EFFECTS OF PROJECTED TWENTY-FIRST CENTURY SEA LEVEL RISE, STORM SURGE, AND RIVER FLOODING ON WATER LEVELS IN THE SKAGIT RIVER FLOODPLAIN

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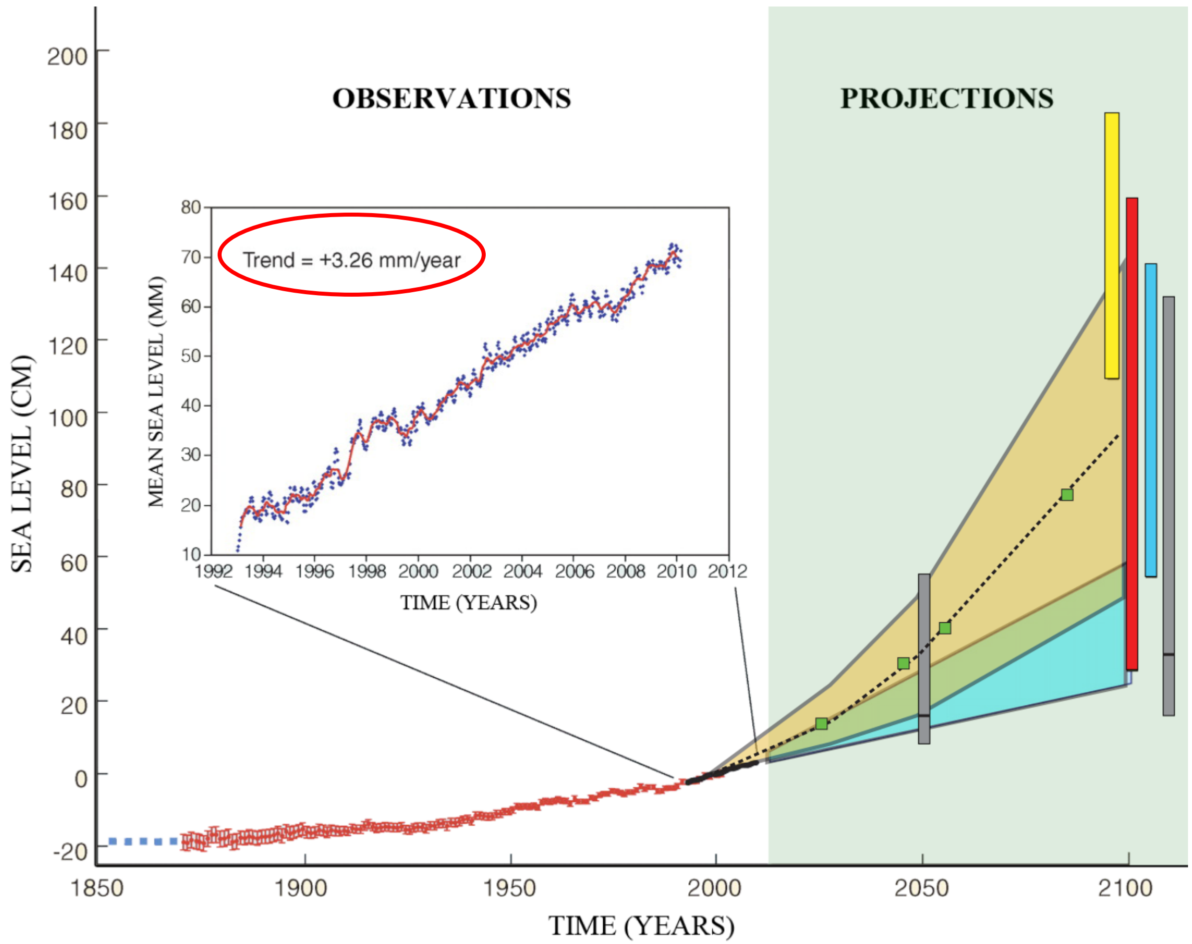
CLIMATE IMPACTS GROUP

Department of Civil and Environmental Engineering

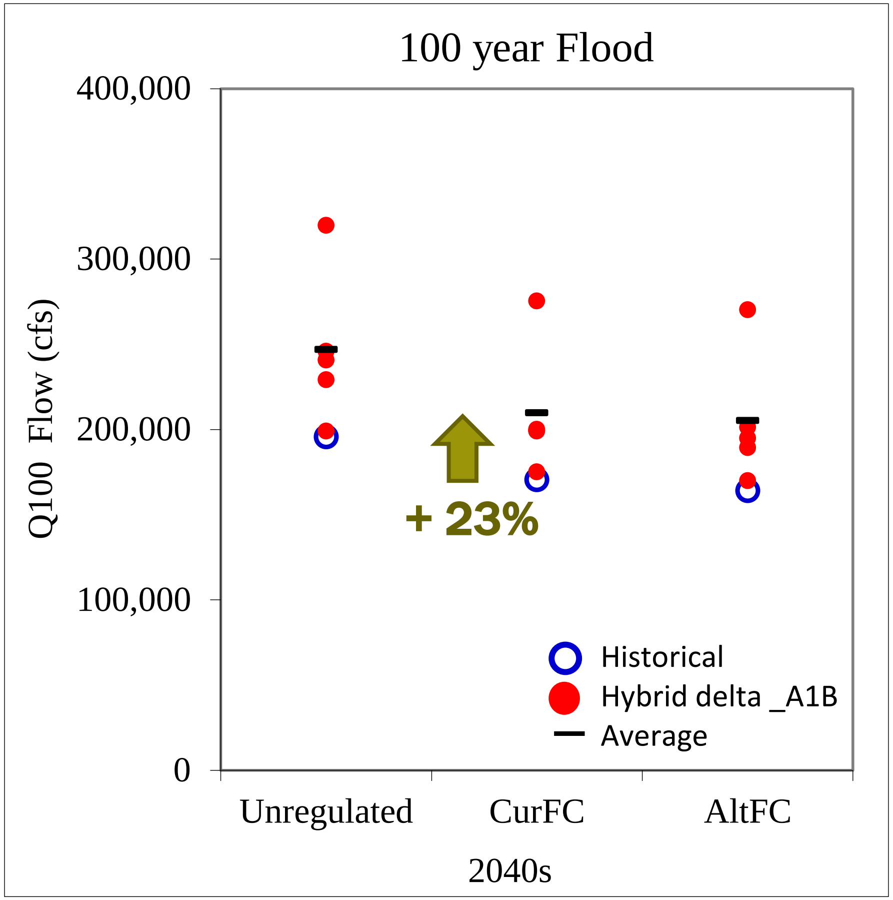
GLOBAL SEA LEVEL RISE

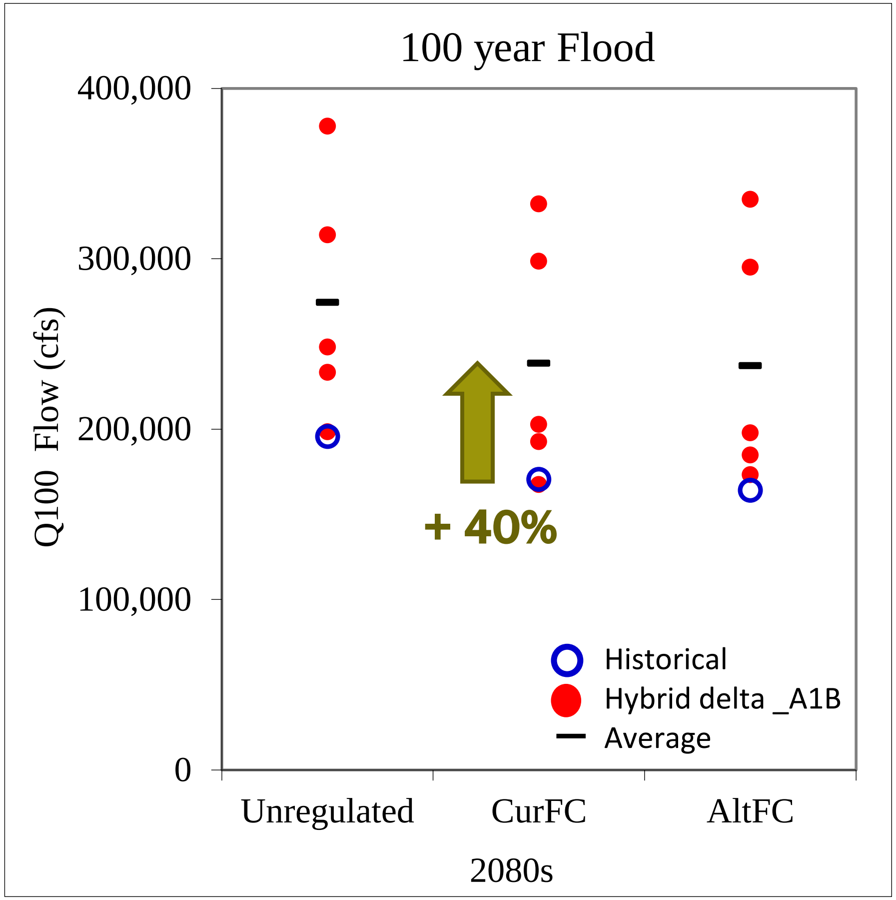


Adapted from Nicholls and Cazenave, 2010

REGULATED FLOODING

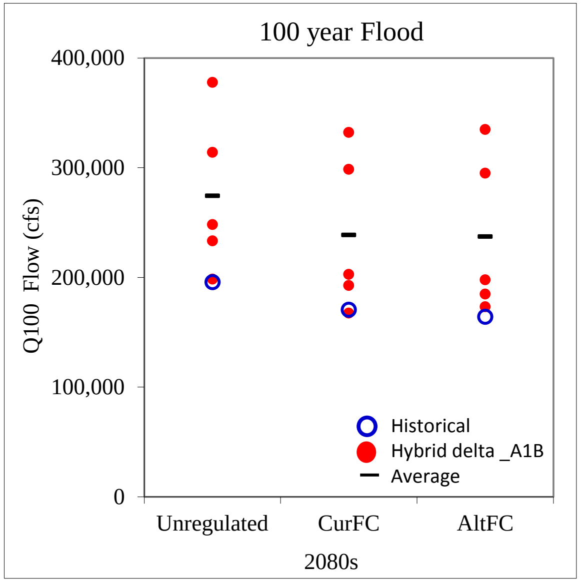
100-yr Flood for Skagit River at Mt. Vernon





Source: Lee & Hamlet, 2012

TOOLS FOR LOCAL PLANNING



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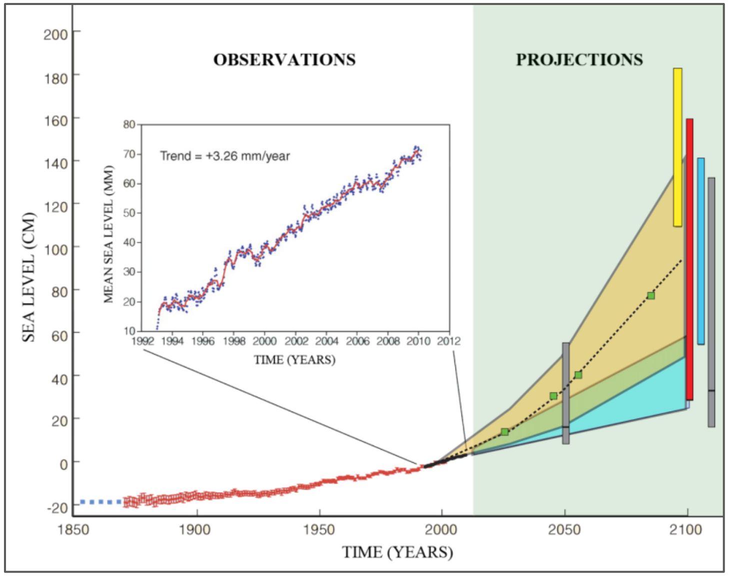
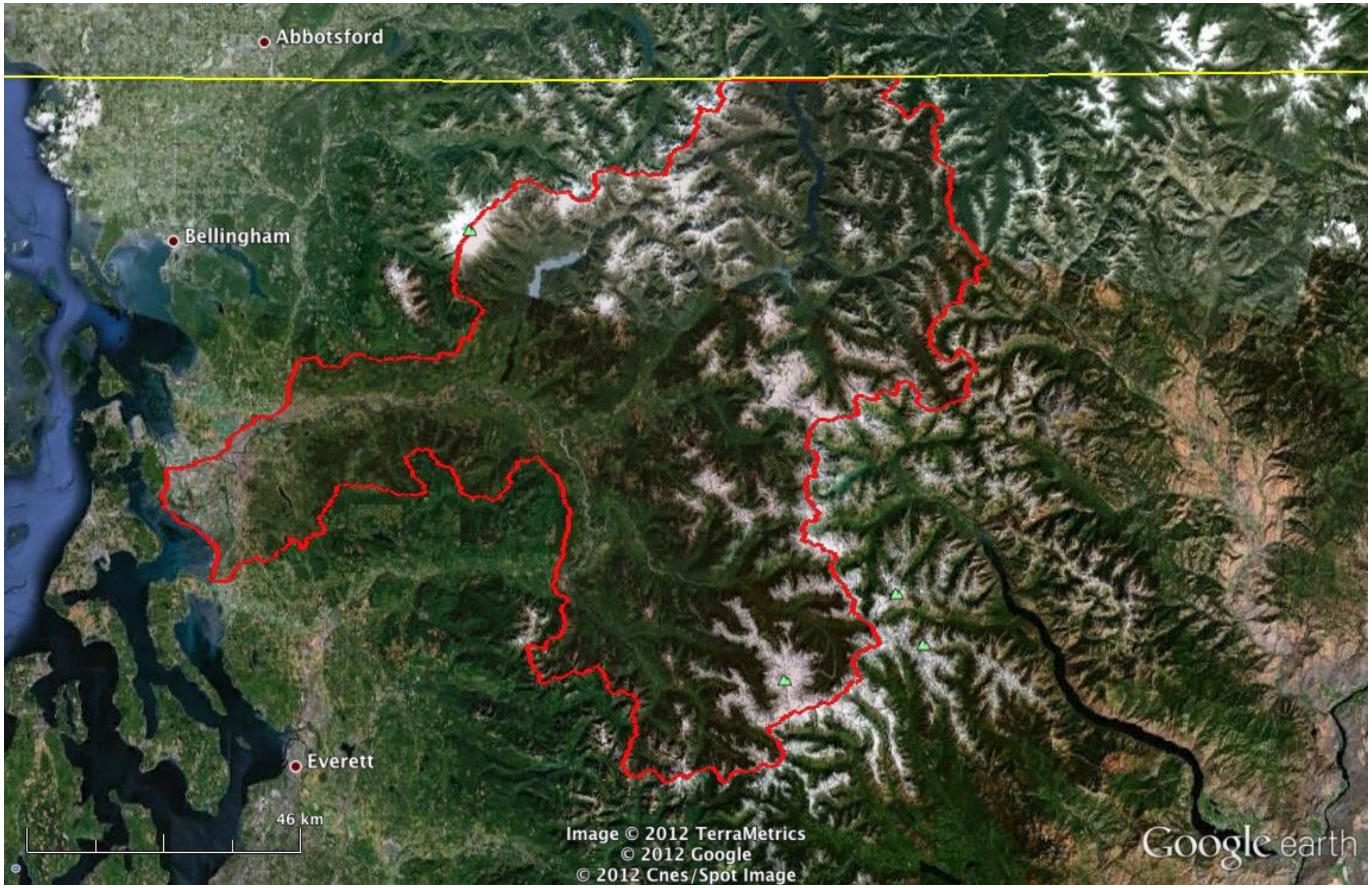
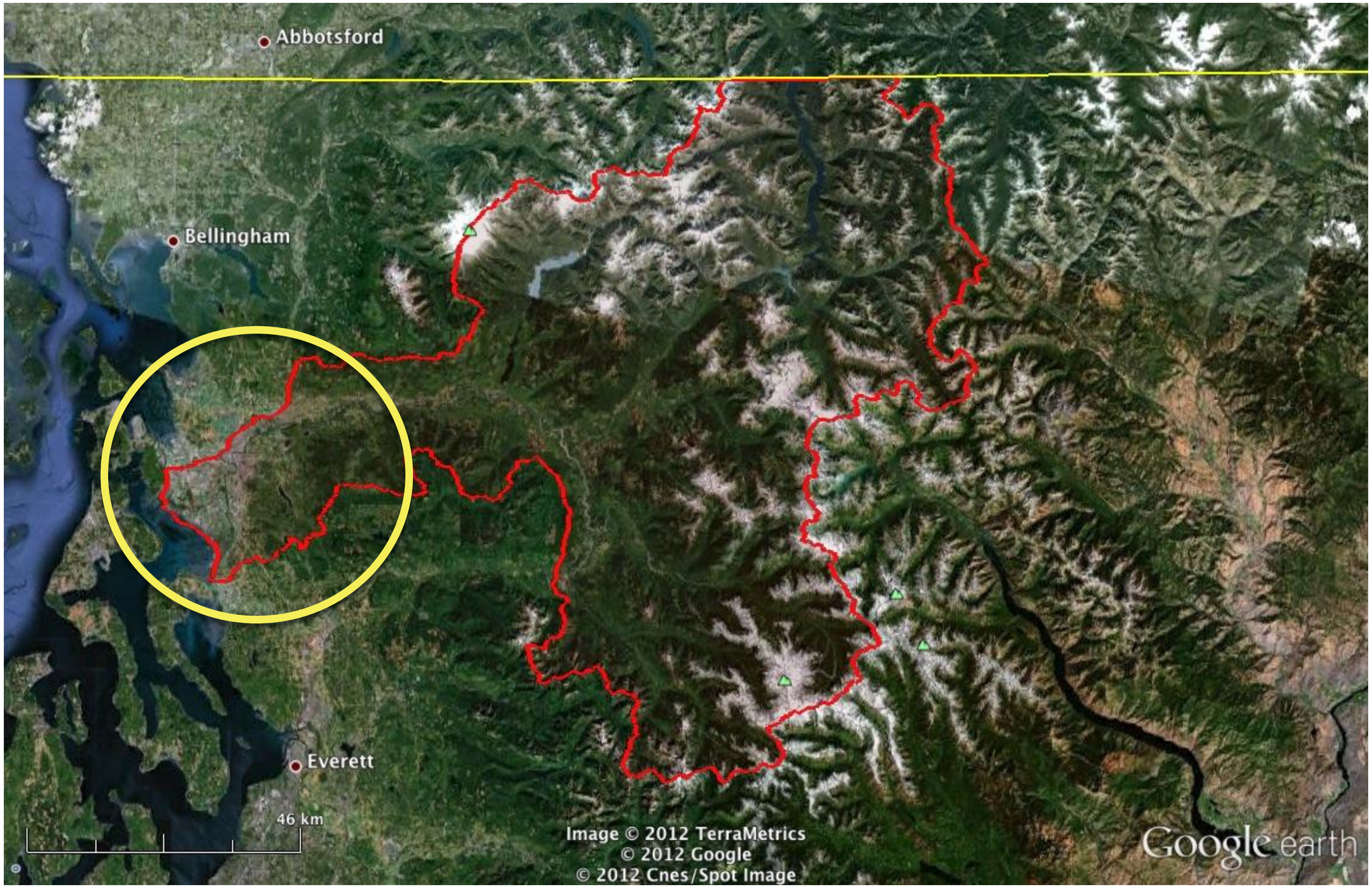


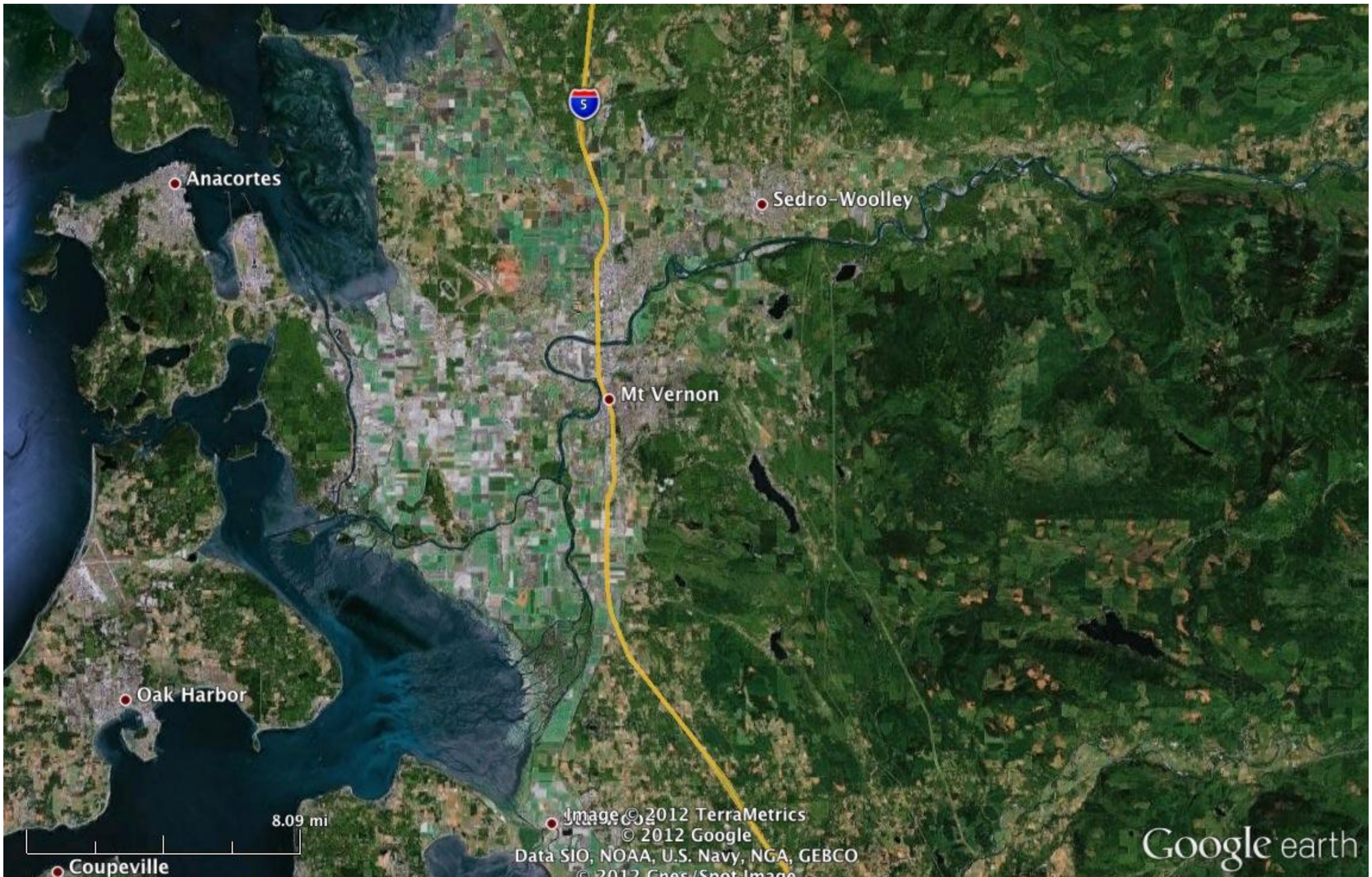
SKAGIT RIVER BASIN



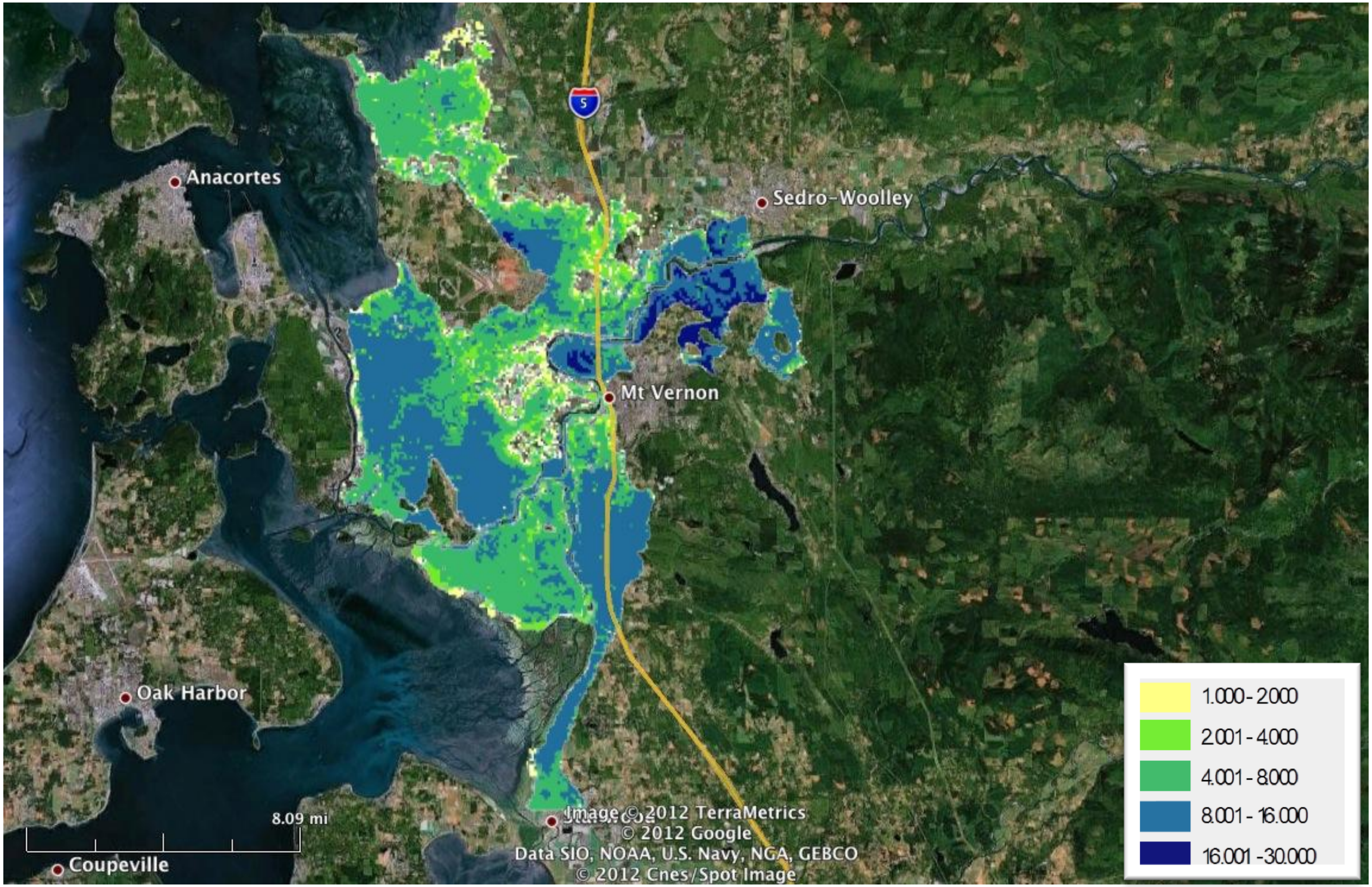
SKAGIT RIVER BASIN



LOWER SKAGIT RIVER BASIN

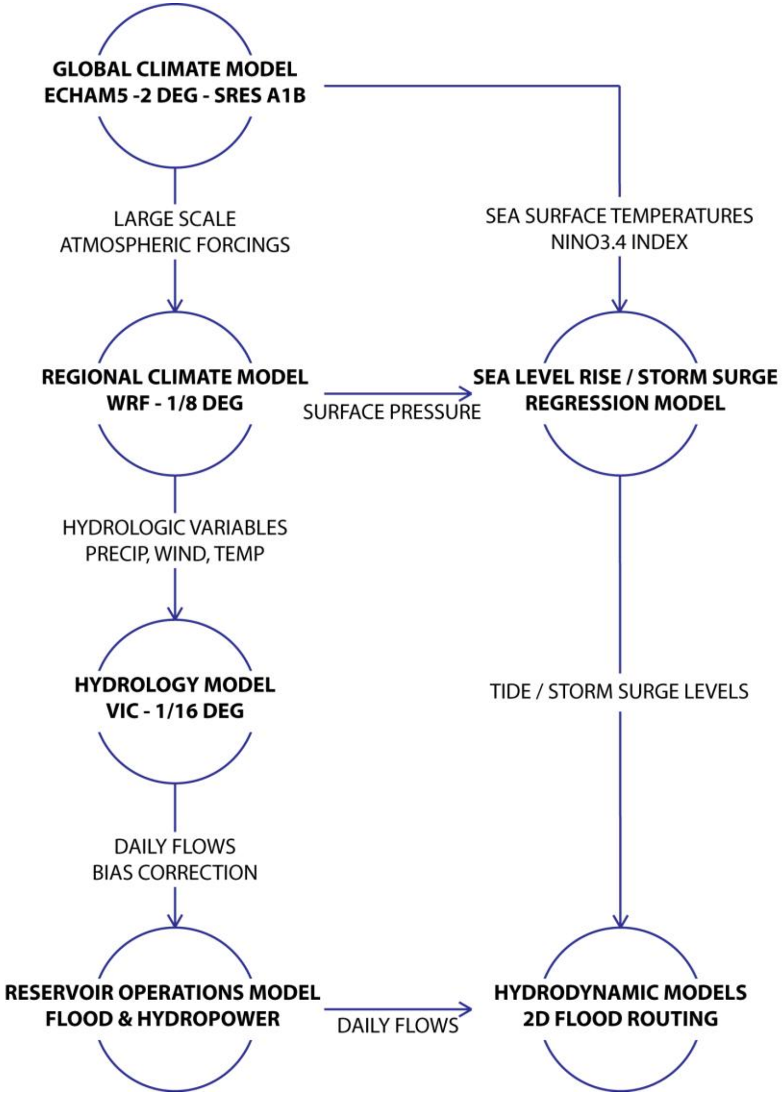


FLOOD MAPPING



METHODS
HYDROLOGY

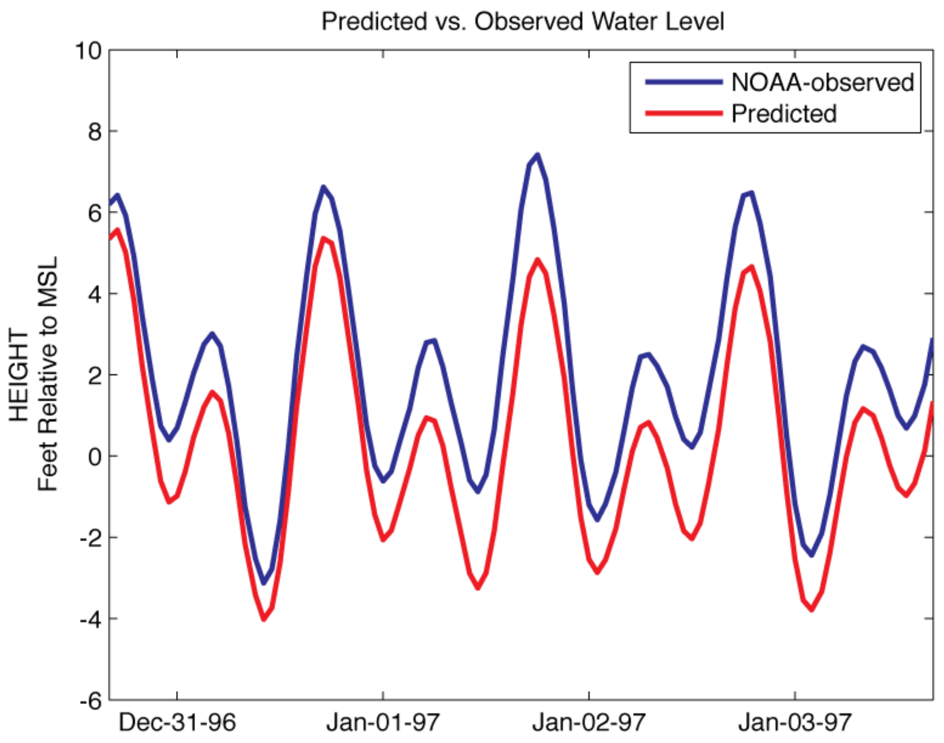
- Goal: Combine hydrology and sea level rise projections to develop new flood maps
- Hydrologic Methods:
  1. Downscale GCM results
     - Statistical Downscaling: Hybrid Delta Method
     - Dynamic Downscaling: WRF Regional Climate Model
  2. Use downscaled GCM results to run hydrology model
     - Hydrology Model: Variable Infiltration Capacity (VIC) Model
  3. Use a reservoir model to simulate hydropower and flood operations



METHODS

SEA LEVEL

- Sea Level Methods:
  1. Use regression model to predict anomalous water levels
     - Anomaly = f (Pressure, Pressure Patterns, ENSO)
  2. Add anomalies to predicted tides
  3. Add sea level rise to modified tidal signal



METHODS
SEA LEVEL RISE

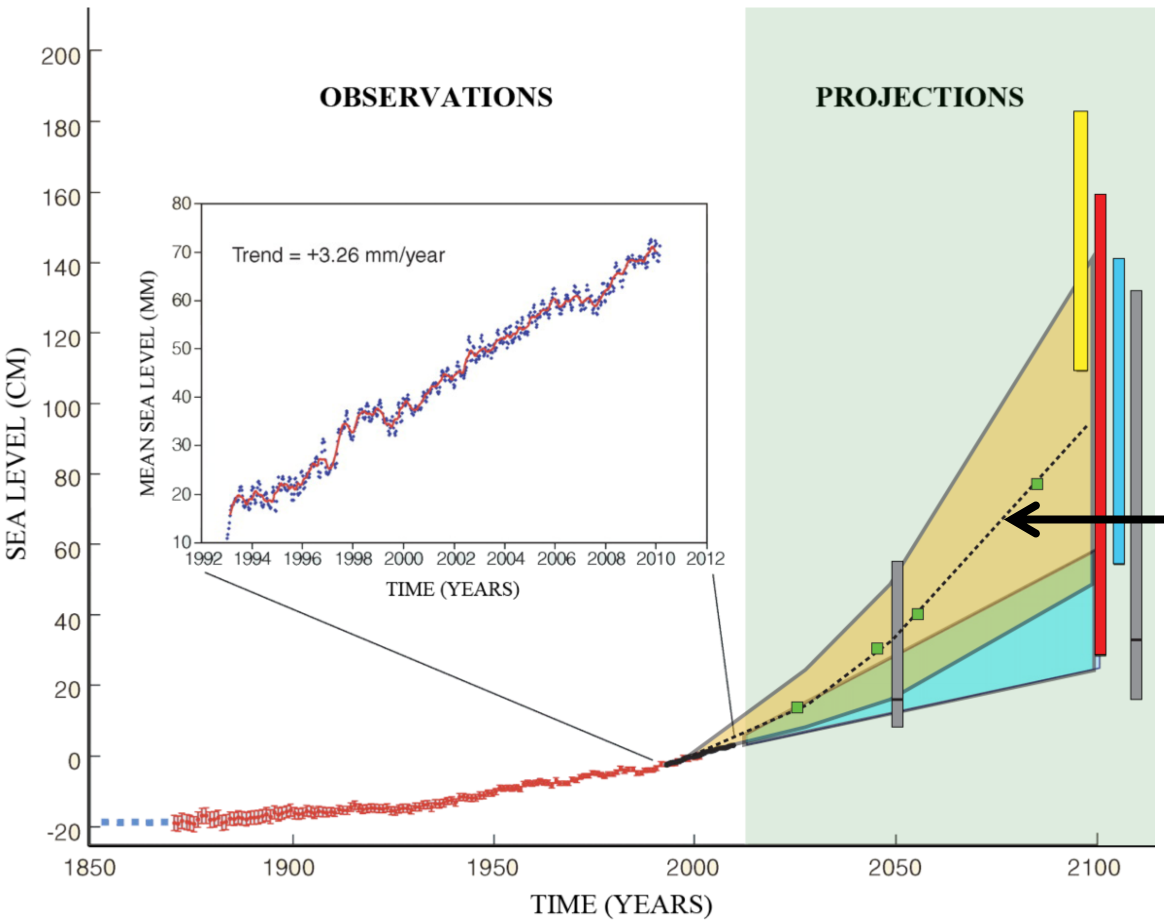
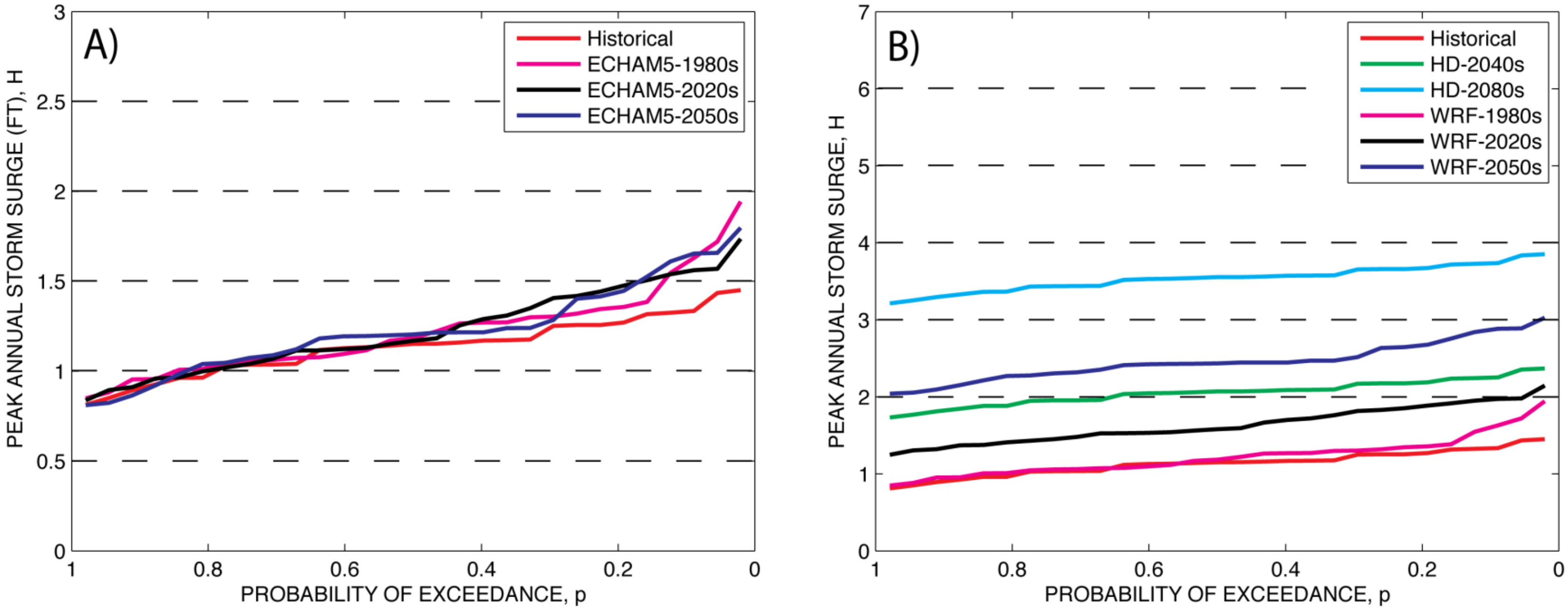


Figure adopted from Nicholls and Cazenave (2010) and Mote et al. (2008).

- Large range in SLR projections
- We used the mean NRC Projections

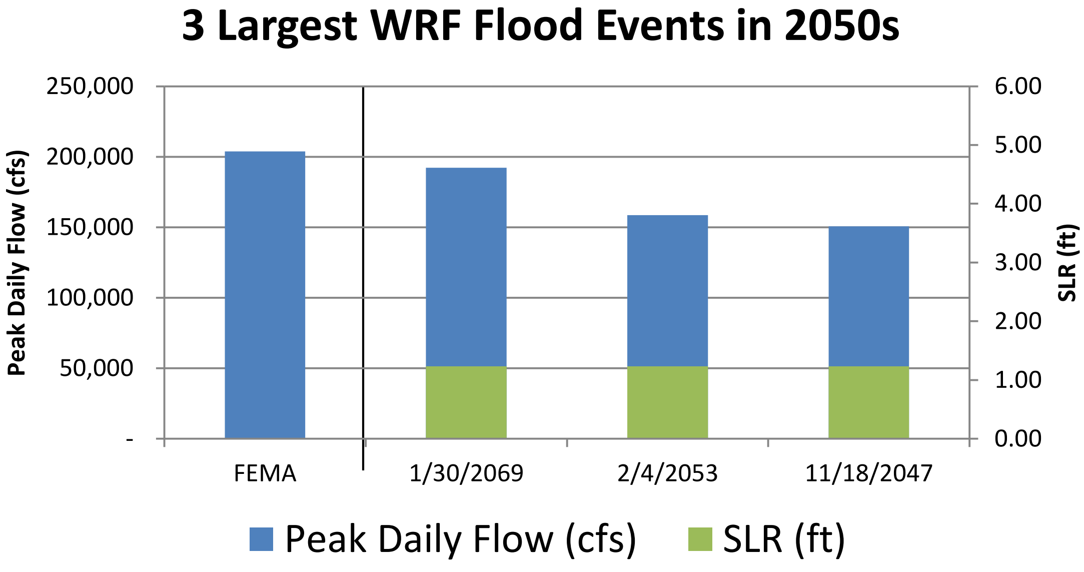
STORM SURGE AND SLR

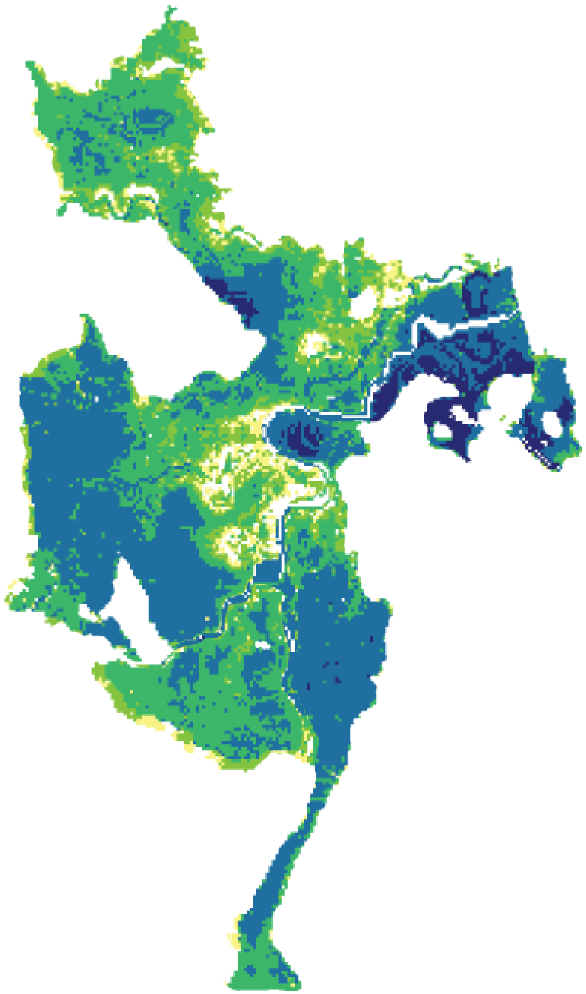


- No change in the CDFs between RCM time periods
- SLR, by comparison, drastically changes the CDFs by shifting them each upward

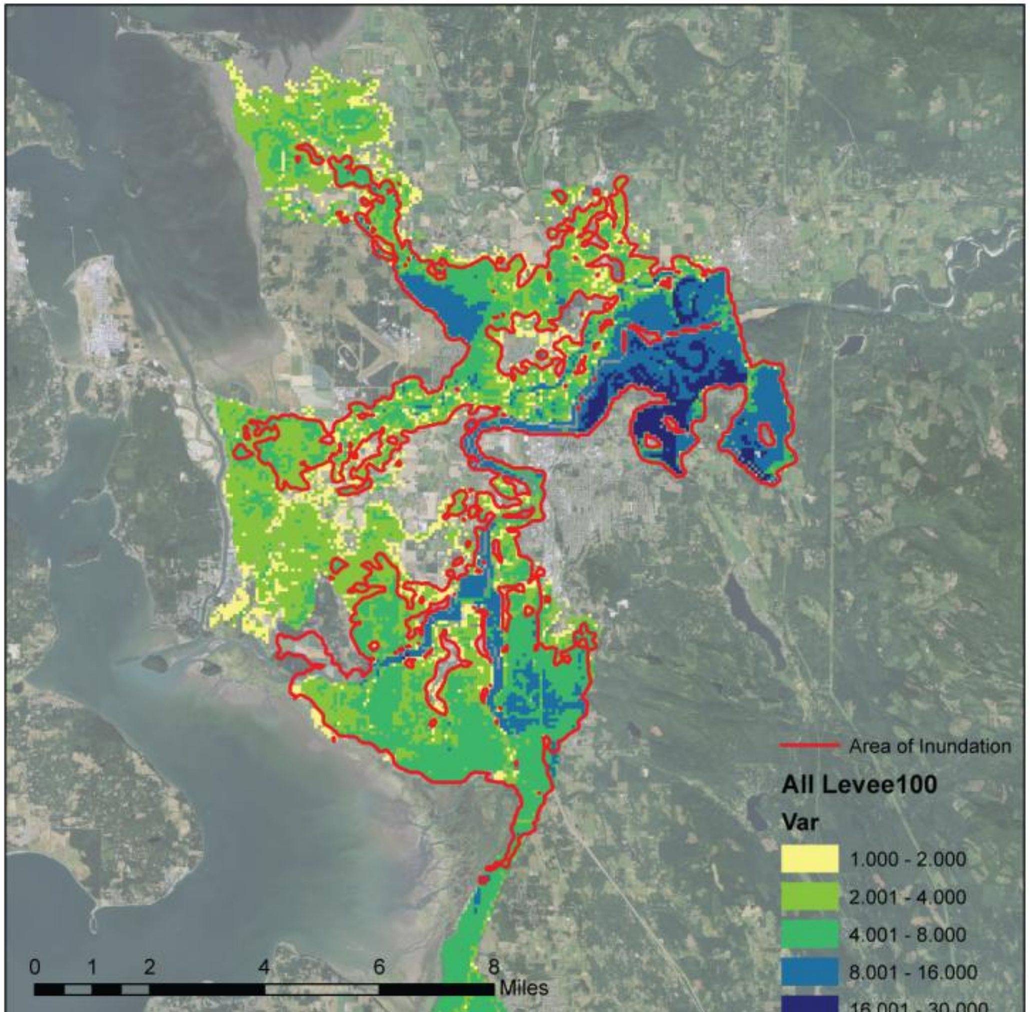
METHODS
HYDRODYNAMIC MODELING

- Skagit Model developed by USACE and FEMA
- 2D hydrodynamic model, Flo2D
- Simulates channel and overbank flow in lower Skagit River Basin
- Includes current levees and dikes



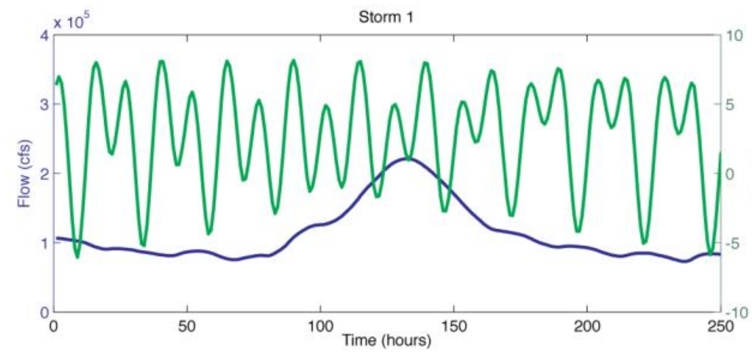


WRF-2050S FLOOD 1
ALL LEVEES INTACT



Inputs:

- Hydrograph: 1/30/2060 (94% of Historical 100yr)
- Sea Level Rise: 1.23 feet

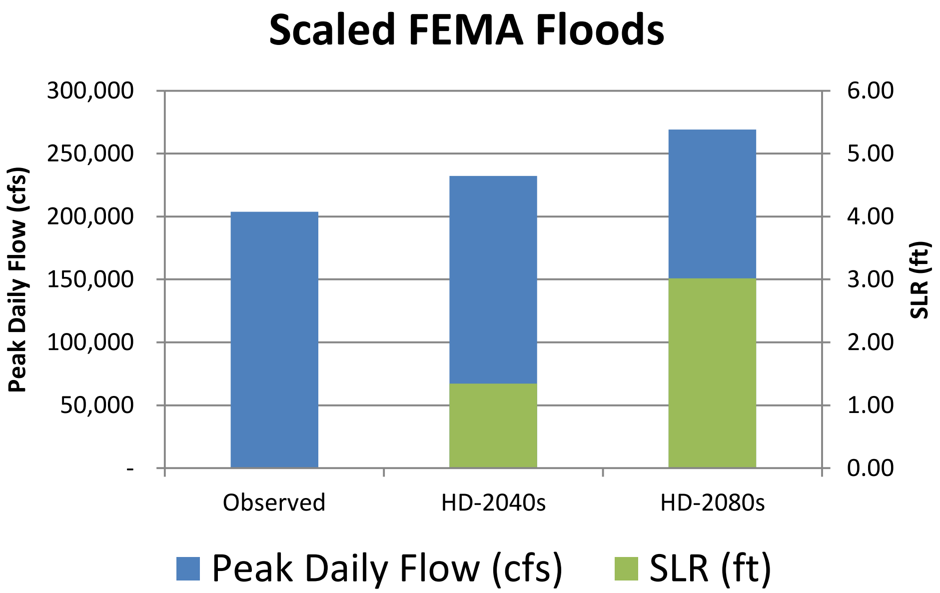


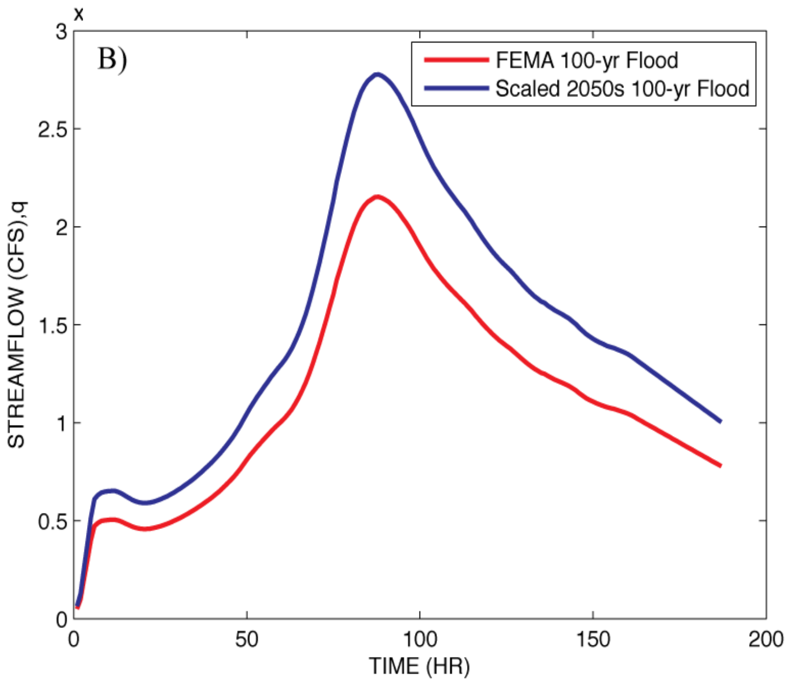
Area Flooded: 51,365 acres (+22%)

METHODS
100-YEAR FLOOD MAPPING

- Applied relative changes in 100-year flood to FEMA hydrograph
- Eliminates model bias in peak flows
- Performed composite flood mapping for 2040s and 2080s
  (7 levee failure scenarios)

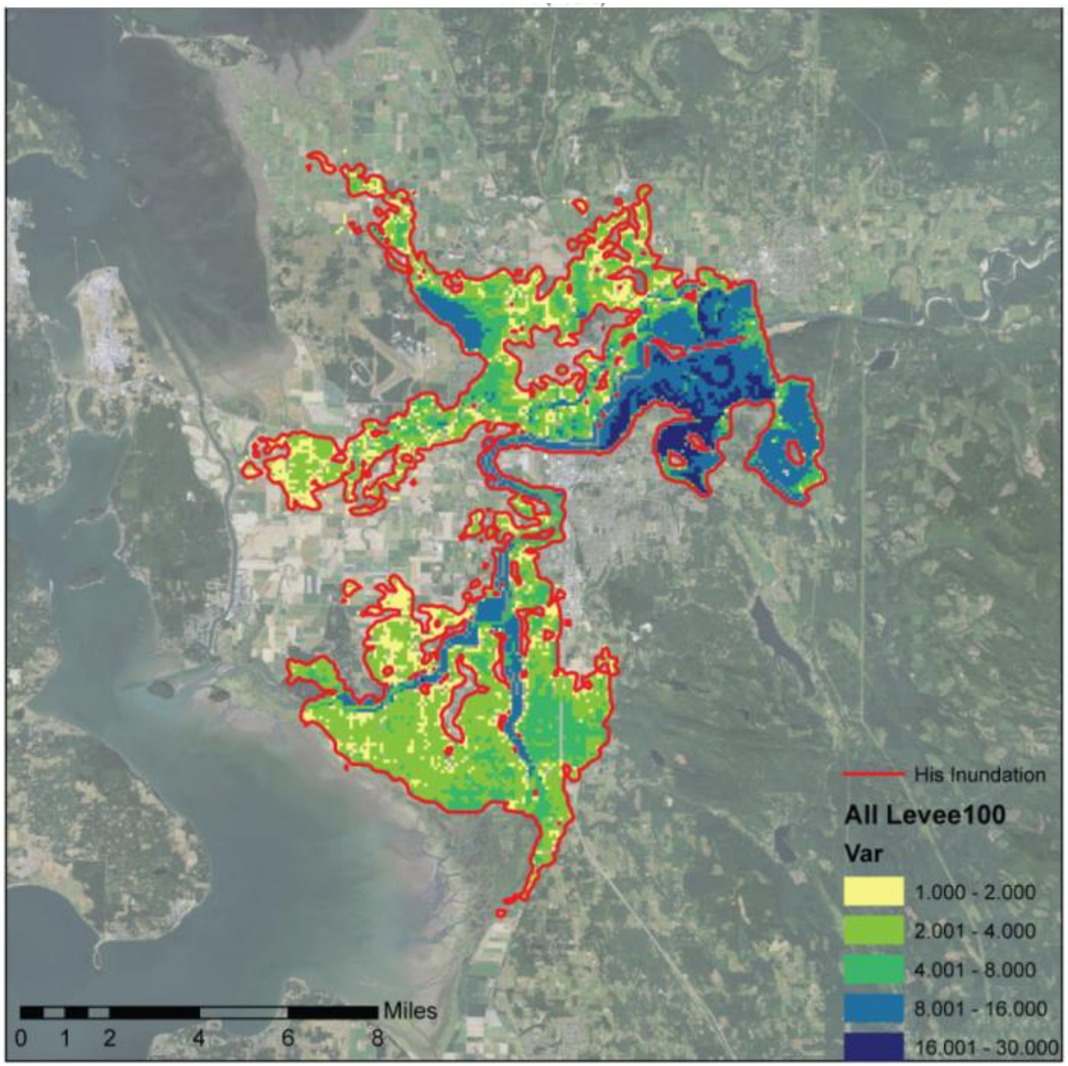
$$FEMA_{2040s} = FEMA \times \frac{100yrHD_{2040s}}{100yrHis}$$





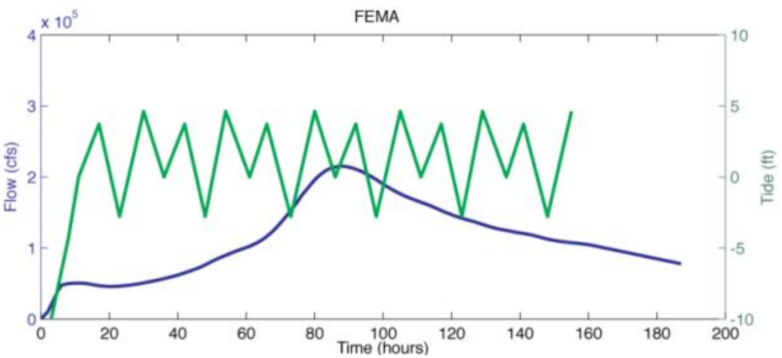
HISTORICAL 100-YEAR FLOOD

ALL LEVEES INTACT



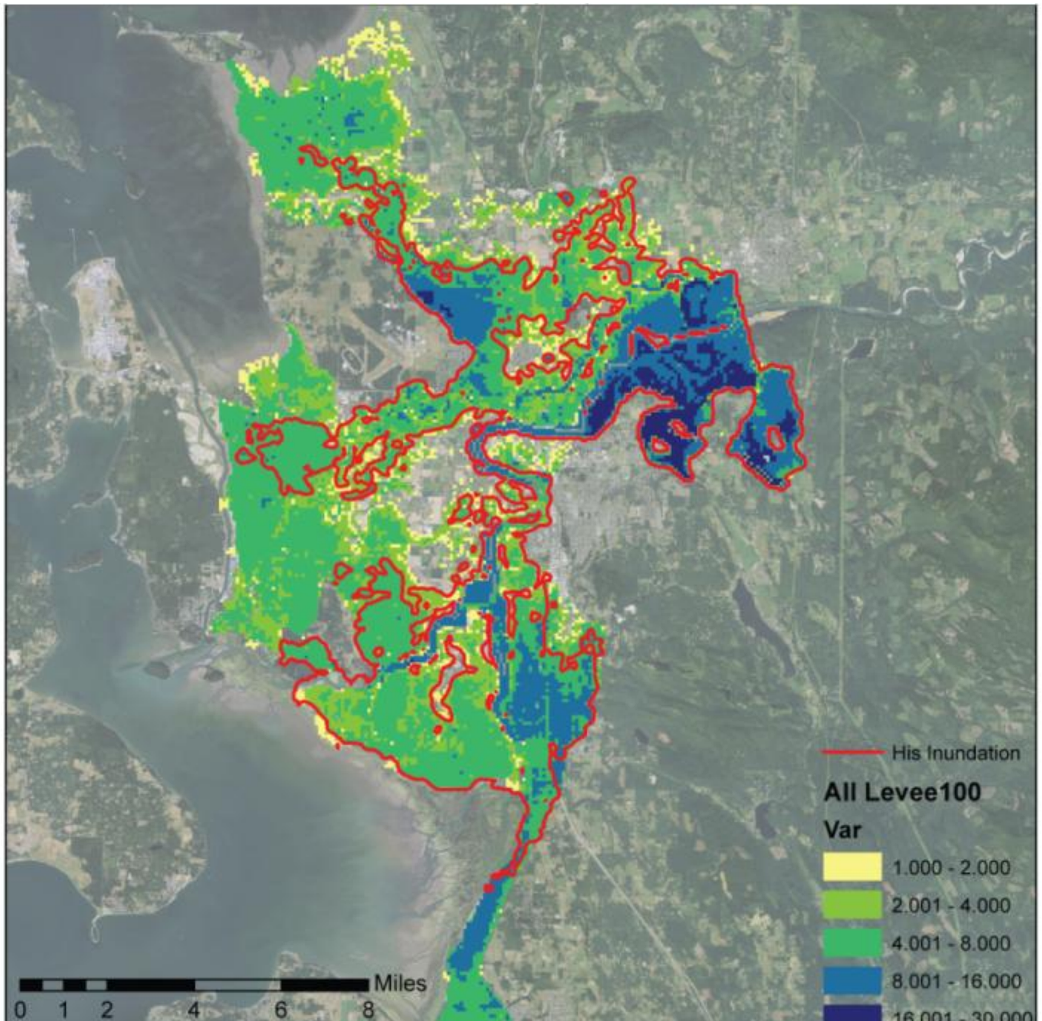
Inputs:

- Hydrograph: Historical 100yr
- Sea Level Rise: 0.00 feet

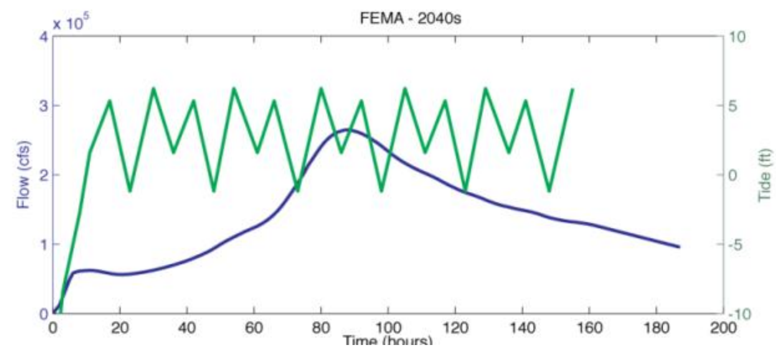


Area Flooded: 42,266 acres

2040S 100-YEAR FLOOD
ALL LEVEES INTACT



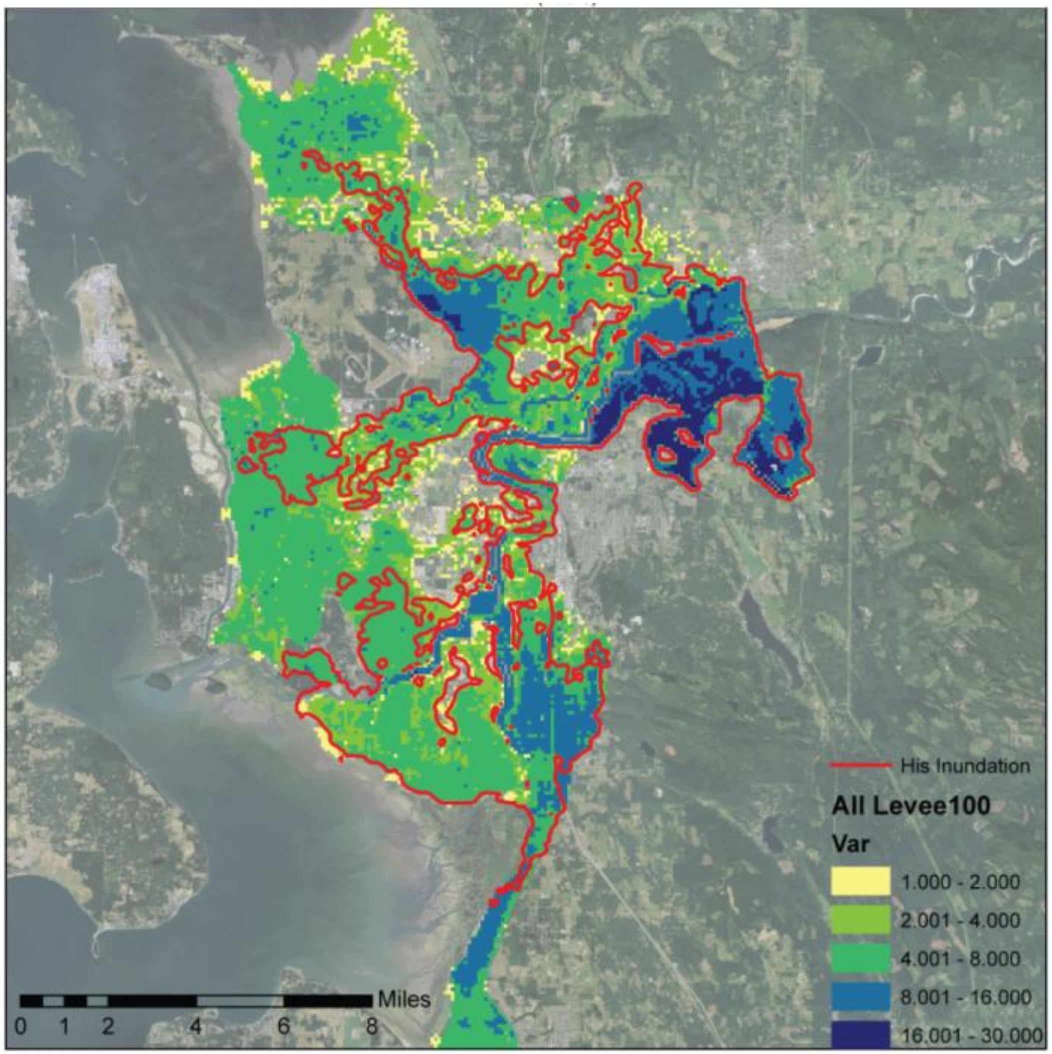
Inputs:
- Hydrograph: 1.14 x (His 100yr)
- Sea Level Rise: 1.35 feet



Area Flooded: 66,248 acres (+57%)

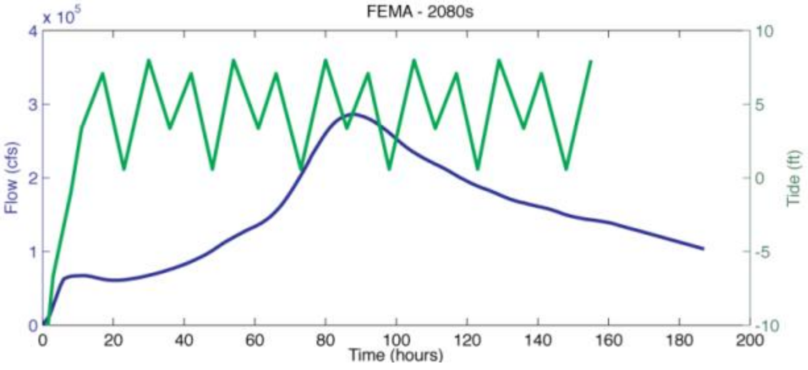
2080S 100-YEAR FLOOD

ALL LEVEES INTACT



Inputs:

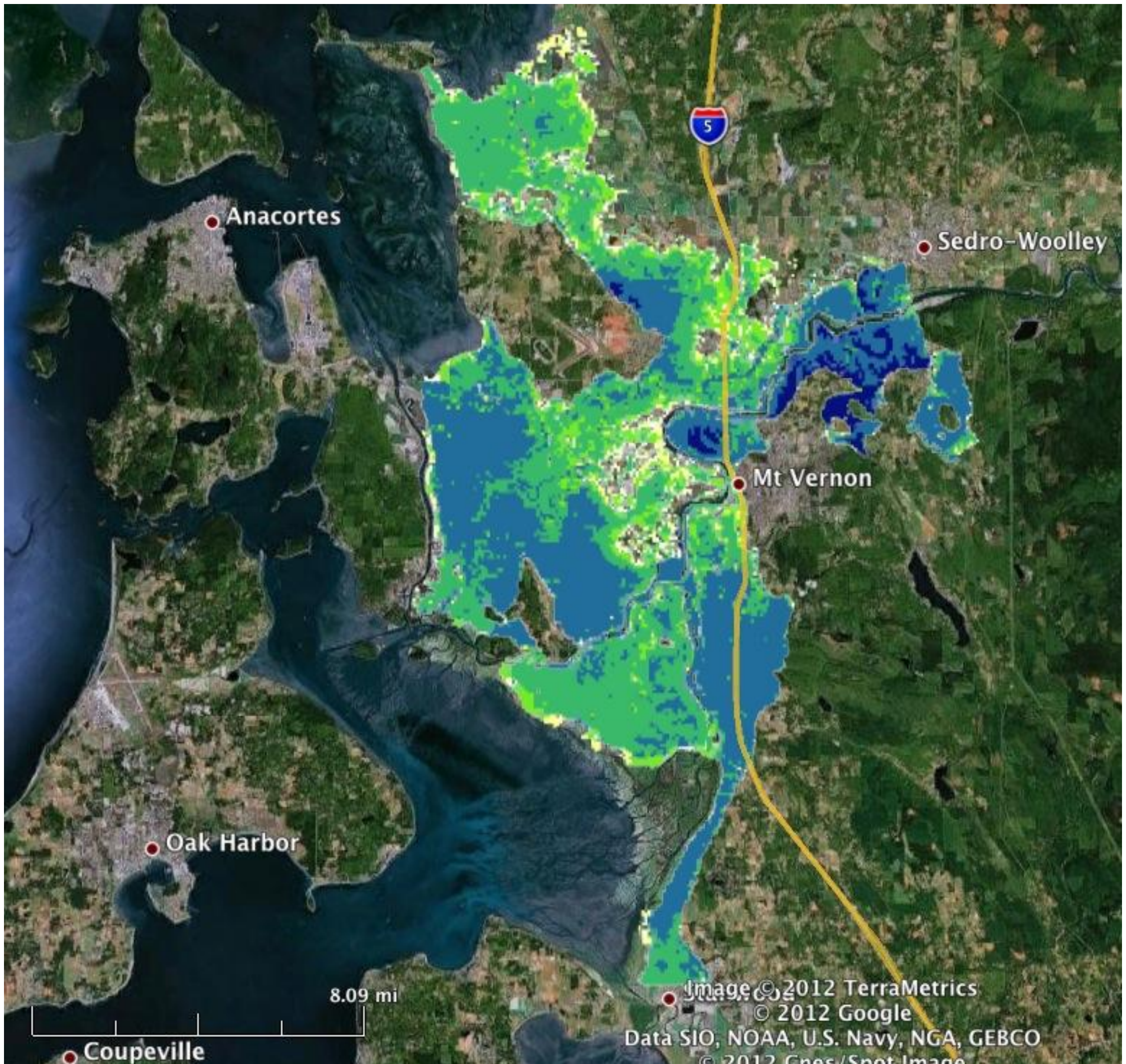
- Hydrograph: 1.32 x (His 100yr)
- Sea Level Rise: 3.02 feet



Area Flooded: 73,594 acres (+74%)

COMPOSITE FLOOD MAPS

HISTORICAL



Inputs:

- Hydrograph: Historical 100yr
- Sea Level Rise: 0.00 feet

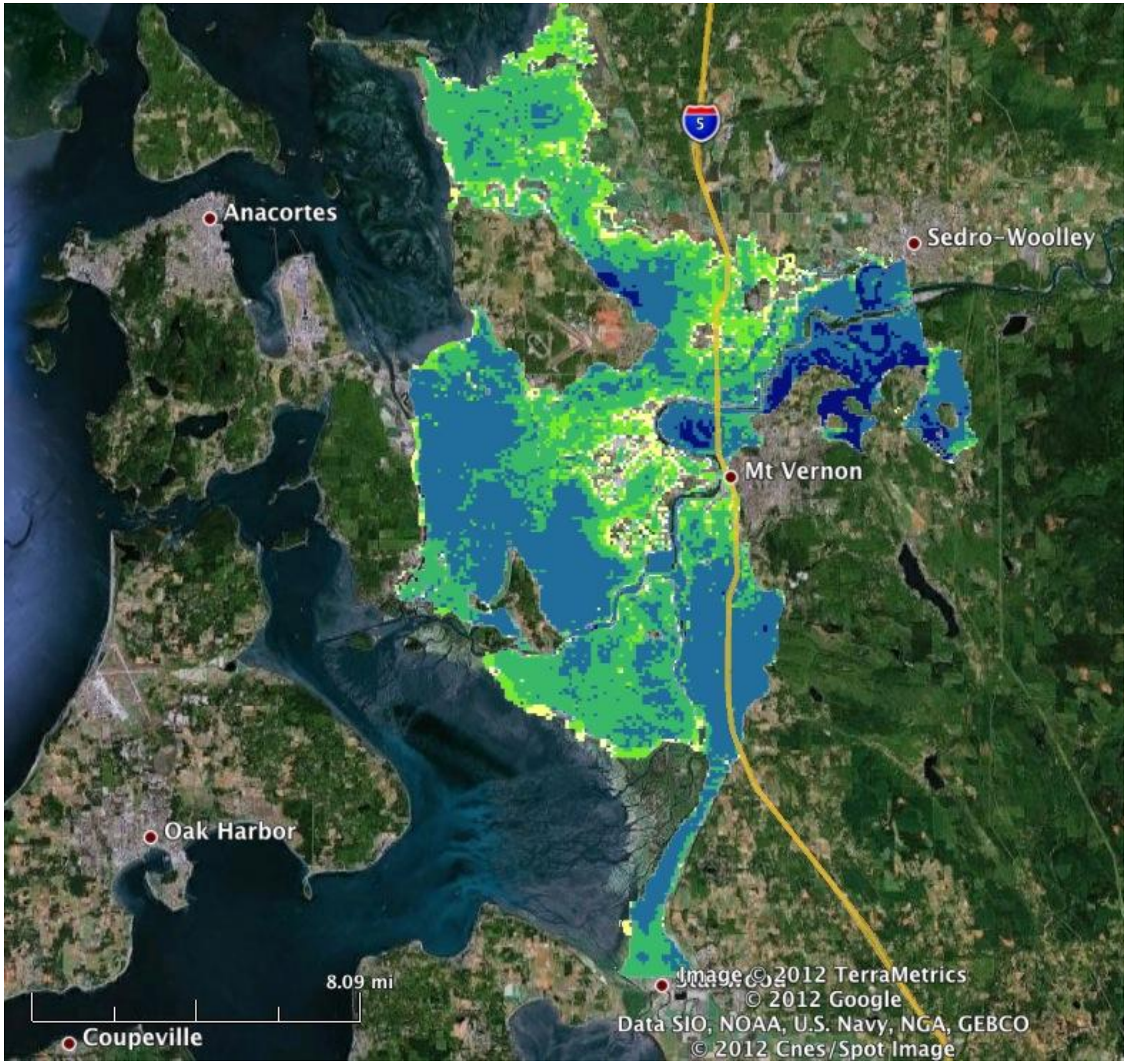
Area Flooded: 71,427 acres

Avg Depth: 7.03 feet

- 1.000 - 2.000
- 2.001 - 4.000
- 4.001 - 8.000
- 8.001 - 16.000
- 16.001 - 30.000

COMPOSITE FLOOD MAPS

2040S



Inputs:

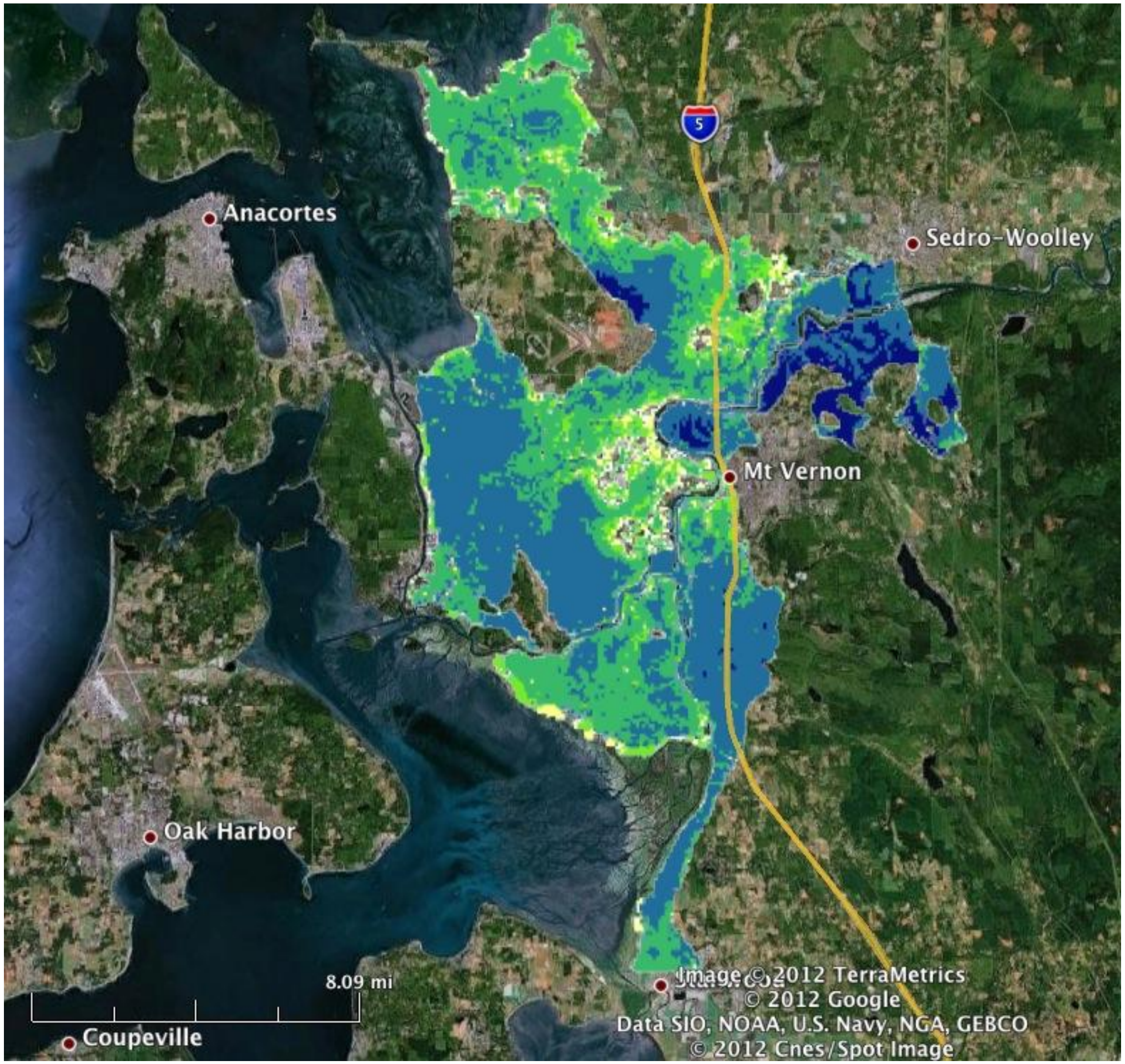
- Hydrograph: 1.14 x (His 100yr)
- Sea Level Rise: 1.35feet

Area Flooded: 72,206 acres (+1%)

Avg Depth: 7.46 feet (+5 inches)

1.000 - 2.000
2.001 - 4.000
4.001 - 8.000
8.001 - 16.000
16.001 - 30.000

COMPOSITE FLOOD MAPS
2080S



Inputs:
- Hydrograph: 1.32 x (His 100yr)
- Sea Level Rise: 3.02 feet

Area Flooded: 72,768 acres (+2%)

Avg Depth: 7.46 feet (+10 inches)

(yellow)	1.000 - 2.000
(light green)	2.001 - 4.000
(green)	4.001 - 8.000
(blue)	8.001 - 16.000
(dark blue)	16.001 - 30.000

CONCLUSIONS

- Future storm surge, brought on by barometric and wind effects, is not expected to change significantly.
- Sea level rise is expected to influence extreme water levels much more than changes in storm surge.
- Inundation from flooding in the Skagit is expected to increase by up to 74% by the 2080s given combined SLR and increased flood magnitudes.
- Average depth in flood map increases by
  - 5 inches in 2040s
  - 10 inches in 2080s
- Using a scenario based approach is an effective way to understand changes in flood magnitudes over time.

QUESTIONS?

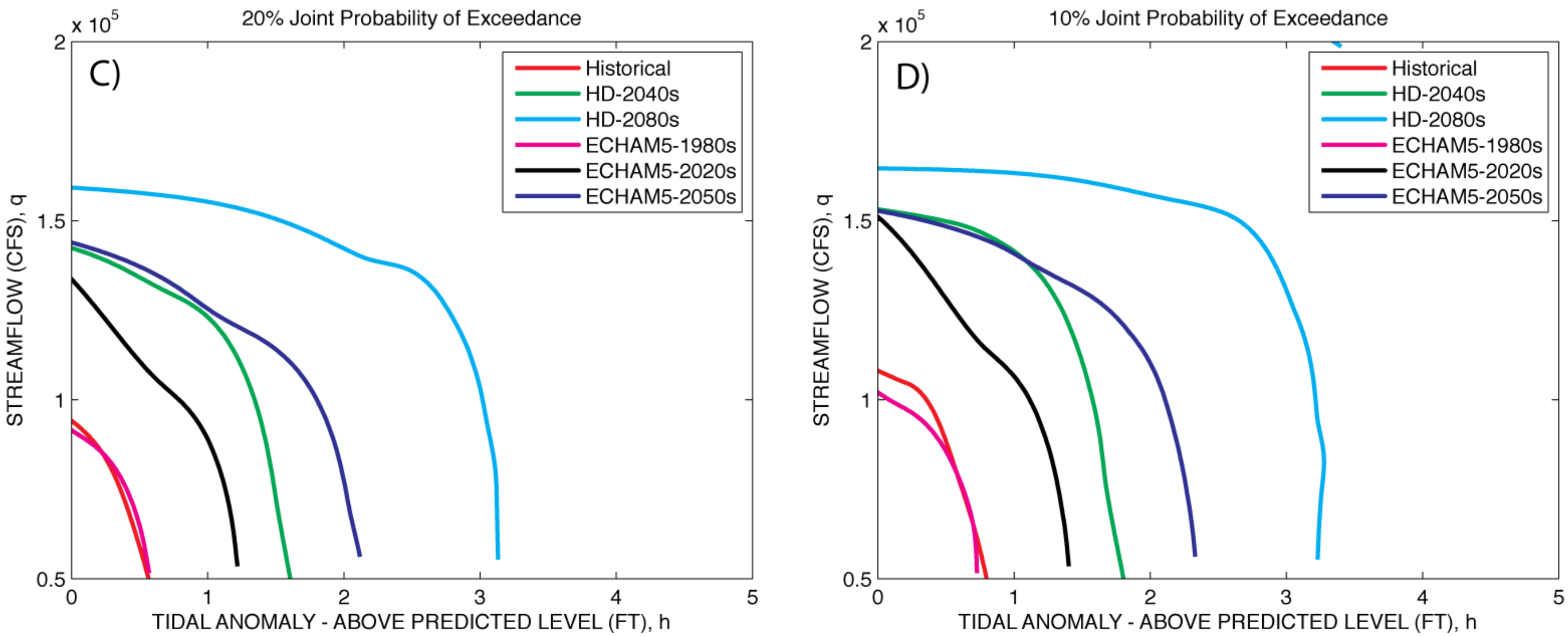
Acknowledgments

- Alan Hamlet, Faculty Advisor
- Contributors
  - Se-Yuen Lee
  - Matt Stumbaugh
  - Eric Salathé
- EPA Funding
  - Roger Fuller
  - Eric Grossman

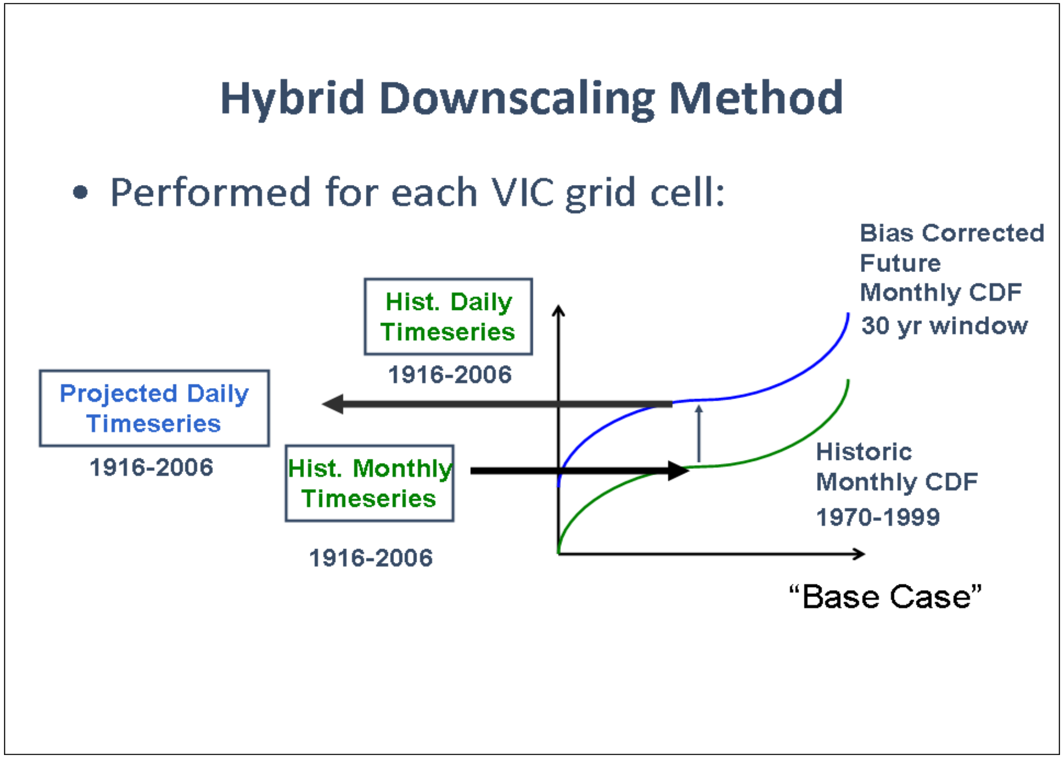
EXTRAS

JOINT PROBABILITY OF EXCEEDANCE

Skagit River

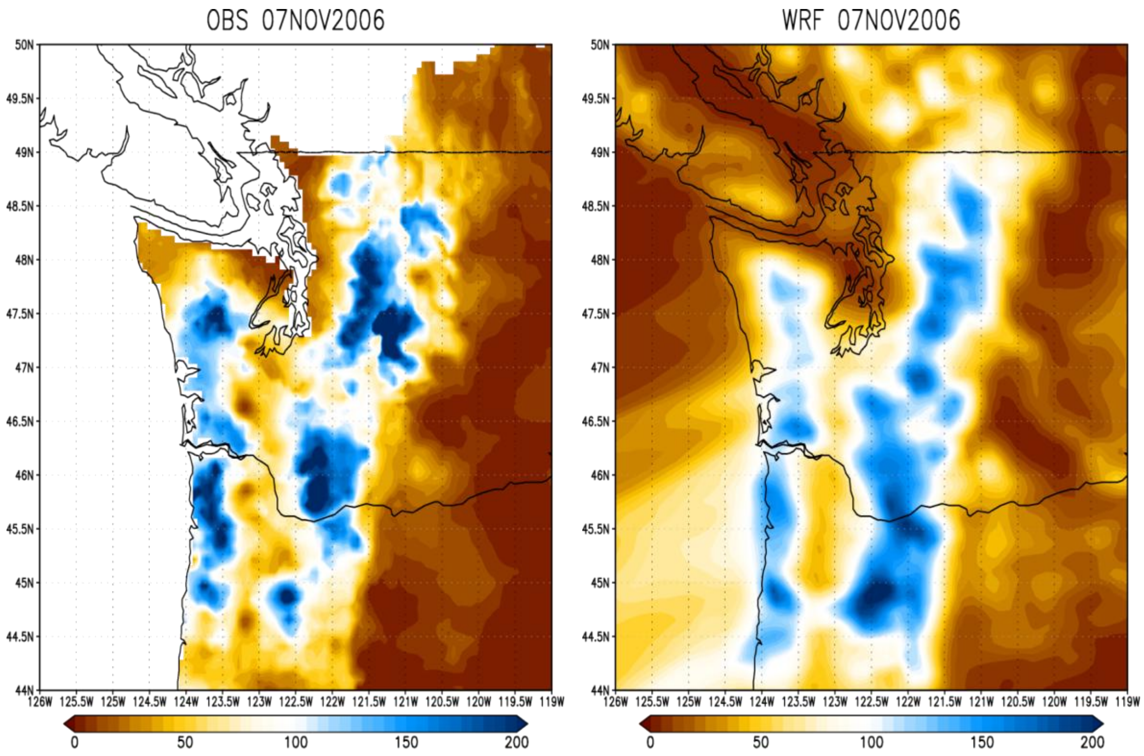


STATISTICAL DOWNSCALING



- Adjusts historic monthly timeseries to match CDF of GCM at each grid cell
- Forces historic daily timeseries to fit new monthly values
- Preserves most of the historical time series behavior
  - Storm size, storm location, interarrival, seasonality, time, etc.
- Two30-year time periods
  - 2040s and 2080s

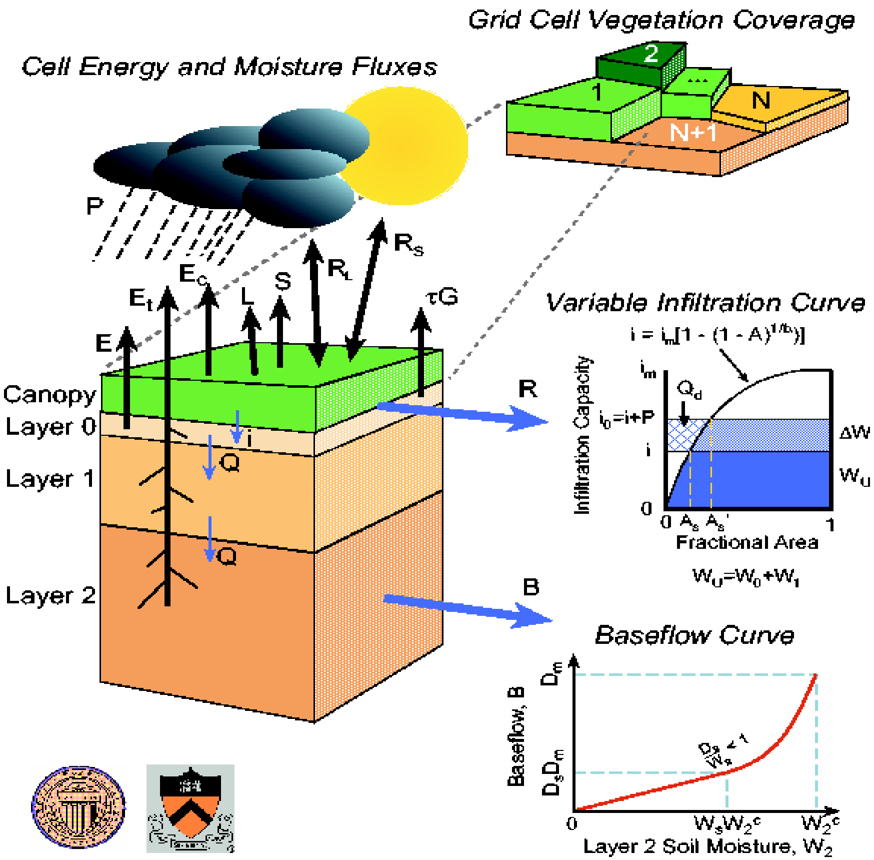
DYNAMIC DOWNSCALING



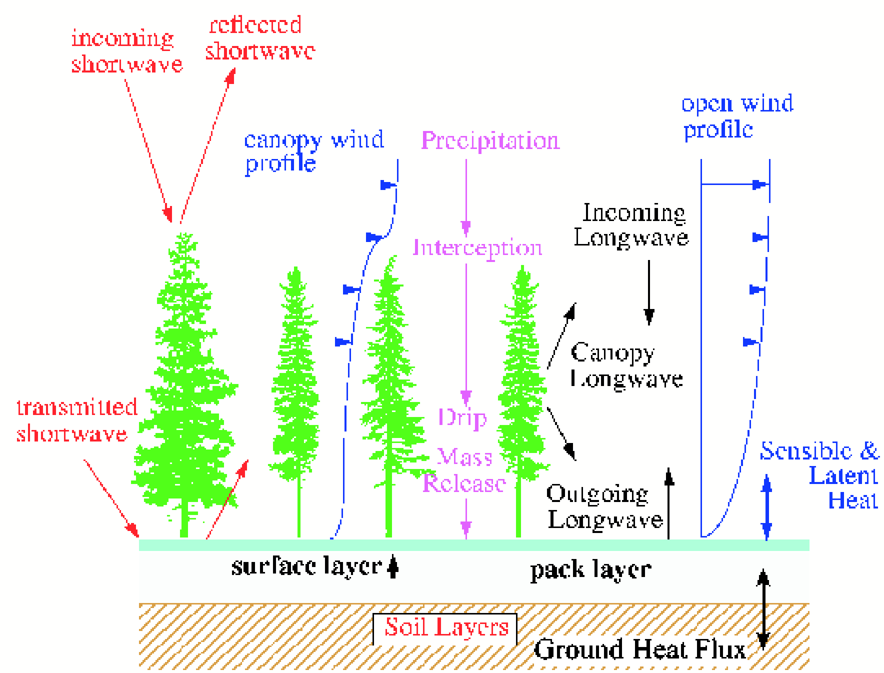
- WRF provides atmospheric conditions at much higher resolution
- Simulates actual weather prescribed by large scale GCM
- Produces actual storms
- Does not rely on the historical time series
- Three 30-year time periods
  - 1980s, 2020s and 2050s

HYDROLOGIC MODELING

Variable Infiltration Capacity (VIC)
Macroscale Hydrologic Model

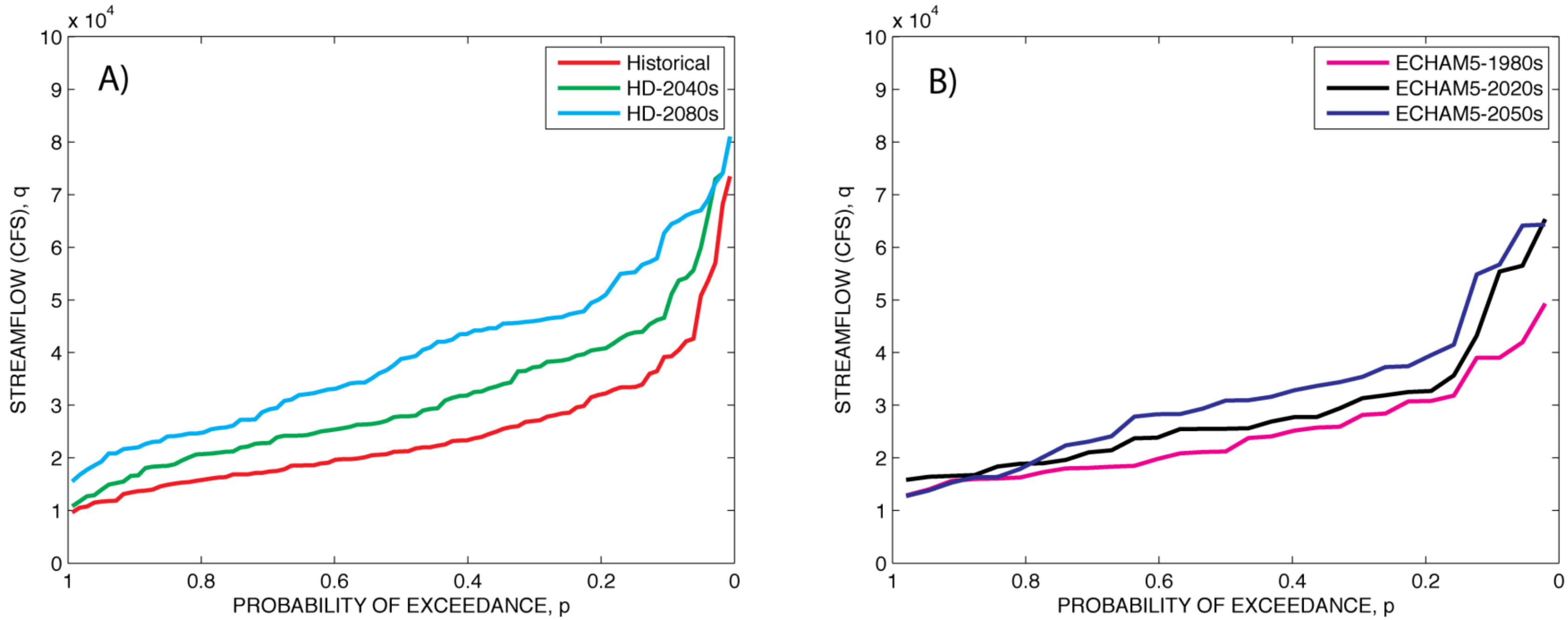


VIC Snow Algorithm



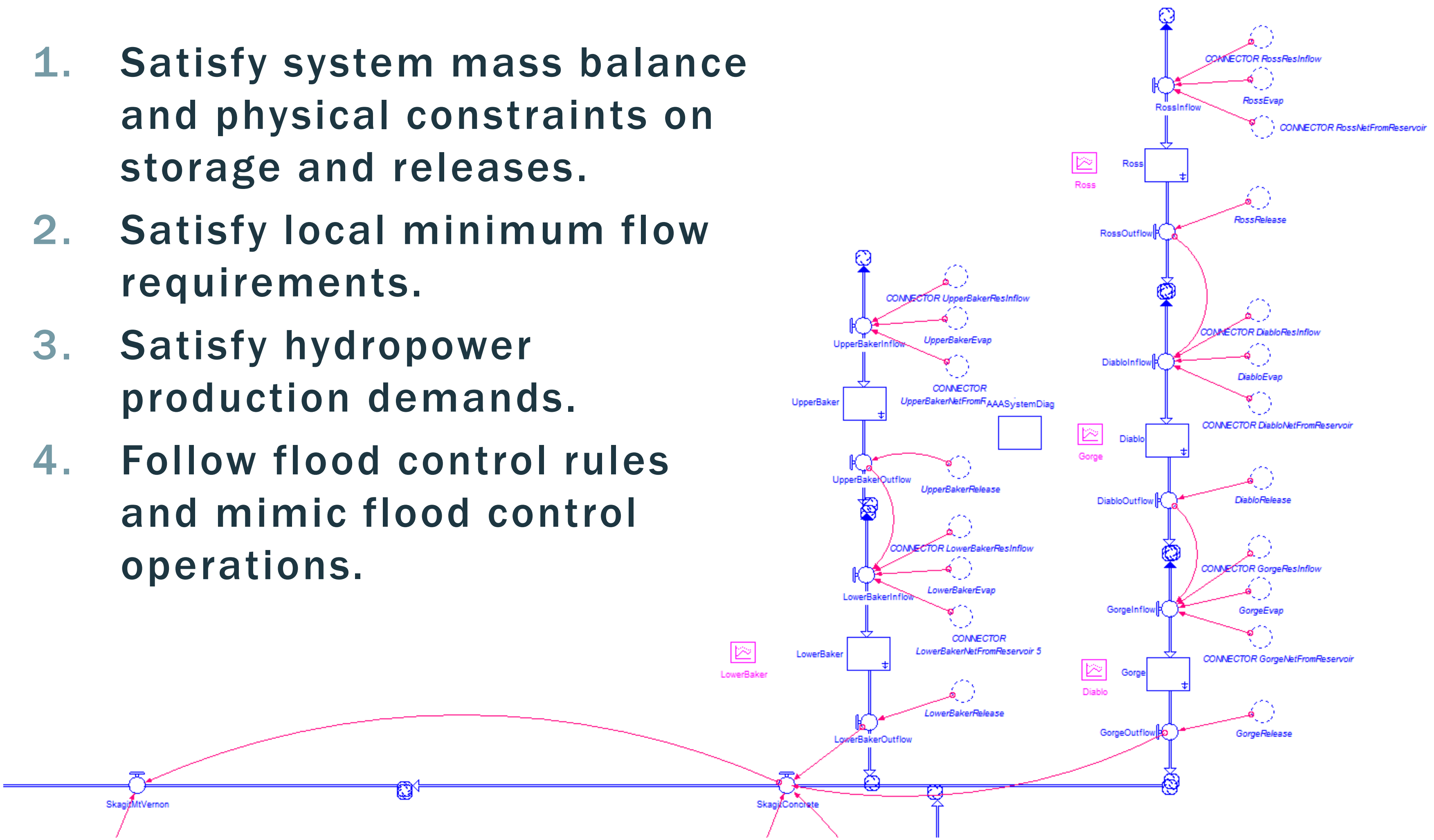
UNREGULATED HYDROLOGY

Sauk River near Sauk, WA

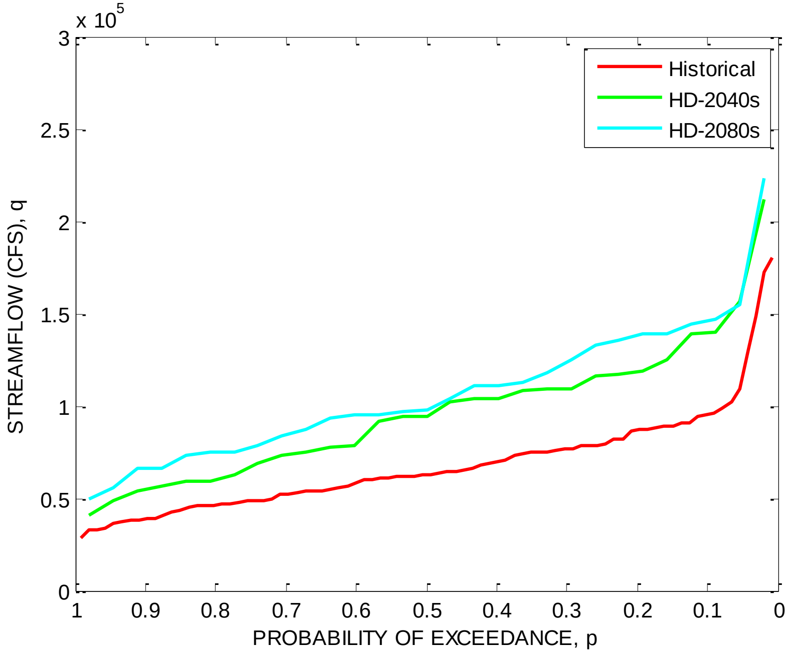


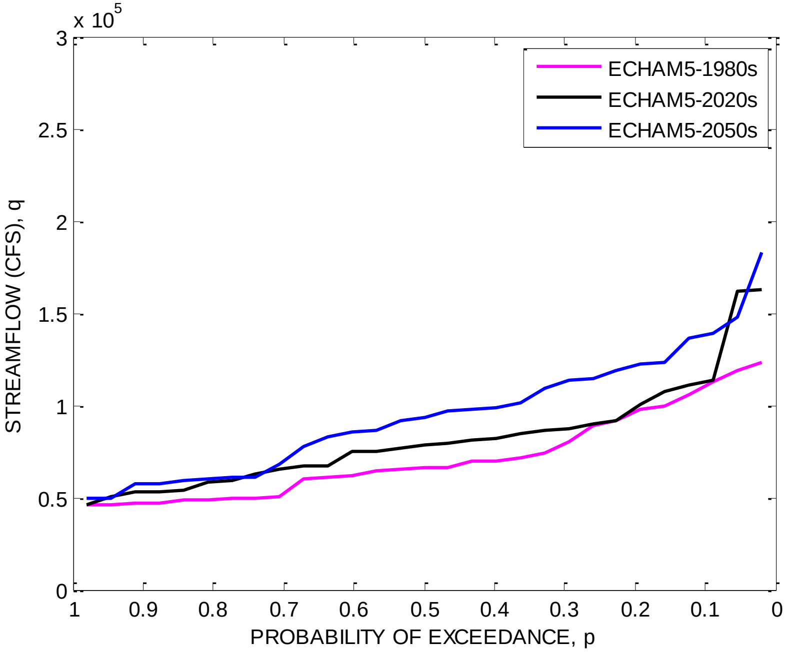
RESERVOIR MODELING

1. Satisfy system mass balance and physical constraints on storage and releases.
2. Satisfy local minimum flow requirements.
3. Satisfy hydropower production demands.
4. Follow flood control rules and mimic flood control operations.



REGULATED PEAK FLOWS





COMPOSITE FLOOD MAPS
7 LEVEE FAILURE SCENARIOS