Impact Analysis of Changing Riverine Flood Frequencies caused by Climate Change on Transportation Infrastructure and Land Use

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Outline

- Introduction
- Research Question
  - Research Challenge
- Research Framework
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- Results
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Introduction

- **Climate Change's Impact on Transportation (TRB Special Report 290, 2008)**
  - Hot waves, Increasing Temperatures
  - Increase in Arctic Temperatures
  - Rising Sea Levels
  - More intense precipitations
  - Extreme Hurricane

Source: http://living.morethan.com/wp-content/uploads/2009/06/flood-road-closed1.jpg

2010年5月2日急速降雨导致田纳西(Tennessee)洪水泛滥，交通路网严重受阻

Tennessee flooding, the impact of a series of storms slamming Downtown Nashville and the Cumberland River

May, 2010

Introduction

- Most places in United States will suffer more intense and frequent precipitation events, which have an average annual increase rate of 6.1 percent per century with regional variations.

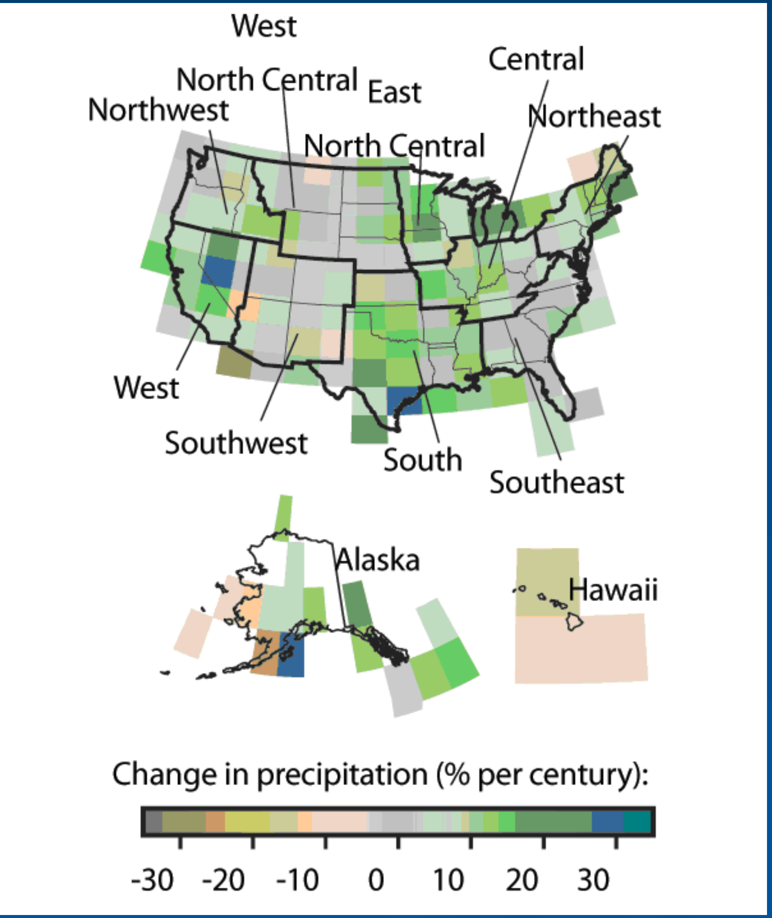


Figure 1 Change of Precipitation in United States 1901-2005
(Source: Environmental Protection Agency, 2010, Precipitation and Storm Changes. available at http://www.epa.gov/climatechange/science/recentpsc.html)

Literature Review

- Lack of emphasis on flood protection in traditional transportation planning
- Inaccurate, outdated, underestimated Flood Insurance Rate Map
- Trade off between operational benefits and flood risk
- Lack of consideration of climate change
- Few quantitative studies at the local level

Research Question

- What kind of impacts will the changing riverine flood frequencies caused by climate change bring to transportation infrastructure and land use?

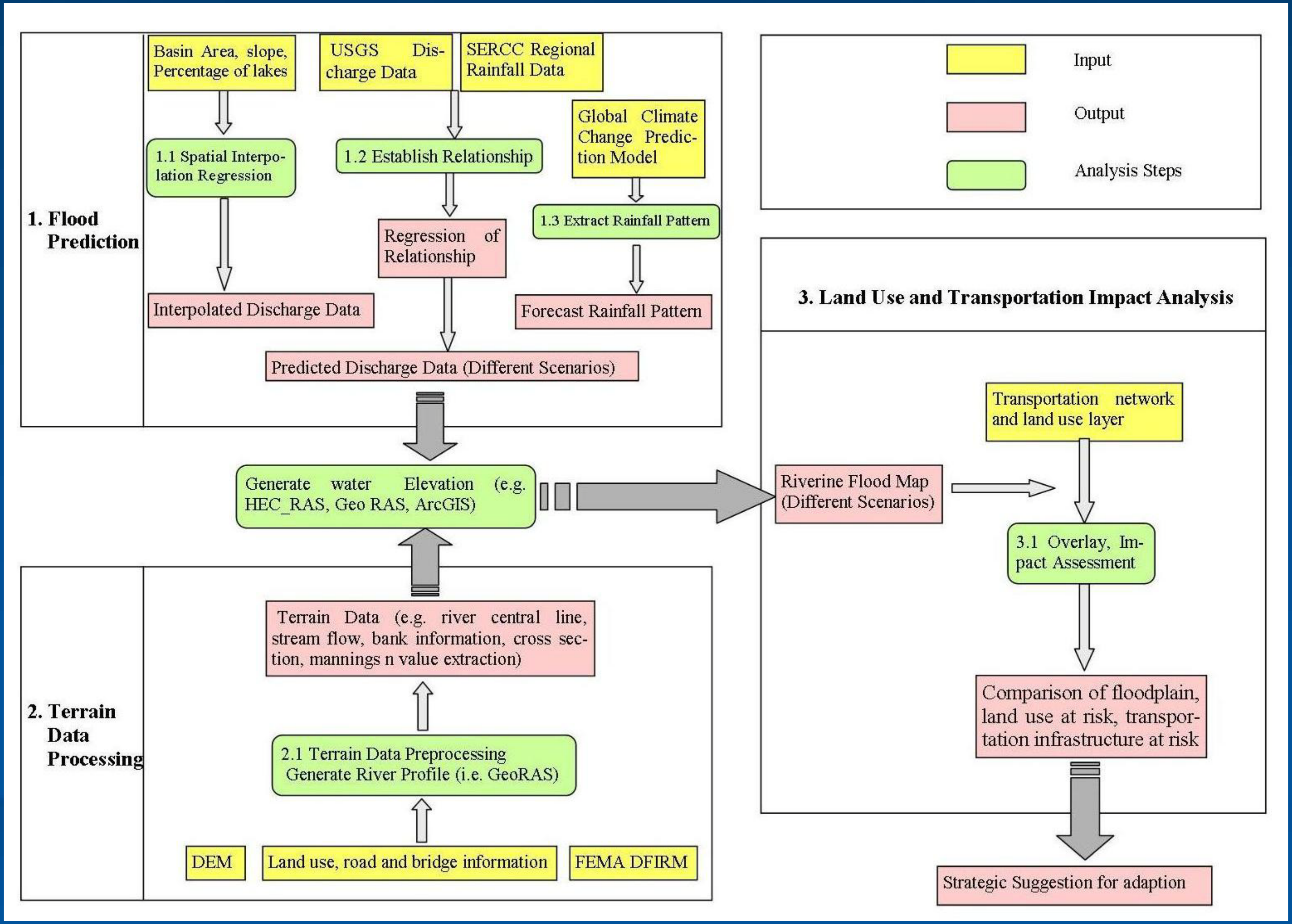
Research Challenge

- No future flood prediction at the local level
  - Extract the relationship between rainfall and flood from the empirical data
    - Extend the current flood frequency information regionally to estimate flood frequencies at unmonitored locations of interest
    - Use historic daily rainfall and flood data to establish the antecedent precipitation conditions which would likely to give rise to flood events
- No climate projection at the local level
  - Use historical rainfall pattern in Upper shillong, India as the subsitute for future simulation

Research Framework

- Flood Prediction
  - Extract relationship between discharge data and rainfall data
  - Spatial interpolation of current discharge data
  - Extract future rainfall pattern
  - Estimate future discharge trend
- Flood Map Making
  - Terrain Data Processing
  - Hydrological Model (HEC-RAS)
- Impact Assessment
  - Flood Plain
  - Transportation
  - Land Use

Research Framework



Study Area

- City of Pensacola, Florida
  - Rapid Population Growth
  - Intensive coastal developme nt
  - Exposure to heavy precipitatoi n events
  - Nature flow

Data and Methodology

- Flood Prediction
  - Spatial Interpolation
  - Data: USGS, Southeast Regional Climate Center
  - The number of gauged stations with discharge records is not enough to interpolate discharge values in our study area.
  - Regression by National Streamflow Statistics (NSS) to estimate current discharge values

$$Q2 = 58.9DA^{0{,}824}SL^{0.387}(LK+3)^{-0.785}$$

$$Q5 = 117DA^{0{,}844}SL^{0.482}(LK+3)^{-1.06}$$

$$Q10 = 164DA^{0{,}860}SL^{0.534}(LK+3)^{-1.21}$$

$$Q25 = 234DA^{0{,}882}SL^{0.586}(LK+3)^{-1.37}$$

$$Q50 = 291DA^{0{,}900}SL^{0.626}(LK+3)^{-1.48}$$

$$Q100 = 351DA^{0{,}918}SL^{0.658}(LK+3)^{-1.58}$$

$$Q500 = 507DA^{0{,}960}SL^{0.725}(LK+3)^{-1.79}$$

Data and Methodology

	Site A			Site B		
Return Period (Years)	Discharge (cubic feet per second)	Standard Error (%)	Equivalent Years	Discharge (cubic feet per second)	Standard Error (%)	Equivalent Years
2	502	44	3	414	44	3
5	998	46	4	819	46	4
10	1420	49	5	1160	49	5
25	2050	55	6	1670	55	6
50	2630	59	6	2130	59	6
100	3230	65	6	2610	65	6
200	3890	70	6	3140	70	6
500	4890	77	6	3920	77	6

Table 1 Current Discharge with Different Return Periods in the Study Area

Data and Methodology

- Establish the Relationship between Antecedent Precipitation and Floods
  - Flood sizes in a region are strongly controlled by the precipitation input during some preceding period. That period and the nature of the relationship need to be determined.
  - Data: Southeast Regional Climate Center and discharge values from U.S. Geological Survey (USGS)
  - Steps:
    - Extract dates and magnitudes of the ten largest annual floods observed in each of eight streamflow records in the region.
    - Compute and correlate partial sums of basin inputs up to 14 days prior to the peak flow to peak discharge.
    - For each of the eight streamflow stations with discharge records in Escambia River Basin, the 10 largest floods at each station is converted to a standardized measure by dividing by basin area to get units of specific discharge.
    - Plot these values against the rainfall total in the 10 previous days.
    - Use regression to simulate the relationship between rainfall, standard runoff and the size of basin area.

Data and Methodology

- Establish the Relationship between Antecedent Precipitation and Floods
  - Plots of correlation versus length of partial sum indicate that 10 days prior is sufficient regardless of basin area.

$$AR = Discharge / Basin\ Area /(9.212 - 1.911 \log(Area))$$

  - Where AR is the 10-days accumulated rainfall in inches, discharge is the peak daily discharge in cubic feet per second, and area is the size of the basin area in square miles. The R-square of the regression is 0.660, standard deviation is 0.852.

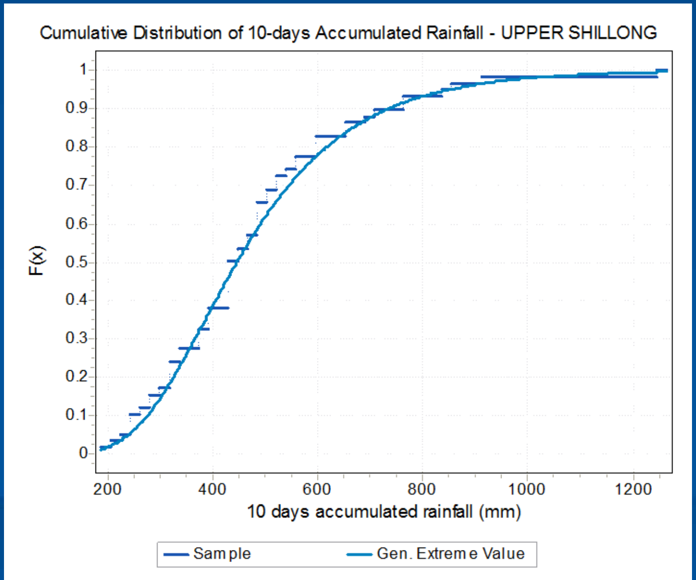
Site	**50-year Flood**		**100-year Flood**	
	Discharge (cfs)	**Rainfall (inches)**	**Discharge (cfs)**	**Rainfall (inches)**
Site A	2630	34.30	3230	42.12
Site B	2130	34.49	2610	42.27

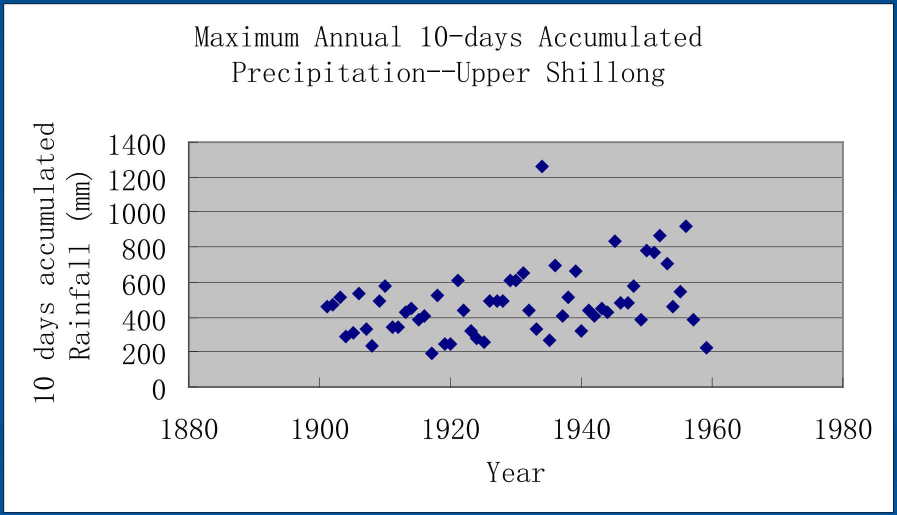
Table 2 Estimated Rainfall sufficient to generate Floods with different Return Periods

Data and Methodology

- Extract Future Rainfall Pattern
  - Extract future extreme distribution of 10-days accumulated rainfall using future daily rainfall simulation
  - According to the global projection, the precipitation of gulf area will increase by 20%-30% by 2060.
  - Upper Shillong in India, which has about 35% more annual rainfall than Pensacola, is selected as the example of future simulation.
  - Generalized Extreme Value Distribution is used to calculate the maximum annual 10-days accumulated rainfall with different return period
  - K= 0.04887, e=144.29, a=392.78

$$F(x) = EXP\left(\frac{-\{1-k(x-\varepsilon)\}}{a}\right)^{\frac{1}{k}}$$



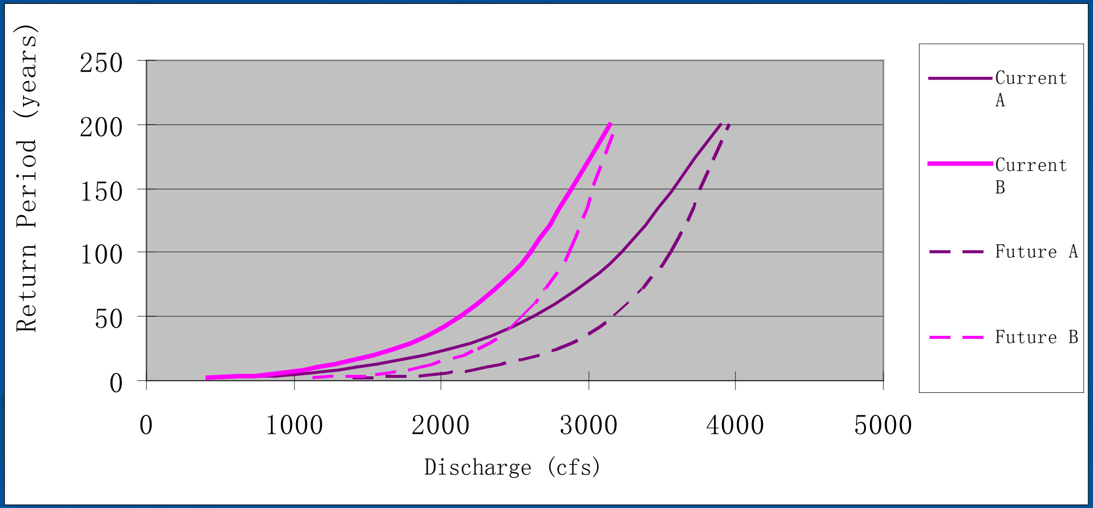


Results

- Estimation of Future Flood

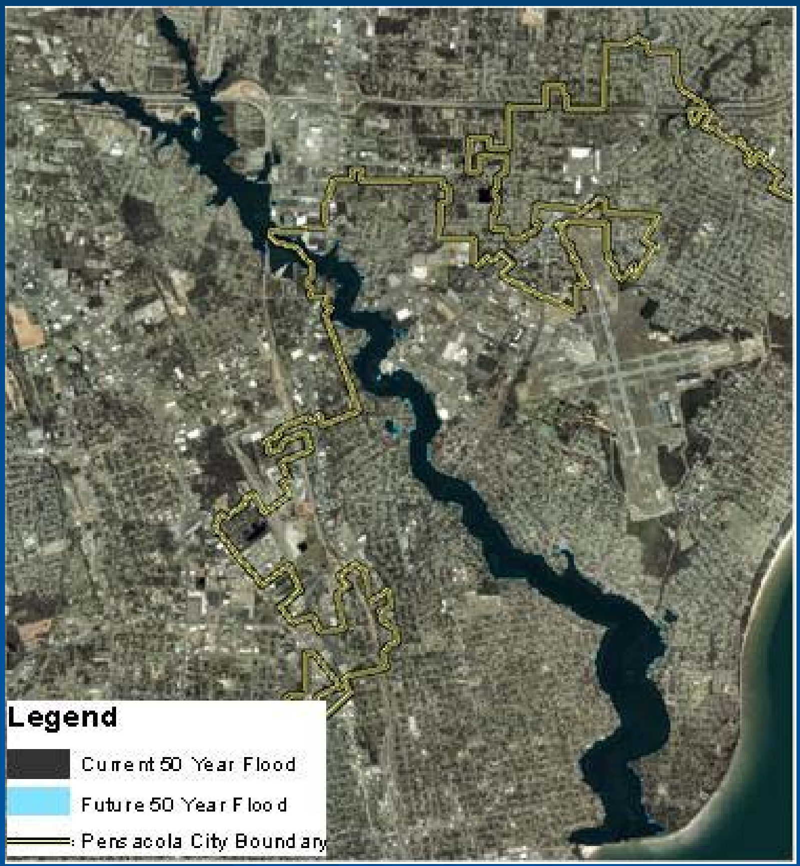
Site	50-year Flood		100-year Flood	
	Discharge (cfs)	Rainfall (inches)	Discharge (cfs)	Rainfall (inches)
Site A	3171	41.35	3559	46.41
Site B	2553	41.35	2866	46.41

Table 3 Future Rainfall and Discharge Values with Different Return Periods



Change of Discharge at Study Area

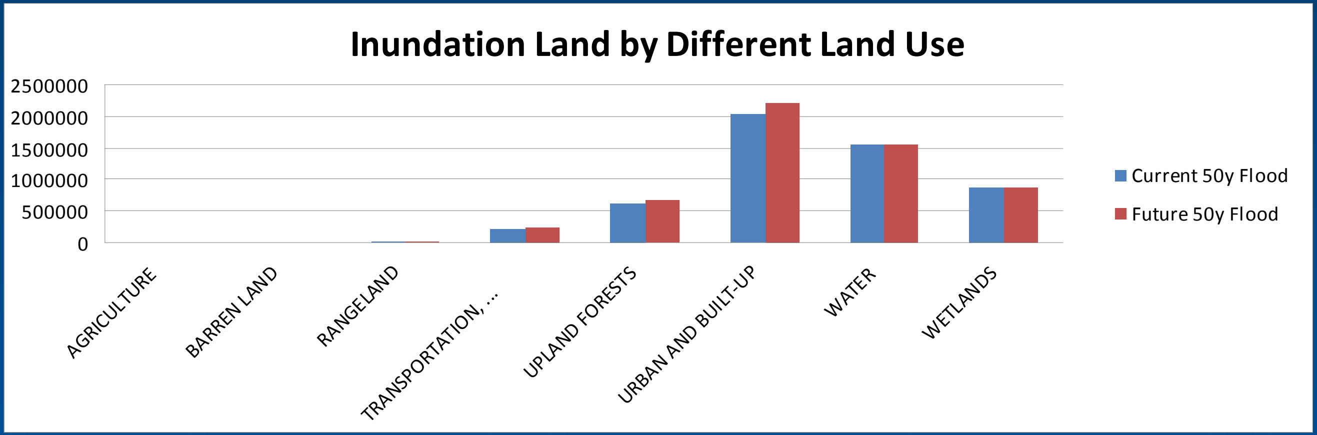
Results



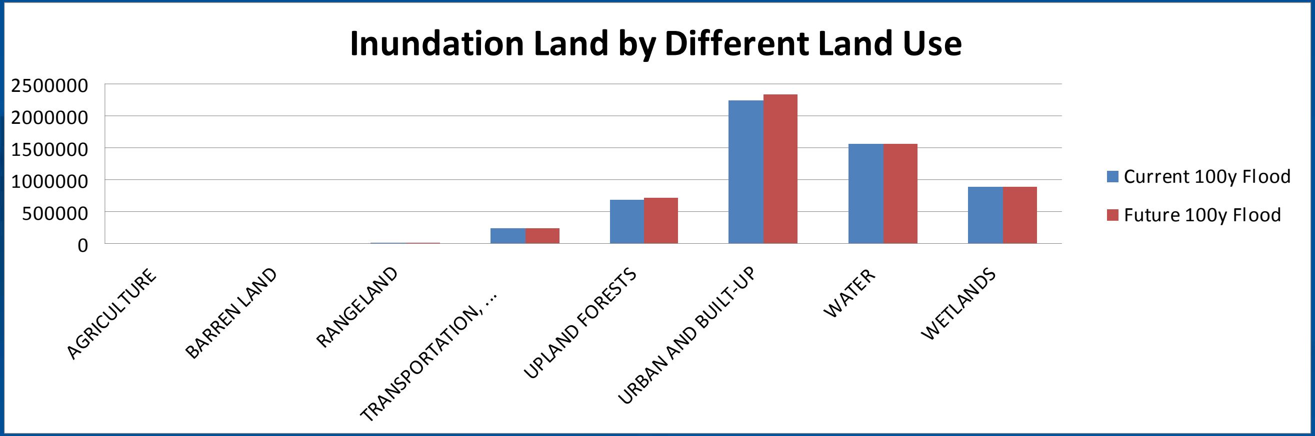
Current and Future Flood Map

Results

- Land Use



Inundation Land by Different Land Use Type (50-year Flood)



Inundation Land by Different Land Use Type (100-year Flood)

Results

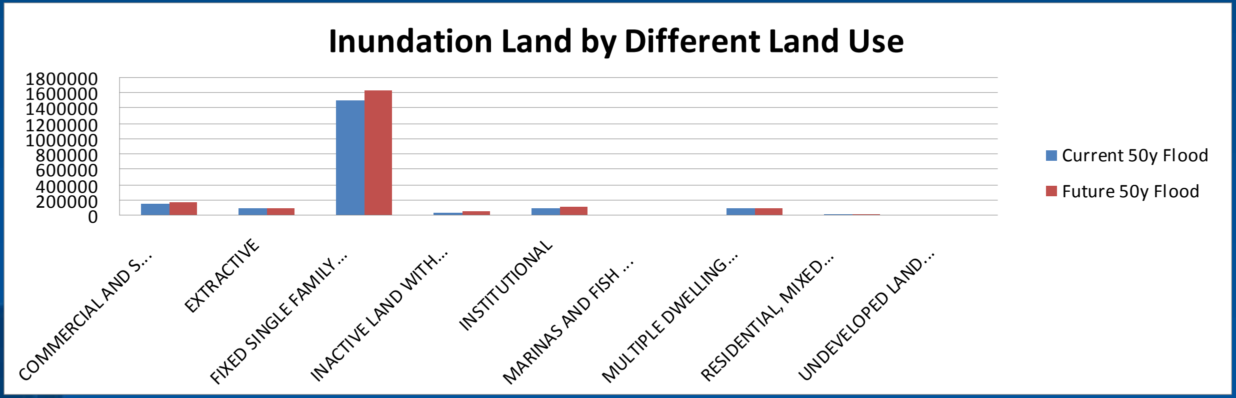
- Transportation Infrastructure at risk

	Major Highway			Major Roads					Affected Bus Routes
	Sum	Intersta te	Other Urban Arterial	Sum	Roadwa y	Urban Collecto r	Urban Local	Urban Minor Arterial	
Current 50y flood	3	2	1	19	5	4	2	8	5
Future 50y flood	3	2	1	20	5	5	2	8	5
Current 100y flood	3	2	1	20	5	5	2	8	5
Future 100y flood	3	2	1	20	5	5	2	8	5

Table 5 Transportation Infrastructure at Risk

Conclusions

- Land Use
  - Urban and built-up environment will be most susceptible to flood caused by increasing precipitation.
  - Furthermore, within urban and built up land use category, single family dwelling units would be the most vulnerable sector to increase of flood.
  - Adaptation strategies should focus on restricting single family residential development within the projected floodplain, and reallocating the current residential development in the following decades.



Inundation Land by Different Land Use Type (50-year Flood, Urban and Built Up)

Conclusions

- Transportation
  - no significant increase of number of transportation infrastructures at risk
  - current design standards are not sufficient
  - Most transportation infrastructures within the study area are designed to convey runoff of existing 50 year return period or 25 year return period flood.
  - Change of Return Period
  - update of design specifications

Site	50-year Flood				100-year Flood			
	Rainfall		Future Cumulative Probability	Future Return Period	Rainfall		Future Cumulative Probability	Future Return Period
	inch	mm			inch	mm		
Site A	34.30	840.35	0.9458	18	42.12	1031.94	0.9820	56
Site B	34.49	845.01	0.9473	19	42.27	1035.62	0.9824	57

Table 6 Projected Flood Return Period

Discussions

- A foundation for further risk assessment and economic cost analysis
- Incorporate land use model to simulate the reallocation of development within the projected flood area, and to estimate the potential economic cost
- Integrated with land use model and transportation model to quantify the indirect cost on transportation system
  - the land use change and restriction of development in the flooding area

Acknowledgement

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Thank you!