THE UNIVERSITY OF TEXAS AT AUSTIN

Floodplain Analysis of Sanderson, Texas – HEC-HMS

Surface Hydrology spring 2010

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1. Introduction

Sanderson city is located in Terrell County; it is on U.S. Highway 90 in Sanderson Canyon in the southwest part of the county. On June 11, 1965, Sanderson was devastated by a flash flood. A wall of water roared down Sanderson Canyon into Sanderson destroying numerous homes and businesses. More than twenty people died in the flood. As a consequence of the flood 11 dams (Figure 1) were built [4] in order to avoid new catastrophes. The objective of this project is to take the efforts which have been already done in order to update the Sanderson floodplain map. Specifically, the water surface elevations computed in that study need to be laid out on up to date digital terrain data so that the extent of inundation during the 100-year flood can be mapped out properly. In order to achieve this objective a group composed of four people has been formed; each one of the integrants works in a different part of this project. In this particular case, the hydrology calculation and modeling is presented. The main objective of the hydrology work is to estimate the peak outflow of the basin for a storm of 100 years. For that purpose the software HEC-GeoHMS and HEC-HMS are used. The storm is going to be calibrated with the storm calculated by a professional of the U.S. Geological Survey in Lubbock, Texas, he used two regression methods developed by personnel of USGS. The points of interest in this study are the outlet of the dams 1, 2, 3, 4, 5, 6, 11, called site 1, 2, 3, 4, 5, 6, 11 respectively; the town of Sanderson, the USGS gage station and the bridge just before the area in which the lagoons are located.
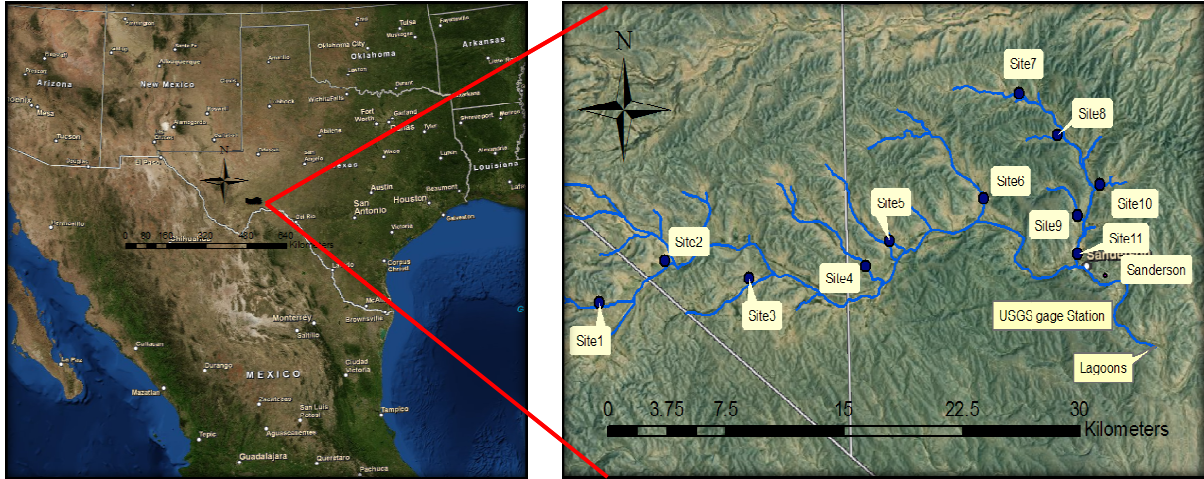
Figure 1: Location of the Dams in Sanderson Texas.

2. Field Trip to Sanderson

During spring break a group of students involved in this project, Dr David Maidment from EWRE in UT Austin and a professional specialist in flood mapping, Glen Wright, from AECOM went to Sanderson to make a scoping process in order to get a better idea of the local situation and how through this activity the project could be delineated. Among the different activities developed in that place, one of the most important was the meeting with survivors of the catastrophe in 1965. They related the impact of that event on their lives and made us realize the importance of our role in this project. Also the group got acquainted with Sanderson's USDA-NRCS office. Finally, the group went to take a look at some of the dams and some places which were flooded in 1965.

Figure 3: Principal outlet of the dam located in the site #11

As a consequence of the field trip the group has a better idea about the project. The work has been delineated by Dr David Maidment. The terrain processing is responsibility of Laura Hurd; the hydrological modeling is responsibility of Marcelo Somos; the dams answer to a flood event, including the discharge curve of the dams is Cody Hudson's work; and finally the HEC-RAS processing is responsibility of Rachel Chisholm.

3. Objectives

> Determine the 100 year flood for 24 hours and 6 hours design storm duration.

> Determine which storm duration gives the highest peak flow.

> Calibrate the 100 year flood with the USGS regression curve results.

> Estimate the 2, 10, 25, 50, 100 and 500 year floods including the dams in the simulation model.

4. Methods

As it was mentioned before the floodplain analysis of Sanderson has been made by four students. The results of two of the students have been used as inputs of the hydrology simulation and the results of the hydrology simulation are the input for the last part which is the calculation of the flood zone and mapping of the flood zone. The inputs are the terrain information which was obtained from a DEM with 10 m resolution and analyzed with the tool Arc Hydro in the ArcGIS software (for more references see Laura Hurd report) and the discharge curves for the 11 dams analyzed in this study, those curves were developed in a software called site (for more references see Cody Hudson report).

4.1. HEC-GeoHMS preprocessing

HEC-GeoHMS is software developed by the US Army Corps of Engineering. This software has been developed for engineers and hydrologists with limited experience in GIS [7]. In GeoHMS it is possible to delineate watersheds, streams. It is also can extract and calculate information for different shapefiles, and so on, in order to create a hydrological model in HEC-HMS. HEC-GeoHMS is a spatial extension of HEC-HMS, so its outputs are compatible with HMS.

The DEM previously processed for the Sanderson basin was used as input of GeoHMS. The work done in this software can be divided in 4 parts: basin processing, define physical parameter, hydrologic parameters and file exportation to HMS (Figure 2).
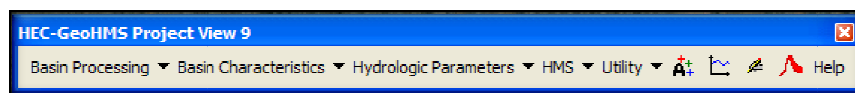

Figure 2: HEC-GeoHMS tools.

Below is a description of the HEC-GeoHMS processing.

➢ Basin Processing: In this part of the project the concept of less is more was applied. Figure 3 shows a shape file of the watershed delineated in ArcHydro. In this project there are ten points of interest so it is necessary to delineated at least one outlet for all of them. Figure 3 shows the quantity of catchments generated by ArcHydro and with this many catchments it is impossible to analyze the watershed and run the software without many difficulties. In order to fix that the Basin processing tool (Figure 4) was used to obtain a result that is shown in Figure 5.
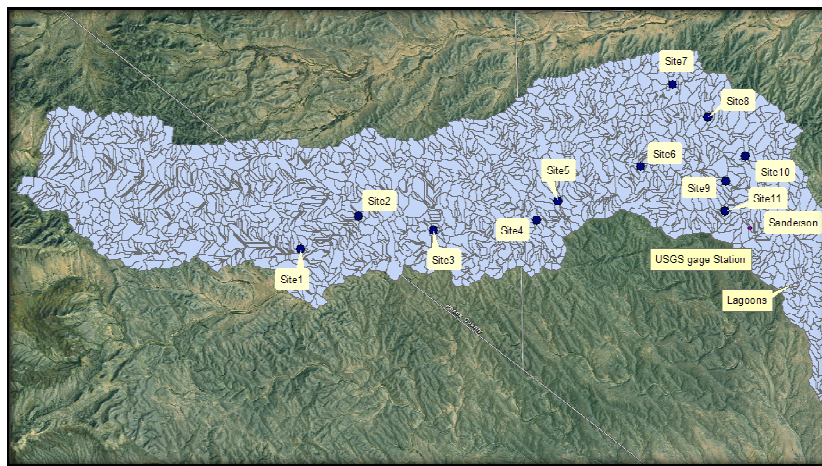

Figure 3: Geo processing resulted from the use of ArcHydro toolbox in ArcGIS.
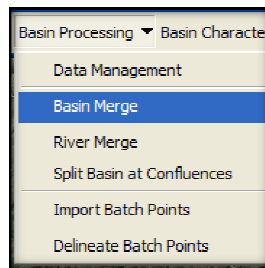

Figure 4: Basin processing tools.
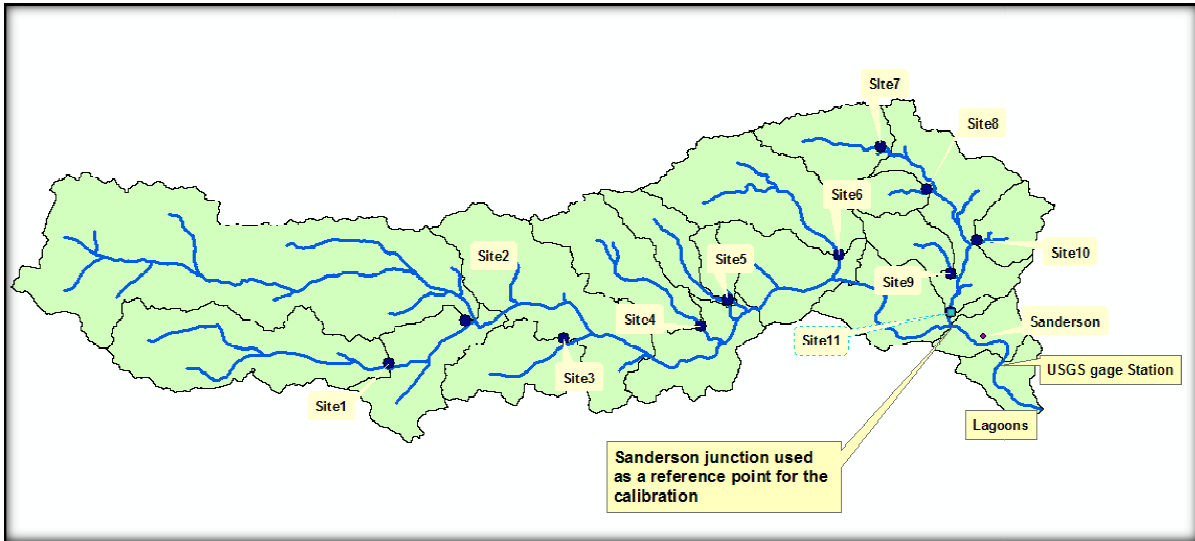
Figure 5: Watershed after the Basin processing.

➢ Define physical parameter: This set of tools (Figure 6) is really useful when calculating parameters which depend on the information contained by the DEM. For this study the River length, slope, basin slope, longest flow path, basin centroid, centroid elevation and centroidal flow path were calculated with those tools (Figure7). Those parameters are fundamental for calculating the Hydrological parameters.

Figure 6: Basin characteristics tools.

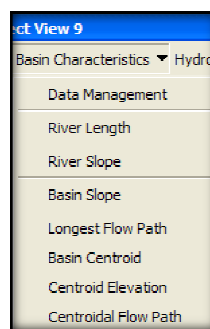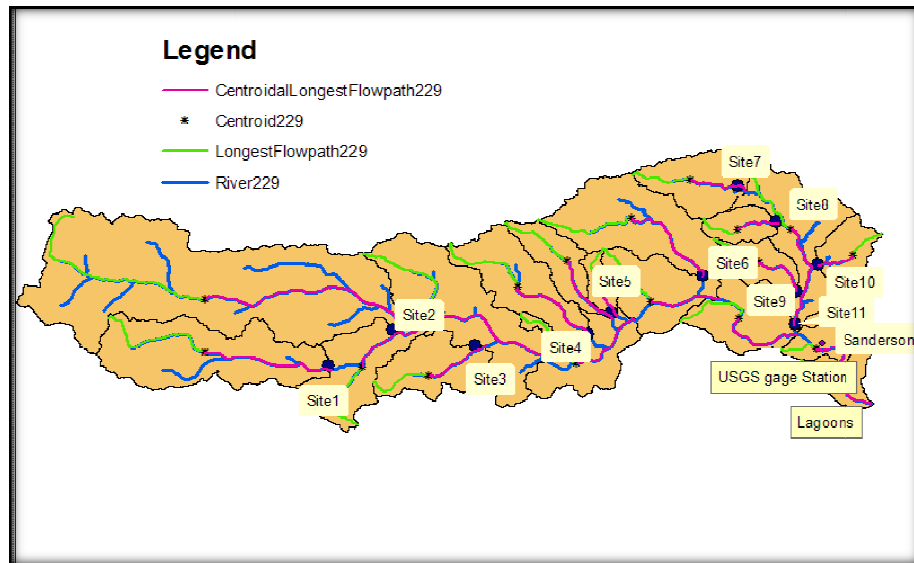Figure 7: Watershed after the basin characteristics.

➢ Hydrologic parameters: One of the main advantages of using GeoHMS is it gives
the user the option to determine hydrological parameters automatically with the
DEM information. As more information contained in the model develops in
GeoHMS, less information will be needed in HMS. In that case, for example, in
Figure 8 the HMS processes selection is shown. Also the CN lag method for the
sub basin was used. That information is exported later in a file readable by HMS so
the users don't need to fill those fields in again.
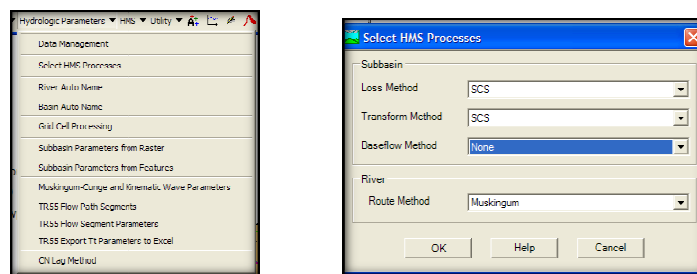
Figure 8: Hydrological parameter tools.

➢ Exportation to HMS: This is the last set of tools (Figure 9) that were used in GeoHMS. The software checks if the watershed was well delineated, especially the connectivity of the streams. Also the software gives the scheme of the future model in HMS (Figure 10). If everything is correct with the command Basin File, it is now possible to export the file to HMS.

Figure 9: HMS set tools.

Figure 10: Watershed ready to be exported to HMS.

In this project a small review of HEC-GeoHMS was done. The manual of this software is easy to understand and has a huge quantity of application examples. Hence for more details see the manual. It could be downloaded from this website

http://www.hec.usace.army.mil/software/hec-geohms/download.html.

4.2. Routing methods

➢ Basin Lag Time

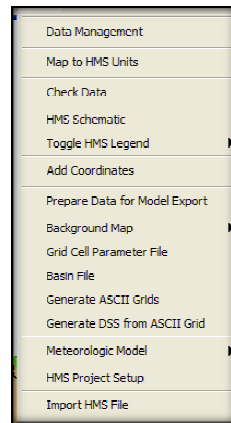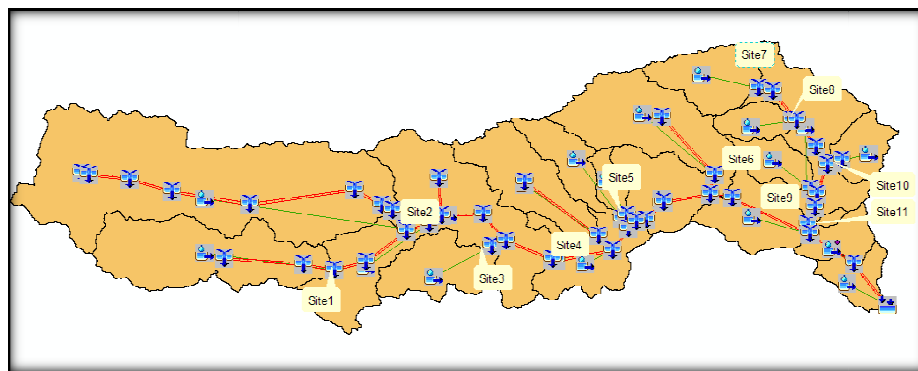In order to calculate the basin lag time, the CN lag method was used from HEC-GeoHMS (Figure 8). The method is described in Figure 11. The important aspect of this method is that it is a function of the length of the rivers and basin slope which are calculated from terrain digital information using HEC-GeoHMS, and the curve number (CN). There are a lot of uncertainties related with the value of the CN. In a study developed by NRCS in 1981 the number 74 was used [5]. Lately some studies came out with the CN for west Texas less than 74. They recommend subtracting 20 from the original value [6] for west Texas. In this study the value of the CN will be use in the calibration process.

$$Lag = \frac{(L^{0.8} * (S+1)^{0.7})}{(1900 * Y^{0.5})}$$

Where: Lag = basin lag time (hours)

L = hydraulic length of the watershed (feet)

$$S = \frac{1000}{CN} - 10$$

CN values between 50 to 95 are appropriate to this equation.

Y = basin slope (%)

Figure 11: Lag time of the basin as a function of the river length, slope and the CN (Applied Hydrology book).

➢ River routing method

The Muskingum method is used for calculating the relationship storage-outflow in the river. This method is described in the book Applied Hydrology [3]. Basically the model resolves Equation 1 (8.4.6 in Applied Hydrology [3]).

$$Q_{j+1} = C_1 I_{j+1} + C_2 I_j + C_3 Q_j$$ Equation 1

Where:

Q_{j+1} : outflow at the time on analysis.

I_{j+1} : inflow at the time on analysis.

I_j : inflow at the step just before to the step on analysis.

Q_j : inflow at the step just before to the step on analysis.

C1, C2 and C3 are showed in equation 2, 3, 4 respectively.

$$C_1 = \frac{\Delta t - 2KX}{2K(1 - X) + \Delta t}$$ Equation 2

$$C_2 = \frac{\Delta t + 2KX}{2K(1 - X) + \Delta t}$$ Equation 3

$$C_3 = \frac{2K(1 - X) - \Delta t}{2K(1 - X) + \Delta t}$$ Equation 4

Where:

$$K = \frac{\text{Lengh of the reach}}{\text{Velocity}} \ [\text{Hours}]$$

$X = 0.2$ and

$\Delta t =$ time step of the simulation, in this case it will be 15 minutes.

In this model a velocity of 2.5 m s^{-1} will be used. That number was come out from the study made by NRCS in 1981 [5]. In that study velocities from 9.6 to 17.2 feet per second were used. For more details about the method and how it could be implemented see references [3] and [8].

4.3. Design Storm

For the precipitation model the SCS rainfall distributions are going to be used. For Terrell County the 100 year precipitation for 24 hours duration is 7.12 inches and for 6 hours duration is 5.36 inches (http://onlinemanuals.txdot.gov/txdotmanuals/hyd/p24lkup.xls). The distribution factors are showed in Table 1. Storm type II correspond to the west part of Texas (Figure 12)

Table 1: SCS rainfall distributions factors

SCS rainfall distributions								
24-hour storm						6-hour storm		
		P_t/P_{24}						
Hour t	$t/24$	Type I	Type IA	Type II	Type III	Hour t	$t/6$	P_t/P_6
0	0	0	0	0	0	0	0	0
2.0	0.083	0.035	0.050	0.022	0.020	0.60	0.10	0.04
4.0	0.167	0.076	0.116	0.048	0.043	1.20	0.20	0.10
6.0	0.250	0.125	0.206	0.080	0.072	1.50	0.25	0.14
7.0	0.292	0.156	0.268	0.098	0.089	1.80	0.30	0.19
8.0	0.333	0.194	0.425	0.120	0.115	2.10	0.35	0.31
8.5	0.354	0.219	0.480	0.133	0.130	2.28	0.38	0.44
9.0	0.375	0.254	0.520	0.147	0.148	2.40	0.40	0.53
9.5	0.396	0.303	0.550	0.163	0.167	2.52	0.42	0.60
9.75	0.406	0.362	0.564	0.172	0.178	2.64	0.44	0.63
10.0	0.417	0.515	0.577	0.181	0.189	2.76	0.46	0.66
10.5	0.438	0.583	0.601	0.204	0.216	3.00	0.50	0.70
11.0	0.459	0.624	0.624	0.235	0.250	3.30	0.55	0.75
11.5	0.479	0.654	0.645	0.283	0.298	3.60	0.60	0.79
11.75	0.489	0.669	0.655	0.357	0.339	3.90	0.65	0.83
12.0	0.500	0.682	0.664	0.663	0.500	4.20	0.70	0.86
12,5	0.521	0.706	0.683	0.735	0.702	4.50	0.75	0.89
13.0	0.542	0.727	0.701	0.772	0.751	4.80	0.80	0.91
13.5	0.563	0.748	0.719	0.799	0.785	5.40	0.90	0.96
14.0	0.583	0.767	0.736	0.820	0.811	6.00	1.0	1.00
16.0	0.667	0.830	0.800	0.880	0,886			
20.0	0.833	0.926	0.906	0.952	0.957			
24,0	1.000	1.000	1.000	1.000	1.000			

Source: U. S. Dept. of Agriculture, Soil Conservation Service, 1973, 1986.
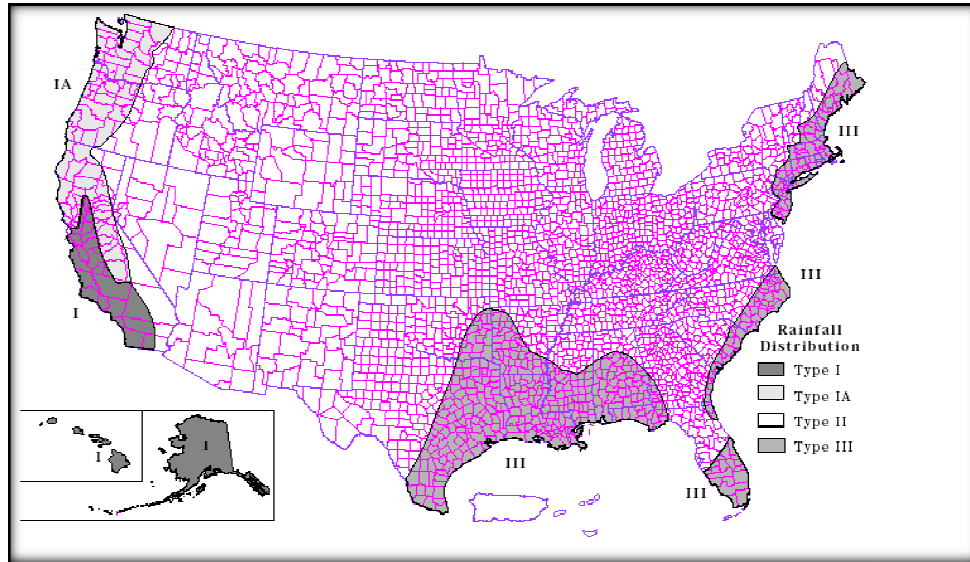
Figure 12: Rainfall distribution.

With the values of the design precipitation mentioned and the factors from Table 1 for a storm type II the graphic shows in Figure 13 was made.
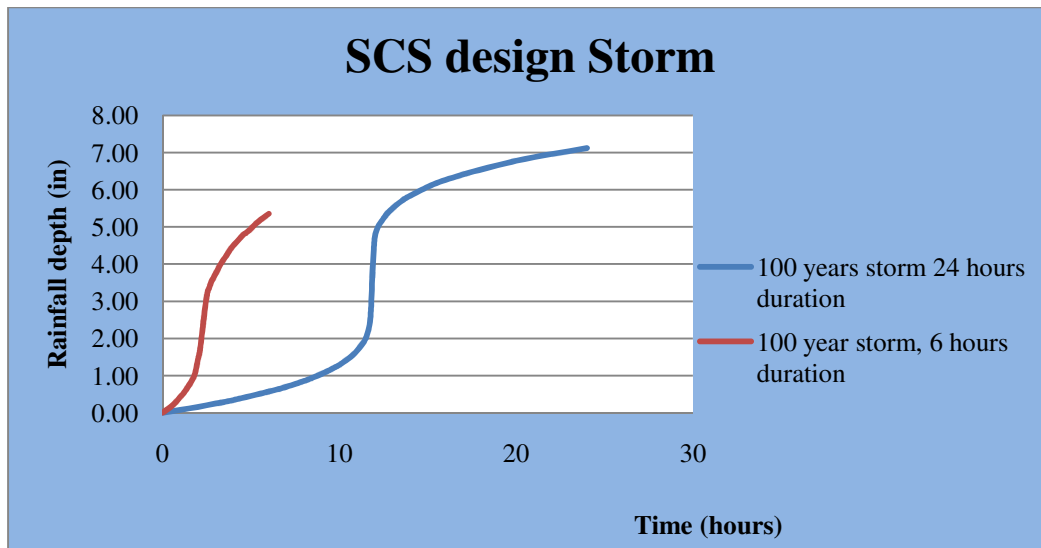
Figure 13: SCS design storms' hyetographs.

The Hyetographs from Figure 13 were introduced in HEC-HMS model (Figure 14)
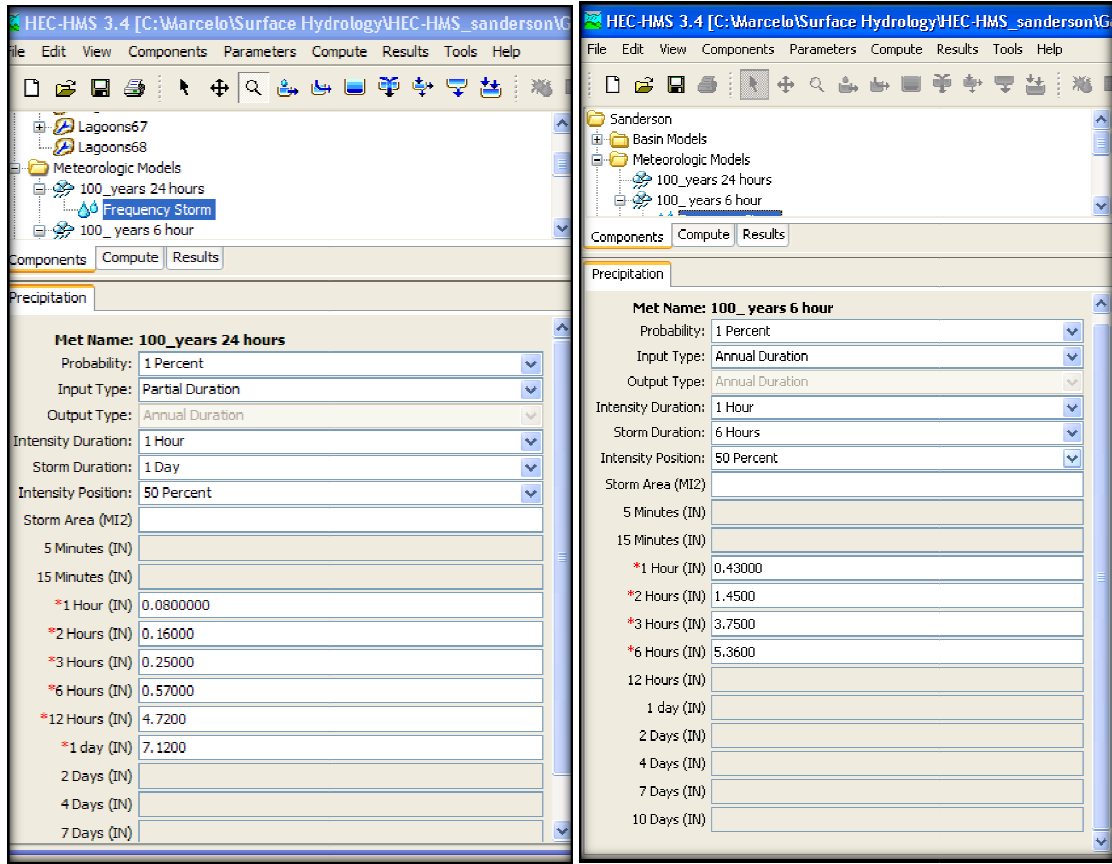
Figure 14: Meteorological model for 100 years storms for 24 and 6 hours duration.

The HMS model indicated that just before the Sanderson watershed (Figure 5) the outflow is 43212 CFS for a 6 hours duration storm and 34818 CFS for a 24 hours duration storm. Hence a 6 hours duration storm gives a highest peak outflow for this basin. Those numbers were calculated using 67 as the CN. Different CN were plugged into the model getting the same conclusion.

Figure 15: Peak outflow for both 6 hours duration and 24 hours duration storm design.

At that point is known that the storm design for 6 hours duration gives the highest peak outflow. Hence the design storms for return periods of 2, 10, 25, 50 and 500 years will be calculated for 6 hours duration as well. The results are showed in Figure 16.

Figure 16: SCS design storm, 6 hours duration.

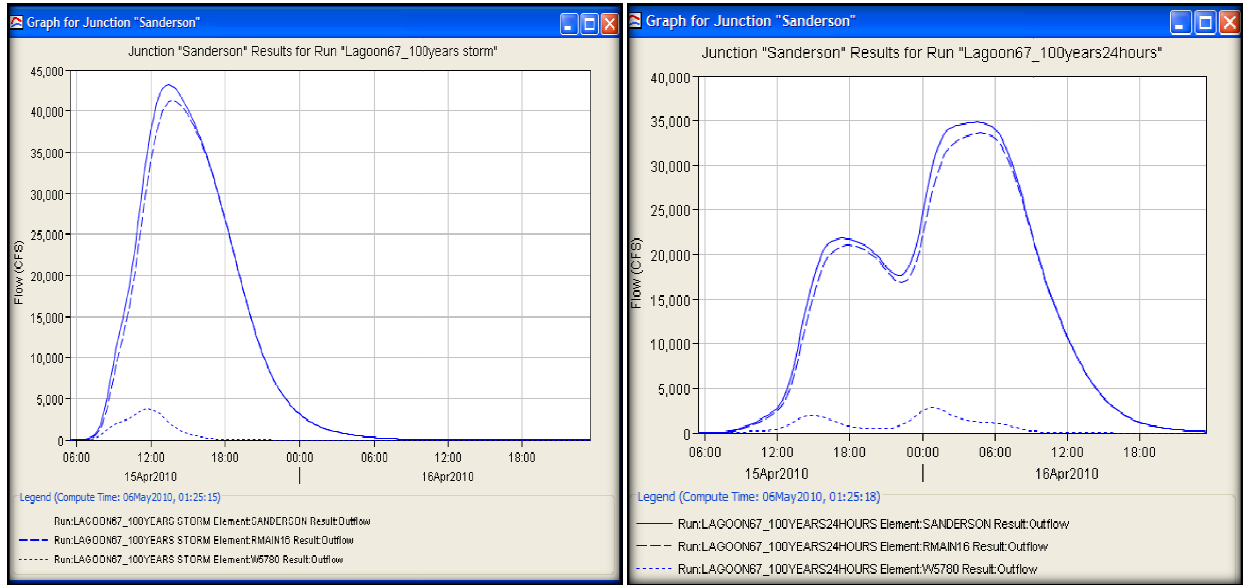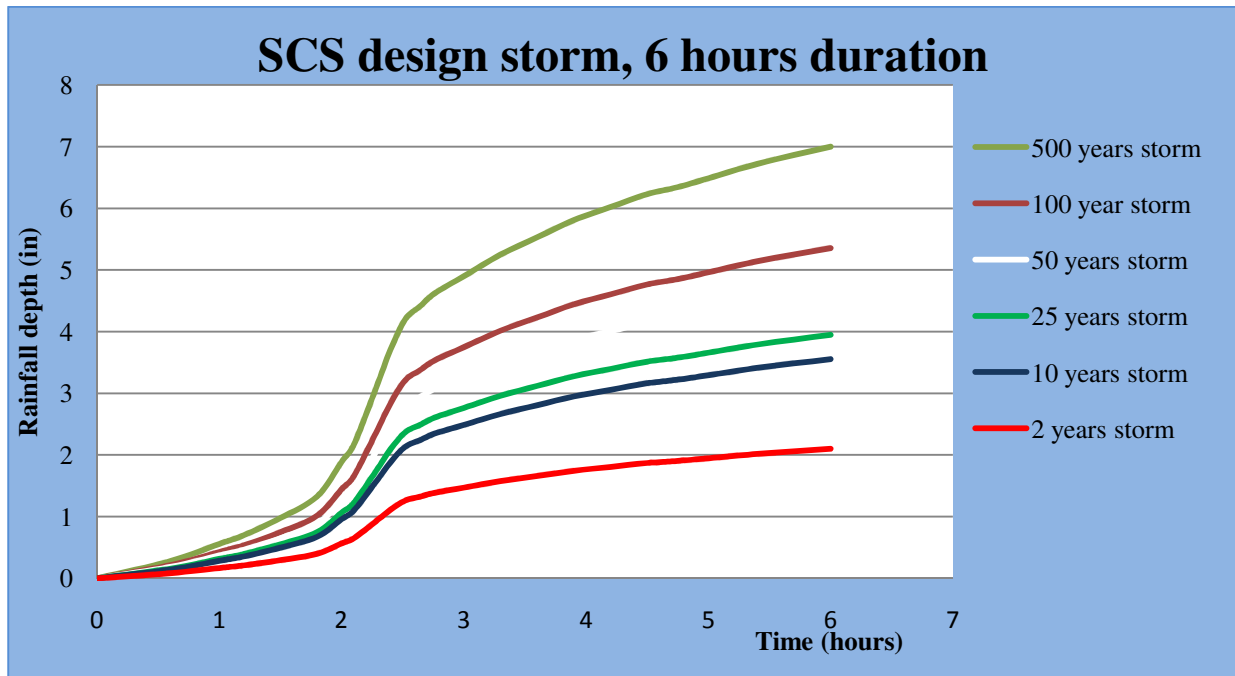## 4.4. Calibration of the HEC-HMS model

William H. Asquith (Ph.D., P.G. Research Hydrologist U.S. Geological Survey, Lubbock,
Texas) estimated the runoff for Sanderson Creek which will be used for the calibration process.
He based his calculation on two regression equations. The regression equation methods are:
Alternative regression equations for estimation of annual peak-streamflow frequency for
undeveloped watersheds in Texas using PRESS-minimization method [1] and Regression
equations for estimation of annual peak-stream flow frequency for undeveloped watersheds in
Texas using an L-moment-based, PRESS-minimized, residual-adjusted approach method [2].
Dr Asquith results are summarized in Figure 17.

New USGS Regression Equations

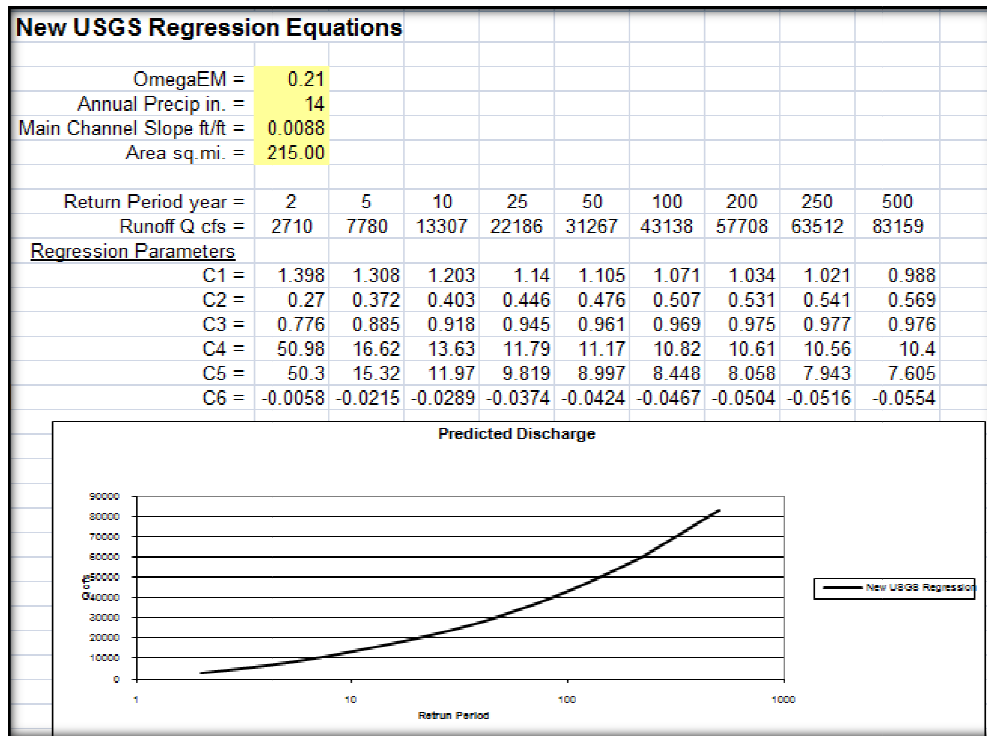|									
OmegaEM =	0.21								
Annual Precip in. =	14								
Main Channel Slope ft/ft =	0.0088								
Area sq.mi. =	215.00								
Return Period year =	2	5	10	25	50	100	200	250	500
Runoff Q cfs =	2710	7780	13307	22186	31267	43138	57708	63512	83159
Regression Parameters									
C1 =	1.398	1.308	1.203	1.14	1.105	1.071	1.034	1.021	0.988
C2 =	0.27	0.372	0.403	0.446	0.476	0.507	0.531	0.541	0.569
C3 =	0.776	0.885	0.918	0.945	0.961	0.969	0.975	0.977	0.976
C4 =	50.98	16.62	13.63	11.79	11.17	10.82	10.61	10.56	10.4
C5 =	50.3	15.32	11.97	9.819	8.997	8.448	8.058	7.943	7.605
C6 =	-0.0058	-0.0215	-0.0289	-0.0374	-0.0424	-0.0467	-0.0504	-0.0516	-0.0554

Figure 17: Regression equation results for Sanderson Canyon.

The HEC-HMS model for the 100 years design storm for 6 hours duration was calibrated
changing the CN. Different curve numbers were used from 54 to 74. The CN which gives the
best approximation for the 100 years runoff (Figure 17) is 67. The runoff obtained with this CN is

43212 CFS which for this simulation is considered acceptable in comparison with 43138 CFS from the regression equation.

4.5. Effect of the dams in the hydrologic model

Since in point 4.3 it was estimated that a 6-hours duration design storm gives a higher peak outflow than a 24-hours duration design storm, also in point 4.2 it was estimated that the CN for this model is 67, the HEC-HMS model is ready for including the dams elements in it. In HMS software it is really easy to include the dams; one example is shown in Figure 18. In the left side the watershed W9 has the outlet 9 as a downstream outlet. On the other hand on the right side of Figure 19 W9, it has the reservoir9 as a downstream element and the reservoir9 has the outlet9 as downstream element.
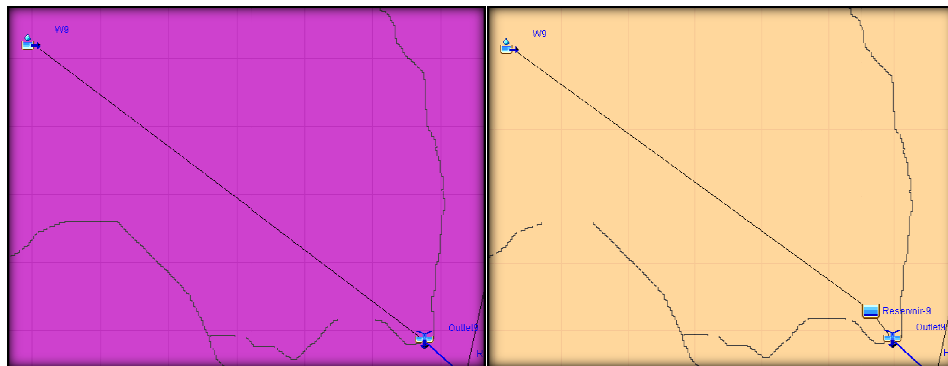

Figure18: Example of the HEC model with dams and without in watershed W9

The input of the reservoir elements are the storage-discharge curves as it is pointed out in figure 19. Those curves were calculated by Cody Hudson.

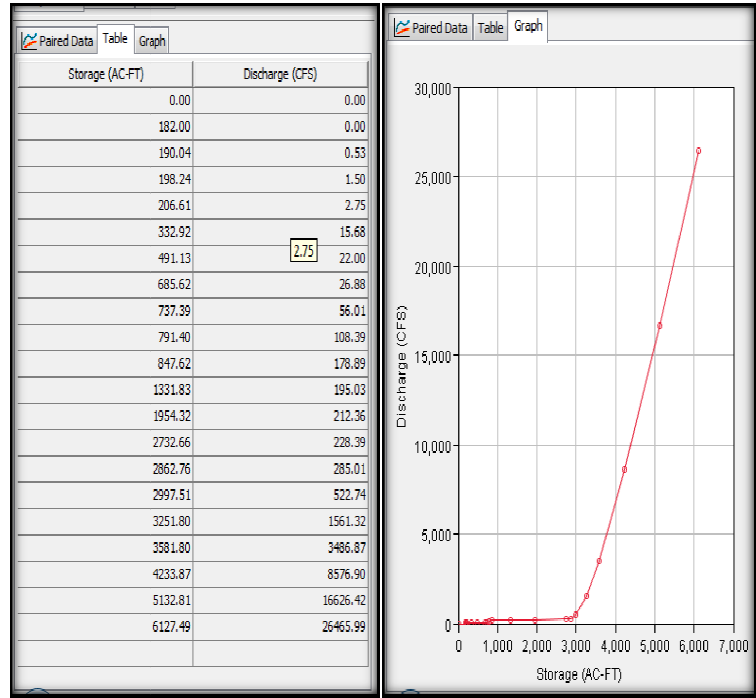| Storage (AC-FT)	Discharge (CFS)
0.00	0.00
182.00	0.00
190.04	0.53
198.24	1.50
206.61	2.75
332.92	15.68
491.13	22.00
685.62	26.88
737.39	56.01
791.40	108.39
847.62	178.89
1331.83	195.03
1954.32	212.36
2732.66	228.39
2862.76	285.01
2997.51	522.74
3251.80	1561.32
3581.80	3486.87
4233.87	8576.90
5132.81	16626.42
6127.49	26465.99

Figure 19: Example of a storage discharge curve.

Once the 11 dams were included in the HMS model, the outflow for 6 hours duration design storms with different return periods were calculated. The results are presented in Table 2.

Table2: Result for the 6 hours duration design storms with different return periods

Return Period year =	2	10	25	50	100	500
Runoff Q cfs =	2904	8717	11363	13220	16043	26730

It is good to mention that those results correspond to the point in which the Sanderson watershed intercepts the Sanderson creek upstream to town of Sanderson (Figure 5).

HEC-HMS gives a lot of information about every element which is not included in this report. That information has been given to Rachel Chisolm in order to calculate the inundation zone using HEC-GeoRAS and HEC-RAS.

5. Conclusions

- ➢ The 6 hours duration design storm gives a higher peak outflow than 24 hours duration design storm.
- ➢ As a result of the calibration the CN used in the simulation has a value of 67.
- ➢ The peaks outflow for 6 hours duration design storms with return period of 2, 10, 25, 50, 100 and 500 are 2904, 8717, 11363, 13220, 16043 and 26730 CFS respectively.

6. References

[1] Asquith, W.H., and Thompson, D.B., 2008, Alternative regression equations for estimation of annual peak-stream flow frequency for undeveloped watersheds in Texas using PRESS-minimization: U.S. Geological Survey Scientific Investigations Report 2008--5084, 40 p. \url{http://pubs.usgs.gov/sir/2008/5084}

[2] Asquith, W.H., and Roussel, M.C., 2009, Regression equations for estimation of annual peak-stream flow frequency for undeveloped watersheds in Texas using an L-moment-based, PRESS-minimized, residual-adjusted approach: U.S. Geological Survey Scientific Investigations Report 2009-5087, 48 p. \url{http://pubs.usgs.gov/sir/2009/5087}

[3] Chow, Maidment and Mays (1988). Applied Hydrology. McGraw-Hill.

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[5] NRCS (1981). Re-evaluation of the Sanderson flood study.

[6] Thompson, David, Harle, H., Keister, H., McLendon, D., and Sandrana, S. (2004). Climatic Adjustments of Natural Resource Conservation Service (NRCS) Runoff Curve

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[7] US Army Corps of Engineers (2009). HEC-GeoHMS user's manual. Hydrologic engineering center, HEC

[8] US Army Corps of Engineers (2009) HEC-HMS user's manual. Hydrologic engineering center, HEC