Task 1: Determine the Exposure

Introduction

The *Vulnerability Assessment Screening Tool (VAST)* developed by FHWA provides detailed guidance on evaluating the vulnerability of transportation assets, but it is limited in scope to climate change incidents. As an inland area, the Killeen-Temple Metropolitan Planning Organization (KTMPO) region faces a slightly different set of vulnerability challenges in comparison to coastal areas of Texas. This first task is therefore to determine the range of incidents that the region is exposed to, and to exclude incidents that are not relevant (i.e., storm surge), or are so unpredictable that their effects cannot be located (i.e., tornados).

After discussion with KTMPO staff, the list of hazard events which are relevant to the region are defined as:

- Flooding from rainfall
- Flooding from dam breach
- Wildfire
- Drought or high temperature
- Key infrastructure disruption points

Data for each of the hazard events was gathered from Federal databases and converted to a score in the range of 1 to 5. The scores were then applied to the ¼ mile grid cells of the Regional Vulnerability & Resilience Framework (RVRF).

To identify disruption points in the network, we relied on the list of bridges from the National Bridge Inventory for the road networks. The rail network disruption points are based on bridges identified through a review of aerial imagery.

In addition, we reviewed and scored land use to determine the infrastructure's exposure to hazard events and to define critical land uses which are particularly at risk. This may be somewhat beyond the scope of this study on transportation infrastructure, but it did not seem logical to ignore the information once it had been gathered. This technical memorandum and the associated GIS data layers therefore present the full range of exposure to hazard incidents for the KTMPO region.

Flooding from Rainfall

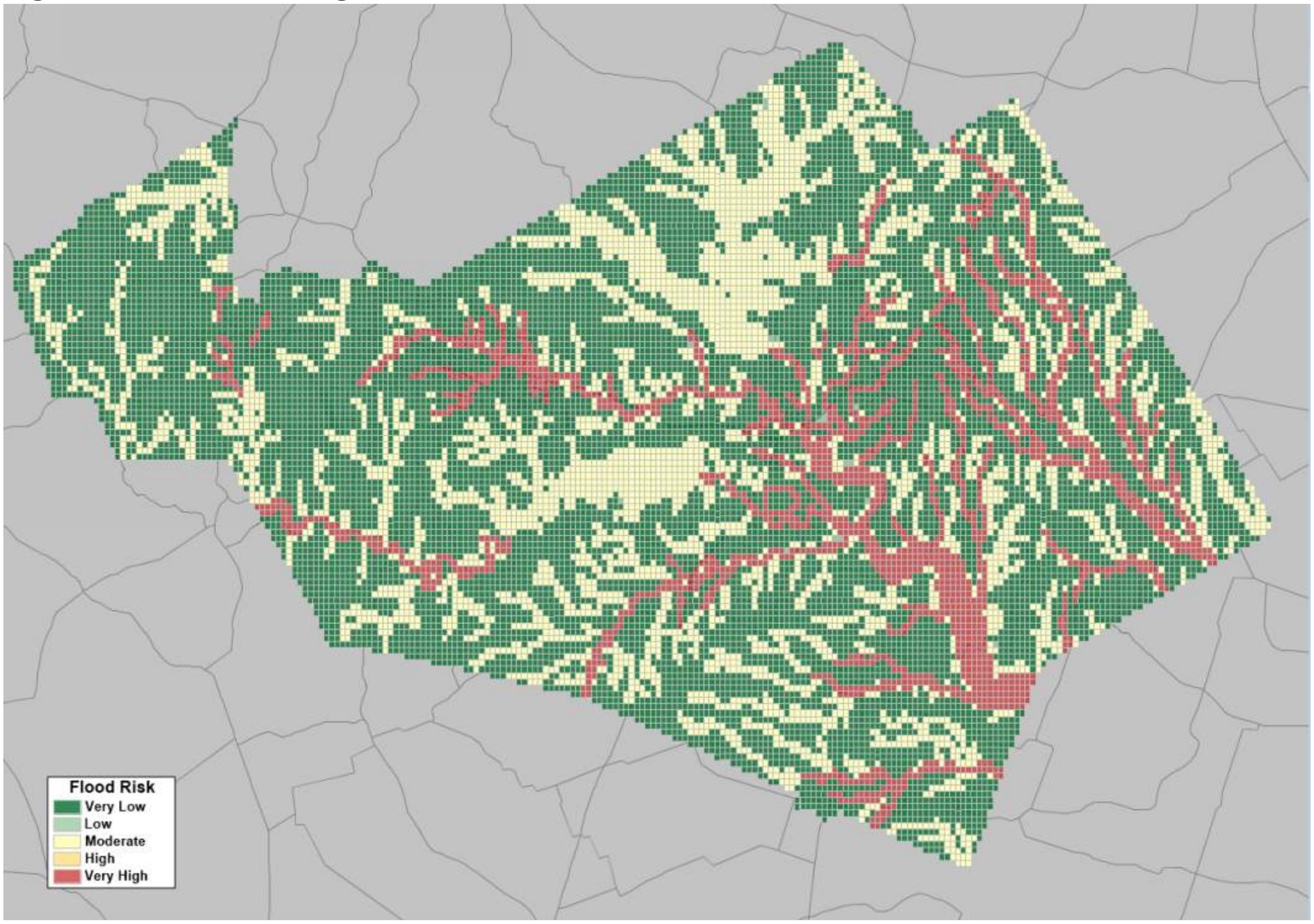
GIS data from the National Flood Hazard Layer maintained by FEMA was used to estimate the risk of flooding from rainfall. The maps are presented by county, and define geographic areas with the attributes of floodway, 100-year floodplain, 500-year floodplain, and minimal risk of flooding.

When applied to the RVRF grid of 16,518 cells, mapping the scores resulted in:

- 59.5% had a minimal risk of flooding
- 0.1% fell in the 500-year floodplain, with a very low risk of flooding
- 27.6% were in the 100-year floodplain, with a moderate risk of flooding
- 12.8% were in defined floodways, scored with a very high risk of flooding

Figure 1 shows the regional risk of flooding from rainfall.

Figure 1: Risk of Flooding from Rainfall



The risk of flooding from rainfall is seen to be very dependent on topology. The map clearly follows natural drainage sheds, with grids rated "very high" placed immediately adjacent to grids rated "very low" due to the channelization. The grid also shows a minimal assignment of cells to the "low" category for risk of 500-year floods, which is due to the topography and the aggregation of the grid to the ¼ mile cells.

Flooding from Dam Breaches

The risk of flooding from dam breaches was developed from a visual identification of dams and impounded waters. A total of 98 dams were identified from aerial photography, which included the two large dams at Stillhouse Hollow Lake and Lake Belton, several Soil & Water Conservation and City reservoirs, and numerous smaller dams which were not named. Water impounded in earthwork tanks were estimated as being below the ground level and not resulting in any risks, so these tanks were excluded from consideration.

Unlike flooding from rainfall, flooding from a dam breach poses a hazard only for areas downstream. Therefore, most of the RVRF grid scores are zero; water from a breached dam cannot flow uphill, so there is no risk to those areas from a dam breach.

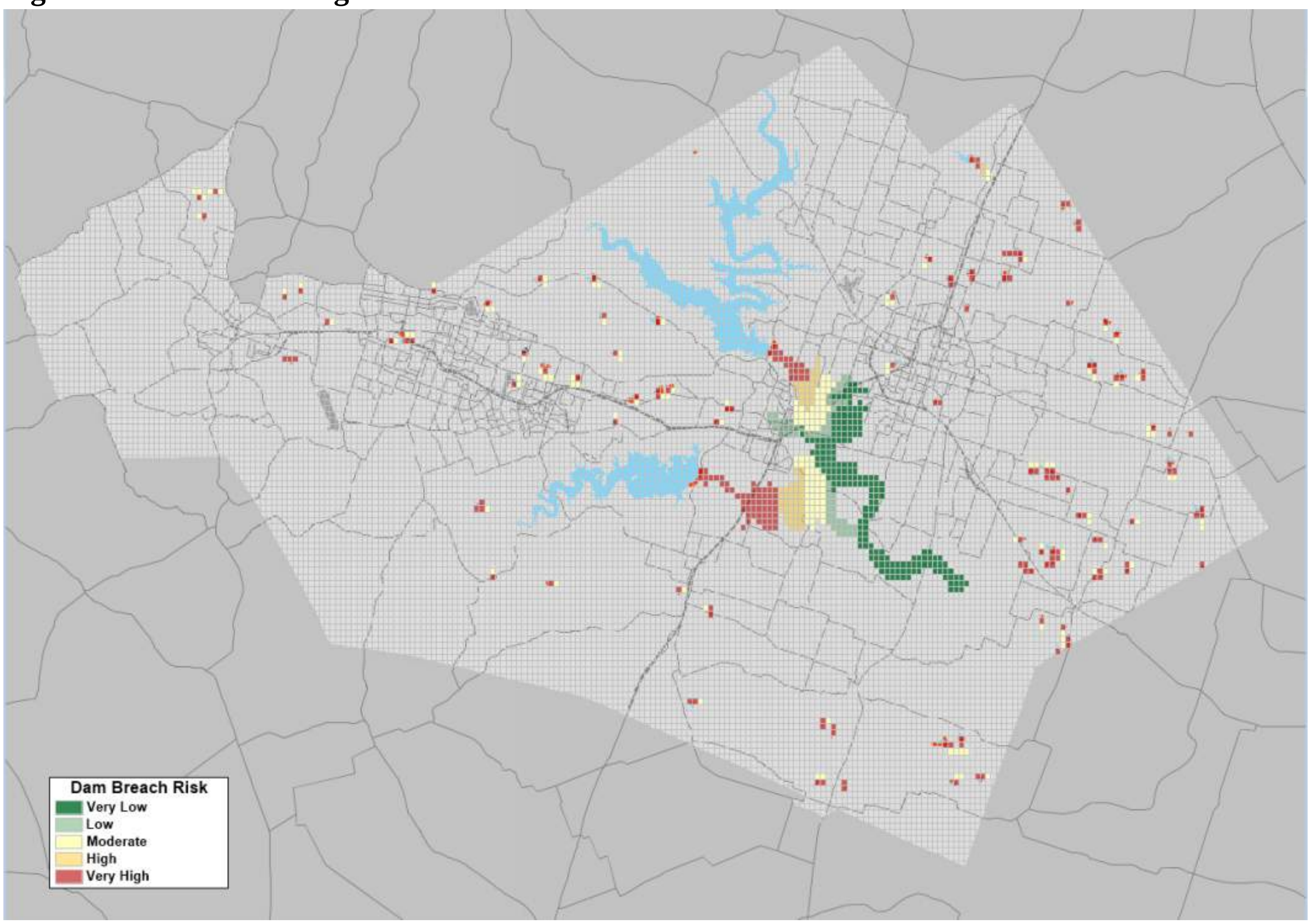
Research showed that data on impounded water volumes was available only for the larger dams. Risk was therefore calculated based on the surface area of impounded water and followed the topology of the ten-foot contour line adjacent to the dam.

When applied to the RVRF grid of 16,518 cells, mapping the scores resulted in:

- 95.8% had a zero risk of flooding due to a dam breach
- 1.1% had a very low risk of flooding
- 0.4% had a low risk of flooding
- 1.0% had a moderate risk of flooding
- 0.4% were rated with a high risk
- 1.3% had a very high risk

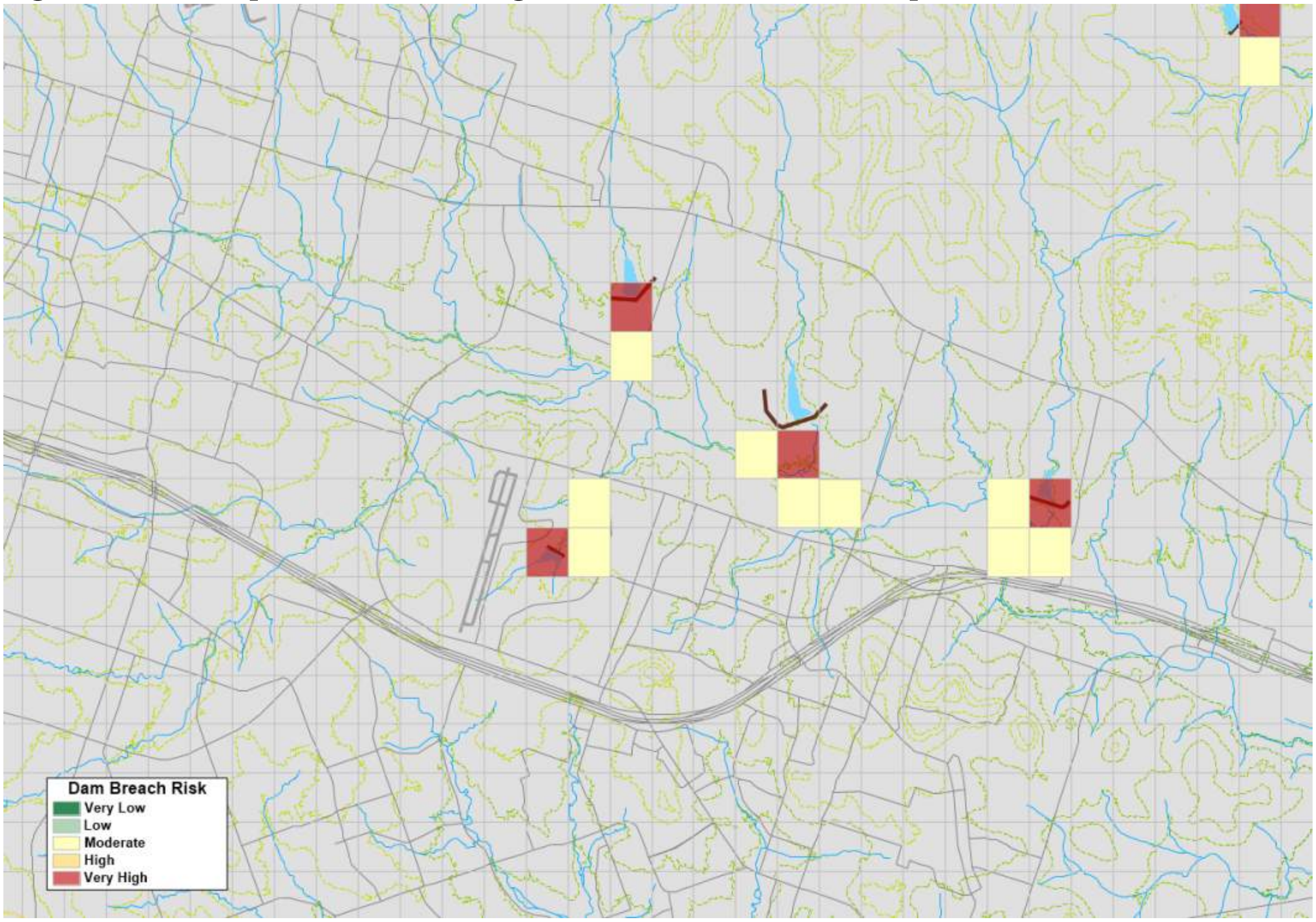
Figure 2 shows the regional risk of flooding from dam breach.

Figure 2: Risk of Flooding from Dam Breach



The inset map in **Figure 3** shows a sample area of risk of flooding from a dam breach applied to the RVRF grid. Risk was rated as very high immediately downstream of the dam face. A grid was scored with a high risk for at least ¼ a mile distance downstream of the dam, which varied based on the direction of the topology. The map shows how the direction of the risk varies according to the direction of the topology.

Figure 3: Inset Map of Risk of Flooding from Dam Breach for a Sample Area



Wildfire

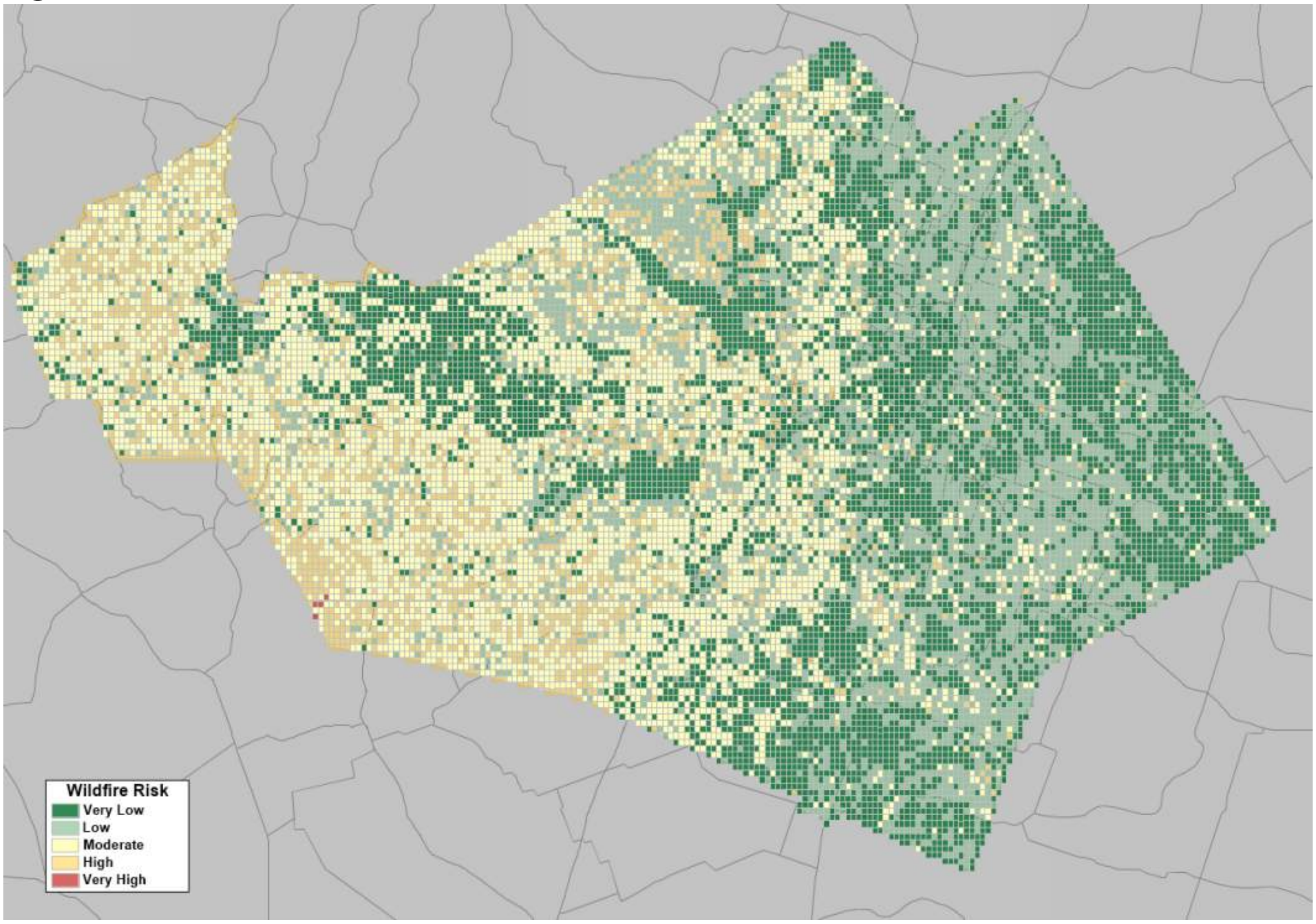
The scoring for wildfire risk is derived from the US Forest Service mapping of wildfire hazard potential. The US Forest Service's map was developed based on their computer model (Large Fire Simulator) with reference to ground cover data from the LANDFIRE 2012 database and to historic wildfire records from 1992 through 2013. This Federal program maps risk in five classes; therefore, their risk assessments were imported directly into the RVRF.

When applied to the RVRF grid, wildfire risk shows a clear distinction between the western hill country and the eastern prairie, due to the difference in the ground cover. Overall, the percentages of risk categories are:

- 30.3% very low risk for wildfire
- 26.5% low risk
- 31.4% moderate risk
- 11.7% high risk
- 0.02% very high risk

Figure 4 shows the regional risk of wildfire.

Figure 4: Risk of Wildfire



The east/west divide is shown by splitting the region along I-35 and tallying the grid scores.

On the west side of IH 35, the percentages are:

- 20.6% very low risk for wildfire
- 19.1% low risk
- 41.9% moderate risk
- 18.4% high risk
- 0.02% very high risk

On the east side of IH 35, the percentages are:

- 45.0% very low risk for wildfire
- 37.9% low risk
- 15.5% moderate risk
- 1.6% high risk
- 0.0% very high risk

Drought or High Temperature

Drought or sustained high temperatures are large-scale atmospheric events that occur uniformly throughout a region. No direct countermeasures, mitigation, or methods exist to avoid these hazards. Despite occurring uniformly across a region, the impacts of drought or sustained high temperatures are not uniform. The indirect effect of drought and sustained high temperatures contributes to soil cracking and shrinking, which can affect transportation infrastructure. Soil types in the region therefore are important considerations, and are used to track the hazard of drought and sustained high temperatures.

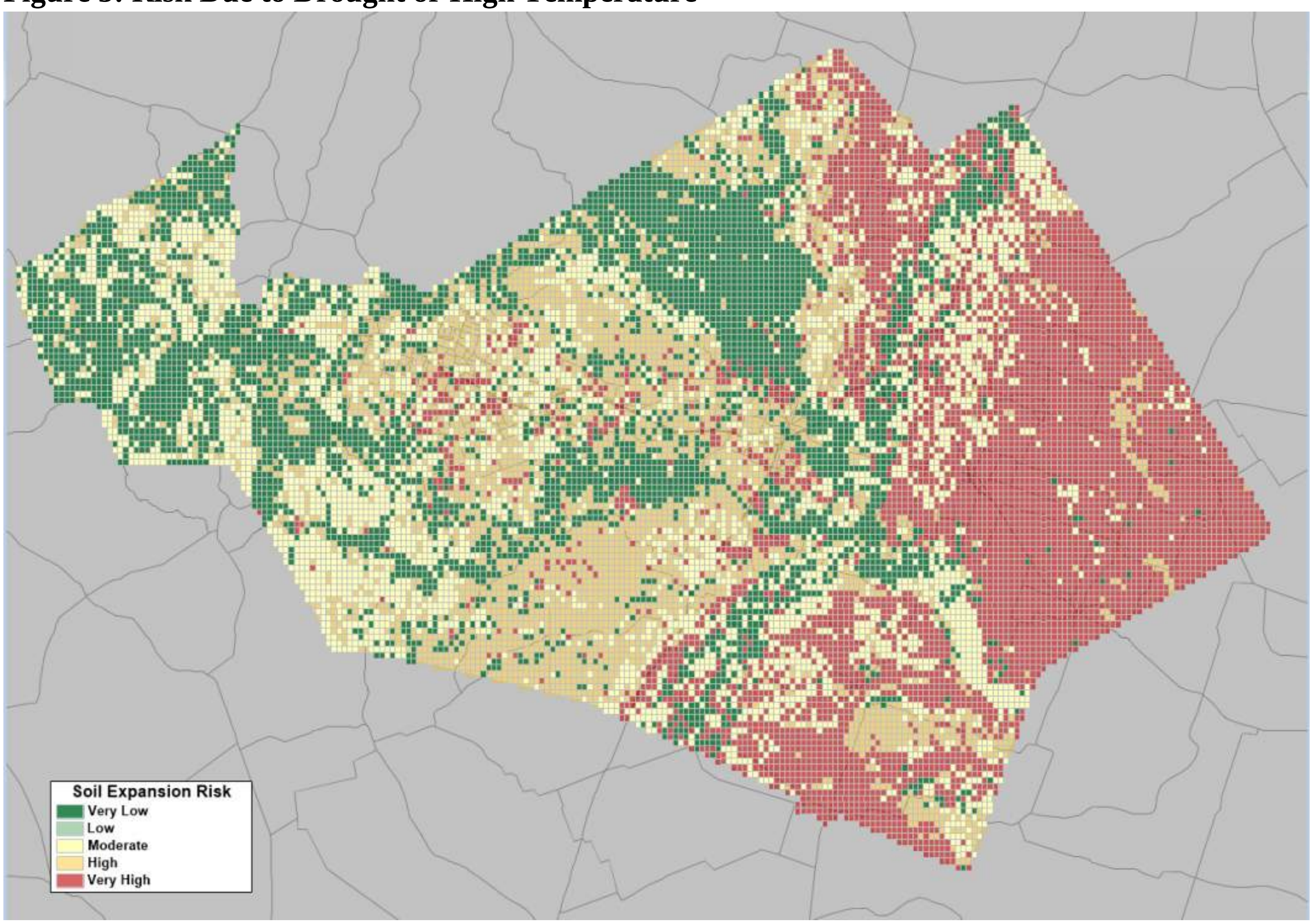
The data source for soil types is county-based GIS maps of soil surveys from the US Soil Survey. This data source list 110 soil types in the region and rated their shrink-swell characteristics in four categories from low to very high. The ratings used in the soil survey were directly applied to the RVRF grid.

As could be expected, there is a definite distinction between the soil types in the hill country and the blackland prairie on the eastern side of the region. The overall percentages are:

- 25.3% had a very low rating for soil expansion
- 24.0% had a moderate rating
- 20.8% had a high rating
- 29.9% was rated very high

Figure 5 shows the regional risk of drought or high temperature. For the region, the percentages of the RVRF grid falling in each rating category are roughly equivalent. However, the percentages are very different when looking at the western and the eastern regions separately.

Figure 5: Risk Due to Drought or High Temperature



On the west side of IH 35, the percentages are:

- 35.1% very low risk for soil expansion
- 26.4% moderate risk
- 28.4% high risk
- 10.0% very high risk

On the east side of IH 35, the percentages are:

- 10.4% very low risk for soil expansion
- 20.3% moderate risk
- 9.1% high risk
- 60.2% very high risk

While there is this clear distinction between east and west for the "very high" rating for the risk of soil expansion, there are still cells with this rating scattered throughout the western area, particularly in the urbanized areas of Copperas Cove, Killeen, and Harker Heights, and a concentration in the Pendleton area north of Temple. There is also much less east/west distinction for the cells rated as "high" risk.

Key Infrastructure Disruption Points

Key disruption points have been identified for the auto, bicycle, bus, rail, truck, and walk transportation modal networks.

Auto Network

The disruption points for the auto network are identified as bridges, sourced from the National Bridge Inventory (NBI) and verified through a review of aerial imagery.

A total of 640 bridges were identified:

- 526 are On System, meaning that these bridges are included in the 2017 model network.
- 18 are On System and are located within the restricted area of Fort Hood.
- 114 are Off System, not on roads which are included in the 2017 model network.
- 19 are Off System and are located within the restricted area of Fort Hood.

Following the NBI data, bridges were scored in the standard 1-5 scale based on the frequency of floodwaters overtopping their decks.

Additionally, 13 bridges were identified as load restricted. Of these bridges, 10 are On System and 3 are Off System. For the 10 On System bridges, all are 2-lane undivided roads, with 9 classed as collector roads, and 1 as a Minor Arterial. Not all the roads with these bridges have available traffic counts, but the highest count recorded is 460 vehicles per day.

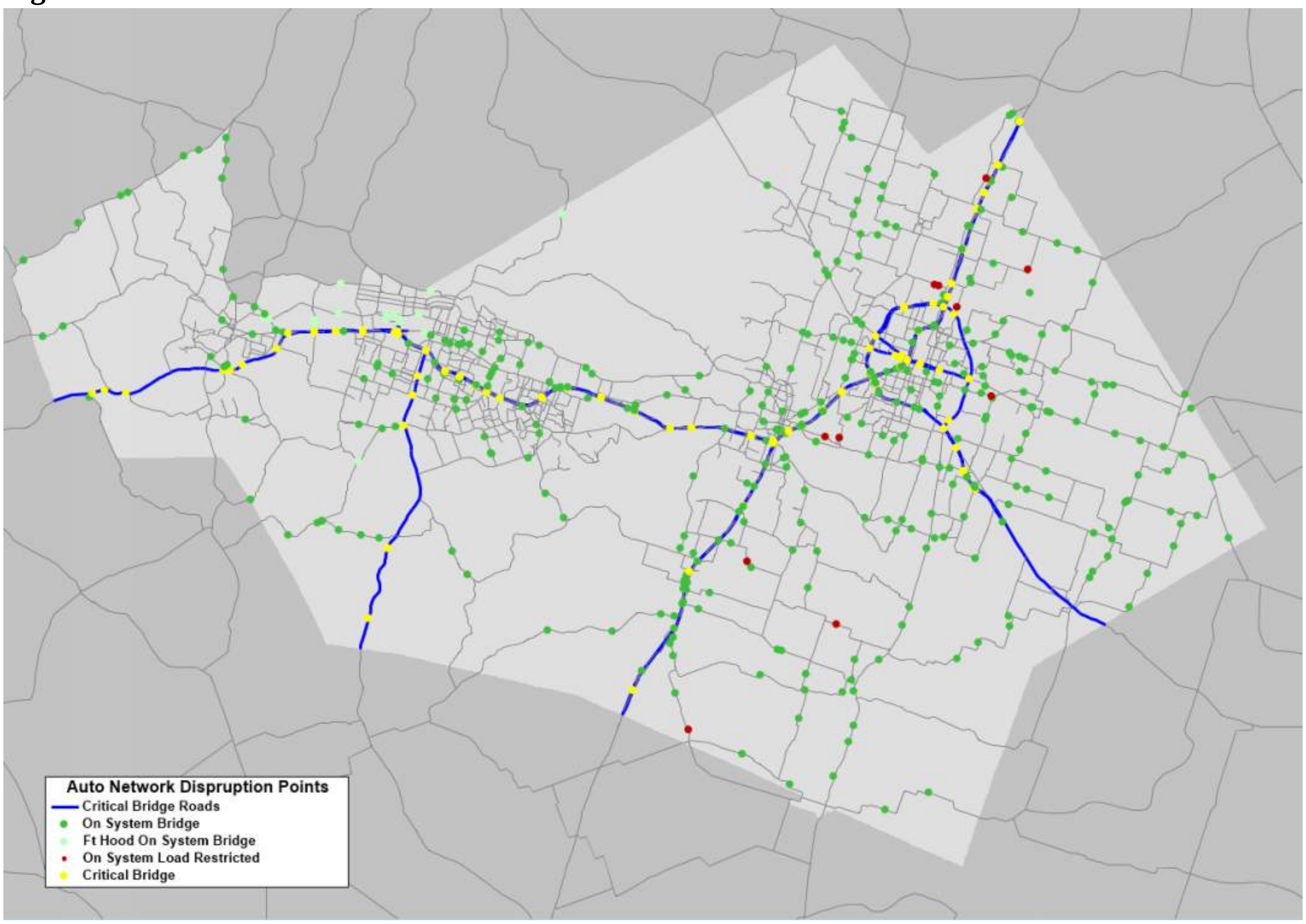
The critical road network is defined as higher functionally classed and regionally significant roads:

- IH 35
- IH 14
- US 190
- Loop 363
- SH 195
- Adams Ave inside Loop 363
- Central Ave inside Loop 363
- T J Mills Blvd from US 190 to the Fort Hood main entrance

We used the critical road network to define 133 critical bridges. Of these, 131 are On System and 2 are On System within Fort Hood. None of these critical bridges are load restricted. The risk scores for the critical bridges based on the NBI are 22 with a score of 2 and 111 with a score of 1.

Figure 6 shows the critical auto network.

Figure 6: Critical Auto Network



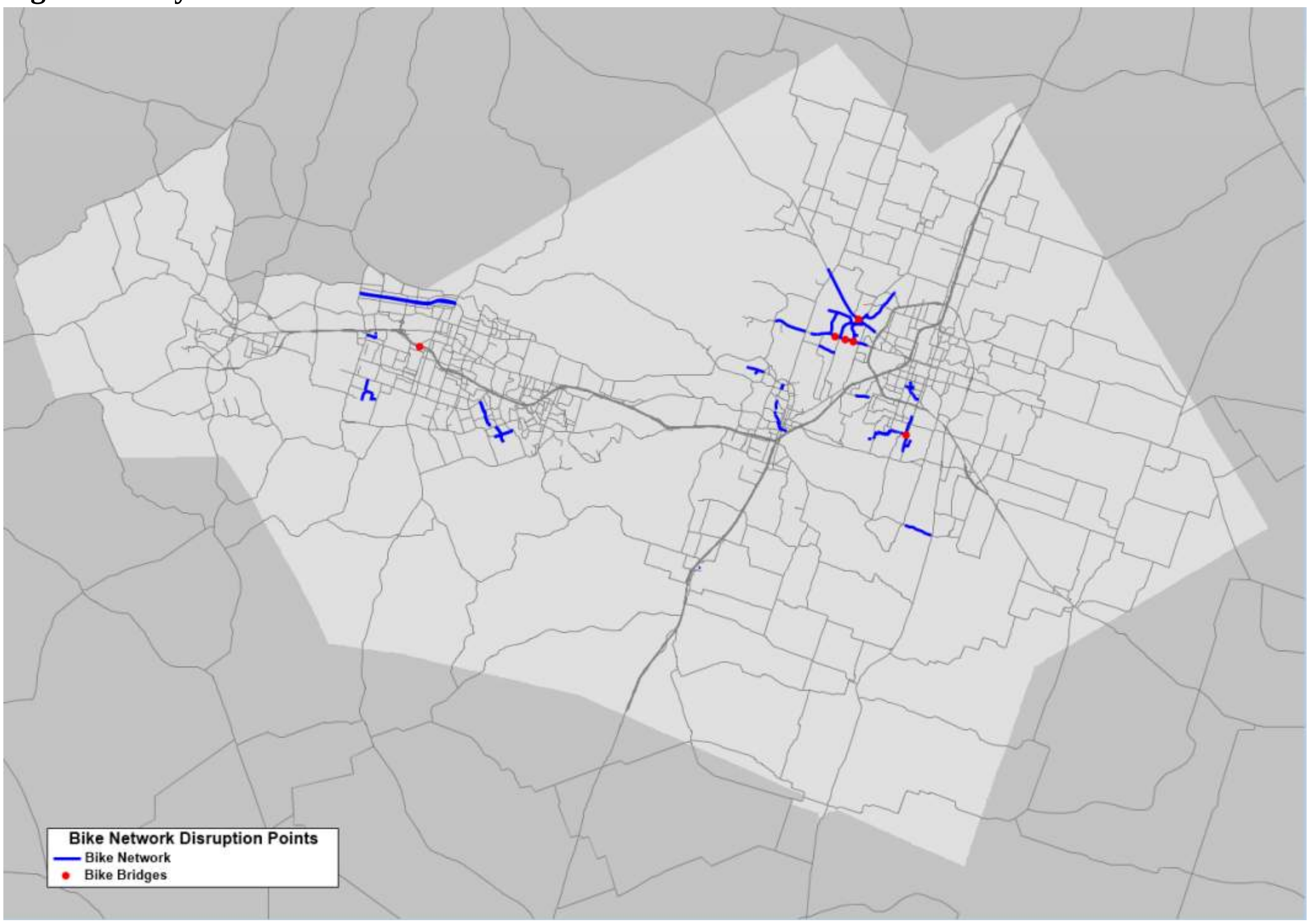
Bicycle Network

The review of disruption points in the bicycle network is based on only the paths used for transportation. It does not consider recreational paths limited to parks, but does include neighborhood paths that connect to the regional network. Of the 6 bridges identified for the bicycle network, only one is shared with the auto network.

- 3 bridges on FM 2305 (W Adams Ave); the bike path and bridges are separate from the road
- 1 bridge on SH 36; the bike path is a wide shoulder and continues over the bridge. The bridge is built as a culvert with a wide grassy berm on each side, so a redundant path is already in place.
- 1 bridge on Waters Dairy Rd; both the bike path and bridge are separate from the road
- 1 dedicated bridge over US 190; ramps on each end connect to sidewalks

Figure 7 shows the bicycle network.

Figure 7: Bicycle Network



With the single exception of the SH 36 bridge, the auto network bridges provide redundancy for the bicycle network. As a result, bridges do not serve as disruption points to the bicycle network. The characteristic sparseness and disconnectedness of the bicycle network is a more realistic definition of its vulnerability.

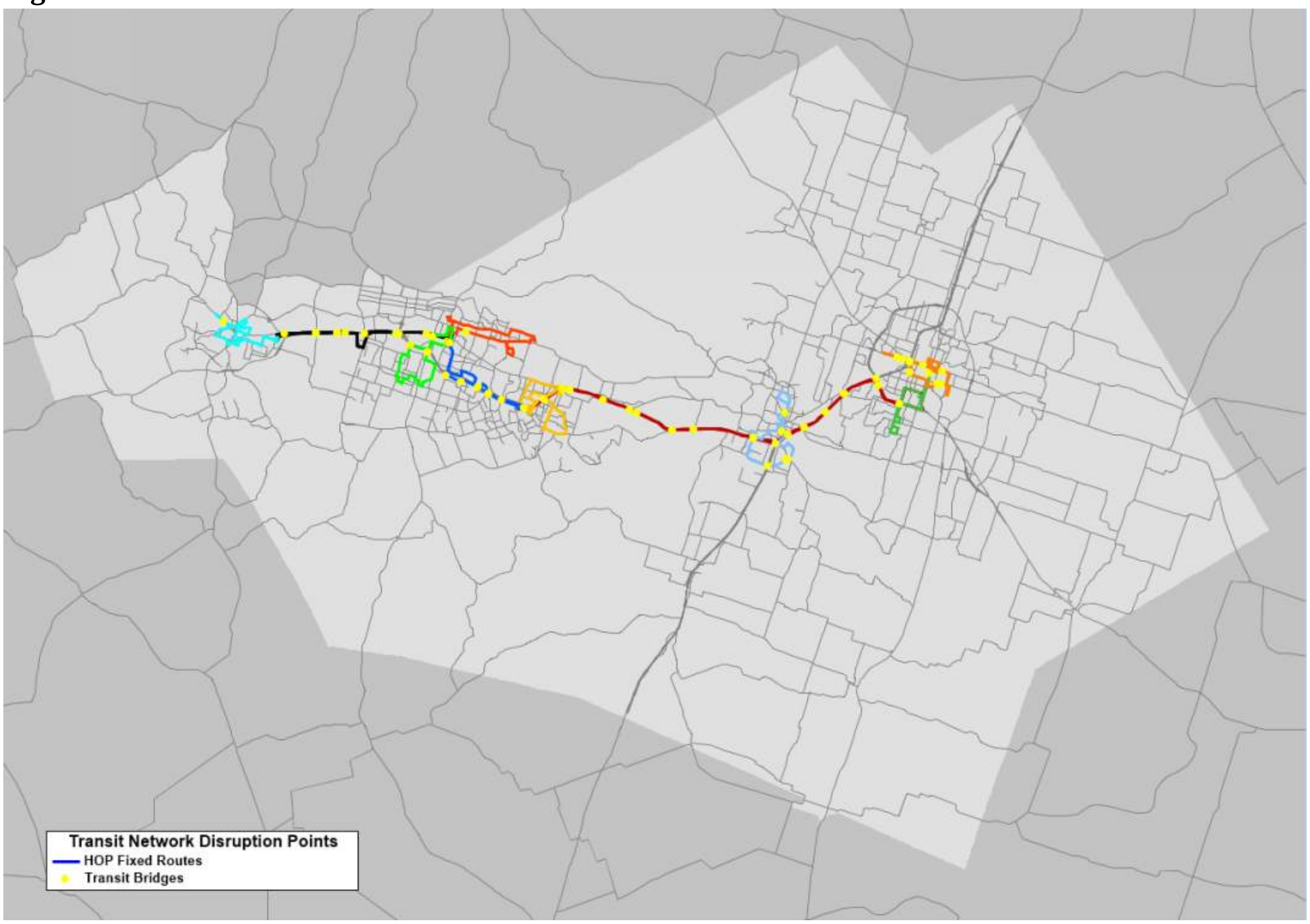
Bus Network

The bus network includes 10 fixed routes operating in communities from Copperas Cove to Temple. The bus network shares 73 bridges with the auto network.

- 72 On System bridges
- 1 Off System bridges, on S Gray St in Killeen. This route is parallel and 0.12 mile away from S 2nd St on the west and from S 10th St on the east, so redundancy is in place.
- 43 of the bridges are in the critical network, located on IH 35, IH 14, US 190, Adams St, and Central St.
- None of the bridges for the transit network have load restrictions.

NBI scores for vulnerability include two bridges with a score of 5, two bridges with a score of 3, 18 bridges with a score of 2, and 49 bridges with a score of 1. The two bridges scored at a 5 are at the Nolan Creek low water crossings of the IH 35 northbound and southbound frontage roads at Confederate Park in Belton. The two bridges scoring 3 are on S Gray St, the Off System bridge over South Nolan Creek in Killeen, and on W Ave B in Copperas Cove. Redundancy is in place at all these locations. The critical bus network is shown in **Figure 8**.

Figure 8: Critical Bus Network



Rail Network

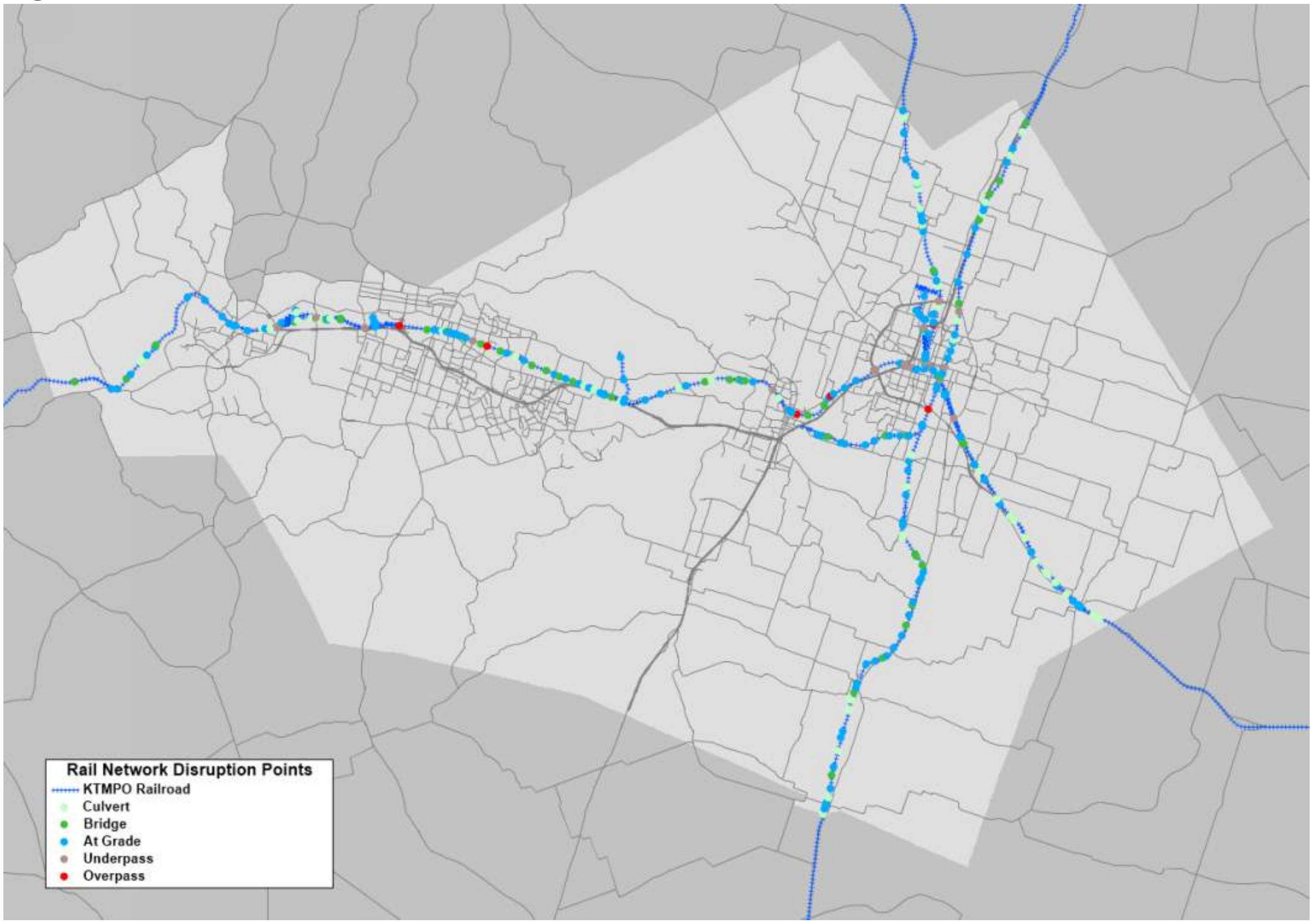
The rail network includes tracks operated by the Burlington Northern Santa Fe and the Union Pacific railroads, including AMTRAK passenger rail service, and rail lines within Fort Hood. The 6 miles of branch line between Belton and Temple which runs just north of FM 93 (E 6th Ave) is included, though it may be an abandoned railroad line.

Disruption points for the railroad networks were identified as:

- 58 culverts
- 44 bridges over creeks or drainage channels
- 27 underpasses
- 6 overpasses
- 215 at-grade crossings, of which 74 were unpaved roads or paths

The critical rail network is shown in **Figure 9**.

Figure 9: Critical Rail Network



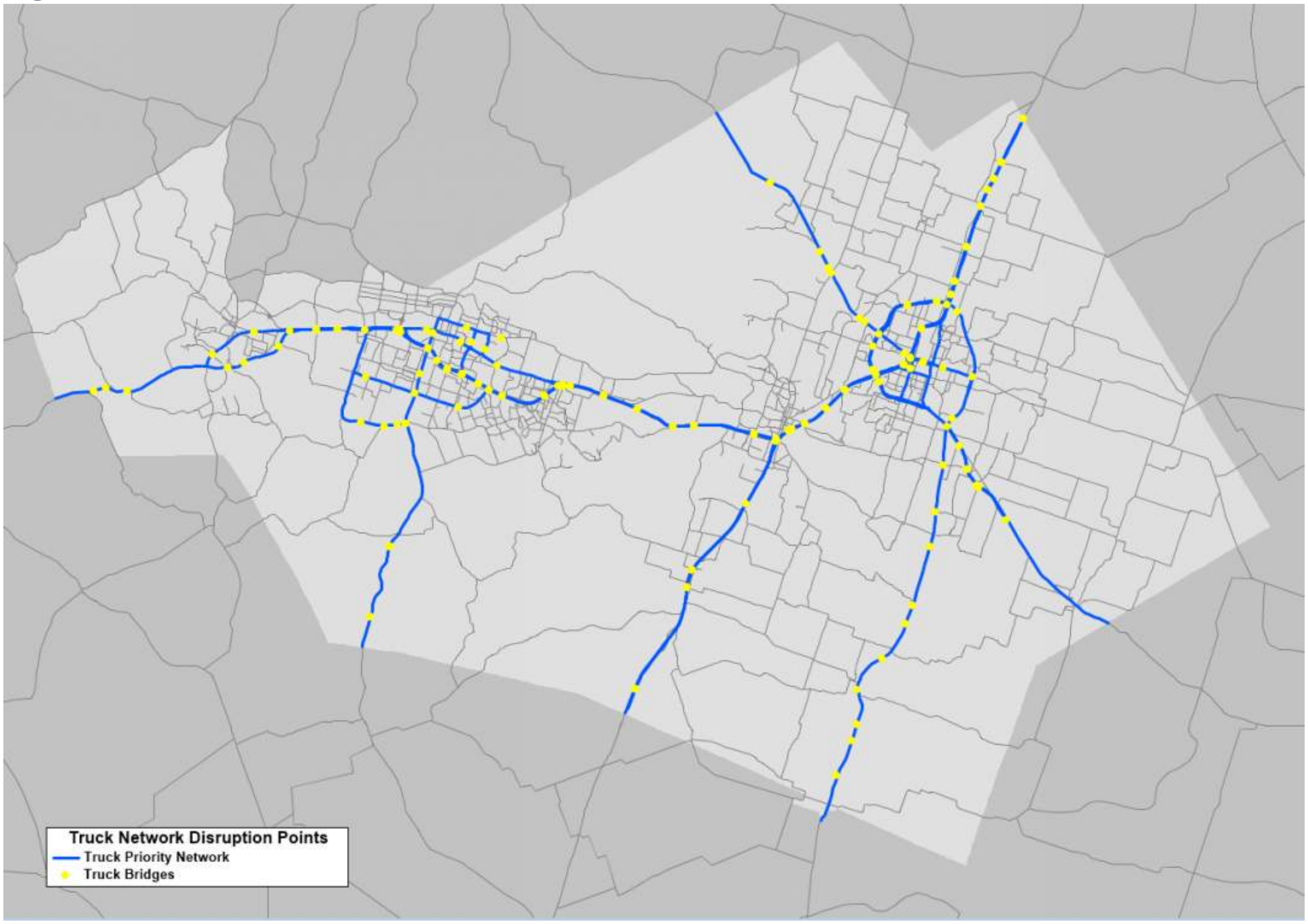
Truck Network

Disruption points for the truck network were based on the Truck Priority Network which was defined in the Regional Multimodal Plan. A total of 161 bridges are located on the Truck Priority Network.

- All 161 bridges in the Truck Priority Network are On System
- None of these bridges have load restrictions
- 124 are identified as critical bridges
- Bridge vulnerability scores based on the NBI were all either 1 or 2. Thirty-seven bridges had a score of 2 and 124 bridges had a score of 1.

The critical truck network is shown in **Figure 10**.

Figure 10: Critical Truck Network

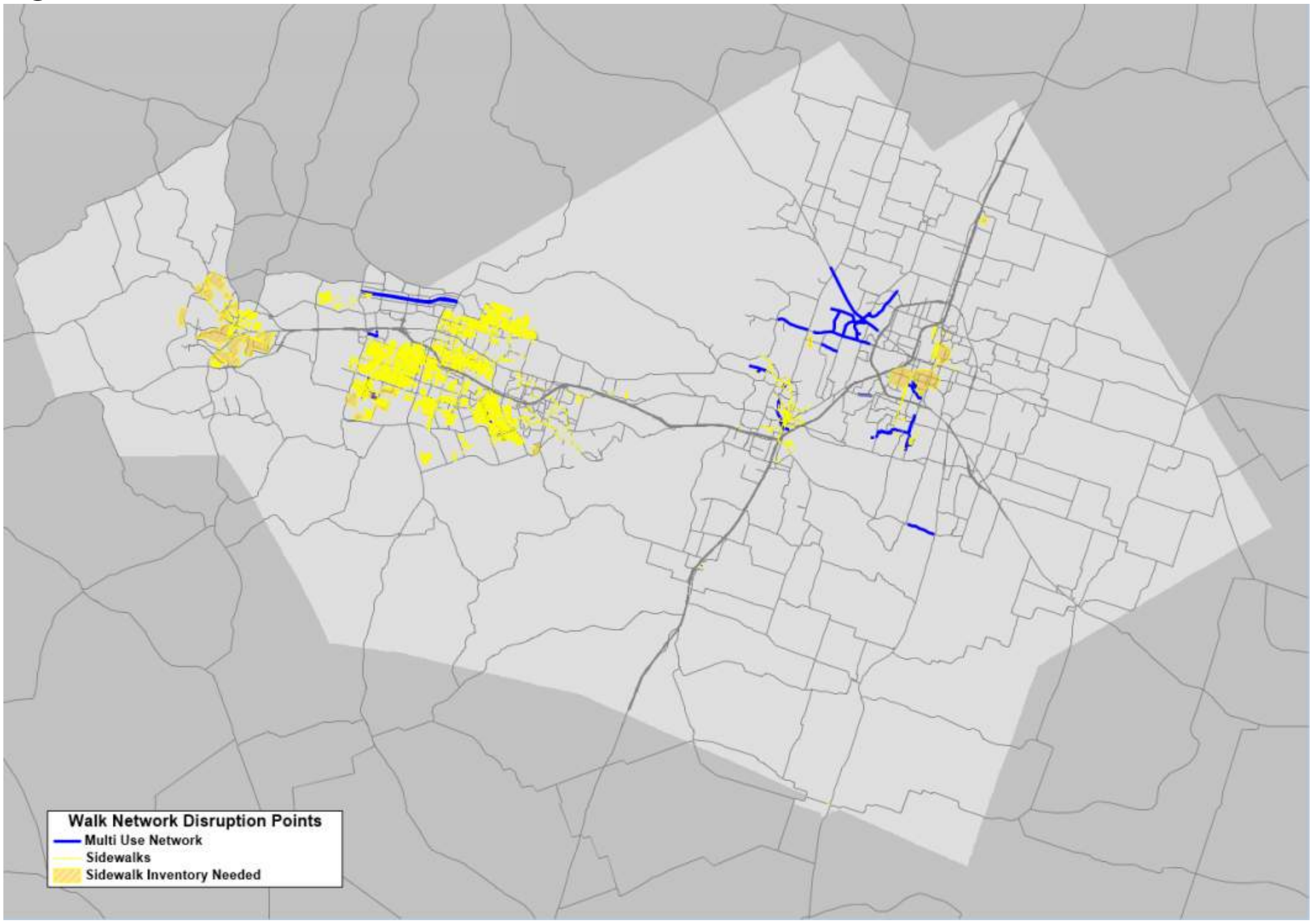


Walk Network

The sidewalk inventory is not fully up to date, with areas of needed updates including some established areas in Temple as well as recently developed areas throughout the region. Even with this consideration, the walk network is focused in the urban areas rather than being connected throughout the region. Like the bicycle network, the walk network is regionally sparse. Rather than having specific disruption points, this lack of walk network connectivity is itself a definition disruption and vulnerability.

The critical walk network is shown in **Figure 11**.

Figure 11: Critical Walk Network



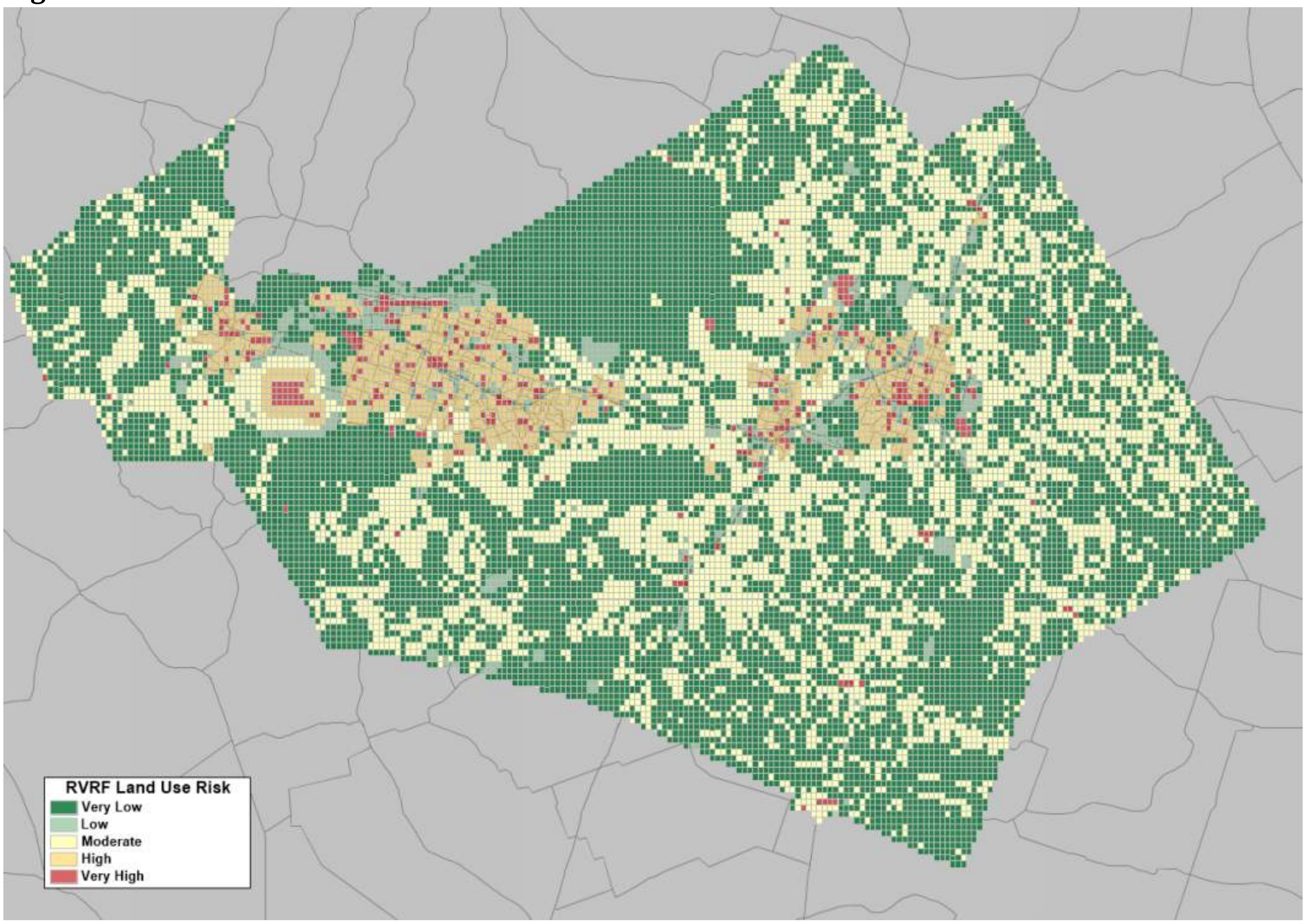
Land Use and Critical Land Uses

The RVRF grid for land use was used to score the effects of hazards. The lowest score of 1 is applied to rural or vacant land, and up to a score of 5 was applied to critical land uses such as:

- Hospitals and nursing homes
- Barracks
- Schools
- Jails
- Police and Fire Stations
- Critical infrastructure including water treatment plants, electrical generation and substations
- Potentially hazardous land uses such as ammo dumps and fuel storage tanks. These locations were rated as a 5 (high hazard), with a buffer area around each rated as a 4. Additional sites were identified for industrial sites processing chemicals, rubber, or petroleum-based products which could be toxic if burned or spilled into the environment from flooding.

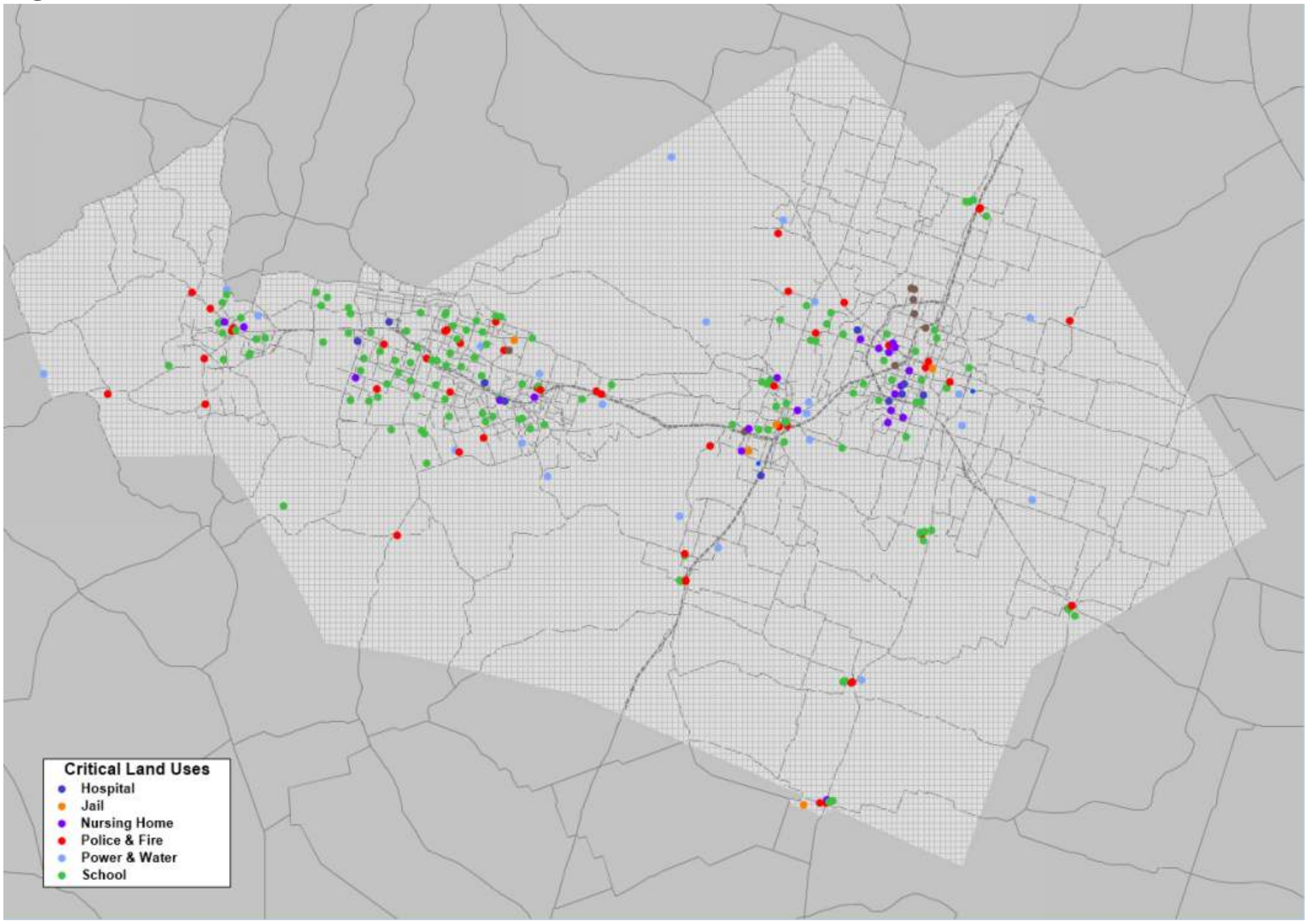
The RVRP land use risk is shown in **Figure 12**.

Figure 12: RVRF Land Use Risk



The critical land uses were also developed as a GIS point layer for further reference as shown in **Figure 13**.

Figure 13: Critical Land Uses



Summary

This memo reports on several aspects of exposure to defined hazards for the KTMPO region:

- Defined hazards are:
  - Flooding from rainfall
  - Flooding from dam breach
  - Wildfire
  - Drought or high temperature
- A Regional Vulnerability & Resilience Framework (RVRF) was set up with a ¼ mile grid to permit consistent and normalized scoring for each of the defined hazards. The grid cells were all populated with scores for each hazard in the range of 1 to 5. Scoring for dam breaches included a special category of 0 risk for areas upstream of the dams.
- Scores were based on national-level datasets without editing. In some cases this results in “lumpy” allocation of scores. Smoothing the data is an option, but that would be a subjective deviation from the datasets and would have to be repeated each time the data were updated. Since four hazards

were defined, the smoothing would have to be repeated for each dataset, and would have to be consistent between the datasets. Smoothing was therefore not applied to the RVRF grid, but may be considered in the future, particularly if the lumpiness of the attributes is seen to affect the link-level network project scoring.

- Key disruption points have been identified for the auto, bicycle, bus, rail, truck, and walk transportation modal networks. For the auto, bus, and truck networks, an inventory of bridges was used to define disruption points. The rail network uses a separate bridge inventory. For the bicycle and walk networks, their characteristic sparse and disconnected networks are themselves considered as definitions of disruption.
- Critical network was defined as a subset of roads with higher functional classes or regional importance. This was based on the critical network defined in the Regional Multimodal Plan.
- Critical land uses were defined as those which would be most significantly impacted by hazards. The defined critical land uses include locations of vulnerable populations (hospitals, nursing homes, schools, and jails), locations of critical infrastructure (police stations, fire stations, electrical transfer stations, water treatment plants), and locations which could have an additional impact on regional infrastructure if they were subject to hazards (ammo dumps, fuel storage tanks, toxic chemicals or smoke). Critical land uses are identified both on the RVRF grid and as a separate GIS point layer.

In summary, this memo documents how the RVRF has been set up and populated with defined hazards scored on a consistent 1 to 5 scale, and how the RVRF has additional information on key disruption points, critical networks, and critical land uses.

The next steps go in two directions. The first will be to develop an inventory of segments of the network for each mode which are impacted by each of the hazards. The second will be to develop the spreadsheet and GIS layer combination, so that individual road projects can be laid over the RVRF grid, the appropriate grid cells selected, and the individual hazard and composite scores for the project generated. These scores may then be input into the overall project scoring spreadsheet directly, or they may be used to inform a subjective scoring evaluation for input into the overall project scoring spreadsheet.

Task 2: Determine Network Sensitivity for the Road Networks

Introduction

Exposure to incidents assessed in Task 1 was quantified and documented by setting up a Regional Vulnerability and Resilience Framework (RVRF). The RVRF defined a ¼ mile grid for the study area and developed scores in the range of 1 to 5 for each grid cell, ranking the vulnerability of each cell to four types of incidents: flooding from rainfall, flooding from dam breaches, wildfire, and drought or sustained high temperatures. For this Task 2, the RVRF grid was linked to the road network to discover specific locations which are vulnerable to each incident type.

This double approach defines two purposes of the RVRF. First, the compilation of vulnerability scores for each cell of the RVRF grid allows network projects to be evaluated, as detailed in the Task 1 memo. This evaluation requires use of both the RVRF grid to capture the scores for a particular project and a spreadsheet to import the grid scores, consolidate and weight them, and to format the composite scores. Secondly, the identification of locations which are vulnerable to each incident type, detailed in this Task 2 memo, defines specific areas with issues and supports generating projects to directly address those issues. These projects may then enter the standard KTMPO project evaluation process.

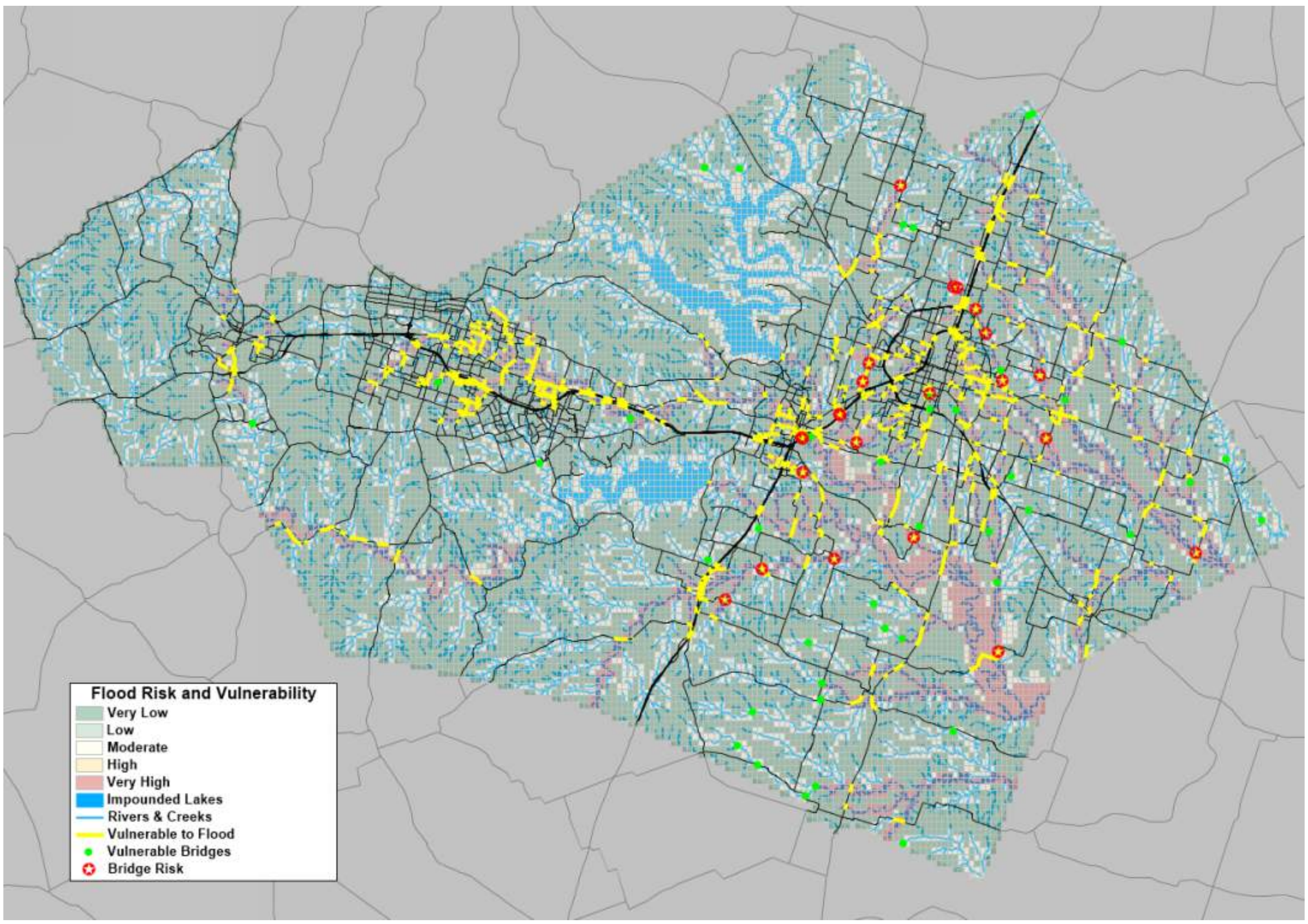
Because of the scale of the region, the number of specific project locations for the four types of incidents is large. For simplicity, this memo has been broken into two documents: one for the road networks, covering the auto, bicycle, bus, and walk networks using the roads; and a separate memo for the rail network. In practice, after the system is documented in these memos, directly referencing the RVRF grid and network within a GIS platform will be more practical.

For both the road networks and the rail network, the assessments of vulnerability determine segments which are rated at “high” or “very high” risk for each type of incident. Bridges are noted as vulnerable based on their ratings in the RVRF grid and were further identified as “at risk” if they were highly rated and located in an RVRV grid cell that was itself highly rated for flood risk or dam breach risk. For clarity, the regional view of vulnerability for each type of risk is shown, followed by several inset views as necessary to show the individual locations. Each location is numbered for reference and listed in a table. To keep the listings manageable, smaller segments of road in close proximity were sometimes combined as a single location.

Flooding from Rainfall

The vulnerability of the road network to flooding from rainfall is fairly evenly distributed throughout the region, but the divide between the hill country in the west and the flatter prairie in the east is evident. Vulnerability in the west is concentrated in the urbanized areas and around the Lampasas River, while in the east vulnerability is more widely distributed in both urban and rural areas. Flooding from rainfall risk and vulnerability in the region is shown in the map in **Figure 1**. As part of this analysis, both bridge and roadway infrastructure vulnerable to flooding from rainfall is identified.

Figure 1: Road Network Vulnerable to Flooding from Rainfall



For a more detailed view, **Figure 2 through**

Figure 10 and **Table 2 through**

Table 10 are a series of maps and tables showing details of the ninety-nine locations where roadway infrastructure in the KTMPO area is vulnerable to flooding from rainfall.

Table 1 lists the TxDOT on-system bridges at twenty-one locations which were identified as vulnerable to flooding due to rainfall. The overwhelming majority of these at-risk bridges are located in the eastern side of the region.

Table 1: Bridges Vulnerable to Flooding from Rainfall List

Site ID	Region	Road	Limits	Notes
23	Belton	IH 35 NB & SB frontage road bridges	Crossing Nolan Creek at Confederate Park	2 bridges score 5 for flood risk
30	E of Salado	Royal St	Crossing Smith Branch	Bridge scores 4 for flood risk
31	E of Salado	Amity Rd	Crossing Salado Creek	Bridge scores 5 for flood risk
33	E of Salado	FM 1123	Crossing Salado Creek	Bridge scores 4 for flood risk
37	E of Belton	Elm Grove Rd	Crossing Mitchell Branch	Bridge scores 4 for flood risk
39	W of Little River - Academy	Wilson Valley Rd	Crossing unnamed creek	Bridge scores 5 for flood risk
45	W of Rogers	Reeds Cemetery Rd	Crossing Little River and Knob Creek	Bridge scores 4 for flood risk
52	SW of Meeks	Big Elm Creek Rd	Crossing Big Elm Creek and Camp Creek	Bridge scores 5 for flood risk
56	Oscar	FM 3117	Crossing Little Elm Creek and unnamed creek	Bridge scores 4 for flood risk
62	NE of Temple	Middle Rd	Crossing Cottonwood Creek	Bridge scores 4 for flood risk
63	NE of Temple	Gun Club Rd	Crossing Little Elm Creek	Bridge scores 5 for flood risk
63	NE of Temple	Old Troy Rd	Crossing Little Elm Creek	Bridge scores 5 for flood risk
64	N of Temple	Moore’s Mill Rd	Crossing Little Elm Creek	Bridge scores 4 for flood risk
64	N of Temple	Moore’s Mill Rd	Crossing Little Elm Creek	Bridge scores 4 for flood risk
72	Pendleton	Southerland Rd	Crossing Cedar Creek	Bridge scores 4 for flood risk
75	W of Temple	Kegley Rd S of Wildflower Ln	Crossing Pepper Creek	Bridge scores 5 for flood risk
75	W of Temple	Kegley Rd N of Charter Oak Dr	Crossing Pepper Creek	Bridge scores 5 for flood risk
83	E of Temple	Dairy Rd	Crossing Little Elm Creek	Bridge scores 4 for flood risk
89	S Temple	Ave R	Crossing Fryers Creek	Bridge scores 5 for flood risk
96	E of Belton	Shallow Ford Rd	Crossing Bird Creek	Bridge scores 4 for flood risk
98	NE of Belton	IH 35 NB & SB frontage road bridges	Crossing Bird Creek	2 bridges score 5 for flood risk

Figure 2: Road Network Vulnerable to Flooding from Rainfall Map - Copperas Cove Area

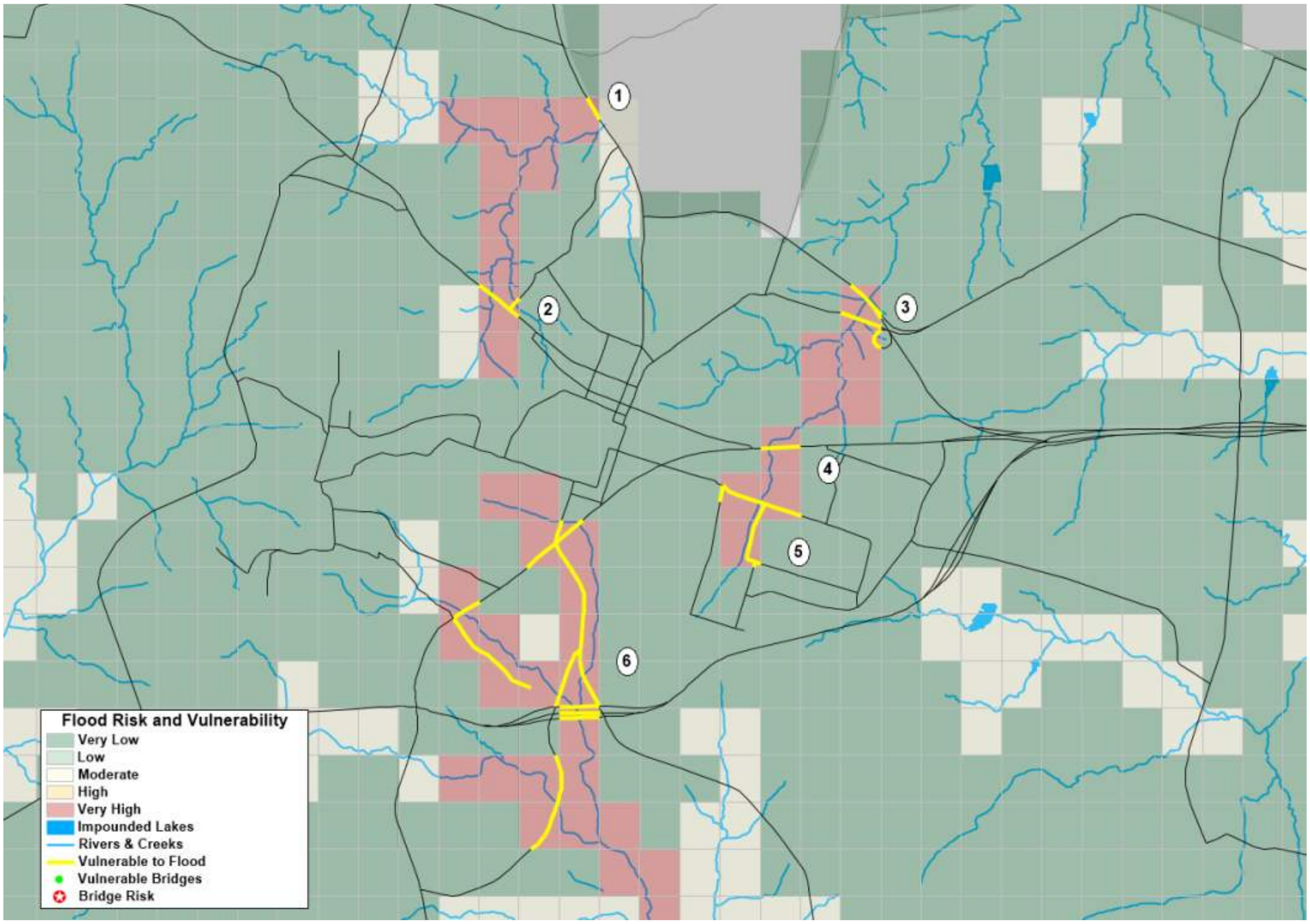


Table 2: Road Network Vulnerable to Flooding from Rainfall Map List - Copperas Cove Area

Site ID	Road	Limits	Notes
1	FM 116	North of Courtney Ln	Site of water treatment plant
2	Ave B & Courtney Ln	North and south of Courtney Ln	
3	SH 9 & Tank Destroyer Blvd	North and west sides of the interchange	Adjacent to a water treatment plant
4	US 190	East of Ave D	
5	Robertson Ave & Creek St	Along Turkey Run Creek	
6	US 190, FM 116, US 190 Bypass, & FM 3046	Along Clear Creek	

Figure 3: Road Network Vulnerable to Flooding from Rainfall Map - Fort Hood, Killeen, Harker Heights, and Nolanville Area

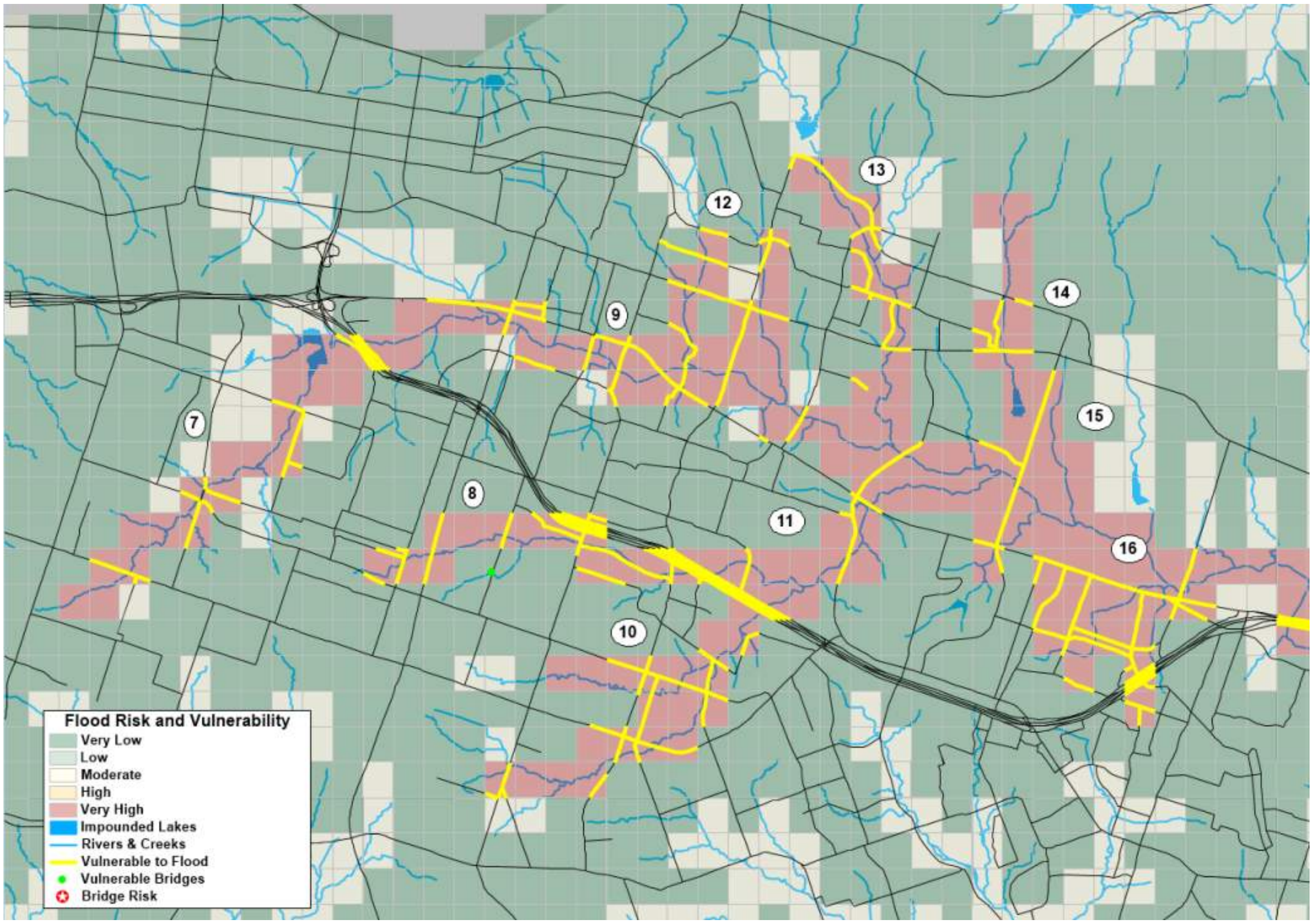


Table 3: Road Network Vulnerable to Flooding from Rainfall List - Fort Hood, Killeen, Harker Heights, and Nolanville Area

Site ID	Road	Limits	Notes
7	Watercrest Rd to Stan Schueuter Loop	Along South Nolan Creek, upstream of Soil Conservation Service Reservoir #1	Segments of 9 collector streets and arterials
8	US 190, Fort Hood St, Trimmier Rd	Along North Branch of Little Nolan Creek	Two sections of US 190 and parts of 13 other streets
9	BU 190, Fort Hood St, Trimmier Rd, W S Young Dr	Along Nolan Creek	Segments of 10 collector streets and arterials
10	Trimmier Rd, W S Young Dr, Stan Schleuter Loop, Elms Rd	Along Little Nolan Creek	Segments of 12 collector streets and arterials
11	BU 190, MLK Blvd, Twin Creek Dr	Along Little Nolan Creek	
12	W S Young Dr, Rancier Ave, Warrior Way	10th St to 38th St	
13	Rancier Ave, Lake Rd, Westcliff Rd	Along Long Branch of Nolan Creek, downstream of Soil Conservation Service Reservoir #5e	Segments of 9 collector streets and arterials
14	Rancier Ave, Lake Rd, Westcliff Rd	Upstream of Soil Conservation Service Reservoir #7	
15	BU 190, Roy Reynolds Dr, Roy J Smith Dr	Downstream of Soil Conservation Service Reservoir #7	
16	US 190, BU 190, Indian Trail	Along Nolan Creek	Segments of 15 collector streets and arterials

Figure 4: Road Network Vulnerable to Flooding from Rainfall Map - Belton Area

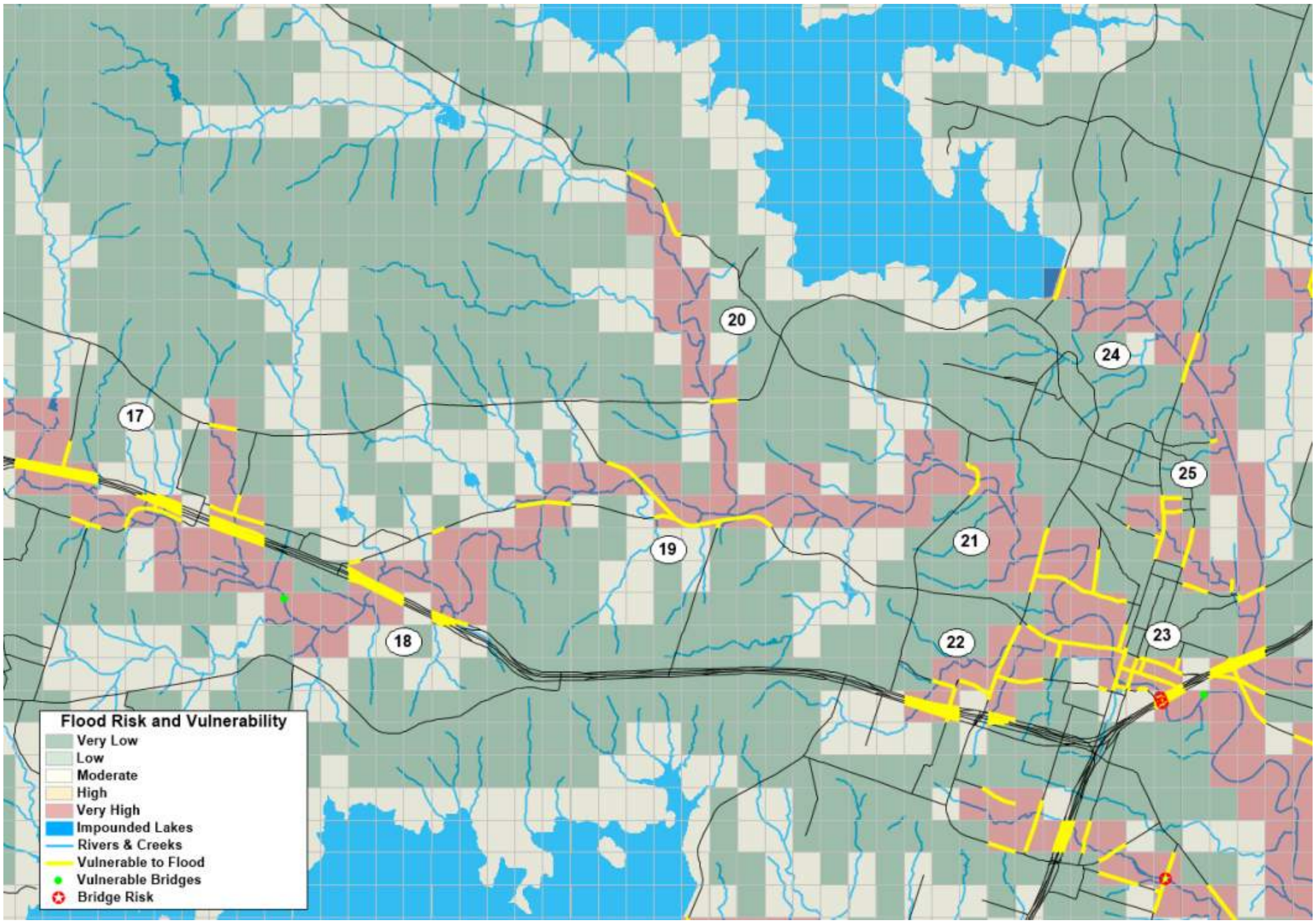


Table 4: Road Network Vulnerable to Flooding from Rainfall List - Belton Area

Site ID	Road	Limits	Notes
17	US 190	Along South Nolan Creek	3 segments of US 190 and other collectors and arterials
18	US 190, Paddy Hamilton Rd	Along South Nolan Creek	2 segments of US 190 and 3 segments of Paddy Hamilton Rd
19	FM 93, Paddy Hamilton Rd	Along South Nolan Creek	
20	FM 439, Sparta Rd	Along North Nolan Creek	
21	Loop 121, W 9th Ave, University Dr	Along Nolan Creek	University of Mary Hardin-Baylor
22	US 190, Loop 121, FM 93		Belton Industrial Park
23	IH 35, SH 317, Central Ave, Ave C, 2nd St	Along Nolan Creek	IH 35 frontage road bridges at Confederate Park score 5 for flood risk
24	SH 317, FM 2271	Along Leon River downstream of Lake Belton dam	Within the defined dam floodway
25	SH 317, 13th St, Waco Rd		Segments of 8 collector streets and arterials

Figure 5: Road Network Vulnerable to Flooding from Rainfall Map - Lampasas River Area in Southwest Bell County

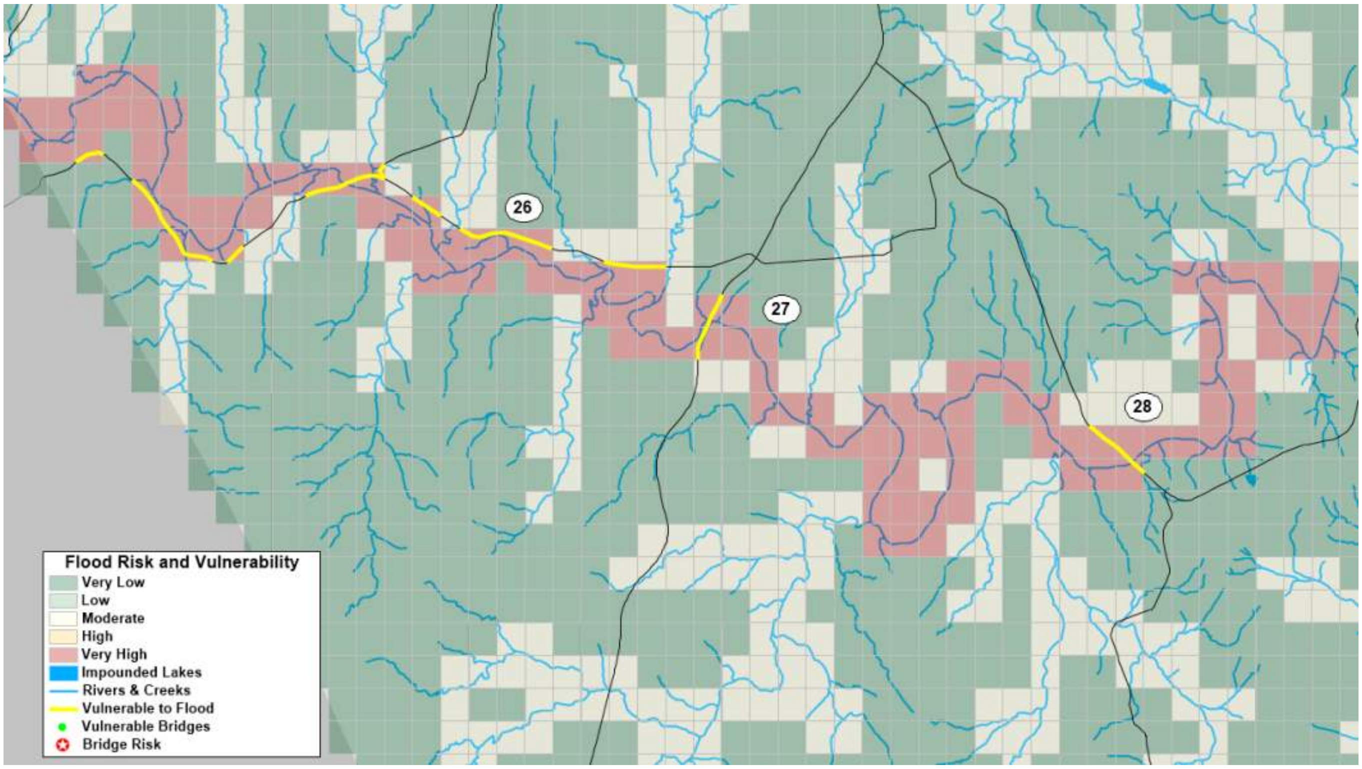


Table 5: Road Network Vulnerable to Flooding from Rainfall List - Lampasas River Area in Southwest Bell County

Site ID	Road	Limits	Notes
26	Maxdale Rd, FM 2670	Along Lampasas River to SH 195	7 segments of road
27	SH 195	Crossing the Lampasas River S of FM 2670	
28	FM 2484	Crossing the Lampasas River NW of Stillman Valley Rd	

Figure 6: Road Network Vulnerable to Flooding from Rainfall Map - Salado Area in South Central Bell County

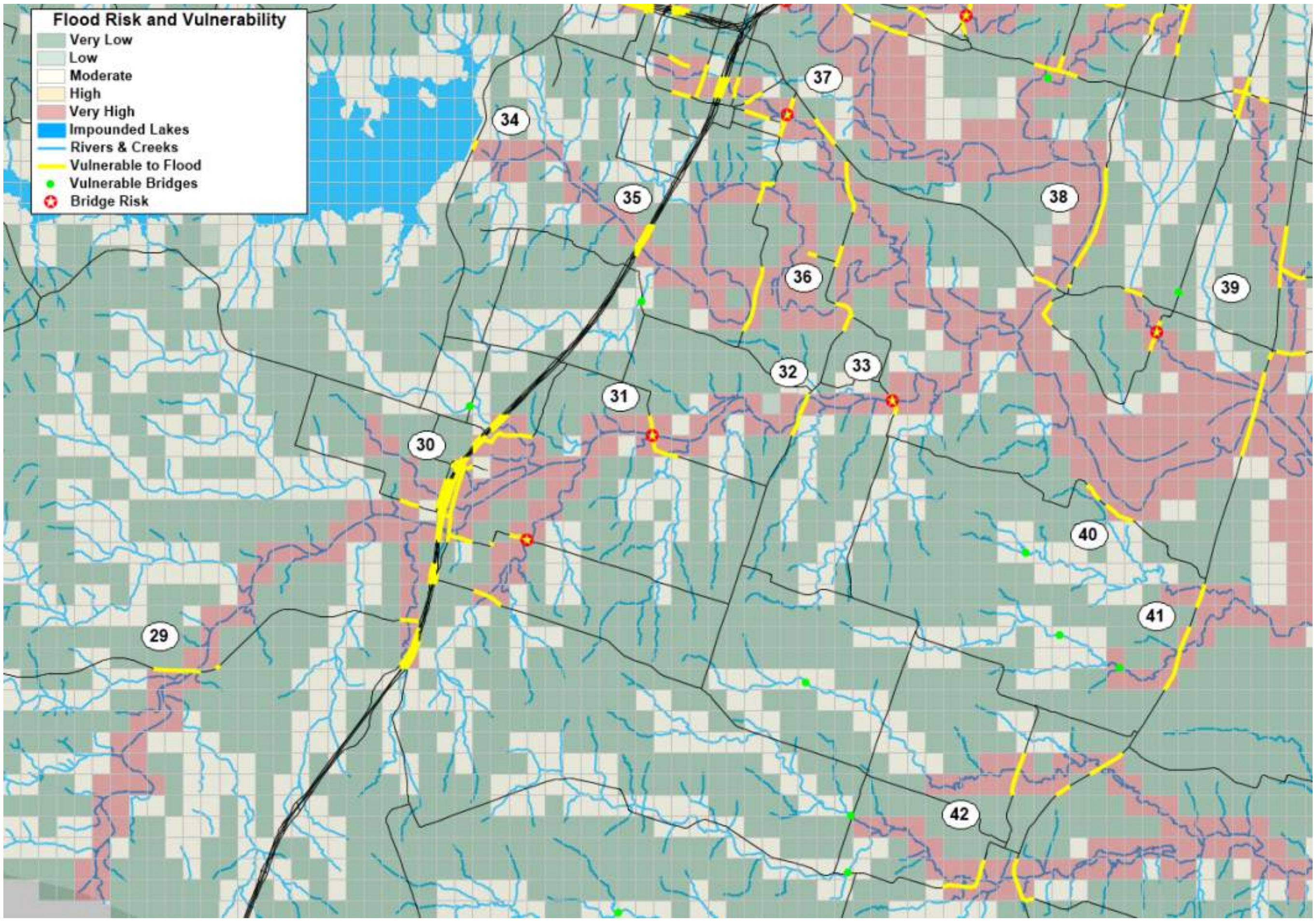


Table 6: Road Network Vulnerable to Flooding from Rainfall List - Salado Area in South Central Bell County

Site ID	Road	Limits	Notes
29	FM 2483	Crossing Salado Creek W of IH 35	
30	IH 35, FM 2843, FM 2268, Royal St, Main St, Thomas Arnold Rd	Crossing Salado Creek	6 segments of IH 35 mainlane and frontage, with connecting streets in Salado
31	Sulpher Well Rd	Crossing Salado Creek	Bridge scores 5 for flood risk
32	Armstrong Rd	Crossing Salado Creek	
33	FM 1123	Crossing Salado Creek	Bridge scores 4 for flood risk
34	FM 1670 / Stillhouse Hollow Dam Rd	Road on the dam	
35	IH 35	Along Lampasas River in dam spillway	
36	Elm Grove Rd, FM 1123, Armstrong Rd	Along Lampasas River in dam spillway	
37	IH 35, Loop 121, Elm Grove Rd, Holland Rd	Crossing Mitchell Branch	Sections of IH 35 and 8 roads
38	Hatrick Bluff Rd, Holland Rd	Along and crossing Leon River	
39	Holland Rd, Wilson Valley Rd	Crossing unnamed creek	Bridge scores 5 for flood risk, load restricted
40	Stage Rd	Between Little River and Willow Creek	
41	SH 95	Crossing Runnels Creek	2 segments of road
42	SH 95, FM 1123, Hackberry Rd	Crossing Cathey Creek and Darr's Creek	

Figure 7: Road Network Vulnerable to Flooding from Rainfall Map - Indian Creek and Donahoe Creek in Southeast Bell County

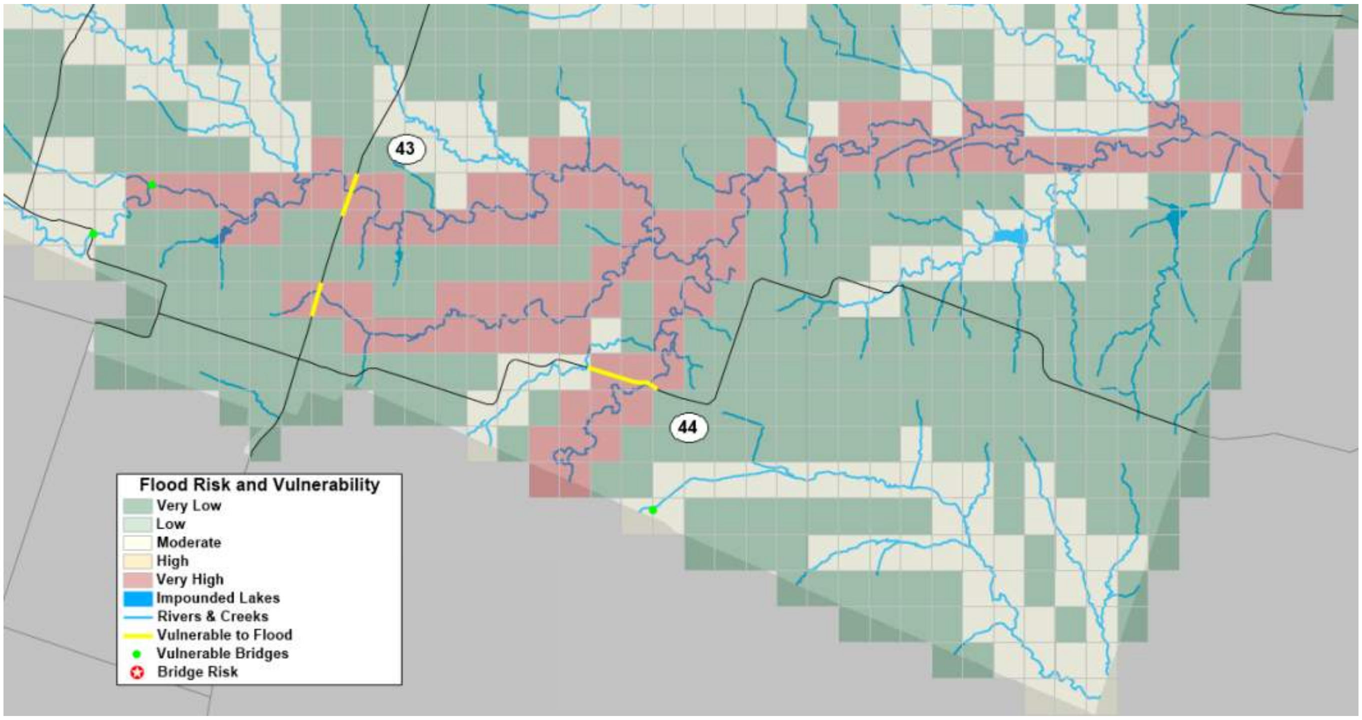


Table 7: Road Network Vulnerable to Flooding from Rainfall List - Indian Creek and Donahoe Creek in Southeast Bell County

Site ID	Road	Limits	Notes
43	SH 95	Crossing Indian Creek and Town Branch	
44	FM 487	Crossing Cottonwood Branch and Donahoe Creek	

Figure 8: Road Network Vulnerable to Flooding from Rainfall Map - Eastern Bell County

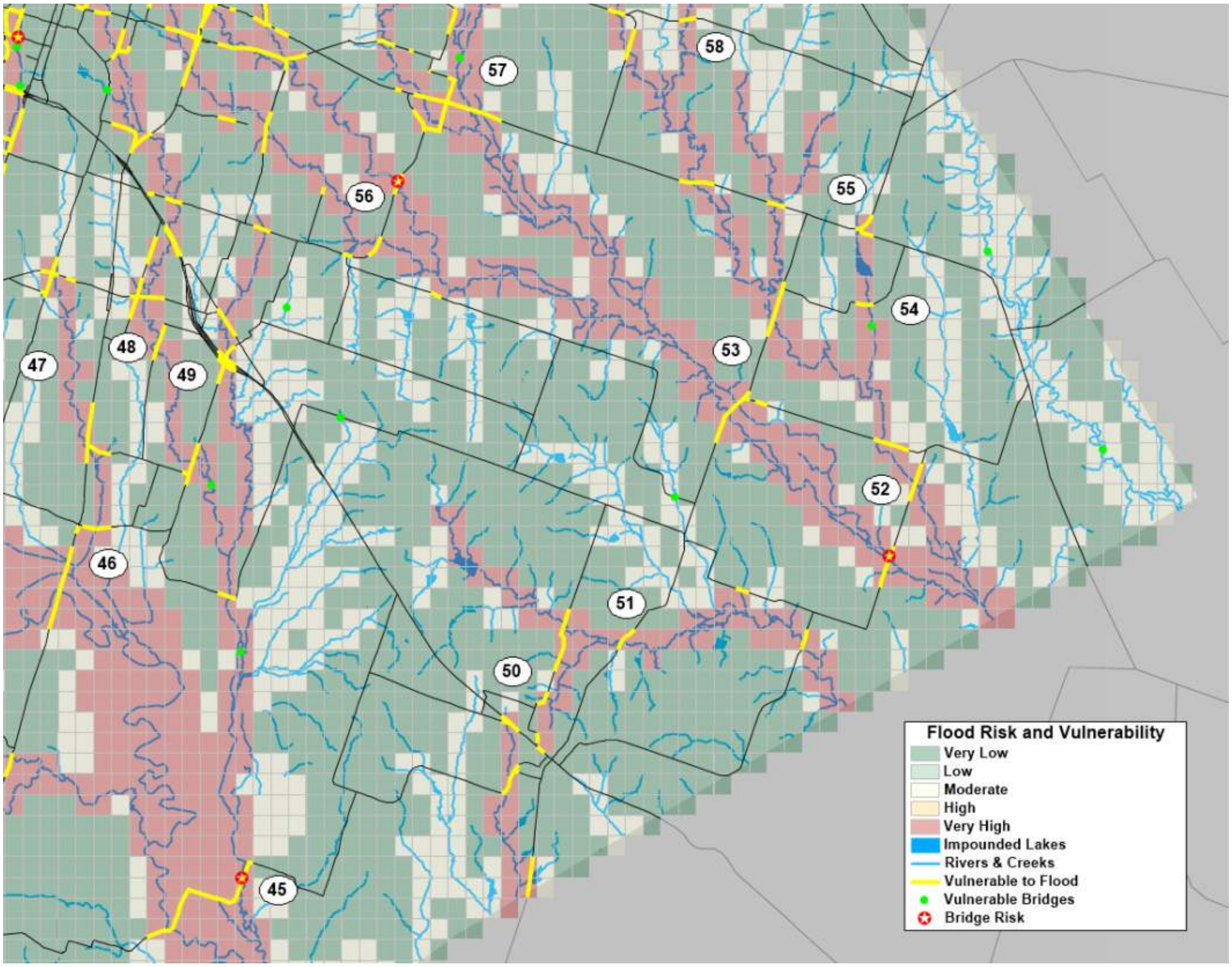


Table 8: Road Network Vulnerable to Flooding from Rainfall List - Eastern Bell County

Site ID	Road	Limits	Notes
45	Reeds Cemetery Rd	Crossing Little River and Knob Creek	Bridge scores 4 for flood risk
46	SH 95, FM 436	Crossing Little River, Boggy Creek, unnamed creeks	
47	SH 95, FM 93, King's Trail	Crossing unnamed creeks	
48	FM 93, Acres Rd, Knob Creek Rd	Crossing Knob Creek	
49	US 190, FM 436	Crossing Margie Lou Branch and unnamed creeks	
50	US 190, FM 2184, FM 437, Hunt Hill Rd	Crossing unnamed creeks	
51	FM 2184, FM 437, Hunt Hill Rd	Crossing South Elm Creek	
52	FM 940, Big Elm Creek Rd	Crossing Big Elm Creek and Camp Creek	Bridge scores 5 for flood risk
53	FM 437, FM 940	Crossing Big Elm Creek and Camp Creek	
54	Cyclone Rd	Crossing Cyclone Branch	
55	SH 53, FM 485	Crossing Camp Creek, Possum Creek, and Cyclone Branch	
56	FM 3117	Crossing Little Elm Creek and unnamed creek	Bridge scores 4 for flood risk
57	SH 53, FM 3117, S Mockingbird Rd	Crossing Big Elm Creek and Cottonwood Creek	
58	FM 2904, FM 2086	Crossing Ratibor Branch, Salt Creek, and Camp Creek	

Figure 9: Road Network Vulnerable to Flooding from Rainfall Map - Northeast Bell County

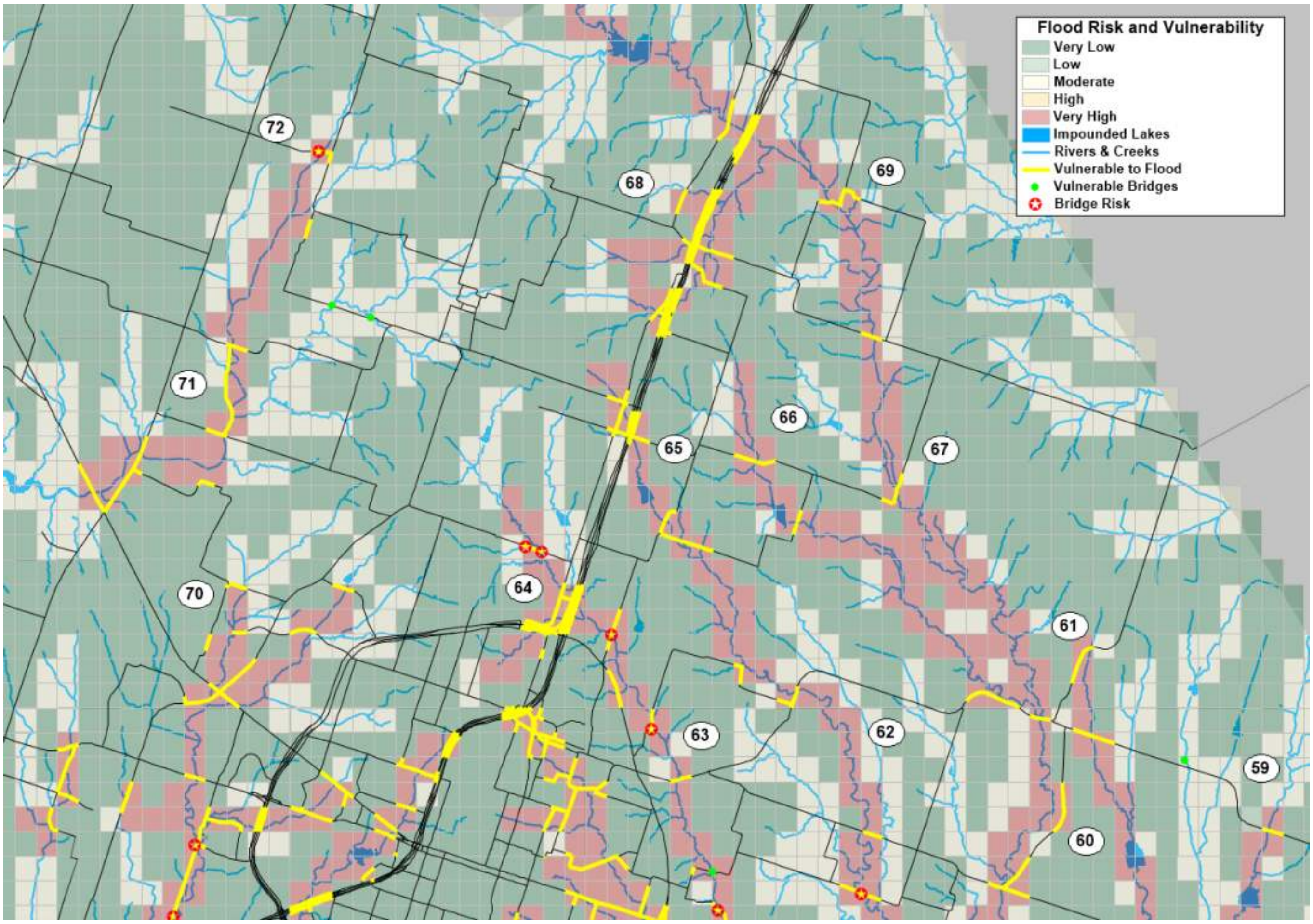


Table 9: Road Network Vulnerable to Flooding from Rainfall List - Northeast Bell County

Site ID	Road	Limits	Notes
59	FM 3369	Crossing Camp Creek	
60	FM 2086, Creek Rd	Along Big Elm Creek	
61	FM 438	Crossing Big Elm Creek and Pecan Creek	
62	FM 2086, FM 438, Middle Rd, Cottonwood Creek Rd	Crossing Cottonwood Creek	Bridge scores 4 for flood risk
63	Loop 363, FM 438, Old Troy Rd	Crossing Little Elm Creek	2 bridges scoring 5 for flood risk
64	IH 35, Loop 363, Pegasus Dr, Moore's Mill Rd	Crossing Little Elm Creek	2 bridges scoring 4 for flood risk
65	IH 35, Berger Rd, Bottoms East Rd, Old Troy Rd	Crossing Cottonwood Creek	
66	Bottoms East Rd, Pecan Rd	Crossing Pecan Creek	
67	Bottoms East Rd	Crossing Big Elm Creek	
68	IH 35, Main St, Old US 81	Crossing King's Branch	
69	IH 35, Old US 81, FM 935, Shiloh Rd	Crossing Big Elm Creek	
70	SH 36, Industrial Blvd, Howard Rd	Crossing Pepper Creek and unnamed creek	
71	SH 36, SH 317, Epperson Rd, Little Mexico Rd	Crossing Cedar Creek	
72	Willow Grove Rd, Southerland Rd	Crossing Cedar Creek	Bridge scores 4 for flood risk

Figure 10: Road Network Vulnerable to Flooding from Rainfall Map - Southern Temple

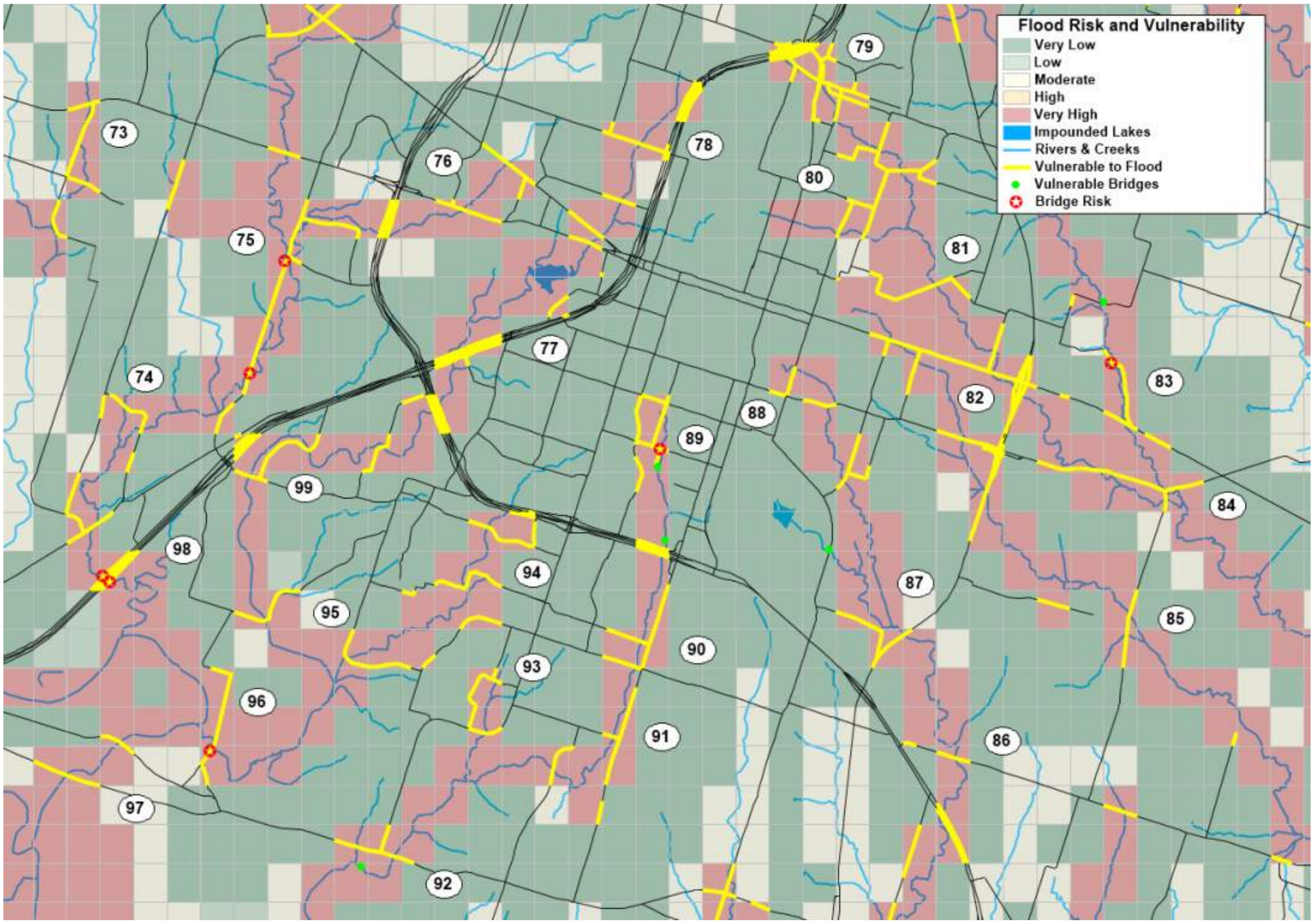


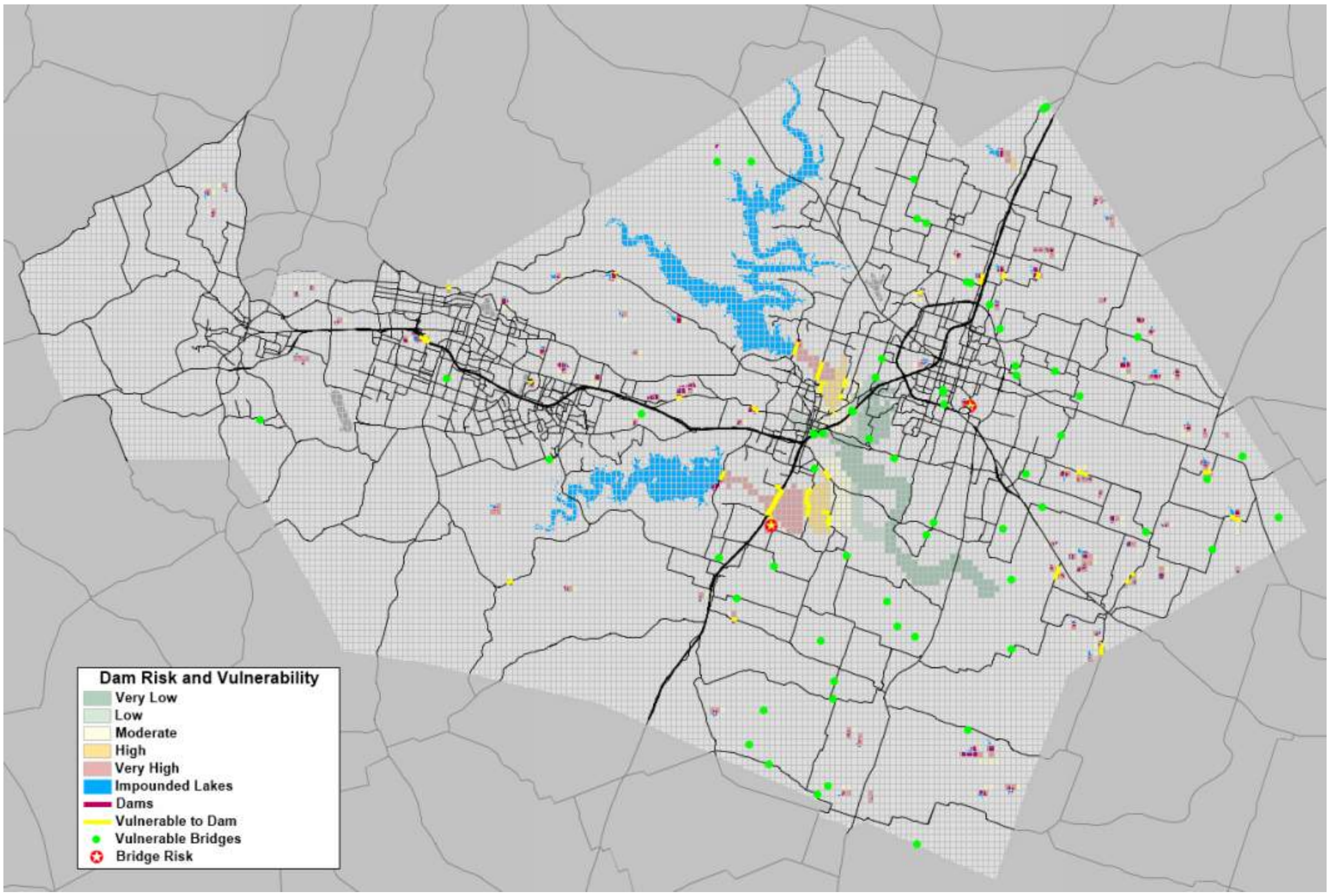
Table 10: Road Network Vulnerable to Flooding from Rainfall List - Southern Temple

Site ID	Road	Limits	Notes
73	FM 2305, S Pea Ridge Rd	Along unnamed creeks	
74	Old Waco Rd, Charter Oak Dr	Along and crossing Pepper Creek	
75	Kegley Rd, Sunflower Ln	Along and crossing Pepper Creek	2 bridges scoring 5 for flood risk
76	Loop 363, SH 53, Adams Ave	Crossing unnamed creek	
77	IH 35	Crossing Bird Creek	
78	IH 35, Nugent Ave	Crossing Bird Creek	
79	IH 35, Industrial Blvd, 3rd St	Along and crossing Williamson Branch	
80	10th St, 14th St, Shell Ave	Along and crossing Williamson Branch	
81	French Ave	Crossing Williamson Branch	
82	Loop 363, SH 53, Ave H	Crossing Williamson Branch	
83	SH 53, Dairy Rd	Along Little Elm Creek	Bridge scores 4 for flood risk
84	Little Flock Rd, Bob White Rd	Crossing Little Elm Creek and Williamson Branch	
85	Bob White Rd	Crossing unnamed creek	
86	FM 3117	Crossing Knob Creek	
87	Loop 363, Case Rd	Crossing Knob Creek	
88	S 24th St, Ave H	Crossing Knob Creek	
89	13th St, 19th St, Ave R	Crossing Fryers Creek	Bridge scores 5 for flood risk
90	5th St, Marlandwood Dr	Along and crossing Fryers Creek	
91	5th St, Hatrick Bluff Rd	Along and crossing Fryers Creek	
92	FM 93, 31st St	Along and crossing Fryers Creek	
93	31st St, Waterbury Dr	Along and crossing unnamed creek	
94	Loop 363, Magnolia Blvd, Canyon Creek Dr	Crossing unnamed creek	
95	Shallow Ford Rd	Crossing Bird Creek	
96	Shallow Ford Rd	Crossing Bird Creek	Bridge scores 4 for flood risk
97	FM 93, Taylors Valley Rd	Crossing Leon River	
98	IH 35	Crossing Pepper Creek	
99	IH 35, Midway Dr, Battle Dr	Along and crossing Bird Creek	2 bridges score 5 for flood risk

Flooding from Dam Breach

The vulnerability of the road network to flooding from dam breach is distributed throughout the region with thirty-nine dams west of IH 35 and sixty dams to the east of IH 35, as shown in **Figure 11**. The differences in the density of the network and topology have an effect, with ten sites of vulnerability to dam breach on the west side and ten sites on the east side.

Figure 11: Road Network Vulnerable to Flooding from Dam Breach



There are two sites of bridges which have a history of flooding and are also within a dam breach risk area. Both locations are east of IH 35, shown in **Table 11**.

Table 11: Bridges Vulnerable to Flooding from Dam Breach

Site ID	Region	Road	Limits	Notes
7	S of Belton	Elmer King Rd	Below Stillhouse Hollow Lake	Bridge scores 5 for flood risk
20	S Temple	Martin Luther King Jr Dr	Below Veteran's Administration Lake	Bridge scores 5 for flood risk

Details of road infrastructure which is vulnerable to flooding from dam breaches are defined for twenty locations.

Figure 12 **through Figure** 22 and **Table 12 through**
Table 22 are a series of maps, tables, and images with details of roadway infrastructure which is vulnerable to flooding due to dam breaches.

Figure 12: Road Network Vulnerable to Flooding from Dam Breach Map - Fort Hood, Killeen, Harker Heights, and Nolanville Area

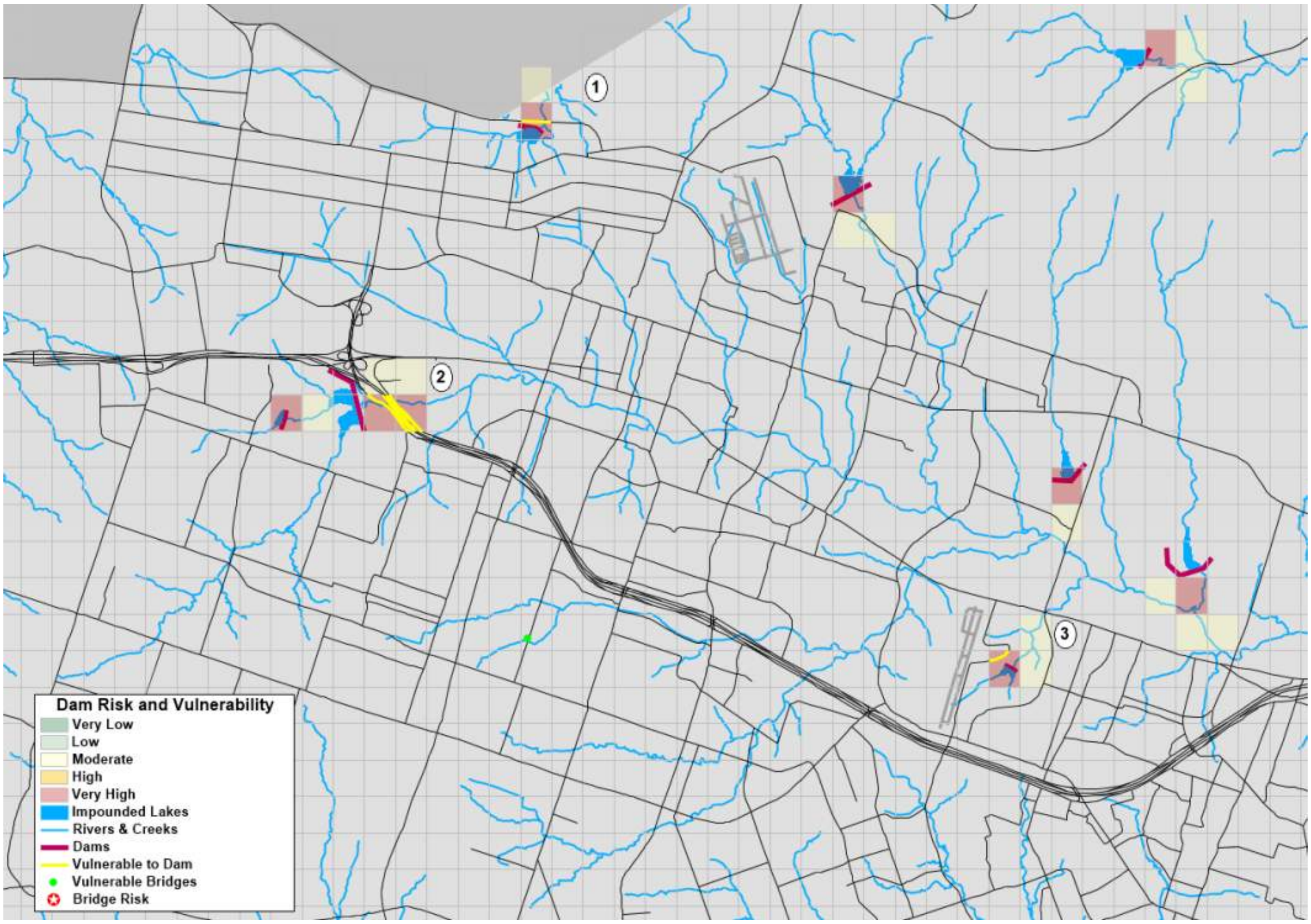


Table 12: Road Network Vulnerable to Flooding from Dam Breach List - Fort Hood, Killeen, Harker Heights, and Nolanville Area

Site ID	Road	Limits	Notes
1	South Range Rd	Below Tank Wash Lake	Simple earth dam, within Fort Hood
2	US 190	Below Soil Conservation Service Site 1	Earth dam with spillway, adjacent to significant interchange
3	Stonetree Dr	Below City of Killeen Reservoir	Stone dam

Figure 13: Road Network Vulnerable to Flooding from Dam Breach Map - Belton Area

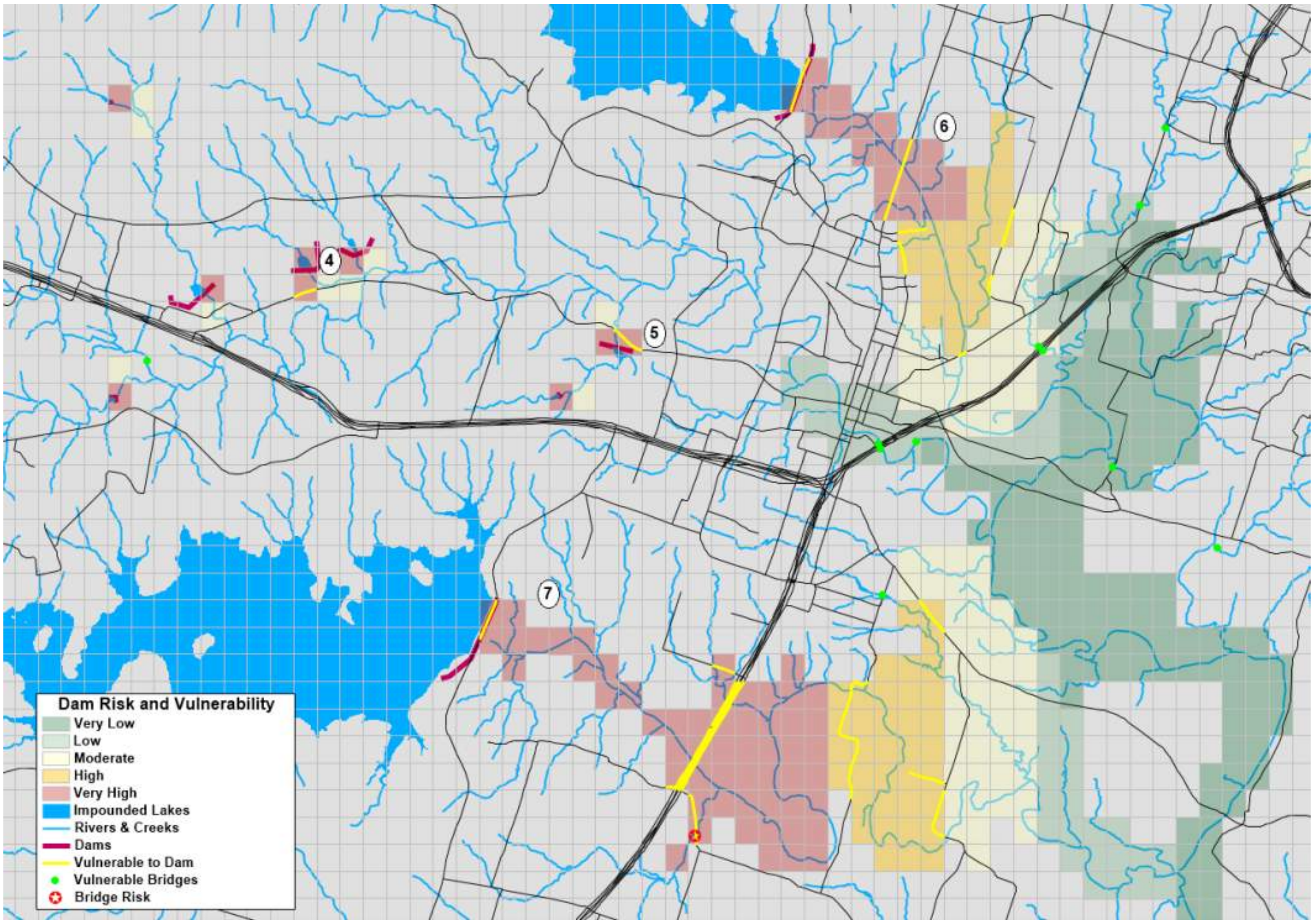


Table 13: Road Network Vulnerable to Flooding from Dam Breach List - Belton Area

Site ID	Road	Limits	Notes
4	Paddy Hamilton Rd	Below Soil Conservation Service Site 12	Earth dam with spillway
5	FM 93	Below Soil Conservation Service Site 15	Earth dam with spillway
6	SH 317, FM 2271, Beal St, S Pea Ridge Rd	Below Lake Belton	Concrete major dam
7	IH 35, FM 1670, Shanklin Rd, Elmer King Rd	Below Stillhouse Hollow Lake	Concrete major dam

Figure 14: Road Network Vulnerable to Flooding from Dam Breach Map - Salado

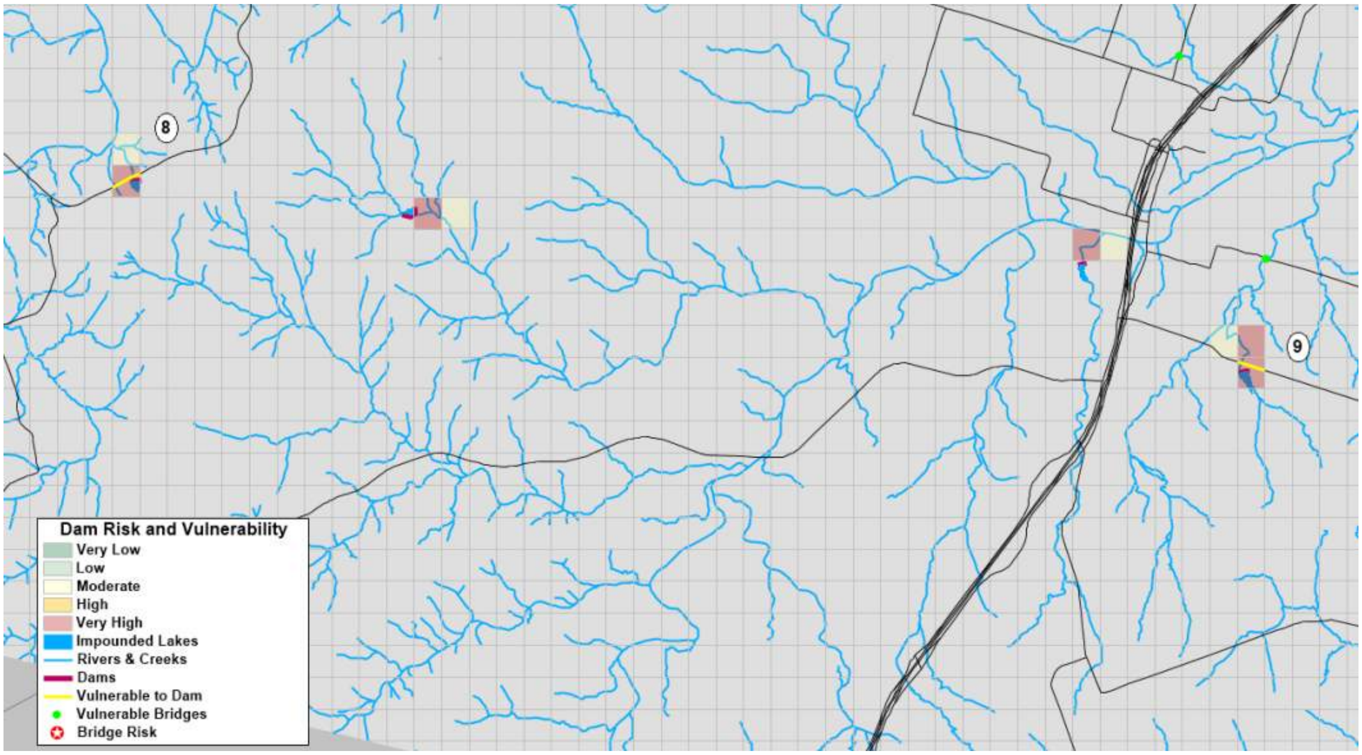


Table 14: Road Network Vulnerable to Flooding from Dam Breach List -Salado

Site ID	Road	Limits	Notes
8	FM 2484	Below unnamed lake	Simple earth dam
9	FM 2268	Below unnamed lake	Simple earth dam

Figure 15: Road Network Vulnerable to Flooding from Dam Breach Map – Eastern Bell County

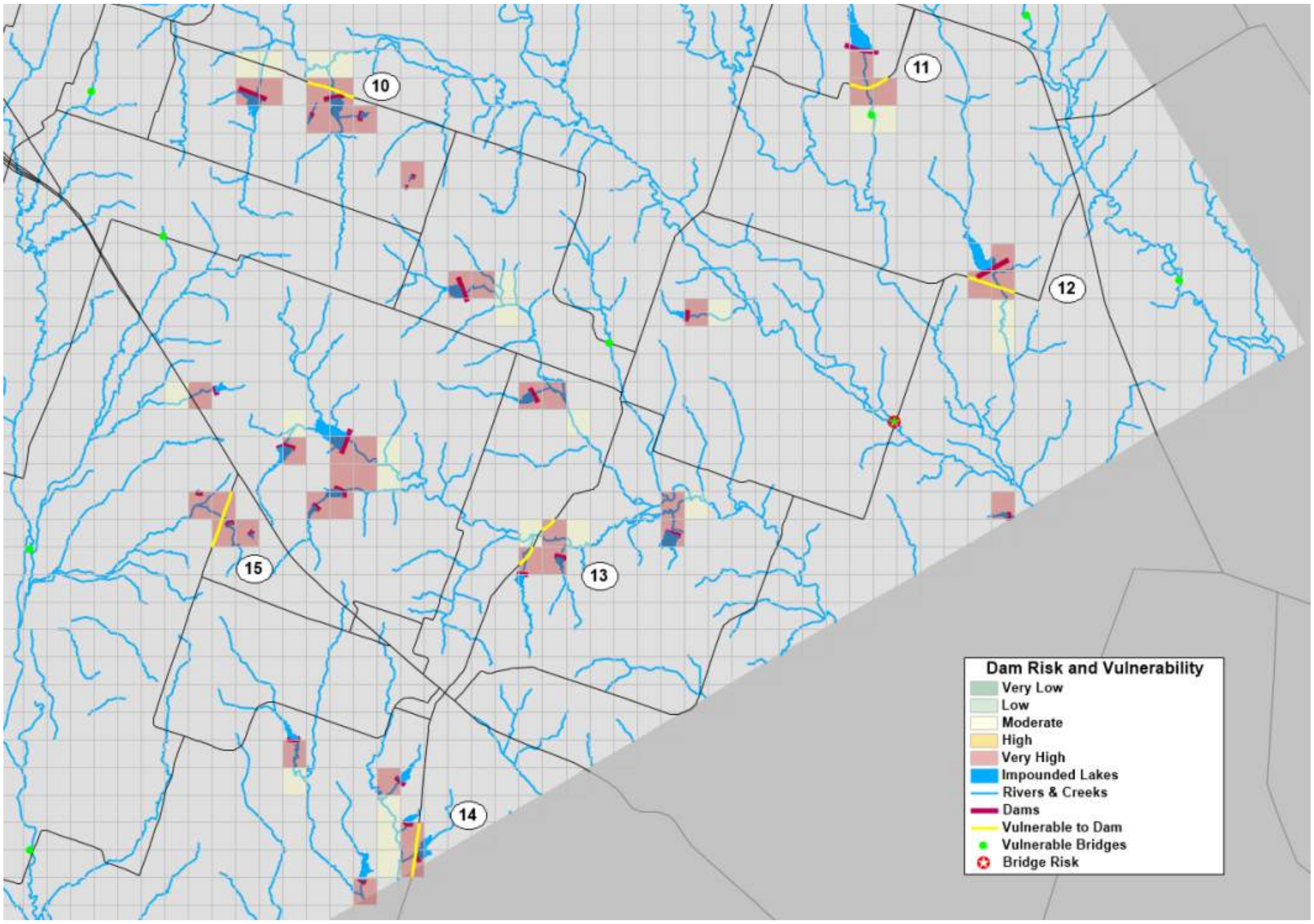


Table 15: Road Network Vulnerable to Flooding from Dam Breach List – Eastern Bell County

Site ID	Road	Limits	Notes
10	Stringtown Rd	Below unnamed lake	Earth dam with spillway
11	FM 964	Below unnamed lake	Earth dam with spillway
12	FM 940	Below unnamed lake	Earth dam with spillway
13	FM 437	Below 2 unnamed lakes	Earth dam with spillway
14	FM 437	Below Rogers Lake	Simple earth dam, breached in Jan 2019 after heavy rains
15	Knob Hill Rd	Below 2 unnamed lakes	Simple earth dam

The Rogers Lake Dam, referenced as #14 in **Table 15,** breached due to rainfall in January 2019. Figure **16** shows FM 437 during the flooding from that event. This illustrates the effects of flooding from this type of small earth dam and provides a vivid example of the probability of a dam breach.

Figure 16: Flooding over FM 437 after breach of Rogers Lake Dam in January 2019

Figure 17: Road Network Vulnerable to Flooding from Dam Breach Map – Temple Area

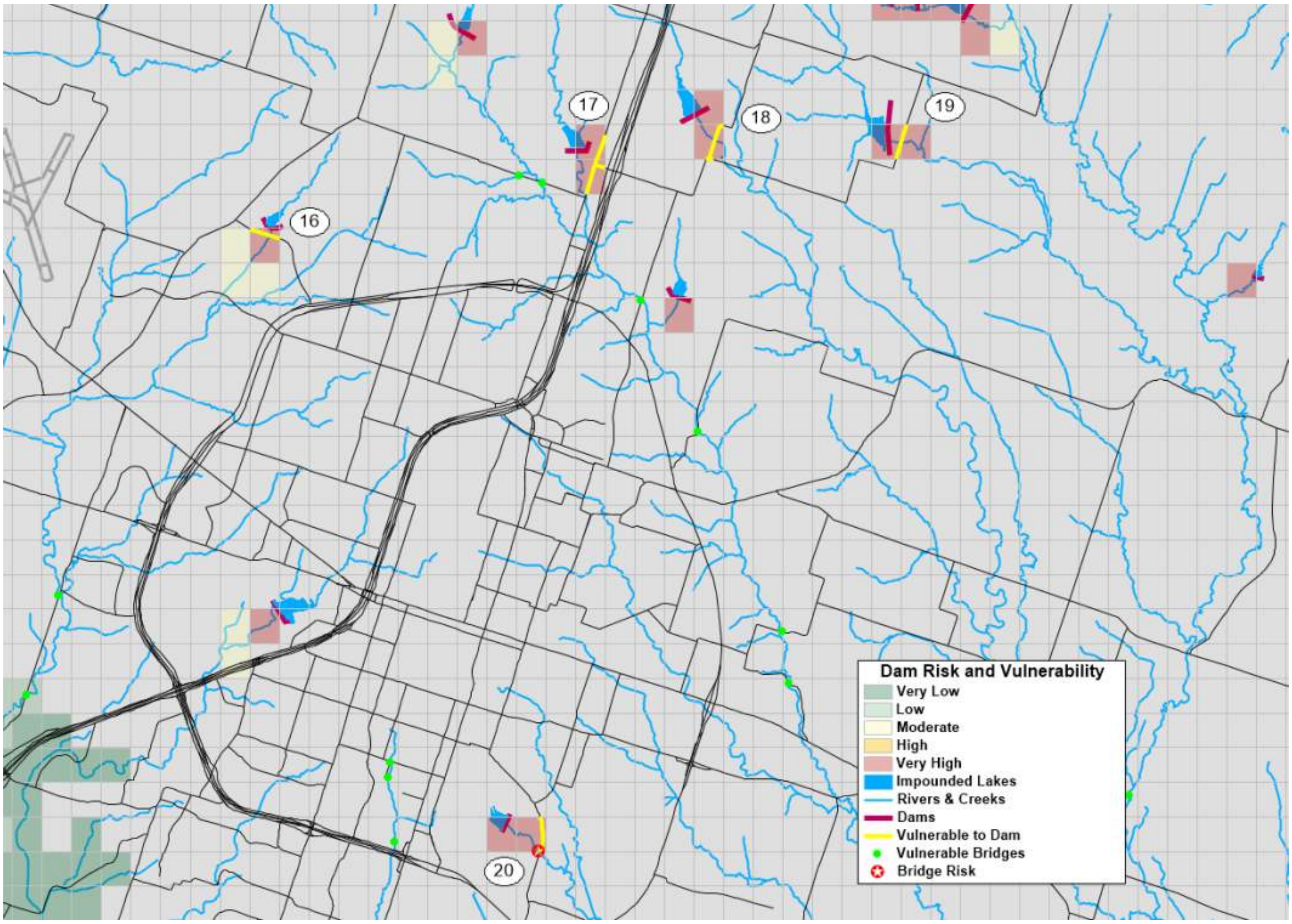


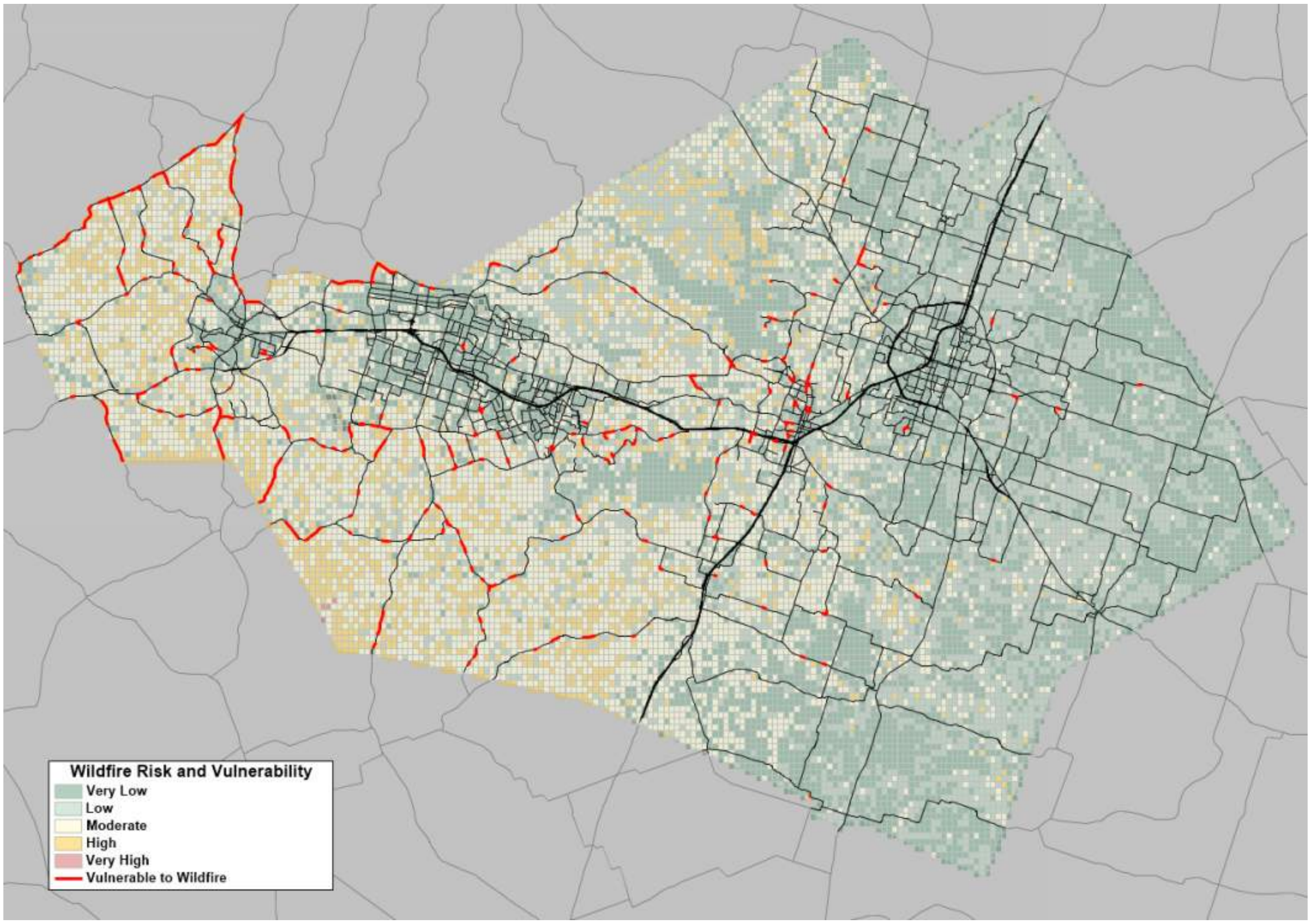
Table 16: Road Network Vulnerable to Flooding from Dam Breach List – Temple Area

Site ID	Road	Limits	Notes
16	McLane Rd	Below Wendland Farms Lake	Earth dam with spillway
17	Pegasus Dr, Hart Rd	Below unnamed lake	Earth dam with spillway
18	Lower Troy Rd, Berger Rd	Below unnamed lake	Earth dam with spillway
19	Pecan Rd	Below unnamed lake	Earth dam with spillway
20	Martin Luther King Jr Dr	Below Veteran's Administration Lake	Simple earth dam. Bridge scores 5 for flood risk

Wildfire

The vulnerability of the road network to wildfire is based on flammable ground cover, and therefore the vulnerability is distributed with a very evident divide between the brushy hill country in the west and the agricultural land of the prairie in the east. Small pockets of vulnerability are also shown scattered throughout the region. **Figure 18** is a map of roadway infrastructure vulnerability to wildfire.

Figure 18: Road Network Vulnerable to Wildfire



Details of road infrastructure which is vulnerable to wildfire are defined for ninety-one locations, shown in six figures and tables. **Figure through 24** and
Table 17 **through**
Table 22 are a series of key area maps and lists of the roadway infrastructure vulnerable to wildfires.

Figure 19: Road Network Vulnerable to Wildfire Map - Copperas Cove and Fort Hood Area

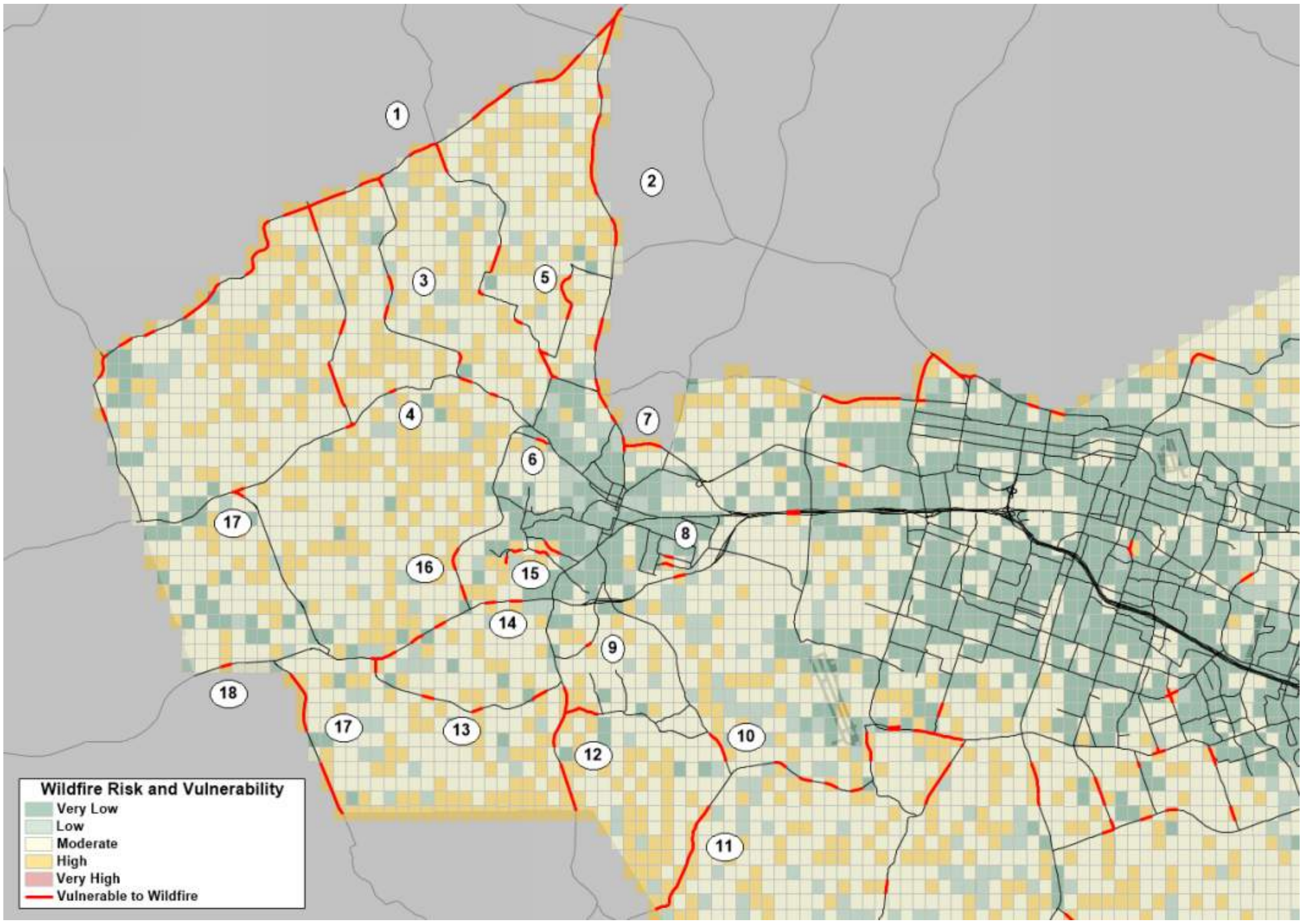


Table 17: Road Network Vulnerable to Wildfire List - Copperas Cove and Fort Hood Area

Site ID	Road	Limits	Notes
1	FM 580	FM 2313 to FM 116	
2	FM 116	FM 580 to S of SH 9	
3	CR 3270, FM 1113, Lutheran Church Rd	FM 580 to CR 3220	
4	CR 3220	FM 2313 to Summers Rd	
5	Wedgewood Ln	Hempel Dr to Lutheran Church Rd	
6	Bradford Dr	Big Divide Loop to Ave B	
7	SH 9	FM 116 to Old Georgetown Rd	
8	Bowen Ave, Constitution Dr, US 190 Bypass	Creek St to Mueller St	
9	FM 3046	US 190 Bypass to FM 2657	
10	FM 116	Boy's Ranch Rd to Okalla Rd	
11	Okalla Rd	County line to Mayberry Park Rd	
12	FM 2657, Boy's Ranch Rd	County line to FM 2808	
13	FM 2808	US 190 to FM 2657	
14	US 190	W of FM 2808 to FM 2657	
15	Pecan Grove Dr, Ogletree Pass, Pony Express Ln	W of Skyline Dr to US 190	
16	Big Divide Loop	Colorado Dr to US 190	
17	FM 3170	County line to US 190	
18	US 190	County line to FM 3170	

Figure 19: Road Network Vulnerable to Wildfire Map – Fort Hood, Killeen, Harker Heights, and Nolanville Area

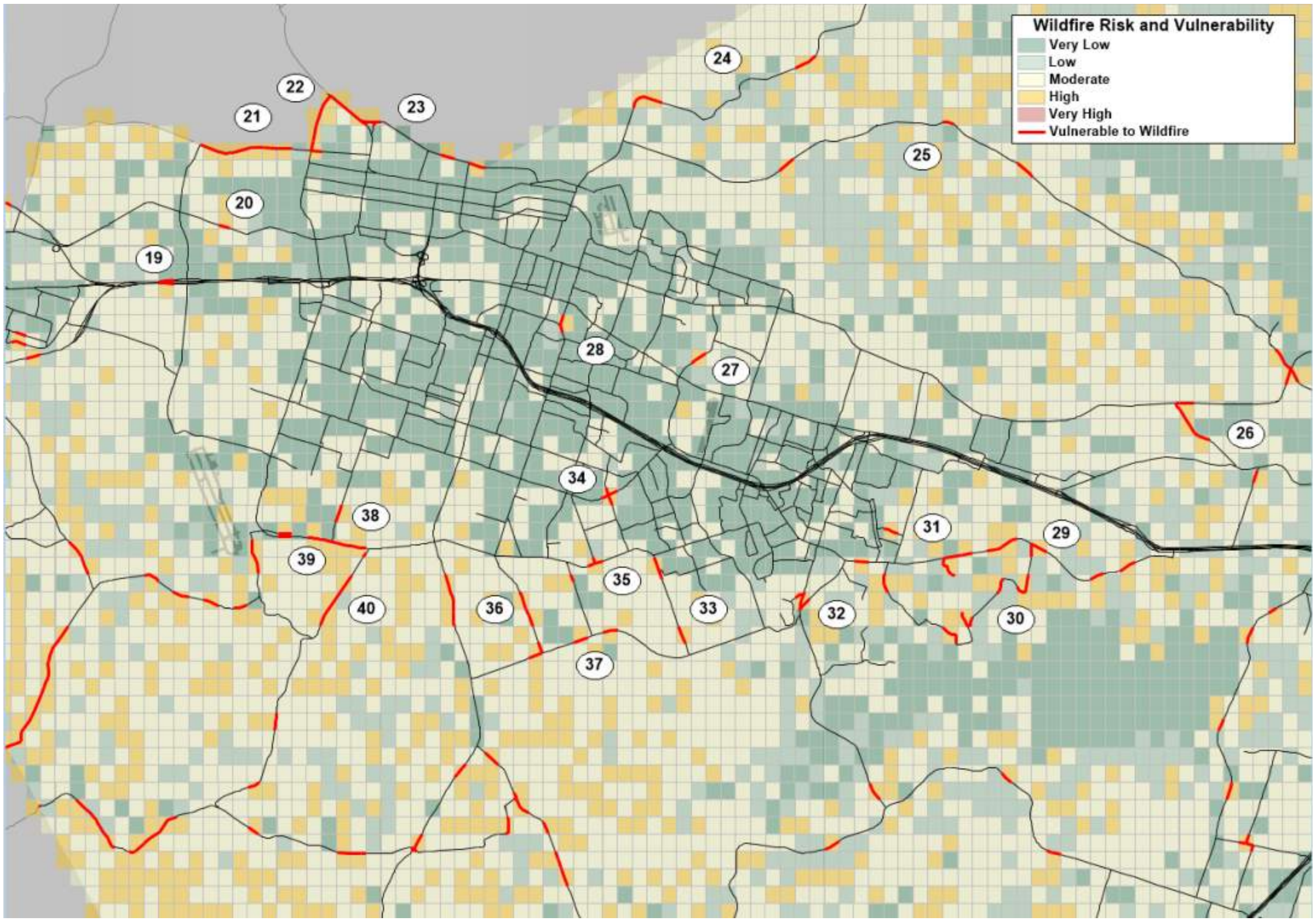


Table 18: Road Network Vulnerable to Wildfire List – Fort Hood, Killeen, Harker Heights, and Nolanville Area

Site ID	Road	Limits	Notes
19	US 190	SH 9 to Clarke Rd	
20	Tank Destroyer Blvd	Clarke Rd to Clear Creek Rd	Within Fort Hood
21	Turkey Run Rd	Clarke Rd to E of Clear Creek Rd	Within Fort Hood
22	Clear Creek Rd	West Range Rd to Turkey Run Rd	Within Fort Hood
23	West Range Rd	Clear Creek Rd to Murphy Rd	Within Fort Hood
24	East Range Rd	County line to Nolan Rd	Within Fort Hood
25	Nolan Rd	East Range Rd to E of FM 439	Within Fort Hood
26	FM 439, FM 93, George Wilson Rd	E of FM 93 to S of FM 93	
27	Twin Creek Dr	Roy J Smith Dr to BU 190	
28	10th St	N of Hallmark Ave to S of Hallmark Ave	
29	FM 2410	US 190 to Cedar Knob Rd	
30	High Oak Dr, Lakeside Dr, Comanche Gap Rd	FM 2410 to FM 2410	
31	Pontotoc Trace	Aztec Trace to Warrior Path	
32	FM 3481, Vineyard Trl, Cedar Knob Rd	Prospector Trl to Chaparral Rd	
33	E Trimmier Rd	Stagecoach Rd to Chaparral Rd	
34	Stan Schleuter Loop, Cunningham Rd	Intersection	
35	Stagecoach Rd, Orion Rd	Intersection	
36	SH 195, W Trimmier Rd, Featherline Rd	Stagecoach Rd to Chaparral Rd	
37	Chaparral Rd	SH 195 to E Trimmier Rd	
38	Bunny Trl	Cotton Patch Dr to SH 201	
39	SH 201	Okalla Rd to Maxdale Rd	
40	Maxdale Rd	SH 201 to FM 2670	

Figure 20: Road Network Vulnerable to Wildfire Map – Southwestern Bell County Area

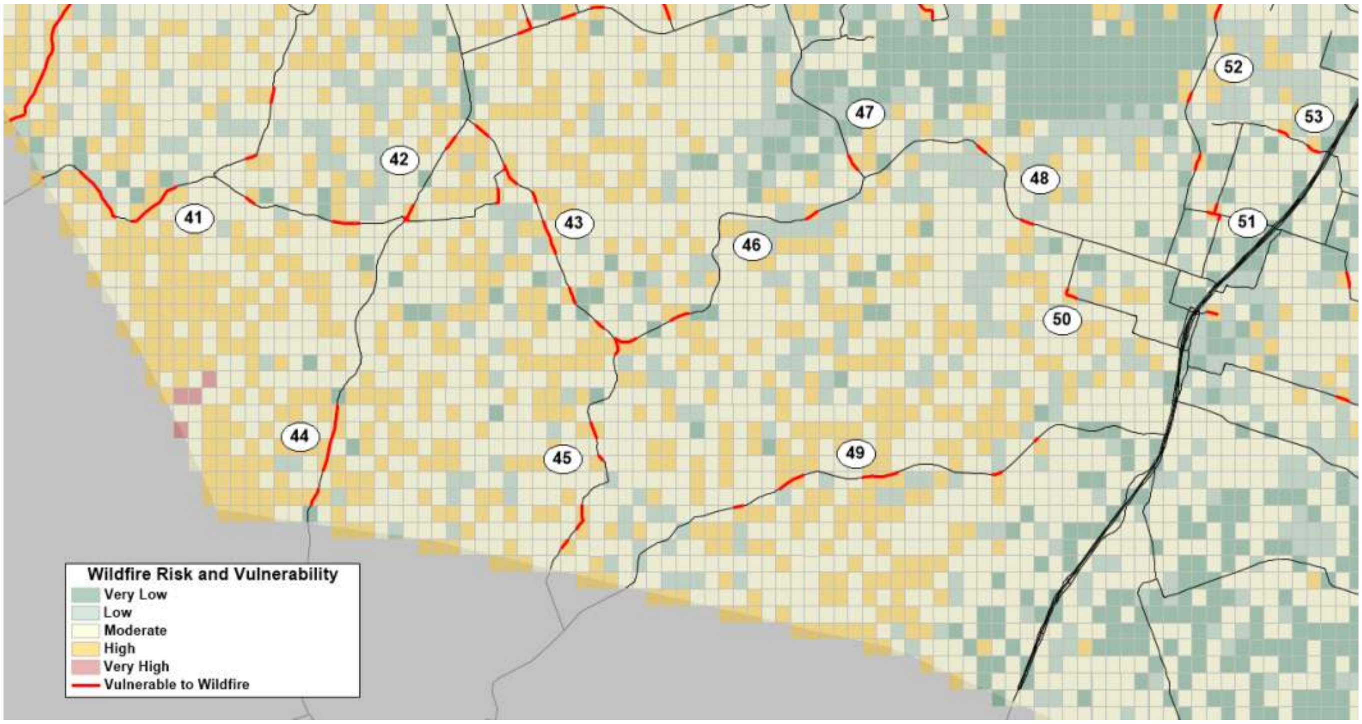


Table 19: Road Network Vulnerable to Wildfire List – Southwestern Bell County Area

Site ID	Road	Limits	Notes
41	Maxdale Rd, FM 2670	County line to FM 2484	
42	SH 195	FM 2484 to Fire Ln	
43	FM 2484	SH 195 to Stillman Valley Rd	
44	SH 195	County line to FM 2670	
45	Stillman Valley Rd	County line to FM 2484	
46	FM 2484	Stillman Valley Rd to FM 3481	
47	FM 3481	N of FM 2484	
48	FM 2484	FM 3481 to Brewer Rd	
49	FM 2843	County line to IH 35	
50	Brewer Rd, Thomas Arnold Rd	Intersection	
51	Smith Dairy Rd, Amity Rd	Intersection	
52	FM 1670	Auction Barn Rd to Amity Rd	
53	Tahuaya Rd	Smith Dairy Rd to IH 35	

Figure 21: Road Network Vulnerable to Wildfire Map – Holland and Bartlett Area

Table 20: Road Network Vulnerable to Wildfire List – Holland and Bartlett Area

Site ID	Road	Limits	Notes
54	Creek Dr	E of IH 35	
55	Royal St	W of Armstrong Rd	
56	FM 2268	Armstrong Rd to Romberg Rd	
57	Harold Clark Rd	Romberg Rd to Brune Rd	
58	FM 1123, Barnes Rd	Intersection	
59	Amity Rd	E of Fox Rd	
60	Summers Mill Rd	Armstrong Rd to FM 1123	
61	FM 1123	Holland Rd to Sand & Gravel Ln	
62	Holland Rd	E of FM 1123	
63	Winchester Dr, Longhorn Trl	Canyon Creek Dr to 31st St	
64	Stage Rd	W of SH 95	
65	Reeds Lake Rd	W of Pritchard Rd	

Figure 22: Road Network Vulnerable to Wildfire Map – Northern Temple and Troy Area

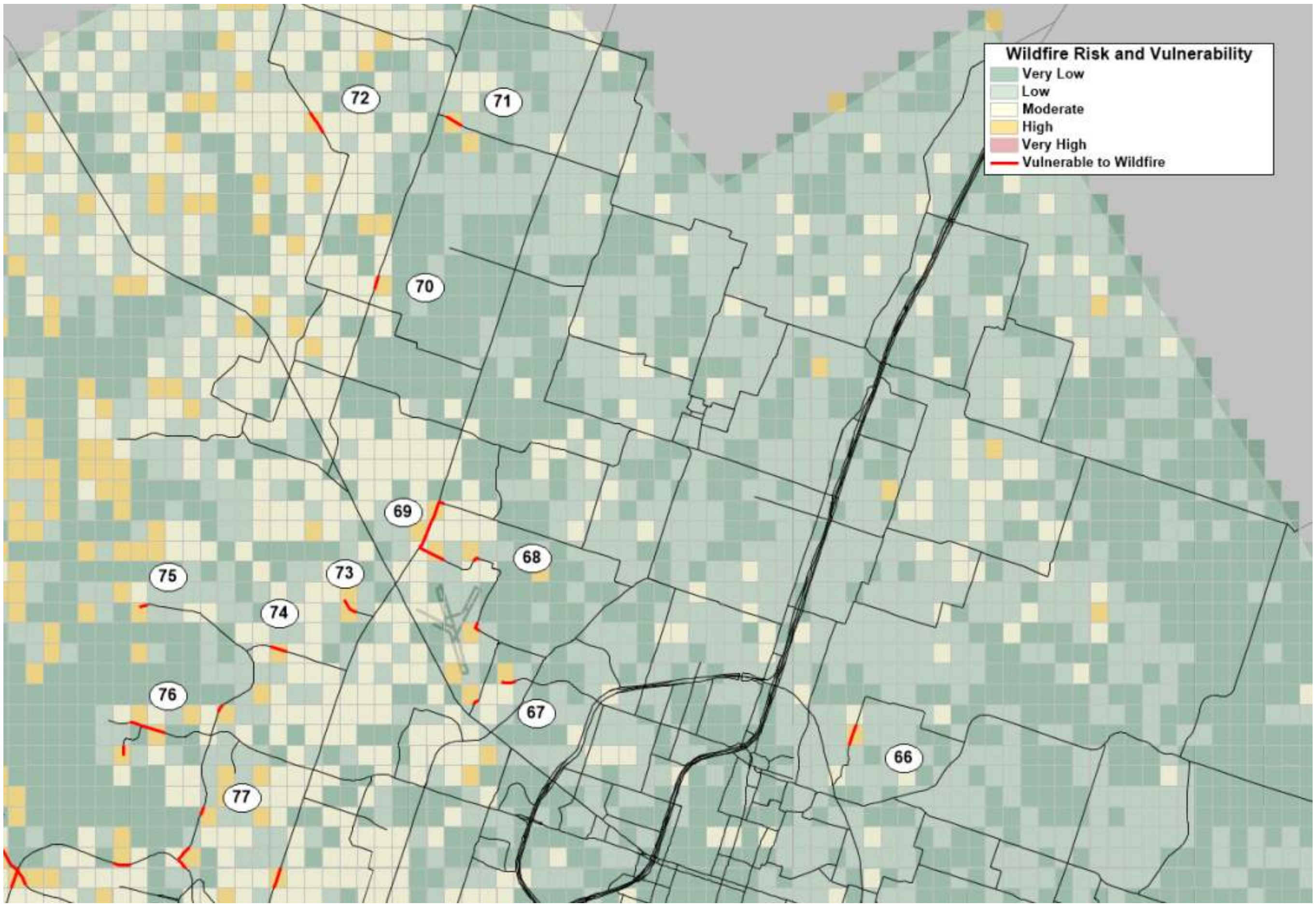


Table 21: Road Network Vulnerable to Wildfire List – Northern Temple and Troy Area

Site ID	Road	Limits	Notes
66	Gun Club Rd	N of Loop 363	
67	Industrial Blvd, Airport Trl	N of SH 36	
68	Airport Trl, Little Mexico Rd	SH 317 to Pepper Creek Rd	
69	SH 317	Little Mexico Rd to Cedar Creek Rd	
70	FM 2409	N of Buckhorn Cemetery Rd	
71	FM 2601	E of FM 2601	
72	Buckhorn Cemetery Rd	S of FM 2601	
73	North Point Rd	W of SH 317 to end of road	
74	FM 2483	FM 2271 to SH 317	
75	FM 2271	FM 2483 to end of road	
76	FM 2305, Arrowhead Point Rd	W of FM 2271	
77	FM 2271	FM 2483 to FM 439	

Figure 23: Road Network Vulnerable to Wildfire Map – Belton Area

Table 22: Road Network Vulnerable to Wildfire List – Belton Area

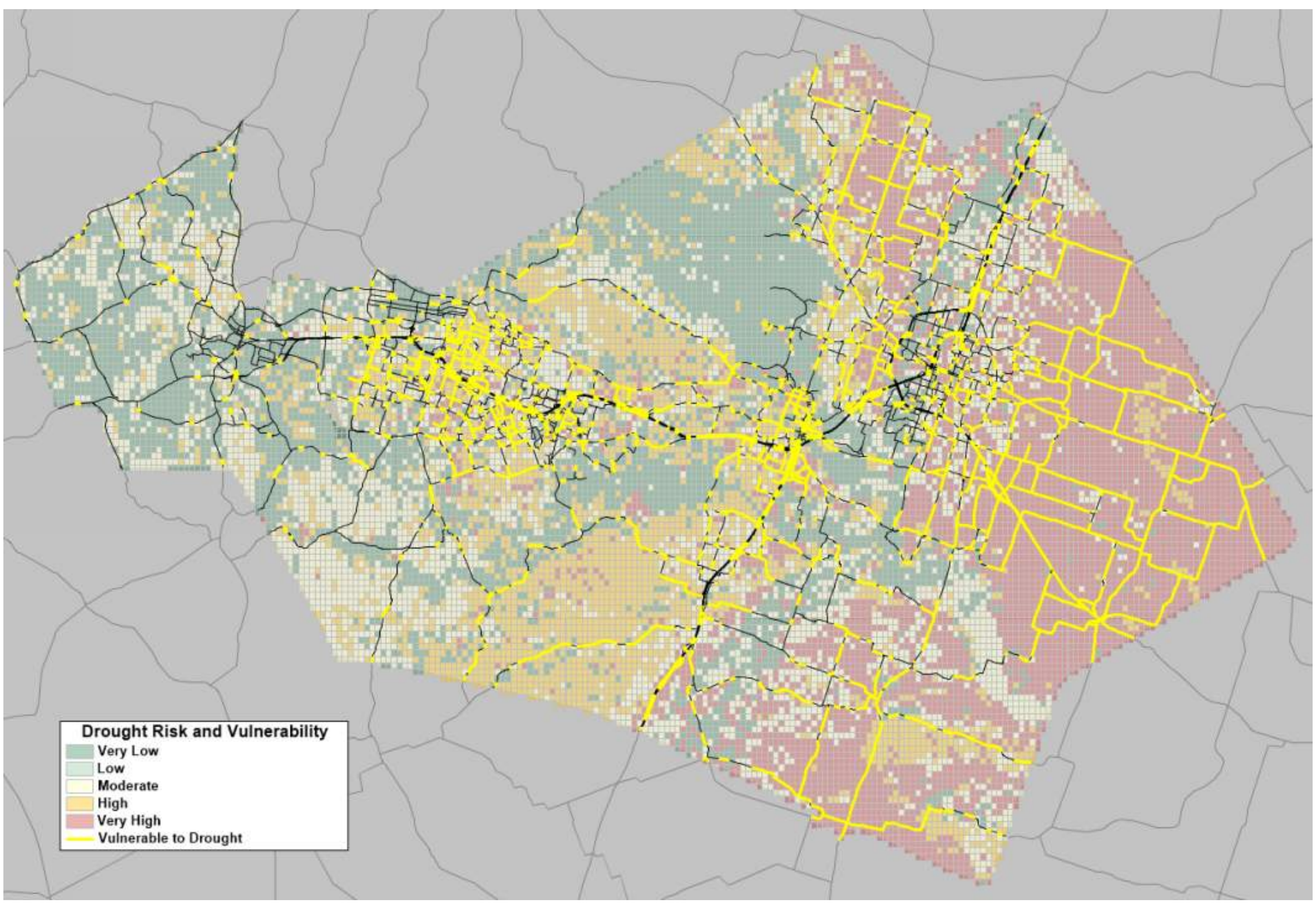
Site ID	Road	Limits	Notes
78	FM 439, Sparta Rd	Intersection	
79	FM 439	Sparta Rd to E of FM 2271	
80	FM 439, River Place Dr	Intersection	
81	SH 317	Tarver Rd to Guthrie Dr	
82	SH 317	Guthrie Rd to 24th St	With 4 crossing streets
83	Riverside Trl, Charter Oak Dr	Intersection	
84	SH 317, Beal St, 13th St, 15th St, Penelope St	Streets in the grid	Crossing streets fill the grid cell
85	University Dr, Crusader Way	Intersection	
86	Wheat Rd	S of Sparta Rd	
87	FM 93, Mitchell St	Intersection	
88	Ave D, Ave H, Saunders St, Connell St	Streets in the grid	Crossing streets fill the grid cell
89	Connell St	S of US 190	
90	US 190	Loop 121 to Connell St	
91	US 190, 190 Ln	FM 1670 to Golf Course Rd	

Drought or Sustained High Temperatures

The vulnerability of the road network to drought or sustained high temperatures is based on the different characteristics of expansion and contraction by soil type. The RVRF grid shows a clear division between the hill country in the west and the heavy clay soils of the prairie to the east. However, while the "very high" rating for soil expansion is clearly concentrated in the east, there are pockets with that rating scattered throughout the region. Further, there are definite swaths of soils rated as "high" in the west. As a result, the distribution of vulnerability of the road networks does not reflect the apparent division between east and west. Actually, a denser network in the urbanized area of Killeen, Harker Heights, Nolanville, and Belton lie in an area of scattered "high" elasticity soil, while the Temple urbanized area lies in a swath of more stable soil. The heavy clay area in eastern Bell County is mostly rural, with a more sparse network. As a result, there is more network in the west of the region which is vulnerable to drought or sustained high temperatures than there is in the east: 412 miles of roads in the west are vulnerable, compared to 329 miles of roads in the east.

Still, the underlying difference in soil types is evident in a clear distinction. In the west, the distribution of vulnerability is somewhat lumpy, with vulnerable and non-vulnerable soil types freely mixed. In the east and southeast, vulnerability is more consistent: the entire towns of Bartlett, Holland, and Rogers and roads for several miles in all directions are all vulnerable. **Figure 24** shows an overview of the roadway infrastructure vulnerable to drought or sustained high temperatures for the KTMPO area.

Figure 24: Road Network Vulnerable to Drought or Sustained High Temperatures



Details of road infrastructure which is vulnerable to drought or sustain high temperatures are defined for 167 locations, shown in eight figures and tables. **Figure 25 through Figure** 31 and **Table 23 through Table** 30 show these key area maps and lists of roadway infrastructure vulnerable to drought or sustained high temperatures across the region As so much of the network was vulnerable, for this incident type some locations were consolidated (e.g., location 34 is South Killeen; location 119 is east Bell County, in each case essentially every road in the area is vulnerable).

Figure 25: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Copperas Cove and Fort Hood Area

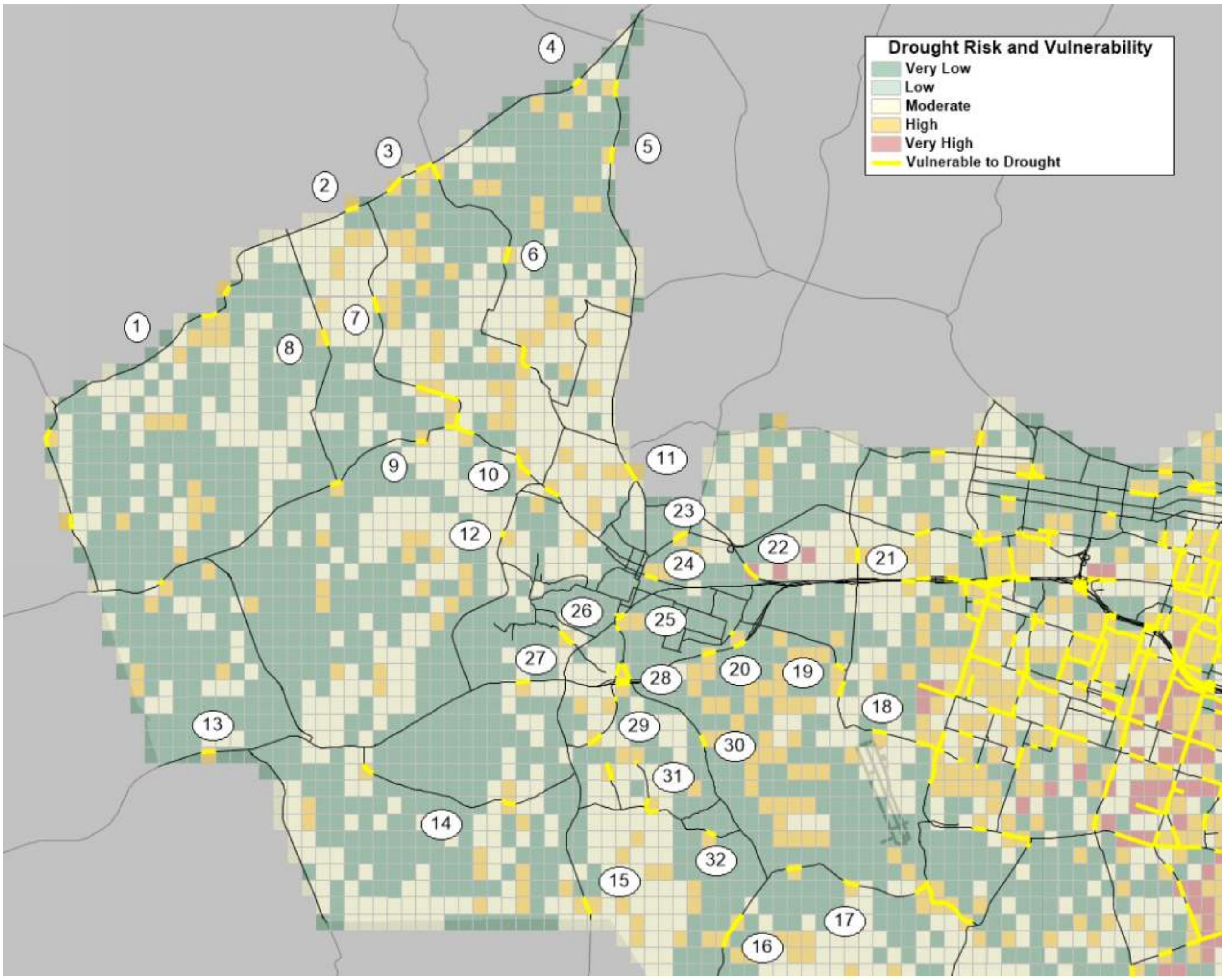


Table 23: Road Network Vulnerable to Drought or Sustained High Temperatures List – Copperas Cove and Fort Hood Area

Site ID	Road	Limits	Notes
1	FM 580	FM 2313 to CR 3270	
2	FM 580	CR 3270 to FM 1113	
3	FM 580	FM 1113 to Lutheran Church Rd	
4	FM 580	Lutheran Church Rd to FM 116	
5	FM 116	FM 580 to Hempel Dr	
6	Lutheran Church Rd	FM 580 to China Ln	
7	FM 1113	FM 580 to CR 3220	
8	CR 3270	FM 580 to CR 3220	
9	CR 3220	CR 3270 to FM 1113	
10	FM 1113	CR 3220 to Big Divide Loop	
11	FM 116	Lutheran Church Rd to Courtney Ln	
12	Big Divide Loop	Bradford Dr to Colorado Dr	
13	US 190	County line to FM 3170	
14	FM 2808	US 190 to FM 2657	
15	FM 2657	County line to Boys Ranch Rd	
16	Okalla Rd	County line to FM 116	
17	Okalla Rd, Mayberry Park Rd	FM 116 to Maxdale Rd	
18	Mohawk Dr, Clarke Rd	Mashburn Rd to SH 201	
19	Mashburn Rd	US 190 bypass to Clarke Rd	
20	US 190 Bypass	Mashburn Rd to FM 116	
21	Clarke Rd	US 190 to Tank Destroyer Blvd	
22	SH 9	US 190 to Tank Destroyer Blvd	
23	Main St	Truman Ave to Old Georgetown Rd	
24	Ave D	Main St to US 190	
25	US 190, Georgetown Rd, FM 116	Intersection	
26	Ogletree Pass	Freedom Ln to US 190	
27	US 190	Big Divide Loop to US 190 Bypass	
28	US 190 Bypass, FM 3046, FM 116	Intersection	
29	FM 3046	FM 2657 to US 190 Bypass	
30	FM 116	US 190 Bypass to Herradura Calzada Rd	
31	Boys Ranch Rd, Edward Dr, Sikes Dr	FM 2657 to Herradura Calzada Rd	
32	Boys Ranch Rd	Herradura Calzada Rd to FM 116	

Figure 26: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Killeen, Harker Heights, and Belton Area

Table 24: Road Network Vulnerable to Drought or Sustained High Temperatures List – Killeen, Harker Heights, and Belton Area

Site ID	Road	Limits	Notes
33	Fort Hood		
34	South Killeen		
35	SH 195	Chaparral Rd to FM 2484	
36	SH 195	FM 2484 to Fire Ln	
37	Fire Ln	SH 195 to FM 2484	
38	FM 2484	SH 195 to Fire Ln	
39	FM 2484	Fire Ln to Stillman Valley Rd	
40	FM 2484	Stillman Valley Rd to FM 3481	
41	FM 3481	Chaparral Rd to FM 2484	
42	FM 2484	FM 3481 to Brewer Ln	
43	FM 2484	Brewer Ln to FM 1670	
44	Brewer Ln, Thomas Arnold Rd	FM 2484 to IH 35	
45	North Salado		
46	South Belton		
47	North Belton		
48	FM 439	Sparta Rd to FM 2271	
49	Sparta Rd	FM 439 to Wheat Rd	
50	FM 93	George Wilson Rd to Wheat Rd	
51	George Wilson Rd	Wheat Rd to US 190	
52	Paddy Hamilton Rd	US 190 to FM 93	
53	FM 93	FM 439 to Paddy Hamilton Rd	
54	FM 439	FM 93 to Sparta Rd	
55	Sparta Rd	Westcliff Rd to FM 439	
56	FM 439	Roy Reynolds Dr to FM 93	
57	North Killeen		
58	Nolan Rd, Sparta Rd	East Range Rd to Westcliff Rd	
59	East Range Rd	County line to Nolan Rd	

Figure 27: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Southwestern Bell County Area

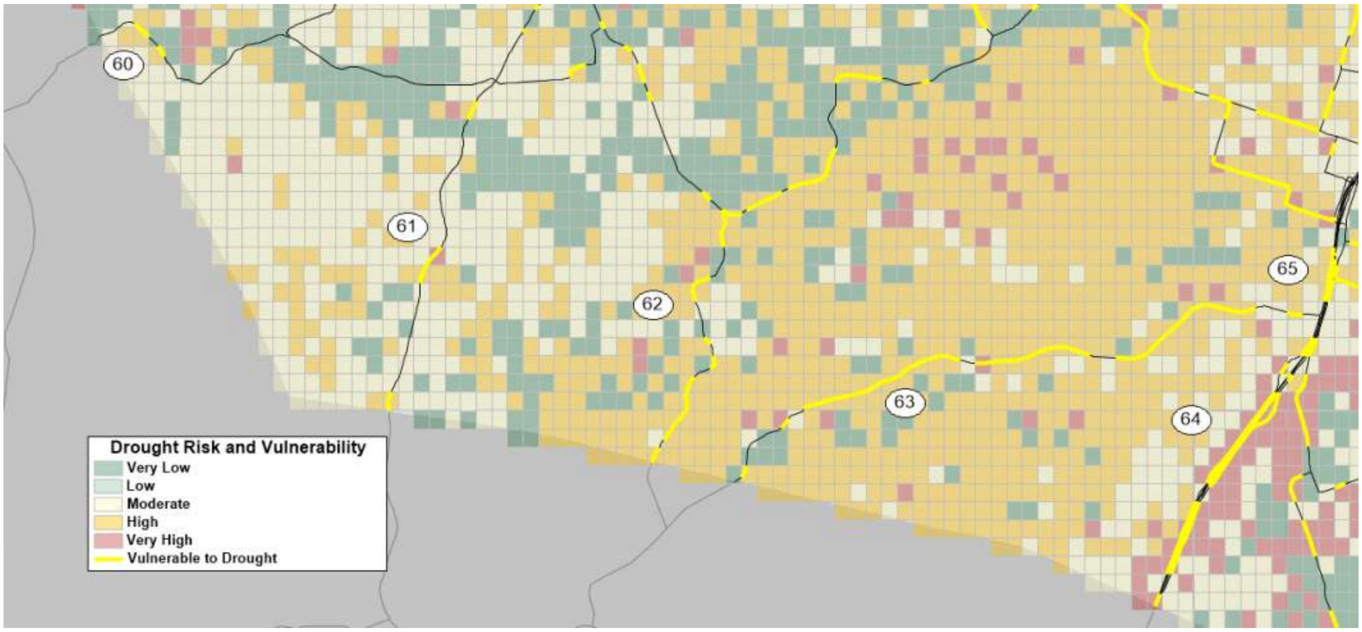


Table 25: Road Network Vulnerable to Drought or Sustained High Temperatures List – Southwestern Bell County Area

Site ID	Road	Limits	Notes
60	Maxdale Rd	County line to FM 2670	
61	SH 195	County line to FM 2670	
62	Stillman Valley Rd	County line to FM 2484	
63	FM 2843	County line to IH 35	
64	IH 35	County line to FM 2843	
65	IH 35	FM 2843 to Thomas Arnold Rd	

Figure 29: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Southeastern Bell County

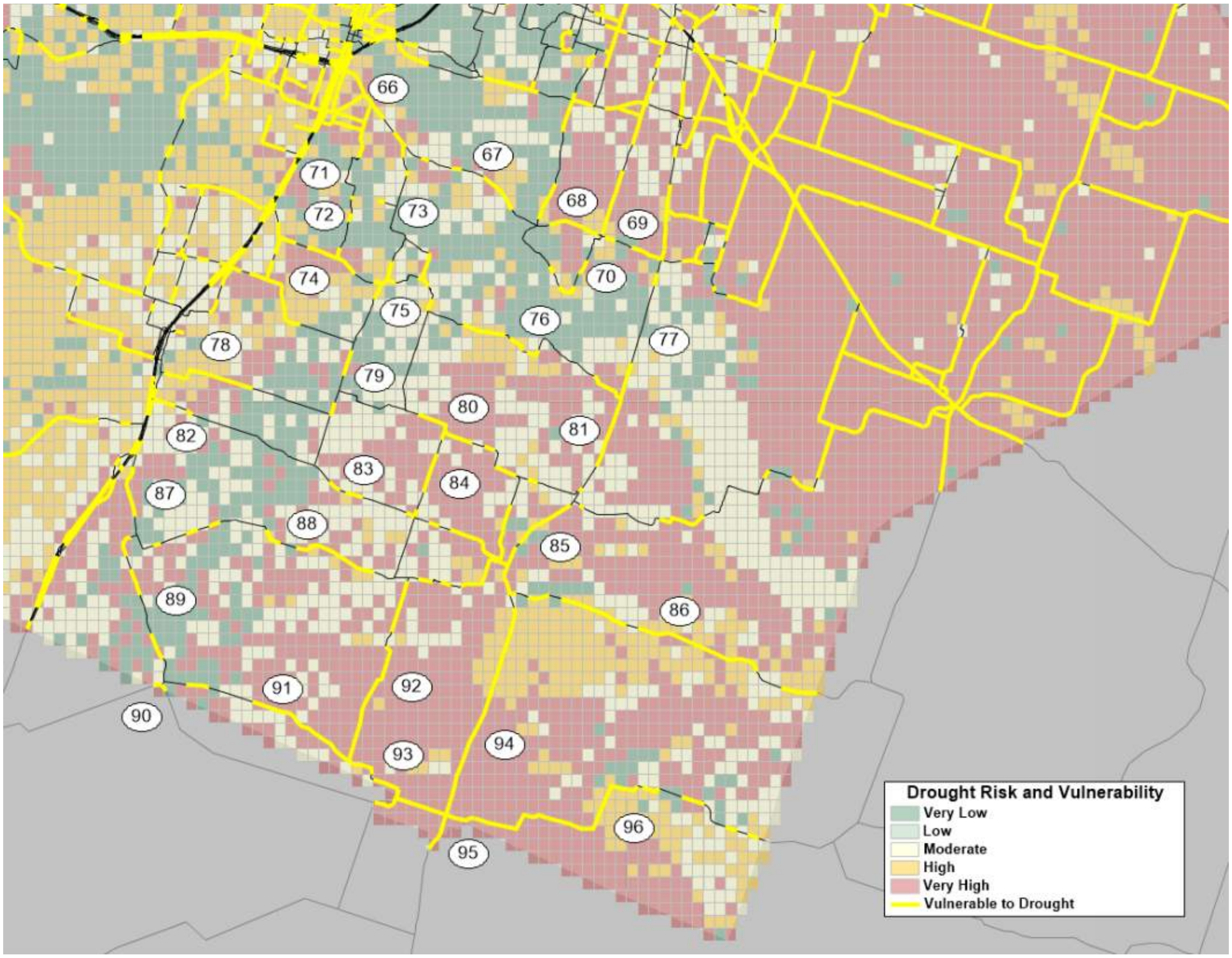


Table 26: Road Network Vulnerable to Drought or Sustained High Temperatures List – Southeastern Bell County

Site ID	Road	Limits	Notes
66	Southeast Belton	Includes sections of IH 35, Wall St, Holland Rd	
67	Holland Rd	FM 1123 to Hatrick Bluff Rd	
68	Holland Rd	Hatrick Bluff Rd to Kings Trail	
69	FM 436	Kings Trail to SH 95	
70	Wilson Valley Rd	Hatrick Bluff Rd to Kings Trail	
71	IH 35	Loop 121 to Tahuaya Rd	
72	Elm Grove Rd	Elm Grove Spur to Elmer King Rd	
73	FM 1123	Holland Rd to Armstrong Rd	
74	North Salado	At the Elmer King Rd crossing of IH 35	
75	Armstrong Rd, FM 1123, Summers Mill Rd	Both intersections	
76	Campbell Hill Rd	FM 1123 to SH 95	
77	SH 95	FM 436 to Stage Rd	
78	Royal St	Main St to Armstrong Rd	
79	Armstrong Rd	Sulpher Well Rd to Royal St	
80	FM 1123	Barnes Rd to Roberts Rd	
81	SH 95	Stage Rd to Sunshine Rd	
82	Salado	Includes sections of IH 35, Royal St, FM 2268	
83	FM 2268	Armstrong Rd to Romberg Rd	
84	Romberg Rd	FM 1123 to RM 2268	
85	Holland	Includes SH 95, FM 1123, FM 2268	
86	FM 2268	SH 95 to County line	
87	FM 2115	IH 35 to Hackberry Rd	
88	Hackberry Rd	FM 2115 to Romberg Rd	
89	FM 2115	Hackberry Rd to Harold Clark Rd	
90	FM 487	County line to County line	
91	Harold Clark Rd	FM 2115 to Romberg Rd	
92	Romberg Rd	Hackberry Rd to Harold Clark Rd	
93	Harold Clark Rd, FM 487	Romberg Rd to SH 95	
94	SH 95	FM 2268 to FM 487	
95	SH 95	FM 487 through Rogers S of the County line	
96	FM 487	SH 95 to County line	

Figure 28: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Southwest Temple

Table 27: Road Network Vulnerable to Drought or Sustained High Temperatures List – Southwest Temple

Site ID	Road	Limits	Notes
97	IH 35, Charter Oak Dr, Battle Dr	N and S of Midway Dr	
98	Midway Dr	Battle Dr to El Capitan Dr	
99	SW Temple	Loop 363, Thornton Dr, Cottonwood Dr	
100	Shallow Ford Rd	Hickory Rd to Shallow Ford West Rd	
101	31st St, Waterbury Dr	W of Waters Dairy Rd	
102	FM 93, Taylors Valley Rd	E of IH 35 at Belton	
103	FM 93, 31st St	Intersection	
104	FM 93, Hatrick Bluff Rd	Intersection	
105	FM 93, 93 Spur, Kings Trail	Intersection	
106	Kings Trail	FM 93 to Blackland Rd	
107	5th St, Canyon Creek Dr, Waters Dairy Rd	2 Intersections	
108	Hatrick Bluff Rd	Waters Dairy Rd to N of FM 93	
109	Marlandwood Rd, Lowes Dr	Intersection	
110	5th St, Marlandwood Rd	Intersection	
111	Loop 363, 1st St, 5th St	Intersection	
112	NW Temple	31st St, Ave T, Scott Blvd	
113	NNW Temple	IH 35, Central Ave, Adams Ave	
114	N Temple	5th St, 30th St, Ave H, MLK Jr Dr	
115	NNE Temple	Loop 363, SH 53, Ave H	
116	NE Temple	Loop 363, Tower Rd	
117	ENE Temple	Loop 363, Case Rd	
118	SE Temple	SH 95	

Figure 29: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Eastern Bell County

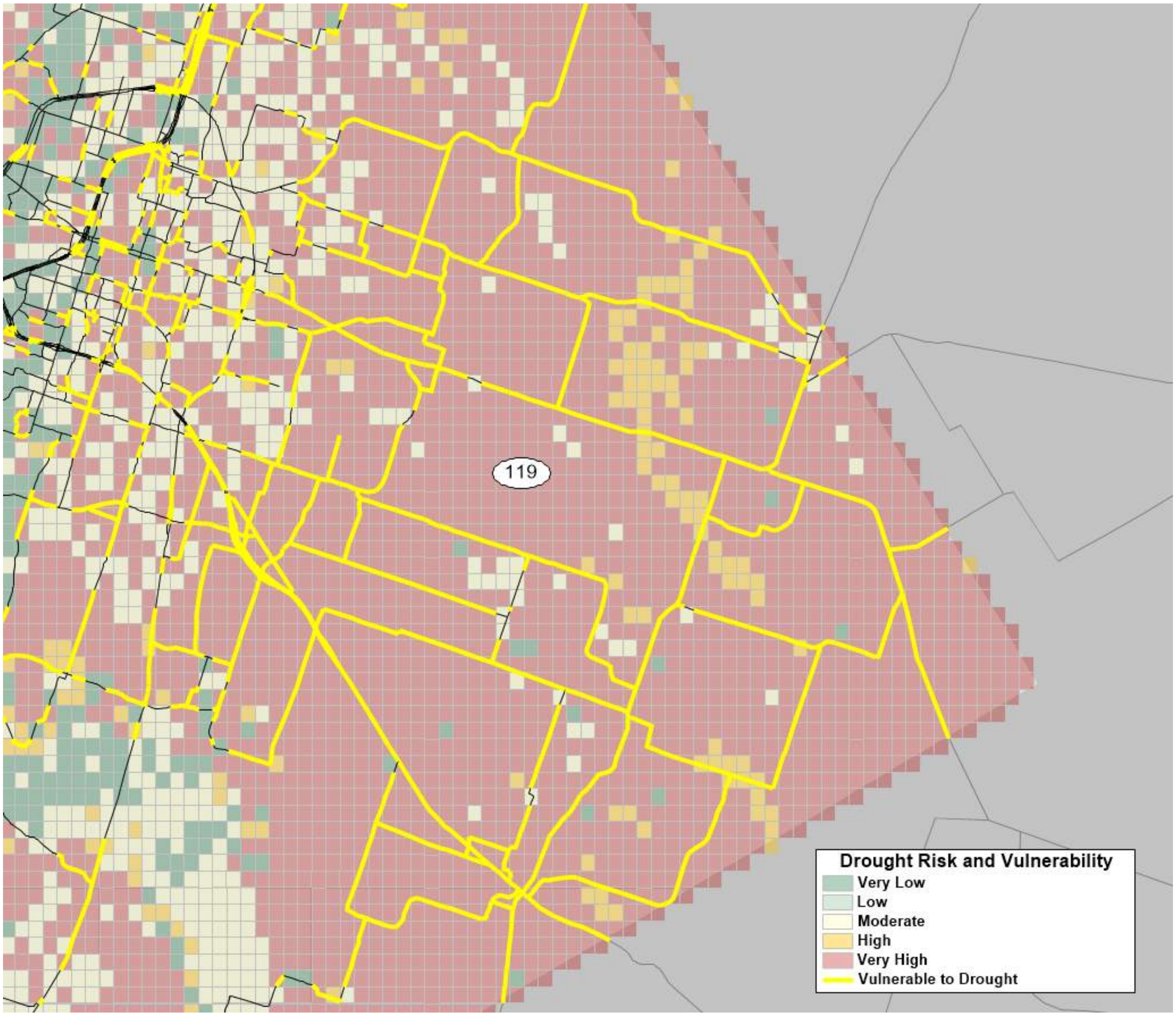


Table 28: Road Network Vulnerable to Drought or Sustained High Temperatures List – Eastern Bell County

Site ID	Road	Limits	Notes
119	East Bell County	US 190, SH 53, FM 436, FM 437, FM 438, FM 485, FM 940, FM 1671, FM 2086, FM 2184, FM 3117, FM 3369	Essentially all roads in the eastern part of the County

Figure 30: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Northern Bell County

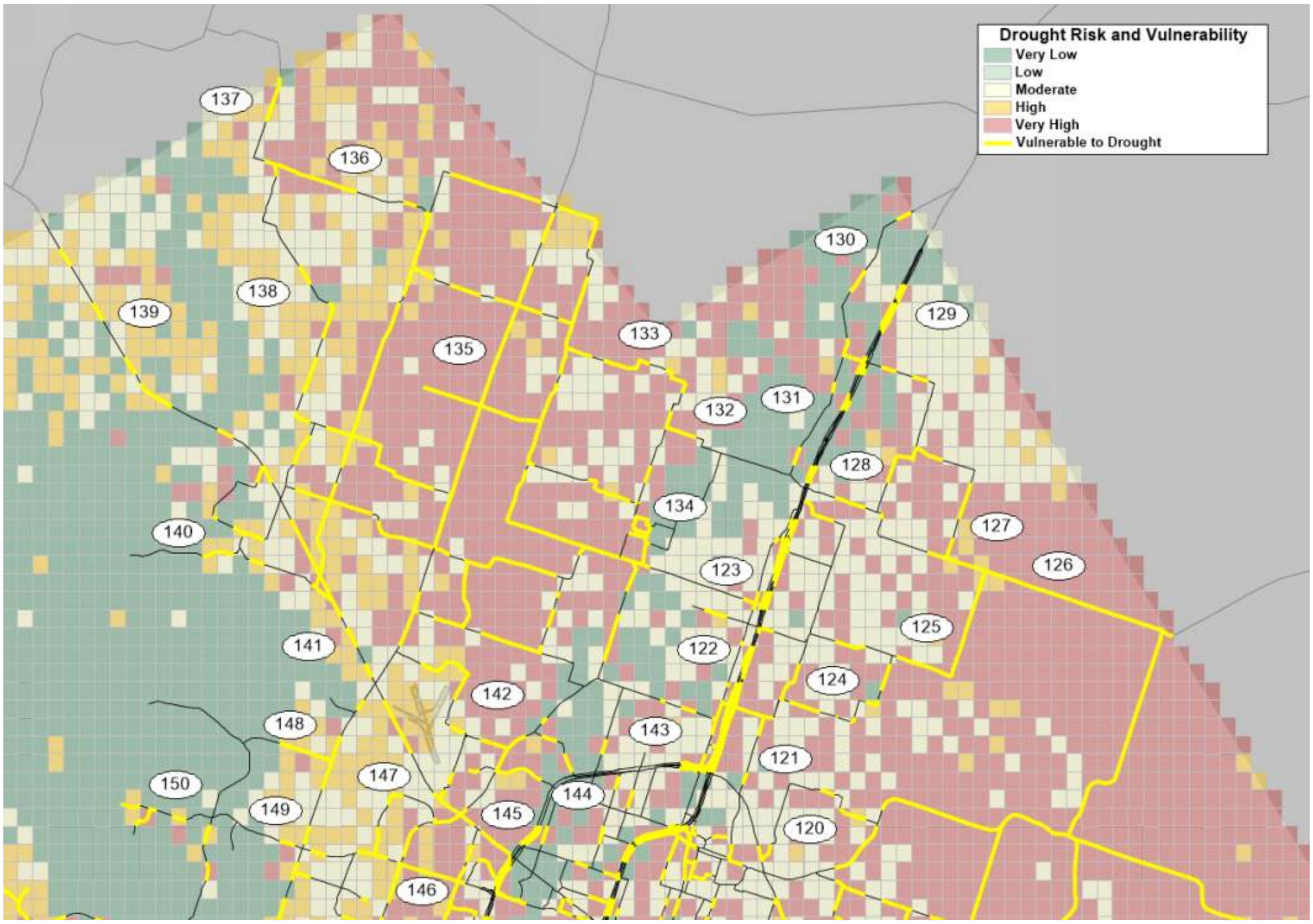


Table 29: Road Network Vulnerable to Drought or Sustained High Temperatures List – Northern Bell County

Site ID	Road	Limits	Notes
120	Cottonwood Creek Rd	Loop 363 to FM 438	
121	Old Troy Rd	Loop 363 to Berger Rd	
122	IH 35, Pegasus Dr	Loop 363 to FM 1237	
123	IH 35, Pegasus Dr	FM 1237 to Austin Rd	
124	South Troy	Lower Troy Rd, Berger Rd, Pecan Rd, Bottoms East Rd	
125	Bottoms East Rd, Bottoms Rd	Pecan Rd to FM 935	
126	FM 935	Bottoms Rd to County line	
127	East Big Elm Rd	FM 935 to Shiloh Rd	
128	IH 35, Main St, Shiloh Rd	Main St to East Big Elm Rd	
129	IH 35	East Big Elm Rd to County line	
130	Old US 81	County line to East Big Elm Rd	
131	Old US 81	East Big Elm Rd to Luther Curtis Rd	
132	Luther Curtis Rd	Pendleton Troy Loop to Vaughn Rd	
133	Vaughn Rd, Franklin Rd	Luther Curtis Rd to Willow Grove Rd	
134	Pendleton	Includes Pendleton Rd, 1237 Spur	
135	NW Pendleton	Includes SH 317, FM 1237, FM 2409, FM 2601, Willow Grove Rd	Essentially all roads north and west of Pendleton
136	FM 2601	Buckhorn Cemetery Rd to Munz Rd	
137	FM 2601, Moody Leon Rd	Buckhorn Cemetery Rd to County line	
138	Buckhorn Cemetery Rd	FM 2601 to FM 2409	
139	SH 36	County line to McGregor Park Rd	
140	Kuykendall Mountain	Includes McGregor Park Rd, Water Supply Rd, Moffat Rd, Kuykendall Mountain Rd	
141	SH 36, Moffat Rd	FM 2409 to SH 317	
142	Little Mexico Rd, Airport Trl, Pepper Creek Rd	SH 317 to Old Howard Rd	
143	Wendland Rd, Moores Mill Rd	Loop 363 to Pegasus Dr	
144	Industrial Blvd, Old Howard Rd, McLane Rd	W of Loop 363	
145	Loop 363, SH 36, Old Howard Rd, Industrial Blvd	W of Loop 363	
146	Loop 363, FM 2305, Hillyard Rd, SH 36	W of Loop 363	
147	Westfield Rd	FM 2305 to Hillyard Rd	
148	SH 317, FM 2483	Intersection	
149	SH 317, FM 2305	Intersection	
150	Morgans Point Resort	Includes FM 2305, FM 2271	

Figure 31: Road Network Vulnerable to Drought or Sustained High Temperatures Map – Northern Temple

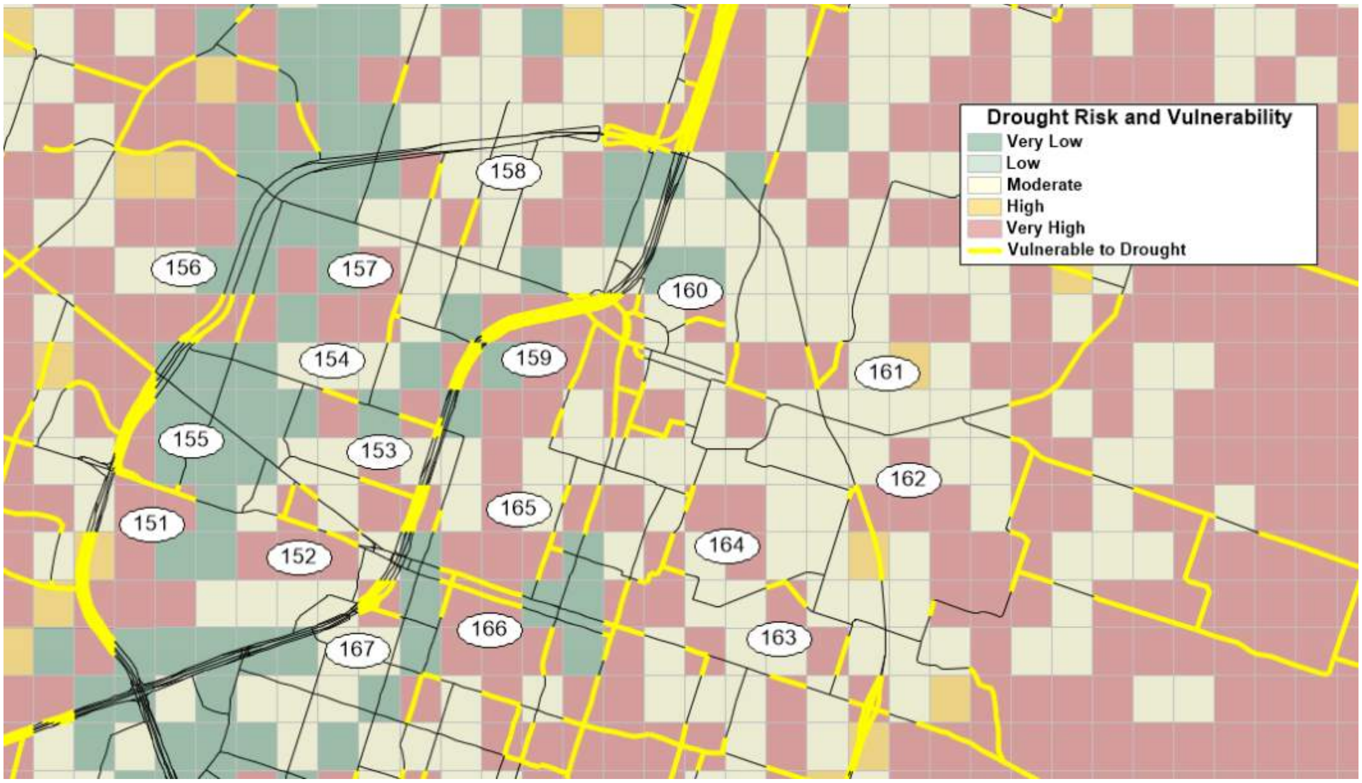


Table 30: Road Network Vulnerable to Drought or Sustained High Temperatures List – Northern Temple

Site ID	Road	Limits	Notes
151	Adams Ave	Loop 363 to E of Woodbridge Blvd	
152	Adams Ave	W of Village Way to Central Ave	
153	IH 35, Salisbury Rd	Nugent Ave to Central Ave	
154	Nugent Ave	John Paul Jones Dr to Eberhardt Rd	
155	Loop 363	SH 36 to Adams Ave	
156	Loop 363	Industrial Blvd to Nugent Ave	
157	Eberhardt Rd, Enterprise Rd	Intersection	
158	Eberhardt Rd, Lucius McCelvey Dr	Loop 363 to Industrial Blvd	
159	IH 35	N of Industrial Blvd to Nugent Ave	
160	NE Temple	Includes Upshaw Ave, 1st St, 15th St, Industrial Blvd	
161	Loop 363, Gun Club Rd	Intersection	
162	Loop 363, 42nd St	Intersection	
163	SE Temple	Includes SH 53, French Ave, Lavendusky Dr, 50th St	
164	8th St, 14th St, Houston Ave	SH 53 to Shell Ave	
165	3rd St, 9th St, French Ave	Adams Ave to Nugent Ave	
166	Adams Ave, Central Ave, 25th St	9th St to 31st St	
167	IH 35, Ave D	Central Ave to Ave H	

Summary

This memo built on the work from Task 1, which defined the Regional Vulnerability and Resilience Framework (RVRF) and set up a regional grid with vulnerability scores for each of four types of incidents: flooding from rainfall, flooding from dam breaches, wildfire, and drought or sustained high temperatures. This task linked the RVRF grid scores to the road network to discover specific locations which are vulnerable to each incident type.

With specific locations in the network which are vulnerable identified, this information can be used to generate projects to address the vulnerability and increase the resiliency of the network. These projects can then enter the standard KTMPO project evaluation process.

The assignment of scores to the RVRF grid was in some cases “lumpy” as the rectangular grid interacted with the more fluid aspects of riverbeds, topology, ground cover, and soil types. The road network is also non-rectangular, so the identification of vulnerable segments was also “lumpy”. Manual smoothing of the grid scores is an option but is not recommended. Manual smoothing would be a subjective deviation from the base data, would impact the relationships between the individual incident scorings, and would have to be repeated with every update to the data. For the same reasons, manual smoothing of the defined vulnerable road segments is not recommended.

This memo has identified the road network’s vulnerable segments with a series of figures and tables for each incident type. This shows a large number of locations for each vulnerability type, with difficulties in defining each location and its individual limits, and in setting a label to identify each location. In practice, it will be more practical to directly reference the RVRF grid and network in a GIS platform.

Task 2: Determine Network Sensitivity for the Rail Network

Introduction

Exposure to incidents assessed in Task 1 was quantified and documented by setting up a Regional Vulnerability and Resilience Framework (RVRF). The RVRF defined a ¼ mile grid for the study area and developed scores in the range of 1 to 5 for each grid cell, ranking their vulnerability to four types of incidents: flooding from rainfall, flooding from dam breaches, wildfire, and drought or sustained high temperatures. In this Task 2, the RVRF grid was linked to the rail network to discover specific locations which are vulnerable to each incident type.

This double approach defines two purposes of the RVRF. First, the compilation of vulnerability scores for each cell of the RVRF grid allows network projects to be evaluated, as detailed in the Task 1 memo. This evaluation requires use of both the RVRF grid to capture the scores for a particular project and a spreadsheet to export the grid scores, consolidate and weight them, and to format the composite scores. Secondly, the identification of locations which are vulnerable to each incident type, detailed in this Task 2 memo, defines specific areas with issues and supports generating projects to directly address those issues.

Because of the scale of the region, the number of specific project locations for the four types of incidents is large. For simplicity, this memo has been broken into two documents: one for the rail network; and a separate memo for the road networks; covering the auto, bicycle, bus, and walk networks. In practice, after the system is documented in these memos, directly referencing the RVRF grid and network within a GIS platform will be more practical.

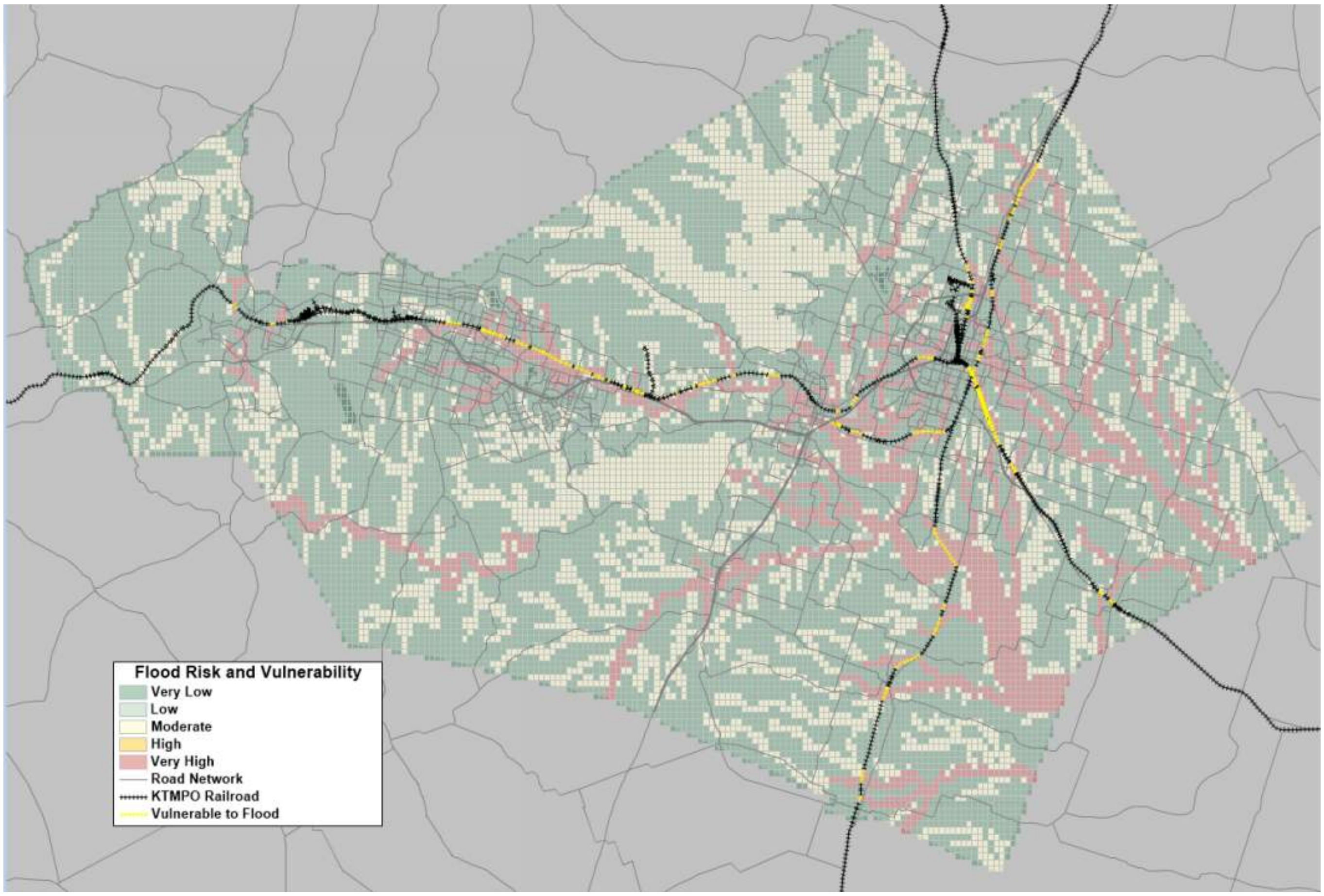
For both the rail network and the road networks, the assessments of vulnerability determine segments which are rated at “high” or “very high” risk for each type of incident. Bridges are noted as vulnerable based on their ratings in the RVRF grid and were further identified as “at risk” if they were both highly rated and located in an RVRV grid cell that was itself highly rated for flood risk or dam breach risk.

For clarity, the regional view of vulnerability for each type of risk is shown, followed by several inset views as necessary to show the individual locations. Each location is numbered for reference and listed in a table. To keep the listings manageable, smaller segments of road in close proximity were sometimes combined as a single location.

Flooding from Rainfall

The vulnerability of the rail network to flooding from rainfall is fairly evenly distributed throughout the region, but the divide between the hill country in the west and the flatter prairie in the east is evident. Vulnerability in the west is concentrated in the urbanized areas and around the Lampasas River, while in the east vulnerability is more widely distributed in both urban and rural areas. The rail network vulnerable to flooding from rainfall is shown within the map in **Figure 1**.

Figure 1: Rail Network Vulnerable to Flooding from Rainfall



Through this analysis, rail infrastructure vulnerable to flooding from rainfall are identified for thirty-six locations, shown in five figures and tables. **Figure 1 through**

Figure 6 and **Table 1 through**

Table 5 are a series of maps and figures with details of rail infrastructure vulnerable to flooding in the KTMPO area.

Figure 2: Rail Network Vulnerable to Flooding from Rainfall Map – Copperas Cove Area

Table 1: Rail Network Vulnerable to Flooding from Rainfall List – Copperas Cove Area

Site ID	Railroad	Limits	Notes
1	BNSF	E and W of Courtney Ln	
2	BNSF	E of US 190 @ Ave D intersection	
3	BNSF	W of US 190 @ SH 9 intersection	

Figure 3: Rail Network Vulnerable to Flooding from Rainfall Map – Killeen, Harker Heights, and Nolanville Area

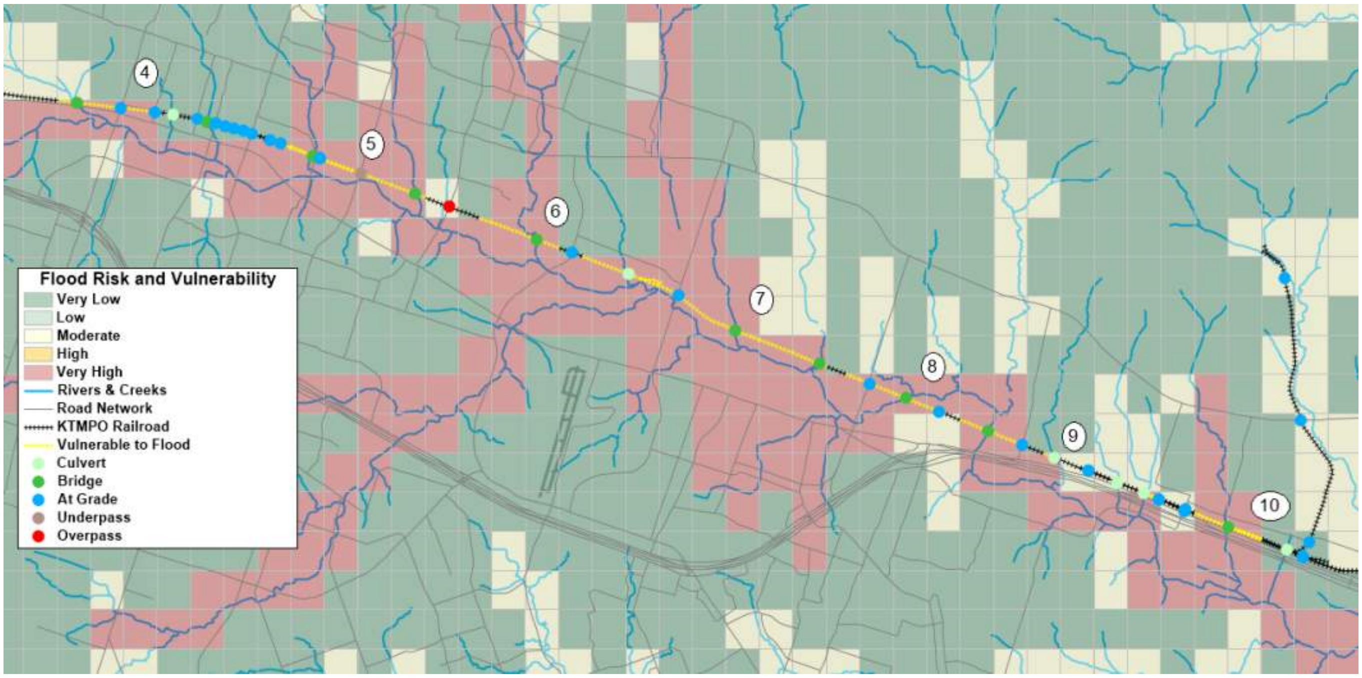


Table 2: Rail Network Vulnerable to Flooding from Rainfall List – Killeen, Harker Heights, and Nolanville Area

Site ID	Railroad	Limits	Notes
4	BNSF	E and W of Fort Hood St	
5	BNSF	10th St to 38th St	
6	BNSF	38th St to Twin Creek Dr	
7	BNSF	Twin Creek Dr to Lookout Ridge Blvd	
8	BNSF	Lookout Ridge Blvd to Pleasant Hill Cemetery Rd	
9	BNSF	Pleasant Hill Cemetery Rd to Old Nolan Rd	
10	BNSF	Old Nolan Rd to Jack Rabbit Rd	

Figure 4: Rail Network Vulnerable to Flooding from Rainfall Map – Belton Area

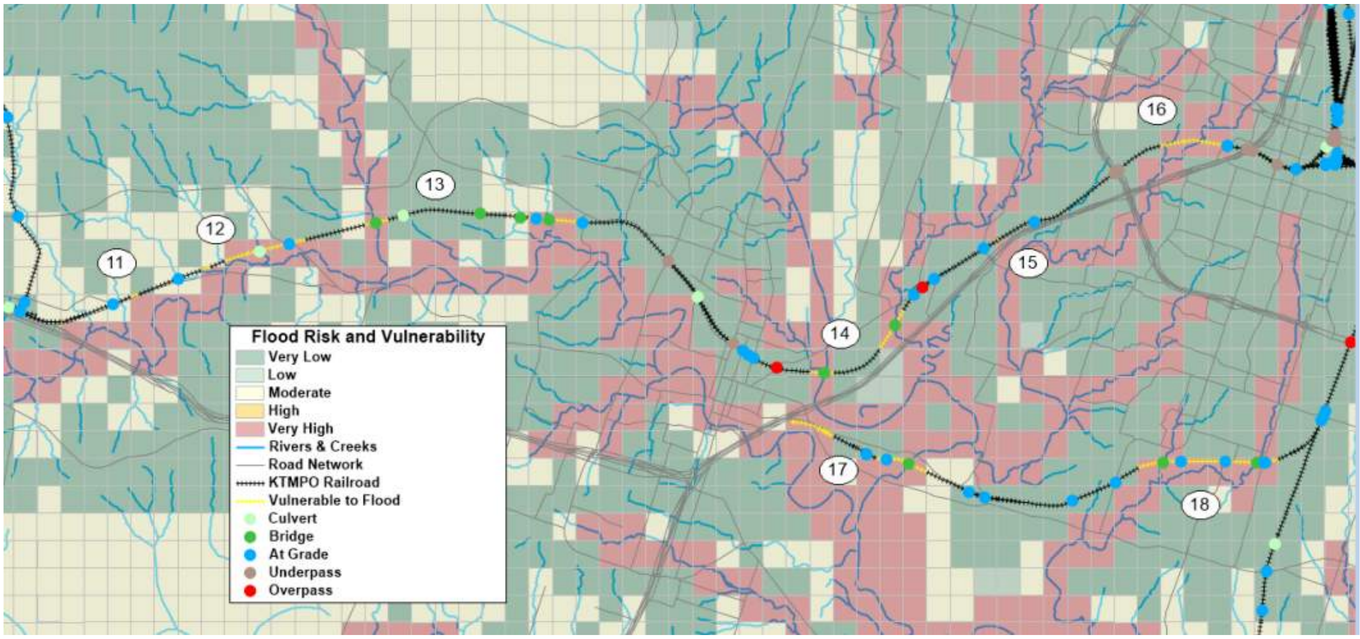


Table 3: Rail Network Vulnerable to Flooding from Rainfall List – Belton Area

Site ID	Railroad	Limits	Notes
11	BNSF	Jack Rabbit Rd E of Paddy Hamilton Rd	
12	BNSF	Paddy Hamilton Rd to FM 93	
13	BNSF	FM 93 to Wheat Rd	
14	BNSF	Waco Rd to Charter Oak Dr	
15	BNSF	E of Kegley Rd	
16	BNSF	Loop 363 to IH 35	
17	Abandoned line	IH 35 to Shallow Ford Rd	
18	Abandoned line	31st St to E of 5th St	

Figure 5: Rail Network Vulnerable to Flooding from Rainfall Map – Southeast Bell County

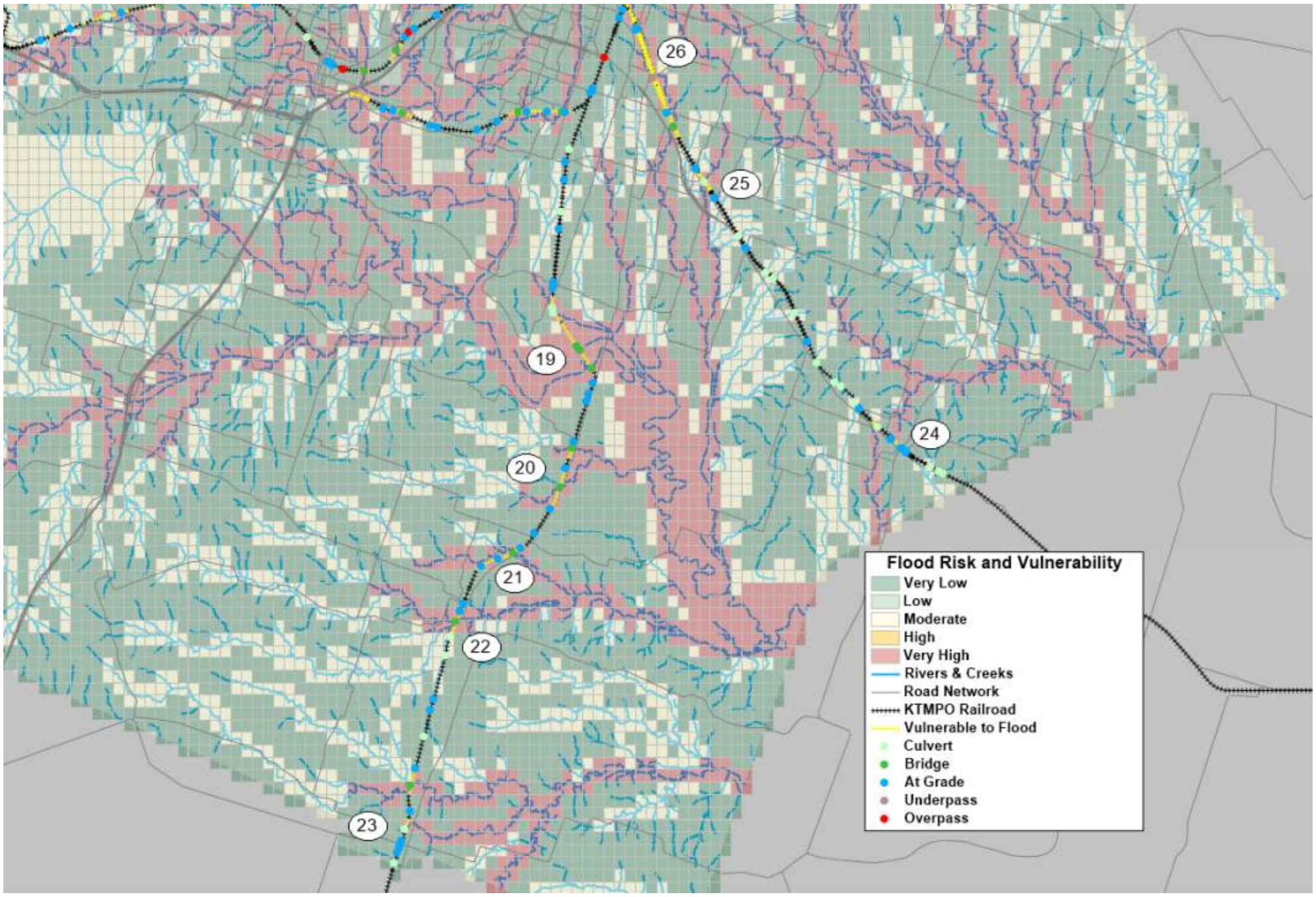


Table 4: Rail Network Vulnerable to Flooding from Rainfall List – Southeast Bell County

Site ID	Railroad	Limits	Notes
19	Union Pacific	FM 436 to SH 95	
20	Union Pacific	Stage Rd to Roberts Rd	
21	Union Pacific	Roberts Rd to FM 1123	
22	Union Pacific	FM 1123 to FM 2268	
23	Union Pacific	FM 2268 to FM 487	
24	BNSF	FM 2184 to Neroc Rd	
25	BNSF	Heidenheimer Rd to Knob Creek Rd	
26	BNSF	Knob Creek Rd to Union Pacific tracks	

Figure 6: Rail Network Vulnerable to Flooding from Rainfall Map – Northern Temple

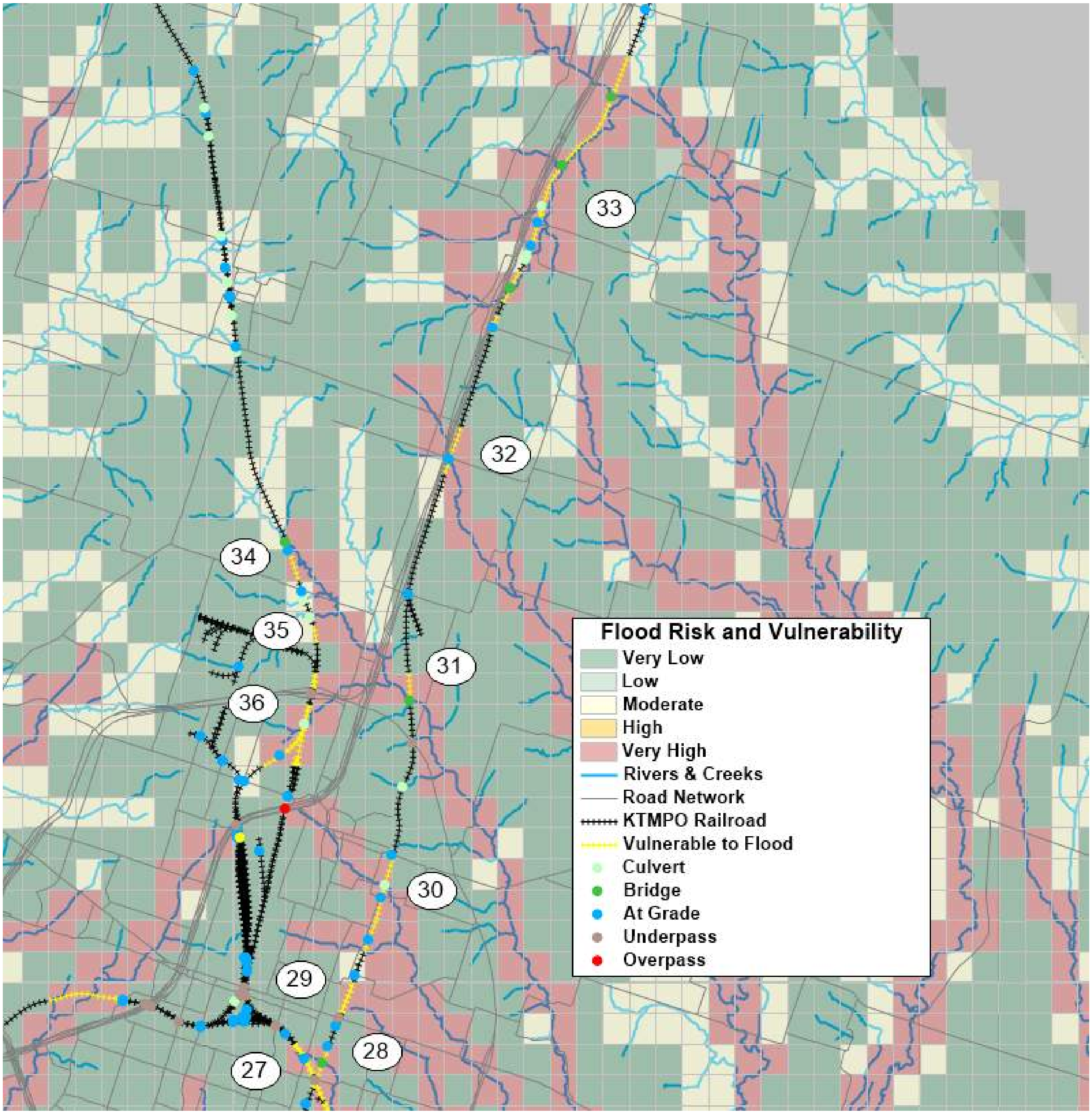


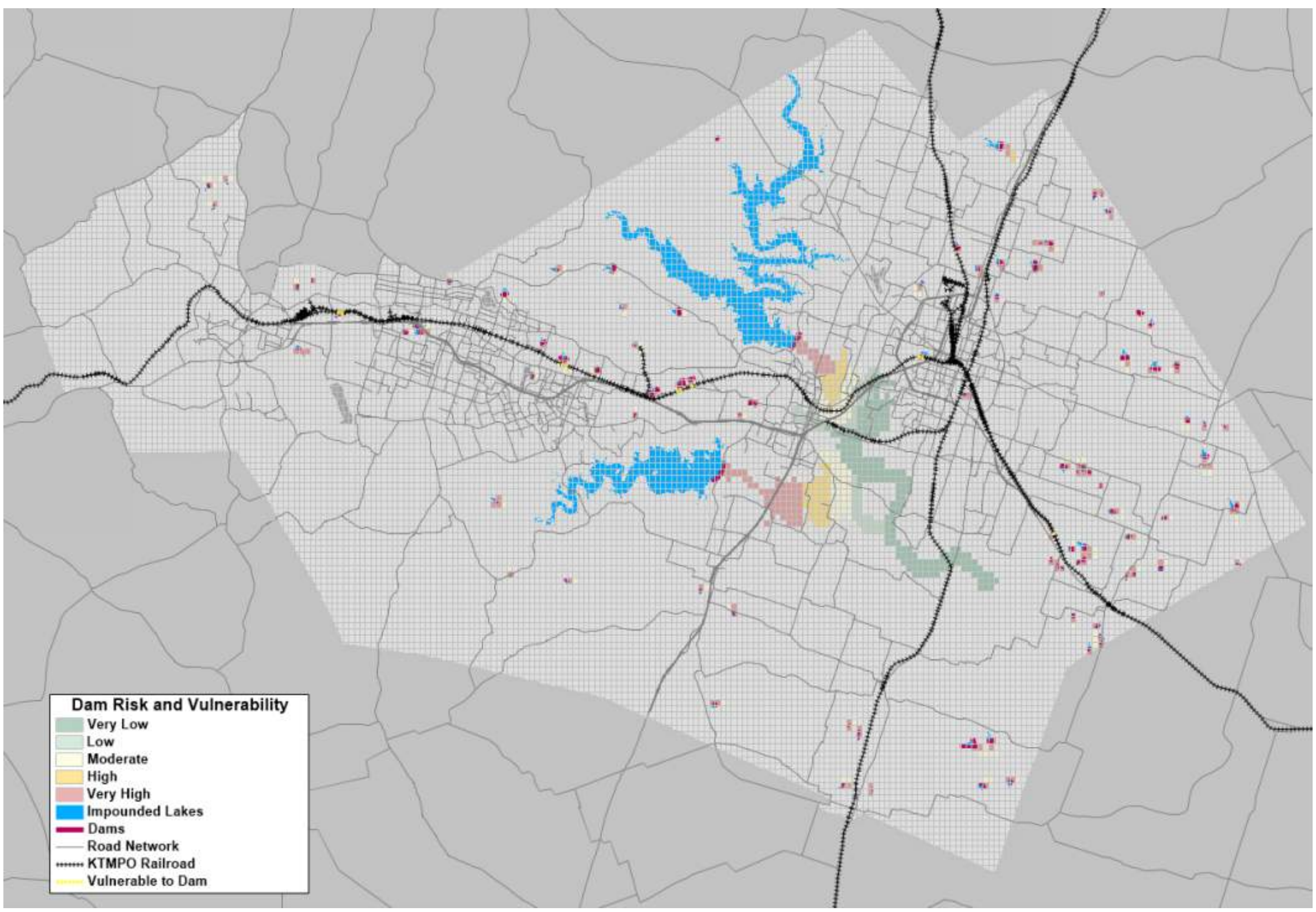
Table 5: Rail Network Vulnerable to Flooding from Rainfall List – Northern Temple

Site ID	Railroad	Limits	Notes
27	BNSF	1st St to Union Pacific tracks	
28	Union Pacific	BNSF tracks to SH 53	
29	Union Pacific	SH 53 to Houston Ave	
30	Union Pacific	Houston Ave to Young Ave	
31	Union Pacific	Loop 363 to Berger Rd	
32	Union Pacific	S of Bottoms East Rd to FM 1237	
33	Union Pacific	S of Lely Dr to East Big Elm Rd	
34	BNSF	N of Moores Mill Rd	
35	BNSF	Moores Mill Rd to Loop 363	
36	BNSF	Loop 363 to IH 35	

Flooding from Dam Breach

The vulnerability of the rail network to flooding from dam breach is distributed throughout the region with thirty-nine dams west of IH 35 and sixty dams to the east. The rail network vulnerable to flooding from dam breach is shown in **Figure 7.**

Figure 7: Rail Network Vulnerable to Flooding from Dam Breach



Details of rail infrastructure which is vulnerable to flooding from a dam breach are defined for seven locations, shown in five figures and tables. **Figure 8 through Figure** 12 and **Table 6 through Table** 10 show a series of maps and figures with details of vulnerable rail infrastructure to flooding from dam breach at key areas within the KTMPO area.

Figure 8: Rail Network Vulnerable to Flooding from Dam Breach Map – Fort Hood Area

Table 6: Rail Network Vulnerable to Flooding from Dam Breach List – Fort Hood Area

Site ID	Railroad	Limits	Notes
1	BNSF, US Govt	E of Clarke Rd, below unnamed lake	

Figure 9: Rail Network Vulnerable to Flooding from Dam Breach Map – Killeen Area

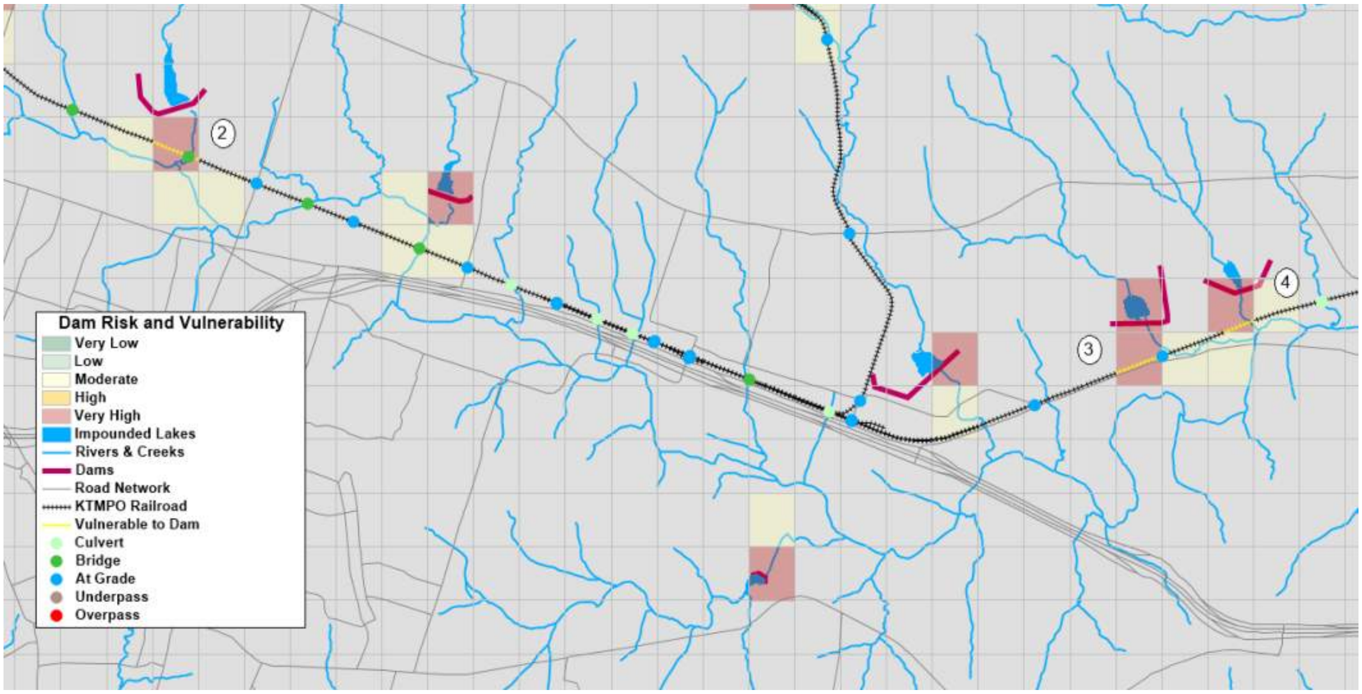


Table 7: Rail Network Vulnerable to Flooding from Dam Breach List – Killeen Area

Site ID	Railroad	Limits	Notes
2	BNSF	Below Soil Conservation Service Site 8	
3	BNSF	Below Soil Conservation Service Site 12	
4	BNSF	Below Soil Conservation Service Site 13	

Figure 10: Rail Network Vulnerable to Flooding from Dam Breach Map – Southwest Temple

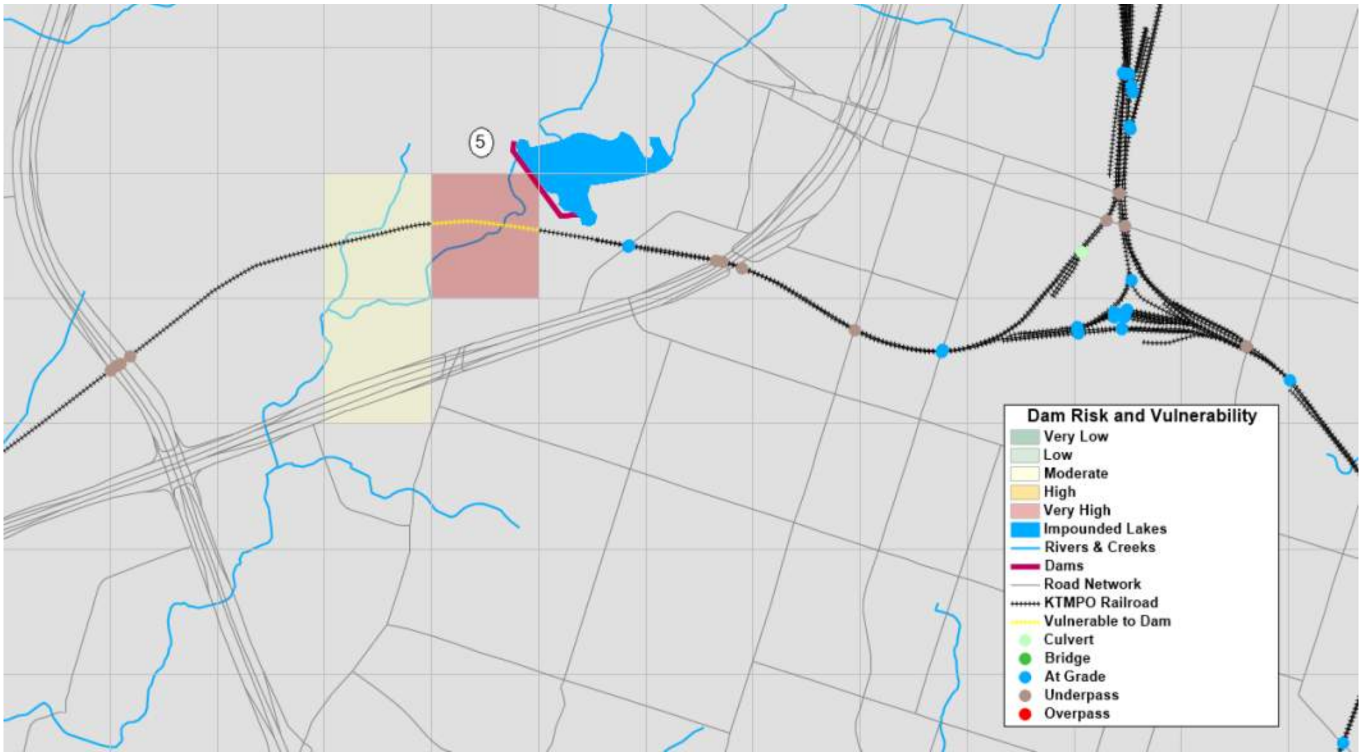


Table 8: Rail Network Vulnerable to Flooding from Dam Breach List – Southwest Temple

Site ID	Railroad	Limits	Notes
5	BNSF	Below Lake Polk	

Figure 11: Rail Network Vulnerable to Flooding from Dam Breach Map – Heidenheimer, Rogers Area

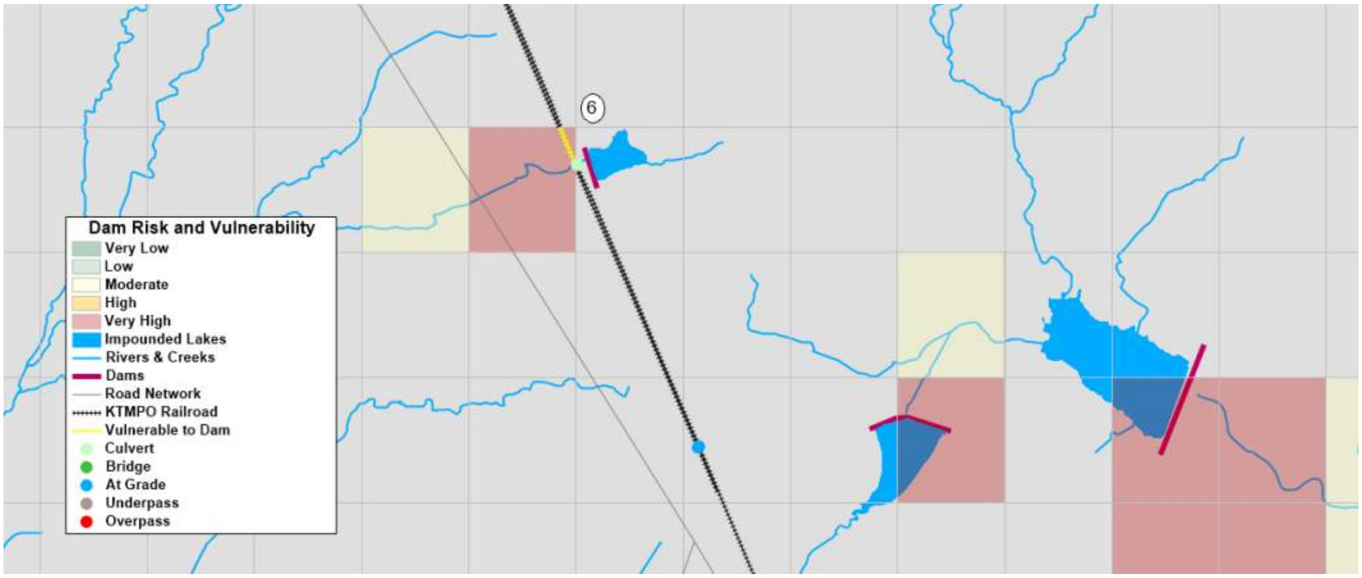


Table 9: Rail Network Vulnerable to Flooding from Dam Breach List – Heidenheimer, Rogers Area

Site ID	Railroad	Limits	Notes
6	Union Pacific	E of US 190, below Lansham Lake	

Figure 12: Rail Network Vulnerable to Flooding from Dam Breach Map – North Temple Area

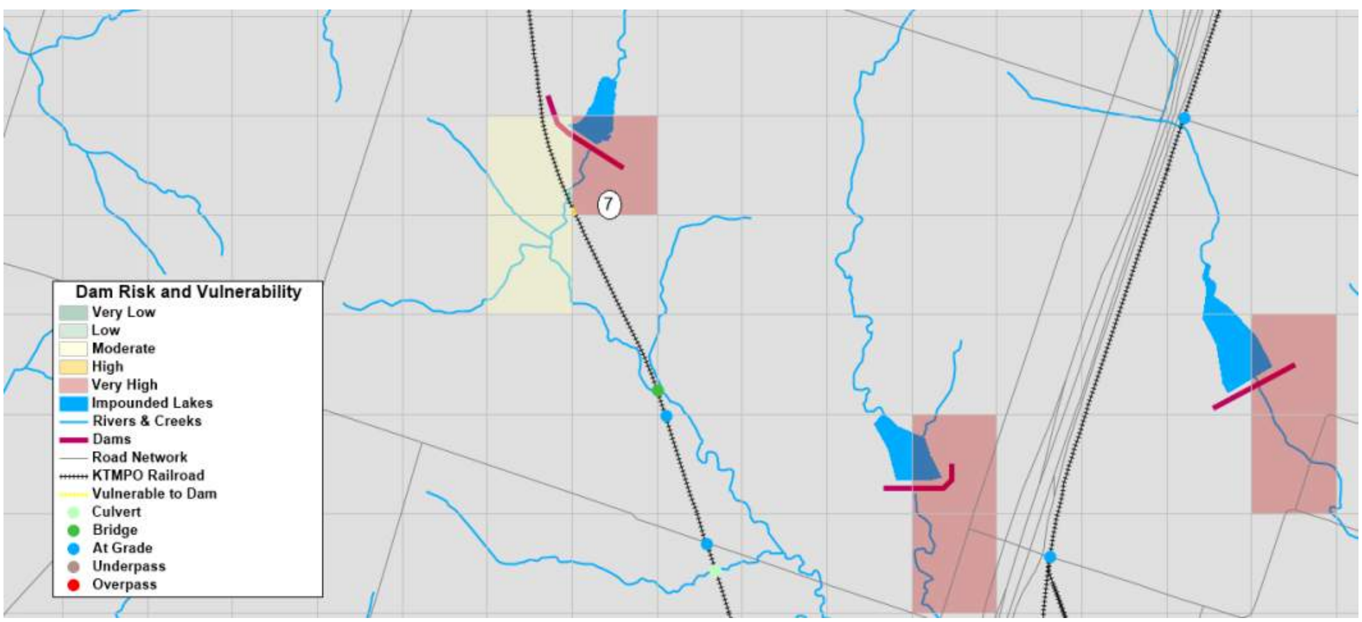


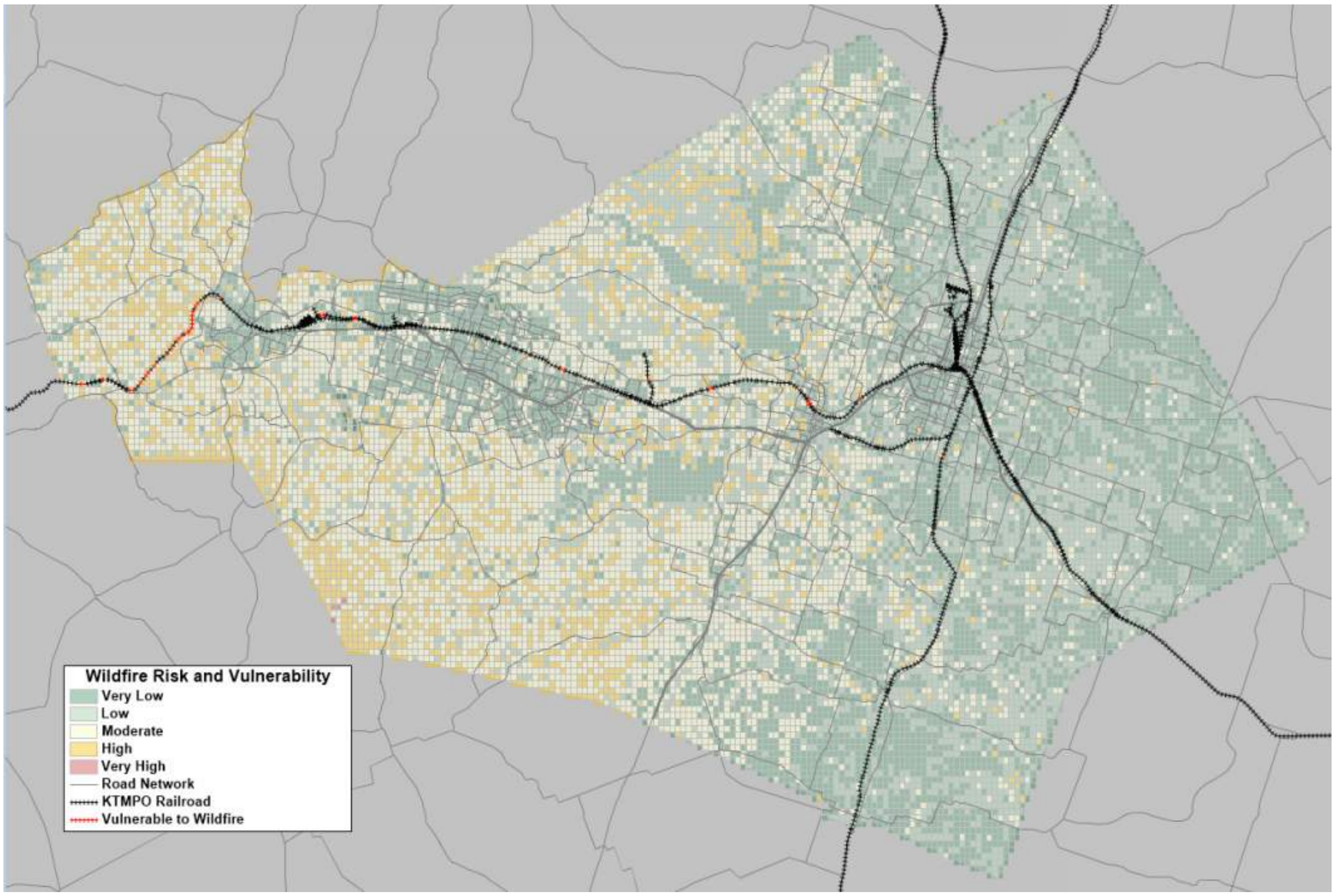
Table 10: Rail Network Vulnerable to Flooding from Dam Breach List – North Temple Area

Site ID	Railroad	Limits	Notes
7	Union Pacific	FM 1237 to Moore’s Mill Rd, below unnamed lake	

Wildfire

The vulnerability of the rail network to wildfire is based on flammable ground cover, and therefore the vulnerability is distributed with a very evident divide between the brushy hill country in the west and the agricultural uses in the prairie to the east. Small pockets of vulnerability are also shown scattered throughout the region. The rail network vulnerable to wildfire is shown within the map in **Figure 13**.

Figure 13: Rail Network Vulnerable to Wildfire



Details of rail infrastructure which is vulnerable to wildfire are defined for eleven locations, shown in two figures and tables. All locations are located to the west of IH 35.

Figure 14 **and**

Figure 15 and **Table 11 and Table** 12 are a series of maps and figures with details of rail infrastructure vulnerable to wildfire in the KTMPO area.

Figure 14: Rail Network Vulnerable to Wildfire Map – Copperas Cove Area

Table 11: Rail Network Vulnerable to Wildfire List – Copperas Cove Area

Site ID	Railroad	Limits	Notes
1	BNSF	County line to FM 2313	
2	BNSF	E of FM 2313	
3	BNSF	W of FM 1113	
4	BNSF	E of Summers Rd	
5	US Government	W of Clarke Rd	
6	BNSF, US Government	E of Clarke Rd	

Figure 15: Rail Network Vulnerable to Wildfire Map – Killeen Area

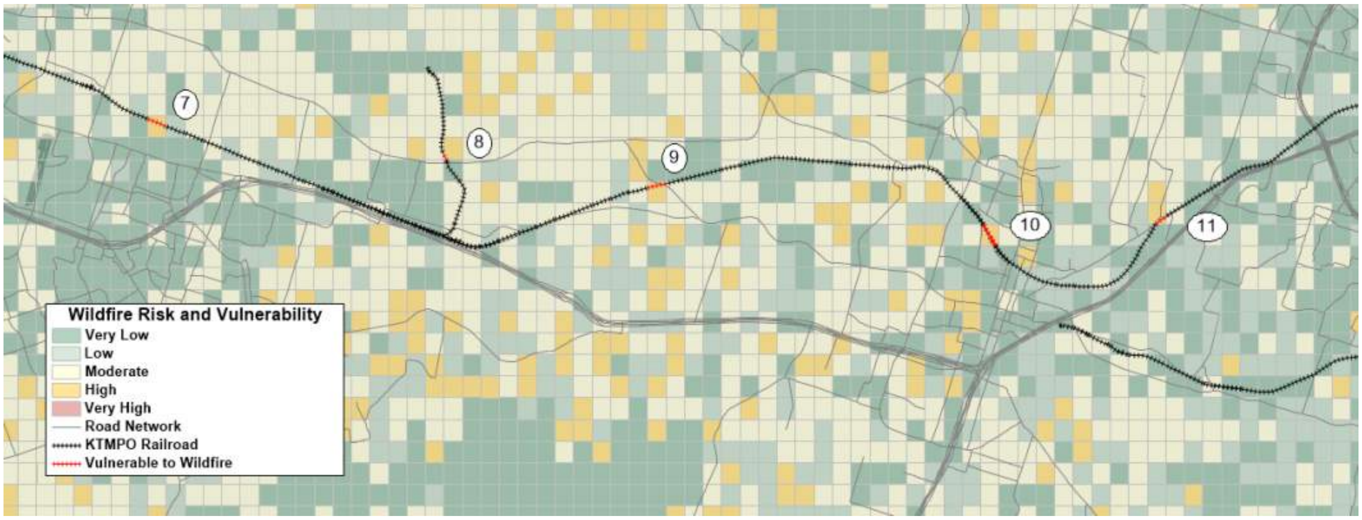


Table 12: Rail Network Vulnerable to Wildfire List – Killeen Area

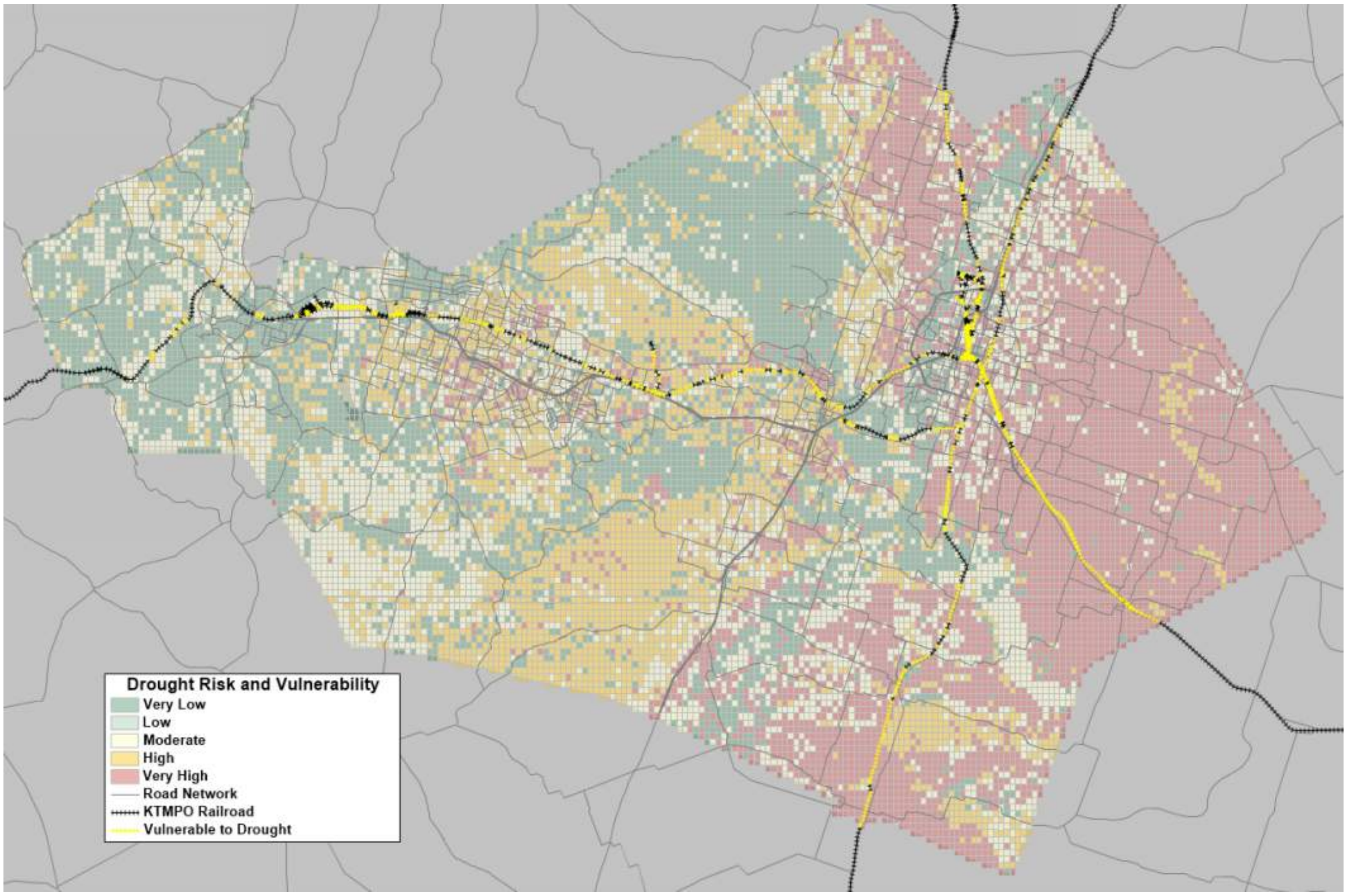
Site ID	Railroad	Limits	Notes
7	BNSF	Roy Reynolds Dr to Lookout Ridge Blvd	
8	BNSF Spur	N of FM 439	
9	BNSF	FM 439 to FM 93	
10	BNSF	University Dr to N Pearl St	
11	BNSF	Pearidge Rd to Twin City Blvd	

Drought or Sustained High Temperatures

The vulnerability of the rail network to drought or sustained high temperatures is based on the different characteristics of expansion and contraction by soil type. The RVRF grid shows a clear division between the hill country in the west and the heavy clay prairie in the east. However, while the "very high" rating for soil expansion is clearly concentrated in the east, there are pockets with that rating scattered throughout the region. Further, there are definite swaths of soils rated as "high" in the west. As a result, the distribution of vulnerability of the rail network does not reflect the apparent division between east and west. Actually, the denser network in the urbanized area of Killeen, Harker Heights, Nolanville, and Belton lie in an area of scattered "high" elasticity soil, while the Temple urbanized area lies in a swath of more stable soil. The heavy clay area in eastern Bell County is in mostly rural areas, with a more sparse network.

For the rail networks, this condition resulted in a higher mileage of vulnerable railroad track in the western part of the region than in the east. For the rail system, there is not much difference in network density between east and west: 118 miles of track in the west and 126 in the east. Therefore, the effect of the different soil types is more evident: there are 47 miles of track in the west identified as vulnerable, compared to 100 miles of track in the east. Vulnerable segments are therefore 40% of the network in the west and 79% of the network in the east. The rail network vulnerable to drought or sustained high temperatures is shown in **Figure 16**.

Figure 16: Rail Network Vulnerable to Drought or Sustained High Temperatures



Details of rail infrastructure which is vulnerable to wildfire are defined for sixty-two locations, shown in six figures and tables. **Figure 17 through**

Figure 22 and **Table 13 through Table** 18 are a series of maps and figures with details of rail infrastructure vulnerable to drought or sustained high temperatures in the KTMPO area.

Figure 17: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Copperas Cove Area

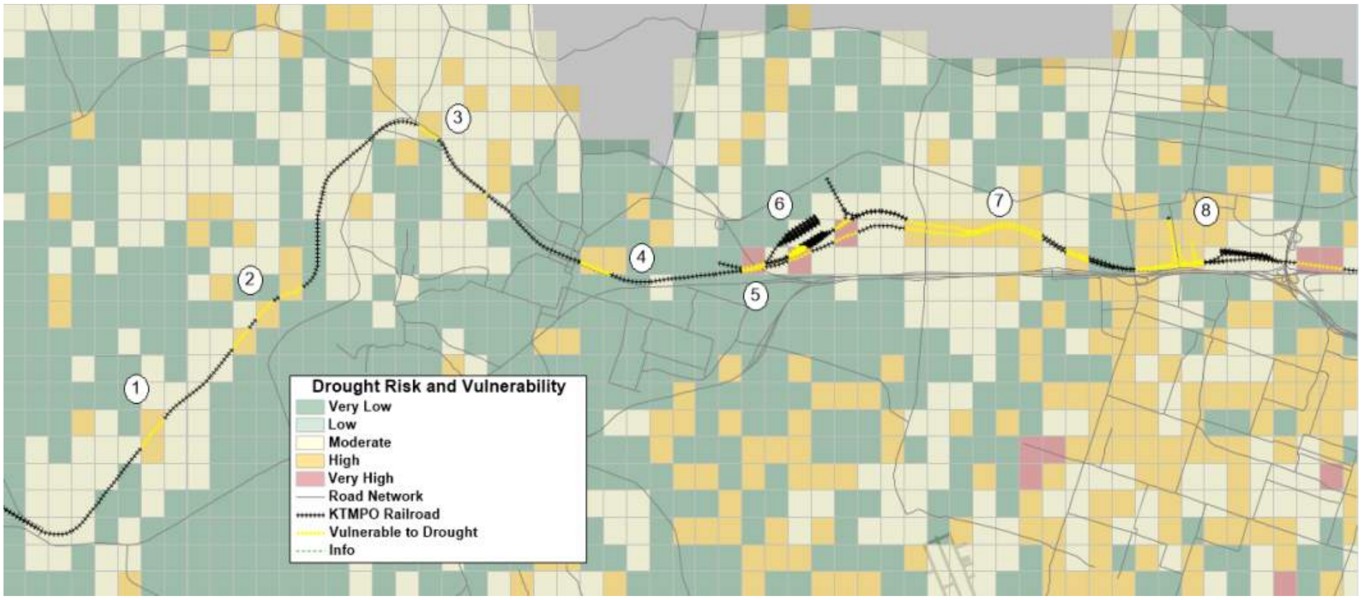


Table 13: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Copperas Cove Area

Site ID	Railroad	Limits	Notes
1	BNSF	E of FM 2313	
2	BNSF	W of FM 1113	
3	BNSF	E of Summers Rd	
4	BNSF	E of Main St	
5	BNSF, US Government	At SH 9	
6	BNSF, US Government	SH 9 to Clarke Rd	
7	BNSF, US Government	Clarke Rd to Clear Creek Rd	
8	BNSF, US Government	Clear Creek Rd to T J Mills Blvd	

Figure 18: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Killeen Area

Table 14: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Killeen Area

Site ID	Railroad	Limits	Notes
9	BNSF	T J Mills Blvd to Fort Hood St	
10	BNSF	Fort Hood St to 28th St	
11	BNSF	E and W of W S Young Dr	
12	BNSF	38th St to Twin Creek Dr	
13	BNSF	W of Roy Reynolds Dr	
14	BNSF	W of Lookout Ridge Blvd to Paddy Hamilton Rd	
15	BNSF Spur	Jack Rabbit Rd to end of spur	
16	BNSF	US 190 to FM 93	

Figure 19: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Belton Area

Table 15: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Belton Area

Site ID	Railroad	Limits	Notes
17	BNSF	E of FM 93	
18	BNSF	W of Wheat Rd	
19	BNSF	W of Wheat Rd to SH 317	
20	BNSF	Penelope St to E of Waco Rd	
21	BNSF	Pearidge Rd to W of Midway Dr	
22	BNSF	W of Midway Dr to Loop 363	
23	BNSF	Loop 363 to IH 35	
24	BNSF	IH 35 to 31st St	
25	BNSF	IH 35 to FM 93	
26	Abandoned line	FM 93 to Shallow Ford Rd	
27	Abandoned line	Kton Rd to 31st St	
28	Abandoned line	W of Hatrick Bluff Rd to Union Pacific line	

Figure 20: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Southeast Bell County Area

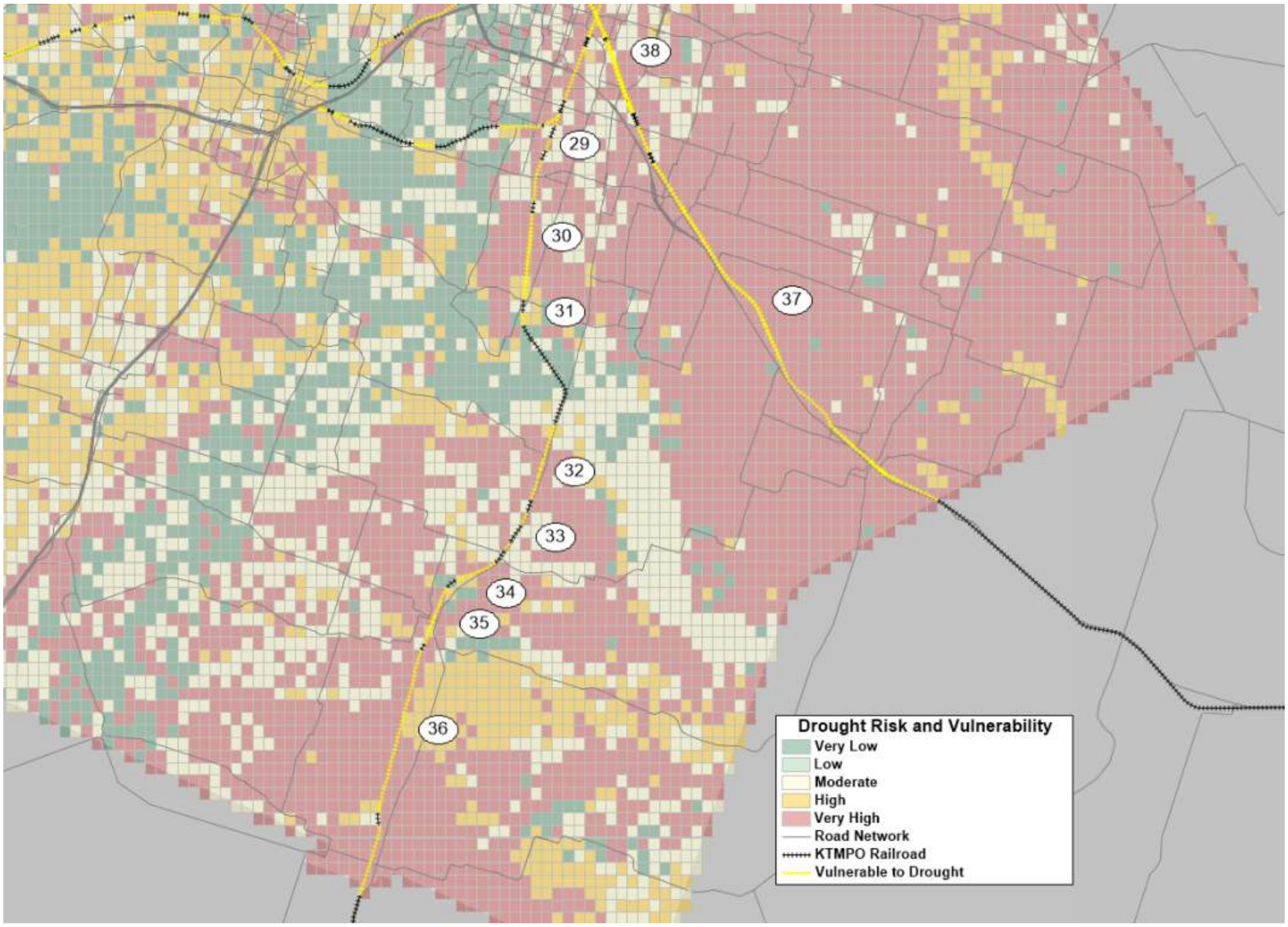


Table 16: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Southeast Bell County Area

Site ID	Railroad	Limits	Notes
29	Union Pacific	BNSF line to FM 93	
30	Union Pacific	FM 93 to FM 436	
31	Union Pacific	S of FM 436	
32	Union Pacific	N and S of Stage Rd	
33	Union Pacific	N of Roberts Rd	
34	Union Pacific	Roberts Rd to N of FM 1123	
35	Union Pacific	N and S of FM 1123	
36	Union Pacific	FM 2268 to County line	
37	BNSF	County line to FM 3117	
38	BNSF	FM 3117 to Union Pacific line	

Figure 21: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Temple and Northern Bell County Area

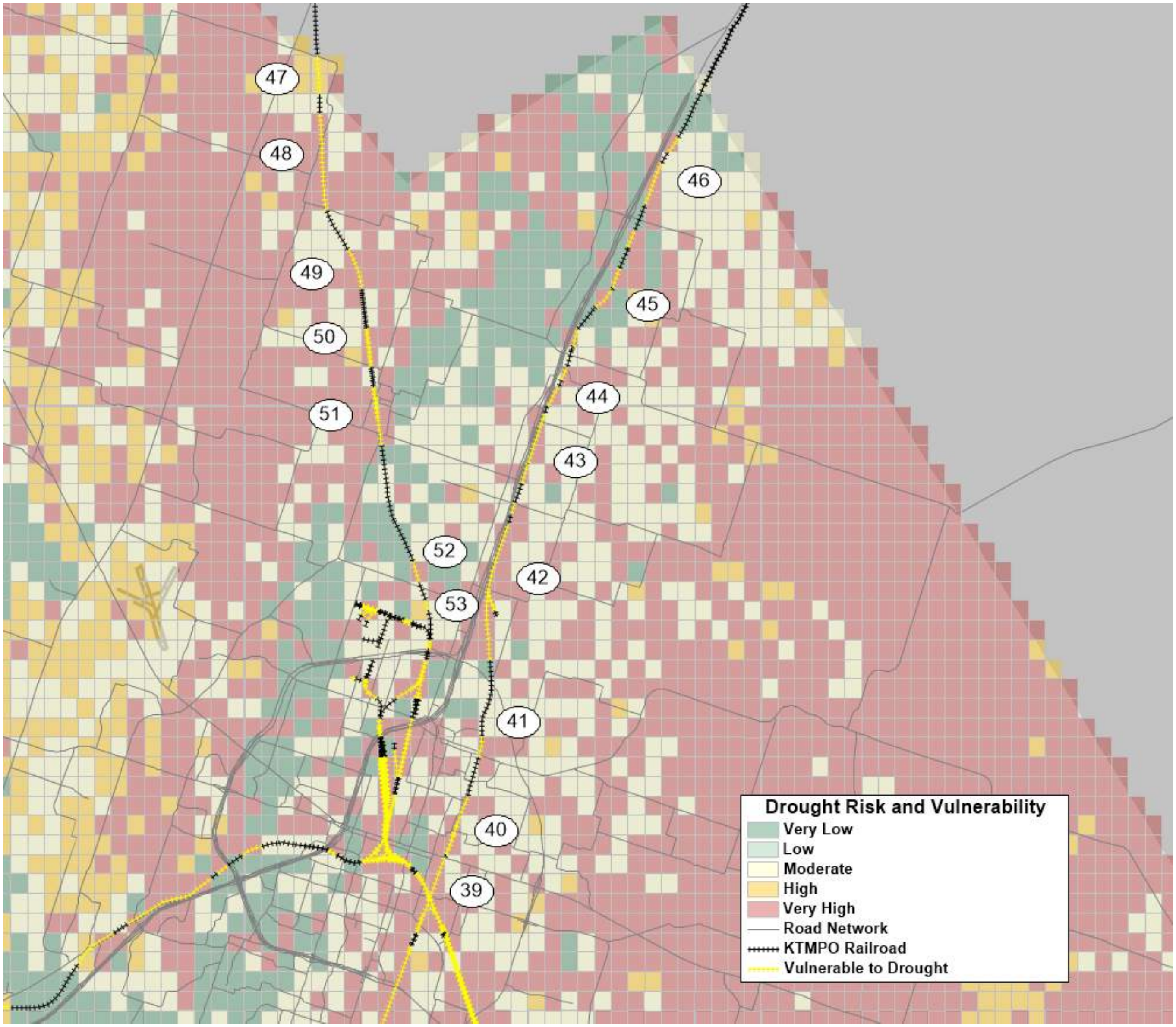


Table 17: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Temple and Northern Bell County Area

Site ID	Railroad	Limits	Notes
39	Union Pacific	BNSF line to SH 53	
40	Union Pacific	SH 53 to Nugent Ave	
41	Union Pacific	Young Ave to E Killeen Ln	
42	Union Pacific	N of Loop 363 to Bottoms East Rd	
43	Union Pacific	Bottoms East Rd to N of Lely Dr	
44	Union Pacific	N of Lely Dr to Main St	
45	Union Pacific	Main St to East Big Elm Rd	
46	Union Pacific	East Big Elm Rd to County line	
47	BNSF	Stampede Rd to N of Willow Grove Rd	
48	BNSF	N of Willow Grove Rd to Franklin Rd	
49	BNSF	S of Franklin Rd	
50	BNSF	N of Southerland Rd	
51	BNSF	Southerland Rd to S of FM 1237	
52	BNSF	N of Moore’s Mill Rd	
53	BNSF	S of Moore’s Mill Rd	

Figure 22: Rail Network Vulnerable to Drought or Sustained High Temperatures Map – Temple Area

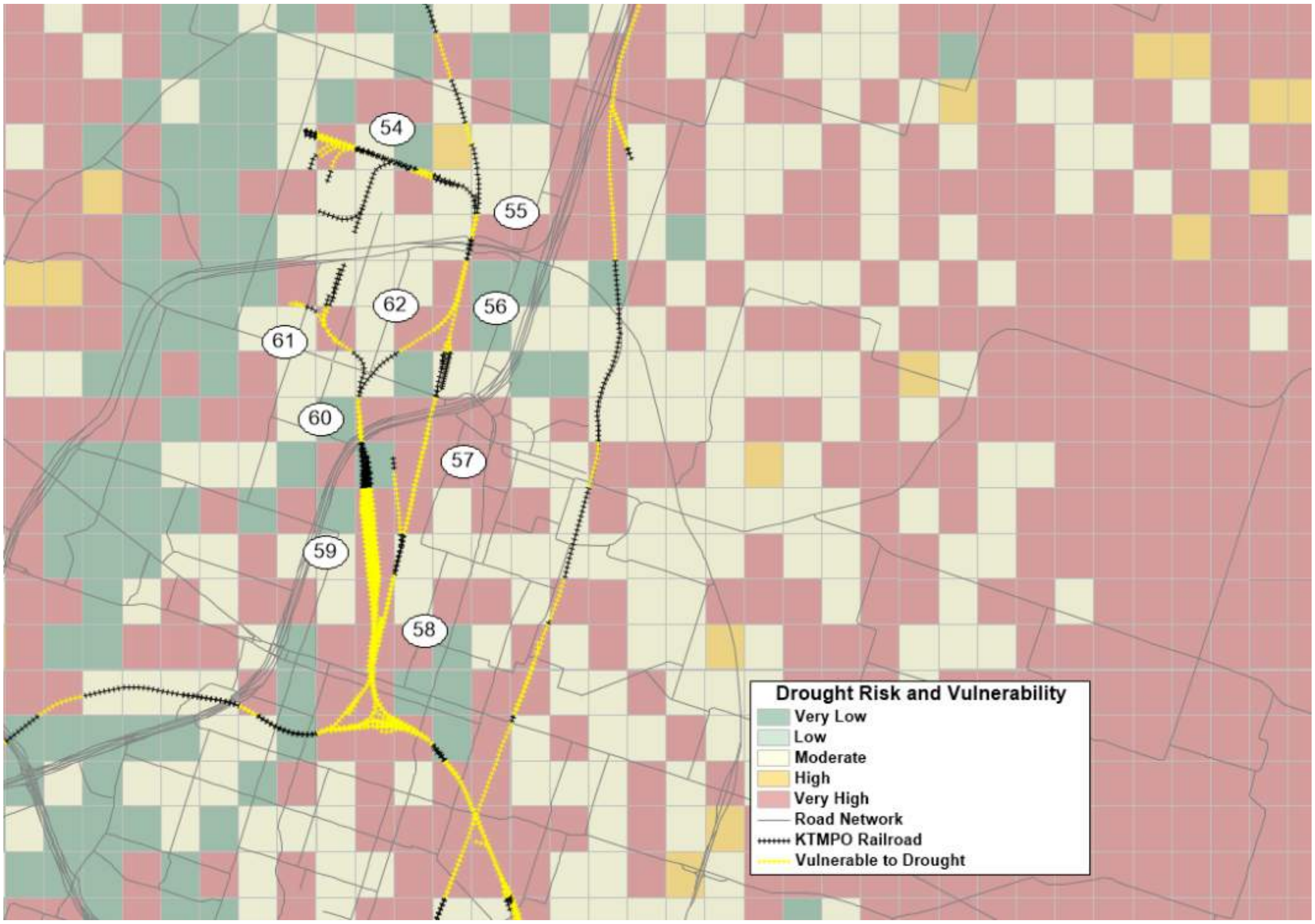


Table 18: Rail Network Vulnerable to Drought or Sustained High Temperatures List – Temple Area

Site ID	Railroad	Limits	Notes
54	BNSF Spur	Main line to end of spur	
55	BNSF	N of Loop 363	
56	BNSF	S of Loop 363 to N of Industrial Blvd	
57	BNSF, BNSF Spur	Industrial Blvd to Nugent Ave	
58	BNSF	Nugent Ave to switching yard	
59	BNSF	Switching yard S and E of IH 35	
60	BNSF	Industrial Blvd to IH 35	
61	BNSF Spur	Industrial Blvd to end of western spur	
62	BNSF	Industrial Blvd to BNSF main line	

Summary

This memo built on the work from Task 1, which defined the Regional Vulnerability and Resilience Framework (RVRF) and set up a regional grid with vulnerability scores for each of four types of incidents: flooding from rainfall, flooding from dam breaches, wildfire, and drought or sustained high temperatures. This task linked the RVRF grid scores to the rail network to discover specific locations which are vulnerable to each incident type.

With specific locations in the network which are vulnerable identified, this information can be used to generate projects to address the vulnerability and increase the resiliency of the network. Since the BNSF and Union Pacific rail systems are privately owned, these projects are not eligible for funding under the current transportation planning mechanisms. However, these private firms are partners in regional transportation, so the findings can be communicated to them for their own planning efforts. Further, the vulnerability information for the abandoned rail lines can be used in planning for possible conversion projects such as rails-to-trails, which can be entered into the standard KTMPO project evaluation process.

The assignment of scores to the RVRF grid was in some cases “lumpy” as the rectangular grid interacted with the more fluid aspects of riverbeds, topology, ground cover, and soil types. The rail network is also non-rectangular, so the identification of vulnerable segments was also “lumpy”. Manual smoothing of the grid scores is an option but is not recommended. Manual smoothing would be a subjective deviation from the base data, would impact the relationships between the individual incident scorings, and would have to be repeated with every update to the data. For the same reasons, manual smoothing of the defined vulnerable rail segments is not recommended.

This memo has identified the rail network’s vulnerable segments with a series of figures and tables for each incident type. This shows a large number of locations for each vulnerability type, with difficulties in defining each location and its individual limits, and in setting a label to identify each location. In practice, it will be more practical to directly reference the RVRF grid and network in a GIS platform.

Asset Vulnerability and Resiliency Study – Project Vulnerability Scoring

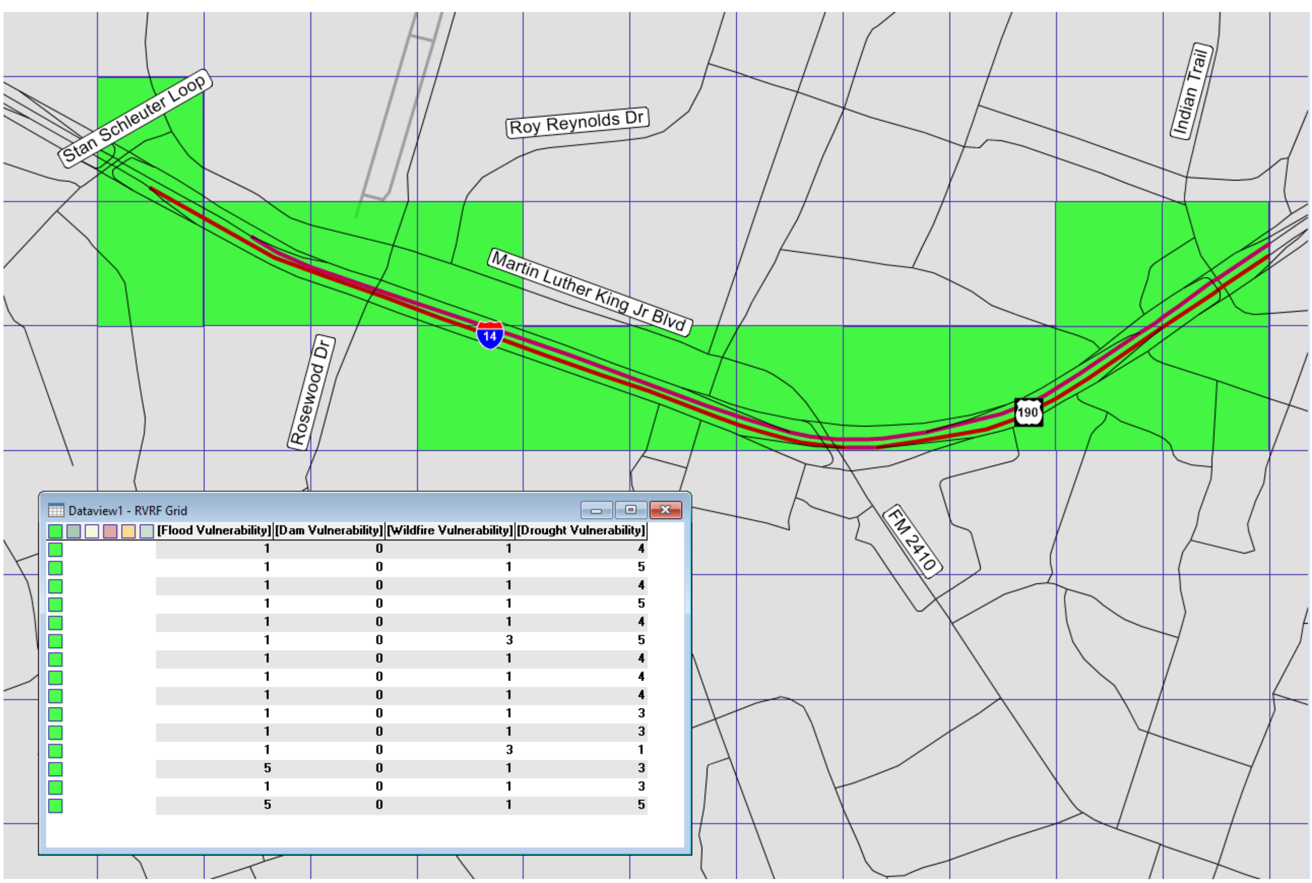
Introduction

Project scoring with the Regional Vulnerability & Resilience Framework (RVRF) uses the RVRF Grid to develop the objective component of the scores, then populates a spreadsheet for the TAC to use with the subjective weighting of the scores. The objective and subjective components of the vulnerability scoring process is designed to be consistent with the overall KTMPO project scoring process.

Two spreadsheets are available for consideration. The base spreadsheet follows the precedent of the FHWA VAST tool, considering the geographic affects, likelihood, and severity of the four types of environmental hazards. The optional spreadsheet also considers the different land uses which are impacted, including the defined critical land uses. The optional spreadsheet is recommended for its more complete consideration of all vulnerability issues.

Objective Component

The objective component is the raw scores for each incident type. This data quantifies the impacts of each type of incident, and defines the geographic areas which are affected. As objective scores are contained the RVRF GIS layer, so it is only necessary to define the project and then select the appropriate grid cells which the project covers. The scores are averaged across all selected cells and then exported into the Vulnerability Scoring Spreadsheet as the "raw scores".



[Flood Vulnerability]	[Dam Vulnerability]	[Wildfire Vulnerability]	[Drought Vulnerability]
1	0	1	4
1	0	1	5
1	0	1	4
1	0	1	5
1	0	1	4
1	0	3	5
1	0	1	4
1	0	1	4
1	0	1	4
1	0	1	3
1	0	1	3
1	0	3	1
5	0	1	3
1	0	1	3
5	0	1	5

Subjective Component

The subjective data quantifies the likelihood of each type of incident happening and its relative importance in regional planning. It is implemented by applying weights to scores for each of the individual types of incident, which are then aggregated into the composite score. The mechanism for doing this is the Vulnerability Scoring Spreadsheet. The spreadsheet is set up to the same format at the KTMPO Project Listing Spreadsheet with the same project categories and headers. To make copying and pasting between spreadsheets easier, each project in the Vulnerability Scoring Spreadsheet is on the same row as the KTMPO Project Listing Spreadsheet.

This figure shows the optional spreadsheet, which features raw scores and weighting factors for land use and for the four types of environmental hazards.

RGANIZATION

ɔrtation Plan Project Vulnerability Scoring

TEGORY 2 PROJETS (METROPOLITAN CORRIDORS)

	Raw Scores					Weighting Factors					
						50	30	1	30	80	
KTMPO ID	Land Use Vulnerability	Flood Vulnerability	Dam Breach Vulnerability	Wildfire Vulnerability	Drought Vulnerability	Land Use Vulnerability	Flood Vulnerability	Dam Breach Vulnerability	Wildfire Vulnerability	Drought Vulnerability	Composite Score
T45-02						0.000	0.000	0.000	0.000	0.000	0.000
B45-02	3.800	1.800	2.400	1.800	4.000	190.000	54.000	2.400	54.000	320.000	3.248
B45-05						0.000	0.000	0.000	0.000	0.000	0.000
B40-12						0.000	0.000	0.000	0.000	0.000	0.000
T45-03	3.667	2.333	0.000	1.667	4.333	183.333	70.000	0.000	50.000	346.667	3.403
B45-04	4.167	2.333	1.333	1.667	3.500	208.333	70.000	1.333	50.000	280.000	3.192
T45-08	3.714	3.286	0.000	1.429	3.571	185.714	98.571	0.000	42.857	285.714	3.209
T45-06	3.778	3.000	0.000	2.556	3.444	188.889	90.000	0.000	76.667	275.556	3.304
T40-25	4.333	5.000	1.000	1.500	3.000	216.667	150.000	1.000	45.000	240.000	3.417

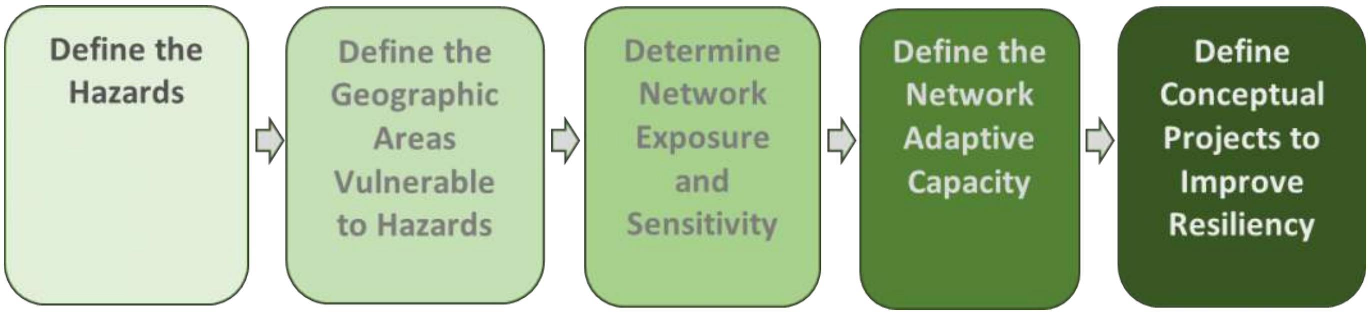
Exporting Vulnerability Scores to the KTMPO Project Selection Spreadsheet

As the Vulnerability Scoring Spreadsheet is set up to the same format at the KTMPO Project Listing Spreadsheet with the same project categories, headers, and rows, exporting the composite vulnerability scores from the RVRF Project Scoring spreadsheet to the KTMPO Project Listing spreadsheet should be straightforward.

Task 4: Adaptive Capacity of Transportation System

Introduction

The Regional Vulnerability & Resilience Framework (RVRF) is a system developed for the KTMPO region to support transportation infrastructure planning with enhanced information on infrastructure vulnerability to environmental incidents and on it adaptive capacity and resiliency. The RVRF follows a logical sequence with several steps and components:



- Four types of hazards are analyzed in the system: flooding from rainfall, flooding from dam breaches, wildfire, and drought or sustained high temperatures.
- To define the geographic areas which are vulnerable, the RVRF is based on a ¼ mile grid covering the full study area. Each of the 16,518 grid cells is populated with scores for each of the four incident types, and flags identifying the presence of bridges for the auto, bike, bus, freight, and rail networks. The RVRF grid also serves as a platform to organize and display the data.
- The RVRF grid also supports a comparison of hazards to vulnerable land uses such as schools, hospitals, nursing homes, and non-road infrastructure such as water treatment plants and electrical distribution stations. This information defines geographic areas of higher sensitivity to hazards.
- The networks for the road-based and the rail modes are compared to the RVRF grid scores for each hazard to identify vulnerabilities at specific locations. This information defines the exposure of the networks, and can then be applied to existing network projects to determine their vulnerability scores for project prioritization, and to determine if they contribute to resilience by helping to avoid, mitigate, or recover from an environmental incident.
- The inventories and attributes of the transportation networks for each mode are examined to determine their abilities to prevent, mitigate, or recover from the defined hazards. This is defined as the networks' adaptive capacity, otherwise known as resilience.
- The RVRF system and reference information can support the analysis of different approaches to define conceptual projects which can enhance the networks' adaptive capacities, so that they have greater abilities to prevent, mitigate, or recover from the defined hazards. These conceptual projects can then be developed into actual projects for specific locations.

This memo describes a final two components of the RVRF in defining conceptual projects which can be developed to address the networks' adaptive capacities, and highlights some best practices or public policies which have been used to address each hazard type.

Road Infrastructure

Flooding from Rainfall

Climate models project continued increases in heavy rainfall events across much of the U.S. Smaller and more frequent rainfall events are projected, which can have a cumulative effect and change both the geographic footprint of the floodplain and the severity of any single flooding event.

Task 2 identified transportation infrastructure within the KTMPO area that is vulnerable to flooding from rainfall. Generally, vulnerable infrastructure is evenly distributed throughout the region, but the divide between the Hill Country in the west and the flatter Prairie in the east is evident. Vulnerability in the west is concentrated in the urbanized areas and around the Lampasas River, while in the east vulnerability is more widely distributed in both urban and rural areas. **Figure 1** shows how flooding from rainfall can cause road damage or interrupt service, and can leave debris behind which further disrupts recovery.

Figure 1: Effects of Flooding from Rainfall

Conceptual Strategies to Prevent Flooding from Rainfall

Rainfall and flooding from rainfall or runoff are such large-scale issues that they cannot absolutely be prevented. However, the vulnerability of transportation networks to these hazards can be prevented at least in part by avoiding placing infrastructure in known vulnerable areas.

The RVRF grid identifies the FEMA 100-year and 500-year floodplains to distinguish areas that are vulnerable to flooding. In practice, avoiding constructing infrastructure within the floodplains is complicated by two issues:

- The floodplains are extensive throughout the region, so it may be physically impossible to avoid them.
- The floodplains are changing due to climate change and construction of impervious cover and other infrastructure, so simply tracking their present extent is not a definitive approach.

The issue of height provides some compensation for these issues; network infrastructure can be designed to be above any anticipated floodwaters even if it is located within a flood-prone area. This approach requires careful design of infrastructure supports which are subject to shear loads, scour, and debris from flooding.

The IH-35 bridges crossing Nolan Creek in Belton provide an example of this approach of avoiding flooding impacts, as shown in **Figure 2**. Nolan Creek flows east-west through the region, and any network infrastructure running north-south has no option but to cross its floodplain. Both frontage road bridges at this site are vulnerable, lying in the floodplain and having a history of being flooded. However, the bridges for the mainlanes are elevated (the sign on the overpass at Confederate Park Dr lists a 12’2” clearance). Although the mainlane bridges are in the floodplain, due to their elevation they have no history of flooding. The elevation of the mainlane bridges is therefore an effective technique to avoid vulnerability, even though the bridges are located in a vulnerable (floodplain) area.

Figure 2: IH-35 at Nolan Creek

Conceptual Strategies to Mitigate Flooding from Rainfall

The concept of mitigation seeks to minimize the impact of rainfall once it occurs. Strategies can be aimed to minimize runoff and stormwater, or to prevent runoff and stormwater from impacting the networks.

- **Green Streets** - The concept of green streets is a best practice for mitigating the impacts of flooding from rainfall by re-imagining the design of transportation facilities. The general approach of green streets is to treat stormwater as a resource rather than as a problem, and to develop infrastructure to naturally and effectively accommodate that resource. Green infrastructure as a concept has been supported and referenced by policies and practices of the Federal Highway Administration (FHWA), the National Association of City Transportation Officials (NACTO), and peer MPOs. Green streets are more fully described in a separate White Paper for reference.
- **Update Design Standards** - To mitigate flooding from rainfall, roadway design standards must also be reconsidered within the context of climate change and the projected increase in the frequency and intensity of rainfall. Where a standard requires withstanding the 100-year storm,

updated standards should recognize that the 100-year storm of the future may be more intense an may cover a larger geographic area.

- **Increase Flow Capacity** – Increase the ability of a culvert or bridge to pass water flows at future peak levels expected with climate change and increased precipitation events. Increased peak flow capacity can be achieved by maintaining the drainage channels so that they are free of vegetation or debris, and by replacing a culvert with larger culverts or a bridge.
- **Restore and Repair Watersheds** – Manage and decrease future peak waterflow rates through a watershed-based approach. Watershed restoration or repair could be achieved through the implantation of a regional drainage management area that considers drainage issues and concerns at a greater spatial scale, the implementation of dispersed stormwater and debris controls throughout a watershed, and the enhancement of streams, floodplains, and wetlands.
- **Protect** – Reduce or eliminate potential damage to infrastructure by providing protective physical barriers to extreme events and climate stressors. Protection could take the form of retrofits to harden roadway embankments and stream banks through the placement of retaining walls. Corrosion protection treatments could be added to bridge and rail facilities to help elongate the life of these facilities as they experience more frequent flooding events.

Conceptual Strategies to Recover from Flooding from Rainfall

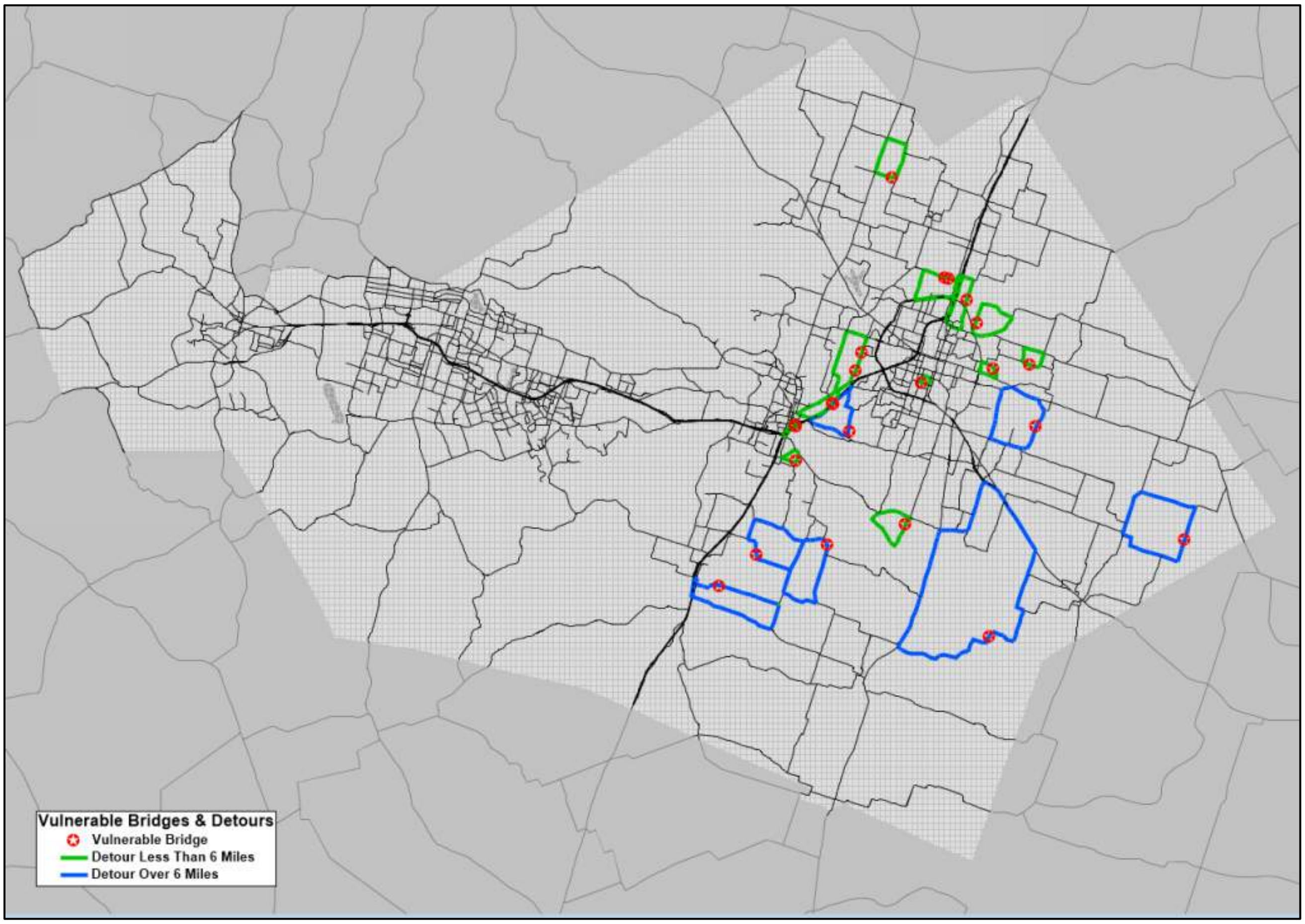
Once rainfall has caused flooding, strategies to recover to normal operations focus on identifying flooded locations and detours.

- **Identify Locations Prone to Flooding** – The KTMPO region has many areas of roads on curves and hills with limited sight distances, or rural areas without streetlights, where a driver might not see a flooded area in advance. Warning signs of flooded roads are therefore a safety feature as well as a strategy for recovery. **Figure 3** shows several types of warning signs and beacons for a flooded road: a manual sign and barricade to be placed across the flooded area, an automated flashing beacon installed at a vulnerable area, and an automated beacon with a barrier, similar to a railroad crossing warning system. Each of these types of warning systems should be tied to regional inventories of low water crossings and vulnerable areas from the RVRF. The automated beacons are capable of individual operations, or can be linked into a system with centralized alerts.

Figure 3: Sample Types of Flood Warning Beacons

- **Identify Detours for Vulnerable Areas** – The RVRF has identified twenty-three bridges which are vulnerable to flooding from rainfall. Each of these were evaluated against the road network to determine the length of detour to go from one side of the bridge to the other side of the bridge. **Figure 4** shows these vulnerable bridges and their detour routes.

Figure 4: Vulnerable Bridges and Detours



Because the paths of local roads through residential areas are sometimes not obvious, and local roads may have insufficient capacities and may themselves be subject to flooding, the analysis of detours around vulnerable bridges used only the roads from the KTMPO modeled network. The average length of detour is 6.6 miles, with eight bridges having detour lengths higher than average. The range of values varied from 1.2 miles (IH 35 frontage road bridges at Confederate Park) to 25.8 miles (Reed's Cemetery Rd). All of the bridges with detour lengths higher than average are located in the more rural parts of the region, where road density is low.

Table 1 lists the twenty-three bridges which are vulnerable to flooding from rainfall with their detour lengths. The Site IDs which are listed are the same used to identify bridges in the *Task 2* memo to determine the network sensitivity for the road networks.

Table 1: List of Vulnerable Bridges and Detour Lengths

Site ID	Region	Road	Detour
23	Belton	IH 35 SB frontage road bridge	1.2
23	Belton	IH 35 NB frontage road bridge	2.4
30	E of Salado	Royal St	10.9
31	E of Salado	Amity Rd	8.1
33	E of Salado	FM 1123	8.8
37	E of Belton	Elm Grove Rd	2.3
39	W of Little River - Academy	Wilson Valley Rd	5.4
45	W of Rogers	Reeds Cemetery Rd	25.8
52	SW of Meeks	Big Elm Creek Rd	11.0
56	Oscar	FM 3117	8.8
62	NE of Temple	Middle Rd	3.5
63	NE of Temple	Gun Club Rd	5.7
63	NE of Temple	Old Troy Rd	6.2
64	N of Temple	Moores Mill Rd	5.9
64	N of Temple	Moores Mill Rd	5.9
72	Pendleton	Southerland Rd	5.5
75	W of Temple	Kegley Rd S of Wildflower Ln	4.7
75	W of Temple	Kegley Rd N of Charter Oak Dr	4.7
83	E of Temple	Dairy Rd	2.7
89	S Temple	Ave R	1.6
96	E of Belton	Shallow Ford Rd	7.7
98	NE of Belton	IH 35 SB frontage road bridge	5.1
98	NE of Belton	IH 35 NB frontage road bridge	7.7

- **Support Post-Flooding Inspections** - Clearing a road, bridge, or other infrastructure for use after a flood will require condition inspections to make sure that they are safe for use. As a flood is an infrequent and intense event, additional inspectors may be needed, and they may not be familiar with the area or with the more specialized inspections required. In particular, diving equipment or remote-controlled cameras may be necessary in order to inspect submerged bridge piles. The availability of qualified inspectors, any specialty tools, specialized training and certification, documentation, and methods for supporting them must be planned for ahead of time to ensure a speedy and efficient recovery from the flooding. Debris removal may be necessary, and will have to be coordinated with the inspections – debris may have to be removed before inspections can be made; but some inspection may be necessary to make sure that the area is safe for people and equipment to remove the debris.

Flooding from Dam Breaches

The effects of flooding from a dam breach is the same as flooding from rainfall, but there are obvious differences in the intensity and duration as well as the cause and affected areas. The conceptual treatments to prevent, mitigate, and recover from this type of flood is likewise similar, but not exactly the same as flooding from rainfall.

Conceptual Strategies to Prevent Flooding from a Dam Breach

Unlike rainfall, dam breaches are discrete events based on infrastructure condition, and so the toolbox for preventing incidents is more robust. There are two main strategies for preventing dam breaches: design and maintenance.

- **Control Design Standards** - There are five types of dams in the KTMPO region, which are more fully described in a separate White Paper:
    - Composite dams
    - Composite earth embankment dams
    - Earth embankment dams with shaped berms
    - Earth embankment dams with berms and bypass spillways
    - Simple earth embankment dams

  The Texas Commission on Environmental Quality (TCEQ) is responsible for the engineering aspects of dam design in Texas. The *TECQ Design and Construction Guidelines for Dams in Texas* identifies heavy clay soils as liable to cause geotechnical foundation issues of cracking, infiltration, instability, and internal erosion. These are direct contributing factors of dam failure. There is therefore a linkage between the drought and sustained high temperature hazard and the dam failure hazard in areas with soil which has a high shrink/swell potential. With this linkage, adherence to design standards with their underlying review of geotechnical issues is a strategy to help prevent the hazard of dam breaches.

  In practice, implementing this strategy will require establishing a thorough inventory of the KTMPO region's dams and the dam attributes associated with their strength and vulnerability. The RVRF can serve as a data management system to format and manage this data and make it available for further analysis.

- Review Dam Maintenance Standards and Practices – TCEQ oversees dam maintenance with their *Guidelines for Operation and Maintenance of Dams* in Texas and their overall Dam Safety Program. The RVRF can serve as a framework to maintain data on hazards, dam condition, and inspections. Compliance with these guidelines is a strategy to help prevent the hazard of dam breaches.

  The TCEQ reports that the vast majority of dam failures are due to design or construction flaws and latent site defects, and so most failures occur early in the life of the dam or at its initial filling. Other issues with dams build gradually with age, so dam maintenance is critical. An accurate inventory of dams and their attributes in the KTMPO region should therefore include the age of the dam. The inventory should be an integral part of a dam safety program which also includes condition assessment, inspections, definitions of maintenance needs, monitoring, and an emergency management plan.

Conceptual Strategies to Mitigate Flooding from a Dam Breach

Different types of dams have different safety features and physical vulnerabilities which lead to several strategies to mitigate the effects of flooding in the event of a dam breach.

- **Evaluate Dam Type** - Dams with the raised shaped berms are designed specifically to mitigate the effects of water overtopping a dam by expanding the embankment to contain the impounded waters. A program to construct raised shaped berms and other safety features where appropriate to the vulnerability, sensitivity, amount of impounded water, and availability of ongoing maintenance is a strategy to mitigate the effects of overtopping or a dam breach.

- **Maintenance** – The capacity of the spillways affects their ability to channel water into the channel rather than allowing it to spread to surrounding land. Ongoing maintenance of spillways to preserve their capacities improves their performance to mitigate the effects of overtopping.

Conceptual Strategies to Recover from Flooding from a Dam Breach

Although a dam breach is an intense event, it is by nature a short-lived event concentrated in a focused downstream area. There are two general effects on road operations from a dam breach:

- If dam failure or overtopping is anticipated, evacuation of downstream areas is necessary before the incident happens.
- After a dam breach, detours are necessary while the road and infrastructure is inspected for damage and necessary repairs are made.

Conceptual strategies to recover from each of these possible events are:

- **Develop a Dam Breach Evacuation Plan** – Regional evacuation plans would be useful for all four types of hazards, but the dam breach hazard is unique because the locations are very specific. The evacuation plans for dam breaches are therefore not regional plans, but individual evacuation plans corresponding to very specific areas which are vulnerable to breaches.

  The RVRF and supporting data has identified vulnerable grid areas, specific road segments, and sensitive land uses. This information can be used to inform an evacuation plan to identify the areas and even specific buildings to be evacuated when anticipating an overtopping or dam breach in any location. Sensitive land uses in the downstream area such as hospitals, nursing homes, jails, electrical power stations, and industrial sites with potentially toxic materials complicate the evacuation. The RVRF data on sensitive land uses can contribute to the evacuation plan by identifying these locations with special concerns.

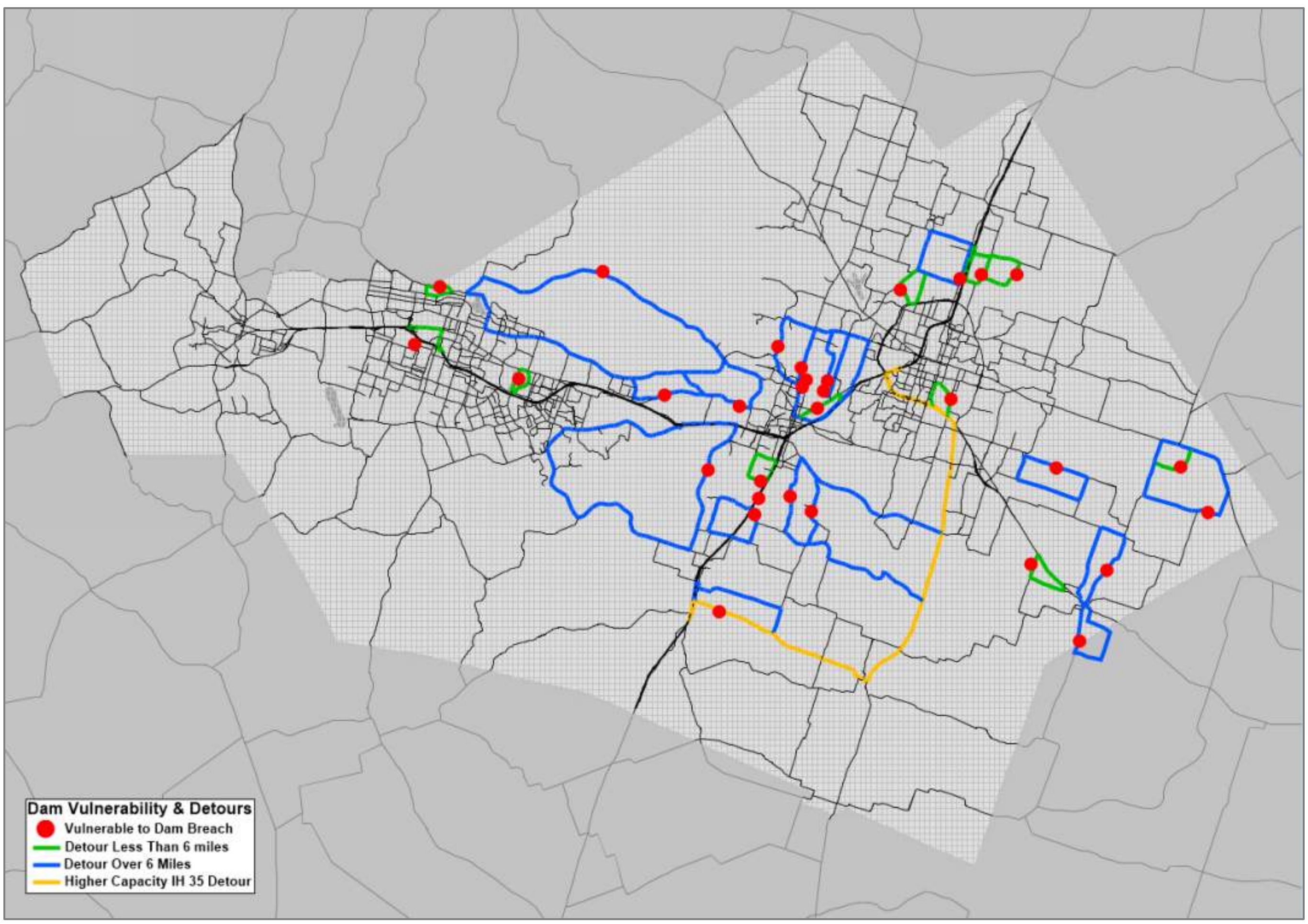
  Additional inventory data on available large spaces such as gymnasiums, warehouses, and churches would be useful in developing evacuation plans by identifying locations for people to evacuate to and to set up emergency command centers. Useful attributes for spaces to be used for evacuations include size of covered space, size of parking lots, presence of bathrooms, presence of kitchen facilities, and contact information.

- **Identify Detours Around Vulnerable Road Segments** - Thirty sites have been identified where a dam breach would impact the road network. Each of these locations was evaluated against the network to determine the length of the detour to go around the affected road segment. **Figure 5** shows the vulnerable locations and their detour routes.

  The paths of local roads through residential areas are sometimes not obvious, and local roads may have insufficient capacities and may themselves be subject to flooding from a dam breach. Therefore, detours were identified for the dam breach hazard based on the same assumptions used to identify detours for flooding due to rainfall: the analysis used only the roads from the KTMPO modeled network.

  The average length of detour is 10.3 miles, with nine locations having detour lengths higher than average. The range of values varied from 1.3 miles (Beal St) to 29.9 miles (Nolan Rd). To allow a comparison between the detours due to the two types of flooding, Figure 13 is color coded to show detour routes above and below the same six mile threshold used for flooding from rainfall.

Figure 5: Vulnerable Road Segments and Detours



The detour route for IH-35 in the event of a breach of the Stillhouse Hollow Lake Dam is shown in yellow. This route shows that evacuation and detour plans for facilities like the Interstate system or US Highways have the added complication of the need for high-capacity regional routes.

Table 2 lists the thirty locations of road segments which are vulnerable to flooding from dam breaches, along with their detour lengths. The Site IDs which are listed are the same used to identify dams in the *Task 2* memo to determine the sensitivity for the road networks.

Table 2: List of Vulnerable Road Segments and Detour Lengths

Site ID	Region	Dam Name	Road	Detour
2	Belton	Belton Lake Dam	Beal St	1.3
			Charter Oak Dr	5.1
			FM 2271	15.7
			S Pea Ridge Rd	7.7
			SH 317	13.0
3	Belton	Stillhouse Hollow Lake Dam	Elm Grove Rd	24.4
			Elmer King Rd	7.2
			FM 1123	21.2
			FM 1670	27.5
			IH 35	28.9
			Shanklin Rd	4.2
5	Cyclone	Unnamed Dam	FM 964	5.1
6	Meeks	Unnamed Dam	FM 940	12.3
7	Heidenheimer	Unnamed Dam	Stringtown Rd	8.7
26	Killeen	City of Killeen Dam	Stonetree Dr	3.6
38	Rogers	Rogers Lake Dam	FM 437	7.4
40	Fort Hood	Tank Wash Lake Dam	South Range Rd	3.1
42	Temple	Veteran's Administration Lake Dam	Martin Luther King Jr Dr	4.1
43	Temple	Wendland Farms Lake Dam	McLane Rd	4.7
46	Killeen	Soil Conservation Service Site 1 Dam	US 190	3.0
49	Belton	Soil Conservation Service Site 12 Dam	Paddy Hamilton Rd	8.6
51	Belton	Soil Conservation Service Site 15 Dam	FM 93	10.1
53	Belton	Soil Conservation Service Site 2 Dam	Nolan Rd	29.9
72	Rogers	Unnamed Dam	FM 437	9.3
73	Rogers	Unnamed Dam	FM 437	9.3
78	Troy	Unnamed Dam	Pecan Rd	5.5
81	Rogers	Unnamed Dam	Knob Hill Rd	5.1
85	Troy	Unnamed Dam	Lower Troy Rd	4.4
86	Troy	Unnamed Dam	Pegasus Dr	8.3
94	Salado	Unnamed Dam	FM 2268	10.9

- **Support Post-Flooding Inspections -** Clearing a road, bridge, or other infrastructure for use after a dam breach will require condition inspections to make sure that they are safe for use. As a dam breach is an infrequent and intense event, additional inspectors may be needed, and they may not be familiar with the area or with the more specialized inspections required. In particular, diving equipment or remote-controlled cameras may be necessary in order to inspect submerged dam structure or affected downstream bridge piles. The availability of qualified inspectors, any specialty tools, specialized training and certification, documentation, and methods for supporting them must be planned for ahead of time to ensure a speedy and efficient recovery from the flooding. Debris removal may be necessary, and will have to be coordinated with the inspections – debris may have to be removed before inspections can be made; but some inspection may be necessary to make sure that the area is safe for people and equipment to remove the debris.

Wildfire

Wildfires which burn off groundcover can reduce the ability of the land to retain and absorb water, so even minor rain can produce flooding and debris flows. In addition to the fire danger, smoke from wildfires can affect visibility and lead to road and airport closures.

Vulnerability due to wildfire is based on flammable ground cover and the wildland-urban interface. As discussed in *Task 2*, the vulnerability of the region to wildfire is distributed with a very evident divide between the brushy Hill Country in the west and the agricultural land within the Prairie in the east. Isolated pockets of vulnerability are also scattered throughout the region.

Fire is a natural process and means for biological renewal across forest, rangeland and grassland Understanding and embracing the concept that “it’s not if an area will burn but when and at what intensity” will help determine appropriate mitigation for fuel reduction.

Conceptual Strategies to Prevent Wildfire

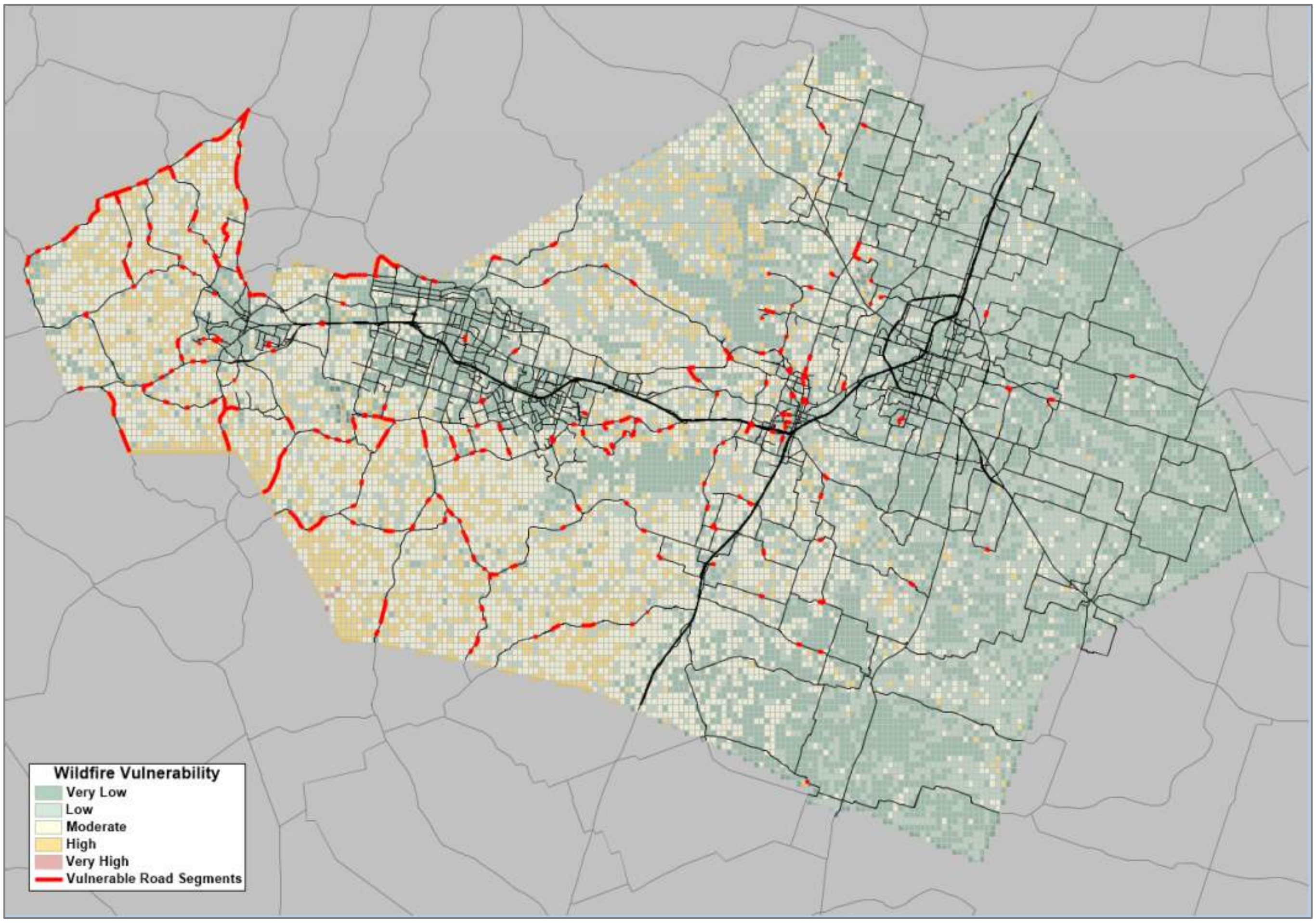
Wildfires are generally seen to be caused by topography, ground cover, and heat or spark incident. None of these factors is directly controllable or impacted by strategies which are within the scope of transportation planning. More general strategies within the context of more general regional planning are:

- **Growth Management** – Collaborate with governmental authorities to create incentives for development and growth that limits development in vulnerable areas.
- **Design Standards** – Review the fire-resistant zoning and building codes and update them as needed to reflect areas of higher vulnerability.
- **Fire Resistant Structures and Landscapes** – Construct or retrofit structures and landscapes that are resistant to wildfires.
- **Manage Ground Cover** – Decrease the supply of flammable ground cover.
- **Education** – Increase wildfire awareness through education. Encourage the community to create a fire-resilient natural landscape and built environment.

Conceptual Strategies to Mitigate Wildfire

As shown in **Figure 6**, the wildfire vulnerability for the region has a distinct pattern. This makes the conceptual strategy of defining wildfire districts more practical by limiting the geographic area which is affected. Local wildfire districts can be established to develop local-level contacts to implement the prevention strategies listed above.

Figure 6: Wildfire Vulnerable Areas and Road Segments



Conceptual Strategies to Recover from Wildfire

Once the fires are extinguished and the smoke clears, the long-term effects of wildfire on transportation infrastructure relate to:

- Damage to asphalt pavement and tar sealants
- Damage to rebar within concrete pavement, columns, and beams
- Damage to secondary structures such as signs, utility poles, traffic signals, transit stops, and street furniture
- Damage to groundcover leading to reduced ability to retain stormwater, particularly in hilly areas
- Damage to soil leading to reduced ability to absorb stormwater
- Cracking, rutting, and upheavals in soil leading to pavement and substrate damage, particularly in areas with highly expansive soils

These effects show that strategies for recovery from wildfires not only needs to repair the immediate damage in the short term, but also needs to consider the long-term synergistic effects of wildfire damage on soils. Wildfire vulnerability is therefore linked to vulnerabilities to stormwater and drought.

With this consideration, strategies for recovery from wildfires include:

- **Identify Evacuation Routes** – Evacuation routes are a common recovery strategy responding to environmental vulnerabilities. However, the pattern for wildfire vulnerability and the vulnerable road segments described in *Task 2* generally cover the entire western side of the study area, which is too large for a feasible and usable evacuation plan. This is coupled with the effects of the speed that wildfires can spread and the range that wildfire smoke can cover to make a regional evacuation plan dependent on the exact circumstances of each fire within local areas. While a pre-set regional evacuation plan may therefore not be feasible, it is possible to develop smaller-scale evacuation plans for the local wildfire districts. These smaller plans would be more responsive to real-time needs, and could be referenced and aggregated to guide evacuation efforts.
- **Support Post-Fire Inspections** - Clearing a road, bridge, or other infrastructure for use after a fire will require condition inspections to make sure that they are safe for use. As a wildfire is an infrequent and intense event, additional inspectors may be needed, and they may not be familiar with the area or with the more specialized inspections required. The availability of qualified inspectors, any specialty tools, specialized training and certification, documentation, and methods for supporting them must be planned for ahead of time to ensure a speedy and efficient recovery from the fire. Debris removal may be necessary, and will have to be coordinated with the inspections – debris may have to be removed before inspections can be made; but some inspection may be necessary to make sure that the area is safe for people and equipment to remove the debris. In addition to the affected infrastructure, after a wildfire the surrounding groundcover and soil will have to be evaluated to determine how much the watershed's availability to retain and infiltrate rainwater has been affected, so full recovery from a wildfire may include additional actions to prevent or mitigate flooding.

Drought or Sustained High Temperatures

An increasing number and severity of droughts, higher temperatures, and periods of sustained higher temperatures are projected due to global climate change. These changes can cause higher rates of evaporation, drier soil affecting groundcover and water infiltration, soil cracking and voids, erosion, and pavement degradation.

Figure 7: Pavement Cracking due to Soil Shrinkage

Task 2 identified the transportation infrastructure vulnerable to drought or sustained high temperatures within the KTMPO region. In the west of the region, the distribution of vulnerability is somewhat lumpy, with vulnerable and non-vulnerable soil types freely mixed. In the east of the region, vulnerability is more consistent – the entire towns of Bartlett, Holland, and Rogers and roads for several miles in all directions are vulnerable.

Figure 7 shows how soil subsidence can cause pavement cracking. **Figure 8** shown how an earthen slope can subside due to shrinkage in the underlying soil. The concrete embankment in the background has not failed, but is subject to the same stresses and risks from its underlying soil.

Figure 8: Slope Failure Caused by Soil Subsidence

Conceptual Strategies to Prevent Drought or Sustained Higher Temperatures

Drought or sustained high temperatures are such large-scale issues that they cannot absolutely be prevented. While a general approach to preventing hazards it to avoid placing infrastructure in vulnerable areas, the distribution of vulnerable soil types is so extensive in the KTMPO region that this strategy is not feasible.

Pavement damage does not automatically occur in every place which has vulnerable soil types. Therefore, a strategy to prevent pavement damage and to allow corrective treatments before the damage becomes extensive is:

- **Continuously Monitor for Damage** – Monitor road, bridges, slopes, and other infrastructure for signs of stress and pavement damage. Monitoring requires having standards to evaluate condition and maintaining records of condition over time so that trends can be identified. The focus for monitoring can be the road segments explicitly identified as vulnerable in *Task 2*, but should be expanded to cover more detail. In particular, *Task 2* identifies road segments but does not inventory slopes.

Conceptual Strategies to Mitigate Drought or Sustained Higher Temperatures

One of the main effects of drought or sustained high temperatures is soil contraction and subsidence. Soil contraction under roads can cause cracking or rutting of pavements and can form voids which may cause pavement collapse. General strategies to mitigate the effects of soil distress on road infrastructure are:

- **Construction Standards** – This issue can be addressed by adjusting the mix design for pavements and binders to provide greater strength. Undercutting and replacing clay soil beneath the pavement or treatment with lime or cement can be used to improve soil performance.
- **Adjust the Pavement Structural Design** — Adjust the pavement structural design to compensate for the expected increase in pavement distress. Providing wide shoulders to support the edge of the pavement and providing gentler side slopes make the slopes less prone to sliding.
- **Modify Specifications** — Modify specifications to improve pavement quality and reduce variations. Modifications could include requiring reduced air voids in asphalt mixtures and more stringent tolerances for the mix.
- **Stabilize Slopes** — Implement adaptation measures that hold the slope surface in place, such as managing surface water to reduce infiltration, establishing vegetation to protect the slope and reduce surface runoff, or installing manufactured slope stabilization and erosion control products.

Conceptual Strategies to Recover From Drought or Sustained Higher Temperatures

Recovery from the pavement or infrastructure damage related to drought or sustained higher temperatures has two components:

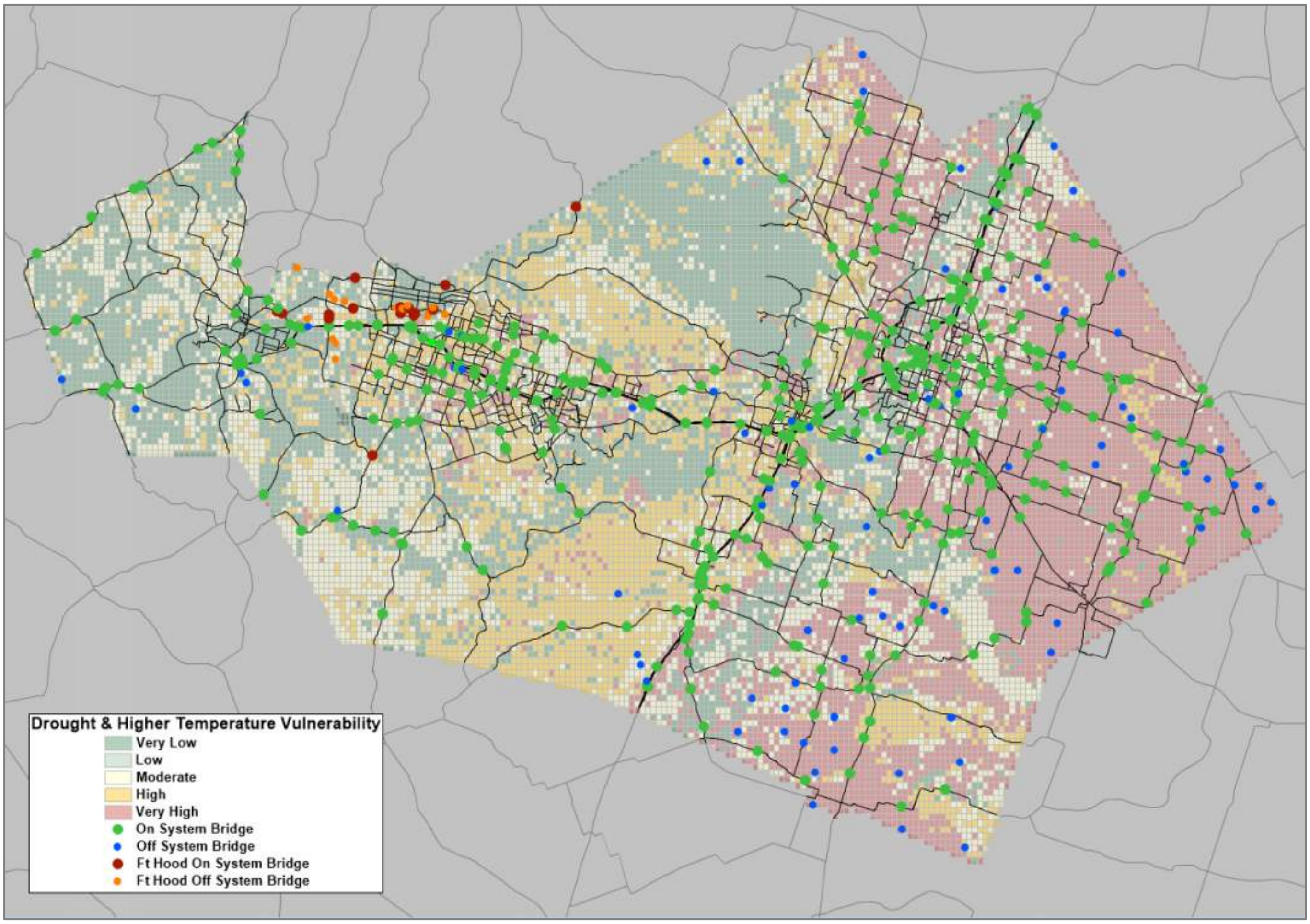
- Recovery from non-emergency damage which does not make the infrastructure unusable, such as pavement cracks or rutting. Maintenance such as chip sealing, hot mix patching, or base & subbase repairs is sufficient to recover from this type of damage. This type of damage occurs slowly over time, and maintenance can be deferred if necessary.
- Recovery from damage which makes the infrastructure unusable requires road closures and more extensive reconstruction. The underlying causes of this type of damage occurs slowly over time, but the significant damage like a slope failure or sinkhole can occur quickly.

Strategies for recovery from these types of damage include:

- **Identify Detour Routes** – Detour routes are a common recovery strategy responding to damage. However, even if the damage requires extensive reconstruction, it may not be necessary to completely close the road, and detours would not be necessary. However, reconstruction of bridges may require the entire road to be closed, so a detour would be necessary.

  In the case of infrastructure damage due to drought of sustained higher temperatures, the scope of the hazard and the localized effect make the development of detour routes for the entire region unfeasible. Detours for specific critical infrastructure, such as bridges, can be defined in order to identify places where the network is less dense and detour routes are excessively long. **Figure 9** shows the general feasibility of this strategy: there are 525 on-system bridges and another 17 in Fort Hood, with 115 off-system bridges plus 19 off-system in Fort Hood for a total of 676 road bridges.

Figure 9: Drought & Higher Temperature Vulnerability and Bridges



In addition to bridges, vulnerable slopes and embankments would have to be identified, along with any ongoing pavement monitoring according to standards and trends. The planning work for defining detour routes ahead of time for every eventuality of damage is quite daunting and would in many cases of damage be unnecessary.

- **Support Post-Repair Inspections** - In addition to the ongoing monitoring and identification of trends which was listed as a preventative strategy, inspection of transportation infrastructure after damage is repaired should be supported. Clearing any affected infrastructure for use after a repairs are made will require condition inspections to make sure that they are safe for use. In terms of simple pavement damage and road reconstruction, the repair work is routine and inspectors are well-qualified and well-equipped to evaluate the repairs. They may need additional support for unusual damage such as slope failures, voids, or sinkholes. Any specialty tools required for the inspections must also be made available.

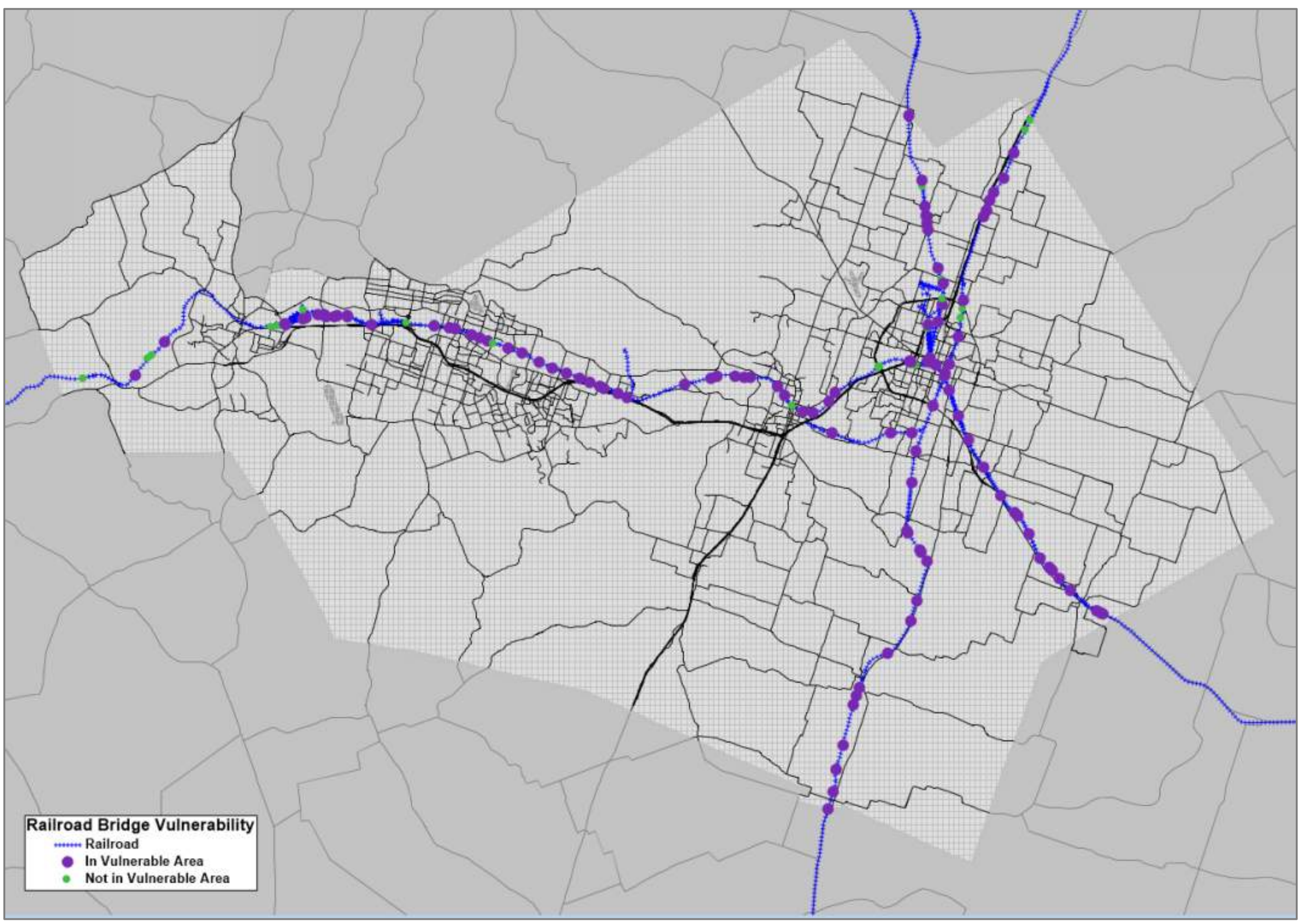
As with wildfires, drought or sustained higher temperatures may affect the surrounding groundcover and soil. These should be a part of the monitoring program to determine how much the watershed's availability to retain and infiltrate rainwater has been affected - full recovery may include additional actions to prevent or mitigate flooding.

Rail Infrastructure

The vulnerability of rail infrastructure to the four types of hazards was detailed in *Task 2*. The prevention, mitigation, or recovery from incidents for rail infrastructure is different from strategies for the road network mostly because the rail network is privately owned. Neither the MPO nor TxDOT have the authority or the funding to plan or implement any projects on the rail network. However, it does not follow that the rail network has no effect on the road network. A significant disruption on the rail network could force freight movements to shift to the truck mode, with a strong impact on regional traffic and traffic loading on pavements. Therefore, while projects to prevent, mitigate, or recover from incidents for the rail network are not directly applicable to transportation planning for the KTMPO region, an awareness of possible strategies can contribute to planning a resilient network.

Figure 10 is an overview of the vulnerable bridges and culverts in the rail network. Of the 142 bridges and culverts in the region, 114 are in vulnerable areas for one or more hazards; only 28 are not in any vulnerable area.

Figure 10: Vulnerable Rail Bridges and Culverts



Railroad infrastructure is particularly vulnerable because, unlike the road network, wood construction of bridges and small bridges over culverts is still common. Flooding, wildfires, and soil expansion which might have only a minor effect on concrete or steel road infrastructure may have a devastating effect on wooden rail infrastructure. The slenderness and exposure of the rails is also a factor in heightening their sensitivity to damage. **Figure 11** shows the damage to a wooden rail trestle over a small culvert caused by a small-scale fire.

Figure 11: Fire Damage to Wooden Railroad Bridge

Figure 12 shows how a rail line and wooden rail culverts can be damaged by flooding.

Figure 12: Rail Line and Culvert Damage from Flooding

Conceptual Strategies to Prevent Railroad Infrastructure Incidents

As with planning for the road network, there are no explicit strategies to prevent environmental hazards, but the effects of incidents can be anticipated and planned for. The general approach to prevention is to:

- **Update Design Standards** – Design standards for rail infrastructure include specifications for materials, subbase, design, and protection. The standards are subject to Federal Railroad Administration oversight, but are largely developed by the private owners. Standards have reasonably been based on the history of past incidents and hazards such as the FEMA floodplain maps, Department of Agriculture fire hazard maps, and Department of Agriculture soil type surveys. With the effects of climate change seen as an ongoing issue rather than as a future possibility, a review of past incidents and hazards and an update of the rail infrastructure design standards is a prudent approach to increasing rail infrastructure resilience.

Conceptual Strategies to Mitigate Railroad Infrastructure Incidents

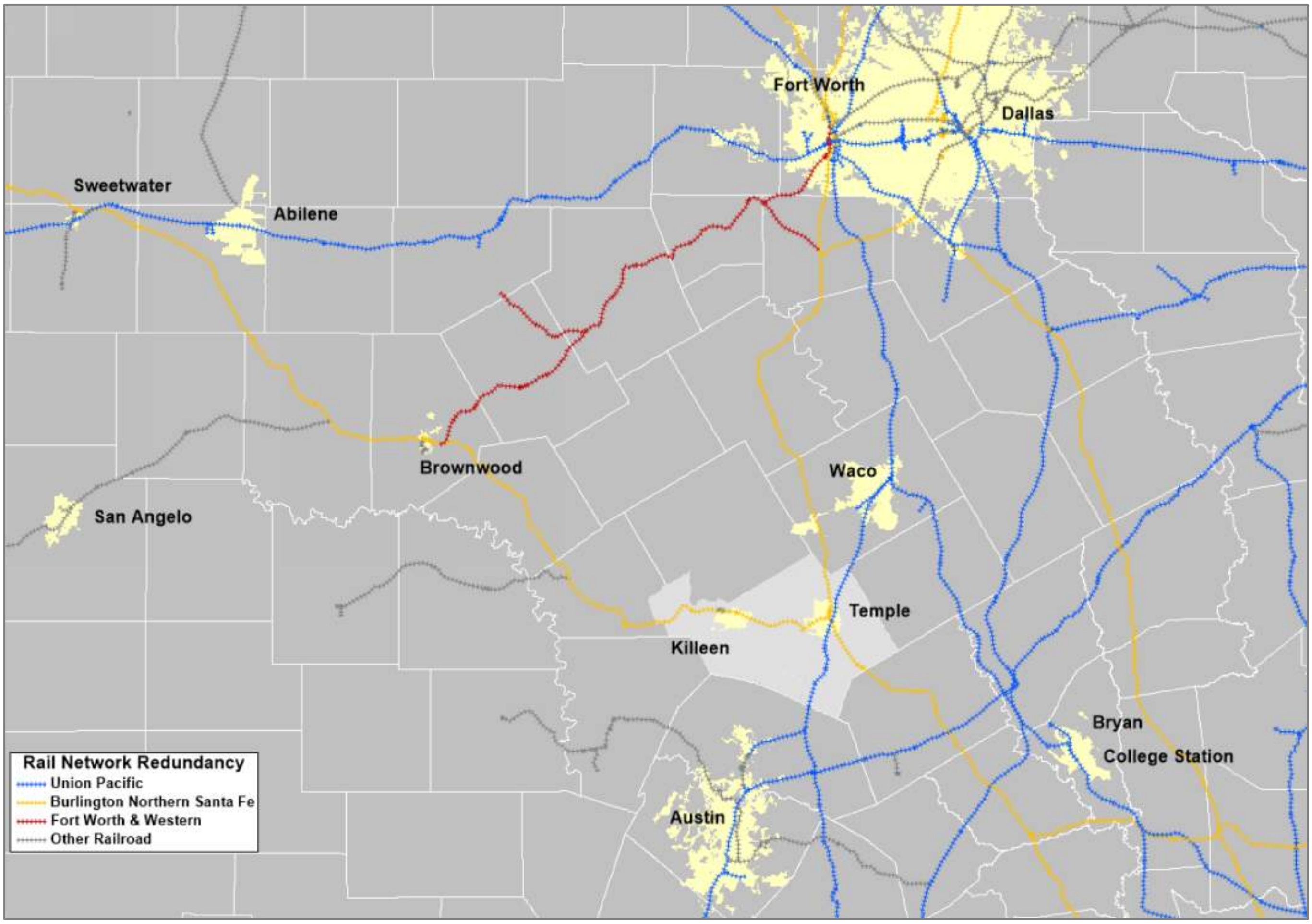
Strategies for mitigating the effects of environmental incidents on rail infrastructure are similar to the strategies for road infrastructure. The primary difference in implementing strategies is that rail lines are privately owned. However, the more regionally-oriented strategies are similar in that they address vulnerabilities that cover large areas, and have to be coordinated across multiple jurisdictions.

- **Increase Flow Capacity** – Increase the ability of a culvert or bridge to pass water flows at future peak levels expected with climate change and increased precipitation events. Increased peak flow capacity can be achieved by replacing a culvert with larger culverts or a bridge.
- **Restore and Repair Watersheds** – Manage and decrease future peak waterflow rates through a watershed-based approach. Watershed restoration or repair could be achieved through the implantation of a regional drainage management area that considers drainage issues and concerns at a greater spatial scale, the implementation of dispersed stormwater and debris controls throughout a watershed, and the enhancement of streams, floodplains, and wetlands.
- **Manage Ground Cover** – Decrease the supply of flammable ground cover.
- **Protect** – Reduce damage to infrastructure by providing protective physical barriers to extreme events and climate stressors. Protection could take the form of retrofits to harden railroad embankments and stream banks with retaining walls. Wooden infrastructure and ties could be replaced with more resistant materials. Corrosion protection treatments could be added to bridge and rail facilities to help elongate the life of these facilities as they experience more frequent flooding events.

Conceptual Strategies to Recover from Railroad Infrastructure Incidents

The rail network is much more regional in scope than the road network. Detours needed to recover from environmental incidents therefore have to be examined at a larger scale. **Figure 13** shows the railroad network for the region around KTMPO. In case of a significant rail network disruption, the Union Pacific railroad (UP) has a convenient detour route to the east of the region, running to north of Bryan and connecting to Waco. North-south detours on the Burlington Northern Santa Fe (BNSF) can use the UP tracks. For east-west rail movements, possible detours on the BNSF line can route on the UP line through Sweetwater and Abilene or the Fort Worth & Western line through Brownwood to meet in Dallas-Fort Worth.

Figure 13: Regional Rail Network and Detours



Conclusion & Next Steps

As climate change and extreme weather present increasing risks to the KTMPO regional transportation infrastructure, it is increasingly important to for planning to address not just traditional metrics such as mobility, reliability, and safety, but to understand and address asset vulnerability and resilience. The critical planning functions necessary for this change are:

- A data collection and management system to support analysis and decision making
- An analysis framework which can access vulnerability and sensitivity, and which can evaluate the resiliency of the system.

These two critical planning functions are provided through the KTMPO Regional Vulnerability & Resilience Framework (RVRF). As the RVRF becomes more fully integrated into regional transportation planning, it will provide a tool to improve the long-term basis for more resilient infrastructure and more effective projects.

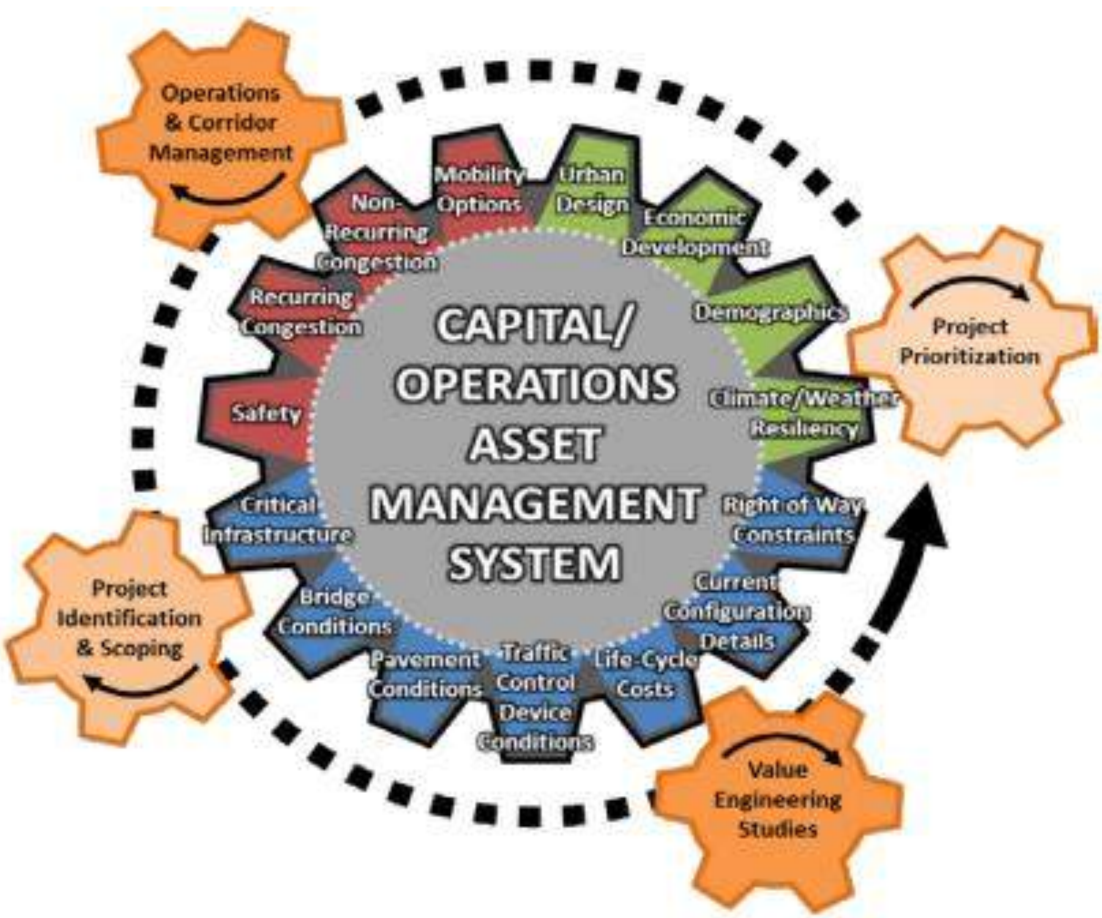
Several planning topics and projects are involved in fully integrating the RVRF into the regional transportation planning process and tools:

- **Define Baseline Conditions** – The scores calculated in the RVRF grid can be used to define vulnerable areas for each hazard. When the network is applied to the vulnerable areas, the grid defines specific road segments which are vulnerable. A more specific inventory of infrastructure attributes and condition can be added to the RVRF data to provide further baseline detail and track long-term trends. The need to define baseline conditions and monitor trends drives the need for more specific and more detailed inventories of infrastructure condition.
- **Identify Sensitivity, Vulnerability, and Resilience** – One of the main purposes of the RVRF grid is to identify geographic areas which are vulnerable to each hazard type. Sensitivity is also defined in terms of critical land uses and tracked in the RVRF data. Resilience is defined in the RVRF partially through identifying detour routes, but the primary treatment is defining conceptual strategies to improve resilience.
- **Deficiency Analysis or Gap Analysis** – The concepts of deficiency or gaps can be extrapolated to cover vulnerability as well. The same process would reference areas where conditions identify a current issue which could be addressed through an infrastructure project. Specifically, the RVRF grid identifies areas which are deficient – that is, vulnerable – to four specific hazards. This information can then be used to generate projects to address the deficiencies.
- **Update Regional Vision and Goals** – Visions and Goals for the region are documented in the long-range Metropolitan Transportation Plan (MTP), providing direct guidance for plans such as the TIP and referenced in plans such as the Congestion Management Plan and the Regional Multimodal Plan. Reviewing the regional vision and goals with consideration of vulnerability and resilience can be supported by data from the RVRF.
- **Project Evaluation and Prioritization** – KTMPO has already updated their project scoring and prioritization process with the RVRF, the RVRF Scoring Spreadsheet, and the updated Project Selection Process. This process directly uses the RVRF to score projects for vulnerability and resilience.
- **Project Development** – In addition to evaluating existing projects, the RVRF can be applied within the overall performance management planning process. This cycle would continuously monitor the vulnerability & resilience of the transportation system, identify deficiencies or issues, and develop projects to address specific issues.
- **Call for Projects** – When responding to the call for projects for the MTP, member jurisdictions submit projects which they develop themselves based on their perceived needs. Making the RVRF layers or printouts available to them early in the process would be useful so that they can consider vulnerability and resilience as they identify their needs and develop transportation projects for submittal.
- **Update the Long-Range Metropolitan Transportation Plan (MTP)** – the sensitivity, vulnerability, and resilience data from the RVRF can be used for project analysis. When linked with the MTP vision and goals, this information can help identify strategies and investment scenarios to promote resilience.
- Prepare Grant Applications – Various state and Federal grants and programs may be available to fund projects focused on building resiliency. The RVRF can provide the underlying data needed to support the application both as a data management platform and as an evaluation and analysis platform. An example of this type of grant is the Texas Water Development Board, which manages the FEMA Flood Protection Grants supporting planning for flood protection, flood early warning

systems, and implementation of local strategies. The program has a target grant amount of 50% of the total project cost.

The RVRF framework can be most fully useful by fully and consistently integrating it into the regional planning process. A precedent for integration of vulnerability and resilience into the planning process is provided by the North Central Texas Council of Governments (NCTCOG) with their TransFACTS program. This program is a data management and analysis tool. At its core it is a framework to use asset management and performance management principles to manage transportation infrastructure. As shown in their program graphic in **Figure 14**, it is designed as an integrated system to coordinate a full range of management programs to drive project development, project prioritization, and TSMO strategies such as operations & corridor management.

Figure 14: NCTCOG TransFACTS Program



It is notable that climate and weather resiliency is represented as just one among fifteen cogs that drive the process. Other cogs include the identification of critical infrastructure, bridge conditions, and pavement conditions. This NCTCOG precedent mirrors the recommendations in the RVRF for more detailed inventories to support several topics:

- A detailed inventory of the types of warning signs and controls for low-water crossing at bridges. Additionally, the National Bridge Inventory used to populate the RVRF includes only bridges; there may be low-lying segments of road in the region which are subject to flooding even if they are not associated with a bridge.
- Slopes, embankments, and retaining walls are vulnerable to soil shrinking and expansion, and can also be affected by loss of groundcover and rainfall. General GIS layers of topography are available, but there is no detailed and precise inventory of this type of infrastructure.
- The available inventories of dams were reviewed and found to be incomplete. The dam inventory for the region is therefore based on a review of aerial images and GIS layers from the Texas Natural Resources Information System (TNRIS). A more comprehensive and more detailed inventory of dams is needed to provide dam and impounded water attributes. Needed attributes include name, age of dam, volume of impounded water, depth, height of dam, soils, and condition.
- Texas Commission on Environmental Quality (TCEQ) Dam Safety Program for public and private dams is robust and has a requirement for dam owners to prepare Emergency Action Plans. However, there are certain exceptions for dams not covered by the regulations. The TCEQ Dam Safety Program also provides data layers for their Probable Maximum Precipitation Study (PMP), which has been updated with the most recent storm data after Hurricane Harvey. Similar to the RVRF, the PMP provides a GIS grid with values.
- The inventory of sensitive land uses covers a limited number of types of facilities such as schools, hospitals, jails, and public infrastructure. The inventory was therefore developed through a review of aerial images. To complement this classification of sensitive areas, a complementary inventory of available large building spaces is needed. The additional inventory data on available large spaces such as gymnasiums, warehouses, and churches would be useful in developing evacuation plans by identifying locations for people to evacuate to and to set up emergency command centers. Useful attributes for spaces to be used for evacuations include size of covered space, size of parking lots, suitability for a helicopter landing, presence of bathrooms, presence of kitchen facilities, communications infrastructure, and contact information.
- Where the scale of vulnerability makes regional evacuation plans impractical, plans can be developed for smaller areas. Defining these small areas, such as wildfire districts, can be a useful way to define the plans for more manageable areas. Smaller plans are also likely to be more realistic and will be a better match to the scale of the incident.
- TxDOT and the public works departments for the various regional jurisdictions monitor pavement condition for their roads. Linking this data to the RVRF is needed to establish common standards, define baseline conditions, and to track trends which may reveal ongoing damage due to soil shrinking and expansion.
- Planning is necessary to support the inspections required to recover from each type of incident. The need for additional inspectors, specialized skills and certifications, specialized equipment, and required documentation must be prepared for ahead of the incident.