Susceptibility of Roads to Flooding in Western Washington

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Introduction

Over the past few years, there has been rising concern for the increase in severity and frequency of natural hazards due to climate change. Flooding in Washington is mainly caused by fall or winter storms or spring snowmelt, the timing and intensity of which are both heavily affected by changes in climate (Hamlet and Lettenmaier 2007). It is projected that the number of days, on average, with over 1 inch of rainfall is to increase by 13% by 2050 due to climate change (Snover et al. 2013). With these projections, it is expected that Western Washington will experience increased flooding in the next few decades.

Urbanization also influences the intensity of flooding in rivers. In urban areas, most of the land is covered by impermeable buildings and roads which prevents water from infiltrating the subsurface (Konrad 2003). This results in more precipitation rapidly flowing directly on the surface to nearby streams and rivers, as opposed to flowing relatively slowly through the subsurface, causing sudden increases in discharge. Consequently, development of urban areas results in increased peak discharges and flood frequency (Konrad 2003). As the population of Western Washington continues to grow, resulting in increased urban development, more severe and frequent flash flooding events are expected to occur.

Roads play a vital role in the transportation infrastructure in Western Washington. They are the primary means of transportation for residents and are rendered unusable by most vehicles if heavily flooded. Even a few road closures could severely impact the daily routine of local residents. Furthermore, in the event of a natural disaster, roads are necessary to efficiently and quickly bring aid to the region. With predictions that the severity and frequency of floods increasing, it will be important to understand how flooding events will affect road infrastructure around Western Washington.

Our project aims to investigate how river flooding in 3 counties in Western Washington, King, Pierce and Thurston will affect local roads. We will accomplish this by simulating 2 flooding events where the water level of rivers increases by 2m and 5m to calculate regions that are inundated. A geospatial analysis will then be employed to determine how the flooding affected local road networks. Work was split up between group members by county with myself focusing on Thurston County, Will focusing on King County and Richard focusing on Pierce County. As such, this report will be primarily on Thurston County.

Methods

For this project, we decided to focus on 3 counties in Western Washington, Thurston, King and Pierce (Refer to Figure 1). The study was limited to only a few counties due to restrictions in time. These counties were chosen as they are heavily populated and because extensive and accurate GIS data of roads and streams in the county were easily accessible and obtainable. Each group member was responsible for 1 county each, with myself analyzing Thurston County, Will analyzing King County and Richard analyzing Pierce County. Datasets of roads, streams/rivers and elevation were used to carry out this analysis by creating a model to simulate river flooding at the county-level.

Model

The model used to simulate the flooding is as follows:

$$Lateral\ Extent\ of\ Inundation = \frac{Rise\ in\ river\ water\ level}{Average\ percent\ slope\ of\ river\ segment}$$

Two models were created which simulated a 2-meter rise in overall river water level and a 5-meter rise in overall river water level.

Several key assumptions were made to create the model. First, it was assumed that river flooding would only occur within 300 meters of stream. We felt that a maximum lateral extent would be necessary as areas where the average percent slope is very small would yield an incredibly large lateral inundation. Secondly, the rise of river water level was assumed to be uniform and constant across all streams and rivers in a county. Although this is not realistic behavior, this helps to simplify otherwise extremely complex mechanisms. Thirdly, it was deemed appropriate to use the rise in river level rather than an increase in volume in order to simplify the analysis and to obtain more consistent results. Finally, we assumed that there was no minimum depth of water to result in a road being affected or closed. Again, this was done to simplify the analysis.

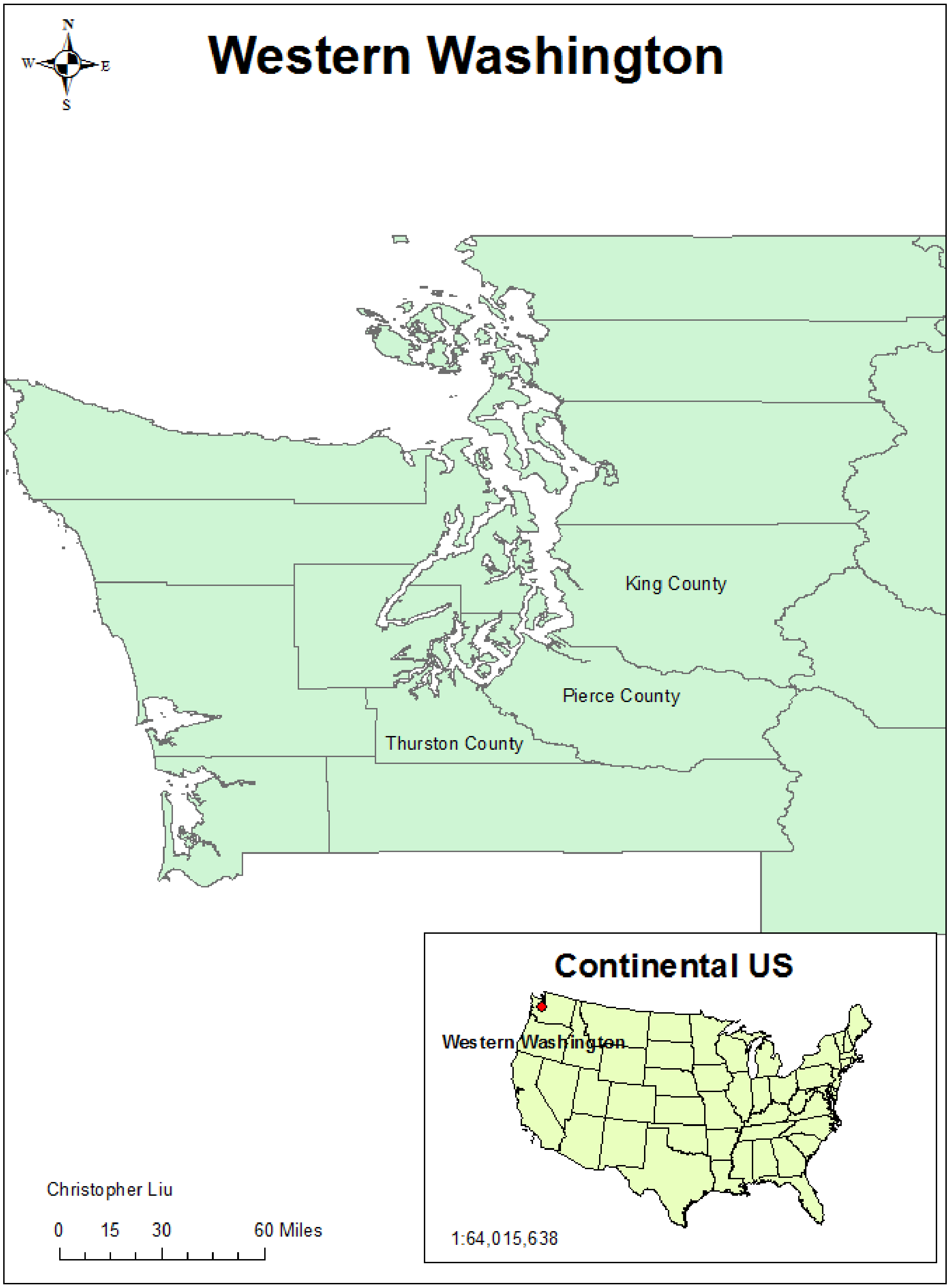

Figure 1 Map of the Study Area showing counties in Western Washington

Sources of Data

Data for analysis was primarily obtained from each county's respective GIS database. Since they were published by the counties themselves, they were deemed to be accurate. Other sources of data were obtained from accredited educational institutions and were also deemed as reputable sources.

The digital elevation model (DEM) of Western Washington used for slope analysis in all 3 counties was obtained from the University of Washington Geomorphological Research Group (UW ESS GIS, 2001). Despite being over a decade old, we chose to use this DEM as the source is reputable and its extent covers our study area to maintain consistency.

Data for roads and streams in Thurston County and the county border were obtained from the Thurston GeoData Center (Thurston Geodata Center, 2017). For the base map, data for counties in Washington was obtained from the Washington Geospatial Open Data Portal (Washington Geospatial 2016) and the map of states in the US was obtained from data for Lab 2 of ESS 420 (ESS420 2018). The coordinate system for the county border, roads and streams of Thurston County is GCS_WGS_1984. The spatial reference for the DEM raster and subsequently the percent slope raster is NAD_1927_UTM_ZONE_10N with a cell size of (X,Y) = (10,10). In order to maintain consistency, all shapefiles and raster data was converted to NAD_1983_Albers. Any calculation of length or area of shapes was also done in NAD_1983_Albers. Data for roads and the centerlines of streams in Pierce County and the county border were obtained from the Pierce County Open GeoSpatial Data Portal (Piercy County 2018). For King County, data for roads, streams and the county border were obtained from the midterm data for ESS 420 (ESS420 2018). Since we are looking at river flooding hazards and how they affect roads in the county, this data is appropriate for the topic of interest.

Analysis Method Procedure

Methods used to carry out the analysis were the same for all three counties to maintain consistency in our results across the three counties and to keep the analysis simple and efficient. Before the analysis, the DEM raster was clipped to each respective county border (Thurston, Pierce and King). Since the DEM included the entire Western Washington and we only need it for 3 counties, clipping is used to save computational time and memory. Next, using the appropriately clipped DEM, the percent slope is calculated using the Slope tool in ArcMap. Percent slope is chosen as it allows us to easily find the lateral extent given a given rise in water level. A 300-meter vector undissolved buffer for the streams in each county, which is found using the Buffer tool, was used in conjunction with the Zonal statistic tool to calculate the average percent slope of each stream segment. From there, the model was applied to each segment for a 2-meter and 5-meter rise in river level to calculate the regions that would be inundated for each rise in river level. Finally, a variable buffer was created for the streams using the calculated lateral extent. To find how the inundation affected roads, an overlay analysis was used to find parts of roads inundated and a Select by Location intersection to find the road segments affected. One difference among the counties is that the Thurston datasets included a field for major roads. As such, the analyses was also carried out separately for major roads as well in Thurston County.

Table 1 shows the information used, in conjunction with the Calculate Geometry tool, to calculate the percentage of area inundated, percentage of road segments affected, and total length of roads inundated as well. They were obtained from the datasets themselves.

The method and model we have employed thoroughly examines every stream recorded in the datasets and compares the flood model to every road in the dataset. Given the complexity and scope of this project, the model and method are of an appropriate simplicity, given our limited resources, and still yield a significant result.

County	Total Area (sq. km)	Number of Roads Segments	Length of Roads (km)
Thurston	1870	18199	4100
Pierce	4679	50903	9091
King	5580	-	23734

Table 1 Information used to calculate statistics

Results and Discussion

Thurston County

Figure 2 shows the location of streams in relation to roads (major and non-major) in Thurston County. Figures 3 and 4 show the inundated region and highlights the roads affected by the flooding. Table 2 show statistics from the flood models for the county.

Immediately from the table we can note that there is an increase in percentage of roads affected and inundated area from the 2-meter rise to the 5-meter rise which is to be expected and suggests that the model is working correctly. Despite a relatively large rise in water level, a large percentage of the area and roads in the county are unaffected with only 7% of area inundated by a 2-meter flood and 13% of area inundated by a 5-meter flood. As for roads affected, the statistics are similarly low and do not exceed 20%.

Looking at Figure 2, we can see that there is a fairly even distribution of streams around the county with a slightly denser distribution of streams in the less developed areas in the northwest and southeast regions of the county. Many of the roads are found in the northern side of the county where it is presumably more developed. There is a major road network that is spreads from the urban area on the northern side of the county.

For a 2-meter flood, Figure 3 shows that the flooding is again somewhat evenly distributed with a slightly higher percentage of inundated area in the western region. Flooding occurs in the northern urban area as well. Despite the statistics being low, the flooding is distributed evenly enough such that a major disruption in transportation is highly probably. If the flooding was centralized in one region of the map, the disruption would be a lot lower since only a small percentage of the population would be affected. The flooding also seems to inundate sections of major roads where alternate routes do not exist and are the main routes in and out of the county. Furthermore, many of the unaffected roads are local roads which connect to the affected major roads. Because of the widespread flooding, lengthy road diversions would need to be made in order to travel in and out of the county. While travel around certain neighborhoods and parts of cities will still be possible, travel in between cities and to surrounding counties is significantly hindered. For the 5-meter flood, referring to Figure 4, the results are similar, but the flooding is more severe with almost all the major routes affected. Local movement is even more impeded and much of the road infrastructure to the west is flooded. In the event of a 5-meter flood, transportation in the region would be severely crippled.

This model suggests that transportation Thurston county is very vulnerable to river flooding. Despite a low percentage of roads affected, many of these roads are local or neighborhood roads that are not used to travel between cities and counties. Flooding in both the 2-meter and 5-meter model shuts down many of the major roads in and out of cities and the county.

Rise in Water Level (m)	Percent Inundated Area	Percent Length of Roads Inundated		Percent number of road segments inundated	
		All Roads	Major	All	Major
2	7.0%	5.1%	5.8%	6.3%	11%
5	13%	9.0%	13%	12%	19%

Table 2 Statistics from the two flood models for Thurston County

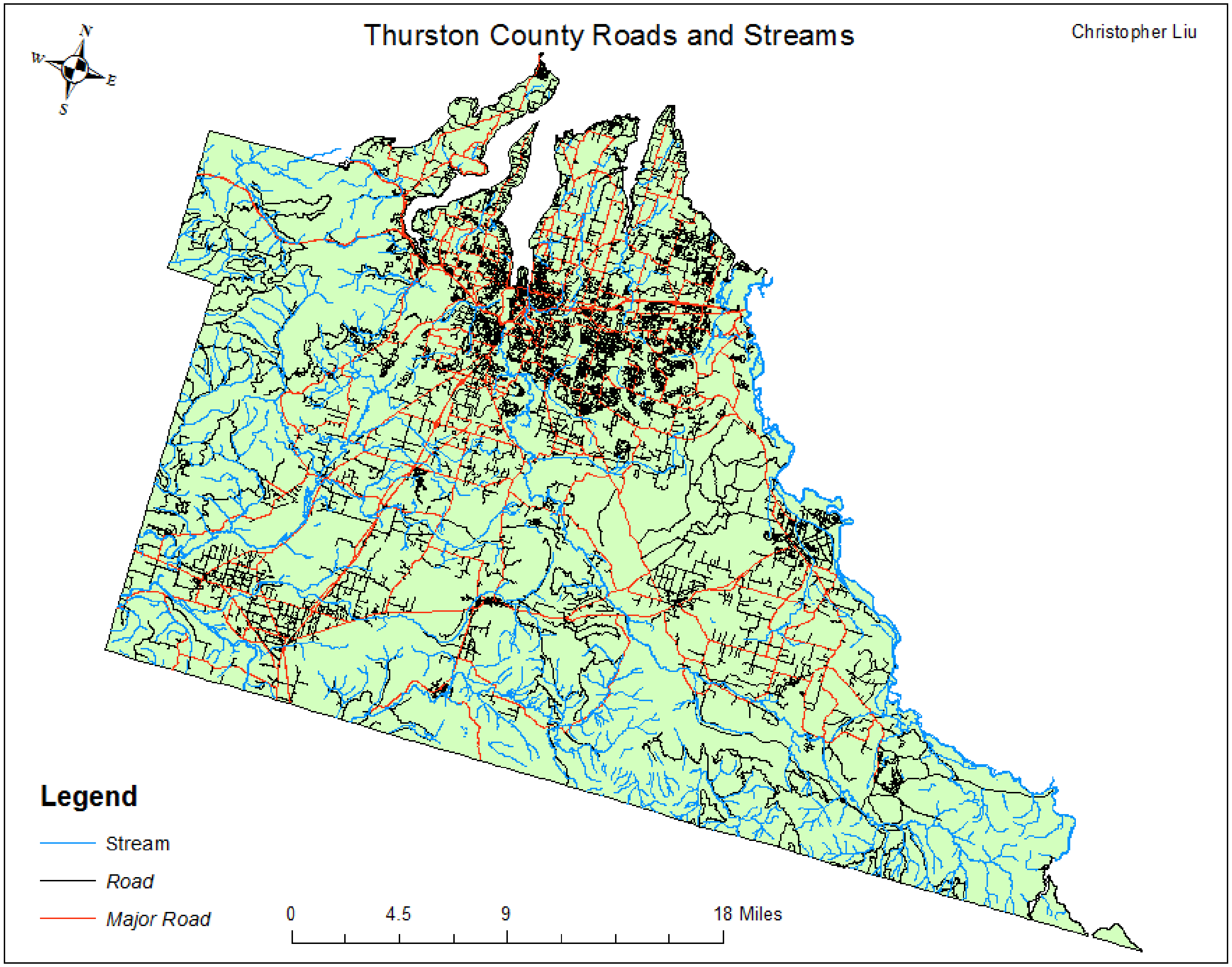
Thurston County Roads and Streams
Christopher Liu
N
W
E
S
Legend
Stream
Road
Major Road
0
4.5
9
18 Miles

Figure 2

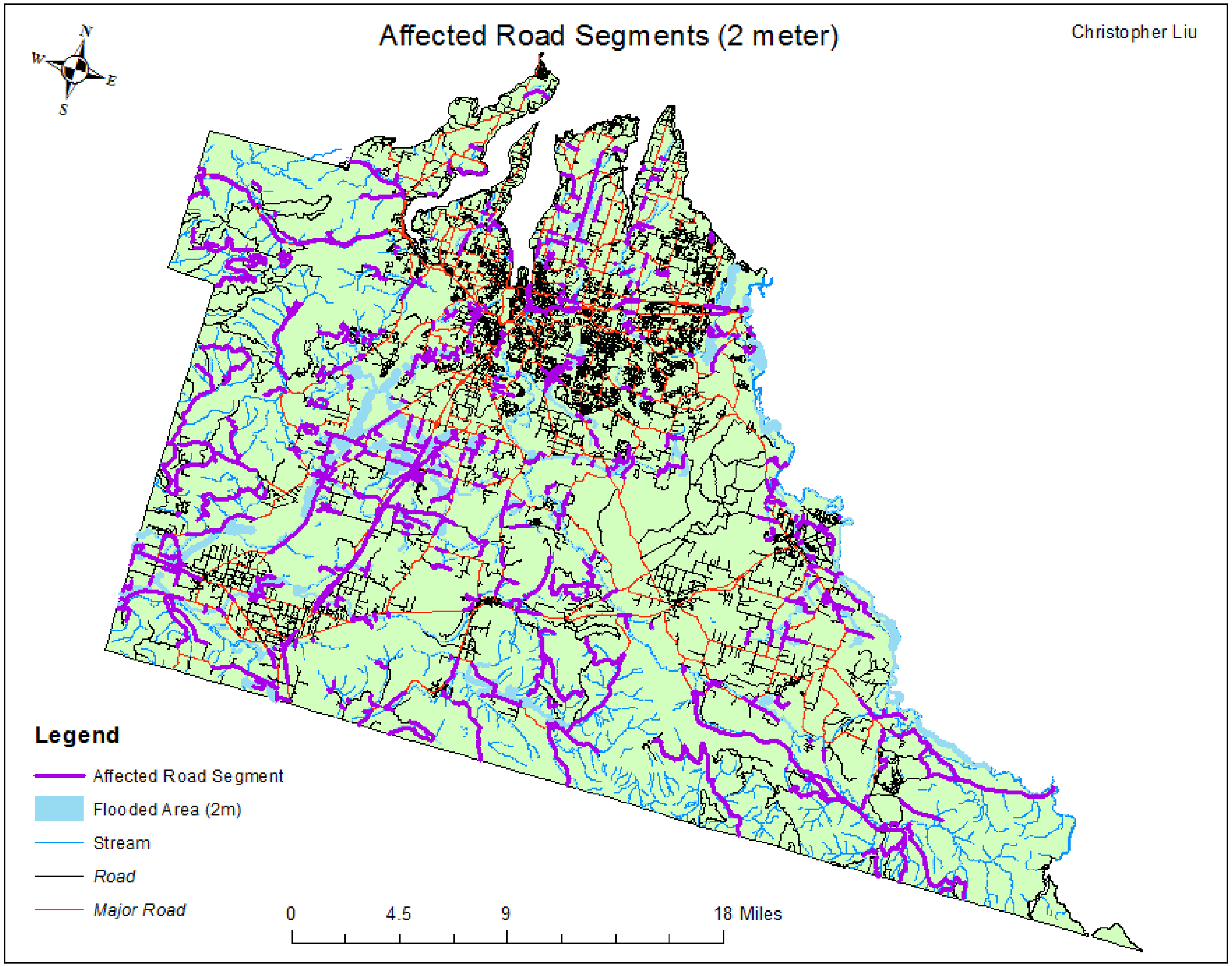

Figure 3 2-meter model and affected roads for Thurston County

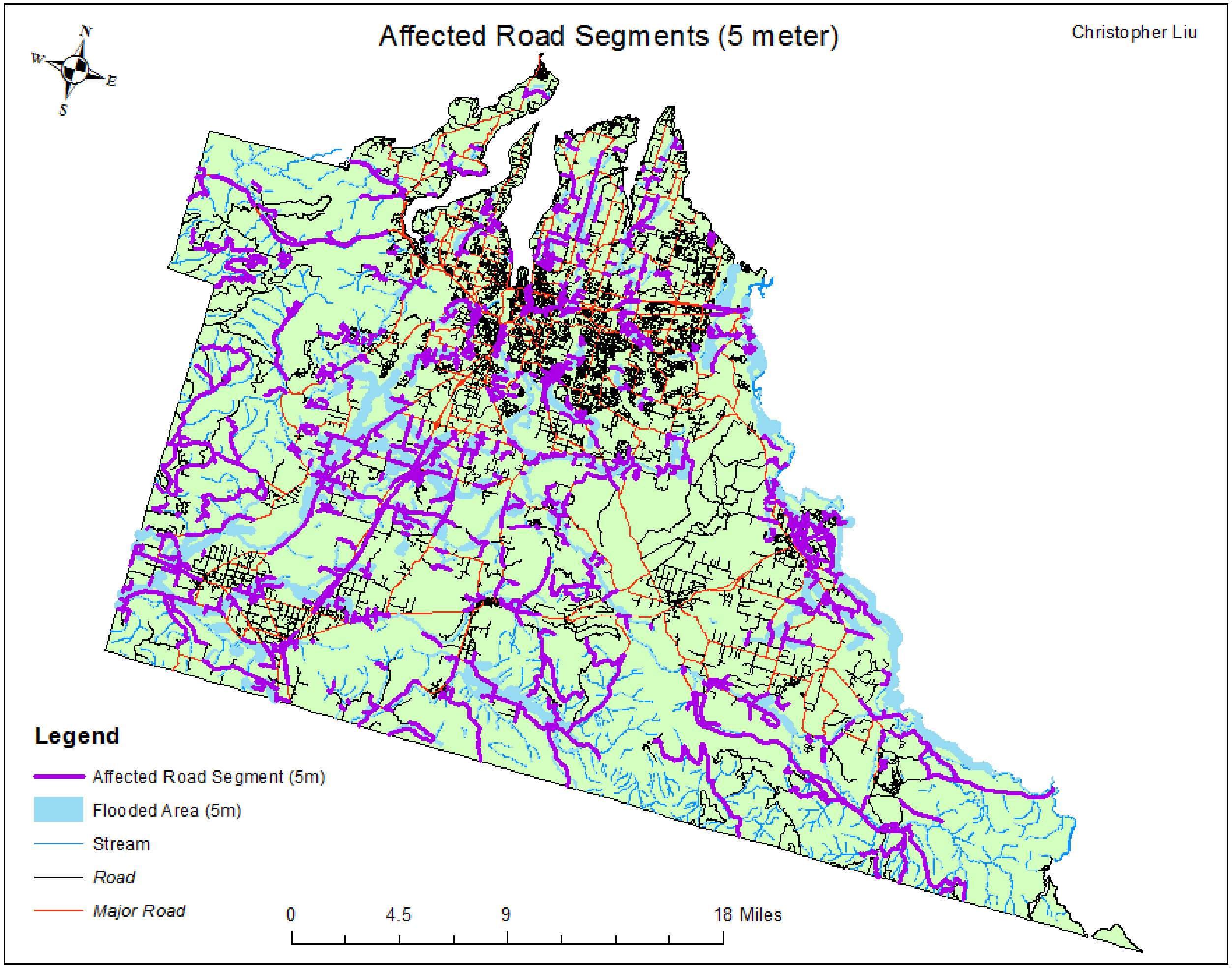

Figure 4 5-meter model and affected roads for Thurston County

Pierce County

Table 3 shows statistics for the county for both the 2-meter and 5-meter models. Figure 5 and 6 show the affected roads and inundated area for the 2-meter and 5-meter models respectively.

Once again, referring to Table 3, there is a clear relationship between the percentage of area and roads affected and the rise in water level. The 5-meter model has double the percent inundated area and length of roads inundated compared to the 2-meter model. Again, suggesting that the model is working correctly. The statistics are also like those for Thurston county with low values ranging from around 10% to 20%.

Looking at the 2-meter model in Figure 5, most of the roads are in the western portion of the county and most of the streams are in the central part. The affected roads are primarily on the western side there are hardly any roads in the rest of the county. We can observe a distribution of affected roads around the western region and a centralized region of flooding on the western side. Local transportation in the centralized region would be severely disrupted and the even distribution of affected roads around the urban areas of the county suggest that road transportation between cities and counties, like Thurston, would also be severely disrupted. Looking at Figure 6, the 5-meter model also has similar results but with an increased density of roads affected.

Like Thurston, Pierce County would be significantly impacted by river flooding due to widespread road closure. Despite the percentage of roads affected being low, the distribution of inundated roads would still result in many road diversions.

Rise in water level (m)	Percent Inundated Area	Percent Length of Roads Inundated	Percent number of road segments inundated
2	8.39%	11.11%	4.99%
5	16.39%	20.13%	4.99%

Table 3 Statistics from the two flood models for Pierce County

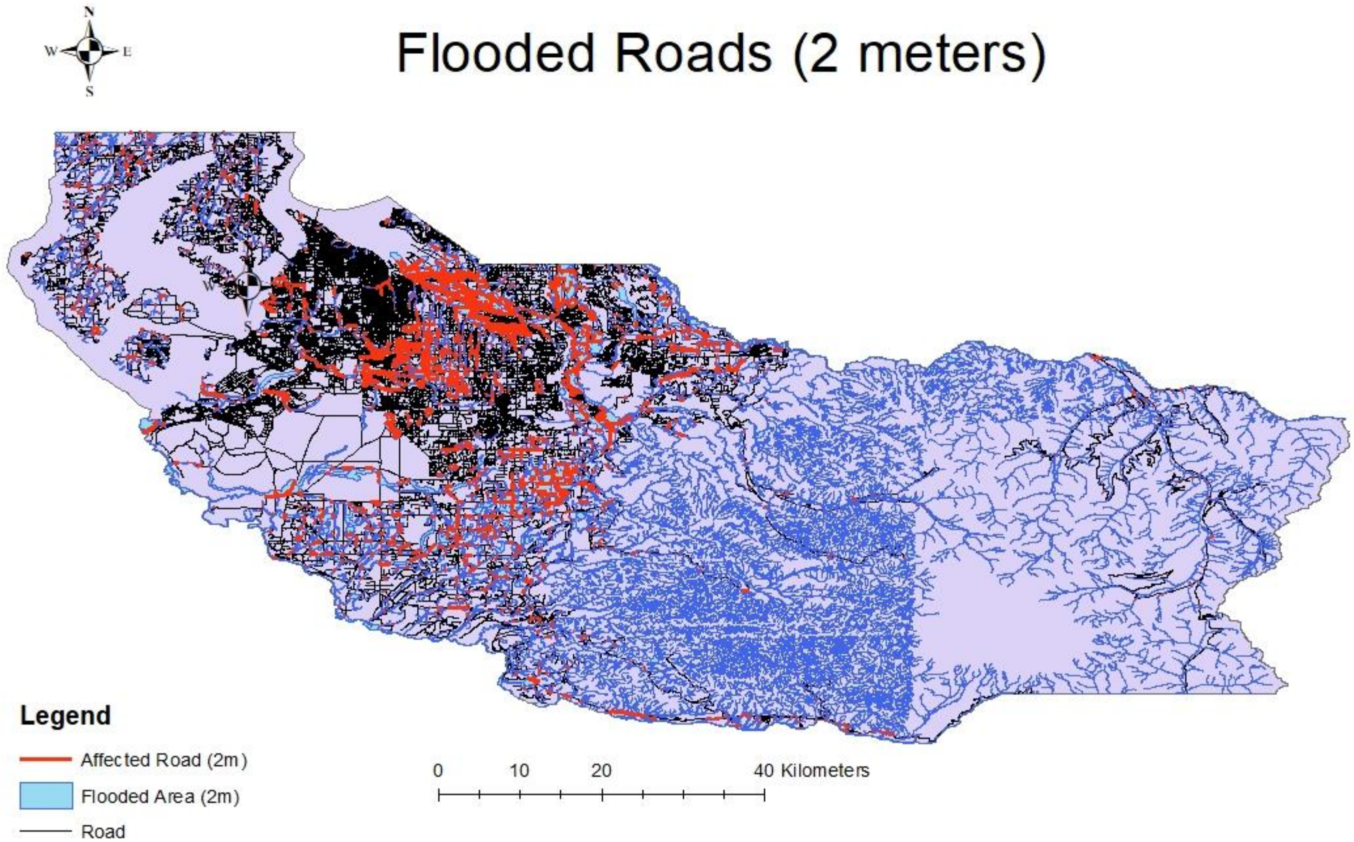

Figure 5 6 2-meter model and affected roads for Pierce County

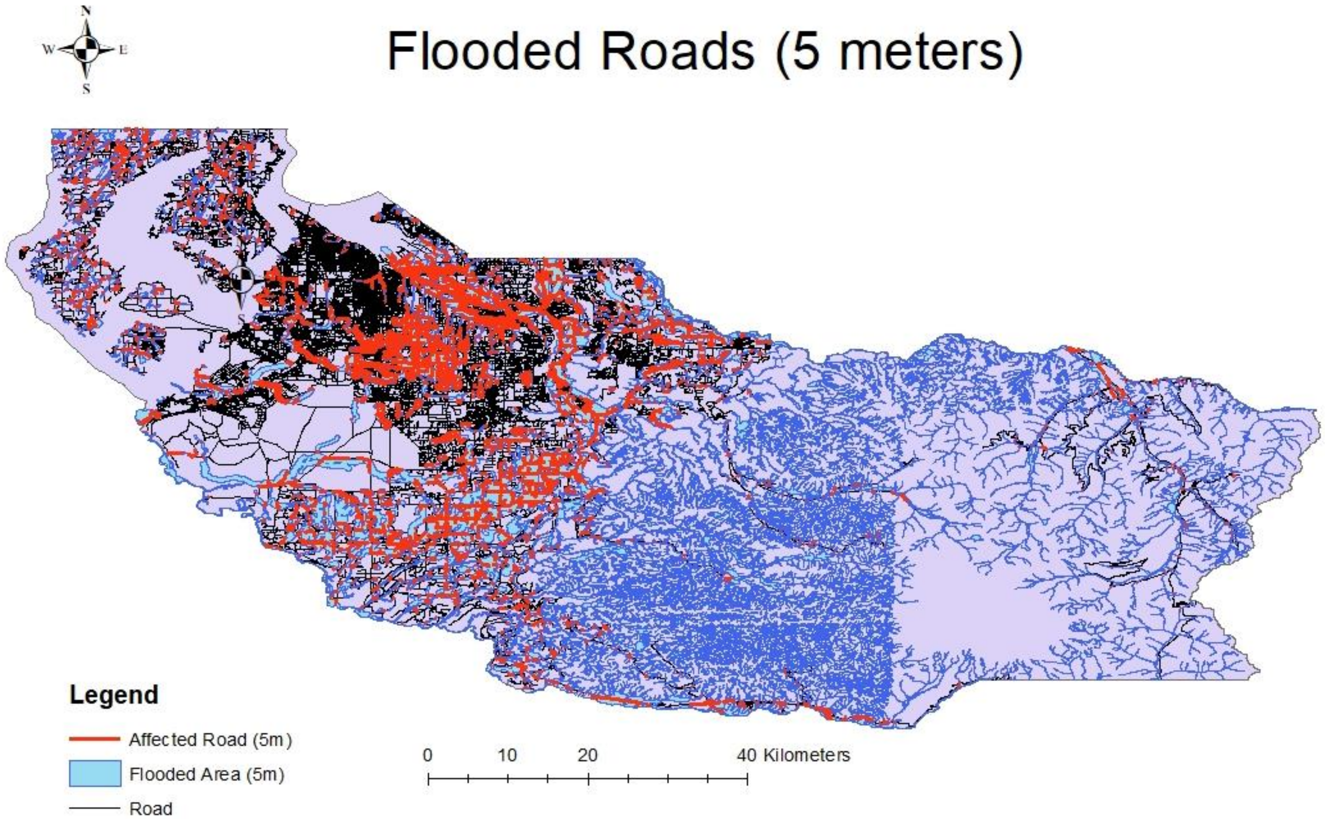

Figure 7 5-meter model and affected roads for Pierce County

King County

Figure 7 shows the affected roads in relation to the rest of the county while Figures 8 and 9 show a close-up of the affected regions for the 2-meter and 5-meter models respectively. Table 4 shows statistics from the flood models for King County.

The same relationship observed in Thurston and Pierce counties between rise in water level and percent inundated area and percent roads affected is still present. However, the percentages themselves are incredibly low with percent length of roads inundated being 0.048% for the 2-meter model. Figures 8 and 9 also show that only the northeastern part of the county is affected and there is very little flooding. The results show that the county is hardly affected by river flooding. While it could be possible that King County is incredibly secure against river flooding, it is more likely that the analysis was carried out incorrectly or the model was not valid for King County.

Rise in Water Level (m)	Percent Inundated Area	Percent Length of Roads Inundated	Percent road segments affected
2	.13%	0.048%	1.14%
5	.31%	0.124%	1.14%

Table 4 Statistics from the two flood models for King County

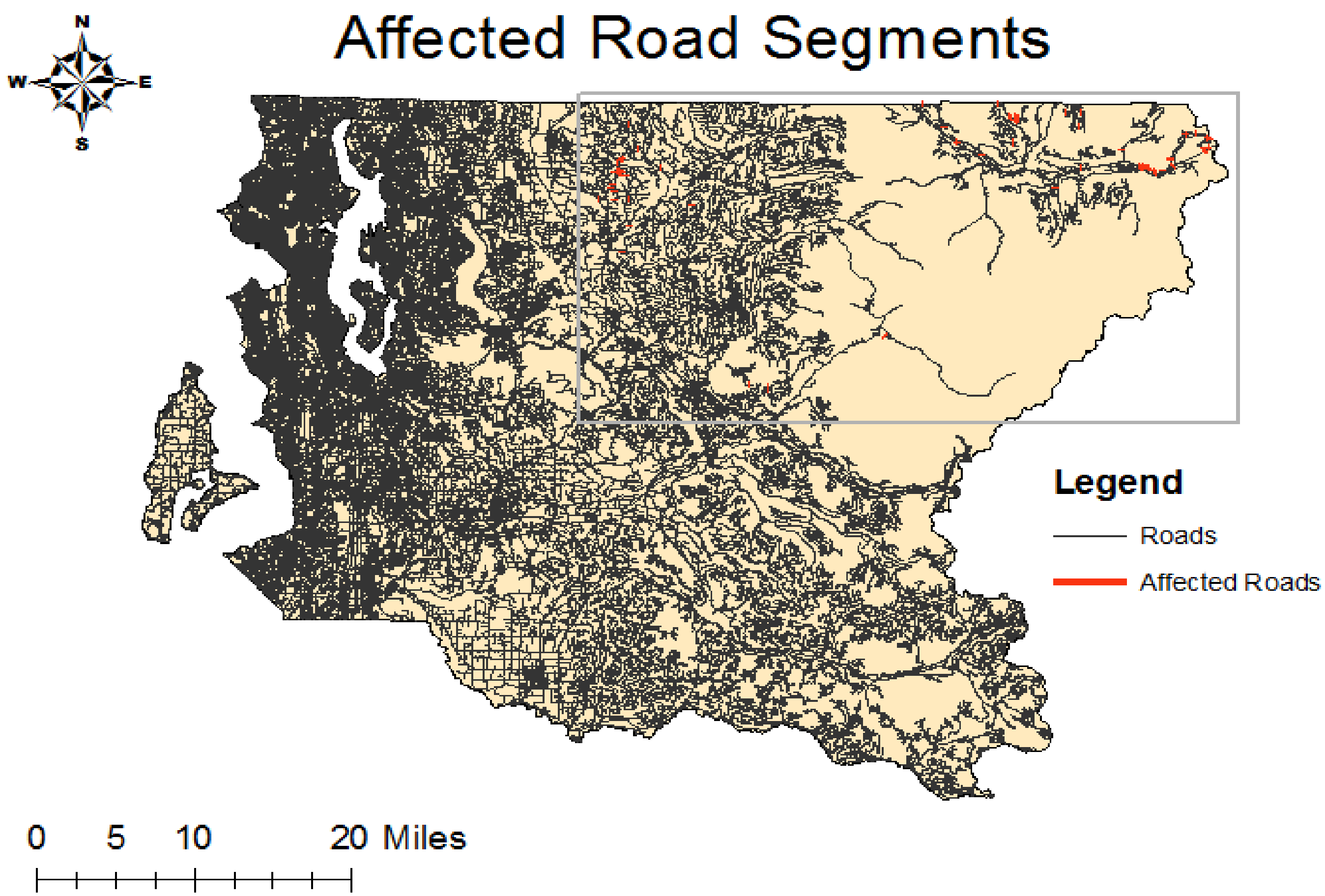

Figure 8 Roads affected in King County

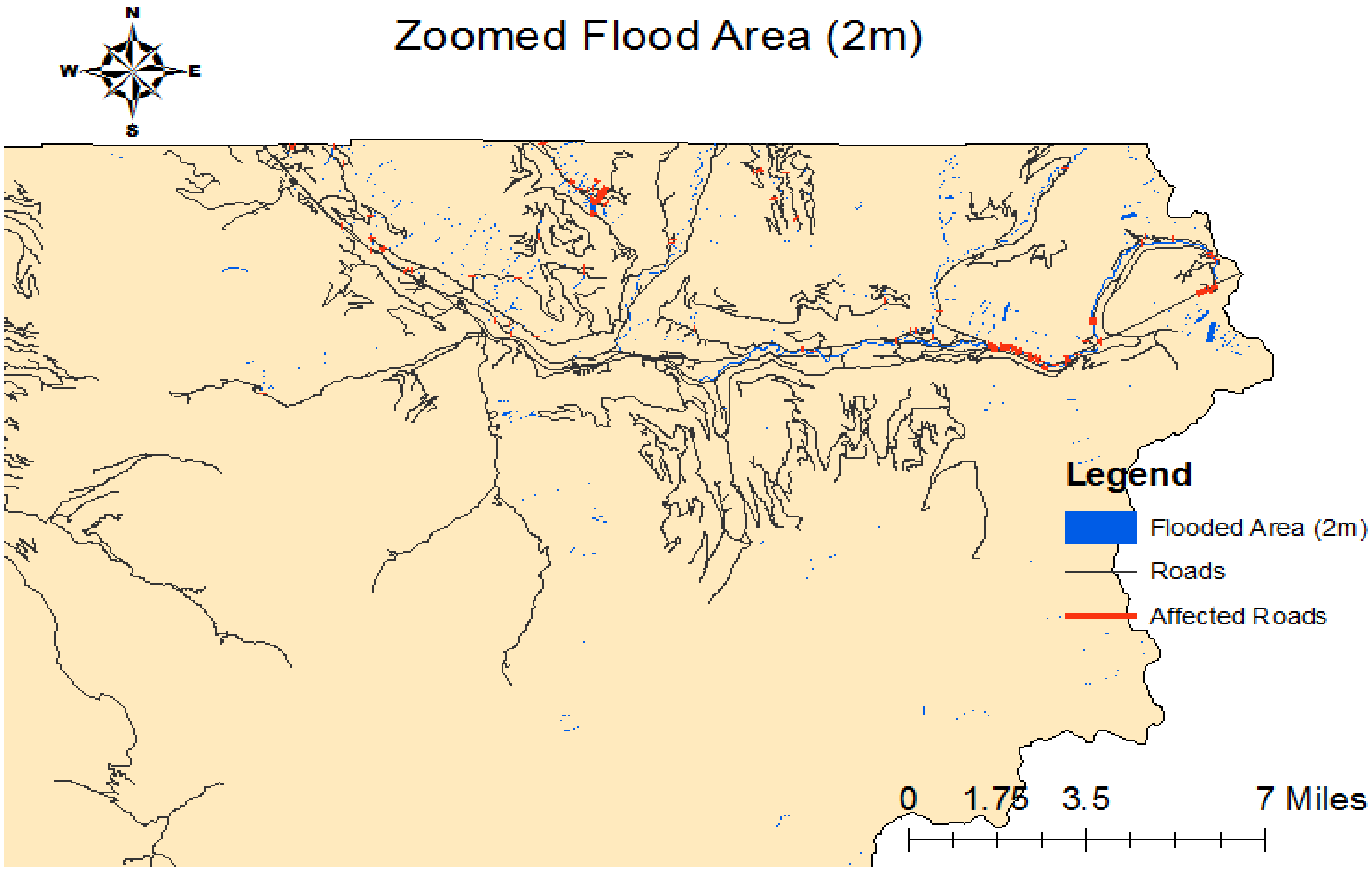

Figure 9 2-meter model and affected roads for King County

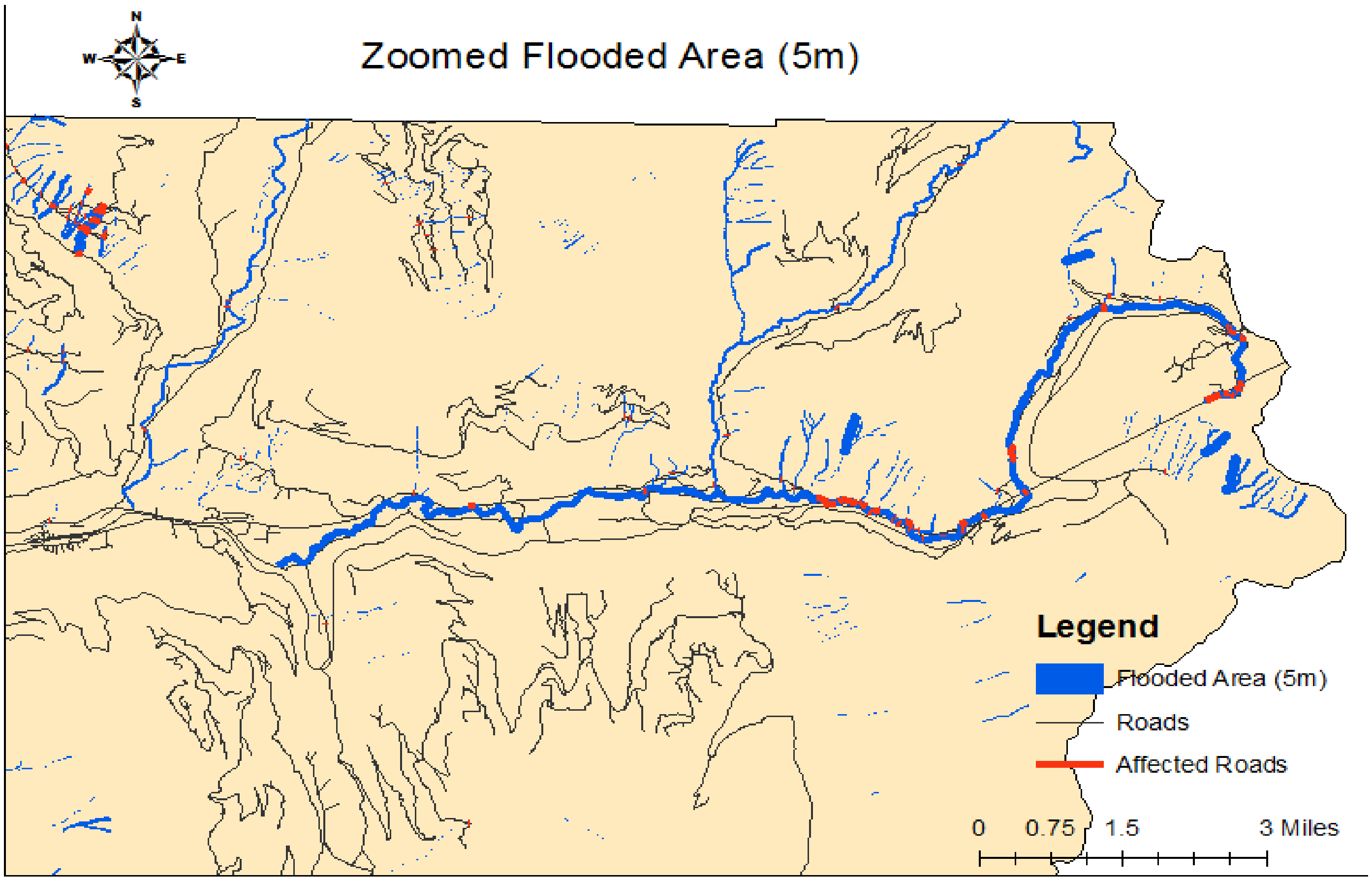

Figure 10 5-meter model and affected roads for King County

Conclusion

Using our two flooding models for a 2-meter and 5-meter rise, the results suggest that the road infrastructure in Pierce County and Thurston County are very vulnerable to river flooding. Despite the low percentage of roads affected, the spatial distribution of the affected roads suggests that widespread road closures along major routes in and out of cities and the county would cause significant disruptions in transportation regardless of the model. Governing bodies in both counties will need to take steps to protect roads from river flooding as climate change and urbanization increase the severity and frequency of major flooding events. As for King County, further studies will need to be conducted to determine the validity of the results. It seems unlikely that the county would hardly be affected by river flooding as many major rivers run through the county.

The model, despite many significant assumptions, has yielded realistic results that highlight major vulnerabilities in road infrastructure if a major flood event were to occur. However, moving forward, a more complex model should be developed which considers the complexities of major precipitation events and discharge, the depth of inundation and makes less simplifications in the geometries of the channels.

References

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GIS Data Sources

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