Term Project – GIS in Water Resources – C E 394 K

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Estimation of the Economic Impacts of IH 35 Bridge Deterioration Due to Floods in Onion Creek

Introduction to the problem

Bridges are a fundamental part of the transportation network. Their proper functionality guarantees the movement goods and people in a safe way. At the same time, bridges are one of the infrastructures that is most exposed to climate change. According to Wright et al. (2012), bridges will be impacted due to both an increase in the intensity and amount of precipitations in the next century. Their study concluded that up to 100,000 bridges in the U.S. could be vulnerable.

Floods can damage bridges in several ways. The two most common problems are the loss of filling materials and a complete collapse of the bridge. Loss of fill materials is due to erosion of the river-bed (also called scour). Though scour happens continually, it increases considerably during flood periods. The loss of filling materials start at the downstream bottom of piers and abutments and it creeps upstream until it affects the stability of the bridge. This process can be gradual or it could happen in a single event, depending on the magnitude of the flood and the characteristics of the bridge. In the case of collapses, if the recurrent loss of filling material due to scour is not treated, the bridge could loss stability and collapse. Likewise, during floods large debris, such as trees or cars, can hit the bridge directly (VicRoads, 2012). The most common case is when the bridge is overtopping.

There are different ways to mitigate the impact on bridges. New design codes and assessments before an flood are being performed worldwide. After a flood it is common inspect the bridges. However, inspections could be a dangerous task. Sometimes the inspections cannot be performed because there is no access to the location, or damages that are not seen clearly seem. Furthermore, bridges are critical to attend the emergencies in a flood event (for example, evacuation, fire fighters rescues, or crane movement).

GIS can be an effective tool to overcome these challenges. GIS can be a tool to assess which bridges are in a vulnerable situation. This could help to prepare a budget for maintenance/replacement even before the occurrence of a flood.

Objective

The objective of the term project is to estimate the expected impact of floods in the bridge deterioration process for highway system bridges that are in the catchments of IH-35 in Onion Creek.

Framework

The proposed framework uses the Height Above the Nearest Drainage (HAND) process. The analysis receives as an input the Digital Elevation Model, Bridge inventory and Hydrological information. The HAND analysis is done in order to obtain the rating curves for the flows in each catchment. Then, the impacts of the bridges is assessed by comparing the inundation depth with the bridge height and the deterioration model. Finally, the impacts are estimated.

The following is the framework proposed:

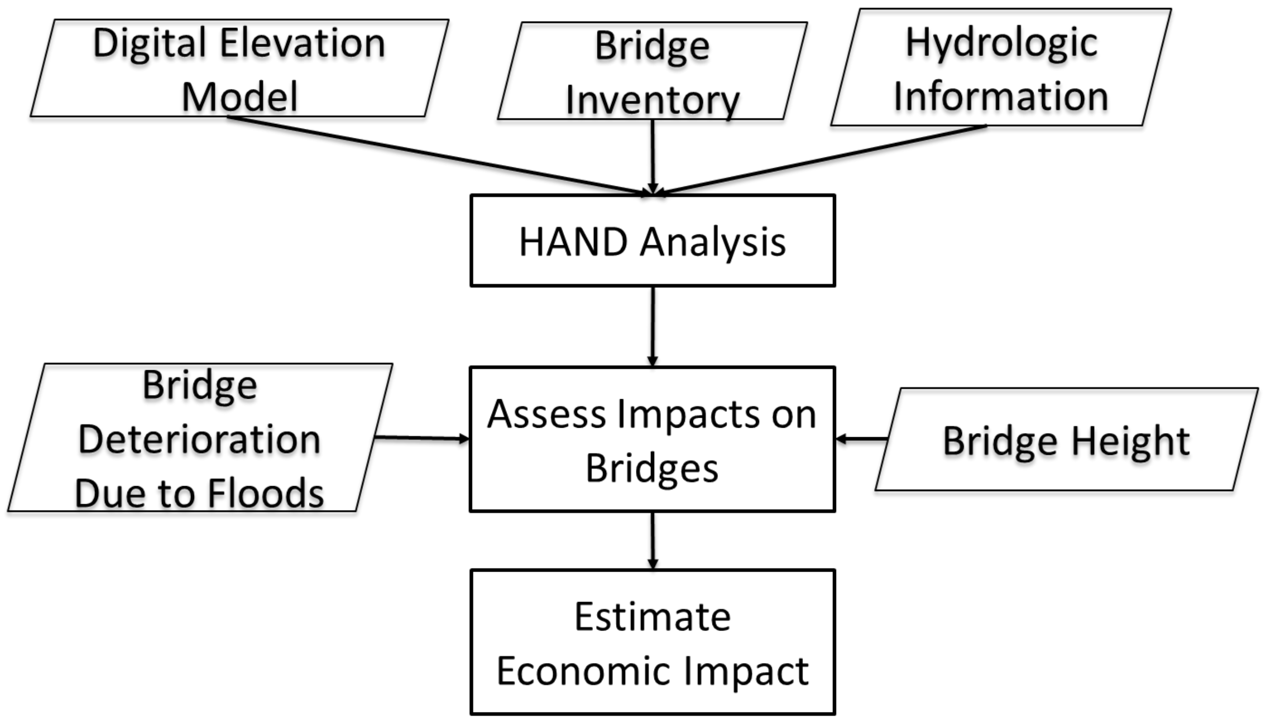


Figure 1. Proposed Framework

Analysis

Location

Figure 2 and Figure 3 presents the location of the Onion Creek Watershed. A total of 110 catchments belong to this Watershed.

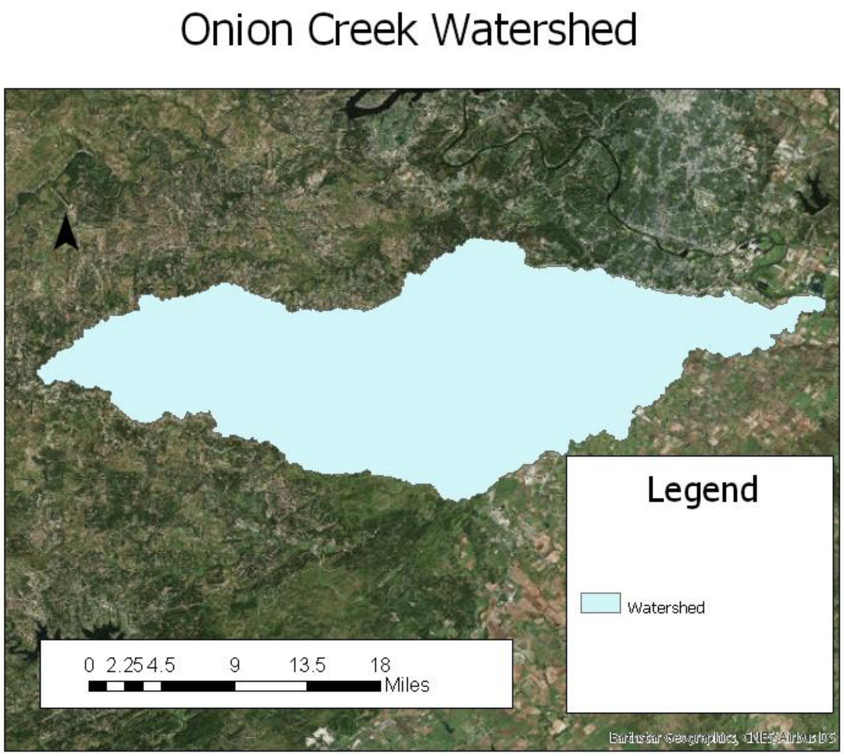


Figure 2. Onion Creek Watershed

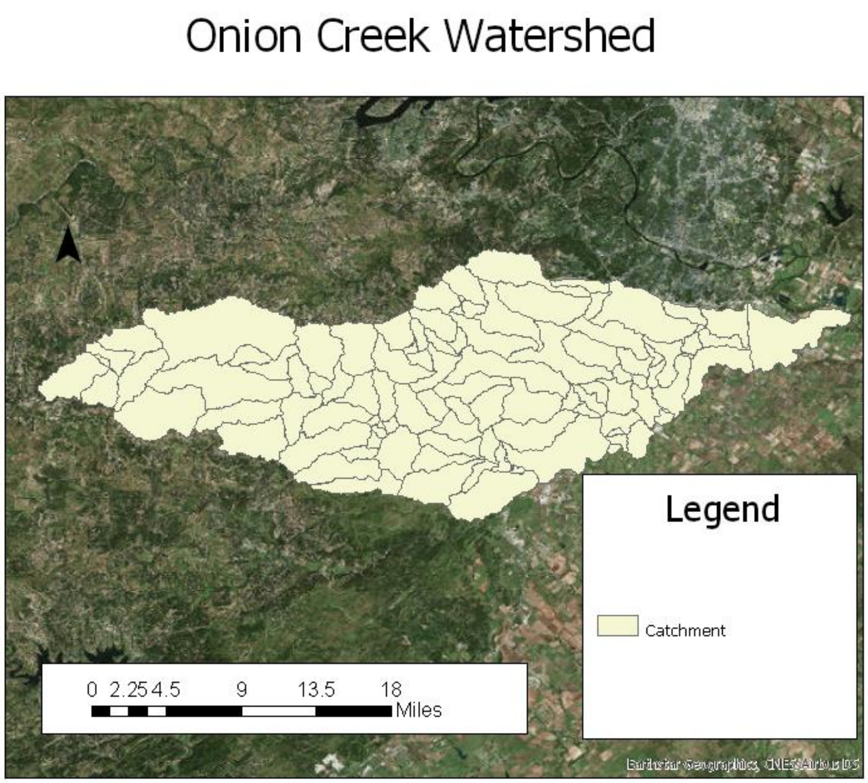


Figure 3. Catchments in Water Creek

Digital Elevation Model

A 10 m DEM is used in the current study. The raster is processed in order to 1) fill pits, and 2) remove infrastructure obstacles that do not impede the flow.

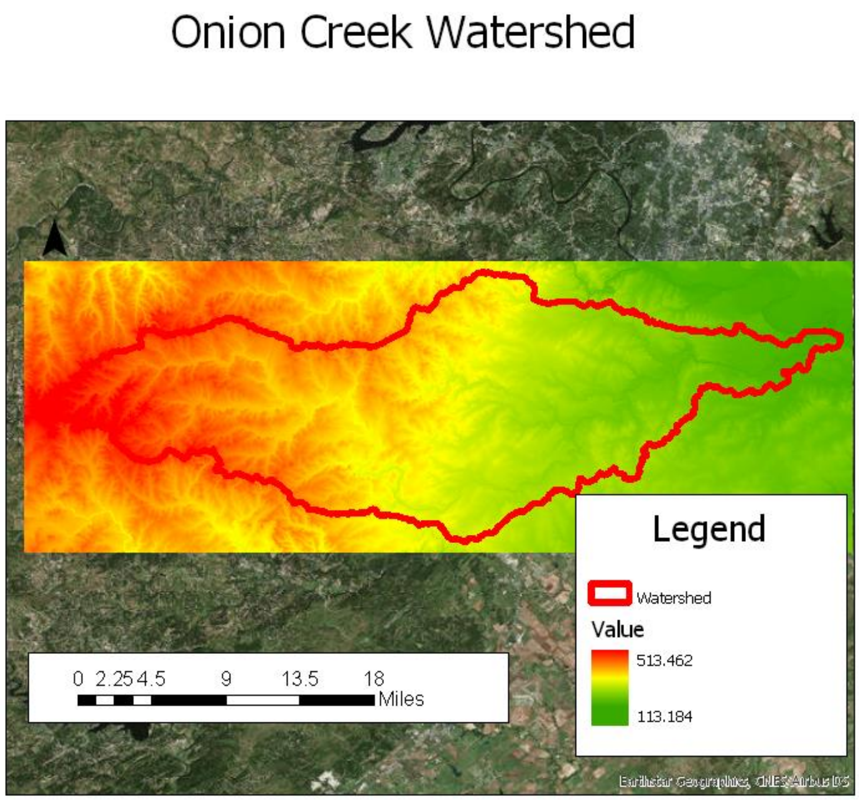


Figure 4. DEM of the Onion Creek Watershed

Bridge Inventory

Bridge inventory was obtained from TxDOT. In order to select the bridges that are relevant to the study, three steps are conducted:

1. Selection of bridges that are in the area of interest. This is done by selecting the bridges within the specific catchments to analyze.
2. Selection of the bridges over water. Only the bridges that are close to a NHD plus (through a buffer zone) are selected.
3. Selection of bridges of the Highway System. The database contains both local and highway bridges. Only the bridges that are for the Highway System are selected through a buffer zone of the highways.

Figure 5 presents all the bridges near and within Onion Creek watershed. Figure 6 presents the bridges and catchments selected for the analysis.

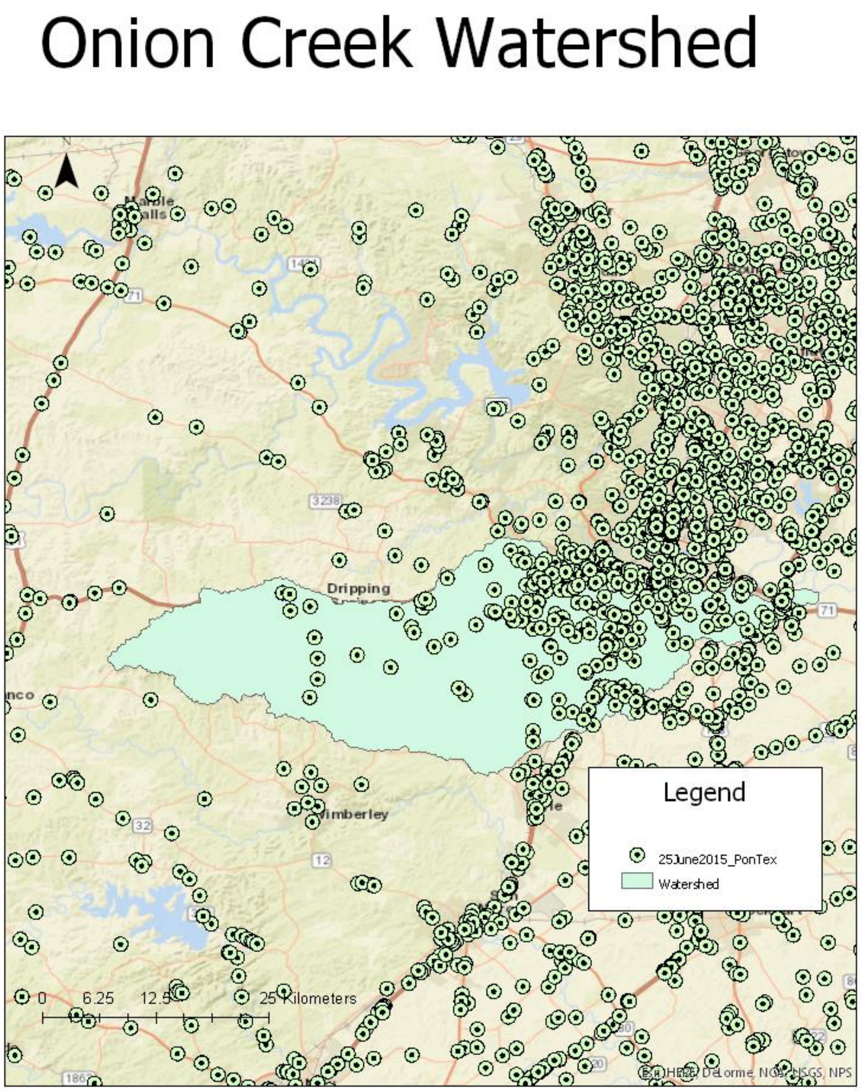


Figure 5. Bridge within and near Onion Creek Watershed

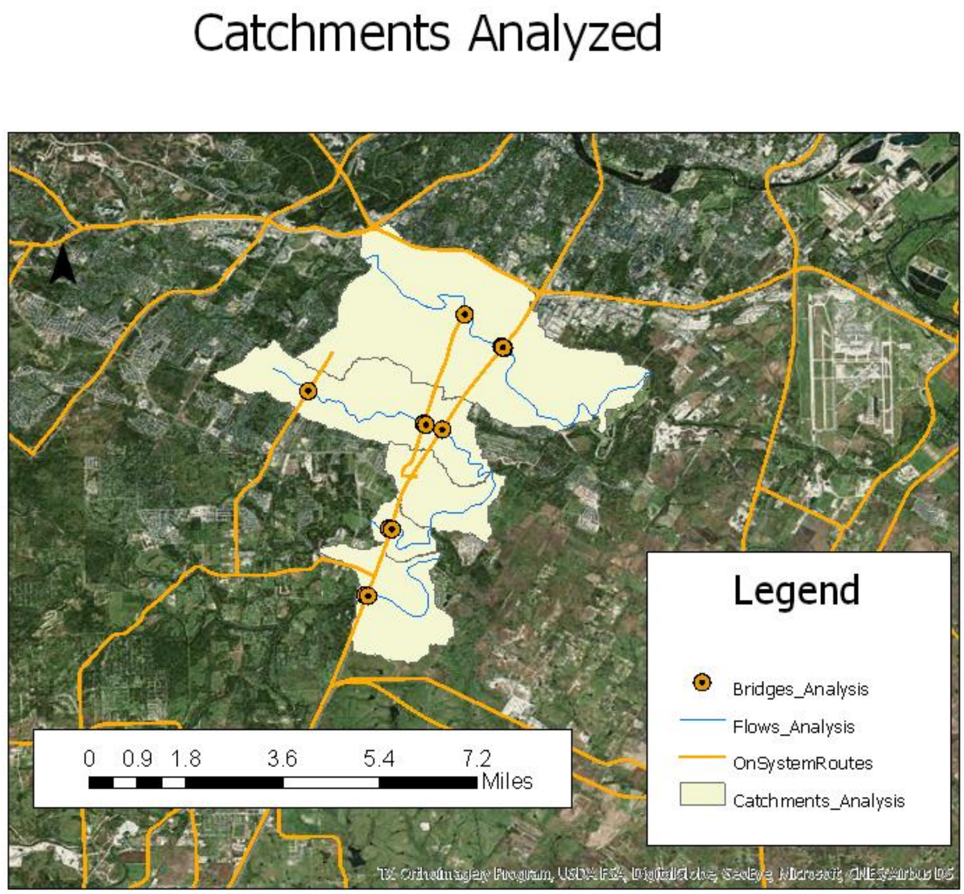


Figure 6. Bridges selected for the analysis

Hydrologic Information

The Hydrologic information is obtained from the National Hydrologic Dataset (NHD), the NHDPlus. Two key information is obtained from there: 1) The flowlines and 2) the maximum flow (field "FloodFlow_cfs").

HAND Analysis

Using the DEM and the TauDEM CyberGIS App page, the Height Above the Nearest Drainage is estimated for the catchments analyzed. The results are presented in

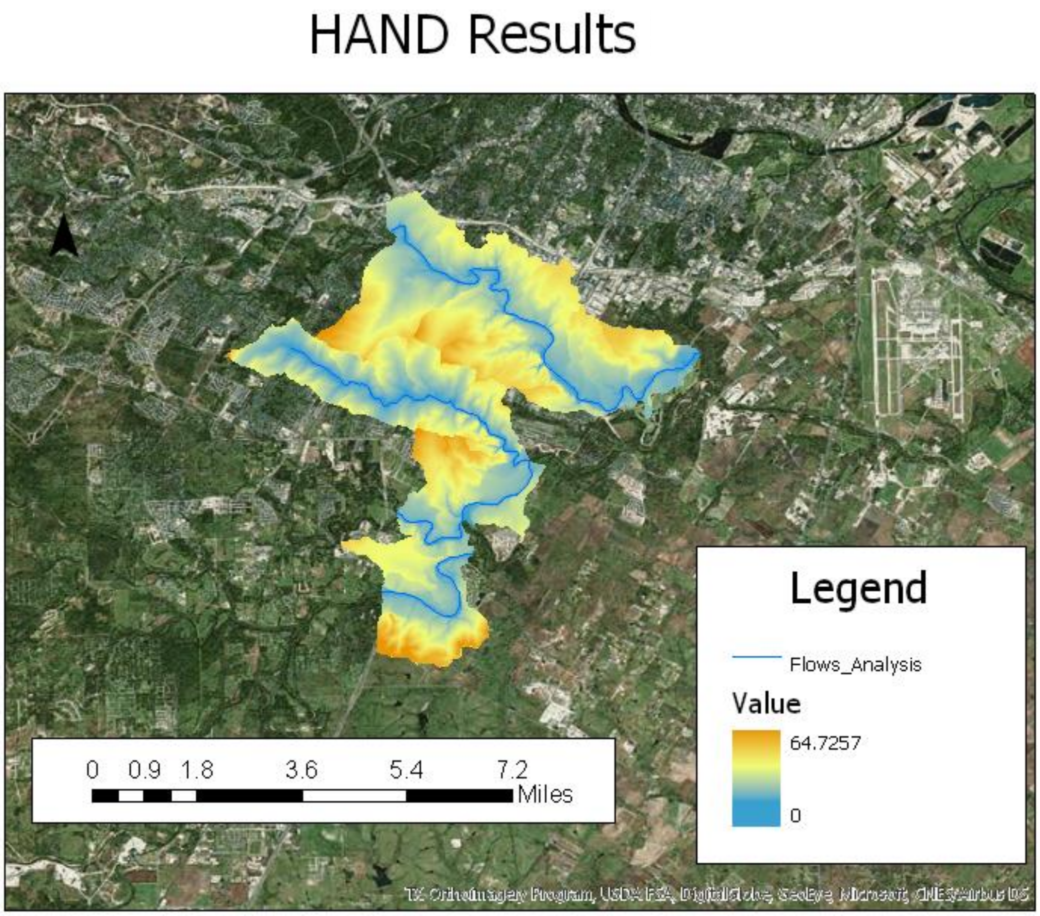


Figure 7. HAND Results for the Catchments Analyzed

Bridge Deterioration due to Floods

The deterioration of bridges, as it is common with other civil infrastructure, is complex and depends on many factors. For the sake of this project, only loss of filling material and overtopping are analyzed. For simplification, it is assumed that the deterioration of bridges are a function of only the inundation depth. For further development, other inputs can be included such as age of the bridge, soil of the bridge, and flow speeds at flood. Table 1 presents the summary of the deterioration model:

Table 1. Summary of Deterioration Model

Bridge impact due to flood	Height Threshold	Remedial Action
Loss of fill material of piers and abutments	Inundation Depth is 70%-90% height bridge	20% of chance of need a replacement
Overtopping	Inundation depth is greater than 90% of bridge height	Replacement of bridge

Bridge Height

Lidar information is used to estimate the height of the bridge. Unfortunately, the TxDOT database for bridges did not contain a metadata file where indicates the field of the height of the bridge. For that reason, using information from LIDAR, it is computed the difference between river-bed and bridge structure. Figure 8 presents an example of the visualization of the bridge in LIDAR raster.

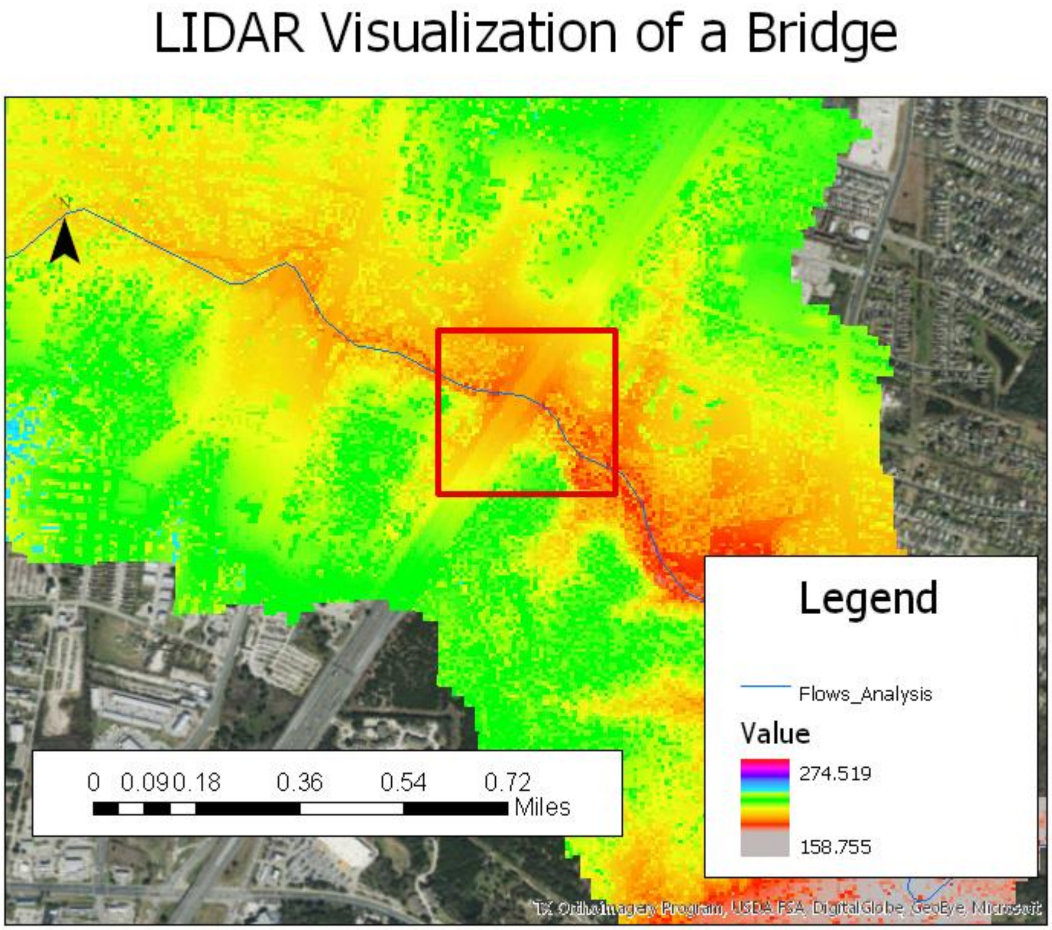


Figure 8. Example of LIDAR Visualization of the Bridge

Assess Impact on Bridges

Using the rating curves for the catchments, four flow scenarios are considered. These scenarios follows the estimations of Wright et al. (2012) and are the following:

1. Current flow (from NHDplus, the field "FloodFlow_cfs" for each catchment)
2. Additional 20% to the current flow
3. Additional 60% to the current flow
4. Additional 100% to the current flow

This scenarios are based on the possible outcomes of climate change for the next century. These flows are read as the maximum flow for a period of 100 years in 2100.

Estimate Economic Impact

Multiple factors can influence the replacement of a bridge (for example, location, if it is in concrete or steel, length, load capacity, etc.). For the purpose of this project, only project level data will be used. The Federal Highway Administration compiles, every year, the average cost of a bridge per square foot for each state (Federal Highway Administration, 2016). The values of Texas are used in this project. Likewise, based on the existing bridges, it can be estimated the average area of a bridge in Texas.

Table 2. Average Cost of a Bridge per Square For Texas (Federal Highway Administration, 2016)

State	2015 Costs Collected in 2016 (Dollars per ft2)
Texas	65

Table 3. Average Area of a Bridge for Texas (Federal Highway Administration, 2016)

State	# Bridges	Area (m2)	Area (ft2)	Average Area of a Bridge (ft2)
TEXAS	53,209	46,419,429	499,473,054	9,387.00

Based on the deterioration model and the costs, the estimated economic impact can be estimated with the following equation:

Equation 1

$$EI = NBO * AA * AC + p * NBL * AA * AC$$

Where:

EI = Economic Impact

NBO = Number of Bridges with Overtopping

AA = Average area of a bridge in Texas

$AC =$ Average replacement cost of a bridge in Texas

$p =$ Chance of a bridge with loss of filling material to collapse (in this case, 20%)

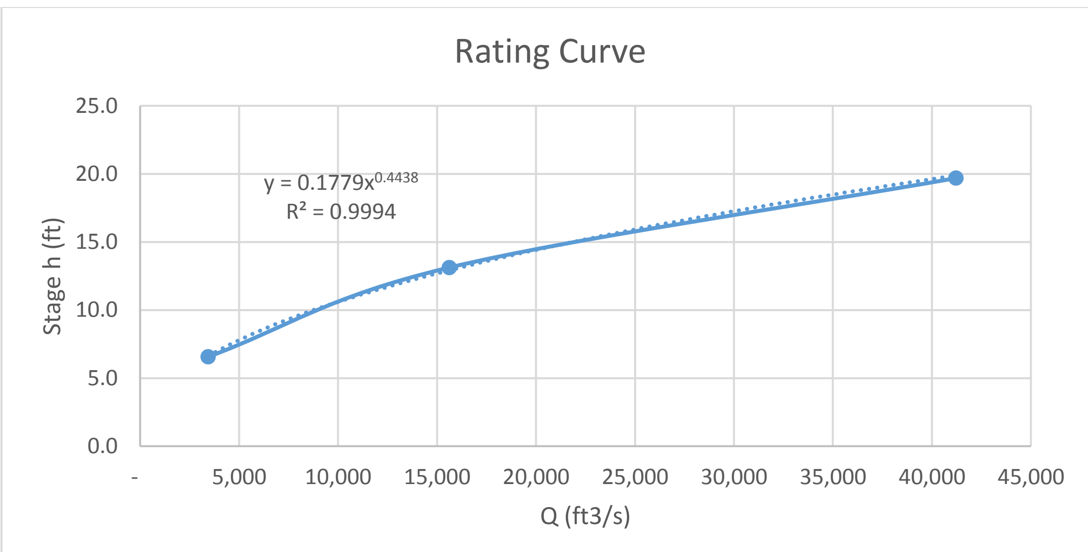
NBL = Number of bridges with loss of filling material

Results

Gridcode 1638025

Stage h (m)	2	4	6
Stage h (ft)	6.6	13.1	19.7
As (m2)	787,561	1,433,909	2,390,981
Ab (m2)	789,082	1,439,952	2,402,362

V (m3)	999,912	3,153,543	6,925,651
Length (m)	13,520	13,520	13,520
A = V/L (m2)	73.96	233.25	512.25
P = Ab/L (m)	58.36	106.51	177.69
R = A/P (m)	1.27	2.19	2.88
So	0.003166	0.003166	0.003166
n	0.05	0.05	0.05
Q (m3/s)	97.46	442.64	1,167.60
Q (ft3/s) = Q(m3/s)*35.3	3,440	15,625	41,216



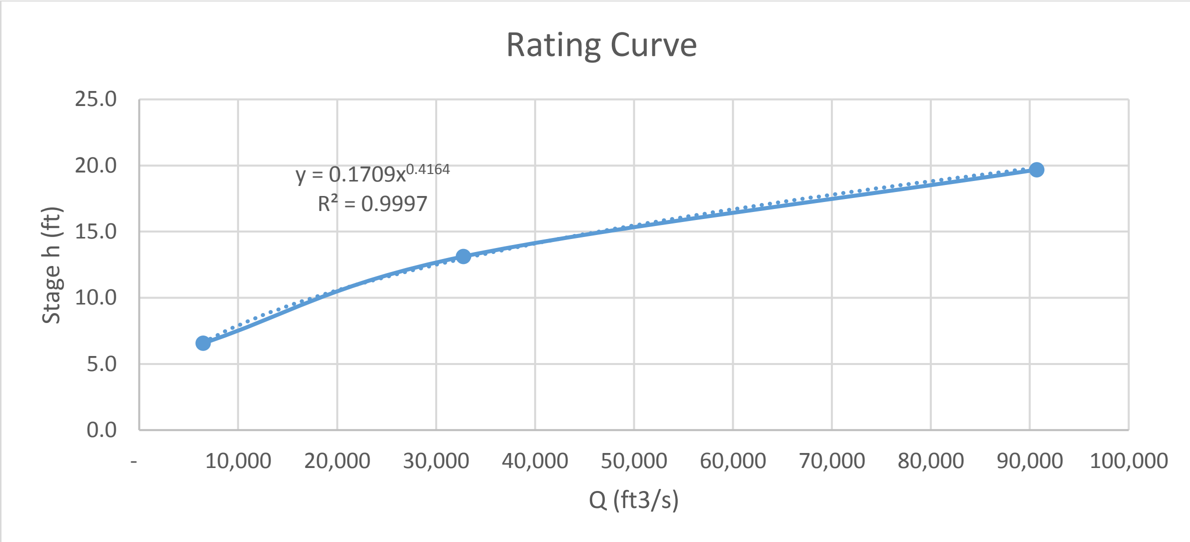
	Q (ft3/s)	Stage (ft)
Maximum Flow (FloodFlow_cfs)	9545	7.76
Flow scenario 1 (+20%)	11454	8.37
Flow scenario 2 (+60%)	15271	9.44
Flow Scenario 3 (+100%)	19089	10.36

ID Analysis	BRDGID	Height (ft)	Current Impact	Impact Scenario 1	Impact Scenario 2	Impact Scenario 3
12	142270001513269	11.6	None	Piers Erosion	Piers Erosion	Piers Erosion
15	142270001513458	11.6	None	Piers Erosion	Piers Erosion	Piers Erosion
14	142270001513457	11.6	None	Piers Erosion	Piers Erosion	Piers Erosion
13	142270001513270	11.6	None	Piers Erosion	Piers Erosion	Piers Erosion
1	142270001601001	6.4	Overtopping	Overtopping	Overtopping	Overtopping

Estimated Impact in the Catchment			
Remedial Costs Current Scenario	Remedial Costs Current Scenario 1	Remedial Costs Current Scenario 2	Remedial Costs Current Scenario 3
$ 610,155	$ 1,098,279	$ 1,098,279	$ 1,098,279

Gridcode 1638160

Stage h (m)	2	4	6
Stage h (ft)	6.6	13.1	19.7
As (m2)	638,263	1,224,248	1,991,045
Ab (m2)	639,067	1,227,266	1,996,240
V (m3)	749,525	2,581,852	5,777,397
Length (m)	8,151	8,151	8,151
A = V/L (m2)	91.95	316.75	708.80
P = Ab/L (m)	78.40	150.57	244.91
R = A/P (m)	1.17	2.10	2.89
So	0.007966	0.007966	0.007966
n	0.05	0.05	0.05
Q (m3/s)	182.55	928.32	2,569.51
Q (ft3/s) = Q(m3/s)*35.3	6,444	32,770	90,704



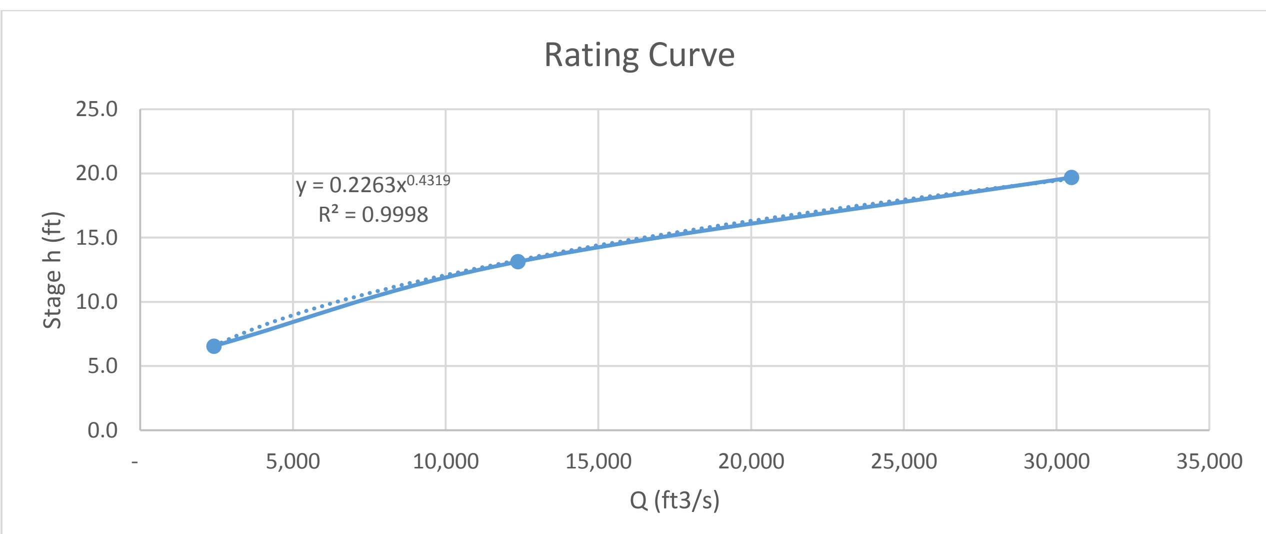
	Q (ft3/s)	Stage (ft)
Maximum Flow (FloodFlow_cfs)	1576	3.67
Flow scenario 1 (+20%)	1891	3.95
Flow scenario 2 (+60%)	2521	4.46
Flow Scenario 3 (+100%)	3151	4.89

ID Analysis	BRDGID	Height (ft)	Current Impact	Impact Scenario 1	Impact Scenario 2	Impact Scenario 3
29	142270001513127	9.9	None	None	None	None
69	142270B03647001	10.08	None	None	None	None
17	142270001601002	6.13	None	None	Piers Erosion	Piers Erosion
51	142270268901001	4.21	Piers Erosion	Overtopping	Overtopping	Overtopping

Estimated Impact in the Catchment			
Remedial Costs Current Scenario	Remedial Costs Current Scenario 1	Remedial Costs Current Scenario 2	Remedial Costs Current Scenario 3
$ 244,062	$ 732,186	$ 1,220,310	$ 1,220,310

Gridcode 1637613

Stage h (m)	2	4	6
Stage h (ft)	6.6	13.1	19.7
As (m2)	128,535	208,926	315,227
Ab (m2)	128,917	210,266	317,742
V (m3)	152,929	495,927	1,005,387
Length (m)	2,949	2,949	2,949
A = V/L (m2)	51.86	168.17	340.92
P = Ab/L (m)	43.72	71.30	107.75
R = A/P (m)	1.19	2.36	3.16
So	0.003455	0.003455	0.003455
n	0.05	0.05	0.05
Q (m3/s)	68.32	350.29	863.81
Q (ft3/s) = Q(m3/s)*35.3	2,412	12,365	30,493



	Q (ft3/s)	Stage (ft)
Maximum Flow (FloodFlow_cfs)	10317	8.02
Flow scenario 1 (+20%)	12380	8.65
Flow scenario 2 (+60%)	16507	9.75
Flow Scenario 3 (+100%)	20634	10.70

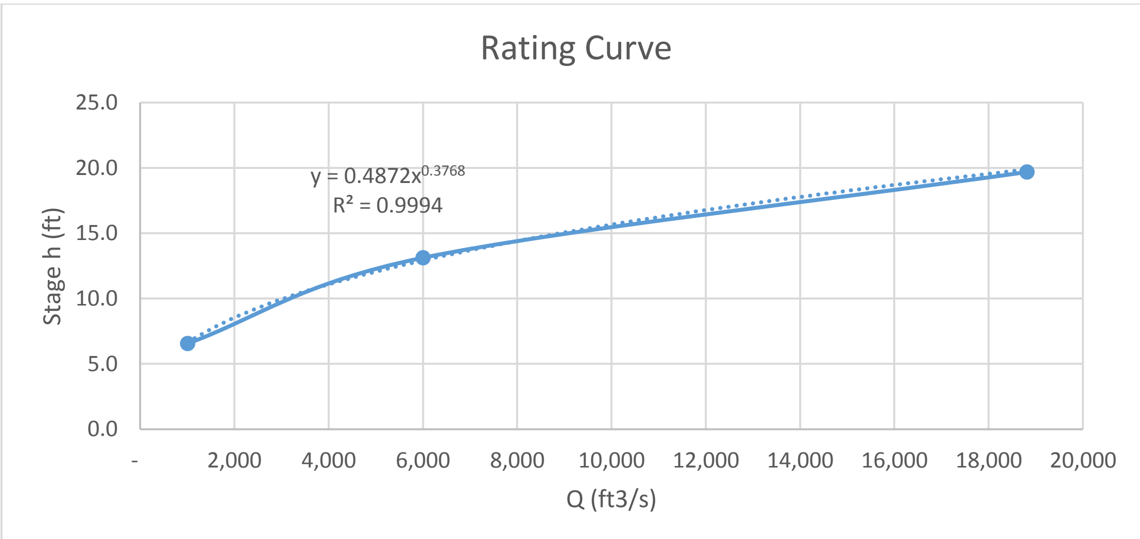
ID Analysis	BRDGID	Height (ft)	Current Impact	Impact Scenario 1	Impact Scenario 2	Impact Scenario 3
8	142270001601190	3.7	Overtopping	Overtopping	Overtopping	Overtopping
3	142270001601003	4.4	Overtopping	Overtopping	Overtopping	Overtopping
5	142270001601064	4.4	Overtopping	Overtopping	Overtopping	Overtopping
7	142270001601189	3.7	Overtopping	Overtopping	Overtopping	Overtopping

Estimated Impact in the Catchment			
Remedial Costs Current Scenario	Remedial Costs Current Scenario 1	Remedial Costs Current Scenario 2	Remedial Costs Current Scenario 3
$ 2,440,621	$ 2,440,621	$ 2,440,621	$ 2,440,621

Gridcode 1638095

Stage h (m)	2	4	6
Stage h (ft)	6.6	13.1	19.7
As (m2)	127,983	324,139	602,982
Ab (m2)	128,598	326,411	607,348
V (m3)	141,792	599,459	1,525,666
Length (m)	4,503	4,503	4,503
A = V/L (m2)	31.49	133.12	338.81
P = Ab/L (m)	28.56	72.49	134.88
R = A/P (m)	1.10	1.84	2.51

So	0.001812	0.001812	0.001812
n	0.05	0.05	0.05
Q (m3/s)	28.61	169.97	533.03
Q (ft3/s) = Q(m3/s)*35.3	1,010	6,000	18,816



	Q (ft3/s)	Stage (ft)
Maximum Flow (FloodFlow_cfs)	81424.2	18.95
Flow scenario 1 (+20%)	97709	20.44
Flow scenario 2 (+60%)	130279	23.04
Flow Scenario 3 (+100%)	162848	25.29

ID Analysis	BRDGID	Height (ft)	Current Impact	Impact Scenario 1	Impact Scenario 2	Impact Scenario 3
10	142270001601199	27.1	None	Piers Erosion	Piers Erosion	Overtopping
6	142270001601069	17.4	Overtopping	Overtopping	Overtopping	Overtopping
4	142270001601004	17.4	Overtopping	Overtopping	Overtopping	Overtopping
9	142270001601198	27.1	None	Piers Erosion	Piers Erosion	Overtopping

Estimated Impact in the Catchment			
Remedial Costs Current Scenario	Remedial Costs Current Scenario 1	Remedial Costs Current Scenario 2	Remedial Costs Current Scenario 3
$ 1,220,310	$ 1,464,373	$ 1,464,373	$ 2,440,621

Summary of Estimated Economic Impact

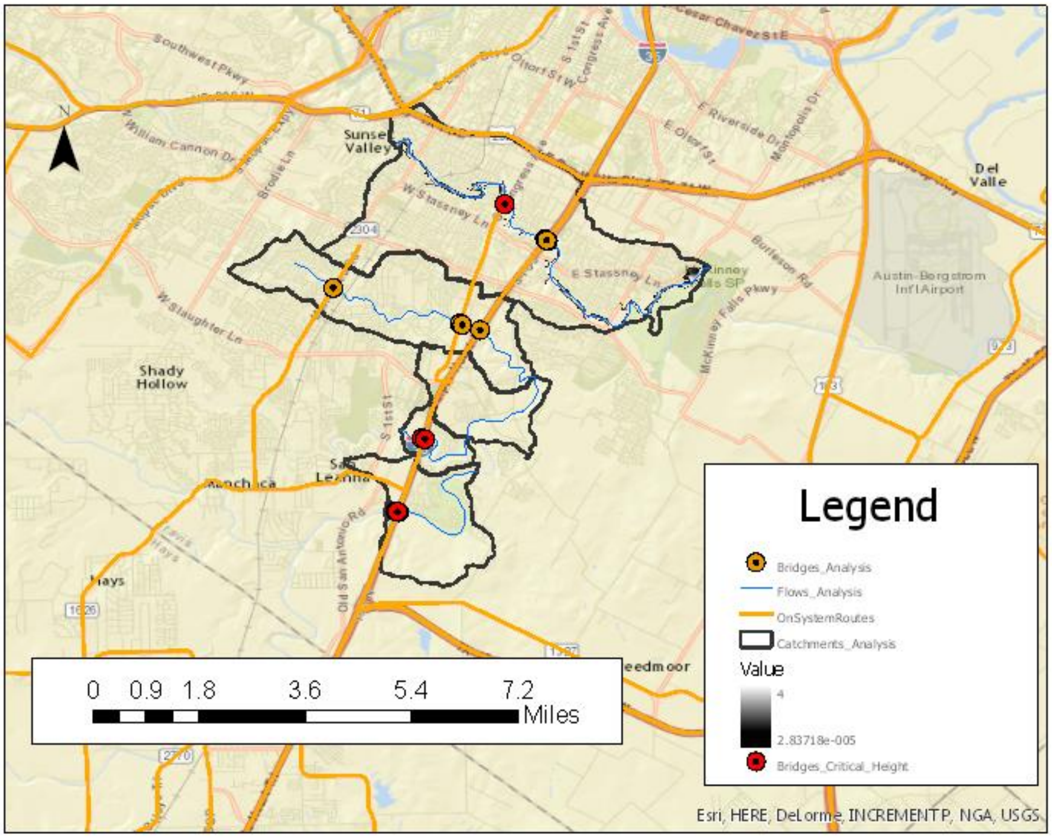
Catchment GRIDCODE	Remedial Costs Current Scenario	Remedial Costs Current Scenario 1	Remedial Costs Current Scenario 2	Remedial Costs Current Scenario 3
1638025	$ 244,062.08	$ 732,186.25	$ 1,220,310.42	$ 1,220,310.42
1638160	$ 610,155.21	$ 1,098,279.38	$ 1,098,279.38	$ 1,098,279.38
1637613	$ 2,440,620.84	$ 2,440,620.84	$ 2,440,620.84	$ 2,440,620.84
1638095	$ 1,220,310.42	$ 1,464,372.50	$ 1,464,372.50	$ 2,440,620.84

Conclusions

As a conclusion, it can be seem that GIS can help to assess which bridges are more vulnerable to an increase in flows. Likewise, it could help to assess and estimate, for new bridges, what could be the safe height of the bridge. Likewise, after a flood event, this process could help to prioritize which bridges would require inspection first.

About the results, it can be concluded that, with the Height obtained from LIDAR, multiple bridges are vulnerable even for the current situation. This is aligned with what Wright et al. (2012) found, where there is deficiency in the U.S. for a portion of highway bridges. Below are presented the bridges with critical height, which have overtopping in all the scenarios.

Critical Bridges



For future development, this process can be automated using Python code. Likewise, using detail soil information and bridge height the analysis con be more robust.

References

VicRoads. (2012). *Post Flood Management of Bridges.* Bridge Technical Note BTN 2012 / 001 .

Wright, L., Chinowsky, P., Strzepek, K., Jones, R., Streeter, R., Smith, J. B., . . . Perkins, W. (2012). Estimated Effects of Climate Change On Flood Vulnerability of U.S. Bridges. *Mitigation and Adaptation Strategies for Global Change, 17*, 939-955. doi:10.1007/s11027-011-9354-2