Interagency Flood Risk Management (InFRM)

Watershed Hydrology Assessment for the Nueces River(Turkey Creek) Basin

Appendix F:
2-Dimensional HEC-RAS Analysis of the Turkey Creek Watershed

March 2025

INTERAGENCY FLOOD RISK MANAGEMENT

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1. 2-Dimensional HEC-RAS Analysis

1.1 INTRODUCTION

Turkey Creek is a rural watershed in South Texas that is located within the Nueces River basin upstream of the USGS gage near Asherton, TX (0819300), as shown in Figure F.1 The Turkey Creek watershed encompasses approximately 2,000 square miles of drainage area, and it is entirely ungaged. With no observed data available to help calibrate the HEC-HMS model, the rainfall runoff response of this portion of the Nueces basin is largely unknown. In addition, no existing hydraulic models were available within the Turkey Creek watershed to develop Modified Puls routing data for HEC-HMS. The lack of observed data and hydraulic modeling data within the Turkey Creek watershed made this portion of the study area a prime candidate for a 2 dimensional (2D) analysis. This appendix will describe the development of a new 2D HEC-RAS model of the Turkey Creek watershed upstream of Highway 83. The 2D HEC-RAS model was used to estimate Modified Puls routing parameters and to calibrate the Snyder's subbasin transform parameters.

Unit hydrograph theory is a commonly utilized method among the hydrologic community that transforms excess precipitation into runoff hydrographs. The Nueces InFRM HEC-HMS hydrology model (covered in detail in Appendix B) uses the Snyder's unit hydrograph method to transform excess rainfall into direct runoff hydrographs. For the Turkey Creek portion of the Nueces River basin, no observed data was available to calibrate the transform parameters. Literature indicates that the lag time (and consequently the time of concentration) of a unit hydrograph generally tend to decrease as storm intensity increases (Snyder, 1938 and Minshall, 1960). Due to the availability of physically based routing routines/methods, HEC-RAS 2D has commonly been utilized by the USACE dam safety community to develop variable unit hydrograph parameters for different rainfall intensities (USACE RMC, 2017).

A primary purpose of this analysis is to utilize a HEC-RAS 2D model to calibrate the unit hydrograph parameters used in the HEC-HMS model for the purpose of improving flood frequency estimates within the Nueces River / Turkey Creek watershed. The 2D diffusion wave transform method in HEC-RAS, which is based on the momentum and continuity equations and is not tied to the assumption of linearity, was used to inform the Snyder's unit hydrograph transform parameters in HEC-HMS particularly for rare, intense rainfall events that have not yet been observed in this portion of the basin. A secondary purpose of the 2D HEC-RAS analysis was to develop storage volumes for a range of discharges that could be applied in the HEC-HMS routing reaches as Modified Puls storage-discharge curves.

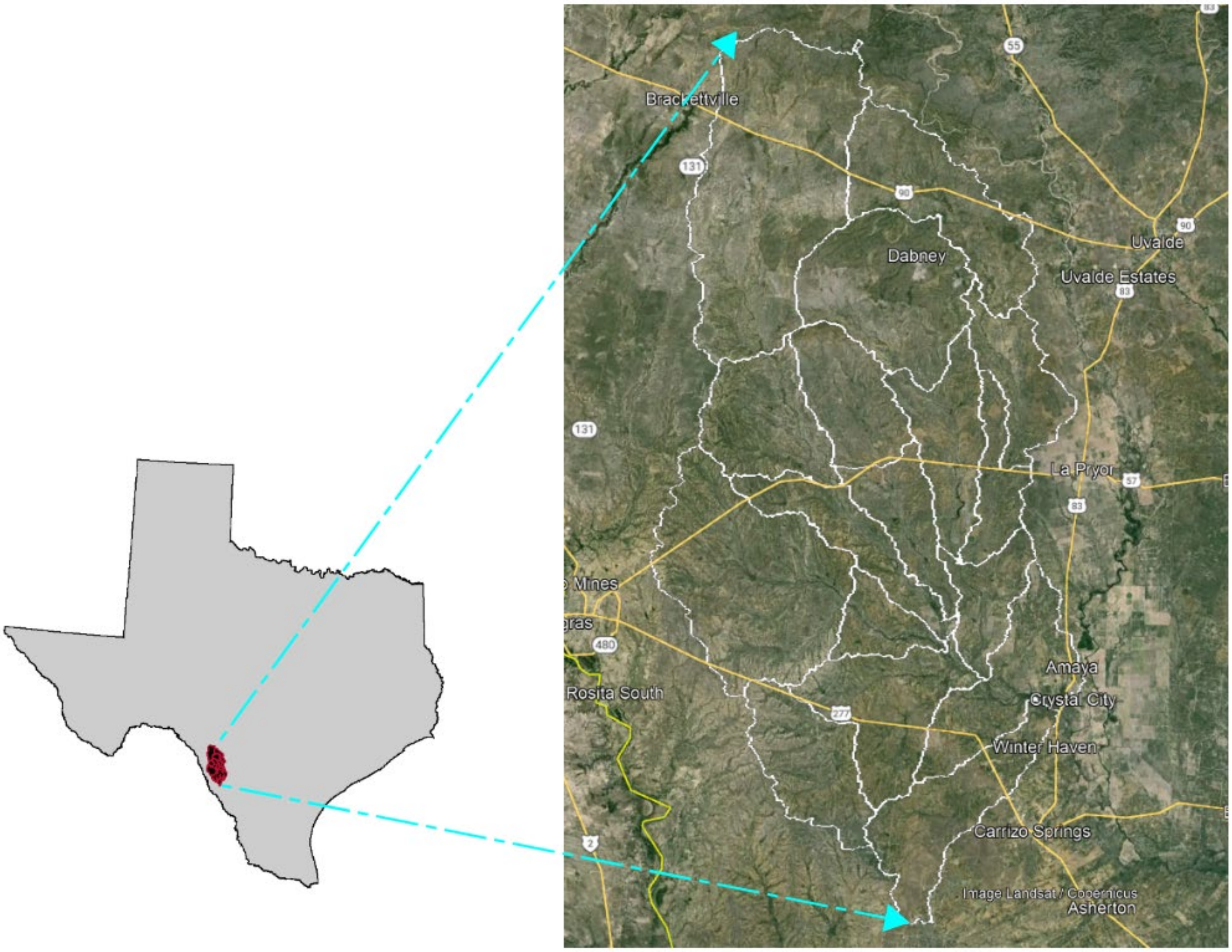


Figure F.1: Turkey Creek Watershed and 2D Modeling Domain

1.2 HEC-HMS MODEL DEVELOPMENT AND CALIBRATION

The Nueces InFRM HEC-HMS model consists of subbasins that utilize the Snyder's transform method and associated parameters (lag time and peaking coefficient) to model how excess precipitation transforms into a direct runoff hydrograph at each subbasin outlet. HEC-HMS calibration was performed for the downstream gage at the Nueces River near Asherton, but for those available calibration events, very little runoff originated from the Turkey Creek basin. See Figure F.2 for the layout of the HEC-HMS subbasins relative to the Asherton gage.

The relevant HEC-HMS subbasins along with their preliminary lag times and peaking coefficients are shown in Table F.1. Prior to the 2D analysis, the preliminary lag times and peaking coefficients in Table F.1 were selected for the 2 through 500-year recurrence intervals based on the preliminary HEC-HMS calibration results. More information on the uniform HEC-HMS model development and calibration can be found in Appendix B.

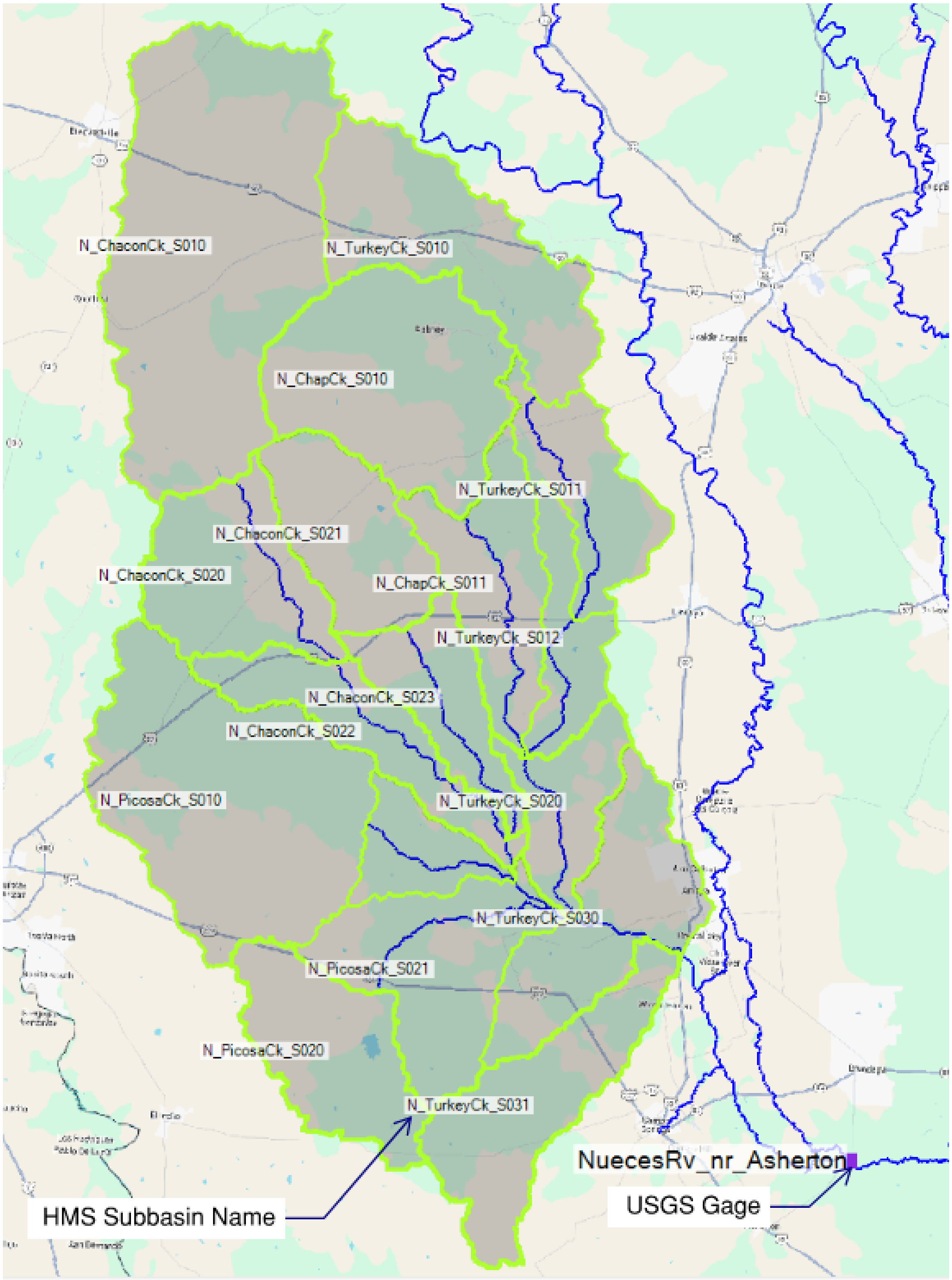


Figure F.2: Nueces InFRM HEC-HMS Model – Relevant Subbasins for 2D Analysis

Table F.1: Turke Creek Preliminary HEC-HMS Subbasin Parameters

Subbasin Name	Drainage Area (sqmi)	Lag Time (hr)	Peaking Coefficient
N_ChaconCk_S010	254.90	17.39	0.7
N_ChaconCk_S020	82.65	12.09	0.7
N_ChaconCk_S021	69.98	10.83	0.7
N_ChaconCk_S023	51.26	14.07	0.7
N_ChaconCk_S022	61.55	16.48	0.7
N_PicosaCk_S010	190.28	17.5	0.7
N_PicosaCk_S011	34.14	9.21	0.7
N_PicosaCk_S020	78.18	7.7	0.7
N_TurkeyCk_S010	111.93	13.54	0.7
N_TurkeyCk_S011	58.59	11.57	0.7
N_TurkeyCk_S012	39.53	11.97	0.7
N_ChapCk_S010	132.77	11.9	0.7
N_ChapCk_S011	71.77	14.69	0.7
N_TurkeyCk_S020	44.51	10.41	0.7
N_PicosaCk_S021	94.57	13.57	0.7
N_TurkeyCk_S030	89.43	9.92	0.7
N_TurkeyCk_S031	88.95	16.11	0.7

1.3 2D HEC-RAS MODEL DEVELOPMENT AND CALIBRATION

At the time of this analysis, the official HEC-RAS release version was 6.4.1. In this version, precipitation can be applied as a boundary condition to the 2D computational mesh. The excess precipitation applied to the HEC-RAS model was taken directly from the HEC-HMS model. The primary purpose of building the 2D HEC-RAS model was to use the 2D diffusion wave method to transform excess precipitation into runoff, everything else being the same as the HEC-HMS model for a direct comparison.

1.3.1 Terrain and 2D Computational Mesh

For the terrain, the seamless statewide LiDAR dataset from the Texas Water Development Board was used (TWDB, 2021). This dataset included the best available 1-meter LiDAR data as of August 2021 for the whole state of Texas, which was then processed into seamless DEMs with 3-meter cell sizes. For the Turkey Creek study area, the TWDB terrain was processed into a single DEM with a 10-foot cell size, and its vertical units were then converted from meters to feet. The final Turkey Creek DEM was re-projected into the same projection as the HEC-HMS model, which was USA Contiguous Albers Equal Area Conic USGS version in feet.

A total of sixteen HEC-RAS 2D flow areas were created with perimeters that exactly matched the subbasin delineations used in HEC-HMS. Next, a 2D computational mesh was developed with 500-foot cell sizes throughout most of the model. A stream centerline file as well as roads that had significant embankments were inserted as breaklines.

An overall view of the terrain and 2D computational mesh can be seen in Figure F.3. Figure F.4 shows a zoomed-in view near the confluence of Chacon Creek with Palo Blanco Creek.

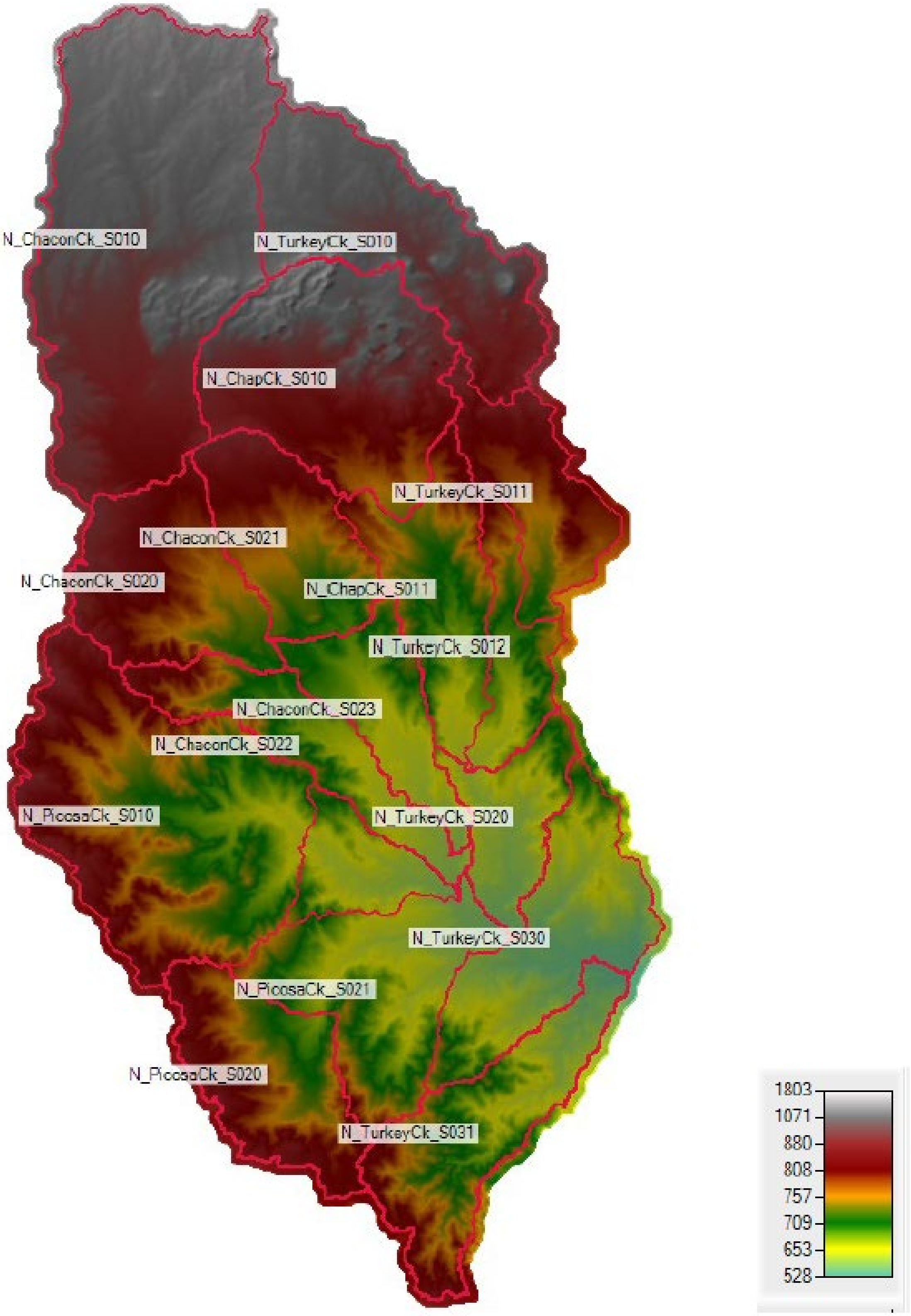


Figure F.3: Overall Terrain Model with Sixteen Subbasin Areas

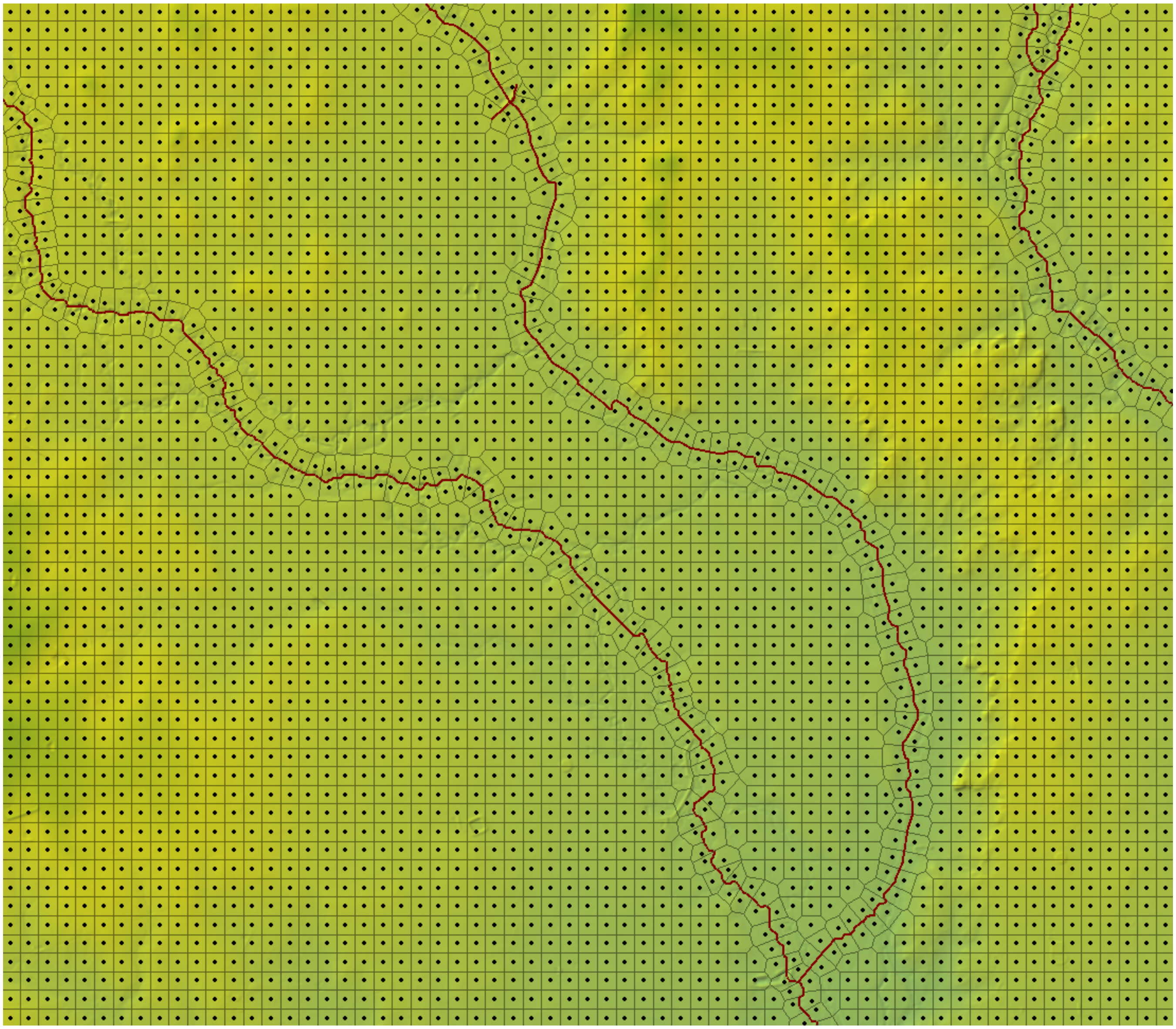


Figure F.4: Terrain Model and 2D Mesh near ChaconCk_R020 (breaklines shown in red)

1.3.2 Unsteady Flow Files and Boundary Conditions

Two separate unsteady flow files were created for this analysis: one for the transform parameters and one for the routing parameters. For the transform parameters, HEC-RAS 2D rain on mesh method was used. Excess precipitation from the HEC-HMS model (losses removed) was applied as a precipitation boundary condition. These conditions were applied for subbasins N_TurkeyCk_S010, N_ChaconCk_S020, and N_PicosakCk_S020 basins in the HEC-RAS unsteady flow data. These subbasins were selected as representative subbasins for the rest of the Turkey Creek watershed. A normal depth based on the river bed profile was used as the downstream boundary condition. A “warm up event” was created in the unsteady flow for the three basins to minize the losses that can occur due to depression storage in the terrain. “Warm up event” had 10 inches in 9 hours, and it was run until most of the water had drained from the system. A restart file was generated at the end of the “warm up event” simulation. The Rain on mesh (excess precipitation from HMS) meteorlogic model linked the initial conditions to the restart file from the “Warm up event” to calculate the hydraulic results from the excess precipitation appropriately. The excess precipitation from the Uniform Rain 100-yr storm for the gage of the Nueces River near Asherton junction was applied to the HEC-RAS model.

For calculating routing parameters, the unsteady flow hydrograph method was used in HEC-RAS. A normal depth was used as the downstream boundary condition. A stepped inflow hydrograph was developed for each reach as an inflow boundary condtion at the upstream end of each reach. See below Figure F.5 for Turkey creek's stepped inflow hydrograph. The stepped flow hydrograph had 20 constant flow "steps" rainging from in-channel flows to a maximum flow that is greater than the expected 500-yr flow for each reach. Similar stepped inflow hydrographs were also developed for the other routing reach tributaries in the Turkey Creek basin. The the warm up simulation was used to ensure that at least a small amount of flow was present in the Turkey Creek channel at the beginning of the routing simulation. At the end of the precursor event, a "restart" file was created. This was used to establish initial conditions for the Turkey Creek run with the stepped flow hydrograph. Other creeks didn't need the warm up simulation, but a number of warm up timesteps were applied in the unstead flow options. The initial conditions for the Turkey Creek routing simulation from the warm up simulation can be seen in Figure F.6.

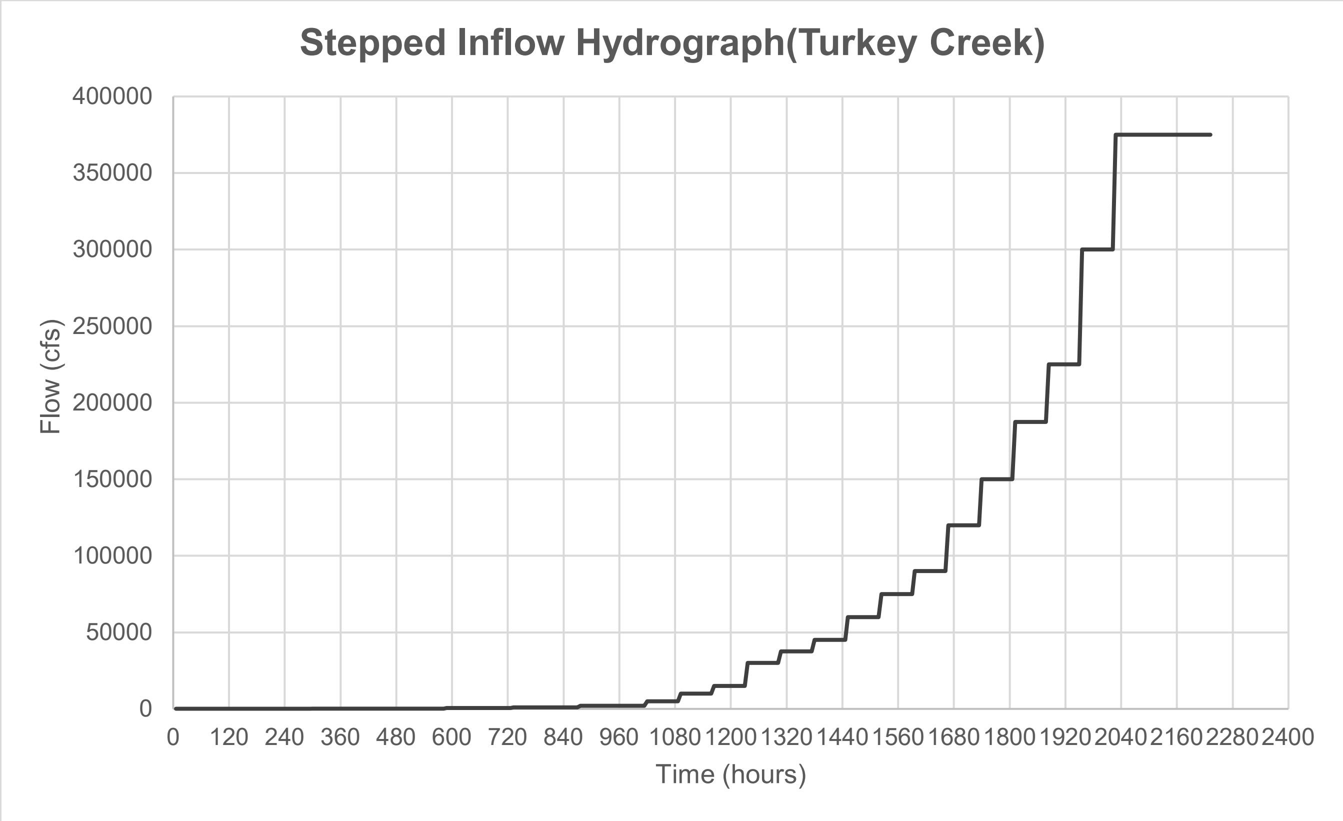


Figure F.5: Stepped Inflow Hydrograph – Upstream Boundary Condition

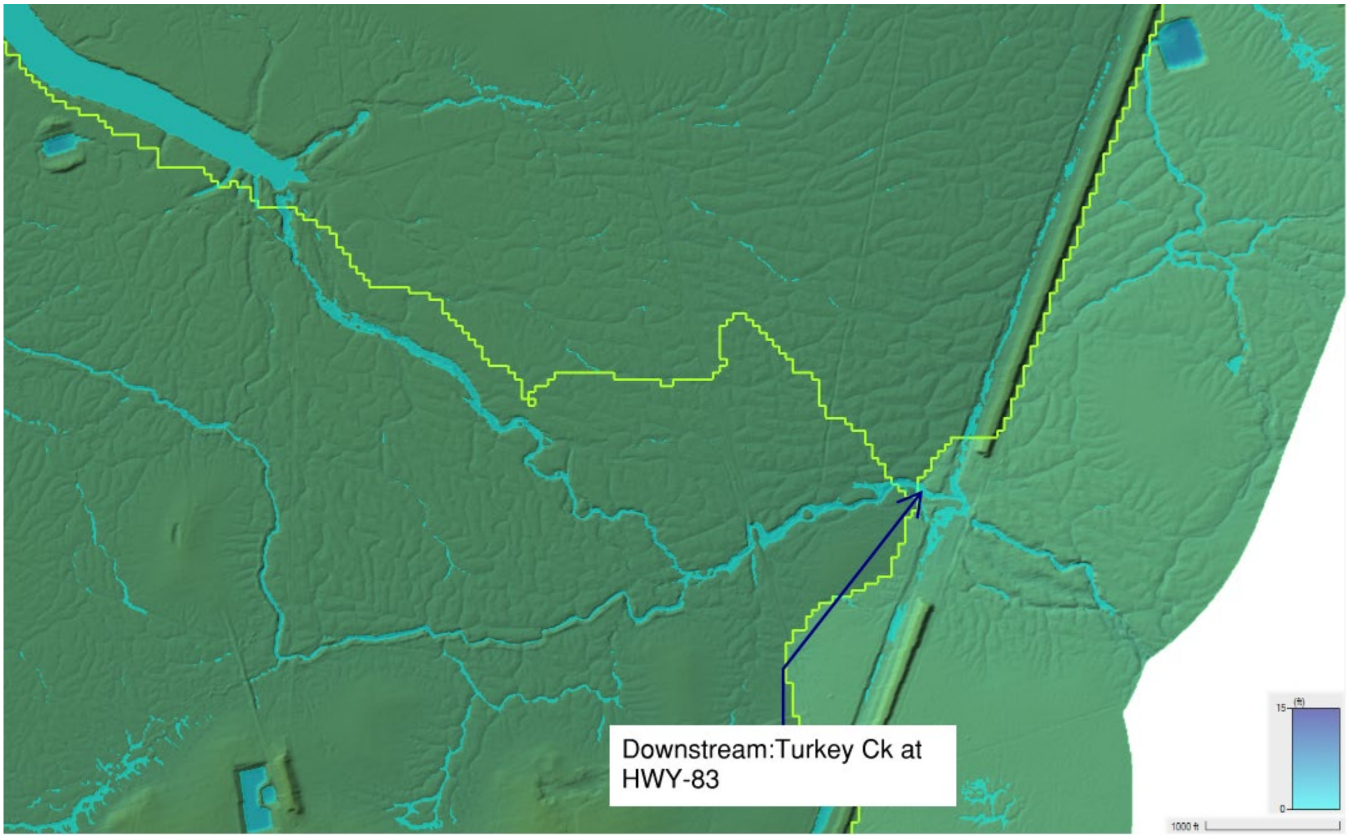
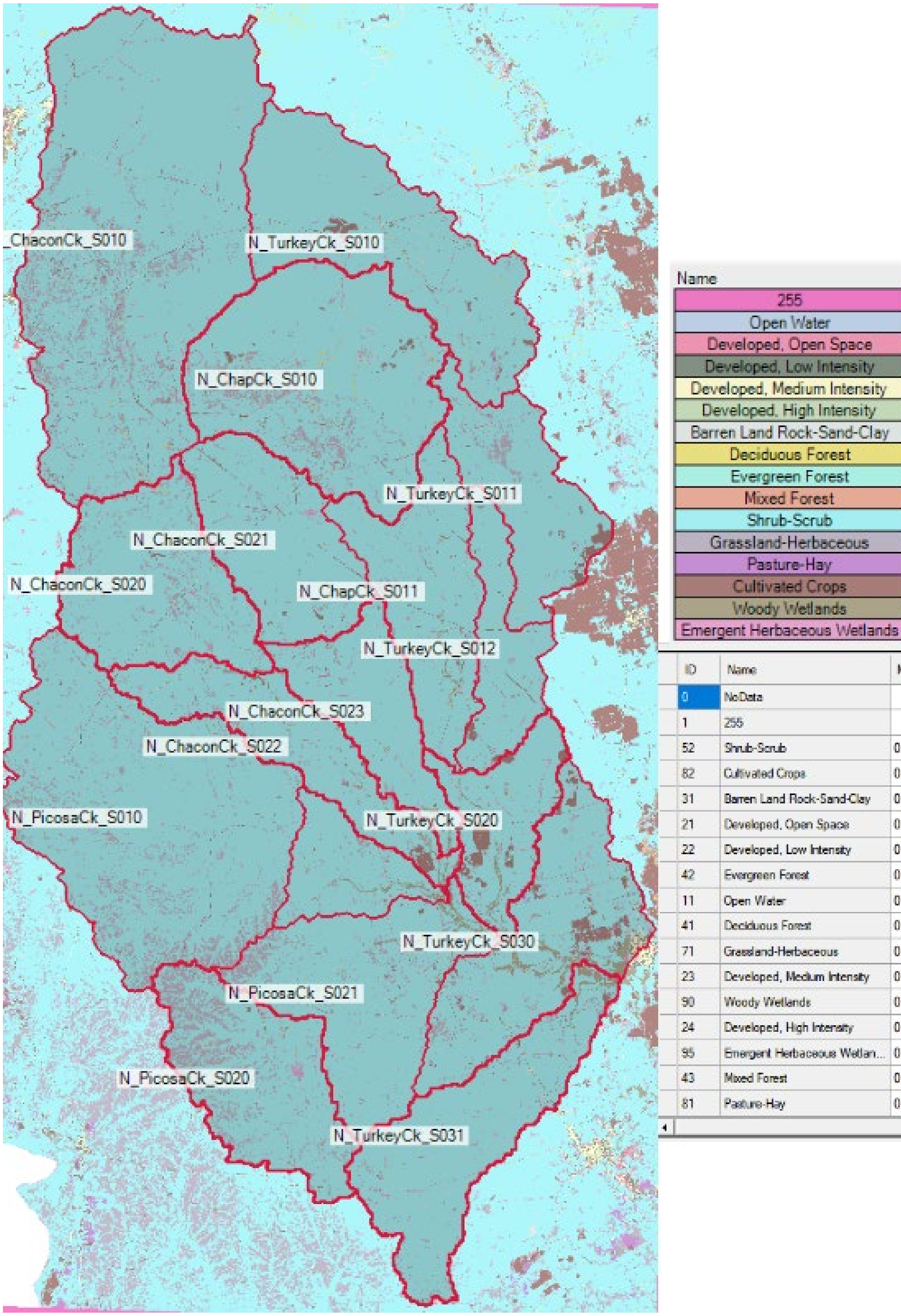


Figure F.6: Warm Up Simulation Initial Conditions for Turkey Creek

1.3.3 National Land Cover Database (NLCD)

2021 National Land Cover Database (NLCD) data were imported into RAS as a Land Cover Layer to establish initial Manning's 'n' estimates based on land cover categories (Figure F.6). Shrub-Scrub was the dominant land use type within the Turkey Creek floodplains; therefore, that is the category that had the greatest impact on the routing of flows within the floodplain.



ID	Name	ManningsN
0	NoData	
1	255	
52	Shrub-Scrub	0.07
82	Cultivated Crops	0.065
31	Barren Land Rock-Sand-Clay	0.07
21	Developed, Open Space	0.065
22	Developed, Low Intensity	0.065
42	Evergreen Forest	0.09
11	Open Water	0.065
41	Deciduous Forest	0.08
71	Grassland-Herbaceous	0.065
23	Developed, Medium Intensity	0.56
90	Woody Wetlands	0.07
24	Developed, High Intensity	0.07
95	Emergent Herbaceous Wetlan...	0.07
43	Mixed Forest	0.08
81	Pasture-Hay	0.07

Figure F.7: Nueces River – Turkey Creek: NLCD Categories

1.3.4 Manning's n Values

Manning's n values were developed for the different land uses and flow regimes throughout the watershed. The final Manning's n included one Manning's 'n' override region for the channel. These values were based on guidance from HEC-RAS Hydraulic Reference Manual (USACE, 2020). The base 'n' values and channel zones can be seen in Table F.2.

Table F.2: Final Manning's 'n' Values

Land Use Category	Base Mann 'n'	Channel Mann 'n'
Shrub-Scrub	0.07	0.05
Cultivated Crops	0.065	0.045
Barren Land Rock-Sand-Clay	0.07	0.05
Developed, Open Space	0.065	0.045
Developed, Low Intensity	0.065	0.045
Evergreen Forest	0.09	0.07
Open Water	0.065	0.045
Deciduous Forest	0.08	0.06
Grassland-Herbaceous	0.065	0.045
Developed, Medium Intensity	0.065	0.045
Woody Wetlands	0.07	0.05
Developed, High Intensity	0.07	0.05
Emergent Herbaceous Wetlands	0.07	0.045
Mixed Forest	0.08	0.05
Pasture-Hay	0.07	0.048

1.4 HEC-RAS RESULTS AND ADJUSTING PARAMETERS ON HEC-HMS

1.4.1 Transform Parameters Analysis

For the transform parameter analysis, a 2D excess rain-on-mesh method was used to simulate the rainfall runoff process. The excess precipitation, which is precipitation minus the losses, was extracted from the HEC-HMS model for the 1% AEP (100-year) storm. This excess precipitation time series was then applied to the 2D HEC-RAS model as a precipitation boundary condition in the unsteady flow file. The HEC-RAS 2D diffusion wave model was then run with the excess precipitation. The resulting flow hydrograph at the downstream end of each 2D subbasin was then extracted and compared to the HEC-HMS results for the corresponding subbasinss. The lag times and peaking coefficients in HEC-HMS were then adjusted to match flow hydrograph from the 2D HEC-RAS results at the subbasin outlets.

N_TurkeyCK_S010 is a representative of the steep headwater subbasins. The HEC-RAS results from this subbain were used to develop transform parameters for subbasins N_TurkeyCK_S010, N_ChaconCk_S010 and NChapCk_S010. Subbasins N_ChanconCk_S020 and N_PicosaCk_S020 are representative of the rest of the subbasins in the Turkey Creek watershed. The average of the results from subbasins N_ChanconCk_S020 and N_PicosaCk_S020 were then used to adjust the lag times and peaking coefficients for the rest of the Turkey Creek subbasins. A summary of Snyder's Transform adjusted parameters are shown below in Table F.4.

Table F.3: Summary of Snyder's Transform Parameters

	Previous HEC-HMS Parameters		New HEC-HMS Parameters from 2D RAS			
Subbasin	Lag Time(hrs)	Peaking Coeff.	Lag Time(hrs)	Peaking Coeff.	Subbasin Type	Percentage Reduction in Lag Time
N_ChaconCk_S010	17.39	0.7	5.77	0.75	Steep headwaters	67%
N_ChaconCk_S020	12.09	0.7	4.5	0.75	Normal slope	63%
N_ChaconCk_S021	10.83	0.7	4.33	0.75	Normal slope	60%
N_ChaconCk_S023	14.07	0.7	5.63	0.75	Normal slope	60%
N_ChaconCk_S022	16.48	0.7	6.59	0.75	Normal slope	60%
N_PicosaCk_S010	17.5	0.7	7.00	0.75	Normal slope	60%
N_PicosaCk_S011	9.21	0.7	3.68	0.75	Normal slope	60%
N_PicosaCk_S020	7.7	0.7	3.25	0.75	Normal slope	58%
N_TurkeyCk_S010	13.54	0.7	4.50	0.75	Steep headwaters	67%
N_TurkeyCk_S011	11.57	0.7	4.63	0.75	Normal slope	60%
N_TurkeyCk_S012	11.97	0.7	4.79	0.75	Normal slope	60%
N_ChapCk_S010	11.9	0.7	3.95	0.75	Steep headwaters	67%
N_ChapCk_S011	14.69	0.7	5.88	0.75	Normal slope	60%
N_TurkeyCk_S020	10.41	0.7	4.16	0.75	Normal slope	60%
N_PicosaCk_S021	13.57	0.7	5.43	0.75	Normal slope	60%
N_TurkeyCk_S030	9.92	0.7	3.97	0.75	Normal slope	60%
N_TurkeyCk_S031	16.11	0.7	6.44	0.75	Normal slope	60%

1.4.2 Routing Parameters Analysis

A second HEC-RAS 2D diffusion wave model simulation was used to generate storage discharge curves for thirteen routing reaches which corresponded to the thirteen routing reaches in HEC-HMS that fall within the 2D modeling domain. As already mentioned in section 1.3.2, for each of these thirteenreaches, an unsteady flow hydrograph was applied as an upstream boundary condition and normal depth was applied as the downstream boundary condition. A range of flows from in channel flows to greater than the expected 500-year flow were applied to the reaches in the form of a stepped flow hydrograph, andtheresulting flow hydrograph at the downstream end of each reach was extracted from the HEC-RAS output. The incremental storage volume for a given flow value was then calculated as the area between the inflow and outflow time series for that reach, as shown in Figure F.8. The cumulative sum of the incremental storage values were then used to calculate the storage-discharge curve for each reach. . Tabular and graphical results of the routing analysis are available in Tables F.4 thorugh F.9 and in Figures F.9 through F.14, respectively.

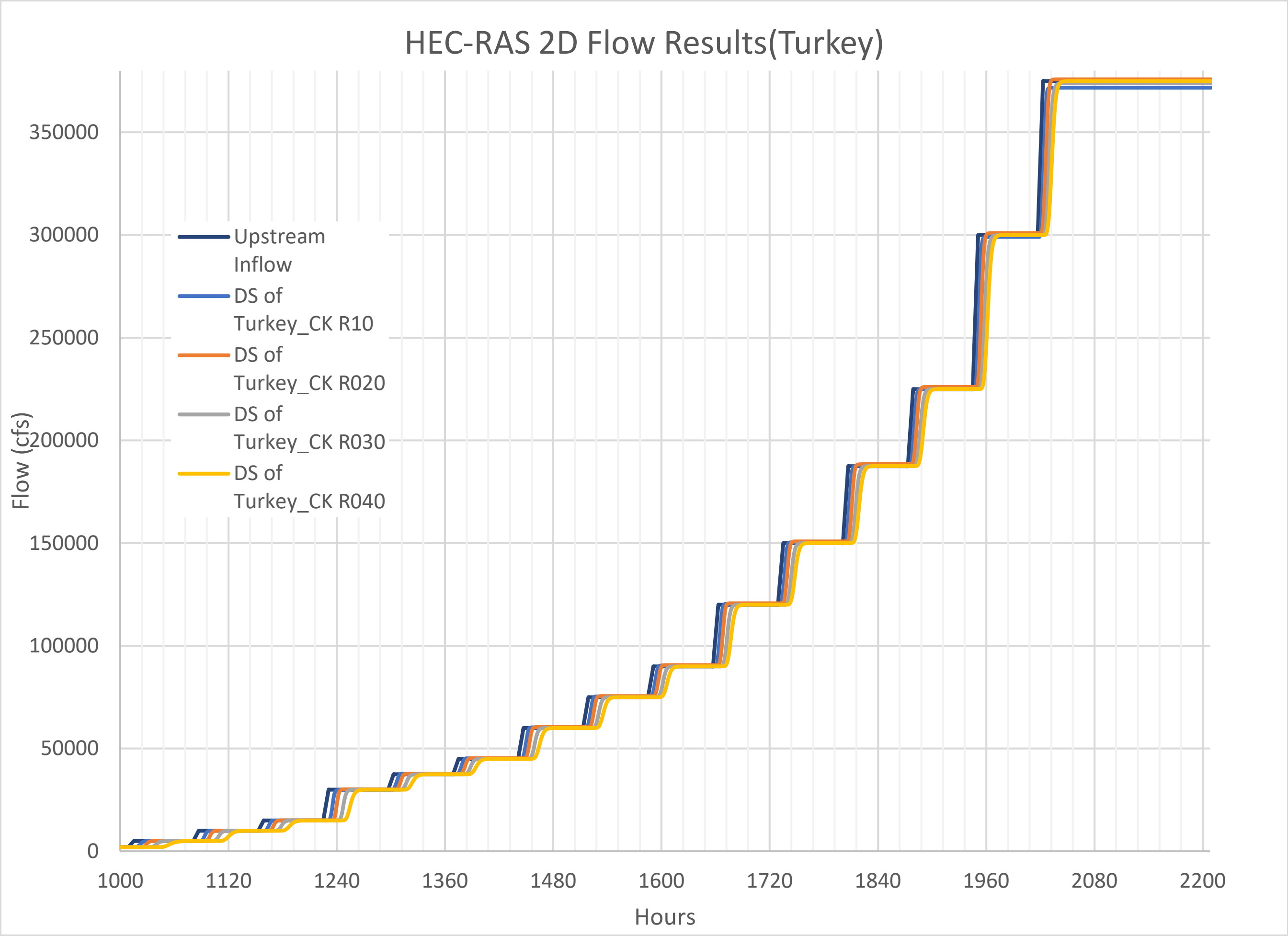


Figure F.8: Reach Inflow and Outflow Hydrographs from 2D HEC-RAS

Table F.4: HEC-RAS 2D Storage-Discharge Table For Turkey Creek

Flow (cfs)	Turkey_Ck_R010 Volume (ac-ft)	Turkey_Ck_R020 Volume (ac-ft)	Turkey_Ck_R030 Volume (ac-ft)	Turkey_Ck_R040 Volume (ac-ft)
0	0	0	0	0.0
100.0	234.44	101.91	256.24	322.8
200.0	373.96	178.44	420.75	574.2
500.0	713.14	396.69	822.32	1295.9
1000.0	1210.27	763.06	1433.65	2281.3
2000.0	2152.61	1401.51	2547.23	3952.6
5000.0	4795.15	3126.61	5434.15	7868.9
10000.0	8880.70	5672.71	9690.63	12816.5
15000.0	12570.22	7911.84	13643.60	16919.9
30000.0	22821.23	13682.22	24151.29	26999.5
37500.0	26951.61	16380.68	29941.13	31368.1
45000.0	30679.39	18890.91	35943.14	35408.5
60000.0	37779.32	23683.15	46197.44	42755.1
75000.0	44281.22	28088.69	56674.02	49433.0
90000.0	50361.93	32159.94	67506.86	55630.9
120000.0	62093.63	39920.70	84988.58	66934.1
150000.0	73169.93	47002.60	102277.19	77238.1
187500.0	86496.74	55277.87	122315.47	89309.9
225000.0	99528.18	62949.05	142123.82	100807.5
300000.0	129292.52	78046.73	174630.86	121418.3
375000.0	203488.15	90976.82	228260.00	139185.3

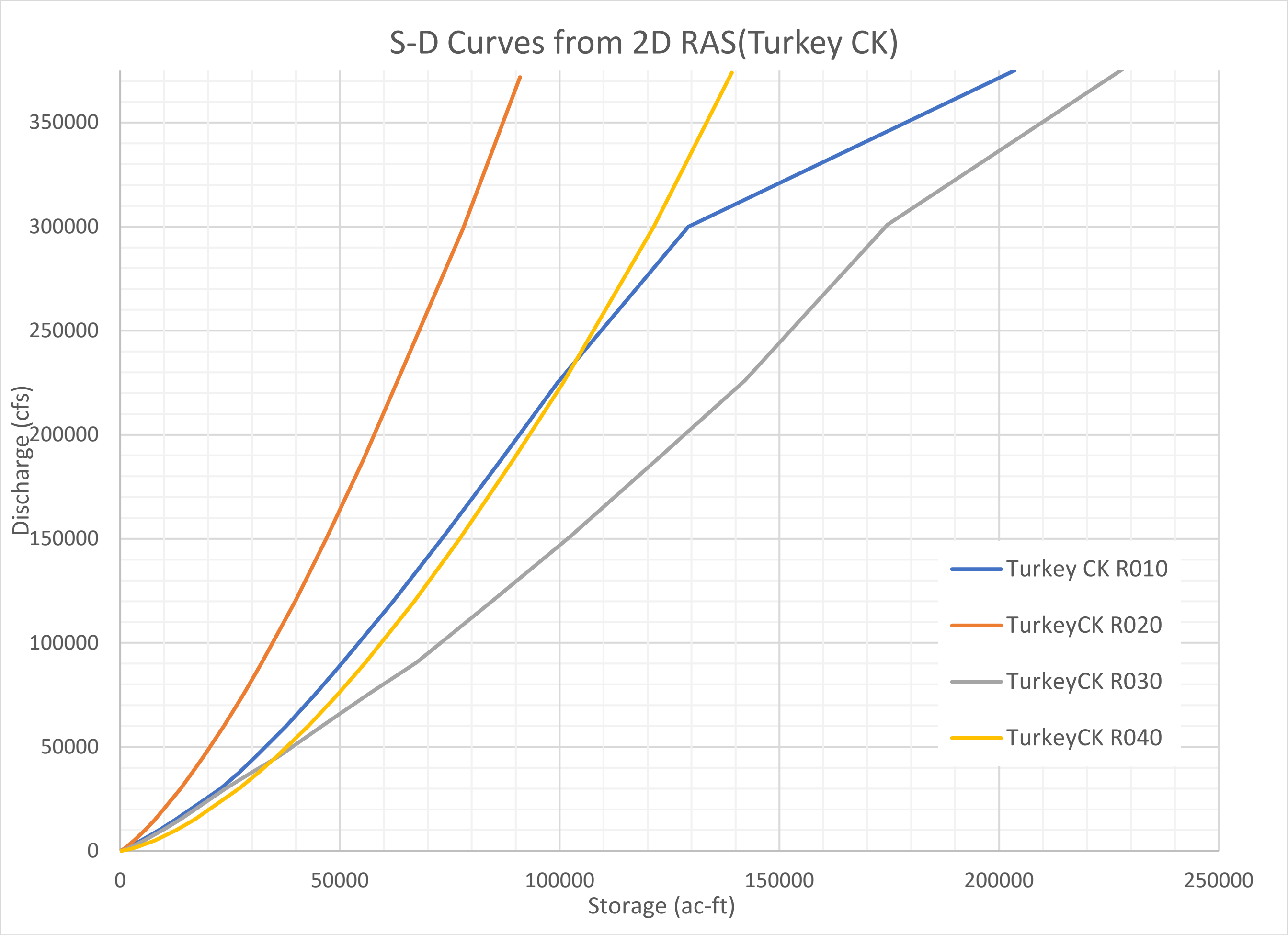


Figure F.9: 2D HEC-RAS Turkey Creek Storage-Discharge Curves

Table F.5: HEC-RAS 2D Storage-Discharge Table For Chaparrosa Creek

Flow (cfs)	Chaparrosa_CK_R010 Volume (ac-ft)
0	0
33.3	244.46
66.7	334.65
166.7	538.09
333.3	814.32
666.7	1280.67
1666.7	2533.15
3333.3	4300.62
5000.0	5765.40
6666.7	7175.77
8333.3	8539.05
10000.0	9923.84
13333.3	12744.73
16666.7	15336.21
20000.0	17782.52
26666.7	22357.18
33333.3	26564.74
41666.7	31548.87
50000.0	36184.93
66666.7	44902.75
83333.3	52863.84

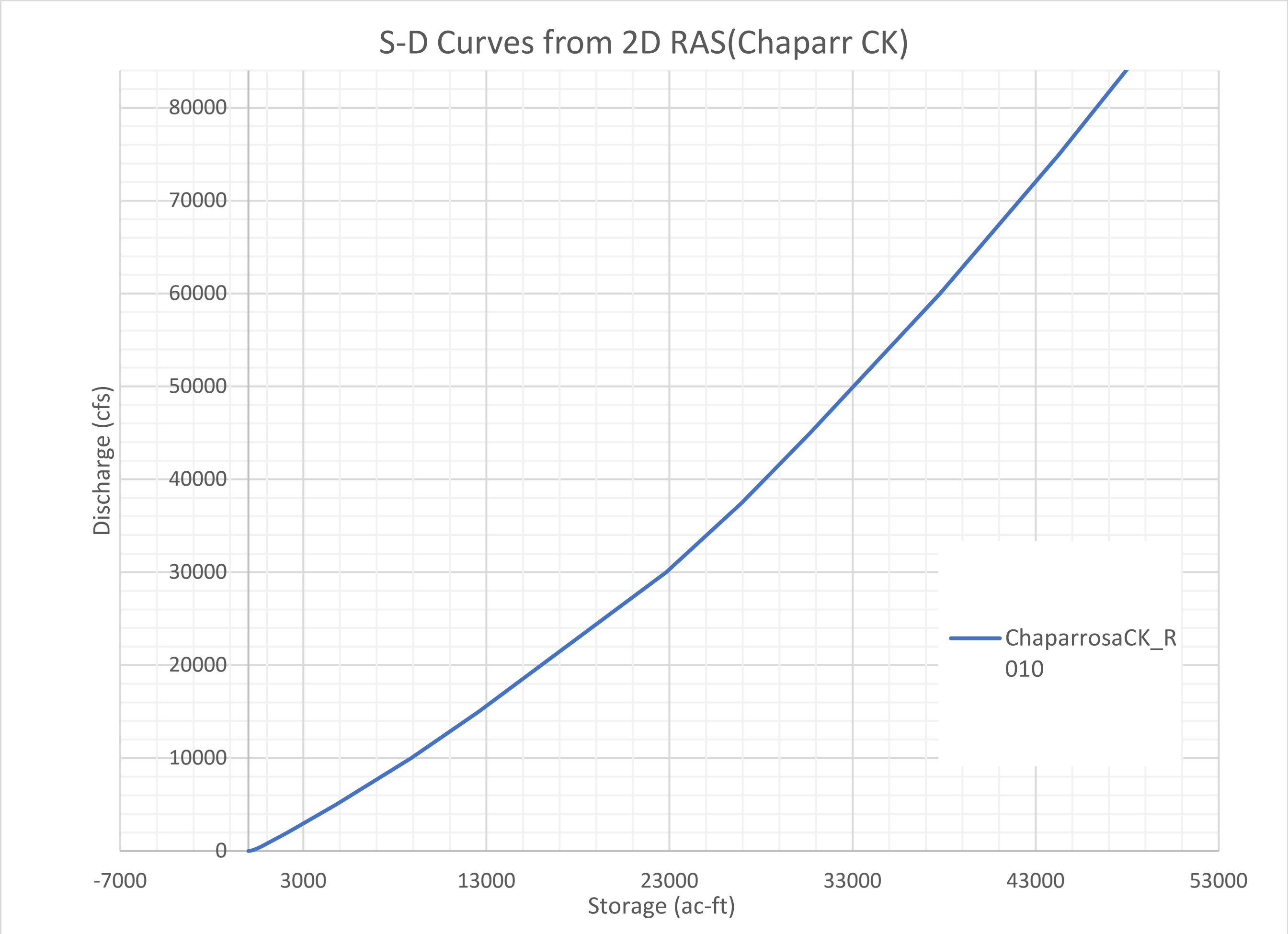


Figure F.10: 2D HEC-RAS Chaparrosa Creek Storage-Discharge Curves

Table F.6: HEC-RAS 2D Storage-Discharge Table For Comanche Creek

Flow (cfs)	Comanche_Ck_R010 Volume (ac-ft)	Comanche_Ck_R020 Volume (ac-ft)
0	0	0
40.0	157.82	11.22
80.0	237.00	17.75
200.0	425.90	45.59
400.0	693.13	86.62
800.0	1187.60	162.45
2000.0	2529.26	386.45
4000.0	4425.75	811.73
6000.0	6126.71	1295.56
10000.0	9296.76	2002.30
12500.0	11041.25	2422.14
15000.0	12686.27	2820.25
26666.7	19740.05	4530.54
33333.3	23332.64	6085.47
60000.0	36945.45	10134.42
80000.0	45993.05	14072.40
100000.0	54159.26	18538.96
125000.0	63691.45	24310.38
150000.0	72491.62	30436.51
200000.0	89590.22	39932.88
250000.0	105367.54	64753.47

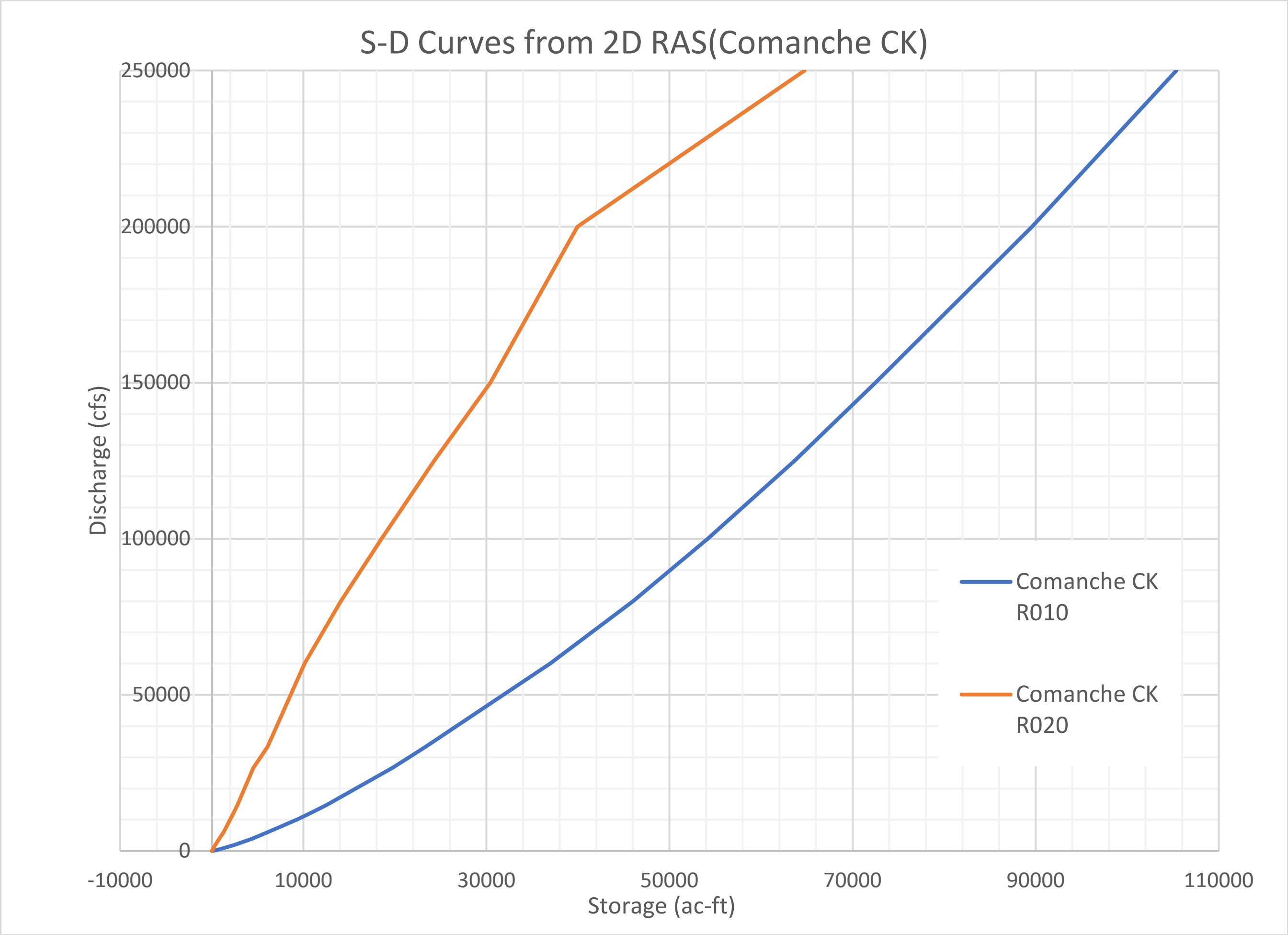


Figure F.11: 2D HEC-RAS Comanche Creek Storage-Discharge Curves

Table F.7: HEC-RAS 2D Storage-Discharge Table For Picosa Creek

Flow (cfs)	Picosa_CK_R010 Volume (ac-ft)
0	0
33.3	118.89
66.7	174.02
166.7	304.52
333.3	479.84
666.7	811.14
1666.7	1790.51
3333.3	3183.30
5000.0	4416.20
6666.7	5507.40
8333.3	6506.75
10000.0	7443.31
13333.3	9238.43
16666.7	10905.69
20000.0	12472.35
26666.7	15423.65
33333.3	18207.51
41666.7	21491.95
50000.0	24590.21
66666.7	30409.96
83333.3	35840.69

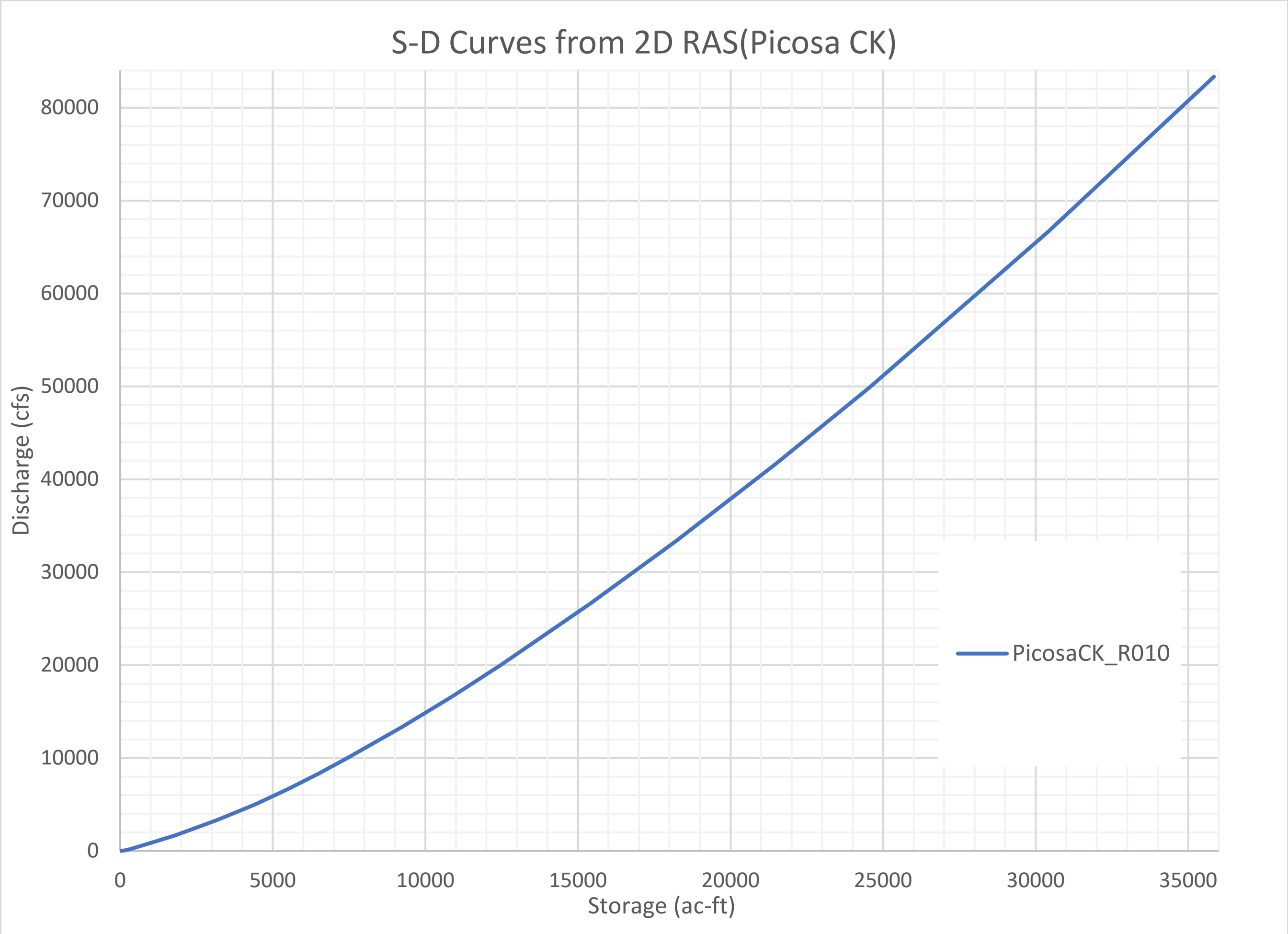


Figure F.12: 2D HEC-RAS Picosa Creek Storage-Discharge Curves

Table F.8: HEC-RAS 2D Storage-Discharge Table For Palo Blanco Creek

Flow (cfs)	Palo Blanco_Ck_R010 Volume (ac-ft)	Palo Blanco_Ck _R020 Volume (ac-ft)	Palo Blanco_Ck _R030 Volume (ac-ft)
0	0	0	0
33.3	261.29	15.00	39.34
66.7	363.41	27.68	59.33
166.7	598.55	66.79	127.50
500.0	1241.93	164.63	278.88
1000.0	2031.65	296.25	497.09
2500.0	4187.11	691.34	1117.71
10000.0	12434.60	2095.61	3569.61
15000.0	16757.33	2798.63	4925.36
20000.0	20660.28	3447.17	6075.89
25000.0	24267.57	4085.86	7115.17
30000.0	27664.23	4687.71	8090.44
40000.0	34164.93	5865.78	9910.75
50000.0	40348.83	6980.21	11565.47
60000.0	46253.75	8009.28	13097.80
80000.0	57303.67	10083.51	16010.75
100000.0	67603.08	12112.55	18436.83
125000.0	79741.50	14609.92	21099.69
150000.0	91288.97	16968.83	23406.67
200000.0	113321.81	21387.64	27918.16
250000.0	133960.63	25583.26	31752.13

Figure F.13: 2D HEC-RAS Palo Blanco Creek Storage-Discharge Curves

Table F.9: HEC-RAS 2D Storage-Discharge Table For Chacon Creek

Flow (cfs)	Chacon_Ck_R010 Volume (ac-ft)	Comanche_Ck_R020 Volume (ac-ft)
0	0	0
50	209.91	138.66
100	294.87	220.23
250	486.42	430.33
500	737.09	758.00
1000	1190.79	1378.67
2500	2431.95	3177.11
5000	4510.73	5788.98
7500	6468.64	8075.09
10000	8384.56	10139.54
12500	10272.48	11988.11
15000	12101.09	13692.52
20000	15626.31	17286.92
25000	18995.88	20628.30
30000	22044.64	23828.46
40000	27625.47	30589.63
50000	32846.15	36672.37
62500	39077.46	43787.17
75000	44882.73	50367.05
100000	55711.69	63298.56
125000	65784.98	74983.02

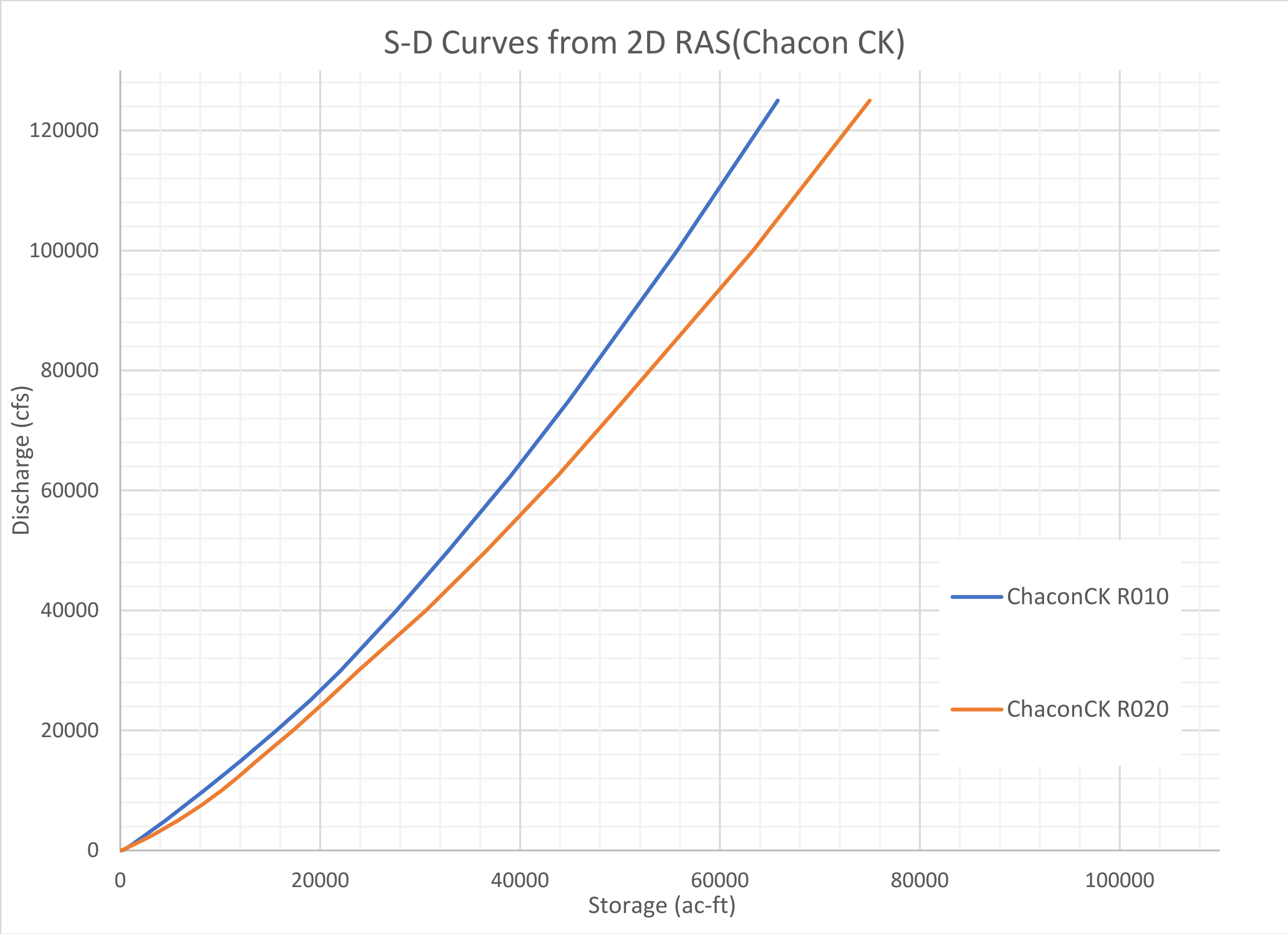


Figure F.14: 2D HEC-RAS Chacon Creek Storage-Discharge Curves

1.4.3 2D-Informed Updates to the InFRM HEC-HMS Model

The thirteen storage-discharge curves computed from the 2D HEC-RAS model were adopted in the InFRM final HEC-HMS model as parameters to the Modified Puls routing reaches in the Turkey Creek watershed.

After updating the routing reaches, the 2D transform results were used to update the Snyder's transform parameter estimates in HEC-HMS. It is important to note that the 2D diffusion wave equations in HEC-RAS have no notion of Lag time and Peaking coefficient parameters which are specific to the HEC-HMS Snyder's transform method. However, the peak magnitude, peak timing, and overall shape of the 2D transform hydrographs can be used to inform Snyder's transform parameters. The subbasinlag time and peaking coefficient parameters were adjusted in HEC-HMS until the Snyder's transform hydrographs more closely matched the 2D HEC-RAS downstream hydrographs. The final adjusted HEC-HMS transform parameters were shown in Table F.3.

The InFRM Uniform and Elliptical storm HEC-HMS models were then recomputed with the final 2D storage-discharge curves and the final Tc and R parameters. Figures F.15 through F.17 compare the 100-yr flow hydrograph results for subbasins N_TurkeyCK, N_ChanconCk_S020 and N_PicosaCk_S020 from 2D HEC-RAS, from the preliminary HEC-HMS transform parameters and from the final HEC-HMS transform parameters, Likewise, Figure F.18 compares the 100-yr preliminary and final HEC-HMS flow hydrograph results at the Turkey Creek at Highway 83 junction, which is at the downstream end of the 2D HEC-RAS analysis, This figure uses the results from the 100-yr elliptical storm for the downstream Asherton gage.

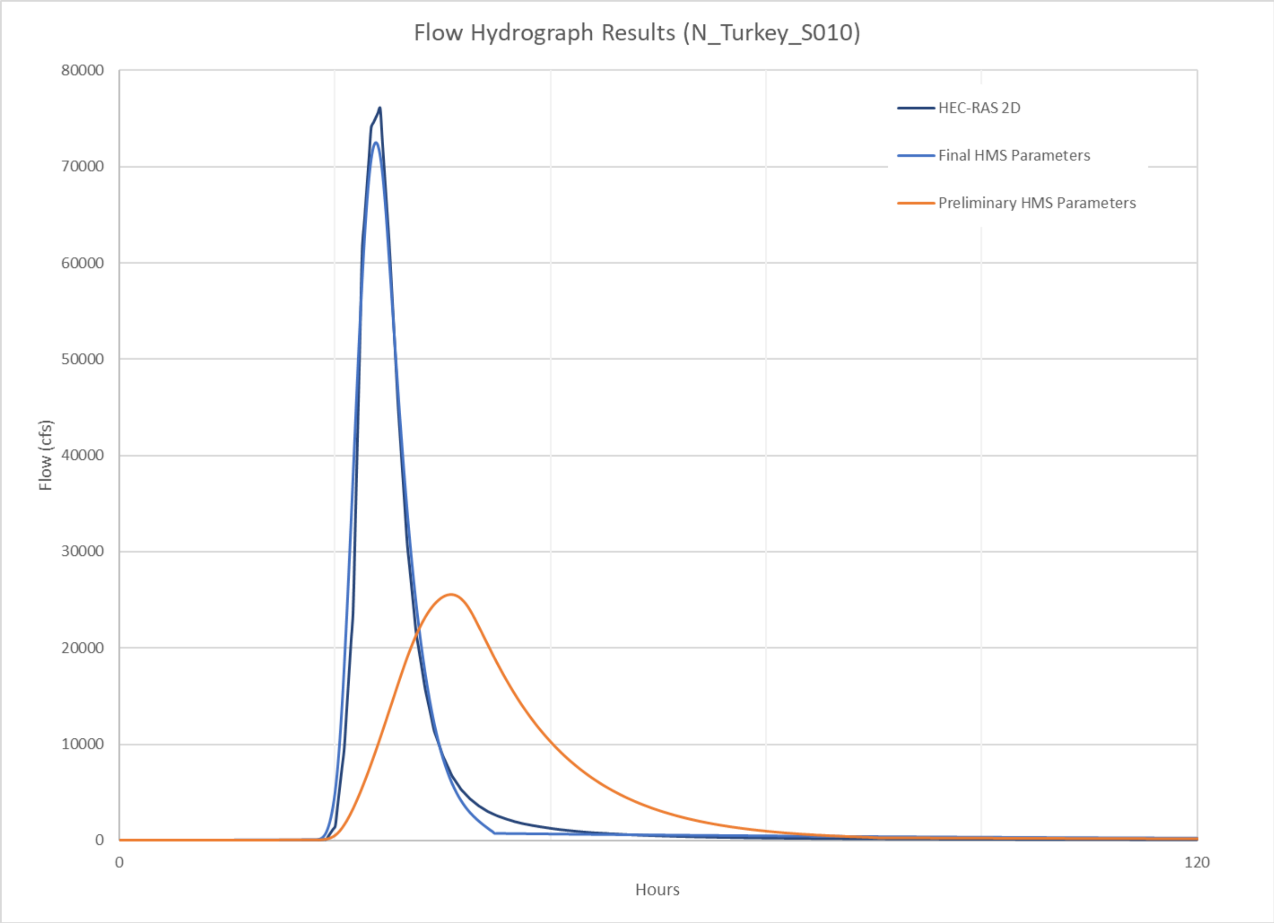


Figure F.15: Comparison Of Flow Hydrogarph Results For Subbasin N_Turkey_S010

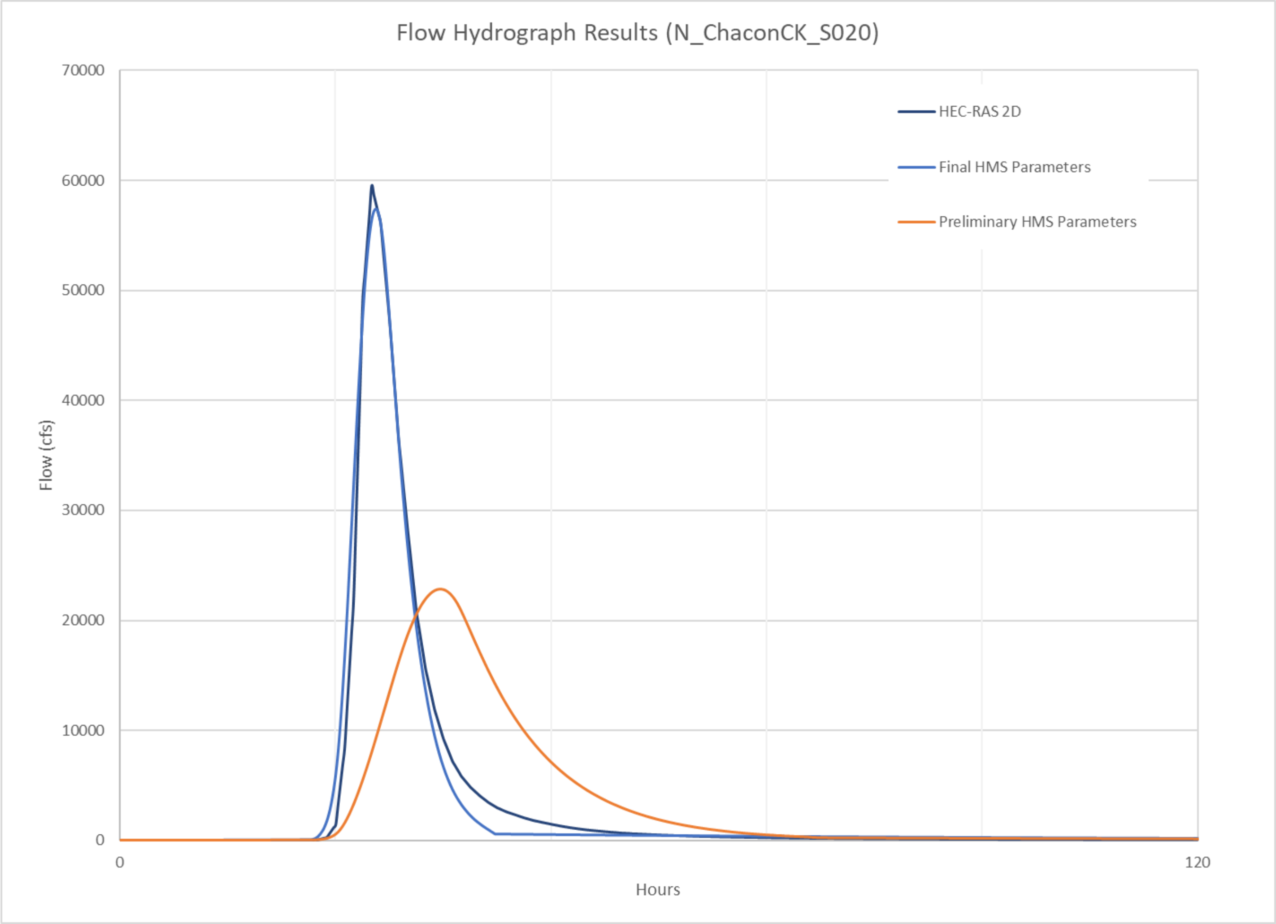


Figure F.16: Comparison Of Flow Hydrogarph Results For Subbasin N_ChacoCk_S020

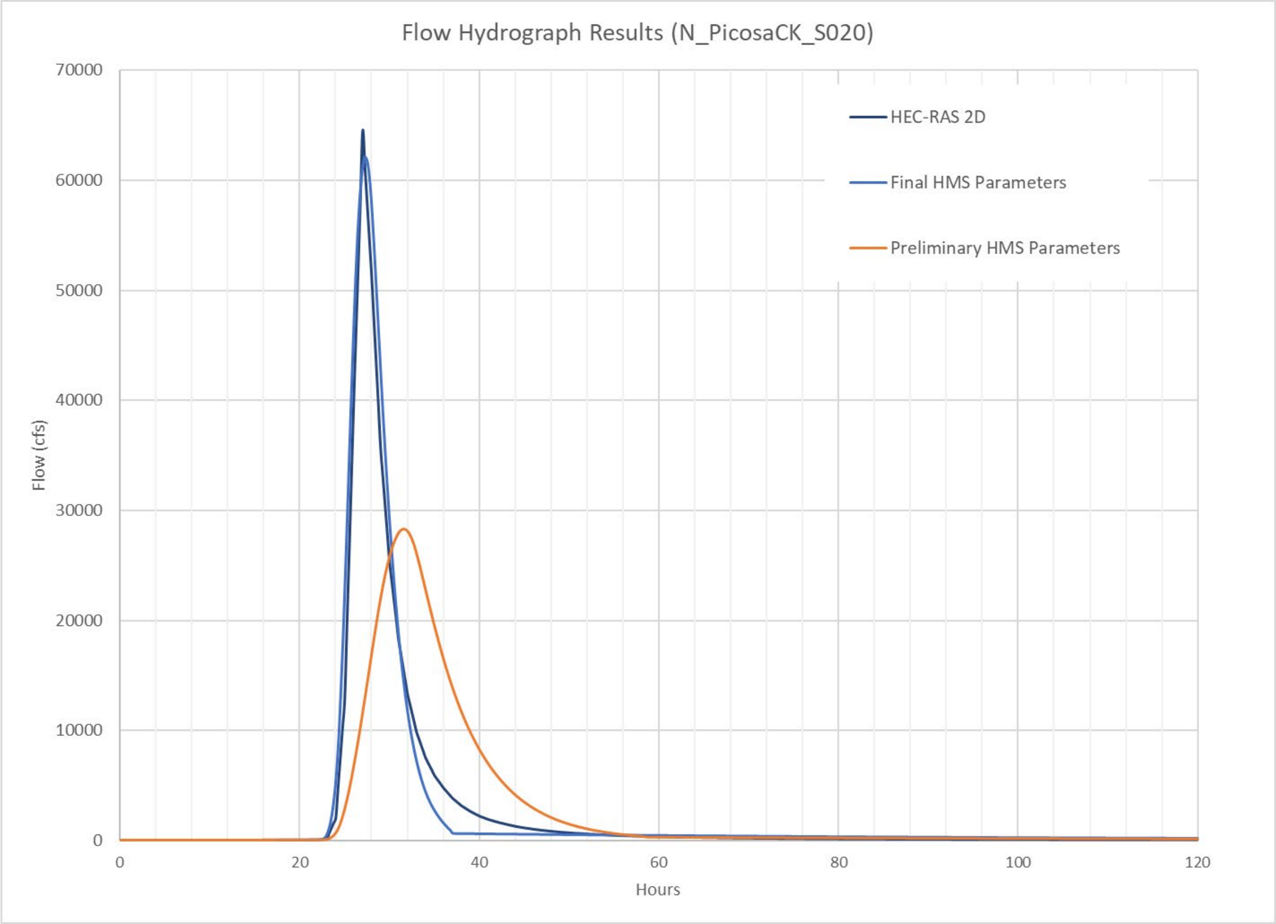


Figure F.17: Comparison Of Flow Hydrogarph Results For Subbasin N_PicosaCk_S020

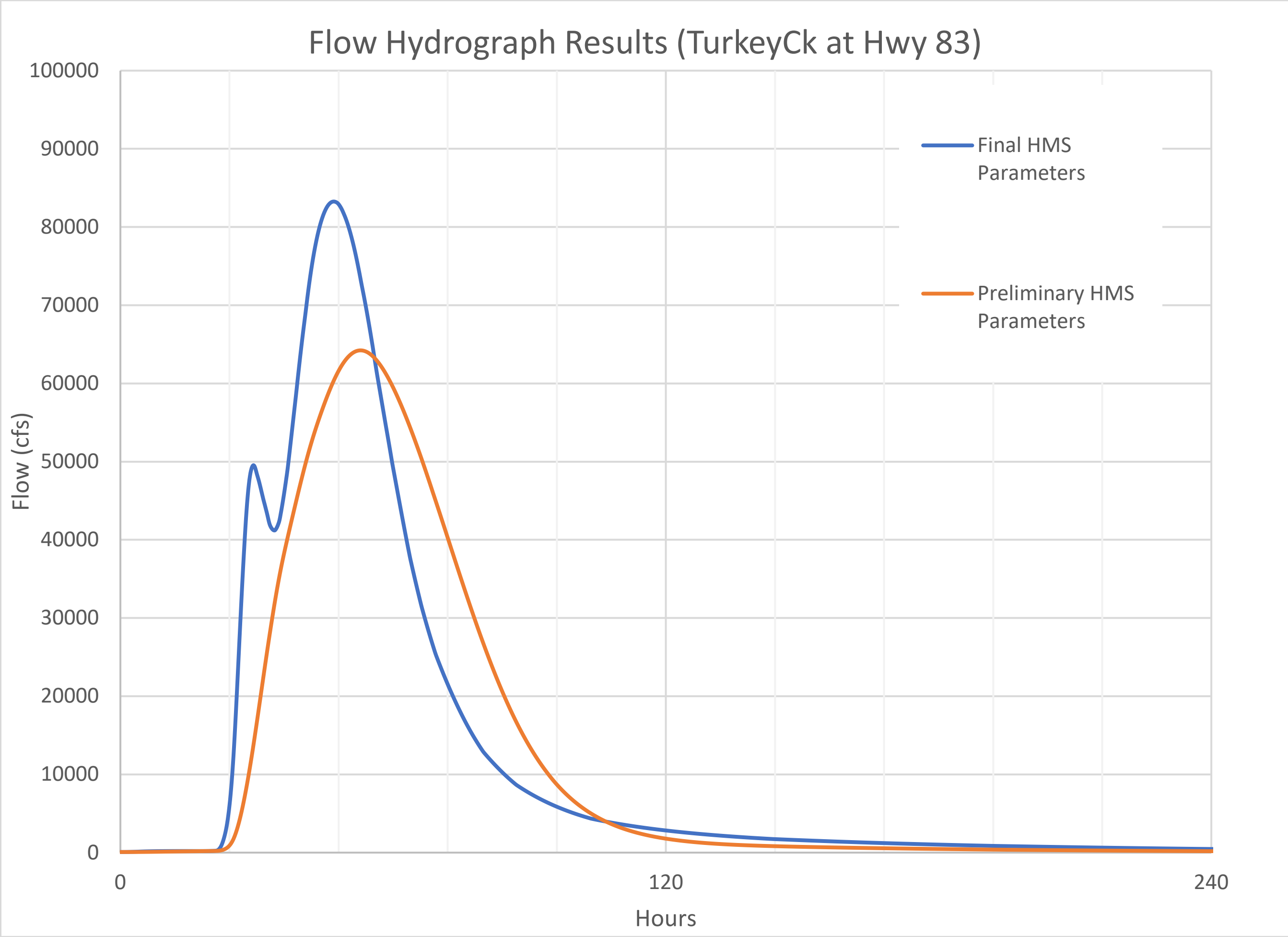


Figure F.18: Comparison Of Flow Hydrogarph Results For Subbasin Turkey Creek at Hwy 83

1.5 LIMITATIONS AND OPPORTUNITIES FOR IMPROVEMENT

Since there was no observed data to assist in calibrating the HEC-HMS model, this analysis utilized 2D HEC-RAS as a calibration and verification tool instead. The modeling domain of the 2D analysis consisted of a drainage area of approximately 2,000 square miles. Given a watershed of this size, it was cost and time-prohibitive to include bridges, culverts,, and other structures that could affect the arrival time and peak magnitudes of flows downstream. However, the overall accuracy of the model over a larger range of event intensities would most likely be improved if the influence of structures would have been specifically accounted for during model development.

In addition, for the sake of efficiency, subbasin transform parameters were directly estimated in HEC-RAS for only three representative subbasins. Proportional adjustments were then applied to the remaining subbasins in the Turkey Creek watershed. Some improvement in accuracy could have been obtained by repeating the same analysis for all 17 subbasins; however, the degree of improvement may have been relatively small relative to the information already gained from this analysis.

Additional sensitivity testing to the mesh cell sizes might also help improve the accuracy of the model, particularly near the main channel. While a finer cell resolution of about 500-feet was implemented, additional refinement could be done so that the cell sizes better fit the varying channel widths observed throughout the terrain model.

This would allow for a more accurate designation of in-bank versus out-of-bank Manning's 'n' values which could have some effect on the computed arrival times and peak water surface elevations.

1.6 CONCLUSIONS

One of the acknowledged limitations of unit hydrograph theory is the assumption of linearity, which implies that a watershed would have the same time of concentration when receiving a very low intensity rain event as it would when receiving a high intensity rainfall event. Concerns with this assumption can be reduced by calibrating the model to storms of similar intensity to the storm of primary interest (i.e., the 1% AEP or 100-yr recurrence interval).

In this analysis, the 2D diffusion wave transform method in HEC-RAS, which is based on the momentum and continuity equations and is not tied to the assumption of linearity, was used to inform the Snyder's unit hydrograph transform parameters in HEC-HMS particularly for rare, intense rainfall events such as the 1% AEP storm. In fact, the results of this analysis led to an average decrease of 60% in the Snyder's lag times for the 1% AEP storm event on the Turkey Creek watershed. These decreases in lag times generally led to higher peak discharges downstream. The results from this analysis were also consistent with those found in literature such as Snyder and Minshall (Snyder, 1938 and Minshall, 1962). However, these increases in individual subbasin peak discharges were tempered by the floodplain storage added to the model in the Modified Puls routing reaches.

The 2D HEC-RAS analysis was used to calculate the storage volumes in the HEC-HMS routing reaches of Turkey Creek above HWY-83. The analysis from 2D model of the Turkey Creek watershed was used to estimate Modified Puls Routing parameters and Snyder's subbains transform paprameters. The results of this 2D analysis were used to update the transform and routing reach parameters in the final InFRM HEC-HMS model. This analysis helped to overcome the lack of observed data in the Turkey Creek watershed and helped to reduce the uncertainty in the flood frequency estimates of the HEC-HMS model for rare events such as the 1% AEP (100-yr) storm.

2 References and Resources

2.1 REFERENCES

Minshall, N. (1960). Predicting storm runoff on small experimental watersheds. ASCE Journal of the Hydraulics Division, 17-38.

Moriasi, D. N. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. 50(3): 885-900.

NOAA. Hydrometeorological Design Studies Center. Precipitation Frequency Data Server (PFDS). https://hdsc.nws.noaa.gov/hdsc/pfds/ Accessed Oct 2018.

NOAA. (2018). *NOAA Atlas 14 Precipitation Frequency Atlas of the United States: Volume 11 Version 2.0: Texas*.

Snyder, F. F. (1938). Synthetic Unit-Graphs. Transactions, American Geophysical Union.

U.S. Army Corps of Engineers. (1991). Engineer Regulation 1110-8-2(FR) Inflow design floods for dams and reservoirs. Washington, D.C.

U.S. Army Corps of Engineers Risk Management Center (RMC). (2017). Probable maximum flood analysis for Whittier Narrows Dam.

U.S. Department of Agriculture (USDA). (1986). Urban hydrology for small watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55).

2.2 SOFTWARE

Environmental Systems Research Institute, Inc., ArcGIS 10.5. (2016). Retrieved from http://www.esri.com/.

U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System, HEC-HMS 4.11.0 (2023). Retrieved from http://www.hec.usace.army.mil.

U.S. Army Corps of Engineers, Hydrologic Engineering Center River Analysis System, HEC-RAS 6.4.1 (2023). Retrieved from http://www.hec.usace.army.mil.

2.3 DATA SOURCES, GUIDANCE, AND PROCEDURES

Environmental Systems Research Institute, Inc. (ESRI). United States National Boundary, County Boundaries, Street Centerlines.
Available from: http://www.esri.com/software/arcgis/arcgisonline/services/map-services

Environmental Systems Research Institute, Inc. (ESRI),
http://www.esri.com/software/arcgis/arcgisonline/map_services.html
ESRI Streetmap2D Image Service - ESRI basemap data, DeLorme basemap layers, Automotive Navigation Data (AND) road data, U.S. Geological Survey (USGS) elevation data, UNEP-WCMC parks and protected areas for the world, Tele Atlas Dynamap® and Multinet® street data for North America and Europe and First American (CoreLogic) parcel data for the United States.
ESRI World Imagery Service - Imagery from NASA, icubed, U.S. Geological Survey (USGS), U.S. Department of Agriculture Farm Services Agency (USDA FSA), GeoEye, and Aerials Express.
ESRI. ArcGIS software. Application reference available from: http://www.esri.com/

National Oceanic and Atmospheric Administration (NOAA). National Geodetic Survey Data Explorer. Available from https://geodesy.noaa.gov/NGSDataExplorer/

Texas Department of Transportation (TxDOT). 2019 Roadway Inventory. Available from: https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html

USACE, HEC. "HEC-HMS Hydrologic Modeling System User's Manual," USACE, Davis, CA, November 2006.

U.S. Geological Survey (USGS). 3DEP LidarExplorer. Available from https://prd-tnm.s3.amazonaws.com/LidarExplorer/index.html#/

U.S. Geological Survey (USGS). National Hydrography Dataset. Available from: http://nhd.usgs.gov/data.html

U.S. Geological Survey (USGS). National Water Information System. Available from: http://waterdata.usgs.gov/nwis/

3 Terms of Reference

2D	two-dimensional
3DEP	Three-Dimensional Elevation Program
AEP	annual exceedance probability
cfs	cubic feet per second
ER	Engineering Regulation
FEMA	Federal Emergency Management Agency
GeoHMS	Geospatial Hydrologic Model System extension
GIS	Geographic Information Systems
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
InFRM	Interagency Flood Risk Management
LiDAR	Light Detection and Ranging
NA14	NOAA Atlas 14
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NSE	Nash Sutcliffe Efficiency
NWS	National Weather Service
PBIAS	percent bias
PMP	Probable Maximum Precipitation
R	Storage
RAS	River Analysis System
RMC	Risk Management Center
RMSE	root mean square error
RSR	observed standard deviation ratio
sq mi	square miles
Tc	time of concentration
TxDOT	Texas Department of Transportation
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey