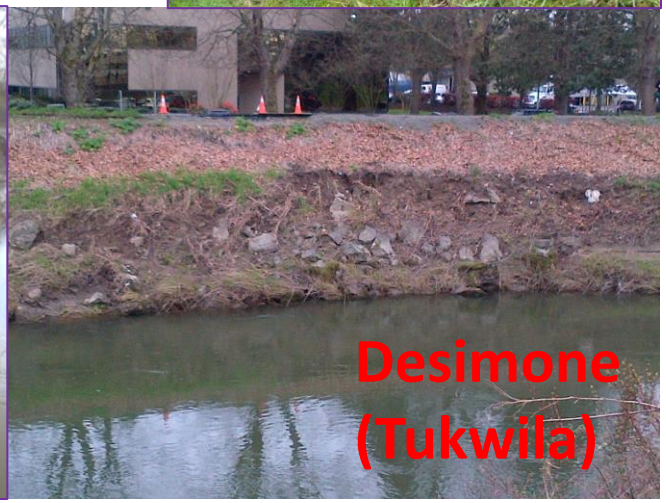
Green River System Wide Improvement Framework (SWIF) – Symposium

Current Conditions Report

Risk Assessment Overview – Geomorphology, Geotechnical, Hydraulic, and Economic Analysis

April 16, 2014



PRESENTATION OUTCOMES

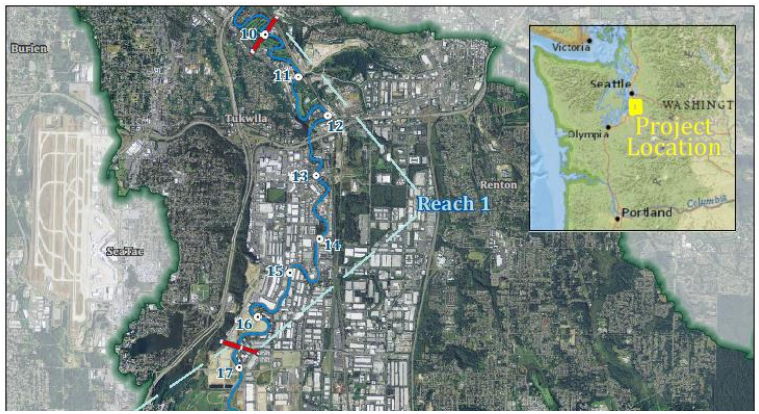
Symposium attendees will learn about:

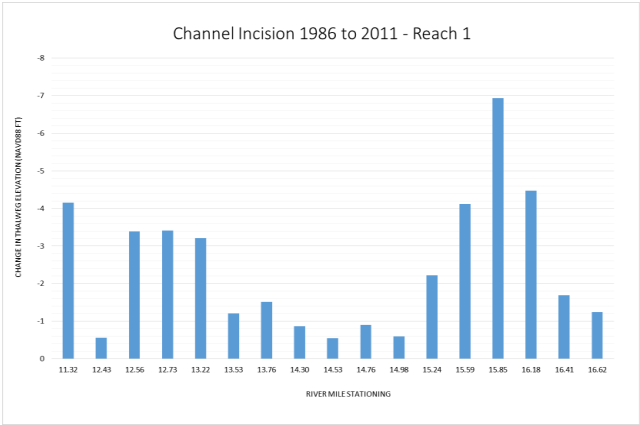
- Existing Flood Risks and Vulnerabilities
- Methods and Key Findings for Flood Risk Assessment
- Geomorphic Assessment – channel patterns and gradient, stream incision, and damages to levees and revetments
- Geotechnical Assessment – levee stability, vulnerability, and potential breach locations
- Hydraulic Assessment – flooding patterns, channel capacity, and floodplain inundation (for flood flows of 12,000 to 26,800 cfs)
- Economic Analysis – Expected annual damages and economic impacts

Risk Assessment – Key Findings

Geomorphology

- Channel incision (bed erosion) between 1986 and 2011 was a minimum of 1-2 feet everywhere, with maximum incision of 7-10.5 feet at channel bends in all four reaches of Lower Green
- Most damaged levees and revetments are located around channel bends
- Channel locations with >5 feet of incision represent a substantial risk of future damage to levees and revetments





Risk Assessment – Key Findings

Geotechnical

- Most levees constructed in 1960s used river alluvium (sand/ gravel), and dragline methods without compaction
- Levee stability analyses indicate shallow failure surfaces that would not result in significant reduction of levee prism
- Shallow failures considered a maintenance issue, with a low probability of causing a levee breach, but must be repaired

Risk Assessment – Key Findings

Hydraulic

- Levee overtopping that exceeds design protection will result in floodplain inundation of 1 to 10+ feet
- Levee overtopping for flows >12,600 cfs are a risk in 3 of 4 damage analysis areas (Auburn-Dykstra, Kent/Renton-multiple locations, Tukwila-Duwamish)
- Tukwila 205 levee provides highest level of protection from overtopping, but it has lowest landward toe, increasing the breach risk
- Black River Pump Station has enough capacity at 18,800 cfs, but is overwhelmed at 26,800 cfs
- Upper Duwamish (RM 8-11) begins overbank flooding at 12,600 cfs and by 18,800 cfs most of reach is inundated

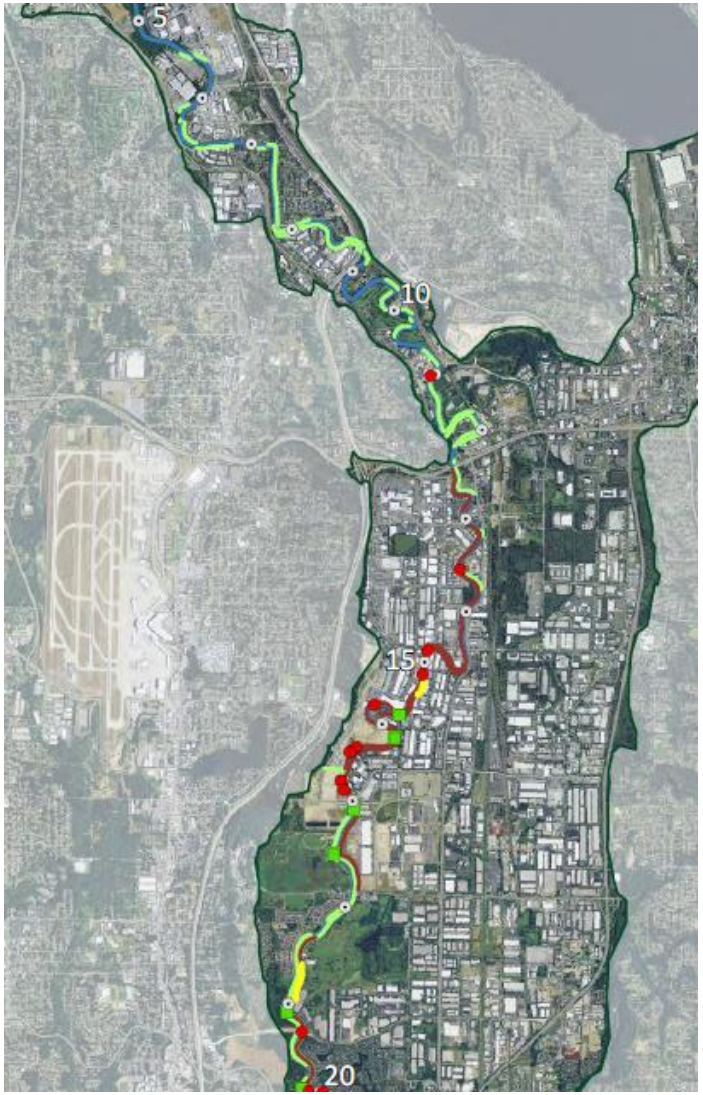
Risk Assessment – Key Findings

Economics

- HEC-FDA (Flood Damages Assessment) modeling estimated system-wide estimated annual damages of $47.1 million
- Present value damages (based on 50 years and 3.5% discount rate) is $1.1 billion
  - Analysis assumes all businesses remain and re-open following downtime caused by flood
  - Loss of life and other social effects were outside scope of analysis
  - There are 5,371 residential structures in planning area

Green River SWIF:

Existing Flood Risks and Vulnerabilities



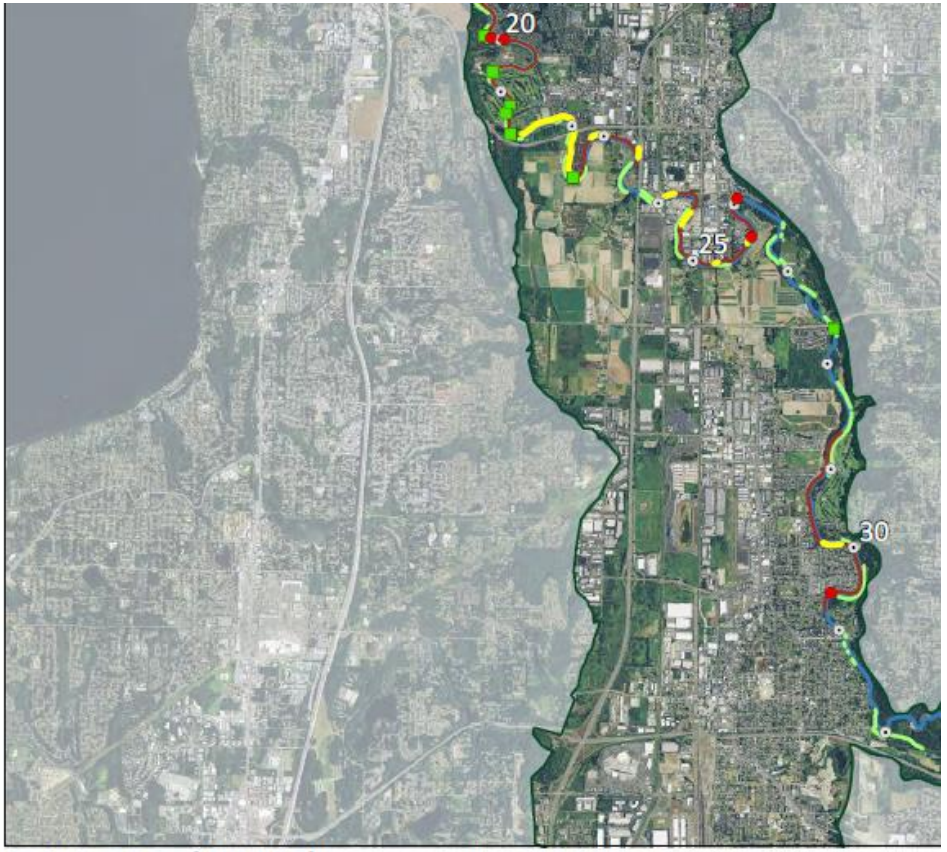


Figure X.X ***(DRAFT)***

Existing Condition Vulnerabilities

Green River SWIF

- Point of Significant Channel Bed Incision
- Identified Geotechnical Area of Concern
- Levee Low Point
- USACE PL 84-99 Levee
- Other Levee or Revetment

Data Sou

Current Conditions Report

Flood Risk Assessment

- What are the system-wide existing levee system flood risks and vulnerabilities?
- At what peak flow rate is there a risk of levee failure (breaching or overtopping followed by breaching)?
- What is the extent of flood inundation in the valley if the existing levee systems overtop and/or breach?
- What are the economic damages associated with different levels of inundation?

Analysis will serve as a baseline for future system-level alternatives development.

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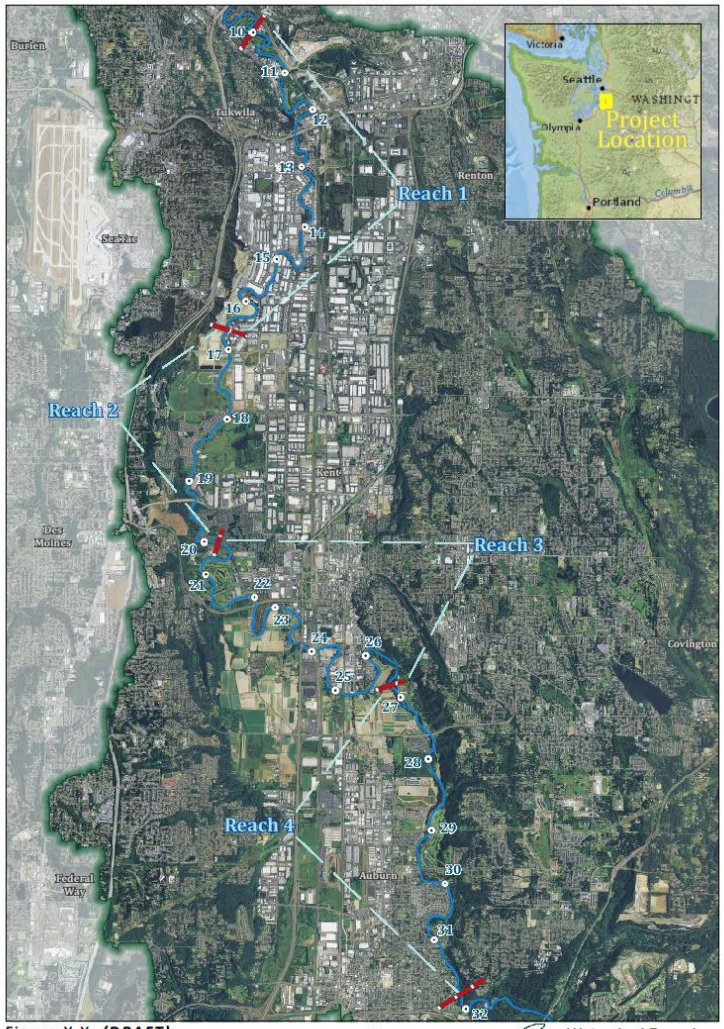
Geomorphic Assessment

Assessment evaluates geomorphic conditions:

- Based on available studies, reports and maps
- Geomorphic factors analyzed:
  - Channel pattern: frequency and geometric form of channel bends
  - Channel gradient
  - Location of damages to levees and revetments
- Stream bed incision estimated by comparing channel cross sections from 1986, 2006, and 2011
  - Incision considered in identification of potential levee breach locations
- Levee and revetment damages, and subsequent repairs, from past floods (1990-2013)

Current Conditions Report: Geomorphic Assessment



Reach Boundaries

Significant Incision Points

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Key Findings – Geomorphic Assessment

Major Channel Alterations

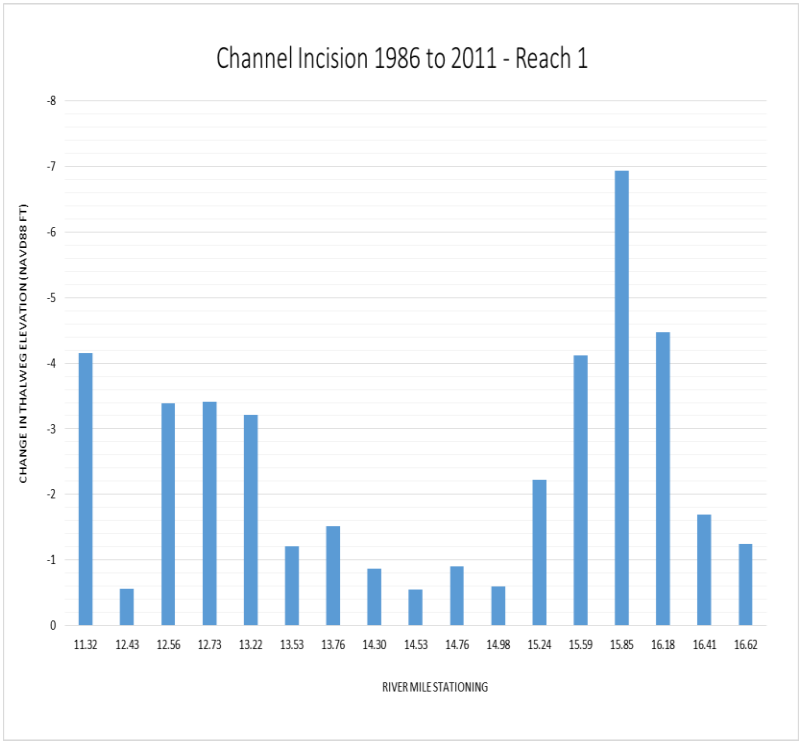
- Historical clearing of trees and confinement of river by construction of levees and revetments between RM 12.44 and 30.8
- Few changes in channel location or migration observed since 1986

Streambed Erosion, Incision, and Damage Locations

- Since 1986, stream bed erosion has lowered channel bed from 1-2 feet; greater incision on channel bends, with several bends having incision >5 feet
- Seven locations with incision of 5-10 feet
- Bend incision common due to high velocities, and is exacerbated by armoring that prevents lateral migration, thus increasing shear stress along toe of levee
- Most damaged levees and revetments located around channel bends
- Findings indicate channel cross sections with >5 feet of incision represent a substantial risk of future damage to adjacent levees and revetments

Current Conditions Report: Geomorphic Assessment

Damage Repair Sites



Channel Incision – Reach 1

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Geotechnical Assessment

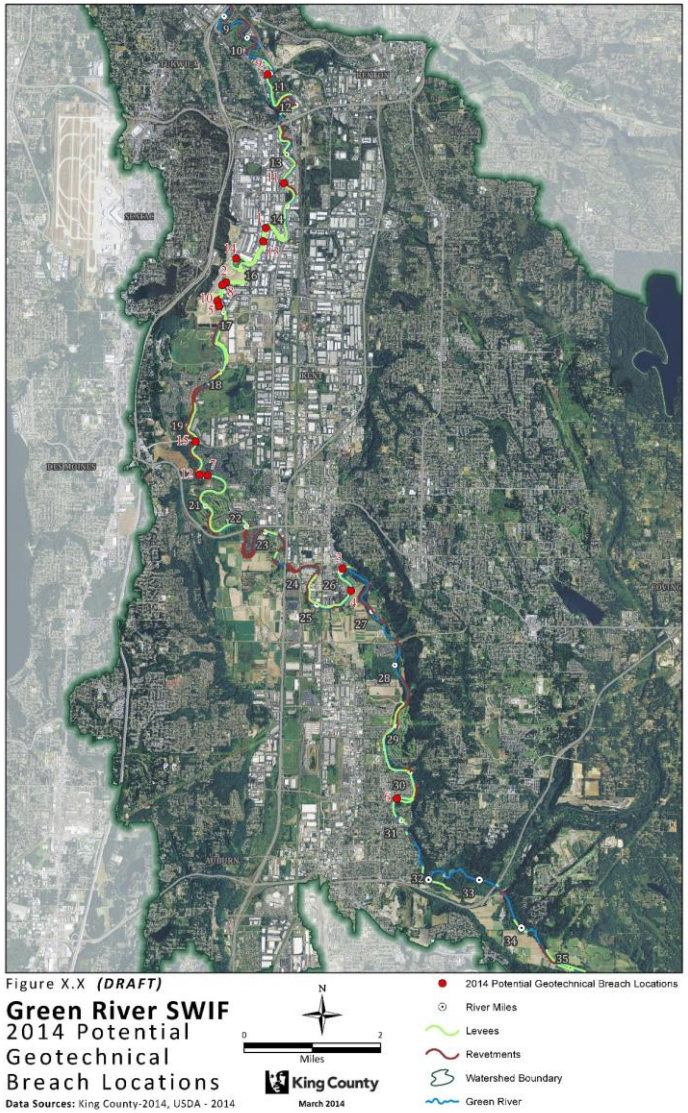
Purpose of geotechnical assessment:

- Summarizes existing condition of levees and identifies locations with significant geotechnical instability
- Characterizes levees most vulnerable to failure

Methods:

- Review existing geotechnical studies, including:
  - Green River Levee Flood Damage Assessment (2007-2009)
  - 2010 periodic inspection reports for PL 84-99 levees
  - 2013 King County Deficiency Action Plan
  - Setback levee reports
  - Reports submitted for FEMA certification within City of Kent
- Calculate weighted score considering levee geometry, revetments and erosion, and channel direction and depth
  - 15 preliminary breach locations identified
- Project team selected 6 potential breach locations
- Fragility curves to support levee system analysis and characterize flood risk

Current Conditions Report: Geomorphic Assessment



15 Potential Breach Locations

6 Selected Breach Locations

Potential Breach	Levee Reach	River Bank	River Mile
1	Dykstra	Left	30.69
2	Tukwila 205	Left	14.83
3	Horseshoe Bend	Right	25.50
4	Meyer's Golf	Right	21.80
5	Lower Russell Road	Right	18.60
6	Briscoe-Desimone	Right	16.62

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Key Findings – Geotechnical Assessment

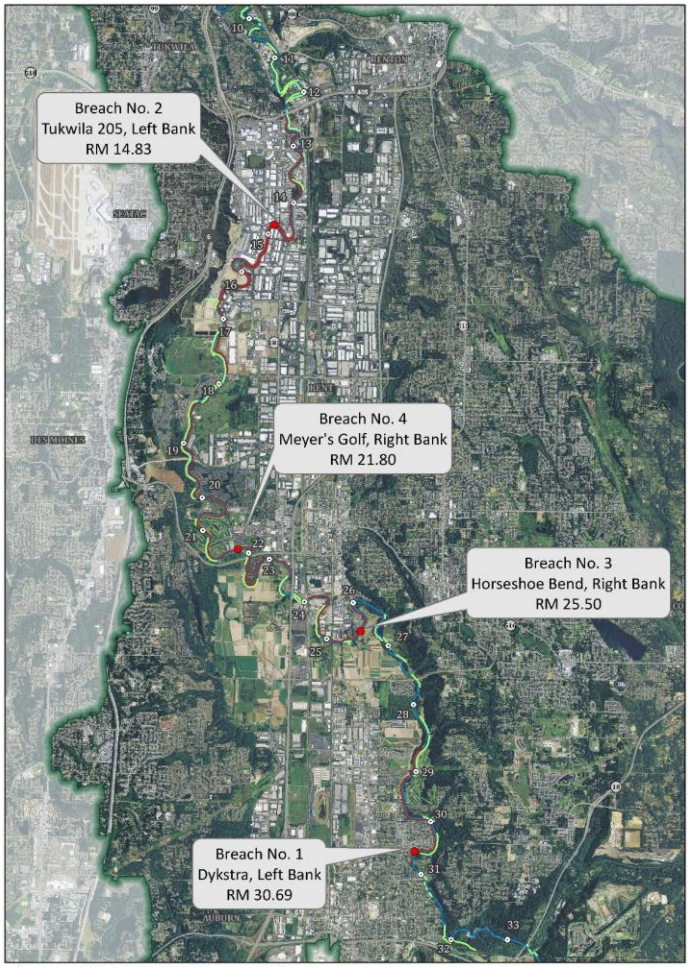
Previous levee stability analyses indicate that shallow failure surfaces do not meet the USACE recommended factors of safety (FOS)

- Failure surfaces were reported to be shallow and thus would not result in significant reduction of the levee prism
- Study conclusions have considered shallow failures as maintenance issues with a low probability of causing a levee breach

Composite fragility curves developed for Green River Levee Assessment and for this study support this conclusion

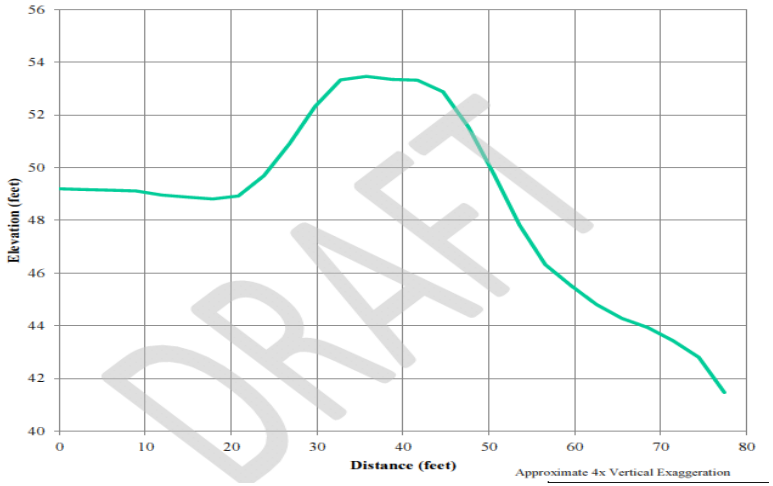
- Relatively low probability of failure calculated for potential breach sites
- Failure modes of rapid drawdown, seismic, and under seepage were most influential
- Levee height, riverside slope, and gradient landward of the landside levee toe strongly influence these failure modes
- Channel bed incision, flooding patterns and knowledge were used with fragility curves to select failure locations for hydraulic/economic modeling

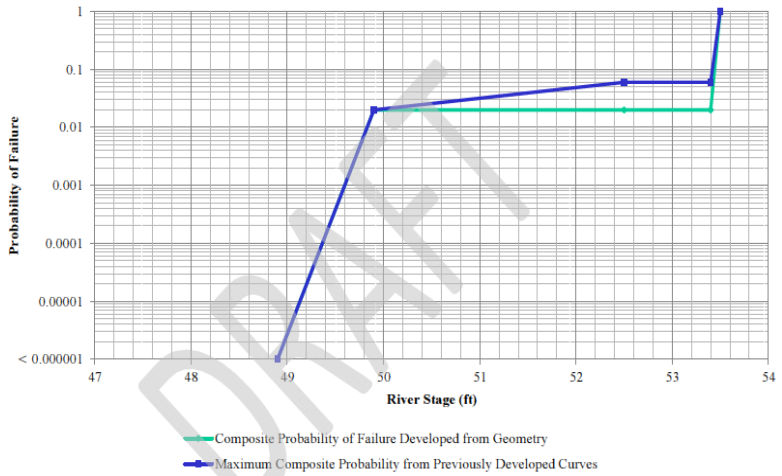
Current Conditions Report: Geotechnical Assessment



4 Breach Locations Analyzed

Horseshoe Bend (RB 25.5) – cross section and stage probability of failure





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Key Findings – Geotechnical Assessment

Additional conclusions and geotechnical considerations:

- Most levees constructed in 1960s used river alluvium (sand/ gravel), and dragline methods without compaction, and are vulnerable to piping
- No breaches have been reported since original construction
- Levee under-seepage was one of the most influential failure modes in the fragility analyses
- Vegetation considerations were not included in geotechnical review
- Existing geotechnical data suggest relatively consistent conditions for PL84-99 levees; however, no data for Signature Point, Galli's, and Dykstra levees
- Recommendation: develop standardized minimum specification to address levee embankment slope stability, and identify all locations where this minimum standard is not currently met
  - Standard should consider a long-term slope geometry and treatment that fully addresses ongoing embankment slumping and minimizes associated maintenance costs

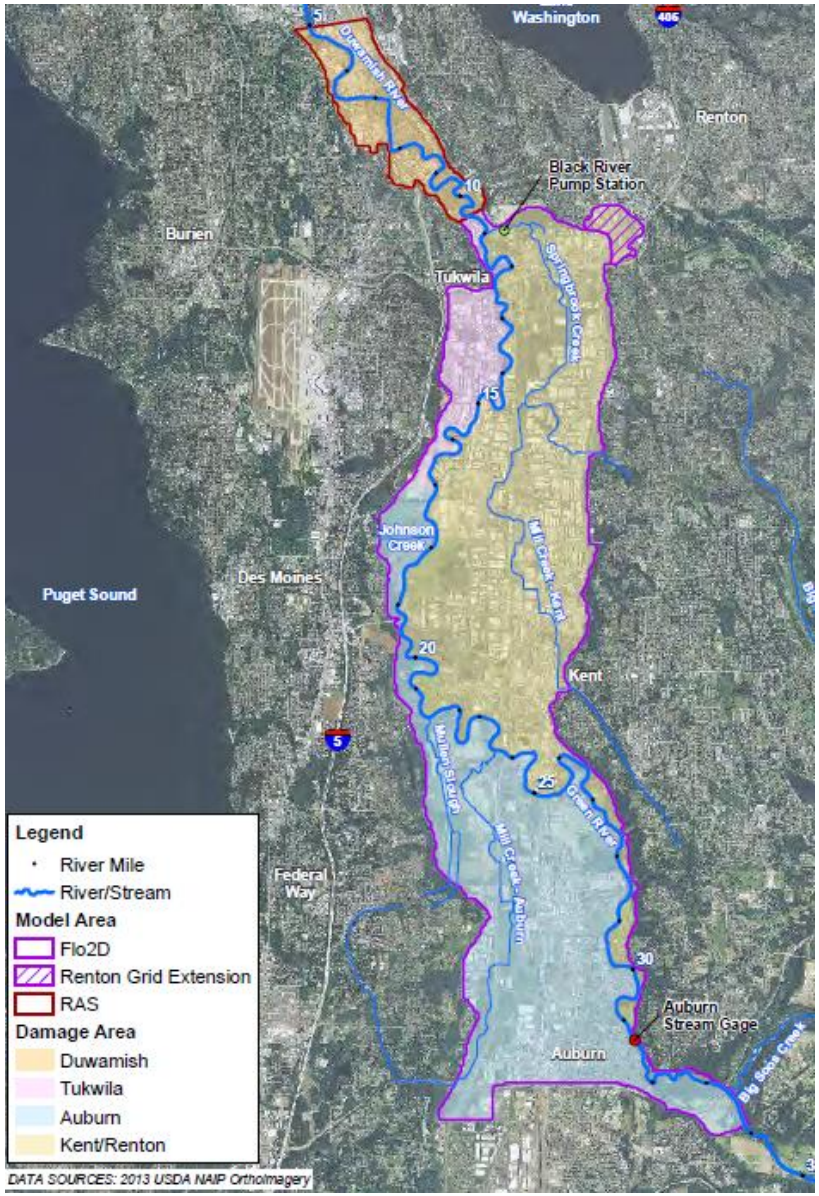
Current Conditions Report

Hydraulic Assessment

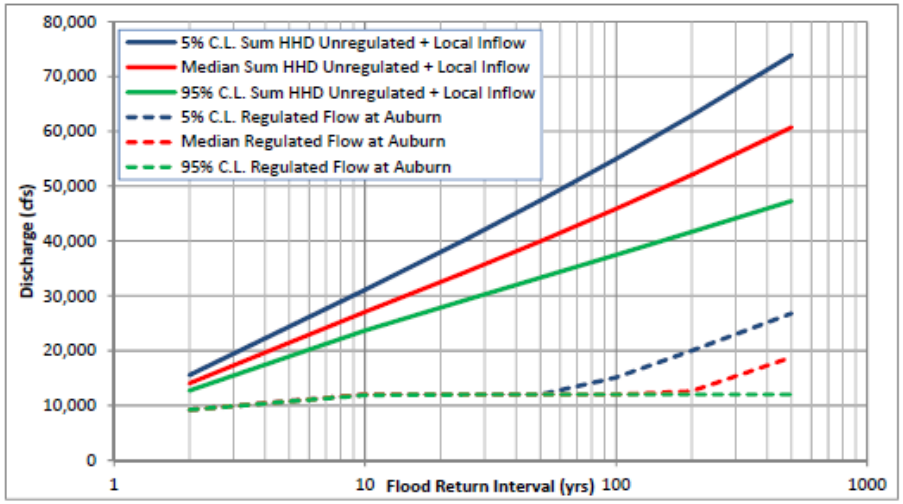
Purpose of hydraulic modeling is to:

- Provide insight into flooding patterns, floodplain depths and floodplain extents under various flood magnitudes and levee breach scenarios
- Estimate channel conveyance capacity provided by the current levee system
- Provide inundation limits, floodplain depths and inundation durations for use in the flood risk assessment and economic modeling of flood damages
- Hydraulic analysis maximizes use of existing models and data from past 8 years
  - Update of hydraulic model includes new 2012 Corps Design Flood Hydrographs and 2013 LiDAR
  - Current configuration, location and condition of facilities, including soon-to-be constructed facilities are included

Current Conditions Report: Hydraulic Assessment



Hydraulic Study Area



Discharge vs. flood frequency at Auburn (unregulated and regulated at HHD)

Flood Event	Flow at Auburn Gage (cfs)	Comment
2-yr 5% C.L.	9,900	2-yr events very similar, well below levee system crest
10-yr 95% C.L.	11,900	Lowest volume 12,000 cfs range peak event
200-yr Median	12,600	Highest volume 12,000 cfs range peak event
100-yr 5% C.L.	15,100	--
500-yr Median	18,800	Also used for the very similar 200-yr 5% event
500-yr 5% C.L.	26,800	--

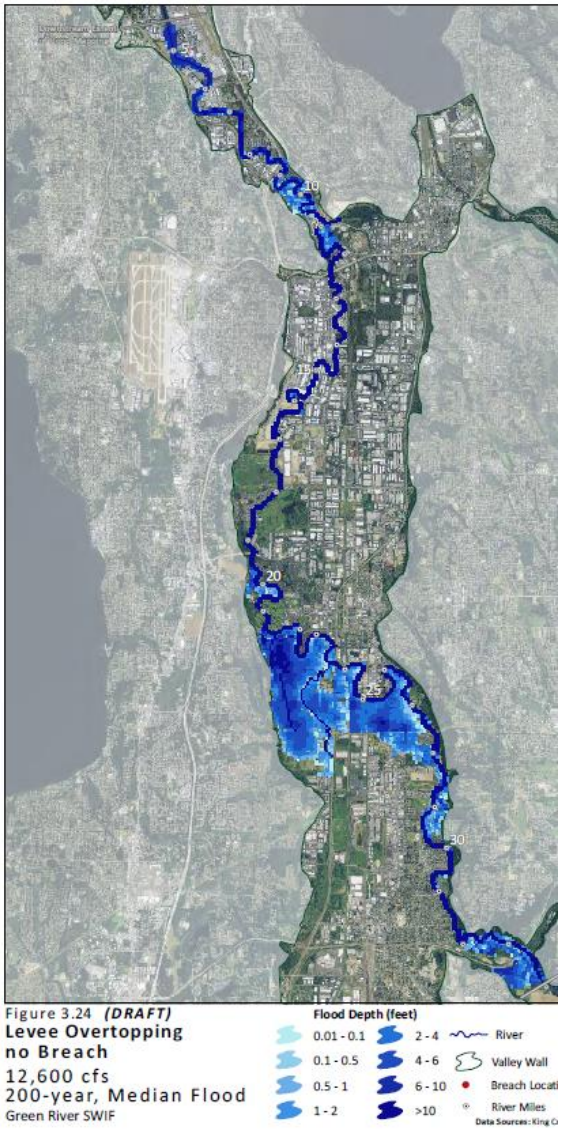
Current Conditions Report

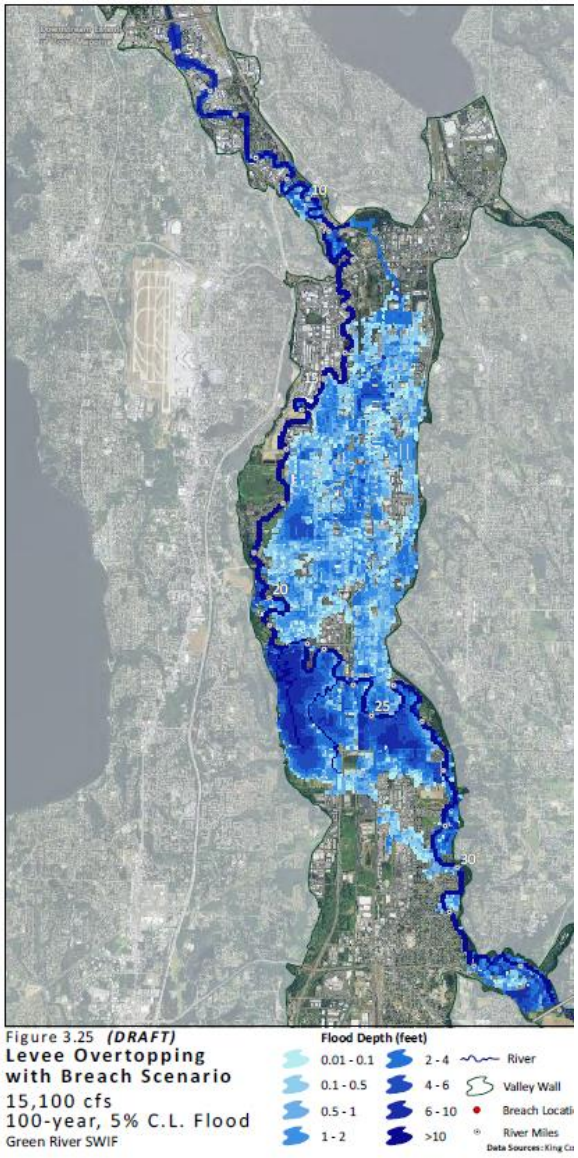
Key Findings – Hydraulic Assessment

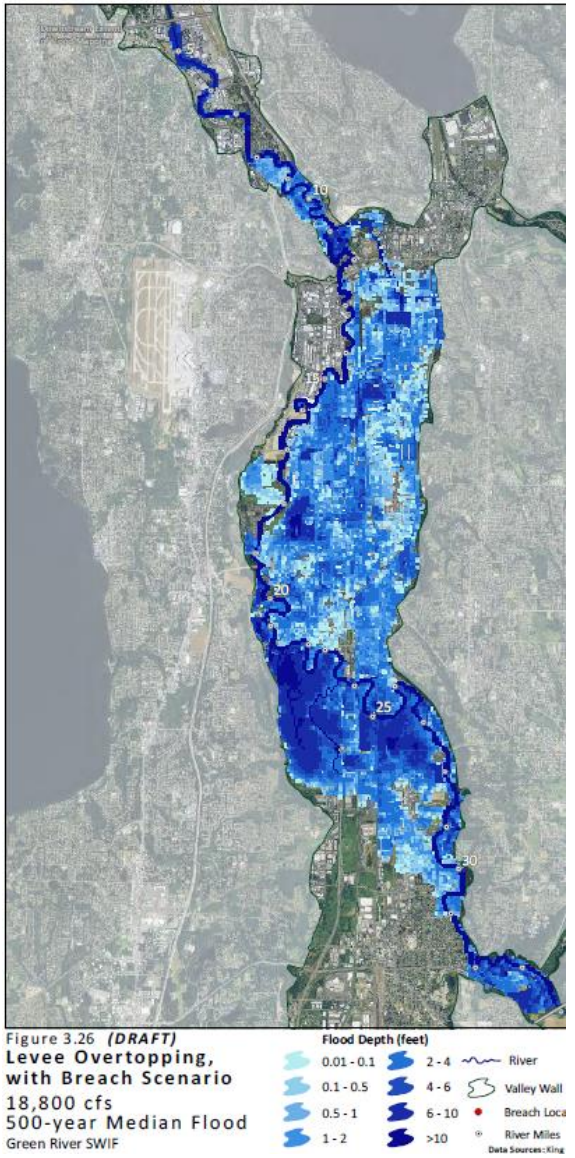
Summary of findings used in combination with depth inundation maps for four damage areas:

- Auburn Damage Area (Focus on urban Auburn)
  - Upstream levees on left bank (RM 28 to 31.75) convey flows between 15,100 cfs and 18,800 cfs, respectively
  - Lowest capacity in reach near RM 29.8; overtopping occurs at ~12,600 cfs
  - Reddington setback levee (RM 28.25 to 29.5) contains 18,800 cfs with some freeboard; 70-90% probability of containing 26,800 cfs (NHC 2013)
- Tukwila Damage Area
  - Tukwila Levee has some of lowest landward toe elevations in Lower Green; there is some chance (albeit very low) of a levee breach in flows below 12,000 cfs
  - Should levee breach, floodwaters entering damage area are confined by levees and must exceed downstream levee crest to spill back into river
  - Tukwila 205 levee provides a high level of protection from overtopping: it only occurs at 26,800 cfs, and in low amounts over the downstream end of the levee

Current Conditions Report: Hydraulic Assessment (Inundation)







12,600 cfs **15,100 cfs** **18,800 cfs**

Current Conditions Report

Key Findings – Hydraulic Assessment

Kent/Renton Damage Area

- Breach risk begins at 11,900 cfs
- In larger floods, breach flows are initially confined by railroad embankments before spreading out over a wider floodplain extent to the north
- At 18,800 cfs, Black River Pump Station has enough capacity to convey flood flows into Green River, preventing flooding of area near and north of I-405
- At 26,800 cfs, the pump station is overwhelmed, floodwaters back up towards Cedar River and spill back into Green River over much of the lower levee system
- The Kent (Lower Green) PL 84-99 right bank levees have lower capacity in upper areas, Horseshoe Bend levee (RM 24-26) and levees around SR516 (RM 22). Minimum capacity at HSB is approximately 12,600 cfs.
- The minimum capacity averaged over levee system is between 15,100 and 18,800 cfs

Duwamish Damage Area

- Levee breach scenarios not applied to Duwamish damage area
- Overbank flooding begins at 12,600 cfs; by 18,800 cfs most of reach is inundated
- Overbank flooding does not occur below RM 8

Current Conditions Report

Flood Risk – Economic Analysis

Four levee failure scenarios analyzed:

- Overtopping/breach failure composite
- Dykstra/Tukwila left bank breach scenario
- Horseshoe Bend breach scenario
- Meyer's Golf breach scenario

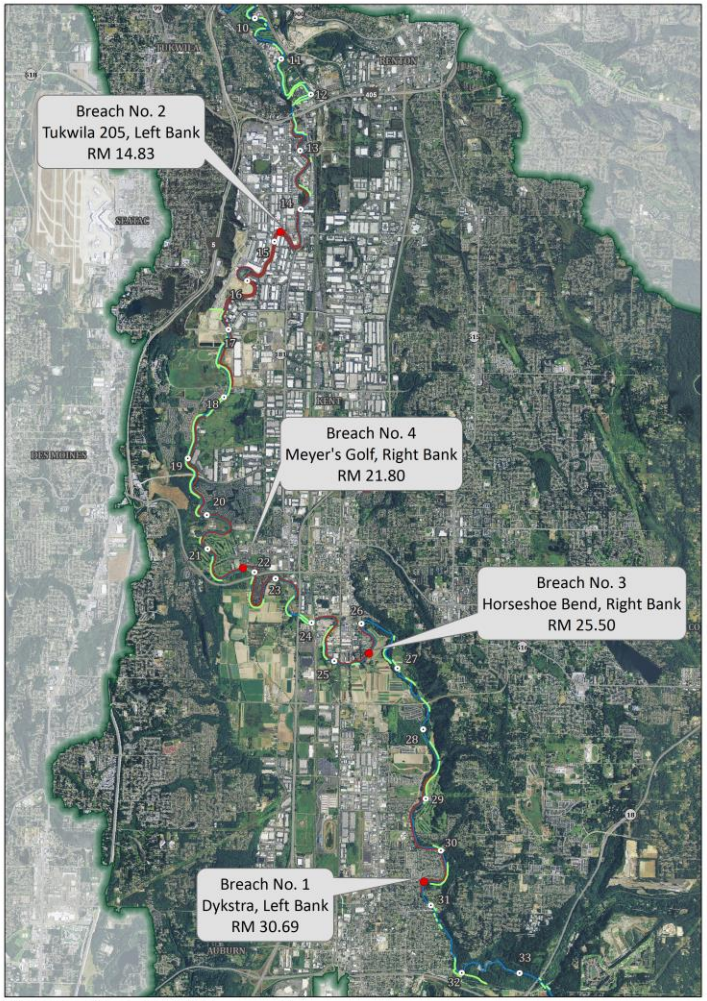
- Economic evaluation includes assessment of flood impacts over range of flood events and 4 scenarios

Current Conditions Report

Flood Risk – Economic Analysis

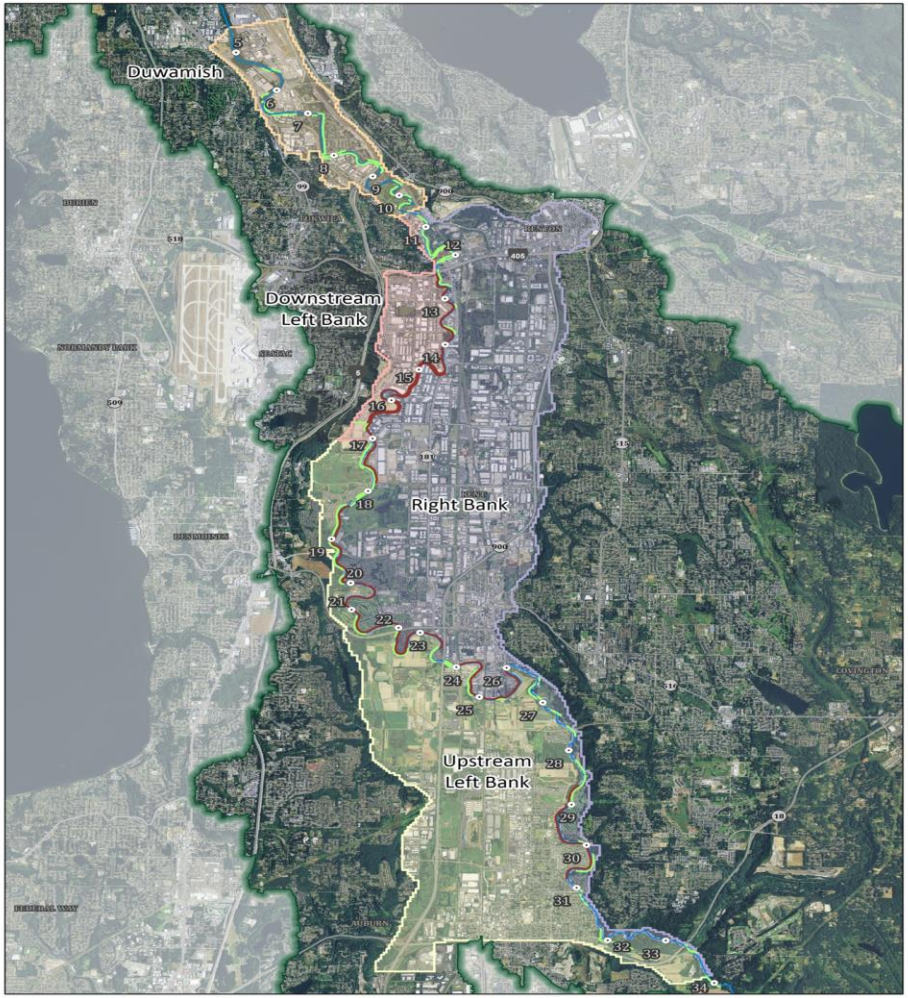
- Estimate system-wide expected annual damages (EAD) over a period of analysis (e.g., 50-100 years)
  - EAD estimates for four scenarios weighted according to likelihood of occurrence
  - Used to generate a single system-wide estimate of existing condition EAD
- Flood damages and impacts characterized into two categories: National Economic Develop (NED) and Regional Economic Development (RED) effects
  - NED includes damage to residential, commercial, and public structures and contents; passenger and commercial vehicles; post-flood cleanup, public assistance, and utility repair costs; vehicle traffic and passenger rail delay costs; freight rail detour costs; agricultural crop losses; and lost recreation value
  - RED damages includes reduced output (sales/gross revenue) that would occur in King County due to temporary reduction of employment due to closure of businesses following inundation
  - Loss of life and other social effects were outside the scope of the flood risk assessment

Current Conditions Report: Flood Risk

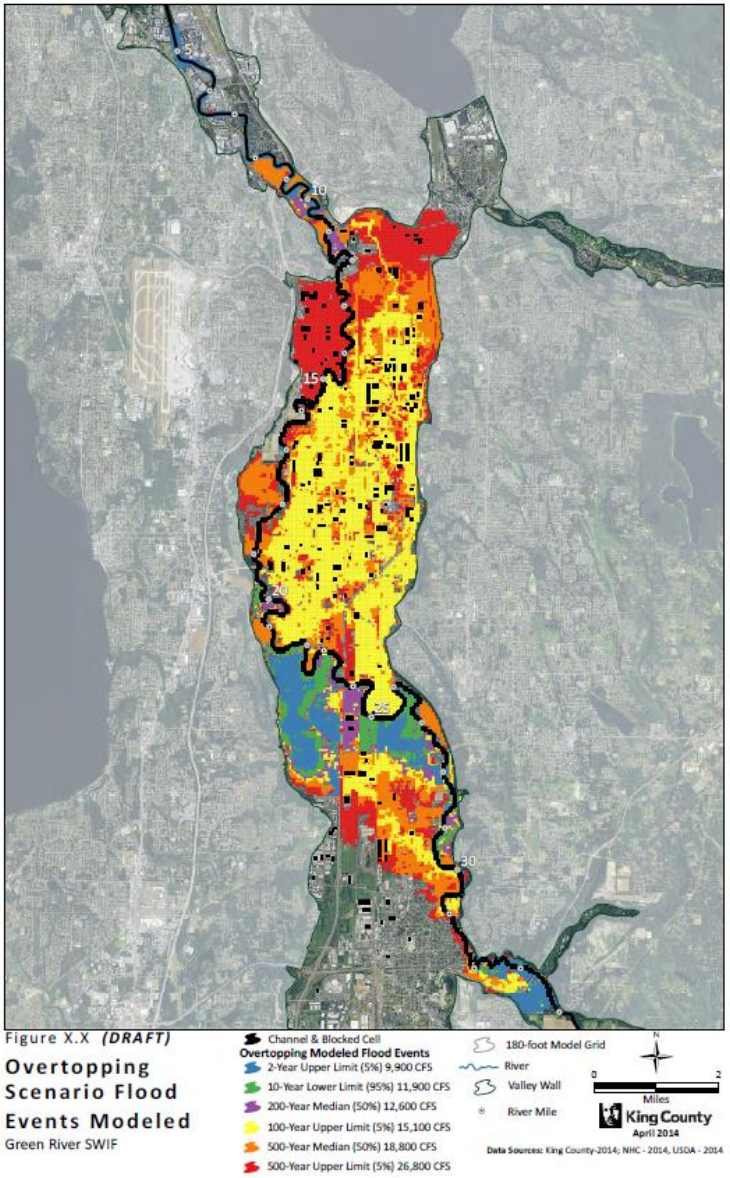


Modeled Breach Locations

Current Conditions Report: Flood Risk



Economic Modeling Areas



Overtopping with Breach Map

Current Conditions Report

Key Findings – Economic Analysis

Estimated Annual Damage (EAD) Ranges for National and Regional Damage Categories:

- The HEC-FDA modeling for four scenarios resulted in:
  - Estimated Annual Damages for the National Economic Damage (NED) categories: $16.9 to $22.5 million
  - EAD for Regional Economic Damage (RED) categories: $22.5 to $32 million

Table 1 – Existing Condition Estimated Annual Damage for Overtopping Scenario and Damage Area

Damage Category	Auburn (Upstream Left Bank)	Tukwila (Downstream Left Bank)	Kent/Renton (Right Bank)	Duwamish (Downstream)	TOTAL
NED Damage Categories Total	$3,449,000 (36.6%)	$240,000 (22.9%)	$10,430,000 (38.6%)	$3,359,000 (46.8%)	$17,478,000 (39.1%)
RED King County Regional Output Effect	$5,970,000 (63.4%)	$810,000 (77.1%)	$16,580,000 (61.4%)	$3,815,000 (53.2%)	$27,175,000 (60.9%)
TOTAL	**$9,419,000 (100%)**	**$1,050,000 (100%)**	**$27,010,000 (100%)**	**$7,174,000 (100%)**	**$44,653,000 (100%)**

Current Conditions Report

Key Findings – Economic Analysis

Table 2 – System-Wide Estimated Annual Damage (EAD) Summary

System-wide ($ EAD)	$47,155,000
System-wide ($ PV)	$1,106,050,000
* 3.75% interest rate and 50-year period of analysis	

LIMITATIONS

- HEC-FDA classifies structures according to established depth-damage functions
- Geotechnical assessment limited to the PL 84-99 levee systems
- Model results intended to estimate EAD at a levee system scale, results are not intended to be applied to individual levee segments

REGIONAL ECONOMIC ANALYSIS (IMPLAN)

- Estimates of lost regional output derived from estimates of employment reduction during post-flood downtime
- Analysis assumes all businesses remain and re-open following downtime; does not consider businesses that choose to relocate
- Analysis does not reflect beneficial effects to businesses that see increase in output (e.g., clean-up /restoration services, construction industries)

Green River SWIF Current Conditions Report

Schedule for Completion

Task	Date
Current Conditions Symposium for TAC and AC, including flood risk assessment results	April 16, 2014
DRAFT Current Condition Report available for review by TAC	May 8, 2014
TAC comments due to SWIF PM (Jennifer Knauer)	May 15, 2014
Current Conditions Report finalized	End May 2014

Questions?