Engineering Report

Midland County Monahans and South Draw Flood Planning

Midland County, Texas

TWDB Commitment #: G1001282

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Prepared for Midland County, Texas, and Texas Water Development Board

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1 Executive Summary

Midland County was awarded a grant by Texas Water Development Board (TWDB) in early 2021. This grant funds an analysis of flood risks expected after nearly full development of the Monahans and South Draws south of Interstate 20.

TWDB is also managing a statewide flood planning process, intended to identify and prioritize flood reduction projects in all regions. Our efforts will assist TWDB in their process and possibly make some local projects eligible for state funding.

A key end product for the study is intended to be GIS mapping of future risk zones with a great deal more accuracy than the current FEMA floodplain maps. These maps will assist the County in reviewing and approving developments in the next few decades, and in targeting funds for resolving flooding and drainage issues. Identification of drainage solutions for a few locations is also included in the scope.

1.1 Purpose and Stakeholders

The FIF Category 1 grant used to create this project has a requirement that governmental entities within the watershed be included in the planning process. Table 1-1 below shows the key stakeholders that were involved in development of this study and the recommended actions herein, plus the level of involvement during the study.

Table 1-1. Key stakeholders.

Stakeholder	Role and Involvement
Midland County	Project owner; direction of all aspects of work
City of Midland	Upstream portions of three subwatersheds are in Midland. City assisted with suggestions for study scope, data provision, review of model results for reasonableness.
City of Odessa	Upstream portions of two subwatersheds plus upstream model are in Odessa. City assisted with suggestions for study scope, data provision, review of model results for reasonableness.
Ector County	The upstream model is mainly in Ector County. County assisted with definition of project scope.
TxDOT	TxDOT was designing upgrades to Interstate 20, a significant impactor of drainage in the study limits. TxDOT and their consultants provided locations of design challenges, early versions of plans, and other coordination.
Midland County Residents	Public provided input at public meetings and directly to County employees and commissioners. Flooding in June 2021 affected hundreds of residents in the study boundary, allowing Midland County to refine direction for mitigation strategies and projects.
Landowners on South Draw	Due to flooding in the South Draw watershed and coincidental timing of oil related development in an area where improvements were needed, Endeavor Energy modified their project to partially address mitigation goals, and the proposed alternates were coordinated with their project.

1.2 Project Area, Scope and Alternates

The project is located in Midland and Ector Counties and consists of drainage area contributing to Monahans Draw and South Draw upstream of their confluences with Midland Draw, plus a small area of additional playa lake drainage located south of Monahans Draw near US 158 and future County Road 1232.

The study area is situated at the most southerly limit of the Llano Estacado, as shown on Figure 1-1. Drainage is characterized by playas and draws. Typically, the upstream portions of the watersheds have a rocky soil with a restrictive caliche layer within a foot of the surface, while the draws are often surrounded by sandy clay loams. Playas dot both types of soils. Both draws and major playas often have a clay bottom. Playa lakes in Midland and Ector County are generally fairly shallow and somewhat likely to overflow, although many are larger and fully contain the upstream runoff. Monahans Draw is well-defined, but the remainder of the natural flow paths studied are hard to identify by contours, subject to multiple split flows.

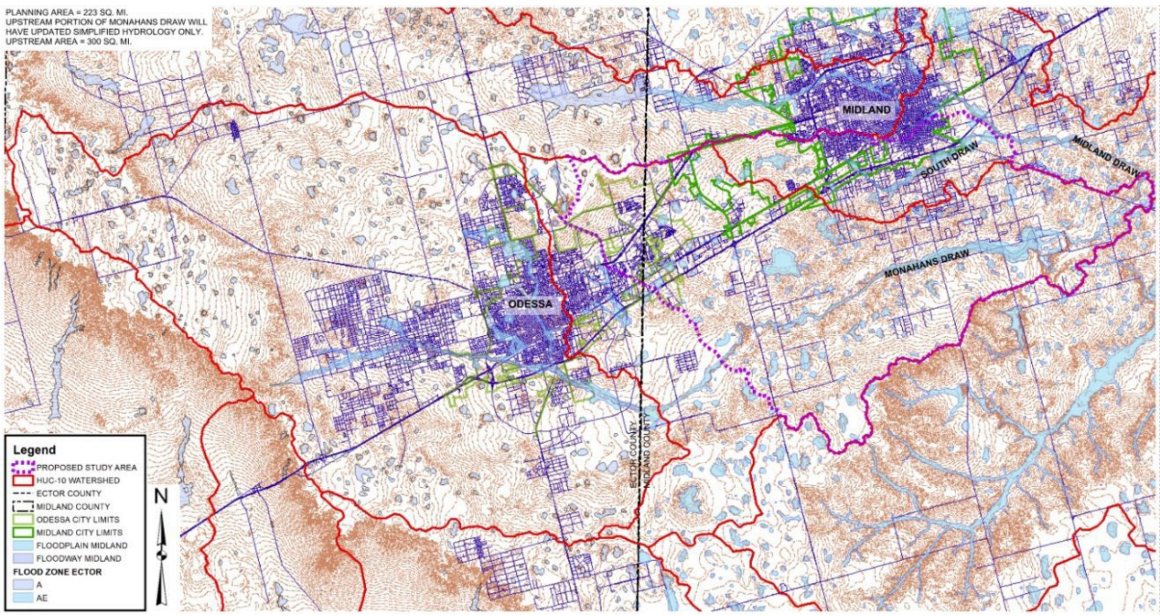


Figure 1-1. Study areas with HUC-10 boundaries and floodplains.

The scope focuses on future condition land use; it is not intended as a revision to the flood insurance study (FIS) for Midland County. It does overcome some limits of the FIS, which include numerous playas and riverine floodplains that are mapped as Zone A with no BFE and inaccurate flood boundaries, flow paths with drainage areas of many square miles with no riverine floodplain mapped. Throughout Midland County, floodplains are mapped that seem either excessively large or too small.

This study gives the affected communities a better sense of which locations need a higher degree of regulatory protection. We produced future floodways for Monahans Draw, South Draw and for four previously unmapped yet significant flow paths.

Proposed solutions to existing problems are a lesser focus of the project scope. There were known flooding issues in the vicinity of Faudree Road in Odessa, Texas and also along I-20 near

Midland, Texas. We proposed to evaluate potential solutions to these problems in the original scope. A flood event after the project began caused significant damage in the Faudree area and south of Midland along South Draw.

TxDOT was designing solutions to drainage problems along I-20. In addition, flooding in 2021 revealed that the most serious I-20 problems were those contributing South Draw. Realizing the solutions needed to be on South Draw, the scope task I-20 in Midland Solutions. As a result, the solution focus was narrowed to the area south of I-20 along South Draw where most of the flooding occurred.

1.3 Methodology Summary

Hydrologic analyses were performed with Interconnected Channel and Pond Routing (ICPR) Version 4, utilizing their 2D option. ICPR 2D simultaneously analyzes rainfall, infiltration, runoff, storm sewer system and culvert flow, overland flow, and reservoir routings. Thus, it can be considered to perform the functions of hydrologic and hydraulic analysis. It produces a map of flood depths, but unlike HEC-RAS it does not plot the computational cell results on the topographic surface.

Because ICPR 2D depth results are less detailed than a HEC-RAS inundation boundary and due to the difficulty of producing a floodway with ICPR, we chose to extract flow hydrographs from the models and use them for detailed HEC-RAS 1D or 2D models, as appropriate. We preferred to use 1D models since they will be easier for other engineers to utilize, but some draws had multiple flow paths that could not be modeled effectively using 1D.

Parkhill investigated a Green and Ampt alternative to the curve number loss rate methodology commonly used in West Texas. It was possible to calibrate this methodology to the flood that occurred in June 2021, providing a level of confidence that the results were believable. The flow rates with the methodology were in most locations MUCH less than the current effective FIS flow rates, which fits with local experience.

NOAA Atlas 14 rainfall was used. For the rainfall distribution, we used the most intense temporal provided with the NOAA Atlas 14.

1.4 Conclusions and Recommendations

Table 1-2 Summarizes the project tasks, findings, and recommendations of the project.

Due to the improved loss rate methodology, flood extents produced in the study are in many cases less than shown on the Flood Insurance Rate Maps (FIRM's). However, many areas not previously shown to be subject to flooding were identified, some quite shallow and diffuse.

Midland County will need to adopt a new development ordinance that uses the results of the study in coordination with the current effective FIRMs. Midland County will find it difficult to channelize the diffuse flow paths due to prior development and a spider web of generally shallow pipelines that already exist. Section 7 discusses potential flood management strategies that can be used with these study results.

A deeper understanding of flood conditions has already resulted in tangible benefits for residents of Midland County. TxDOT has designed and will install a culvert at a lower elevation that can later be used to drain flooded areas in the OIME playa east of Faudree Road. Midland County has a study underway to identify the best route for draining this area. TxDOT has also modified their design along I-20 in Midland to make some improvements to flooding conditions there. Midland County has acquired property on South Draw that can be used for retention storage.

The Interim Flood Planning Framework report and the solutions in Section 8 were submitted to the Upper Colorado Regional Flood Planning Group for inclusion in the statewide flood plan. Midland County has been able to apply for additional grant funding for the Faudree area/OIME outfall route study because it was included in the flood plan. Midland County should continue to identify and submit worthy projects to the Regional Flood Planning Group as the state develops the next 5-year plan for funding studies and improvements in Texas.

Table 1-2. Scope, Conclusions, and Next Steps.

Task Name	Task	Detailed Description of Work	Conclusions	Next Steps
1SET	Base layer development and setup	Methodology investigation and data development	Use ICPRv4 2d for hydrology, with Green & Ampt loss rate methodology.	None
2PLA	Study playas in detailed area (~210)	Combined with 5RIV, develop ICPRv4 models for nine breakout areas	Future flood depths from ICPRv4 uploaded to geodatabase.	Use future flood depths to regulate development and to design infrastructure.
3FAU	Faudree 2dICPR and solutions	Develop ICPRv4 2d model for Faudree Area. Investigate a gravity drain outlet for the OIME playa.	The OIME playa has no outlet and will capture much more runoff. A gravity outfall can reduce duration of flooding. Upstream portion developed as FMP.	ROW will need to be acquired and pipelines avoided or lowered. Midland County has hired a consultant for route analysis.
4MAF	Update MAF ICPR hydrology	Develop ICPRv4 2d model for Midland International Airport Area.	Airport sits in flow path for several playa overflows. Ponding on the airfield is caused by TxDOT and railroad crossings at the south end.	Investigate structure upsizing downstream of airport. Acquire easements on caliche pits.
5RIV	Riverine Hydrology, Detail Study Area	Combined with 2PLA, develop ICPRv4 models for nine breakout areas.	Future flood depths from ICPRv4 uploaded to geodatabase	Use future flood depths to regulate development and to design infrastructure.
6I20	I-20 in Midland Solutions	TxDOT will implement some solutions. Modified task 8SOU HEC-RAS models to find solutions on South Draw in three locations.	To eliminate pumping after major storms, gravity outlet options for two locations were developed as FMPs. Upstream storage in existing caliche pits was developed as a third FMP.	Midland County has purchased some upstream caliche pits/ponds, plus one pit for the eastmost gravity solution. Continue implementation of solutions.

Task Name	Task	Detailed Description of Work	Conclusions	Next Steps
7UPS	Upstream Hydrology for Monahans Dr	Develop a model of the 445 square mile Monahans Draw watershed that contributes to Midland County to obtain hydrograph input to remainder of study.	Model produced flow rates much less than FIS models. We chose to double the hydrograph into the rest of the study to provide a greater factor of safety.	Make model available to City of Odessa and Ector County for their use in additional master planning.
8SOU	Hydraulic analysis of South Draw	Update and revise FIS HEC-RAS 1d models. Split models at the major playa east of SCR 1180	These are more detailed and accurate floodplains using future land use and lower flows from ICPR models.	Use floodways to assist in locating easements for projects along the draws.
9FP4	Hydraulic analysis of 4 flow paths	Create HEC-RAS 2d models for the Faudree draw upstream of Hwy 191 and downstream of I-20, for the MAF outfall, and for a tributary to Upper South Draw. Develop floodways for all four.	These are detailed and accurate floodplains using future land use and flows from ICPR models. FIS did not include these flow paths.	Use flood elevations to regulate development since there are no FIS models. Use floodways to locate easements along the draws.
10MO	Hydraulic analysis of Monahans	Updated HEC-RAS 1d models in area of FIS study. New 2d model of the Salt Lake area. Create 1d models of other portions of Monahans Draw. Develop floodway for all models.	Use of much lower ICPR flow hydrographs in the models reduces floodplain widths in the FIS studied area. It increases floodplain in other areas where FIS showed Zone A.	Use flood elevations to regulate development where there are no FIS models. Use floodways to locate easements along the draws.
11PA	Project Administration and Report	Write report and develop GIS layers for TWDB and for Midland County's use in floodplain regulation.	See above.	Adopt findings in revised court order for development and subdivisions.
SRVY	Survey for ICPR and Hydraulic analyses	Survey of structures crossing many roadways in Midland and Ector County.		None

2 Introduction and Project Background

This section covers the project scope and explains how it relates to the regional specific needs of the community.

2.1 Introduction

The project scope in the contract contained these tasks:

- 1SET Base layer development and setup.
- 2PLA Study playas in detailed area (~210).
- 3FAU Faudree 2D ICPR and solutions.
- 4MAF Update MAF ICPR hydrology.
- 5RIV Riverine Hydrology, Detail Study Area.
- 6I20 I-20 in Midland Solutions.
- 7UPS Upstream Hydrology for Monahans Dr.
- 8SOU Hydraulic analysis of South Draw.
- 9FP4 Hydraulic analysis of 4 flow paths.
- 10MO Hydraulic analysis of Monahans.
- 11PA Project Administration and Report.
- SRVY Survey for ICPR and Hydraulic analyses.

The scope as initially conceived and structured in the contract assumed that two areas would have ICPR hydrologic models and the remainder would be studied with HEC-HMS. It was assumed that the upstream contributing portion of Monahans Draw would be studied by converting the Flood Insurance Study model from SWFHYD to HEC-HMS. However, as the project methodology was developed, it became clear that a more consistent approach would be better. We decided to perform all analyses with Interconnected Channel and Pond Routing (ICPR) Version 4, utilizing their 2D option. This caused tasks 2PLA and 5RIV to be combined, and forced task 7UPS to be completed simultaneously, as it produced an upstream hydrograph input to the remaining models.

The hydraulic analyses were performed in HEC-RAS. This portion of West Texas is excessively flat, with many drain paths having no defined channel. Small ridges along fences that can divert water substantially. 2D models proved more effective for these paths in task 9FP4 and also for a portion of the models in 8SOU and 6I20. Monahans Draw and South Draw are more defined. Both already have FIS models using 1D HEC-RAS of HEC-2. We were able to produce HEC-RAS 1D models for these, although the new topo is so different from the 7.5-minute quad contours used for the FIS study that we completely replaced all of the sections, maintaining only the stationing.

2.2 Community Need and Previous Studies

The modeling for Flood Insurance Study for the project area was completed in the 1990's and published in 1999. It was republished in 2005 with a new base map in a map modernization effort with the only change being an upgrade to NAVD88 vertical datum.

Many of the playas are mapped as Zone A, using the 7.5-minute quadrangle contour maps as a means of identifying an overflow limit and assuming all of them overflow. Of course, the quadrangle maps miss some playas. There are also caliche pits that are positioned to capture a substantial amount of flow, some of which are mapped as Zone A but others not. The playas do not have inflow or overflow paths mapped as a flood hazard area, and this has led to developments being placed in highly flood-prone locations. There is a need to identify routes in and out of playas that should be protected with drainage easements or channelized. Both Midland County and landowners will benefit from the computed water surface elevations in the playas developed in this study.

In the FIS, South Draw and a portion of Monahans Draw have detailed hydraulic models, but local experience suggests that the flow rates and flood hazards shown are exaggerated. This study extends detailed mapping of Monahans Draw upstream to the county line and downstream to the confluence with Midland Draw. This will greatly enhance Midland County's ability to design infrastructure of appropriate capacity and to regulate development.

Flooding issues in the study area tend to be playas that overflow without a protected downstream route, development in playas that pre-dates the community joining the NFIP, and the tendency of Interstate 20 to act as a dam throughout the study reach.

2.3 Typical Watershed Flooding Issues

Flooding problems in the study area are related to three typical natural or constructed features.

2.3.1 Playa Drainage

Most of the land in Midland County drains to playas, dry lake-closed basins that fill and then dry through evaporation and infiltration. Playas vary in depth and size, typically very shallow up to around 20-feet deep. The largest one in Midland County is around 1,100 acres, but most are less than 100 acres. Our study area has at least 210 playas. Some playas have enough area that drains to them that they can fill and overflow, creating a chain of ponded areas connected by flowing water during storms. South Draw is actually a chain of playas.

Landowners may not realize the flooding potential of playas, and place structures and roadways within them that later are damaged. Landowners may also attempt to fill playas, resulting in displacement of flood waters onto adjacent property in later rains. Overflow routes rarely carry any water, and there is a tendency to place buildings and other obstructions in them.

As development occurs, paved, roofed or smoothly graded areas replace farm and ranch land. Typically, the result is decreased ability for rainfall to soak into the developed area and more runoff leaving the site. If the site drains to a playa, it will fill to a greater depth than it did previously, and it will fill more frequently.

A large portion of eastern Odessa drains through playas and channels on the two Odessa Country Club golf courses and then into a playa in unincorporated Midland County, which was the location of significant flooding in 2021. This playa system is an example of increasing impacts due to urbanization of the watershed.

2.3.2 Drainage in Draws

Draws in Midland County are generally dry, poorly defined channels that are sometimes hard to see from the ground, best identified by darker, thicker vegetation patterns on aerial photographs. They do not have steep banks or permanent flow.

Monahans Draw is the chief drainage feature south of Midland and Odessa. It captures all of the runoff from Odessa and from many of the quickly developing areas in unincorporated Midland County. Because of urban runoff, it has more frequent wet periods than purely undeveloped West Texas draws such as Johnson Draw further south in Midland County.

South Draw, the other subject of the grant study, drains about two square miles of southeast Midland through a playa that now contains water almost all of the time, the I-20 Nature Preserve, then across I-20 and into rural subdivisions in unincorporated Midland County. As a chain of playas with connecting overflow routes, some areas of the draw will have flowing water and others will simply capture it. Several caliche pits along the draw are functioning as retention basins and reducing the flooding potential.

Again, landowners are often unaware of the flooding potential along draws in Midland County. Our arid region and flat terrain absorb most rainfalls, so flow in the draw is not a regular occurrence. Buildings and roads might be placed in the draw with no flooding observed for several years.

Developments in areas that drain directly to a draw, without passing through a playa, will have less impact than developments that drain to playas, because the runoff can flow away. Although there will be more runoff, because the draws are flat and wide, it will spread out rather than up. However, in a watershed as large as Monahans Draw, with rapid development of the area between Midland and Odessa and areas south of I-20 expected, it is inevitable that observed flooding in Monahans Draw will increase.

2.3.3. Impact of Interstate 20

Interstate 20 forms a band across the watersheds of Monahans and South Draws. The main lanes are typically elevated higher than the adjacent natural ground, but the frontage roads are at the same level as natural ground. Culverts pierce the main lanes at low points allowing flow to cross from north to south. The frontage roads are designed to flood on both ends of the culverts in all storm events.

The culverts were designed and installed for undeveloped runoff, and, as development has occurred, they are increasingly undersized. This means that large storms can create ponding north of the interstate as water waits for a chance to flow under the main lanes, or in some cases, the north frontage road functions as a ditch carrying runoff to the next low point.

Long-term solutions to inadequate cross drainage are exacerbated by the lack of ditches upstream and downstream of the cross-drainage culverts. TxDOT often obtains downstream easements to carry runoff from their highway into a nearby playa, but I-20 was constructed without such downstream outfalls for the most part.

As development has occurred, fill has been placed on properties adjacent to the frontage roads near the culverts. On the north upstream ends, this means water has only the frontage roads themselves to travel to get into the culvert, leading to access problems during rain events. On the south side, fill blocking the exit route from the frontage roads means water literally is trapped on TxDOT right-of-way. An example is in Midland east of Cotton Flat Road.

TxDOT is planning major upgrades to the interstate over several years. Plans are already fairly complete for some locations. Now is the time to coordinate with TxDOT to implement cross-drainage culverts that will function better on both sides, benefitting landowners, TxDOT and County and City operations. TxDOT wants to raise the frontage roads so they will not flood in smaller rains and increase the size of culverts under the main lanes.

Midland County has had several meetings with TxDOT, and its' consultants, requesting that TxDOT provide deeper culverts across the interstate in key locations where major flows are expected, and obtain drainage easements up and downstream of each culvert so ditches can funnel water into the cross drainage culverts.

TxDOT has been receptive to these requests, but in order to comply with their own internal procedures, needed assurance that the downstream ditches will be continued and made a part of a drainage system. An early version of this project report, titled "Monahans and South Draw Interim Flood Planning Framework," was presented to the Midland County Commissioner's Court and approved by them on December 13, 2021.

3 Hydrologic Methodology

This Section explains the methodology used throughout the Study. Parkhill created eleven individual Interconnected Channel and Pond Routing (ICPR) 2D models of the detailed study area, and one large-scale model of the upstream Monahans Draw contributing area. After ICPR models were completed, we performed HEC-RAS hydraulic analysis of the Monahans Draw, South Draw, and four flow paths with significant flow rates. Floodways were developed for these routes. A limited number of drainage solutions were investigated in two of the ICPR model areas.

Several preliminary investigations were performed in order to select the best methodology for hydrologic analysis. We did not adopt methodology used by Federal Emergency Management Agency (FEMA) for the Flood Insurance Study (FIS) studies of Midland and Ector Counties, nor did we use the Master Drainage Plan methodologies used in Midland. Instead, we utilized a 2021 storm event to calibrate one of our ICPR models with an existing land use map and extrapolated those findings to our future condition models.

The rainfall was developed from latest NOAA Atlas 14 data. Loss rate methodologies considered were NRCS Curve Number and Green & Ampt, with Green & Ampt chosen. A future condition land use map was developed from the Midland and Odessa latest planning documents extended outside their planning areas. Each land use was associated with surface roughness values. Impervious cover data for previously developed areas were downloaded from a national database, and roughness values associated with each value in coordination with the expected land use.

ICPR models were set up with existing structures and some future structures along I-20. A GIS data collection application and partial survey were used to organize data used to model structures.

Data was provided to Midland County and to Texas Water Development Board (TWDB) in the form of GIS layers showing playas with their maximum overflow extents plus their predicted future ponding elevation. Output from both the ICPR models and the HEC-RAS models' extents with floodways was also provided.

For the proposed solutions, all necessary analyses required by TWDB were performed and delivered, including opinions of probable cost and cost/benefit ratios.

3.1 Hydrologic Software Selection

Parkhill set up the initial scope of the Project assuming we would use HEC-HMS for the hydrology and HEC-RAS for the hydraulics. However, after some initial tests we concluded that using ICPR v4 from Streamline Technologies, Inc., for hydrology would be more accurate. The program handles hydrology and hydraulic calculations, plus surface and storm drain flows, simultaneously. Unlike HEC-RAS, it computes infiltration losses on the surface.

The elements we used to make our determination included:

- 1D or 2D model.
- Split-flow prevalence.
- Ability to identify all watershed storage.
- Loss methods available.

3.1.1 Comparison of 1D or 2D Airport Models

In a previous project, Parkhill created a 1D HEC-HMS master drainage plan model for the airport watershed, and in another project, a 2D ICPR model of the airfield area with several miles of storm drains. We decided to compare the models to see if they produced similar results. This proved more complex than we expected, as the models needed adjustment to be comparable.

The Master Drainage Plan (MDP) model used specific future land use assumptions that had to be completed in GIS before it could be used in ICPR as a comparison. Both models used NRCS Curve number losses, but we had to update the soil map, as the NRCS has made several changes to the soil group classifications for Midland County soils. The vertical datum used on the MDP model was NGVD29, whereas the LiDAR data for this Study is NAVD88, necessitating a datum adjustment on the results of the MDP playa elevations.

Our ICPR 2D model considered only flows in the vicinity of the airfield, so the area of LiDAR surface had to be enlarged. We changed the land use to match the airport MDP model. We did not have pond control volumes in our model initially and decided to test the playa elevations with and without them. We found that the playa elevations were reduced by generally about 1/10 of a foot, but in two cases, 1-2.4 feet. We decided to use pond control volumes for all significant ponding areas in ICPR 2D models.

We wanted to compare flow rates throughout the watershed between the two models, but for various reasons almost none of the playa subareas were directly comparable. We took a more detailed look at a single subarea, Playa E0235-05_Lake-08, shown on Figure 3-1. We noticed that the overflow relationship between elevation and depth/flow rate for the HMS model was not accurate based on the LiDAR terrain, so we recomputed that and updated the HMS model, making the overflow more similar to the ICPR overflow characteristics.

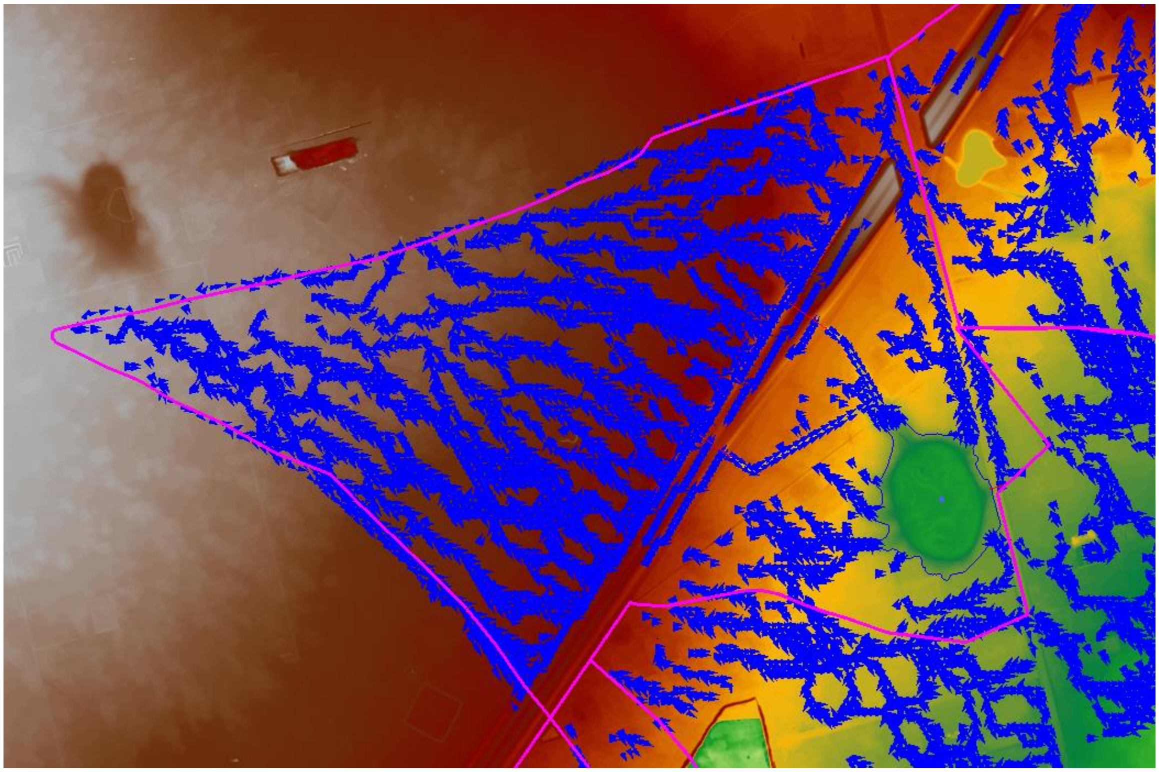


Figure 3-1. Playa E0235-05 Lake-08 drainage area.

Results, shown below, indicate roughly similar inflow volumes into the playa, though peak flows are not as similar. Volumes may differ partly because we did not update the HEC-HMS drainage area boundary to exactly match the flow directions in the latest surface. Note, however, that the overflow volumes were less for the ICPR 2D model, and the peak elevations also a bit less. However, we still see overflow at the 5-year frequency. The infiltration column is blank because curve number method does not account for infiltration in the basin.

Table 3-1. Comparison of ICPR and HEC-HMS results for Playa E0235-05 Lake-08.

HEC-HMS Overflow Results					
Storm	**Peak Inflow (CFS)**	**Peak Overflow (CFS)**	**Total Inflow (AC-FT)**	**Total Outflow (AC-FT)**	**Peak Elevation (88 Datum) (FT)**
5-yr	569	229	113.8	74.4	2912.1
10-yr	721	405	145.2	105.9	2912.4
100-yr	1154	979	236.5	197.2	2913.1

ICPR Model CN Results							
Storm	**Peak Inflow (CFS)**	**Peak Overflow (CFS)**	**Total Inflow (AC-FT)**	**Basin Outflow (infiltration) (AC-FT)**	**Link Outflow (overflow) (AC-FT)**	**Total Outflow (AC-FT)**	**Peak Elevation (88 Datum) (FT)**
5-yr	675	20	106.6	0.0	16.6	16.6	2912.0
10-yr	1006	60	136.3	0.0	46.3	46.3	2912.2
100-yr	1614	760	216.9	0.0	127.1	127.1	2912.8

3.1.2 Split Flow and Watershed Storage Considerations

Examination of the ICPR model results revealed that one of the Airport MDP model playas overflows in two directions, one of which leaves the model area. We found numerous locations where flows do not follow the drainage area boundaries used in the airport HEC-HMS model. In addition, caliche pits and oil development pads have altered the terrain in ways that both divert and capture flows.

It quickly became obvious that a 2D model would be much more accurate in depicting the split flow situations, and, in fact, easier to create than a 1D model with several split flow relationships.

3.1.3 Loss Methods Comparison

Parkhill has noticed that local observations of flood extents do not match the FEMA maps for many of the playas. Specifically, South Draw is actually a chain of playas, all of which are predicted to overflow in a 10-yr frequency storm. However, the largest has never been known to overflow. We have suspected that infiltration occurs throughout the watershed, not just at the location of rainfall, and that channel losses could be a factor. Current FEMA FIS models do not include channel loss methods.

Use of a 2D model would allow us to use the Green & Ampt loss rate methodology, which in ICPR will compute losses at each time step, so runoff might infiltrate after leaving the point of origin. We performed comparisons of Curve Number and Green & Ampt method results for the same Playa E0235-05_Lake-08 and documented them in Section 3.3.

3.2 Rainfall

Any project intended to be consistent with FEMA methodology should utilize accepted national standards. Rainfall methodology is not as established in Texas as we would prefer. The statistical rainfall amounts for a particular point are well established, being taken from a report published in 2018.

There are two other elements to rainfall modeling:

- First, the rainfall at a point is larger than the rainfall that should be used for a larger area. There are techniques for reducing the rainfall amount to account for the fact that rain does not fall evenly across a large area.
- Second, the time distribution of rainfall must be chosen. Twenty-four hours is typical for FEMA studies, but shorter or longer times are studied where appropriate. Within the chosen duration, there are options on how to distribute the rainfall – slow and steady or faster.

3.2.1 NOAA Atlas 14 Rainfall Depth Data

National Oceanic and Atmospheric Administration (NOAA) publishes rainfall atlases for the United States. Texas is covered in Atlas 14, Volume 11, recently published in 2018. The point data is available as a map online, but we wanted to do calculations with the data. Using the Precipitation Frequency Data Server (PFDS), the statewide NOAA14 point precipitation frequency estimates were downloaded in GIS formatted ascii files.

The question next is whether to use the same rainfall for the entire study area, since it varies geographically. See Figure 3-3, which shows the 24-hour duration storm amounts to vary from 6.25 inches to 6.85 inches in our study area. The ICPR model can use a single rainfall amount for an entire model, or it can use spatially varied information, dividing the model into shapes that correspond to the rainfall contours from NOAA Atlas 14.

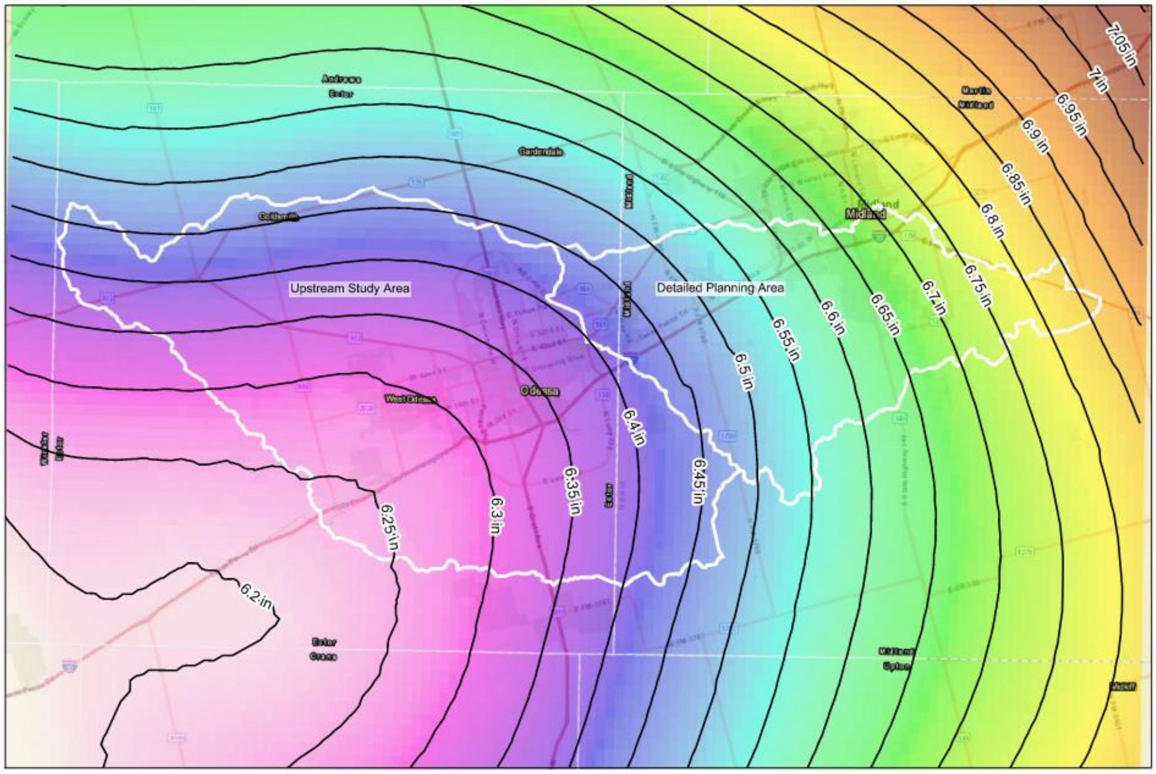


Figure 3-2. **NOAA Atlas 14 100-yr 24-hr Rainfall**

Use of a single rainfall value may be considered valid for areas where the rainfall varies less than 10% across the area. Since our rainfall varies by 0.6 inches across the entire area, we could have chosen a single middle value. However, we chose to break our model into several submodels and to use a single average rainfall for each submodel area. Using the data raster on Exhibit 3-2, Geographic Information Systems (GIS) created a spatially weighted average of average point rainfall per study area. Our study is targeted solely to the 100-year event, so we did not develop rainfall amounts for other recurrence intervals.

Table 3-2. Spatially weighted average rainfall for ICPR models.

100-year Rainfall Amount (in.)	
ICPR Model Name	**Rainfall**
Upstream	6.36
Faudree	6.44
Midland Airport (MAF)	6.50
Monahans West	6.50
West of Loop	6.56
Monahans Loop	6.56
Monahans Middle	6.63
Salt Lake	6.74
Lower Monahans	6.81
Middle Playas	6.68
Upper South	6.62
Lower South	6.70

3.2.2 Areal Reduction Factors

NOAA Atlas 14 documentation states that the precipitation frequency estimates from NOAA Atlas 14 are point estimates and are not directly applicable to larger areas and recommends the use of Technical Paper No. 29 (US Weather Bureau, 1958) as a basis for reducing the point rainfall to an amount that corresponds to the study area.

The conundrum associated with Areal Reduction Factors (ARF) is that if the rainfall is reduced to get a realistic flow on the main draw, such as Monahans Draw, we may underestimate flooding that can occur on a local level, where a point rainfall might be more accurate. Traditional hydrologic models such as HEC-1 and HEC-HMS have methods to have the best of point and areal rainfall, by computing the model with several rainfalls and interpolating at each point of interest to show just the reduction that applies to the upstream area at that point. This is called a consistent areal reduction factor.

ICPR does not have this consistent reduction capability, so we had to make a choice of what reduction factor to choose for each of our submodels. Because our calibrated Green & Ampt methodology produced peak flows lower than the Flood Insurance Study in many areas, we decided not to use any areal reduction factor at all. The decision to omit an areal reduction factor is because the ICPR models would be used to size infrastructure for relatively small portions of each model, and we wanted a conservative flow rate.

3.2.3 Rainfall Distribution

There are two possibilities for rainfall distribution. First and most traditional is the NRCS Type II distribution, which places most of the rainfall at the midpoint of the storm duration in an intense manner. This is a standard method, but the NOAA Atlas 14 report contains statistical analysis of thousands of storms that casts doubt on this distribution.

NOAA Atlas 14 contains graphs showing storm types for three regions in Texas, of which Midland County is in the western interior highlands region. For each region, a number of rainfall types are plotted as % of rainfall versus time. Parkhill investigated the most intense of the 24-hour storms in the Atlas 14 report, in which over 99% of rainfall has fallen within four hours in a 24-hour event. We compared it to NRCS Type II distribution on five playas in the Midland Airport model area. We kept all factors equal and changed only the rainfall distribution.

No clear trend was observed. On three of the playas, NRCS Type II distribution yielded a higher peak flow, but on the other two, the temporal distribution created the higher peak. With respect to volume, the same ratio of three higher on NRCS and two higher on NOAA Atlas 14 was observed, but it was not the same playas in each case. With these inconsistent results, we chose to move forward using the more modern highest intensity temporal from NOAA Atlas 14. This I illustrated below, where we chose the 10% first-quartile storm.

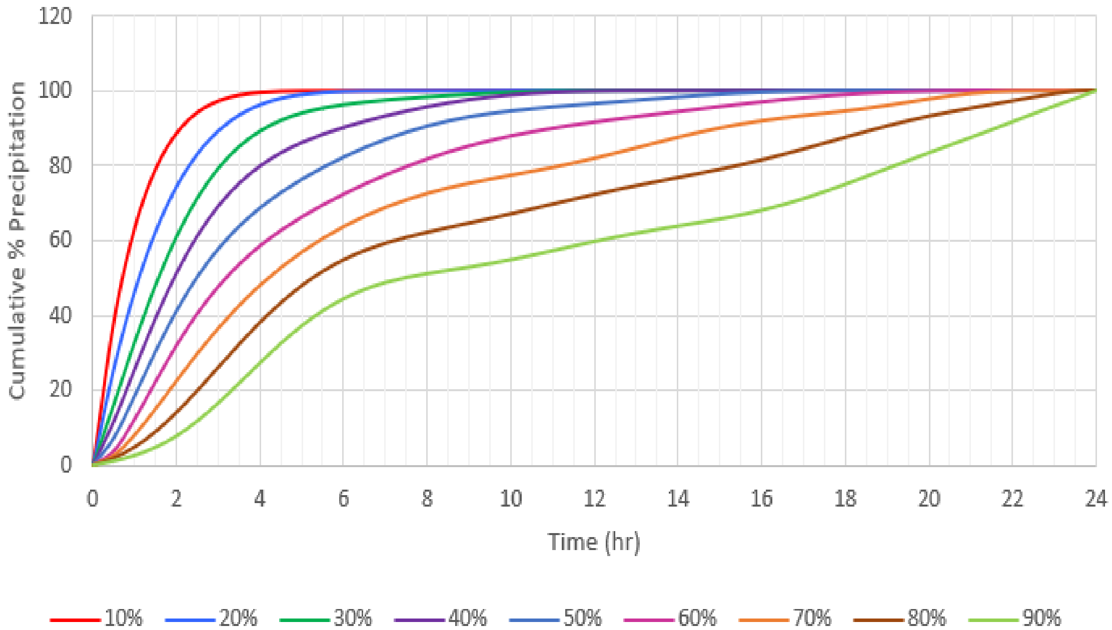


Figure 3-3. **NOAA Atlas 14 Temporals for Region 1, interior highlands, first quartile storms.**

3.3 Loss Rate Methodology

This section explains how the Green and Ampt loss rate methodology was chosen.

3.3.1 Initial Comparison of Curve Number vs. Green and Ampt

Parkhill made an initial test comparing NRCS Curve number loss rate methodology to the Green and Ampt method in a 2D ICPR model of a single playa, described in Section 3.1. The playa selected for analysis, E0235-05_Lake-08 (Figure 3-1) was chosen as one previously modeled in HEC-HMS for a future condition as part of an existing City of Midland Airport Drainage Master Plan. It receives runoff from an assumed mixed-use development. The available LiDAR shows partial development north of US 191 and a drainage easement into the playa from two culverts under that freeway.

Table 3-3 compares playa inflow, overflow, and peak flow for ICPR 2D curve number and two Green and Ampt scenarios. Because curve number does not account for infiltration within the basin during the storm, we separated the infiltration and overflow portions of the ICPR output so the overflow could be directly compared.

Table 3-3. Comparison of ICPR 2D curve number with Green and Ampt results.

ICPR 2D Model Curve Number Results

Storm	Peak Inflow	Basin Outflow (Infilt.)	Peak Total Outflow	Peak Overflow	Total Inflow	Basin Outflow (Infilt)	Link Outflow (overflow)	Total Outflow	Peak Elevation (88 Datum)
	(CFS)	(CFS)	(CFS)	(CFS)	(AC-FT)	(AC-FT)	(AC-FT)	(AC-FT)	(FT)
5-yr	675	0	0	20	106.6	0.0	16.6	16.6	2912.0
10-yr	1006	0	0	60	136.3	0.0	46.3	46.3	2912.2
100-yr	1614	0	0	760	216.9	0.0	127.1	127.1	2912.8

ICPR 2D Model Green & Ampt Results (MCInitial = MCField)

Storm	Peak Inflow (CFS)	Basin outflow (Infilt.) (CFS)	Peak Total Outflow (CFS)	Peak Overflow (CFS)	Total Inflow (AC-FT)	Basin Outflow (Infilt) (AC-FT)	Link Outflow (Overflow) (AC-FT)	Total Outflow (AC-FT)	Peak Elevation (88 Datum) (FT)
5-yr	362	2	2	0	44.0	10.3	0.0	10.3	2908.7
10-yr	589	2	2	0	74.3	10.6	0.0	10.6	2910.7
100-yr	1210	2	134	132	164.8	10.3	70.4	80.8	2912.3

ICPR 2D Model Green & Ampt Results (MCInitial = Average of MCField and MC Saturated)

Storm	Peak Inflow (CFS)	Basin outflow (Infilt.) (CFS)	Peak Total Outflow (CFS)	Peak Overflow (CFS)	Total Inflow (AC-FT)	Basin Outflow (Infilt) (AC-FT)	Link Outflow (overflow) (AC-FT)	Total Outflow (AC-FT)	Peak Elevation (88 Datum) (FT)
5-yr	658	2	4	2	96.5	7.4	2.3	9.7	2911.8
10-yr	906	2	45	43	127.4	7.1	33.0	40.1	2912.1
100-yr	1702	2	1267	1265	207.6	6.6	113.4	120.0	2912.8

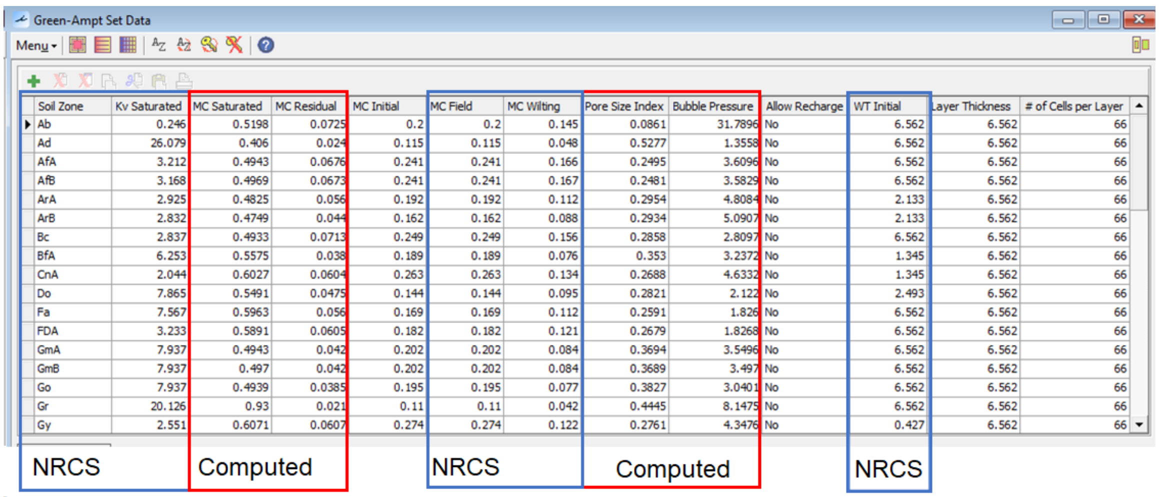
Notice that the playa is shown to overflow in the 5-year through 100-year rainfalls for curve number. Use of the default Green and Ampt initial moisture content MC Initial = MC Field resulted in no overflow for the 5 and 10-year events, matching our understanding of playa hydrology.

However, the 100-year peak inflows, and especially overflow were so much lower (132 cfs vs 760 cfs for curve number) that we were concerned the Green and Ampt method was overestimating infiltration. We tried another run with MC Initial increased to the average of MC Field and MC Saturated. This resulted in output very similar to the curve number peak flow into the playa, but still had much less overflow at all frequencies.

Seeing that the model was highly sensitive to the Green and Ampt initial moisture MC Initial, we determined that we could calibrate a model to find the most appropriate value for our region. Based on better estimates of runoff infiltration and playa overflow, we chose Green and Ampt as our loss rate method.

3.3.2 Development of Green and Ampt Tables

The Green and Ampt table input into ICPR was developed using a tutorial and spreadsheet provided by Streamline Technologies, creators of ICPR. The tutorial on how to fill this spreadsheet is in the ICPR help manual, which can be accessed in the program. A screen image of a portion of the ICPR Green and Ampt data table is shown on Figure 3-4.



Soil Zone	Kv Saturated	MC Saturated	MC Residual	MC Initial	MC Field	MC Wilting	Pore Size Index	Bubble Pressure	Allow Recharge	WT Initial	Layer Thickness	# of Cells per Layer
Ab	0.246	0.5198	0.0725	0.2	0.2	0.145	0.0861	31.7896	No	6.562	6.562	66
Ad	26.079	0.406	0.024	0.115	0.115	0.048	0.5277	1.3558	No	6.562	6.562	66
AfA	3.212	0.4943	0.0676	0.241	0.241	0.166	0.2495	3.6096	No	6.562	6.562	66
AfB	3.168	0.4969	0.0673	0.241	0.241	0.167	0.2481	3.5829	No	6.562	6.562	66
ArA	2.925	0.4825	0.056	0.192	0.192	0.112	0.2954	4.8084	No	2.133	6.562	66
ArB	2.832	0.4749	0.044	0.162	0.162	0.088	0.2934	5.0907	No	2.133	6.562	66
Bc	2.837	0.4933	0.0713	0.249	0.249	0.156	0.2858	2.8097	No	6.562	6.562	66
BfA	6.253	0.5575	0.038	0.189	0.189	0.076	0.353	3.2372	No	1.345	6.562	66
CnA	2.044	0.6027	0.0604	0.263	0.263	0.134	0.2688	4.6332	No	1.345	6.562	66
Do	7.865	0.5491	0.0475	0.144	0.144	0.095	0.2821	2.122	No	2.493	6.562	66
Fa	7.567	0.5963	0.056	0.169	0.169	0.112	0.2591	1.826	No	6.562	6.562	66
FDA	3.233	0.5891	0.0605	0.182	0.182	0.121	0.2679	1.8268	No	6.562	6.562	66
GmA	7.937	0.4943	0.042	0.202	0.202	0.084	0.3694	3.5496	No	6.562	6.562	66
GmB	7.937	0.497	0.042	0.202	0.202	0.084	0.3689	3.497	No	6.562	6.562	66
Go	7.937	0.4939	0.0385	0.195	0.195	0.077	0.3827	3.0401	No	6.562	6.562	66
Gr	20.126	0.93	0.021	0.11	0.11	0.042	0.4445	8.1475	No	6.562	6.562	66
Gy	2.551	0.6071	0.0607	0.274	0.274	0.122	0.2761	4.3476	No	0.427	6.562	66

Figure 3-4. ICPR Green and Ampt partial data set.

The spreadsheet uses as variables the following nine tables that are downloaded from the NRCS Web Soil Survey (WSS).

- Percent Clay
- Percent Sand
- Organic Matter
- Bulk Density, 1/3 Bar
- Saturated Hydraulic Conductivity
- Water Content, 1/3 Bar
- Water Content, 15 Bars

- Water table depth
- Depth to any soil-restrictive layer

The step-by-step process yields the table that can be found in Appendix 3-A. Below is a column-by-column analysis of how each column of information was developed.

Each soil is identified with MUName, MUKey, and MUSYM. Kv-sat, or saturated vertical conductivity is also directly from the WSS, however it must be converted from micrometer per second to feet per day. MC Sat is saturated moisture content and is calculated using the following formula:

$$\varphi = f_{air}(1.0 - \frac{\rho_{bulk\ dry}}{\rho_{particle}})$$

Where,

$$\varphi\ is\ porosity\ or\ saturated\ moisture\ content$$

$$f_{air}\ is\ air\ multiplier, usually\ 0.93$$

$$\rho_{bulk,dry}\ is\ dry\ bulk\ density\ of\ the\ soil\ (gm/cm)^3$$

$$\rho_{particle}\ is\ soil\ particle\ density\ (gm/cm)^3$$

The air multiplier is assumed to be 0.93, and both density values are from the WSS.

MC Residual is residual moisture content. This should always be less than MC Wilting and is calculated using the following equation.

$$\theta_r = [-0.018 + 0.0009(S) + 0.005(C) + 0.029(\varphi) - 0.0002(C^2) - 0.001(S)(\varphi) - 0.0002(C^2)(\varphi^2) + 0.0003(C^2)(\varphi) - 0.002(\varphi^2)(C)]$$

Where,

$$\theta_r\ is\ residual\ moisture\ content\ (volume\ fraction)$$

$$C\ is\ \%\ clay$$

$$S\ is\ \%\ sand$$

$$\varphi\ is\ porosity\ or\ saturated\ moisture\ content\ (volume\ fraction)$$

The values for % clay and % sand for each soil type are in the WSS. MC Initial is the initial moisture content and is assumed to be equal MC Field. Adjusting this value was one of the main methods of calibrating our models. This process is described in more depth in the Calibration Report, Section 3.9. MC Field refers to the moisture content by volume fraction at field capacity. These values are available from the Soil Survey and must be greater than MC Wilting, but less than MC Saturated. MC Wilting is the moisture content by volume fraction when most plants wilt and fail to recover their turgor upon wetting. This can be obtained directly from the NRCS Web Soil Survey and should always be greater than MC Residual and less than MC Field.

Pore Size Index is calculated using the following formula.

$$\lambda = \exp\,[-0.784 + 0.018(S) - 1.062(\varphi) - 0.00005(S^2) - 0.003(C^2) + 1.111(\varphi^2) - 0.031(S)(\varphi) + 0.0003(S^2)(\varphi^2) - 0.006(C^2)(\varphi^2) - 0.000002(S^2)(C) + 0.008(C^2)(\varphi) - 0.007(\varphi^2)(C)]$$

Where,

$$\lambda \; is \; Brooks - Corey \; pore \; size \; index$$

$$C \; is \; \% \; clay$$

$$S \; is \; \% \; sand$$

$$\varphi \; is \; porosity \; or \; saturated \; moisture \; content \; (volume \; fraction)$$

Bubble pressure is calculated by the following formula.

$$h_b = \exp\,[5.340 + 0.185(C) - 2.484(\varphi) - 0.002(C^2) - 0.044(S)(\varphi) + 0.001(S^2)(\varphi^2) - 0.009(C^2)(\varphi^2) - 0.00001(S^2)(C) + 0.009(C^2)(\varphi) - 0.0007(S^2)(\varphi) + 0.000005(C^2)(S) + 0.500(\varphi^2)(C)]$$

Where,

$$h_b \; is \; bubble \; pressure \; (in)$$

$$C \; is \; \% \; clay$$

$$S \; is \; \% \; sand$$

$$\varphi \; is \; porosity \; or \; saturated \; moisture \; content \; (volume \; fraction)$$

For the allow recharge column, all values are set to "no." The ICPR help manual conveys that allowing recharge means that "the soil column is allowed to drain vertically to recharge the water table." This would require 2D groundwater data, which is not considered for these models. By selecting "no," "the soil column fills to saturation, and can only recover via evapotranspiration."

WT Initial, is initial elevation of the water table. This is obtained from the Soil Survey as depth to water table; however, information on the water table was only collected up to 200 cm (6.562 ft.). In this region, the water table usually sits significantly deeper than 6.5 feet. Additionally, the prevalence of caliche means that there is often a restrictive soil layer located above the water table. This data is also accessible in the WSS. This column controls the amount that can infiltrate into the soil to be stored. The depth to restrictive layer was found to be the more conservative option, allowing for less infiltration, so these values are used for the WT column.

There is a column for extractable iron content, which was set to zero for our region.

Columns layer thickness and number of cells per layer are only available if the refined box is selected in the Green and Ampt Data Set. This breaks the soil column into several smaller computational cells. Upon direction from Streamline Technologies, the refined box was checked, Additionally, they suggested using 6.562 feet as the layer thickness. This is equal to the largest value in the WT Initial column, discussed above. Number of cells per layer is set to 66, which is layer thickness multiplied by 10.

3.3.3 Calibration of Initial Moisture Condition Green and Ampt

The Calibration Report in Section 3.9 contains details of iterations of both initial moisture MCInitial and surface roughness that were made to most closely match a 2021 storm event.

3.3.4 Cautions

The Green and Ampt loss rate methodology is superior to NRCS curve number because it relies on measured field data related to numerous individual soil types rather than a simplistic four groups of soil. The ICPR implementation of the method allows infiltration to be computed at every time step and at every location, allowing a more detailed and accurate depiction of the fate of rainfall runoff during the storm.

As mentioned previously, we noted that the NRCS continues to update the soil group for various soil on a regular basis, with dramatic impact on hydrologic results. The Green and Ampt method suffers from some of the same issues. This study has soils in two counties, and some soils are found in both counties. We discovered that the published values used for the Green and Ampt tables varied somewhat by county, and also that when we downloaded the data at different times we discovered that some soils' published data had been revised.

Nevertheless, we feel that the Green and Ampt hydrologic results will be less affected by the spatial and temporal variations on the input variables than curve number, and it is the preferred methodology.

3.4 Land Cover and Roughness Zone Mapping

ICPR inputs include tables of surface roughness zones and impervious cover that are linked to maps via a roughness zone name or a land cover name. Parkhill created a single map that could be linked to both tables for this study. The land cover name is not important in the calculations, but the associated percent imperviousness and surface roughness values are. This Section describes the process of creating the future condition land cover and roughness zone map.

We chose to use future condition land cover because this is a master planning study whose components may not be completed for decades. Use of future conditions also provides a conservative approach where the County will regulate developments along the draws, along which channelization is not likely due to the environmental concerns and the presence of multiple oil and gas pipelines.

We drew from several sources to create the cover and roughness map layer in GIS. We used national databases of percent impervious cover and land cover. We also used local planning maps and aerial photos showing existing developments. Our approach varied depending on the location.

3.4.1 National Land Cover Database

The National Land Cover Database (NLCD) is provided by the Multi-Resolution Land Characteristics (MRLC) consortium (https://www.mrlc.gov/data). We made use of the 2016 Impervious Cover dataset from this site initially (see Section 3.5), but the 2019 NLCD data became available in June 2021, so we proceeded with the newest information.

The National Land Cover Database, NLCD, can be downloaded as either a land cover database or a percent impervious database. We used both the Land Cover and Impervious Cover maps to derive our composite land cover layer.

Appendix 3-B shows the NLCD 2019 Impervious Cover as an example of the NLCD data appearance. The Land Cover map is similar, but instead of numeric percent impervious cover assigned to each pixel, it assigns a land cover description. We used the land cover map mainly in undeveloped areas.

3.4.2 Fully Developed Portions of Midland and Odessa

We drew boundaries in GIS around the fully developed parts of the two cities, then clipped out the areas within the boundaries for use in the future land cover map.

Since the eventual use of the data is to link to tables of impervious percentages and roughness zones, we decided to start with the impervious percentage database. This necessitated our giving each impervious percentage category a land cover name. We simply named each according to the percentage. For example, to all areas mapped as 28 percent impervious, a land cover name of 28 was assigned.

3.4.3 Land Cover Categories Within Midland and Odessa Land Use Planning

Midland and Odessa had maps that project land use categories out to their extra-territorial jurisdictional (ETJ) boundaries. Odessa provided a GIS layer called ULU Clipped, which was sourced from their latest utility planning study. Midland's land use came from their comprehensive plan, Tall City Tomorrow. These datasets are shown on Appendix 3-C.

Of course, the land use categories used by the two cities are not the same. Both datasets were complicated by the fact that they excluded street rights-of-way (ROW). ICPR demands complete coverage, so where this data was used, we had to extend the land covers to the approximate center of the ROW. Both cities had a large number of categories that would be treated minimally differently in a typical hydrologic study, so we lumped them into fewer similar categories.

Midland's comprehensive plan made extensive use of mixed-use categories of Urban with a value such as high or low indicating density. The comprehensive plan document explained the allowable uses for these areas, and they were not readily relatable to a percent impervious estimate or land cover category. Employment Reserve and Future Planning Area were composed of even more obscure categories. Parkhill had to map the actual land cover of developed parcels in these areas and make educated guesses of the future land cover where it was not yet developed.

Table 3-4. Translation of Odessa and Midland land use categories to ICPR land cover name.

ICPR Land Cover	Odessa Category	Midland Category
Retail	Downtown Airport (Parking, terminal, hangars)	
Commercial	Commercial Commercial - Moderate Oil Activity Mixed Use Non-Residential	Community Commercial Regional Commercial Business Park
Industrial	Industrial Industrial - Moderate Oil Activity Undevelopable Hi Oil Activity	General Industrial
Urban Residential	Low Density Residential Medium Density Residential High Density Residential	Urban Residential - Low Urban Residential - Medium Urban Residential - High
Public Campuses	University/ Campus Airport (runways, airfield) Public/Semi-Public	School/University Civic/Institutional
Rural Residential with Water	Residential - moderate oil activity	Urban Residential - Large Lot
Open Space, Parks, ROW	Parks/Open Space Golf Course	Parks/Open Space

3.4.4 Land Cover Categories Outside Midland and Odessa Land Use Planning

Most of our study areas fell outside either of the two cities' land use maps, so Parkhill had to derive a land cover map for the rest of the study area. We added some land cover categories at this stage. These categories allowed us to distinguish not only their imperviousness but also roughness, because we intended to link two ICPR tables to the same GIS layer, relating to both of these items.

Thus, a thickly vegetated area like the bottom of Monahans Draw was named Woody Wetland, where a more parklike drainage area would be called Open Space. Rural Residential developments were broken into with and without water, because if water lines are present, the land can be subdivided into smaller lots. The categories of Woody Wetland, Range, Barren Land and Caliche Pits came from the land cover version of the NLCD rather than the percent impervious version. A full list of land cover categories used in the study follows.

Table 3-5. ICPR land cover categories.

Retail and Open Water	Open Space, Parks, ROW
Commercial	Rural Residential w/o Water
Industrial	Range, Grassland
Urban Residential	Range, Shrub
Public Campuses	Cultivated Crops
Rural Residential with Water	Woody Wetland
Percent Impervious Cover #'s 1-100	

Residential portions of Ector County Utility District's currently served area were mapped as Rural Residential with Water.

Some areas south of Midland are already developed and judged by us as unlikely to change land cover. Boundaries were drawn for these areas. We drew some areas that are likely to retain a drainage related land cover, such as the bottoms of deeper playas, and the center of Monahans Draw. We then drew in likely roadway alignments and drew industrial land cover along them. Finally, we filled in remaining areas with likely use, choosing between industrial and rural residential without water for most.

Finally, we considered areas unlikely to develop west and south of Odessa. However, there is substantial oil field activity in those areas, so 0% impervious cover would not be correct. We then referred back to the NLCD and extracted areas with percent impervious of more than 5%, only in the non-developing remainders. Last of all we filled in the remaining non-developing areas with range in shrub or grassland as shown on the land cover version of the NLCD.

The final future land cover map is attached as Appendix 3-D.

3.5 Impervious Cover and Roughness Data

Section 3.4 described our development of a composite future land cover map. ICPR uses a raster version of this map. Two associated tables link this map to impervious cover and to surface roughness values. The land cover name is not important in the calculations, but the associated values are. This Section explains how Parkhill chose the impervious and roughness values linked to each land cover name.

We started with the impervious cover database for 2016. We then analyzed the data to see if it provided a strong basis for estimating the impervious percentages for future Midland County developments. We found it good within developed urban areas, but not helpful in the types of semi-rural locations that are the focus of our study. We then developed appropriate impervious cover estimates for our selected land cover types.

We conducted research into surface roughness values used in 2D hydraulic analyses and selected roughness values that would apply to each land use category. These were adjusted as part of a calibration process described in Section 3.9. The final calibrated values are provided here.

3.5.1 Accuracy of NLCB Percent Impervious Layer

Midland and Ector Counties have had substantial development in the recent years, so for a good representation of data and to minimize variability, the 2016 NLCD was compared against the detailed 2016 Midland Aerial imagery, as it was the best available data with similar dates.

In this analysis, we used the 2016 NLCD percent impervious GIS data to compute average imperviousness in selected test plots showing various typical Midland and Ector County developments. Results are shown as Appendix 3-E. The table in this exhibit shows that in rural areas, the NLCD matched typical % impervious values used by the City of Midland, but in the rural or semi-rural developments, it seemed too low.

We verified the actual % impervious against the 2016 NLCD % impervious calculation on a selection of land tracts in Midland as well as the outlying areas around Midland and Odessa County. We calculated the percent impervious on the selected test tracts based on manual calculations. Measurements were made using 2016 Google Earth imagery to identify homes, buildings, pavement, and land coverings. Calculations are summarized in Appendix 3-F and in Table 3-6.

Table 3-6. Summary of test plots for impervious cover.

		% Impervious with Caliche assumed to be		
ID#	**Land Use Type**	**0% Impervious**	**70% Impervious**	**95% Impervious**
31	Single Family- High Density (Urban)	63	67	68
8	Mobile Home (Rural)	20	31	35
36	Singe Family- Medium Density (Semi-Rural)	33	40	42
37	Singe Family- Medium Density (Semi- Rural)	36	43	46
7	Single Family-Low Density (Semi Rural)	14	25	29
21	Agricultural Estates (Single Family-Rural)	13	19	20
3	Industrial	31	74	94
6	Industrial	14	70	90

How to treat compacted caliche lots was the subject of extra investigation. We tested assumptions that caliche is 0% impervious like bare ground, 95% impervious like pavement, and 70% consistent with values for gravel land covering in the COM Drainage Manual. Since 70% proved a better match to standard references, we selected those 70% calculated values.

Table 3-7 compares the NLCD, City of Midland Master Plan, NRCS Data, and the manual calculations in Table 3-6. Appendix 3-G contains the comparison NRCS and City of Midland tables. A percent impervious database for Ector County was not available for comparison.

Table 3-7. Comparison of calculated to typical % impervious values.

		Lot Size (Acres)		% Impervious			
ID#	**Land Use Type**	**Min**	**Max**	**2016 NLCD**	***Manual Calculation**	**City of Midland**	**NRCS Range**
31	Single Family-High Density (Urban)	1/8	1/8	61	67	60	65
8	Mobile Home (Rural)	1/8	1/4	4	31	55	38-65
36	Singe Family-Medium Density (Semi-Rural)	1/8	1/2	18	40	60	25-65
37	Singe Family-Medium Density (Semi- Rural)	1/8	1/2	23	43	60	25-65
7	Single Family-Low Density (Semi Rural)	1/2	1	3	25	60	20-25
21	Agricultural Estates (Single Family-Rural)	1.7	2	4	19	32	12-20
3	Industrial	3	12	36	74	50-65	72
6	Industrial	15	15	46	70	50-65	72

*Manual Calculation is based on using 70% impervious for Caliche

The impervious percentage found in this analysis in most land use areas was more consistent with the NRCS Data than either the City of Midland Master Plan or the NLCD. It was, however, determined that the Single-Family land use in a fully developed area complete with paved roads was comparable to the NLCD.

3.5.2 ICPR Impervious Tables

Section 3.4 explains which land cover categories were developed to group future residential areas into broader categories. Mobile Home, Agricultural Estates, and Low Density-Rural Single-Family land uses were grouped into Rural Residential without Water. Low and Medium Density-Semi Rural Single-Family Residential areas with a city water tap were grouped into the land use type Rural Residential with Water. High-Density Single-Family and Multi-Family Residential were grouped into the land use type Urban Residential.

The impervious percentages from Table 3-7 were then assigned to the land cover categories intended for use. Table 3-8 shows the results of the above process.

Table 3-8. Land cover categories with assumed percent impervious.

Land Use Type	Assumed Percent Impervious
Range, Grassland	0%
Range, Shrub	0%
Woody Wetlands	0%
Open Space, Parks, ROW	5%
Rural Residential w/o Water	25%
Rural Residential with Water	45%
Public Campuses	50%
Urban Residential	65%
Industrial	70%
Commercial	85%
Retail and Open Water	98%

As described in Section 3.4, the future land use map was a combination of a percent impervious map for developed areas, and a land use type for undeveloped areas, and the land cover was either a number or a name. The numbered land covers are in previously developed areas or areas that will not develop.

The process of inputting the data into the correct format for ICPR is described below.

If the land cover was a number, it represented the percent impervious of the area, so the % Impervious column in ICPR could be set to match the name. If the land cover was a name, then Table 3-8 was used to fill the % Impervious column in ICPR. See Appendix 3-H for the ICPR input data table for Impervious Land Cover.

The %DCIA column is short for percent directly connected impervious areas. This was assumed to be equal to the % impervious value. The remaining columns in Appendix 3-H are not used for Green & Ampt computations.

3.5.3 ICPR Roughness Tables

Table 3-9 was generated to relate the text and numbered land cover names to surface roughness. ICPR uses a different roughness value depending on the depth of flow in the cell being calculated.

The deep roughness column was filled using a combination of the ICPR user's manual, which has a table with suggested roughness ranges for certain land uses, the HEC-RAS 2D user's manual, which has a similar table that related back to NLCD values, and past ICPR models completed by Parkhill in the Midland area. We also examined other sources such as the Harris County Flood Control District (HCFCD) standards for 2D analysis.

If a shallow roughness value could not be determined from the above sources, it was assumed to be roughly 1.7 times the deep roughness value. This was based on information from the ICPR manual, previously observed cases, and the calibration process described in Section 3.9. The default ICPR transition depth from shallow to deep flow is 3 feet, however, this value was changed to 0.5 feet, because outside of channels and playas, depths rarely reach the 3-foot criteria. This is also consistent with HCFCD practice.

Table 3-9. Roughness values related to land cover and percent impervious.

Land Cover Type, Text	Land Cover Name, Numbered	Shallow Roughness	Deep Roughness
Barren Land and Caliche Pits	-	0.05	0.05
Cultivated Crops	-	0.12	0.07
Range, Grassland	-	0.09	0.05
Range, Shrub	0%	0.10	0.06
Woody Wetlands	-	0.34	0.20
Open Space, Parks, ROW	1%-15%	0.07	0.04
Rural Residential w/o Water	16%-40%	0.14	0.08
Rural Residential with Water	41%-49%	0.17	0.10
Public Campuses	50%-59%	0.17	0.10
Urban Residential	60%-69%	0.17	0.10
Industrial	70%-80%	0.05	0.03
Commercial	81%-90%	0.05	0.03
Retail	91%-100%	0.05	0.03

This table was used to create Appendix 3-I, which was the input data for ICPR Roughness sets. Similar to the Impervious Tables described above, the land cover name was either a number or a land use name. If the land cover name was a number, Column 2 of Table 3.5.4 was used. If the land cover name was a land use type, Column 1 was used.

3.6 Soil Type Mapping

The Green & Ampt loss rate method relies on measurements of soil properties, which we obtained from a national data server.

3.6.1 Web Soil Survey Data

Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS) (https://websoilsurvey.sc.egov.usda.gov/). The data is plotted as Appendix 3-J. The data we needed to compute the input for Green & Ampt loss rates was also downloaded from the same data portal. This data is tabulated on Appendix 3-A.

3.6.2 Differences Between Midland and Ector County Soils

The field studies to produce the county soil reports were done at different times by different teams, and their published results are not entirely consistent. The soil names and types differ slightly from Ector to Midland County.

For instance, note soil type KSA (Kimbrough-Stegall) in Ector County adjacent to Ks (Kimbrough-Slaughter) in Midland County. The physical soil properties on these slightly different yet clearly related soils are not so different, as seen on Appendix 3-A. We would expect to obtain about the same infiltration on the two soils.

This is a big advantage for using Green & Ampt instead of Curve Number method for computing losses. When we tested Curve Number, we noticed that some adjacent and clearly related soils in the two counties were assigned differing soil groups, which would have produced much different infiltration on the adjacent soils. The NRCS has revised the soil group classification on several Midland County soils several times in the last few years, and this rendered drainage reports using curve numbers out of date on a regular basis. We hope the underlying soil measurements for Green & Ampt will not be revised so frequently, as they are closer to the actual field measurements.

3.7 ICPR Model Setup

This project has a detailed and an upstream study area. The detailed study area is 228 square miles and the upstream study area is 445 square miles. A total of twelve ICPR models were set up to analyze the area in sufficient detail to meet project objectives.

This section explains the LiDAR data, structure of the various ICPR models and how they are kept consistent and related to one another.

3.7.1 Topographic Data

We used the latest available Light Detection and Ranging (LiDAR) data from the state of Texas data hub, dated 2018, as the surface for all ICPR 2D models.

Texas Natural Resources Information System (TNRIS) is the host for GIS data provided by the State of Texas. The US Geological Survey (USGS) prepared LiDAR for the entire state to support FEMA's development of improved floodplain maps, and this data is highly suitable for our study.

We downloaded portions of the Texas West Central LiDAR project through the TNRIS data hub. This USGS LiDAR project covers portions of 70 counties across west Texas and northern central Texas. The acquisition was conducted from February 1, 2018, through May 27, 2018. Reflights were collected on November 5, 2018. Resolution is 70 cm.

Appendix 3-K shows the topography of our study area.

Because the LiDAR data is from 2018, we made efforts to correct it for basins, channels, and roadways constructed since that time in locations where the studied draws would be impacted. We were able to get contour drawings on some basins and splice them into the LiDAR. We anticipate that future users of these models will acquire newer LiDAR and rerun the model with more basins in place. For now, we can consider our future models as more conservative than the true future conditions. Specific topographic adjustments are described with the individual models. Surfaces are saved in the GIS section for each individual model.

For the calibration in Section 3.9, we updated the LiDAR by adding one basin present before 2021 that we thought would have had an effect on the calibration results. Some other basins were built which did not affect runoff directly into the calibration locations.

3.7.2 Breakout of ICPR Model Regions

Parkhill found we could not analyze the entire detailed study area with the fine level of detail that we needed. Therefore, the downstream study area was broken into eleven sub-models. The upstream study area is necessary only to obtain a hydrograph for input to the upstream end of our Monahans Draw study reach, so it could be handled as a single coarse-grid model. The names of the models are as follows and are shown on Figure 3-5 below and described in Table 3-10.

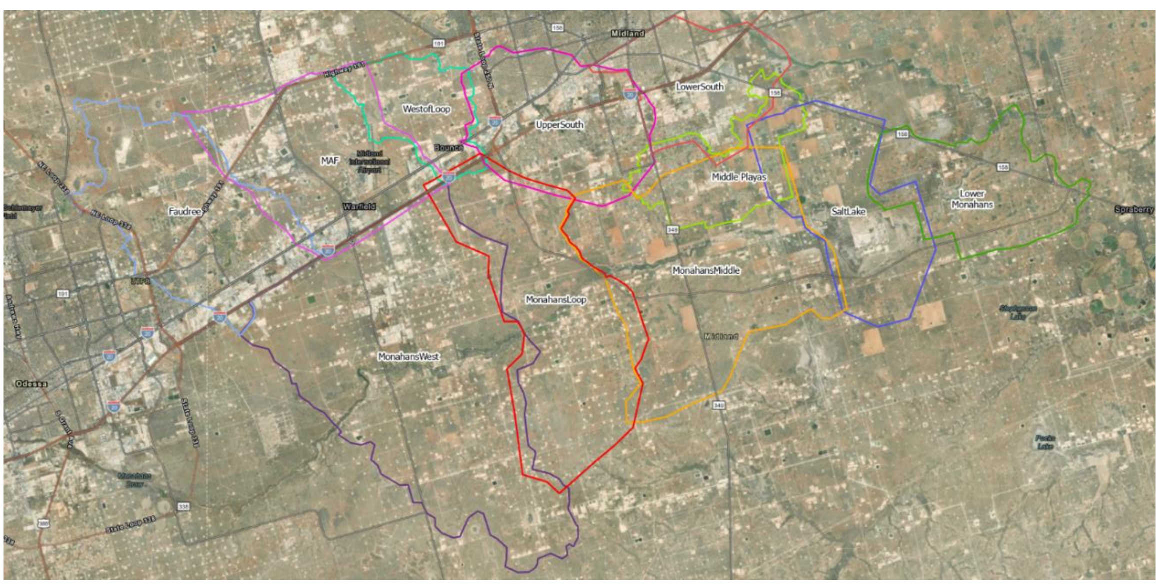


Figure 3.5. ICPR model breakout.

Table 3-10. ICPR model regions.

Model Name	General Location
Faudree	Area drained near Faudree Road, north of I-20
MAF	Area east of Faudree model that drains through Midland International Air and Space Port, north of I-20
West of Loop	Drains to playas located west of Loop 250, mostly north of Interstate 20, and east of MAF model
Monahans West	Area that drains to Monahans Draw, west portion of detailed study area, south of I-20
Monahans Loop	Area that drains to Monahans Draw, east of Monahans West, to the point where future CR 1232 (extension of Loop 250) crosses the draw
Monahans Middle	Area that drains to Monahans Draw, east of CR 1232, to a point approximately aligned with SCR 1150
Salt Lake	Area that drains to Monahans Draw, east of SCR 1150, where Monahans Draw interacts with overflow into Consavvy Lake, a salt lake south of the draw
Lower Monahans	Area that drains to Monahans Draw east of the Consavvy Lake overflow area, to the confluence with Midland Draw
Middle Playas	An area that drains to non-overflow playas situated south of the South Draw watershed and north of the Monahans Draw watershed
Upper South	The upstream portion of the Upper South Draw watershed, to US349 (Rankin Hwy)
Lower South	Downstream portion of Upper South Draw watershed, from US349 to confluence with Midland Draw
Upper Monahans	Upstream study area, draining to Monahans Draw and encompassing much of Ector County

Several of the models drain to a downstream model. Where this occurs, Parkhill extracted hydrographs at the connection point on the upstream model and input them to the downstream model. We carefully split the study area in such a way as to minimize the number of hydrographs to be transferred between models. Several of the models break along Interstate 20 because it functions somewhat as a dam with only limited locations where flow can pass through it.

3.7.3 Surface Flow

For rainfall to be modeled in ICPR, a grid must be created. This was done using a triangular pattern of breakpoints. The distance between breakpoints can be manually set and is determined based on the size of the study area, thus it varies for each sub-basin. Midland County is so flat that the 2D model would misdirect flow past minor swales or across roadways unless breaklines are added. Features to be addressed include roadways, ridges, large features like airport runways, and channels, which are discussed in Section 3.7.5. We utilized automated GIS routines to identify flow paths and interior minor catchment boundaries. Importing this information into ICPR allowed the modelers to more quickly set up needed breaklines to refine the flow patterns.

Additional features can be used to refine the surface when needed. This includes extrusions to block off large buildings that would intercept flow, 2D weirs that can be used to fix areas where the LiDAR shows small inaccuracies, and exclusions for larger noncontributing areas in a sub-basin.

ICPR takes the triangular grid, along with breaklines and other features, to create a pattern of computation polygons that are hexagons unless modified by nearby features.

3.7.4 Playa Naming Conventions

There are hundreds of playas within our study areas, and a primary study objective was to provide information that Midland County can use to regulate development near or in them. This is easier with a consistent naming system.

We decided to use the same grid that FEMA uses for floodplain maps as the basis of playa names. Within each grid rectangle, we used a prefix derived from the FEMA map name, then assigned numbers to each playa as we created the ICPR models. Some of the playas already had a name from a prior Flood Insurance Study or master plan. In those instances, we appended the old name to our new name. Appendix 3-L shows the playa naming prefix grid.

3.7.5 Development of Pond Control Volumes

A pond control volume is a boundary around each of the basins, playas, or other features where water is expected to function as a lake rather than surface or channel flow. We found in an initial test on the MAF model that adding such a boundary could affect the predicted flooding elevation by over a foot, so they are important features. They also allow us to more easily map and number the playas for regulation.

For the Faudree model, the modeler used the surface terrain to manually draw pond controls. These boundaries are a little below the overflow elevations of the features and roughly track a single contour around them.

For the remaining ICPR models, a semi-automated GIS approach was used in determining which closed contour areas to treat as playas. Using the ArcHydro "Extract Smooth Depression DEM" tool, the first step was to generate an elevation raster for the depressions that had a footprint of at least one acre for each modeling area. Step two was to convert the depression DEM from a pixel size of $1m^2$ to $5ft^2$ to simplify the contour boundary shape for use in ICPR. To approximate depression overflow elevations, the spatial analyst tool was used to extract elevation contours at 1-foot intervals from the depression raster. Lastly, it was observed that some interconnected playas fell within the boundaries of larger depressions; so, it was determined that the larger depressions were to be broken up at lower elevations to show how the playas flowed into each other for a more accurate representation. Figure 3-6 below shows an example using of the West of Loop model LiDAR, overlaid with the depression raster, the 1-foot contours and lastly the approximate playa boundary.

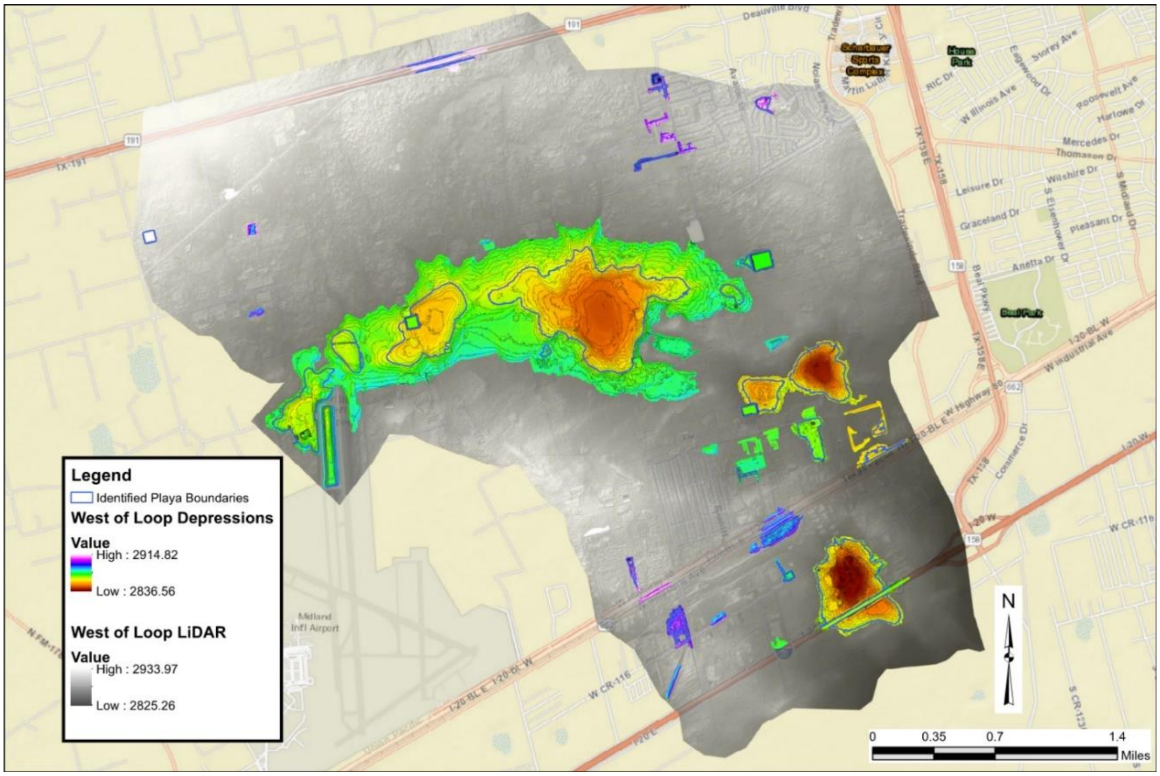


Figure: 3-6. West of Loop Playa boundary delineation.

After initial development of the pond control boundaries, the modeler needed to eliminate shallow depressions less than two feet deep by comparing the pond control boundary elevation to the low point elevation. The modeler then used ICPR to auto-generate elevation tables for each pond control volume. We set a warning stage for each pond control at the overflow elevation of the playa, pit, or basin, so ICPR can notify us if the pond control overflows during the simulation.

As the ICPR models were further developed, some playas were noted to not overflow. For these, the modeler typically used a contour close to the maximum elevation in order to create a smaller pond control volume boundary. This allows a more accurate ICPR calculation of water surface elevation outside the stillwater areas.

Other initial pond controls captured so little runoff that they were eliminated from the ICPR simulation.

A third situation occurred when ponding locations were embedded in stream bottoms where they may fill and then overflow later. We kept some of these as pond controls where we thought the model accuracy would be better.

3.7.6 Use of Channel Control Volumes

Once the base model was complete, we began adding breaklines to direct flow into ditches, channels, and streets. Typically, the breakline is located at the centerline of the ditch. Throughout several iterations, we ran the model and adjusted the breaklines to better simulate actual flow conditions. In some locations we needed breaklines on one or both channel banks, especially if the channel diverts water from its natural path to another location.

Where channels are significant in size, we found that model stability was increased by addition of channel control volumes instead of breaklines. These boundaries are situated at the banks of the channel and facilitate transfer of water from the surface model mesh into a single flow path.

3.7.7 Pipe and Inlet Data

Pipes and culverts were created from our extensive compilation of GIS survey data. Manning's N values, entrance, and exit loss coefficients as well as culvert codes were entered for each pipe and culvert based on their specific characteristics.

Where culverts were noted on aerial photos, but no access was available, we used Connect Explorer to measure sizes from highly accurate and up to date oblique photo imagery. In locations were no on-ground survey was available, we used FIS model elevations, plans that could be obtained from TxDOT or Midland County, or as a last resort, elevations from the LiDAR surface.

3.7.8 2D Weirs and Hydrographs for Transfer of Flow

Weirs are used in ICPR both to simulate actual physical weirs or to serve as locations where a hydrograph can readily be viewed. For the draws to be modeled with HEC-RAS later, we added weirs at points where we anticipated a change in peak flow rate. We also needed a weir at playa overflow locations in order to measure flow out of the playa, which will assist Midland County in sizing infrastructure downstream of the playas that overflow.

We attempted to draw the model boundaries along ridge lines to minimize transfer of flow from one model to another, but there are locations where an upstream flow hydrograph needed to be extracted from ICPR and input to the downstream model. We positioned a weir alone where there was no culvert at the model interface. Where a roadway formed the model boundary, such as Interstate 20, we used a weir for roadway overflow plus the pipe hydrograph at the crossing culvert. The sum of the two hydrographs was computed for model input to the next downstream ICPR model at that location.

3.8 Data Collection

Parkhill determined that it was necessary to gather information for culverts, bridges, and storm drain systems from multiple sources for use in the modeling of the watersheds in Midland County. Some areas needed very accurate survey level data, while in other areas we needed to know structure sizes, and elevations obtained from the LiDAR for Midland County would provide enough accuracy. Some locations were inaccessible due to construction that was occurring and for those we obtained the design plans of the crossings.

Since our model depicts future land cover, we also obtained and used plans for reconstruction of Interstate 20 culverts. This roadway is to be reconstructed throughout most of the study reach within the next few years.

3.8.1 Development of GIS Application

Gathering and organizing field data for drainage structures located in watersheds spanning more than one county is a daunting task. Parkhill determined that organization and accessibility of the data was a key component of project success. To keep the data organized and easily accessible for modeling, Parkhill developed a data collection application utilizing GIS capabilities. The application can be loaded onto a smartphone or tablet and taken into the field for data collection.

The application was developed using the "ArcGIS Survey123 Connect" software. As with any application that is developed, multiple iterations were completed before finally settling on an application that fulfilled the needs of our project. With each version of the app that was used, feedback from those gathering the information in the field was key to development of successful application updates. Parkhill had to balance the data that is needed for modeling with the time spent in the field collecting the data.

3.8.2 Gathering Information

Gathering the correct information is pertinent to limiting repeated trips to obtain missed information. Through refinement of the application, Parkhill determined that a guided walkthrough for information is best for getting the specifics needed for each type of structure. The application was set up in an effort to allow anyone to take it into the field and get the correct information needed to model the structure. The application can collect information for three main types of structures: vertical structures (i.e. manholes or area drains), curb inlets, and culvert entrances and outlets. With the understanding that there are unique structures that could be encountered in the field, a custom category was also created.

The application allows for real time in office viewing of data that is being gathered in the field. This allows for unique coordination between field and office personnel. After the structure is submitted through the application, the location can be seen with an accuracy of 15-feet along with photos and structure measurements. The real time viewing allows for any questions regarding the structure to be answered prior to field personnel leaving the area. Any additional information can be obtained at this point without a subsequent trip.

The application is structure based, so everything is recorded from the perspective of the structure you are gathering information about. The application allows for gathering information about the means of conveyance to and from the structure. A unique aspect of this feature is that the application uses the device’s compass to automatically take a bearing of the pipe or channel so that connections between structures can be more easily made in the office. See Figure 3-7 for example of the data collection application.

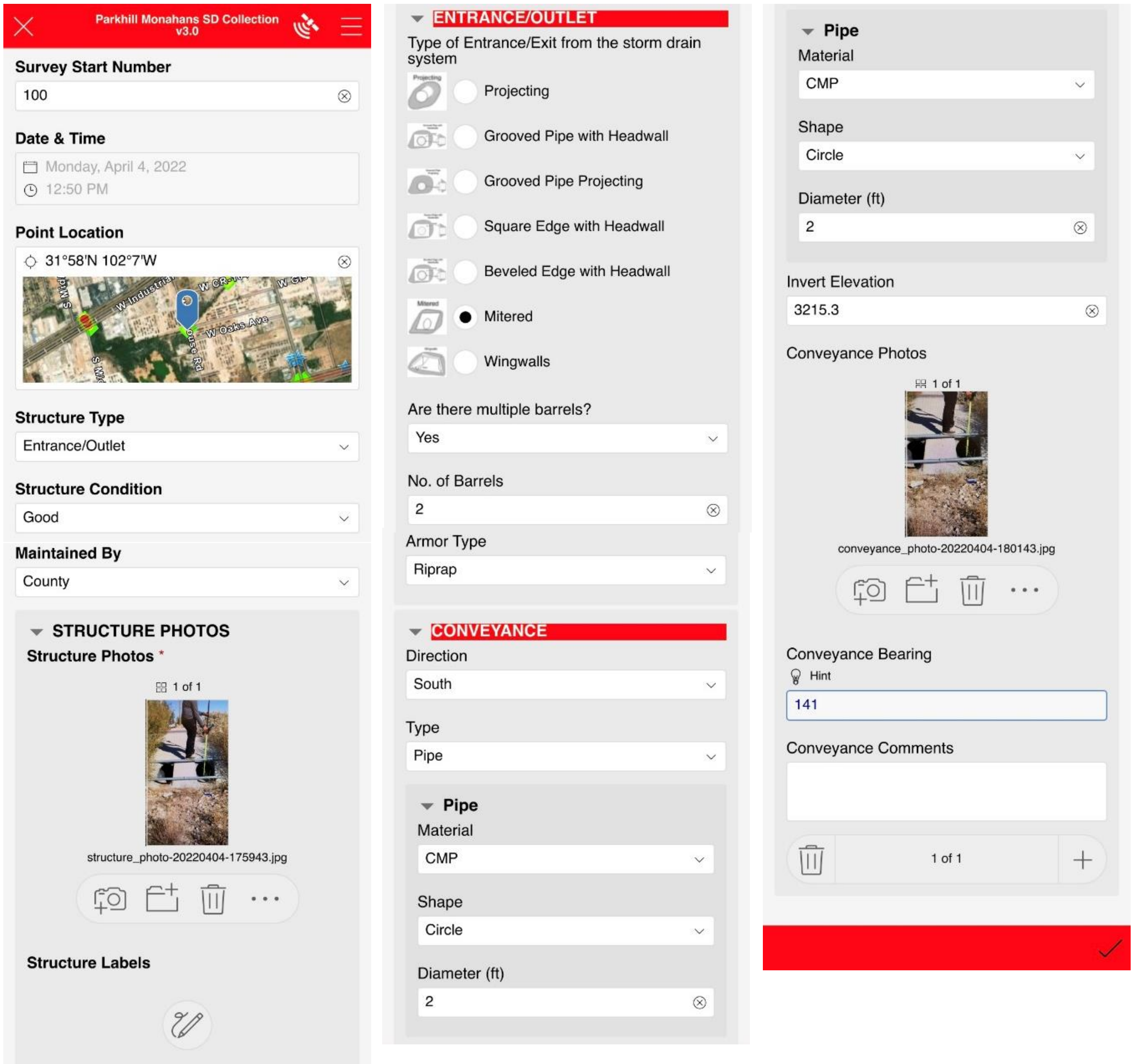


Figure 3-7. Data collection application interface.

3.8.3 Survey Data Collection

Parkhill's surveyors provided the modeling team with survey data on July 19, 2021, August 27, 2021, October 27, 2021, and December 6, 2021, to gather specific requested information that was needed for producing accurate hydraulic models. The areas gathered during each survey can be seen in Appendix 3-M.

3.8.4 Field Data Collected with GIS Application

Parkhill has gathered information on hundreds of structures throughout Midland County using the application developed with "ArcGIS Survey123 Connect." The locations of the data collected can be seen in Appendix 3-N.

3.8.5 Information Gathered from Plans

A portion of Interstate 20 was under construction during the gathering of field data. This means that the information for the culverts crossing the highway needed to be obtained from design plans. Teague Nall and Perkins, Inc. (TNP) provided Parkhill with various stages of design drawings ranging from 60% to 90% plans. We incorporated the 90% plans into the ICPR models along I-20 west of Midland. The 60% set within the City of Midland was complex and preliminary, so generally it was not incorporated.

We obtained plans for various basins, ditches, and drainage facilities in the Faudree model area from the City of Odessa.

Midland County is improving several roadways that cross South and Monahans Draw. For these, we used plans to update the ICPR model crossing sizes and flowline elevations. We also updated roadway elevations at these crossings by modifying the LiDAR surface.

3.8.6 Information Gathered in Office

Some data that was both inaccessible and had no plans available was obtained with aerial photography and LiDAR information. When running preliminary models, flow paths that might not have been evident during the initial identification of structures were found and investigated with Google Earth and CONNECTExplorer for any evidence of a structure. The crossing sizes, number of pipes or boxes, and conduit materials were measured or determined from the photos. Elevations were taken from the LiDAR data.

3.9 Calibration of Loss Rate and Roughness

Since Flood Insurance Studies (FIS) were adopted for Midland and Ector Counties in the 1990s, local experience has suggested that they overestimate the flood hazard, especially for the lower flood frequencies. Many playas shown in Flood Insurance Studies (FIS) studies to overflow in a 10-year frequency event have never been known to fill. Wide floodplains in some areas have been observed to be accurate, but in others, much exaggerated.

Both counties' FIS utilize Natural Resource Conservation Service (NRCS) loss rates and either Snyder's or NRCS unit hydrographs. Staff at Parkhill have long suspected that runoff infiltrates along its travel path and even in the draws and playas, in a way not well accounted for by the NRCS curve number loss rates or 1d modeling.

After the 2d ICPR modeling method was selected, we realized that the Green and Ampt loss rate method could model the continued infiltration of runoff after it left the location where it was generated. Tests showed that using Green and Ampt with default initial moisture values tended to greatly reduce runoff peak flows and volumes, probably to an unrealistic extent. Therefore, we needed to calibrate the model to a known flooding event.

Calibration in this region must rely on comparisons of high-water marks, because there are no streamflow gauges on any of our draws. Playas capture and retain water, so even without a stream flow gauge, we can estimate the volume of runoff.

Early in the study, a flood event occurred that offered an opportunity to obtain high water marks for calibration. From June 26 to July 3, 2021, a series of rains totaling six to seven inches fell across the area. Substantial flood damage occurred. At the time of the rains, no calibration was planned, so we missed the opportunity to obtain direct surveyed high-water marks. Instead, we had to infer them from photographs.

The calibration effort focused on the Faudree Road area of east Odessa and Midland County, because it is at least 50% developed and has a chain of basins and playas that capture and overflow. We succeeded in producing a model that closely matched observed flooding by varying the initial moisture content in Green and Ampt.

We modeled other areas with the same assumption of initial moisture in Green and Ampt.

3.9.1 Rainfall Data for June/July 2021

Historical rainfall events can be recreated by using the Level III NOAA Next Generation Radar (NEXRAD) datasets. NEXRAD offers various types of datasets stored as radar reflectivity. Though refined, NEXRAD level III data is known to be highly conservative and is recommended to undergo further calibration by using gages and removing various anomalies. Once calibrated, it is at the Level IV stage and a more accurate product suitable for use in hydrologic modeling.

The National Center for Atmospheric Research, managed by the University corporation for Atmospheric Research (UCAR/NCAR) manually processes the River Forecast Centers (RFC) Level III data every month to create the Level IV datasets, called "NCEP/EMC 4KM Gridded Data (GRIB) Stage IV Data." We obtained the data from the Earth Observing Laboratory web site https://data.eol.ucar.edu/dataset/21.093. This rainfall is formatted to UTC (Coordinated Universal Time).

Using the UCAR/NCAR NEXRAD Level IV gridded hourly precipitation data, a historical storm (Storm1) was replicated for the 8-day event between June 26th and July 3rd, 2021. The rainfall datasets are stored as multi-sensor hourly GRIB2 files. Parkhill converted the data to 193 hourly raster files. The raster files were then used to derive a 6x4 grid over the study area (see Figure 3-8). This resulted in 24 grid-cell specific hyetographs with a 1-hour timestep for the historical event.

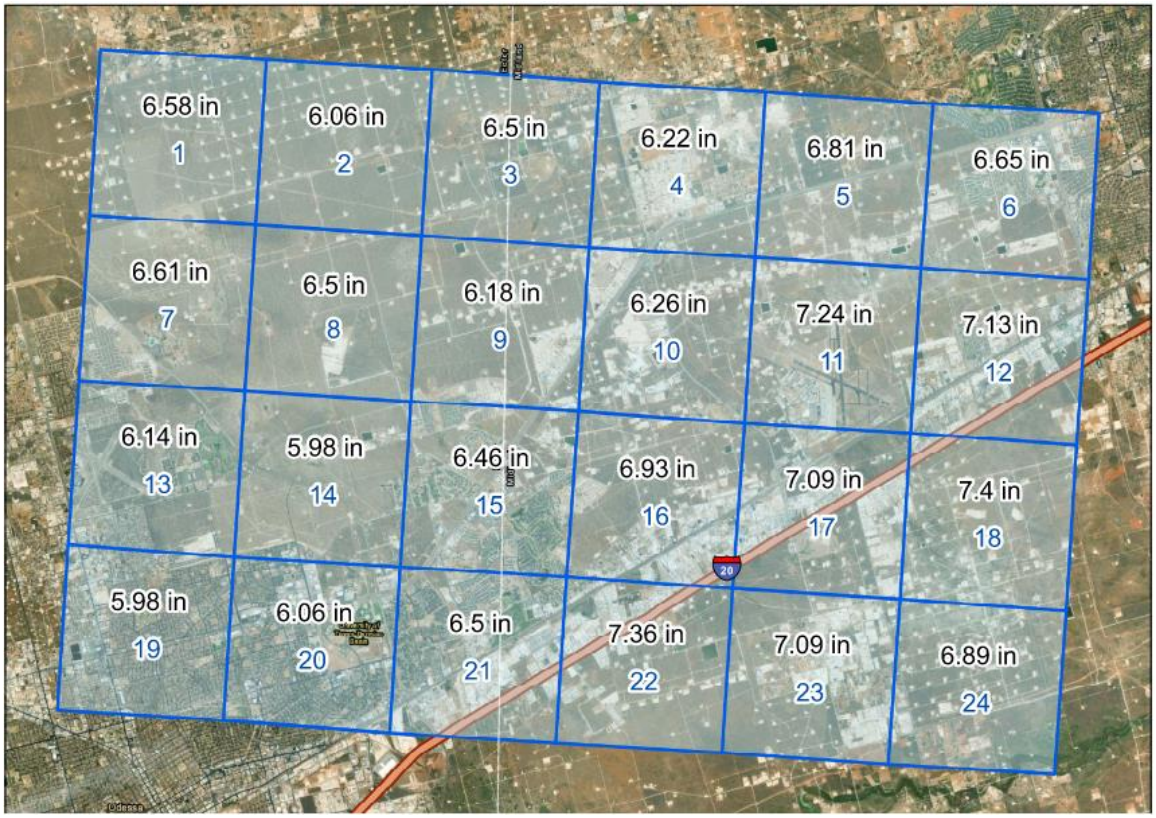


Figure 3-8. Nexrad grid cells with total rainfall.

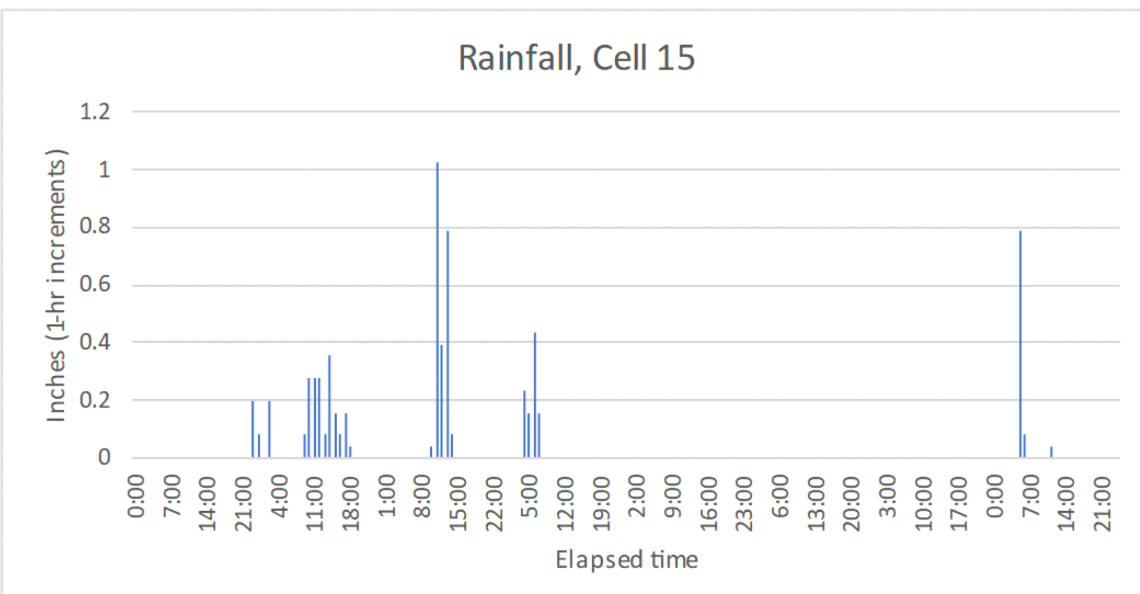


Figure 3-9. Storm1 Hyetograph for Grid Cell 15.

Storm1 varied across the grid-cells and resulted in in four to five peaks on June 27, 28, 29, 30, and July 3. The Incremental hourly rainfall varied from 0.7 to 1.6 inches per hour, totaling six to seven inches of rainfall over the Faudree model area during the storm. Exhibits 3-9 and 3-11 also clearly show the impact of the successive rain events on the ponding in various playas. Our simulations ended prior to the full impact of the last event, but all photos for calibration were earlier, so we did not extend it.

3.9.2 Land Use and Topography for Calibration

This study scope called for using percent impervious values associated with future developed land use throughout most of the watersheds. However, to match a 2021 storm we needed existing condition land use. For this purpose, we downloaded the latest available USGS National Land Cover Database (NLCD) Percent Developed Impervious GIS dataset, which was dated 2019. There has been some development in the Faudree watershed since that date, so our runoff generation will be considered a bit low.

The 2018 LiDAR was modified to include one basin that was excavated after 2018 and not present in the existing LiDAR contours. Elevation linework was created and imported from ACAD C3D into ICPR and spliced into the existing LiDAR to create a new current surface for the model. There are some other basins that were built, but we were unable to obtain contours for them. They were not located in the main path of flow into the basins being used for calibration, so the impact is likely small.

3.9.3 High Water Marks for Calibration

Photos from the June 2021 storm were analyzed to determine high water marks in identifiable locations. Four ponds were chosen as reference points for calibration. These ponds are the Racetrack Basin (E0245-16), Old Course Playa (E0245-15), East Course Pond (E0245-09), and OIME playa north (E0245-18).

Figure 3-10. Locations of the calibration points overlaid on an early calibration output.

All of our photos were taken on June 29 and June 30, 2021, prior to the final rainfall. Odessa Country Club provided photos and video showing runoff early on June 29, just after the rainfall that caused the East Course Playa to overflow. By a fortunate coincidence, Google Earth street view for Business 20 had photos dated June 2021 that show extensive flooding in the two playas adjacent to that roadway. Based on comparisons to the simulations, the Google Earth photos must have been taken June 30, 2021, as elevations do not match the other dates. After we had completed initial calibration, we received additional photos taken June 30, 2021, from City of Odessa that were used to validate our results. These were at the Racetrack Basin and OIME South playa. Because the rainfall data is on UTC, we added 7 hours to the time of the photos to match the rainfall.

We determined flooding elevations at the photograph times by comparison to aerial photography in ARCGIS. Inundation limits were drawn using 3D Analyst to create contours that best matched the observed inundation. Appendix 3-O shows the details of high-water elevation development with the contours that best match observed ponding.

We noted that the Old Course high water mark was very accurate due to the flat topography, where only one elevation would reproduce the observed inundation. The other locations must be considered accurate to about half of a foot. The time of day is uncertain on the Old Course and OIME North locations, but fortunately the model results show a rather flat-water surface throughout June 30, so the data is usable.

Table 3-11. Locations, Photos, and Elevations Used for Calibrating the Model

Location	(0245-15) Old Course	(0245-16) Racetrack	(0245-16) Racetrack	(0245-09) East Course	(0245-18) OIME North	(0245-19) OIME South
Photo/Video High Water Mark	2862.3	2866	2869.1	2870.9	2859.8	2857.3
Photo Source	Google Street View	OCC Video	City of Odessa	OCC Video	Google Street View	City of Odessa
Photo Date	Est June 30, 2021	June 29, 2021	June 30, 2021	June 29, 2021	Est June 30, 2021	June 30, 2021
Photo Time, CDT	Daylight	7:30 am	Just after Noon	7:30 am	Just After Noon	Just After Noon
UTC Time Step	Est. Hr 110-122	Hr 86.5	Hr 116	Hr 86.5	Est. Hr 110-122	Hr 116

3.9.4 Model Adjustments

The calibration process was run multiple times. Each time we ran the model with a range of MC Initial values, then used various plots of the data to analyze results. We sought to determine which value of MC Initial yielded the closet match to observed high water marks in the five locations where photos were available. However, we encountered a need to improve our model early in the process.

Several types of plots were useful in analyzing the results. Figure 3-11 below illustrates how we plotted the playa stage over time and compared it to the dots indicating photo elevations. Dots are color-matched to the playa graph. This image shows the Racetrack basin (0245-16) consistently modeled lower than the photos, indicating our model is not directing enough water into the basin, while other locations provide a good match to the photos. We paused our calibration process to adjust the model so it would provide results as consistent as possible between basins.

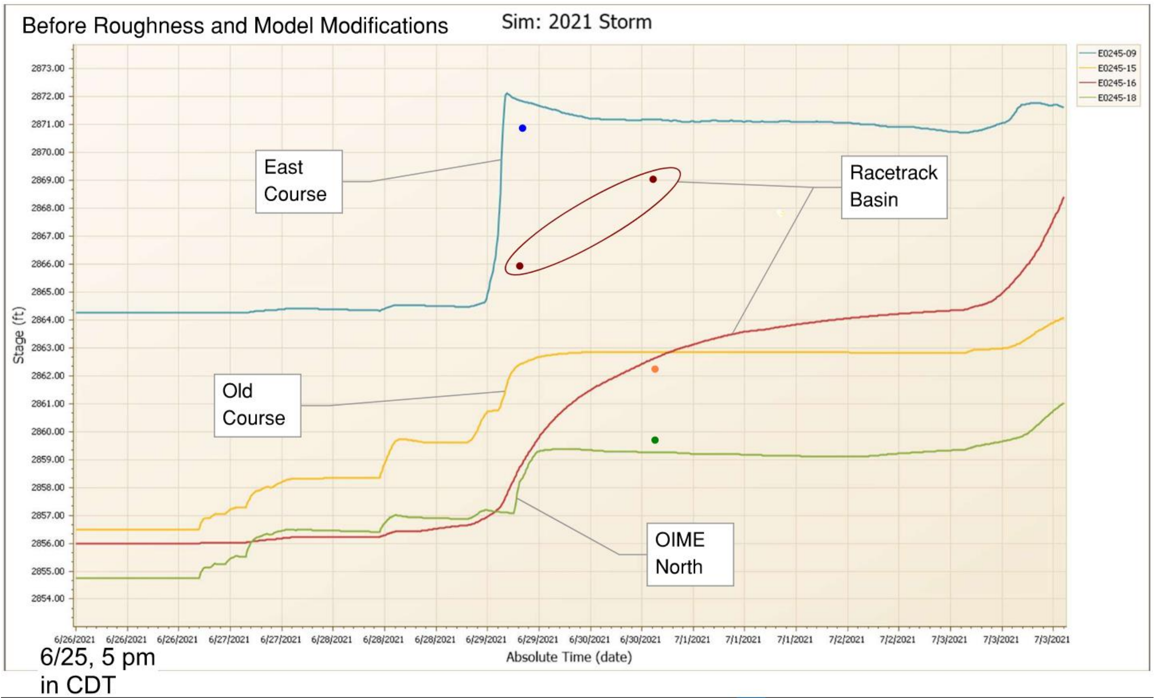


Figure 3-11. Initial playa stage over time plot.

To improve model accuracy, we reconsidered our roughness estimates. ICPR uses a shallow and deep Mannings N, and by default considers deep as 3 feet or more. We noted Harris County Flood Control District (HCFCD) uses 0.5 feet for this transition point, and that most of our model was in shallow. Hoping to get more water to Racetrack basin, we reduced the transition point to 0.5 feet.

We also adjusted the roughness ratio between shallow to deep Mannings N ratio from 2 to 1.7, after examination of standards for HCFCD. This change should also increase velocity in the watershed. Finally, we checked the roughness assigned to each of the percent impervious numbers in the map. Noting that several roadway rights-of-way had percent impervious from 5 to 15, we reduced the roughness for these.

One additional adjustment was made to the model in order to direct more flow into the Racetrack Basin. Breaklines were adjusted and a pipe error found and corrected. Figure 3-12 compares two runs with the same initial moisture with and without the model adjustments. More flow is reaching the Racetrack Basin, but still 2.5 to 4.0 feet less than photos indicate. Interestingly, OIME South went up when more flow reached the Racetrack Basin. This indicates that the Racetrack basin may be interacting with flow on the opposite side of Faudree Road more than we expected.

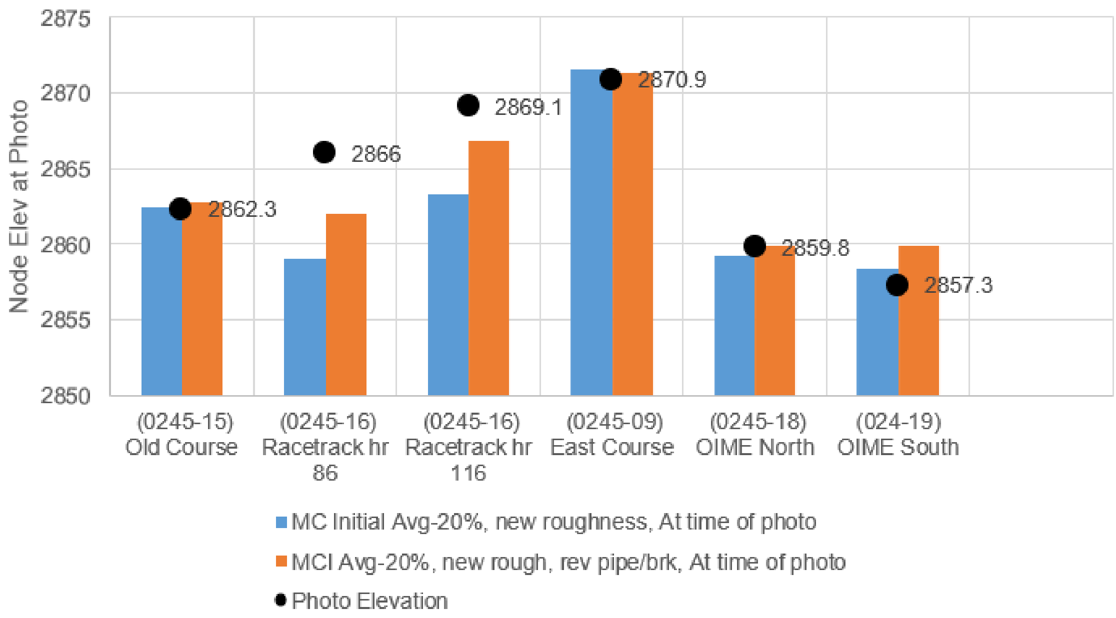


Figure 3-12. Effect of model adjustments and roughness value changes.

3.9.5 Initial Moisture Calibration Process

With the model corrected as well as possible, it was then possible to test a range of values for initial moisture, MC Initial, and evaluate the sensitivity of the model to this factor. Recall that MC Initial is typically set to match MC Field. We reduced or added 5% increments of the MC Field value to produce the range of MC Initial used in the calibration. Figure 3-14 shows the resulting graph of adjustment compared to computed playa node elevation, noted at the time of the photos we had.

It became apparent that some of our calibration locations were not useful for calibration. Figure 3-14 below shows that one location, East Course, overflows in every simulation. The graph is a straight line, indicating that MC Initial had no impact on the results. It is helpful to know that our simulation matched the observed photos rather well, however.

We were never able to match the Racetrack basin levels accurately, and this casts doubt on our results for the Old Course location which is downstream of the Racetrack basin. If too little flow enters Racetrack, it would go to Old Course instead, so if Racetrack is too low then Old Course must be too high.

OIME North and OIME South are really a single playa connected by a single equalizer pipe. Figure 3-13 shows how they function independently until the point that OIME North overflows into OIME South and they have the same elevation. This indicates that only OIME South functions as a somewhat natural playa. OIME South photo elevation matched the simulation with an adjustment of about four percent reduction in MC Initial compared to MC Field. OIME South matched better at a fifteen percent reduction, but we noted that the playa was rather insensitive to initial moisture over the range where OIME North matched better.

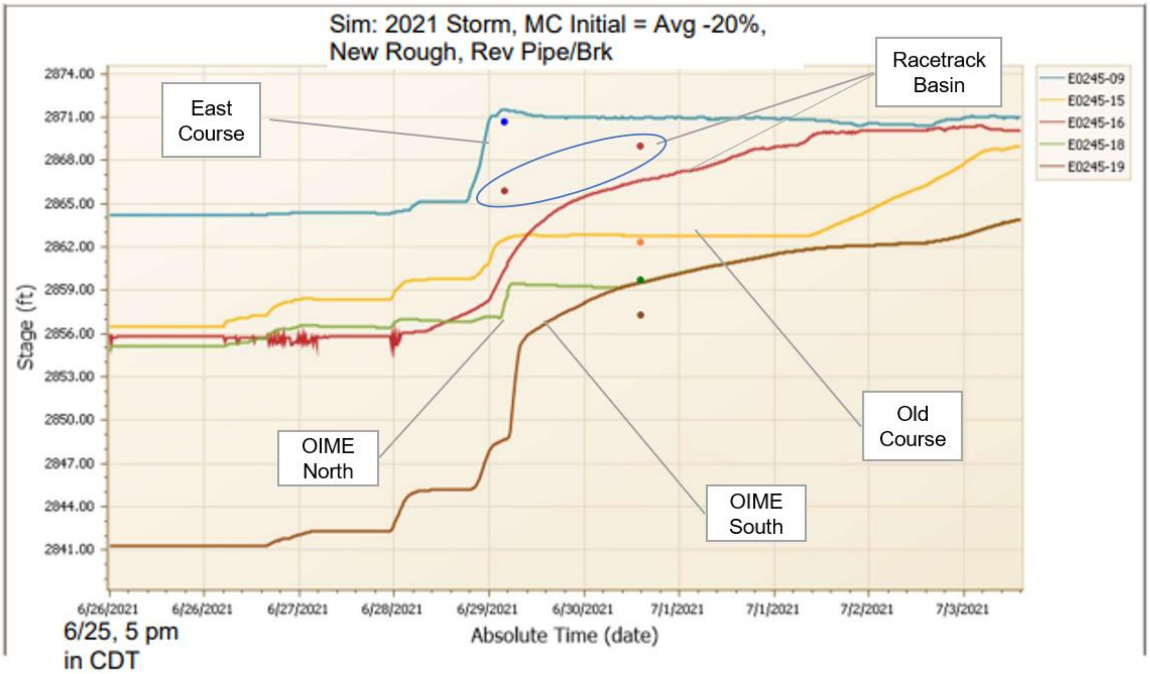


Figure 3-13. Playa stage time plot after model adjustments.

We chose to adopt the four percent reduction because it made sense that the ground in our region would be drier than in a normal region, but not excessively drier.

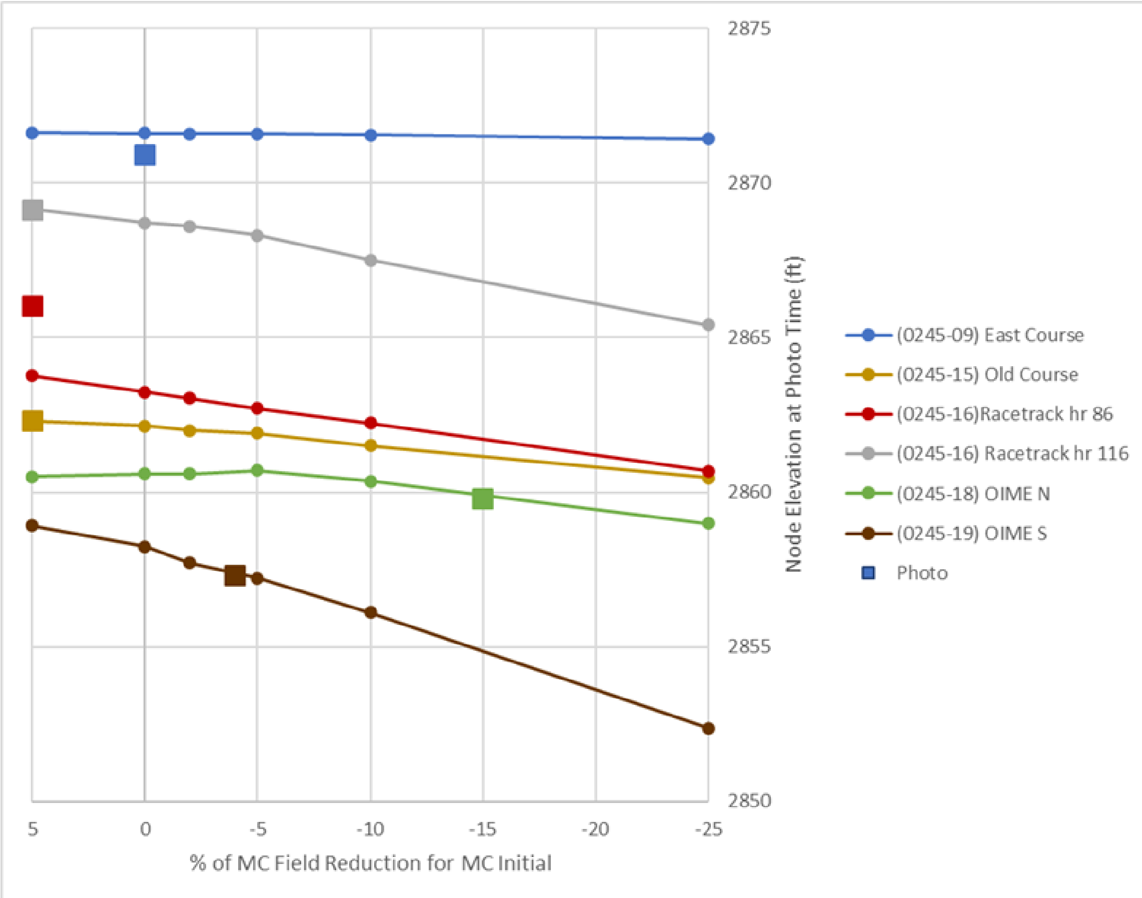


Figure 3-14. MC initial adjustment vs. playa elevation at photo time.

3.9.6 Cautions

The Green and Ampt loss rate methodology is superior to NRCS curve number because it relies on measured field data related to numerous individual soil types rather than a simplistic four groups of soil. As mentioned previously, we noted that the NRCS continues to update the soil group for various soil on a regular basis, with dramatic impact on hydrologic results. However, the Green and Ampt method suffers from some of the same issues. This study has soils in two counties, and some soils are found in both counties. We discovered that the published values used for the Green and Ampt tables varied somewhat by county, and also that when we downloaded the data at different times we discovered that some soils' published data had been revised.

4 Hydraulic Methodology

This section describes the draws and flow paths studied with HEC-RAS and the methods used.

4.1 Routes Studied with HEC-RAS

Hydraulic models for South Draw, Monahans Draw and four flow paths were part of this study scope. Although ICPR provides water surface elevations, the results require external processing in ArcGIS to produce a typical floodplain map similar to other 2D hydraulic models. ICPR is also hard to use to define floodways, and Midland County could use unofficial floodway maps to regulate development on unmapped streams. Finally, ICPR is proprietary and has a learning curve to use. We wanted to have hydraulic models more accessible to the engineering community. For all of these reasons, HEC-RAS v6.2 models were developed with the goal of matching the ICPR results.

FEMA FIS models exist for South Draw and for a portion of Monahans Draw, but the other four flow paths were previously unstudied. The FIS omitted most of the playa inflow paths and overflow paths, showing only still water ponding at the playas. The newly studied flow paths selected were those that had many square miles of contributing area plus significant anticipated development along the route. Figure 4-1 shows the locations of the models described in Section 6.

Figure 4-1. HEC-RAS reaches studied.

This section describes the process to finalize each of the models. All were created with future land use 100-year flow rates from the ICPR models. A floodway for each model was developed. Output consists of GIS floodplain and floodway extents.

To check the models we verified that the flooding extents were generally similar to the inundation extents produced by the ICPR maximum depth output, and spot-checked that water surface elevations were within a foot of the ICPR results.

4.2 Modeling Methodology and Assumptions

Input data for crossings is generally the same as for the ICPR models described in Section 5, with some exceptions described below and in the individual model writeups in Section 6.

4.2.1 Basic Model Data and Setup

The terrains are based on the same 2018 LiDAR. For the HEC-RAS models, some localized terrain modifications to show post-2018 development were made that are not in the ICPR models. These instances are explained in Section 6, Hydraulic Models Details and Results. Culverts were taken from survey, plans, field measurements, or Connect Explorer measurements as appropriate. Best available flowline and top of road elevations were input.

Our initial runs used 1D HEC-RAS modeling, but in many cases, we discovered that the terrain had so many obstructions and split flow paths that a 2D model was the only option for analysis. The individual descriptions in Section 6 provide the type and reasons for each model.

We attempted to keep our stationing the same as the FIS models where they existed, and to maintain cross sections in the same locations as the FIS, to the extent that they aligned with the features to be modeled.

Manning's n values were related to the future condition land use / roughness layer developed for ICPR. ICPR has a deep and shallow roughness, and we experimented with both to choose the best match with ICPR for each model.

4.2.2 Hydrographs and Flow Rates

Flows for the various models were taken from the ICPR models. In the case of 1D HEC-RAS, only the peak flow was used. For the 2D models, a flow hydrograph was applied as an external or internal boundary condition.

Extracting flow hydrographs and peak flows from ICPR was not as straightforward as we initially expected. ICPR can provide hydrographs at the nodes on each end of a culvert, in the pipe itself, or crossing a 2D weir that is set to the same elevation as the ground surface. Some of the ICPR hydrographs have some instability, especially those that are located in pipes. West Texas slopes are so flat that flow sometimes oscillates back and forth in the culvert, resulting in negative flow rates. This can be a modeling discrepancy or a realistic effect.

Typically, we placed flow measurement locations in ICPR where we thought flow rates might change. We tried to place them where we expected a smooth reliable hydrograph, but some still had issues.

For the 1D HEC-RAS models, we simply needed to obtain the peak flows from ICPR and input them at appropriate locations. Judgement was needed to choose the real peak flow and not an unstable spike.

HEC-RAS 2D models cannot accept negative flows in a hydrograph, so where we needed to input a hydrograph with some instability, we set the negative flows to zero. HEC-RAS also accounts for storage in floodplain, so the flow rates decrease in a downstream direction, as evidenced when we cut a cross section line and view the hydrograph along that line. Because of these decreases, we made some efforts to keep the HEC-RAS model flows closer to ICPR. The most successful was for the Upper Faudree model, where we used the internal boundary conditions to iteratively add in flow along the flow path until we obtained a peak flow match at key points. For most of the other models, it was accurate enough to choose the highest peak hydrograph on a reach and place it on the upstream end.

4.3 Floodway Delineation

A future condition floodway was delineated for each of the studied routes. We did not attempt to match the FEMA floodways because our flow rates were generally lower, and because the FIS floodways were developed with lower quality data.

For all of the floodways, we placed the floodways in the region of greatest flow intensity. For the 1D HEC-RAS models, we utilized method 4 to initially create a floodway with equal conveyance reduction on both sides. Next, we smoothed the floodway from this initial result, keeping the limits parallel to the vegetation changes and elevation changes indicated on the aerial photos and LiDAR data.

For the 2D HEC-RAS models, we developed plots of Depth X Velocity as a guide to floodway placement. The diffuse nature of flow in these models made this plot essential to locating the main flow paths, which were not always connected. We used Geo-HEC-RAS for its more convenient terrain modification to raise the areas outside the floodway being tested.

Midland County will not be able to use the floodways we developed where they are narrower than the FIS floodways, but they will be useful as guides to the more intense flooding locations. Property owners are often unaware of the flow potential on their sites. We found on one model, Faudree Outfall, that buildings and fill pads had been placed in the floodway we identified. This caused us to revise the terrain to show the blockages, rerouting the floodway through the buildings.

5 Hydrologic Models Details and Results

This section describes details of model development for each of the thirteen ICPR models and discusses their results. The hydrologic methodology for the study is described in Sections 3.2-3.7. Generally, the model setup for rainfall, loss rates, land cover, roughness, and soil types were described in Sections 3.2 through 3.6. These processes are identical for all areas.

Topographic data for all areas has the same source. Base terrain from USGS lidar was modified for some of the models. The modified terrains are within the ICPR models but also provided in our GIS results.

Other computational layers of soils, land use/roughness, model boundaries, pond control boundaries, and flow measurement locations were output to GIS. Supplementary layers of rainfall graph and playa naming grid are also included.

As Section 3.8 explains, unsurveyed drainage structures were located using Google Earth and Connect Explorer satellite imagery. These same programs were used to gather data, such as culvert size, number of boxes, culvert material, etc., while culvert upstream and downstream inverts were obtained from the surface.

The maximum flood depth plots for each model, with the exception of Upstream, were output to GIS. Depressions in the terrain that capture significant flow are treated as pond controls in the ICPR models. For these, the GIS contains the name, model source, overflow elevation of the depression or playa, future 100-year ponding elevation, lowest depression ground elevation, resulting ponding depth and storage volume, and total flow in cubic feet per second into the depression.

From the ICPR models, we extracted hydrographs at 2D weirs positioned at the downstream lip of overflow playas and within the riverine flow paths where we intended to do HEC-RAS modeling. The locations of these weirs are shown in the GIS. Data attached to each weir includes the model name, weir name, associated depression if any, peak flow rate in cfs, direction of flow, and what feature the flow enters. Some of the peak flows are taken from a culvert alone or a sum of culvert and overflow hydrographs at the same location.

Excel spreadsheets of the GIS attributes for depressions and weirs are uploaded with the models.

Appendix 5-A shows the ICPR maximum depth results from all models.

5.1 Upstream ICPR

The Upstream model is located mainly in Ector County. It has a limited detail and is used only to generate hydrographs for input to the detailed study area.

5.1.1 Model Details

There is a 445 square mile contributing area upstream of the detailed study area. This large-scale area contributes to Monahans Draw. The goal of our upstream analysis was to create an input hydrograph at Monahans Draw for the Monahans West ICPR model.

Section 3.7 explains the remainder of ICPR model setup. For the upstream model, there is less detail in the ICPR model. Since it is one huge area, model processing time was several days. Thus, it was necessary to use a large (300-foot) breakpoint spacing, generating large computational polygons.

We did not have survey or data collection for most culverts and storm sewer systems. We input proposed Interstate 20 structures and weir overflows from the TxDOT Segment 1 60% plans and Segment 2 90% plans. We located pipe information from limited Odessa GIS data and others from Google Earth and Connect Explorer photos for structure size along Monahans Draw and several contributing tributaries.

Not all structures in the watershed were modeled, but the model polygon size was large enough that most roadways were crossed by a polygon, so the model ignored them for computational purposes. We examined the model results for ponding areas and resolved problems using breaklines and additional culverts.

We created pond controls for major playas in the upstream area, but not as many as for the detailed study area. We added fewer breaklines as were used in the main study area detailed flow models. Breaklines were chiefly along the center of Monahans Draw, Muskingum Draw and major tributaries throughout study area, and along major roadways that would block flow such as Interstate 20, Business 20, Hwy 385 and Loop 338.

5.1.2 Analysis of Model Results

Upstream model max depth plot is shown below as Figure 5.1. Appendix 5-B contains the same results at a closer zoom level. Due to the possible underestimation of inundation on this model, we have not output the flood depths layer to GIS for floodplain management purposes. A future study may be needed to better understand the City of Odessa and upstream model drainage.

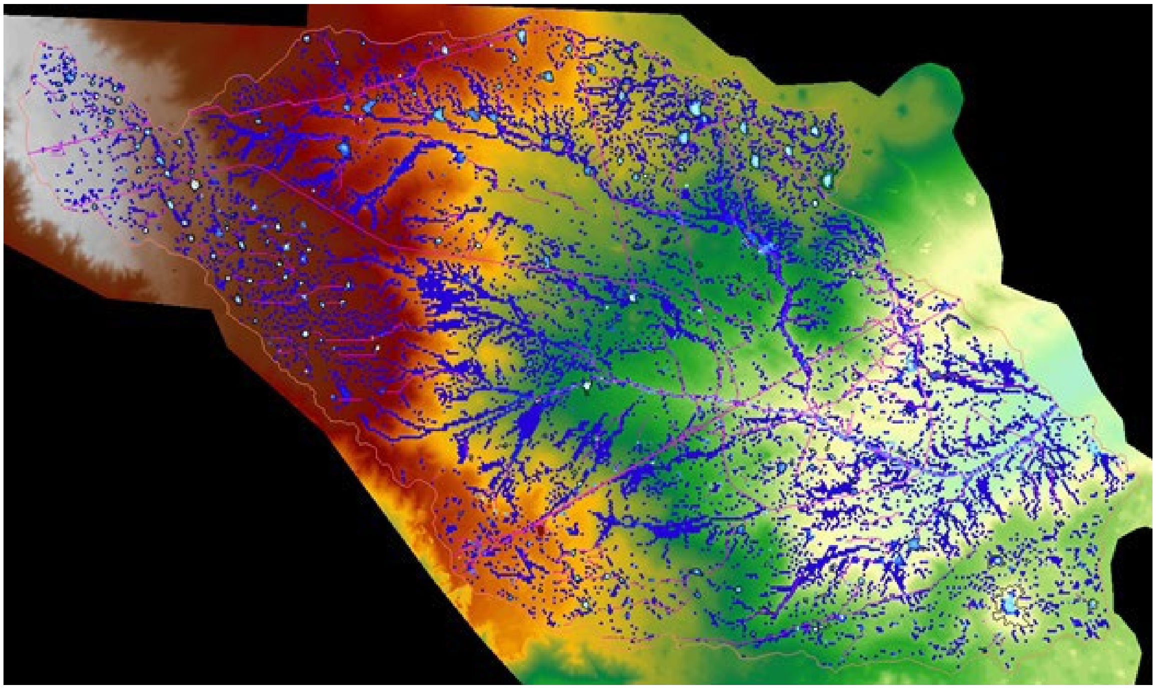


Figure 5-1. Upstream ICPR model maximum depth.

Our sole interest in the Upstream model was to create input hydrographs for the remainder of our study. We placed 2D weirs along the eastern limit of the upstream model boundary showing flow into the Monahans West model at three mostly contiguous locations. Results were compared to the FEMA Flood Insurance Study and found to be much, much less. The flow rate table in the Ector County FIS states that the 1% annual chance flow rate in Monahans Draw 5,000 feet downstream of the Ector County line is 17,865 cfs. This is approximately the same location as the east end of our Upstream model, where it generated a peak of 3,444 cfs.

We compared FIS inundation to our ICPR results in several Odessa locations. We noted that results in more highly developed portions of the model matched rather well.

In areas with less impervious cover, even though our land use is a future condition, flood widths were much less than the FIS. The anticipated land use in the upper portions of the watershed is still dominated by rangeland. This supports our understanding that NRCS curve number losses are better suited to urbanized areas in our region, whereas our Green & Ampt loss methodology is better for undeveloped locations.

As a further check on the model results, we conferred with the City of Odessa Engineering staff in March 2023. City staff agreed or did not have information to contradict the inundation limits shown. City staff reported San Jacinto Park completely inundated, whereas our model showed only partial flooding. City staff reported more flooding at Beechwood Street cul-de-sac than the model showed. In some other locations our model matched City observations.

5.1.3 Input Hydrographs for Detailed Study Area

Despite confirmation that our model results seem realistic, we were concerned with how low the peak flow was compared to the FIS model. Residual doubts remained that the coarse nature of the model might be omitting conveyance that would speed runoff to Monahans Draw. In addition, future factors beyond mere land use change, such as enlargement of drainage structures that currently serve to restrict and slow runoff, could increase runoff into Monahans Draw.

Eventually we decided that this study is intended for future drainage infrastructure and easement purposes. We felt that Midland County would be better off overestimating the upstream inflow and planning accordingly. Rather than trying to further modify the ICPR model to obtain a more conservative result, we simply doubled the flow at each time step in the outflow hydrograph for Monahans Draw used as input to the Monahans West model.

We made two other modifications to the input hydrograph for Monahans West model. First, we noted a dip in two time periods (15-min interval) just at the peak, which appeared to be caused by a model instability. We smoothed those values to eliminate the dip in flow. Second, we artificially tapered the flow to zero beginning from 106 cfs at hour 100, to 0 cfs instead of 48 cfs at hour 150, eliminating a long duration outflow from the upstream model. These long duration outflows are caused by areas that impound water and continue to trickle tiny flows for a very long time, or by culverts input using survey or design elevations that are slightly different from the LiDAR data.

5.2 Faudree ICPR

The Faudree model watershed is approximately 32.4 square miles with no upstream or adjacent contributing areas. The MAF model shares a boundary on the east and the Monahans West model shares a boundary on the south of the Faudree model. This model contributes to the Monahans West area located south of I-20. External hydrograph flow data from this model was used for the Monahans West model at three culvert locations draining south of I-20: east of SCR 1310, at SCR1300, and west of SCR 1290. Flow Path #4 is located adjacent to Faudree Road draining southeast across Hwy 191.

5.2.1 Model Details

Breakpoint spacing was set at 150 feet. Breaklines were placed along major roads and channels as well as flow paths leading to basins and playas. Several grouped breaklines were used along I-20 to incorporate the higher elevations along the road and frontage as well as the roadside and centerline ditches. More focus was placed around the Midland Country Club area where future road improvements are expected at WCR 122 and a higher level of detail in breaklines was used.

Culvert information was obtained using Connect Explorer and archived survey data. All culvert locations that were previously unknown were surveyed during the project to ensure accurate elevation and size data was used.

The surface was modified to include a basin at Mission Drive which is expected to provide relief to the adjacent subdivision. Some culverts and inlets were added to the model along Hwy 191 based on TxDot plans for road improvements.

The Faudree model was unique in that we used this area to calibrate the Green and Amp soil conditions to be used for all of the Monahans models. Because of this, the Faudree area model has both Existing and Proposed conditions scenarios. See Section 3.9 for details on the soil initial moisture calibrations.

Weirs were placed along Flow Path #4 that was modeled in detail separately as well as at the overflow locations on all playas and basins with distinct overflow paths in the 100-Yr storm event. Many of the playas in the Faudree model overflow from various points without a distinct path and inundate the surrounding area. Further recommendations have been made to improve flooding in those locations.

5.2.2 Analysis of Model Results

Faudree model max depth plot is shown below as Figure 5-2.

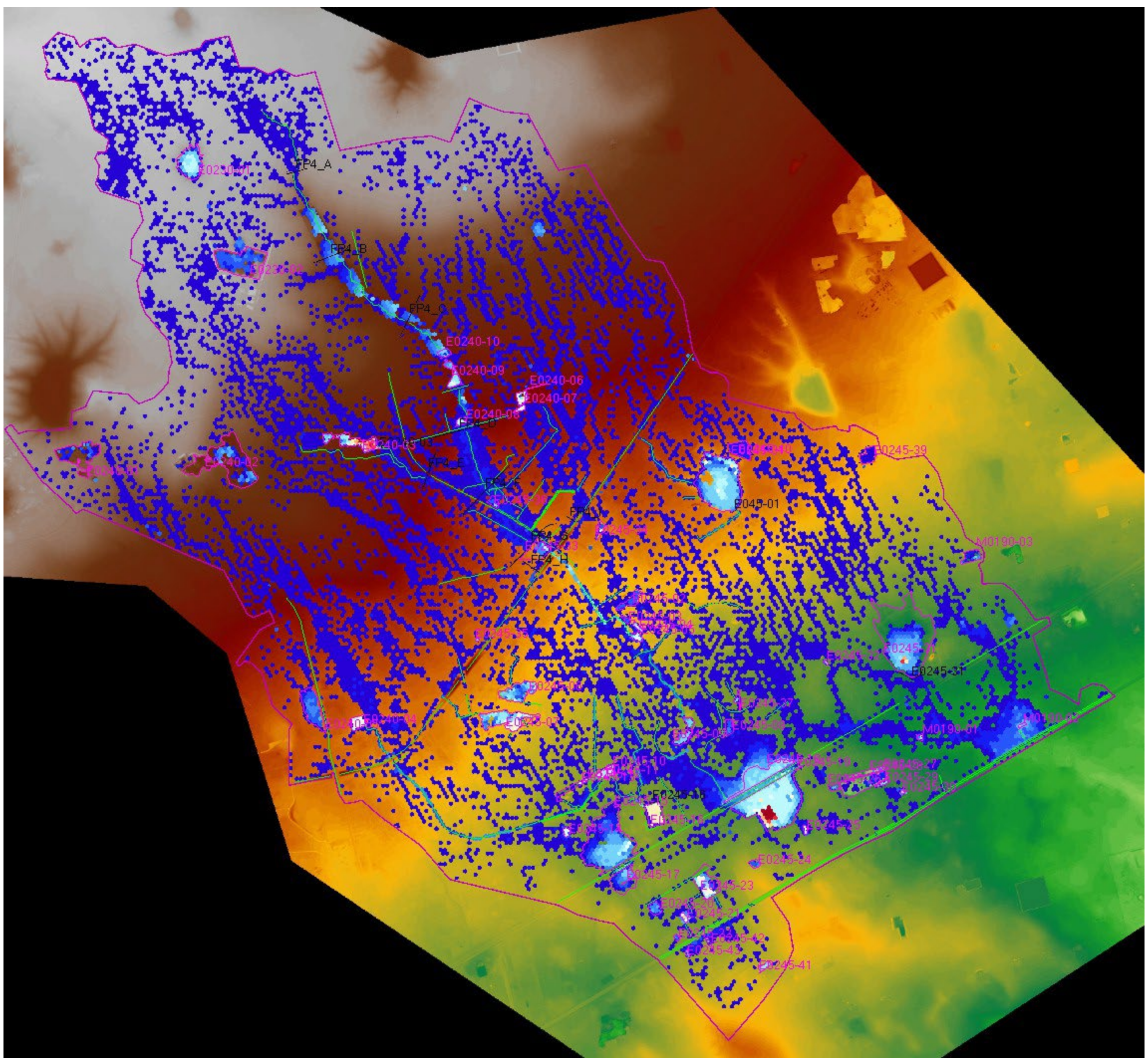


Figure 5-2. Faudree ICPR model maximum depth.

This ICPR model is in the same location as our calibration effort described in Section 3.9, which contains information about the model results for existing land use and a specific rainfall. For future land use and a 100-year rainfall, a great increase in inundations was noted.

The FIS contains only a few of the playas in the Faudree area and ignores flow paths in and out of them. No flow rates are listed in the FIS report. The FIS playa overflow extents are wider in many of the studied playas as compared to the playa overflow extents in the ICPR model. Since the FIS model ignores flow paths, the ICPR model results differ greatly and does not show many consistencies in comparison. The recently updated BLE map in this area is quite comparable to the Faudree ICPR model and also shows heavy inundation and playa overflow in the area.

5.3 MAF ICPR

The watershed that contributes to the Midland International Air & Space Port (MAF) is 24 square miles. No upstream areas contribute to the MAF model. In addition to analyzing the drainage at the airport and the surrounding playas, the MAF model contributes to both the Monahans West ICPR and West of Loop ICPR models.

5.3.1 Model Details

This region provided a unique challenge because the MAF is contained within the boundary. This facility has miles of storm drain systems. On the east side of the airfield, we found flow that splits east into the West of Loop model.

Breaklines were placed at all important locations, with special detail given to the airfield, which all drains to a culvert system under Business 20 and the existing railroad south of the highway. Then, a large (250-foot) breakpoint spacing was used to generate computational polygons. This allowed for highly detailed results where needed, and less detail in areas where relatively simple surface flow was taking place. This significantly reduced processing time.

We had significant survey data from a previous project for all storm sewer systems located in the airfield, meaning the taxiways and runways and the area in between. This allowed us to include a detailed storm system for this area. We did not have any survey data for storm systems located in the areas of the airport that included parking lots, the terminal, and other airport buildings. Because of this, we assumed overland flow for this area. Our previous project treated major airport buildings as extrusions, since they block significant overland flow. No other exclusions were created for this project.

There are frac ponds in the vicinity that do not capture water outside their perimeter, nor allow it to escape. These show up as tentative pond controls from our screening process, but they do not function as such. They were eliminated by placing an exclusion around the top of the berms.

Culverts located in the rest of the region were located using Google Earth and Connect Explorer satellite imagery, and the data gathered in the field by our surveying team. We input some proposed Interstate 20 structures and weir overflows from the TxDOT Segment 2 90% plans. I-20 is to be raised at the critical crossing point of the MAF outfall channel. The proposed roadway elevation was input to the model by means of a 2D weir. TxDOT plan information not input is in the FM 1788 area, where a complex series of basins, ditches, and culverts is planned. This area is not extremely significant in the context of the entire watershed.

Pond controls were created for all major playas in the MAF region. Many playas were included from a previous master drainage plan for this area and named in a similar fashion to allow for comparison if desired. A channel control was needed upstream of Business 20 for model stability.

All playas that were determined to overflow in the 100-year storm had weirs placed to measure the peak flow. Weirs were also placed along the main flow path in order to obtain hydrographs contributing to the Monahans West model.

5.3.2 Analysis of Model Results

MAF model max depth plot is shown below as Figure 5-3.

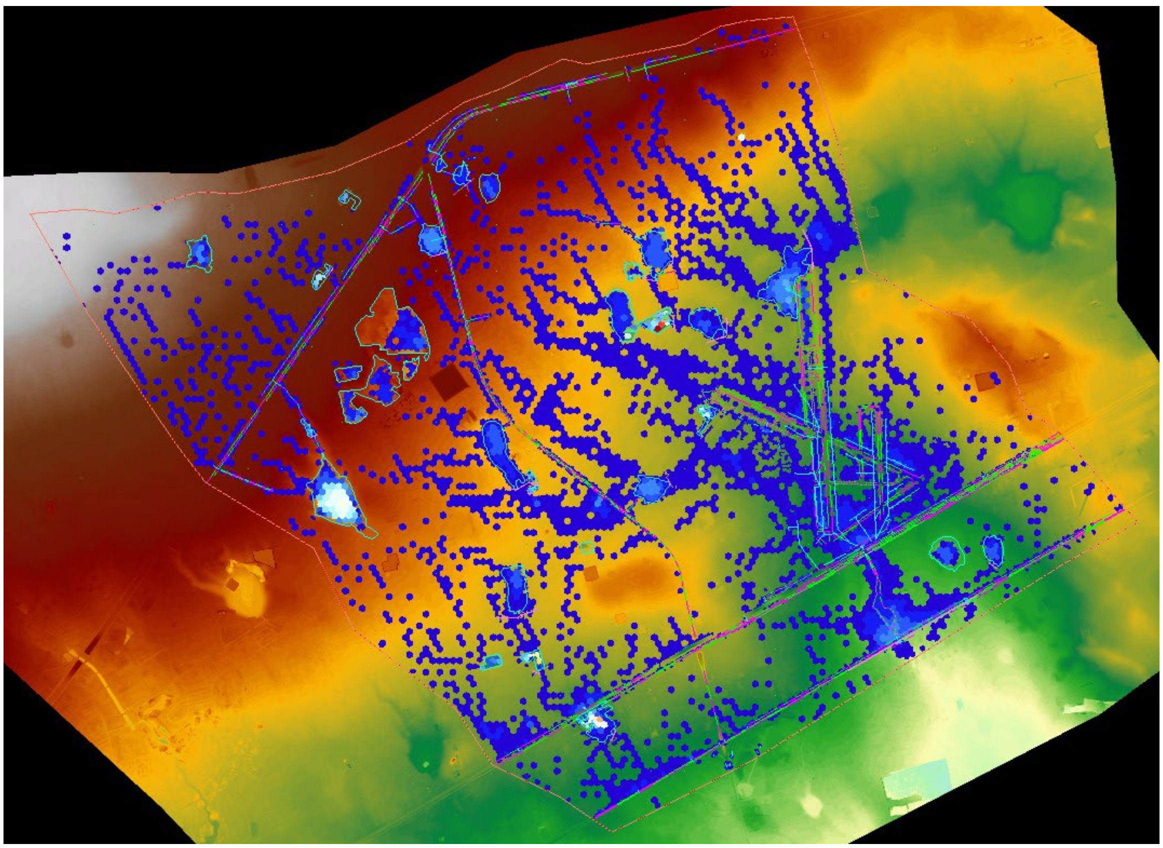


Figure 5-3. MAF ICPR model maximum depth.

This model provided important data when selecting an overall study methodology for rainfall input values and loss rates due to there being a previous study in place for the playas of this region. The process of refining the overall methodology using this model is described in Sections 3.1 through 3.3.

An important analysis point was the culvert located just south of the airfield under Business 20. A previous HEC-HMS model showed the flow arriving at this culvert in fully developed condition to be 4,650 cfs in the 100-year, 24-hour storm. Our 2D ICPR models shows the culvert max flow to be peaking at 930 cfs. At first this decrease may seem concerning, but after running multiple tests and examining the reasoning, we concluded that the ICPR output was the more accurate number. The most significant test we ran involved upsizing the culvert to a width that would provide no flow restriction. This was because we believed more flow was actually arriving at this analysis point, but ICPR accounts for the culvert constricting flow and creating ponding upstream. In this test, we saw the rate of water passing the enlarged culvert to be 3,150 cfs at the peak, tending to affirm our conjecture.

We concluded the rest of the difference between the ICPR and HEC-HMS models was due to the increased detail that we were able to model in 2D ICPR. The original 1D HEC-HMS model did not include any culverts or channels; it just modeled drainage subareas and their contributions to playas and how the playas overflowed. Adding culverts, storm drain systems, and increased overland flow detail resulted in two things: first, additional storage occurred by using the surface overland flow. Second, HEC-HMS represents all of the flow paths using a single time of concentration. With ICPR, the peak flow is reduced because ICPR is able to more accurately predict when different flows will arrive at the analysis point.

Hydrographs were collected for all points where flow crosses I-20 from this model into the Monahans West model. The I-20 culvert flow hydrographs were collected at ICPR time-stage nodes on the downstream ends, and the overflow was collected with a 2D weir. The model is slightly unstable at BI-20, so minor corrections to the hydrograph were made.

There are nine culverts under I-20 and one location where flow would overtop I-20 at the largest culvert downstream of the airport on the main flow path. We modeled the TxDOT proposed culvert at this location. Our model results suggested overflow across I-20, which contradicts the plans prepared for TxDOT.

Additionally, overflow from Playa M0180-05 2D weir was turned into a hydrograph which contributed to the West of Loop ICPR model.

Along the MAF Outfall, culvert flow at Business I-20 were collected as input for the HEC-RAS model for that flow path. Weir and culvert flows at I-20 were collected and added together for the HEC-RAS model.

5.4 West of Loop ICPR

The West of Loop model is roughly bound by State Highway 191 to the north, Midland International Air and Space Port on the West, Tradewinds Blvd to the east and extends south past I-20 by roughly 2,000 ft.

5.4.1 Model Details

West of Loop shares boundaries and overlaps with three models; MAF to the West, Upper South to the east, and Monahans Loop to the South. Due to the low topographical relief and nested playas in this area the model boundary overlap allowed for a more accurate depiction of if and how flow paths crossed apparent catchment boundaries.

Though current conditions show mostly open space, West of Loop was modeled as a mix of Urban Residential, Commercial, Industrial and Open Space. TxDOT plans along I-20 were incorporated to update the terrain for modeling using breaklines to modify the existing roadway terrain to design conditions and adding additional storm drain and culverts to promote conveyance to the south.

No other alterations were made to the model input data and model setup described in Sections 3.2 through 3.7.

Breakpoint spacing was set to 250 feet to create the general grid of the model. Breaklines with a spacing of 75-90 feet were used to refine the mesh in areas with more variability and we placed on street centerlines, roadside ditches, local catchment boundaries, stream centerlines, and any features that promote or inhibit conveyance/storage.

Storm drain and culverts were sparse as this model is mostly comprised of three large cascading playas. The data for the culverts were collected via survey, ground inspection, TxDOT design plans on I-20, and using Connect Explorer to fill any gaps. The culverts that are present are mostly along BI-20 and I-20 within the median ditches or providing cross drainage. We modeled fill in a flow path on Haliburton property located south of W. Industrial Avenue and west of SCR 1242 by adding a weir at the approximate elevation estimated by field photographs. This site also includes a culvert under a private railroad spur within the Haliburton property which allows flow to cross the spur. Data for this culvert was from Connect Explorer.

ICPR 2D pond control volumes were used to quicken runtimes and promote stability by using level pool hydraulics to which a depression playa or pond could determine stage storage characteristics based on the surface DEM.

2D weirs act as cross sections and were used at locations just downstream or upstream of overflowing pond controls to extract hydrographs of flow entering or leaving a pond control or model boundary.

The West of Loop basin is mostly self-contained. There is one inflow external hydrograph from MAF. The inflow external hydrograph from MAF flowed from west to east and was placed just upstream of the West of Loop playa M0180-13. Using the temporal rainfall this hydrograph peaks at hour 2.75 and has a max flowrate of 1,309 cfs.

5.4.2 Analysis of Model Results

The West of Loop max depth plot with a minimum threshold of 0.35 feet at the final timestep of 200 hours is shown below as Figure 5-4. The flood depths and pond control layers, plus additional information, were output to GIS for floodplain management purposes.

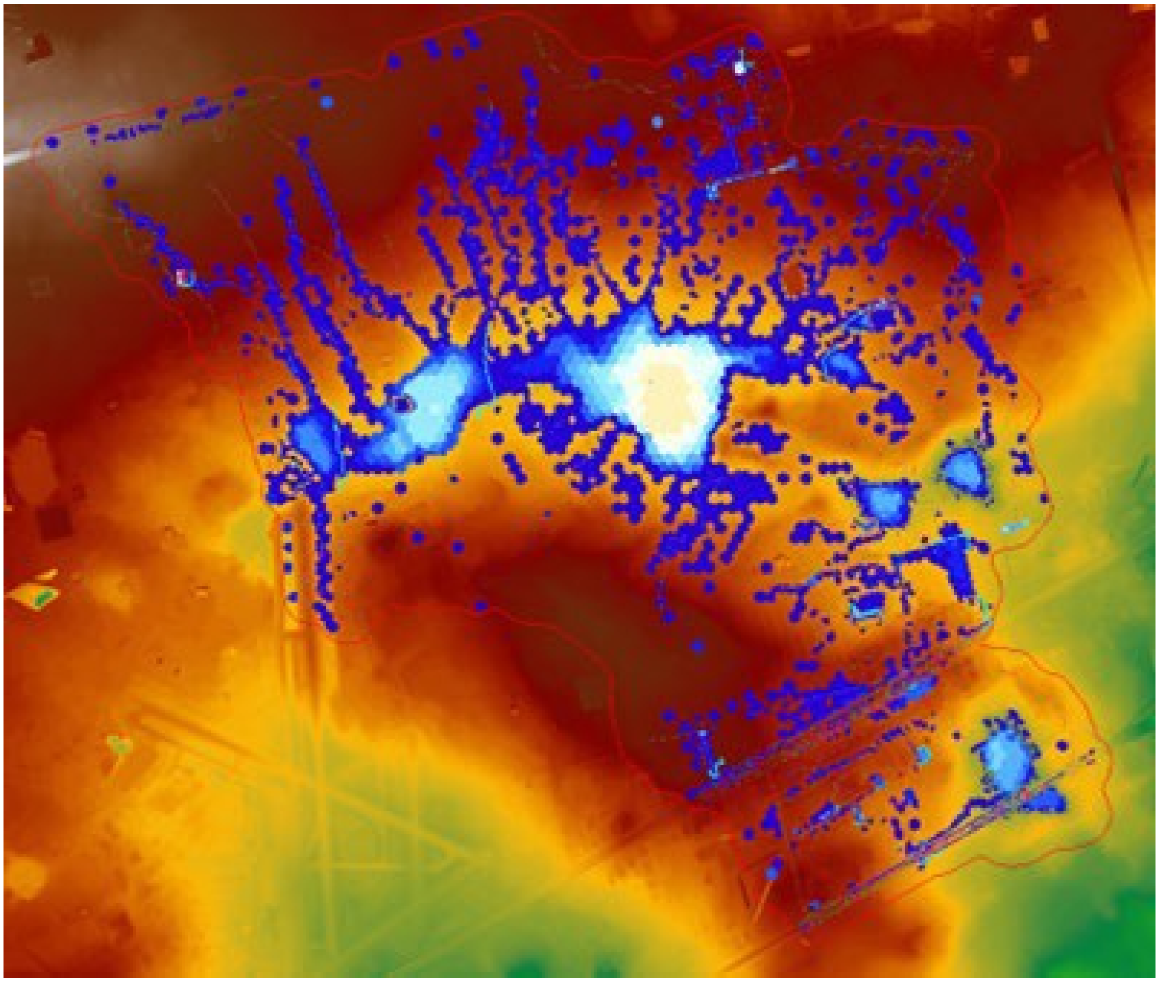


Figure 5-4. West of Loop ICPR model maximum depth.

Any playa that was determined to overflow in the 100-year storm event was measured using 2D weirs and a peak flow calculated. In this region, the Special Flood Hazard Areas are designated solely as Zone A, confined to the playa boundaries, with no riverine features identified at present.

There are approximately twenty playas, depressions, or ponds that were identified in this model with eleven that show significant overflow of 50 cfs or more. The seven most notable playas studied are M0180-13, M0180-14, and M0185-01 that cascade in that respective order, M0185-07 and M0185-08, that do not overflow, M0185-09, that overflows into the Upper South model, and M0185-16, M0185-17 that equalize under I-20.

After reviewing the final results, it was determined that there are five locations where 2D weirs were placed to measure outflow external hydrographs leaving the model. Three of these drain away from the remainder of our study area. The two remaining locations showed significant flows to the Upper South Model. The first weir named "Weir Overflow_M0185-09_E" shows approximately 155 cfs leaving playa M0185-09 at hour 2.25. The second weir named "Business 20 East" shows approximately 117 cfs leaving playa the frontage roadside ditch at hour 1.75.

5.5 Monahans West ICPR

Monahans West is the drainage area that accumulates on Monahans Draw from about five miles east of the Midland/Ector County line to the Monahans Loop model.

5.5.1 Model Details

The western (upstream limit of the model was selected as a location likely to have only one upstream input from Monahans Draw. As the Upstream model was developed, we realized water crossed into the Monahans West model in more than one location. Also contributing to this model are inflows from Faudree and MAF models. We set the north model boundary near I-20, since it acts somewhat as a dam and has flow across or under it at only specific locations. The model area is 55.56 square miles.

Model setup was as described in Section 3. This model has extensive oilfield development and industrial development chiefly along FM 1788. A major feature of the model area is a large playa (M0195-07) located about one mile south of I-20, into which the outflow from the MAF and Faudree area accumulate.

We had survey of one structure along Monahans Draw at FM 1788, but some additional structures along Monahans Draw were picked up with our data collection app. Monahans Draw has several private dams, one of which was in this model, that were inaccessible to us. We had to estimate the outfall structures using Connect Explorer. We also obtained measurements of culverts in the MAF Outfall path and along FM 1788 with the data collection app.

Breaklines were set up at the centerline and toes of slopes for Monahans Draw, plus along flow restrictions on the draw, and at the overflow locations of the various playas that overflow. The routes of the Faudree and MAF outfalls were given special attention with breaklines and pond controls, since we intended to model these routes with HEC-RAS. Breakpoint spacing for the model was 300 feet.

5.5.2 Analysis of Model Results

Monahans West model max depth plot is shown below as Figure 5-5. Additionally, we output the flood depths layer to GIS for floodplain management purposes.

A key finding was that the large playa that receives flow from MAF and Faudree models does not overflow. This is in contrast to the FEMA hydrology study for the current FIS. We determined that a large caliche pit on the Faudree Outfall route captures a large fraction of the runoff from that route, and recommend strongly that Midland County obtain it for retention after the pit is no longer active.

The input hydrograph from the Upstream model was doubled to account for possible model inaccuracy, regrading to remove surface ponding, plus future removal of flow restrictions that we could not model. We found that his peak diminished as the flow moved east in Monahans Draw. See Table 6-5 for the flows used in the HEC-RAS model. Flow decreases due to the dam on the draw, the storage in the channel, the sandy nature of the soils in the area, combined with limited inflow along this reach due to upstream capture in playas and caliche pits. The peak flow exiting this model and entering Monahans Middle is 4,214 cfs.

Monahans Draw has several locations where flow can leave the main channel and follow a parallel route back to the channel.

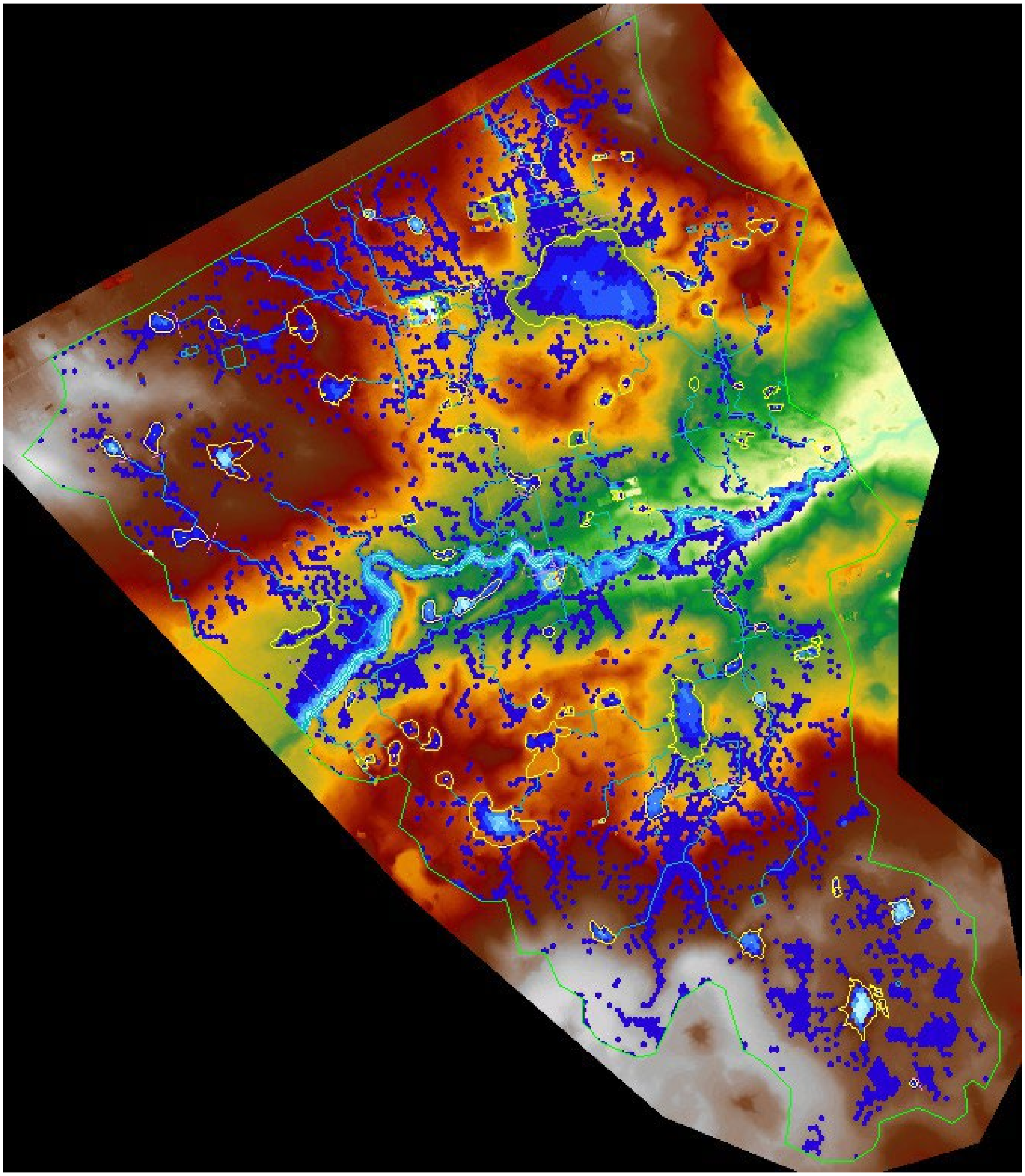


Figure 5-5. **Monahans West ICPR model maximum depth.**

5.6 Monahans Loop ICPR

The Monahans Loop ICPR model was given this name because it studies flow in Monahans Draw up to the eastern limit of the model follows the future loop road SCR 1232, which is under construction by Midland County, where it crosses Monahans Draw. It includes a watershed that is 31.5 square miles.

5.6.1 Model Details

Upstream of Monahans Loop is the Monahans West ICPR model, and it contributes to the Monahans Middle ICPR model. West of Loop ICPR model borders Monahans Loop to the north, but the flooding is contained within that boundary.

Other than the FEMA Flood Insurance Study, no pre-existing drainage studies exist for this area.

No alterations were made to the model input data and model setup described in Sections 3-2 through 3-7. The Monahans Loop region development pattern was anticipated to consist mostly of rural residential without water lots plus industrial development along major roadways. Because of this factor and the large study area, we selected a wide breakpoint spacing (250-foot) while inputting much more detail for overland flow via breaklines. All natural high points and channels were marked with a breakline, in addition to high levels of detail within the Draw, on roads, and at overflow paths for playas.

The only culvert on Monahans Draw is the crossing of SCR1232, which was modeled from the construction plans. There are no storm sewers or inlets in this area. The only external hydrograph needed was from the Monahans West model.

Pond controls were created for all major playas in the Monahans Loop region. Of interest is a large C-shaped playa shown on the FEMA maps, located about 1.5 miles south of I-20 and west of SCR 1232. This playa turns out to be comprised of several smaller ponding areas which needed separate pond controls.

All playas that were determined to max overflow in the 100-year storm had weirs placed to measure the peak flow.

5.6.2 Analysis of Model Results

Monahans Loop model max depth plot is shown below as Figure 5-6. These flood depths were output to GIS for floodplain management purposes.

Within this model area, only a few playas were shown to contribute to Monahans Draw. Due to this and the extremely sandy soils along the draw, flows in Monahans Draw diminished throughout this model. See Table 6-5 for the peak flows at various points on the draw.

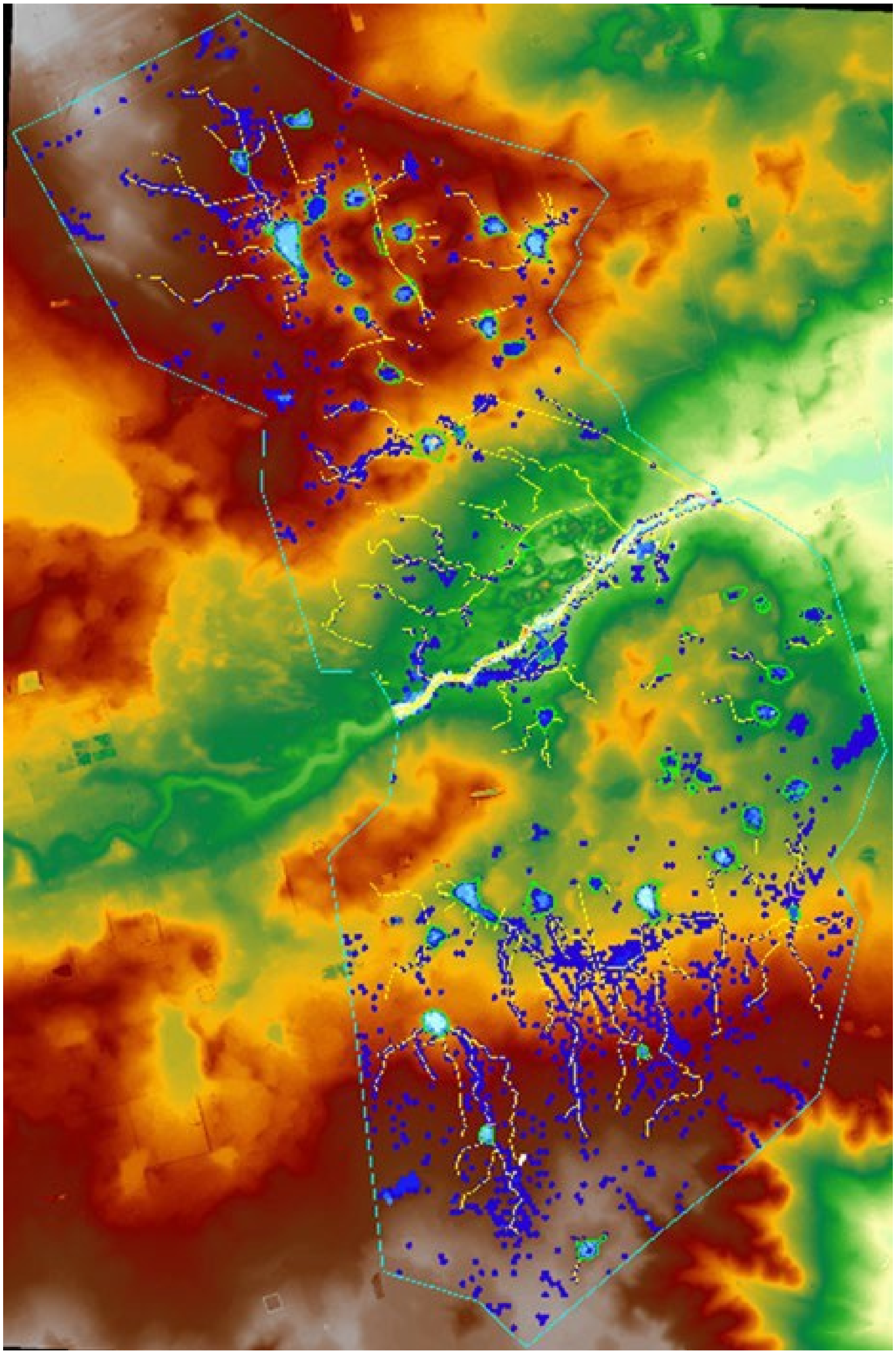


Figure 5-6. Monahans Loop ICPR model maximum depth.

The flow into the Monahans Loop model from the Monahans West model peaks twice: first local drainage peaks at hour 1.5 at 9 cfs, while the flow that was generated further upstream arrives at hour 27.5 at 4,214 cfs. This is a pattern that was repeated in the Monahans Loop model as well.

At the downstream end of the model, a weir was placed to indicate the location of SCR 1232 on the east limit of Monahans Loop model. A set of seven culverts under SCR 1232 allow flow eastward into the Monahans Middle model. The peak flow of culverts was at 32 hours with 3,721cfs, and the peak at a weir located just downstream is 3,591 cfs.

All playa tables and max depth results are located in the online GIS and the appendix.

5.7 Monahans Middle ICPR

The Monahans Middle ICPR model watershed is 39 square miles and contributes directly to Monahans Draw. The upstream limit is SCR 1232 and the Monahans Loop model. It flows downstream into the Salt Lake ICPR model. Additionally, Middle Playas ICPR model borders Monahans Middle to the north, but there is no overflow from the Middle Playas model.

5.7.1 Model Details

Other than the FEMA Flood Insurance Study, no pre-existing drainage studies exist for this area.

The Monahans Middle region development pattern was anticipated to consist mostly of 21-30% impervious residential lots plus industrial development along major roadways. Because of this factor and the large study area, we selected a wide breakpoint spacing (350-foot) while inputting much more detail for overland flow via breaklines. All natural high points and channels were marked with a breakline, in addition to high levels of detail within the draw, on roads, and at overflow paths for playas.

Little survey was obtained for this area, only for culverts crossing SCR 1210, Hwy 349, and FM 715. All other structures were located and sized using Google Earth and Connect Explorer satellite imagery. There are no storm sewers or inlets in this area. The Monahans Middle ICPR model does not cross the TxDOT I-20 highway. The upstream end of the model boundary is just east of the proposed SCR 1232 and the external hydrograph from the Monahans Loop model consists of the flow through the culvert. No flow overtops the road.

Pond controls were created for all major playas in the Monahans Middle region. All playas that were determined to overflow in the 100-year storm had weirs placed to measure the peak flow. Additional weirs were placed across the draw at the downstream end and other locations useful for preparing the HEC-RAS models.

5.7.2 Analysis of Model Results

Monahans Middle model max depth plot is shown below as Figure 5-7.

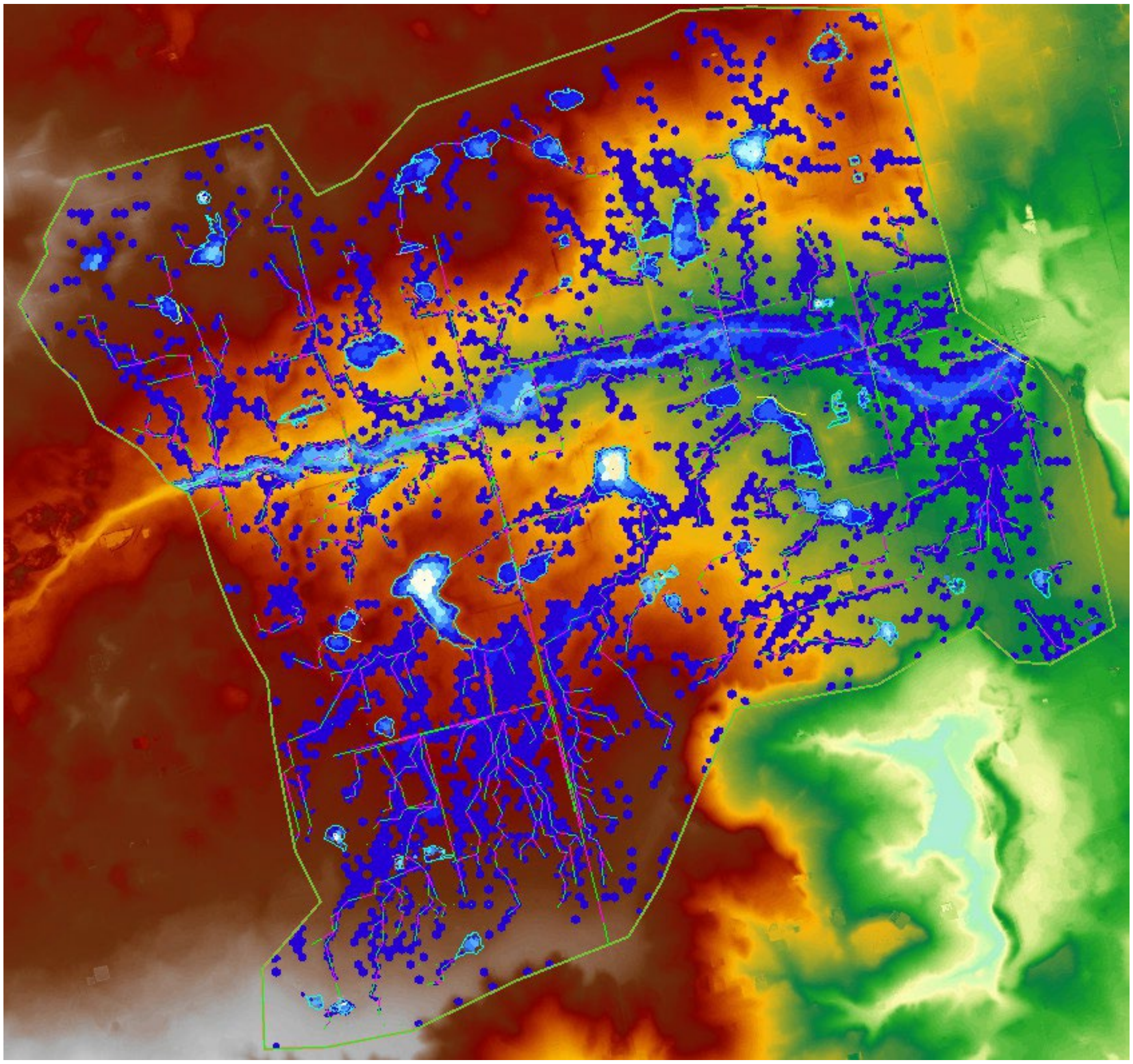


Figure 5-7. Monahans Middle ICPR model maximum depth.

The flow into the Monahans Middle model from the Monahans Loop model peaks twice: first local drainage peaks at hour 1.25 at 56 cfs, while the flow that is generated further upstream arrives at hour 32 at 3,591 cfs.

This is a pattern that is repeated in the Monahans Middle model as well. At the downstream end of the model, three weirs were placed to measure flow into the Salt Lake model. The first weir, in the main area of the draw, has a peak flow of 2,902 cfs. Two local flow-only weirs transfer small peaks into the Salt Lake model. The Monahans Draw flow of 2,902 cfs is lower than the peak flow coming into the model. This is due to a significant widening of the draw and undersized culverts, which creates significant storage in the draw. Table 6-5 shows flows throughout the Monahans Draw length.

The 100-year flood at the upstream end of the model is roughly 600-feet wide and by the downstream end it widens to about 1,500 feet. The culverts at the intersection of ECR 160 and FM 715 carry a combined max of roughly 300 cfs, meaning ECR 160 acts as a dam.

There is a FEMA Flood Insurance Study model of this portion of Monahans Draw. It is based on a 100-year flow rate of 21,663 CFS just downstream of HWY 349. As seen in the rest of Monahans Draw, the peak flows generated in ICPR are significantly lower than the FEMA Flood Insurance Study model. At the same location, the ICPR model yielded a peak flow of 3480 CFS.

5.8 Salt Lake ICPR

The Salt Lake ICPR model is so named because it studies the reach of Monahans Draw which overflows into a feature known as Consavvy Lake, which appears white in some aerial photos.

5.8.1 Model Details

It includes a watershed that is 20.12 square miles and contributes to the Lower Monahans Draw model to the east. The FEMA Flood Insurance Study eastern detailed limit extends slightly (and inaccurately) into this model area. In addition to Consavvy Lake, there is a natural ridge with a check-mark shape that impounds flow on Monahans Draw until overflow to the east can occur. These features are visible on Figure 5-8.

The Middle Monahans model contributes a hydrograph to the Salt Lake model on its western boundary, located just south of the location where FM 1213 makes a 90-degree bend. The Middle Playas model borders the Salt Lake model to the north but does not contribute to its watershed. The eastern boundary is a location where flow is restricted by a private road and contributes to Lower Monahans ICPR model.

Land use in this area varies. The northern portion of the Monahans Draw model area is largely Industrial, rural residential without water, and the southern portion is a mix of rural residential without water, woody wetlands, and industrial areas.

The only culvert crossing in this model is located at ECR 160. It was identified using Connect Explorer and Google Earth imagery and placed accordingly based on the terrain identifiers.

This model contains a chain of playas beginning north at north of drainage area and overflowing south perpendicular to and contributing to Monahans Draw. Pond controls were created to analyze the flow paths and flow quantity that overtops each pond and contributes to runoff and ponding.

Breaklines were drawn at the crown of all major roadways and in low lying areas such as ditches and natural flowpaths. Within the Monahans Draw ponding area, a number of breaklines helped to delineate the various paths that water takes during the simulation, as it overflows first one direction and then others.

2D weirs were placed at the overflows of all playas that were determined to overflow in the future 100-year storm to measure the peak flow. 2D weirs were placed to create external hydrographs showing the flow leaving Salt Lake and entering the Lower Monahans model to the east.

5.8.2 Analysis of Model Results

The flow into the Monahans Salt Lake model from the Monahans Middle Playas has a first peak of local drainage at hour 1.5 and 41 cfs, while the flow that was generated further upstream arrives at hour 48 at 2,902 cfs.

Weir 3, shown on Figure 5-8, was placed to show flows that were generated from upstream of the Monahans Middle drainage area. This image was taken at an early point in the simulation and shows local flows plus the initial overflow of the playa on the main Monahans Draw at ECR 160, eastward.

Weir 2 was placed east of Salt Lake ponding areas at the bend of Monahans Draw where the large natural check mark ridge terminates, as shown on Figure 5-9. At this location, the local drainage peaks at hour 60.50 at 193 cfs, while the flow that was generated further upstream arrives at hour 86.25 at 573 cfs. The figure also shows the maximum ponding depths at a time in the simulation when flow of Monahans Draw has filled Consavvy Lake and most of the area behind the check mark ridge. Once Consavvy Lake fills, flows start to push eastward to Weir 2 location and continue down the draw.

Weir 1 was placed at a private road downstream of the ponding area where all flow in the model is restricted to one location. This location marks the end of the Salt Lake Model and the inflow into Lower Monahans Draw. The plot on Figure 5-10 is from the end of the simulation and shows the cumulative maximum ponding depth at all points in time at each computational mesh element. There is only one peak that leaves the Salt Lake ponding area, at hour 101.0 at 531 cfs.

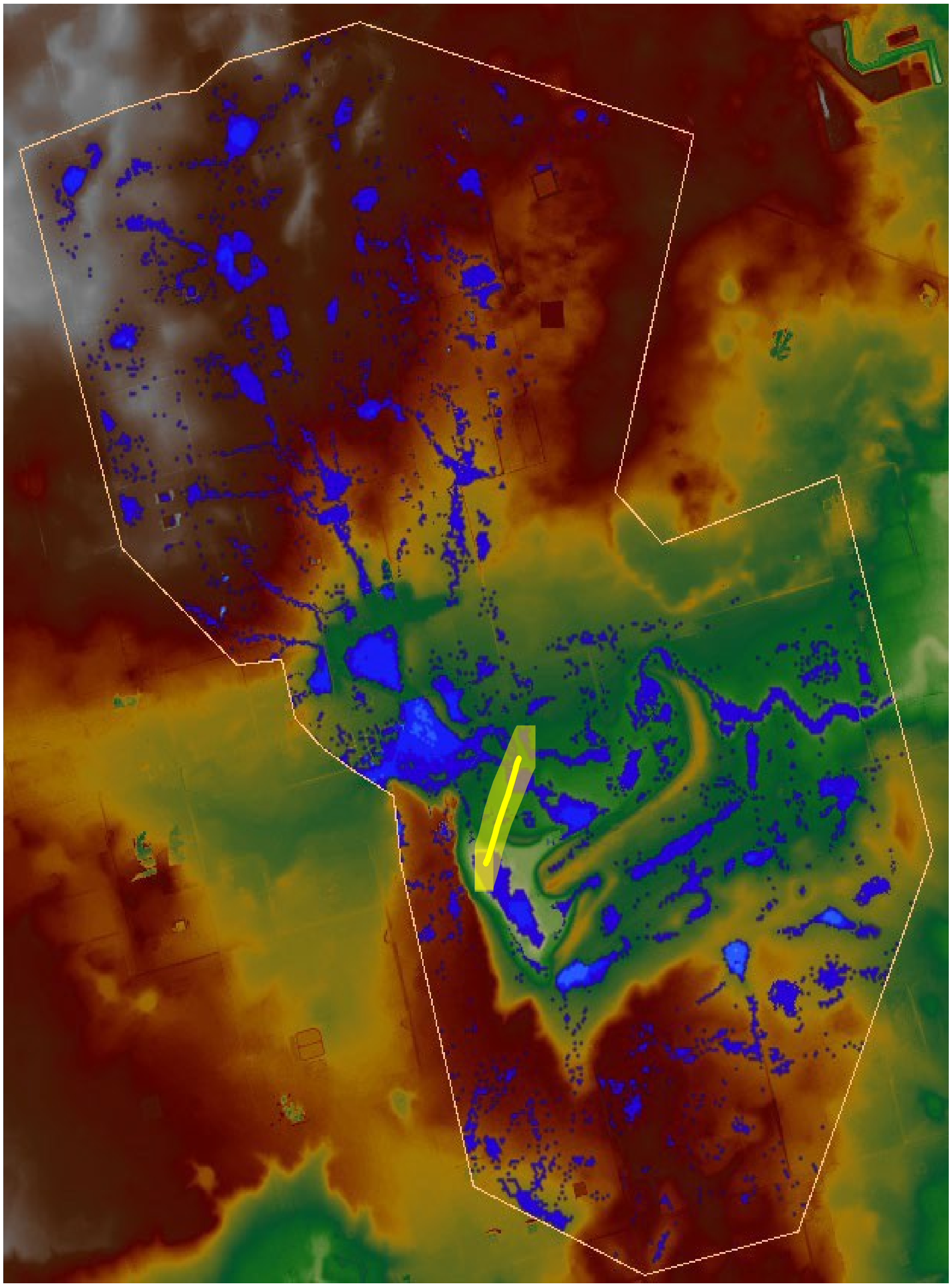


Figure 5-8. Salt Lake ICPR model depth at weir 3 beginning of overflow.

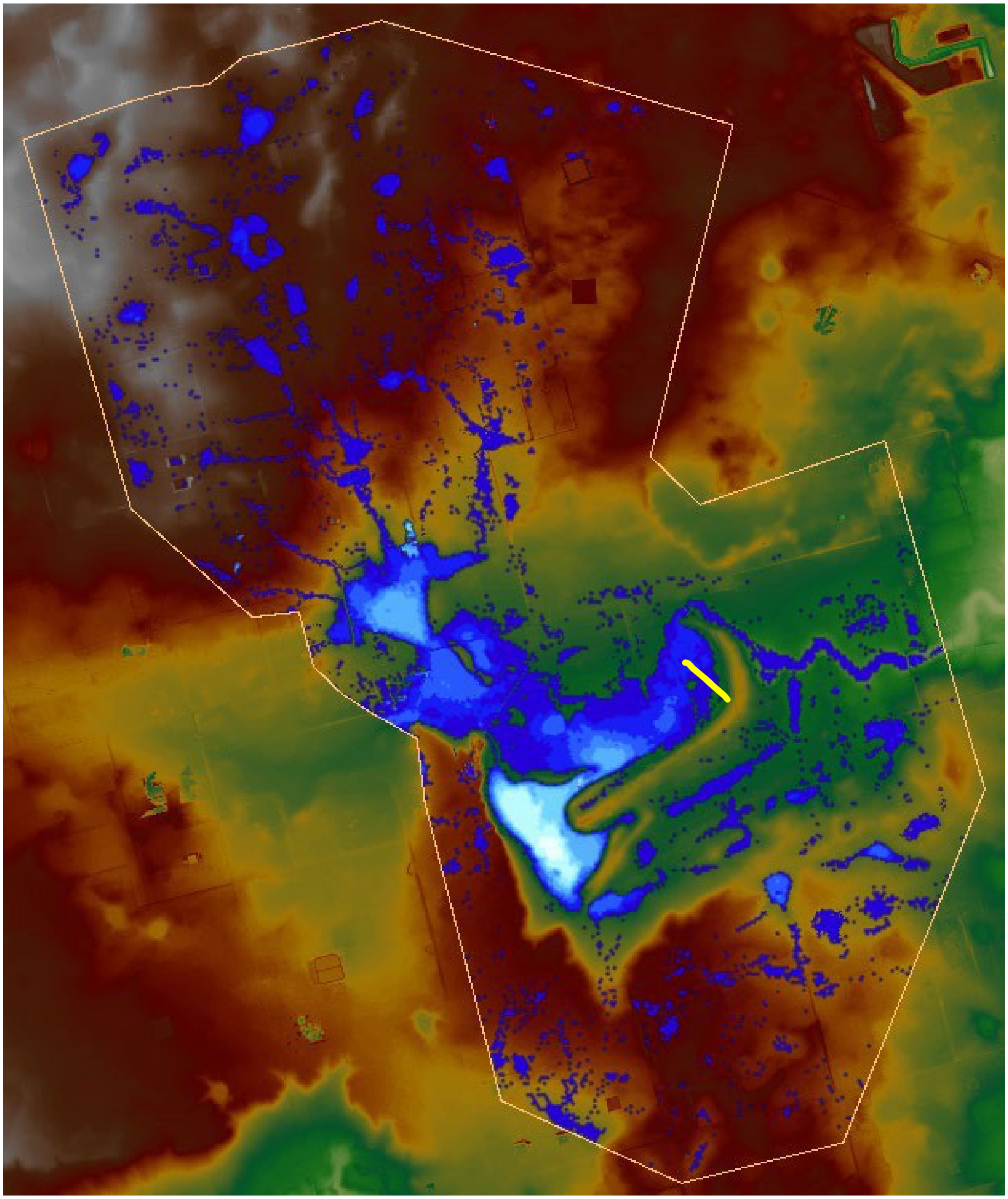


Figure 5-9. Salt Lake ICPR model maximum depth at weir 2 ponding area overflow.

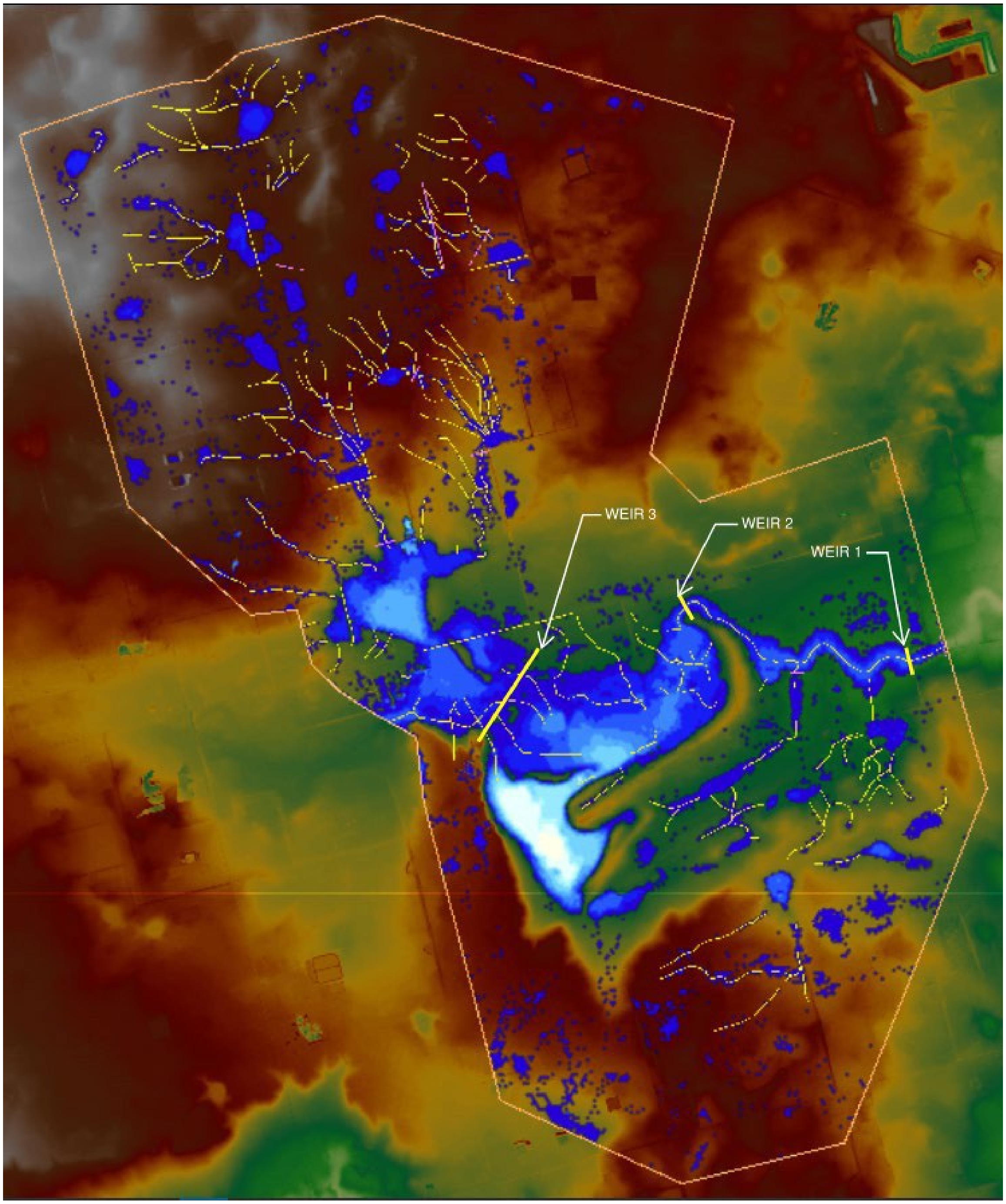


Figure 5-10. Salt Lake ICPR model maximum depth at final simulation time.

5.9 Lower Monahans ICPR

Lower Monahans model is the most downstream portion of Monahans Draw, extending to the confluence with Midland Draw.

5.9.1 Model Details

The Lower Monahans ICPR model watershed is 16 square miles. Upstream of Lower Monahans is the Salt Lake ICPR model, and it flows downstream into Midland Draw. This model concludes Monahans Draw at the project boundary limits. This model also goes outside the Monahans Draw watershed limits in order to include some playas within one-half mile of proposed outer loop roadway SCR 1232.

There is one external hydrograph contributing to Lower Monahans Draw from the Salt Lake model, located closes to the end downstream of its model boundary limit across Monahans Draw. This model is approximately 4.4 miles from beginning to end.

The Lower Monahans region is mostly rural residential without water and a portion of industrial areas. Some of the soils in this watershed are extremely sandy. Even with a developed condition, some locations generate no runoff with the 100-year rainfall used in this model.

We selected a wide breakpoint spacing (350-foot). All natural high points and channels were marked with a breakline, in addition to high levels of detail within the draw, on roads, and at overflow paths for playas.

The only survey for this model was the culvert crossing at Hwy 158. All other structures were located using Google Earth and Connect Explorer satellite imagery and site visits. Culverts upstream and downstream inverts were obtained from the surface. There are no storm sewers or inlets in this area.

Pond controls were created for all major playas in the Lower Monahans region. All playas that were determined to overflow in the 100-year storm had weirs placed to measure the peak flow. Additional 2D weirs were placed to identify flows for the HEC-RAS model.

5.9.2 Analysis of Model Results

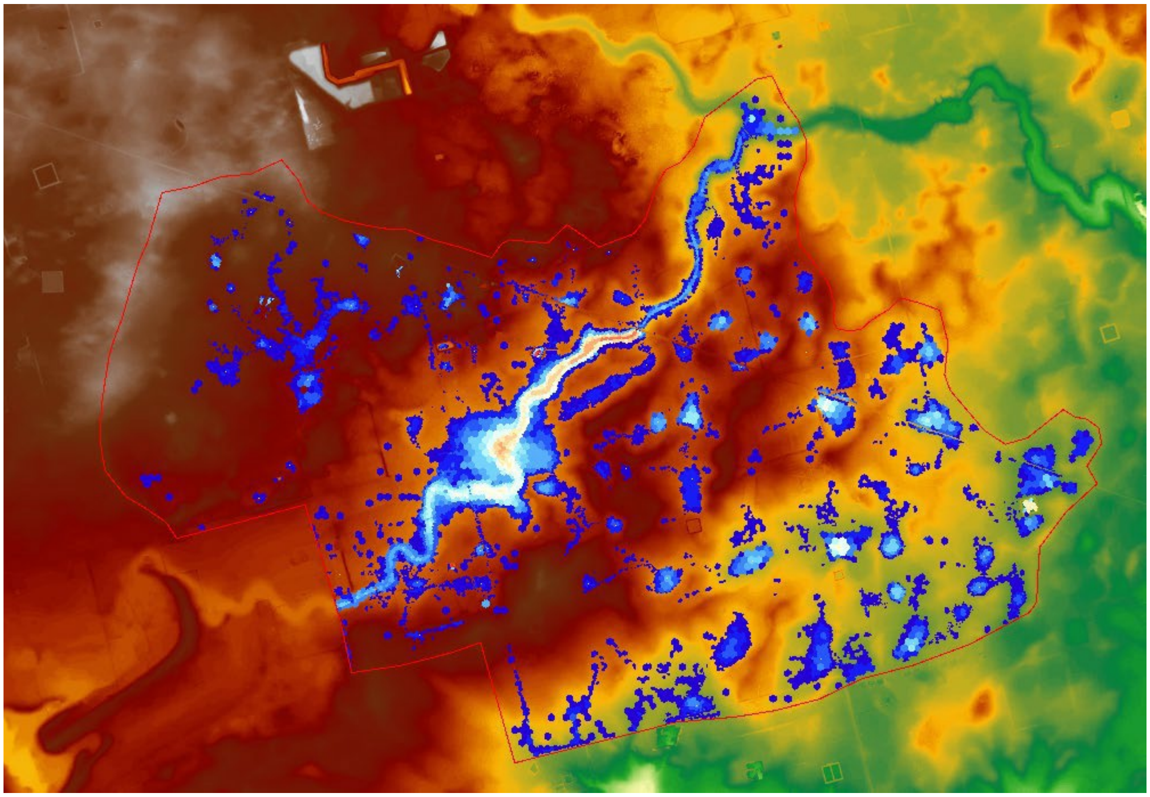


Figure 5-11. Lower Monahans ICPR model maximum depth.

Peak flow from the Salt Lake model into this one is 533 cfs. Hwy 158 functions as a dam in this model, creating a backwater of deeper ponding. Hwy 158 has a total flow of 328 cfs: 161 cfs overflow and 167 cfs through culverts. Finally, Monahans Draw carries a total flow of 286 cfs to Midland Draw at the confluence.

There is no detailed model of Monahans Draw in the Flood Insurance Study to compare these results to.

5.10 Middle Playas ICPR

The Middle Playas ICPR model includes a watershed that is 31.5 square miles which does not flow out to any other model. Middle Playas model is adjacent to Lower South and Salt Lake ICPR models, but there are no overflows from those models into Middle Playas.

5.10.1 Model Details

No alterations were made to the model input data and model setup described in Sections 3.2 through 3.7. The Middle Playas area was anticipated to contain mostly developed conditions of rural residential lots without water plus industrial development.

We selected a breakpoint spacing of 250-feet. All natural high points and channels were marked with a breakline, in addition to high levels of detail on roads and at overflow paths for playas.

The only survey obtained for this area was for culverts on Hwy 349. All structures were located using Google Earth and Connect Explorer satellite imagery. These same programs were used to gather data, such as culvert size, number of boxes, culvert material, etc., while culvert upstream and downstream inverts were obtained from the surface. There are no storm sewers or inlets in this area.

Pond controls were created for all major playas in the Middle Playas model.

5.10.2 Analysis of Model Results

Middle Playas model max depth plot is shown below as Figure 5.10. The appendix contains the same results at a closer zoom level. Additionally, we output the flood depths layer to GIS for floodplain management purposes.

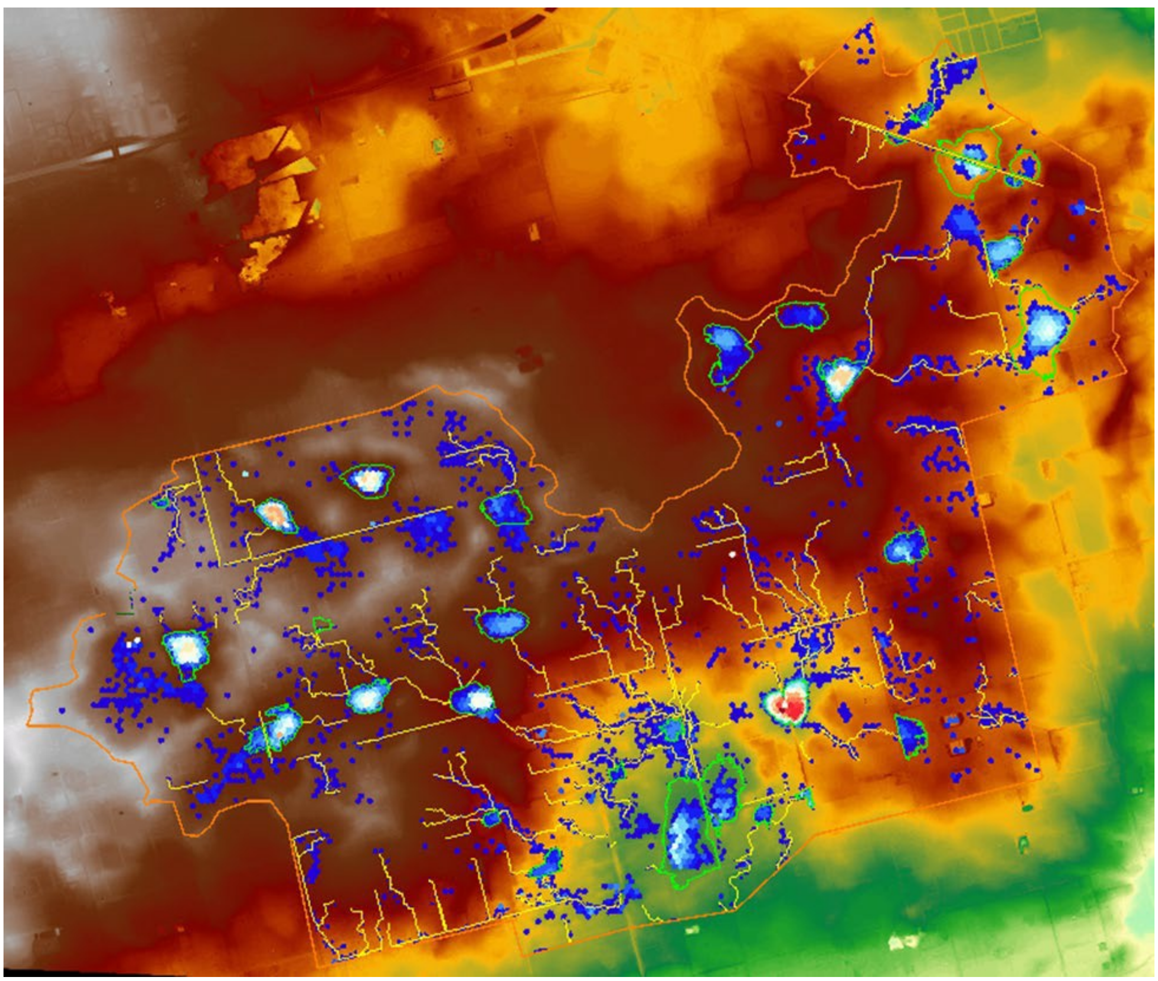


Figure 5-12. Middle Playas ICPR model maximum depth.

No flow from this model leaves the model boundaries, although some playas overflow internally, any overflow is captured by another playa. All playas that were determined to overflow had weirs placed to measure the peak flow.

Other than the FEMA Flood Insurance Study, no pre-existing drainage studies are located for this area. Comparison to the FEMA study shows most of the playas to have smaller ponding limits. However, the FIS study misses some playas that were located in this model.

5.11 Upper South ICPR

The Upper South ICPR model includes a watershed that is 19.75 square miles and contributes directly to the Lower South Draw model. The modeled area includes a large portion within Midland city limits and extends west past Loop 250 and east to Hwy 349.

5.11.1 Model Details

The West of Loop model has two small contributing overflow hydrographs to the Upper South model on its western boundary. The Upper South model borders the Lower South model on the east and contributes to its watershed in two locations.

Land use in this area varies. The southern portion of the model area is largely Industrial and Rural Residential without water and the northern portion incorporation the City of Midland is a mix of Urban Residential and Commercial areas.

Significant revisions to the base LiDAR data were performed in ArcMap, as follows:

- Incorporation of as-constructed topo survey provided by Endeavor Energy, showing their fill pads, roadways and partial channel improvements west of Midkiff and south of I-20. These improvements are further described in Section 8.1.

- TxDOT plans dated 5/4/2020, showing a new I-20/Midkiff interchange plus other I-20 improvements in CSJ 0005-14-067 were incorporated. We did not have a surface or survey, so we used plans to modify our I-20 and Midkiff Road area LiDAR manually. These plans indicate lowering of Midkiff in the interchange and raising I-20 to add an overpass much above the original grades.

Most of the culverts in this model were surveyed for this project. However, I-20 culverts were under construction during the modeling, so the plans mentioned were used to replace survey data for culverts along 3.5 miles of the interstate. Planned storm drain systems from these plans were also added. A few unsurveyed pipes and culverts were identified using Connect Explorer and Google Earth imagery and placed accordingly based on the terrain identifiers.

In models further west, we had more complete plans for additional TxDOT improvements to I-20. Although 60% plans were available for this model, we did not find it possible to incorporate them into the South Draw models due to their great complexity and incomplete status.

This model contains a chain of playas beginning north of BI-20 and overflowing south perpendicular to I-20 then east contributing to South Draw. Pond controls were created to analyze the flow paths and flow quantity that overtops each pond and contributes to runoff and ponding in South Draw and the adjacent areas. Breaklines were drawn at the crown of all major roadways and in low lying areas such as ditches and natural flowpaths.

2D weirs were placed to create external hydrographs showing the flow leaving Upper South and entering the Lower South Model from its west. The main channel flow into Lower South was a combination of culvert and weir overflow across Hwy 349. An additional flow location is just east of Hwy 349, where flow trapped north of I-20 passes under I-20, overflow Hwy 349, and enters a drainage channel. Additional 2D weirs were used to evaluate flows in South Draw for use in the HEC-RAS models for it and a large tributary west of the main draw.

5.11.2 Analysis of Model Results

The Upper South model max depth is plotted below.

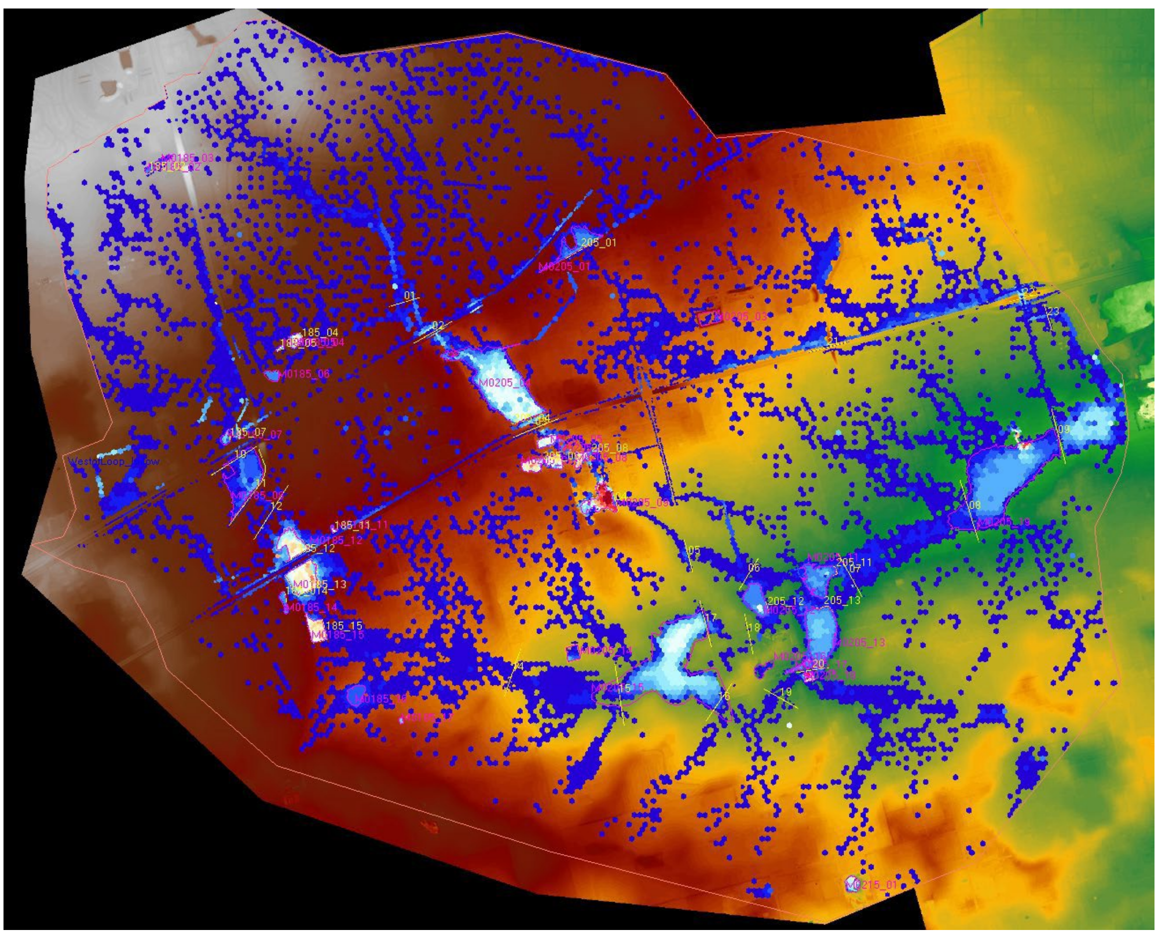


Figure 5-13. Monahans Upper South ICPR model maximum depth.

Two external hydrographs were created for flow into the Lower South model. One hydrograph provides the overflow from Playa M0205-19 into the Lower South model peaking at hour 4 with 321 cfs of runoff. The second hydrograph includes culvert flow under I-20 and peaks at hour 6 providing 370 cfs of runoff into the Lower South model.

An FIS report for several flow paths in the model area, including South Draw is available. The FIS flow data for this area differed greatly from the flow results from the Upper South model. The ICPR model resulted in much lower flows consistently along the South Draw. While the cross-section locations in the FIS and ICPR model differ slightly, they are close enough in proximity that the measurements taken should be comparable. Due to the fact that the ICPR model results are more realistic and therefore reliable, we choose to use the Upper South ICPR flow results in the HEC RAS Upper South Draw simulation. The table below compares flow results from the Upper South model in comparison to flows found in the FIS.

Table 5-2. Upper South Draw flow comparison.

XS Location	Upper South Model Flow (cfs)	FIS Flow (cfs)
Upstream of BI-20 vicinity	1,205	3,260
Downstream of Hwy 349 vicinity	690	4,585

5.12 Lower South ICPR

The Lower South ICPR model encompasses a 13 square mile watershed on the south side of the City of Midland that contributes to South Draw. Upstream of this model is the Upper South ICPR model. In this region, South Draw ends at Midland Draw, which is not modeled in this project.

5.12.1 Model Details

South Draw is actually a series of playas that overflow into one another, terminating in a huge playa that crosses SCR 1180. The FIS study indicates this large playa overflows and the remaining flow is picked up by a man-made channel system installed by TxDOT to drain Interstate 20. Our study divided the South Draw watershed at Hwy 349.

No alterations were made to the model input data described in Sections 3.2 through 3.6. Input hydrographs from the Upper South model were applied at two locations: on South Draw at Hwy 349 and on a flow path just east of Hwy 349 that captures overflow down Hwy 349 from north of I-20.

One surface alteration was required. Just west of SCR 1180, a series of caliche pits exists. The furthest south pit, named M0210-22, was expanded after the topographic data was collected. This is particularly important because the pit is located at the bottom of South Draw. We did not have a survey of the new pit but could see the limits on aerial photos. We assumed the bottom was approximately the same as the adjacent original pit. The surface was edited to have the approximate storage added. Midland County purchased this pit property after the study models were completed.

In models further west, we had more complete plans for additional TxDOT improvements to I-20. Although 60% plans were available for this model, we did not find it possible to incorporate them into the South Draw models due to their great complexity and incomplete status.

The Lower South watershed is close to fully developed at the time of this report and includes very dense residential and commercial spaces, as well as more sparsely filled industrial and large lot residential.

In highly urbanized areas, it is not detailed enough to simply place a breakpoint grid. Instead, we placed breaklines at most major roads that carry water, in addition to the man-made section of South Draw. We then selected a medium sized breakpoint spacing (250-foot) to surround this system of breaklines.

Just south of South Draw, in between Midland Draw and SCR 1150, there is a large industrial site that consists of two frac ponds. The entire site is surrounded by a berm that is as high as 5 feet. Because this area blocks overland flow and no rain that falls within its boundary escapes, it was modeled as an exclusion.

We had gathered survey data for all major drainage structures within this study boundary. Some smaller structures were added into ICPR using data gathered through Google Earth and Connect Explorer. Finally, proposed structures crossing I-20 were modeled according to the TxDOT plans.

5.12.2 Analysis of Model Results

The Lower South model max depth plot is shown below as Figure 5.12.

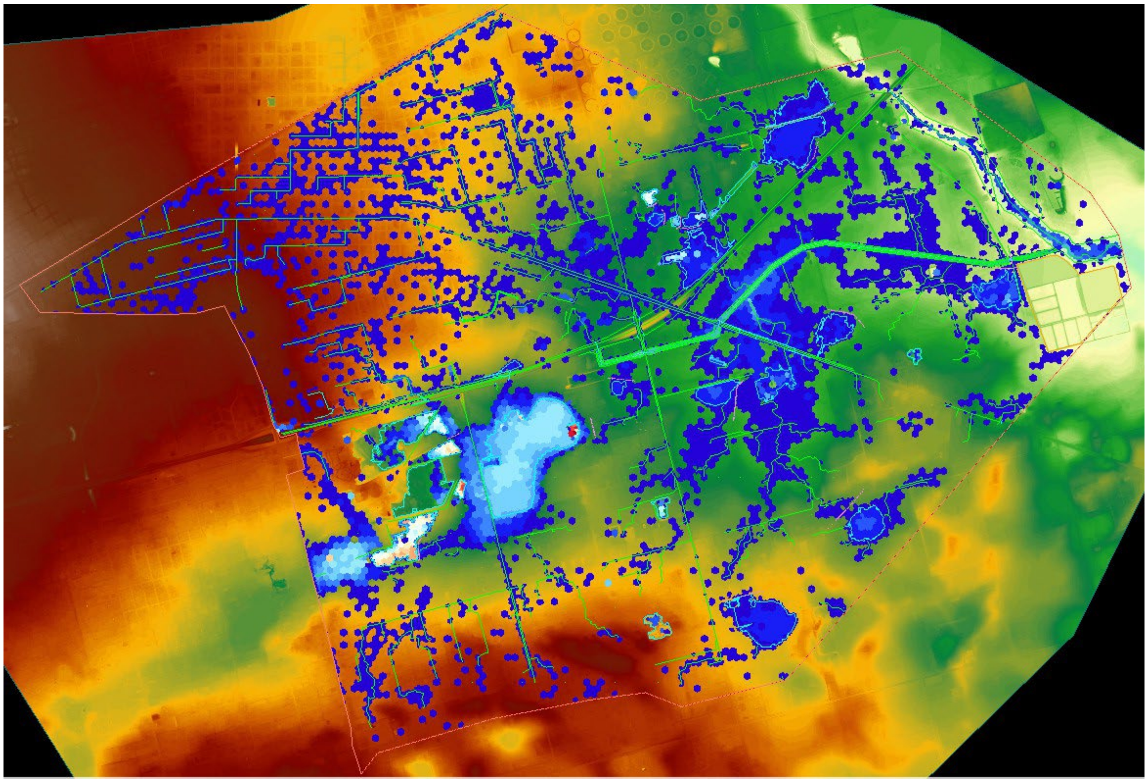


Figure 5-14. Lower South ICPR model maximum depth.

A major focal point of our analysis was the large playa that is on either side of CR 1180, to determine if it overflows in the 100-year storm or not. As can be seen in Figure 5-12, our methodology shows it will not, in contrast to the FIS models that show overflow in all frequencies. This creates a break in the natural flow of South Draw, but it can be seen picking up again in the man-made channel that starts just west of I-20's intersection with Fairgrounds Rd.

Flow rates in the FIS models for South Draw include 4,585 CFS just downstream of Hwy 349 and 3,455 CFS approximately 2,350 ft. downstream of HWY 158. The ICPR results at similar locations are 680 CFS and 1,170 CFS respectively. The decrease at HWY 349 is likely due to the culvert under the highway being undersized. This means that flow crosses more slowly, lowering the peak flow. The peak flow downstream of HWY 158 is likely due to the lack of overflow discussed in the previous project. Additionally, the 2D ICPR models have consistently produced lower peak flows, and the reasons are discussed previously.

All playas that were determined to overflow in the 100-year storm had weirs placed to measure the peak flow. Flow measurement weirs across the channel were added to provide hydrograph information for the HEC-RAS models developed for South Draw.

6 Hydraulic Models Details and Results

This section contains detailed descriptions of the HEC-RAS v6.2 models developed for Monahans Draw, South Draw and four newly studied flow paths. See Section 4, Hydraulic Methodology for a general description of the modeling objectives and standards. Scope for the project mentions four flow paths that were not studied by FEMA. We named these paths South Draw Tributary (6.1.3), Upper Faudree Flow Path (6.2.1), Faudree Outfall Flow Path (6.2.2), and Midland Airport Outfall (6.3).

6.1 South Draw HEC-RAS

The South Draw FIS models were divided into Lower South, which comprised a man-made channel intended to serve as an outfall for drainage structures under I-20, and Upper South, which covers a series of playas that overflow connected by flow paths, and which acts as a tributary to Lower South model, entering that ditch just downstream of the upstream end of Lower South.

Our ICPR analysis proved that the most downstream playa on Upper South Draw does not actually overflow in the studied rain event. Therefore, the Upper South and Lower South HEC-RAS models function independently.

6.1.1 Lower South Draw

Lower South Draw starts at cross section 1477 (at existing culvert I-20 crossing 0.29 miles west of S. Fairgrounds Rd.) and ends at cross section 10 (at the confluence of Midland Draw). This model is analyzed using HEC-RAS 1D. It was separated from Upper South Draw because there is not an overflow in the big playa that forms the downstream end of the Upper South Draw model. 1D analysis is effective for this flow path because there is a well-defined channel.

The terrain surface used for this analysis was obtained from TNRIS LiDAR 2018. The LiDAR differs from the cross-section geometry data in the FIS, and development has changed Manning's n values.

Parkhill started with the FIS model for Lower South Draw, including an Autocad drawing showing the locations of all cross sections. Six cross sections shown on the FIRM (XS A – XS F) are noted on Figure 6-1. All FIS cross sections were realigned to better fit the more detailed LiDAR data and to take development since the FIRM date into account. Additional cross sections were also added. All cross sections from the model were extracted from a 2018 LiDAR DEM. There were no modifications to the terrain.

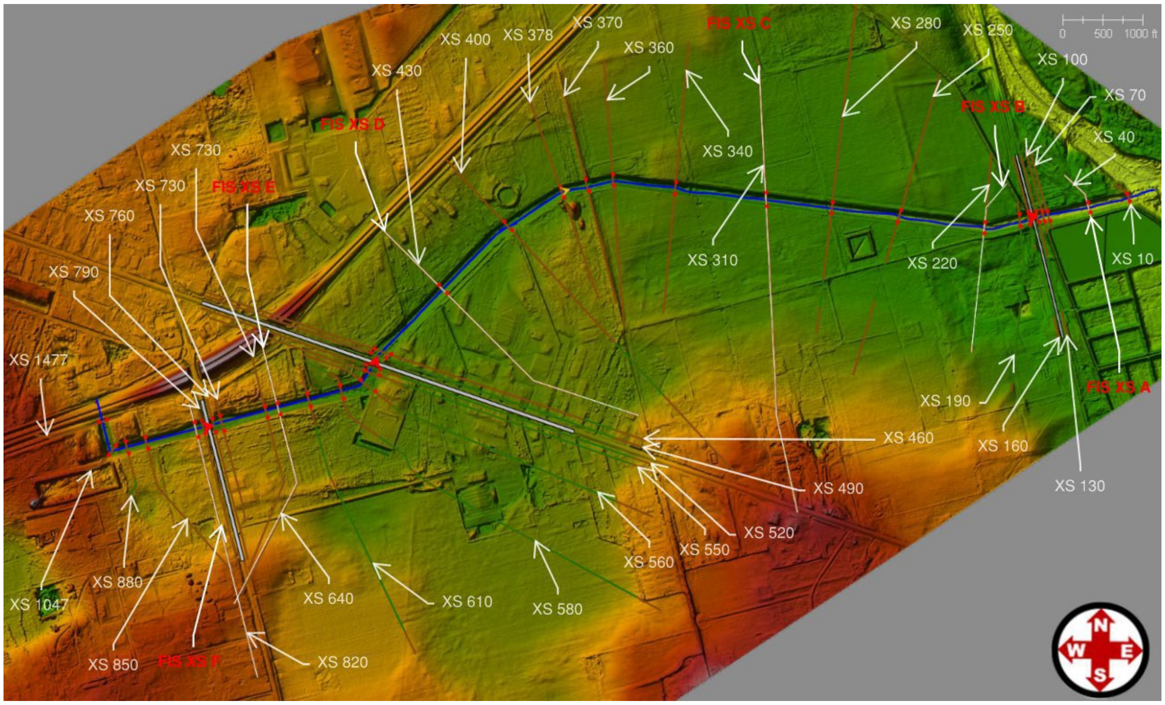


Figure 6-1. Lower South Draw cross sections.

Steady state 1d modeling used the peak flows from the ICPR model hydrographs, applied at the cross sections in Table 6-1. Figure 6-2 shows that there is a large ponding area along US Hwy, where flow enters from several directions. This area overflows at approximate section 340, so an ICPR weir was placed there. This generated the highest flow rate of 1,150 cfs. We found that we best matched the ICPR ponding extents by applying 1,150 cfs further upstream at section 520.

Table 6-2. Lower South Draw flow rates.

Station	Flow Rate (cfs)
1,477	241
760	449
520	1150
130	596

Deep Manning's n values taken from the ICPR future land use layer were applied in this model to best match the ICPR flooding extents. The downstream boundary condition was set as normal depth with a slope of 0.00444.

The 100-year floodplain extents from the HEC-RAS 1D model closely match the ICPR 100-year floodplain extents as shown in Figure 6-2. ICPR maximum depths are taken at 0.35-foot depth. Figure 6-3 has water surface elevations, which illustrate the large ponding area in the vicinity of US Hwy 158.

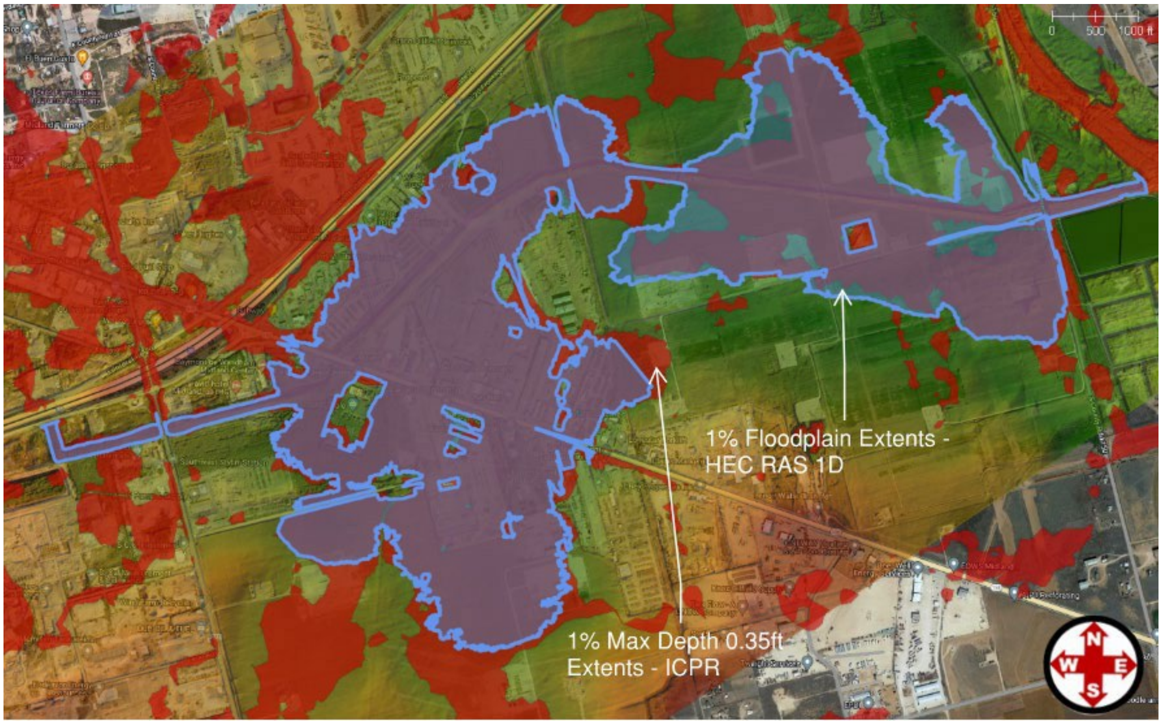


Figure 6-2. Lower South Draw ICPR and HEC-RAS inundation limits.

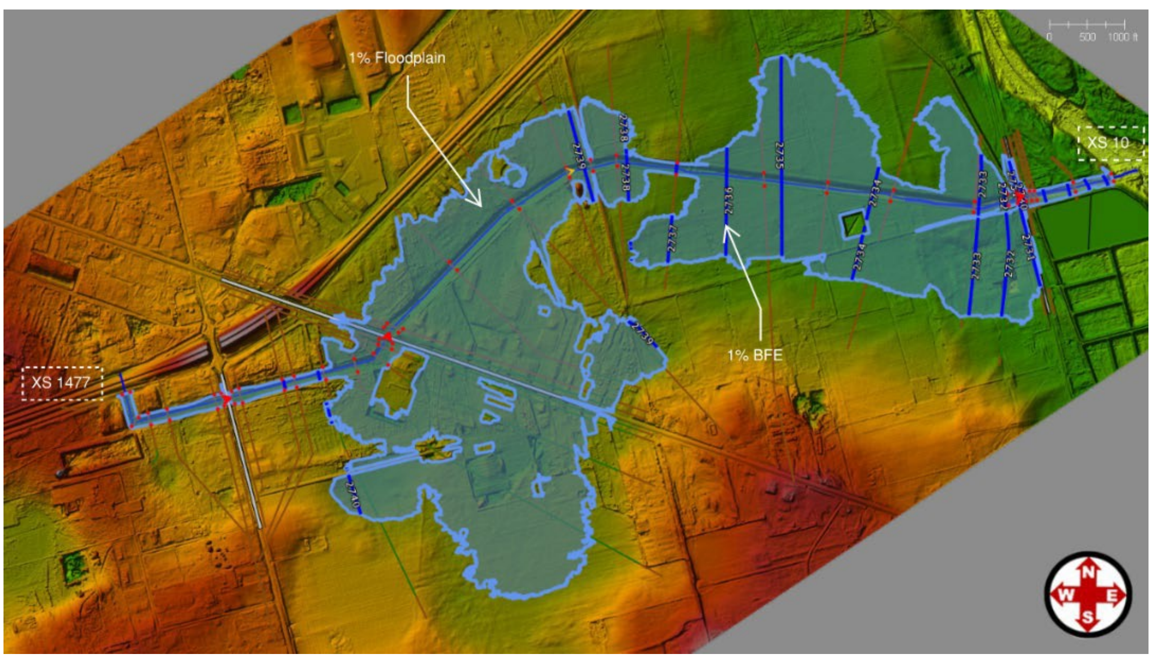


Figure 6-3. Lower South Draw HEC-RAS inundation limits with flood elevations.

6.1.2 Upper South Draw

Upper South Draw was fully analyzed in 1D using HEC-RAS software. For Upper South Draw, Parkhill had the original topographic work map layers and HEC-2 models used for the FIS study, so we imported the model to HEC-RAS and imported the AutoCad cross sections as a starting point for analysis.

We found that our LiDAR was significantly more up to date and accurate than the cross sections in these models, so we recut them from LiDAR 2018. There were many locations where minor berms and roadways, or natural features diverted or impounded water. These were identified by noting where RAS mapper showed gaps in the floodplain extents plots. We added or realigned cross sections in the blocked location of the model to force water to rise higher than the blocking feature. Upper South Draw FIS cross sections D to O are shown in Figure 6-4 below in white. The brown cross sections are from our model, showing the types of additions and adjustments needed to accurately depict the floodplain.

This model starts from cross section 34705 (Industrial Avenue) and ends at cross section 7896 (at the edge of the big playa). The downstream boundary condition was set as the playa max water surface elevation of 2,748.58 feet.

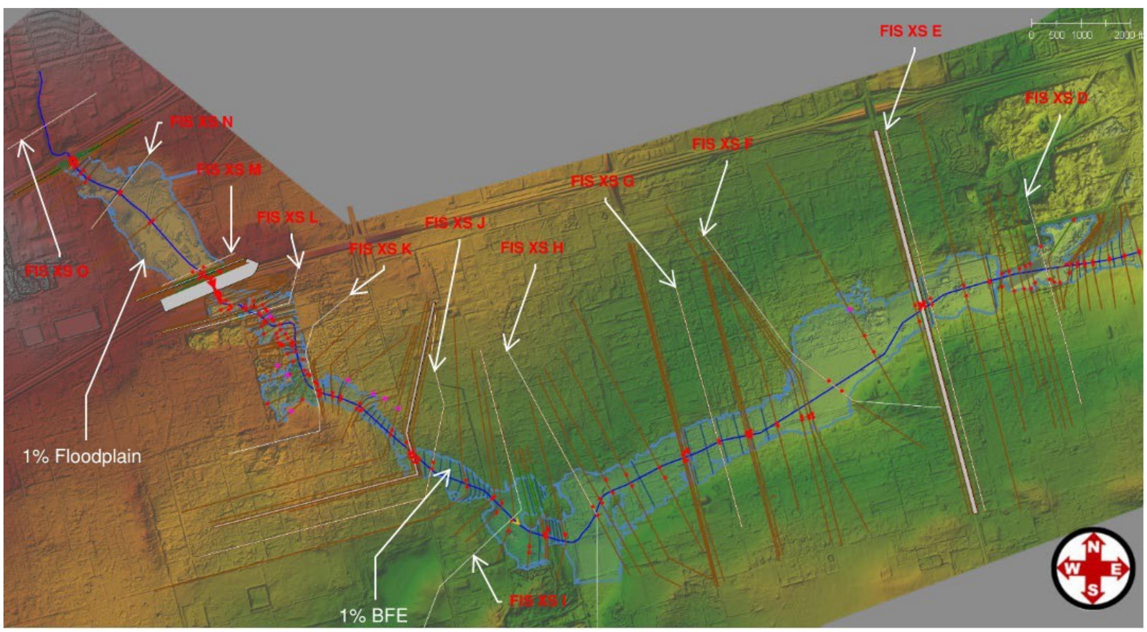


Figure 6-4. Upper South Draw cross sections.

Flow rates were extracted from the ICPR model for Upper South Draw, and applied as shown:

Table 6-2. Upper South Draw flow rates.

Station	Flow Rate (cfs)
34705	1,607
30575	816
23000	661
19500	906
8862	549

The upstream boundary condition was set as critical depth. Deep Manning's n values taken from the ICPR future land use layer were applied in this model to best match the ICPR flooding extents.

The floodplain extents from HEC RAS closely match the ICPR max elevation extents at depths greater than 0.35 feet as shown in Figure 6-5.

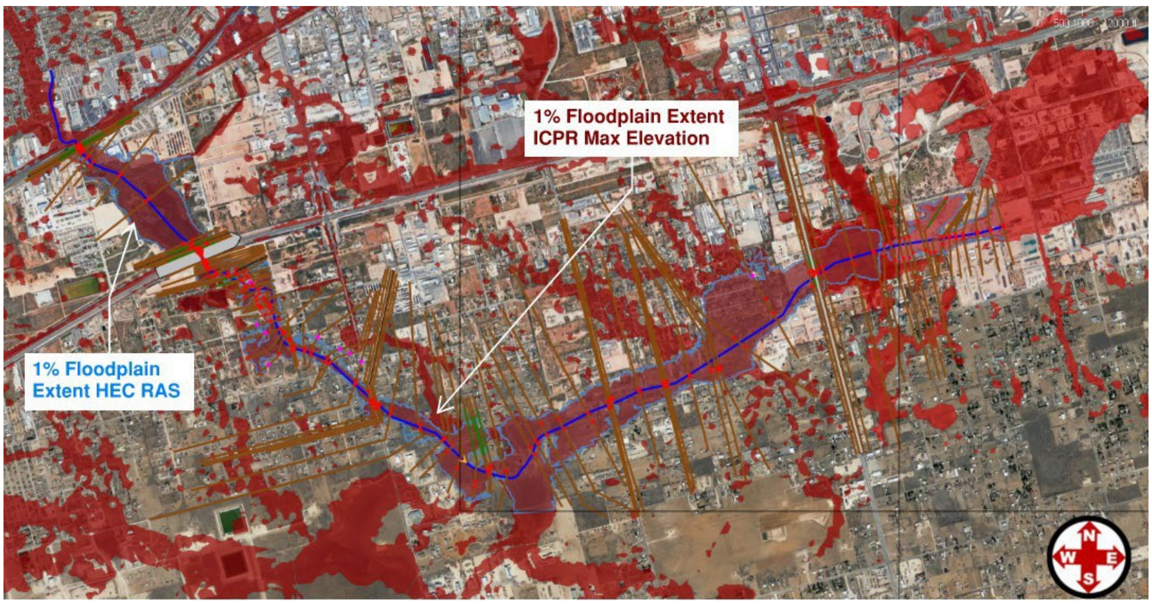


Figure 6-5. Upper South Draw ICPR and HEC-RAS inundation limits.

6.1.3 South Draw Tributary

There is no FIS study for this South Draw Tributary flow path, which passes through two playas. One playa is located at the upstream end of the flow path and is a Zone AH and the other is located at the lower end of the flow path and is shown as Zone A.

The DEM surface from TRNIS LiDAR 2018 was used as a basis of analysis with no modifications. We noticed late in the study that an aerial photo shows fill in the flow path and in the downstream playa, but we did not have enough data to incorporate these encroachments. The model reflects pre-development conditions as regards these items.

Because there is no uniform channel for this tributary and several locations with flow splits, South Draw Tributary was analyzed using 2D HEC-RAS software. The 2D mesh and terrain surface are shown in Figure 6-6.

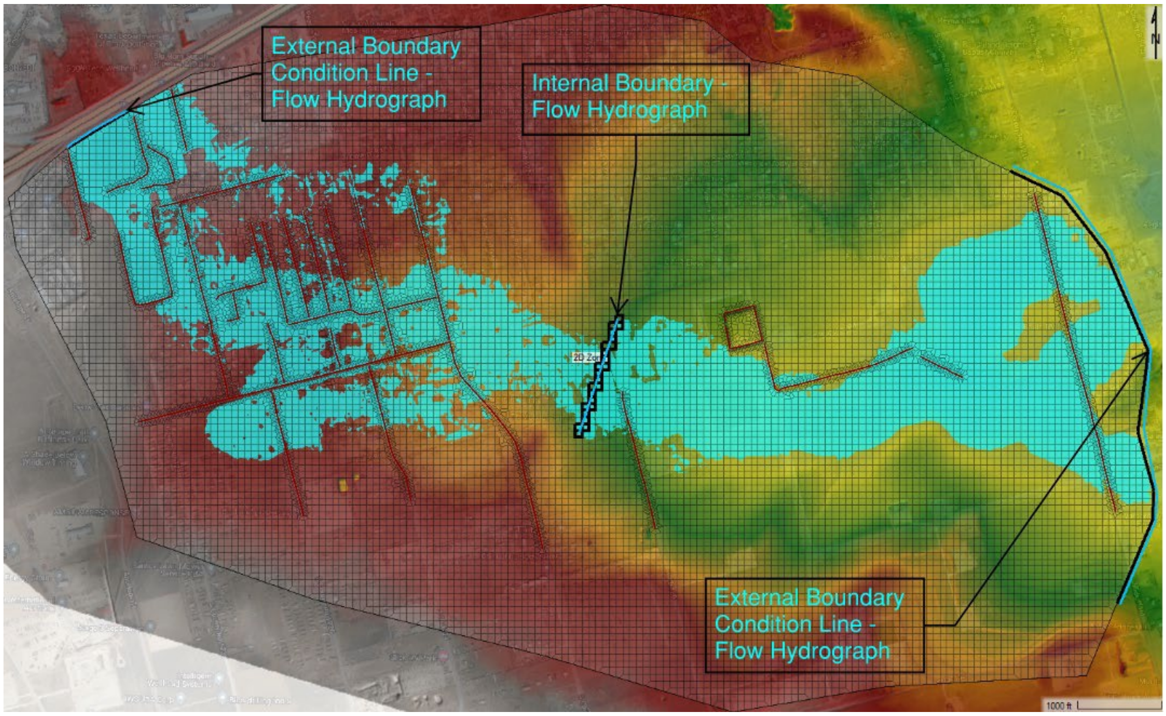


Figure 6-6. South Draw Tributary route and boundary conditions.

2D models require implementing boundary conditions lines across a flow path. We added three boundary condition lines with flow hydrographs taken from ICPR as shown in Figure 6-6. The upstream starting boundary condition was taken from ICPR weir 185-13, located just outside the pond control limit of the upstream playa. Because that hydrograph had some unstable negative flows caused by flow crossing both into and out of the pond control, we edited the hydrograph to set all negative values to 0 cfs. The peak flow is 986 cfs.

The second, internal, boundary condition is in the middle of the flow path with a peak flow of 1,072 cfs, taken from ICPR weir 14. We got a better match to the ICPR inundation limits by choosing the highest flow along the route. The third boundary condition has a peak flow of 582 cfs. This is a sum of hydrographs for weirs 18 and 19 and represents overflow from the downstream playa.

The HEC-RAS model extends through the playa. Most of our models use a normal depth for a downstream boundary condition, but since this one goes through an overflowing playa, it was much more accurate to use the playa overflow hydrograph from ICPR.

The data time interval was set to 15 minutes for all boundary condition lines. The energy grade slope for distributing flow along all boundary condition lines was set as 0.001, based on approximate natural ground slopes.

The floodplain extents from 2D HEC RAS closely match the ICPR max elevation extents that have displayed depths greater than 0.35 feet as shown in Figure 6-3. The water surface elevation lines were shown to reasonably match between the two models, as shown in Figure 6-7. The model results were trimmed to terminate at the pond control boundary for the downstream playa so there would be no overlap in the GIS results.

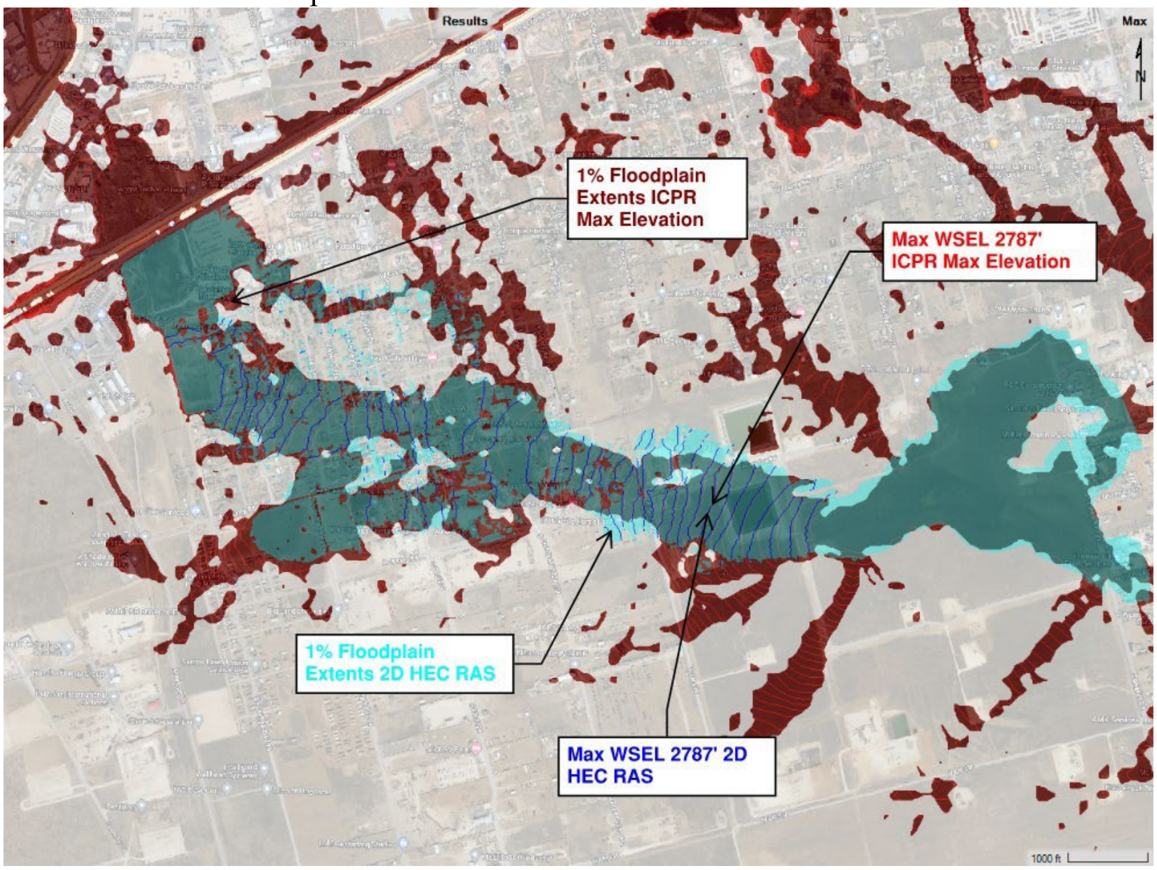


Figure 6-7. **South Draw Tributary ICPR and HEC-RAS inundation limits with water surface elevations.**

6.2 Faudree Area HEC-RAS

Faudree Road follows a natural draw that terminates in a large playa referred to as OIME Playa. No floodplains into the OIME channel have been defined by FEMA, despite the large watershed and the fact that this is a major source of flooding.

The central portion of the watershed from Hwy 191 to Odessa Country Club has a large well-defined channel through a developed area, which was not modeled. The upstream end of the watershed is undeveloped, so we modeled that flow path and created a floodway for it. The OIME playa has a slight overflow to the east which is joined by other inflows that are essentially dammed by I-20. The area north of I-20 is already developed, so we did not model it. However, the area south of I-20 is undeveloped. We studied that route to assist Midland County in managing future developments along the route.

6.2.1 Upper Faudree Flow Path

Upper Faudree was chosen as a new model because it is in a developing area just outside FIS floodplains, with a large drainage area.

The terrain model was taken from the ICPR analysis of the Faudree area. It included several basins that were new after the 2018 LiDAR was flown, or were under construction or definitively planned, as requested by the City of Odessa, using plans provided for the basins. Odessa has and is constructing a series of basins that follow the flow path. These basins are typically broken by roadway or pipeline crossings, and many do not have connecting culverts.

The diffuse nature of the flow in this area dictated the use of a 2D HEC-RAS model. Figure 6-8 below, shows the Upper Faudree 2d mesh, terrain, boundary condition lines, and peak flow rates that were used and their respective locations along the flow path.

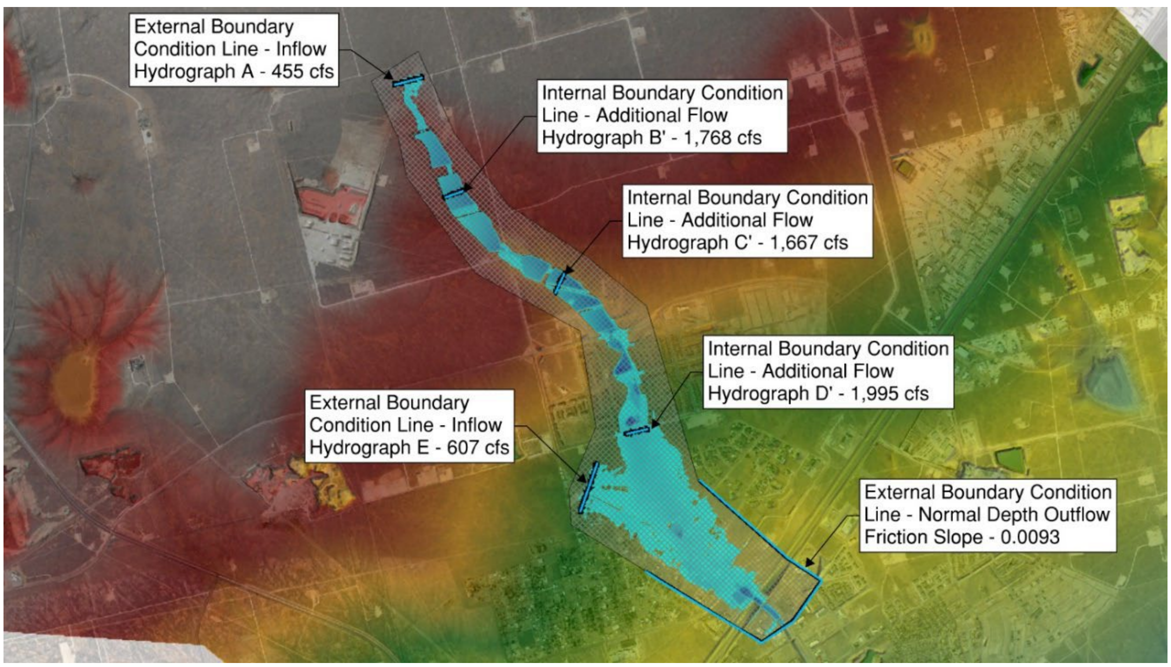


Figure 6-8. Upper Faudree route and boundary conditions.

The flows and locations shown above were extracted from the larger ICPR 2d rain-on-grid model for Faudree and were either directly imported or manipulated to adjust for any variability in calculations between the modeling software.

The HEC-RAS model was developed using a future land cover that is primarily Urban Residential with pockets of Commercial, Open Space, and Public Campus. Approximate dimensions and data for the three (3) culverts modeled were field verified but not surveyed. A deep Manning’s n value was used to account for differences in software computations and ensure that the flood extents/depths exhibit parallel geometries.

Before importing any of the hydrographs from ICPR, any negative flows were set to 0. Because the inflow hydrographs at locations A and E are at the boundary, and the furthest upstream in the HEC-RAS model, they were not affected by variability and were directly imported from the ICPR model.

HEC-RAS flow measurements were taken just upstream of all internal boundary condition lines and were used to rectify any losses in flow at each timestep that were not seen in ICPR. This was done by taking the difference between ICPR observed and HEC-RAS observed, which was then used as an internal boundary stage hydrograph. This process was reiterated until the downstream flows in HEC-RAS matched ICPR within tolerance.

The floodplain extents from 2D HEC RAS closely match the ICPR max elevation extents that have displayed depths equal to or greater than 0.35 feet as shown in Figure 6-7.

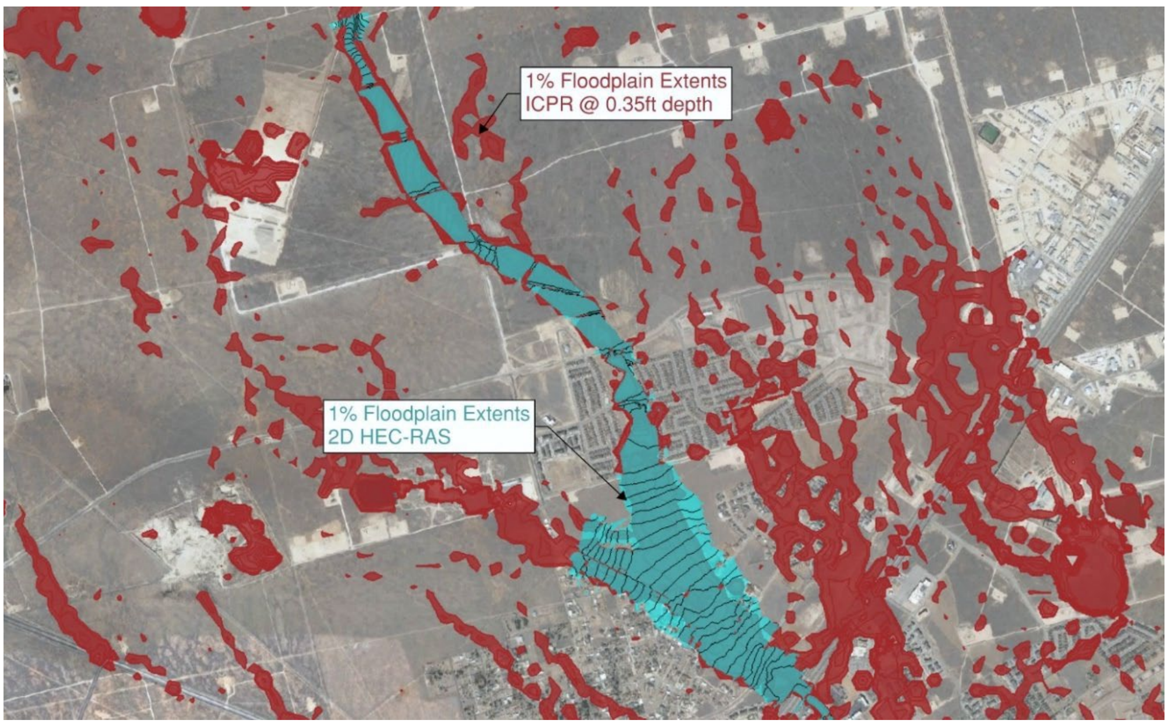


Figure 6-9. Upper Faudree ICPR and HEC-RAS inundation limits.

6.2.2 Faudree Outfall Flow Path

The Faudree Outfall flow path is not part of the FIS study. This 2D model starts upstream at the road crossing under I-20 and continues to a large non-overflow playa located about a mile south of the interstate and east of FM 1788.

The DEM used for this model was downloaded from TNRIS LiDAR 2018. We determined an industrial subdivision had recently been constructed directly in the flow path. We modified the DEM by adding building and lot pads and two pits that were constructed after the DEM data. We had no survey of this area, so we estimated the pad elevations by using an elevation similar to pads that were picked up in the LiDAR data. For the caliche pits, the Connect Explorer application enabled us to measure the depth with decent accuracy. The limits of all pads and pits were taken from the aerial photographs. See Figure 6-10. These buildings greatly affected the location of the floodway we developed.

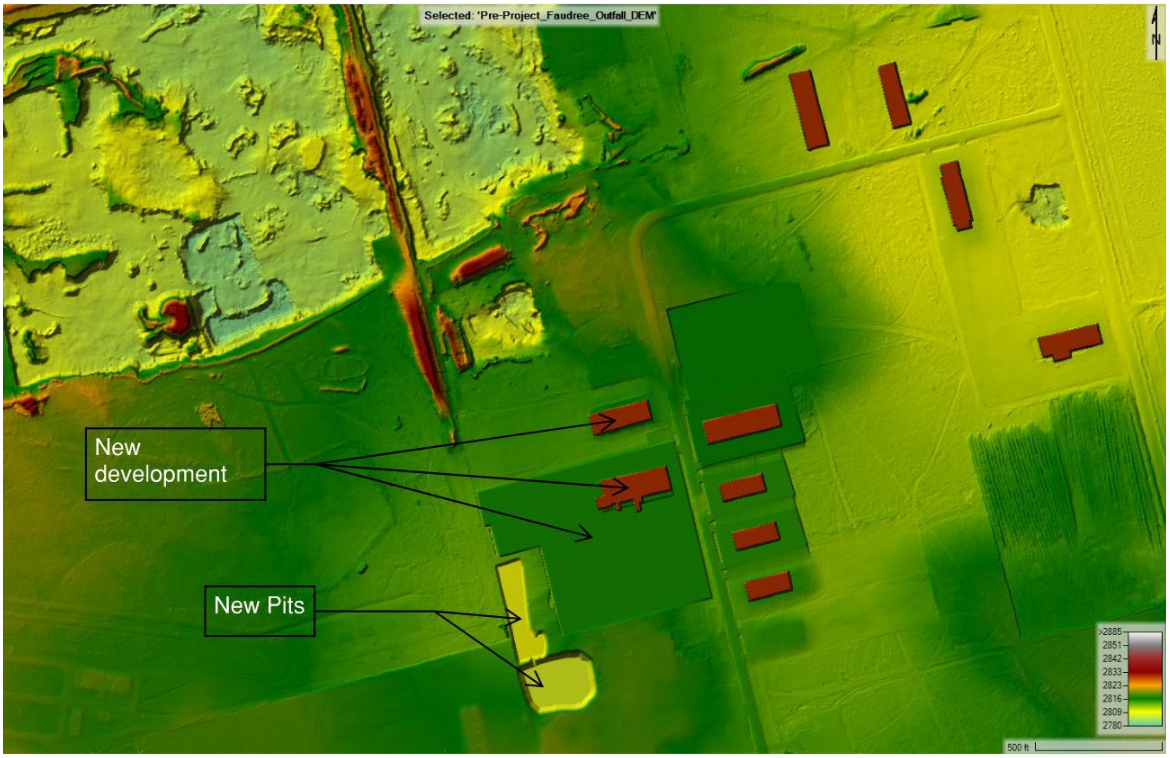


Figure 6-10. Faudree Outfall DEM modifications.

This model has two external boundary condition lines. The upstream boundary condition was an imported flow hydrograph taken at BI-20, with a peak flow of 581 cfs, applied at the north end of the model as shown in Figure 6-11. This hydrograph was taken from the largest peak flow location on the studied route in the ICPR model, shifted to the upstream end.

The energy grade slope for distributing flow along the upper boundary condition was set as 0.02 ft/ft. The data time interval for the input hydrograph was five minutes. The downstream boundary condition was set to normal depth with a slope of 0.02 ft/ft. This boundary line is inside the limit of the pond control for the downstream playa.

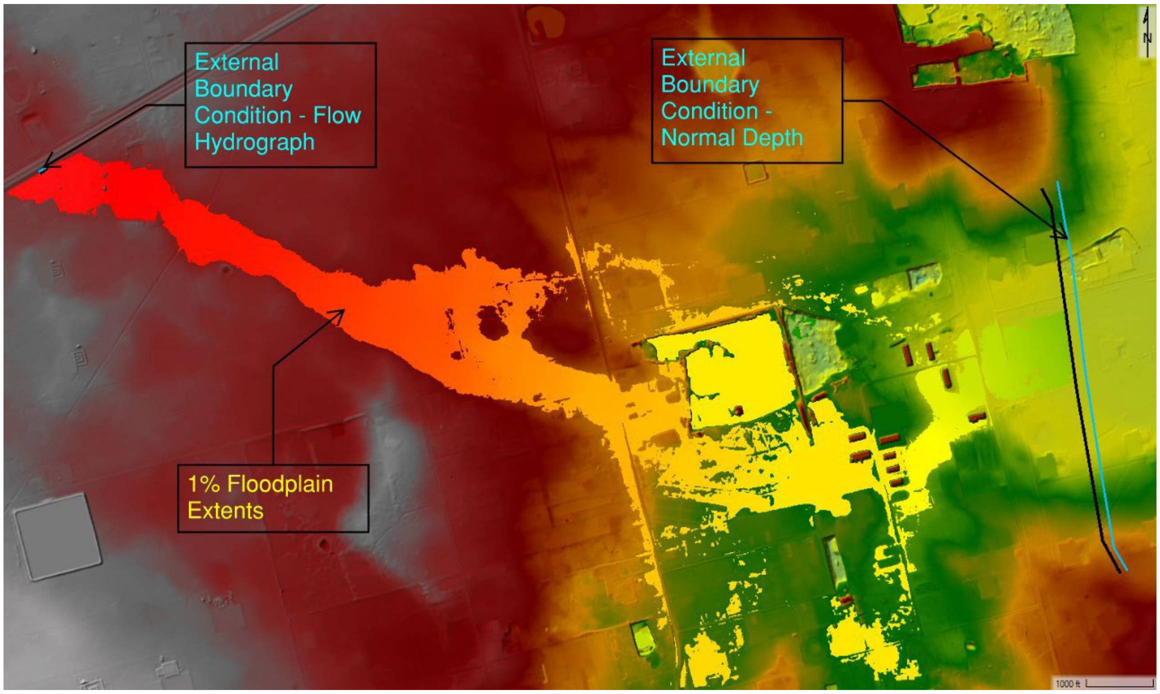


Figure 6-11. Faudree Outfall route and boundary conditions.

This 2D model does not have any road crossings with culverts; all are low water crossings. The large caliche pit shown in Figure 6-10 at the upper left is a major factor in this model. We studied this model carefully and determined that a large part of the flow enters the west part of the pit. The pit was determined not to overflow in the future developed 100-year event.

We experimented with adjusting the boundary hydrographs and tested internal hydrograph boundaries in order match the ICPR results, particularly to duplicate the flow split into and out of the caliche pit. We decided to use shallow Manning's n values from the future ICPR roughness map to better fit the 2D model extents to ICPR extents.

Table 6-3 below compares the flow split into the pit from ICPR and shows our HEC-RAS model matched it exceptionally well. The HEC-RAS elevation in the pit is higher than ICPR, indicating that our HEC-RAS model does not have as much storage reduction in it as the ICPR model does.

Table 6-3. Faudree Outfall flow split at caliche pit.

Location	Flow Rate, ICPR (cfs)	Peak Elevation, ICPR (ft)	Flow Rate, HEC-RAS (cfs)	Peak Elevation, HEC-RAS (ft)
Upstream of pit	541		546	
Into pit	343	2,808.39	354	2,814.89
Bypass south of pit	155		183	

The floodplain results from 2D model reasonably match the ICPR max elevation extents with depths greater than 0.35 feet as shown in Figure 6-12.

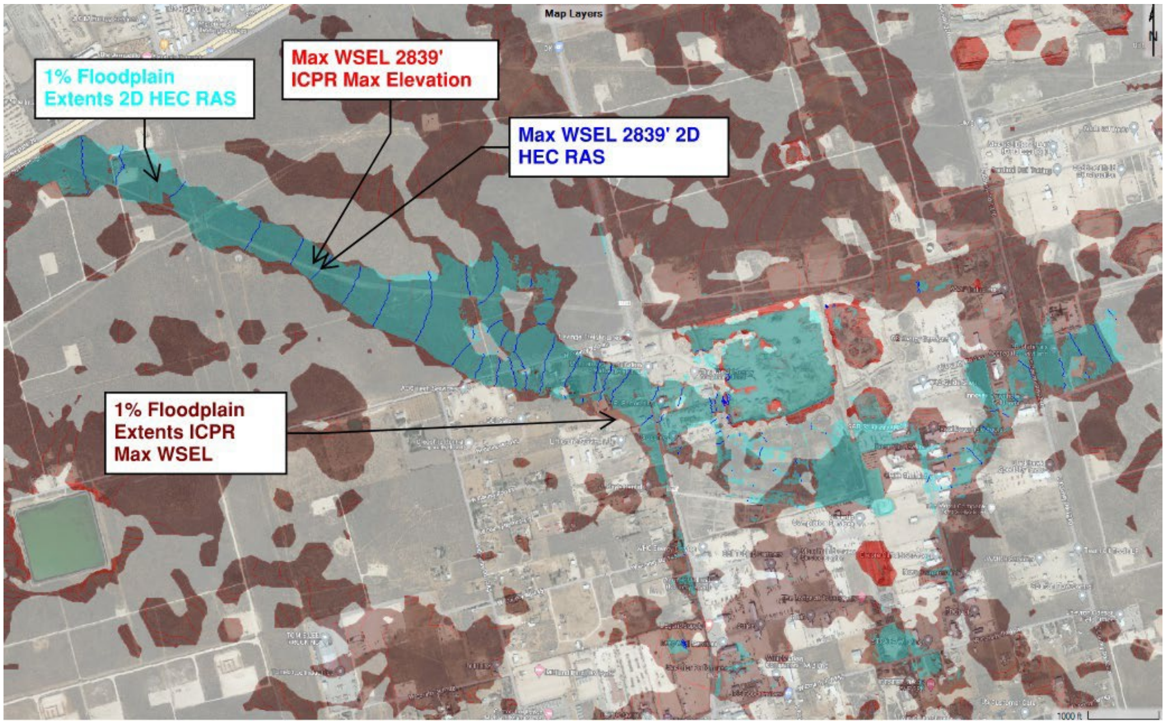


Figure 6-12. Faudree Outfall ICPR and HEC-RAS inundation limits.

6.3 Midland Airport Outfall HEC-RAS

This flow path has no FIS floodplain. The upstream end of MAF Outfall flow path starts downstream of BI-20 (Hwy 80) and ends about a mile south of I-20 at a large non-overflow playa. The route passes through an industrial subdivision that has no drainage easements in it due to the lack of understanding of the potential for runoff. The owners of these lots have constructed various ditches and basins to try to cope with the flooding they have experienced.

The DEM from TNRIS LiDAR 2018 was modified to include work proposed by TxDOT, raising the I-20 Hwy profile, and expanding the small pond located downstream of I-20 as shown in Figure 6-13.

Culverts at I-20 were modeled using the proposed drawings. This 2D model has a total of eight road crossings such as I-20 and Frontage, WCR 127, WCR 130, and private roads. The invert elevations for culverts other than I-20 were found using the terrain DEM surface and topo data.

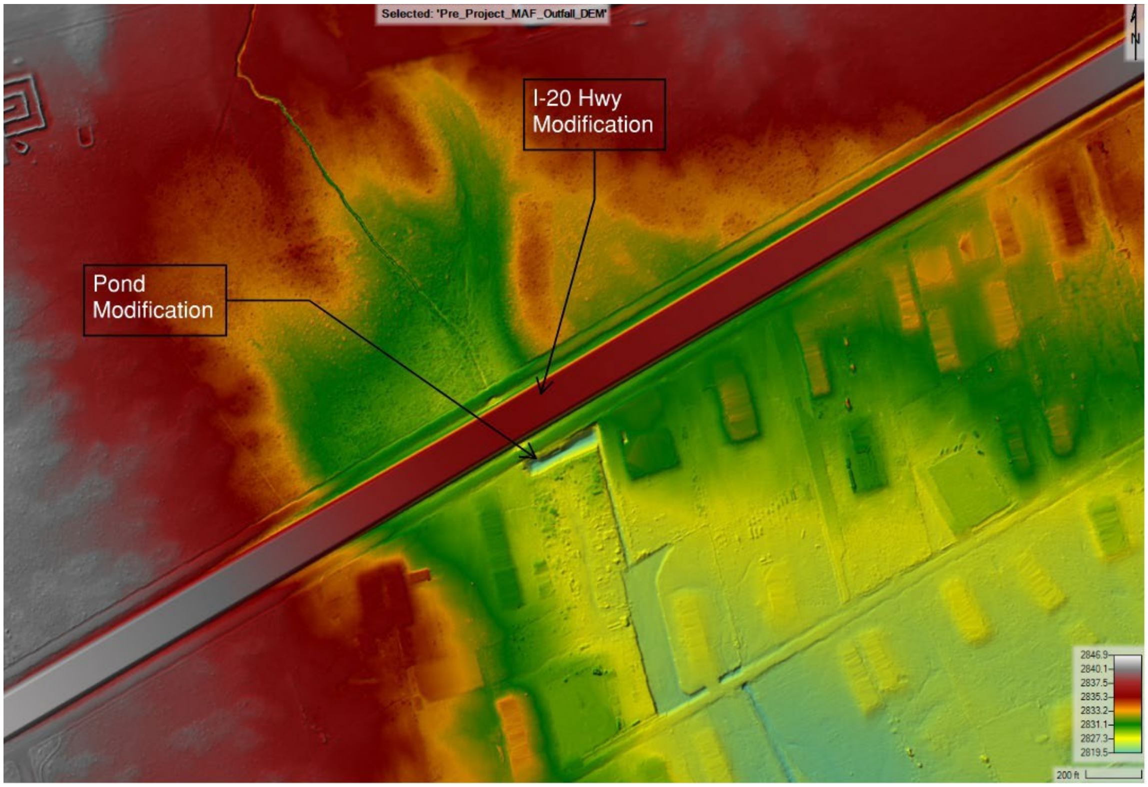


Figure 6-13. MAF Outfall terrain surface modifications.

We tried 1D modeling first, but there was a complex downstream area where the floodplain split into two paths that could not be accurately represented with a 1D model. Thus, we decided to use 2D modeling to get realistic and efficient results.

The MAF Outfall flow path has a total of three boundary condition lines: two external (flow hydrograph and normal depth) and one internal (flow hydrograph) as shown in Figure 6-14. The first boundary condition line starts at the upstream end of the model (north) with a peak flow of 2,640 cfs. The source of this hydrograph is a sum of I-20 weir overflow and culvert flow from the MAF ICPR model. We applied this flow at the upstream end because it provided the best match between ICPR and HEC-RAS inundation limits.

The second boundary condition is located on a tributary to the northeast and has a peak flow of 688 cfs. It is sourced from the Monahans West ICPR model as the overflow from a playa. The data time interval was 15 mins for the two-flow hydrograph boundary condition lines.

The last boundary condition is located at the end (downstream) of the model with a normal depth of 0.02. The model extends into the downstream playa so we can model lower frequency events. Instead of a fixed downstream tailwater based on the ICPR playa maximum flooding elevation, we chose to trim the model results at the playa limits.

We decided to use shallow Manning's n values to better fit the 2D model extents to ICPR extents.

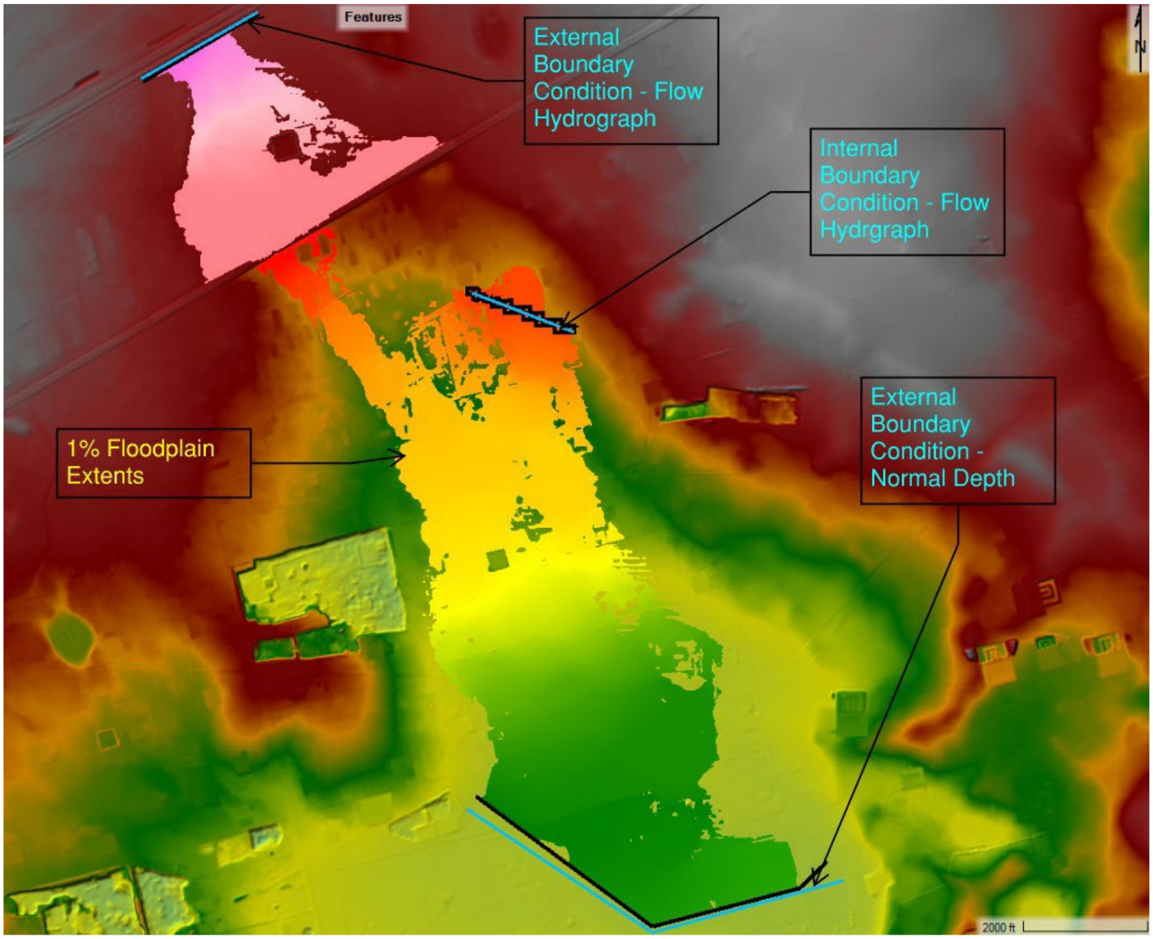


Figure 6-14. MAF Outfall route and boundary conditions.

The floodplain extents from 2D model closely match the ICPR max elevation with depths greater than 0.35 feet, as shown in Figure 6-15., For the GIS output, we trimmed the results at the downstream pond control boundary to avoid a conflict in flood elevations.

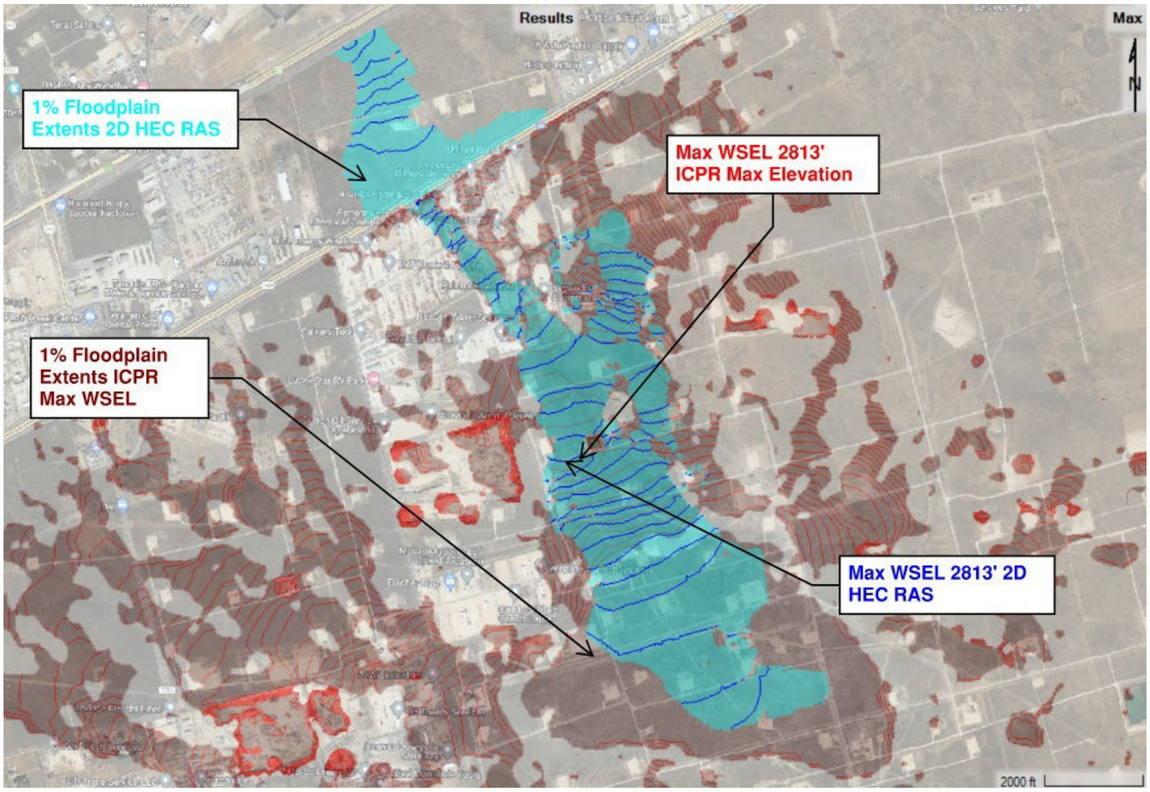


Figure 6-15 MAF Outfall ICPR and HEC-RAS inundation limits.

6.4 Monahans Draw HEC-RAS

Monahans Draw had a detailed FIS model in the central portion of the county from about 1/2 mile west of SCR 1210 to about 1/2 mile east of FM 1213. Outside those limits, an approximate Zone A floodplain is shown on the FIRMs for Monahans Draw. Parkhill extended modeling downstream to the confluence with Midland Draw and upstream to the west Midland County line.

Monahans Draw has two reaches with 1D modeling: Upper Monahans Draw and Lower Monahans Draw. These are separated by a complex 2D model in the vicinity of Consavvy Lake (called Salt Lake in the ICPR model).

6.4.1 Lower Monahans Draw 1D HEC-RAS

1D analysis is used for this model because most of the floodplain is contained in Monahans Draw. We placed cross sections to capture the flow restrictions and wider areas in Monahans Draw as shown in Figure 6-16.

Lower Monahans 1D model upstream end is cross section 19459 and the confluence with Midland Draw is cross section negative14070. This model is new, with no FIS model as a starting point.

The DEM for this model was downloaded from TNRIS LiDAR 2018. No terrain modification was applied to this surface. Mannings n values are from the ICPR future land roughness map using the deep values.

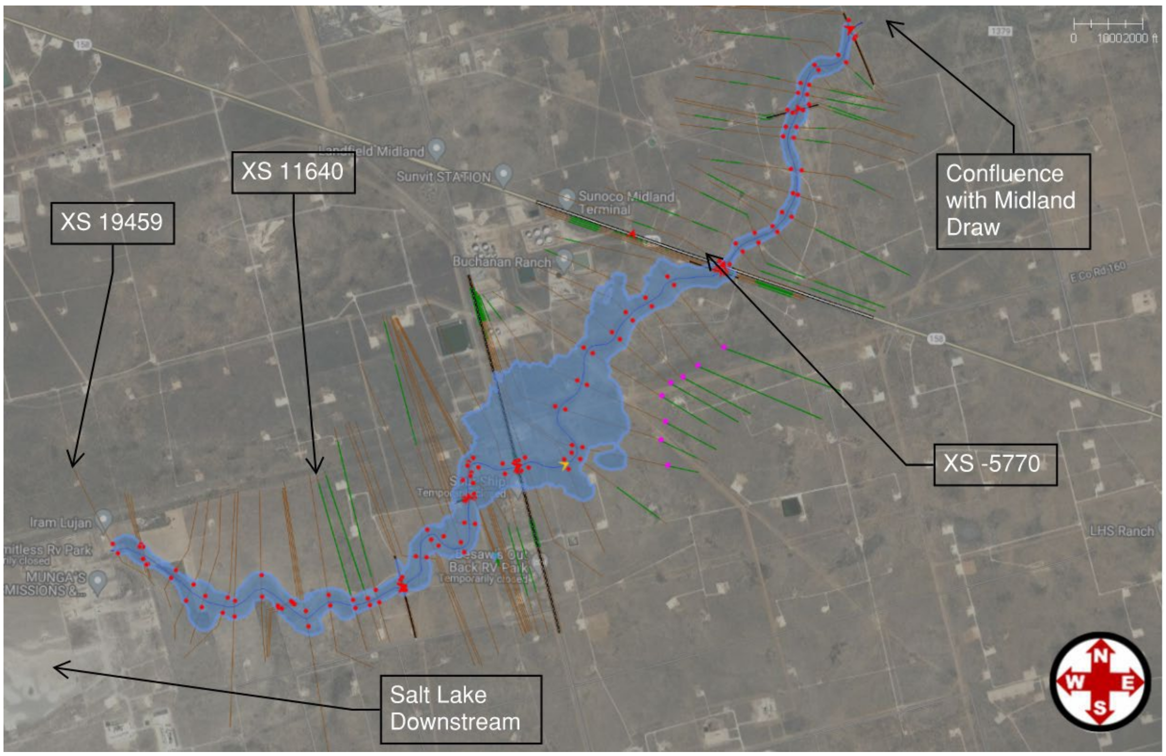


Figure 6-16. Lower Monahans Draw cross sections.

Table 6-4. Lower Monahans Draw flow rates.

Station	Flow Rate (cfs)
19459	573
11640	533
-5770	328

All the flow rates are quite low because little overflow from the Salt Lake model occurs. Cross section -5770 peak flow is the Hwy 158 overflow plus culvert flow. The other locations use hydrographs from the Lower Monahans Draw ICPR model for the peak flows.

It has a total of seven road crossings such as Hwy 158, SCR 1110, and some private dirt road crossings. The invert elevations for each culvert were found using the terrain DEM surface and survey data. Only Highway 158 culverts were surveyed.

For Lower Monahans Draw, we set an upstream boundary condition as a known water surface of 2,687 feet to force a match to the downstream model extents end of the 2D model as shown in Figure 6-17. This known water surface elevation was obtained from the ICPR results.

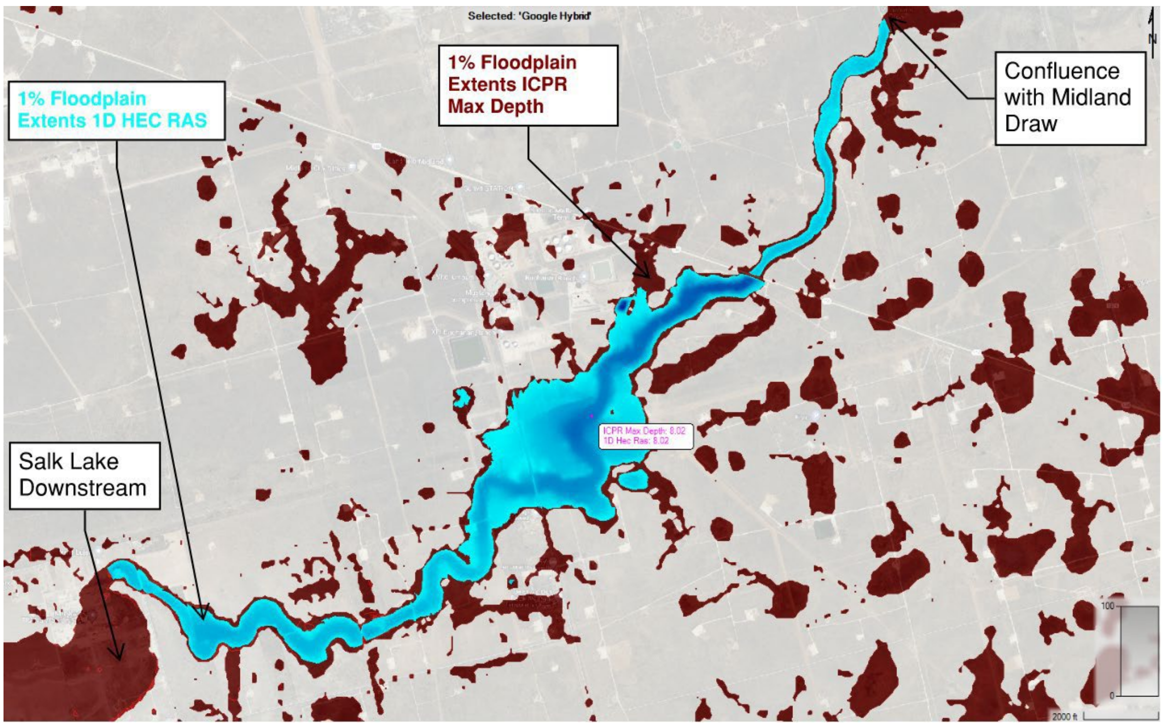


Figure 6-17. **Lower Monahans Draw ICPR and HEC-RAS inundation limits.**

The floodplain extents from the lower Monahans Draw 1D model closely match the ICPR max depth extents with depths exceeding 0.35 feet, as shown in Figure 6-17. This exhibit notes a location with an exact match of 8.02 feet max depth from 1D model and ICPR max depth results.

6.4.2 Upper Monahans Draw 1D HEC-RAS

Upper Monahans Draw includes the reach with a detailed FIS study. 1D analysis is appropriate for this model because most of the floodplain is contained in Monahans Draw.

We did not have the HEC-2 model developed by FEMA, so we used the FIRM mapped cross sections to establish the stationing for the model. We placed additional cross sections to capture the flow restrictions and wider areas in Monahans Draw as shown in Figure 6-18. The upstream west end of Upper Monahans 1D model is cross section 181848 and the lower end is cross section 55507, where the model enters the Monahans Draw 2D model.

No terrain modifications were made to the DEM for this model. We decided to use deep Manning's n values to better fit the 1D model extents to ICPR extents.

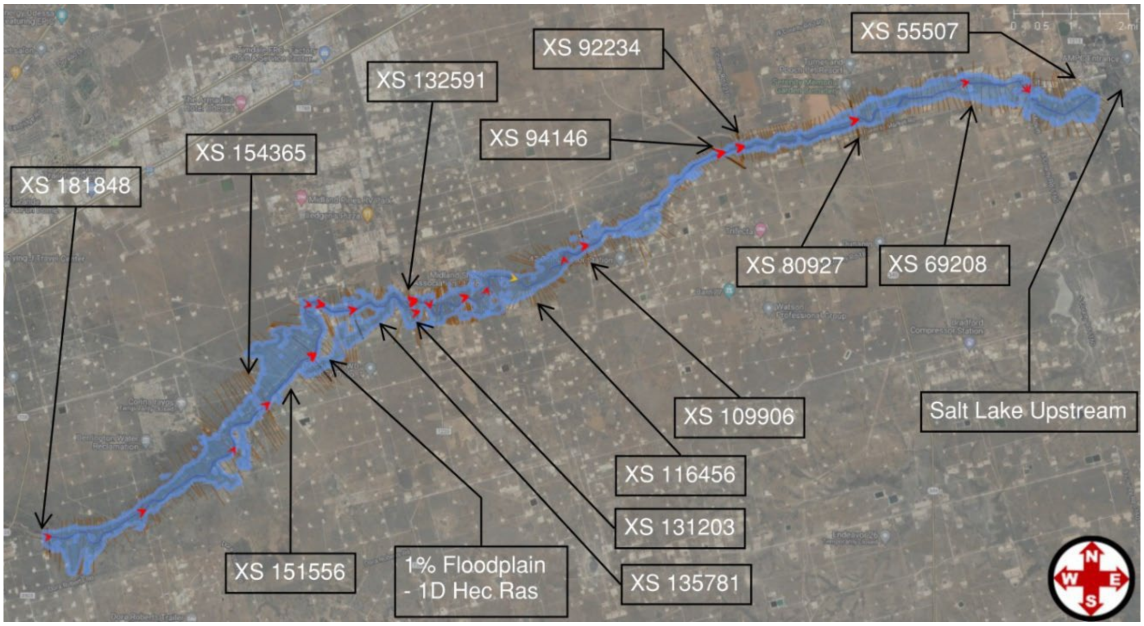


Figure 6-18. Upper Monahans Draw cross sections.

The Upper Monahans Draw 1D model has thirteen steady flow locations distributed in cross sections as shown in Figure 6-18 and Table 6-5. These are taken from ICPR 2d weir flow measurement locations on the Monahans West, West of Loop, and Monahans Middle ICPR models. The Monahans West model is our westmost detailed study, and it does not extend all the way west through Midland County, as shown on Figure 6-19. We used the same flow rate from the upstream end of the Monahans West model all the way to the Midland County line.

Table 6-5. Upper Monahans Draw flow rates.

Station	Flow Rate (cfs)
181848	6986
154365	6986
151556	6707
135781	5465
132591	4857
131203	7875
116456	4384
109906	4214
94146	3721
92234	3662
80927	3480
69208	2974
55507	2902

There are a total of 19 road crossings such as FM 1788, SCR 1270, WCR 170, Hwy 349, FM 715, ECR 160, and some private roads in this model. We modeled proposed SCR 1232 from recent plans for seven Conspan arch culverts of 31.33 feet span and 10 feet rise. Similarly, Midland County replaced the existing culverts for SCR 1210 to fifteen 8-foot wide by 4-foot-high box culverts, and we input these culverts from plans. There is also a new SCR 1270 where we used plans to input the proposed multi-box structure. These roadways are elevated above natural ground, so we input the proposed profiles into the culvert models.

Upper Monahans Draw has several private dams that were inaccessible to us. We had to estimate the outfall structures using Connect Explorer. These dams were all overtopped in the simulations for the 100-year event.

We were able to force a match between the 1D floodplain extents at the east, downstream end of Upper Monahans Draw and the Monahans Draw 2D portion by setting a downstream boundary condition of a known water surface taken from the 2D model of 2,695 feet. We decided to use deep Manning’s n values to better fit the 1D model extents to ICPR extents.

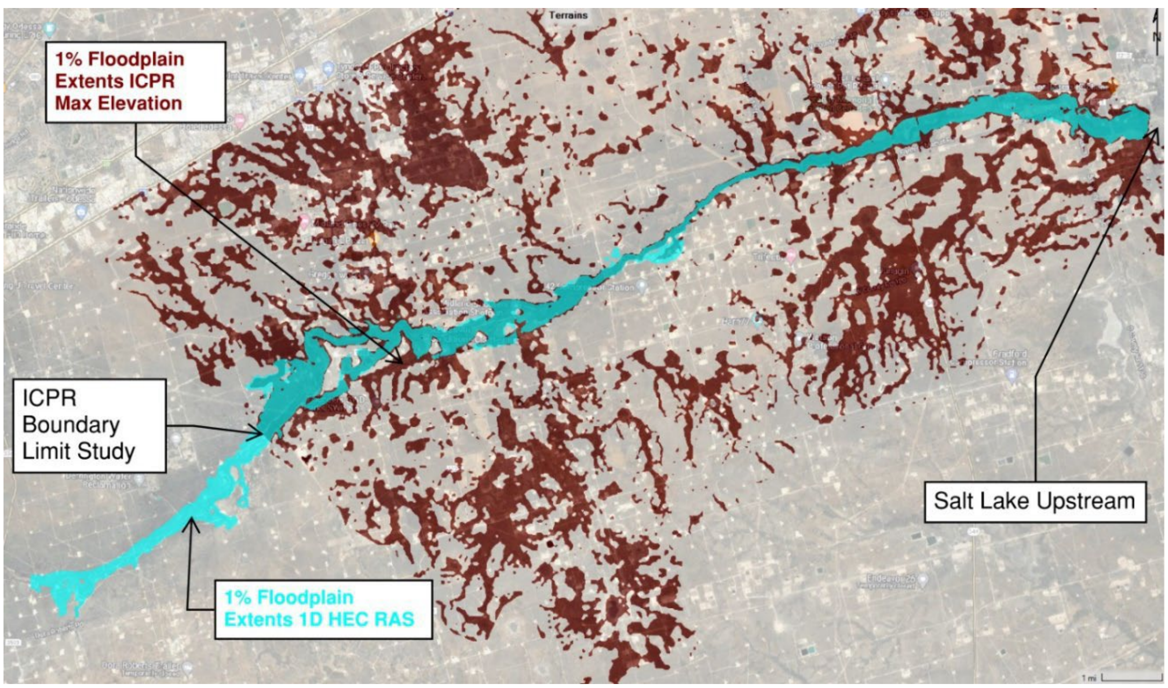


Figure 6-19. **Upper Monahans Draw ICPR and HEC-RAS inundation limits.**

Figure 6-19 compared the results of the ICPR analysis with the HEC-RAS model for Upper Monahans Draw.

6.4.3 Monahans Draw 2d HEC-RAS model.

Monahans Draw includes a 2D model located between Upper and Lower Monahans Draw. This model area will drain only when storage rises to a certain overflow elevation. The FIS model terminates just upstream of this complex area.

The ICPR model shows flow from Upper Monahans Draw enters this area, fills a playa near ECR 160, which overflows south into Consavvy Lake (called Salt Lake), then backflows to fill the ECR 160 area to a deeper extent, finally overflows eastward across a wide floodplain and out a narrow exit.

This is a difficult analysis that only 2D modeling can capture. We feared even a 2D model could not match the ICPR results but were surprised to discover it could.

The DEM for this model was downloaded from TNRIS LiDAR 2018. No modifications to the surface were needed.

There is only one low water crossing at the north side of the lake named ECR 160.

The Monahans Draw 2D model has a total of three external boundary condition lines: two flow hydrographs and one normal depth as shown in Figure 6-20. The first boundary condition line is located at the upstream end of the model (west side) where Upper Monahans Draw enters the 2D model. The entering peak flow is 2,902 cfs. The second boundary condition, from the Salt Lake ICPR model, is located at north of the model and has a peak flow of 377 cfs. The data time interval was 15 mins for the two-flow hydrograph boundary condition lines. The energy grade slope for distributing flow along these boundary condition lines was set as 0.002478 ft/ft.

The last boundary condition is located at the east end (downstream) of the model with a normal depth of 0.000108 ft/ft. We decided to use shallow Manning’s n values to better fit the 2D model extents to ICPR extents.

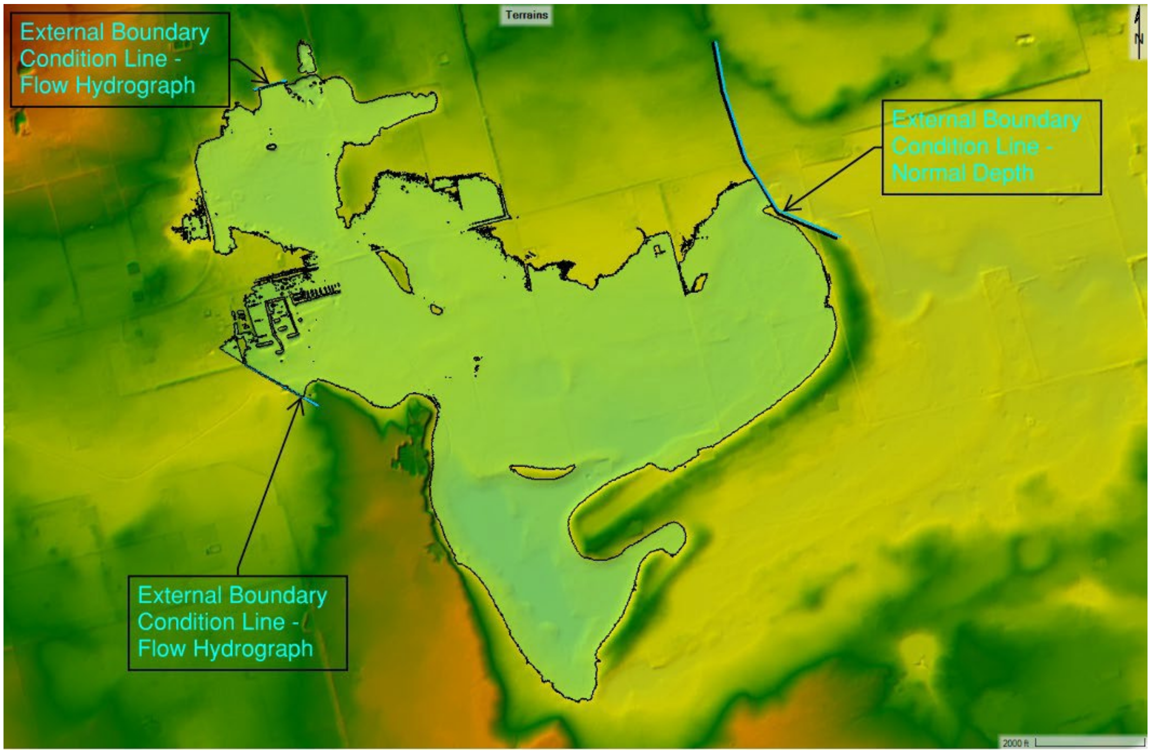


Figure 6-20. Monahans Draw 2D model boundary conditions.

We were able to match the 2D floodplain extents with the Upper and Lower Monahans Draw 1D extents by replacing the deep Manning's n values with the shallow ones and selecting the most effective normal depth and energy grade slope for the distributed flow along the flow hydrograph boundary conditions.

The floodplain extents from the Monahans Draw 2D model somewhat match the ICPR maximum elevation extents that have displayed depths greater than 0.35 feet as shown in Figure 6-21. We note a location with the water surface elevation contours from 2D model as 2,792 feet and ICPR as 2,791 feet. The width of the 2D HEC-RAS model flood extents is greater than the ICPR extents.

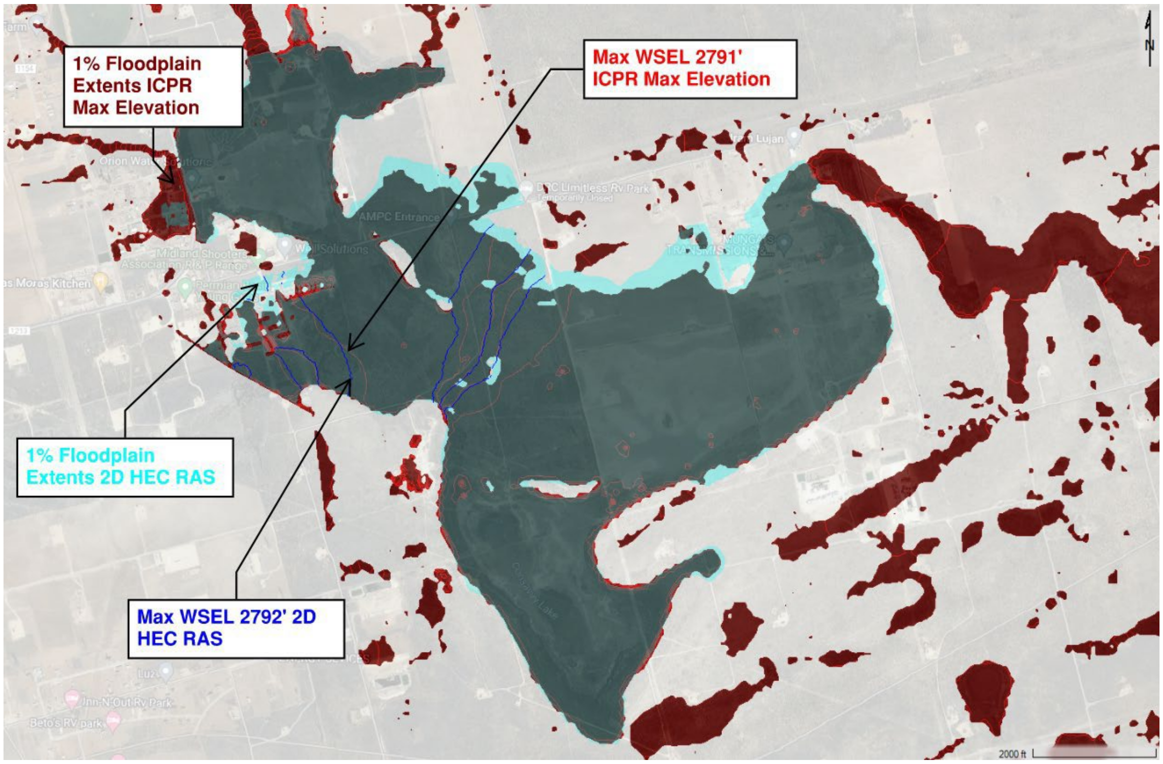


Figure 6-21. Monahans Draw 2D ICPR and HEC-RAS inundation limits.

Figure 6-22 shows the floodplain extents connections between the 2D model and the two adjacent 1D models on Monahans Draw.

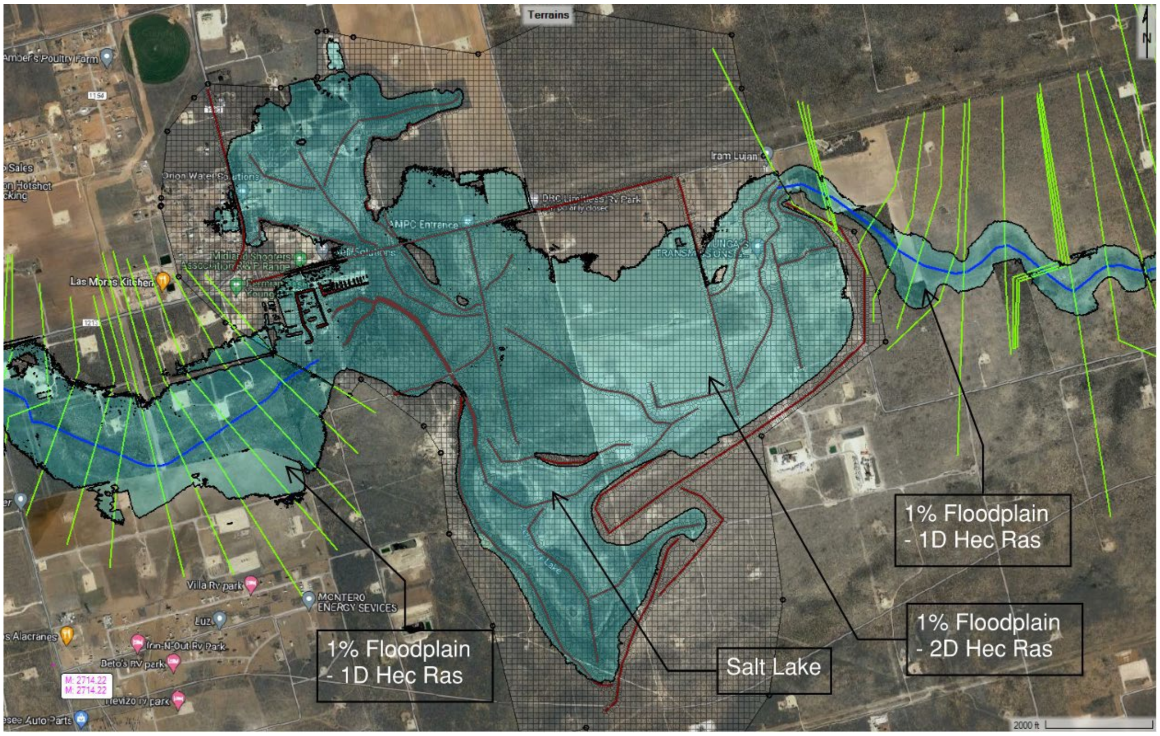


Figure 6-22. Connections between Upper, Lower and 2D Monahans Draw models.

7 Flood Management Guiding Principles

Every community needs to develop their own drainage approach that takes into account the type of drainage present, the complicating factors, and the terrain. Summer 2021 flooding revealed the top problems in Midland County to be related to lack of positive drainage routes, and inadequate flow capacity in a few locations.

In general, it is less expensive to prevent a flooding situation than to resolve it. For this reason, FEMA requires communities that want to make federal flood insurance available to adopt damage prevention regulations.

The recommended guiding principles that will help Midland County resolve current problems and prevent new ones include:

- Preventing flooding problems:
    - Protect floodways with easements.
    - Protect playa bottoms and caliche pits that capture flood waters.
    - Protect playa overflow routes with easements.
    - Use full development flood estimates to regulate structure elevations and easement widths.
- Addressing existing flooding problems:
    - Connect ponding locations with constructed ditches or pipes to drain them without pumping, where flooding has been an issue.
    - Limited channelization projects.

The following recommendations were originally submitted for approval by the Midland County Commission in order to allow TxDOT to implement portions of an adopted drainage plan. They are updated here to incorporate findings of the completed study.

7.1 Easements

Drainage easements are essential regulatory elements. This section explains how easement strategies can be implemented in Midland County.

7.1.1 Floodway Easements

Monahans and South Draws are mapped in the Flood Insurance Study (FIS) with floodways, the central portion of the stream where FEMA regulation prohibits any fill or buildings, or even solid fences that can block flow. This allows the outer parts of the floodplain area to be developed but still provides for adequate flow conveyance.

Governments often seek to reduce the floodplain extents or offset development by deepening and widening channels in the floodways. These projects may be more challenging in Midland County due to the flat slopes. If we dig a ditch five feet deep in one location, we must extend it downstream at an even flatter slope until we encounter natural ground that is low enough for it to drain out, or "daylight." This explains why channels in Midland are up to ten feet deep on the west side of the city, but only three to five feet on the east side, where they are close to daylighting into the original draw.

Thus, channelization projects need to be long. Any new project to deepen a channel will encounter oil and gas pipelines, generally quite expensive to lower. For these reasons, channelization is not recommended as the first choice. Instead, it would be better to protect the floodways in their natural condition.

Until now Midland County has not been aware of the flood potential in some flow paths because they are not shown on the FEMA flood maps. An example is a subdivision south of I-20 directly in the path of the major drainway that runs out of the airport. It is not shown as flood prone on the floodplain maps. Property owners quickly discovered that hazard after their lots and buildings flooded and have constructed small ditches and basins to compensate.

This study included future floodway delineation on drainage flow paths expected to convey flow from large areas. With the floodways identified, Midland County can require drainage easements that prohibit fill and buildings in those locations during plat review. For routes not studied in the FIF grant, County may wish a best estimate for any new subdivisions on those routes or to require the developer's engineer to provide a study.

Admittedly, not all developments even come to the County for review, so floodway easements are not a full solution. However, it will be beneficial for the County to adopt a principle that the major drainways need floodways and drainage easements their full length.

7.1.2 Playa and Caliche Pit Easements

FEMA maps show playas as ordinary floodplains with no floodways because floodways are defined based on an assumption of flowing water, and playas are standing water. An exception is South Draw, which is assumed to both flow and stand. Thus, FEMA does not prohibit fill in playas. Midland County currently does not have any prohibition on filling in playas, but cities such as Midland, Lubbock and Amarillo have regulations that go beyond the FEMA minimum because playas are a special type of flooding. Filling in a playa will raise the estimated flood elevation and push floodwaters onto adjacent properties.

It would be possible for Midland County to modify the flood damage prevention court order to require any fill in a playa to be balanced with an equal amount of cut. However, due to the limited regulatory power of the County, it may be better to take a different approach.

A more minimal way to protect playas would be similar to a floodway, obtaining drainage easements on the central lowest portions of the major playas when they are platted. This would reduce the fill in the playa and result in an open area with no buildings. If flooding becomes an issue later, the open area could be excavated to catch more runoff. The difficulty in this approach is deciding how large of an area to protect. If Midland County wants to adopt this approach, a method for choosing a size needs to be developed.

It may not be practical to protect all playas. Smaller playas or those shallow predicted flooding might not create much flood risk. The Flood Planning Framework panels in Appendix 8-A show the playas that were identified as pond control volumes in our ICPR study. Generally, this means they are depressions that were shown to capture somewhat significant volumes of runoff.

In summer 2021, several caliche pits situated along South Draw captured a great deal of runoff and provided inadvertent flood protection. In one case, residents complained that a caliche pit that had recently been filled in no longer provided such protection. Thus, caliche pits function like playas if they are in or near the flow path. A caliche pit is the cheapest form of drainage retention basin because it is already constructed. Our grant study identified pits that capture a lot of runoff and will map them as flood-prone. Midland County can begin to regulate those locations and treat them as pond controls.

7.1.3 Playa Overflow Easements

South Draw, a chain of connected playas, was the source of significant flooding in 2021. In some locations, the County discovered that a development or just a build-up of sediment was blocking the passage of floodwaters.

Our grant study identified which playas overflow, and the amount of flow predicted to escape from them. During development, it will be important to place a street or drainage easement along the overflow route to a draw or another playa. This will prevent buildings being placed in a flow path at risk for flooding, and fill will not block the route. If the overflow is substantial, we could establish a floodway to protect it.

South Draw, a chain of connected playas, was the source of significant flooding in 2021. This region was developed long before publication of any floodplain map, and many residences are located within the playas and in the overflow routes between them. In response to their flooding, Midland County provided a pumping operation to remove floodwaters from two playa ponding areas, pumping it into a caliche pit downstream.

7.2 Use of Future Condition Flooding Estimates

The adopted flood damage prevention court order that Midland County has includes the minimum provision that all new buildings in floodplain areas be built above the expected flood elevation as published in the Flood Insurance Rate Maps. These maps, based on conditions in the early 1990's, omit several important flow paths and do not show flood elevations on most of the playas.

Our grant study provides the missing information on the omitted flow routes and provide a regulatory elevation for all the major playas. We went further to show a future fully developed flood elevation computed by assuming the watershed will be developed and generate more runoff. The following paragraphs explain why this is the right approach for Midland County.

The City of Midland has required each developer to construct improvements that would offset the impact of their increased runoff, but this may not be fully protective of the downstream unincorporated Midland County areas. Some developments were "grandfathered" if they were already platted, but not yet built, when the Midland Master Drainage Plan was developed.

The City of Odessa's Drainage Manual describes a method to compute the size of stormwater retention, but it does not clearly require it in all instances. Developers have provided retention but have sometimes chosen to use a smaller rainfall as the basis of their mitigation improvement sizing. Larger rains can fill the constructed basins and continue downstream, impacting Midland County. There are developments located in what should have been mapped as a floodway but was not treated as such by FEMA, and these are subject to increased flooding with continued development. South County Road 1317 is an example of this.

In addition, Midland County itself has limited ability to require stormwater retention in the unincorporated areas. Even within the extra-territorial jurisdictions of Midland and Odessa, where the city regulations apply, they are not as well enforced.

Finally, the incomplete and inadequate floodplain maps will eventually by updated by TWDB and FEMA. This will expose property owners to flood insurance requirements based on the FEMA study. Flood elevations and floodways will show results of development that has occurred, thus telling us how deep the water can get and where development should not have taken place, but too late to prevent it.

For all the listed reasons, the safest approach for the County will be to plan for full development and regulate to that level. Buildings in playas especially will be safer if they are raised high enough to account for future increases in ponding. By predicting a fully developed floodway, the County can more effectively protect the needed width of the streams. When the flood maps catch up with reality, landowners will not get such unpleasant surprises.

7.3 Resolving Flooding Issues

Midland County needs to recognize two types of flooding, playa, and riverine, and adopt differing approaches to each.

7.3.1 Playa Flooding

Because many developments occurred long before the County had floodplain maps, and the current ones are not as helpful as they should be, and because of the limited regulatory authority of the County, there are flood problems in playas that need to be resolved.

Any existing ponding locations within the playas, such as caliche pits and portions of playas that have not been developed yet, should be targeted for acquisition of drainage easements. This will at the minimum prevent the displacement of flood waters into already flood-prone properties, and better yet provide a location for a future flood reduction project with further excavation of ponding capacity.

The minimal solution for playas where buildings are subject to flooding is to provide an outfall route that will drain without the need for pumping. This can take the form of a ditch or pipe. Ideally the elevation of the upstream end of the new route is lower than the lowest flooding structure. A pipe or small ditch provides a way for runoff to escape slowly, without pumping. It does not reduce the mapped floodplain extents or prevent structural flooding, but it does reduce the flooding duration and the necessity for governmental response.

Lubbock is an example of a city that has invested many millions of dollars into a pipe system to interconnect their playas, often up to 50 feet deep and very large. In doing so, they have greatly reduced the floodplain areas in the playa overflow routes but have not eliminated floodplains at the playas.

It is probably not practical for Midland County to eliminate all flooding in previously developed playas, but the Flood Planning panels show opportunities to improve conditions.

Midland County has already purchased one of the key caliche pits on South Draw to serve as an outfall for playas that flood homes. Midland County has also coordinated with Endeavor Energy to protect, enlarge, and divert flow into a caliche pit west of S. County Road 1210 in order to lessen flooding of residences on that roadway.

7.3.2 Limited Channelization and Storm Drain Outfalls

Although floodway protection was recommended as preferable to channel construction, there are some locations where channels will be the best option for Midland County. This study identified potential projects on South Draw and the Faudree Outfall of this nature.

Most culverts under Interstate 20 currently are only one to two feet below the ground level, because there were few natural draws or drainways for them to be constructed into. This presents few options to engineers trying to design drainage systems to prevent or correct flooding issues. We have identified at least three locations where substantial flows need to pass under the interstate. If that flow is placed in the natural drainway that is only one or two feet deep, it will spread out wide. A deeper channel could be much narrower. The best way for orderly development to occur and to prevent wide areas of nuisance ponding is to provide an established route for drainage, in essence create a draw where none is present.

Other locations for constructed channels were described as routes to link playas that already have flood-prone structures in them. It is not desirable to drain playas with ditches if they are not flooding structures.

8 Flood Mitigation Alternatives

Our original scope for the project included suggesting improvements for the Faudree area and along Interstate 20 in Midland, however after flooding in 2021, it was discovered that attention would also need to be directed south of I-20 to South Draw. We investigated three locations along South Draw and one interconnected system of playas and channels in the Faudree area.

Improvements in all cases were mainly aimed at playa drawdown after storms. This means reducing the amount of time that flood waters stand in the playas. The max surface elevation is not significantly reduced, but the duration is shortened by having a gravity flow outlet. This is to avoid a repeat of the situation in 2021, where Midland County had to implement an extensive pumping operation in the South Draw to relieve flooding.

FMP tables for the flood mitigation alternatives are included in the digital deliverables. A summary follows.

Table 8-1. Summary of flood mitigation alternatives.

Project Name	I-20 Caliche Pit Connector	WCR 120 Rebuild	Channel across S Hwy 349	Faudree Storm Drain
FMP ID	South D 1	South D 2	South D3	Faudree Storm Drain
Associated Regional Flood Plan Project	FME 091000146 FMS 092000136	FME 091000146 FMS 092000137	FME 091000146 FMS 092000137	FME 091000142 FMS 092000133
Location	Upper South Draw	Upper South Draw	Upper South Draw	Faudree Area
Description	Includes four gravity ditches to connect caliche pits: three with bottom widths of 95-115' across the Endeavor Area and one downstream with 10' bottom width, through a residential area. Also, it includes reshaping the overtopping zone from the largest caliche pit. It was assumed that the area can be used for public recreation.	Improvements to convey water from SCR 1200 to the cotton field east of the end of ECR 120. Includes acquiring ROW and widening and lowering three inverted crowned county roads: 60' ROW WCR 120, SCR 1200, and 60' ROW SCR 1198. Also, it includes two ditches.	Includes one ditch that connects the cotton field to a caliche pit downstream and east of Hwy 349, plus a 7'x7' box culvert crossing under Hwy 349.	Phase 2 connects the OIME south playa to the existing caliche pit, and under I20 with a 48" pipe. Phase 3 connects the detention pond northeast of the Faudree Rd and W CR 122 intersection to the OIME south playa with a 36" pipe.
Cost	$5,404,125	$2,281,443	$1,738,028	$17,329,575
Structures removed	0	6	12	19
Damages Reduction	$170,244	$973,095	$1,675,318	$6,320,931
BCA	2.2	0.1	3.1	0.1

These projects were initially part of an Interim Flood Planning Framework report adopted by Midland County so the County could request TxDOT participation. We provided that report to the Upper Colorado Regional Flood Planning group and it was incorporated as panels shown in Appendix 8-A.

As the RFPG finalized the regional flood plan, the Flood Mitigation Projects shown here were not sufficiently developed to be classified as FMPs. The regional flood plan classified these projects as both FMEs and FMSs. Alignment between our FMPs and the regional flood plan is not exact. The FME lumped our three South Draw projects together along with a fourth Lower South Draw project that we did not develop as a separate FMP. Our Faudree Area FMP excludes Phase 1, though we described it in the body of this report, because we could not assess costs accurately enough. Appendix 8-B contains a copy of the Regional Flood Plan FMEs and FMSs related to Monahans and South Draw.

8.1 South Draw Improvements (I-20 in Midland Solutions)

When the project was initially scoped, we knew I-20 blocks flow, potentially creating upstream (north side) drainage problems. As part of the project, we coordinated with TxDOT related to a series of I-20 reconstruction projects throughout the study area. We alerted TxDOT to the issues and collaborated on ideas for improvements that are being implemented by TxDOT. In June 2021, a major flood event caused significant flooding downstream from I-20 on South Draw. Realizing that the more intensive problems related to I-20 are located on the south side, we refocused task 6120 on South Draw. The solutions investigated are along South Draw and intended to mitigate flows that pass under I-20.

Gravity drainage ditches and retention storage for three problem area locations were modeled in HEC-RAS 1d. None of the projects have a negative impact. All are permittable, constructable, and implementable.

Our main objectives for these three hydraulic project analyses are mitigating flooding and protecting life and personal property in a 100-year storm. Since most flooding is caused by development within playa boundaries in subdivisions established prior to Midland County's joining the NFIP, the flooding has a long duration of several weeks. Therefore, solutions are targeted at providing additional retention storage in areas that will not flood buildings, or gravity drainage for areas where buildings are known to flood. The flooding will still occur, but the duration will be much less.

8.1.1 I-20 Caliche Pit Connector

The first project area we modeled using HEC-RAS 1d is located crossing downstream I-20 Wildlife Study Center. We called this model I-20 Caliche Pit Connector. The hydraulic analysis for this area takes place between cross-sections 30575 and 25500. Cross-section 30575 is located downstream I-20 Hwy and cross section 25500 is located 400 ft upstream of S County Road 1210. Rains in 2021 exposed several properties to flooding.

Some of the flooding has its source in the City of Midland and flows down Midkiff Road across I-20 and into SCR 1210, where it encounters a low area and floods homes. The County has previously constructed a ditch to alleviate this flooding, but problems remain, perhaps exacerbated by improvements to the roadway and partial ditch blockage by trees and an adjacent development. However, some of the flow into SCR 1210 is an overflow condition from South Draw, down WCR 113.

Improvements to South Draw are possible because the natural flow of the draw was diverted decades ago by the owners of caliche pits that lie in and near the natural path of flow. We analyzed a potential flooding solution that will redirect the flow to the natural path and allow it to be captured in the pits, which are no longer in service as quarries. A great deal of runoff will be stored in the pits as retention, and the flow that previously was diverted down WCR 113 will no longer contribute to that flooding condition.

The proposed improvements are also referred to as the Endeavor Area improvements because Endeavor Energy owns two of the caliche pits planned for retention. Improvements consist of four gravity ditches across the project area. The first gravity ditch is 255 feet long, 4:1 side slope (H: V), 95 ft bottom width, and 0.05% slope located downstream of I-20 culverts and allowing flow from the roadway and the upstream I-20 Wildlife Preserve to enter a caliche pit just south of I-20. This pit is located on the south rim of the original playa that the preserve is centered on, and it is important not to drain this wetland by lowering or greatly increasing the size of the outlet to this pit. The current overflow is across Jasmine Road and through a small CMP pipe under the roadway.

The second gravity ditch is 925 feet long, 4:1 side slope, 100-foot bottom width, and 0.6% slope, and it connects a temporary lake to a second downstream caliche pit. The upstream flowline of this ditch must be set no lower than the pipe under Jasmine Road in order to maintain the upstream storage in the I-20 Wildlife Preserve. Additional survey to refine this flowline would be desirable prior to construction. Detailed consideration and modeling of the outlet width would also be useful to ensure that upstream capture duration is not disrupted. Currently only the 100-year future event has been modeled. Changes to the design are possible.

The third gravity ditch is 220 feet long, 4:1 side slope, 115-foot bottom width, and 1% slope. This channel cut will connect both the second and third caliche pits. Endeavor Energy has constructed a portion of the third ditch in conjunction with filling for their drilling and service pads in the area. This partial work was verified with a HEC-RAS model to cause no increase in the 100-year floodplain compared to the FIS BFEs, and it complies with the proposed improvement scheme for this area.

Additionally, Endeavor Energy has a pad that blocks flow into WCR 113 and has extended a north-south access roadway on their property east of South Draw that will further eliminate any overland flow to SCR 1210, as desired. All of the completed Endeavor Energy improvements were incorporated into the pre-project model.

A 200- by 20-foot regrading cut area is recommended on the east edge of the third caliche pit, where flow will overtop the pit and flow out into a residential area. This will prevent a rise in flood elevation at the edge of the caliche pit.

Finally, the fourth gravity ditch consists of 1,507 ft long, 4:1 side slope, 10-foot bottom width, and 0.4% slope that will cross through the residential zone connecting the location of the overtopping caliche pit flood zone to the lower downstream area. The residences have fences and other minor blockages that will not allow free flow of water through the subdivision. This ditch provides for positive drainage out to the open portion of South Draw.

All of the ditches between I-20 and the third caliche pit are affected by existing oil field pipelines. We obtained some depths from Endeavor, but a final design would need additional pothole locations. Endeavor Energy broke the third channel at a pipeline crossing. The cost estimate includes allowances for pipeline lowering which have not been verified with the line owners.

Figures 8-1 and 8-2 below compare pre-project and post-project flood extents and water surface profiles. The 100-year water surface will be reduced, so there is no negative impact related to this project.

The BCA for this project is 2.2. We treated the improvements as green infrastructure because the channels are pervious surfaces with stormwater retention intended to reduce downstream runoff. Without this assumption the BCA would not exceed 1.0. We also assumed that the Endeavor-owned caliche pits can be acquired for public use such as mountain-biking or bird-watching, providing a recreational benefit, but public use is not the key factor in the BCA calculation.

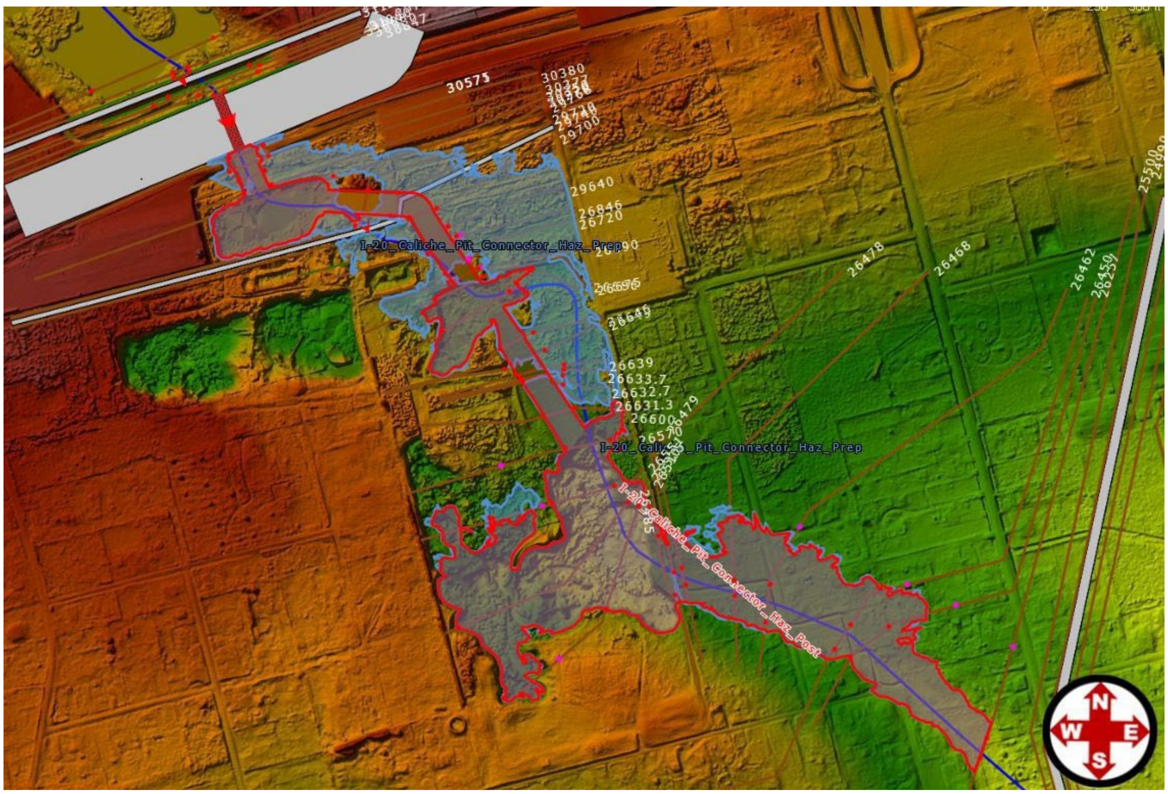


Figure 8-1. I-20 Caliche Pit Connector proposed terrain, cross sections, and model results.

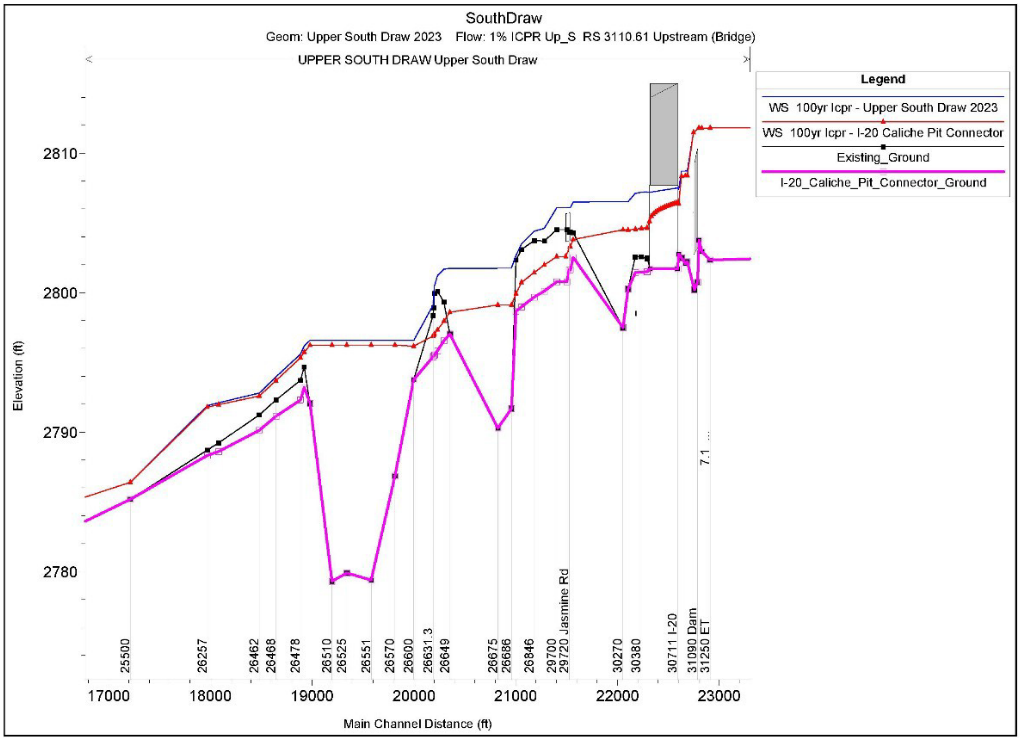


Figure 8-2. I-20 Caliche Pit Connector HEC-RAS profile results.

8.1.2 WCR 120 Rebuild

The main drainage problem in this area is that WCR 120 is the drainway for South Draw, with no defined channel other than the roadway. Homes were constructed in the center of South Draw prior to the initial FIRM, due to the deceptive nature of playa overflow paths in this region, which have no defined banks and carry water only every few decades. Additionally, there are several impediments to flow, including SCR 1200 itself, which though it has two dips, is higher than the ground to the west and blocks the flow of water. During major floods in 2021, Midland County spent significant money pumping flooded areas west of SCR 1200. Providing a positive gravity drainage pathway could eliminate some flooding and shorten the duration of future floods.

The solution for this project area is focused on roadway construction because flooded roads are narrower than County standard, and in poor condition. This type of project will improve drainage and roadway condition simultaneously. The scope includes constructing two ditches and rebuilding portions of three county roads, WCR 120, SCR 1200, and SCR 1198.

Currently these roads do not have sufficient ROW width to install a standard width county roadway. Based on our 2016 LiDAR, SCR 1200 had two dips across the roadway, but neither aligned with the main drainway, WCR 120, which is inverted to carry water in the center of the roadway. There have been improvements to the roadway since the date of the LiDAR, but these improvements did not prevent the June 2021 flooding.

Parkhill modeled additional rebuilding on SCR 1200 to lower and align the two dips with WCR 120 and with the property line about 350 feet south of WCR 120, where a ROW for a ditch to carry additional water could be acquired. This ditch would terminate on SCR 1198, which needs to be widened and lowered to carry the runoff. On the west side of SCR 1200, a roadside ditch is needed to connect the two roadway dips and allow water to cross SCR 1200 in both locations. At the end of WCR 120, a cotton field exists that is the natural bottom of a playa. This field naturally captures runoff, but a better ditch into the field is needed to take water from WCR 120.

A more detailed description of the project needs follows:

- For SCR 1200, the roadway ditch west of the road will require some relocations of utilities. Residents have berms at their property lines, either accidentally as a result of wind-blown build-up or deliberately to protect their property from runoff coming south down SCR 1200. It will be necessary to regrade the entire ROW and possibly to convince adjacent owners to reshape their entrances. For traffic safety, we did not model the roadway dips lower than the existing ground – it still is raised somewhat, and all ponding west of the road will not be eliminated.
- For WCR 120, a 60-foot ROW is needed, and some ROW acquisition will be required. We assumed a 36-foot roadway with a cross slope of 2% to a center invert. The longitudinal slope of the roadway is proposed to be 0.3%. The ROW outside the roadway also needs to be regraded to drain to the roadway.
- SCR 1198, ROW acquisition on the east side to obtain a full 60 feet will allow it to be repaved as an inverted crown road with a 36-foot width. The roadway cross section will be similar to WCR 120, and the longitudinal slope will be 0.6%.
- The ditch south of WCR 120 will be 2,144 feet long, 4:1 side slope, 8-foot bottom width. This ditch route crosses several properties but avoids all structures. ROW of 20 feet will need to be acquired.
- At the east end of WCR 120, the cotton field captures runoff and allows infiltration of floodwaters. It needs to be purchased or an easement acquired for it to prevent it being filled or developed. A 60-foot long ditch with a 4:1 side slope, and 10-foot bottom width was modeled to take runoff out of the road ROW and into the field.

Figure 8-3. WCR 120 Rebuild proposed terrain, cross sections, and model results.

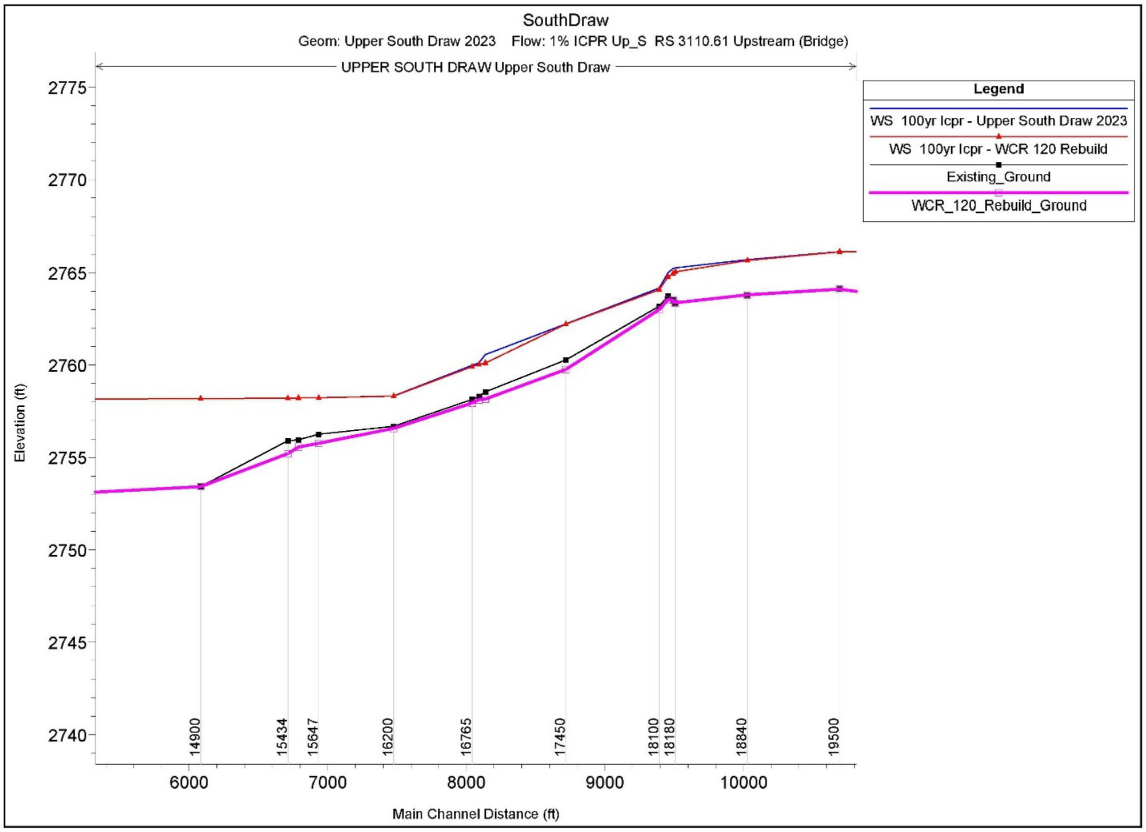


Figure 8-4. **WCR 120 Rebuild HEC-RAS profile results.**

As Figure 8-3 shows, there is no negative impact based on the reduction in water surface elevations, but the positive impact on the 100-year floodplain is not large. The benefits are in flooding duration rather than extents. We found the TWDB methodology for computing the benefit-cost ratio for these projects did not adequately address flooding duration. It is a factor for roadway closures but not for structure flooding. Therefore, we think the true benefits of this project are greater than the 0.1 computed.

8.1.3 Channel across S Hwy 349

The main problem is this area is the accumulation of flooding in a residential area situated in a playa west of Hwy 349. The low point of the playa is a field known as the cotton field. The residential area has an average 100-year flood depth of 5 ft. Buildings are flooded for about one to two weeks because there is no gravity ditch to drain and convey water from one side to another. There is an existing box culverts (four 5 feet by 2.8 feet) under S Hwy 349 and a caliche pit 0.29 miles downstream from the same highway as shown on Figure 8-5. This hydraulic analysis starts from cross-section 16816 and ends at cross-section 10523.

A recommendation to mitigate flooding in this project area is implementing a gravity ditch connecting the cotton field and an existing caliche pit. The proposed earth channel requires a bottom width of 10 feet, 4,320-foot long, 4:1 side slope (H: V), and 0.25% slope. Furthermore, one 7- by 7-foot box culvert is needed to connect the proposed channel through the crossing road (S Hwy 349) as shown in Figure 8-5. An easement or purchase of the cotton field is also required. Midland County has already purchased the caliche pit east of Hwy 349.

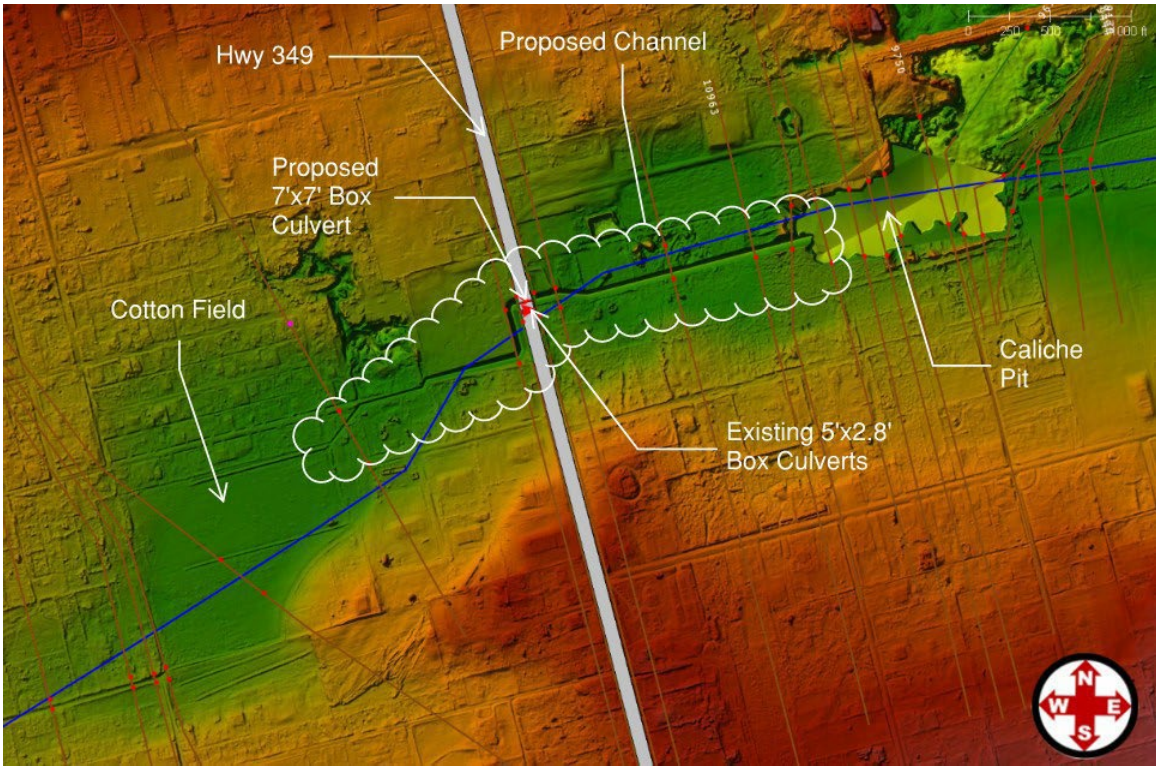


Figure 8-5. **Channel across S Hwy 349 improvements and existing features location.**

This flooding solution does not have a negative impact on the water surface elevation, as shown in Figures 8-6 and 8-7. At station 106+92, the existing profile shows a dip in water surface, caused when flow crosses critical depth dropping in the existing caliche pit. At this location we modeled a smoother transition into the pit, causing the proposed water surface to be higher than existing.

We were also concerned about whether draining the cotton field playa into a downstream series of pits and playas with no outfall would have a negative impact. The volume capacity of the cotton field playa below the outfall of the proposed ditch is 72 ac-ft. The volume of the caliche pit which will receive additional runoff, and which has now been protected from filling is at least 205 ac-ft. Since this pit has recently been increased in size by the previous owner, and was not previously protected as a drainage feature, we consider the project to have a net benefit in storage.

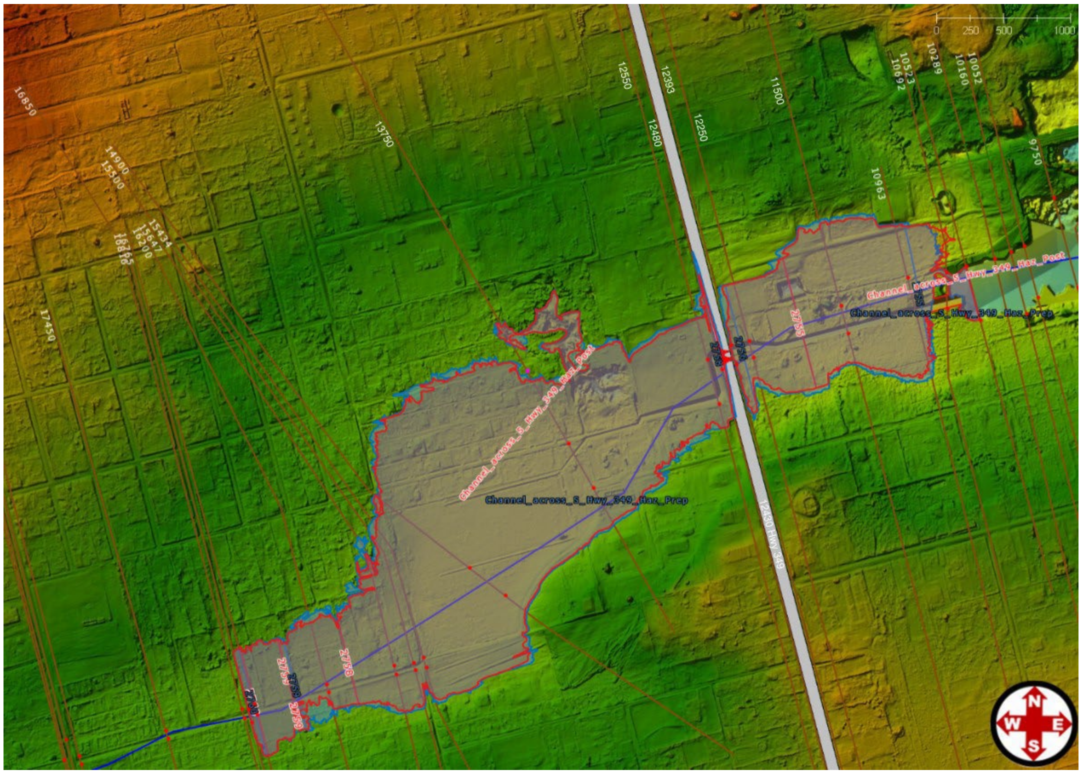


Figure 8-6. **Channel across S Hwy 349 proposed terrain, cross sections, and model results.**

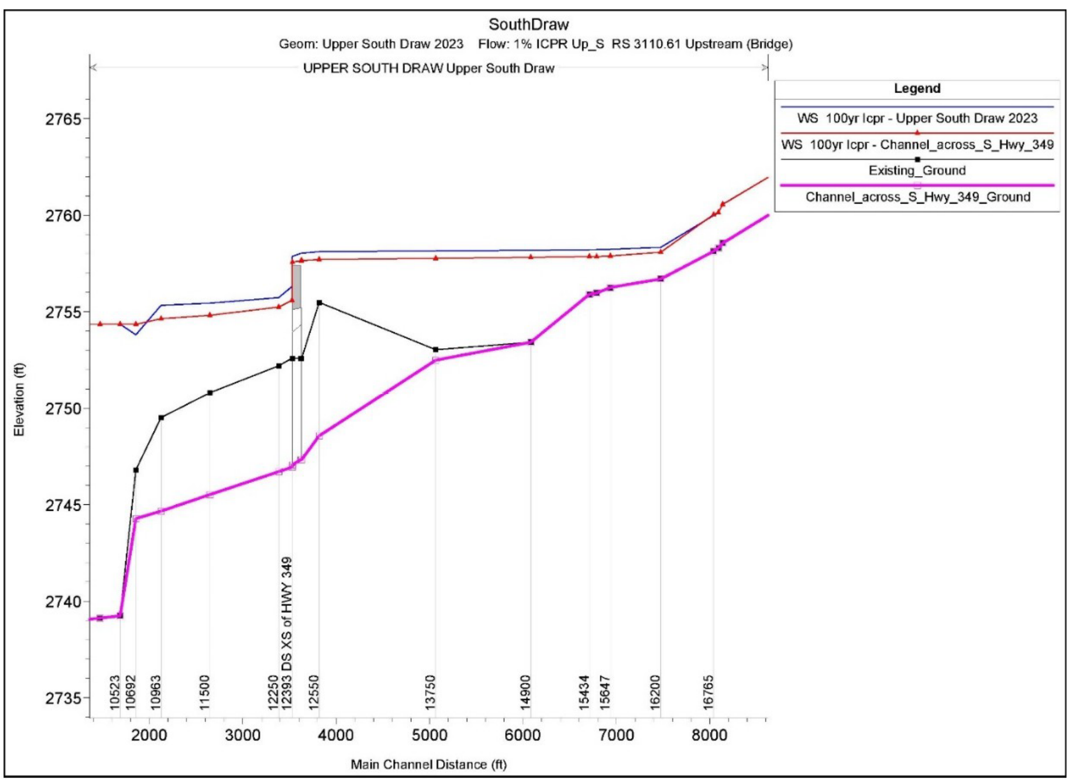


Figure 8-7. **Channel across S Hwy 349 HEC-RAS profile results.**

8.2 Faudree Area Improvements

The proposed Faudree area improvements aim to reduce the flooding in the OIME playa that is bisected by Business 20 (B20) and the corridor between BI-20 and Interstate 20 (I-20). Our plan consists of three phases, which are described below. Figure 8-8 shows the approximate locations of the proposed improvements. Midland County as hired a consultant to further develop the route and costs Phases 1 and 2 of the Faudree area outfall, and applied for funding for the route study under the latest TWDB grand opportunity.

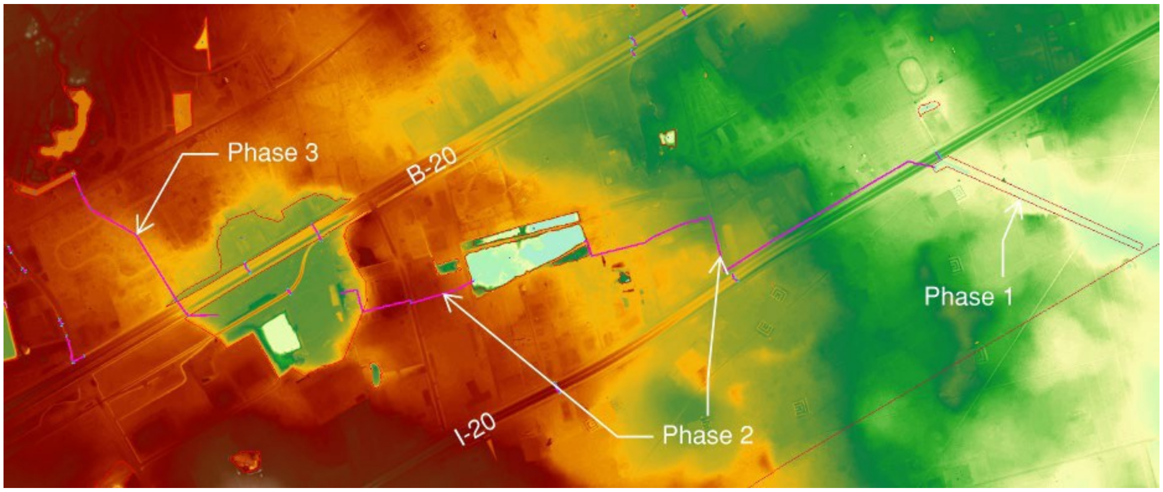


Figure 8-8. Approximate Faudree improvement locations.

8.2.1 Phase 1

Phase 1 is a channel located at the outlet of Culvert 3G, located at the east limit of Phase 2 beneath I-20. Culvert 3G is located approximately 1.4 miles west of the I-20 interchange with Hwy 349 and consists of a planned set of nine 6- by 2-foot boxes at the existing natural ground flowline. In addition, there will be an additional 48-inch circular pipe that we requested TxDOT add and plug, with a flowline lower than the existing natural ground. The channel will flow southeast until the flowline daylights. The design of the channel was not part of this study; thus, we do not yet know the dimensions, slope, and length needed to daylight. The ICPR model boundary is just south of I-20, so we added a triangular channel into the surface in ICPR to allow flow from the culvert to exit the model freely. This channel will provide an outfall for the storm drain system that will link ponding areas in phases 2 and 3. Phase 1 was not included in the FMP for this report due to a lack of information on route and crossing pipelines.

8.2.2 Phase 2

Phase 2 of the Faudree area improvements consists of connecting the OIME playa to the existing caliche pit (E0245-27), and that pit to a 48-inch culvert under I-20 mentioned in Phase 1. The section connecting the pit to the culvert we called Phase 2A, and the section connecting the OIME playa to the pit we called Phase 2B. The pipe in Phase 2A will include roughly 6,000 feet of 48-inch HDPE pipe at a 0.1% slope. The estimated path this will follow is shown below in Figure 8-9.

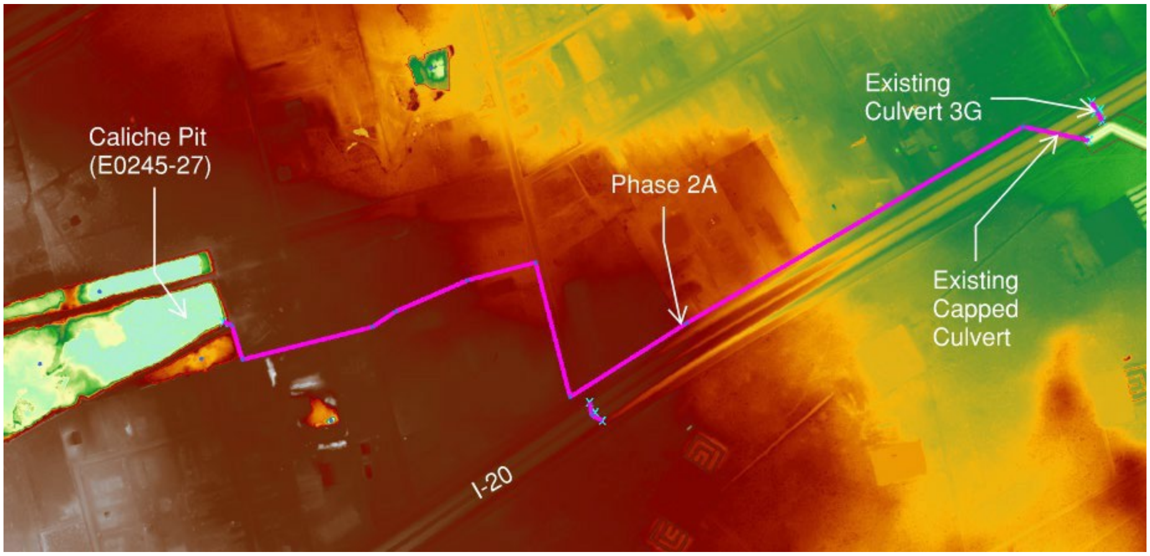


Figure 8-9. Approximate phase 2A Faudree improvement location.

Phase 2B will be roughly 2,300 feet of 48-inch HDPE pipe at 0.1%. The estimated path for this pipe is shown in Figure 8-10. Some grading in the OIME playa will be required to direct water to the inlet of this pipe.

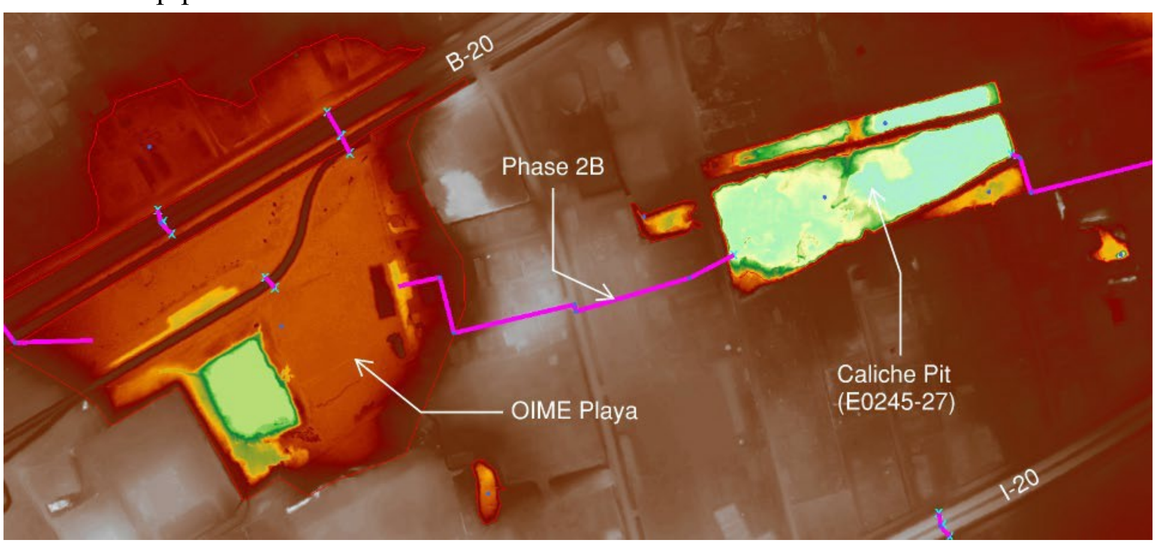


Figure 8-10. Approximate phase 2B Faudree improvement location.

Because the outfall is not significantly lower than the bottom of the pit and the OIME playa, we needed to use very flat slopes in the pipes. While this limits the capacity that the pipes can carry, maxing out at 70 CFS in phase 2A and 120 CFS in phase 2B, it still accomplishes the goal of draining both the OIME playa and E0245-27 significantly faster than pre-project conditions. This is especially helpful in the OIME north area, where businesses are currently experiencing significant flooding that lasts for weeks.

8.2.3 Phase 3

Phase 3 is a pipe that connects the existing detention pond northeast of the intersection of Faudree Rd and W CR 122 (E0245-44) to the south OIME Playa. The intent of the design is to bypass S County Rd 1317, Business 20, and the railroad. In pre-project conditions, flooding must flow overland to an existing 4- by 2-foot culvert under BI-20, which is located over 1,000 feet east of SCR 1317. This results in serious flooding along SCR 1317, in the surrounding neighborhood, and in the businesses that line the highway.

These improvements will require roughly 3,400 feet of 36-inch HDPE pipe. To achieve enough cover, the first stretch of the pipe will be at a 1.2% slope. It evens out at about a 0.4% slope along SCR 1317 and across the highway and the railroad. Finally, the last section is at a 0.1% slope to daylight into the OIME playa. The estimated path for this phase can be found below in Figure 8-11.

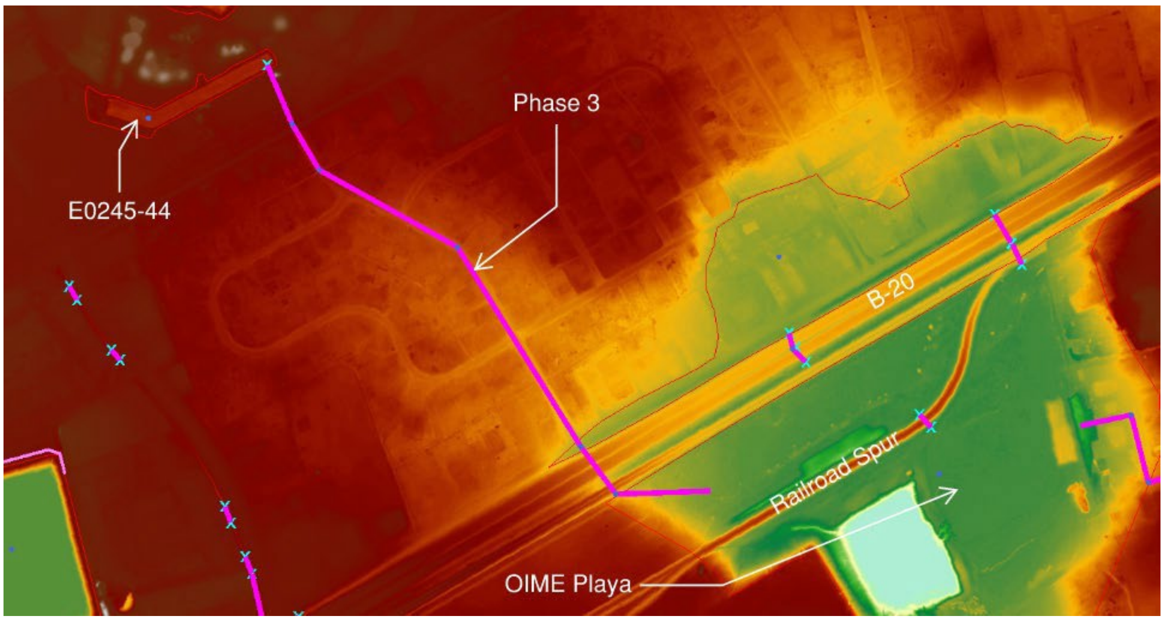


Figure 8-11. Approximate phase 3 Faudree improvement location.

Results

A benefit-cost analysis was completed for the Faudree area, and a summary of the results are shown in Table 8-1. The main goal of these improvements was to reduce the depth and duration of flooding that occurs in the north section of the OIME playa and along SCR 1317, by giving the south OIME playa an outlet and utilizing the storage in the existing caliche pit, which currently does not capture significant volumes of runoff.

As seen in Figure 8-12 below, that maximum flood extents are modestly reduced from existing (pre-project) to proposed (post-project). The max flood depth in and around the north OIME playa is reduced by roughly 1 foot. Most of this water is diverted to the caliche pit in the proposed conditions.

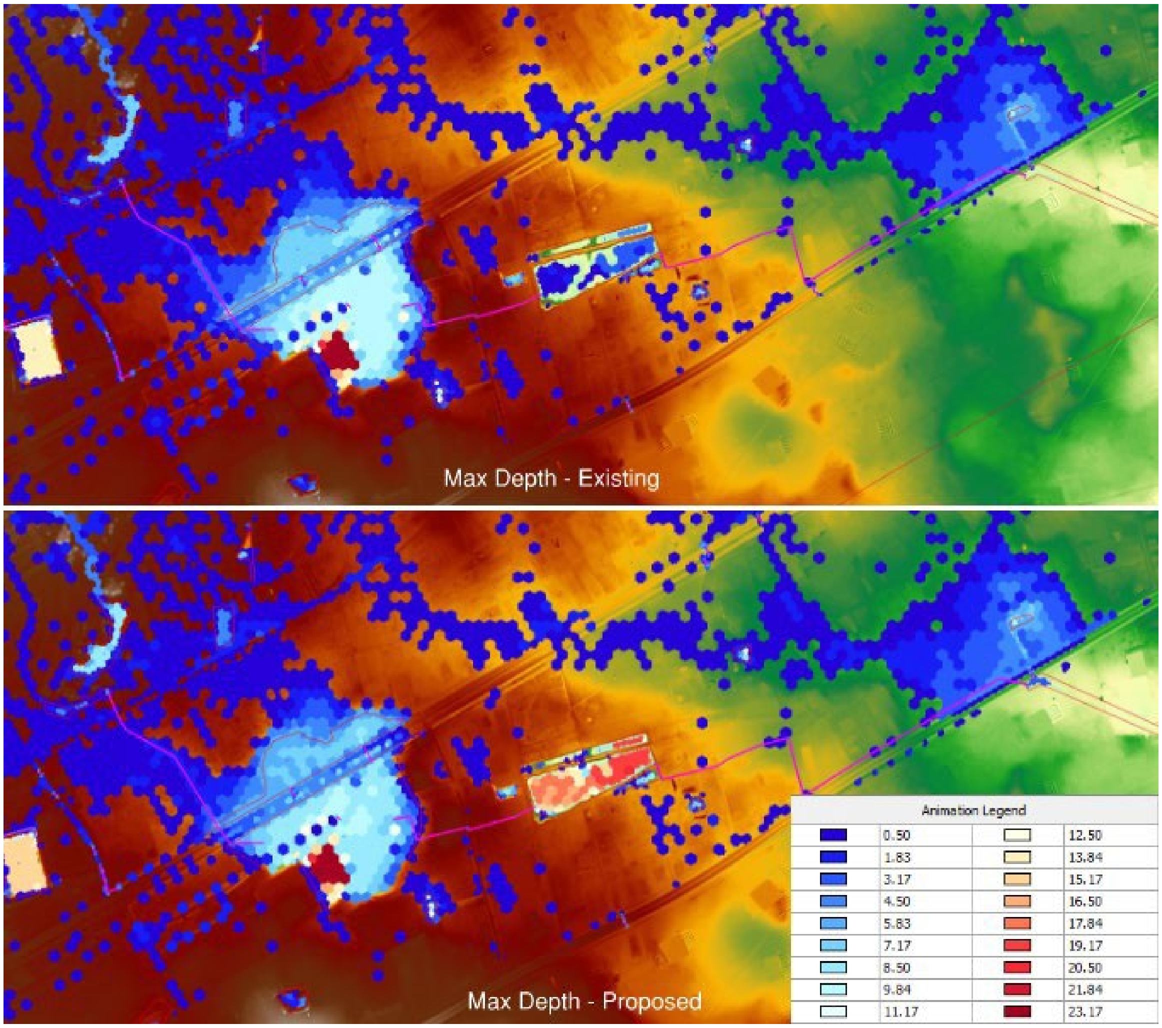


Figure 8-12. Maximum depth with and without project.

The most significant improvement seen in the proposed conditions is the duration of the flooding. The max flooding comes between hour 5 to 7 in both scenarios. By hour 20 in the existing scenario, the north and south OIME playas equalize and since there is no outlet, it remains at this level through the end of the simulation at hour 220. This is shown in Figure 8-13.

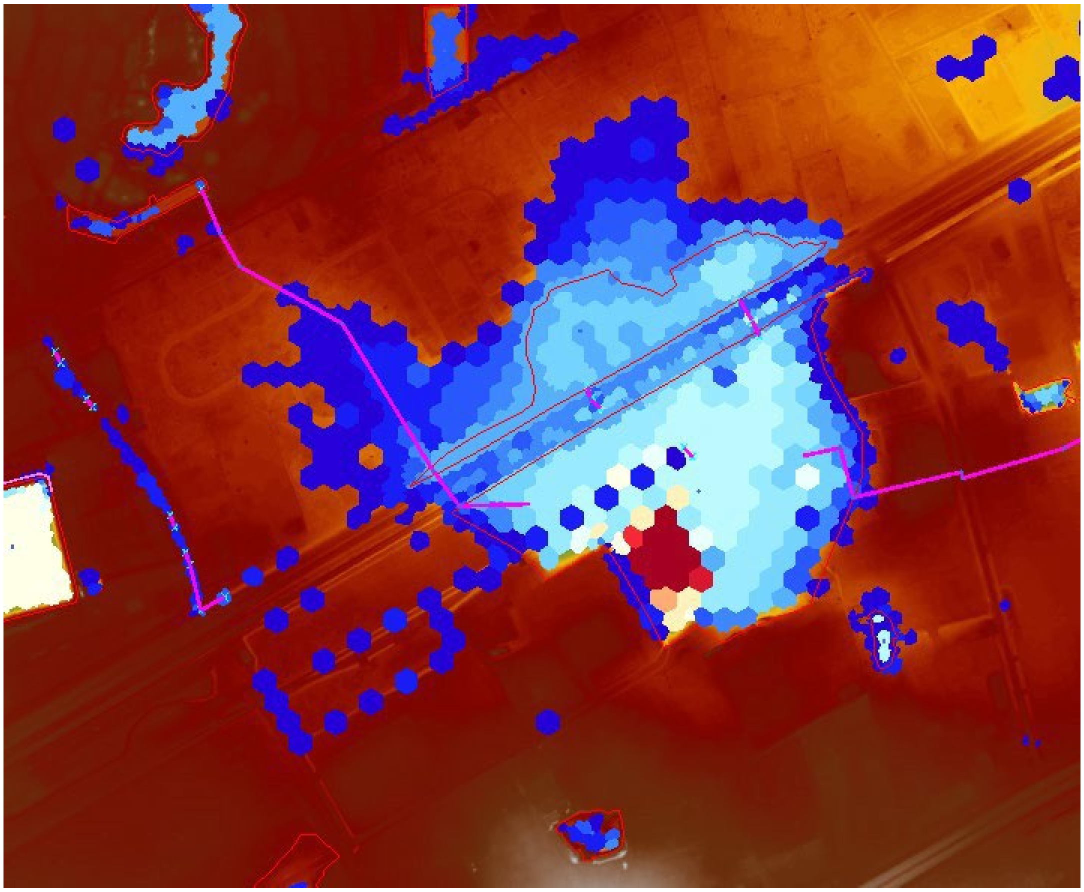


Figure 8-13. Pre-project flood depths at hour 220.

The flooding duration is reduced in the proposed scenario due to the new outlet. The extents shown at hour 220 of the pre-project scenario are matched at hour 15 of the proposed scenario and it slowly drains through the proposed pipes. The flooding is mostly out of SCR 1317 by hour 72, marking a significant improvement from the pre-project scenario.

There is no negative impact on water surface in the Phase 2 and 3 area. The water ponded in the caliche pit of course increases, but if it is purchased for the purpose of flood control, that increase will be acceptable. Phase 1 of the project provides a downstream outfall that could have a negative impact on downstream water surfaces. The runoff will be captured in either another caliche pit or a large non-overflow downstream playa. Because Phase 1 will need currently undefined easements to accommodate these increases, it was not included in our FMP recommendations.

8.3 Specific Recommendations

Appendix 8-A contains the previously prepared Flood Planning Framework panels. Detailed panels A through I depict the recommendations and needs for Midland County as we know them currently. The Upper Colorado Regional Flood Plan integrated nine of these suggestions as Flood Management Strategies. See Appendix 8-B for a copy of the relevant pages.

8.3.1 Panel A

Panel A covers the area north of Interstate 20 between Midland and Odessa. The Monahans Draw watershed north boundary is roughly aligned with US Hwy 191.

Playas west of FM 1788 and in the area that drains through the airport have previous master drainage plans that comply with City of Midland regulations. Most of the playas from the airport west are predicted to overflow. Overflow routes are not shown but may need protection in the final report. A large playa system east of the airport does not overflow as studied by FEMA. We have shown easements for the lowest portions connected with a ditch.

Some playas near Avalon Drive are also regulated or owned by the City of Midland. Several small retention basins exist or are planned to reduce flows into roadways. Some locations for drainage ditches to provide outfalls for the roadway have also previously been identified.

South of Business 20 at the airport, channel improvements are needed to reduce constant ponding inside the airport and provide a better outfall. An outfall floodway and easements between Business 20 and I-20 needs to be protected.

8.3.2 Panel B

Panel B addresses an area centered by FM 588, Faudree Road, and containing a number of well-known flooding issues. This area is partly in the City of Odessa, with a number of drainage improvements previously constructed by or regulated by the City. Odessa Country Club has two golf courses on each side of Faudree Road, both of which provide significant drainage benefit as they are located in two main flow paths.

Summer 2021 highlighted repeated flooding in the playa called "OIME" by the City of Odessa, located along Business 20 east of Faudree Road. This playa filled and flooded several homes for an extended period this summer, but ponding was not the only issue. Homes along South County Road 1317 also flooded as runoff overtopped the ponds in the golf course to the north.

Panel B includes the Faudree Area Improvements from Section 8.2 and a ditch to drain it along the Faudree Outfall floodway route.

8.3.3 Panel C

Panel C shows three main flow paths into an enormous deep playa located south of I-20 and east of FM 1788. Our study showed that this playa is unlikely to overflow. This playa collects all the flow from a large part of eastern Odessa, and all the area from there to the airport.

This study includes the MAF and Faudree outfalls into the playa with floodway determinations, easements, and construction of drainage channels. Development is imminent, and implementing these elements will prevent many of the issues experienced in the rest of the watershed.

Several routes from the interstate into the large playa are possible. The panel shows one that may cross fewer pipelines, avoid existing developments, and take an existing caliche pit into the drainage system. Further development of these routes will be needed in separate projects.

8.3.4 Panel D

Panel D extends west of the detailed study area for the Flood Planning grant to the county line. It is centered on Monahans Draw. It also includes some of the deeper playas and the overflow route from the large playa on Panel C.

The area west of our study boundary is known to have another major outfall from the City of Odessa on it. Although not in our study boundary, it is a similar route that needs to have a floodway definition, easements, and a constructed channel.

8.3.5 Panel E

Panel E has overlap with Panel D. It contains a closer view of the overflow route for the playa on Panel C and numerous playas that will need protection. Monahans Draw is also centered in this panel.

Also of note to the west of the new South County Road 1232 are several pond controls within a single depression. None were shown to overflow in the study, but all should be protected.

8.3.6 Panel F

Panel F illustrates the remainder of Monahans Draw to its confluence with Midland Draw. The effective detailed flood insurance study of Monahans Draw ends just east of the 90-degree bend northward in FM 1213. At that point, the draw widens into a huge flat area where it overflows into Consavvy Lake and other depressions before a lesser flow continues eastward.

A floodway was determined for this area that indicates what portions of the complex flow paths need to be protected with easements.

8.3.7 Panel G

Panel G is a close view of the upper end of South Draw east to Cotton Flat Road.

The contributing area for the western arm of South Draw starts north of Business 20 and west of Loop 250, draining through a channel into an easement in a playa north of I-20 owned by TxDOT. The south half of this playa still needs easement protection. This playa is found to overflow southward across areas already mostly developed.

A route for the overflow is shown on the panel, passing through a caliche pit, connecting through a second small playa, and terminating in a large deep playa west of South County Road 1210 (Midkiff Road). This route was studied as South Draw Tributary, and a floodway defined. Oil development in the floodway has already taken place.

The main South Draw leaves the I-20 Nature Preserve by way of a culvert across I-20. TxDOT has provided preliminary plans for reconstruction of the interstate at this location, showing it is intended to be raised by over a foot, and larger culverts installed. TxDOT initially had a plan that included an easement south of I-20, but no excavation or enlargement of the existing small ditch. After coordination with Midland County as part of this project, additional downstream easement was proposed with a small retention basin downstream of I-20.

South of I-20, there are five caliche pits located near the route of South Draw, which fill in with most storms due to some ditches that divert water into them. However, a great deal of flow is also diverted away from the pits and flows down West County Road 113 to Midkiff Road, where it flooded several homes in summer 2021.

County staff have coordinated with Endeavor Energy, which owns two of the pits and surrounding land. A proposed system of ditches to connect three of the caliche pits with ditches is illustrated. Endeavor Energy has constructed a portion of a ditch and used the caliche material to fill their pads and provide a berm that prevents water from being diverted to South County Road 1110. Midland County has also purchased three of the caliche pits not owned by Endeavor Energy.

Section 8.1 describes additional improvements proposed along South Draw.

8.3.8 Panel H

Panel H follows South Draw from Cotton Flat Road to FM 715.

Cotton Flat Road brings flow from Midland to South Draw. It has no well-defined roadside ditches. TxDOT has requested that the County establish them. Any ditches on Cotton Flat need an outfall to the east. The road has two dips just north and south of West County Road 120. In summer 2021, ponding west of Cotton Flat was pumped out by the County. A solution is shown that should eliminate the need for further pumping. This area can be drained with a shallow ditch. Sectio 8.1 describes additional improvements proposed along South Draw.

The area on both sides of Lamesa Road is in a very deep playa, over 10 feet. Though no one has seen such extensive flooding, increased urbanization is likely to direct more water into this playa. There are several large caliche pits separated by pipeline routes, Midland County has purchased a caliche pit east of Hwy 349. There is also a ditch under I-20 just west of Lamesa Road that contributes a good deal of runoff from Midland and needs a defined flow path to the draw.

8.3.9 Panel I

Panel I completes the path of South Draw to Midland Draw. From I-20 across FM 715 and US Hwy 158 (Garden City Hwy), it is a constructed channel similar to the ones advocated in other locations. The easement is owned by TxDOT.

There is a history of flooding in the triangle north of I-20 formed by FM 715, Hwy 158, and I20. Solutions to the flooding could be enhanced if South Draw were deepened. It is feasible to deepen South Draw all the way to Midland Draw because currently it enters Midland Draw about four feet up the bank of Midland Draw.

Midland Draw itself is outside the watershed of our Flood Planning Study, but TxDOT is reconstructing the overpass where Midland Draw, FM 307 and I-20 all intersect. In meetings with TxDOT's consultants, we were asked to evaluate whether any improvements to Midland Draw were feasible or advisable. Due to the excessive numbers of crossing pipelines, a minimal approach is recommended. This panel shows an area just up and downstream of I-20 that could be slightly deepened if it benefited the TxDOT design.

9 Conclusion

This project was successful in addressing the scope elements and objectives. In particular, we were able to show that ICPRv4 2d modeling with Green & Ampt loss rate methodology is highly effective in portraying flood conditions in West Texas more believably.

9.1 Implementation

ICPR model results will be useful to the stakeholders in ongoing regulatory and project-specific pursuits. Upgraded and new HEC-RAS models with floodways will assist the County in protecting vulnerable draws and flow paths in the areas subject to the most development pressure.

The specific FMPs in Section 8 and the additional flood framework panels show an ambitious drainage system that will be decades in completion. Midland County will need to coordinate with two cities, TxDOT, numerous landowners and an array of oil and gas interests to implement the recommendations. Opportunities for cost sharing will arise, but the County will need to be alert for opportunities. The report makes an effort to identify high priority projects, but local needs will change. Development will spur many of the drainage improvements.

The principles for flood prevention and reduction in Section 4.0 should be adopted as the guide for implementation and adaptation of this and the final drainage report. Implementation will have several elements:

- Development review process:
  - Enforce the Flood Damage Prevention order as possible.
  - Modify the Subdivision Regulation court order as needed to better incorporate the flood prevention principles.
  - Key element for development is to obtain easements for drainage on floodways and in playa bottoms.
  - Use full development flood estimates to regulate structure elevations and easement widths.
  - Projects can be funded by developers as part of the overall system in the adopted report.
- Flood Reduction Projects:
  - Detailed route studies to identify the best path for proposed ditches and pipes.
  - Acquisition of right-of-way or easements through existing developments.
  - Construction is likely funded mostly by County, with some TxDOT, Midland and Odessa participation.
- Outfall Channelization Projects:
  - Needed at key drainage routes where flood waters cross I-20 southward and no defined channel exists.
  - Prevent future and existing flooding where easement acquisition will not be sufficient.
  - Detailed route studies to identify the best path for proposed ditches and pipes.
  - Establish route prior to development for least expense.

Table 9-1. Detailed Scope, Conclusions, and Next Steps.

Task Name	Task	Detailed Description of Work	Conclusions	Next Steps
1SET	Base layer development and setup	Methodologies investigated to select ICPRv4 as hydrology model. Rainfall and roughness zone table data developed. Soils data downloaded and prepared for ICPR use. Accuracy of NLCD data investigated. Data collection app developed and used to collect structure measurements along with survey.	2d Analysis is needed for majority of watershed due to braided flow paths. ICPRv4 with Green & Ampt loss rates allows infiltration throughout the computational time, resulting in much reduced flow rates compared to other methods. NLCD impervious % was found inaccurate in semi-rural areas, so we decided to modify land use maps based on measured average imperviousness.	None
2PLA	Study playas in detailed area (~210)	Combined with 5RIV due to ICPRv4 2d modeling. GIS layers for land use and roughness developed. Develop ICPRv4 models for nine breakout areas. Playas studied with level-pool routings.	Models described in Section 5. Future flood depths from ICPRv4 uploaded to geodatabase.	Use future flood depths to regulate Midland County development and to design infrastructure.
3FAU	Faudree 2dICPR and solutions	Develop ICPRv4 2d model for Faudree Area, assuming little or no upstream retention but including detention under design. Coordinate with TxDOT, City of Odessa and Odessa Country Club on flooding problems. Investigate a gravity drain outlet for the OIME playa. Get TxDOT to add a 48" pipe under I-20 for future connection in the gravity solution.	Upstream development without retention or downstream conveyance improvements will seriously impact areas around Mission Estates. The OIME playa has no outlet, already floods severely and will capture much more runoff. The most important need is a gravity outfall to reduce duration of flooding. A three-phase solution was chosen for and two phases were developed as FMPs.	Midland County has a consultant working on route and cost assessment of two of the phases. TWDB grant applied for on this work. ROW will need to be acquired and numerous pipelines avoided or lowered to make the outlet possible.
4MAF	Update MAF ICPR hydrology	Develop ICPRv4 2d model for Midland International Airport Area, assuming no upstream retention other than caliche pits. Incorporate I-20 proposed crossing upgrade and mainlane rise.	Airport sits in flow path for several playa overflows. Large caliche pits are serving as retention. Ponding on the airfield is caused by TxDOT and railroad crossings at the south end. I-20 may still overtop despite improvements.	Make model available to City of Midland so they can plan improvements to protect airport. Investigate structure upsizing downstream of airport. Acquire easements on caliche pits.

Task Name	Task	Detailed Description of Work	Conclusions	Next Steps
5RIV	Riverine Hydrology, Detail Study Area	Combined with 2PLA due to ICPRv4 2d modeling. GIS layers for models developed. Develop ICPRv4 models for nine breakout areas. Playas studied with level-pool routings.	Models described in Section 5. Flood depths from ICPRv4 uploaded to geodatabase.	Use future flood depths to regulate Midland County development and to design infrastructure.
6I20	I-20 in Midland Solutions	Coordinated with TxDOT in I-20 design phase to allow TxDOT to implement solutions. Altered focus to South Draw south of I-20 where major flooding occurred in 2021. Modified task 8SOU HEC-RAS models to find solutions in three locations.	Midland County's main need is to eliminate pumping after major storms. Gravity outlet options for two locations were developed as FMPs. Upstream storage in existing caliche pits with channels to connect them was developed as a third FMP. Coordination with Endeavor Energy resulted in their construction of portions of the third system.	Midland County has purchased three of the upstream caliche pits/ponds, plus one pit for the eastmost gravity solution, to protect them as stormwater retention. Analyze them further to maximize benefits. Obtain ROW and construction the projects.
7UPS	Upstream Hydrology for Monahans Dr	Develop a model of the huge 445 square mile Monahans Draw watershed that contributes to Midland County. Purpose of the model is to provide an input hydrograph for the remainder of the Monahans Draw ICPR models.	Model produced flow rates much less than FIS models. They may be accurate but do not include all the culverts in the model, possibly leading to volume not reaching the outfall. Flow rates may also increase if undersized culverts are upgraded. We chose to double the hydrograph into the rest of the study to provide a greater factor of safety.	Make model available to City of Odessa and Ector County for their use in additional master planning.
8SOU	Hydraulic analysis of South Draw	Update and revise FIS HEC-RAS 1d models. Split models at the major playa east of SCR 1180.	These are more detailed and accurate floodplains using future land use and lower flows from ICPR models.	Use floodways to assist in locating easements for projects along the draws.
9FP4	Hydraulic analysis of 4 flow paths	Create HEC-RAS 2d models for the Faudree draw upstream of Hwy 191 and downstream of I-20, for the MAF outfall, and for a tributary to Upper South Draw. Develop floodways for all four.	These are detailed and accurate floodplains using future land use and flows from ICPR models. FIS did not include these flow paths.	Use flood elevations to regulate development since there are no FIS models. Use floodways to assist in locating easements for projects along the draws.

Task Name	Task	Detailed Description of Work	Conclusions	Next Steps
10MO	Hydraulic analysis of Monahans	Update and revise FIS HEC-RAS 1d models in area of FIS study. Create 2d model of the incredibly complex Salt Lake area. Create 1d model of remaining portions of Monahans Draw not studied by FEMA. Develop floodway for entire Monahans Draw in Midland County.	Use of much lower ICPR flow hydrographs in the models reduces floodplain widths in the FIS studied area. It increases floodplain in other areas where FIS showed Zone A.	Use flood elevations to regulate development in portions where there are no FIS models. Use floodways to assist in locating easements for projects along the draws.
11PA	Project Administration and Report	Write report and develop GIS layers to TWDB standards. Also develop GIS layers for Midland County's use in floodplain regulation.	See above.	Adopt findings in revised court order for development and subdivisions.
SRVY	Survey for ICPR and Hydraulic analyses	Survey of structures crossing many roadways in Midland and Ector County.		None