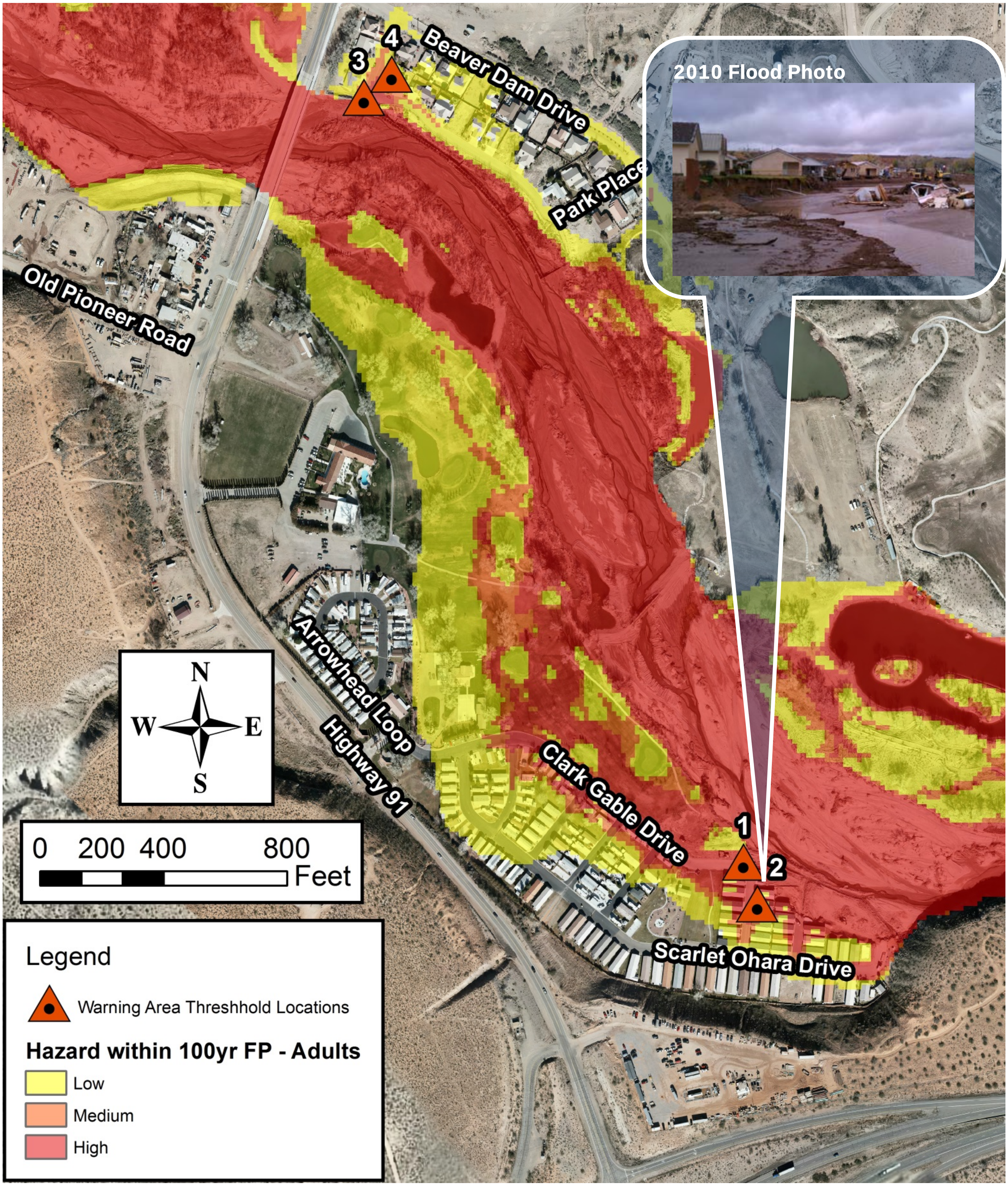
BEAVER DAM, AZ
FLOOD WARNING RESPONSE PLAN
HYDROLOGY AND HYDRAULICS REPORT



BEAVER DAM, AZ

FLOOD WARNING RESPONSE PLAN

HYDROLOGY AND HYDRAULICS REPORT

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January 2014

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1 INTRODUCTION

1.1 Project Objective

The Mohave County Flood Control District contracted with Arid Hydrology & Hydraulics, LLC (AridHH) in December 2007 to prepare a Flood Response Plan (FRP) as one component of the Beaver Dam Wash Flood Hazard Assessment (FHA), per Agreement Number 06024. After the December 2010 flood, Mohave County Flood Control District contracted with AridHH to prepare a new Flood Warning Response Plan (FWRP), per Agreement Number 11-PS-09, to reflect the changed conditions in the wash and to make adjustments to the FRP based on lessons learned during the flood fight. This report contains the documentation of the hydrologic and hydraulic modeling done to support the new FWRP.

The project site is located in the extreme northwest corner of Mohave County as shown on Figure 1.1. The project General Study Area, as shown on Figure 1.2, is located in the W1/2 of Section 4 and the E1/2 of Section 5, T40N, R15W, GSRM, Mohave County, Arizona, at the community of Beaver Dam, Arizona. In January 2005, Beaver Dam, Arizona was impacted by a large multi-day flood in Beaver Dam Wash. Many homes were flooded and filled with several feet of flood water. Some were washed away or severely damaged by high velocity flows and erosion that affected the structures foundation. In December 2010, another multi-day flood occurred, although smaller in magnitude than the 2005 flood. However, four (4) homes in Beaver Dam Resort were totally destroyed and two (2) others extensively damaged. Lateral migration of the southwest bank destroyed the homes and removed a portion of Clark Gable Drive and a side street and removed the wastewater lift station.

The objective of the technical component of the project is to prepare revised and updated hydrologic and hydraulic models of the watershed and Beaver Dam Wash. The models are to be used to estimate flow rates at the Highway 91 Bridge in Beaver Dam based on rainfall measurements at the watershed rain gages. The estimated flow rate at the bridge can then be related to critical threshold locations in the Beaver Dam community, which when approached, trigger FWRP warning levels. These models are also used for determining the extent of flood hazard within the community for various flow rates.

Figure 1.1 Location Map

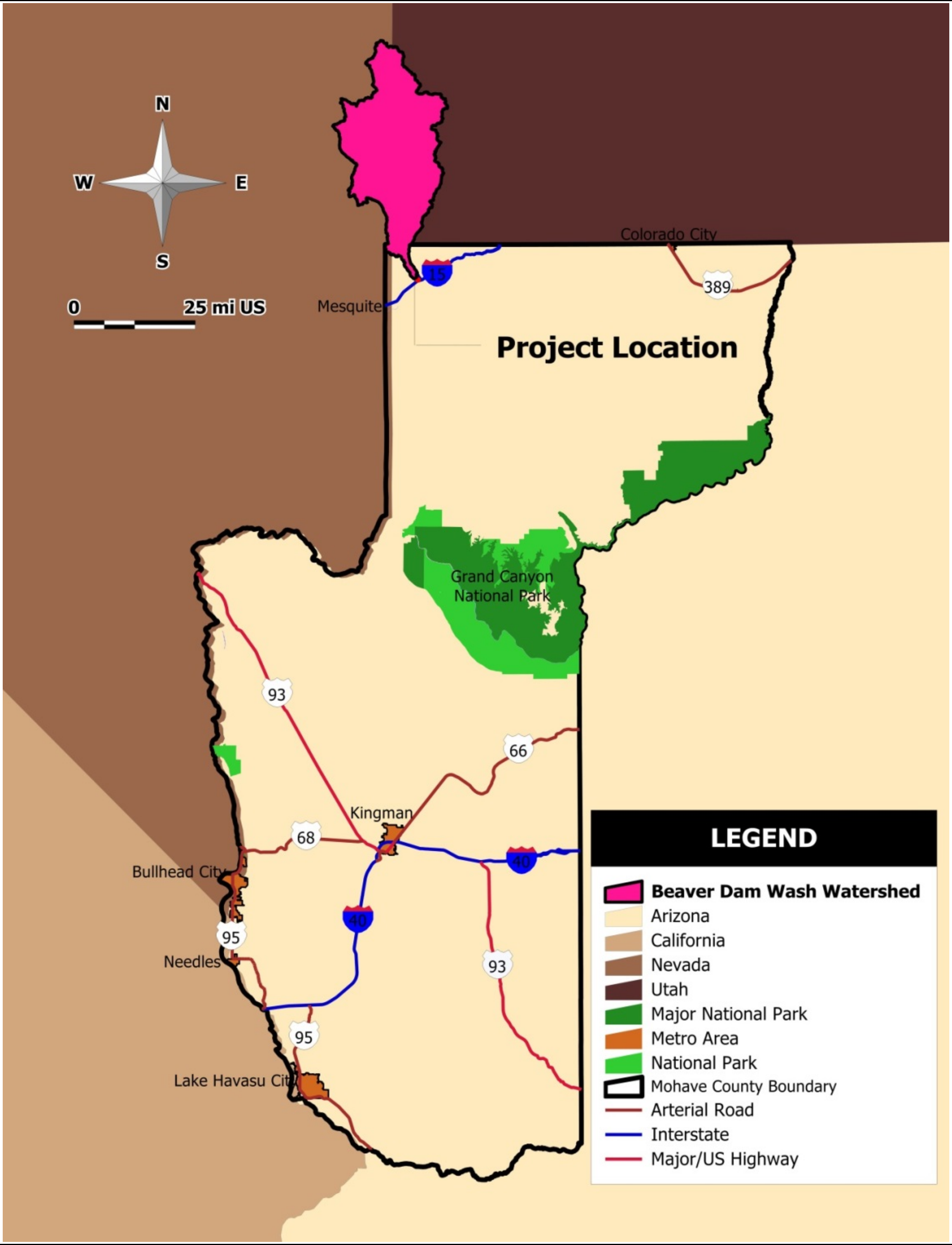
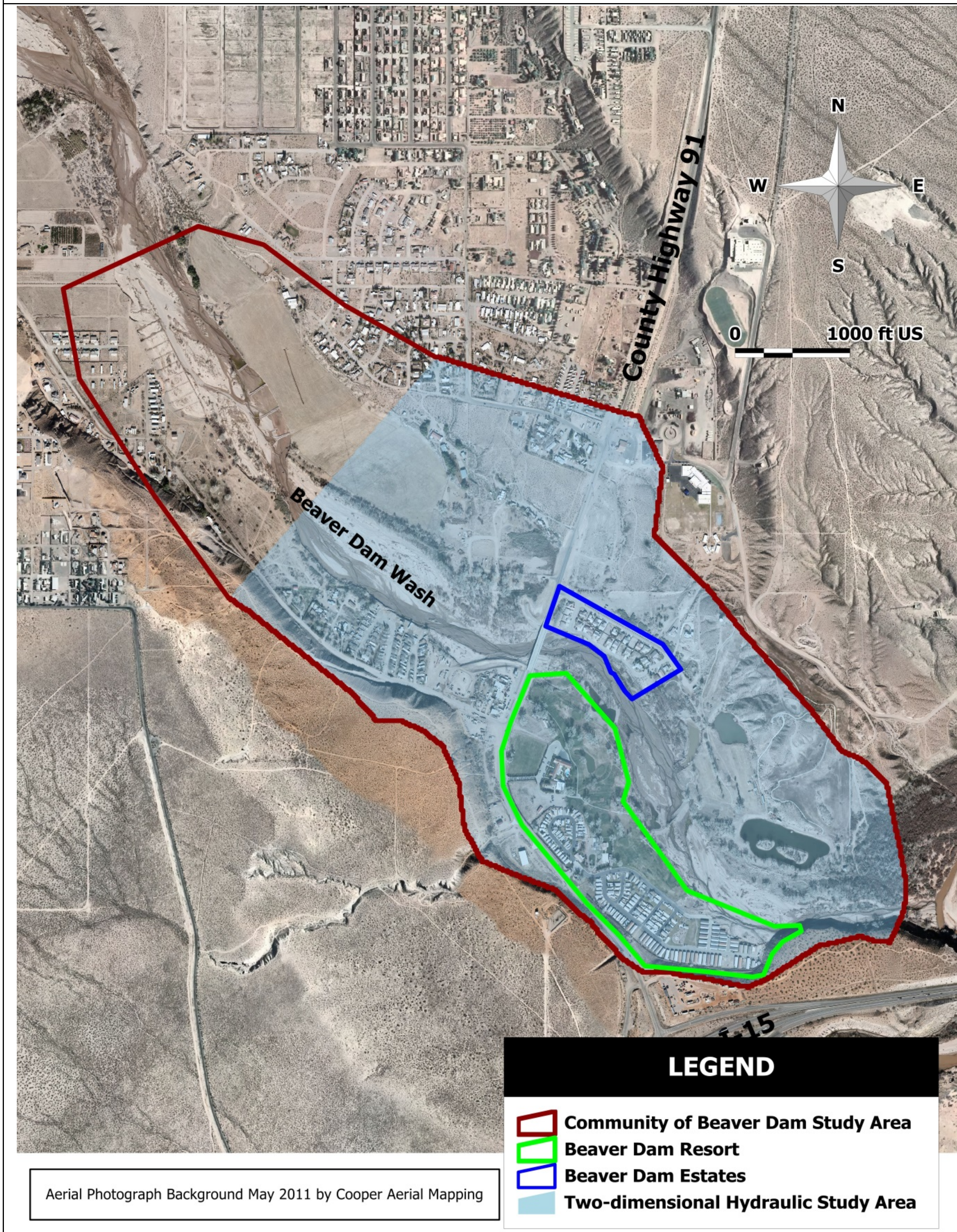


Figure 1.2 Vicinity Map



1.2 Summary of Findings

The morphology of Beaver Dam Wash changed significantly as a result of the December 2010 flood event. This is particularly true in Beaver Dam due to the constriction at the new bridge and channel degradation and migration. The channel now has a higher capacity downstream of the Highway 91 Bridge and can convey more flow before going overbank. As a result of the morphology changes, the three stream flow gaging stations, Motoqua, Catclaw Canyon, and the Highway 91 Bridge required preparation of new hydraulic rating curves.

The peak discharge during the December 2010 flood at the Highway 91 Bridge is estimated to be in the range of 8,700 to 16,000 cfs. The HEC-HMS model developed as a part of this study produces an estimate of 13,300 cfs, which is a reasonable estimate of the peak.

The HEC-HMS, HEC-RAS and FLO-2D models developed as a part of the study were calibrated to the December 2010 flood event. These models were then used to develop flood warning threshold information for the critical locations identified in the FWRP. The models are also for use in estimating the watershed response to various types of storm events and then estimating where and when flooding may occur in the Beaver Dam area. It was determined that the FLO-2D model of the Beaver Dam Wash through Beaver Dam provides a better estimate of the hydraulics of the wash for various discharge scenarios than the HEC-RAS model. For this reason, the FLO-2D model was used for the detailed hydraulic calculations within the Beaver Dam community, and the HEC-RAS model was used for developing the hydrograph routing information used in the HEC-HMS model.

1.3 Project Approach

1.3.1 General

The approach to developing appropriate models for the FWRP consisted of the following:

1. Develop a hydrology model of the watershed that can be used to estimate flow rates at the three stream flow gage sites given rainfall measurements at the precipitation gage sites in the watershed.
2. Develop a hydraulic model of Beaver Dam Wash between the Motoqua stream flow gage site and Beaver Dam that can be used for hydrograph routing in conjunction with the

hydrology model, and for development of hydraulic rating curves for the Motoqua and Catclaw Canyon stream flow gages.

3. Develop a detailed hydraulic model of the Beaver Dam area that can be used to establish flood warning thresholds to work together with, and development of, a hydraulic rating curve of the Highway 91 stream flow gage site.

4. Use the above models to develop the technical data needed for flood detection and warning criteria for the FWRP.

1.3.2 Hydrology

A new one dimensional (1D) model of the Beaver Dam Wash watershed was created. The model was calibrated against the December 2010 storm using the watershed rain gages as rainfall input and checking the resulting hydrographs against the hydrographs measured at the Motoqua, Catclaw Canyon, and Highway 91 Bridge stream flow gage sites. Parameters adjusted for calibration were rainfall, initial abstraction, initial soil moisture, and routing. The model is setup so that rainfall measured at the gage sites during a storm event can be easily read and estimates of runoff volume, discharge, and timing produced for use in making decisions on flood hazards at Beaver Dam. The model was used to build rainfall-runoff response tables for the FWRP. Refer to Section 6 for more information.

1.3.3 Hydraulics

A new 1D model of the Beaver Dam Wash was built that extends from the Virgin River to just upstream of the Motoqua gage site. It was built using detailed post 2010 flood topographic mapping for the reach from the Virgin River to the Catclaw Canyon gage site and for the vicinity of the Motoqua gage site. The USGS National Elevation Dataset (NED) 10-meter mapping was used for the reach between the Catclaw Canyon and Motoqua gage sites. The model was calibrated to the measured travel times between the Motoqua, Catclaw Canyon and Highway 91 Bridge gage sites. The channel n-values were adjusted for model calibration. This model was used to prepare hydrograph routing tables for use in the 1D hydrology model, to create travel time versus discharge curves for use with the FWRP, and to prepare hydraulic rating curves for the three stream flow gages. Only rating curves for minimum and maximum roughness estimates were prepared for the Highway 91 Bridge hydraulic rating curve using RAS.

A new two dimensional model (2D) was created of the reach of Beaver Dam Wash within the Beaver Dam community. This model was calibrated to match the flood limits from the December 2010 flood by adjusting n-values, to prepare a hydraulic rating curve for the Highway 91 Bridge stream flow gage for normal n-value conditions, and to link critical threshold locations within Beaver Dam to stage and flow rate at the Highway 91 stream flow gage. Refer to Section 3.3 for more information.

1.3.4 December 2010 Flood Assessment

As described above, the hydrologic and hydraulic models were prepared, and then calibrated to the December 2010 flood. This provides confidence that the models can produce reasonable estimates of flood discharge, depths and extents for various storm scenarios. However, due to channel bed change, uncertainty in the rain and stream flow gage measurements, and the normal range of uncertainty in the model physical parameters, there is significant uncertainty in the model results. This fact should be considered when making decisions using this information. As a result of these uncertainties, the peak discharge from the 2010 flood event at Beaver Dam is estimated to range from 8,700 cfs to 16,000 cfs. The 1D hydrologic model produces an estimated peak discharge of 13,300 cfs. Extensive bank erosion occurred during the event, resulting in loss of homes and infrastructure. This information was used in establishing flood detection and warning criteria for the FWRP. Refer to Section 6 for more detail.

1.3.5 Flood Detection and Warning

Eight (8) critical threshold locations were established in the Beaver Dam area after evaluation of the 2010 flood and the hydrologic and hydraulic model results. These are locations where, when flood depths exceed a certain threshold, or flow rates exceed a certain discharge, homes, access routes, and people are in immediate danger from rising flood waters. These thresholds, and the hydrologic and hydraulic “measuring sticks” used to estimate when a given threshold is reached, are the basis for the warning levels in the FWRP. Refer to Section 6 for more detail.

2 DATA COLLECTION

2.1 Precipitation Data

2.1.1 December 2010 Storm Gage Data

The rainfall gages present in the Beaver Dam Wash watershed during the December 2010 storm are shown on Figure 2.1. The Indian Canyon rain gage has since been removed from service. The data measured at these gages during the December 2010 storm was collected from MCFCD. Four (4) of the gages are equipped with extension tubes for measuring snowfall. The snow tubes had a design flaw that wasn't discovered until after the 2010 event when the measured data was inspected. The design flaw resulted in the gage collecting rain that ran down the outside of the tube rather than just rain that fell into the collector. This resulted in invalid measurements. MCFCD prepared a study to estimate a correction factor so the data could be used for the FWRP and arrived at a factor of 0.4. AridHH further refined this factor as a part of the HEC-HMS model calibration process based on adjusting rainfall-runoff to match the runoff hydrographs measured at the watershed stream flow gages. The NWS NEXRAD sites covering the watershed were not functioning during the storm, so radar data could not be used for calibration. The total storm rainfall amounts before and after adjustments are listed in Table 2.1. These values represent the total rainfall from December 17, 2010 at 12:00 AM through December 23, 2010 at midnight. The gage data was converted to even 15-minute intervals. The adjusted rainfall distributions are shown on Figure 2.2.

Table 2.1 December 2010 storm rainfall totals

Gage		AridHH Adjustment Factor	Total Storm Rainfall in inches	
Sensor	Name		Unadjusted	Adjusted
1506	5 Upper Lime Mountain	0.65	22.95	14.92
1507	7 Pahcoon Flat	0.70	23.47	16.43
1508	6 Bull Valley Mountains	0.40	40.22	16.09
7780	4 Beaver Dam State Park	0.60	23.10	13.86
1645	1 Motoqua	n/a[1]	9.20	n/a
1655	3 Indian Canyon	n/a[1]	5.00	n/a
7570	8 Beaver Dam Sheriff's Station	n/a[1]	3.60	n/a

[1] A snow tube was not used at this gage.

Figure 2.1 Beaver Dam Wash Entire Watershed and Gage Locations

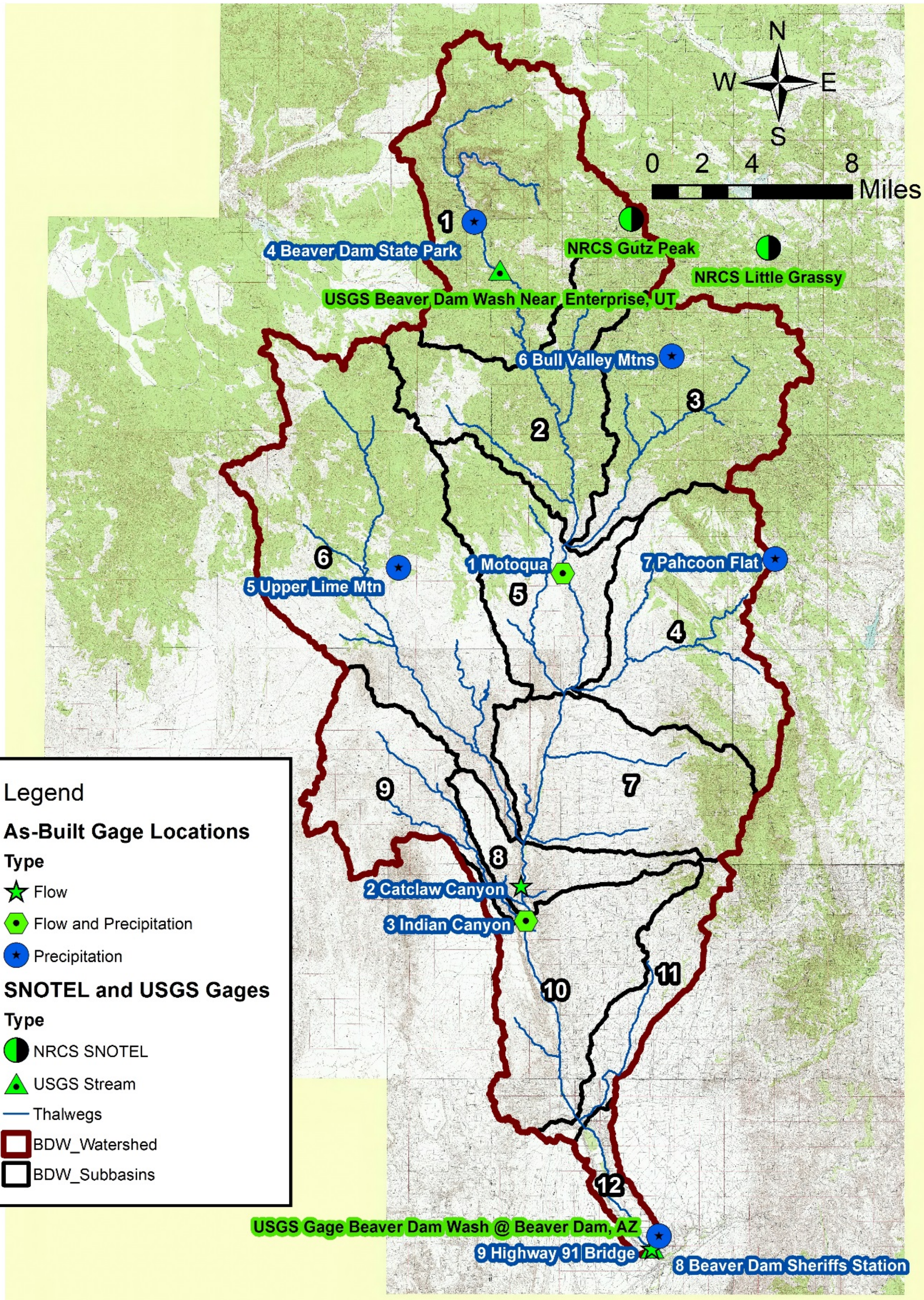
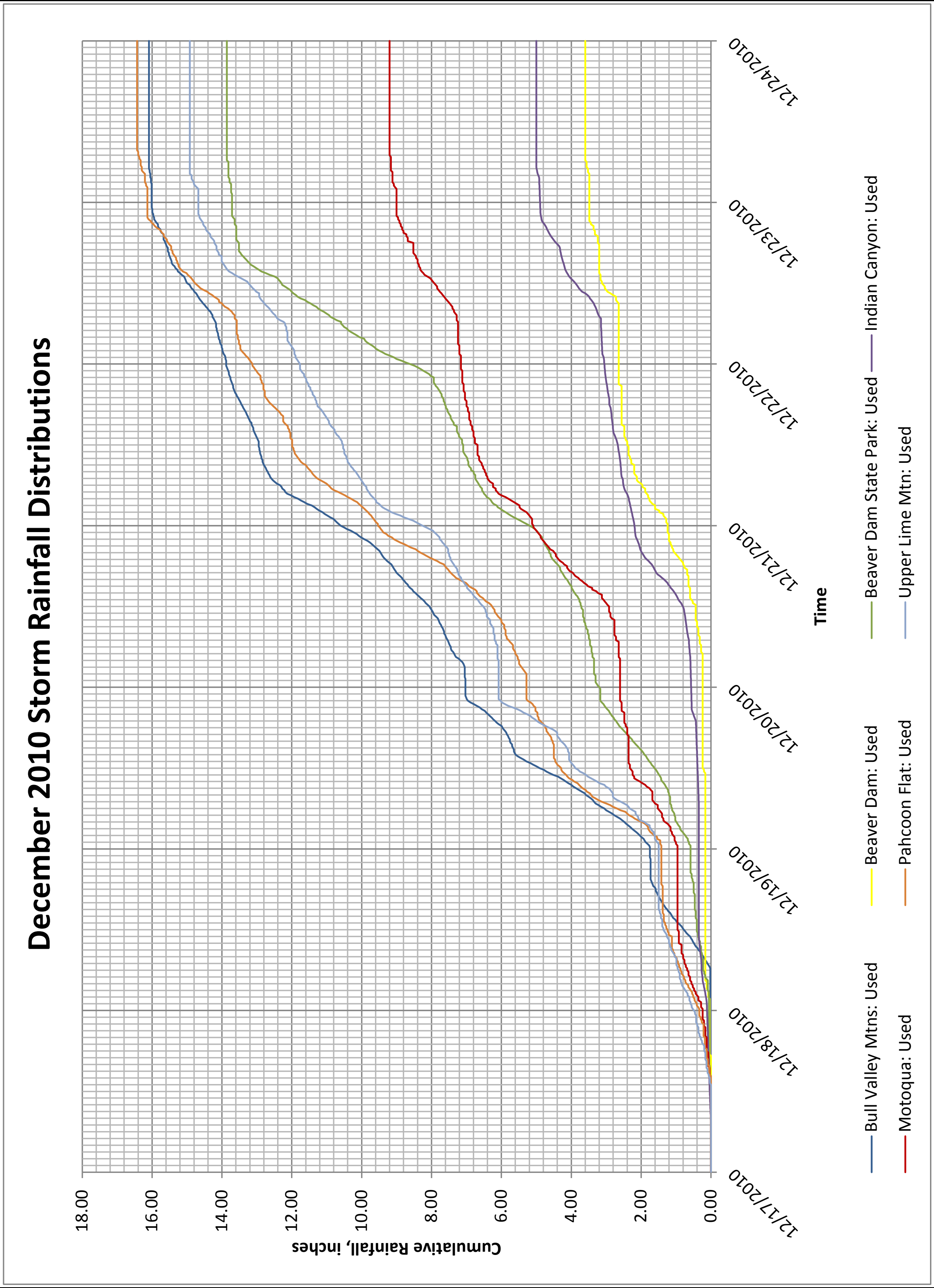


Figure 2.2 Watershed gage rainfall distributions for December 2010 storm



2.2 Stream Gage Data

There were four (4) stream flow gages in the watershed during the December 2010 flood. Refer to Figure 2.1. The Indian Canyon gage sensor did not function as expected during the event. The wash concentrated flow in other channels than where the gage sensor was located, due to the very wide floodplain width at this location. That gage has since been removed from service as a result. The new Highway 91 Bridge gage was not installed yet so Mohave County staff took manual readings from the bridge deck during most of the event. Measurements taken after 6:00 PM on December 22nd at the Highway 91 Bridge are suspect as a large cottonwood tree became lodged against a bridge pier about that time resulting in backwater and turbulence. Both the Catclaw Canyon and Motoqua gages were damaged during the flood, but continued to operate. The readings fluctuated significantly, but the results are still useable. The gage readings were obtained from MCFCD, as well as gage data from the USGS for their gage at the Highway 91 Bridge. The collected gage data is shown graphically on Figure 2.3, Figure 2.4, and Figure 2.5. Note that small fluctuations in gage height result in large variations in discharge for the Motoqua and Catclaw Canyon gages. There is good correlation between the MCFCD manual measurements and the USGS gage data. Keep in mind that the discharge estimates for all three gages, shown on Figure 2.3, Figure 2.4, and Figure 2.5 are based on pre-2010 flood rating curves. The wash morphology changed significantly during the event, so the pre-2010 rating curve based discharge values are not realistic. This data was later adjusted using the post-2010 flood rating curves developed as a part of this study.

Figure 2.3 Motoqua stream flow gage readings, pre-2010 rating curve

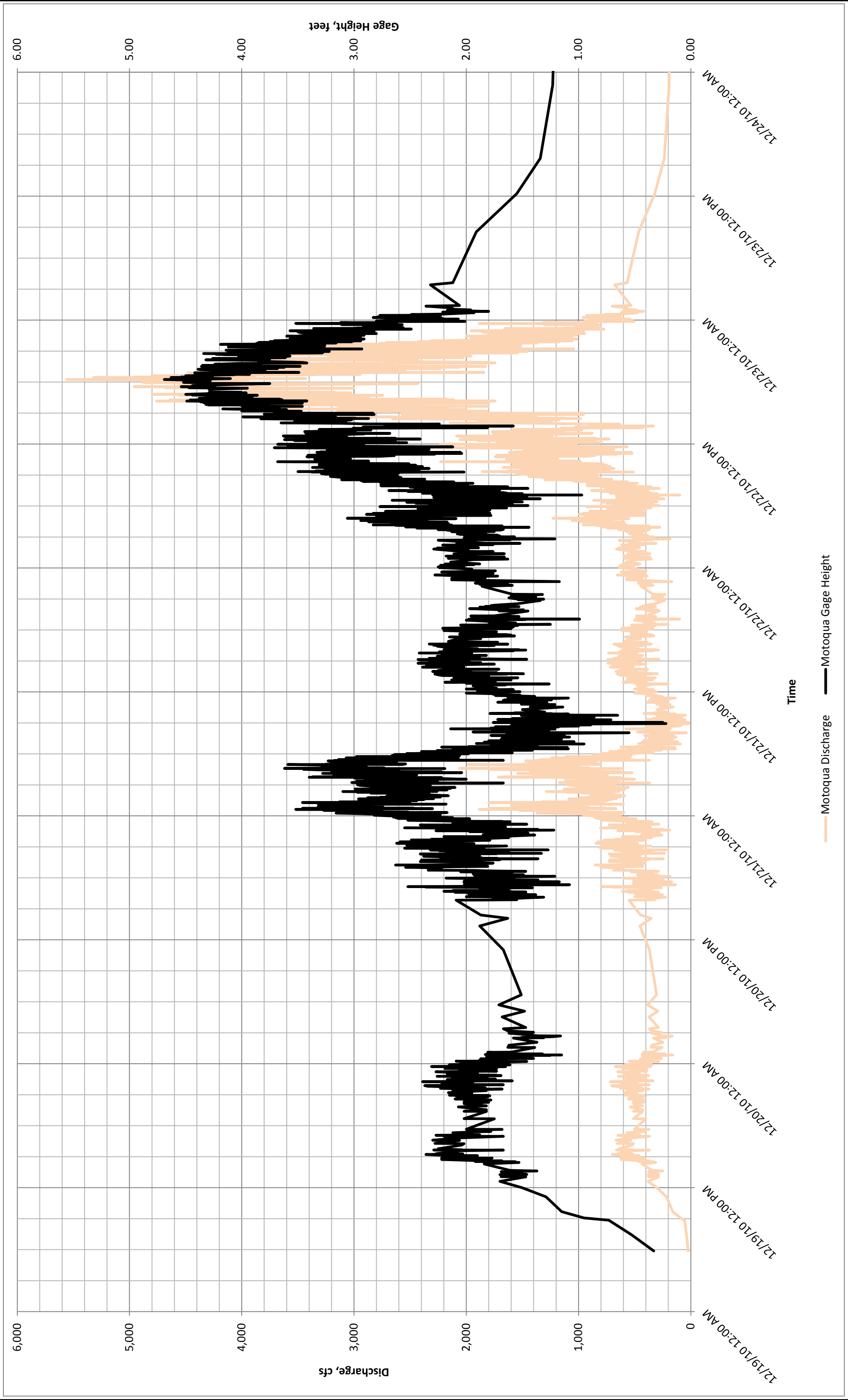


Figure 2.4 Catclaw Canyon flow gage readings, pre-2010 rating curve

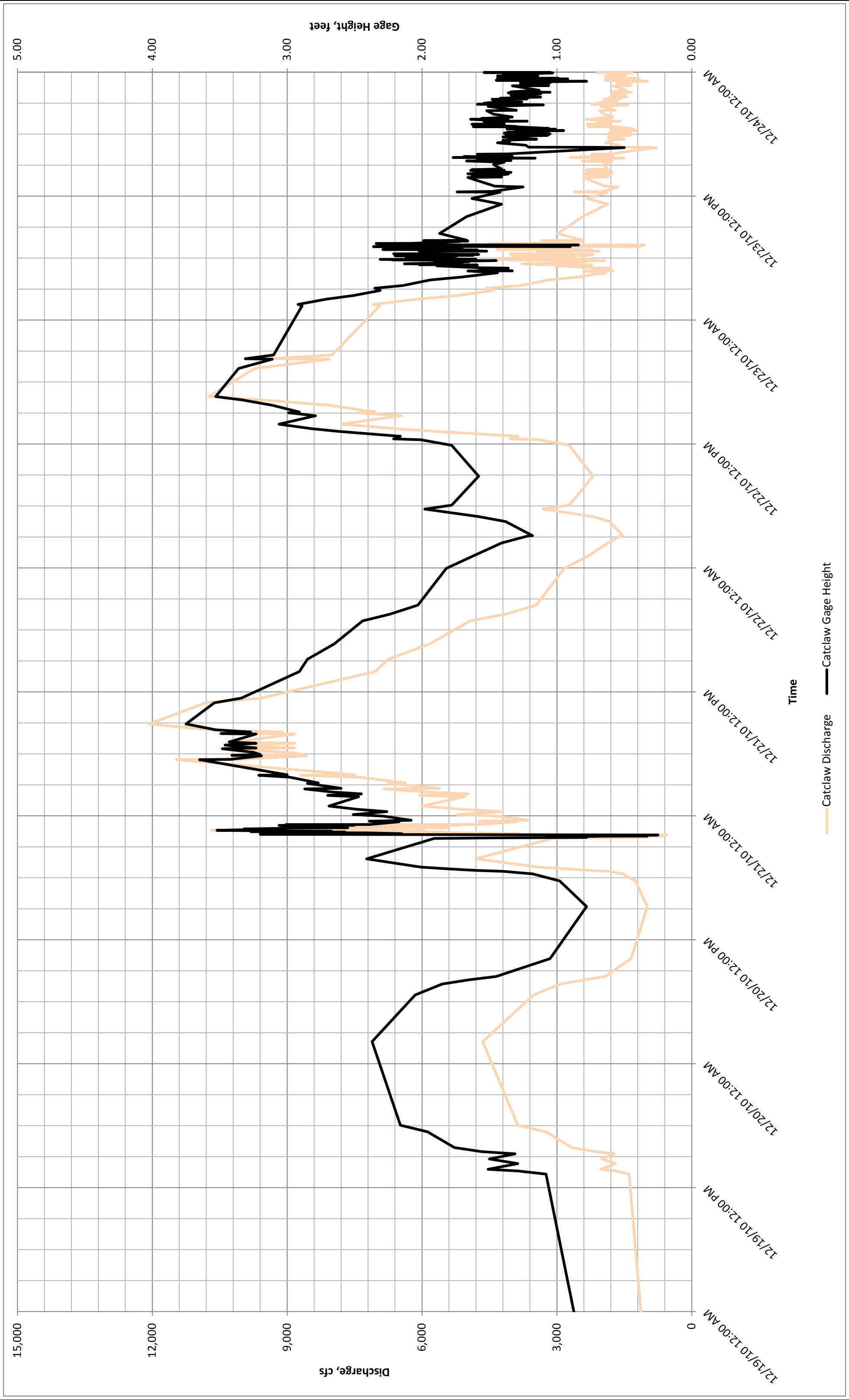
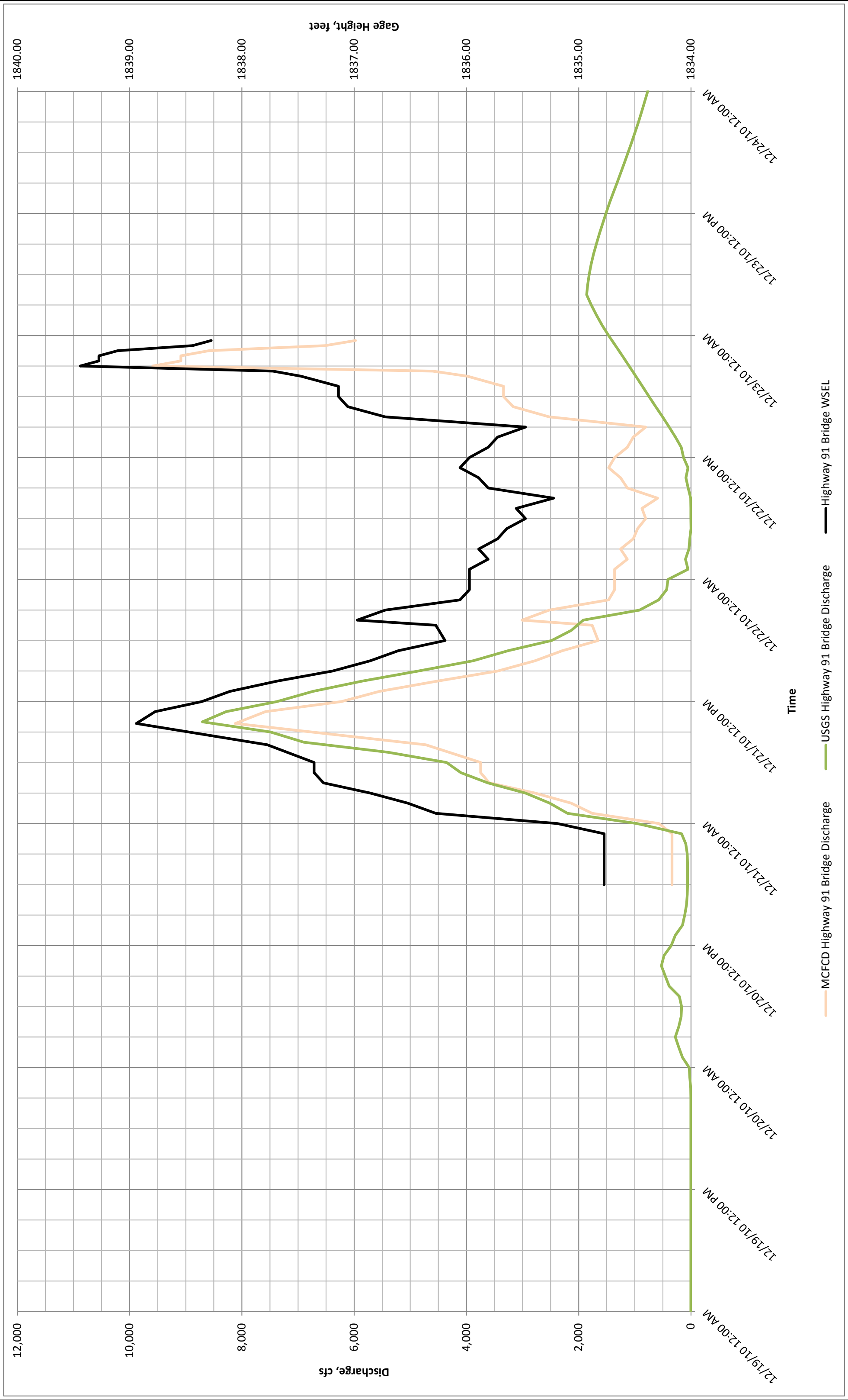


Figure 2.5 Highway 91 Bridge data, pre-2010 rating curves



2.3 Topographic Mapping and Aerial Photography

2.3.1 Detailed Topographic Mapping

MCFCD contracted with Cooper Aerial to prepare topographic mapping and aerial photographs of Beaver Dam Wash after the December 2010 flood. The topography prepared represents conditions as surveyed by photogrammetric techniques in January 2011. Cooper Aerial prepared 1-foot contour interval accuracy mapping for the Beaver Dam Wash through Beaver Dam, and at the Catclaw Canyon and Motoqua gage sites. Two-foot contour interval mapping was prepared for the reach between Beaver Dam and the Catclaw Canyon gage area. Refer to Figure 2.6 for the limits of the various mapping sets used for hydraulic modeling the Beaver Dam Wash. Aerial photographs of the 1-foot contour mapping area at Beaver Dam and at the Motoqua gage site have a 0.1 foot pixel resolution. The aerial photographs of the remaining topographic mapping area were done at a 0.2 foot pixel resolution. Topographic features were also collected, including tree and brush lines, wash bottoms, buildings, concrete, bridges, golf course features, visible utilities, culverts, cultivated fields, guardrails, walls, fences, etc. Topographic surfaces were provided in ArcGIS TIN and DEM formats, including 3D break lines and mass points. The topographic mapping information was provided by the MCFCD in the Mohave County standard GIS projection and coordinate system:

- Projection: Transverse Mercator
- Horizontal Coordinate System: State Plane, NAD83, AZ West, International feet
- Vertical Coordinate System: NAVD88

The above projection and coordinate system was used for all GIS and hydrologic and hydraulic modeling data produced as a part of this project. Graphics of the TIN surface at Beaver Dam, Catclaw Canyon, and Motoqua are shown on Figure 2.7, Figure 2.8, and Figure 2.9, respectively.

Figure 2.6 Beaver Dam Wash topographic mapping limits

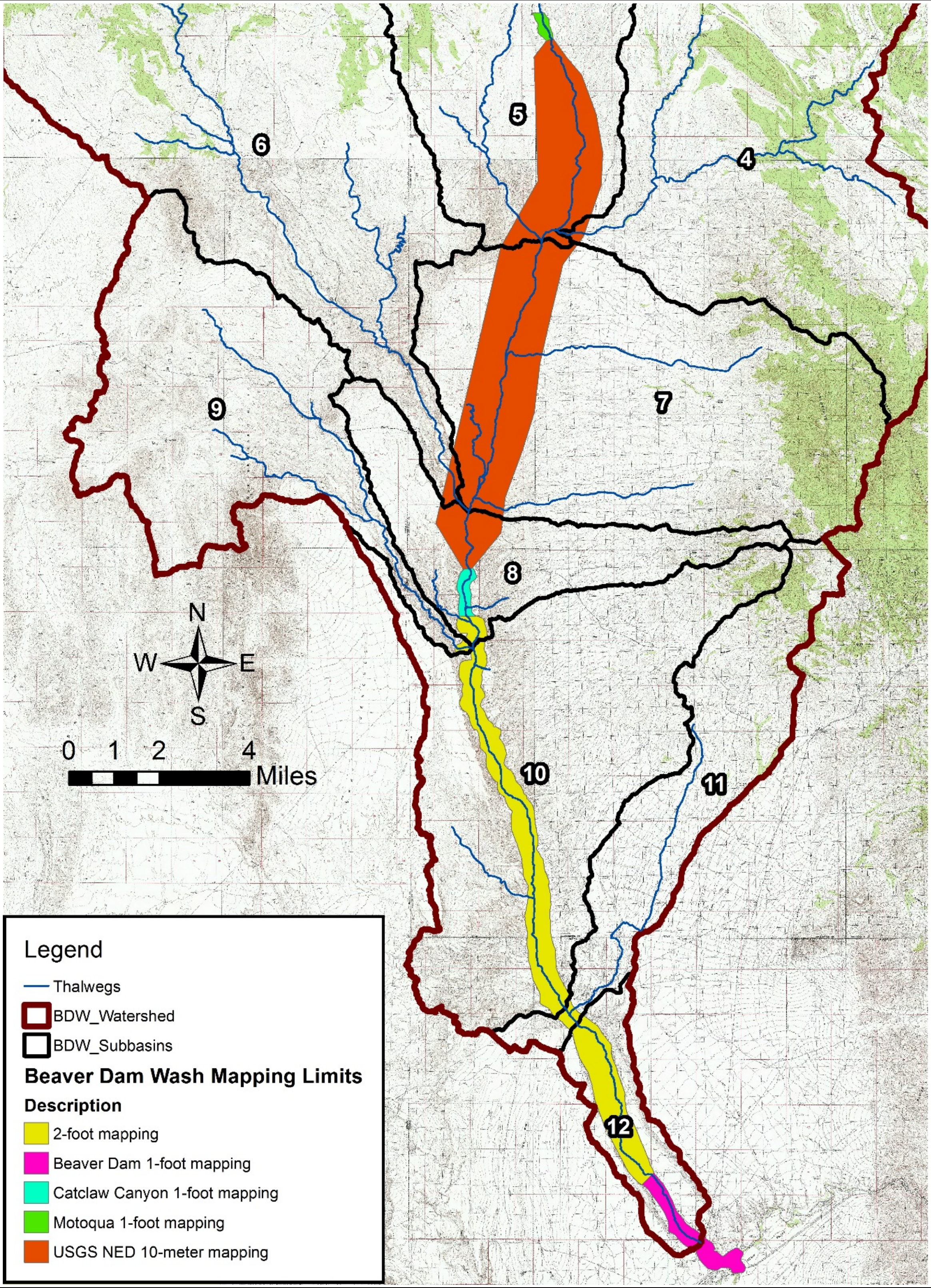


Figure 2.7 Beaver Dam TIN surface

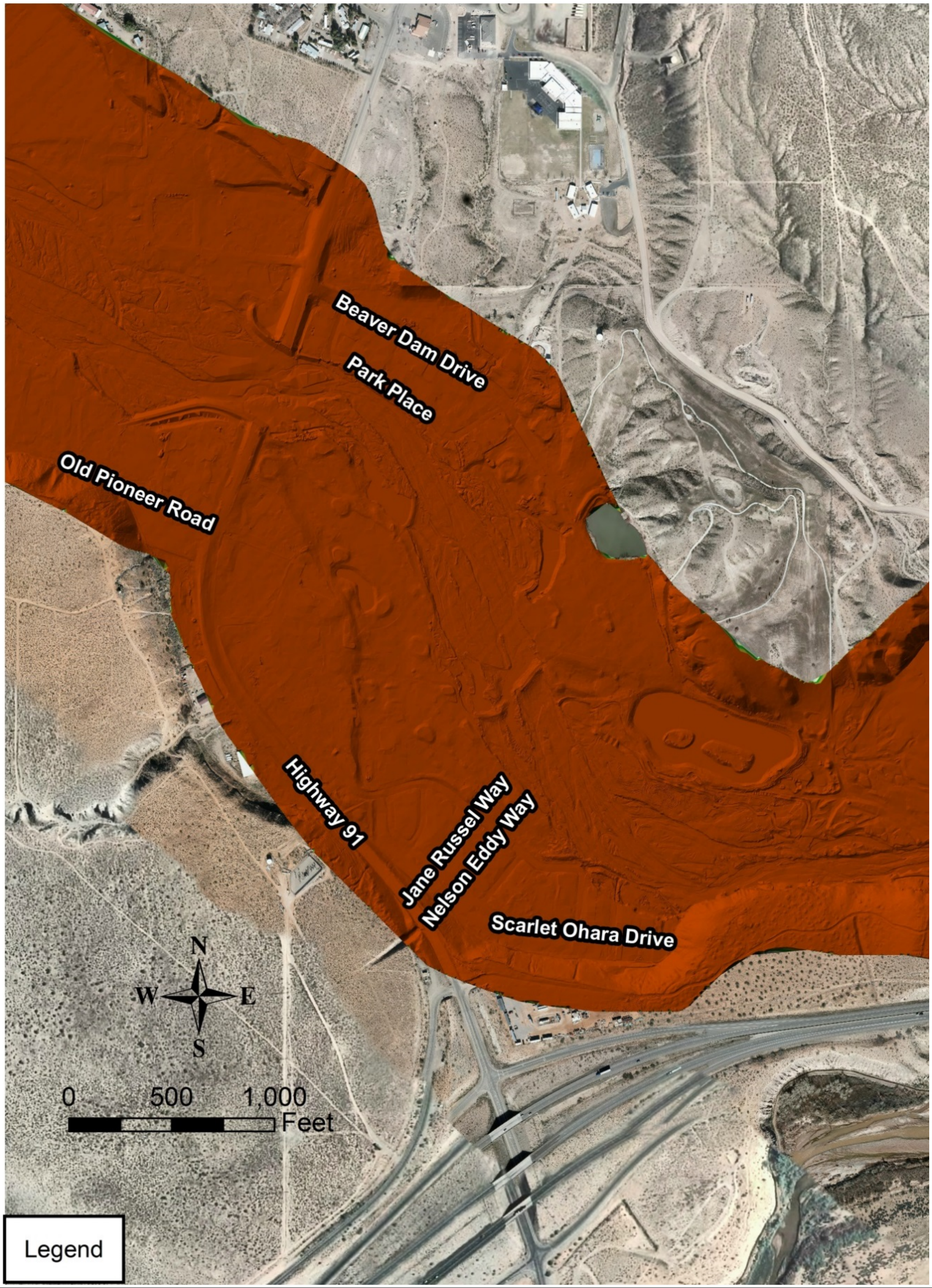


Figure 2.8 Catclaw Canyon TIN surface

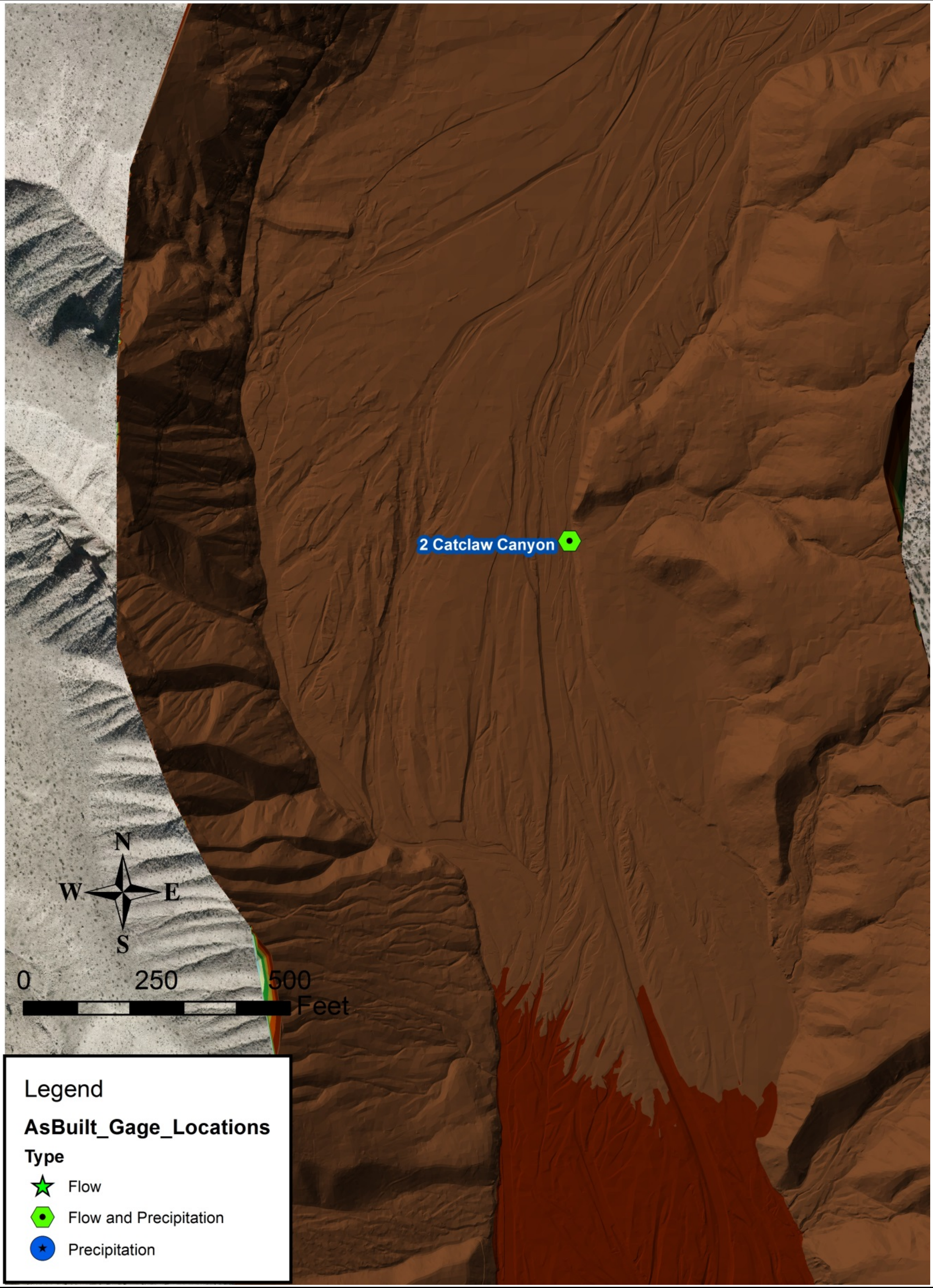
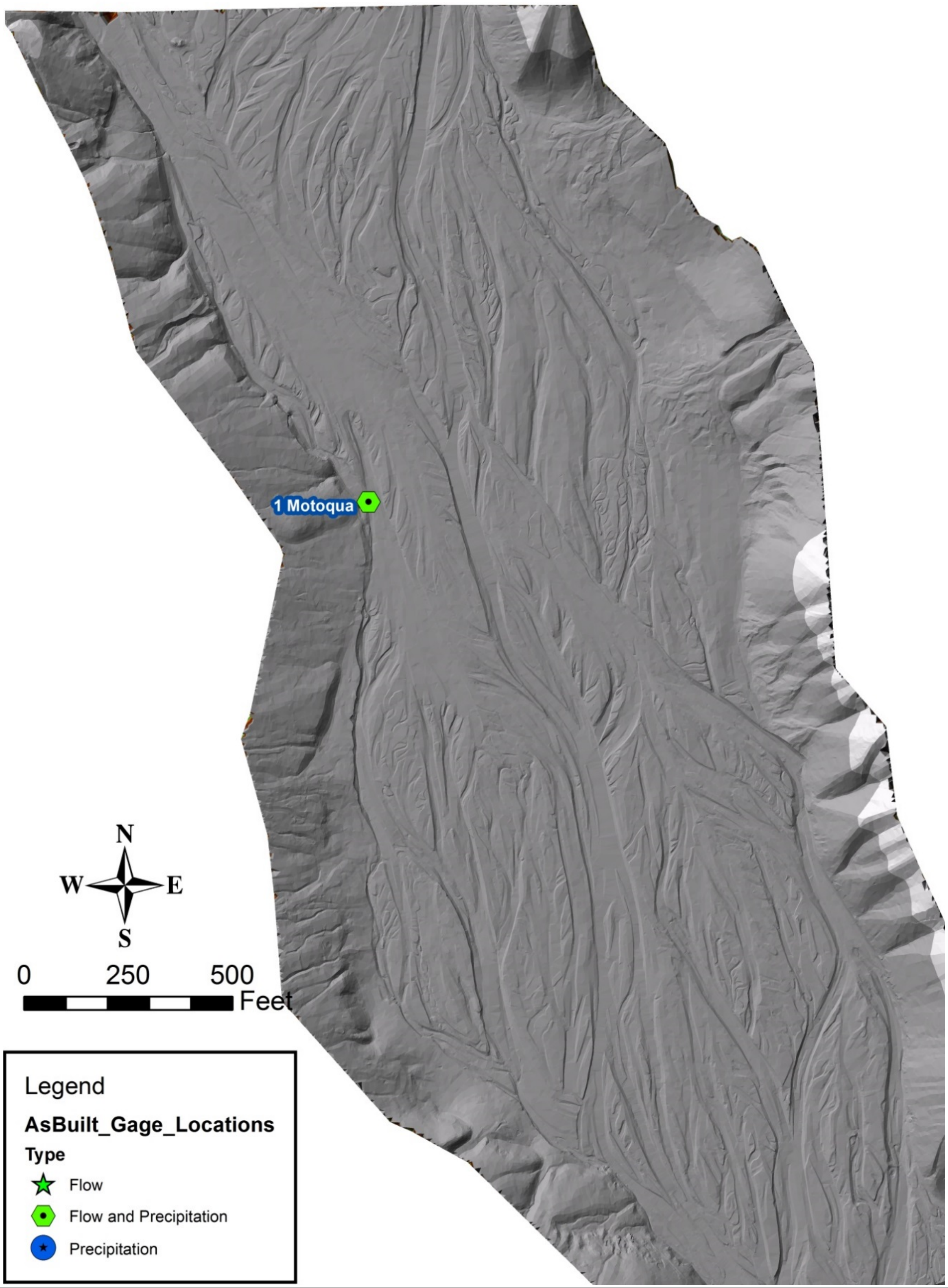


Figure 2.9 Motoqua TIN surface



2.3.2 USGS Topographic Mapping

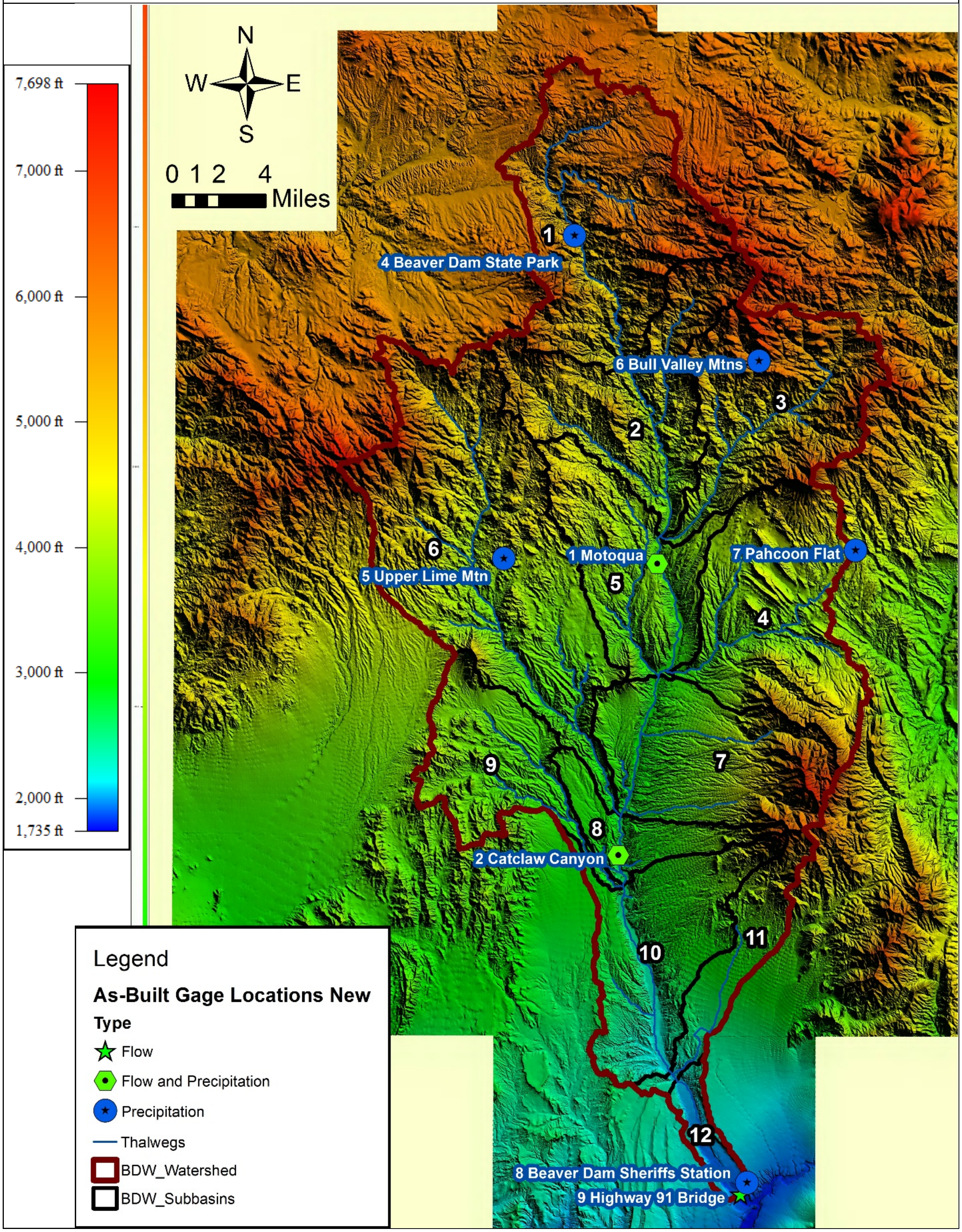
The USGS NED 10-meter Digital Elevation Maps (DEM) were used to create the surface of Beaver Dam Wash between the Catclaw Canyon and Motoqua detailed mapping surfaces. The NED was also used to create a surface of the entire Beaver Dam Wash watershed as shown on Figure 2.10.

2.4 Field Survey Information

MCFCD contracted with Forsgren Associates, Inc. to perform a field survey of the completed Highway 91 Bridge and immediate vicinity. The survey information was provided to AridHH by MCFCD and used to modify the 2011 Cooper Aerial surface to reflect the as-built condition of the bridge, particularly the area under the bridge that was not visible using photogrammetry. The survey report (Forsgren, 2013) is included as digital data. Refer to Section 10. Additional information for the revetment along Beaver Dam Estates was used to supplement the field survey data. That information was provided by MCFCD and included:

1. Mohave County/NRCS Beaver Dam – Site 3, Park Place Road Project Improvement Plans by Sunrise Engineering, 2006.
2. Beaver Dam Estates Report 05/27/2011.
3. Park Place Job #1 Report 07/15/2011.
4. Park Place Revetment Inspection Report 9-12-12

Figure 2.10 Beaver Dam Wash watershed topographic surface



3 HYDROLOGY

3.1 Approach

A hydrologic model of the Beaver Dam Wash watershed was needed to meet the project goals. The US Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) computer program, version 3.5, was selected for use. The current standard hydrology model for use in Mohave County is the USACE HEC-1 computer program. HEC-1 was not selected because there is a data limitation of 300 ordinates on the number of rainfall values that can be read in. The model must be able to handle enough ordinates for a seven (7) day storm using 15-minute intervals. Also, the HEC-1 JD Record option, which is not available in HMS, was not needed for this study. HMS can handle the number of rainfall values needed and HEC-1 cannot. The USACE River Analysis System (RAS) model, version 4.1.0, was selected to model hydraulics of the Beaver Dam Wash and to prepare the data needed for hydrologic routing of runoff hydrographs in the HMS models.

The HMS model needed must, as a minimum, provide the following:

1. Runoff hydrographs at or near the Motoqua, Catclaw Canyon, Highway 91, and the future Mormon Well stream flow gage sites.
2. Sufficient sub-basin delineation to simulate the Beaver Dam Wash major tributaries and application of the gage-measured rainfall data.
3. Accurate estimate of rainfall excess for various rainfall scenarios based on calibration to measured runoff data.
4. Accurate hydrologic routing between the stream flow gages locations based on calibration to measured runoff data. This is critical due to the long stream lengths and the need for accurate modeling of travel times and hydrograph attenuation.
5. Ability to read in MCFCD ALERT system rainfall data and make estimates of peak discharge and time to peak at the stream flow gage sites.

The approach to prepare the needed HMS models consisted of the following steps:

1. Watershed delineation into appropriate sub-basins.
2. Prepare rainfall input using the watershed rainfall gage locations.

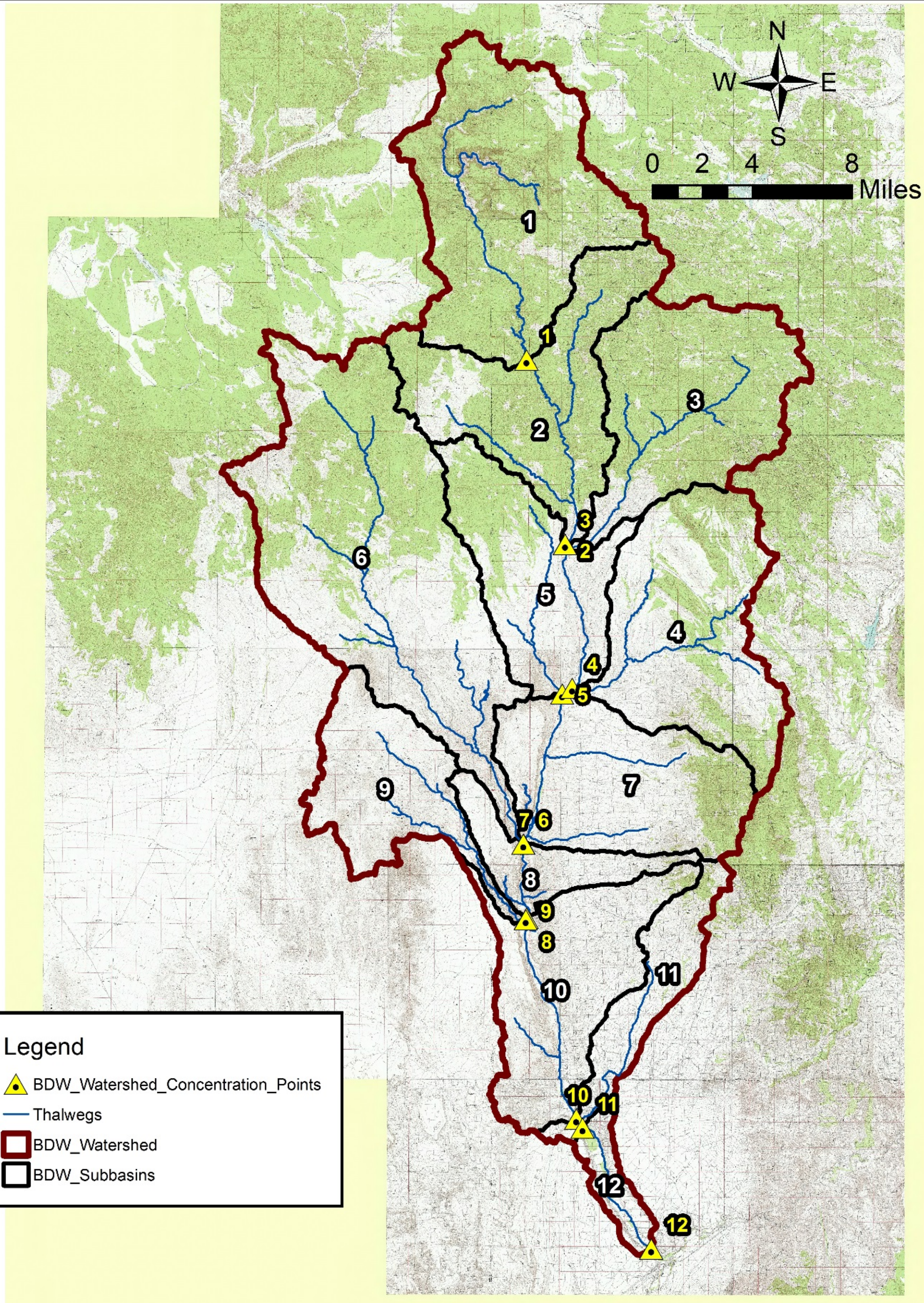
3. Prepare the sub-basin rainfall loss parameters.
4. Prepare the sub-basin unit hydrograph parameters.
5. Prepare the hydrologic routing data using the calibrated RAS model (refer to Section 4.2).
6. Calibrate the HMS model using measured rainfall and runoff information from the December 2010 storm event.
7. Prepare the following models:
    a. Calibrated model of the December 2010 storm.
    b. Models of the watershed for the following storms using the calibrated December 2010 storm model as a base.
        i. 24-hour storm for uniform watershed rainfall values of 0.5, 1.0, 1.5, 2.0, 3.0 and 4.0 inches.
        ii. 4.67 day storm based on 20 inches of total rainfall, and depth-area reduced similar to what occurred in December 2010.
8. Summarize model results for use in the FWRP.

Each step of the hydrologic modeling approach is discussed in the following sections.

3.2 Watershed Delineation

The watershed delineation used is shown on Figure 3.1. The watershed sub-basin concentration points from the 2009 FRP were used as a starting point. A new concentration point was added near the future Mormon Well stream gage site in the lower watershed (concentration point (CP) 11). A GIS DEM surface of the entire watershed was built using the USGS 10-meter DEM data. The sub-basin boundaries were then delineated using that surface. Refer to Figure 2.10 for a depiction of the surface with the sub-basin boundaries shown.

Figure 3.1 Beaver Dam Wash watershed delineation



3.3 Rainfall Events

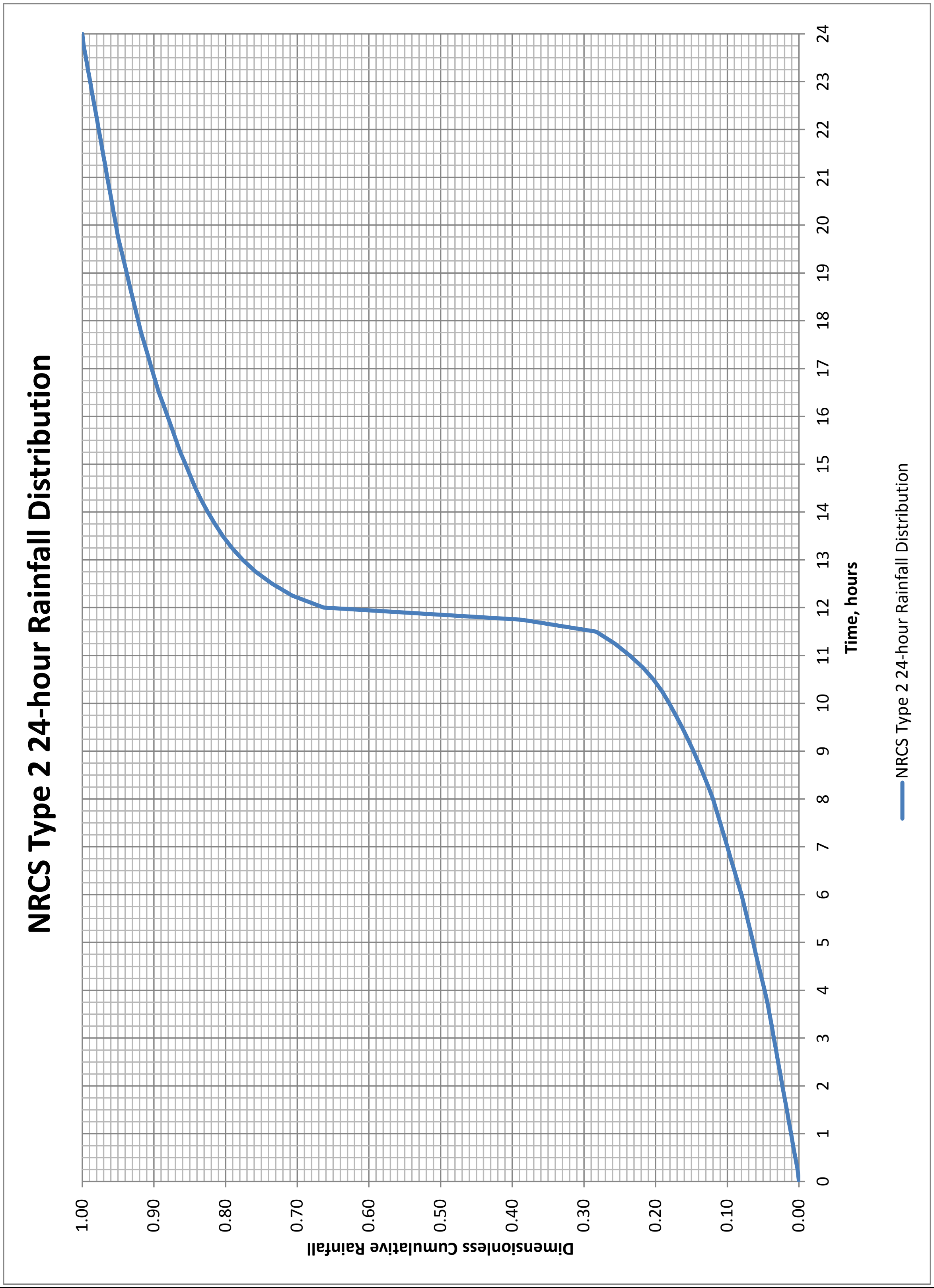
3.3.1 General

The rainfall events modeled include a series of 24-hour duration storms, the December 2010 storm, and a synthetic 112 hour storm based on the December 2010 storm. Each storm type is described in the following sections.

3.3.2 24-hour Short-Duration Synthetic Storms

A 24-hour duration synthetic storm was selected for modeling the short-duration storm scenario needed for the FWRP. The MCFCD standard 24-hour storm rainfall distribution, which is the NRCS Type 2 24-hour rainfall distribution, was selected for use. That distribution contains the peak 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour and 12-hour storm rainfall intensities nested around the mid-storm time of 12-hours. Although conservative, it provides a good estimate of watershed response for a number of different rainfall-duration-intensity combinations. The response of the watershed to a number of different rainfall depths was needed for preparation of the FWRP. The 100-year 24-hour point precipitation in the upper Beaver Dam Wash Watershed is about 3.25 inches. Therefore, the upper rainfall depth value used was 4.00 inches to provide the rainfall-runoff response for a storm more conservative than the 1% annual exceedance point rainfall. The other storm rainfall values modeled were 0.5-, 1.0-, 1.5- 2.0-, and 3.0-inches. Each rainfall depth was applied at all the watershed gages as measured rainfall. The HMS inverse distance approach was used, the centroid of each sub-basin was defined, and a weight of 1.0 assigned to each. This approach will be the same used when real measured rainfall data is read in to the model during an actual event. The NRCS Type 2 24-hour rainfall distribution used is shown on Figure 3.2.

Figure 3.2 NRCS Type 2 24-hour rainfall distribution



3.3.3 December 2010 General Storm Rainfall

The rain gage measured data discussed in Section 2.1.1 was used for reconstitution of the December 2010 storm, which was a long-duration general winter storm that lasted about 5.5 days. Refer to Figure 2.2 for the rainfall distributions used for each gage. Refer to the Excel spreadsheet listed in Section 10.1 for the data.

The rain gage readings for Upper Lime Mountain, Pahcoon Flat, Bull Valley Mountains, and Beaver Dam State Park are all suspect for the December 2010 storm. A faulty snow tube design at each gage resulted in higher readings than actually occurred. An attempt was made by Mohave County staff to determine a correction factor, and the adjustments recommended were refined by AridHH during the model calibration process. It should be kept in mind that the measurements at these gages have a higher than normal degree of error.

The gage-measured rainfall distributions were implemented in HMS by assigning each to a gage location as measured rainfall. The HMS inverse distance approach was used, the centroid of each sub-basin was defined, and a weight of 1.0 assigned to each.

3.3.4 112 Hour Long-Duration Synthetic Storm

A synthetic storm was created to simulate long-duration tropical and general winter storm types for use with the FWRP. The December 2010 storm was used as the basis. To develop the synthetic rainfall distributions, the gages were grouped to represent the upper, middle and lower watersheds as follows:

1. Upper Watershed: Upper Lime Mountain, Bull Valley Mountains, Pahcoon Flat, and Beaver Dam State Park.
2. Middle Watershed: Motoqua
3. Lower Watershed: Indian Canyon and Beaver Dam Sheriff's Station.

The Indian Canyon rain gage has been discontinued but will be replaced in the future at the Catclaw Canyon gage site.

The measured values from the gages in each group were averaged for every 15-minute time step. Then a central moving average was applied to the average data to obtain a representative rainfall distribution for each grouping as shown on Figure 3.3. The time step was shortened to 10-minutes to create a more intense storm of 112 hour duration. The results are the synthetic rainfall distributions used for the long-duration storm criteria in the FWRP. A total storm long-duration rainfall depth of 20 inches was selected. This depth was applied to the upper watershed distribution and then depth-area reduced values applied to the middle and lower watershed distributions. The depth area reduction factors were derived from the December 2010 storm data. Rainfall depths of 12 inches and 5.6 inches were applied to the middle watershed and lower watersheds, respectively. Refer to Figure 3.4 for a plot of the cumulative rainfall distributions applied in HMS for the long-duration storm scenario used in the FWRP.

3.4 Rainfall Loss Parameters

The Green and Ampt rainfall loss method was applied in accordance with MCFCD (2013). The parameters applied to each sub-basin are listed in Table 3.1.

Table 3.1 Sub-basin rainfall loss parameters

Sub-basin	Area mi^2	Storage in	XKSAT in/hr	PSIF in	Moisture Content		RTIMP %
					Initial	Saturation	
1	76.800	1.50	0.14	9.17	0.30	0.40	6
2	53.384	1.30	0.17	8.80	0.15	0.40	4
3	55.908	1.25	0.25	7.62	0.15	0.40	0
4	60.392	0.05	0.16	8.56	0.25	0.40	16
5	42.160	0.05	0.20	8.07	0.25	0.40	10
6	110.12	0.05	0.17	8.61	0.25	0.40	6
7	51.672	0.05	0.24	7.48	0.25	0.40	10
8	16.495	0.24	0.25	7.36	0.10	0.40	10
9	34.321	0.21	0.29	7.05	0.09	0.40	7
10	46.527	0.24	0.23	7.74	0.10	0.40	17
11	20.414	0.27	0.28	7.04	0.09	0.40	8
12	7.888	0.29	0.91	2.16	0.06	0.40	0

The storage and initial moisture content parameters listed in Table 3.1 are the final calibrated values (Section 3.7). The other parameters are the standard values from the MCFCD hydrologic method.

Figure 3.3 December 2010 storm representative rainfall distributions

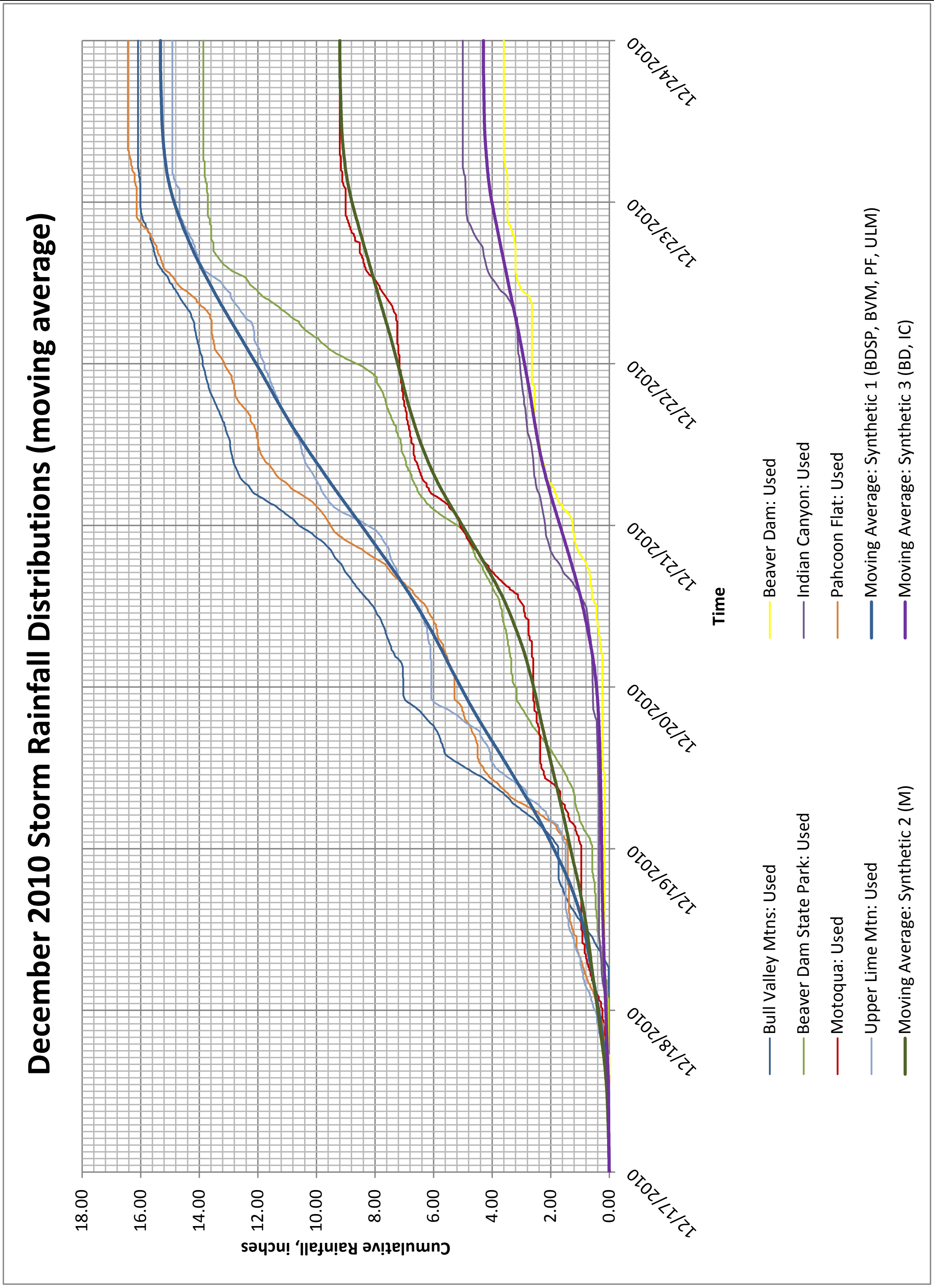
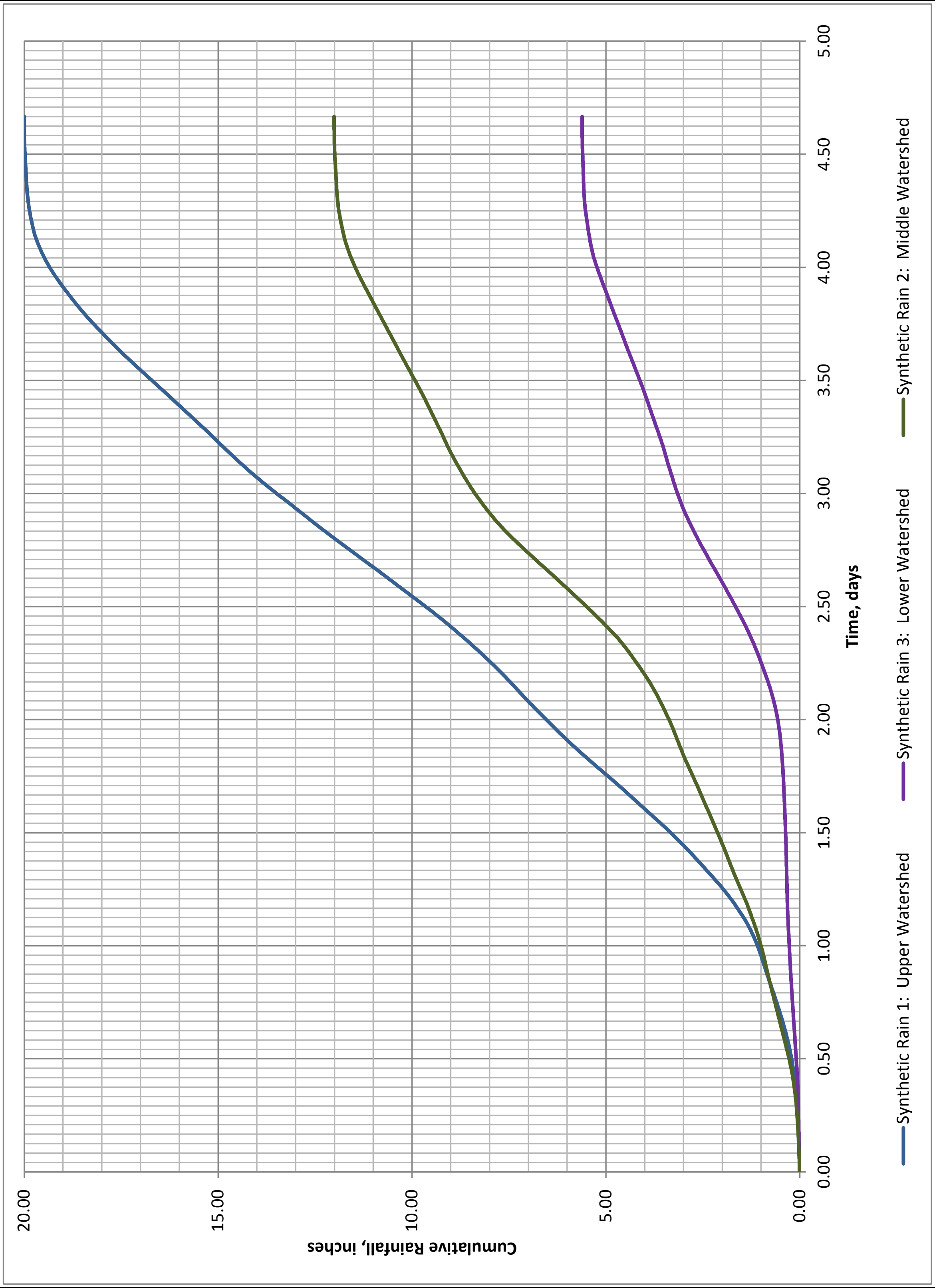


Figure 3.4 Long-Duration 112 hour storm synthetic rainfall distributions



3.5 Unit Hydrograph Parameters

The Clark unit hydrograph method was applied in accordance with MCFCD (2013). The unit hydrograph parameters were derived from the USGS NED surface and GIS sub-basin data. The unit hydrograph parameters applied for each sub-basin are listed in Table 3.2.

Table 3.2 Sub-basin unit hydrograph parameters

Sub-basin	Area	T_c Path Data				L_{ca}	T_c	R
	mi²	Upstream feet	Downstream feet	Length mi	Slope ft/mi	mi	hours	hours
1	76.800	6617.4	4217.6	21.33	113	8.42	5.27	2.28
2	53.384	7372.5	3509.6	17.24	224	7.91	4.14	1.81
3	55.908	7090.0	3509.6	17.22	208	9.11	4.37	1.87
4	60.392	6973.2	3134.7	16.68	230	6.98	4.00	1.58
5	42.160	5390.6	3106.3	15.68	146	6.39	4.08	1.89
6	110.121	6413.9	2733.7	29.58	124	16.46	6.88	3.24
7	51.672	7198.9	2733.7	15.95	280	7.22	3.78	1.57
8	16.495	6742.6	2564.9	9.47	441	2.58	2.09	1.03
9	34.321	5365.7	2559.0	15.87	177	9.99	4.31	2.28
10	46.527	6980.7	2094.9	16.61	294	5.23	3.45	1.55
11	20.414	6605.6	2072.0	15.21	298	6.96	3.33	2.23
12	7.888	2424.7	1843.3	7.46	78	3.49	2.79	1.78

3.6 Hydrologic Routing

Most of the hydrographs were routed through the watershed using the modified Puls method. The storage–discharge and elevation–discharge data was generated using the RAS model of the Beaver Dam Wash (Section 4.2). The RAS model timing was calibrated to the known travel times measured by the stream flow gages. The locations of the seven (7) routing reaches are shown on Figure 3.6. The first reach, 001002, is upstream of the Motoqua gage and outside of the RAS model limits. That reach was modeled with the Muskingum-Cunge method. The stage-storage-discharge data for each of the modified Puls reaches is shown on Figure 3.7 through Figure 3.12. The routing summary data is listed in Table 3.3.

Figure 3.5 Sub-basin unit hydrograph parameters map

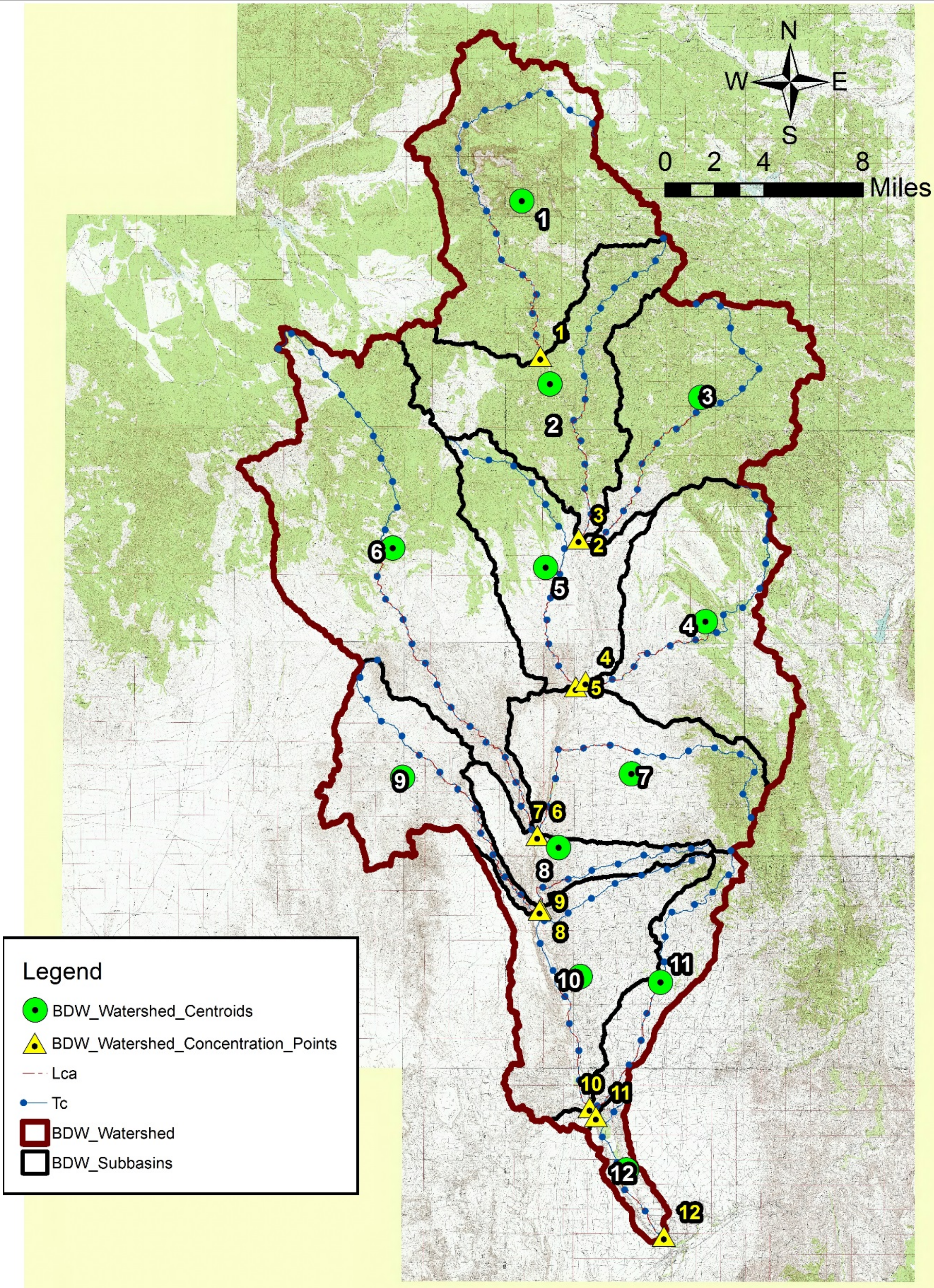


Figure 3.6 Watershed routing reaches map

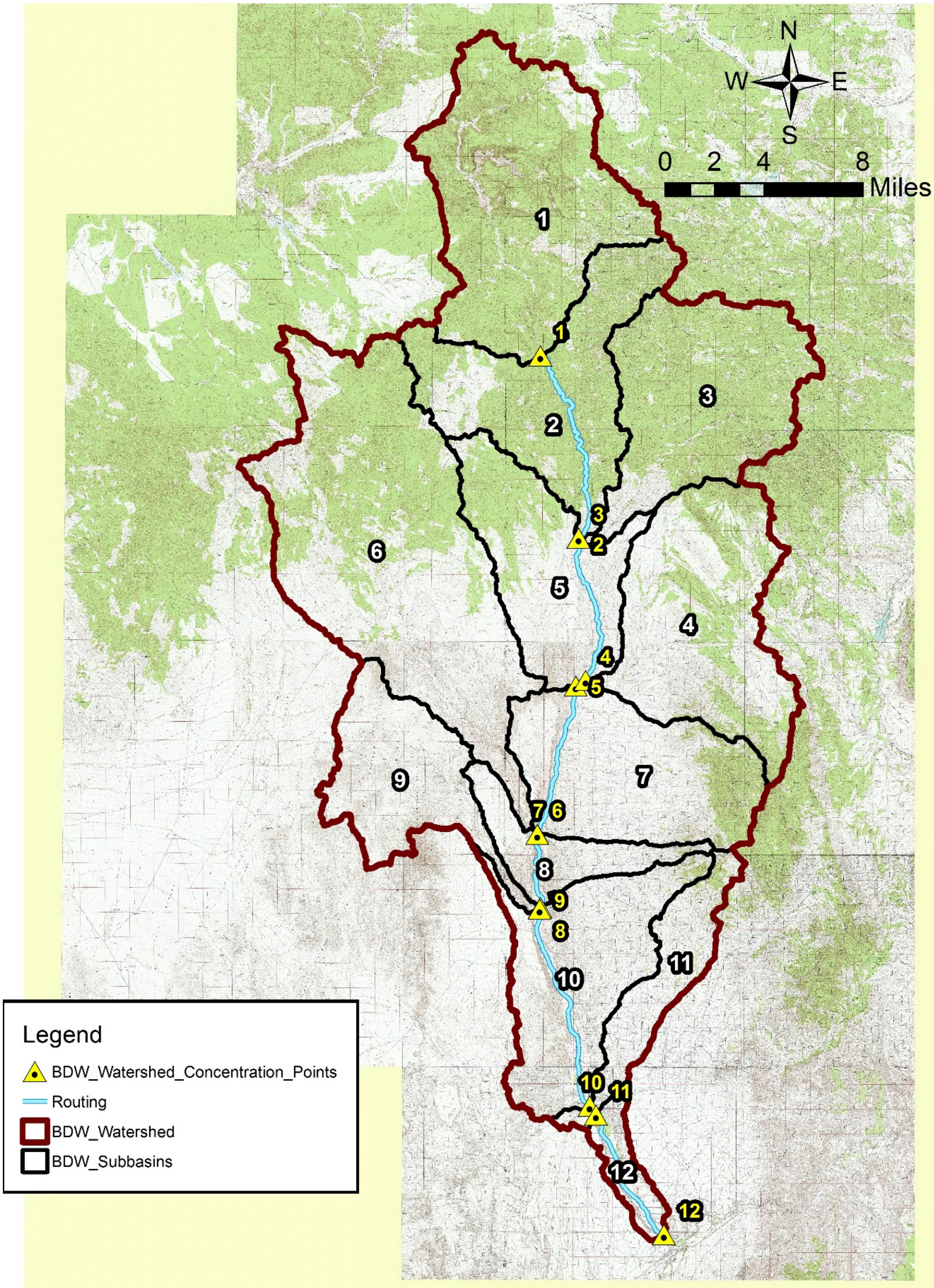


Figure 3.7 Reach 003A005 routing data

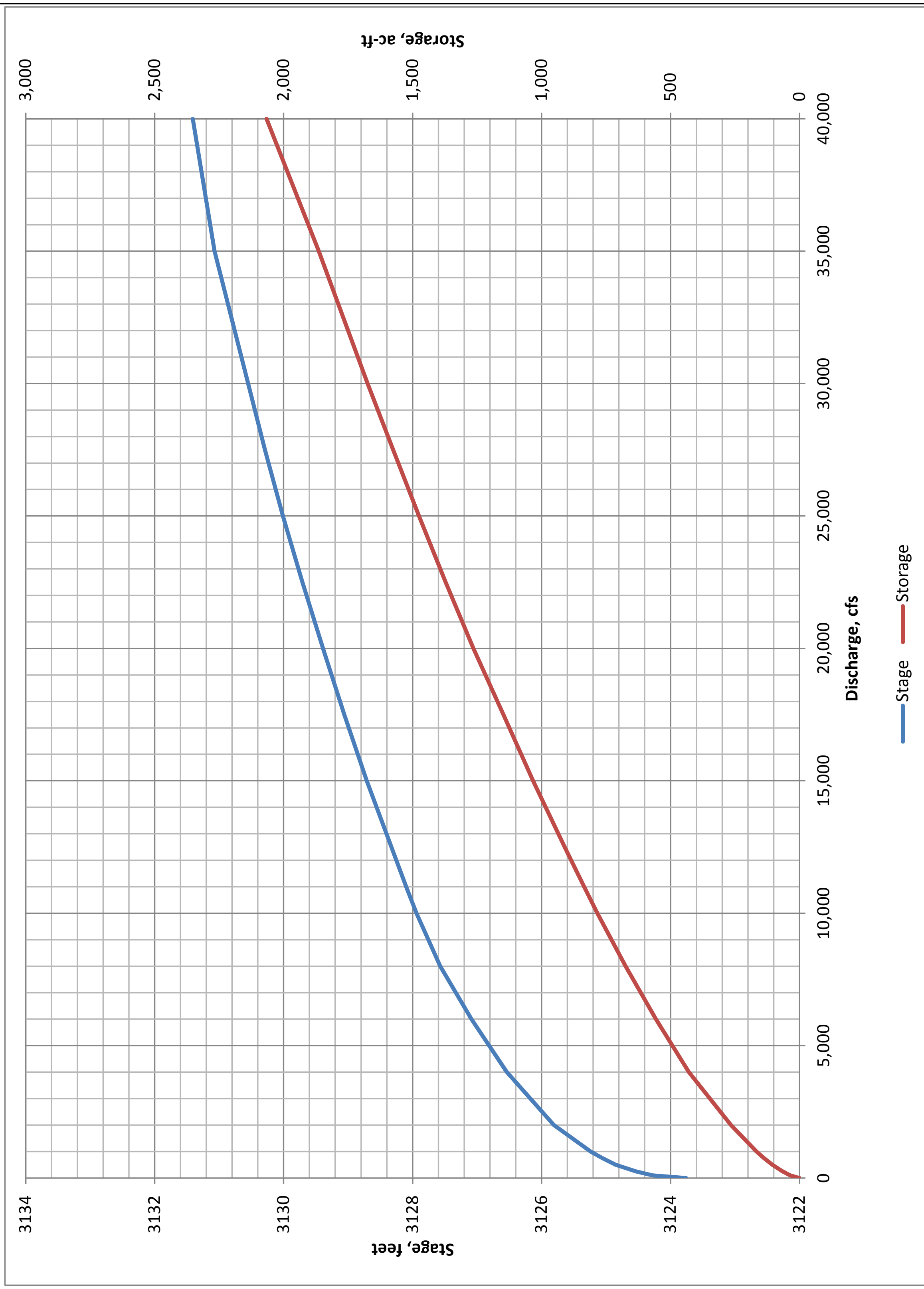


Figure 3.8 Reach 005007 routing data

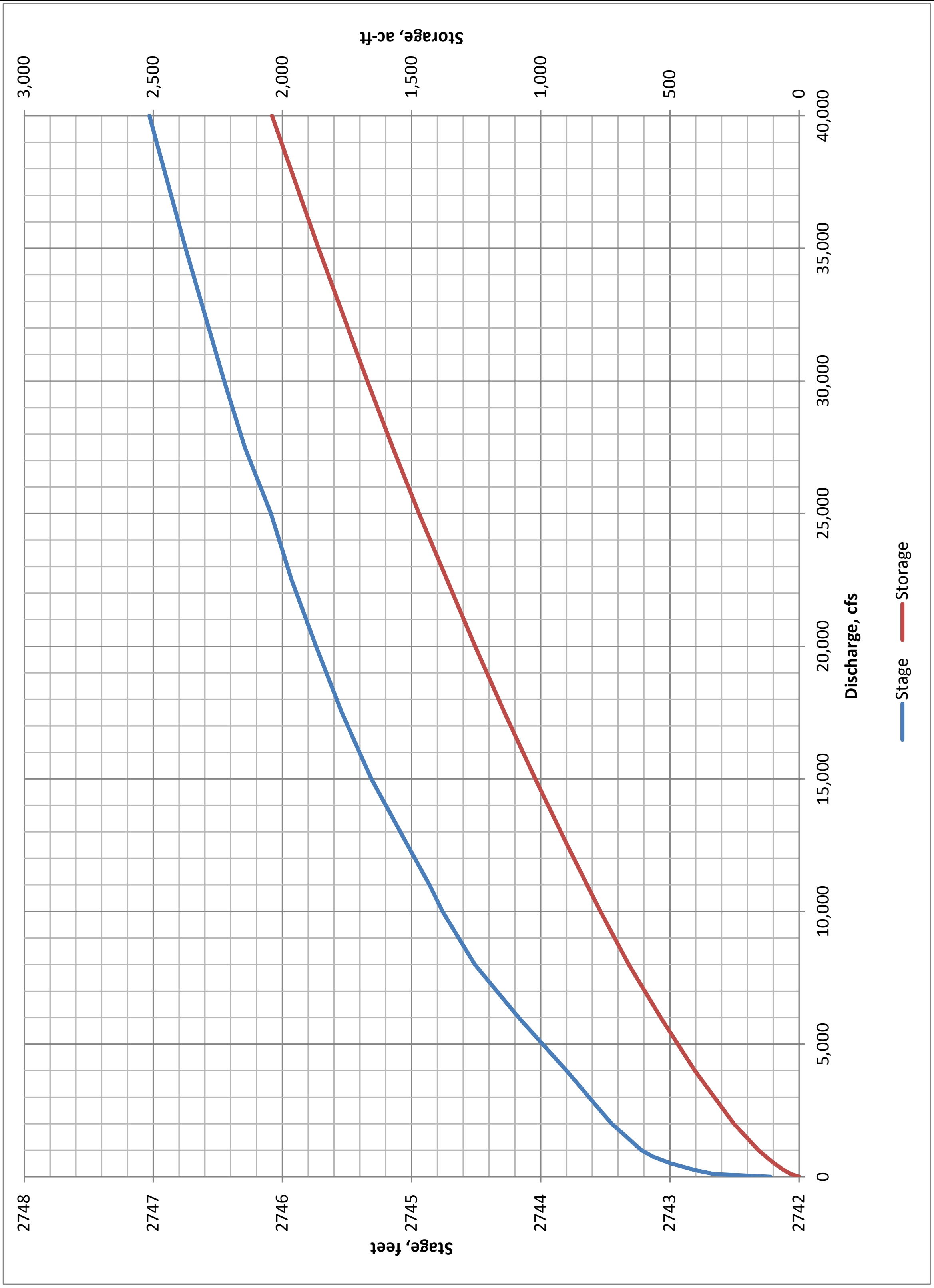


Figure 3.9 Reach 007009 routing data

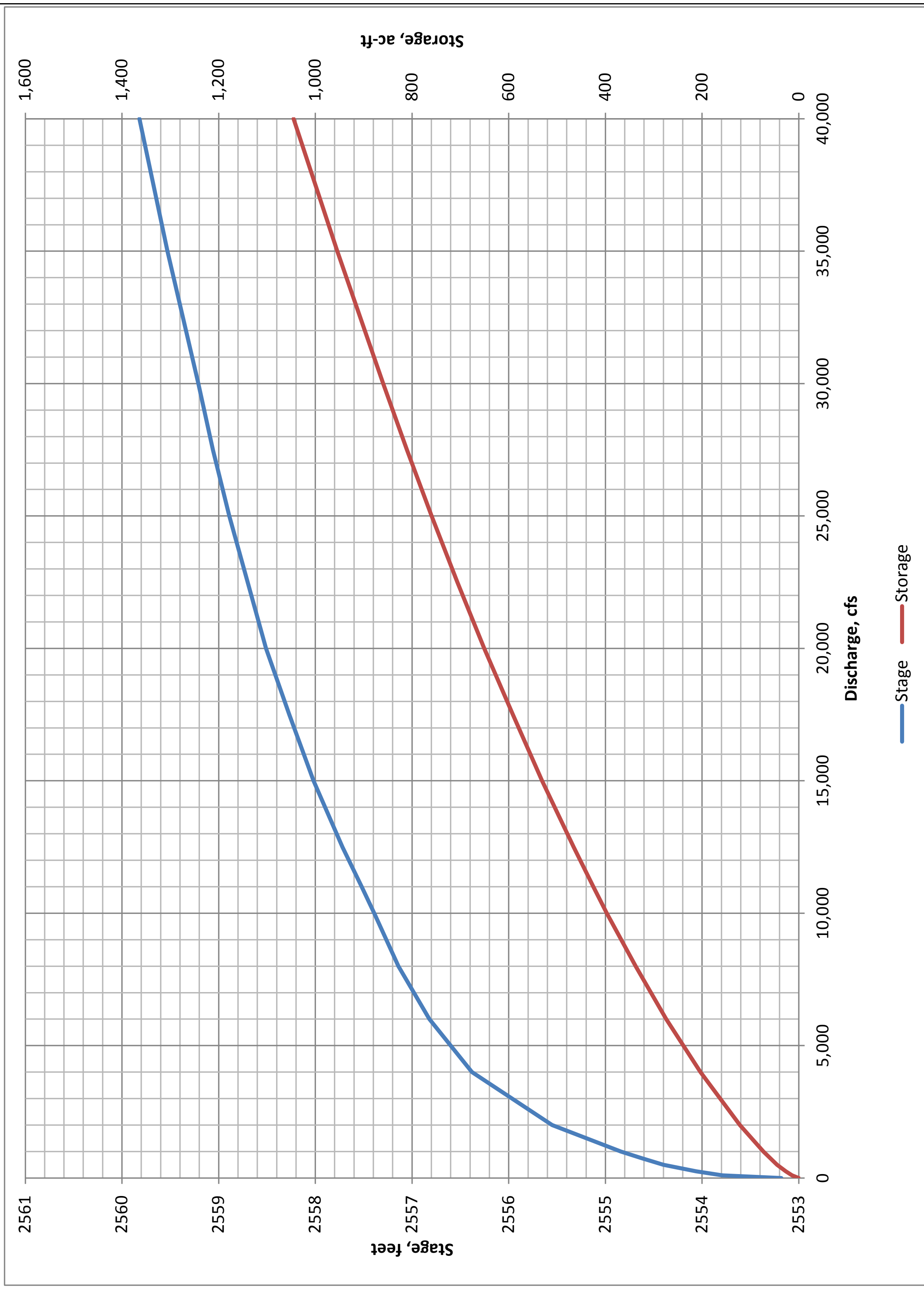


Figure 3.10 Reach 009010 routing data

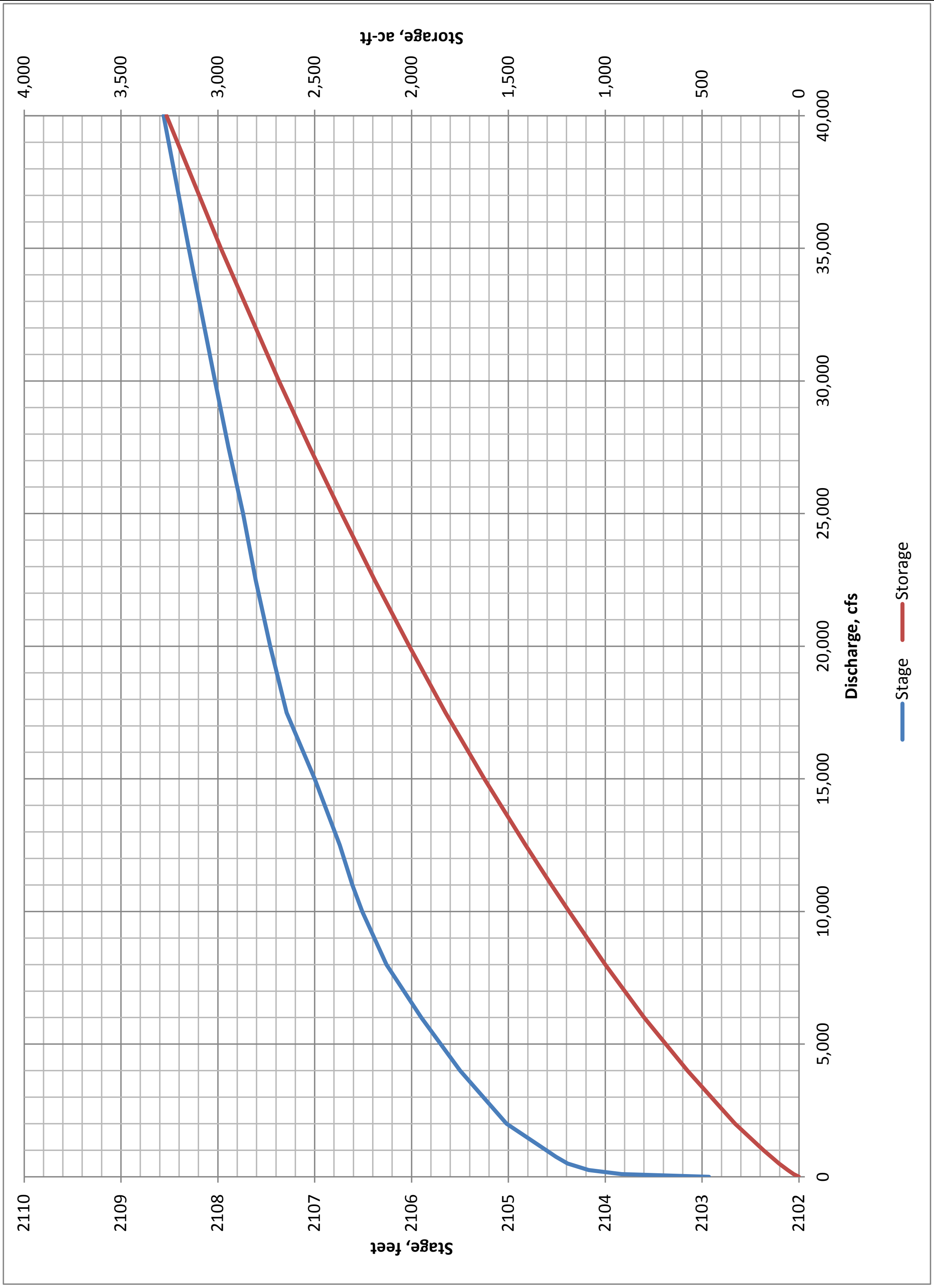


Figure 3.11 Reach 010011 routing data

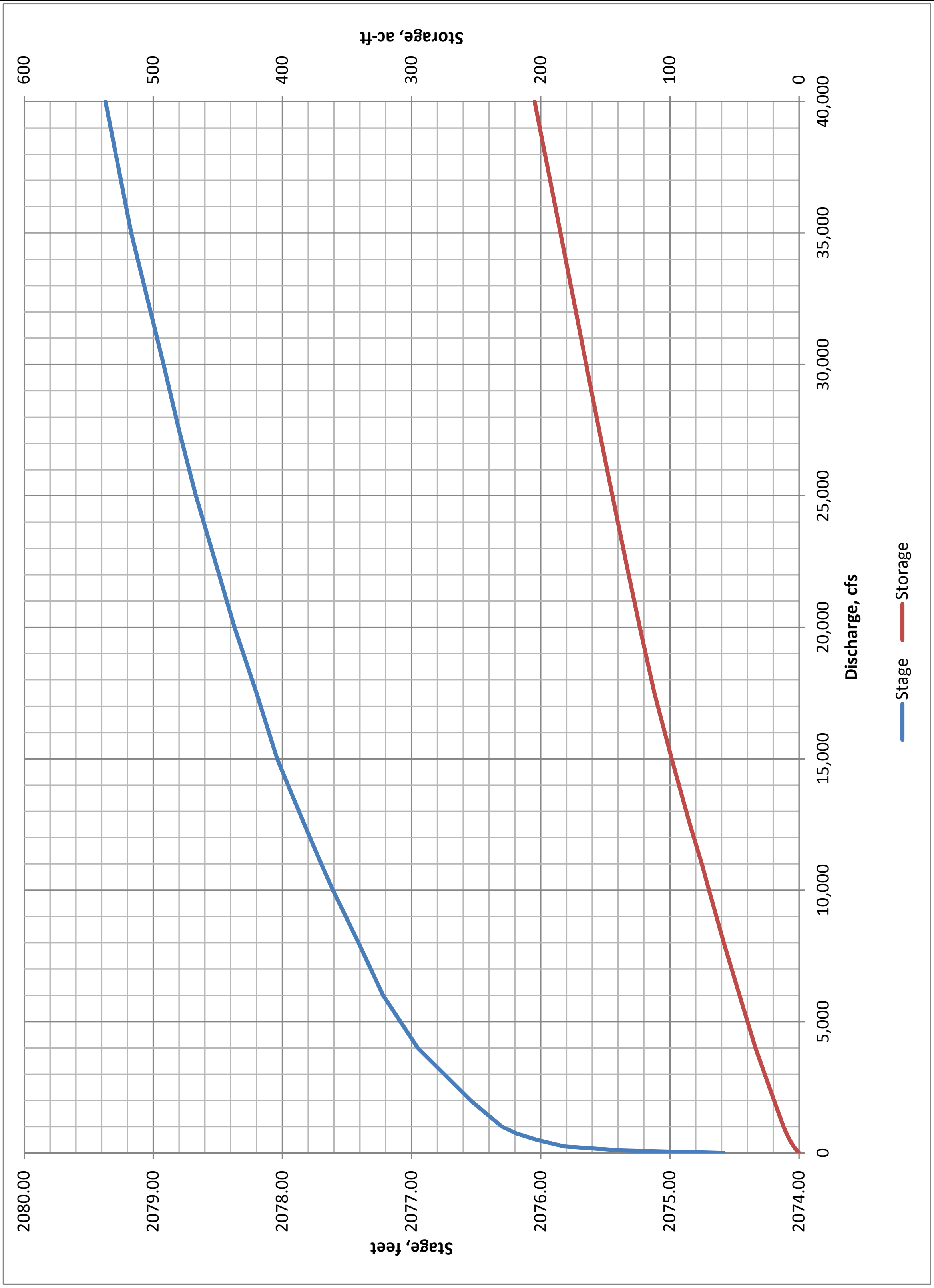


Figure 3.12 Reach 011012 routing data

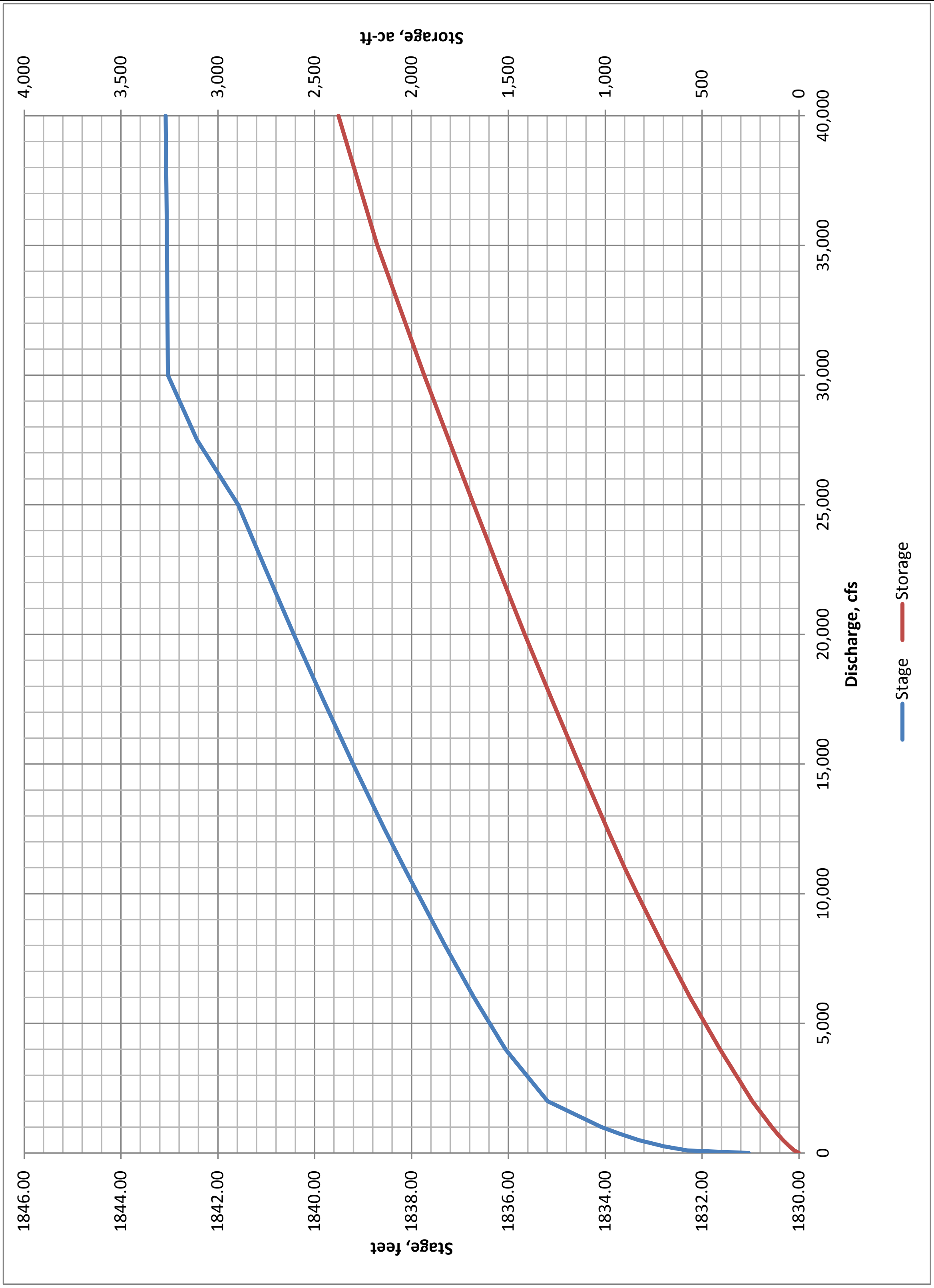


Table 3.3 Routing data for each reach

Reach	Sub-reaches	Elevations		Length feet	Slope %	Infiltration Rate cfs/ac
		Top feet	Bottom feet			
001002	n/a	4217.6	3509.6	53,944	1.31	0.10
003A005	13	3509.6	3106.3	37,113	1.09	0.10
005007	14	3106.3	2733.7	33,883	1.10	0.10
007009	6	2733.7	2564.9	17,428	0.97	0.10
009010	18	2564.9	2094.9	46,674	1.01	0.10
010011	1	2094.9	2072.0	2,379	0.96	0.10
011012	14	2072.0	1843.3	31,169	0.73	0.10

A transmission loss of 0.10 cfs/ac-ft was applied to each reach. This value came out of the RAS calibration process.

3.7 Model Calibration

The HMS model was calibrated against the measured runoff hydrographs at the Motoqua, Catclaw Canyon and Highway 91 Bridge gage sites. The key parameters that were adjusted in the HMS model calibration process were:

1. Gage rainfall adjustment factors for the gages with snow tubes (Section 2.1.1).
2. The surface storage (initial abstraction).
3. Initial soil moisture content.
4. Reach route transmission loss rate.

The most significant adjustments were made to the rainfall. Instead of a uniform correction factor of 0.4 for the snow tube problem, the correction factor was revised to be in the range of 0.4 to 0.7, as described in Section 2.1.1. The adjustments made to items 2 and 3 are listed in Table 3.4. Item 4 was set to 0 cfs/ac initially, and 0.10 cfs/ac-ft in the calibrated model.

The un-calibrated HMS model results compared with the measured are shown on Figure 3.13. Note that there is not even close to enough runoff volume. Due to the major differences in runoff volume, the rain gage correction factors for gages with snow tubes were adjusted as the first step. The final calibrated results are presented in Section 3.8.

Figure 3.13 Comparison of un-calibrated HMS results with measured

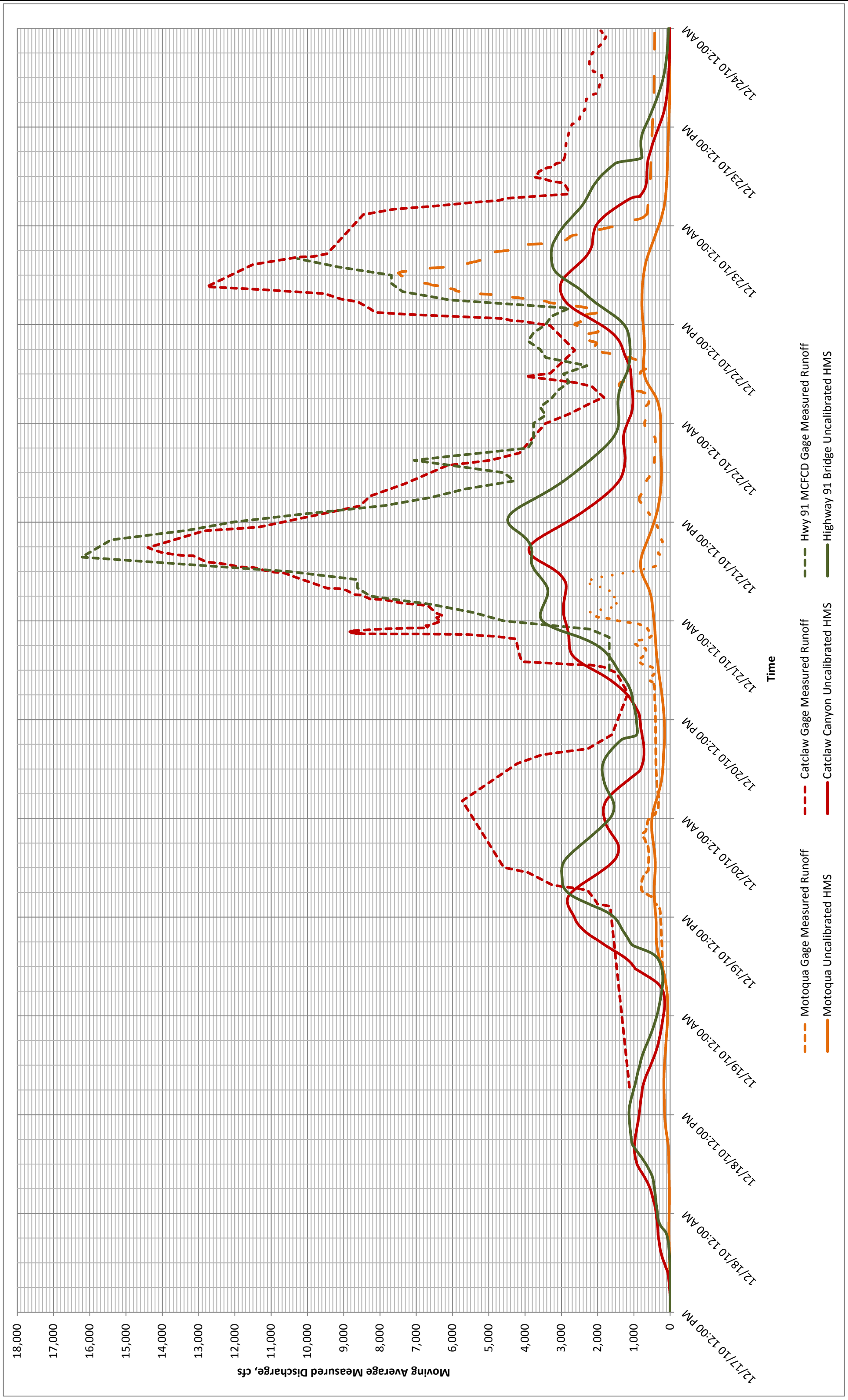


Table 3.4 HMS model calibration parameter settings

Sub-basin	Maximum Storage		Moisture Content	
	Initial inches	Calibrated inches	Initial	Calibrated
1	0.25	1.50	0.12	0.30
2	0.25	1.30	0.11	0.15
3	0.24	1.25	0.10	0.15
4	0.21	0.05	0.11	0.25
5	0.21	0.05	0.10	0.25
6	0.23	0.05	0.11	0.25
7	0.19	0.05	0.10	0.25
8	0.24	0.24	0.10	0.10
9	0.21	0.21	0.09	0.09
10	0.24	0.24	0.10	0.10
11	0.27	0.27	0.09	0.09
12	0.29	0.29	0.06	0.06

3.8 HMS Model Results

3.8.1 December 2010 Storm

The HMS calibrated model results for the December 2010 storm are listed in Table 3.5. Hydrographs from the calibrated model at the Motoqua, Catclaw Canyon and Highway 91 Bridge gage sites are shown on Figure 3.14, Figure 3.15, and Figure 3.16 compared with the measured.

Table 3.5 December 2010 storm calibrated HMS model results

Hydrologic Element	Drainage Area mi^2	Peak Discharge cfs	Time of Peak date-time	Runoff Volume ac-ft
1	76.800	6,388	22Dec2010, 16:45	7,666
001002	76.800	6,287	22Dec2010, 18:15	7,506
2	53.384	379	21Dec2010, 05:30	1,582
C002	130.184	6,487	22Dec2010, 18:15	9,087
3	55.908	0	17Dec2010, 00:00	0
C003	186.092	6,487	22Dec2010, 18:15	9,087
003A005	186.092	6,456	22Dec2010, 19:00	9,040
5	42.160	1,243	21Dec2010, 07:15	2,509
C005R	228.252	6,782	22Dec2010, 19:00	11,549

Table 3.5 December 2010 storm calibrated HMS model results

Hydrologic Element	Drainage Area mi²	Peak Discharge cfs	Time of Peak date-time	Runoff Volume ac-ft
4	60.392	4,548	20Dec2010, 23:30	10,224
C005	288.644	7,864	22Dec2010, 16:30	21,773
005007	288.644	7,813	22Dec2010, 17:15	21,574
7	51.672	629	20Dec2010, 19:15	2,329
C007L	340.316	8,236	22Dec2010, 16:30	23,904
6	110.120	7,607	21Dec2010, 06:45	15,048
C007	450.436	13,707	21Dec2010, 07:45	38,951
007009	450.436	13,623	21Dec2010, 08:00	38,534
8	16.495	192	20Dec2010, 17:45	460
C008	466.931	13,682	21Dec2010, 08:00	38,994
9	34.321	263	22Dec2010, 15:30	1,202
C009	501.252	13,872	21Dec2010, 08:00	40,196
009010	501.252	13,120	21Dec2010, 09:00	36,490
10	46.527	811	22Dec2010, 13:45	2,063
C010	547.779	13,394	21Dec2010, 09:00	38,554
010011	547.779	13,386	21Dec2010, 09:00	38,552
11	20.414	145	22Dec2010, 14:00	405
C011	568.193	13,455	21Dec2010, 09:00	38,957
011012	568.193	13,245	21Dec2010, 09:45	37,825
12	7.888	0	17Dec2010, 00:00	0
C012	576.081	13,245	21Dec2010, 09:45	37,825

Figure 3.14 Calibrated HMS results compared with measured at Motoqua

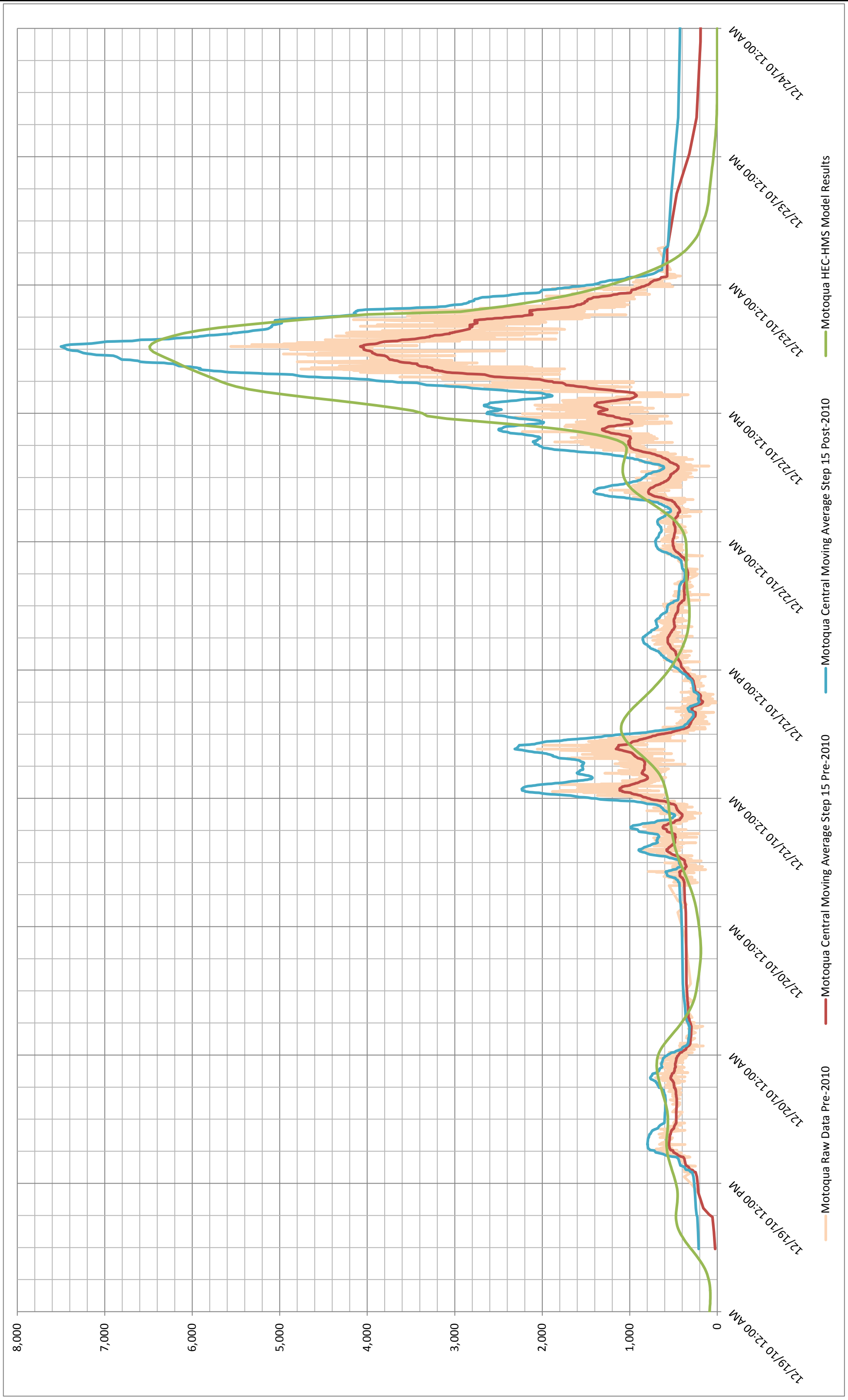


Figure 3.15 Calibrated HMS results compared with measured at Catclaw

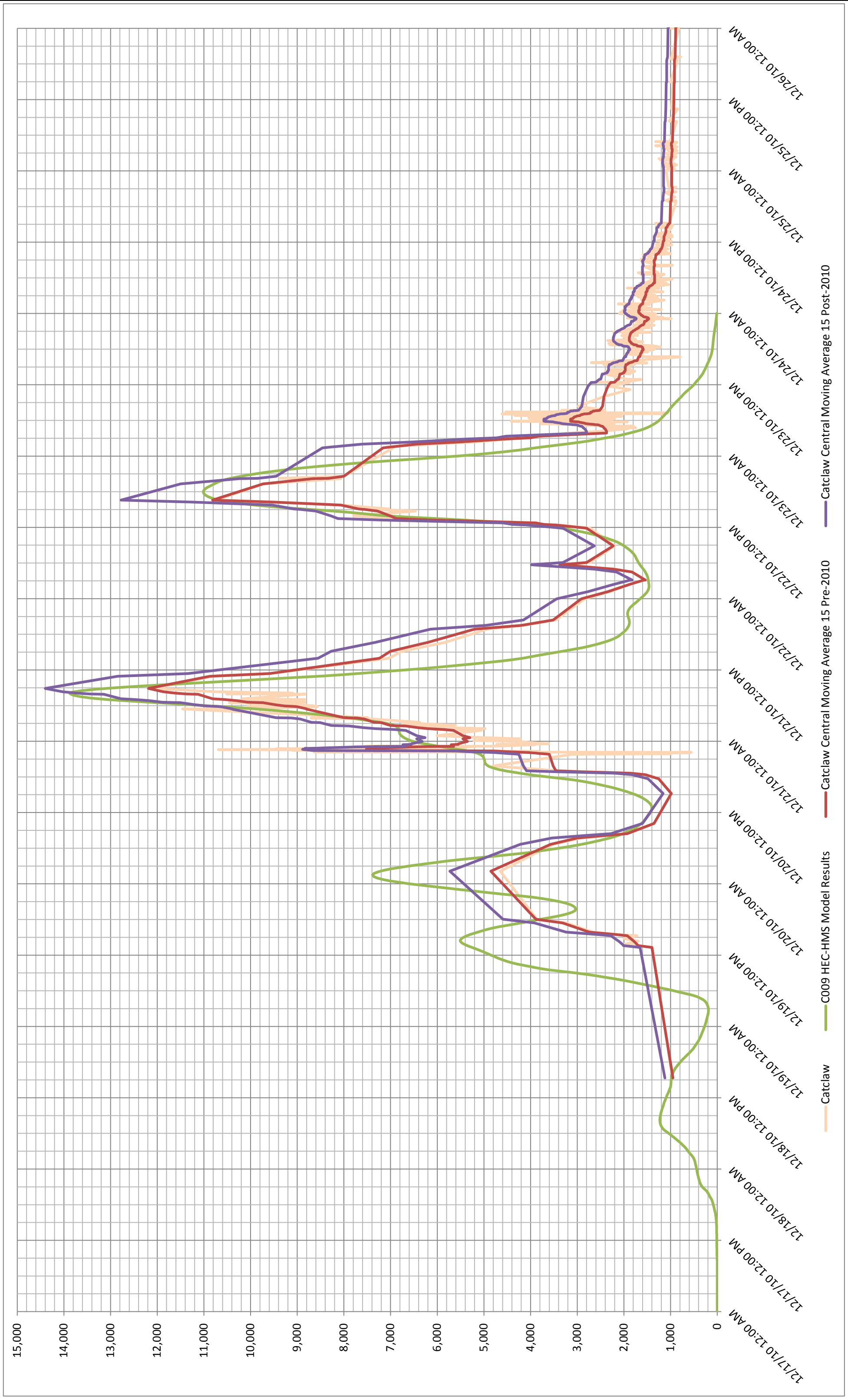
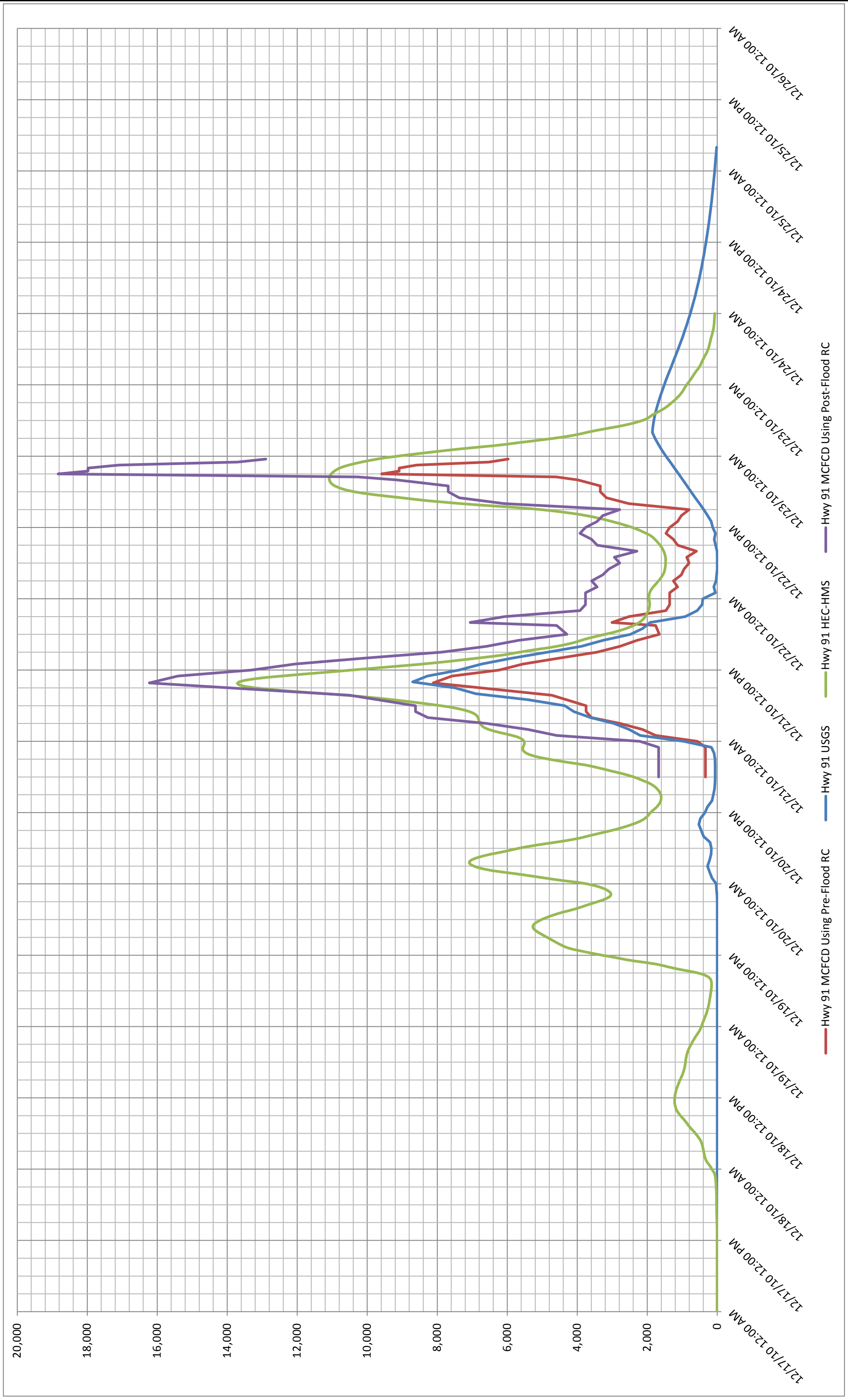


Figure 3.16 Calibrated HMS results compared with measured at Hwy 91



3.8.2 Watershed Response Models for Short-Duration Storms (24-hour)

An HMS model of the entire watershed was built for the rainfall scenarios described in Section 3.3.2. In addition, HMS models of three other watershed scenarios were built to address situations where a given storm only covers a portion of the watershed. The three additional scenarios are designated as the Upper Watershed (sub-basins 1-5), the Middle Watershed (sub-basins 4-7), and the Lower Watershed (sub-basins 7-12). The four scenarios are shown individually on Figure 3.18, Figure 3.19, Figure 3.20 and Figure 3.20. All four HMS models were built using the December 2010 storm calibrated model sub-basin and routing data. Only the rainfall was changed. The results from all four modeling scenarios are listed in Table 3.6, Table 3.7, Table 3.8, and Table 3.9. The results are shown graphically on Figure 3.21, Figure 3.22, Figure 3.23, and Figure 3.24.

Figure 3.17 Beaver Dam Wash entire watershed and gage locations

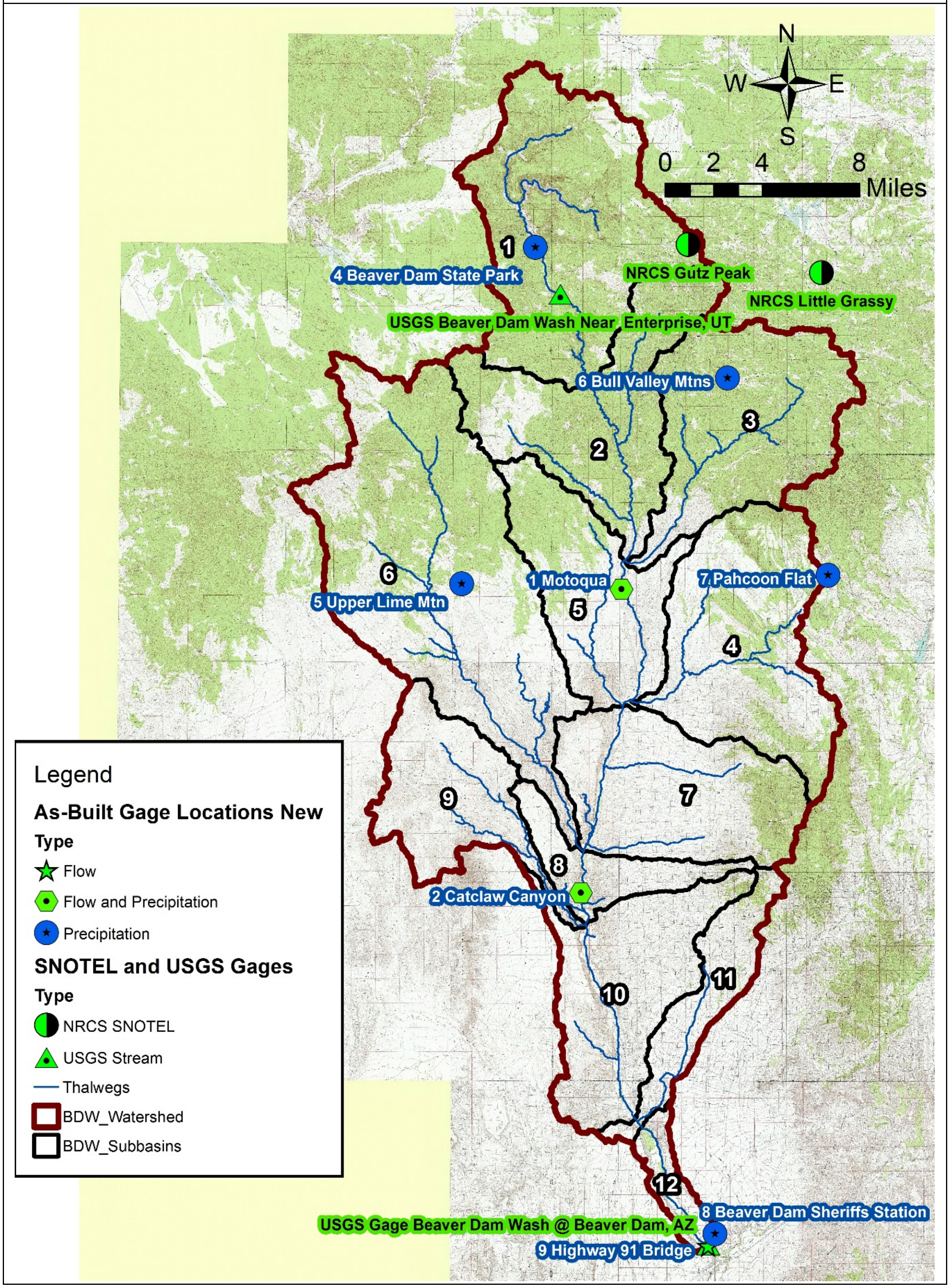


Figure 3.18 Upper Beaver Dam Wash watershed

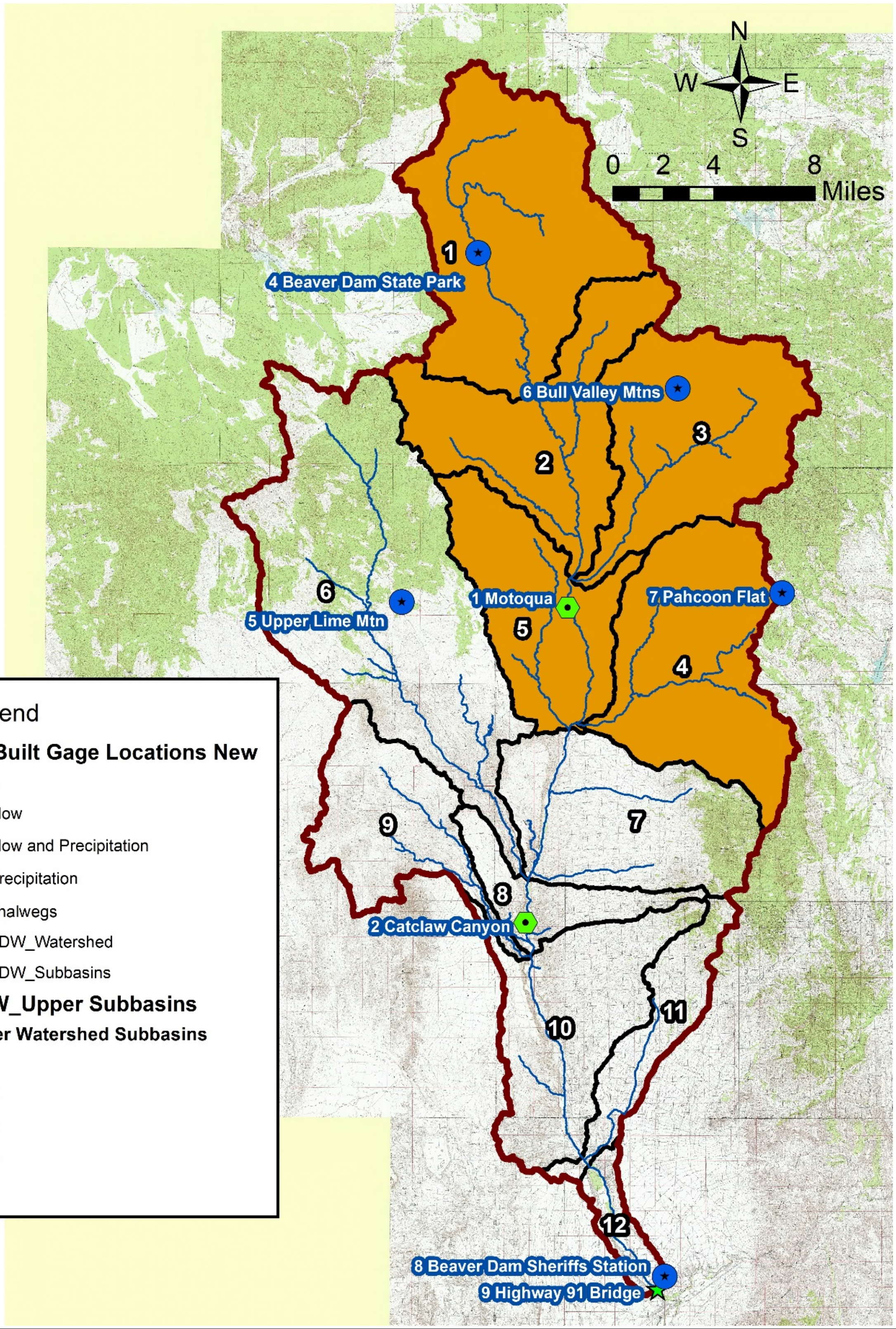


Figure 3.19 Middle Beaver Dam Wash watershed

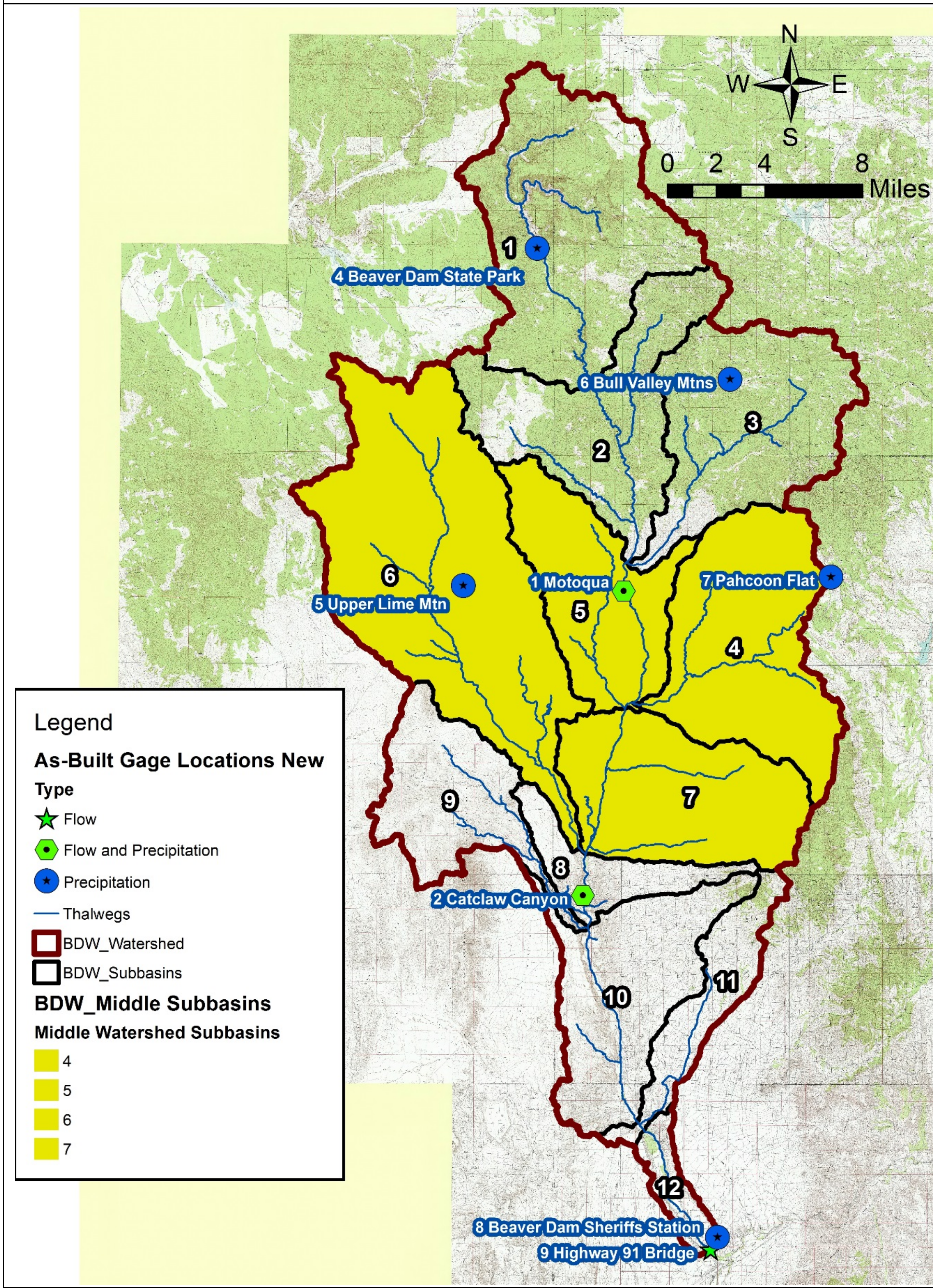


Figure 3.20 Lower Beaver Dam Wash watershed

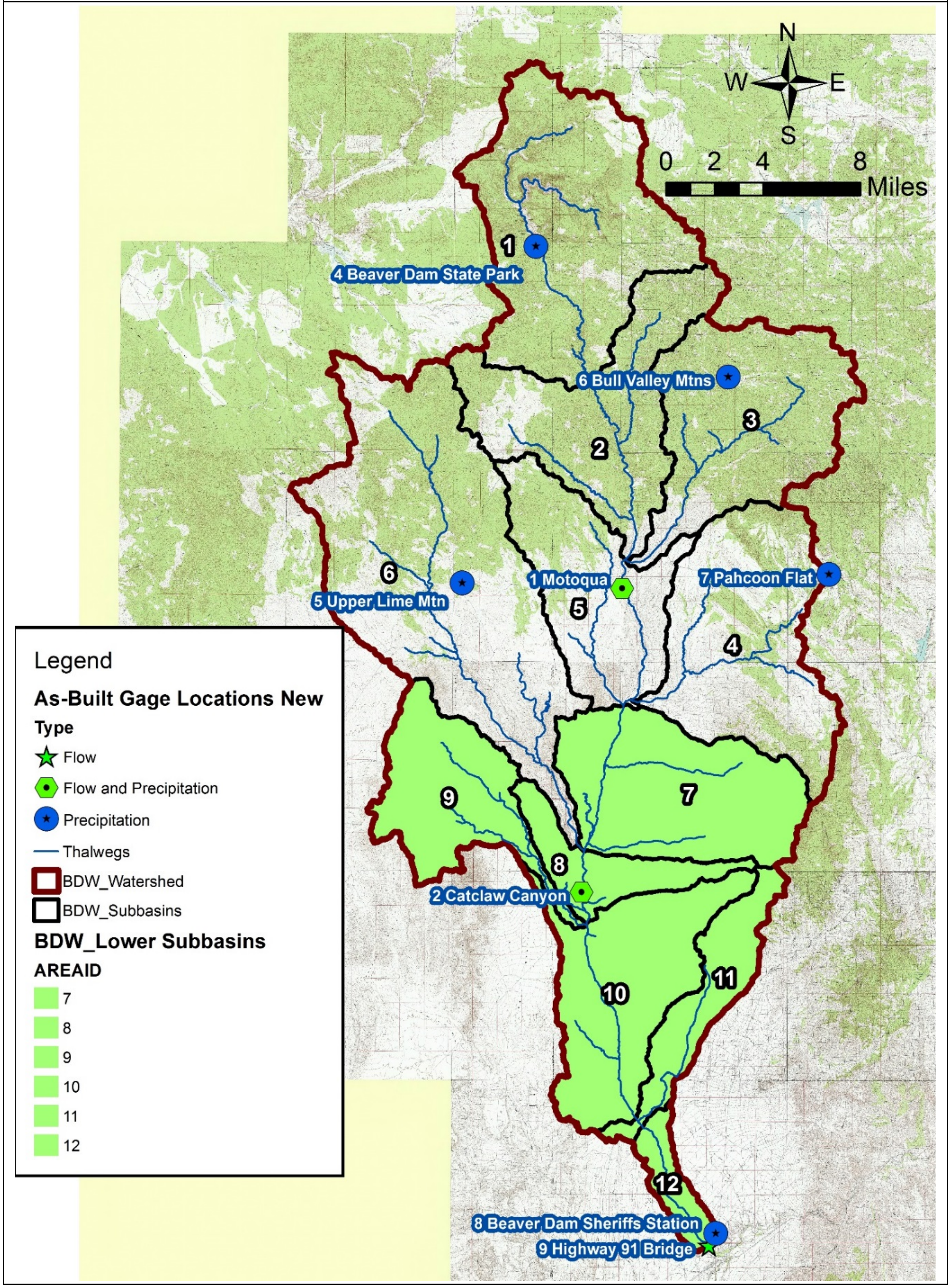


Table 3.6 Entire watershed short-duration storm tabulated results

Total 24-hr Rainfall	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
inches	cfs	hours	cfs	hours	cfs	Hours
0.00	0	0:00	0	0:00	0	0:00
0.50	220	18:00	1,140	16:45	970	20:00
1.00	470	17:15	4,040	16:15	3,800	19:00
1.50	720	17:00	10,400	16:00	10,100	18:00
2.00	980	16:45	18,400	15:45	18,700	17:30
3.00	2,500	15:45	37,100	15:45	40,000	16:45
4.00	8,300	15:45	60,800	15:45	66,300	16:45

Figure 3.21 Entire watershed short-duration storm graphic results

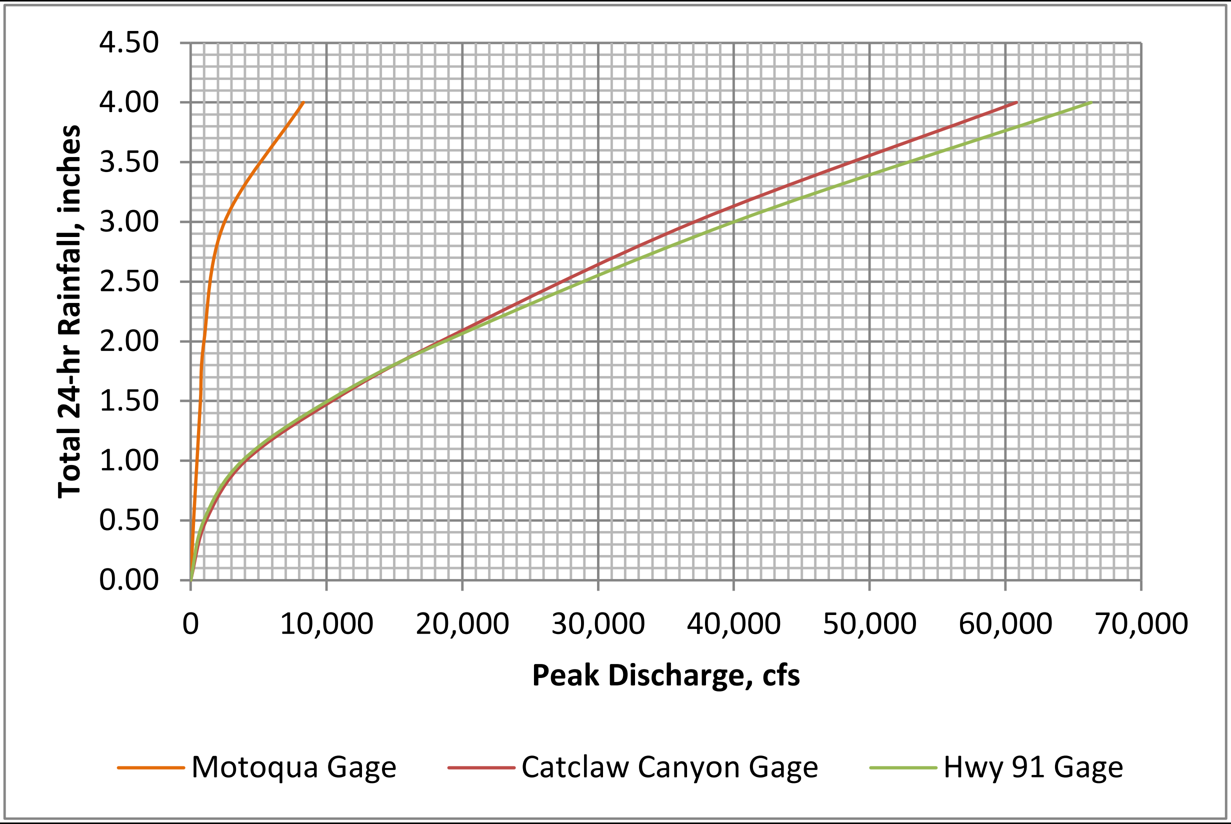


Table 3.7 Upper watershed short-duration storm tabulated results

Total 24-hr Rainfall inches	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Q_p cfs	T_p hours	Q_p cfs	T_p hours	Q_p cfs	T_p Hours
0.00	0	0:00	0	0:00	0	0:00
0.50	220	18:00	660	17:15	430	21:15
1.00	470	17:15	2,300	16:30	1,800	19:45
1.50	720	17:00	5,600	16:15	4,800	18:30
2.00	980	16:45	9,400	16:00	8,500	18:00
3.00	2,500	15:45	18,500	16:00	17,300	17:45
4.00	8,300	15:45	31,800	16:00	30,300	17:15

Figure 3.22 Upper watershed short-duration storm graphic results

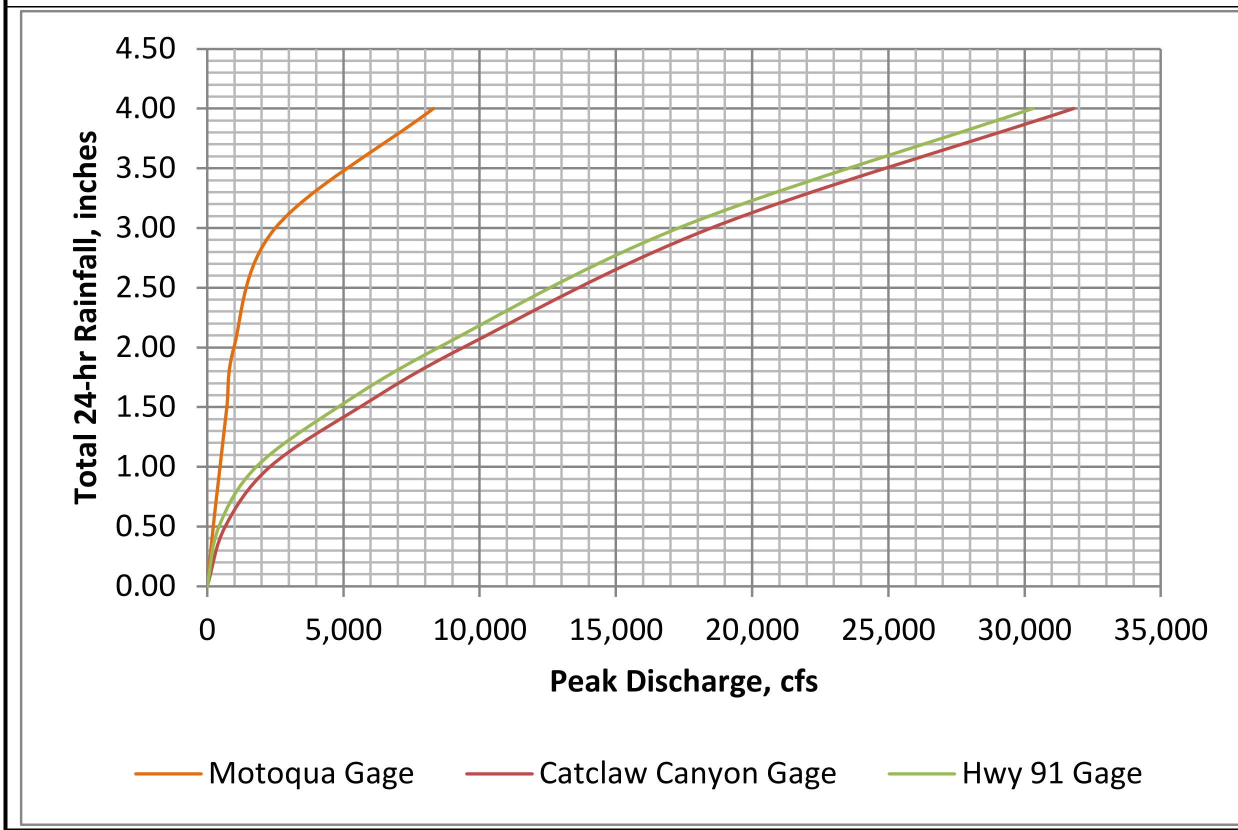


Table 3.8 Middle watershed short-duration storm tabulated results

Total 24-hr Rainfall	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
inches	cfs	hours	cfs	hours	cfs	Hours
0.00	0	0:00	0	0:00	0	0:00
0.50	---	---	1,000	16:45	740	20:30
1.00	---	---	3,700	16:15	3,100	19:00
1.50	---	---	9,800	16:00	8,900	18:00
2.00	---	---	17,100	15:45	16,000	17:30
3.00	---	---	32,400	15:45	31,000	17:00
4.00	---	---	48,900	15:45	47,100	16:45

Figure 3.23 Middle watershed short-duration storm graphic results

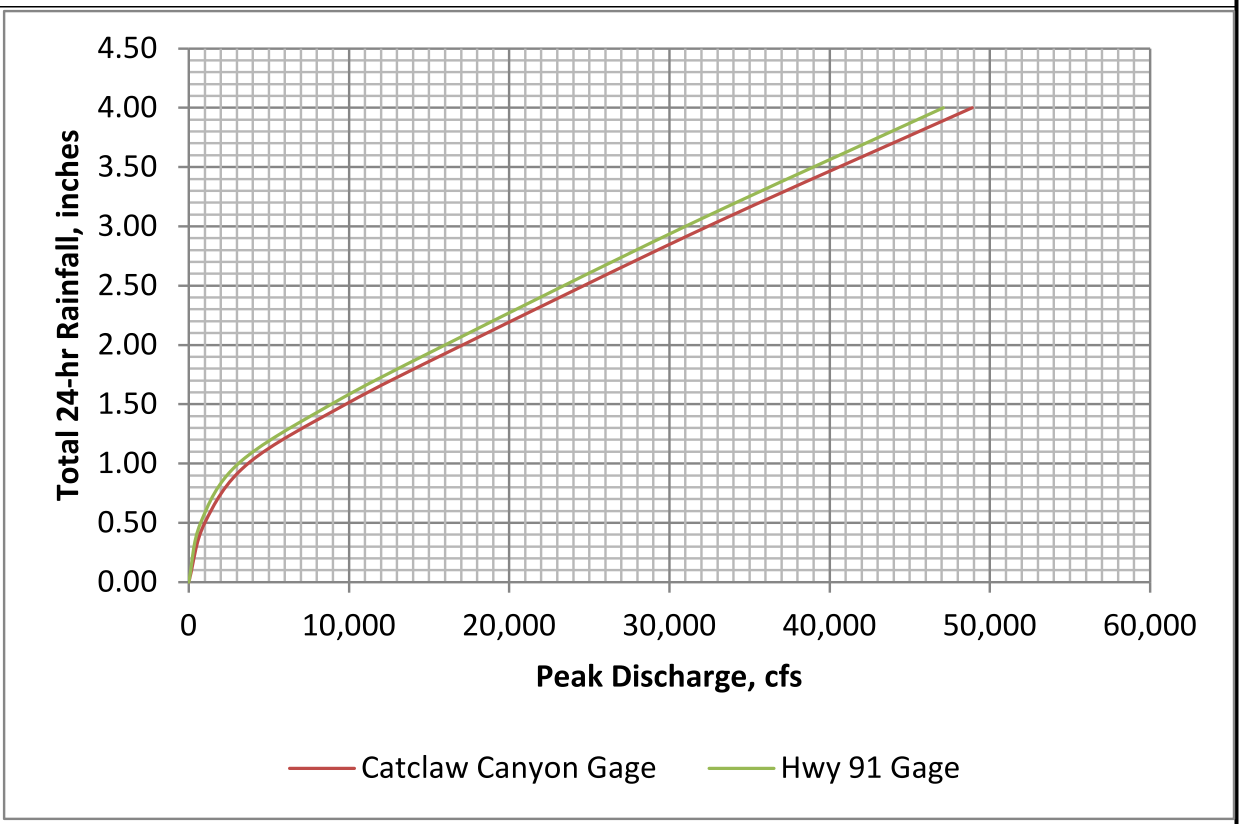
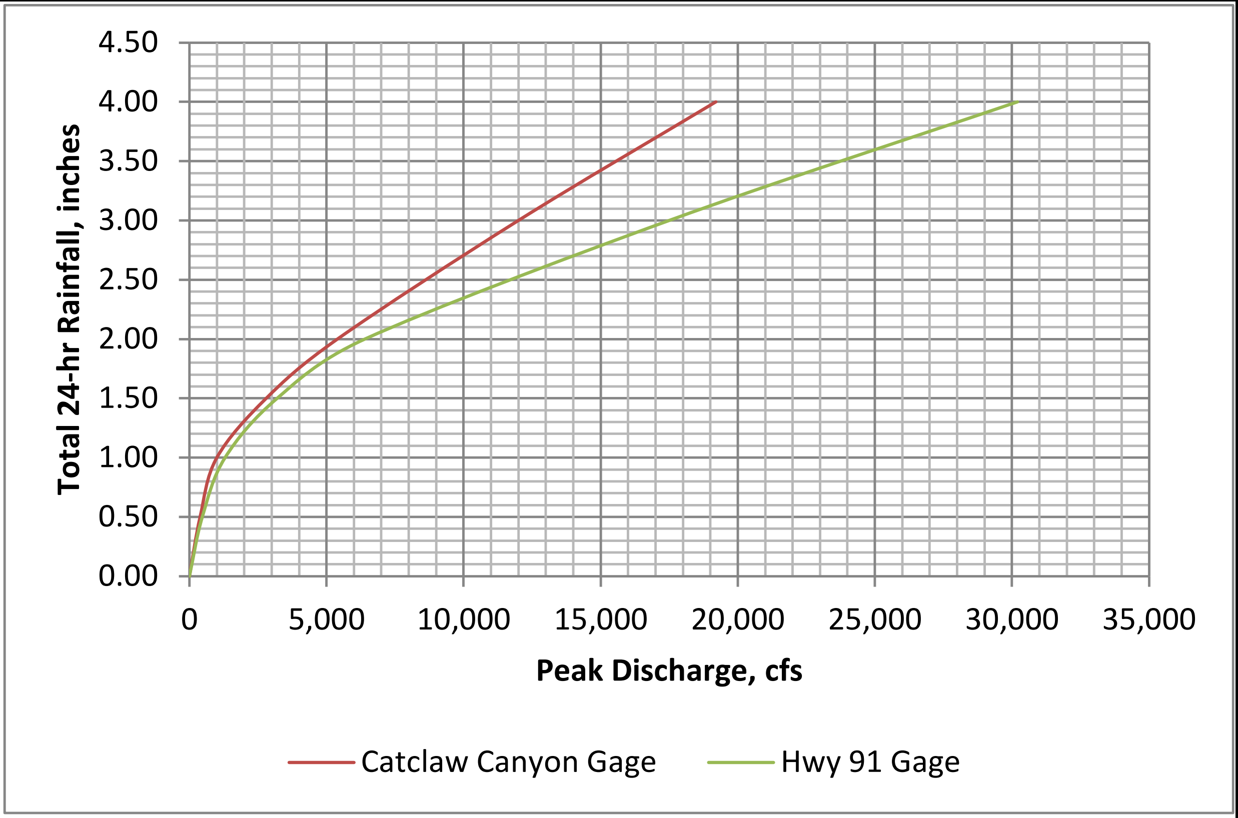


Table 3.9 Lower watershed short-duration storm tabulated results

Total 24-hr Rainfall inches	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Q_p cfs	T_p hours	Q_p cfs	T_p hours	Q_p cfs	T_p Hours
0.00	0	0:00	0	0:00	0	0:00
0.50	---	---	390	15:30	470	17:00
1.00	---	---	1,000	15:15	1,300	17:30
1.50	---	---	2,800	15:15	3,200	17:30
2.00	---	---	5,400	15:00	6,400	17:00
3.00	---	---	12,000	15:00	17,500	16:00
4.00	---	---	19,200	14:45	30,200	15:45

Figure 3.24 Lower watershed short-duration storm graphic results



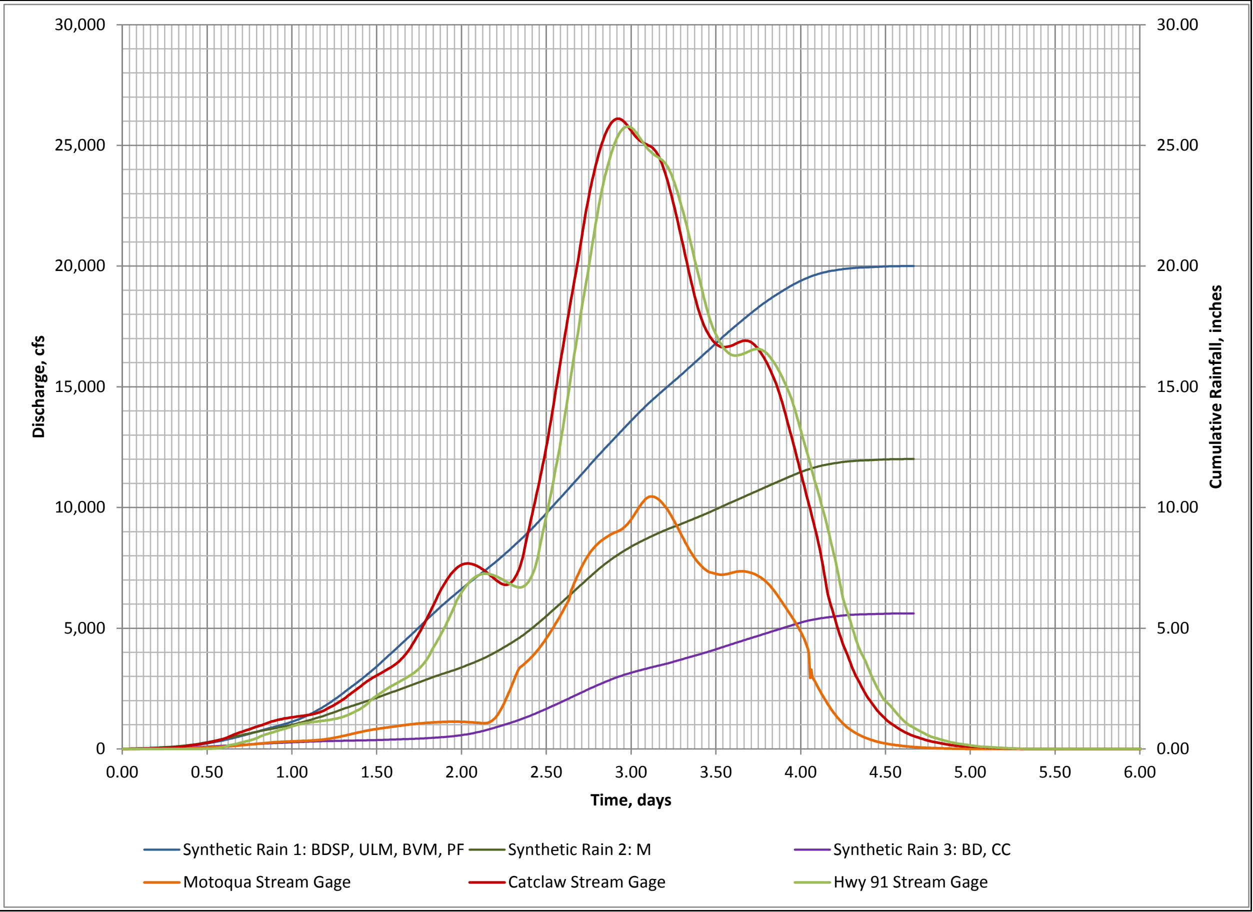
3.8.3 Watershed Response for Long-Duration Storm

An HMS model was built for the rainfall scenario described in Section 3.3.4 for a long-duration synthetic storm. This model was only built for the Entire Watershed scenario, not the other three since the long duration storms typically cover the entire watershed. The HMS model results are summarized in Table 3.10 and shown graphically on Figure 3.25.

Table 3.10 112 hour long-duration storm tabulated results

Hydrologic Element	Drainage Area mi²	Peak Discharge cfs	Time of Peak date-time	Runoff Volume ac-ft
1	76.800	8,775	03Jan2013, 21:30	24,982
001002	76.800	8,665	03Jan2013, 23:30	24,586
2	53.384	2,183	04Jan2013, 03:30	4,153
C002	130.184	10,457	04Jan2013, 02:50	28,739
3	55.908	0	01Jan2013, 00:00	0
C003	186.092	10,457	04Jan2013, 02:50	28,739
003A005	186.092	10,427	04Jan2013, 03:30	28,645
5	42.160	1,417	03Jan2013, 20:10	3,191
C005R	228.252	10,962	04Jan2013, 03:20	31,836
4	60.392	5,372	03Jan2013, 20:10	13,829
C005	288.644	15,425	03Jan2013, 21:00	45,665
005007	288.644	15,347	03Jan2013, 21:40	45,375
7	51.672	689	03Jan2013, 19:20	2,755
C007L	340.316	16,017	03Jan2013, 21:30	48,131
6	110.120	9,795	03Jan2013, 23:20	30,087
C007	450.436	25,710	03Jan2013, 22:00	78,218
007009	450.436	25,628	03Jan2013, 22:10	77,777
8	16.495	161	03Jan2013, 18:00	571
C008	466.931	25,772	03Jan2013, 22:10	78,348
9	34.321	339	03Jan2013, 20:20	1,534
C009	501.252	26,106	03Jan2013, 22:10	79,882
009010	501.252	25,207	03Jan2013, 23:00	75,589
10	46.527	721	03Jan2013, 19:00	2,512
C010	547.779	25,860	03Jan2013, 22:50	78,100
010011	547.779	25,859	03Jan2013, 23:00	78,097
11	20.414	156	03Jan2013, 19:30	574
C011	568.193	26,004	03Jan2013, 22:50	78,671
011012	568.193	25,777	03Jan2013, 23:30	77,452
12	7.888	0	01Jan2013, 00:00	0
C012	576.081	25,777	03Jan2013, 23:30	77,452

Figure 3.25 112 hour long-duration storm graphical results



4 HYDRAULICS

4.1 General

Two different approaches to modeling the hydraulics of Beaver Dam Wash were applied. The first was the use of the one-dimensional (1D) RAS model. That model was used for the entire reach of Beaver Dam Wash from the Virgin River to the Motoqua stream flow gage site. The second approach was the use of the two-dimensional (2D) FLO-2D model. That model was used for the Beaver Dam Wash from the Virgin River to approximately 1,700 feet upstream of the Highway 91 Bridge. Both approaches are discussed in more detail in the following sections.

4.2 1D Hydraulics

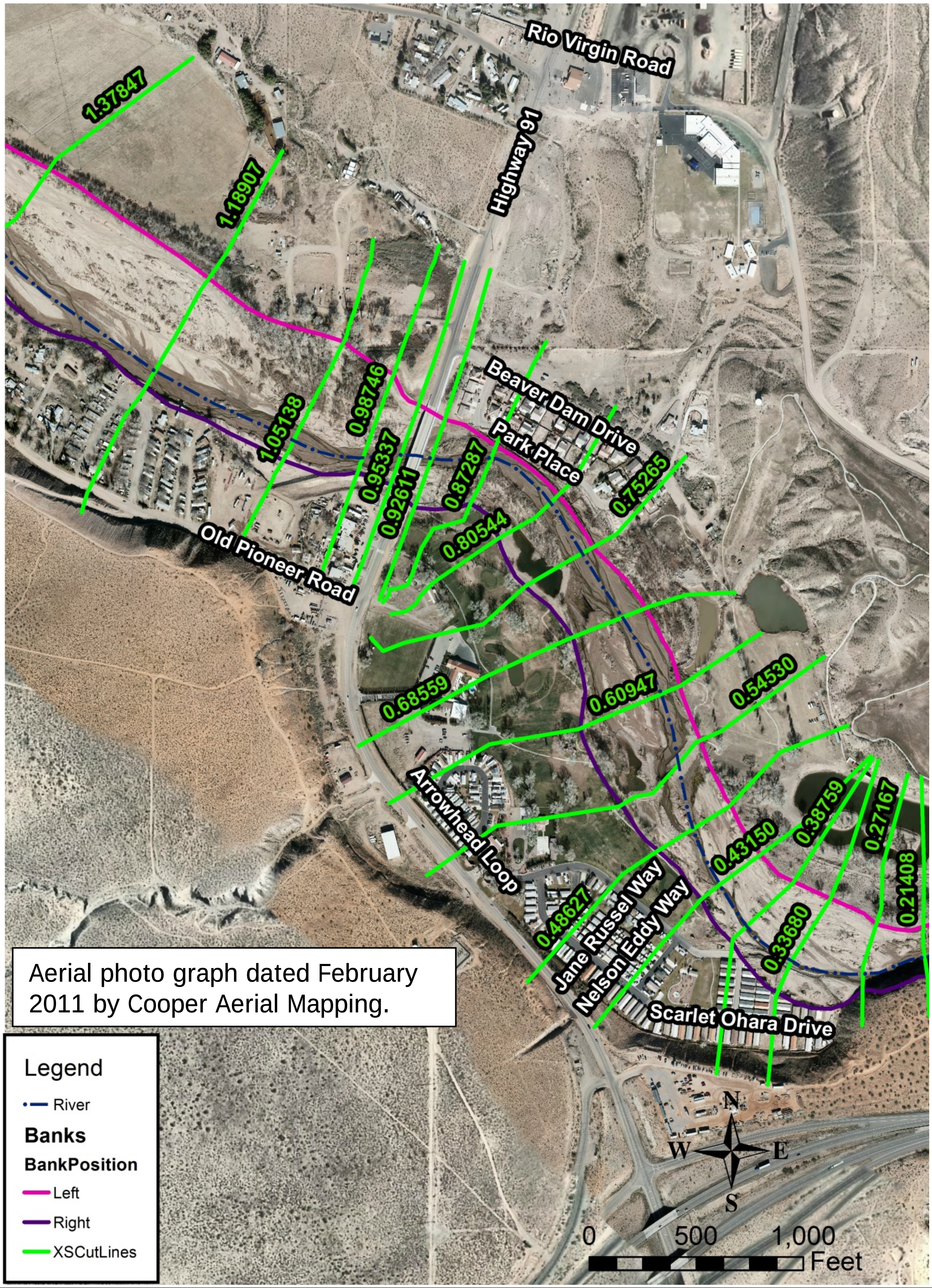
4.2.1 General

A new steady flow RAS model was built using the topography described in Section 2.3. The surface without the golf cart path bridge and embankments, constructed after the December 2010 flood, was used. HEC-GeoRAS Version 10.1 (GeoRAS) was used to develop the cross sections, land use polygons for defining n-values, obstructions to flow, ineffective flow areas, bank locations and thalweg and overbank lengths between cross sections. The first cuts at setting bank locations and ineffective flow areas were then manually revised in RAS and then reviewed with MCFCD. GIS feature classes for the supporting GeoRAS data and the RAS models are available and listed in Section 10.7.

The Highway 91 Bridge is modeled as a bridge with the piers, low chord and bridge deck defined using four cross sections. The upstream and downstream cross section separations were set using the expansion and contraction criteria recommended in Appendix B of the *HEC-RAS River Analysis System Hydraulic Reference Manual* (USACE, 2010).

The entire model reach is 31.55611 miles in length. There are 185 cross sections with an average spacing of 900 feet. An average cross section spacing of 250 feet was used at the Motoqua and Catclaw Canyon gage sites and in Beaver Dam between the Virgin River and just upstream of the Highway 91 Bridge. An example cross section layout for the Beaver Dam area is shown on Figure 4.1.

Figure 4.1 RAS example cross section layout map



The profile steady state discharges used in the model were: 50, 100, 250, 500, 750, 1000, 3000, 4000, 5000, 7500, 10000, 12500, 15000, 17500, 20000, 25000, 30000, 35000, and 40000 cfs. The discharges were used to define rating curves for the three stream flow gages.

4.2.2 n-values

The model n-values were calibrated against the measured travel times from the December 2010 flood between the Highway 91 Bridge, Catclaw Canyon, and Motoqua. Only small adjustments were needed from the values initially assumed. Minimum, normal and maximum condition n-values were also defined and separate RAS plans were created for each condition. This approach allows for a range of vegetative conditions to be addressed. Vegetation growth, particularly in the Beaver Dam area, occurs rapidly. This changes the roughness in the channel significantly. However, the vegetation can be assumed to be removed under extended high flow rate conditions. Both the 2005 and 2010 floods removed virtually all vegetation from the high flow areas as shown on Figure 4.2 through Figure 4.5. The December 2010 peak discharge was in the range of 8,700 to 16,000 cfs with an estimated peak of 13,300 cfs. The 2005 flood peak was in the range of 17,000 to 25,000 cfs with an estimated peak of 21,000 cfs. Peak discharges at or above 10,000 cfs can be expected to remove heavy build-up of vegetation as long as it has not been established over a very long period and reached a size that is not easily removed. Therefore, the normal n-values, which are a little higher than the December 2010 calibrated n-values, can be assumed for most hydraulic conditions except flow rates lower than about 5,000 cfs. In 2010, the vegetation was removed before the flow went overbank and flooded homes. The n-values used in the model, related by land use, are listed in Table 4.1. An example of the land use polygons used in GeoRAS is shown in Figure 4.6.

Table 4.1 Manning's n-values for RAS model

Land Use	Initial n-value	Calibrated n-value
Active Wash	0.030	0.022
Wash	0.040	0.032
Vegetation	0.050	0.042
Heavy Vegetation	0.080	0.072
Overbank	0.045	0.037
Grass	0.025	0.017
Graded Field	0.035	0.027
Urban	0.025	0.017

The results of the RAS model used to define stage-storage-discharge data are shown on Figure 3.7 through Figure 3.12. This data was used for the HMS model hydrograph routing. The RAS model results are too lengthy to include in this report. Refer to the digital files to obtain detailed output and cross section and profile plots for the model. The RAS digital files available in digital format in APPENDIX A are listed in Section 10.7.

4.2.3 Obstructions to Flow

Flow obstructions consisting of existing buildings were included in the model. An example of the locations of the buildings used as flow obstructions is shown on Figure 4.7.

4.2.4 Ineffective Flow Areas

Areas designated as ineffective conveyance in the Beaver Dam area are shown on Figure 4.8. Other ineffective flow areas are designated in addition to those shown on the figure. Refer to the RAS model to view the other areas.

Figure 4.2 Pre-2005 vegetation in Beaver Dam

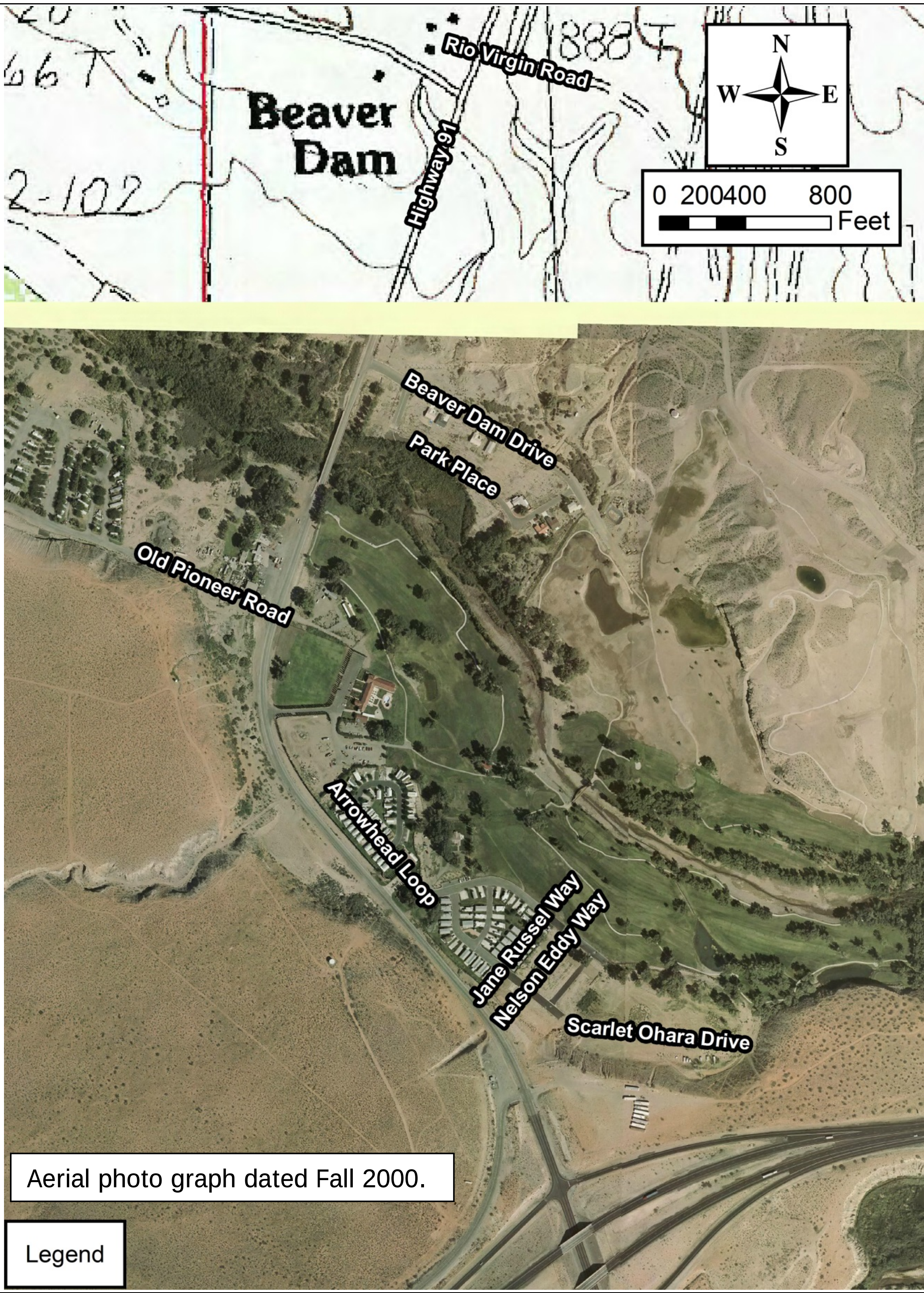


Figure 4.3 Post-2005 vegetation in Beaver Dam

Figure 4.4 Pre-2010 vegetation in Beaver Dam

Figure 4.5 Post-2010 vegetation in Beaver Dam

Figure 4.6 RAS example land use map

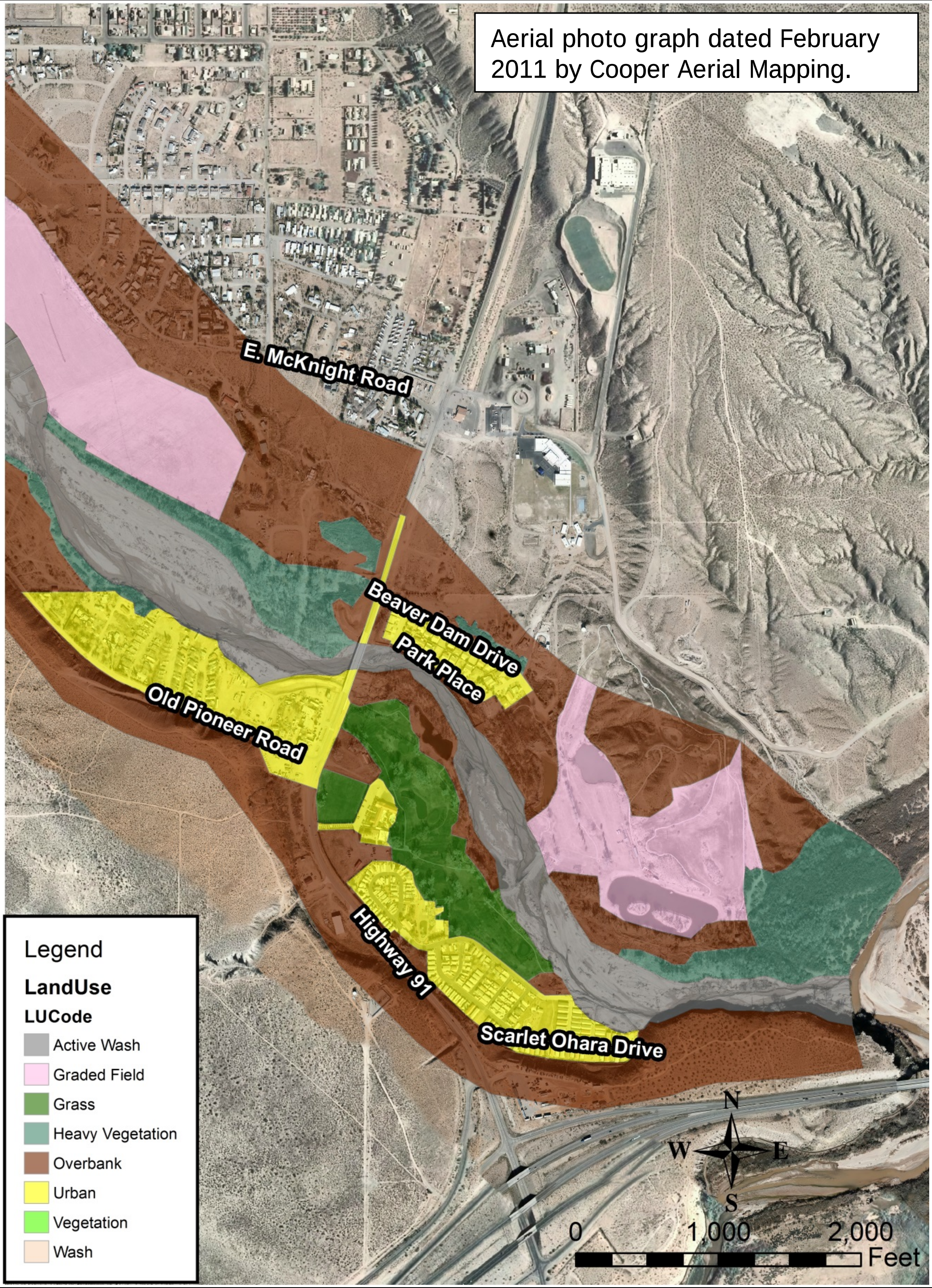


Figure 4.7 RAS example obstructions to flow map

Figure 4.8 RAS example ineffective areas map

4.2.6 Stream Flow Gage Rating Curves

New rating curves for the Motoqua and Catclaw Canyon stream flow gages were developed using the RAS model discussed in Section 4.2. New rating curves were needed due to the changes in channel morphology resulting from the December 2010 flood. These curves were developed for use with the Mohave County flood warning ALERT system and are shown in tabular form in Table 4.2 and graphically on Figure 4.9 and Figure 4.10. The documentation for development of each rating curve is in a separate report.

Table 4.2 Rating curve data for stream flow gages

Discharge	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Height	WSEL	Height	WSEL	Height	WSEL
cfs	ft	ft	ft	ft	ft	ft
0	0.00	3424.84	0.00	2632.32	0.00	1827.85
100	0.90	3425.74	0.00	2633.63	1.25	1830.76
250	1.47	3426.31	0.00	2634.18	1.88	1831.39
500	1.93	3426.77	0.26	2634.62	2.70	1832.21
750	2.40	3427.24	0.58	2634.94	3.16	1832.67
1,000	2.72	3427.56	0.85	2635.21	3.49	1833.00
2,000	3.47	3428.31	1.48	2635.84	3.75	1833.26
4,000	4.28	3429.12	2.39	2636.75	4.20	1833.71
6,000	4.86	3429.70	2.96	2637.32	4.59	1834.10
8,000	5.21	3430.05	3.41	2637.77	5.19	1834.70
10,000	5.39	3430.23	3.78	2638.14	5.70	1835.21
11,000	5.63	3430.47	3.94	2638.30	6.10	1835.61
12,500	5.90	3430.74	4.13	2638.49	6.89	1836.40
15,000	6.16	3431.00	4.46	2638.82	7.57	1837.08
17,500	6.44	3431.28	4.76	2639.12	8.22	1837.73
20,000	6.70	3431.54	5.03	2639.39	8.78	1838.29
22,500	6.93	3431.77	5.31	2639.67	9.33	1838.84
25,000	7.20	3432.04	5.56	2639.92	9.78	1839.29
27,500	7.27	3432.11	5.81	2640.17	10.67	1840.18
30,000	7.46	3432.30	6.05	2640.41	11.45	1840.96
35,000	7.79	3432.63	6.50	2640.86	12.04	1841.55
40,000	8.13	3432.97	6.93	2641.29	12.71	1842.22
Sensor Elev:	3424.63		2634.36		1829.51 (ground)	
(orange)	Height above Pressure Transducer Sensor					
(yellow)	Height above average ground elevation below radar transmitter.					

Figure 4.9 Motoqua gage rating curve

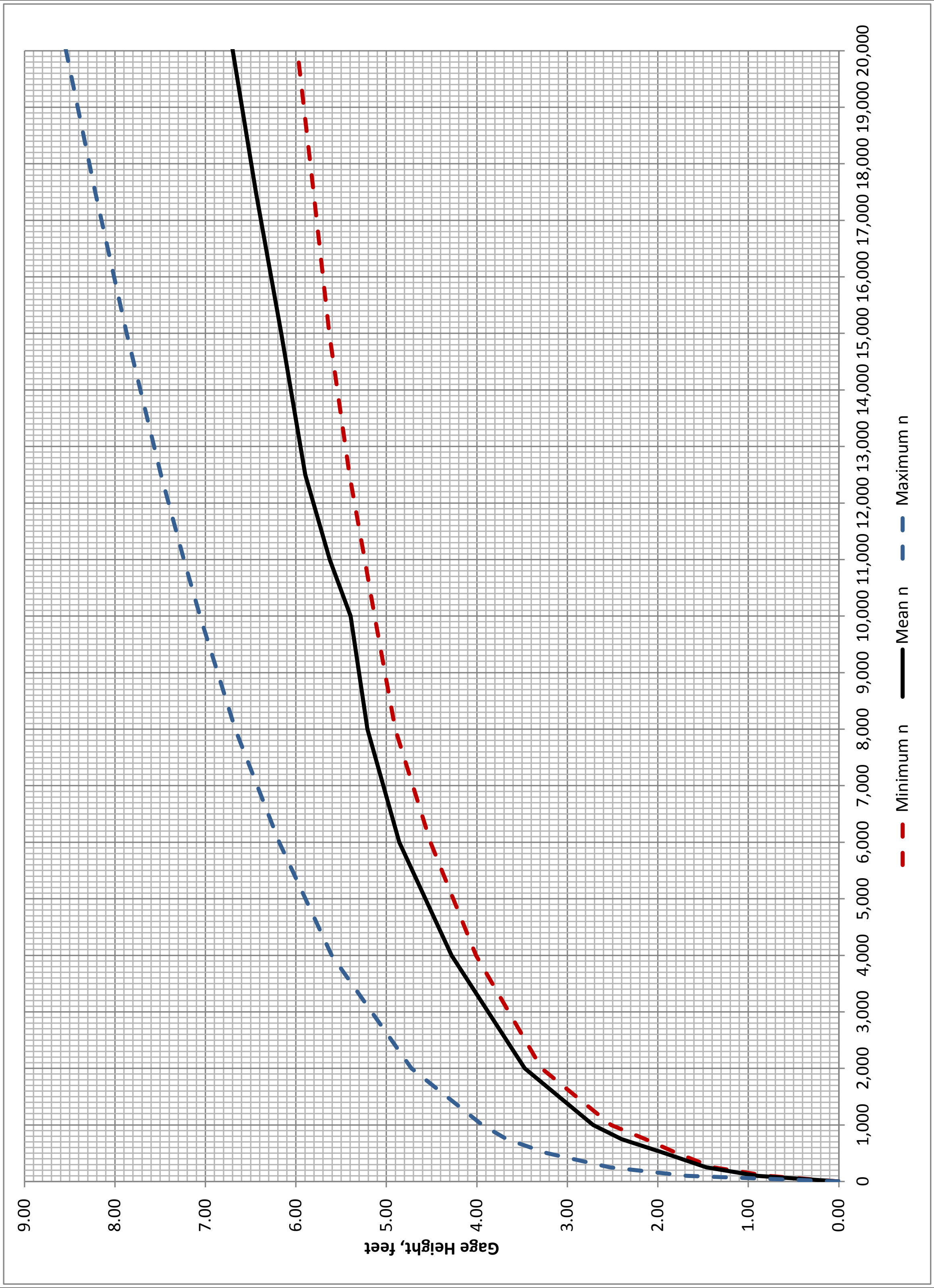
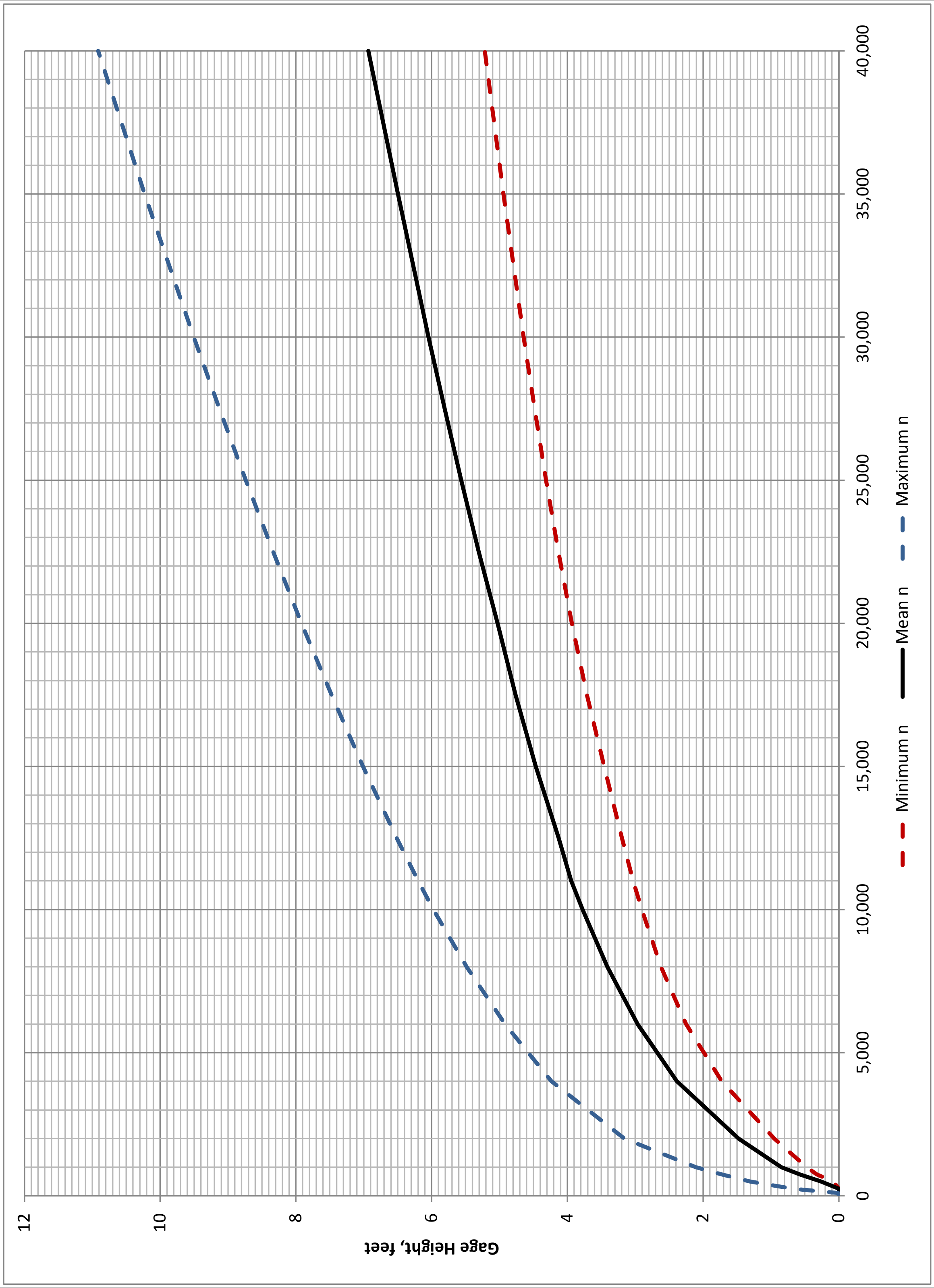


Figure 4.10 Catclaw Canyon gage rating curve



4.2.7 Travel Time Curves

The RAS model results were used to prepare travel time curves for various flow rates. Refer to Figure 4.11, Figure 4.12, and Figure 4.13. Curves are provided for minimum, normal and maximum roughness estimates.

These curves are intended to be used as a tool to estimate travel time between the Motoqua, Catclaw Canyon and Highway 91 gage sites. If a very high peak discharge is observed at the Catclaw Canyon gage, for instance, the curves can be used to estimate when that peak discharge will arrive at Beaver Dam.

Figure 4.11 Estimated travel times for minimum roughness

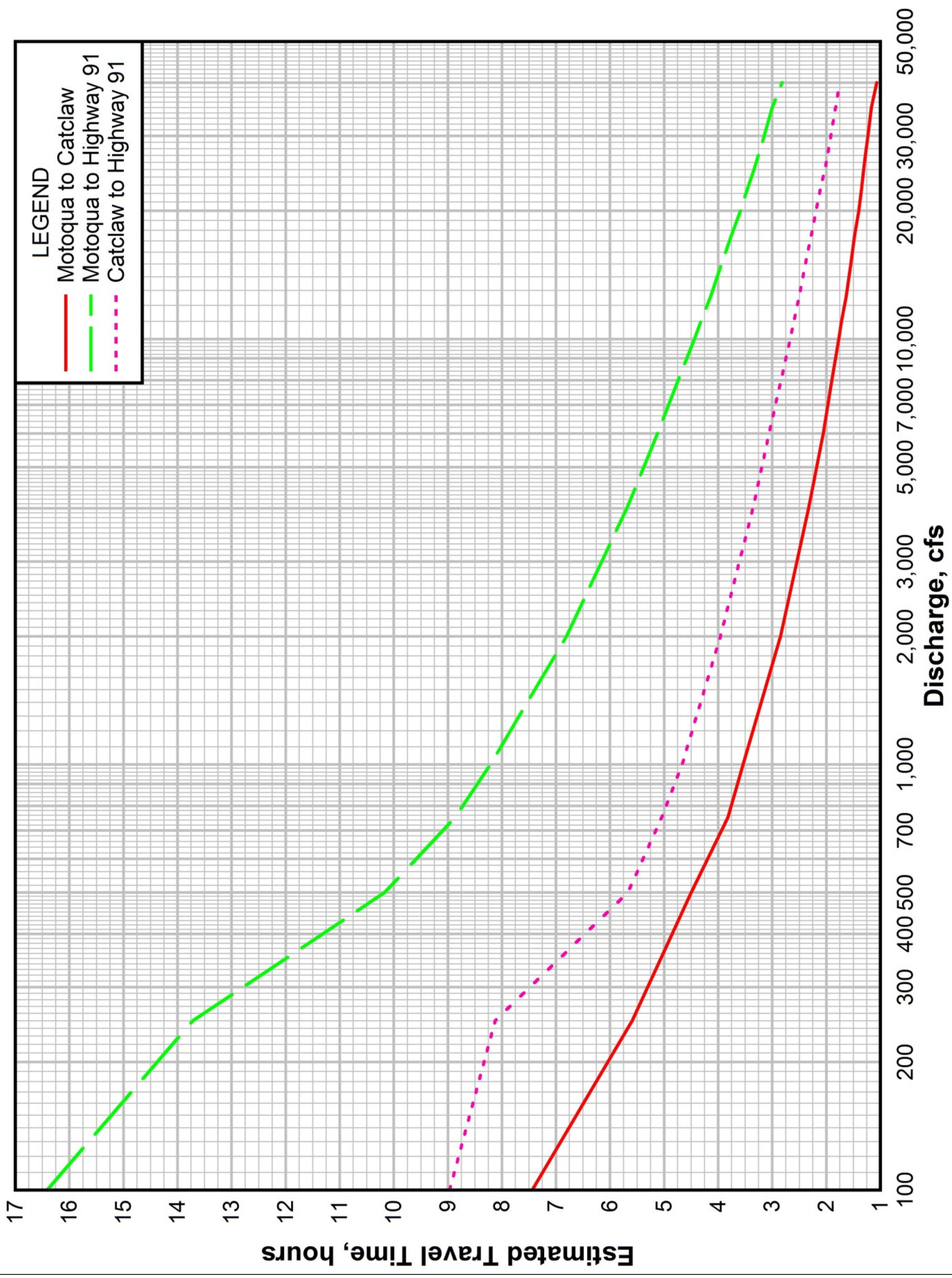


Figure 4.12 Estimated travel times for normal roughness

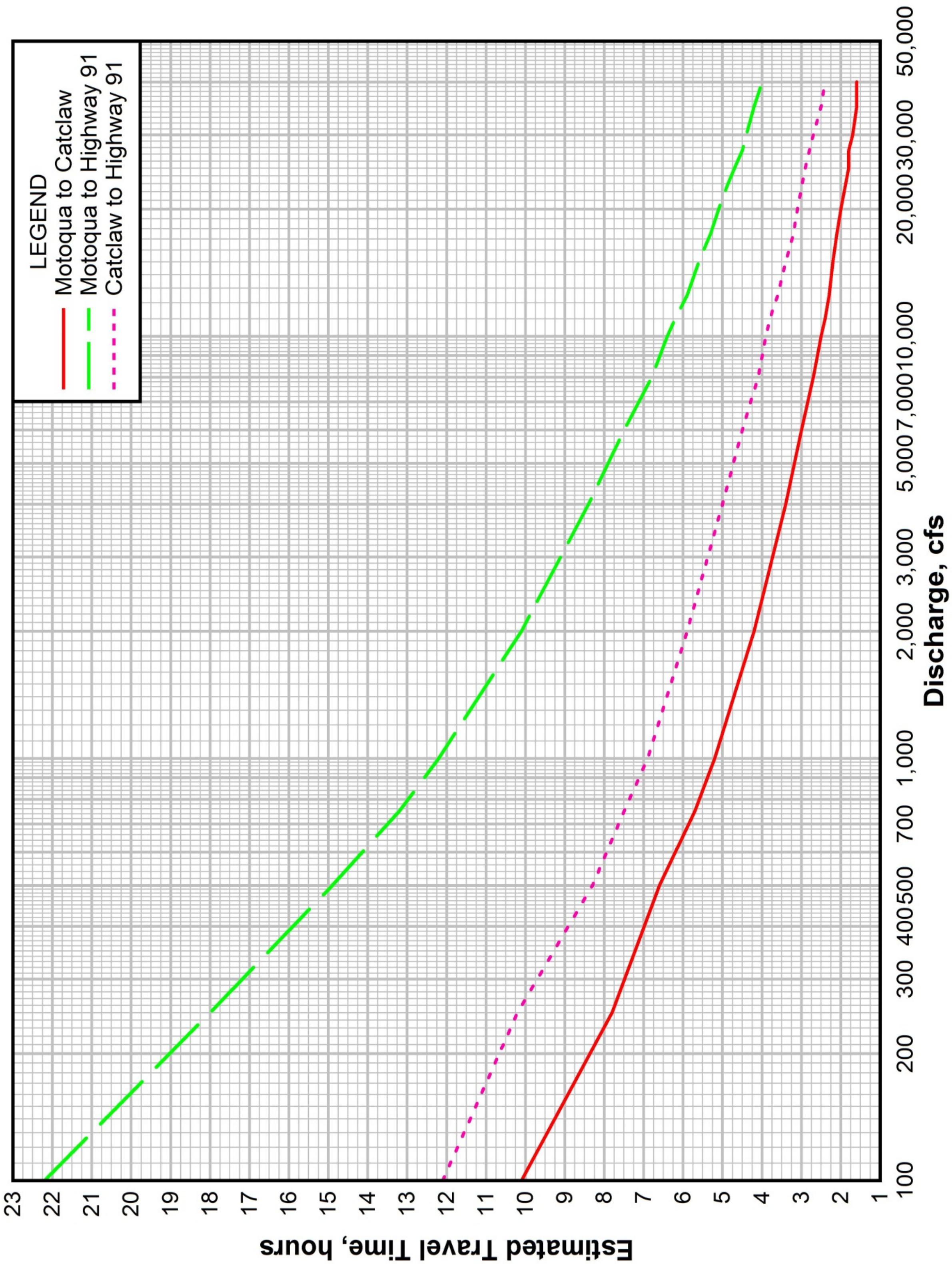
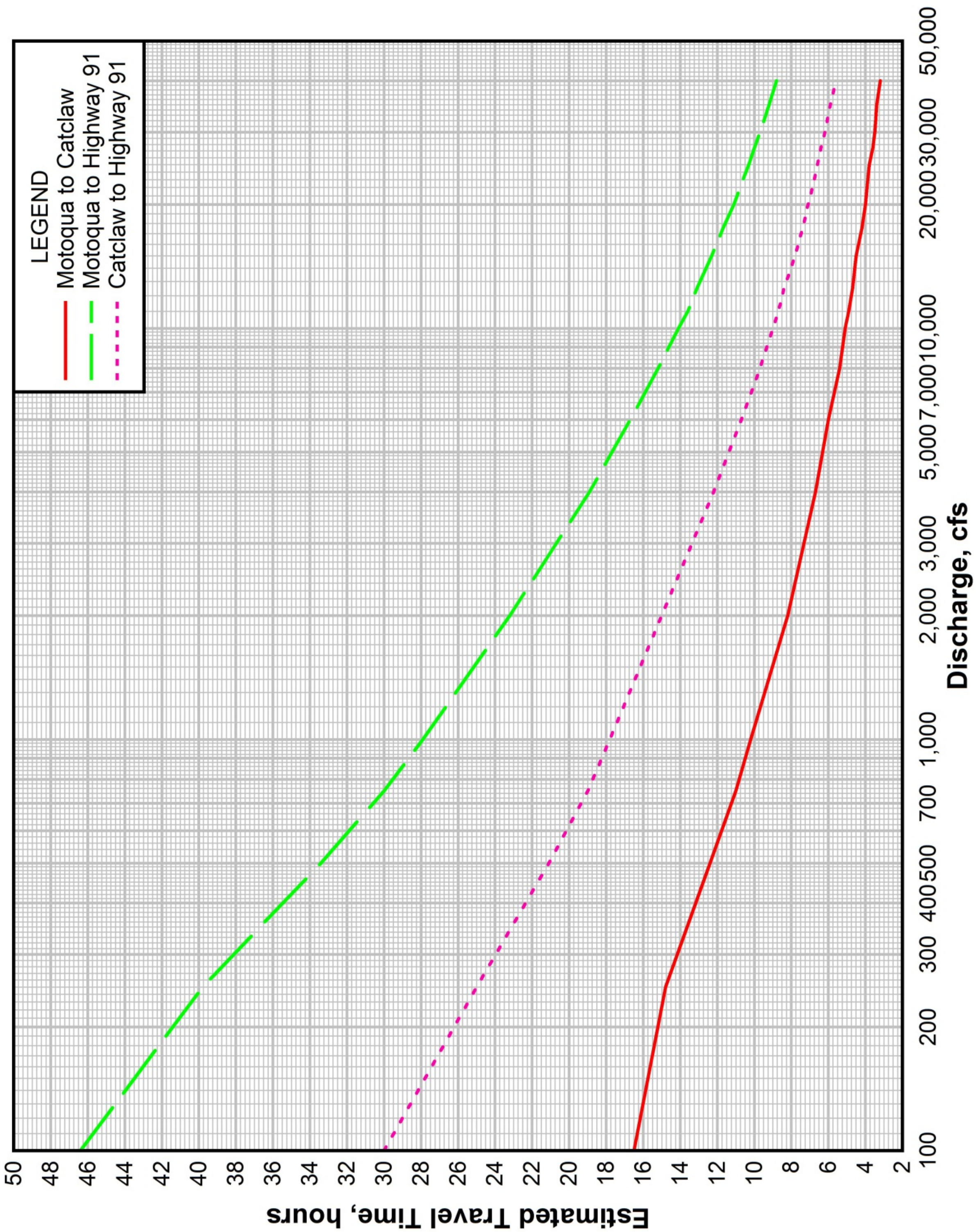


Figure 4.13 Estimated travel times for maximum roughness



4.3 2D Hydraulics

4.3.1 Base Model

The FLO-2D 2D computer model was selected for use in this study. The FLO-2D Pro Model, Build No. 13.02.04, was used. A base FLO-2D dataset was prepared and then different hydrologic conditions imposed to suit the needs of the study. The following models were created using the base, with the only difference being the inflow hydrographs: 1. December 2010 flood model and 2. Highway 91 Bridge stream flow gage hydraulic rating curve model.

Both are discussed in the following sections. The base model uses the following FLO-2D options and each is discussed in the following paragraphs. Note that rainfall and rainfall losses were not modeled.

- Overland floodplain-only grid.
- Assignment of roughness coefficients to each grid element.
- Limiting Froude number.
- Area and width reduction (ARF) factor.
- Assignment of inflow hydrographs.

Overland Floodplain-Only Grid

There are two methods available to simulate the ground surface of the 2D model area. The first is a 1D channel superimposed upon a 2D floodplain grid for modeling the overbank areas. The second is to use an overland floodplain-only grid, which simulates the hydrology and hydraulic conditions for the entire 2D model surface by computing flow parameters between each individual grid element in eight directions. The first method could have been used, but was not selected because the study area is small enough to use a high-resolution floodplain-only grid. The same grid used in the 2009 FRP (AridHH, 2009) was used for this study. The 2D area was divided into 74,714 uniform 15-foot square grids comprising a total study area of about 386 acres. The topography used to simulate the ground surface and compute an elevation for each is the mapping referenced in Section 2.3.1. A 4 foot DEM was built from the TIN surface provided by Cooper Aerial. That surface includes the golf cart bridge embankments. A second 4 foot DEM was constructed with the golf cart path embankments removed. The GDS module of the FLO-2D computer program was used to compute the average grid element elevations for both surface scenarios. Models built using these surfaces are referred to as “with Golf Cart Bridge” (wgcb) and “without Golf Cart Bridge” (wogcb). The abbreviations are used in the digital folder name containing the FLO-2D models (Section 10.4).

Assignment of Roughness Coefficients to Each Grid Element

The same land use GIS coverage used for assigning Manning’s n-values for the RAS models (Section 4.2.2) was used for assigning a Manning’s n-value to each grid element. The n-values used were based on the post-2010 flood aerial photographs. Refer to Figure 4.4 and Figure 4.5 for a comparison of pre- and post-flood photographs. The final n-values used in the model were adjusted so that the flood limits match the known limits of the December 2010 flood

The final n-values are shown graphically on Figure 4.14. Note that the 2D n-values are slightly higher than those used in the 1D model. This is appropriate and follows the procedures recommended in the FLO-2D user manual. Refer to the FPLAIN.DAT FLO-2D input data files in digital format in APPENDIX A for final model n-values.

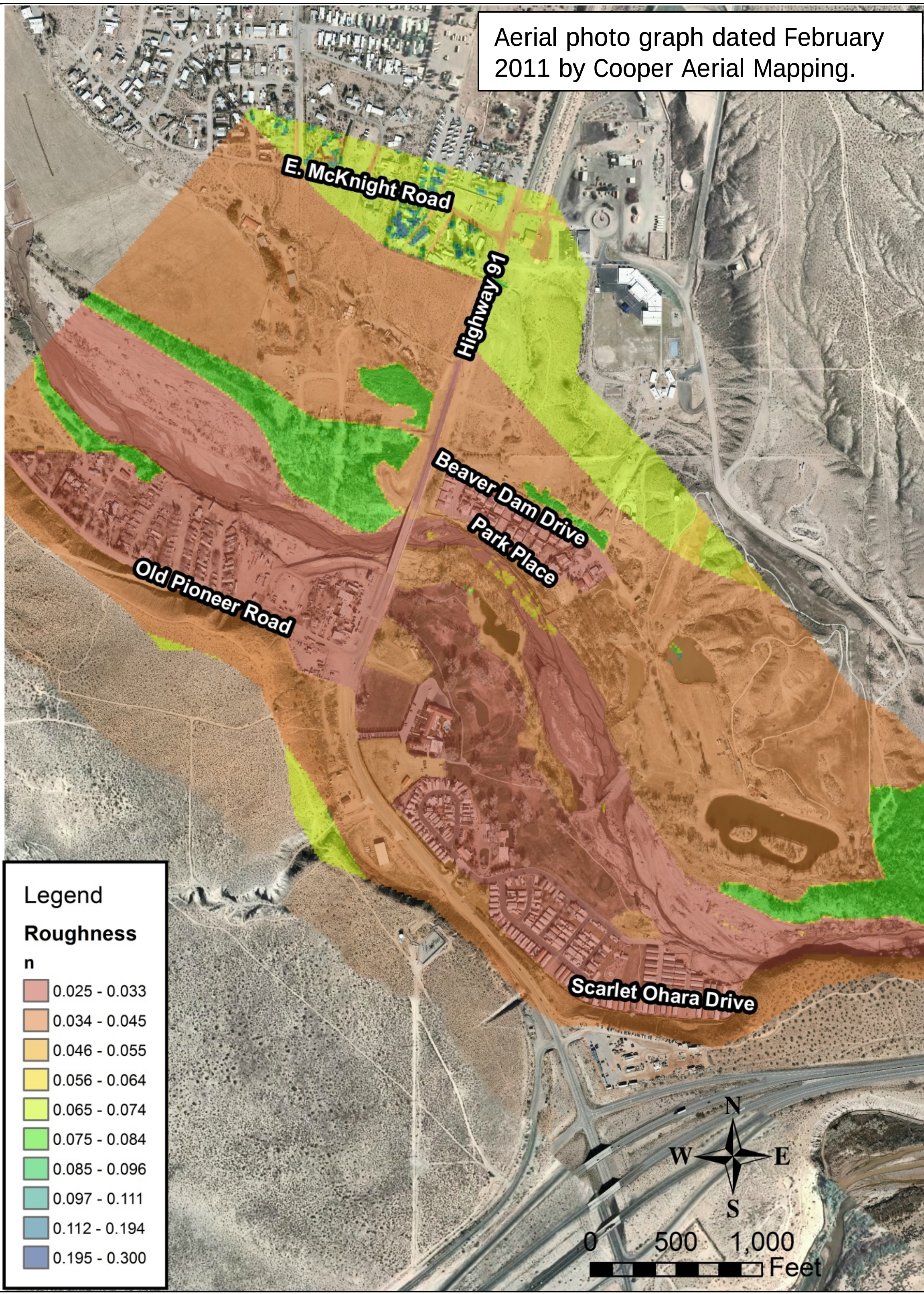
Limiting Froude Number

The flood hazard assessment is based on the water surface elevations at the structures in question. Examination of the HECRAS model results show that flow in the Beaver Dam Wash is either subcritical or close to critical depth. The 2D model analyses were done assuming subcritical flow. To accomplish this, a maximum Froude number of 0.95 was set. When the specified limiting Froude number is exceeded, the floodplain n-value is increased by 0.001 for that grid element for the next time step. This iterative procedure is used to force subcritical flow.

Area and Width Reduction (ARF)

The existing structures within the Beaver Dam Wash floodplain are obstructions to flow. The effects of these obstructions were modeled using the FLO-2D Area Reduction Factor (ARF) option. The polygons defining the structures present at the time of the 2011 aerial photographs by Cooper, included in the Cooper topography, were used as the basis for assigning ARF factors. The structures used to define ARF factors are shown on Figure 4.7. The grid elements that intersect the building polygons were assigned ARF and WRF values in the ARF.DAT FLO-2D input data file. This has the effect of blocking that portion of each grid element covered by a structure from flow conveyance and storage.

Figure 4.14 FLO-2D n-values map



Assignment of Inflow Hydrographs

Two different inflow conditions were considered. The first is the December 2010 flood hydrograph. The calibrated HMS model hydrograph at the Highway 91 Bridge was used for inflow to the FLO-2D model for this condition. Refer to Section 3.8.1. The second is a 24-hour storm hydrograph for generation of a hydraulic rating curve at the Highway 91 Bridge. The NRCS Type 2 rainfall distribution was applied with 3-inches of rain over the entire watershed in the HMS model to produce a 40,000 cfs peak discharge at the Highway 91 Bridge. Twenty eight (28) grid elements, shown on Figure 4.15, were used as inflow grid elements. Each hydrograph ordinate was divided by 28 and the resulting ordinates entered into the FLO-2D INFLOW.DAT input data file for every one of the 28 grid elements shown on Figure 4.15. A plot of the rating curve inflow hydrograph is shown on Figure 4.16. Both FLO-2D models are discussed in the following sections.

Figure 4.15 Grid elements used for inflow hydrograph

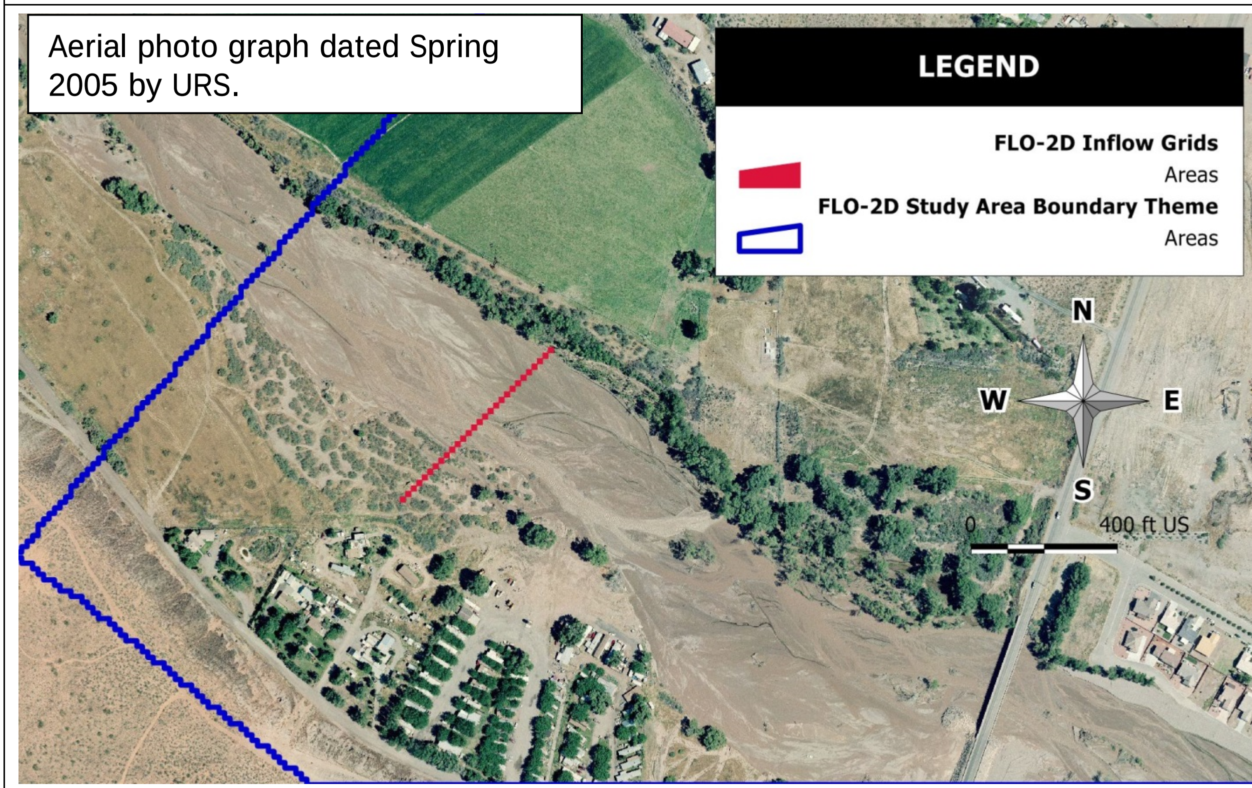
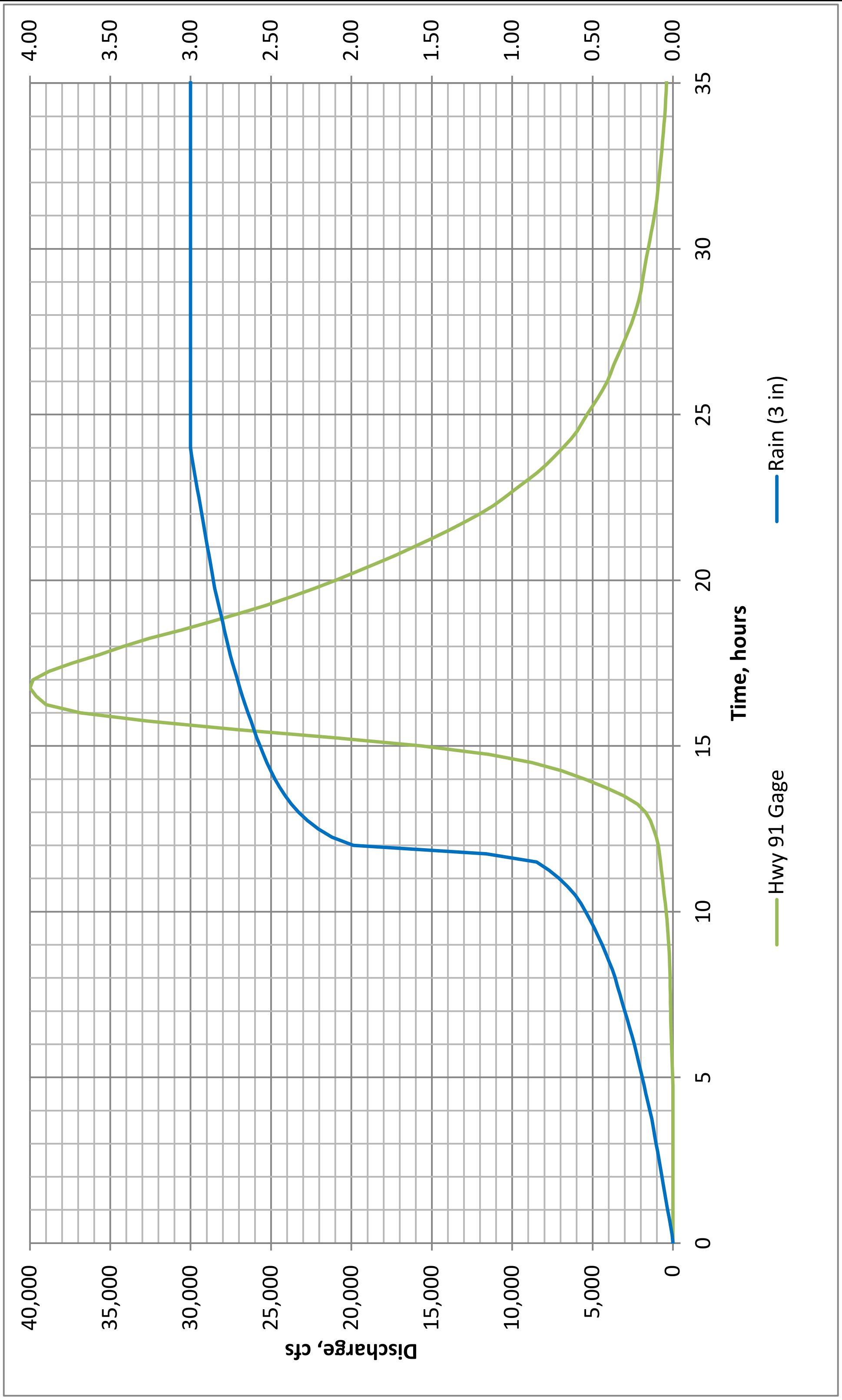


Figure 4.16 FLO-2D rating curve model inflow hydrograph

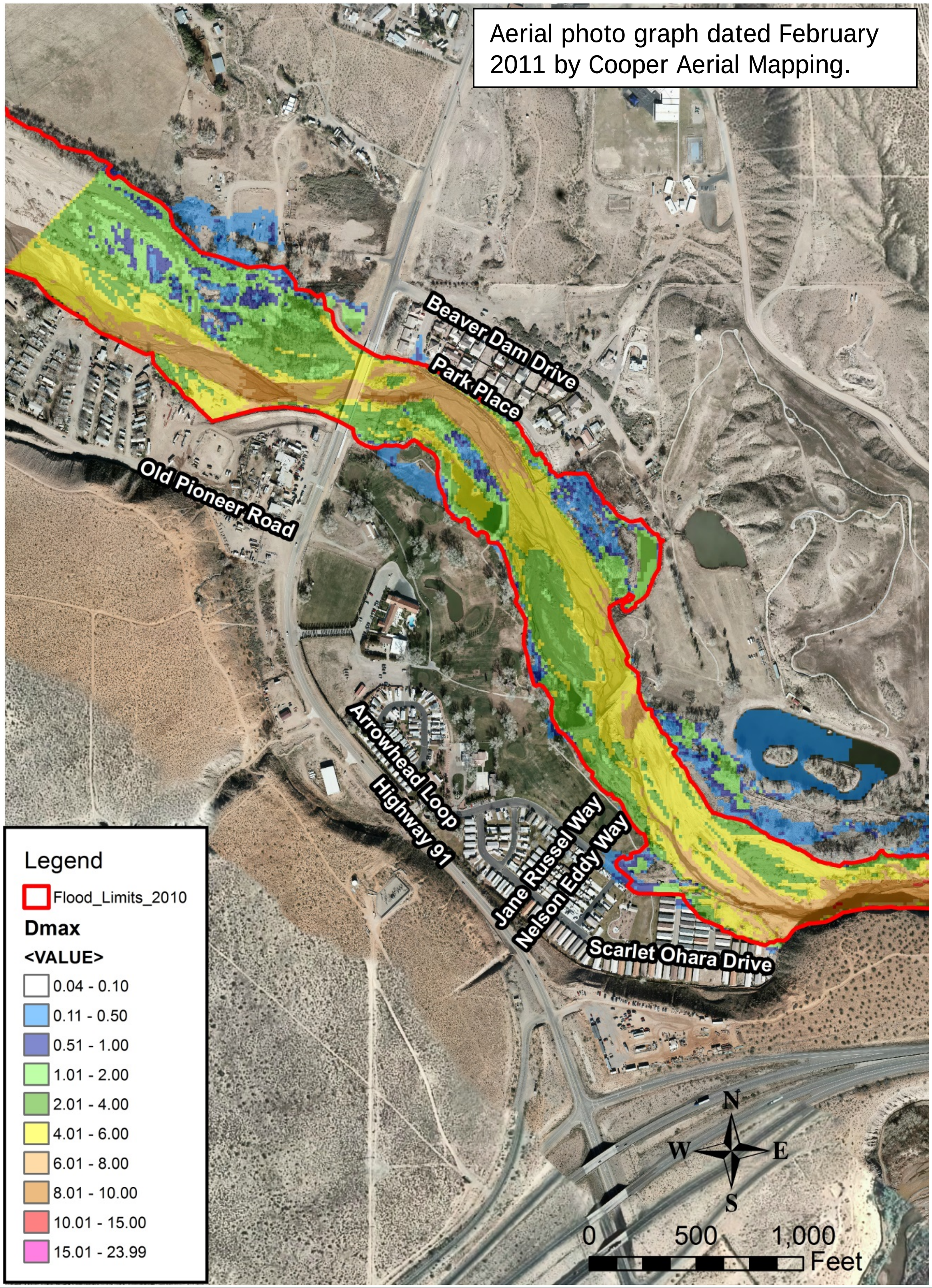


4.3.2 December 2010 Storm FLO-2D Model

This storm was modeled to verify that the FLO-2D model is producing reasonable results when compared with the observed. The base model n-values were adjusted slightly as discussed in Section 4.3.1 to match the observed flood limits from the subject storm. The flood limits were defined using the February 2011 aerial photographs by Cooper aerial. Since the limits are based on visible flood marks, shallow flow low velocity effects are not visible and therefore not included in the limits created. The estimated flood limits overlaid on the post-flood aerial photograph are shown on Figure 4.17. The estimated flood limits compared with the FLO-2D results are shown on Figure 4.18. The FLO-2D model using the HMS peak discharge, replicates the visible flood limits very well. This calibrated model was accepted for use in creating the hydraulic rating curve for the Highway 91 Bridge.

Figure 4.17 Estimated December 2010 flood limits

Figure 4.18 FLO-2D results and December 2010 flood limits



4.3.3 Highway 91 Bridge Rating Curve FLO-2D Model

The flow in Beaver Dam Wash through Beaver Dam is hydraulically complex. Even when flow is contained in the channel, the water surface elevations (WSEL) can vary more than 1 foot at any given cross section. When flow exceeds the channel and enters the flood plain, it is truly two-dimensional as shown on Figure 4.19. Since a 1-foot variance in depth relates to a significant difference in peak discharge for this wash, the hydraulic rating curve for the Highway 91 Bridge stream flow rating curve was prepared using the FLO-2D model instead of the RAS model. The RAS model is based on the assumption of a level water surface at each cross section. This allows for a better estimate of flow depth at the gage location. This approach also works better than RAS when establishing a hydraulic relationship between the critical warning locations and the gage.

The radar sensor is at the boundary between FLO-2D grid element numbers 30121 and 30409. Therefore, the average of the depth results for these two elements was used for the rating curve. The depth versus time data was extracted from the FLO-2D TIMDEM.OUT file. Each depth was then added to the average ground elevation of a 10 foot diameter circle below the radar sensor. The WSEL for both grid elements was then averaged to obtain the flow depth below the radar sensor. To relate the flow depth below the radar sensor at each time step to flow rate in the Beaver Dam Wash, three FLO-2D cross sections were used; cross sections 10, 11 and 12 as shown on Figure 4.20. The discharge for each time step from the three cross sections was summed to obtain the total flow under the bridge and checked to verify that the peak flow at the bridge matched the inflow peak discharge of 40,000 cfs. That hydrograph was then used to relate the peak discharge in the wash to the flow depth below the radar sensor using the time step. The resultant rating curve data is listed in Table 4.2 and shown graphically on Figure 4.21 (gage height) and on Figure 4.22 (WSEL). The full documentation for development of the Highway 91 Bridge hydraulic rating curve is in a separate report.

Additional FLO-2D floodplain cross sections were also defined. Those cross section locations are shown on Figure 4.23 with the peak discharge per grid element as background. Refer to the FLO-2D output data files to view the hydrographs for these cross sections.

Figure 4.19 FLO-2D complex flow patterns at 40,000 cfs

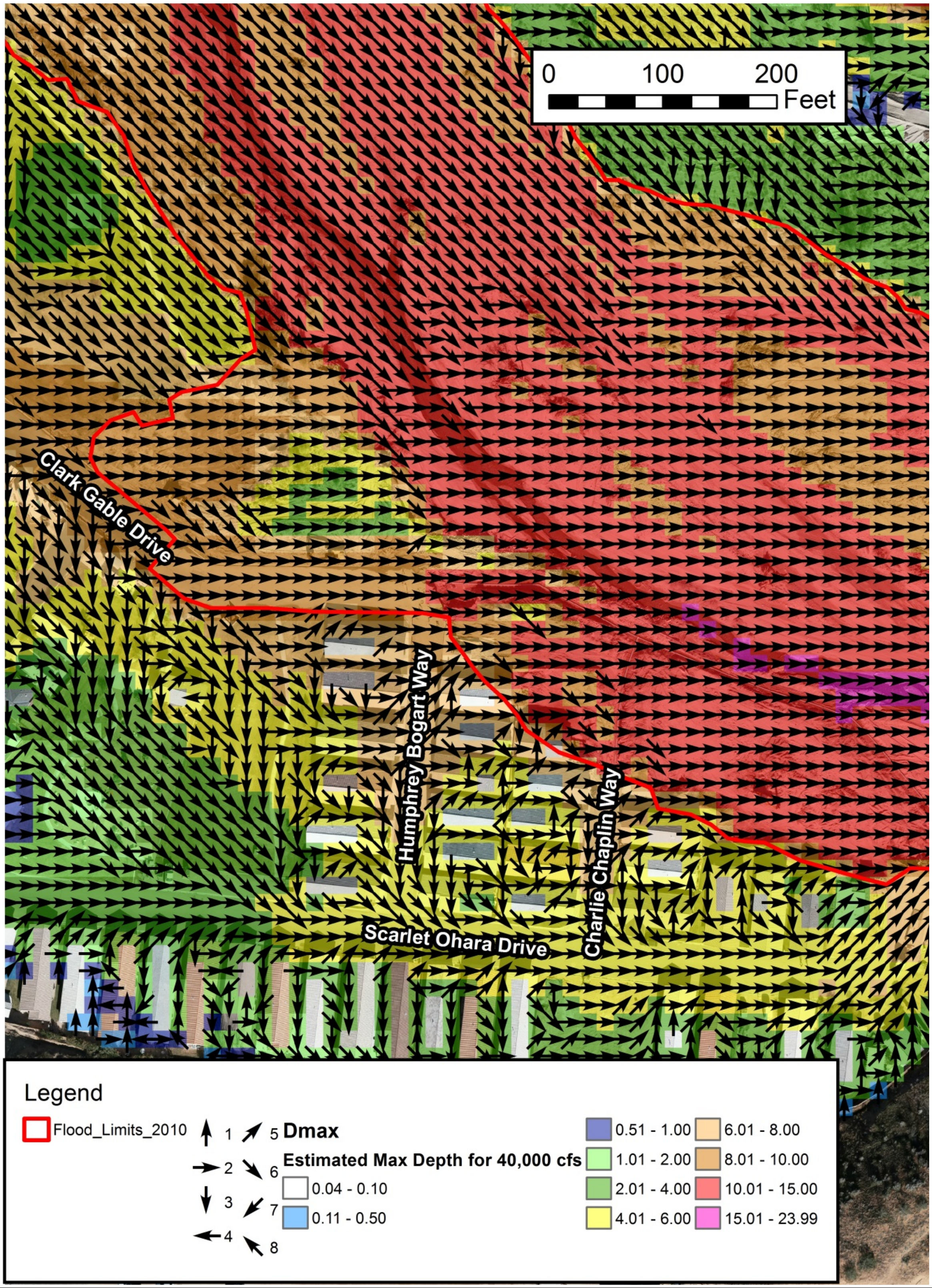


Figure 4.20 FLO-2D cross sections at Highway 91 Bridge (40,000 cfs)

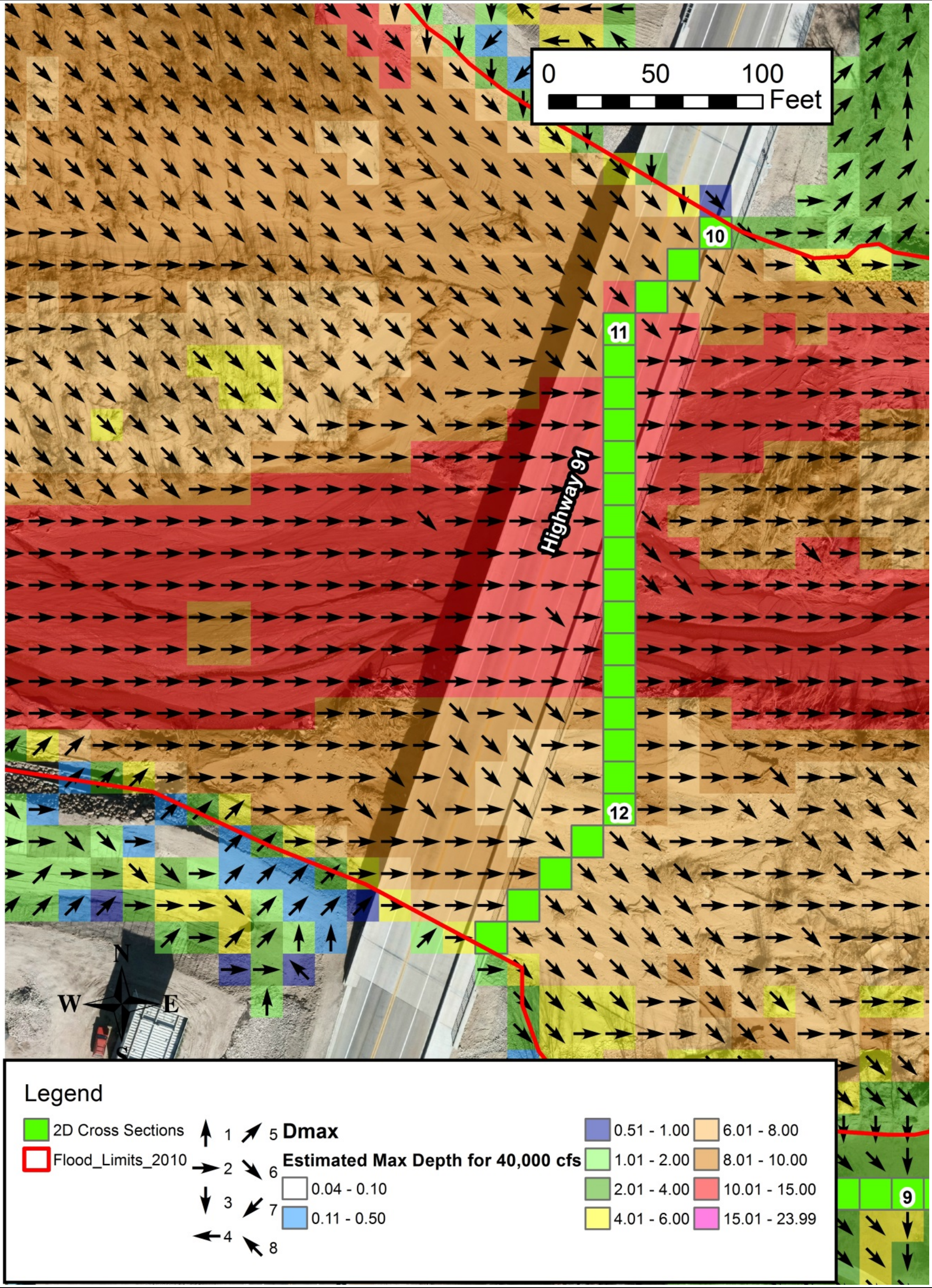


Figure 4.21 Highway 91 Bridge hydraulic rating curve (gage height)

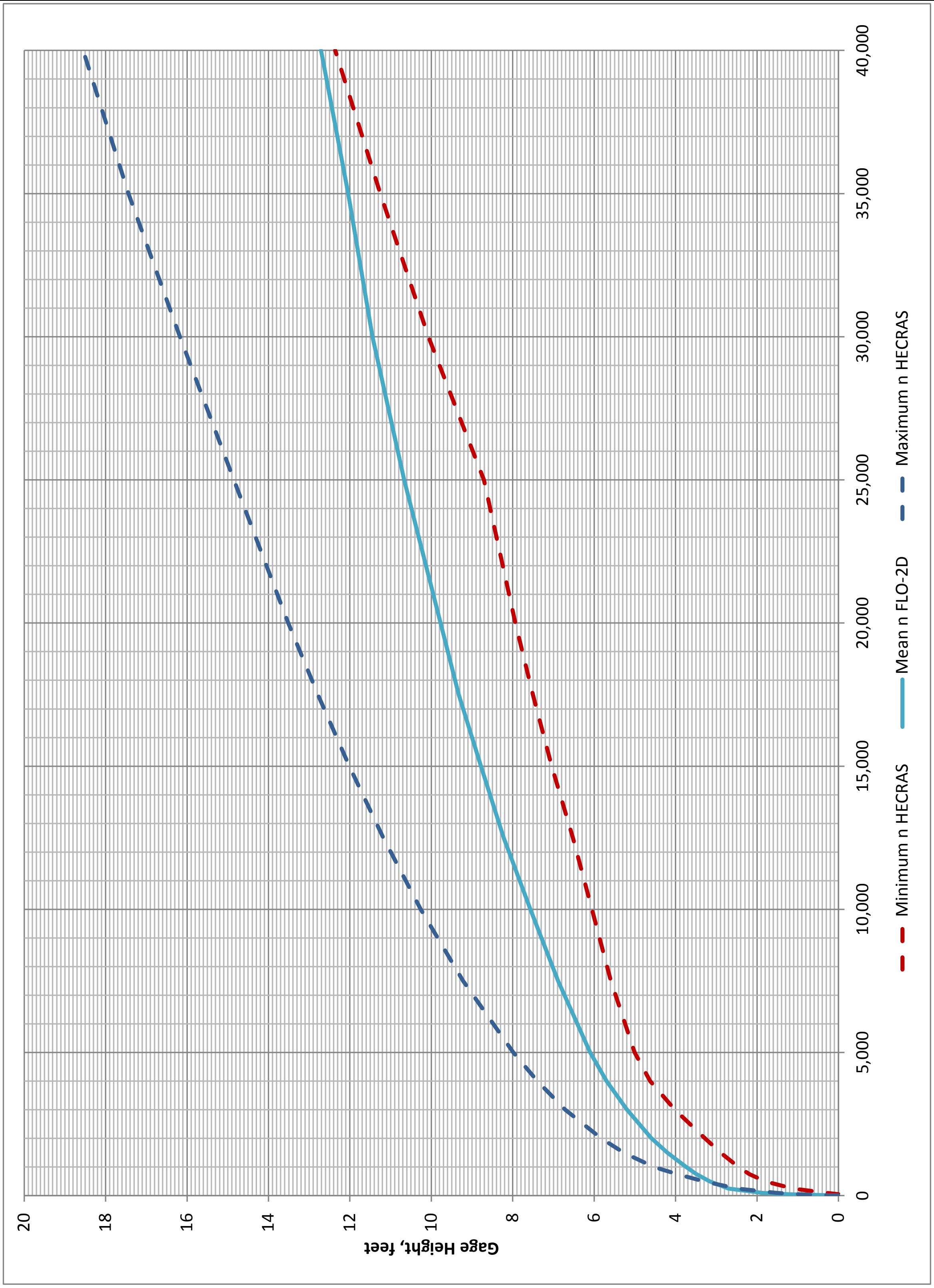


Figure 4.22 Highway 91 Bridge hydraulic rating curve (WSEL)

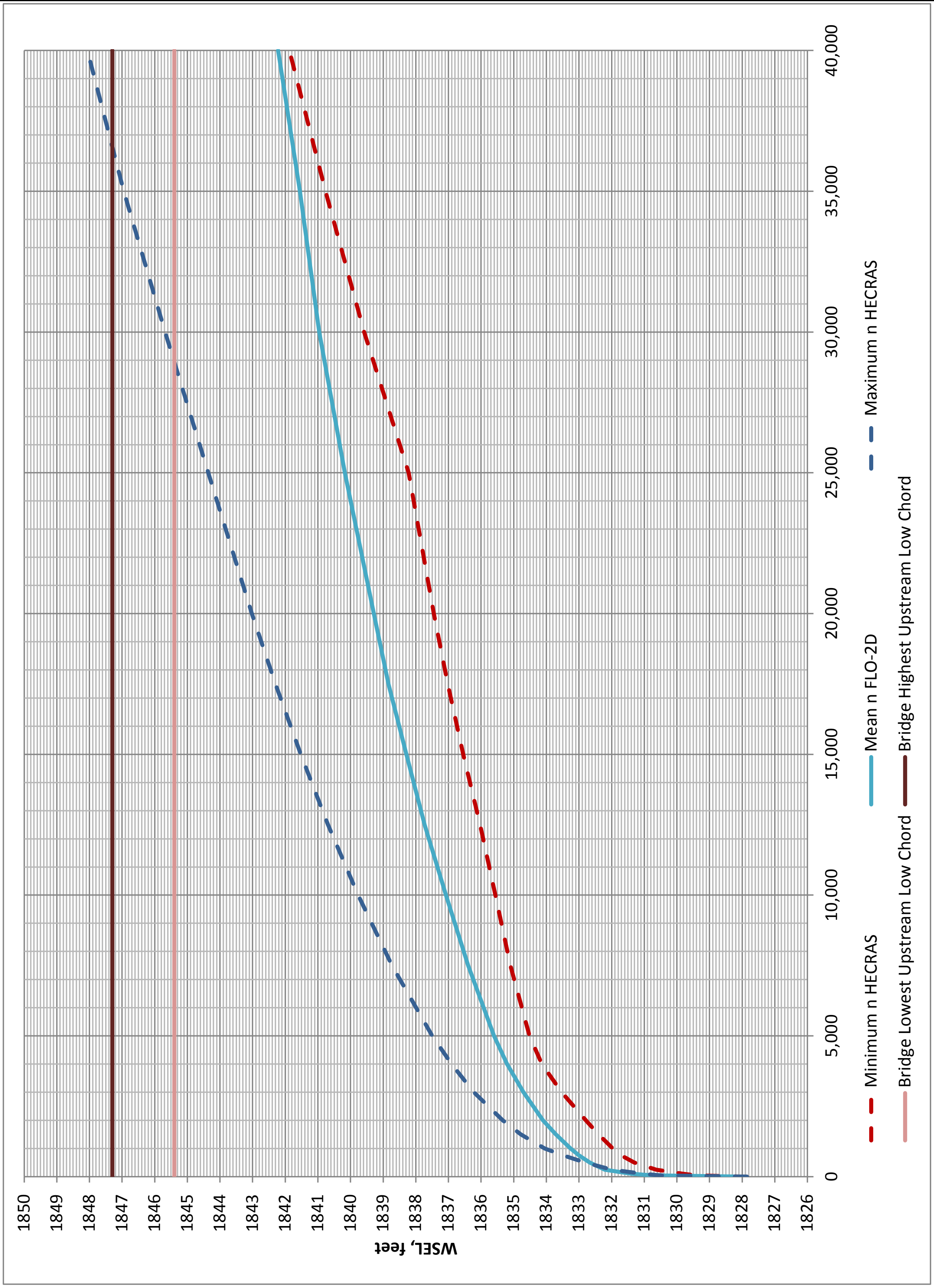
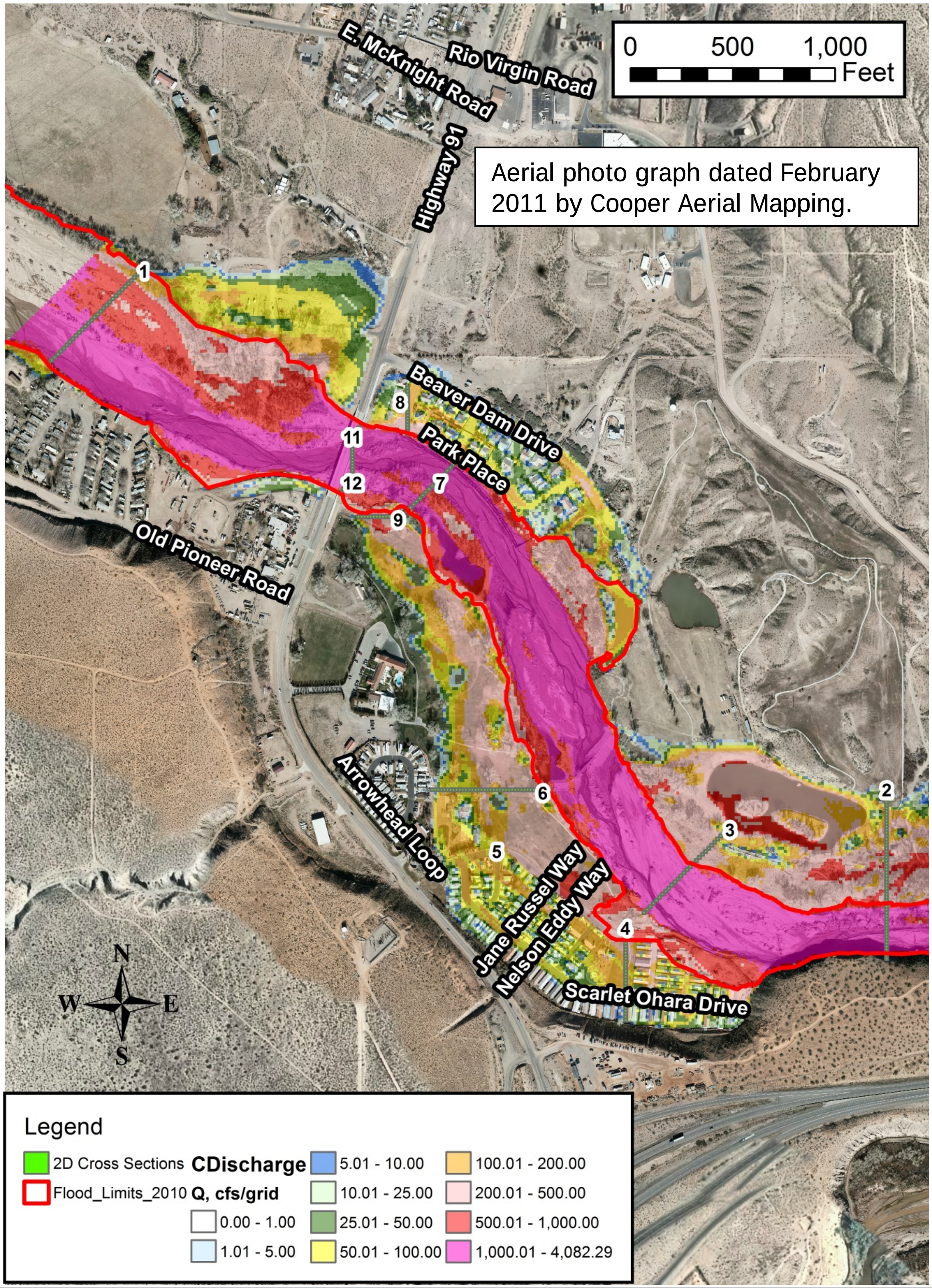


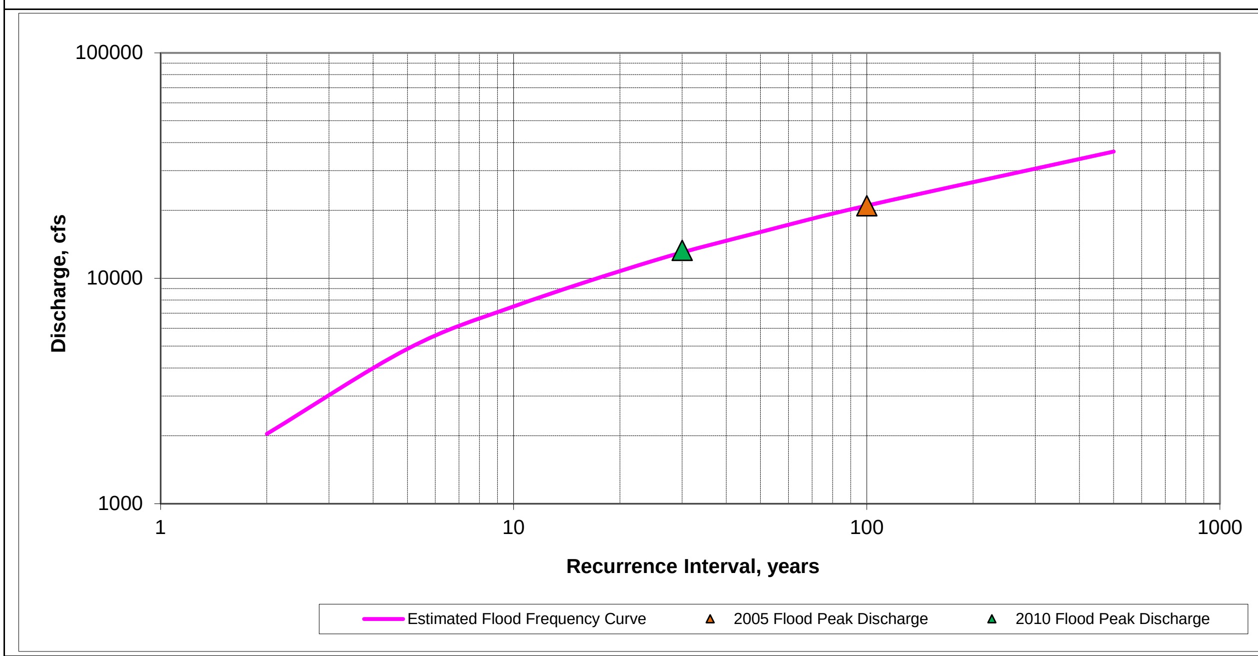
Figure 4.23 FLO-2D cross section locations



5 DECEMBER 2010 FLOOD FREQUENCY ESTIMATE

Estimating the flood frequency of the peak discharge from the December 2010 flood was done by plotting the estimated discharge on a flood frequency curve. The flood frequency curve was developed using HEC-1 model results in combination with peak discharge estimates of the 100-year and 500-year floods (FEMA, 2009). Refer to Figure 5.1. The Beaver Dam Wash watershed lies within USGS Flood Region 6 as described in Chapter 7 of the Drainage Design Manual for Mohave County (MCFCD, 2012). Unfortunately, the regional regression equations for Region 6 cannot be used for this watershed because the watershed area is outside the range of data used to develop the equations (MCFCD, 2012, Figure 7.30). Therefore, the results of the HEC-1 model of the watershed (AridHH, 2009) were used in combination with the FEMA peak discharge estimates from FEMA (2009) to develop the estimated flood frequency curve shown on Figure 5.1. The 2005 peak is shown with an orange triangle and the 2010 peak with a green triangle. Using this curve, the peak discharge of 13,300 cfs estimated for the December 2010 flood has a flood frequency of approximately 30-years.

Figure 5.1 Flood frequency curve for Beaver Dam Wash at Hwy 91



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6 FLOOD DETECTION AND WARNING

6.1 Detection and Warning Criteria Description

The flood detection criteria from the January 2009 FRP were revised based upon analysis of the measured watershed rainfall and stream flow gage data and the results of hydrologic and hydraulic analyses described in Section 3 and Section 4. Alarm settings for the ALERT system gages were established based on minimum thresholds necessary to provide best available warning time. Recommended alarm settings for the ALERT system gages are listed in Table 6.1. When an Alarm level is reached, the rainfall and runoff readings should be carefully evaluated, monitored and compared with the flood warning stage criteria listed in Table 6.2. The alarm levels are set based on working backwards from the Highway 91 Bridge critical discharges.

Table 6.1 Recommended ALERT system alarm settings

Gage	Alarm 1	Alarm 2	Alarm 3
Motoqua, or	200 cfs	500 cfs	1,500 cfs
Catclaw Canyon, or	500 cfs	2,000 cfs	10,000 cfs
Highway 91, and	1,000 cfs	3,000 cfs	6,000 cfs
Rain gages (Entire watershed group)	Depth: 0.25 inches	Depth: 0.50 inches Intensity: >0.2 in/hr	Depth: 1.00 inches Intensity: >2.0 in/hr
Rain gages (Upper watershed group)	Depth: 0.25 inches	Depth: 0.50 inches Intensity: >0.2 in/hr	Depth: 1.00 inches Intensity: >2.5 in/hr
Rain gages (Middle watershed group)	Depth: 0.25 inches	Depth: 0.50 inches Intensity: >0.2 in/hr	Depth: 1.00 inches Intensity: >2.0 in/hr
Rain gages (Lower watershed group)	Depth: 0.25 inches	Depth: 0.50 inches Intensity: >0.2 in/hr	Depth: 1.00 inches Intensity: >2.5 in/hr

For Level 1, a discharge of 1,000 cfs and rising at the Highway 91 Bridge is above the small storm threshold. Discharges of 200 cfs at Motoqua or 500 cfs at Catclaw Canyon or 1,000 cfs at the Highway 91 Bridge signifies that the gages should be monitored closely.

For Level 2, a discharge of 3,000 cfs and rising at the Highway 91 Bridge is at the threshold where bank erosion could begin occurring. Discharges of 500 cfs at Motoqua or 2,000 cfs at Catclaw Canyon or 3,000 cfs could result in the beginnings of bank erosion in Beaver Dam and that there is a possibility that much higher flow rates could occur.

For Level 3, a discharge of 6,000 cfs and rising at the Highway 91 Bridge is lower than the overbank flooding discharges, but those levels could be reached in a short amount of time. The rainfall intensity levels are a second indication that the overbank thresholds could be reached. Discharges of 1,500 cfs at Motoqua or 10,000 cfs at Catclaw Canyon in combination with sustained rainfall intensities from Table 6.1 signify that the overbank threshold discharges will soon be reached in Beaver Dam if those intensities continue.

The rainfall level depths listed in Table 6.1 are the average total storm rainfall from the rain gages for each of the four watershed scenarios (refer to Section 3.8.2. The rainfall intensities listed in Table 6.1 are the average rainfall intensity from the rain gages for each of the four watershed scenarios. Any one of the flow rate scenarios listed, in combination with the corresponding rainfall depth and intensity value, could be cause to issue the appropriate alarm level warning.

Seven critical locations within the Beaver Dam community were defined for the purpose of setting peak discharge thresholds. Threshold locations 1-6 are shown on Figure 6.1. Threshold locations 5-7 are shown on Figure 6.2. The four locations most critical to the residents are shown in more detail on Figure 6.3 (locations 1 and 2) and Figure 6.4 (locations 3 and 4). When the estimated flow rate in Beaver Dam Wash exceeds a threshold value for locations 1-5, flow can be expected to begin flooding the area adjacent to the threshold location. The threshold discharge values were determined using the FLO-2D model built to develop the gage hydraulic rating curve for the radar gage at the Highway 91 Bridge. The gage is located near the boundary between FLO-2D grids 30121 and 30409. The FLO-2D grid number corresponding to each threshold location is shown in column 6 of Table 6.2. A depth versus time data set was extracted from the FLO-2D output for each threshold location. The time when flow depth exceeds 0.1 feet was then related back to the FLO-2D hydrograph at the Highway 91 Bridge to obtain the estimated discharge where flow begins to flood the threshold location. Refer to the *Rating Curve at Gage 7601 Hwy 91 Post 2010 Storm Topo Radar Sensor FLO-2D and HECRAS.xlsx* spreadsheet (Section 10.1) for the digital data used. Each location is described as follows:

Location 1. Beaver Dam Resort: Clark Gable Drive at Humphrey Bogart Way. When the discharge exceeds the Location 1 threshold value, the Beaver Dam Resort area will begin to experience flooding.

Location 2. Beaver Dam Resort: Lowest Floor (APN 402-87-012). When the discharge exceeds the Location 2 threshold value, the residence at this location, which has the lowest finished floor elevation, will be affected.

Location 3. Beaver Dam Estates: North end Park Place at revetment. When the discharge exceeds the Location 3 threshold value, the Beaver Dam Estates area will begin to experience flooding.

Location 4. Beaver Dam Estates: Lowest Floor (APN 402-86-005). When the discharge exceeds the Location 4 threshold value, the residence at this location will be affected.

Location 5. Northeast bank upstream of Hwy 91 Bridge: When the discharge exceeds the Location 5 threshold value, the residences downstream of this area in the Northeast overbank will begin to be affected.

Location 6. Southwest bank upstream of the Highway 91 Bridge: Reach along the southwest bank upstream of the Highway 91 Bridge subject to potential bank migration.

Location 7. Southwest bank 4,000 feet upstream of the Highway 91 Bridge: Reach along the southwest bank 4,000 feet upstream of the Highway 91 Bridge subject to potential bank migration.

The threshold gage height and discharge values for each threshold location are listed in Table 6.2. As described above, each threshold location has been referenced to the Highway 91 stream flow gage (gage number 8). The gage heights shown in the table are for that gage.

Three storm types are considered in this plan for defining flood detection criteria:

1. Short Duration Storm. A synthetic 24-hour duration storm that includes the peak 15-minute, 1-hour, 3-hour, 6-hour, and 12-hour storms nested and centered at hour 12.
2. Long Duration Storm. A synthetic 112 hour storm based on the December 2010 flood.
3. Warm rain on snow pack.

Storm type 1 would typically result from a fall tropical storm or hurricane storm remnant. It also represents large convective summer storms. Storm type 2 addresses the longer duration general storm that typically occurs in the winter months, but could also include longer duration tropical storms and hurricane storm residue that normally occur in the fall. Storm type 3 is usually associated with a winter or spring storm, similar to the storm type that is suspected to have resulted in the 2005 flood. Specific criteria for storm type 3 are not provided due to the high level of uncertainty and variation in conditions that can occur. Instead, suggestions for adjusting the criteria from the short duration storms is provided that could be used to assess conditions as they occur and make a reasonable judgment regarding the potential hazard.

The flood detection criteria for the FWRP plan are based upon the rainfall intensities and depths required to produce and exceed the critical stages or discharges corresponding to the threshold locations shown on Figure 6.1 through Figure 6.4 and listed in Table 6.2. These criteria are recommended for use by the MCEM and the National Weather Service (NWS) to disseminate flood warning messages to residents in the warning area and to appropriate emergency response agencies, thereby triggering implementation of the FWRP. Table 6.3 (entire watershed), Table 6.4 (upper watershed), Table 6.5 (middle watershed) and Table 6.6 (lower watershed) below contain summaries of the threshold criteria for each level of flood alert in the warning sequence for the short duration storm. These criteria are intended for use with storms in the 6-hour to 24-hour duration range, using engineering judgment.

Table 6.7 contains summaries of the threshold criteria for each level of flood alert in the warning sequence for the long duration storm. These criteria are intended for use with storm durations in the range of two (2) to seven (7) days, again using engineering judgment.

Each watershed scenario is capable of producing runoff discharges sufficient to reach the threshold values in Table 6.2, assuming the average listed amounts of precipitation occur over the watershed area considered.

Section 6.2 contains a graph of the December 2010 storm gage-measured rainfall and runoff hydrographs. Rainfall intensities for critical portions of the storm that resulted in high runoff rates are identified to help understand how the watershed responded during an event of this type.

Section 6.3 contains information for the short-duration storm type. Tables and figures are provided that relate peak discharge to total storm rainfall of 24-hour duration for the four watershed scenarios (entire, upper, middle and lower). The intent is to use this information as a storm approaches the watershed by relating the anticipated total rainfall estimated by the NWS to expected peak discharge. Section 6.4 contains graphs of 24-hour precipitation and resulting runoff response over time for each watershed scenario. The information on the four graphs is the basis for the warning stage criteria for short duration storms shown in Table 6.3, Table 6.4, Table 6.5, and Table 6.6.

Section 6.5 contains a graph (Figure 6.15) showing the synthetic storm rainfall distributions developed from the December 2010 storm data. These distributions were then scaled to a 112 –hour storm duration as shown on Figure 6.16. Also shown on Figure 6.16 is the estimated rainfall-runoff response from the entire watershed for a multi-day storm. The information on Figure 6.16 is the basis for the warning stage criteria for long duration storms shown in Table 6.7.

Section 6.6 contains guidance for addressing the warm rain on snow pack storm type.

Section 6.7 contains curves for use in estimating travel times between the Motoqua gage site, the Catclaw Canyon gage site, and the Highway 91 bridge gage site for a range of flow rates.

Section 6.8 contains discussion of the ALERT system hydraulic rating curves for the three stream flow gages.

Section 6.9 contains conservative estimates of areas where lateral migration of the watercourse banks due to erosion is possible.

Figure 6.5 shows recommended evacuation areas for when overbank flooding is expected.

Much of the information in the following sections is repeated from previous sections in order to have the critical data in one location for easier access when using the report during a flood emergency.

Figure 6.1 Warning area threshold locations map 1

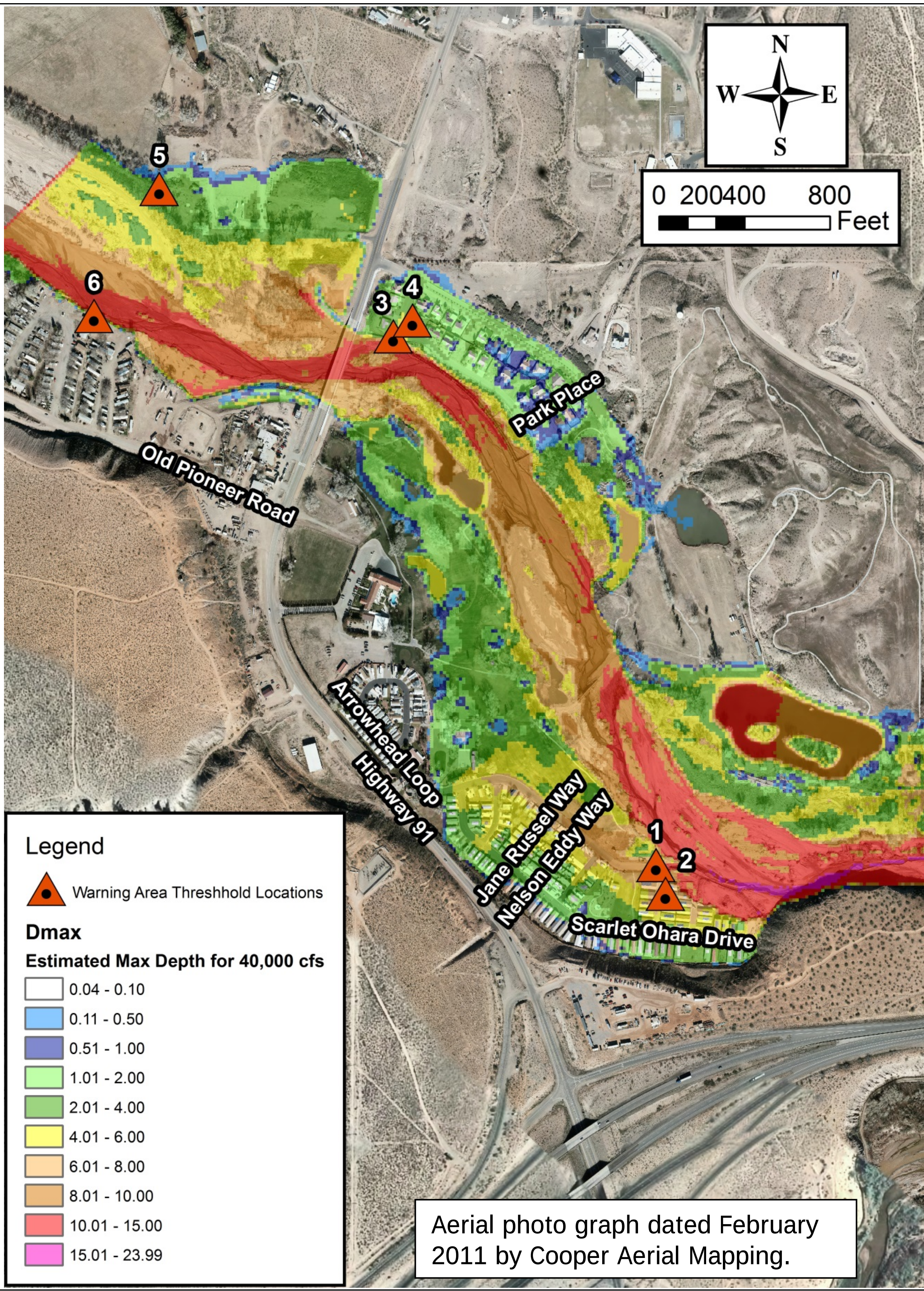


Figure 6.2 Warning area threshold locations map 2

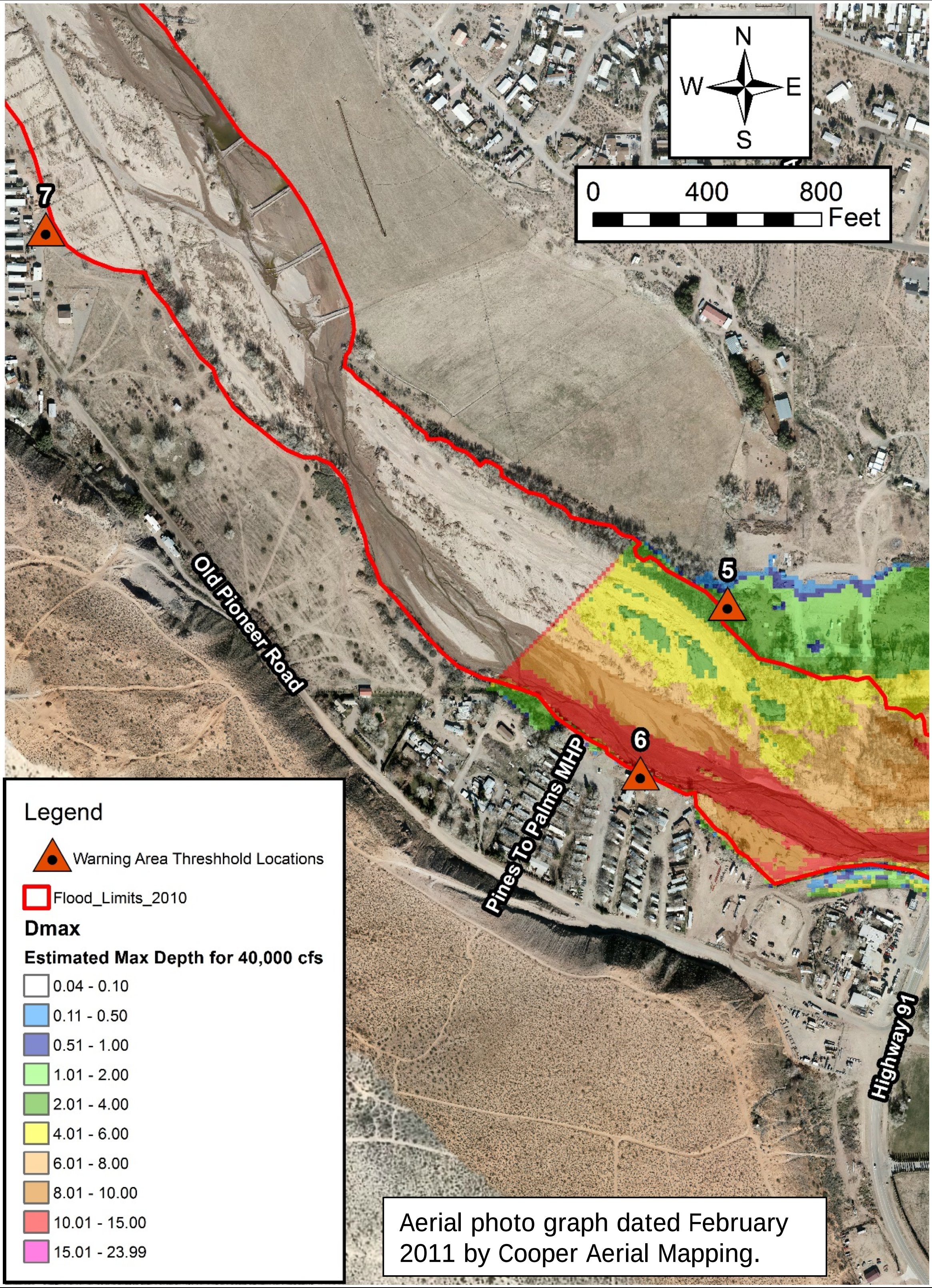


Figure 6.3 Warning area threshold locations 1 and 2 map

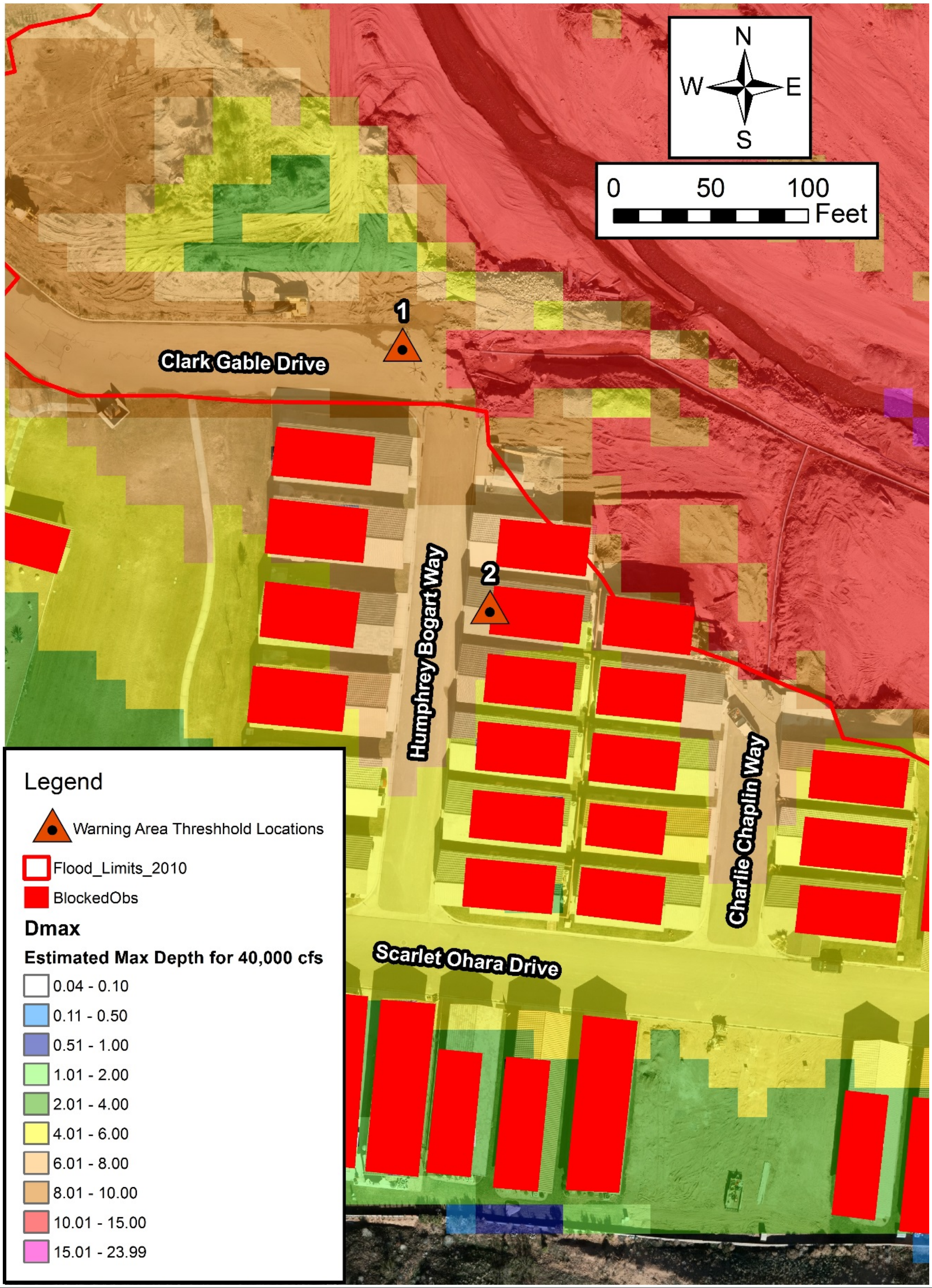


Figure 6.4 Warning area threshold locations 3 and 4 map

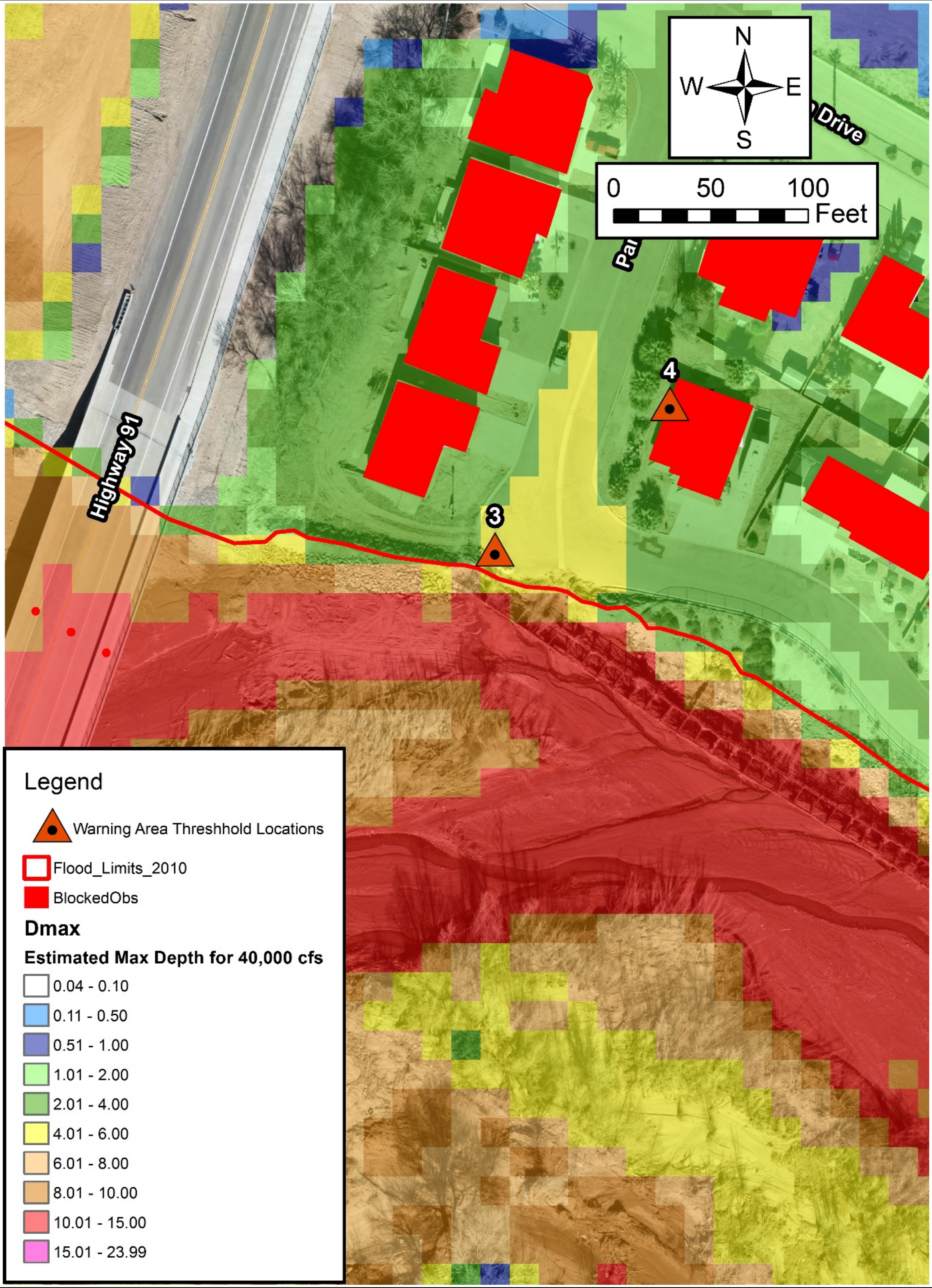


Table 6.2 Threshold gage heights and discharge values for warning areas

Location Number	Location[1]	Highway 91 Gage (7601) Gage Height, ft	Highway 91 Gage (7601) WSEL	Threshold Discharge, cfs	FLO-2D Grid
(1)	(2)	(3)	(4)	(5)	(6)
1	Beaver Dam Resort: Clark Gable Drive at Humphrey Bogart Way. Condition: Possible bank erosion.	5.2	1834.7	3,000	57938
1	Beaver Dam Resort: Clark Gable Drive at Humphrey Bogart Way.	7.7	1837.2	10,400	57938
2	Beaver Dam Resort: Lowest Floor (APN 402-87-012)	9.3	1838.8	17,400	58605
3	Beaver Dam Estates: North end Park Place at revetment	8.3	1837.8	12,700	34772
4	Beaver Dam Estates: Lowest Floor (APN 402-86-005)	9.5	1839.0	18,600	36555
5	North bank upstream of Hwy 91 Bridge	7.1	1836.6	8,100	14525
6	Southwest overbank upstream from Hwy 91 Bridge	5.2	1834.7	3,000	n/a
7	Southwest overbank area 4,000 feet upstream of Highway 91 Bridge to be monitored for bank erosion	5.2	1834.7	3,000	n/a
1	Gage heights and threshold discharges are for possible overbank flooding unless otherwise noted.				

Table 6.3 Warning criteria for short duration storms (entire watershed)

Flood Warning Stage	Rainfall[1] Total Depth	Rainfall[1] Intensity & Duration	Measured Discharge Motoqua (1)	Measured Discharge Catclaw Canyon (2)	Measured Discharge Highway 91 (8)
	inches	in/hr, hr	cfs	cfs	cfs
(1)	(2)	(3)	(4)	(5)	(7)
1	≥ 0.5	≥ 0.1, ≥ 5	≥ 200	≥ 500	≥ 300
2	≥ 1.0	≥ 2.0, 0.3	≥ 500	≥ 2,000	≥ 500
3	≥ 1.5	≥ 2.0, 0.5	≥ 1,500	≥ 10,000	≥ 2,000

[1] Average of measured values at gages 1, 2, 4, 5, 6, 7 and 9.

Table 6.4 Warning criteria for short duration storms (upper watershed)

Flood Warning Stage	Rainfall[1]		Measured Discharge		
	Total Depth	Intensity & Duration	Motoqua (1)	Catclaw Canyon (2)	Highway 91 (8)
	(in)	in/hr, hr	(cfs)	(cfs)	(cfs)
(1)	(2)	(3)	(4)	(5)	(7)
1	≥ 0.5	≥ 0.15, ≥ 5	≥ 200	≥ 500	≥ 300
2	≥ 1.5	≥ 2.5, 0.3	≥ 500	≥ 2,000	≥ 500
3	≥ 2.0	≥ 3.0, 0.5	≥ 1,500	≥ 10,000	≥ 2,000

[1] Average of measured values at gages 1, 4, 6, and 7.

Table 6.5 Warning criteria for short duration storms (middle watershed)

Flood Warning Stage	Rainfall[1]		Measured Discharge		
	Total Depth	Intensity & Duration	Motoqua (1)	Catclaw Canyon (2)	Highway 91 (8)
	(in)	in/hr, hr	(cfs)	(cfs)	(cfs)
(1)	(2)	(3)	(4)	(5)	(7)
1	≥ 0.5	≥ 0.15, ≥ 5	n/a	≥ 500	≥ 300
2	≥ 1.0	≥ 2.0, 0.3	n/a	≥ 2,000	≥ 500
3	≥ 1.5	≥ 2.0, 0.5	n/a	≥ 10,000	≥ 2,000

[1] Average of measured values at gages 1, 2, 5, and 7.

Table 6.6 Warning criteria for short duration storms (lower watershed)

Flood Warning Stage	Rainfall[1]		Measured Discharge		
	Total Depth	Intensity & Duration	Motoqua (1)	Catclaw Canyon (2)	Highway 91 (8)
	(in)	in/hr, hr	(cfs)	(cfs)	(cfs)
(1)	(2)	(3)	(4)	(5)	(7)
1	≥ 0.5	≥ 0.15, ≥ 5	n/a	≥ 500	≥ 500
2	≥ 1.0	≥ 2.0, 0.3	n/a	≥ 1,000	≥ 1,000
3	≥ 2.5	≥ 3.0, 0.5	n/a	≥ 5,000	≥ 5,000

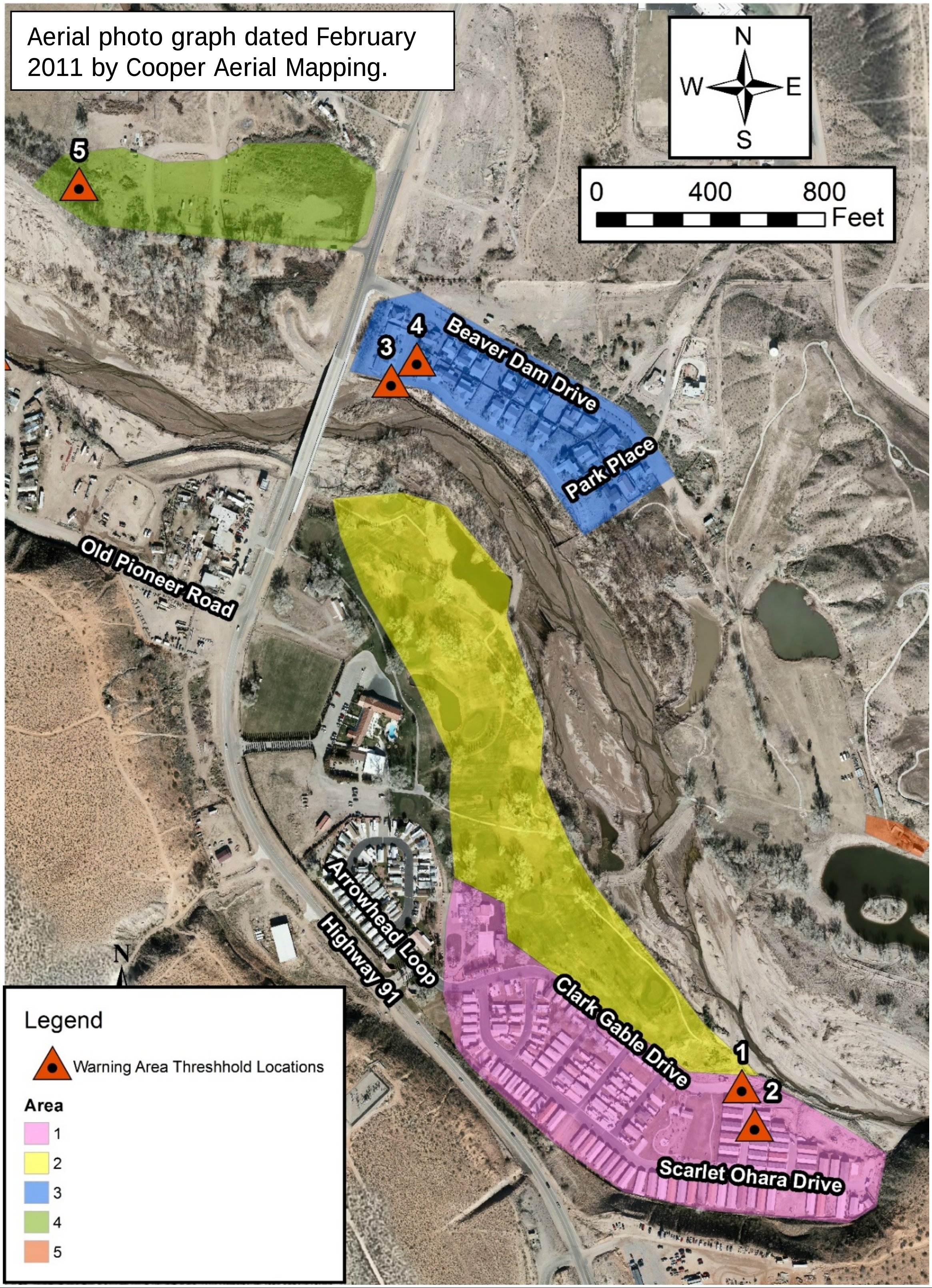
[1] Average of measured values at gages 2 and 9.

Table 6.7 Warning criteria for long duration storms (entire watershed)

Flood Warning Stage	Rainfall[1]		Measured Discharge		
	Total Depth	Duration	Motoqua (1)	Catclaw Canyon (2)	Highway 91 (8)
	(in)	(hrs)	(cfs)	(cfs)	(cfs)
(1)	(2)	(3)	(4)	(5)	(7)
1	≥ 1.0	≥ 0.12, ≥ 24	≥ 400	≥ 1,000	≥ 1,000
2	≥ 5.0	≥ 0.25, ≥ 18	≥ 1,000	≥ 5,000	≥ 3,000
3	≥ 10.0	≥ 0.25, ≥ 36	≥ 4,000	≥ 10,000	≥ 6,000

[1] Average of measured values at gages 1, 2, 4, 5, 6, 7 and 9.

Figure 6.5 Recommended evacuation areas due to overbank flooding



6.2 December 2010 Storm Rainfall-Runoff Response

6.2.1 Description

The information in this section is derived from the calibrated HEC-HMS model of the December 2010 storm. The gage-measured and HEC-HMS modeled hydrographs for that storm are shown on Figure 6.6. Also shown are the actual rainfall distributions from each rain gage. Note that the measured hydrograph at Highway 91 stops on 12/22/12 at 8 PM. The observed readings after that point are highly suspect as a large cottonwood tree caused an obstruction to flow at the measurement location at about that time. Also shown on Figure 6.6 are locations of highest rainfall intensity.

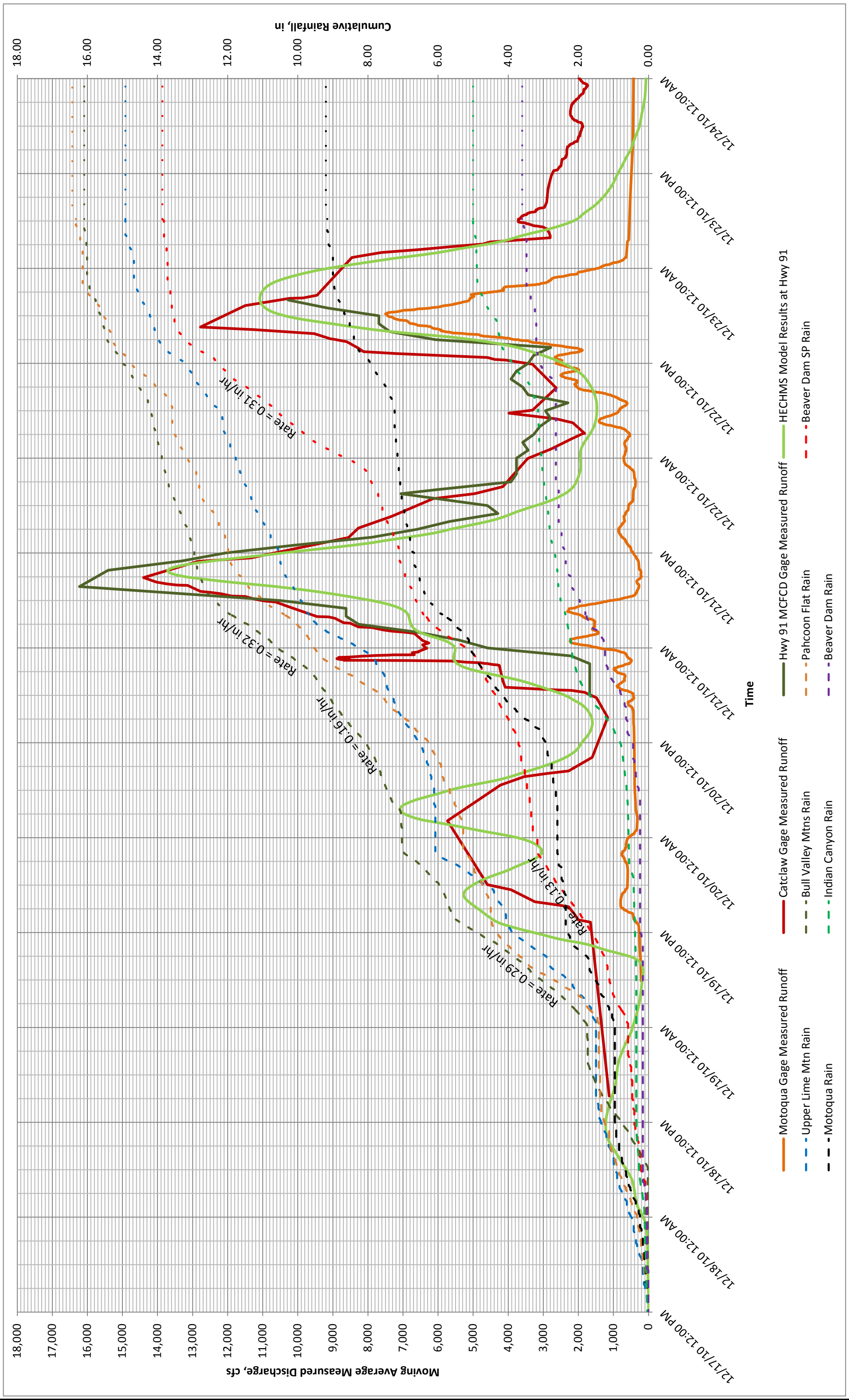
6.2.2 Intended Use

The intention is to show how the watershed responded to the rainfall event of December 2010, and to learn from that information. Note how increases in discharge correspond to increases in rainfall intensity. When the rainfall intensity exceeds 0.1 inches/hour, runoff increases significantly. When gage readings during an actual event are similar to what was observed in 2010, a similar watershed response can be expected. This example also shows how much variation in rainfall can occur within a storm event, even a long general storm.

6.2.3 Limitations

The rain gage readings for Upper Lime Mountain, Pahcoon Flat, Bull Valley Mountains, and Beaver Dam State Park are all suspect for the December 2010 storm. A faulty snow tube design at each gage resulted in higher readings than actually occurred. An attempt was made by Mohave County staff to determine a correction factor, and the adjustments recommended were refined by AridHH during the model calibration process. It should be kept in mind that the measurements at these gages have a higher than normal degree of error. The stream gage readings are also suspect. The Indian Canyon gage did not provide meaningful data due to flow being concentrated in a different area of the very broad floodplain. The new Highway 91 gage was not installed yet and the Motogua and Catclaw Canyon gages sustained damage. There was also extensive bed movement during the event at all the locations. The final bed topography after the event was used to create revised hydraulic rating curves for each gage. The actual bed elevations during the event are unknown.

Figure 6.6 2010 storm hydrograph



6.3 Short-Duration Storm Type Rainfall-Runoff Response

6.3.1 Description

The information in this section is derived from HEC-HMS models of the watershed for a 24-hour duration storm using an NRCS Type 2 rainfall distribution and is a repeat from Section 3. The HEC-HMS model hydrologic and hydraulic parameters were calibrated using measured rainfall and flow rates from the December 2010 flood event. The model was run for scenarios of the entire watershed, the upper watershed, the middle watershed, and the lower watershed as described in Section 2. Each watershed scenario was run for total storm rainfall values of 0.50, 1.0-, 1.5-, 2.0-, 3.0-, and 4.0-inches. This information was then used to estimate the 24-hour total rainfall required to produce the threshold peak discharges in the Beaver Dam area as described in Section 2. The threshold locations are shown graphically on Figure 6.1 through Figure 6.4. The threshold discharge values are listed in Table 6.8. The results for each watershed scenario are listed in Table 6.9, Table 6.10, Table 6.11, and Table 6.12 for the Motoqua, Catclaw Canyon and Highway 91 gage sites. These results are shown graphically on Figure 6.7, Figure 6.8, Figure 6.9, and Figure 6.10.

6.3.2 Intended Use

This information is intended to provide early guidance when a storm of shorter duration (6 to 24 hours) is approaching the watershed. The forecast total storm rainfall estimates from the NWS can be used to check if any of the critical threshold peak discharges may be reached by the event. This will help with advance notice for early notifications, as response times for these shorter duration, high intensity rainfall events is much shorter than for the longer duration, lower intensity storms such as occurred in 2005 and 2010.

6.3.3 Limitations

The rainfall intensity is based on the peak intensity of the NRCS Type 2 rainfall distribution, which varies from 2.3 to 3.0 inches/hour for these scenarios. The actual rainfall intensity and timing will vary significantly within a natural storm. This approach is also based on the assumption that the total storm rainfall is the average total rainfall over the entire watershed. Keep in mind that the actual rainfall will vary significantly over the watershed. This approach is only intended to provide an estimate of what effect an incoming storm may have at Beaver Dam.

Table 6.8 Watershed response data to produce threshold peak discharges

Hwy 91 Threshold Discharge, cfs	Entire Watershed			Upper Watershed			Middle Watershed		Lower Watershed	
		Discharge, cfs			Discharge, cfs			Discharge, cfs		Discharge, cfs
	Rain, in[1]	Motoqua	Catclaw	Rain, in	Motoqua	Catclaw	Rain, in	Catclaw	Rain, in	Catclaw
8,100	1.4	650	8,500	2.0	950	9,000	1.4	7,800	2.2	6,400
10,400	1.5	720	10,400	2.3	1,400	11,700	1.6	11,300	2.4	8,000
12,700	1.7	800	12,800	2.5	1,700	14,000	1.8	14,200	2.6	9,400
17,400	1.9	930	16,800	3.0	2,500	18,500	2.1	18,600	3.0	12,000
18,600	2.0	980	18,400	3.1	3,100	19,800	2.2	19,400	3.1	12,700

[1] Total rainfall over the watershed in 24 hours needed to produce the threshhold discharge at Highway 91.

Table 6.9 Rainfall-runoff response data for entire watershed

Total 24-hr Rainfall, in	Motoqua Gage		Catclaw Canyon Gage		Hwy 91 Gage	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
0.00	0	0:00	0	0:00	0	0:00
0.50	220	18:00	1,140	16:45	970	20:00
1.00	470	17:15	4,040	16:15	3,800	19:00
1.50	720	17:00	10,400	16:00	10,100	18:00
2.00	980	16:45	18,400	15:45	18,700	17:30
3.00	2,500	15:45	37,100	15:45	40,000	16:45
4.00	8,300	15:45	60,800	15:45	66,300	16:45

Table 6.10 Rainfall-runoff response data for upper watershed

Total 24-hr Rainfall, in	Motoqua Gage		Catclaw Canyon Gage		Hwy 91 Gage	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
0.00	0	0:00	0	0:00	0	0:00
0.50	220	18:00	660	17:15	430	21:15
1.00	470	17:15	2,300	16:30	1,800	19:45
1.50	720	17:00	5,600	16:15	4,800	18:30
2.00	980	16:45	9,400	16:00	8,500	18:00
3.00	2,500	15:45	18,500	16:00	17,300	17:45
4.00	8,300	15:45	31,800	16:00	30,300	17:15

Table 6.11 Rainfall-runoff response data for middle watershed

Total 24-hr Rainfall, in	Motoqua Gage		Catclaw Canyon Gage		Hwy 91 Gage	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
0.00	0	0:00	0	0:00	0	0:00
0.50	---	---	1,000	16:45	740	20:30
1.00	---	---	3,700	16:15	3,100	19:00
1.50	---	---	9,800	16:00	8,900	18:00
2.00	---	---	17,100	15:45	16,000	17:30
3.00	---	---	32,400	15:45	31,000	17:00
4.00	---	---	48,900	15:45	47,100	16:45

Table 6.12 Rainfall-runoff response data for lower watershed

Total 24-hr Rainfall, in	Motoqua Gage		Catclaw Canyon Gage		Hwy 91 Gage	
	Q_p	T_p	Q_p	T_p	Q_p	T_p
0.00	0	0:00	0	0:00	0	0:00
0.50	---	---	390	15:30	470	17:00
1.00	---	---	1,000	15:15	1,300	17:30
1.50	---	---	2,800	15:15	3,200	17:30
2.00	---	---	5,400	15:00	6,400	17:00
3.00	---	---	12,000	15:00	17,500	16:00
4.00	---	---	19,200	14:45	30,200	15:45

Figure 6.7 24-hour storm rainfall-runoff response for entire watershed

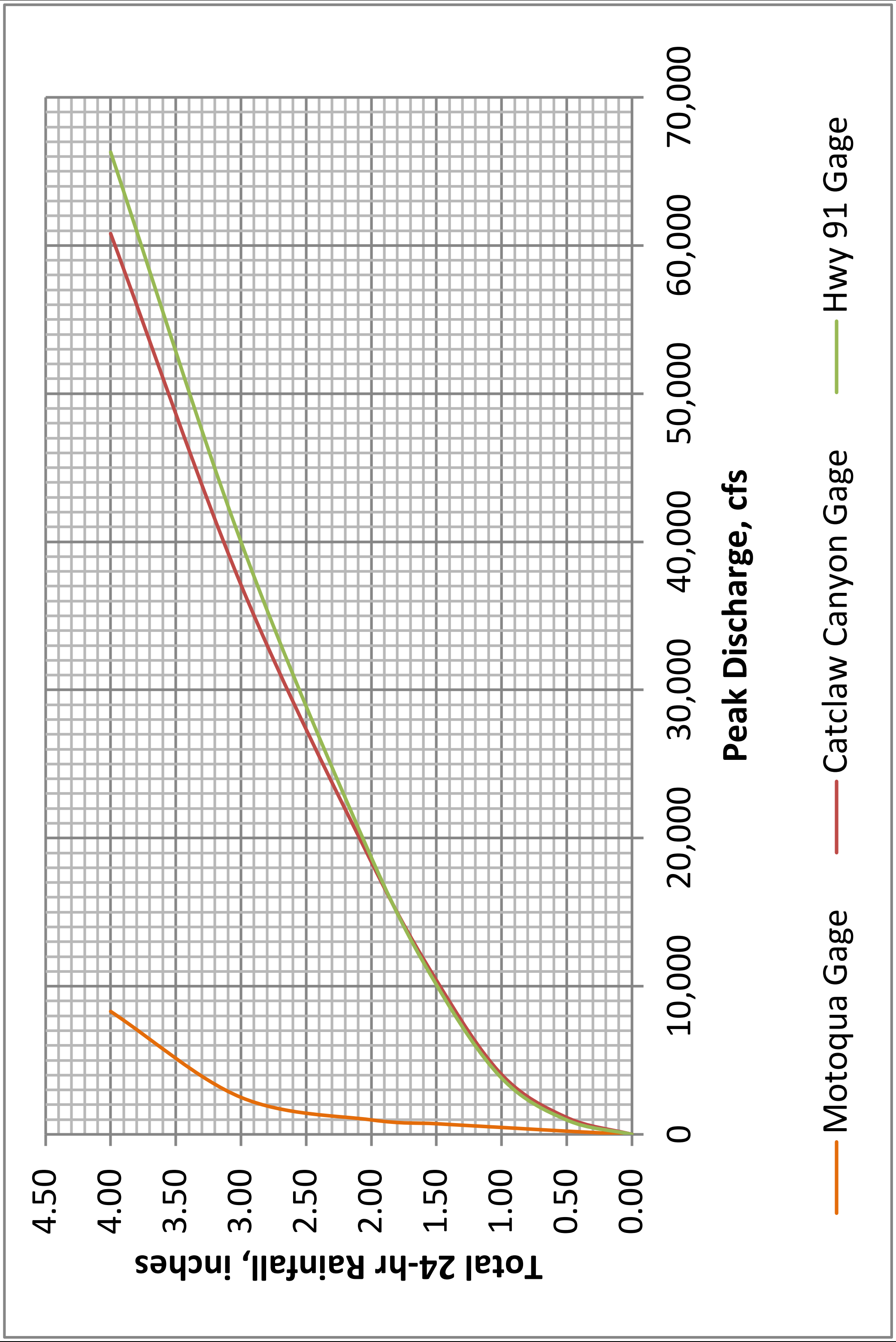


Figure 6.8 24-hour storm rainfall-runoff response for upper watershed

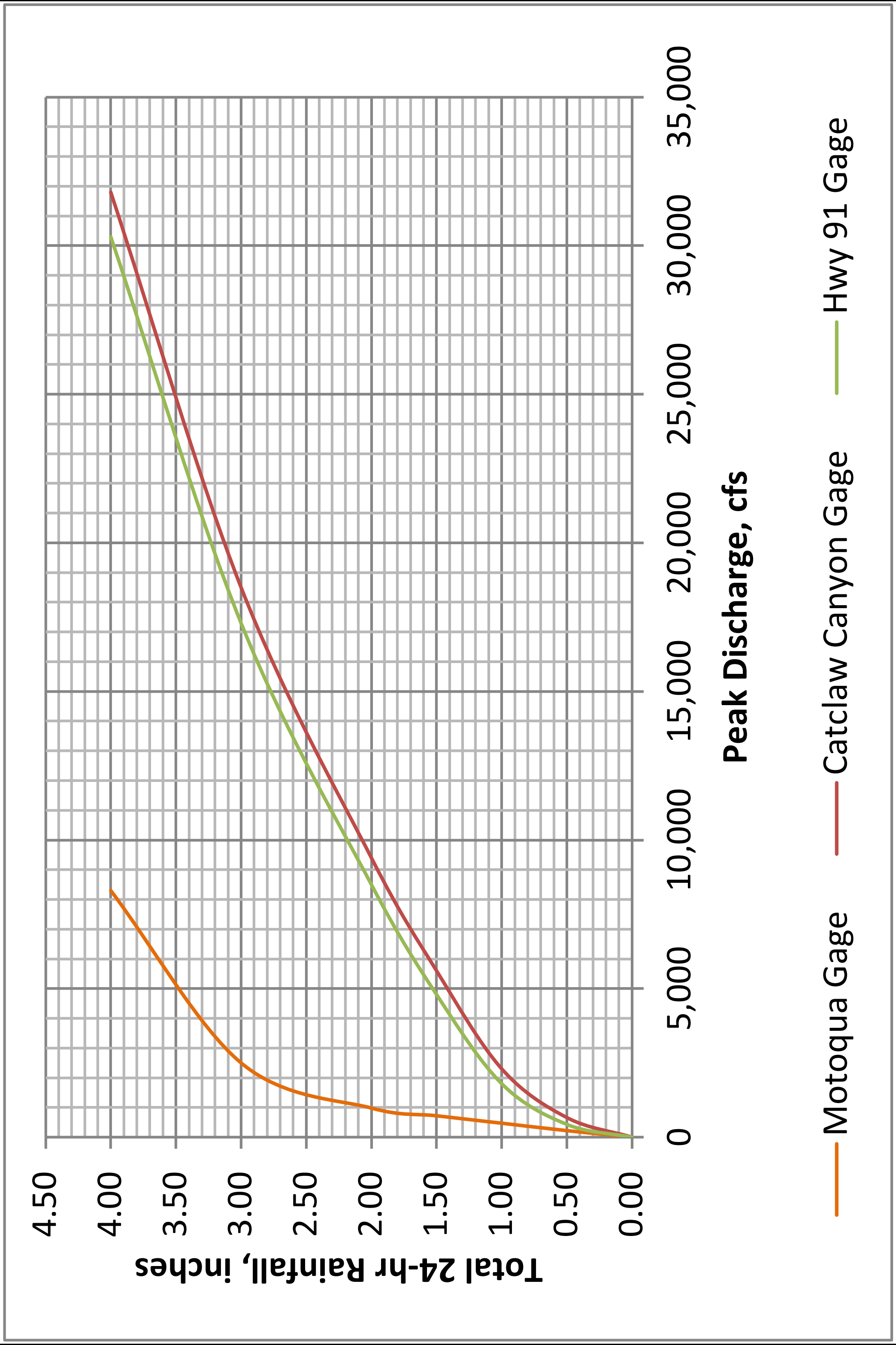


Figure 6.9 24-hour storm rainfall-runoff response for middle watershed

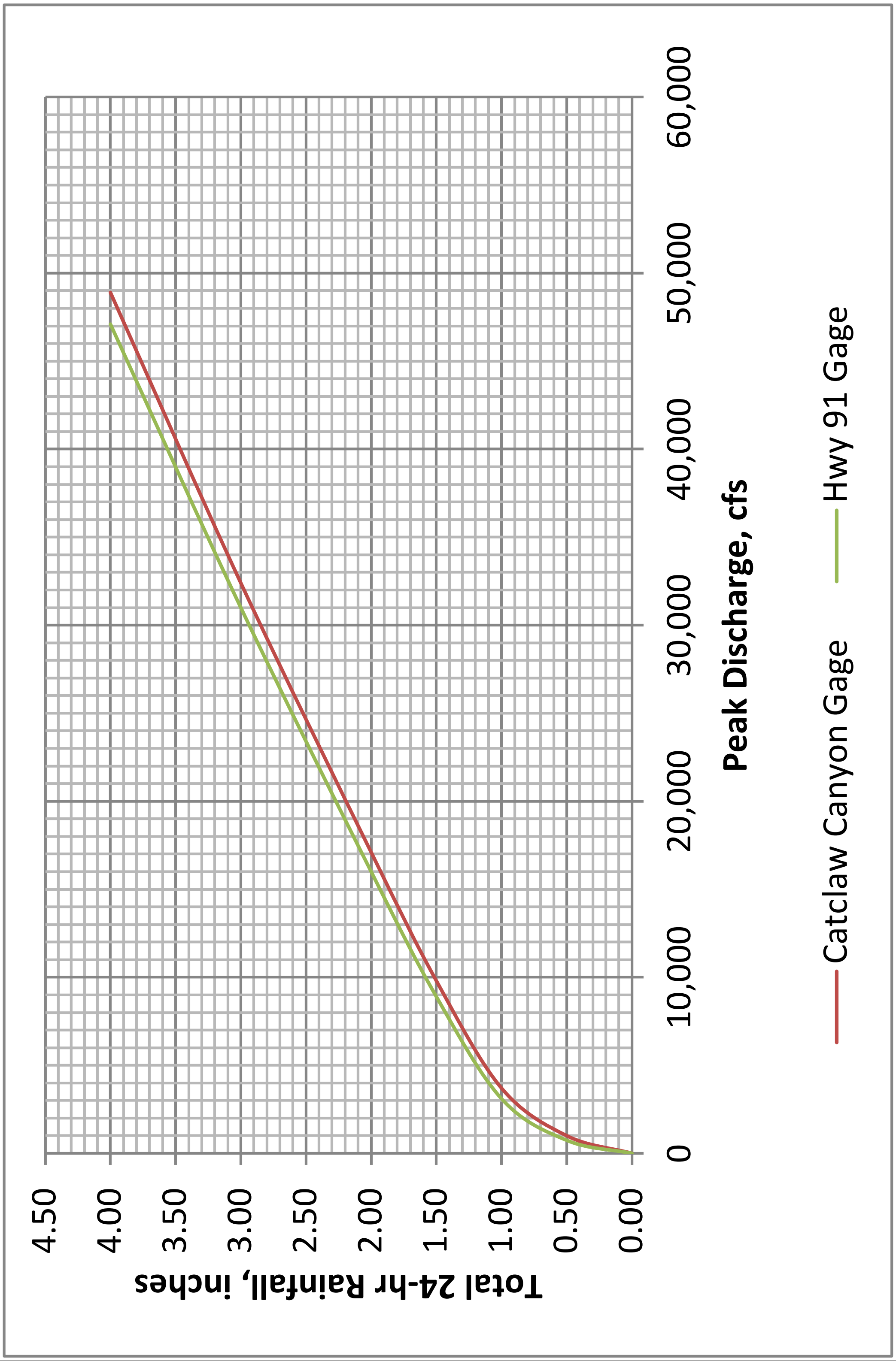
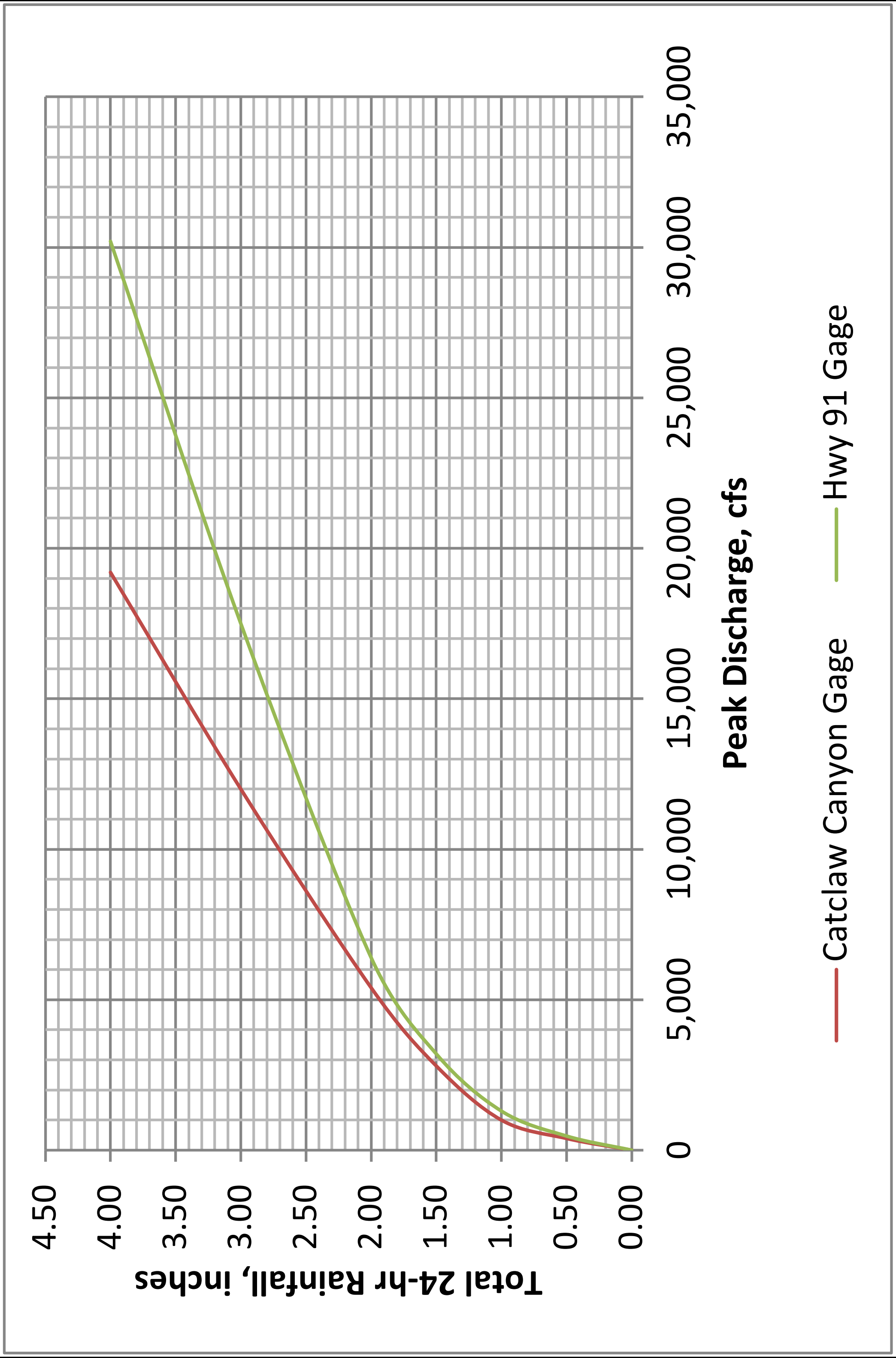


Figure 6.10 24-hour storm rainfall-runoff response for lower watershed



6.4 Short-Duration Storm Type Rainfall-Runoff Hydrographs

6.4.1 Description

The same HEC-HMS models described in Section 6.3.1 were used to prepare the figures in this section. The hydrographs for each watershed scenario and rainfall event described in Section 6.3.1 are plotted on Figure 6.11, Figure 6.12, Figure 6.13, and Figure 6.14. Other critical information shown includes:

- where the threshold location peak discharges plot on each hydrograph
- a table of model results for each threshold location
- the rainfall intensity for the hydrograph rising limb.

6.4.2 Intended Use

The figures provide a visualization of the relationship between modeled rainfall intensity and runoff for each watershed scenario. As rain gage data for the storm event begins to be tabulated, the measured intensity at each gage can be checked against the figures to estimate what the watershed response might be. For each watershed scenario, the following gages should be checked for total rainfall and intensity:

1. Entire Watershed: All Beaver Dam Wash watershed rain gages;
2. Upper Watershed: Beaver Dam State Park (BDSP), Bull Valley Mountains (BVM), Motoqua (M), and Pahcoon Flat (PF);
3. Middle Watershed: Upper Lime Mountain (ULM), Motoqua (M) and Pahcoon Flat (PF); and
4. Lower Watershed: Beaver Dam Sheriff's Station (BD) and Catclaw Canyon (CC).

Rainfall intensities in the range of 2 to 3 inches/hour for a prolonged period greater than 15 minutes could result in the threshold discharges being met or exceeded. Extended rainfall intensities of 0.2 inches/hour or greater for longer periods (hours or days) could also cause the threshold discharges to be met or exceeded. Refer to Section 6.5 for the long duration scenarios. Note that the response time between threshold locations is virtually zero for these scenarios.

6.4.3 Limitations

Same as described in Section 6.3.1.

Figure 6.11 3-inch 24-hour storm hydrographs for entire watershed

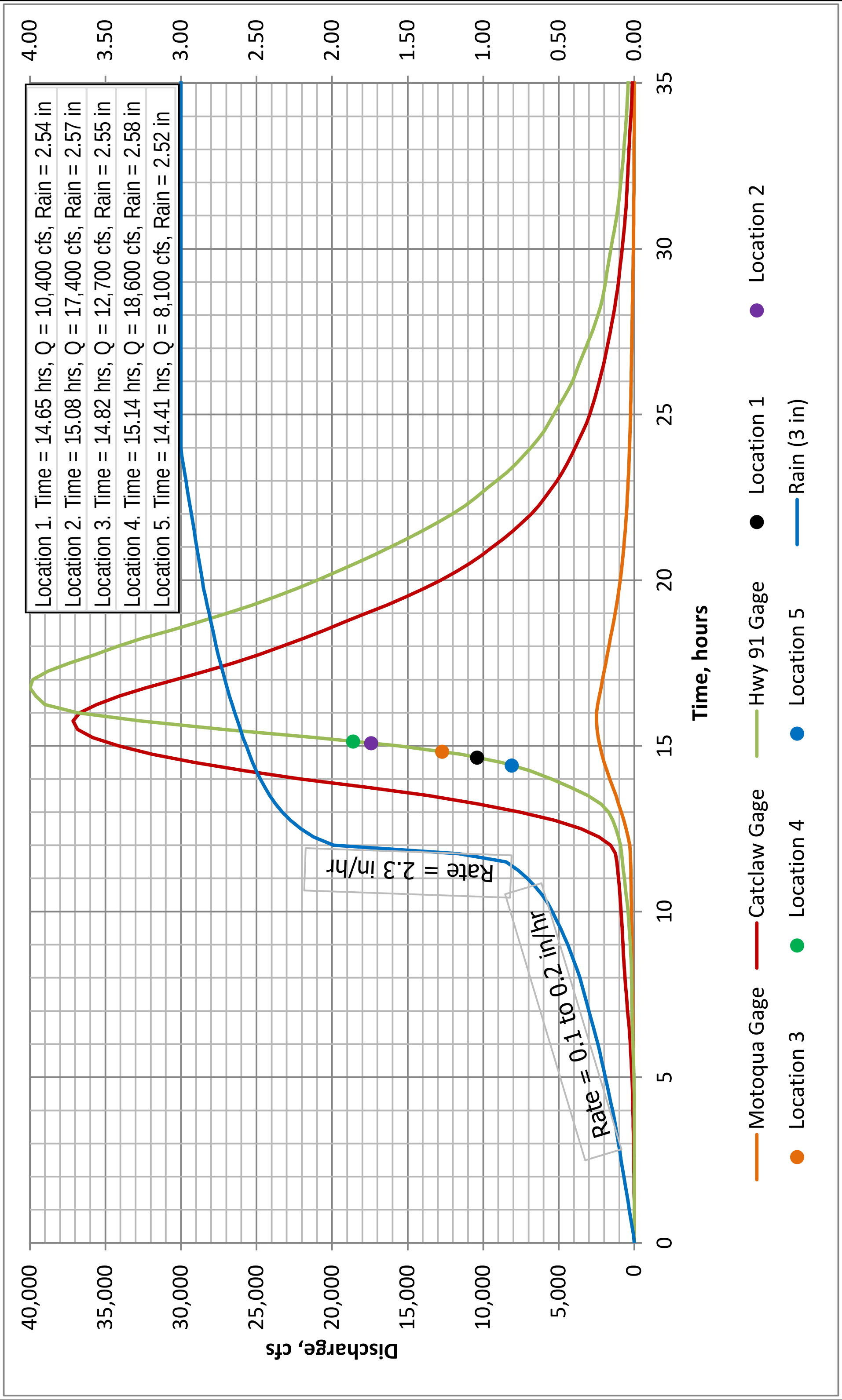


Figure 6.12 4-inch 24-hour storm hydrographs for upper watershed

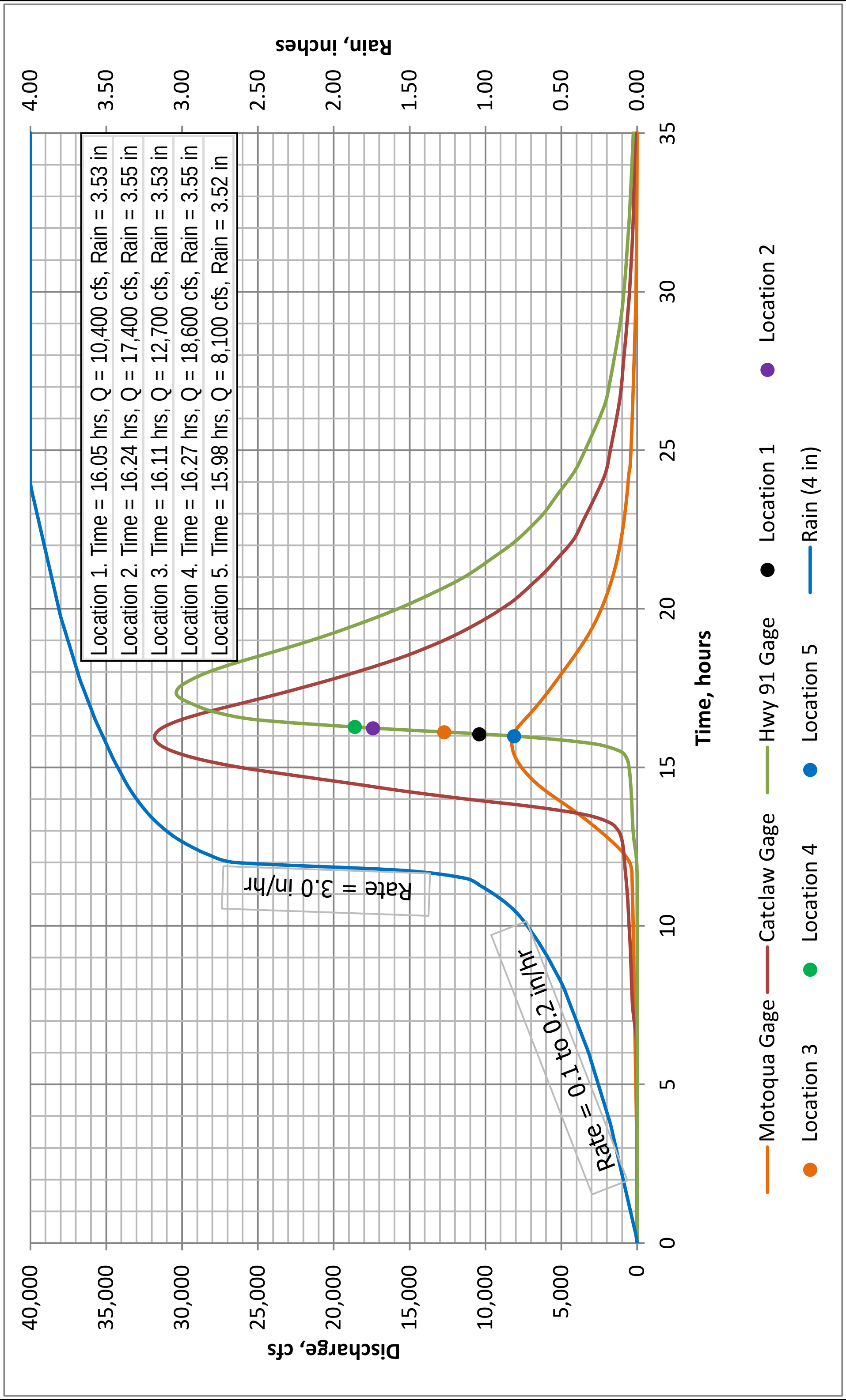


Figure 6.13 3-inch 24-hour storm hydrographs for middle watershed

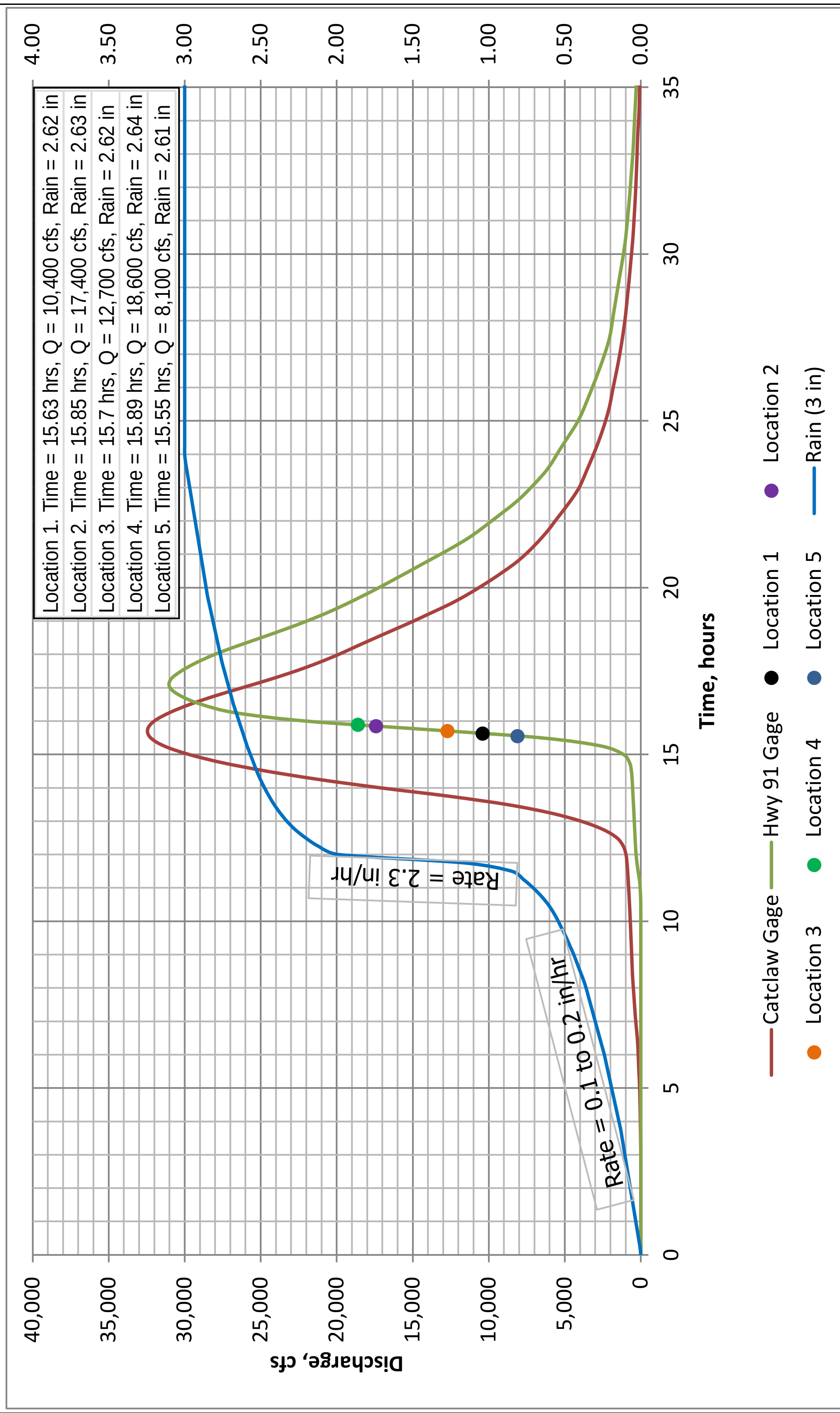
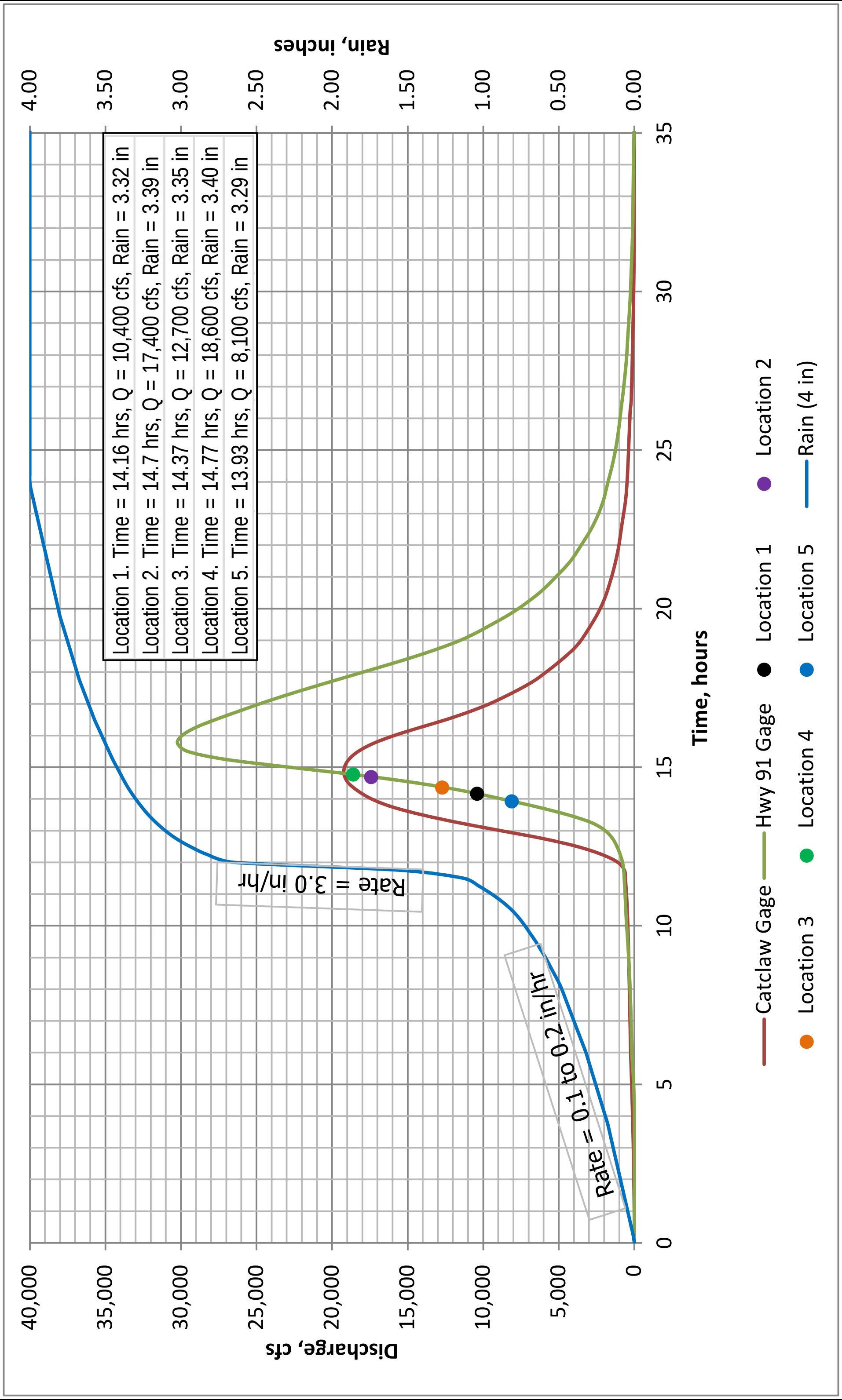


Figure 6.14 4-inch 24-hour storm hydrographs for lower watershed



6.5 Long-Duration Storm Type

6.5.1 Description

The information in this section is derived from HEC-HMS models of the watershed for a 112-hour duration storm using a synthetic rainfall distribution for each rainfall gage. The synthetic rainfall distributions were derived from the December 2010 storm gage measured data as shown on Figure 6.15. The December 2010 storm lasted a little under seven days. The storm duration was scaled to 112 hours by changing the time interval from 15 minutes to 10 minutes. The total synthetic storm rainfall was set at 20 inches. This equates to an average rainfall intensity of 0.18 inches/hour. The duration and total rainfall were based on engineering judgment. The intent is to simulate the business portion of the 2010 storm and to increase the intensity in order to result in peak discharges high enough to flood the areas of concern in Beaver Dam. The HEC-HMS model hydrologic and hydraulic parameters were calibrated using measured rainfall and flow rates from the December 2010 flood event. The model was only run for the entire watershed scenario as a general storm of this type will typically extend over the entire watershed. The results are shown on Figure 6.16. Other critical information shown includes:

- where the threshold location peak discharges plot on the hydrograph rising limb;
- a table of model results for each threshold location; and
- rainfall intensity values.

6.5.2 Intended Use

Figure 6.16 provides a visualization of a possible general or tropical storm scenario relationship between gage-measured rainfall and runoff for the entire watershed. As rain gage data for the storm event begins to be tabulated, the measured intensity at each gage can be checked against the figure to estimate what the watershed response might be. The synthetic rainfall distributions used represent the existing rain gages as follows:

1. Synthetic 1: Beaver Dam State Park (BDSP), Upper Lime Mountain (ULM), Bull Valley Mountains (BVM), and Pahcoon Flat (PF);
2. Synthetic 2: Motoqua (M); and
3. Synthetic 3: Beaver Dam Sheriff's Station (BD) and Catclaw Canyon (CC).

Extended rainfall intensities of 0.1 to 0.3 inches/hour or greater for long periods (4 days in this scenario) could cause the threshold discharges to be met or exceeded.

This scenario is also intended to provide an estimate of response time to reach the various threshold location peak discharges. Figure 6.16 can be used as a basis for estimating how much time will elapse between critical thresholds being reached.

6.5.3 Limitations

The rainfall intensity is based on the intensities that occurred during the December 2010 storm event, although the variations in intensity have been smoothed out for the synthetic storm distributions. The intent is to depict how the watershed may respond to long duration uniform rainfall. The actual rainfall intensity, duration and timing will vary significantly within a natural storm. This approach is only intended to provide an estimate of what effect an incoming storm may have at Beaver Dam.

This scenario is based on the initial soil moisture and initial abstraction estimates made for the modeling of the December 2010 storm. The initial moisture content (DTHETA) is assumed to be “normal” as defined in Mohave County (2012). The initial abstraction values were calibrated using the available gage data. Actual initial soil moisture content and abstraction will vary and will affect the watershed response.

The synthetic rainfall distributions assigned to the rain gage locations are based on the December 2010 storm. Actual rainfall distributions could vary dramatically from storm to storm and within any given storm.

The HEC-HMS routing parameters were taken from a calibrated HEC-RAS model of Beaver Dam Wash. The calibration effort was only done for the 2010 flood peak travel times. Routing results for very low and very high peak discharges have the potential for more error than peak discharges in the 8,700 to 16,000 cfs range.

Figure 6.15 2010 storm synthetic cumulative rainfall distributions

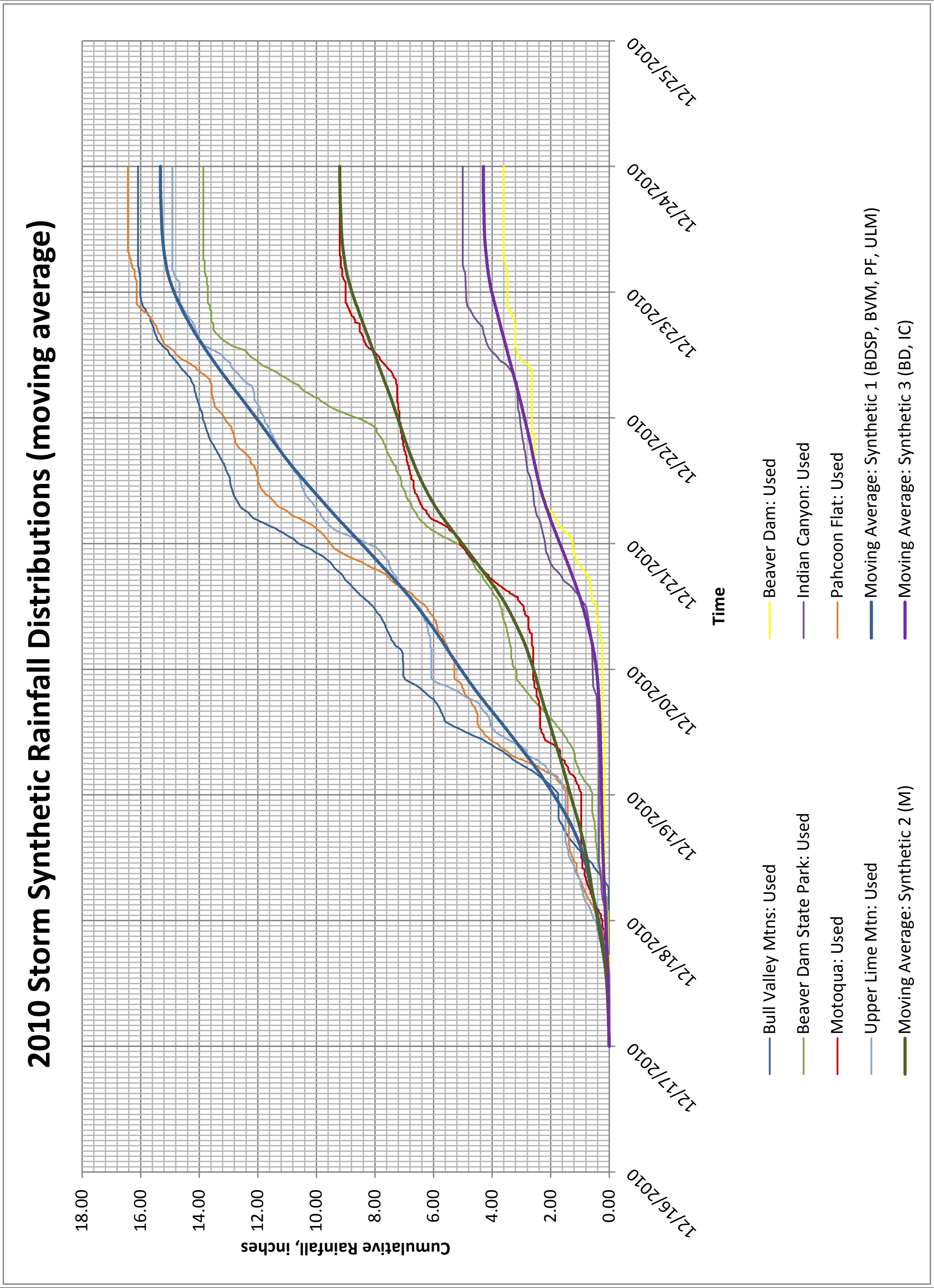
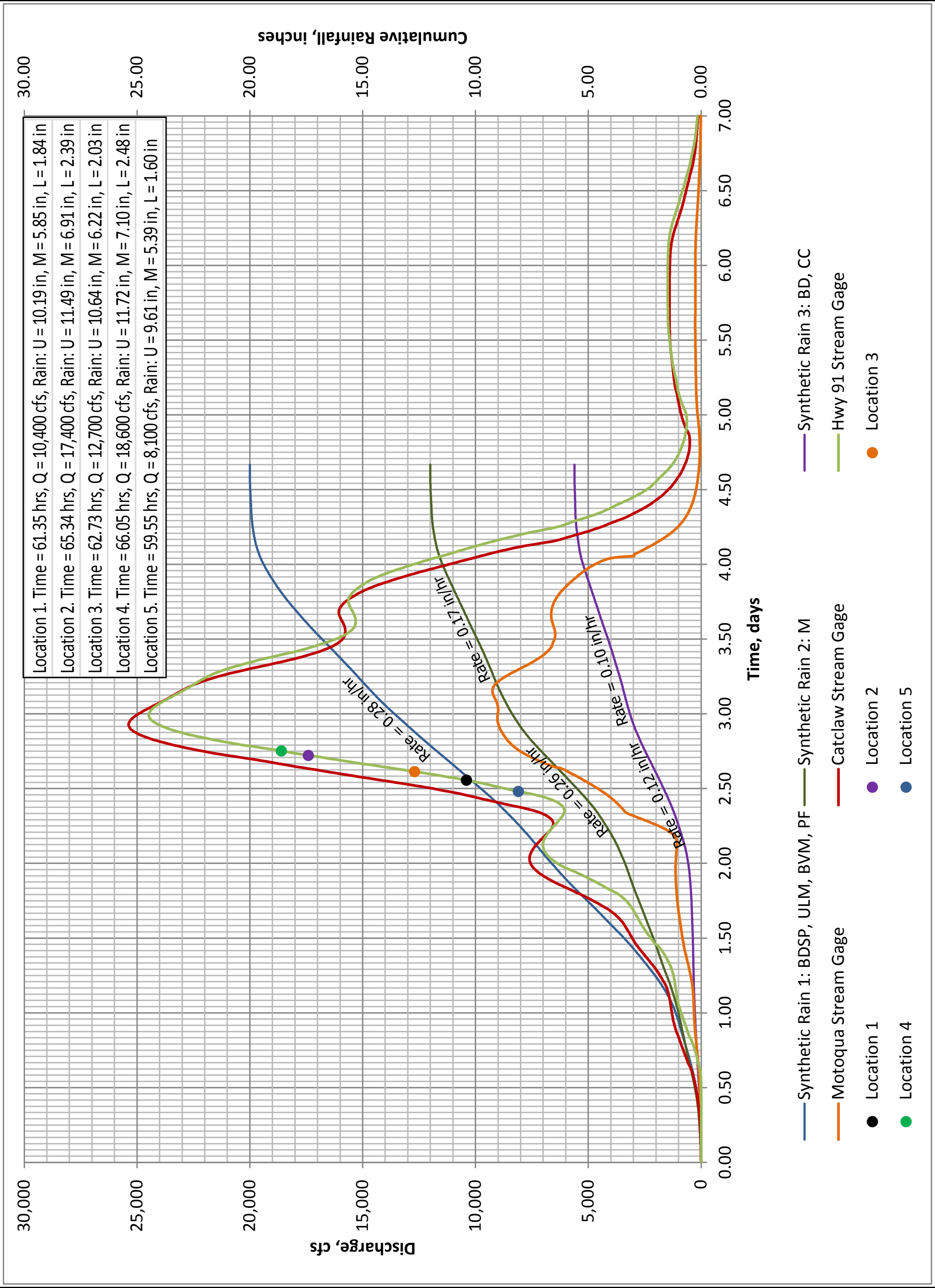


Figure 6.16 20-inch 112-hour storm hydrograph



6.6 Warm Rain on Snow Pack Storm Type

The upper and middle portions of the watershed range in elevation from 3,000 to over 7,500 feet in elevation and are subject to snow accumulation in the winter months. There are two NRCS SNO-TEL sites in or near the watershed as shown on Figure 3.17. A mechanism for high flood volumes and peak discharges in Beaver Dam Wash is to have a large general storm deliver a warm rain on snow pack. This is a difficult scenario to model. Instead, a simplified approach is proposed to estimate the effects of this storm scenario. The steps are as follows:

1. Estimate the average snow pack depth and water content over the upper and/or middle watershed areas.
2. Assume 75% of all melted snow will result in runoff (rainfall loss including IA of 25%)
3. Estimate an equivalent depth of water using the snow pack water content and depth added to the total rainfall received. If estimates of snow pack depth and water content cannot be obtained, carefully monitor the rain gages for rapid increases in water resulting from melted snow. Note that this will result in shorter response times.
4. Use Figure 6.8 and Figure 6.9 to estimate a resulting peak discharge.
5. Closely monitor the Motoqua and Catclaw Canyon gage readings for trends toward reaching the estimated peak discharge.
6. Make Warning Stage judgments based on this information.

For example, the Colorado Basin River Forecast Center indicates the presence of a snow water-equivalent depth of 1.5-inches at the two SNO-TEL sites. The Beaver Dam State Park reports 6-inches of snow depth in and around the park. It is estimated through conversations with the NWS that the water content of the snow pack is about 30%. It has rained an estimated 1-inch on the upper watershed.

Estimated Equivalent Rain at Beaver Dam State Park= 6*0.3*0.75 + 1 = 2.4-inches.

SNO-TEL sites indicate 1.5-inches. Estimated rain equivalent = 1.5 + 1 = 2.5-inches.

Use an estimated rain equivalent of 2.4-inches.

From Figure 6.8 and Figure 6.9, the peak discharge estimates for 2.4-inches of rain are:

Motoqua: 1,400 cfs, Catclaw Canyon: 14,000 cfs, Highway 91: 12,000 cfs

6.7 Travel Time Curves

6.7.1 Description

A HEC-RAS model was created of the entire length of Beaver Dam Wash between the Motoqua gage and the Virgin River. Post 2010 flood detailed topographic mapping was available from the Virgin River to the Catclaw Canyon gage, and for the Motoqua gage site. The USGS National Elevation Data (NED) was used where detailed topographic mapping was not available. The HEC-RAS model was calibrated to match measured travel times of peak discharge between gage sites for the December 2010 flood and to match observed high water marks. The model was run in steady state mixed flow regime mode for a range of peak discharges between 50 and 40,000 cfs. The model results were used to prepare travel time curves for various flow rates. Refer to Figure 6.17, Figure 6.18, and Figure 6.19. Curves are provided for minimum, normal and maximum roughness estimates.

6.7.2 Intended Use

These curves are intended to be used as a tool to estimate travel time between the Motoqua, Catclaw Canyon and Highway 91 gage sites. If a very high peak discharge is observed at the Catclaw Canyon gage, for instance, the curves can be used to estimate when that peak discharge will arrive at Beaver Dam.

6.7.3 Limitations

The HEC-HMS routing parameters were taken from a calibrated HEC-RAS model of Beaver Dam Wash. The calibration effort was only done for the 2010 flood peak travel times. Routing results for very low and very high peak discharges have the potential for more error than peak discharges in the 8,000 to 15,000 cfs range.

Rainfall occurring in the watershed can dramatically influence when flood peaks arrive in Beaver Dam. If rainfall in the lower watershed is occurring simultaneously with rain in the middle watershed, a peak discharge at Catclaw Canyon could be replicated at nearly the same time at Highway 91.

Figure 6.17 Estimated travel times for minimum roughness

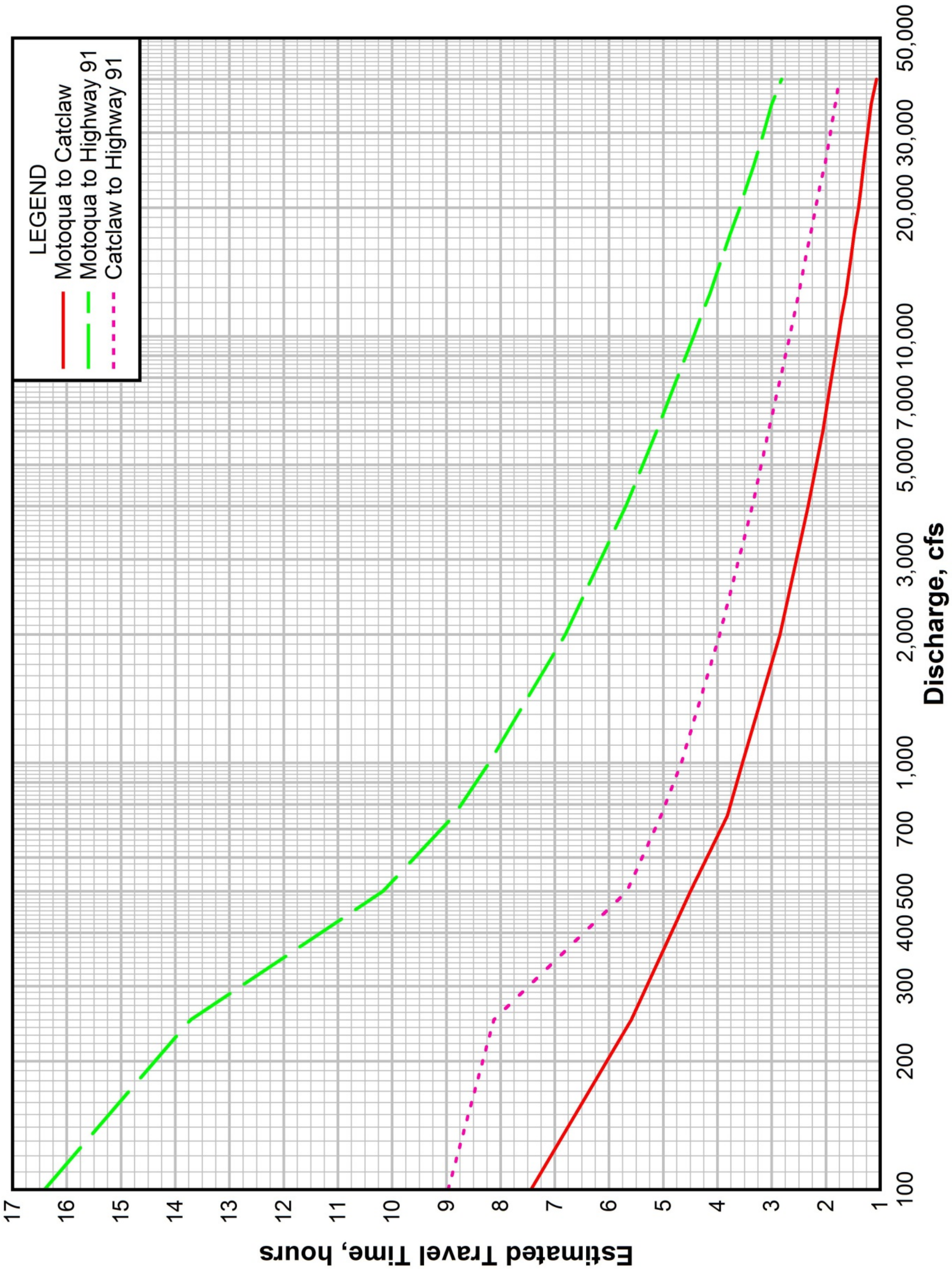


Figure 6.18 Estimated travel times for normal roughness

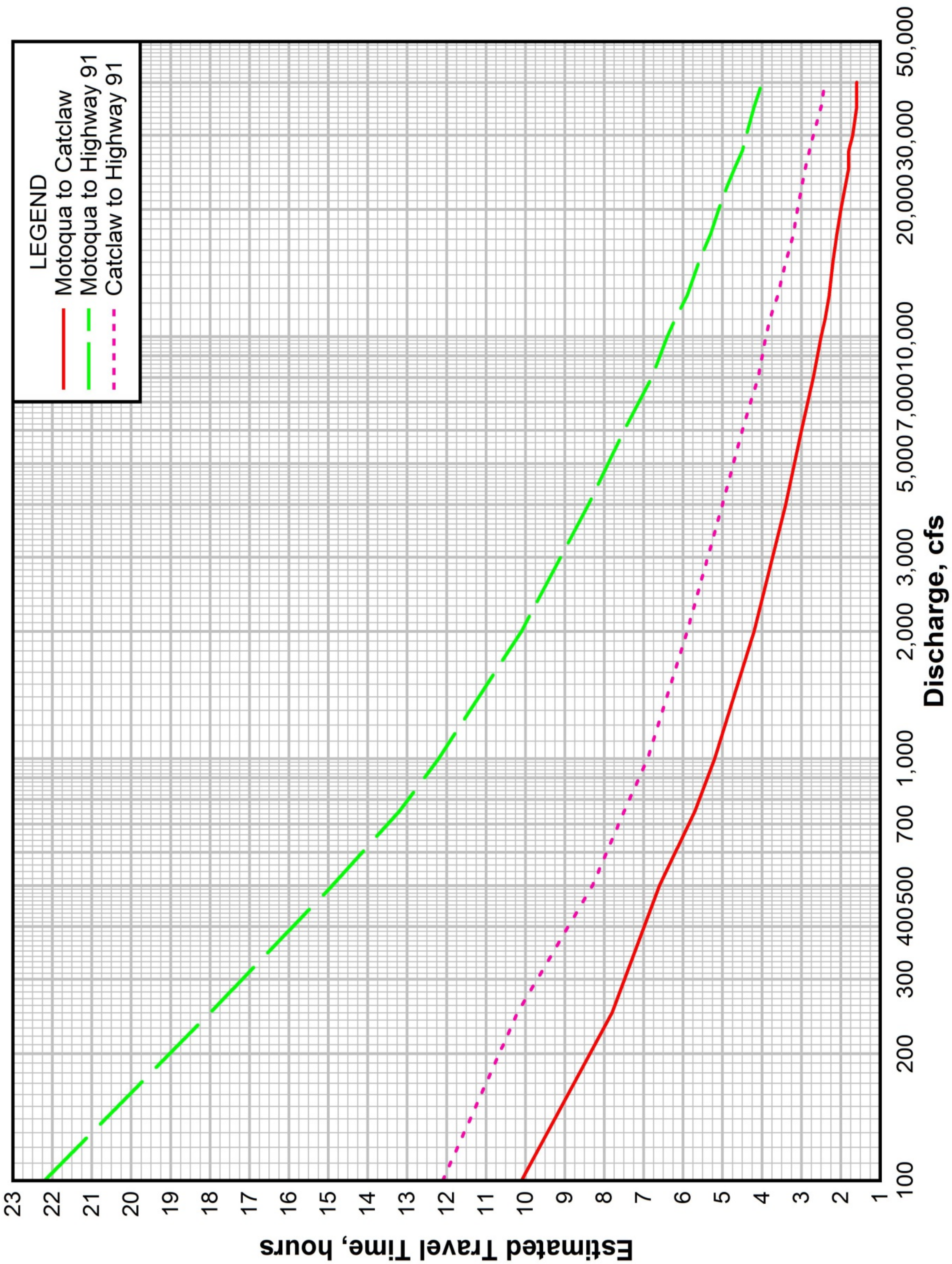
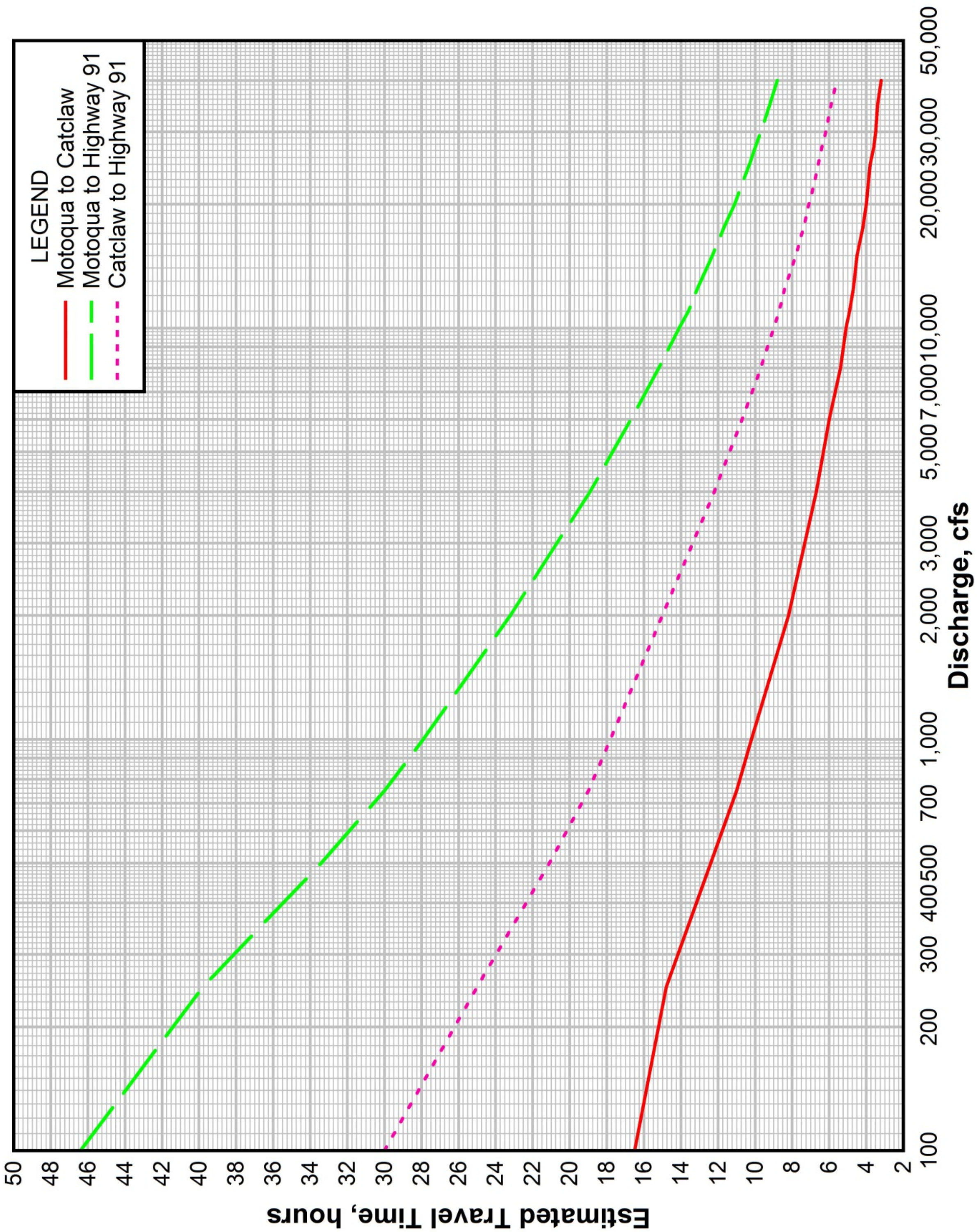


Figure 6.19 Estimated travel times for maximum roughness



6.8 Stream Flow Gage Rating Curves

6.8.1 Description

Hydraulic rating curves were developed as a part of this study for three stream flow gages recommended in AridHH (2007). The Indian Canyon gage has been removed from service. These curves were developed for use with the Mohave County flood warning ALERT system. The rating curves are shown in tabular form in Table 6.13 and graphically on Figure 6.20 through Figure 6.22. The Motoqua and Catclaw Canyon rating curves are based on HEC-RAS model results. The Highway 91 Bridge rating curve is based on a FLO-2D model.

6.8.2 Intended Use

These curves are intended to be used as a tool to estimate peak discharge from stream gage readings.

6.8.3 Limitations

The HEC-HMS routing parameters were taken from a calibrated HEC-RAS model of Beaver Dam Wash. The calibration effort was only done for the 2010 flood peak travel times. Routing results for very low and very high peak discharges have the potential for more error than peak discharges in the 8,000 to 15,000 cfs range.

Rainfall occurring in the watershed can dramatically influence when flood peaks arrive in Beaver Dam. If rainfall in the lower watershed is occurring simultaneously with rain in the middle watershed, a peak discharge at Catclaw Canyon could be replicated at nearly the same time at Highway 91.

Table 6.13 Rating curve data for stream flow gages

Discharge	Motoqua		Catclaw Canyon		Highway 91 Bridge	
	Height	WSEL	Height	WSEL	Height	WSEL
cfs	ft	ft	ft	ft	ft	ft
0	0.00	3424.84	0.00	2632.32	0.00	1827.85
100	0.90	3425.74	0.00	2633.63	1.25	1830.76
250	1.47	3426.31	0.00	2634.18	1.88	1831.39
500	1.93	3426.77	0.26	2634.62	2.70	1832.21
750	2.40	3427.24	0.58	2634.94	3.16	1832.67
1,000	2.72	3427.56	0.85	2635.21	3.49	1833.00
2,000	3.47	3428.31	1.48	2635.84	3.75	1833.26
4,000	4.28	3429.12	2.39	2636.75	4.20	1833.71
6,000	4.86	3429.70	2.96	2637.32	4.59	1834.10
8,000	5.21	3430.05	3.41	2637.77	5.19	1834.70
10,000	5.39	3430.23	3.78	2638.14	5.70	1835.21
11,000	5.63	3430.47	3.94	2638.30	6.10	1835.61
12,500	5.90	3430.74	4.13	2638.49	6.89	1836.40
15,000	6.16	3431.00	4.46	2638.82	7.57	1837.08
17,500	6.44	3431.28	4.76	2639.12	8.22	1837.73
20,000	6.70	3431.54	5.03	2639.39	8.78	1838.29
22,500	6.93	3431.77	5.31	2639.67	9.33	1838.84
25,000	7.20	3432.04	5.56	2639.92	9.78	1839.29
27,500	7.27	3432.11	5.81	2640.17	10.67	1840.18
30,000	7.46	3432.30	6.05	2640.41	11.45	1840.96
35,000	7.79	3432.63	6.50	2640.86	12.04	1841.55
40,000	8.13	3432.97	6.93	2641.29	12.71	1842.22
Sensor Elev:	3424.63		2634.36		1829.51 (ground)	
(orange)	Height above Pressure Transducer Sensor					
(yellow)	Height above average ground elevation below radar transmitter.					

Figure 6.20 Motoqua gage rating curve

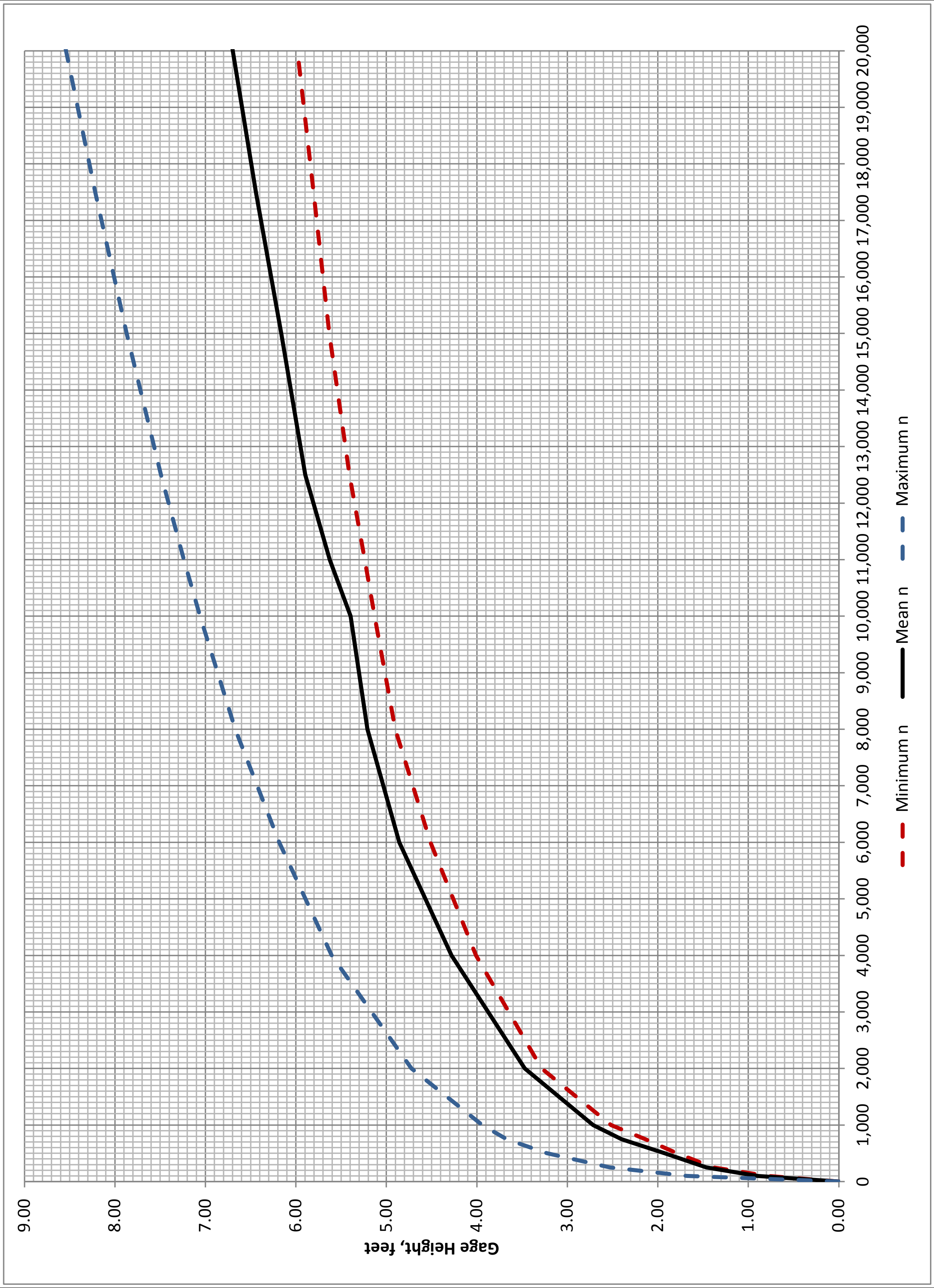


Figure 6.21 Catclaw Canyon gage rating curve

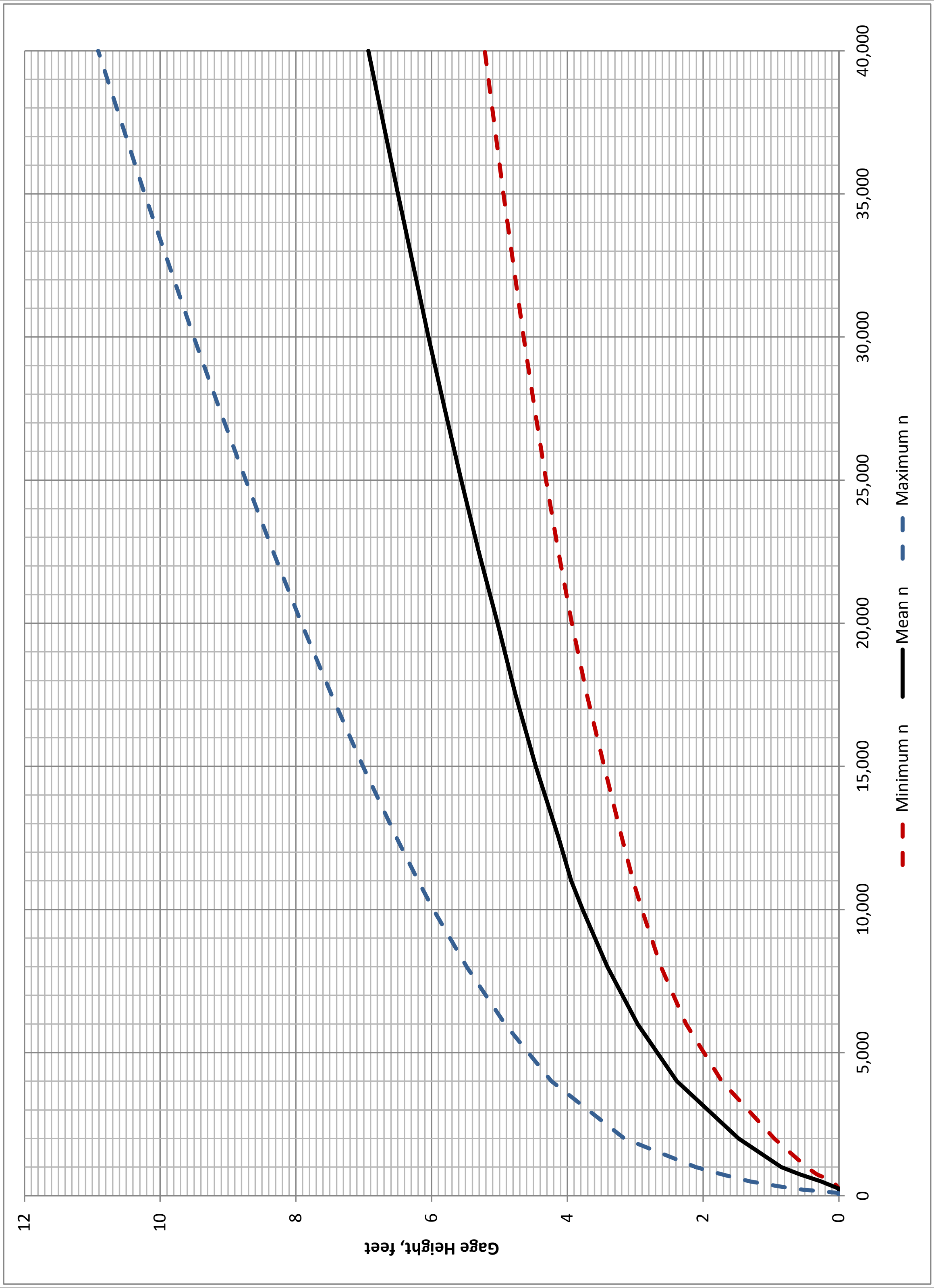
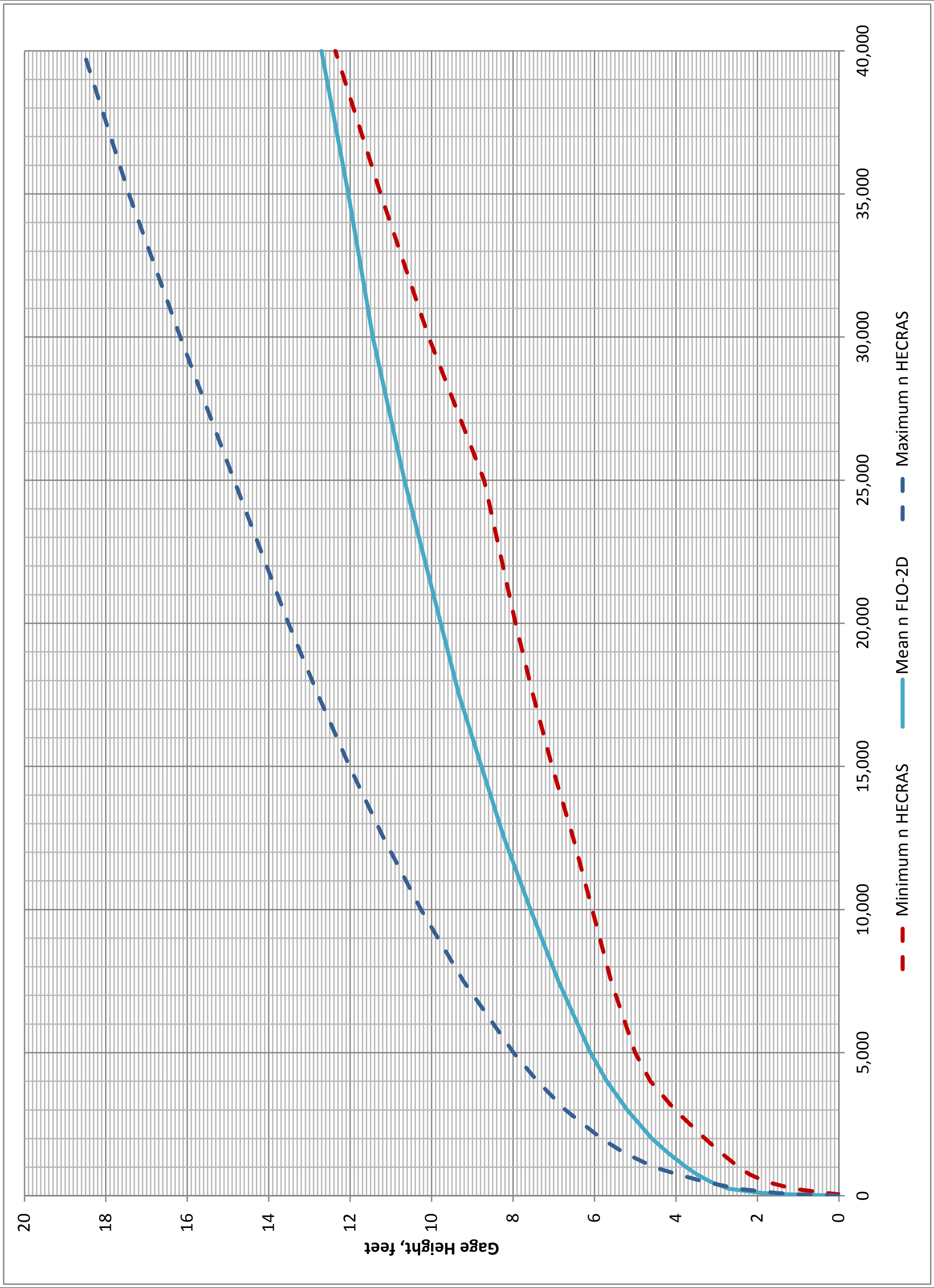


Figure 6.22 Highway 91 Bridge rating curve



6.9 Erosion Hazards

6.9.1 General

Erosion resulting in lateral migration of the Beaver Dam Wash channel is a significant hazard. The January 2005 flood, with a peak discharge in the range of 17,000 cfs to 25,000 and a flood duration of about 5 days, resulted in lateral migration distances ranging from 0 feet to over 400 feet, as shown on Figure 6.23. The December 2010 flood, with a peak discharge of about 13,300 cfs and a flood duration of seven days, resulted in lateral migration distances ranging from 0 feet to over 275 feet, as shown on Figure 6.24 and Figure 6.25. In the 2010 flood, four homes were totally destroyed due to lateral migration of the channel.

Therefore, considerations for lateral migration of the Beaver Dam Wash channel are a component of the hydrology & hydraulic investigations supporting the FWRP. Lateral erosion can be expected to begin occurring for flow rates as low as 3,000 cfs. For this reason, critical threshold estimates for erosion are included in Table 6.2 for locations 1, 6 and 7. Locations 1 and 6 are shown on Figure 6.1 and Location 7 is shown on Figure 6.2. Note that the entire length of bank where existing structures are located could be affected. Separate recommended evacuation areas for Location 1 and Location 6 are shown on Figure 6.27. The channel bank in both areas should be closely monitored during a flood event to determine if bank migration is occurring to help with an evacuation decision.

Location 7 is an area protected by erosion control measures that could fail. Therefore, it is recommended that this area be monitored during flood events to check for possible bank erosion. The area that could be affected and is subject to possible evacuation is shown on Figure 6.28.

The Beaver Dam Estates area (Locations 3 and 4) is protected from bank erosion by structural measures. This area should also be monitored during a flood event to identify and react to any indications of structural failure.

6.9.2 Approach

The estimates of erosion extent from the January 2005 and December 2010 floods were made based on aerial photographs taken before and after each event. These estimates were checked against the equations in ADWR (1996), which are used for estimating erosion setback distances. Those equations are recommended by ADWR to be limited to watershed sizes less than 30 square miles. The peak discharges for the 2005 and 2010 events are estimated to be 21,000 cfs and 13,300 cfs, respectively. Applying the ADWR equation for *channels with obvious curvature or channel bend* assuming that the equation applies for any discharge, not just the 100-year peak, yields:

Setback = $2.5Q_{100}^{0.5} = 2.5 \times (25{,}000)^{0.5}$ = 395 feet, which is a reasonable check against the estimated 415 feet that actually occurred.

Setback = $2.5Q_{100}^{0.5} = 2.5 \times (13{,}300)^{0.5}$ = 288 feet, which is a reasonable check against the estimated 275 feet that actually occurred.

Using the above equation for threshold discharges of 10,000 cfs and 21,000 cfs, erosion hazard zones were determined using setback distances of 250 feet and 360 feet, respectively. The setbacks are measured from the post December 2010 flood bank limits. Those zones are shown on Figure 6.26. The recommended evacuation areas shown on Figure 6.27 and Figure 6.28 are derived from the erosion setback zones.

6.9.3 Limitations

Actual erosion or bank movement at any given location could be negligible or even more severe depending on the discharge and duration of flow. These areas should be closely monitored and judgment exercised when applying this information during a flood event.

Figure 6.23 Bank migration as a result of the January 2005 flood event

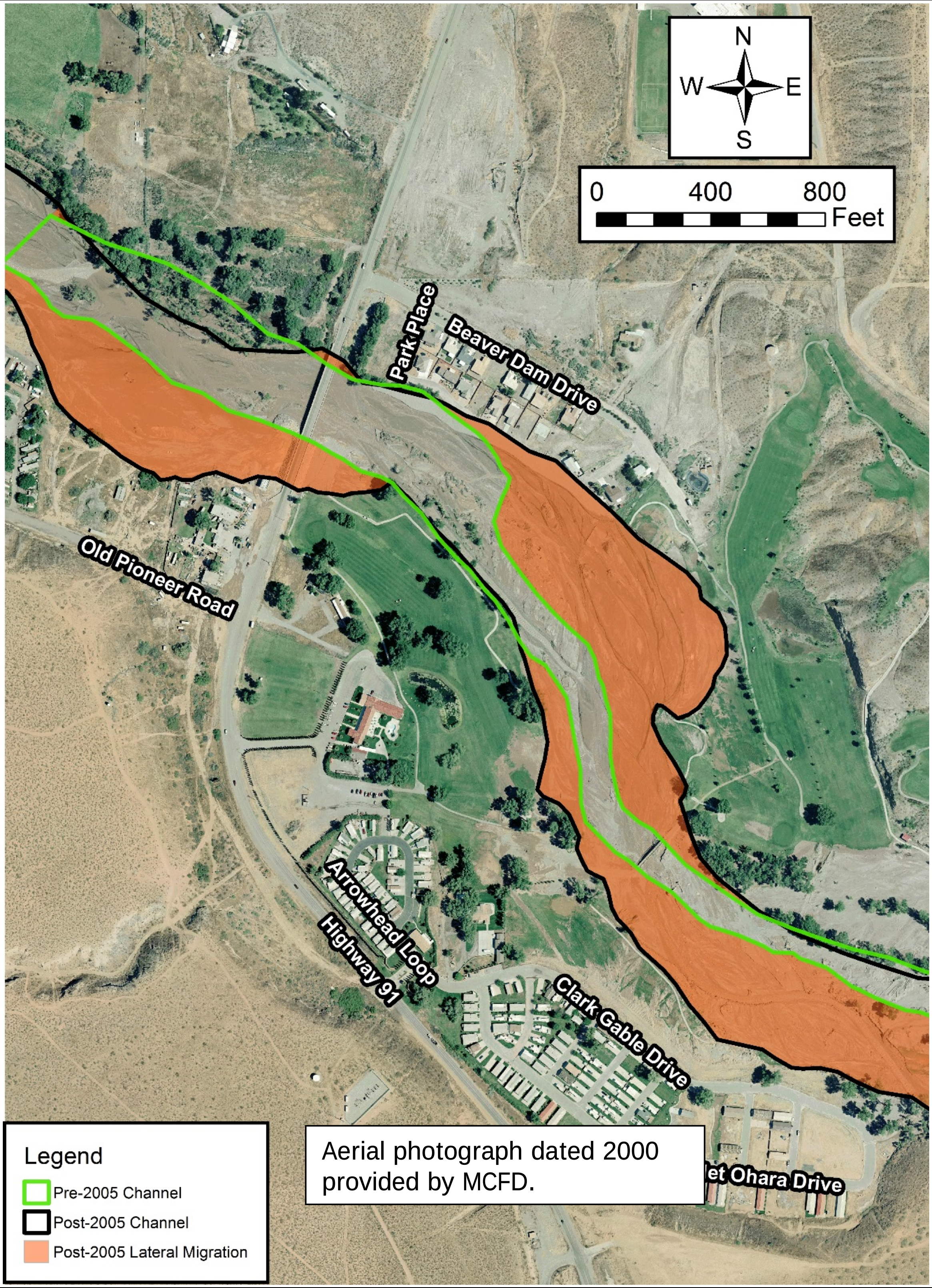


Figure 6.24 Bank migration as a result of the December 2010 flood event 1

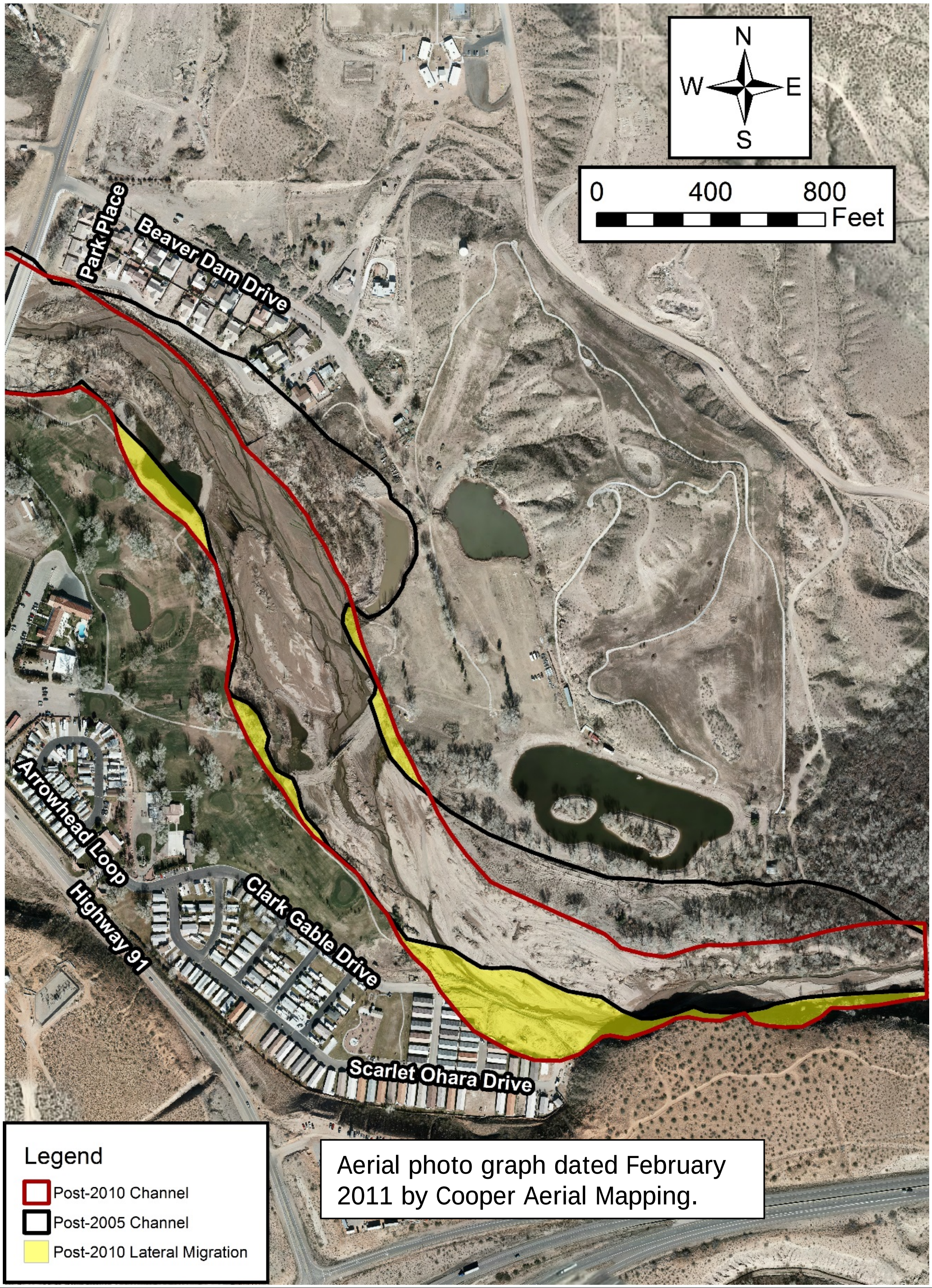


Figure 6.25 Bank migration as a result of the December 2010 flood event 2

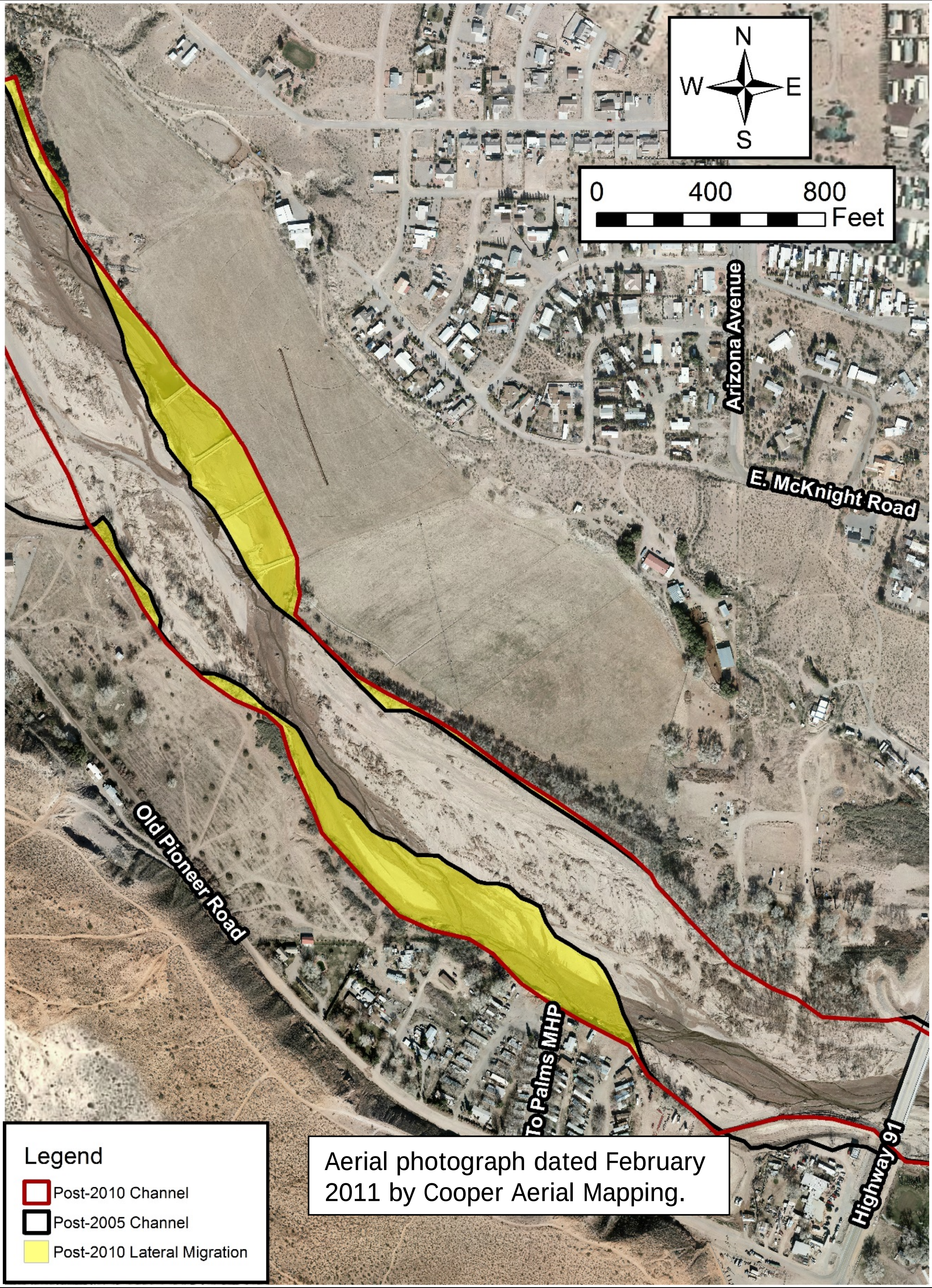


Figure 6.26 Erosion setback zones for critical threshold discharges

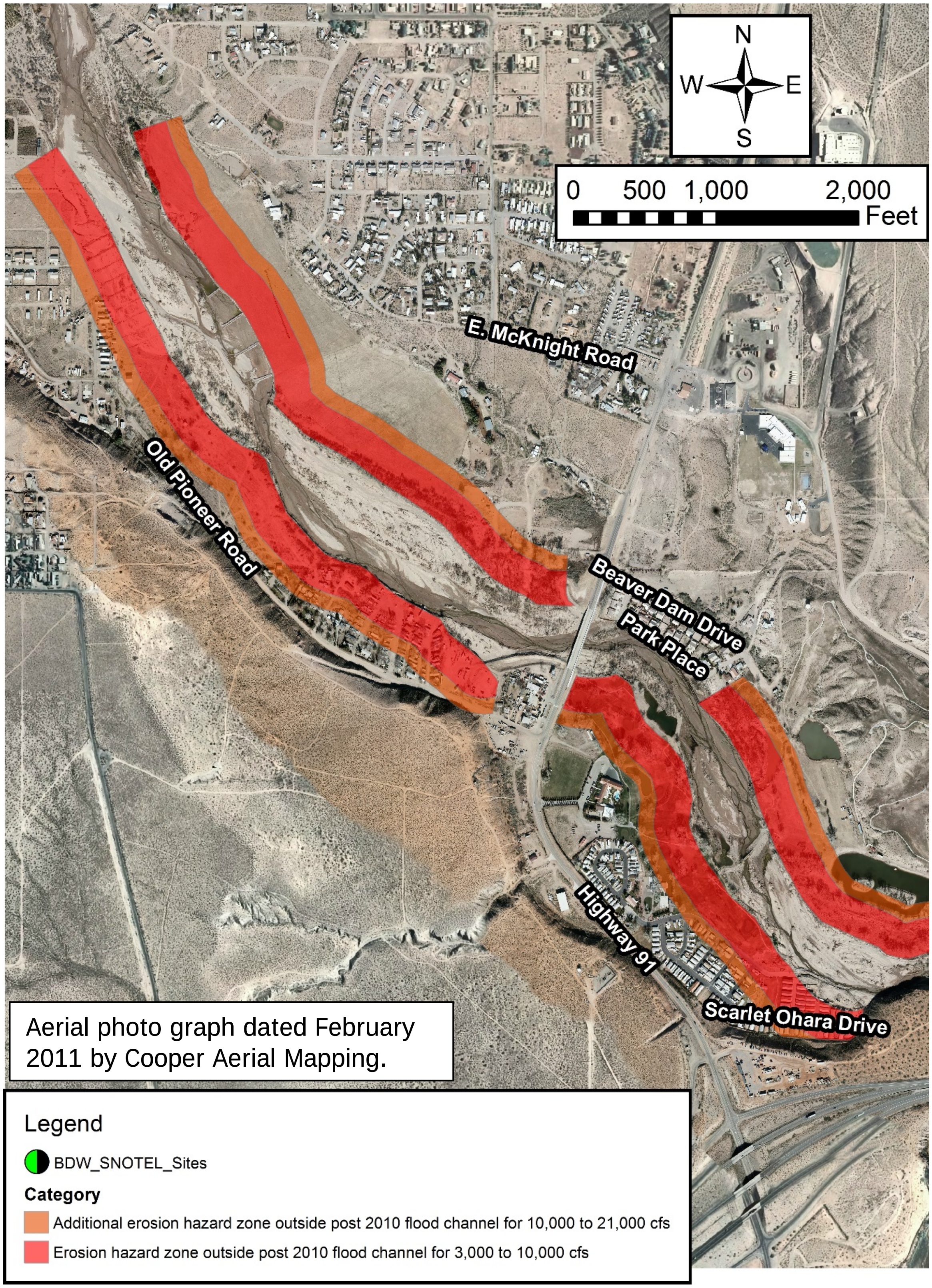


Figure 6.27 Recommended evacuation areas due to erosion hazard

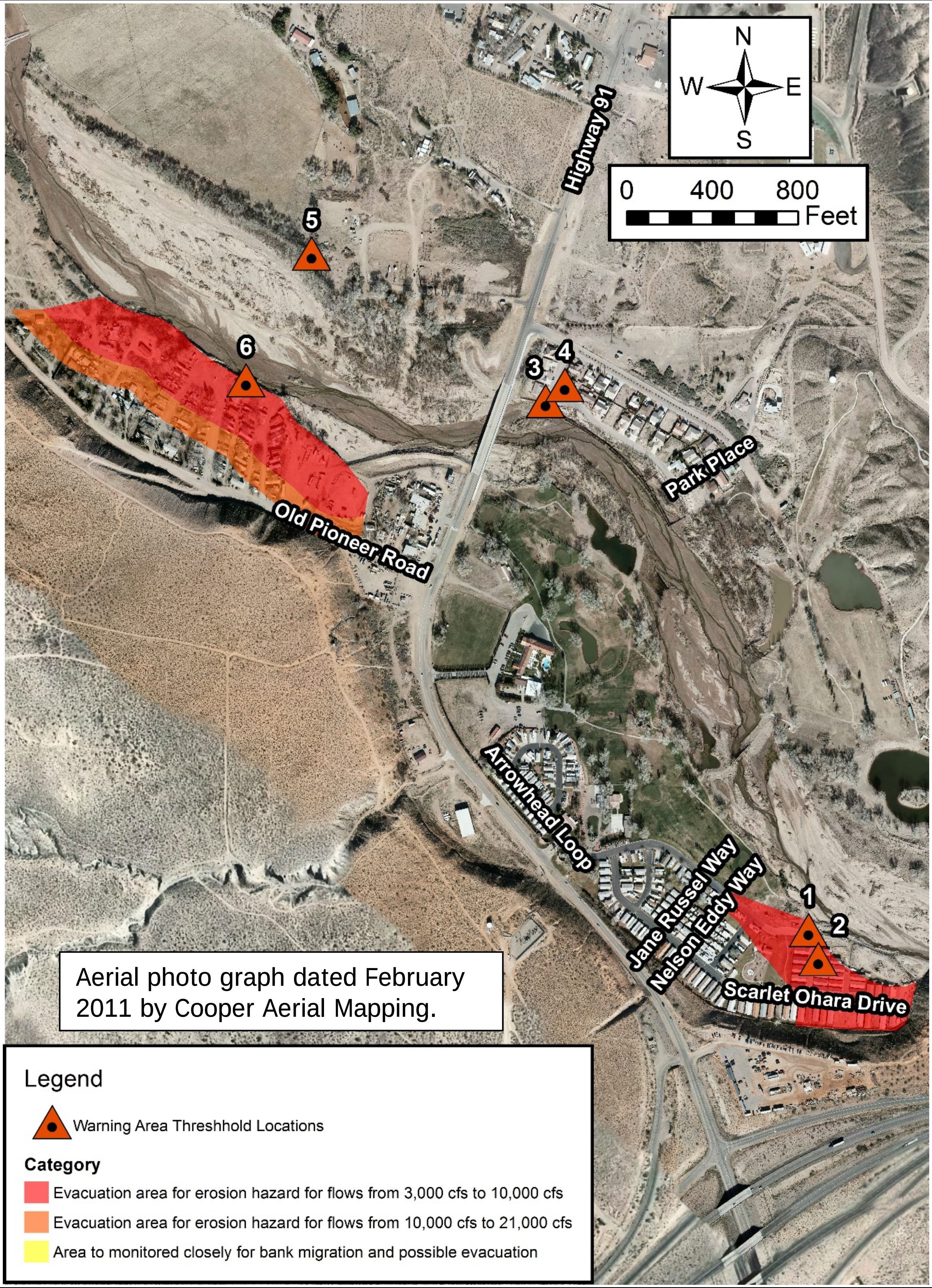
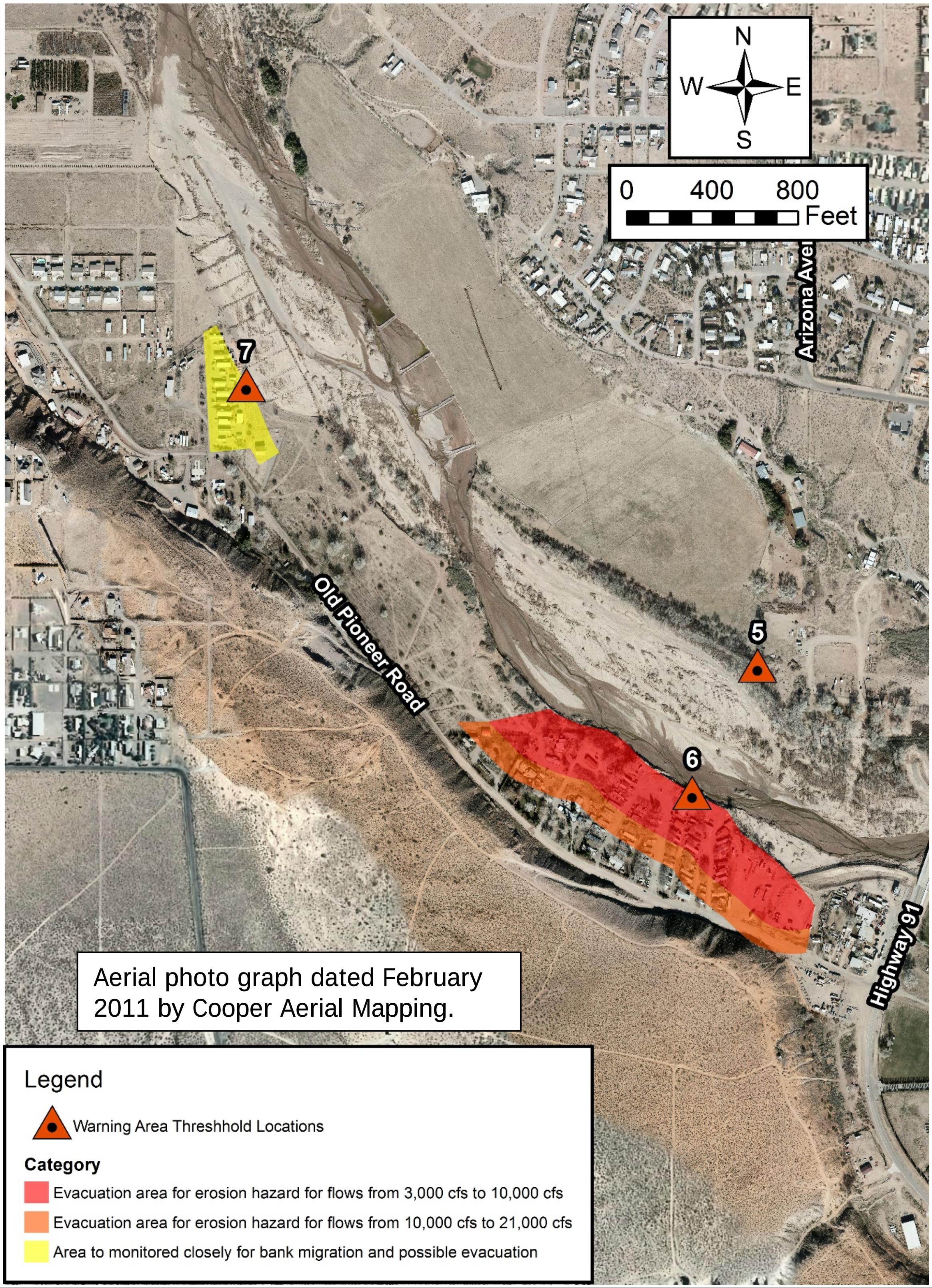


Figure 6.28 Recommended areas monitor for erosion hazard



6.10 Highway 91 Stream Flow Gage not Functioning Scenario

In the event the Highway 91 stream flow gage is not functioning, the following is the recommended procedure to follow as a backup plan.

1. Keep an appropriate measuring device at the Sheriff's Station Rain Gage storage shed. The device should consist of a nylon-coated steel measuring tape such as the *Keson NR10100 Nylon Coated Steel Blade 100-Foot Measuring Tape In Tenths With Extra Dead Foot And Ring End* or equivalent, and a 16 oz. plumb bob (with string) such as an *Stanley 47-974 16 oz Brass Plumb Bob.* An alternative is a laser measuring device such as the *Johnson Laser Distance Measure 40-6004*. The physical approach is preferred as batteries are not required, other than for a flashlight for night time measurements.

2. Station a qualified person, with an assistant, at the gage location on the bridge. Refer to Figure 6.29.

3. Take measurements every 15-minutes from the bottom of the cabinet at the radar sensor to the water surface directly below the radar sensor cabinet. The average bottom elevation of the radar sensor cabinet is 1852.55. Subtract each reading from 1852.55 to obtain an estimate of the water surface elevation. The assistant should record each reading. The WSEL can then be used with the information in Table 6.2 for checking warning level thresholds, and with Figure 6.22 for estimating peak discharge at the Highway 91 Bridge. Figure 6.22 is in terms of gage height. To obtain gage height from the physical measurement, subtract 1829.5 from the estimated WSEL. 1829.5 is the average ground elevation below the radar sensor as of January 2013.

Figure 6.29 Location of Highway 91 stream gage radar sensor cabinet

7 TOOL FOR USING RAIN GAGE DATA WITH HMS

7.1 Description

This program is designed to move measured rainfall data from a group of rain gage data files into an HMS model of the watershed containing the gages. The intent is to use this program during a flood emergency to estimate runoff at critical locations. The tool could also be used for calibration of HMS models. Data from an ALERT system rain gage group must first be exported to an ASCII text file or files. This is done using the MCFCD ALERT web page and the "Custom Reports" option.

When a group of rain gages is selected, the data is exported in uniform time steps specified by the user. The program will load the data from all of the gages in the selected group and convert it from incremental to cumulative. The user can then select which gages are to be used. The MCFCD ALERT system can only export a little over 24-hours of data at a time when a 15-minute time step is used. Therefore, this program allows selecting multiple data files for successive time periods. The data is then parsed and checked for missing data.

A Python script is created and used to write the parsed and collated data into a single DSS file for use in HEC-HMS. The DSS file is in a binary format that the US Army Corps of Engineers uses for data exchange between its various software programs. The Python script is executed and the data written into the specified DSS file. The HEC-HMS program is then executed so the user can load the previously prepared model of the watershed containing the gages, run it, and obtain estimates of peak flow at various locations defined within the model.

It is critical that an HMS model of the watershed be constructed first for the watershed of interest. The HMS model should then include rainfall using the physical MCFCD ALERT system rain gages present in the watershed based on their spatial location and weighting each gage appropriately in relation to the centroids of the model sub-basins or other points. The precipitation gages should be defined as time-series data using the external DSS file source instead of by manual entry. Refer to the HEC-HMS User Manual for guidance.

A template HMS project of the Beaver Dam Wash watershed has been prepared for use during flood emergencies. The gages are pre-defined and setup to work with this program. The template HMS project is included in APPENDIX A on the USB storage drive under the

\Rain_To_HMS Tool\BDW_Storm_Template folder. An example HMS project is also included in APPENDIX A on the USB storage drive under the *\Rain_To_HMS Tool\Storm_DSS* folder.

It is assumed the user has a working knowledge of HMS. This section does not attempt to cover appropriate use of the HMS model.

7.2 Installation and Setup of the Program

7.2.1 Installation

The install package is included in APPENDIX A on the USB storage drive under the *\Rain_To_HMS Tool\Tool Installation* folder. Run the setup.exe file and follow the prompts. The program is installed under the user's individual account folder, so administrative privileges are not required. The program can be run from the Start menu under *Start\All Programs\Mohave County Flood Control District\Hydrology Applications*. The program name is "*ALERT Group Rain Gage to HEC-HMS*". A shortcut is not created on the Desktop during installation. The user will need to do this manually if one is desired.

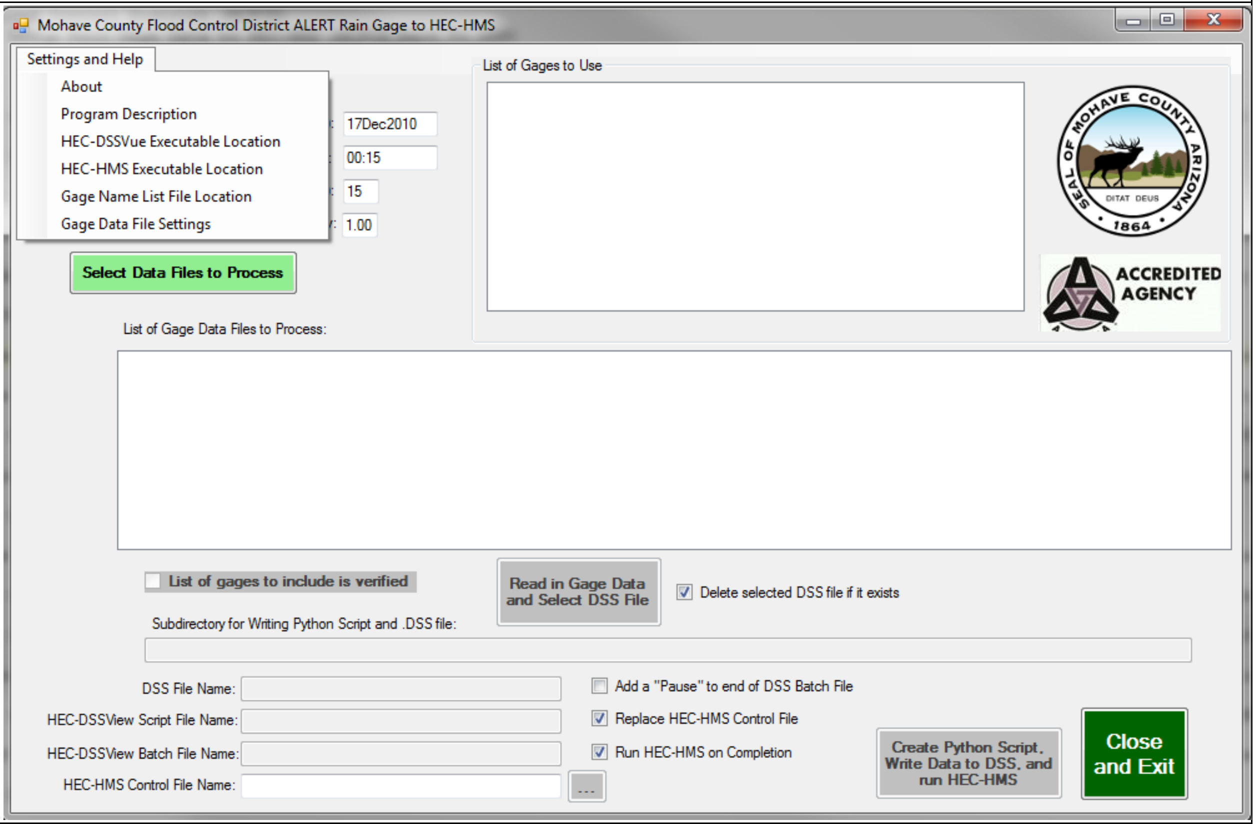
Use of this program also requires that the USACE computer programs HEC-DSSVue and HEC-RAS be installed on the same computer. The program was developed using HEC-DSSVue.exe Version 2.0 dated February 2010, Revision 2.0.1.16, Release Update 1. The HEC-DSSVue installation package can be downloaded from http://www.hec.usace.army.mil/software/hec-dssvue/. The program was tested using HEC-HMS Version 3.5, Build 1417, Date: 10Aug2010. The HEC-HMS installation package can be downloaded from: http://www.hec.usace.army.mil/software/hec-hms/.

7.2.2 Setup

Run *ALERT Group Rain Gage to HEC-HMS*. If this is the first time the program has been run, click on the Settings and Help menu bar tab. The Settings and Help tab, opened on the program main form, is shown on Figure 7.1.

1. Use the Settings options to specify the location of the HEC-DSSVue and HEC-HMS executables. The default locations are the USACE default installation locations for HEC-DSSVue Version 2.0.1.16 and HEC-HMS 3.5 for the Windows 64-bit operating system (Wiindows 7 and Windows 8). The default locations are:

Figure 7.1 Program Settings and Help form



C:\Program Files (x86)\HEC\HEC-DSSVue\HEC-DSSVue.exe

C:\Program Files (x86)\HEC\HEC-HMS\3.5\ HEC-HMS.exe

The links on the Settings and Help tab can be used to change these default program locations if different locations were used. The revised settings will be saved in the Windows Registry so this will only need to be done once, unless a different version is installed later.

2. Define the location of the ASCII text file containing the list of all MCFCD rain gages. This file is provided with the installation files and must be copied to the user's folder area or a network location. The file name is: *Rain_To_HMS Tool\ MCFCD ALERT Rain Gage List.txt*. After this file has been copied to the permanent location, use this setting to point the program to the file location. Click on the Gage List Name File Location option and navigate to the file. This file is comma delimited (Gage Number, Gage Name). However,

it will need to be updated each time a new rain gage is added to the MCFCD ALERT system. Each gage should be on a separate line.

3. Verify that the Gage Data File Settings matches the format of the ASCII files containing the group rain gage data exported from the ALERT system. See Section 7.3 for instructions on obtaining these data files. The form for these settings is shown on Figure 7.2. The option to change these settings is provided in case the MCFCD ALERT system software provider revises the format of its export file structure. Note that the rainfall values listed in the data files are incremental in units of inches. One value for each specified time interval is provided. Each setting is described below:

   A. Number of Header Lines Before 1st Data Row. Refer to Figure 7.3 for an example of an ALERT Group Rain Gage data file. Only the left side of the file is shown because the data extends far to the right. Note that there are five lines of informational text before the first gage (Scrub Peak Utah) is listed. The program ignores all but one of these lines. The setting is the number of informational lines, which is 5.

   B. Line Number Containing Name of Rain Gage Group. This setting is the line number containing the name of the rain gage group. For this example, the name is "Littlefield – Beaver Dam Area Rainfall." This name is extracted and written to the DSS file in data Part A. If the line number is changed in future updates, this setting should be changed.

Figure 7.2 Settings for Reading Gage Group Data Files form

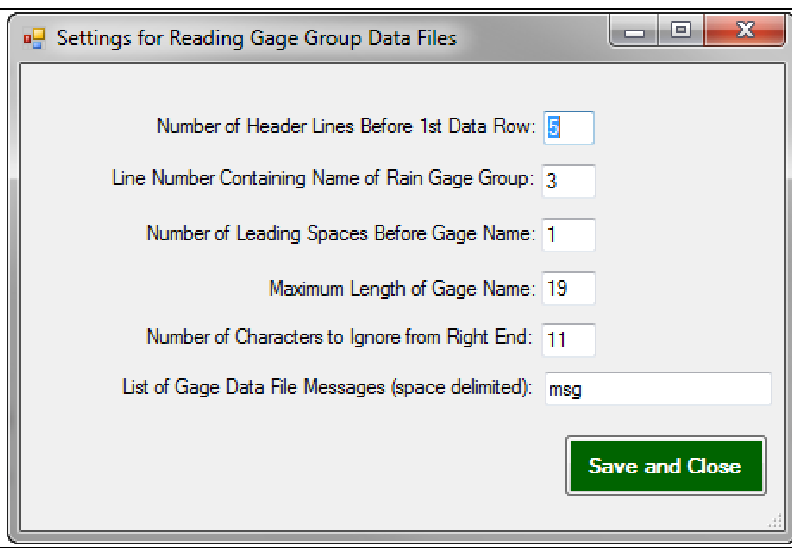


Figure 7.3 Example group rain gage data file (left side)

```
Started
Mohave County ALERT Flood Warning System
Littlefield - Beaver Dam Area Rainfall
Report Date: DECEMBER 21 2010      Report Time 13:43
Site Name
 Scrub Peak Utah            0.03   0.06   0.06   0.06   0.08   0.09   0.06   0.05   0.06
 Beaver Dam                 0.00   0.04   0.00   0.00   0.04   0.04   0.00   0.12   0.00
 Big Bend Wash @ I15        0.00   0.00   0.00   0.00   0.00   0.04   0.04   0.00   0.04
 Virgin River @ Scen        0.00   0.00   0.00   0.00   0.00   0.08   0.00   0.00   0.00
 Motoqua                    0.04   0.00   0.00   0.00   0.04   0.04   0.04   0.04   0.08
 Pahcoon Flat               0.00   0.03   0.02   0.02   0.02   0.02   0.03   0.02   0.03
 Upper Lime Mountain        0.06   0.05   0.06   0.08   0.08   0.06   0.08   0.08   0.05
 Bull Valley Mtns           0.06   0.05   0.05   0.05   0.09   0.08   0.08   0.06   0.09
 Figure 4                   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.08
 Beaver Dam State Pa        0.06   0.06   0.06   0.06   0.06   0.06   0.05   0.05   0.05
 Catclaw Canyon              msg    msg    msg    msg    msg    msg    msg    msg    msg
```

C. Number of Leading Spaces Before Gage Name. There is currently one leading space at the start of each gage data line. If this is changed in future updates, this setting should be changed.

D. Maximum Length of Gage Name. The name of each gage in the group rain data file is truncated to 19 characters as shown in Figure 7.3 for the Beaver Dam State Park gage. The complete name as listed in the MCFCD ALERT system can be longer. The complete name for each gage is listed in the *MCFCD ALERT Rain Gage List.txt* file. If the truncation length changes in future ALERT system updates, this setting should be revised.

E. Number of Characters to Ignore from the Right End. Refer to Figure 7.4 for the right end of the data file. The current file format uses 11 characters to define the units at the end of each data line. If this changes in future updates, this setting should be revised.

F. List of Gage Data File Messages (space delimited). If there was a problem with the rain gage reading for a time interval, a text message is entered instead of a null depth value. Referring to Figure 7.3, note the data fields are populated with "msg" for the Catclaw Canyon gage. This is because this gage did not exist during the December 2010 flood. The program will stop and give a warning message when a text value listed under this setting is encountered. The user is given the option to set the value to 0.00 or exit and address the problem. Check with the ALERT System

Manager to verify that there are no other null data message abbreviations other than the defaults listed. Add any new ones. All of the settings are stored in the Windows Registry and will be available each time the program is run.

Figure 7.4 Example group rain gage data file (right side)

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	inches
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	inches
0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	inches
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	inches
0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	inches
0.02	0.00	0.00	0.03	0.02	0.02	0.02	0.02	0.02	0.00	inches
0.00	0.02	0.02	0.00	0.03	0.02	0.02	0.00	0.00	0.00	inches
0.02	0.00	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.00	inches
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	inches
0.00	0.00	0.06	0.03	0.05	0.06	0.05	0.06	0.06	0.09	inches
msg	msg	msg	msg	msg	msg	msg	msg	msg	msg	inches

7.3 Obtaining ALERT System Group Rain Gage Data

The ALERT system group rain gage data files must be exported from the MCFCD ALERT web page manually. The web page is at: http://weather.co.mohave.az.us/perl/DWReports.pl. Use the following instructions to export the needed data files for a given storm event:

1. Click on the “Custom Report” option on the MCFCD ALERT web page. An example of the “Custom Reports” screen is shown on Figure 7.5 for the December 2010 storm over the Beaver Dam Wash watershed.

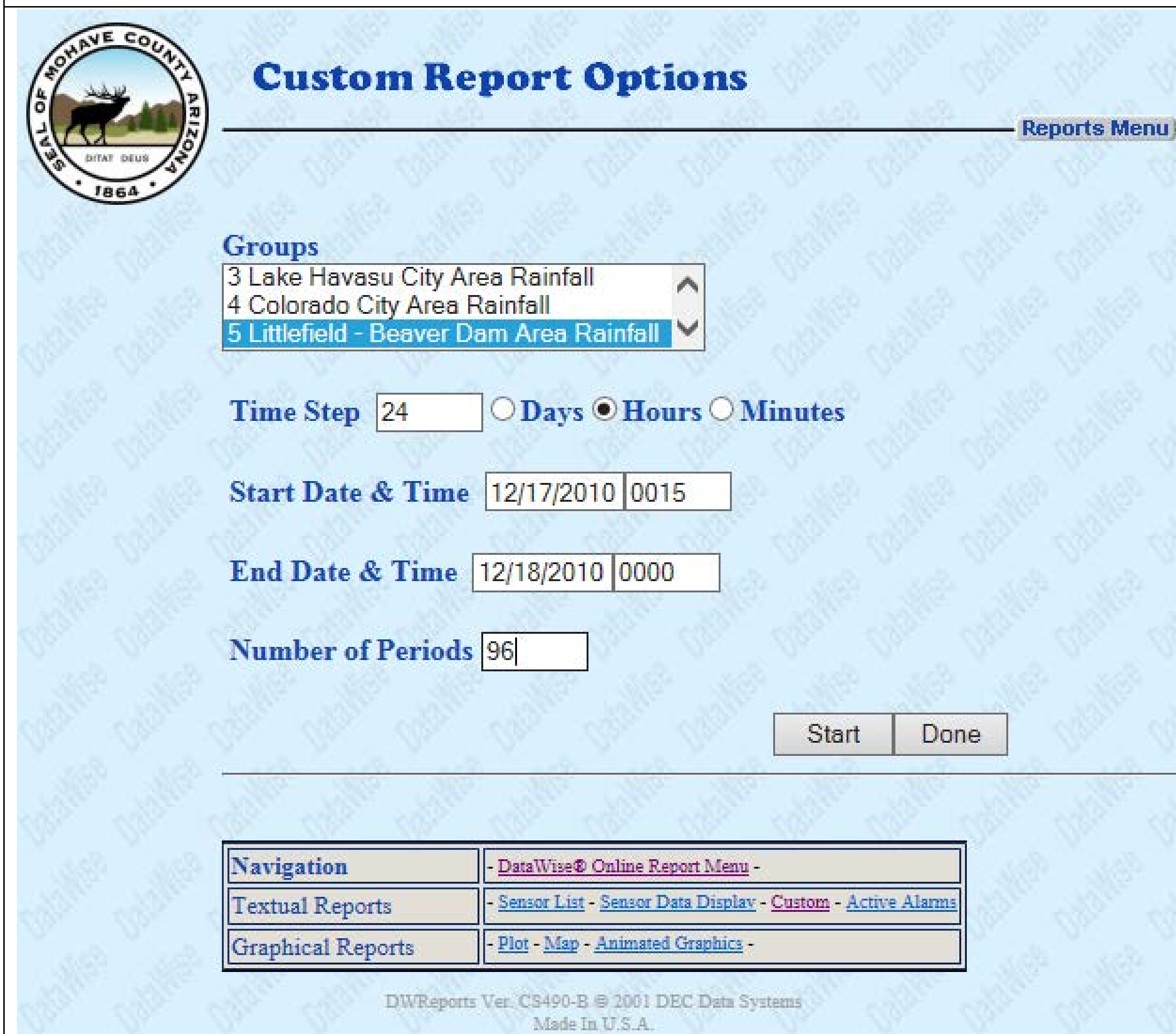
2. In the Groups field scroll down to "5 Littlefield - Beaver Dam Area Rainfall"

3. Set the "Timestep". When working with the USACE HEC-DSSVue program, it is simplest to extract data for an entire day, even if the storm period is less than 1 day. Also, from a practical standpoint, the ALERT system group rain gage reporting method will only report for 1 day at a time using 15-minute intervals. It seems to have a maximum number of reporting intervals of about 140. Therefore, set the time step to 24 hours. This is not an intuitive setting, but that is how it is applied.

4. Set the start and end date and time as needed to cover the storm time period. For the Beaver Dam Wash storm of December 2010, the settings are shown on Figure 7.5 to cover the first day of the storm. It is recommended to use a full day for every file.

5. In number of periods field, set the number of reporting intervals to use. If a 24 hour report at 15 minute increments is desired, set the number of periods to 96 (24x(60/15)). This establishes the reporting interval.

Figure 7.5 Example MCFCD ALERT System Custom Report Settings



6. Click the "Start" button. You may need to hold down the <Ctrl> key while clicking on the "Start" button to bypass the Internet browser pop-up blocker.

7. After the report loads, click on the "Download Current Custom Report" link. The results should look similar to those shown on Figure 7.3 and Figure 7.4. Select all the text, right click, and Copy. Then paste into a text editor and save to a file name that represents the

date and time and using a file extension of ".txt." An example file name used for the Beaver Dam Wash study is: "LittleFIeld-Beaver Dam Area Rainfall 121710.txt." This is all rainfall from the gages in the group for December 17, 2010. The first entry in the file will be at 00:15 minutes if a start time of 00:15 was used. The first value will represent the previous 15 minute period between midnight and 15 minutes after midnight.

8. Repeat this process to create a separate file for each consecutive day covering the storm period. Save all of the exported data files in the HMS project folder for the storm being modeled.

7.4 Using the Program

The process for using the *ALERT Group Rain Gage to HEC-HMS* program consists of the following steps:

1. Program Initiation and Loading Rain Gage Data

   A. Set the beginning date and time and the time step in the provided text boxes using the format specified. Use the date and time specified for the first day of the storm when exporting the group rain gage data from the MCFCD ALERT web page.

   B. The <u>Factor to Multiply Each Rainfall Value By</u> textbox can be used to globally increase or decrease the gage measured rainfall if the HEC-HMS model runoff estimates differ significantly from measured. This is an adjustment or calibration tool that could be used as the storm progresses and the HMS model results can be checked against the stream flow gage readings. Normally, this should be set to 1.00.

   C. Click on the <u>Select Data Files to Process</u> button. It will have a light green background. When a button or checkbox in the program has a light green background, it has been enabled for use. Buttons and checkboxes critical to the program operation flow will change from a silver background to light green when the prerequisite steps have been completed. Checkboxes that are not critical to the program progression will not have a background shading. These boxes are program options only.

D. Navigate to the folder containing the HEC-HMS model and select the group rain gage data file or files (refer to Section 7.3). To select multiple files, hold down the <Shift> key to select a contiguous block of files and the <Ctrl> key to select multiple individual files.

E. If multiple files are selected, the user will next be prompted to assign an order number by time period. Assign "1" to the file that covers the 1st time period, "2" to the file covering the 2nd time period, "3" to the 3rd, etc.

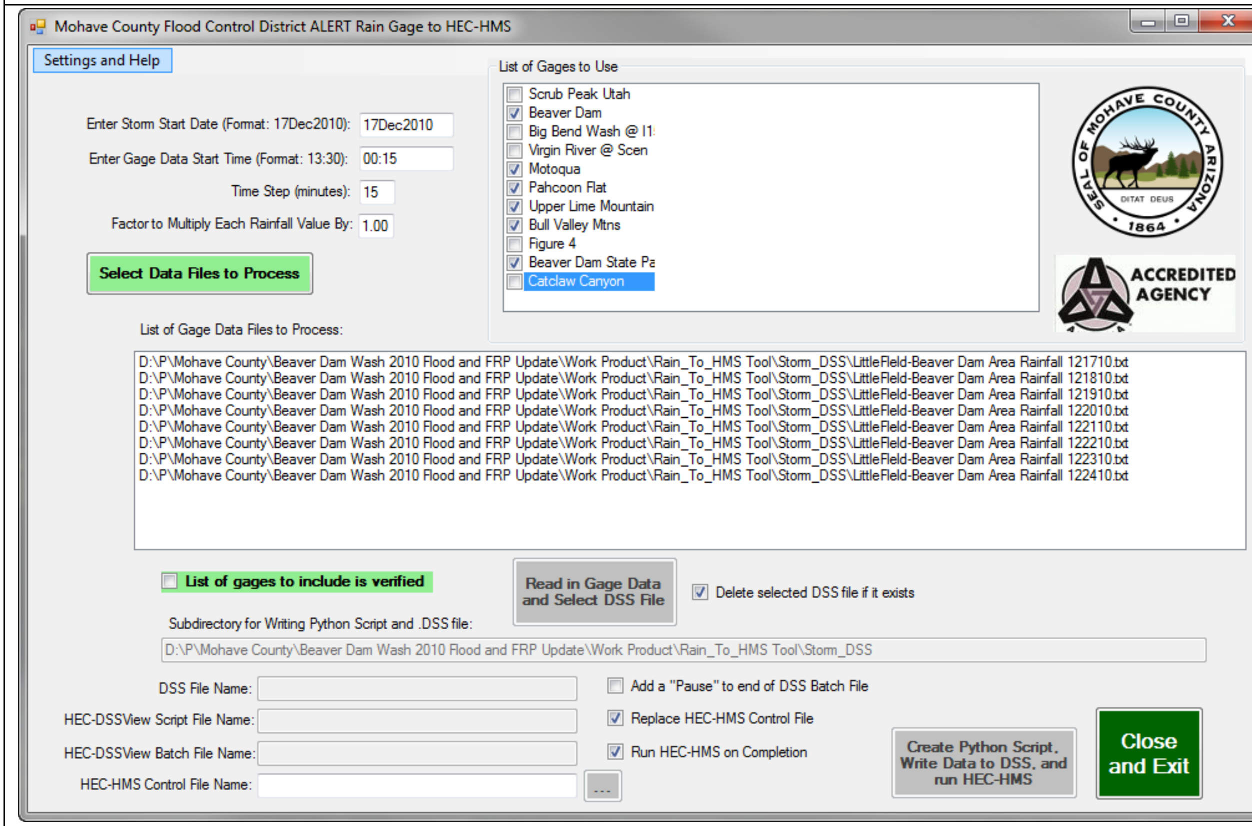
F. After the group rain data files are selected, the list of gages in the group will be populated in the List of Gages to Use checkbox list. Uncheck gages that are not to be considered in the analysis. For the Beaver Dam Wash watershed, the Scrub Peak Utah, Big Bend Wash @ I15, Virgin River @ Scenic, and Figure 4 are not situated within the watershed. Because this program was written primarily for Beaver Dam Wash, these gages are automatically excluded. The user could turn them on by checking the boxes. Note that Catclaw Canyon is checked on. For the December 2010 storm example, this gage should be unchecked since that gage was not physically installed at the time. The original Indian Canyon gage is not included because it has since been removed from service. The program form should now look like Figure 7.6.

G. The List of gages to include is verified checkbox should now have a light green background. Make sure the appropriate gages have been selected, and then check this box. The Read in Gage Data and Select DSS File button will turn to a light green background.

2. Writing the Rain Gage Data to DSS

A. If there is a reason to not delete the existing external DSS file, then uncheck the Delete selected DSS file if it exists checkbox. Otherwise, leave it checked. Click on the Read in Gage Data and Select DSS File button. Select the DSS file to use for the external storage of precipitation gage data. **DO NOT select the DSS file that has the same name as the HEC-HMS model.** That file contains the other HMS project data. If the external DSS file does not exist in the HEC-HMS model folder, then provide the DSS file name to be used. Make sure the file selected is the one referenced in the HEC-HMS model for each precipitation gage (refer to Section 7.6).

Figure 7.6 Example program form after gage files are loaded

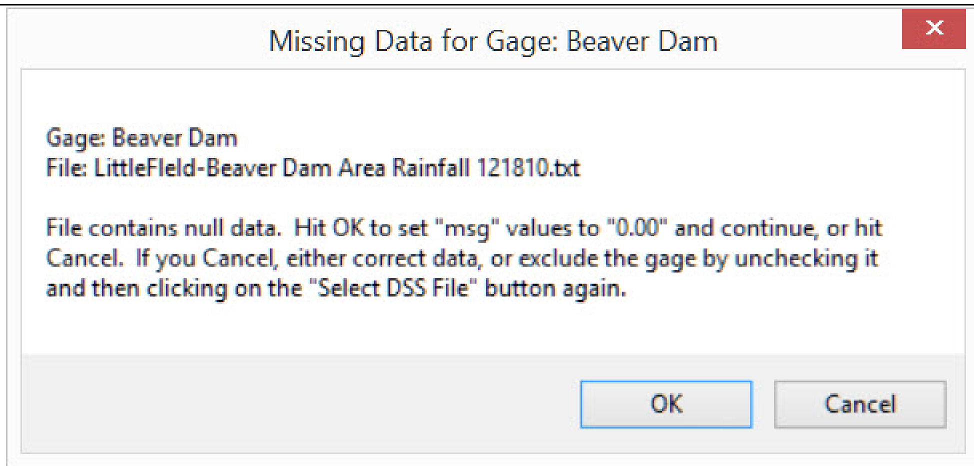


B. If there is null data in any of the group rain gage data files, a warning message box will pop up. This will normally be the text "msg." Other messages, defined in the program settings, may also be referenced. Decide if these rain data values should be set to 0.00, or if the gage data needs to be excluded. If the data needs to be excluded, hit "Cancel" and either uncheck that gage, or modify the data files appropriately. See Figure 7.7 for an example message box.

C. The various file name and location text boxes will then be populated. All will have a silver background and be disabled except the HEC-HMS Control File Name textbox. If the default HEC-HMS Control File Name is not the one specified in the HEC-HMS Model (under “Control Specifications”), then use the ellipse button to the right of the text box to navigate to the file, or just edit the text box.

D. The DSS File Name is the selected external DSS file name. The HEC-DSSView Script File Name is the Python script that will be run by the HEC-DSSView executable and write the rain gage data into the external DSS file. The HEC-DSSView Batch File Name is the Windows batch file that will execute HEC-DSSView and run the Python script. These files will all be written to the HMS model project folder.

Figure 7.7 Example missing data message box



E. The Add a "Pause" to the end of DSS Batch File checkbox is used to keep the Windows command window from closing if there are error messages when it is run. This should normally be left unchecked.

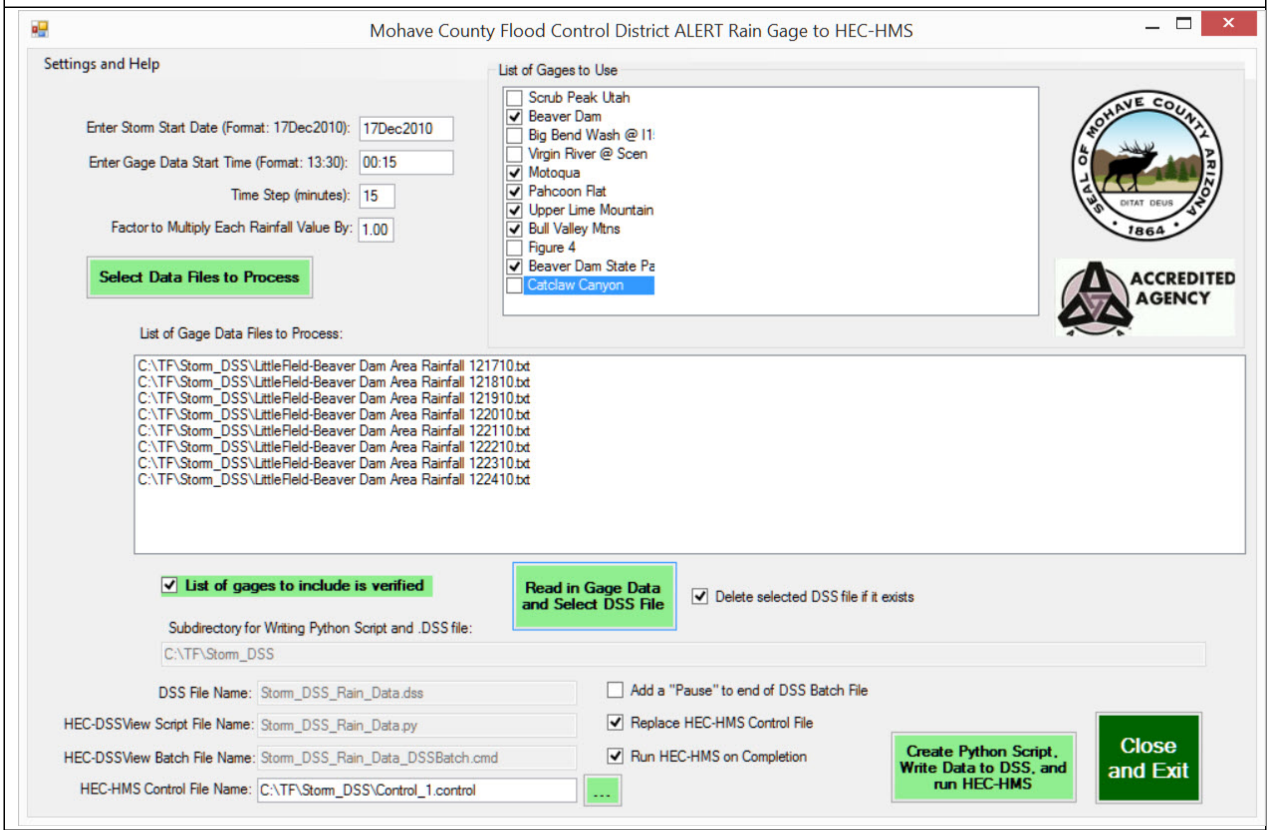
F. The Replace HEC-HMS Control File checkbox is used to change the HEC-HMS start and end date and times when the HEC-HMS model is run. If checked, the existing HEC-HMS control file will be deleted and rewritten using the start and end dates and times from the rain gage data. The user can also provide a description for the HEC-HMS run name. If unchecked, the user should enter the appropriate time controls manually within HMS before running the model.

G. The Run HEC-HMS on Completion checkbox allows the user to load the HEC-HMS program after the rain gage data is written to the external DSS file. The watershed model can then be loaded and run using the new rain gage data.

H. The Create Python Script, Write Data to DSS, and run HEC-HMS button will now have a light green background. Click on the button to write the rain gage data to the external DSS file and then load HEC-HMS. Refer to Figure 7.8 for how the program form should look when ready to click the Create Python Script, Write Data to DSS, and run HEC-HMS button.

I. In HMS, load the project file from the drop down file menu. Run the model and check the results.

Figure 7.8 Example program form ready to write to DSS



7.5 Using HMS to Obtain Needed Results

This section is written specifically for the Beaver Dam Wash HMS watershed model. The intent is that the rain gage data be exported periodically during the event and read into the external HMS DSS file. Each time this is done, the previous DSS file will be deleted and recreated with the latest data. Therefore, if the HMS model is being updated hourly, the gage data file for that day should be deleted and recreated each time with the starting time set to 00:15. If the storm extends over multiple days, then the data file for the previous day should be kept and the data file for the current day repeatedly replaced as new data becomes available, etc. The user should keep the following in mind when running the HMS model using real storm data:

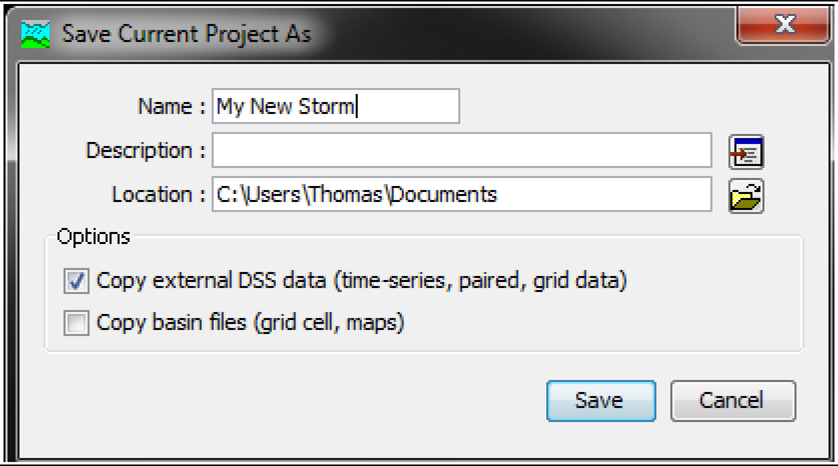
1. Check the Time-Series Data in HMS each time the DSS file is replaced to be sure the data was read in appropriately.
2. Check the Control Specifications to be sure the beginning and ending date and time are set appropriately.
3. Check the Meteorologic Models to be sure the appropriate gages are turned on. For instance, in the example model, the Catclaw Gage is turned off, which is appropriate for the December 2010 storm. It is turned on by default in the template project.
4. Be sure that the DSS file specified for the Time-Series Data is the correct folder and file name file.
5. Be sure that the DSS file specified for project output under Compute and the Run name is the correct folder and file name. Refer to Section 7.6.

7.6 Using the Beaver Dam Wash Watershed HMS Template File

The *BDW_Storm_Template* HMS project is included in APPENDIX A on the USB storage drive under the *\Rain_To_HMS Tool* folder. The intent is for this template to be used as a base and copied when a new storm event is modeled. To make a workable copy of the template project, complete the following steps:

1. Load the" Storm_Template" project into HMS.
2. From the File pull down menu, select "Save As." Provide a name for the new project and then select a folder location to create the project in. Under Options, check the box for copying the external DSS data. Refer to Figure 7.9. Click the "Save" button. A new folder named for the project will be created as a sub folder under the selected location.
3. Close HMS.
4. Use Windows Explorer to examine the new project folder. Delete the three files named "Storm_Template.dsc", "Storm_Template.log", and "Storm_Template.out."
5. Re-load the new project into HMS. Check to be sure the appropriate rain gages are set active as shown in Figure 7.10.

Figure 7.9 Example HMS project copy dialog box



6. Click on the "Compute" tab, expand "Simulation Runs", and click on "Run 1." Click on the "Simulation Run" tab in the lower window as shown on Figure 7.11. Note that the project DSS file is still pointed to the original "Storm_Template.dss" file. Browse to the new project folder and select the DSS file for your new project. **It will have the same name as the project folder**.

7. Note that there are three other DSS files in the new project folder. The file named for the new project with "_TimeSeries" added to the name is the new external DSS file that will contain the rain gage data. This is the file that should be selected when writing the group rain gage data to DSS from the *ALERT Group Rain Gage to HEC-HMS* program.

8. The new HMS project is now ready to have new storm data loaded into it.

Figure 7.10 Example HMS project Meteorologic Models settings

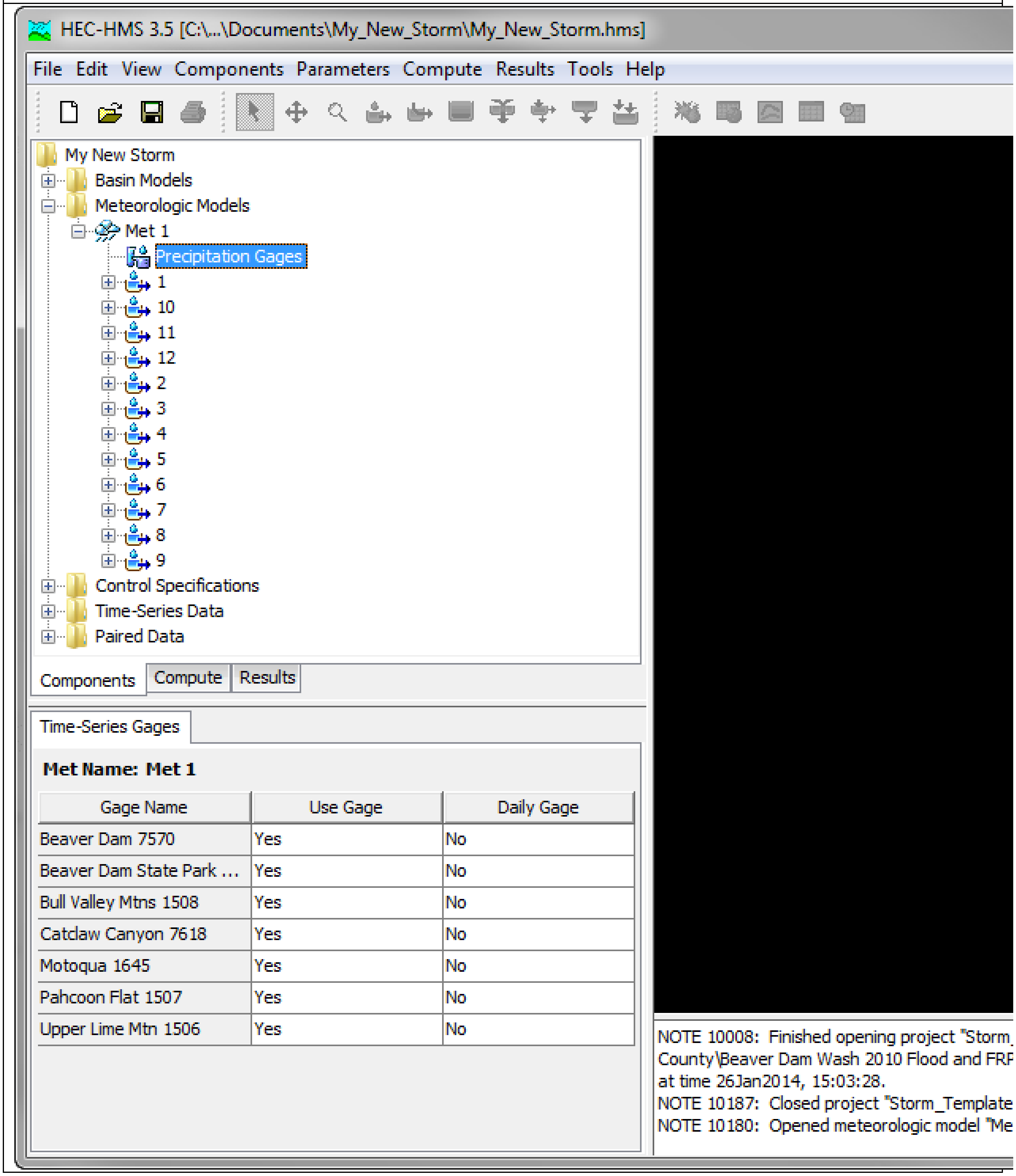
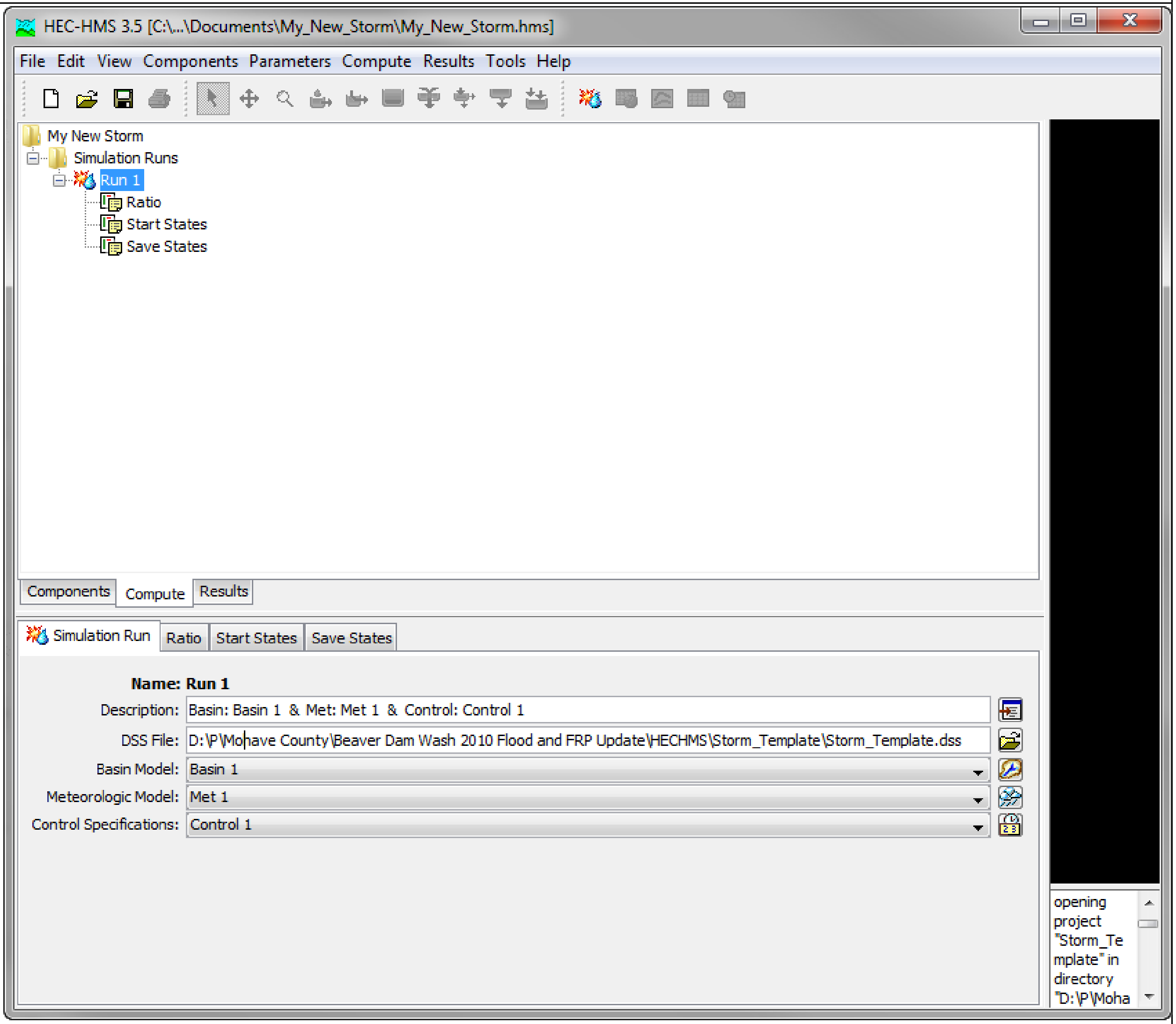


Figure 7.11 Example HMS project simulation compute DSS file setting



8 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study is intended to document the technical analyses done in support of the FWRP for the Beaver Dam area. The hydrologic and hydraulic results are intended for risk assessment and emergency management purposes only. The results of this study should not be considered as "best available technical information" for floodplain management purposes." Certain limiting assumptions used in the development of the technical basis for this study, including friction loss parameters and model control options, are designed to produce reasonable estimates of peak discharge and flood stage for a range of possible discharges. They are based on the topographic conditions present following the December 2010 flood. Over time, the wash channel vegetation conditions will change resulting in an increase in roughness. If a series of small flows occur over the next several years without a major flood event, the channel may aggrade, trending back toward the conditions present prior to the January 2005 flood. As a result, these analyses may not be appropriate for regulatory floodplain management purposes.

The maximum available effective lead time, accounting for decision and action time, for a short duration storm over the watershed and assuming the flood warning gages are functioning, is estimated to vary from 1- to 2.5-hours. For a long-duration storm similar to the January 2005 and December 2010 storms, the maximum effective lead time is estimated to be about 15-hours. Based on the assumptions and technical analyses presented in this study, twenty three (23) of the residential structures in the Beaver Dam Resort are in a high hazard zone and fifty four (54) are in a low hazard zone. Thirteen (13) of the residential structures in the Beaver Dam Estates are in a low hazard zone. These hazard ratings correspond to a possible life threatening situation for adults from flow rates up to 40,000 cfs, based on criteria from USBR (1988), if the area is not evacuated in a timely manner.

The primary structural alternative for mitigating the flood hazard is an extensive levee system. A levee system is not recommended because of prohibitive cost and because the flood risk will increase due to the threat of failure of the structure. Considering all these factors combined, and the small number of residents in the hazard area, the conclusion is that flood warning and other non-structural alternatives for the Beaver Dam Wash area be given a high priority by the Mohave County Flood Control District. If structural measures are considered, bank stabilization to prevent channel migration should be given a high priority.

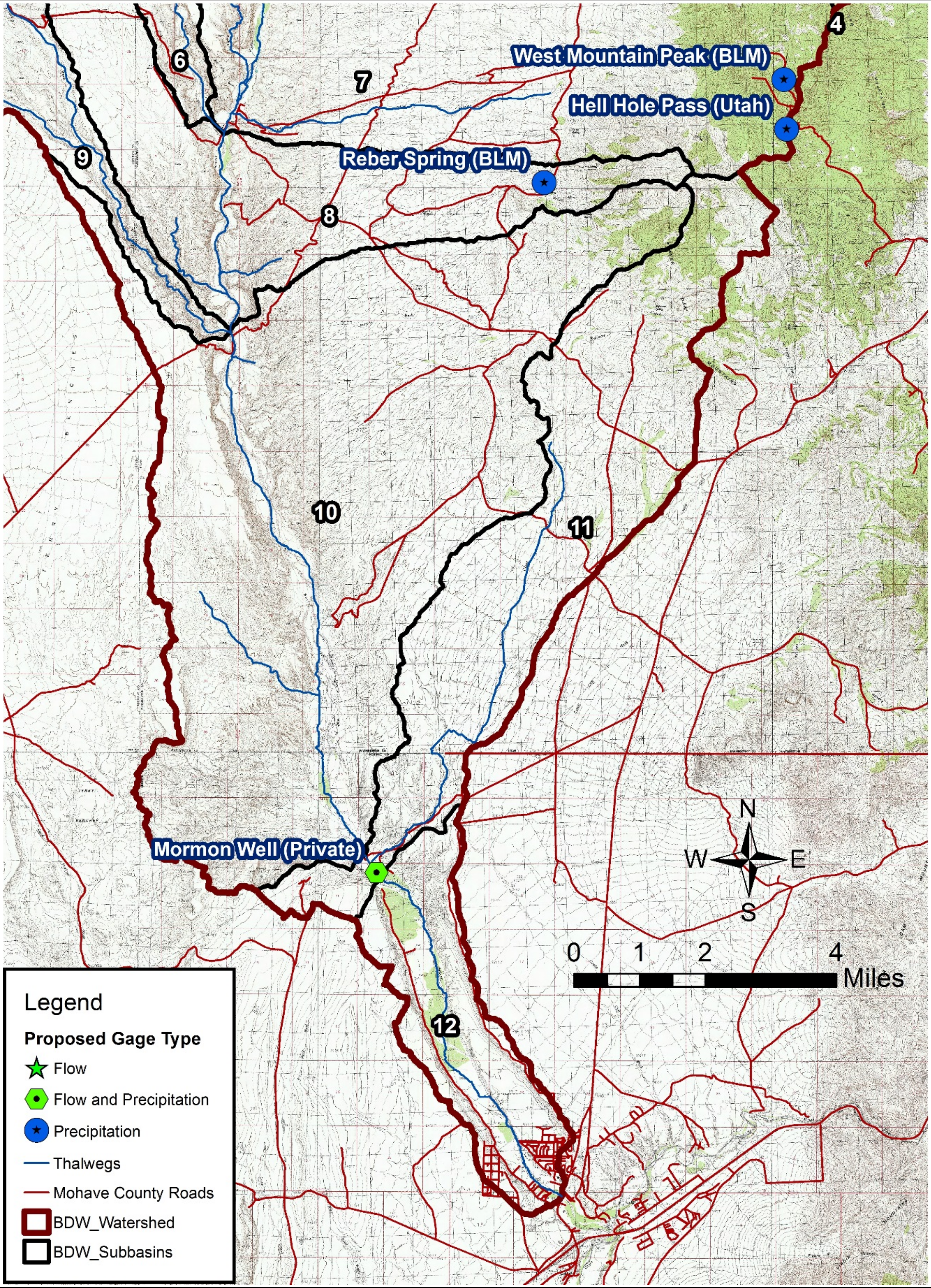
Recommendations for addressing the concerns identified as a result of this study are as follows:

1. **Flood Warning Instrumentation**: Install a new recording rain gage in the Beaver Dam Wash watershed in the vicinity of the upper watershed where sub-basins 7, 8, 10, and 11 share a common boundary as soon as is practical. Possible gage sites are near West Mountain Peak (BLM) or Hell Hole Pass (Utah State Land) in sub-basin 7. A secondary choice is near Reber Spring (BLM) in sub-basin 8 (not as desirable). Install a new combination precipitation and stream flow gage at the downstream end of sub-basin 11, near the location designated as the Mormon Well site (private land). Refer to Figure 8.1. All the gages should be automatic and be connected to the Mohave County and Arizona flood warning systems with real-time telemetry. It is also recommended that real-time cameras be installed at each gage site for the purpose of verifying that precipitation is actually falling or water running and that the gage is not malfunctioning. This could save a verification field trip, which is a full-day round trip from Kingman.

2. **Erosion Protection, Flood Proofing, Relocation or Buyout.** Investigate possible federal funding from FEMA and the U.S. Army Corps of Engineers for voluntary participation programs for homes with repetitive flood losses. Under such programs, property owners can undertake options such as flood proofing, relocation of their home, or buyout and demolition of the existing high-hazard repetitive loss structure. Continue to work with the U.S. Natural Resources Conservation Service for installation of bank protection, particularly in the Beaver Dam Resort reach.

3. **Regulation.** Continue regulating development within the 100-year floodplain using the current flood insurance study for the area. Then the adopted FEMA technical data should be used.

Figure 8.1 Location of proposed ALERT system gages



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9 REFERENCES

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2013, *Beaver Dam Wash Flood Warning Response Plan*.

Arizona Department of Water Resources (ADWR), 1996, *State Standard for Watercourse System Sediment Balance*, State Standard 5-96.

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Forsgren Associates, Inc., 2013, *Beaver Dam – US 91 Bridge and Beaver Dam Wash Topography Survey*.

Mohave County Flood Control District (MCFCD), 2012, *Drainage Design Manual for Mohave County*.

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10 DIGITAL DATA FILES CONTENT LIST

The digital data provided with this report is provided on a USB drive in Appendix A. The data provided is listed in the following sections. Each section, 10.1, 10.2 etc., is listed in alphabetical order. Each name of each section or sub-section is the name of the corresponding file folder on the USB drive, or the name of the GIS File Geodatabase. An ESRI project file is located in the MXD folder. Predefined symbology layer files are in the Layers folder.

10.1 ALERT Group Rain to HEC-HMS Tool (folder)

This folder contains the installation package for the computer program that will write rain gage data from a predefined group of MCFCD ALERT system rain gages into a USACE HEC-DSSVue DSS file for use in HEC-HMS. Refer to Section 7 for instructions on installation and use.

10.2 DPlot (folder)

DPLO is a proprietary computer program with more plot controls than Excel. It was used to generate some of the spreadsheet plots and to generate the moving average rainfall and hydrograph curves.

1. *Catclaw.grf*. Used to create the moving average hydrograph from the Catclaw Canyon stream flow gage using the pre-2010 rating curve.
2. *Catclaw_PostStormRC.grf*. Used to create the moving average hydrograph from the Catclaw Canyon stream flow gage using the post-2010 rating curve.
3. *Motoqua.grf*. Used to create the moving average hydrograph from the Motoqua stream flow gage using the pre-2010 rating curve.
4. *Motoqua_PostStormRC.grf*. Used to create the moving average hydrograph from the Motoqua stream flow gage using the post-2010 rating curve.
5. *Moving Average Lower 2010 Storm.grf*. Used to create the moving average rainfall distribution for the Lower Watershed scenario described in Section 3.3.4.
6. *Moving Average Middle 2010 Storm.grf*. Used to create the moving average rainfall distribution for the Middle Watershed scenario described in Section 3.3.4.

7. *Moving Average Upper 2010 Storm.grf*. Used to create the moving average rainfall distribution for the Upper Watershed scenario described in Section 3.3.4.

10.3 Excel Spreadsheets

1. *Hydrograph Routing Data.xlsx*. Contains the reach route stage-storage-discharge data from RAS used in the HMS model. Also contains the figures used in the report. See Section 3.6.
2. *Storm 2010 Rain Gage Data - Synthetic 112-hour Storm and HMS Results.xlsx*. Contains the rainfall data figures, the moving average plots generated using DPLOT, and the HMS model hydrographs for the synthetic 112-hour storm. Refer to Section 3.8.3.
3. *Storm 2010 Stream Gage Data.xlsx*. Contains the December 2010 storm hydrograph data and plots of the RAS travel time computations used for calibration of the RAS model.
4. *Synthetic 24-hour Storm Rainfall and HMS Model Results.xlsx*. Contains the rainfall and HMS results for the synthetic 24-hour storm. Used to create figures for the stream flow gage rating curves and the critical threshold time-discharge information.

10.4 FLO-2D Models

1. Storm 2010 (folder)
    A. *Storm 2010 with Golf Course Bridge*. FLO-2D model of the December 2010 storm using the topography surface with the golf cart bridge embankments in place and not allowed to fail. Refer to Section 4.3.2.
    B. *Storm 2010 with Golf Course Bridge Levee Failure*. FLO-2D model of the December 2010 storm using the topography surface with the golf cart bridge embankments modeled as levees and allowed to fail using predefined horizontal and vertical failure rates. Refer to Section 4.3.2.
    C. *Storm 2010 without Golf Course Bridge*. FLO-2D model of the December 2010 storm using the topography surface with the golf cart bridge embankments removed. Refer to Section 4.3.2.
2. *Rating Curve without Golf Course Bridge*. FLO-2D model based on the topography surface with the golf cart bridge embankments removed. The 24-hour synthetic storm with a

peak discharge of 40,000 used for preparation of the Highway 91 stream flow gage rating curve. Also used for the critical threshold hydraulics. Refer to Section 4.3.3.

10.5 GIS Data

The following sections list the GIS data prepared for the project. The file folder or File Geodatabase where the data can be found is listed. File Geodatabase names are underlined, Dataset names are underlined and in italics, Feature Class, Raster names, model names, and file names are in italics. The type of GIS data is specified after the name (i.e. Point, Polyline, Polygon, Raster, TIN, and DEM).

10.5.1 Hydrology Data (Hydrology.gdb)

1. *Watershed_DDMSW_Proposed_Gage_Sites*: Point FC. Proposed new precipitation and stream flow gage site possible locations.

2. *Watershed_DDMSW_As_Built_Gage_Locations_New*: Point FC. Precipitation and stream flow gages in Beaver Dam Wash watershed including the new precipitation gage at Catclaw Canyon.

3. *Watershed_DDMSW_As_Built_Gage_Locations_Old*: Point FC. Precipitation and stream flow gages in Beaver Dam Wash watershed including the old Indian Canyon gage.

4. *Watershed_DDMSW_BDW_Watershed_Centroids*: Point FC. Contains the sub-basin centroids used to set the L_{ca} path and for relating the rain gage rainfall to each sub-basin in HMS.

5. *Watershed_DDMSW_BDW_Watershed_Concentration_Points*: Point FC. Contains the concentration point for each HMS sub-basin.

6. *Watershed_DDMSW_SNOTEL_and_USGS_Gages*: Point FC. Contains the point locations of the USGS stream flow and NRCS SNOTEL gages in or near the Beaver Dam Wash watershed.

7. *Watershed_DDMSW_BDW_Watershed__25smThalwegs*: Polyline FC. Contains the wash thalwegs for all washes with a minimum contributing drainage area of 0.25 square miles.

8. *Watershed_DDMSW_Lca*: Polyline FC. Contains the L_{ca} flow path polylines for each sub-basin.

9. *Watershed_DDMSW_Routing*: Polyline FC. Contains the reach route polylines for each HMS routing reach.

10. *Watershed_DDMSW_Tc*: Polyline FC. Contains the T_c flow path polylines for each sub-basin.

11. *Watershed_DDMSW_Thalwegs*: Polyline FC. Contains the thalwegs of the major washes in the Beaver Dam Wash watershed. Used in many of the watershed figures.

12. *Watershed_DDMSW_BDW_Lower_Subbasins*: Contains the sub-basins comprising the Lower Watershed scenario.

13. *Watershed_DDMSW_BDW_Middle_Subbasins*: Contains the sub-basins comprising the Middle Watershed scenario.

14. *Watershed_DDMSW_BDW_Upper_Subbasins*: Polygon FC. Contains the sub-basins comprising the Upper Watershed scenario.

15. *Watershed_DDMSW_BDW_Subbasins*: Polygon FC. Contains the sub-basins comprising the Entire Watershed scenario.

16. *Watershed_DDMSW_BDW_Watershed*: Polygon FC. Contains the polygons of the entire watershed without any sub-basins.

17. *Watershed_DDMSW_BDW_Soils*: Polygon FC. Contains the NRCS soils polygons for the Beaver Dam Wash watershed.

18. *Watershed_DDMSW_Landuse*: Polygon FC. Contains the land use polygons for the Beaver Dam Wash watershed.

10.5.2 1D Hydraulics Data (Hydraulics_1D.gdb)

1. *Erosion_Hazard_Zones_Post_2010*: Polygon FC. Contains the erosion hazard zone polygons described in Section 6.9.

2. *Flood_Limits_2010*: Polygon FC. Contains a polygon of the December 2010 flood limits estimated using the 2011 Cooper Aerial photographs. Refer to Section 4.3.2.

3. *BDW_Channel_Migration* (Feature Dataset)

   A. *BDW_Channel_Migration_Post_2005_Channel*: Polygon FC.

B. *BDW_Channel_Migration_Post_2005_Lateral_Migration*: Polygon FC.

C. *BDW_Channel_Migration_Post_2010_Channel*: Polygon FC.

D. *BDW_Channel_Migration_Post_2010_Lateral_Migration*: Polygon FC.

E. *BDW_Channel_Migration_Pre_2005_Channel*: Polygon FC.

4. *BDW_HECGeoRAS* (Feature Dataset)

A. *BDW_HECGeoRAS_BankPoints*: Point FC. Contains the points for the left and right channel bank stations for each RAS cross section.

B. *BDW_HECGeoRAS_Banks*: Polyline FC. Contains the polylines of the left and right RAS model channel banks.

C. *BDW_HECGeoRAS_Bridges3D*: Polyline FC. Contains the 3D polylines of the Highway 91 Bridge.

D. *BDW_HECGeoRAS_Bridges*: Polyline FC. Contains the 2D polylines of the Highway 91 Bridge.

E. *BDW_HECGeoRAS_River3D*: Polyline FC. Contains the 3D polyline of the Beaver Dam Wash thalweg.

F. *BDW_HECGeoRAS_River*: Polyline FC. Contains the 2D polyline of the Beaver Dam Wash thalweg.

G. *BDW_HECGeoRAS_Flowpaths*: Polyline FC. Contains the polylines of the RAS overbanks used to define the overbank flow path lengths.

H. *BDW_HECGeoRAS_XSCutLines3D*: Polyline FC. Contains the 3D polylines of the RAS cross sections.

I. *BDW_HECGeoRAS_XSCutLines*: Polyline FC. Contains the 2D polylines of the RAS cross sections.

J. *BDW_HECGeoRAS_LandUse*: Polygon FC. Contains the polygons of the land use areas used to define roughness in the RAS model.

K. *BDW_HECGeoRAS_BlockedObs*: Polygon FC. Contains the polygons of the obstructions to flow.

L. *BDW_HECGeoRAS_BlockedObs_Elevs*: Polygon FC. Contains the polygons of the obstructions to flow and the database table contains the elevations for defining overtopping.

M. *BDW_HECGeoRAS_IneffAreas*: Polygon FC. Contains the polygons of the defined ineffective flow areas.

10.5.3 2D Hydraulics Data

1. Hydraulics_2D.gdb

   A. *FLO_2D_Model_Results_General_2D_Cross_Sections*: Polygon FC. Contains polylines of the pre-defined FLO-2D flood plain cross sections used for generating hydrographs at run time.

   B. *FLO_2D_Model_Results_General_BDW_FLO2D_Elev_n*: Polygon FC. Contains polygons of the land use areas used to define roughness.

   C. *FLO_2D_Model_Results_General_FLO_2D_Building_Obstructions*: Polygon FC. Contains polygons of the obstructions to flow.

   D. *FLO_2D_Model_Results_General_GridOnly15: Polygon FC*. Contains polygons of every grid element with only the grid number in the database table.

   E. *FLO_2D_Model_Results_General_InflowGrids: Polygon F*C. Contains polygons of the inflow grid elements.

2. FLO-2D Model Output Standard GIS Feature Classes

   These feature classes are generated for each FLO-2D model listed in item 3 below.

   A. *FLO2DGIS*: Point FC. Contains a point feature class of the centroid of each grid element. The database contains the most important FLO-2D output data.

   B. *FPXSec_gis*: Point FC. Contains a point feature class of each grid element used to define a FLO-2D floodplain cross section.

   C. *ELEVATION*: Raster FC. A raster of the elevations for each grid element.

   D. *N*: Raster FC. A raster of the Manning's n-values for each grid element.

   E. *WSELMAX*: Raster FC. A raster of the maximum WSEL for each grid element.

F. *CDischarge*: Raster FC. A raster of the maximum discharge for each grid element.

G. *DMax*: Raster FC. A raster of the maximum flow depth for each grid element.

H. *VMax*: Raster FC. A raster of the maximum velocity for each grid element.

I. *QTimeP*: Raster FC. A raster of the time to peak discharge for each grid element.

J. *ToneFt*: Raster FC. A raster of the time to one foot of flow depth for each grid element.

K. *TtwoFt*: Raster FC. A raster of the time to two feet of flow depth for each grid element.

3. Hwy 91 Bridge Rating Curve without Golf Course Bridge (folder) (flo2dGIS.gdb). This folder contains the FLO-2D input and output files for the Highway 91 Bridge stream flow gage hydraulic rating curve model. The model uses the surface with golf cart bridge embankments removed. The flo2dGIS.gdb File Geodatabase described in item 2 above is also contained in the folder.

4. Storm 2010 without Golf Course Bridge (folder) (flo2dGIS.gdb). This folder contains the FLO-2D input and output files for the December 2010 storm model. The model uses the surface with the golf cart bridge embankments removed. The flo2dGIS.gdb File Geodatabase described in item 2 above is also contained in the folder.

5. Storm 2010 with Golf Course Bridge (folder) (flo2dGIS.gdb) . This folder contains the FLO-2D input and output files for the December 2010 storm model. The model uses the surface with golf cart bridge embankments in place. The flo2dGIS.gdb File Geodatabase described in item 2 above is also contained in the folder.

6. Storm 2010 with Golf Course Bridge Levee Failure (folder) (flo2dGIS.gdb) . This folder contains the FLO-2D input and output files for the December 2010 storm model. The model uses the surface with golf cart bridge embankments removed and modeled as levees. The levees are allowed to fail. The flo2dGIS.gdb File Geodatabase described in item 2 above is also contained in the folder.

10.5.4 Imagery (folder)

1. *Beaver Dam Wash Watershed DEM Image.ecw*: Raster FC. A raster image of the Beaver Dam Wash watershed surface based on the USGS NEW DEM data.

2. *Watershed DEM Legend.bmp*: Image. An image of the symbology scale used for the *Beaver Dam Wash Watershed DEM Image.ecw*.

3. *Beaver_Dam_Wash_2011.ecw*: Raster FC. A combined aerial photograph image from the 2011 Cooper Aerial survey.

4. *NAIP_Upper_Reach_NoComp.tif*: An image of Beaver Dam Wash from the Catclaw Canyon stream flow gage site to the Motoqua stream flow gage site. Source is the NRCS NAIP.

5. *Motoqua_2011*: Aerial photograph of the Motoqua stream flow gage site from the 2011 Cooper Aerial survey.

6. *USGS_Quads.ecw*: Raster FC. A combined image of the USGS 7.5 minute quadrangle maps of the Beaver Dam Wash watershed.

10.5.5 Topography (folder)

1. Topography.gdb

   A. *BDW_MassPoints_Erased_wo_GCB*: 3D Point_FC. The combined 2011 Cooper Aerial 3D mass points of the Beaver Dam Wash detailed mapping from the Virgin River through the Catclaw Canyon stream flow gage site used in building the TIN surface (item 3C below). The points within the Highway 91 bridge area, defined by the polygon from item 2A3 below, are erased from the feature class. The golf cart bridge embankments have been removed.

   B. *BDW_Breaklines_Erased_wo_GCB*: 3D Polyline FC. The combined 2011 Cooper Aerial 3D break lines of the Beaver Dam Wash detailed mapping from the Virgin River through the Catclaw Canyon stream flow gage site used in building the TIN surface (item 3C below). The polylines within the Highway 91 bridge area, defined by the polygon from item 2A3 below, are erased from the feature class. The golf cart bridge embankments have been removed.

   C. *BDW_MassPoints_Erased*: 3D Point_FC. The combined 2011 Cooper Aerial 3D mass points of the Beaver Dam Wash detailed mapping from the Virgin River through the Catclaw Canyon stream flow gage site used in building the TIN surface (item 3C below). The points within the Highway 91 bridge area, defined by the polygon from item 2A3 below, are erased from the feature class. The golf cart bridge embankments are in place.

D. *BDW_Breaklines_Erased*: 3D Polyline FC. The combined 2011 Cooper Aerial 3D break lines of the Beaver Dam Wash detailed mapping from the Virgin River through the Catclaw Canyon stream flow gage site used in building the TIN surface (item 3C below). The polylines within the Highway 91 bridge area, defined by the polygon from item 2A3 below, are erased from the feature class. The golf cart bridge embankments are in place.

E. *Motoqua_Gauge_Site_Breakline*: 3D Polyline FC. The 2011 Cooper Aerial 3D break lines of the Beaver Dam Wash detailed mapping through the Motoqua stream flow gage site used in building the TIN surface listed in item 3C below.

F. *Motoqua_Gauge_Site_Spot_elev*: 3D Point_FC. The 2011 Cooper Aerial 3D spot elevation points of the Beaver Dam Wash detailed mapping through the Motoqua stream flow gage site used in building the TIN surface listed in item 3C below.

G. *Motoqua_Guage_Site_Point*: 3D Point_FC. The 2011 Cooper Aerial 3D mass points of the Beaver Dam Wash detailed mapping through the Motoqua stream flow gage site used in building the TIN surface listed in item 3C below.

H. *BDW_Upper_Reach_USGS_NED_DEM_Points*: 3D Point_FC. The USGS NED 3D elevation points of the Beaver Dam Wash mapping from the Catclaw Canyon stream flow gage site to the Motoqua stream flow gage site used in building the TIN surface listed in item 3C below.

I. *Surfaces_BDW_Overall_TIN_Limits*: Polygon FC. Contains polygons of the area of each topographic data set used.

J. *Surfaces_Jan2013_Comb_Contours_wgcb_2ft*: Polyline FC. Contains 2-foot contours of Beaver Dam Wash created from the *Bdwtinwgcb* TIN surface.

2. Hwy_91_FieldSurvey_Jan13.gdb

A. *Hwy91_BridgeDeck_Surface* (Dataset).

Contains the data used to build a surface of the Highway 91 Bridge deck across Beaver Dam Wash.

a. DTMBridgeDeckMassPoints: 3D Point_FC. Contains points of the Highway 91 Bridge deck used in building the TIN surface listed in item 3A below. Extracted from item C1 below.
b. DTMBridgeDeckBreaklinesGM: 3D Polyline FC. Contains polylines of the Highway 91 Bridge deck used in building the TIN surface listed in item 3A below. Extracted from item C2 below.
c. Hwy91TinLimits: Polygon FC. Contains a polygon of the Highway 91 Bridge area used to define the TIN Contains polylines of the Highway 91 Bridge deck used in building the TIN surfaces listed in items 3B and 3C below.
d. BridgeDeck: Polygon FC. Contains a polygon of the Highway 91 Bridge deck.
e. BridgeDeck1ftBuffer: Polygon FC. Contains a polygon of the Highway 91 Bridge deck TIN surface Contains polylines of the Highway 91 Bridge deck used in building the TIN surface listed in item 3A below.

B. *Hwy91_Area_GroundSurface* (Dataset)

Contains the data used to create the ground surface TIN of the as-built Highway 91 Bridge area. This TIN was then cut in to the TIN provided by Cooper Aerial, replacing the pre-bridge data.

a. DTMMassPoints: 3D Point_FC. Contains points of the Highway 91 Bridge area ground surface used in building the TIN surface listed in items 3B and 3C below. Extracted from item C1 below.
b. FieldSurveyDEMFinalPoints: 3D Point_FC. Contains DEM points of the Highway 91 Bridge area ground surface. Extracted from item C1 below and then interpolated to an evenly spaced grid.
c. DTMBreaklinesGM: 3D Polyline FC. Contains break lines of the Highway 91 Bridge area ground surface used in building the TIN surface listed in items 3B and 3C below. Extracted from item C2 below.

C. Hwy91_Bridge_Area_Combined_FieldSurveyData (Dataset)

Contains all the field survey data from Forsgren (2013).

a. MassPoints: 3D Point_FC. Contains all the survey points of the Highway 91 Bridge area by Forsgren (2013).
b. Breaklines: 3D Polyline FC. Contains all the survey break lines of the Highway 91 Bridge area by Forsgren (2013).
c. Survey_Boundary: Polygon FC. Contains a polygon of the field survey area of the Highway 91 Bridge by Forsgren (2013).

3. Surfaces (folder)

A. *Bdbdecktin*: TIN Surface. TIN surface of the as-built Highway 91 Bridge deck.

B. *Bdwtinwgcb*: TIN Surface. Combined TIN surface of the entire study reach of Beaver Dam Wash including the golf cart path bridge embankments. Includes data from Cooper Aerial (2011), USGS DEM, and Forsgren (2013).

C. *Bdwtinwogcb*: TIN Surface. Combined TIN surface of the entire study reach of Beaver Dam Wash with the golf cart path bridge embankments removed. Includes data from Cooper Aerial (2011), USGS DEM, and Forsgren (2013).

D. *bdwdemwogcb4*: 4ft DEM Surface. Combined DEM surface of the entire study reach of Beaver Dam Wash with the golf cart path bridge embankments removed. Includes data from Cooper Aerial (2011), USGS DEM, and Forsgren (2013).

10.5.6 FWRP (FWRP.gdb)

1. *Critical_Locations_from_2D_Grid*: Point FC. The FLO-2D grid points at the critical threshold locations.

2. *Evacuation_Areas*: Polygon FC. Polygons of the recommended overbank flooding evacuation areas.

3. *EvacuationAreasforErosion*: Polygon FC. Polygons of the recommended erosion hazard evacuation areas.

4. *Hazard*: Raster FC. A raster of the adult hazard classifications for the 100-year flood.

10.6 HEC-HMS Models (HECHMS folder)

1. *Storm_2010_Calibrated*. Contains the data to run the simulation of the December 2010 storm. This is the final calibrated model.

2. *Watershed Response Calibrated*. Contains the models for the Entire, Upper, Middle, and Lower watershed scenarios. It is based on the *Storm_2010_Calibrated* model. Runs are set for total rainfall depths of 0.5-, 1.0-, 1.5-, 2.0-, 3.0-, and 4.0-inches for each watershed scenario. Model is of a 24-hour duration storm using the NRCS Type 2 distribution.

3. *Storm Event Base Model*. Contains a base model built from the *Storm_2010_Calibrated* model for use with the *Rain_to_HMS* tool described in Section 7.

10.7 HEC-RAS Model (HECRAS folder)

1. *BDW_Rating_Table*. This model contains the following plans:

    A. *2010 Storm Peak*: This is a steady state model of the 2010 storm discharge from the HMS model for the bottom 3.08 miles of Beaver Dam Wash. The golf cart bridge embankments are included in the model.

    B. *2010 Storm Peak woGolf Course Bridge*: This is a steady state model of the 2010 storm discharge from the HMS model for the bottom 3.08 miles of Beaver Dam Wash. The golf cart bridge embankments are excluded from the model.

    C. *BDW_Min_n*: This is the rating curve model based on the minimum Manning's n-value GIS coverage. It includes a range of flow rates from 50 through 40,000 cfs.

    D. *BDW_Mean_n*: This is the rating curve model based on the mean Manning's n-value GIS coverage. It includes a range of flow rates from 50 through 40,000 cfs.

    E. *BDW_Max_n*: This is the rating curve model based on the maximum Manning's n-value GIS coverage. It includes a range of flow rates from 50 through 40,000 cfs.

10.8 Reports (folder)

1. *SURVEY REPORT FOR BEAVER DAM WASH AND US 91 TOPO SURVEY.doc*, Forsgren (2013).

2. *ADDITIONAL PHOTOS OF US 91 BRIDGE AND BEAVER DAM WASH.docx*.
3. *Beaver Dam - Site 3 - Park Place Road Project 2006.pdf*.
4. *Beaver Dam Estates.pdf*.
5. *BEAVER DAM WASH_HWY 91 STATE PLANE COORDS.xlsx.*
6. *Park Place Job # 1.pdf.*
7. *Park Place Revetment Inspection 9-12-12.pdf.*

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APPENDIX A DIGITAL DATA FILES