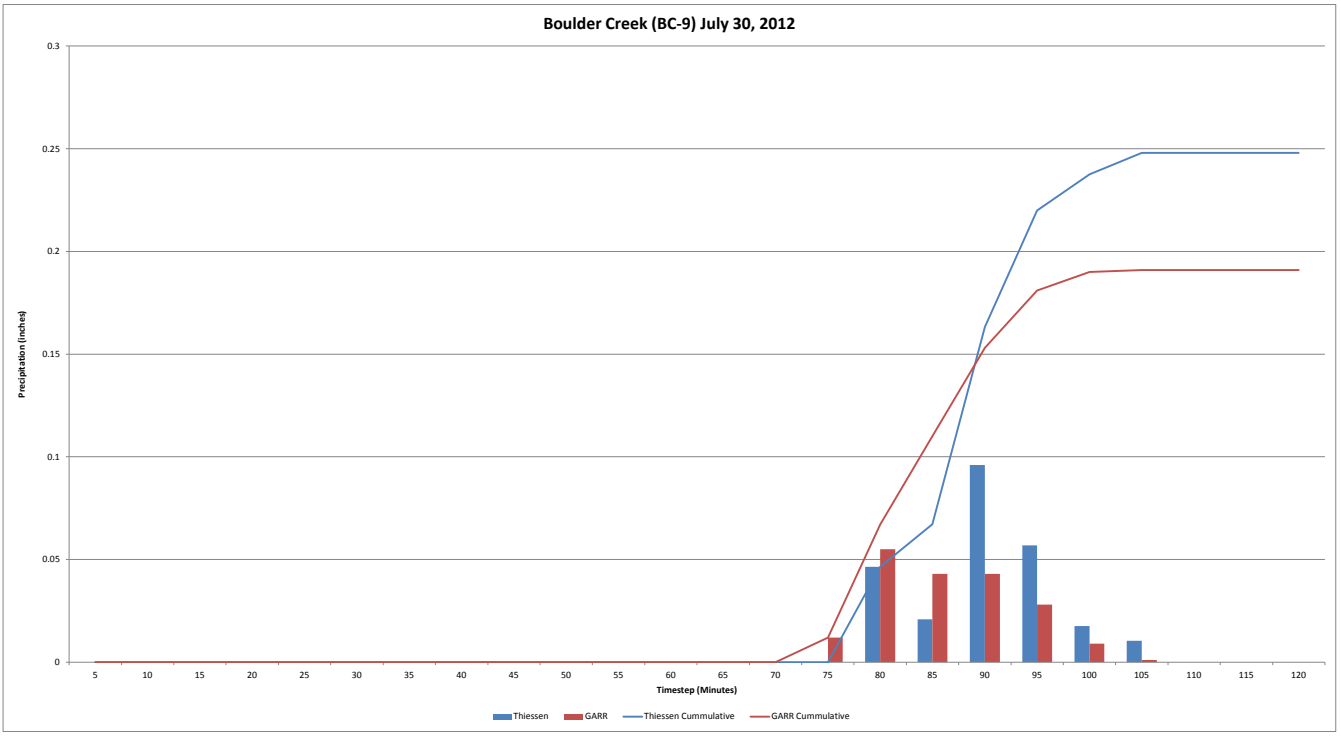
Appendix A7 Hyetograph (BC-8)



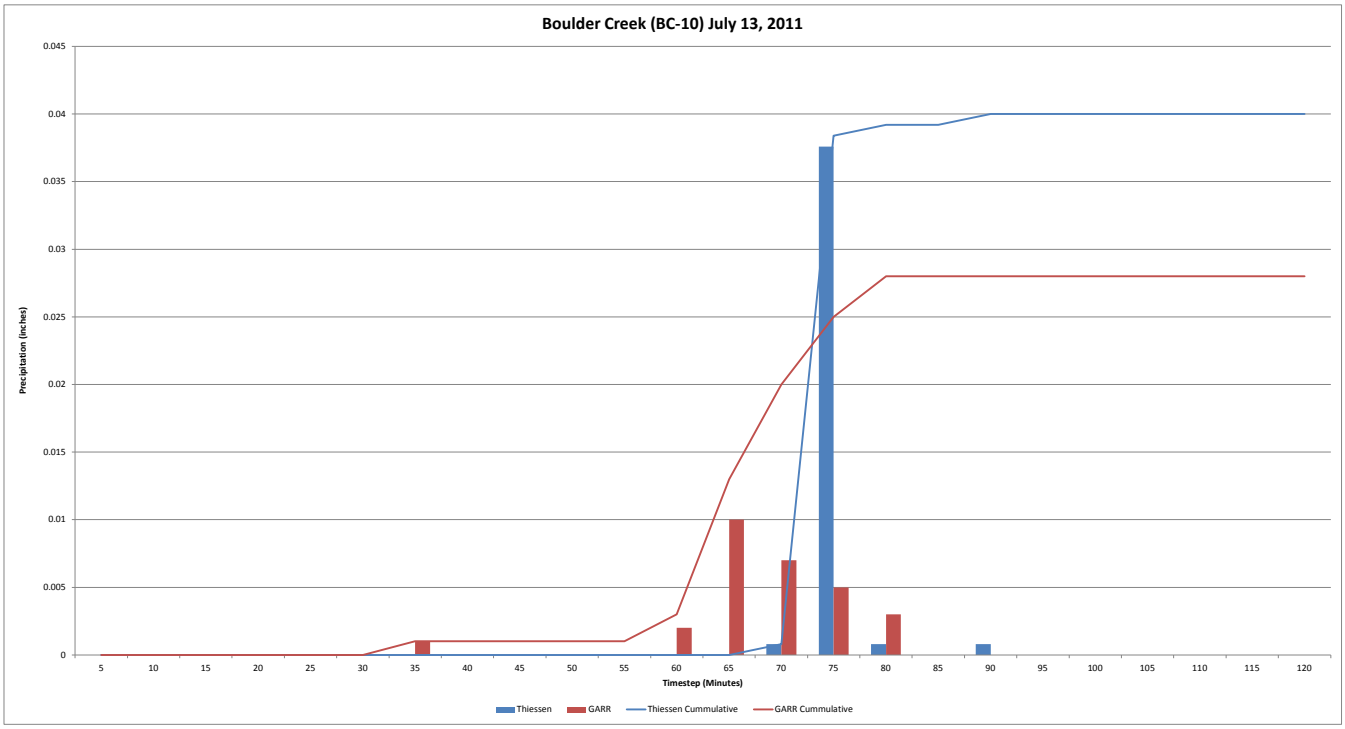


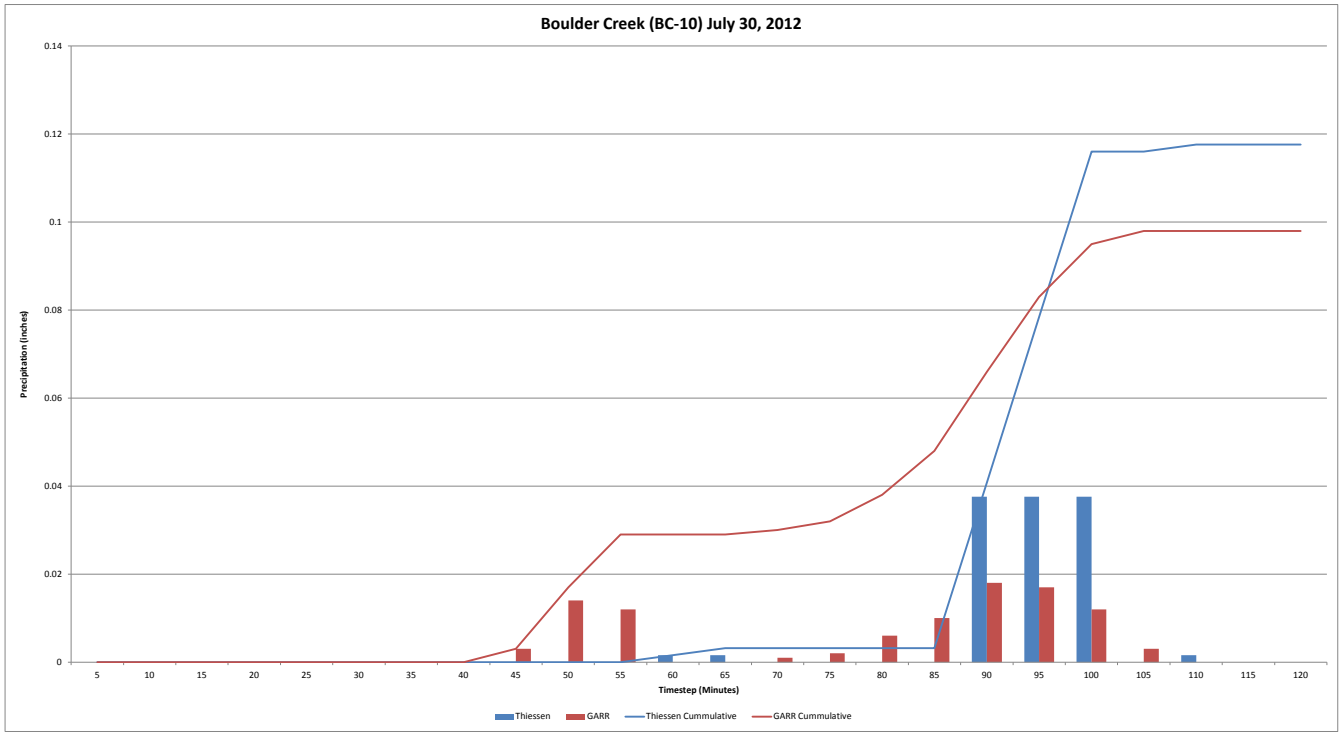
Appendix A8 Hyetograph (BC-9)



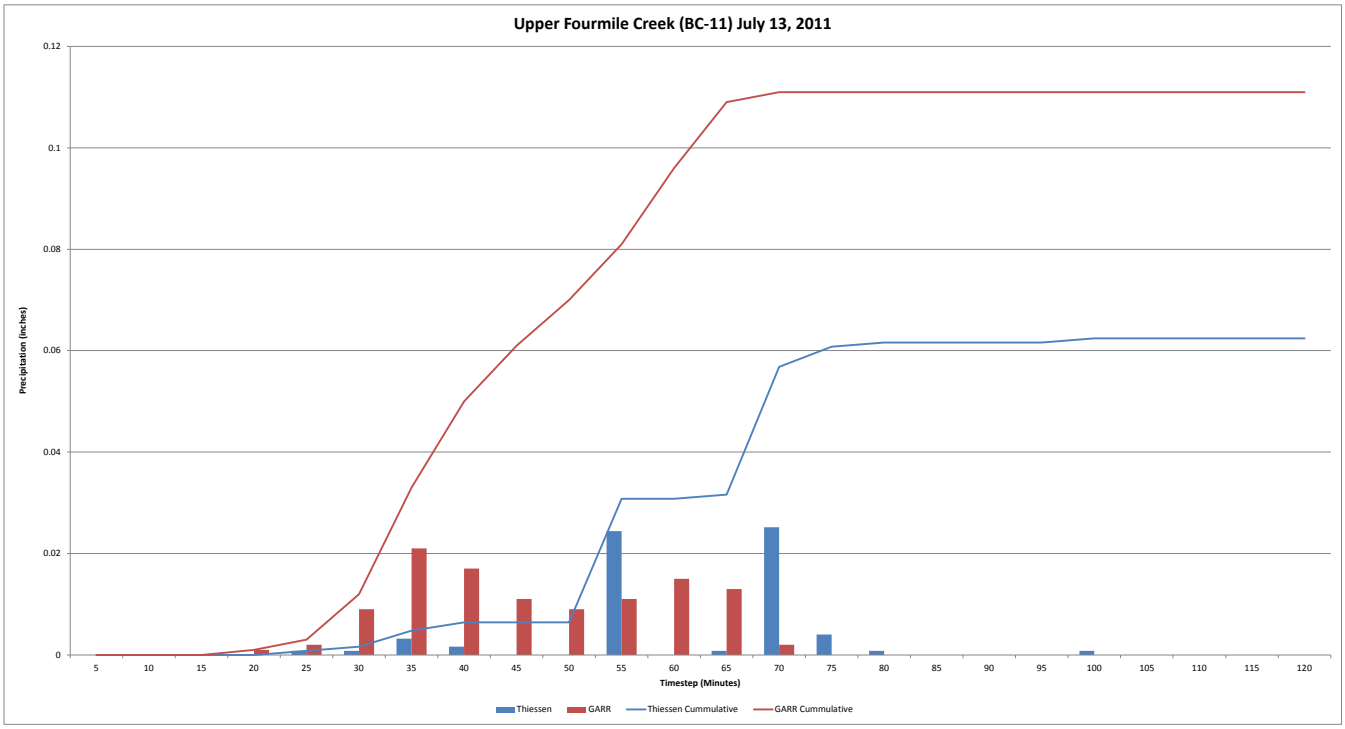


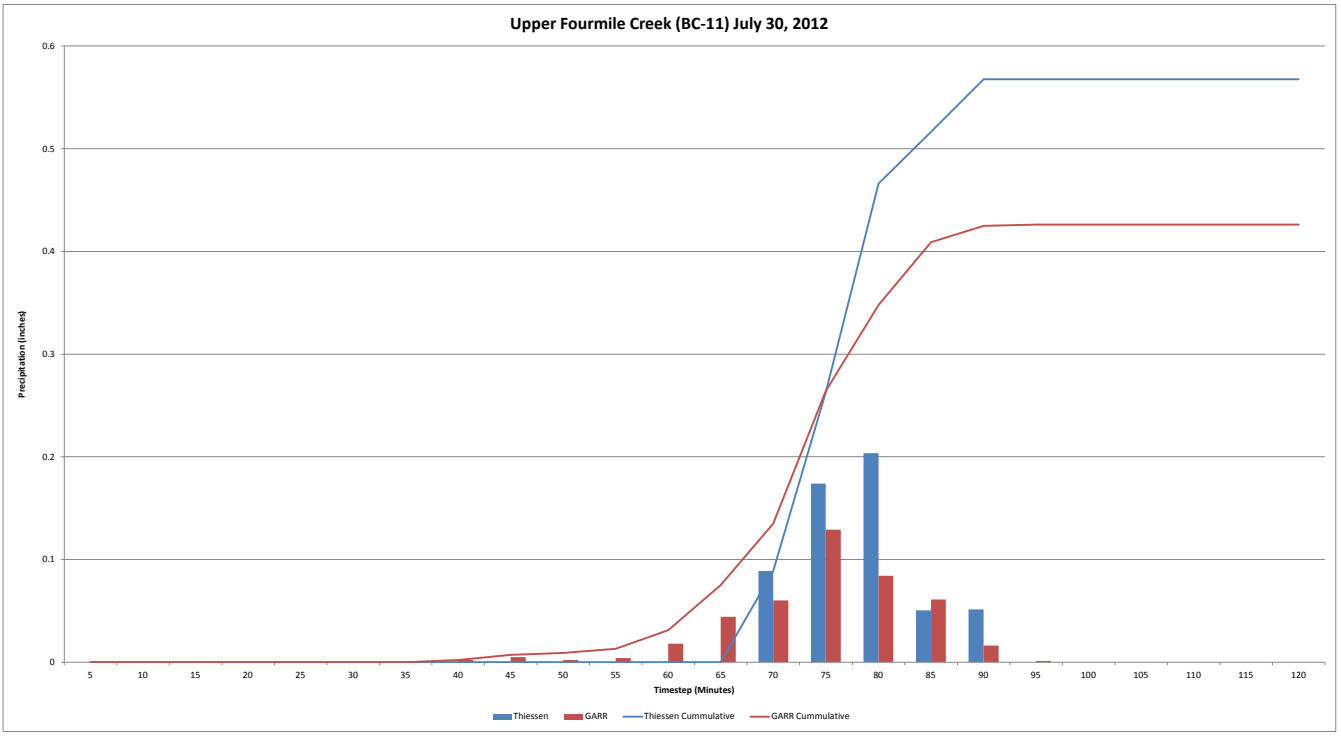
Appendix A9 Hyetograph (BC-10)



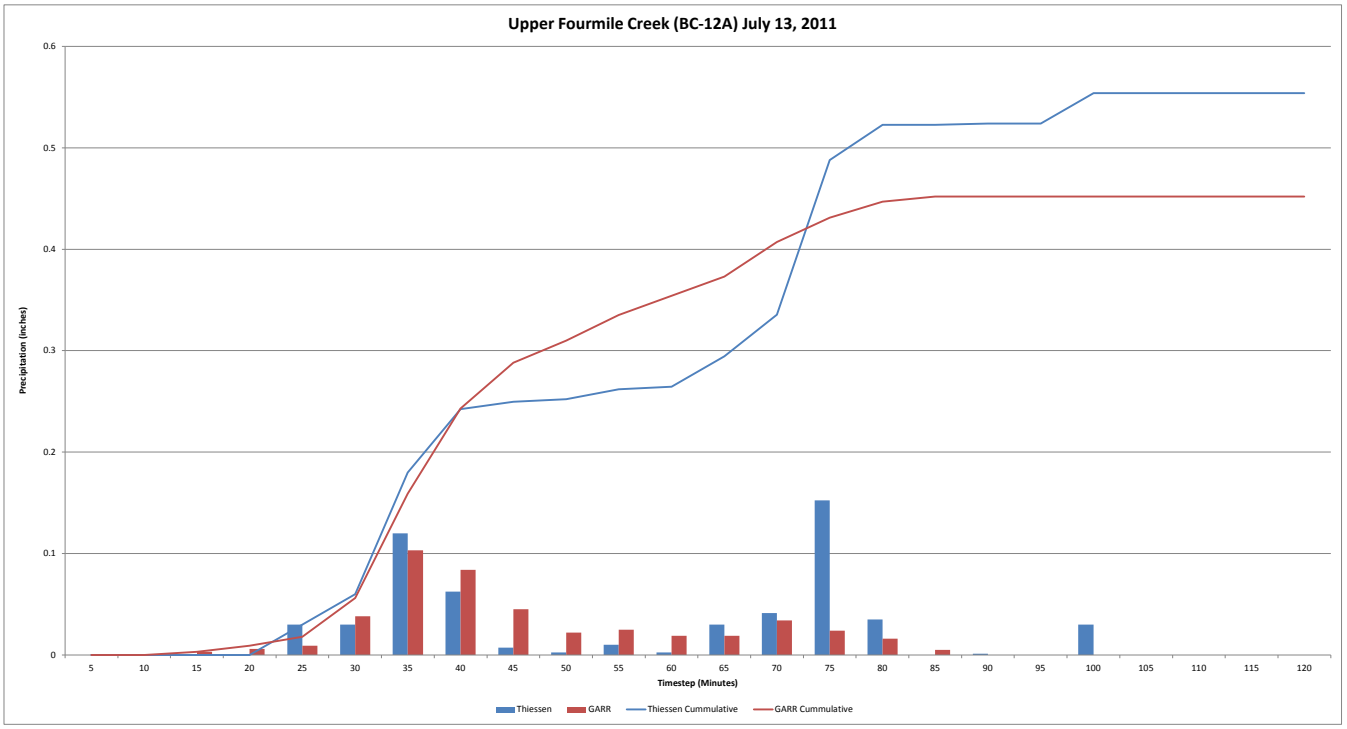


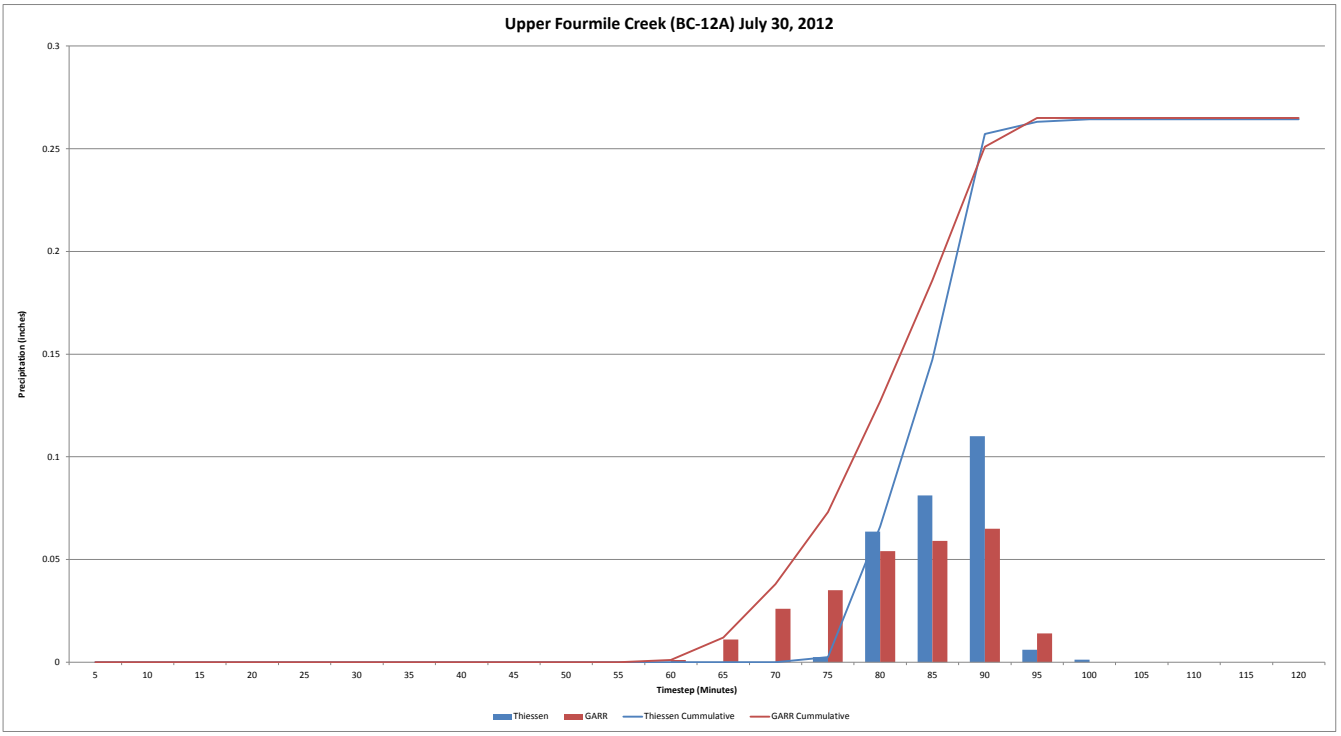
Appendix A10 Hyetograph (BC-11)



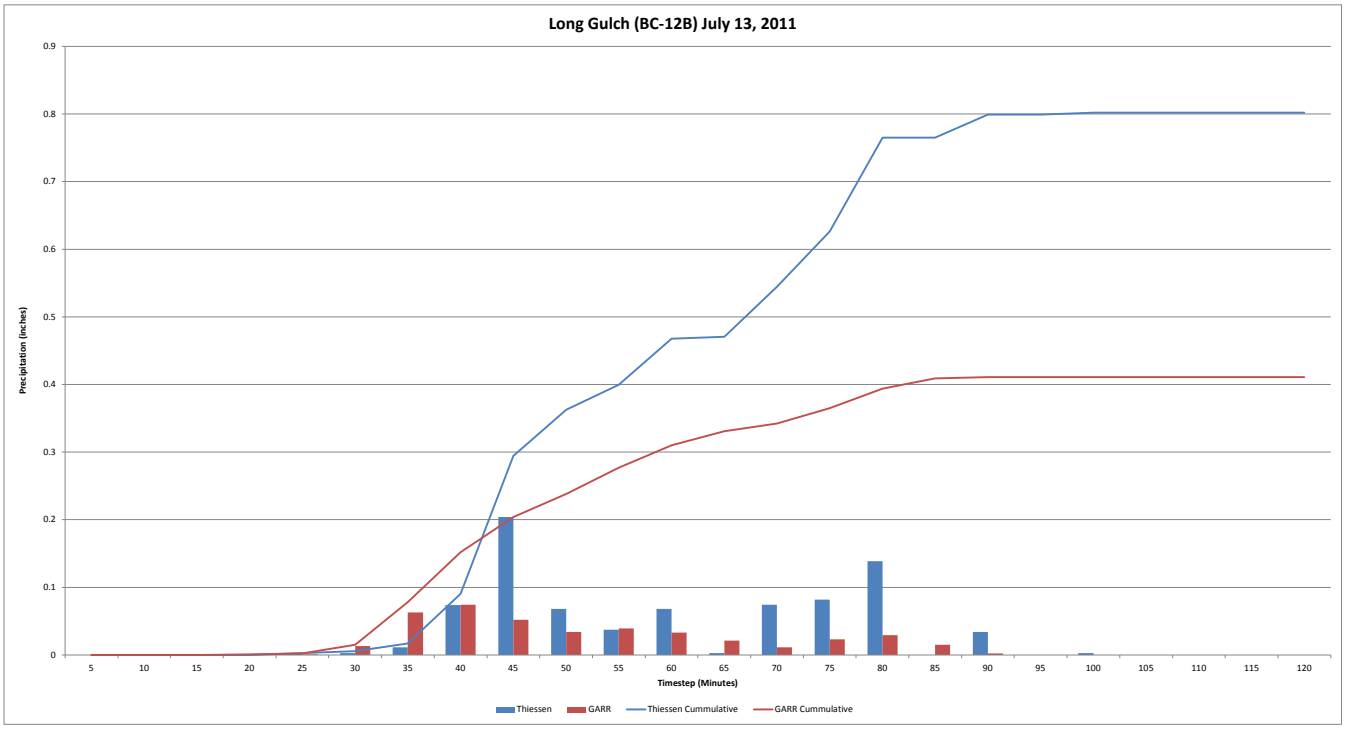


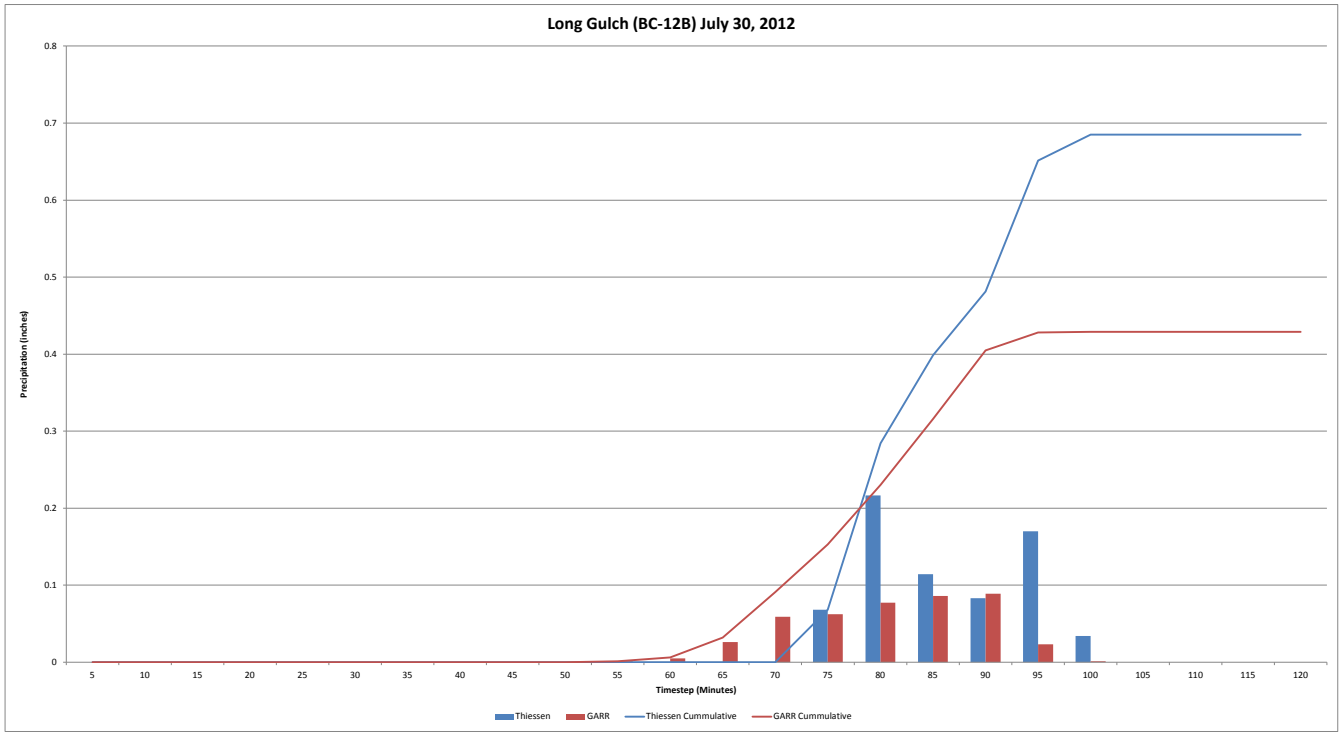
Appendix A11 Hyetograph (BC-12A)



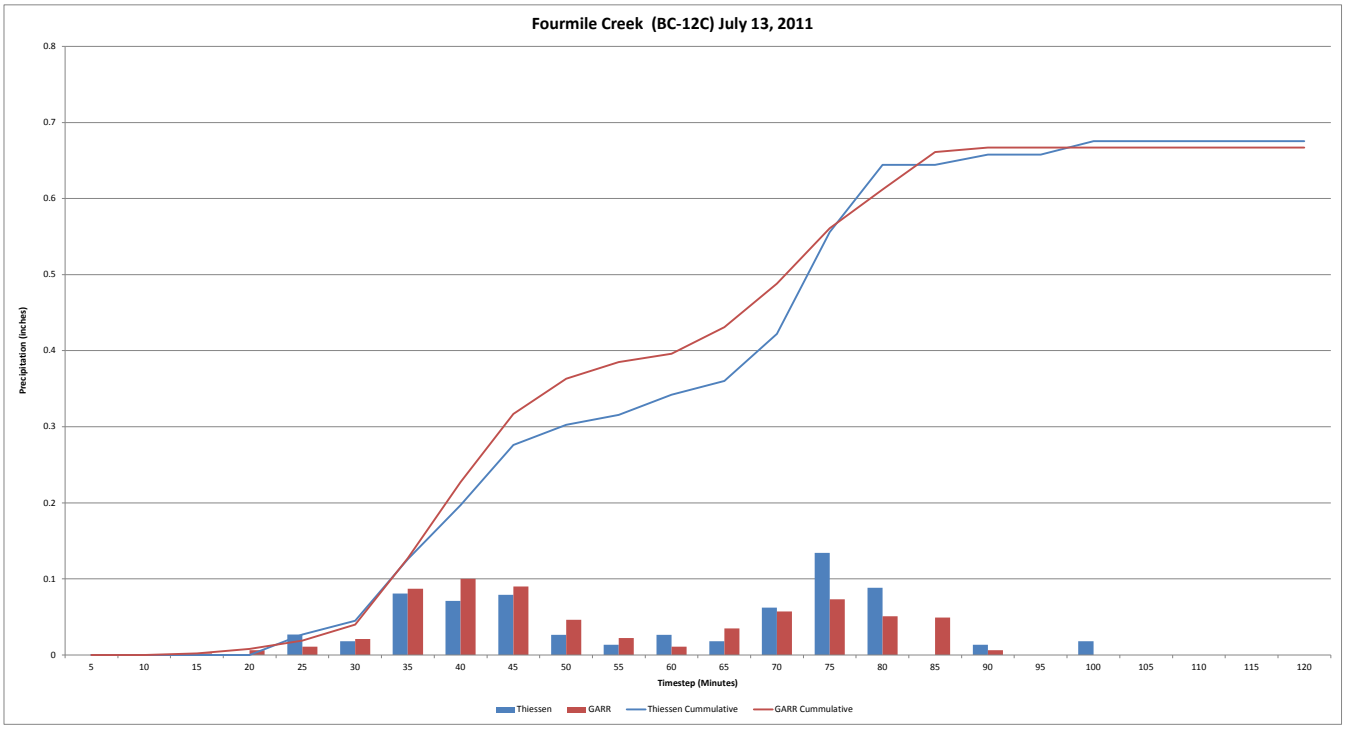


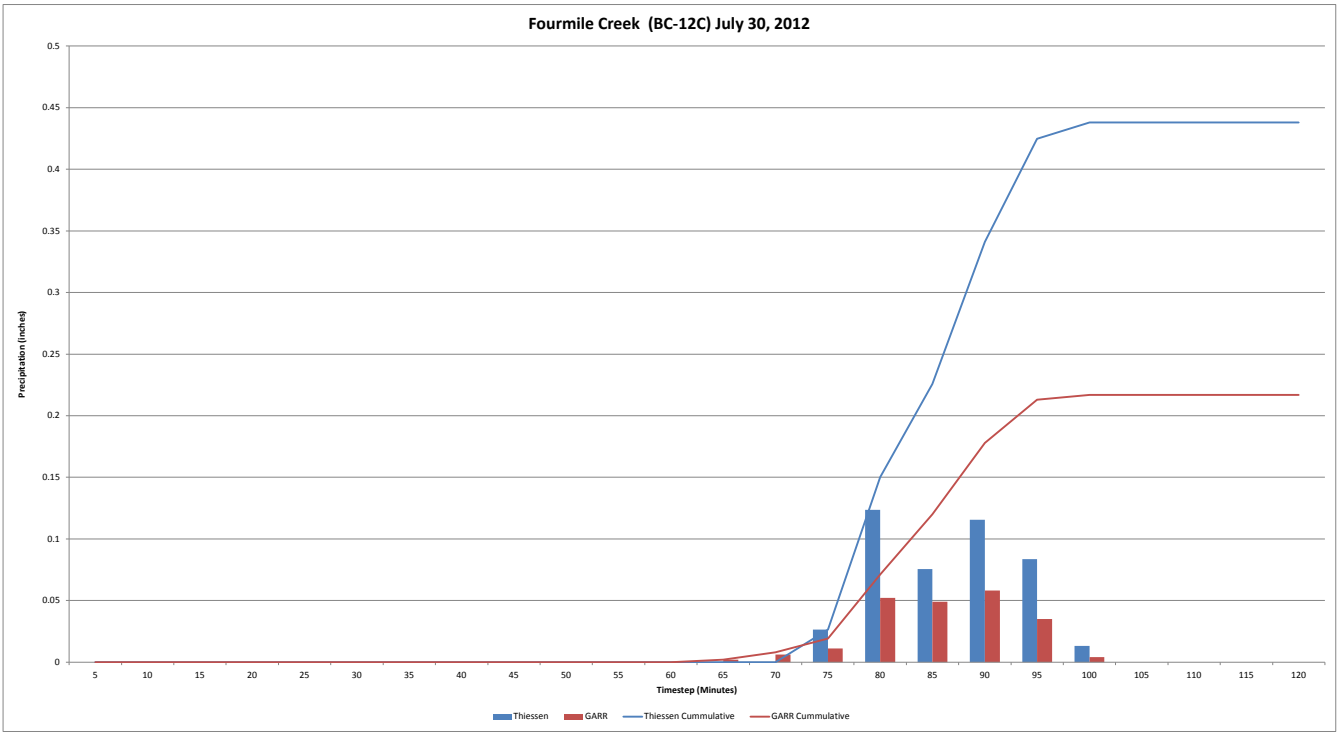
Appendix A12 Hyetograph (BC-12B)



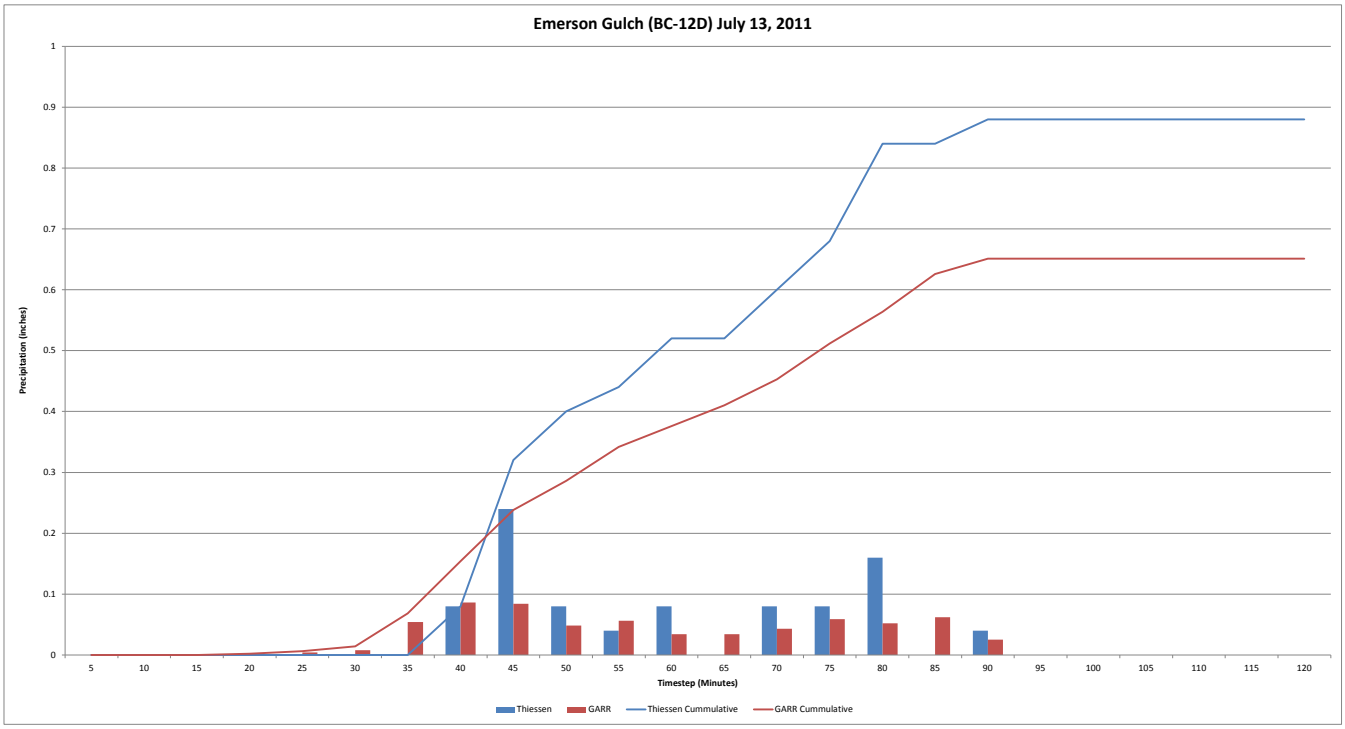


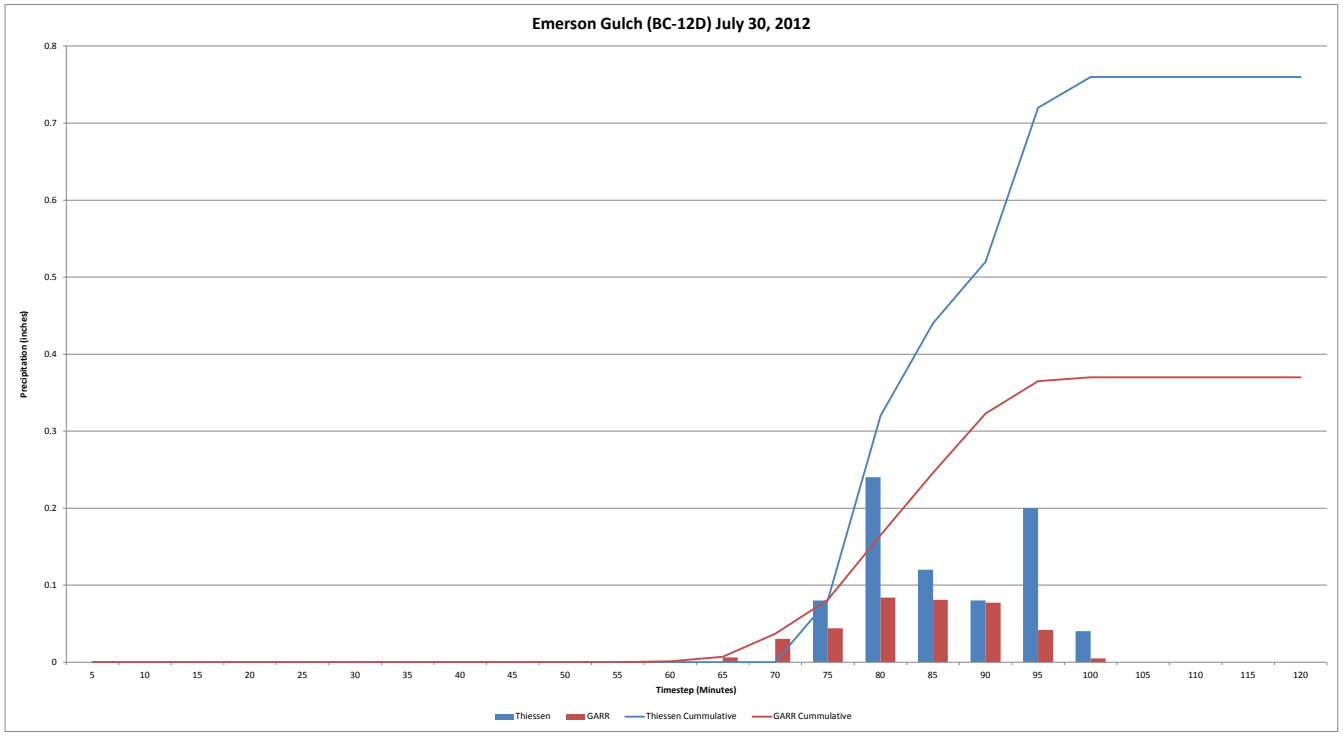
Appendix A13 Hyetograph (BC-12C)



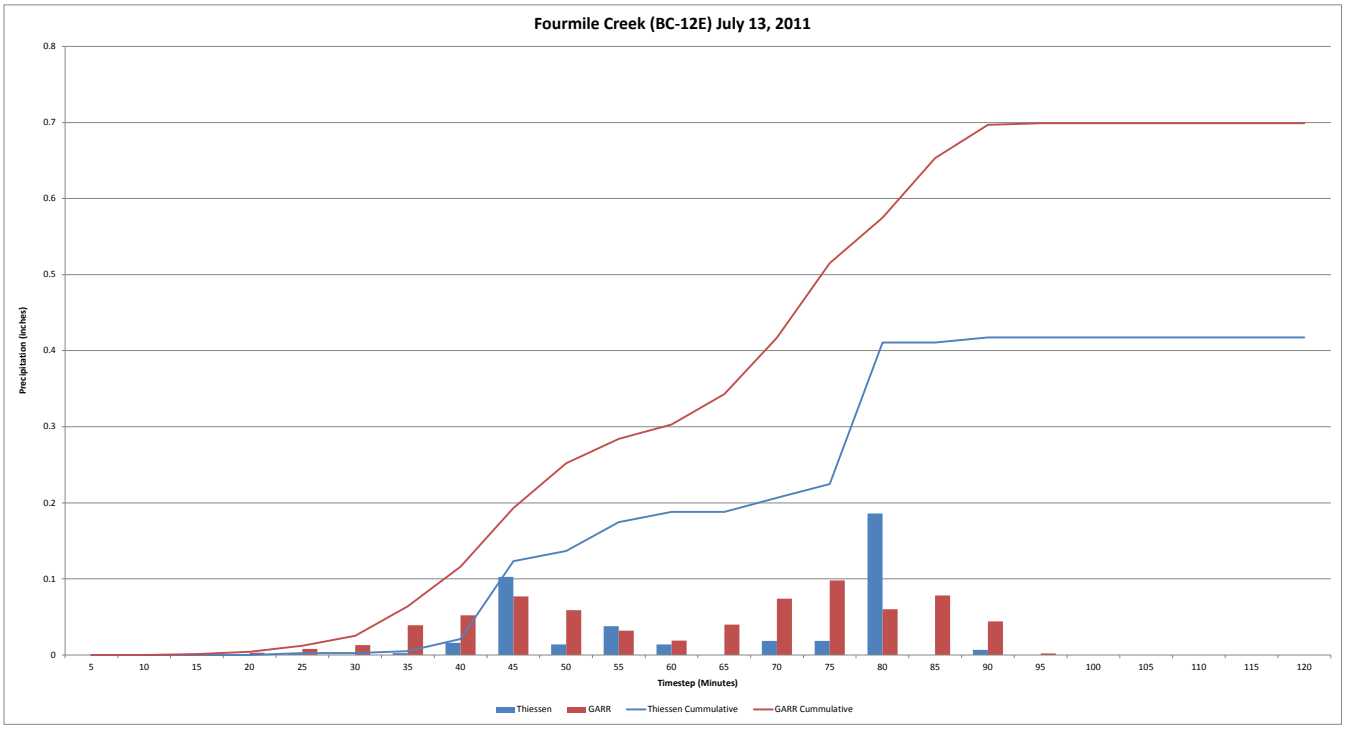


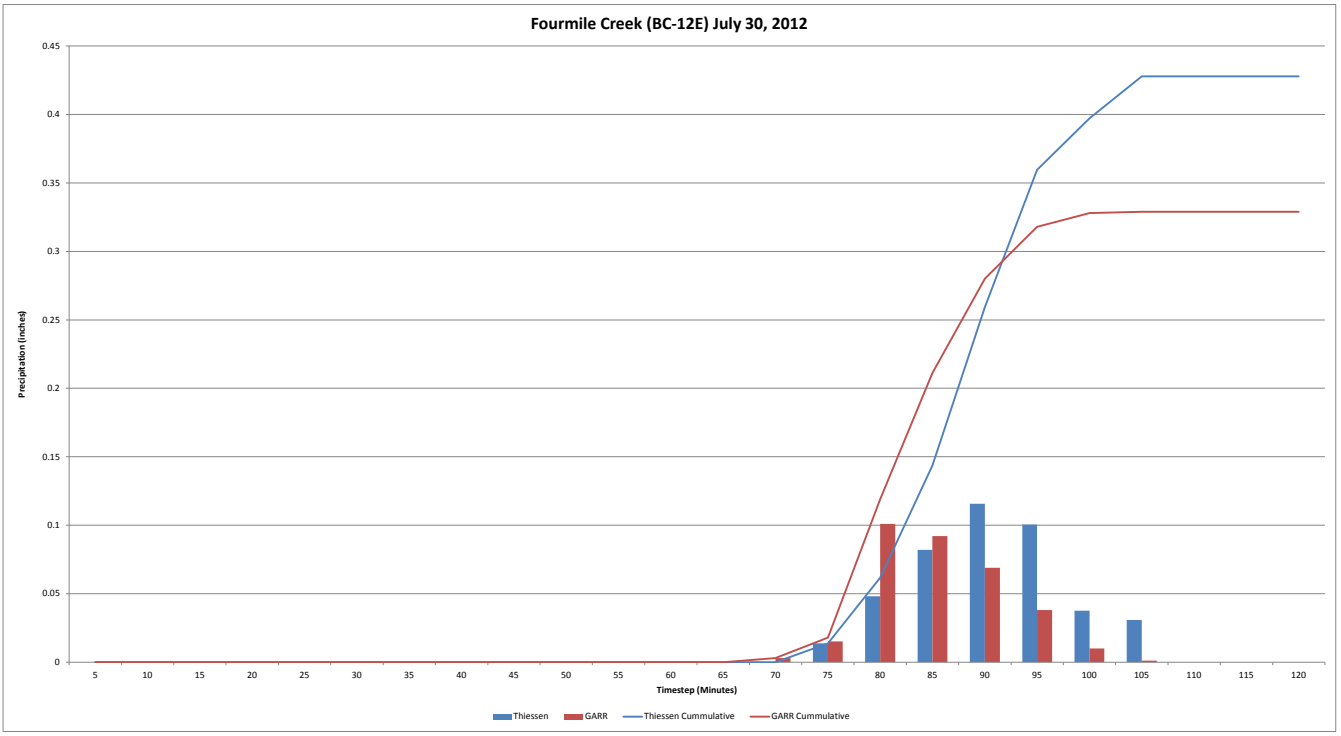
Appendix A14 Hyetograph (BC-12D)



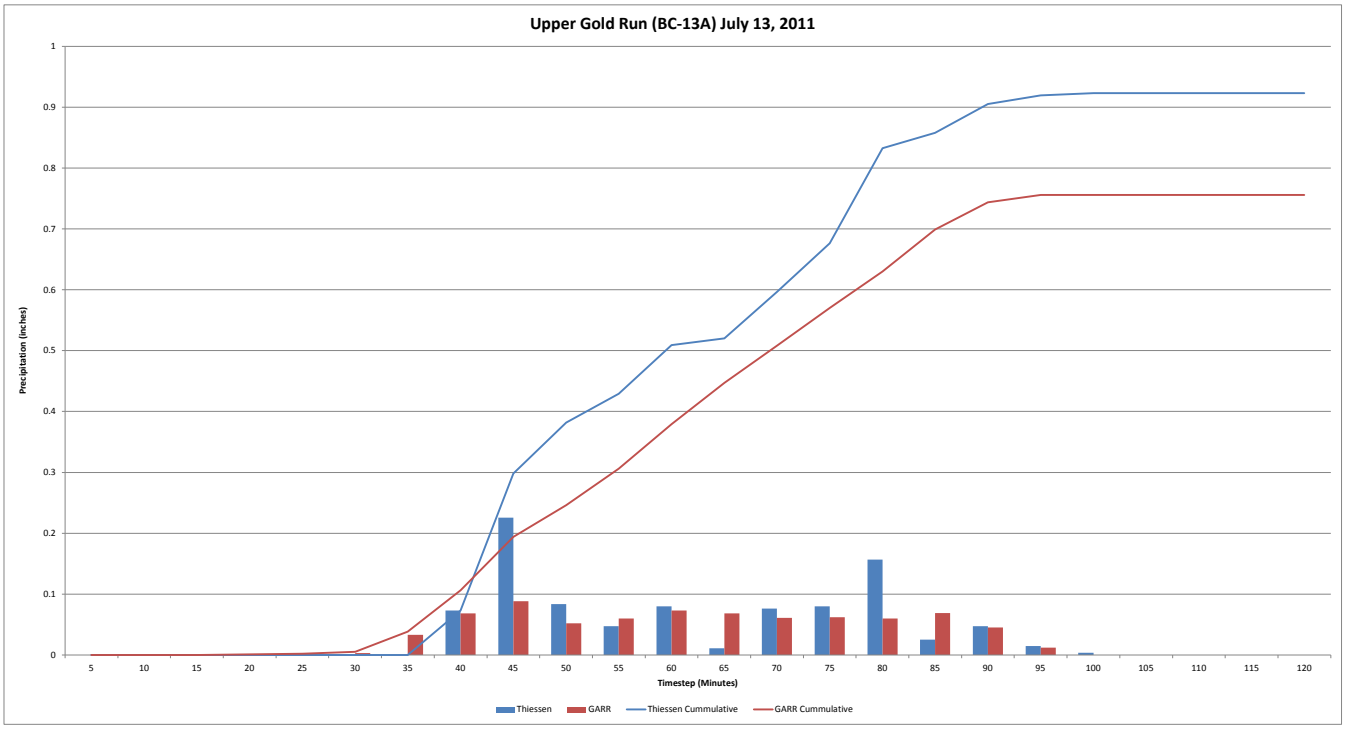


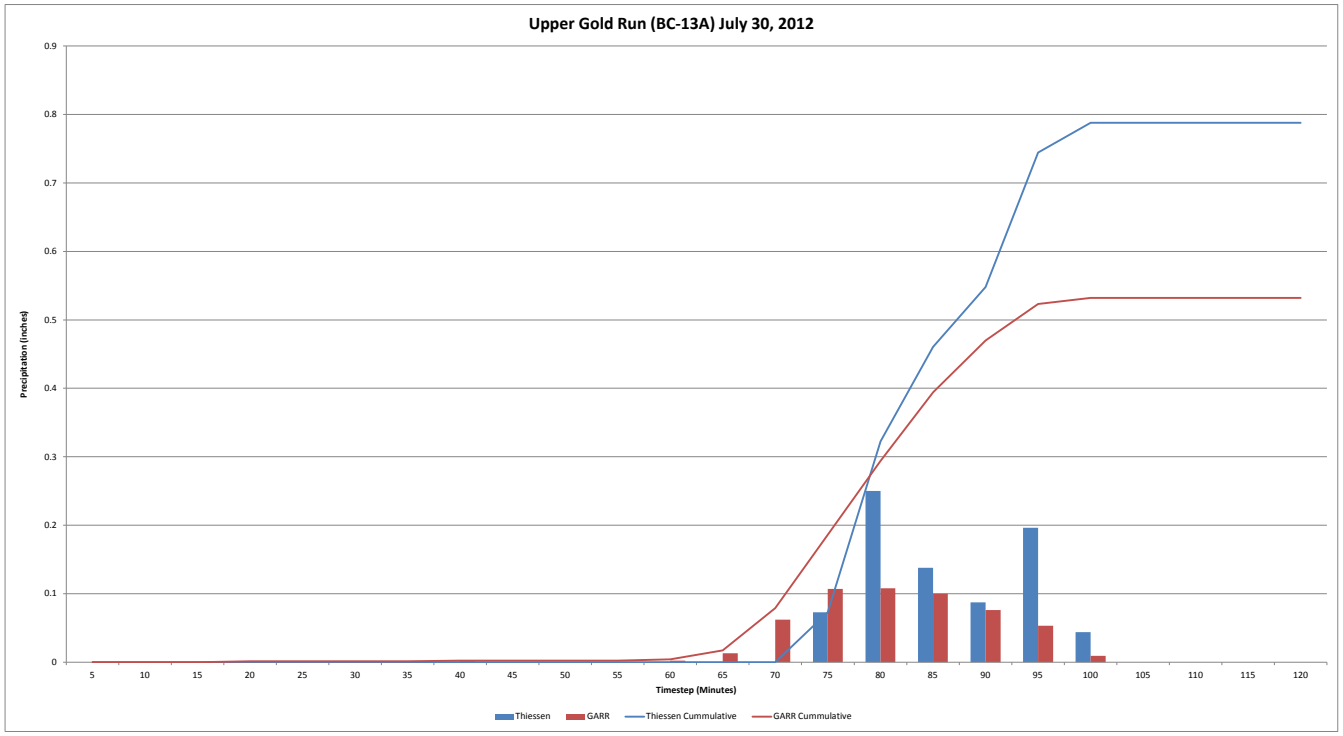
Appendix A15 Hyetograph (BC-12E)



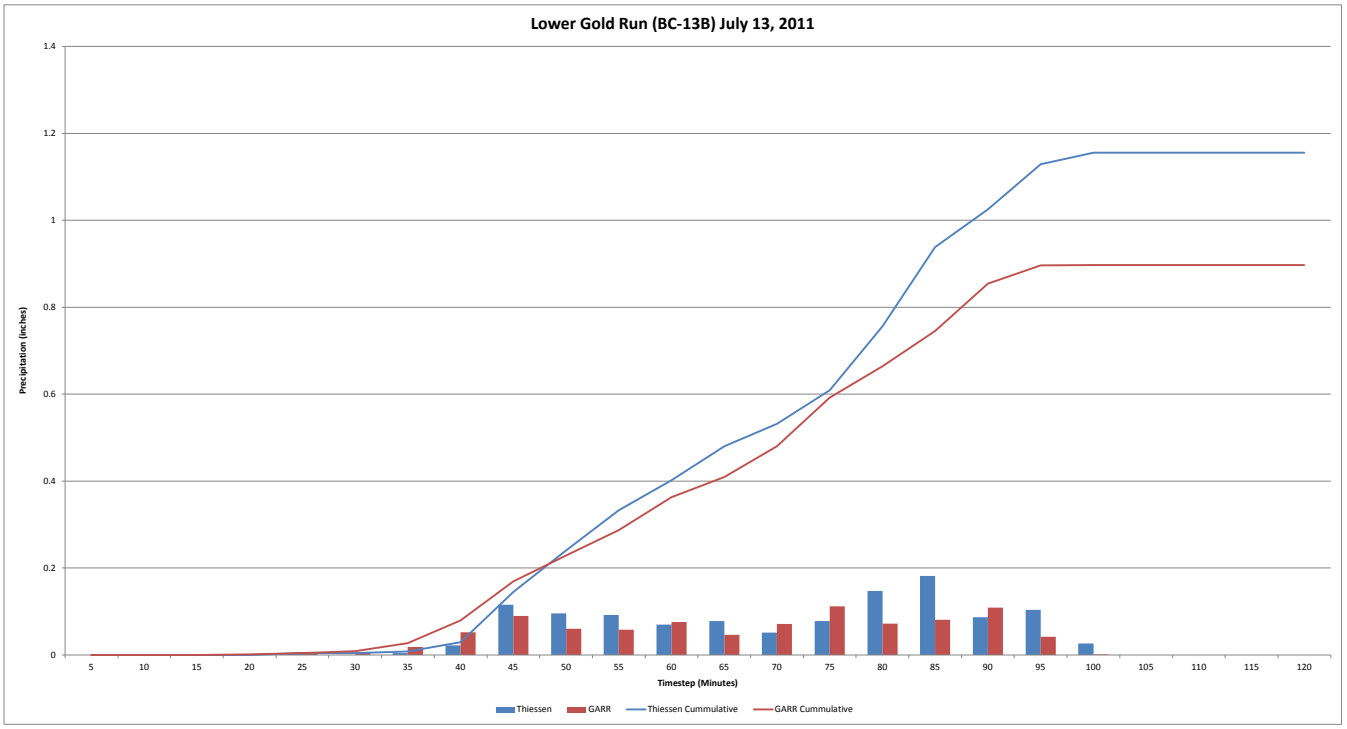


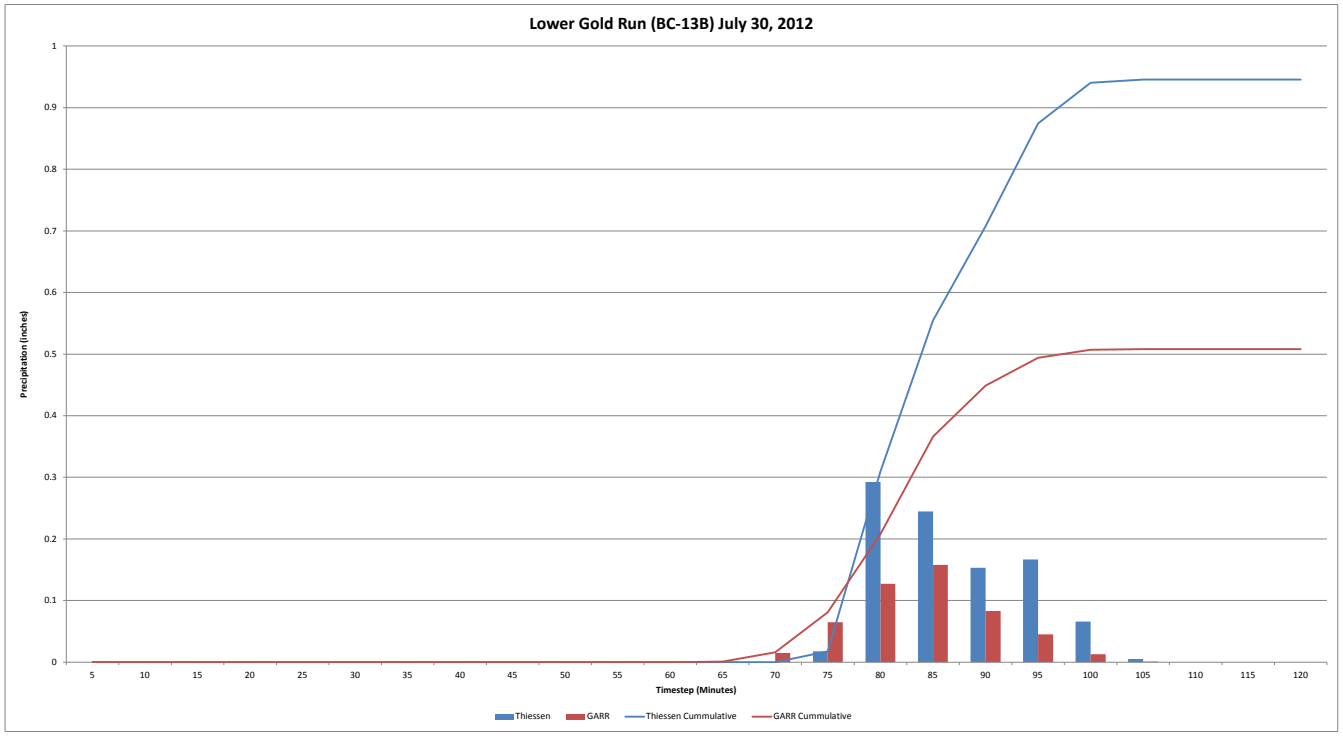
Appendix A16 Hyetograph (BC-13A)



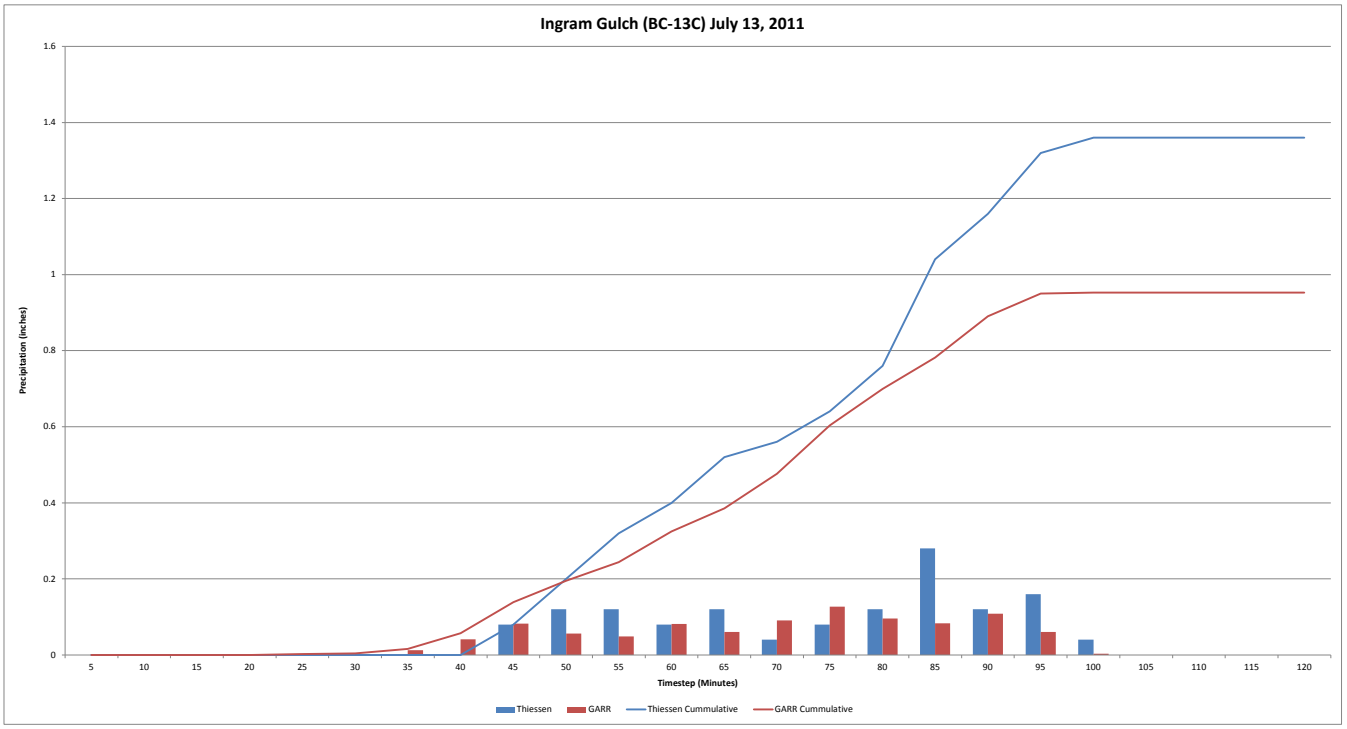


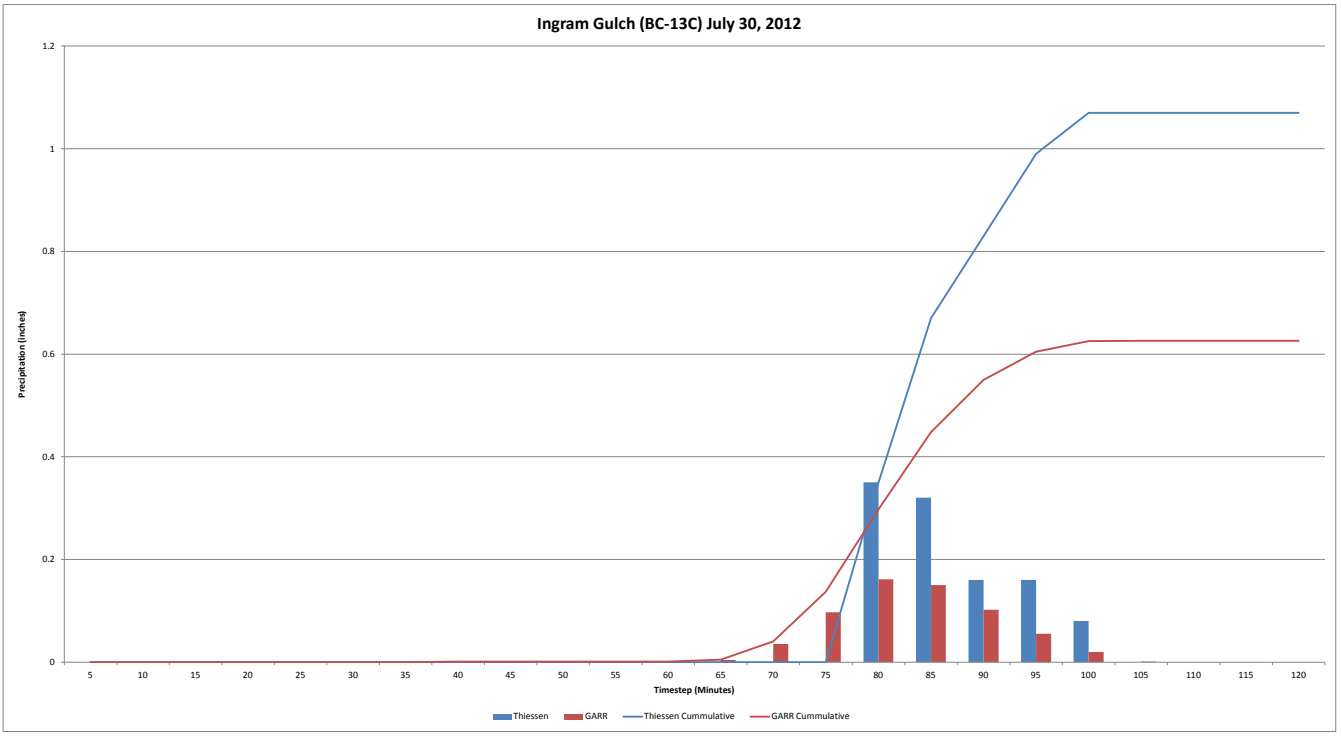
Appendix A17 Hyetograph (BC-13B)



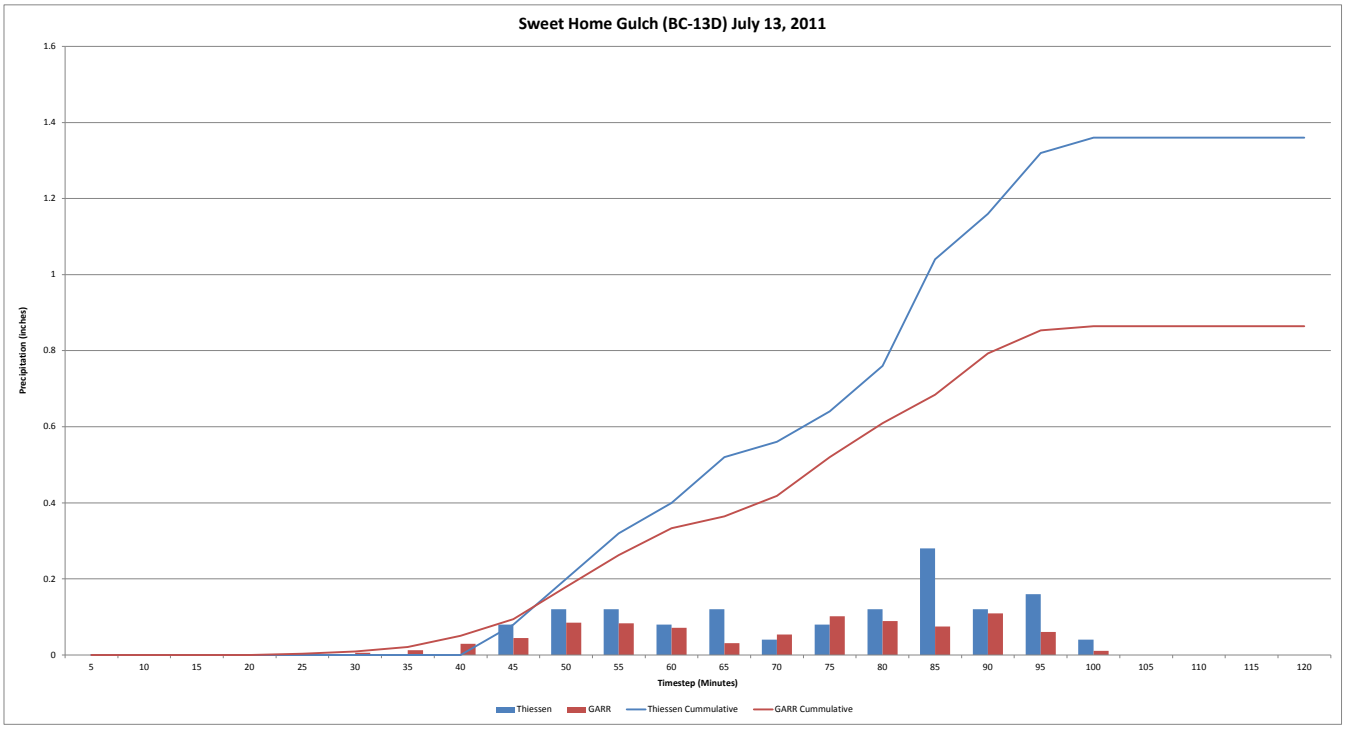


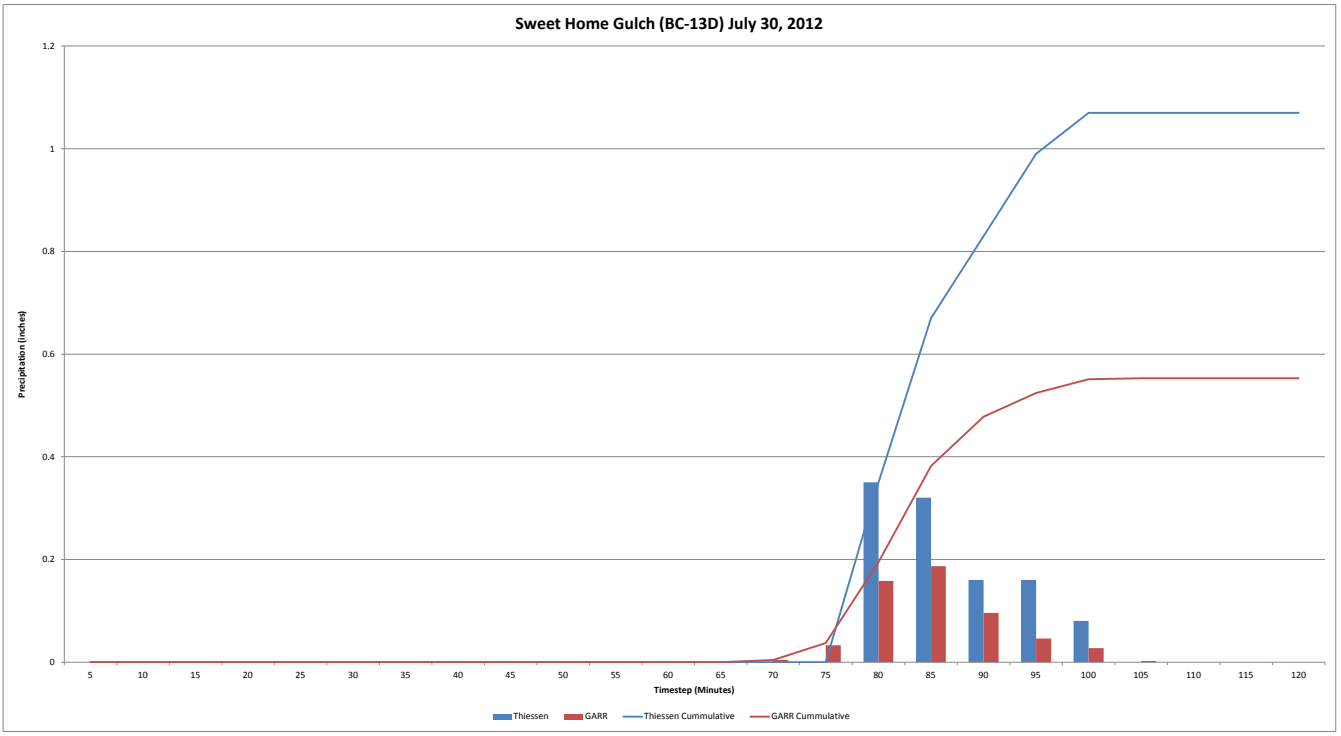
Appendix A18 Hyetograph (BC-13C)



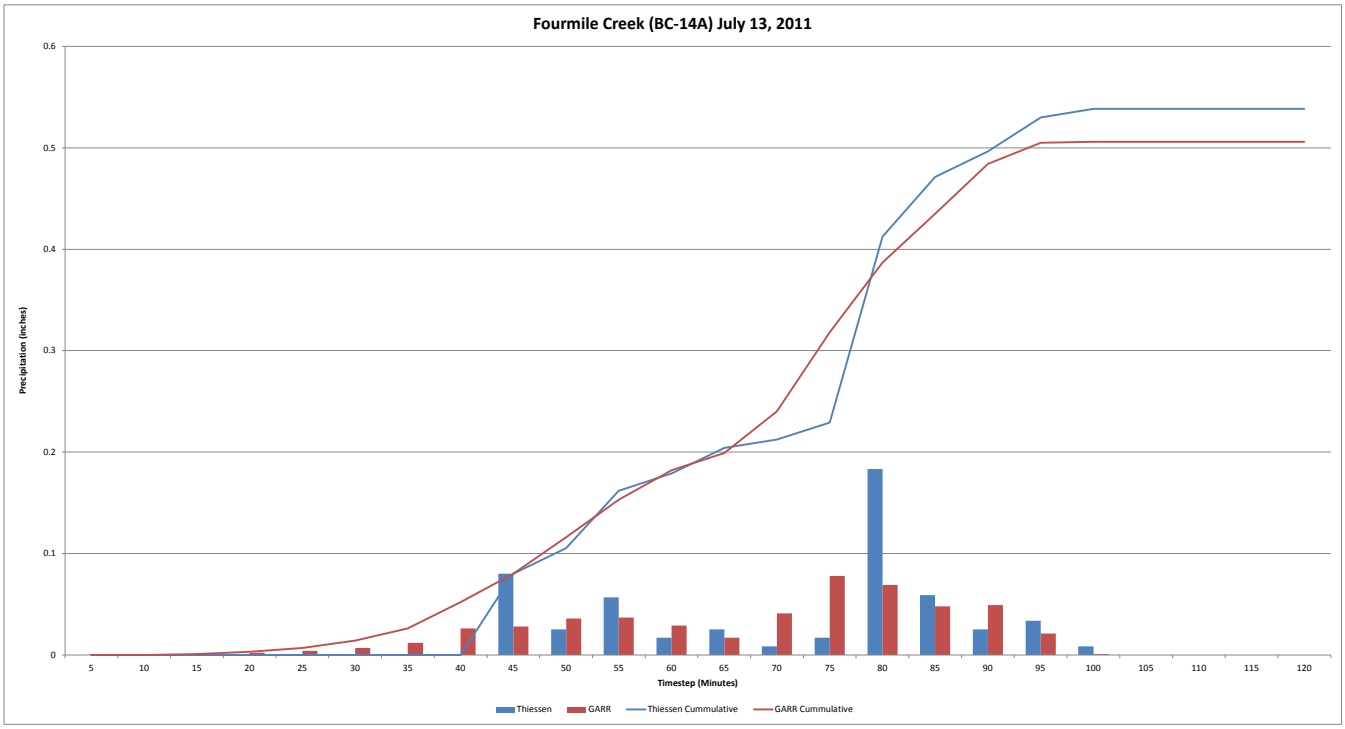


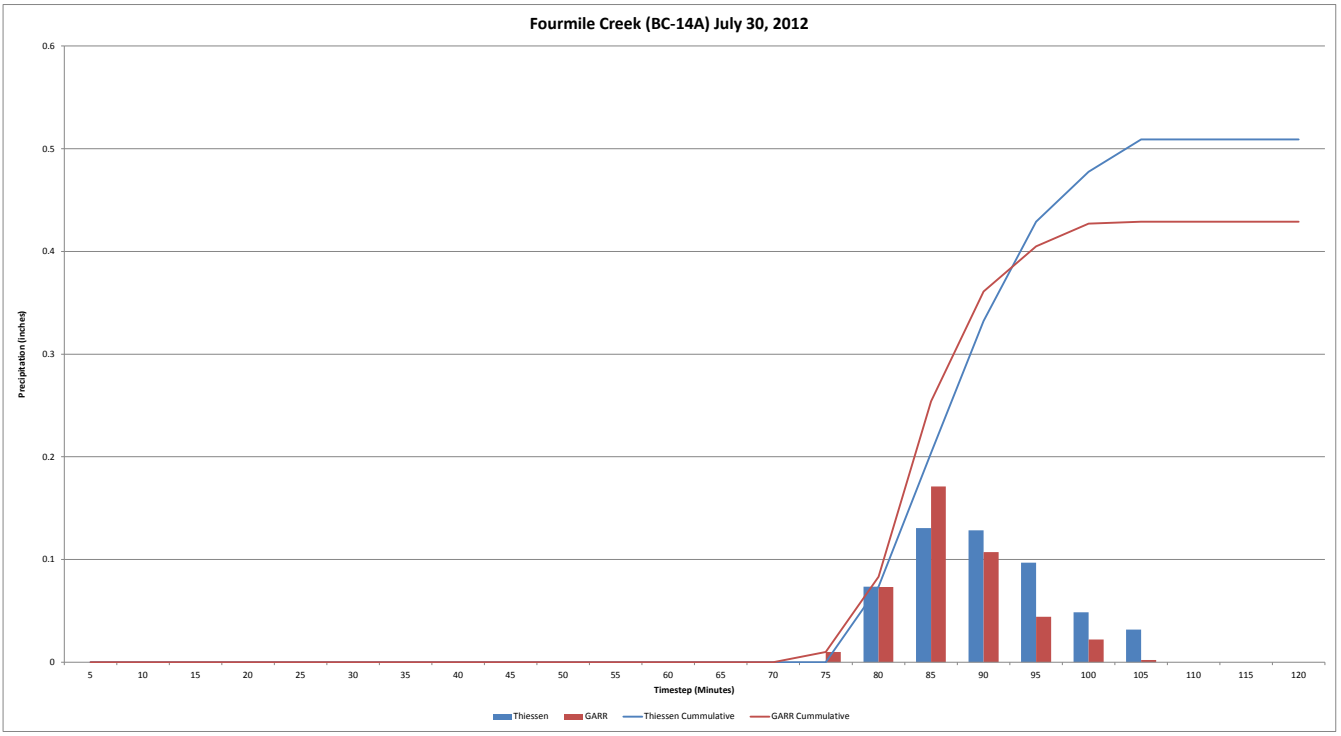
Appendix A19 Hyetograph (BC-13D)



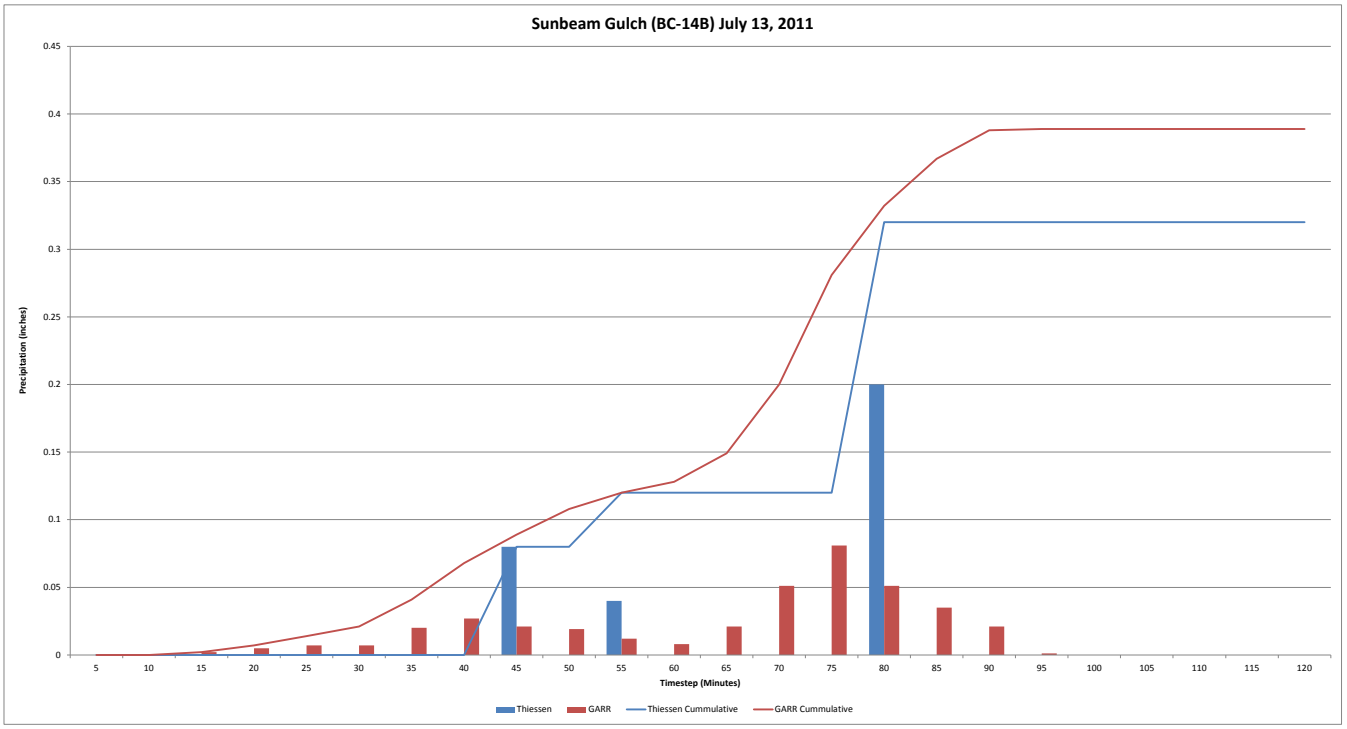


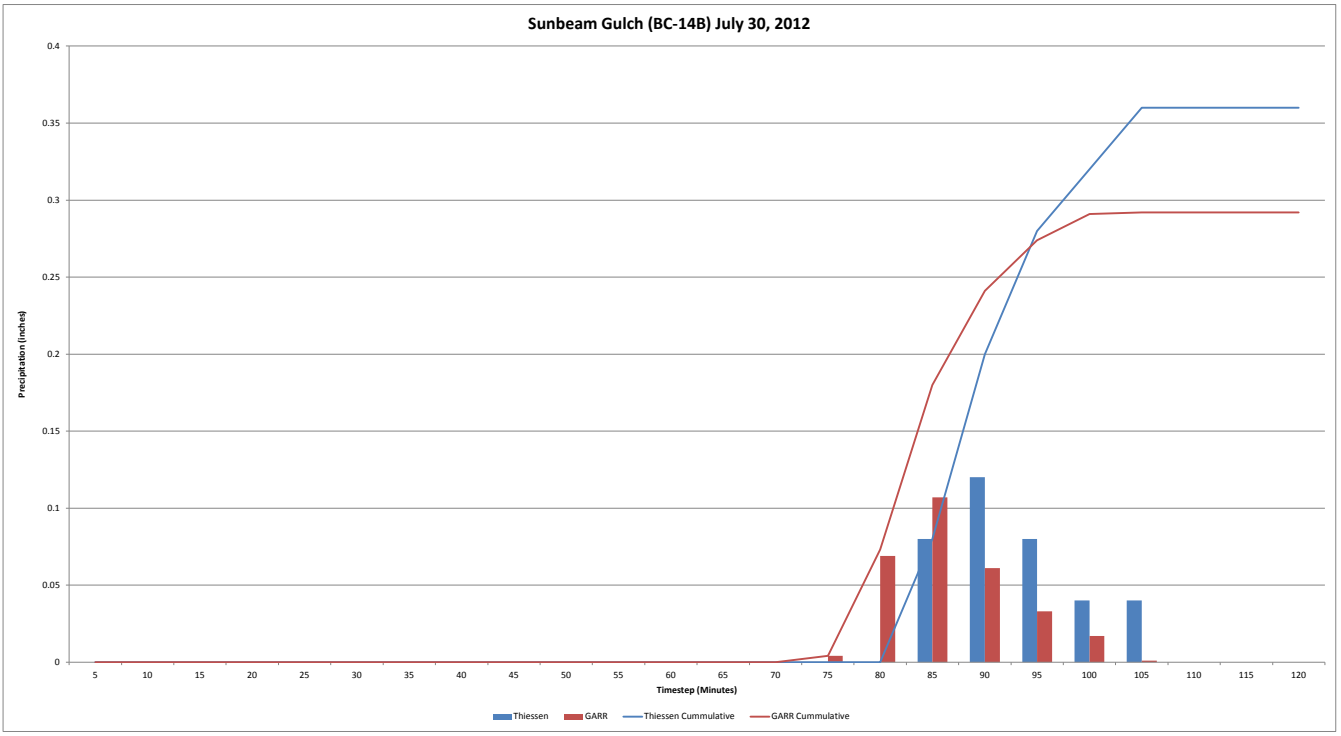
Appendix A20 Hyetograph (BC-14A)



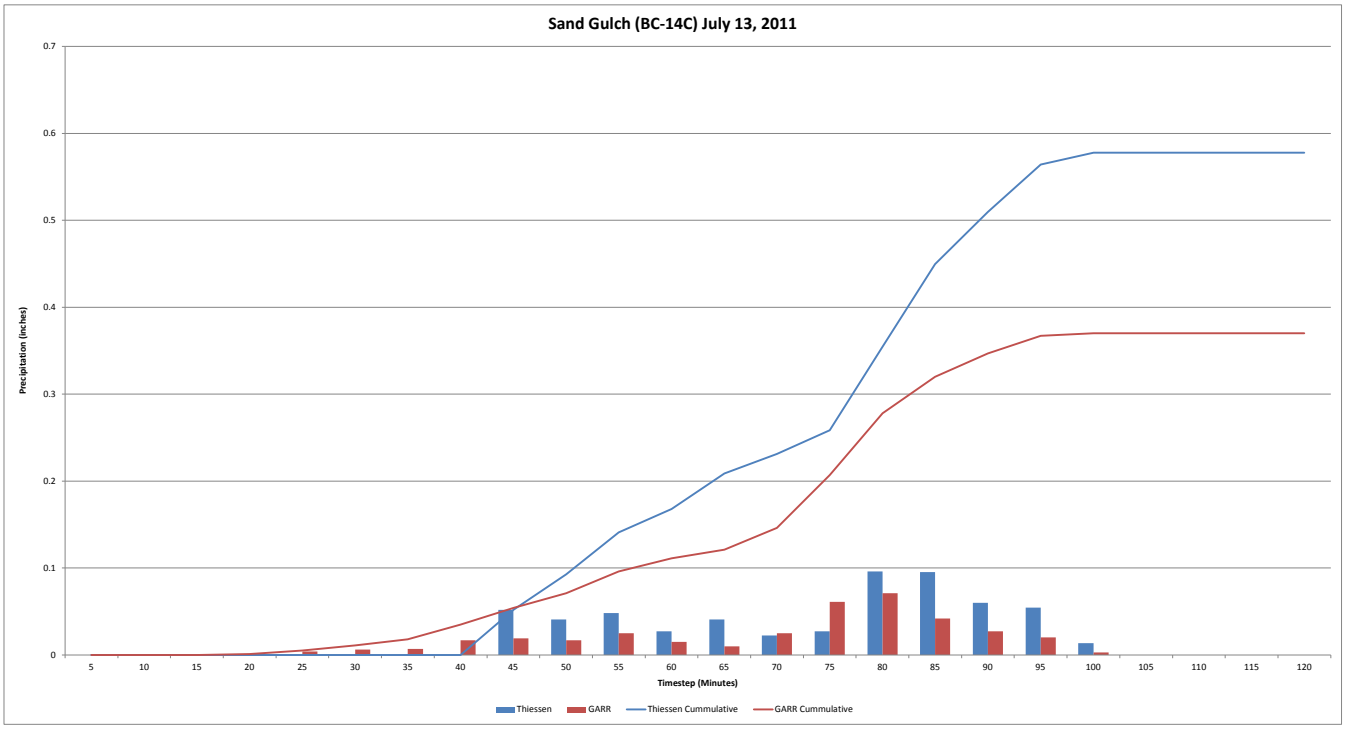


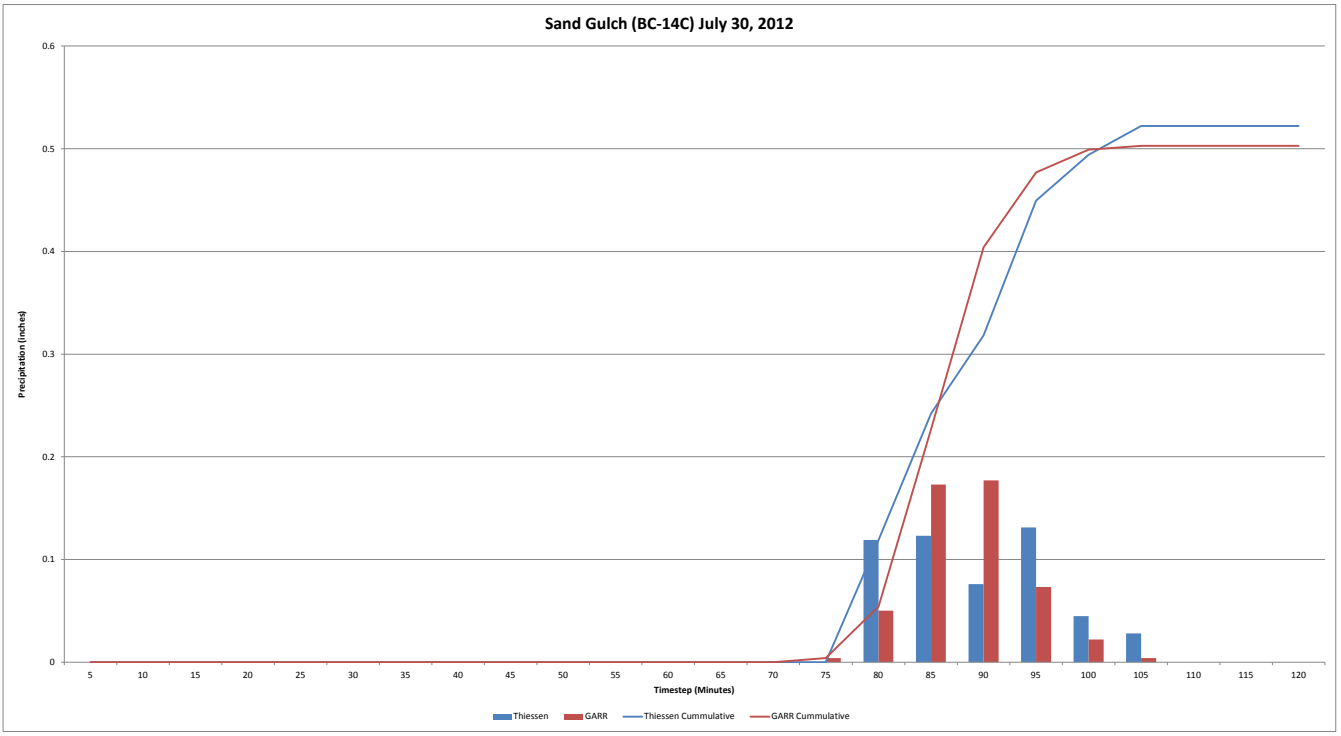
Appendix A21 Hyetograph (BC-14B)



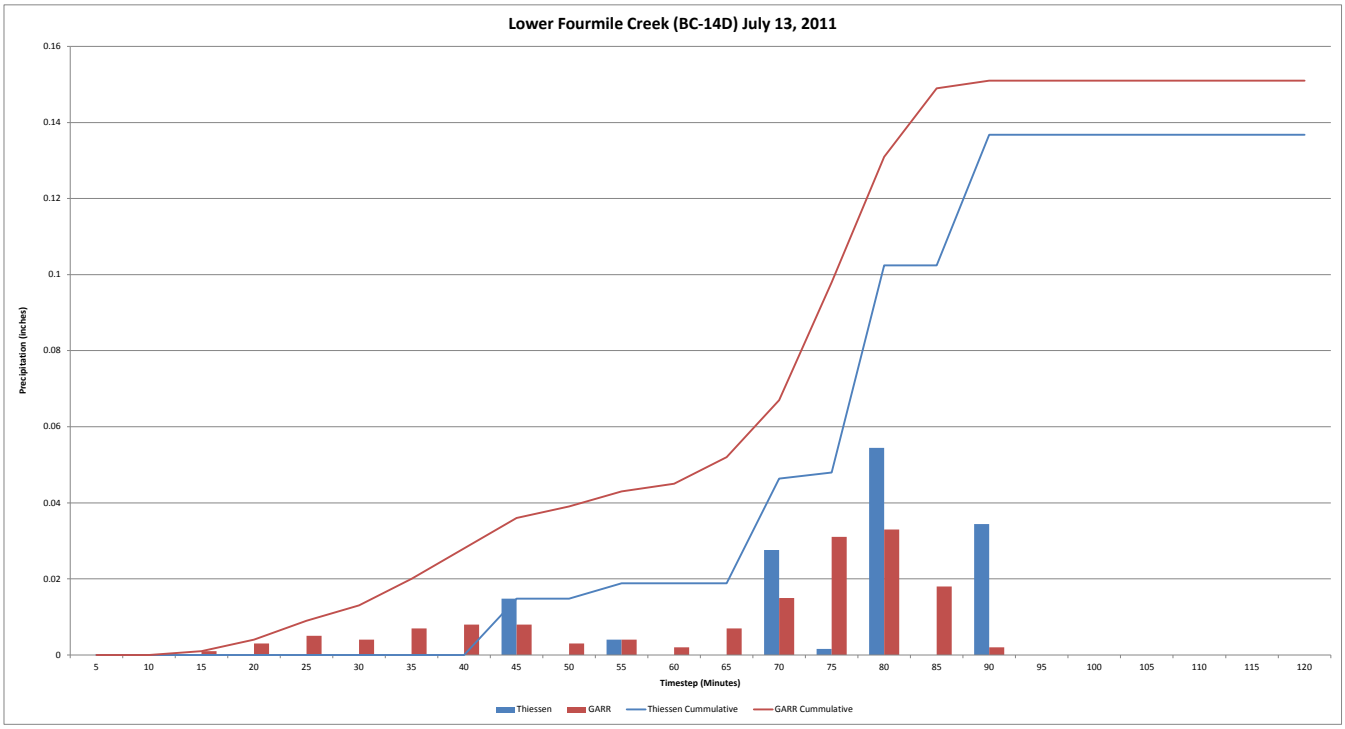


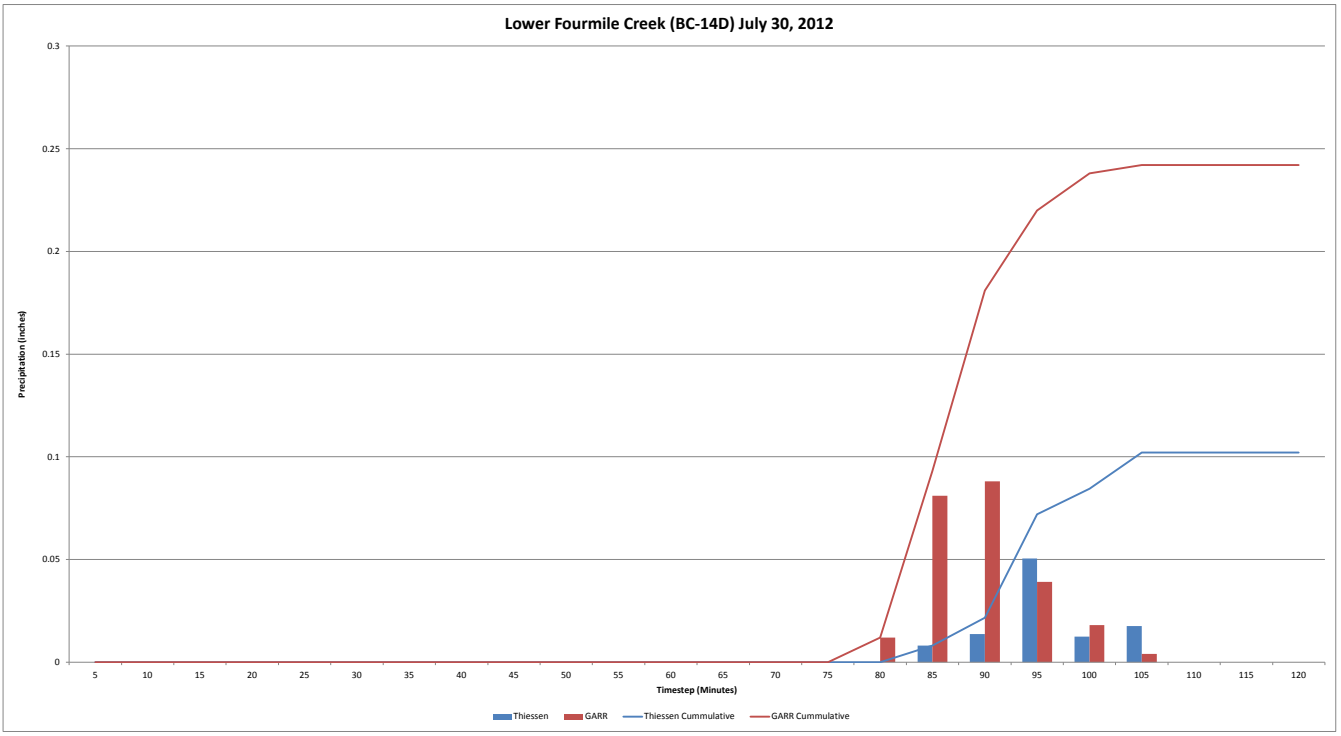
Appendix A22 Hyetograph (BC-14C)



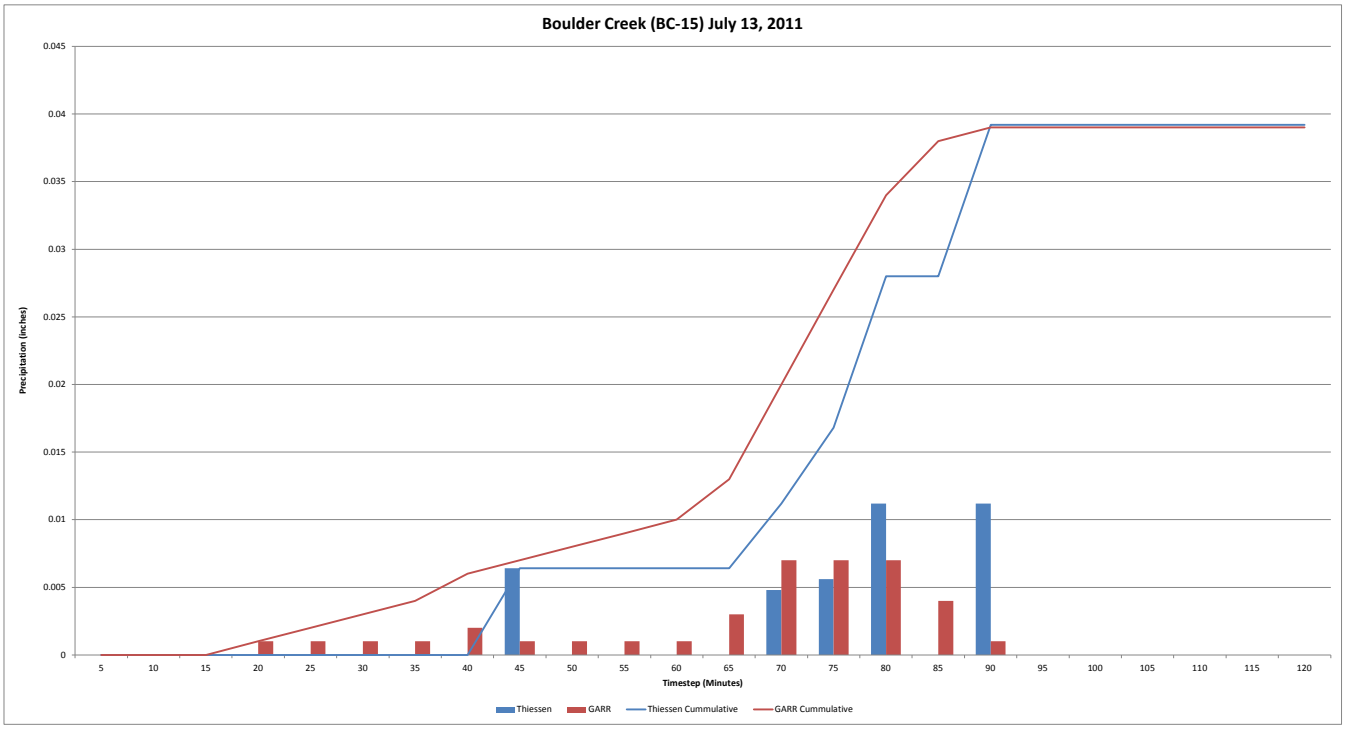


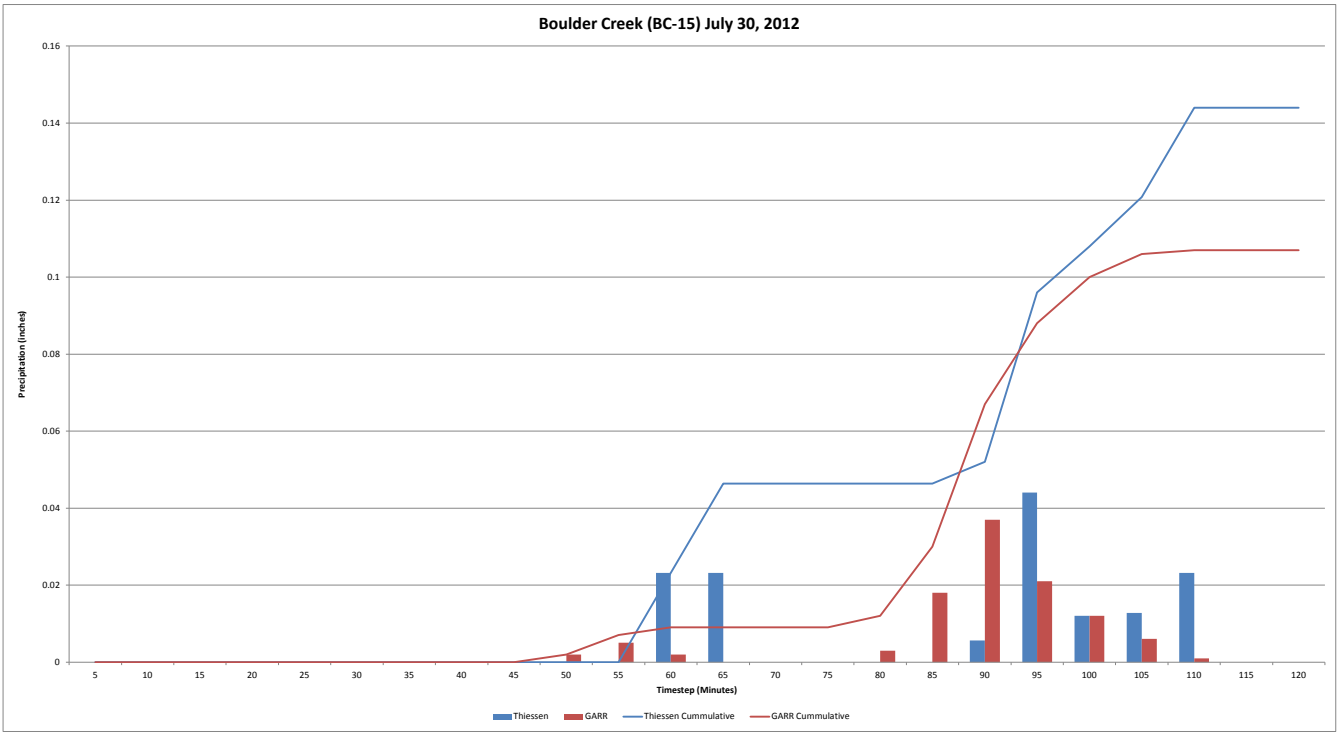
Appendix A23 Hyetograph (BC-14D)





Appendix A24 Hyetograph (BC-15)





Appendix B - Precipitation Comparison Tables

Appendix B1 – July 13, 2011 Boulder Creek Basin Rainfall Distributions

Thiessen Basin Total Rainfall from July 13, 2011 (LRE)

Time	Time Step	Basin2	Basin3	Basin4	Basin5	Basin6	Basin7	Basin8	Basin9	Basin10	Basin11	Basin12A	Basin12B	Basin12C	Basin12D	Basin12E	Basin13A	Basin13B	Basin13C	Basin13D	Basin14A	Basin14B	Basin14C	Basin14D	Basin15	Basin Total
7/13/2011 17:35	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 17:40	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 17:45	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 17:50	100	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
7/13/2011 17:55	95	0.00	0.00	0.00	0.01	0.04	0.02	0.00	0.01	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
7/13/2011 18:00	90	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
7/13/2011 18:05	85	0.00	0.00	0.01	0.05	0.11	0.01	0.00	0.01	0.00	0.00	0.12	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41
7/13/2011 18:10	80	0.00	0.00	0.00	0.02	0.06	0.01	0.00	0.01	0.00	0.00	0.06	0.07	0.07	0.08	0.02	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51
7/13/2011 18:15	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.20	0.08	0.24	0.10	0.23	0.12	0.08	0.08	0.08	0.08	0.05	0.01	0.01	1.39
7/13/2011 18:20	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.03	0.08	0.01	0.08	0.10	0.12	0.12	0.03	0.00	0.04	0.00	0.00	0.68
7/13/2011 18:25	65	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.04	0.01	0.04	0.04	0.05	0.09	0.12	0.12	0.06	0.04	0.05	0.00	0.00	0.71
7/13/2011 18:30	60	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.03	0.08	0.01	0.08	0.07	0.08	0.08	0.02	0.00	0.03	0.00	0.00	0.56
7/13/2011 18:35	55	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.01	0.08	0.12	0.12	0.03	0.00	0.04	0.00	0.00	0.55
7/13/2011 18:40	50	0.00	0.00	0.00	0.02	0.06	0.02	0.00	0.04	0.00	0.03	0.04	0.07	0.06	0.08	0.02	0.08	0.05	0.04	0.04	0.01	0.00	0.02	0.03	0.00	0.70
7/13/2011 18:45	45	0.00	0.00	0.01	0.06	0.15	0.02	0.01	0.03	0.04	0.00	0.15	0.08	0.13	0.08	0.02	0.08	0.08	0.08	0.08	0.02	0.00	0.03	0.00	0.01	1.17
7/13/2011 18:50	40	0.00	0.00	0.00	0.01	0.06	0.02	0.00	0.09	0.00	0.00	0.03	0.14	0.09	0.16	0.19	0.16	0.15	0.12	0.12	0.18	0.20	0.10	0.05	0.01	1.87
7/13/2011 18:55	35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.18	0.28	0.28	0.06	0.00	0.10	0.00	0.00	0.92
7/13/2011 19:00	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.01	0.04	0.01	0.05	0.09	0.12	0.12	0.03	0.00	0.06	0.03	0.01	0.61
7/13/2011 19:05	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.16	0.16	0.03	0.00	0.05	0.00	0.00	0.53
7/13/2011 19:10	20	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.03	0.04	0.04	0.01	0.00	0.01	0.00	0.00	0.24
7/13/2011 19:15	15	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
7/13/2011 19:20	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 19:25	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 19:30	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**0.06**	**0.00**	**0.08**	**0.24**	**0.54**	**0.12**	**0.04**	**0.24**	**0.04**	**0.06**	**0.55**	**0.80**	**0.68**	**0.88**	**0.42**	**0.92**	**1.16**	**1.36**	**1.36**	**0.54**	**0.32**	**0.58**	**0.14**	**0.04**	**11.17**

GARR Basin Total Rainfall from July 13, 2011 (Vieux)

Time	Time Step	BC-2	BC-3	BC-4	BC-5	BC-6	BC-7	BC-8	BC-9	BC-10	BC-11	BC-12A	BC-12B	BC-12C	BC-12D	BC-12E	BC-13A	BC-13B	BC-13C	BC-13D	BC-14A	BC-14B	BC-14C	BC-14D	BC-15	Basin Total
7/13/2011 17:35	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
7/13/2011 17:40	110	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
7/13/2011 17:45	105	0.01	0.00	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
7/13/2011 17:50	100	0.01	0.00	0.02	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.11
7/13/2011 17:55	95	0.01	0.00	0.03	0.03	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.17
7/13/2011 18:00	90	0.00	0.00	0.02	0.06	0.04	0.01	0.00	0.01	0.00	0.01	0.04	0.01	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.28
7/13/2011 18:05	85	0.00	0.00	0.02	0.08	0.06	0.01	0.00	0.03	0.00	0.02	0.10	0.06	0.09	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.68
7/13/2011 18:10	80	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.02	0.00	0.02	0.08	0.07	0.10	0.09	0.05	0.07	0.05	0.04	0.03	0.03	0.03	0.02	0.01	0.00	0.79
7/13/2011 18:15	75	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.05	0.05	0.09	0.08	0.08	0.09	0.09	0.08	0.04	0.03	0.02	0.02	0.01	0.00	0.79
7/13/2011 18:20	70	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.03	0.05	0.05	0.06	0.05	0.06	0.06	0.09	0.04	0.02	0.02	0.00	0.00	0.57
7/13/2011 18:25	65	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.02	0.06	0.03	0.06	0.06	0.05	0.08	0.04	0.01	0.03	0.00	0.00	0.55
7/13/2011 18:30	60	0.03	0.00	0.03	0.01	0.02	0.02	0.01	0.01	0.00	0.02	0.02	0.03	0.01	0.03	0.02	0.07	0.08	0.08	0.07	0.03	0.01	0.02	0.00	0.00	0.61
7/13/2011 18:35	55	0.04	0.00	0.08	0.03	0.08	0.05	0.02	0.04	0.01	0.01	0.02	0.02	0.04	0.03	0.04	0.07	0.05	0.06	0.03	0.02	0.02	0.01	0.01	0.00	0.77
7/13/2011 18:40	50	0.02	0.00	0.04	0.03	0.09	0.05	0.01	0.05	0.01	0.00	0.03	0.01	0.06	0.04	0.07	0.06	0.07	0.09	0.05	0.04	0.05	0.03	0.02	0.01	0.93
7/13/2011 18:45	45	0.00	0.00	0.01	0.01	0.06	0.03	0.00	0.07	0.01	0.00	0.02	0.02	0.07	0.06	0.10	0.06	0.11	0.13	0.10	0.08	0.08	0.06	0.03	0.01	1.13
7/13/2011 18:50	40	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.03	0.00	0.00	0.02	0.03	0.05	0.05	0.06	0.06	0.07	0.10	0.09	0.07	0.05	0.07	0.03	0.01	0.81
7/13/2011 18:55	35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.05	0.06	0.08	0.07	0.08	0.08	0.08	0.05	0.04	0.04	0.02	0.00	0.67
7/13/2011 19:00	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.11	0.11	0.11	0.05	0.02	0.03	0.00	0.00	0.55
7/13/2011 19:05	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.06	0.02	0.00	0.02	0.00	0.00	0.22
7/13/2011 19:10	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
7/13/2011 19:15	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 19:20	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 19:25	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/13/2011 19:30	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**0.14**	**0.03**	**0.28**	**0.35**	**0.48**	**0.18**	**0.05**	**0.30**	**0.03**	**0.11**	**0.45**	**0.41**	**0.67**	**0.65**	**0.70**	**0.76**	**0.90**	**0.95**	**0.86**	**0.51**	**0.39**	**0.37**	**0.15**	**0.04**	**9.74**
																								Percent Difference		**-13%**

Appendix B2 – July 30, 2012 Boulder Creek Basin Rainfall Distributions

Thiessen Basin Total Rainfall from July 30, 2012 (LRE)

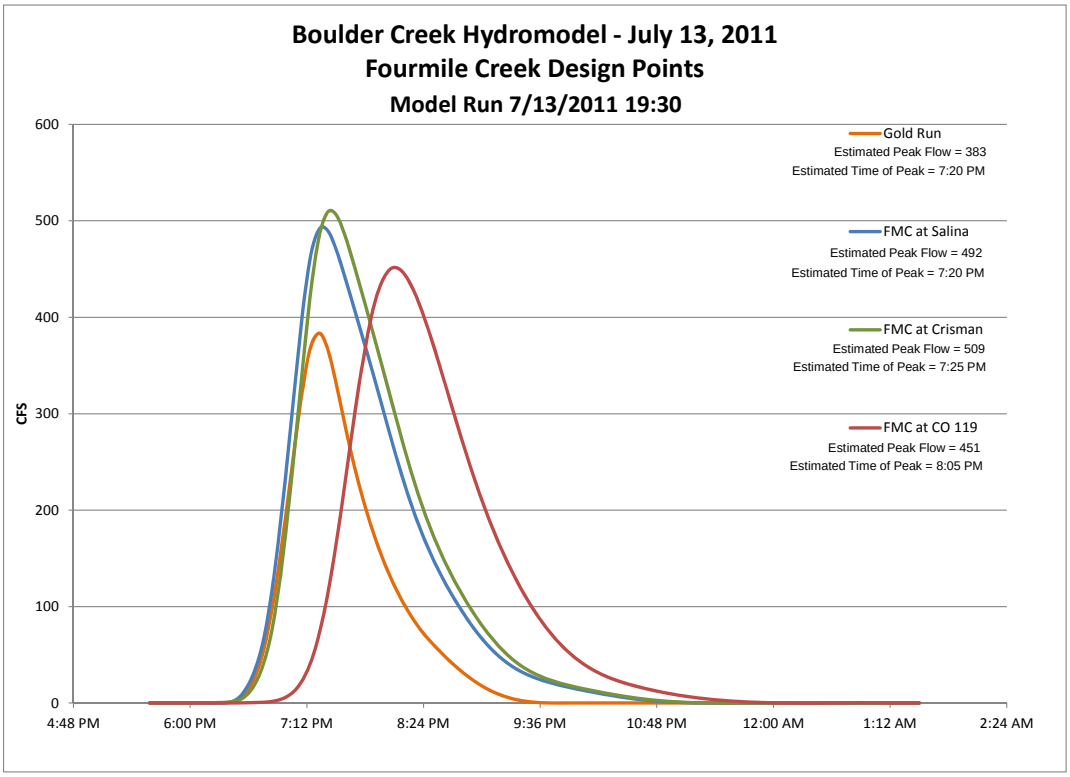
Time	Time Step	Basin2	Basin3	Basin4	Basin5	Basin6	Basin7	Basin8	Basin9	Basin10	Basin11	Basin12A	Basin12B	Basin12C	Basin12D	Basin12E	Basin13A	Basin13B	Basin13C	Basin13D	Basin14A	Basin14B	Basin14C	Basin14D	Basin15	Basin Total
7/30/2012 14:05	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:10	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:15	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:20	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:25	95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:30	90	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
7/30/2012 14:35	85	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
7/30/2012 14:40	80	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
7/30/2012 14:45	75	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
7/30/2012 14:50	70	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
7/30/2012 14:55	65	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
7/30/2012 15:00	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
7/30/2012 15:05	55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
7/30/2012 15:10	50	0.00	0.22	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37
7/30/2012 15:15	45	0.00	0.41	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.17	0.00	0.07	0.03	0.08	0.01	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92
7/30/2012 15:20	40	0.00	0.31	0.04	0.07	0.07	0.08	0.06	0.05	0.00	0.20	0.06	0.22	0.12	0.24	0.05	0.25	0.29	0.35	0.35	0.07	0.00	0.12	0.00	0.00	3.01
7/30/2012 15:25	35	0.00	0.03	0.22	0.15	0.05	0.01	0.00	0.02	0.00	0.05	0.08	0.11	0.08	0.12	0.08	0.14	0.24	0.32	0.32	0.13	0.08	0.12	0.01	0.00	2.36
7/30/2012 15:30	30	0.00	0.01	0.12	0.11	0.14	0.09	0.04	0.10	0.04	0.05	0.11	0.08	0.12	0.08	0.12	0.09	0.15	0.16	0.16	0.13	0.12	0.08	0.01	0.01	2.11
7/30/2012 15:35	25	0.00	0.00	0.00	0.00	0.03	0.05	0.04	0.06	0.04	0.00	0.01	0.17	0.08	0.20	0.10	0.20	0.17	0.16	0.16	0.10	0.08	0.13	0.05	0.04	1.86
7/30/2012 15:40	20	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.02	0.04	0.00	0.00	0.03	0.01	0.04	0.04	0.04	0.07	0.08	0.08	0.05	0.04	0.04	0.01	0.01	0.67
7/30/2012 15:45	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.03	0.04	0.03	0.02	0.01	0.18
7/30/2012 15:50	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
7/30/2012 15:55	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 16:00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**0.42**	**0.99**	**0.43**	**0.39**	**0.29**	**0.26**	**0.18**	**0.25**	**0.12**	**0.57**	**0.26**	**0.69**	**0.44**	**0.76**	**0.43**	**0.79**	**0.95**	**1.07**	**1.07**	**0.51**	**0.36**	**0.52**	**0.10**	**0.14**	**11.98**

GARR Basin Total Rainfall from July 30, 2012 (Vieux)

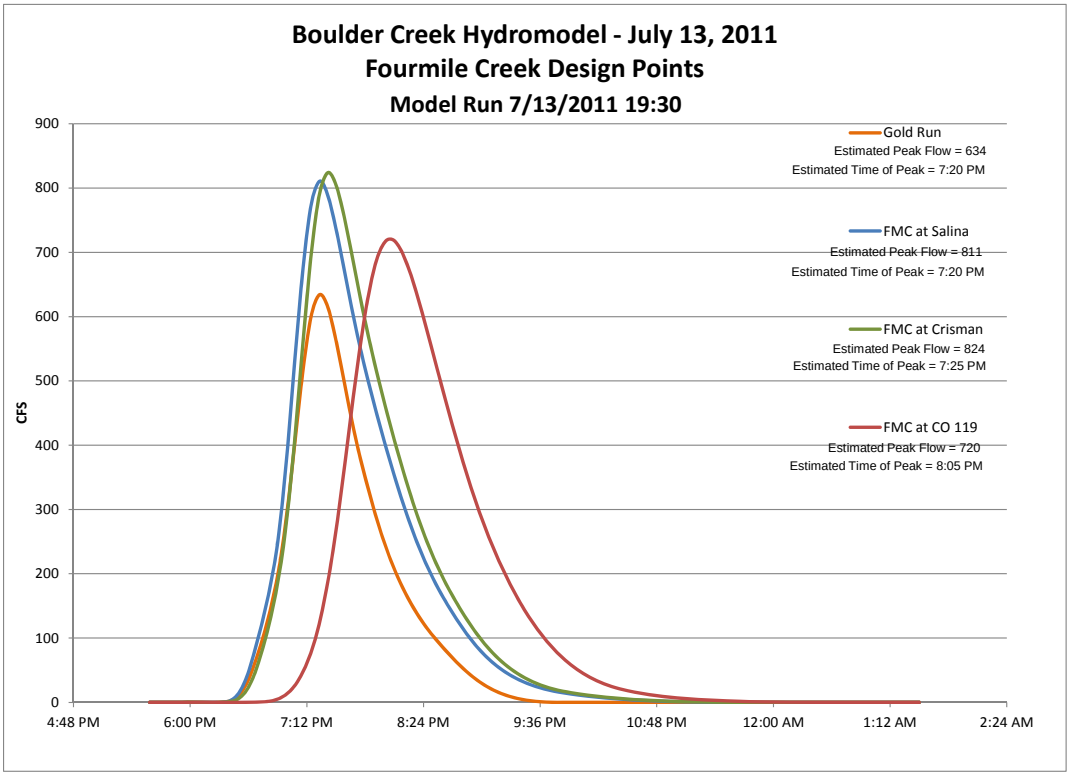
Time	Time Step	BC-2	BC-3	BC-4	BC-5	BC-6	BC-7	BC-8	BC-9	BC-10	BC-11	BC-12A	BC-12B	BC-12C	BC-12D	BC-12E	BC-13A	BC-13B	BC-13C	BC-13D	BC-14A	BC-14B	BC-14C	BC-14D	BC-15	Basin Total
7/30/2012 14:05	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:10	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:15	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:20	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:25	95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:30	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:35	85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 14:40	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
7/30/2012 14:45	75	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
7/30/2012 14:50	70	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
7/30/2012 14:55	65	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
7/30/2012 15:00	60	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
7/30/2012 15:05	55	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.03	0.002	0.01	0.00	0.01	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
7/30/2012 15:10	50	0.03	0.04	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.06	0.03	0.06	0.006	0.03	0.00	0.06	0.015	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.42
7/30/2012 15:15	45	0.03	0.05	0.04	0.05	0.02	0.02	0.01	0.01	0.00	0.13	0.04	0.06	0.011	0.04	0.02	0.11	0.065	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.85
7/30/2012 15:20	40	0.05	0.01	0.05	0.07	0.04	0.03	0.01	0.06	0.01	0.08	0.05	0.08	0.052	0.08	0.10	0.11	0.127	0.16	0.16	0.07	0.07	0.05	0.01	0.00	1.53
7/30/2012 15:25	35	0.07	0.00	0.05	0.05	0.05	0.03	0.01	0.04	0.01	0.06	0.06	0.09	0.049	0.08	0.09	0.10	0.158	0.15	0.19	0.17	0.11	0.17	0.08	0.02	1.89
7/30/2012 15:30	30	0.04	0.00	0.02	0.02	0.05	0.04	0.02	0.04	0.02	0.02	0.07	0.09	0.058	0.08	0.07	0.08	0.083	0.10	0.10	0.11	0.06	0.18	0.09	0.04	1.44
7/30/2012 15:35	25	0.01	0.00	0.00	0.00	0.01	0.03	0.02	0.03	0.02	0.00	0.01	0.02	0.035	0.04	0.04	0.05	0.045	0.06	0.05	0.04	0.03	0.07	0.04	0.02	0.68
7/30/2012 15:40	20	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.004	0.01	0.01	0.01	0.013	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.22
7/30/2012 15:45	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
7/30/2012 15:50	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 15:55	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/30/2012 16:00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**0.25**	**0.18**	**0.18**	**0.19**	**0.18**	**0.17**	**0.10**	**0.19**	**0.10**	**0.43**	**0.27**	**0.43**	**0.22**	**0.37**	**0.33**	**0.53**	**0.51**	**0.63**	**0.55**	**0.43**	**0.29**	**0.50**	**0.24**	**0.11**	**7.37**
																								Percent Difference		**-38%**

Appendix C – Model Output

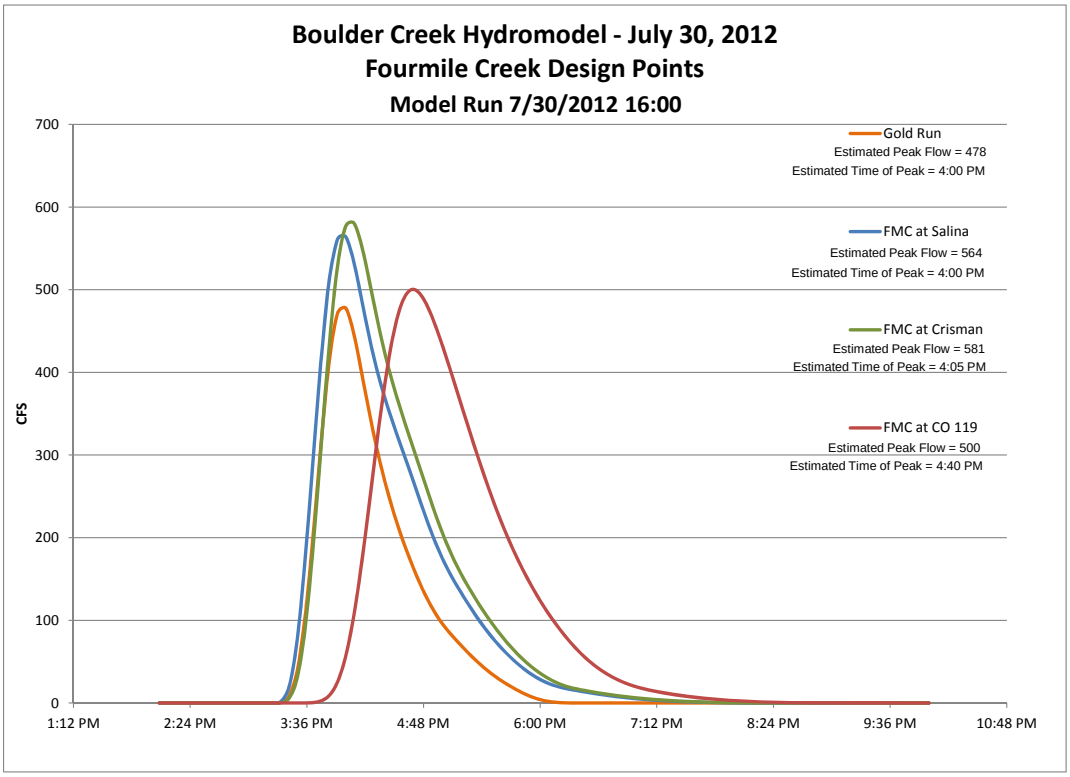
Appendix C1 – Thiessen Simulated Rainfall Runoff (July 13, 2011)



Appendix C2 – GARR Simulated Rainfall Runoff (July 13, 2011)



Appendix C3 – Thiessen Simulated Rainfall Runoff (July 13, 2012)



Appendix C4 – GARR Simulated Rainfall Runoff (July 30, 2012)