IMPACTS ON FLOODING IN THE SKAGIT RIVER
DEVELOPING TOOLS FOR BETTER FLOODPLAIN MANAGEMENT

Joe Hamman

October 10, 2012

King County Brownbag Seminar Series: Responding to Climate Change

Seattle, WA

CLIMATE IMPACTS GROUP

Department of Civil and Environmental Engineering

GLOBAL CLIMATE CHANGE

PRESENTATION OUTLINE

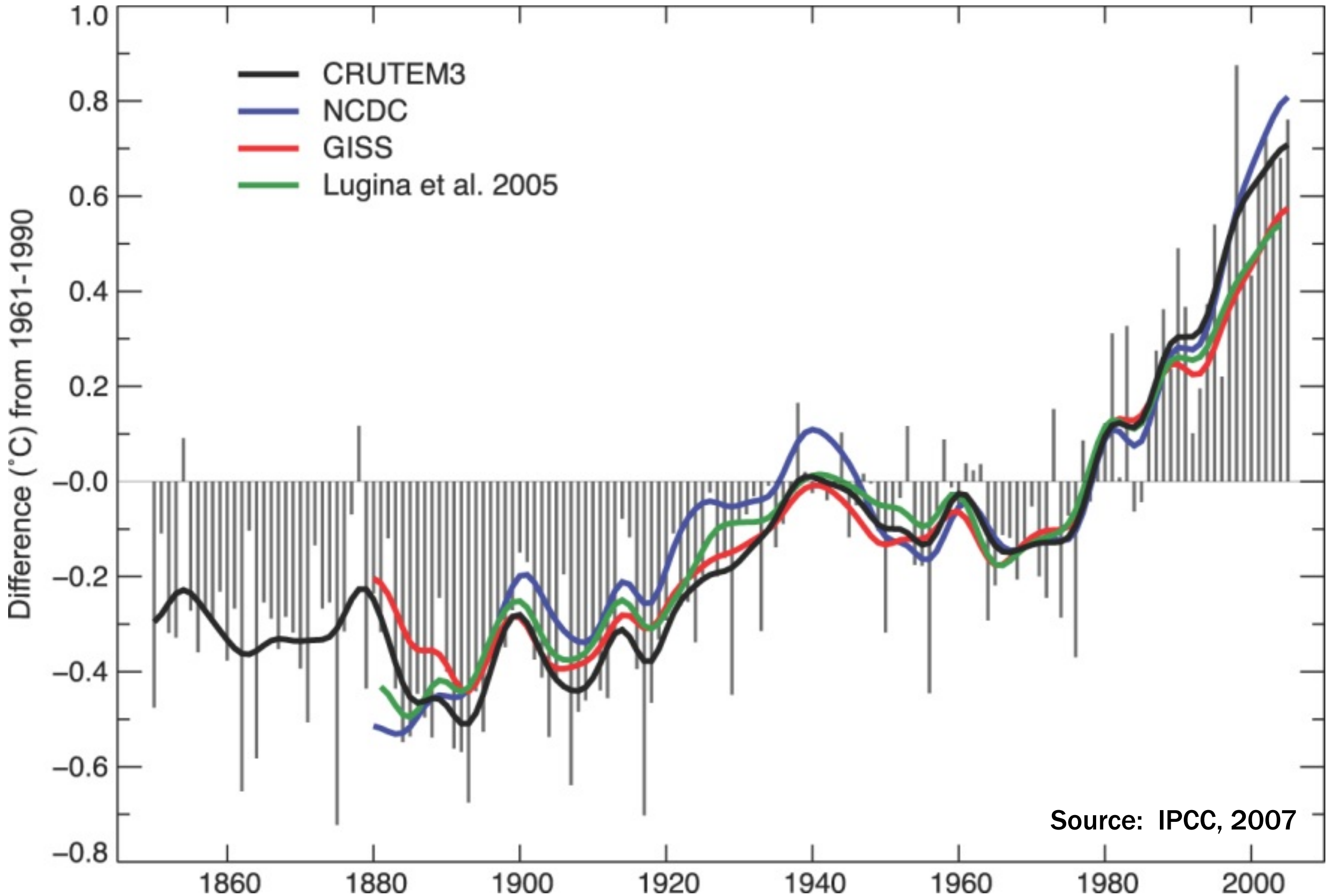
1. Brief overview of current climate science
2. Implications of climate change for river flooding and sea level rise
3. Overview of the Skagit River Watershed and flood history
4. Climate change impacts on flooding in the Skagit River
5. Potential for risk reduction
6. Questions

Aerial computer generated depiction of large flood event from Burlington to Mount Vernon to Padilla Bay

Picture Courtesy Skagit County Public Works Department

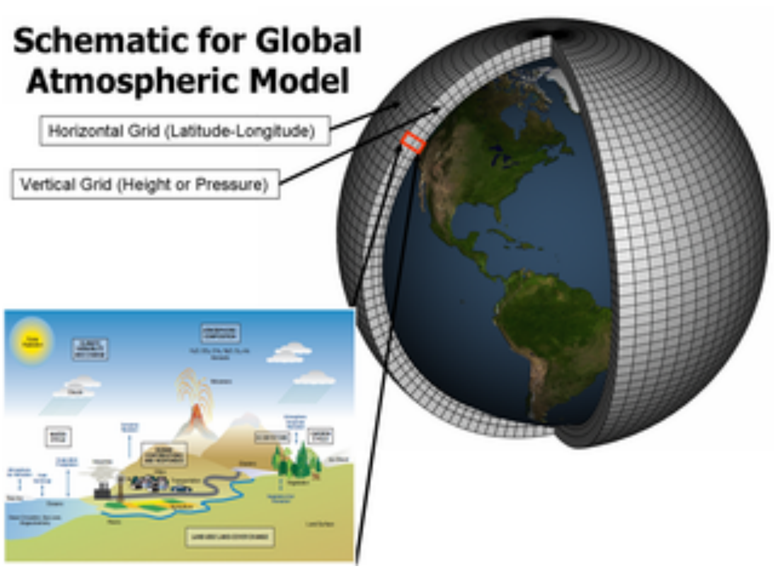
GLOBAL CLIMATE CHANGE
THE BASICS

20th century warming between 0.75 and 1°C

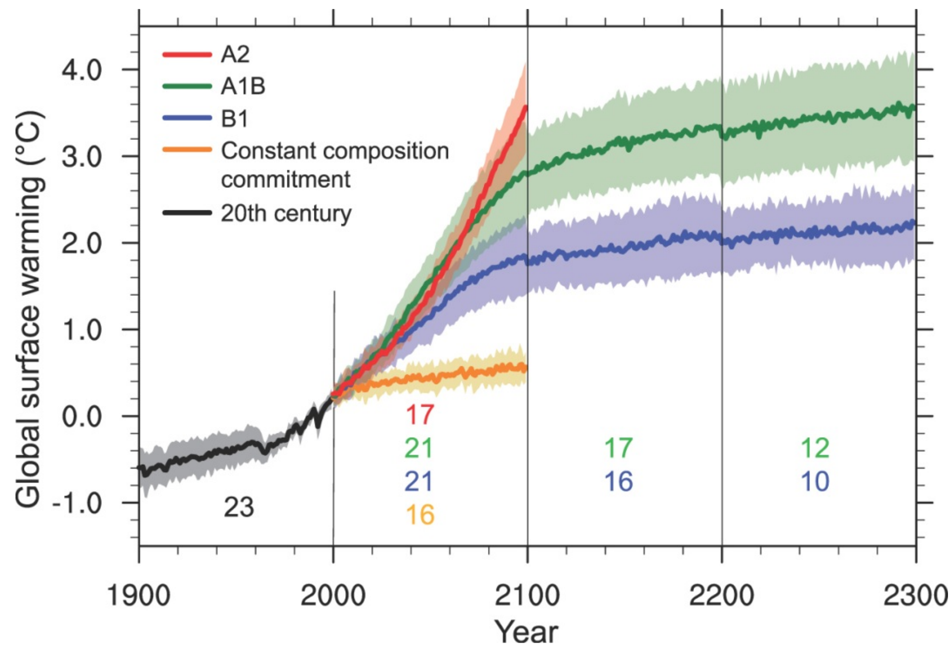


Source: IPCC, 2007

GLOBAL CLIMATE MODELS



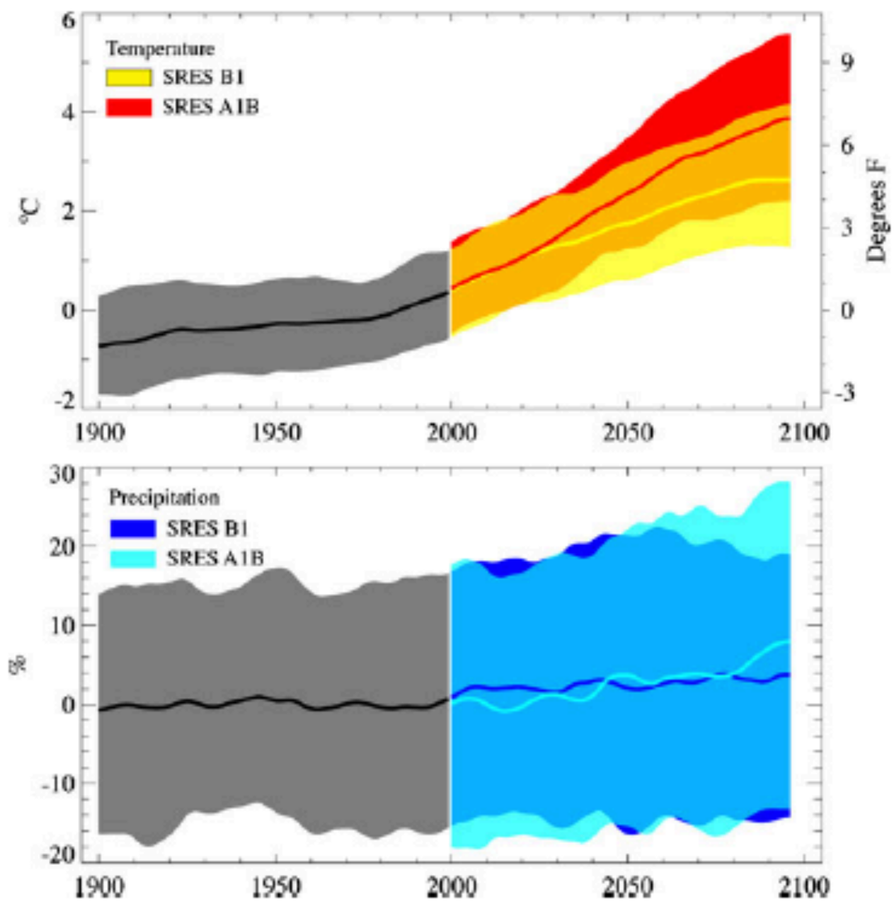
Projections from GCMs
21th century warming
between 1.5 and 3°C



Source: IPCC, 2007

FUTURE CLIMATE CHANGE IN THE PACIFIC NORTHWEST

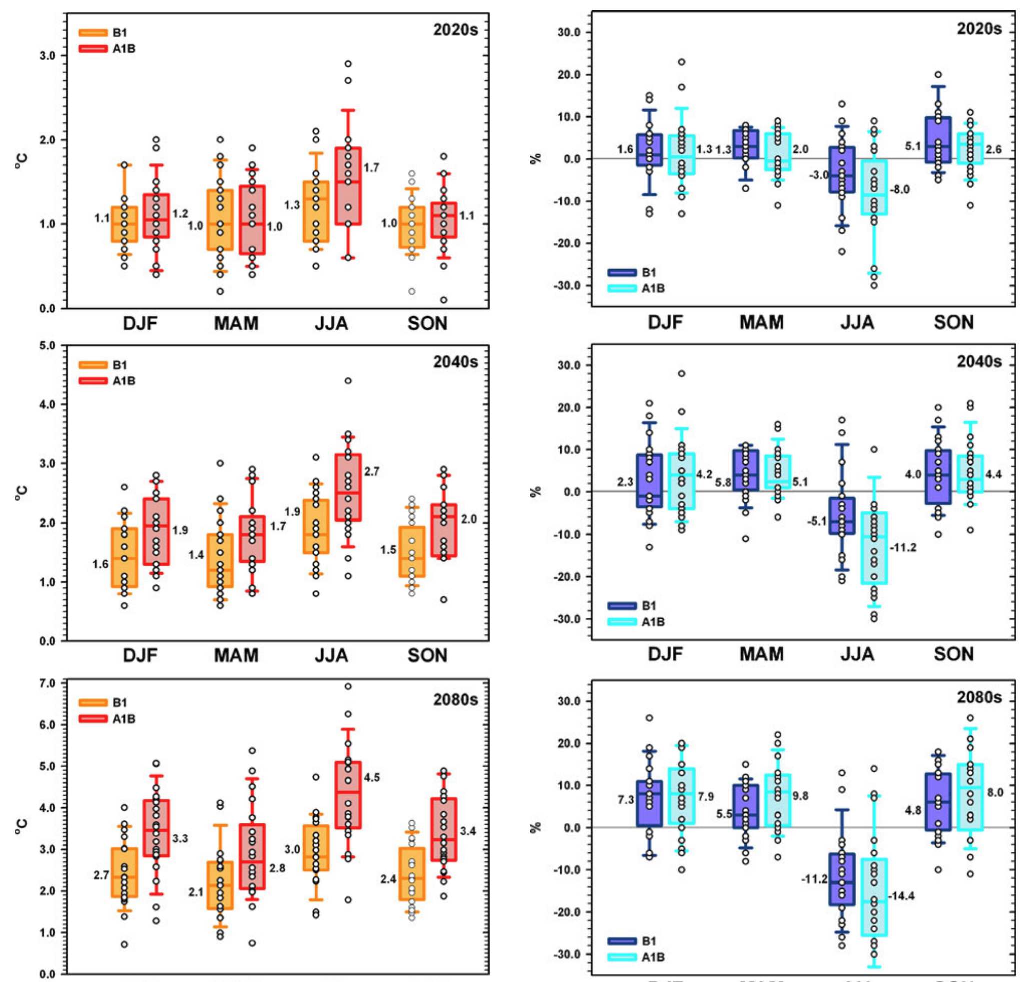
- Mote et al. (2010) looked at the output from 20GCMs
- Strong signal-to-noise ratio for changes in temperature
- No clear signal for changes In precipitation
- Temperature
  - 2020s – 1.1°C
  - 2040s – 1.8°C
  - 2080s – 3.0°C
- Precipitation
  - +1% to +2%



Source: Mote et al, 2010

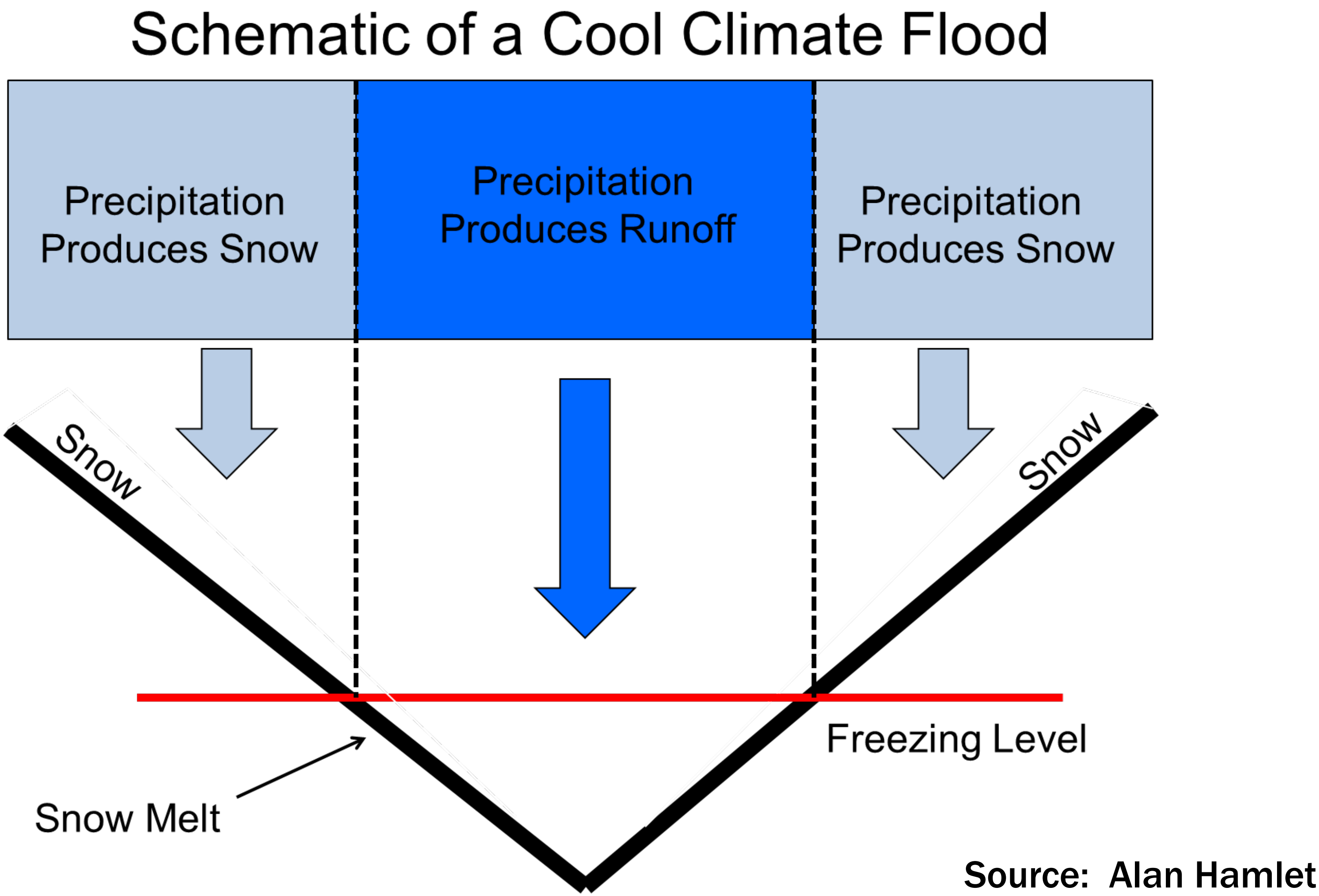
FUTURE CLIMATE CHANGE IN THE PACIFIC NORTHWEST

- Seasonal Temperature
  - Largest increases during Summer months
- Seasonal Precipitation
  - Increase in Winter/ Spring/Fall precipitation
  - Decrease in Summer precipitation

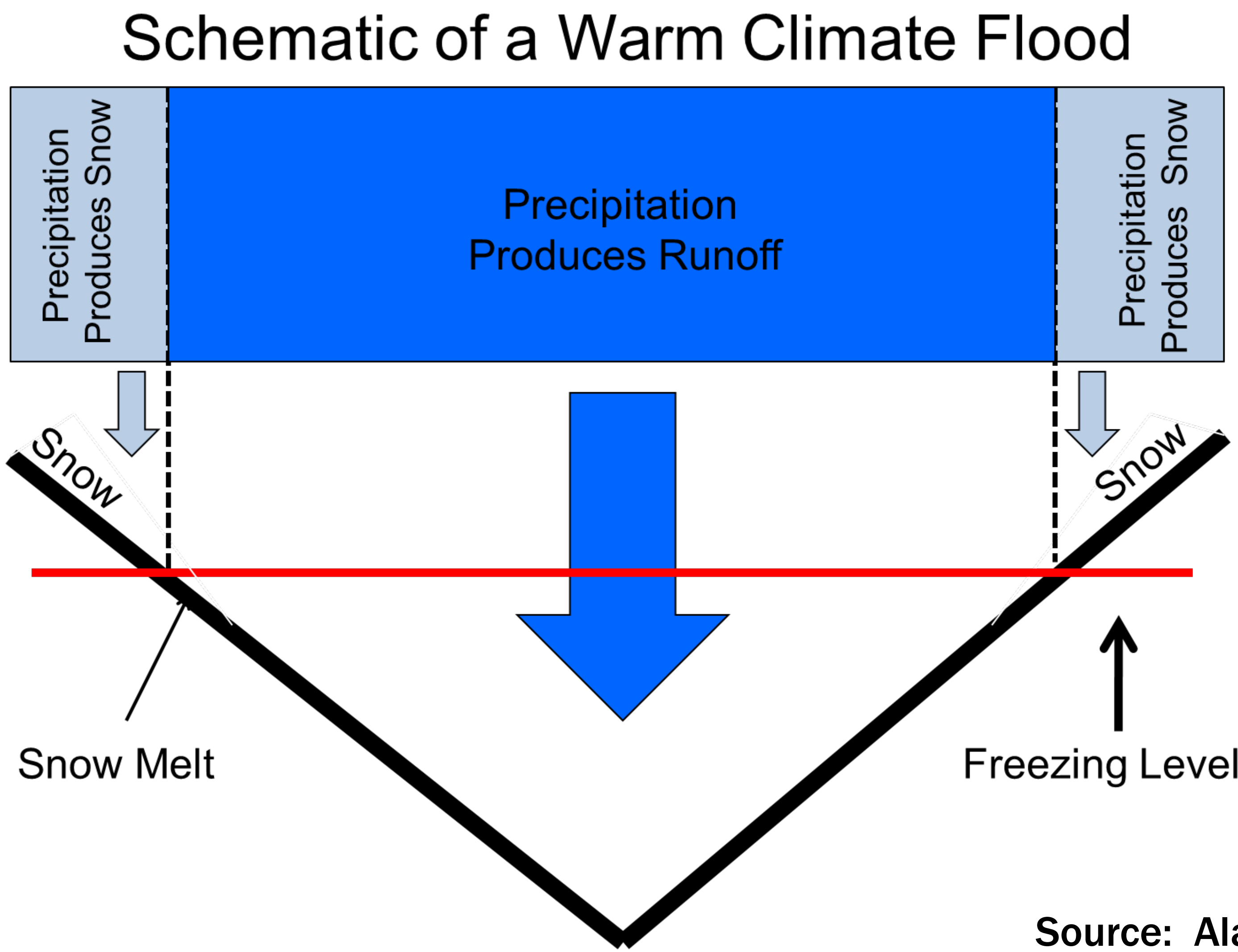


Source: Mote et al, 2010

IMPLICATIONS OF WARMING ON HYDROLOGY



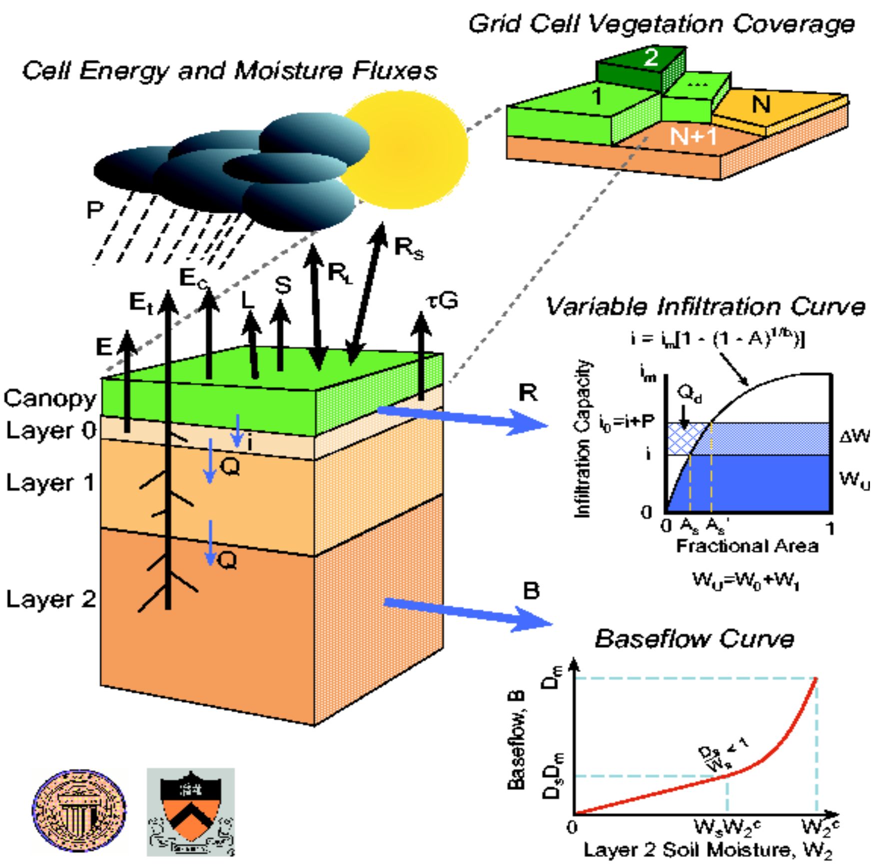
IMPLICATIONS OF WARMING ON HYDROLOGY



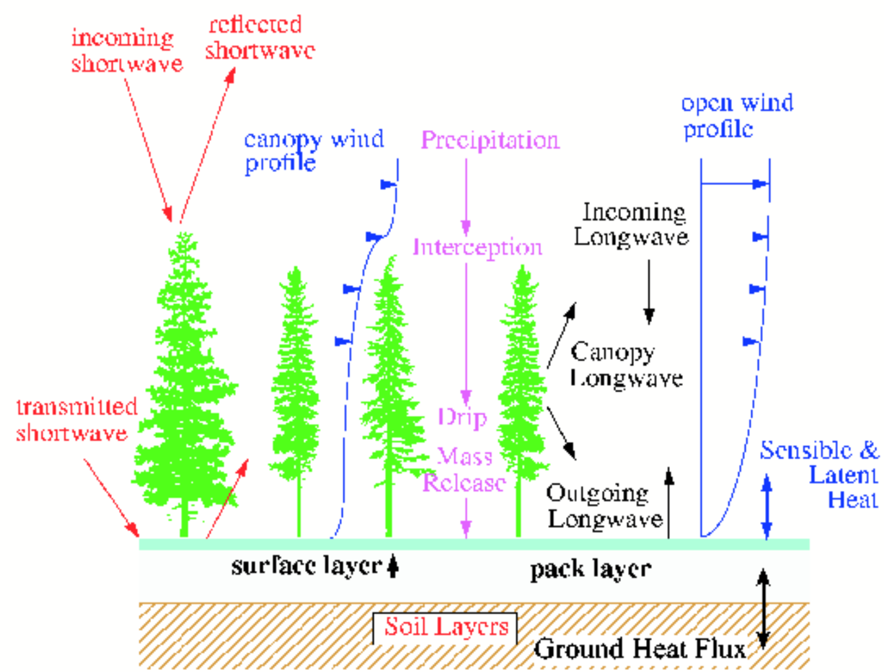
Source: Alan Hamlet

HYDROLOGIC MODELING

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

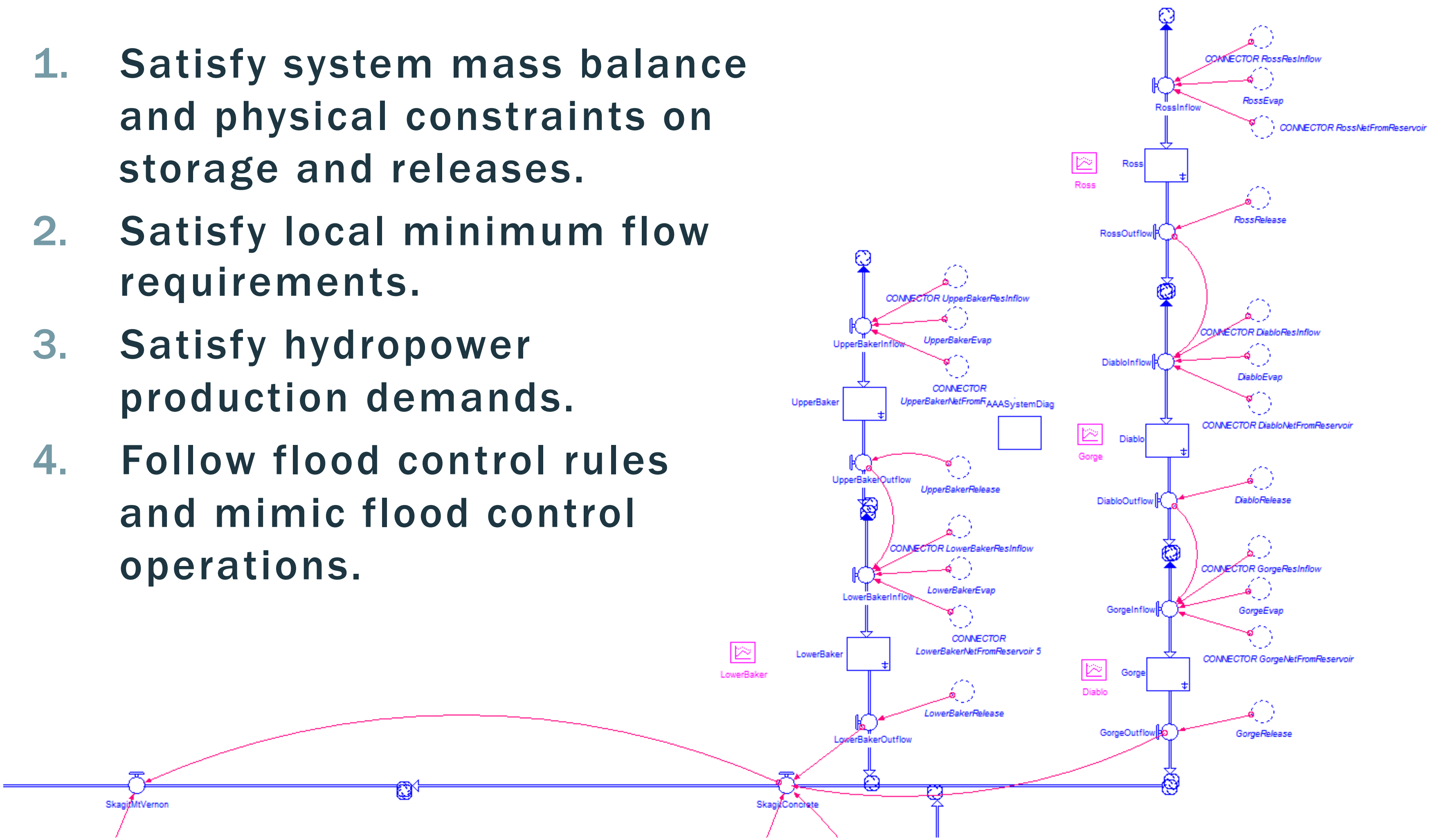


VIC Snow Algorithm



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.



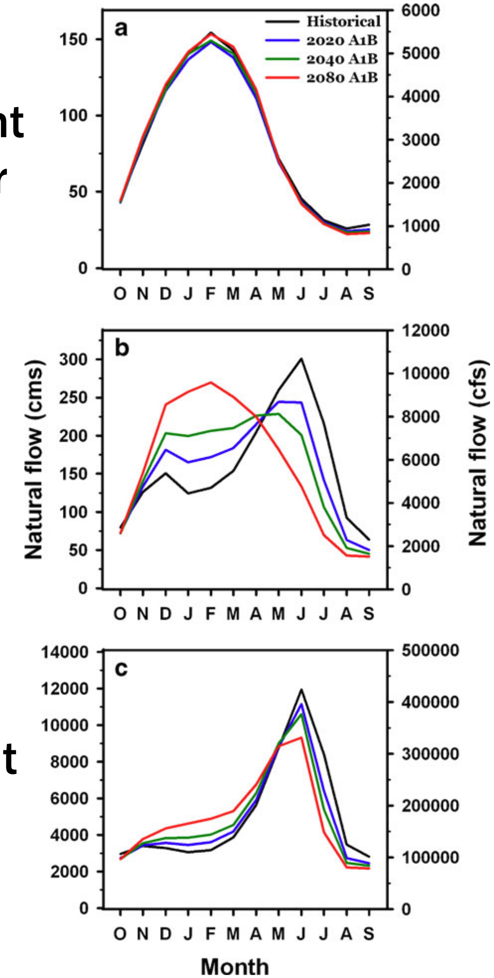
CHANGES IN STREAMFLOW TIMING

- **Changes due to warmer temperatures and increased Winter precipitation**
  - Rain Dominant Basins: small increases
  - Transient Rain-Snow Basins: shift from spring peak to Fall/ Winter peak
  - Snowmelt Dominant Basins: decrease in Spring/Summer flow

Rain Dominant
Chehalis River

Transient Rain-Snow
Yakima River

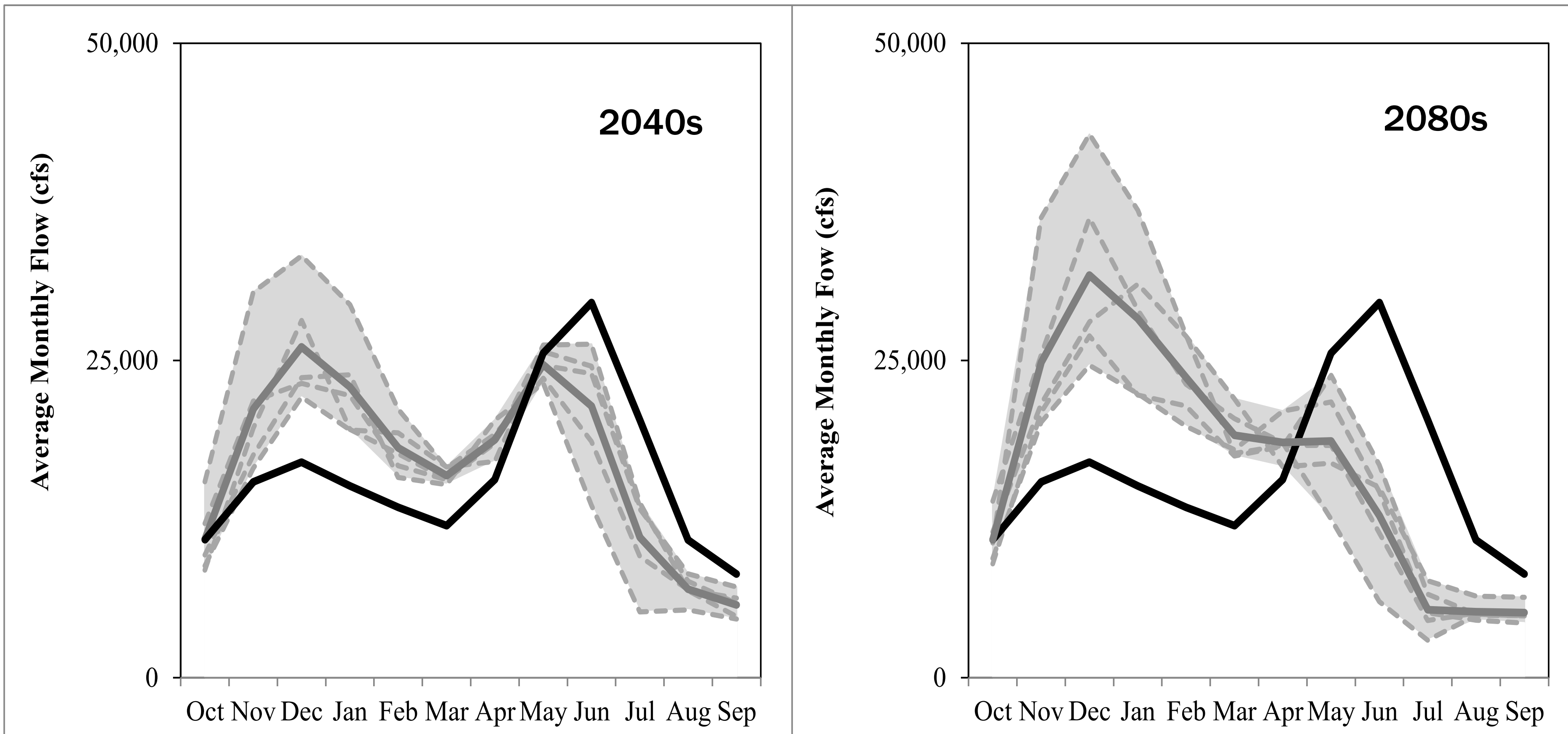
Snowmelt Dominant
Columbia River



Source: Elsner et at., 2010

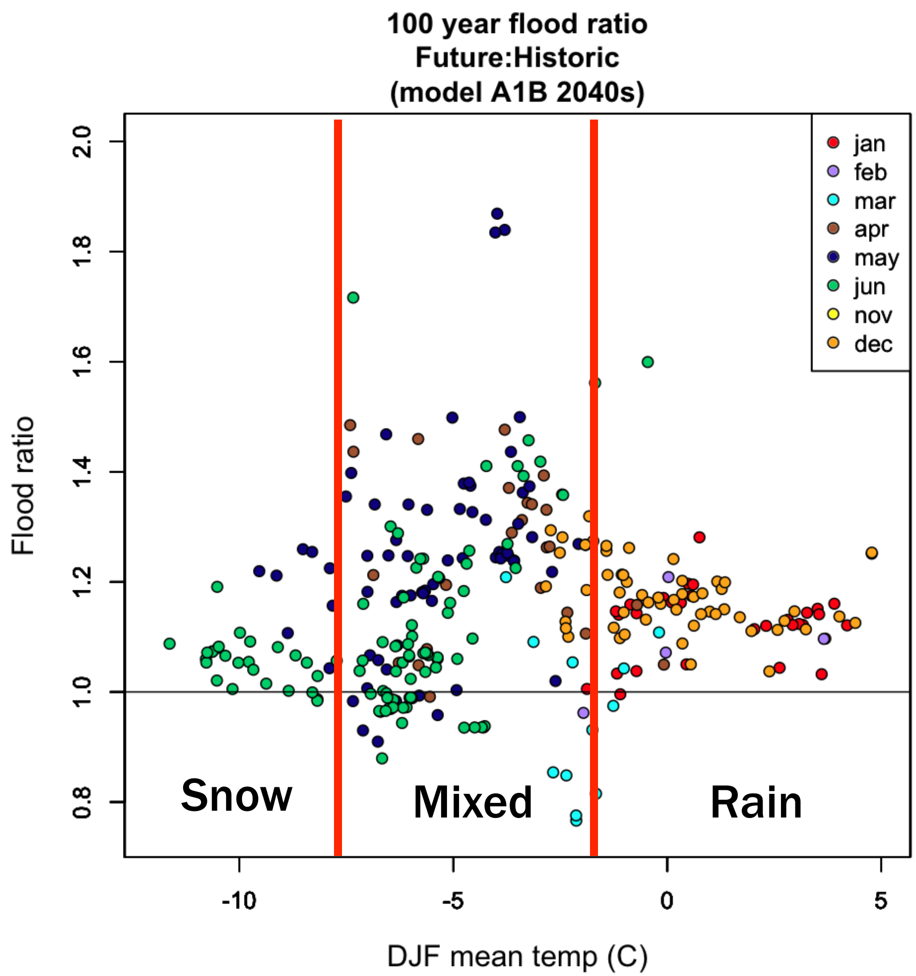
CHANGES IN MONTHLY AVERAGE STREAMFLOW

Skagit River Basin near Mount Vernon



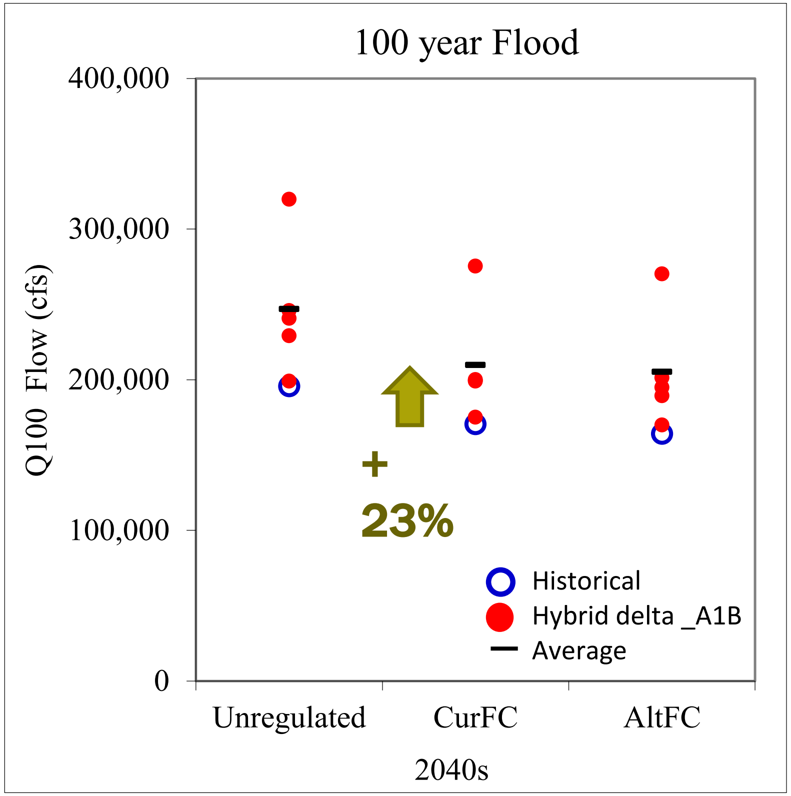
Source: Lee & Hamlet, 2012 (In Preparation)

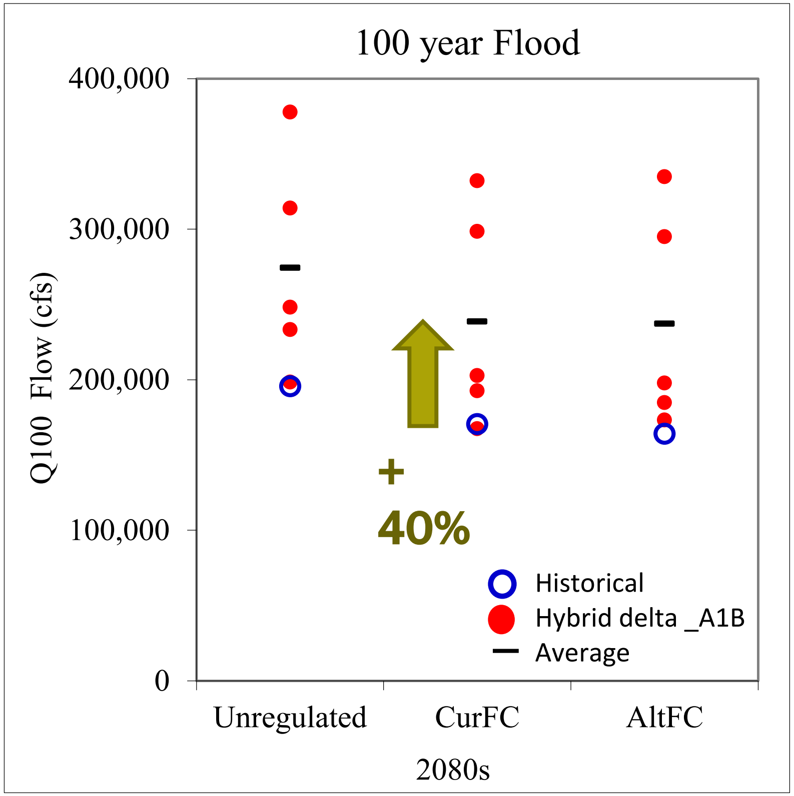
CHANGES IN FLOODING



Source: Tohver and Hamlet (2010)

CHANGES IN 100-YEAR FLOOD STATISTICS

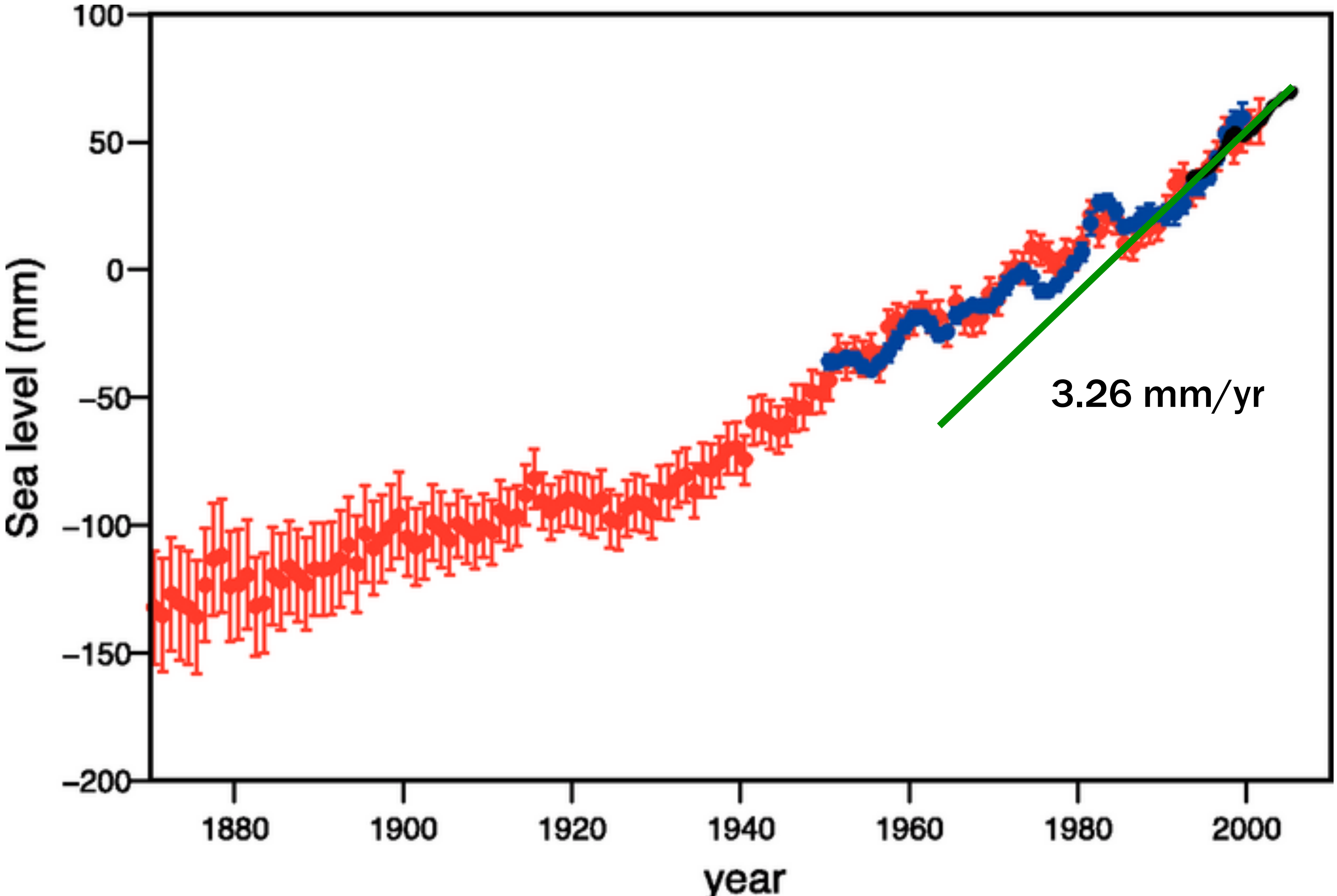




- 100-year flood risks are reduced only 3 % for the 2040s and 1 % for the 2080s under the alternative flood control curves.
- The alternative flood control operations are largely ineffective in mitigating the increased flood risks.

Source: Lee & Hamlet, 2012

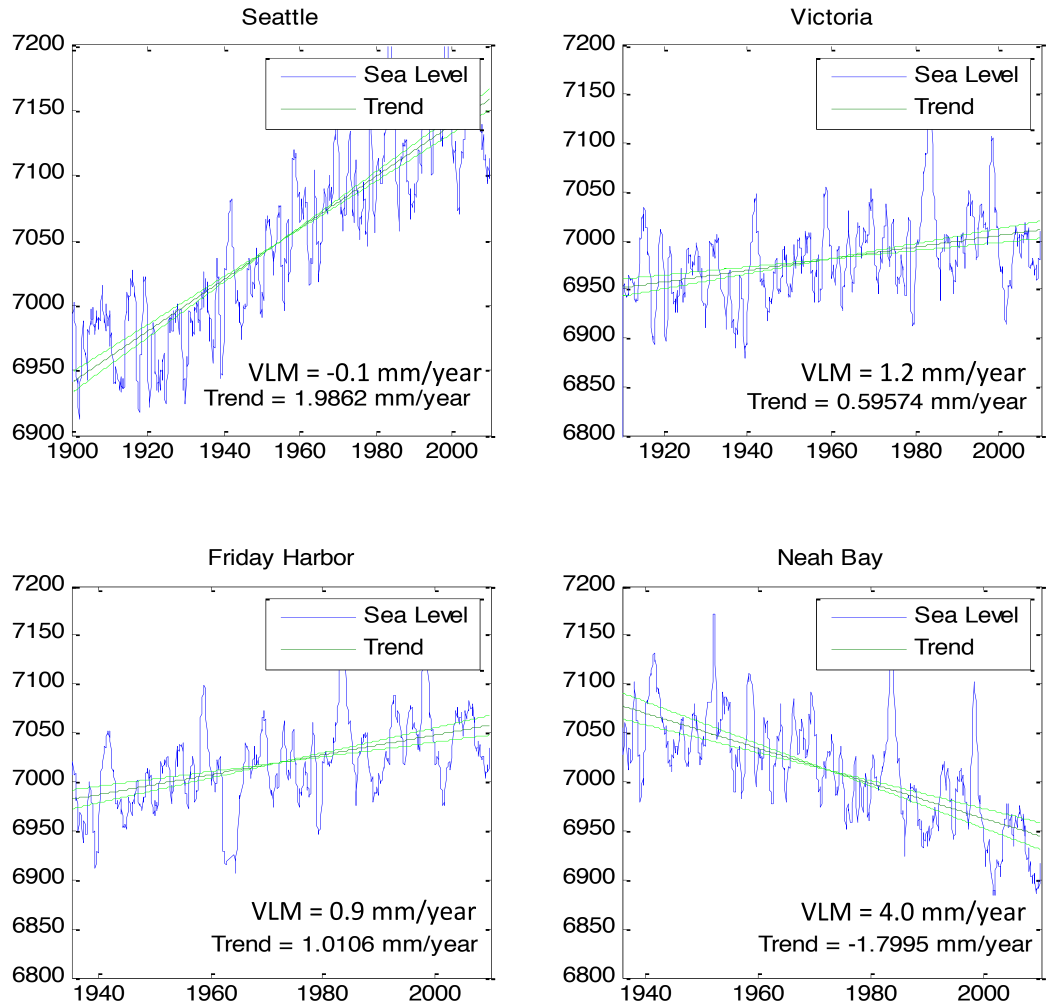
GLOBAL SEA LEVEL RISE



Source: IPCC, 2007

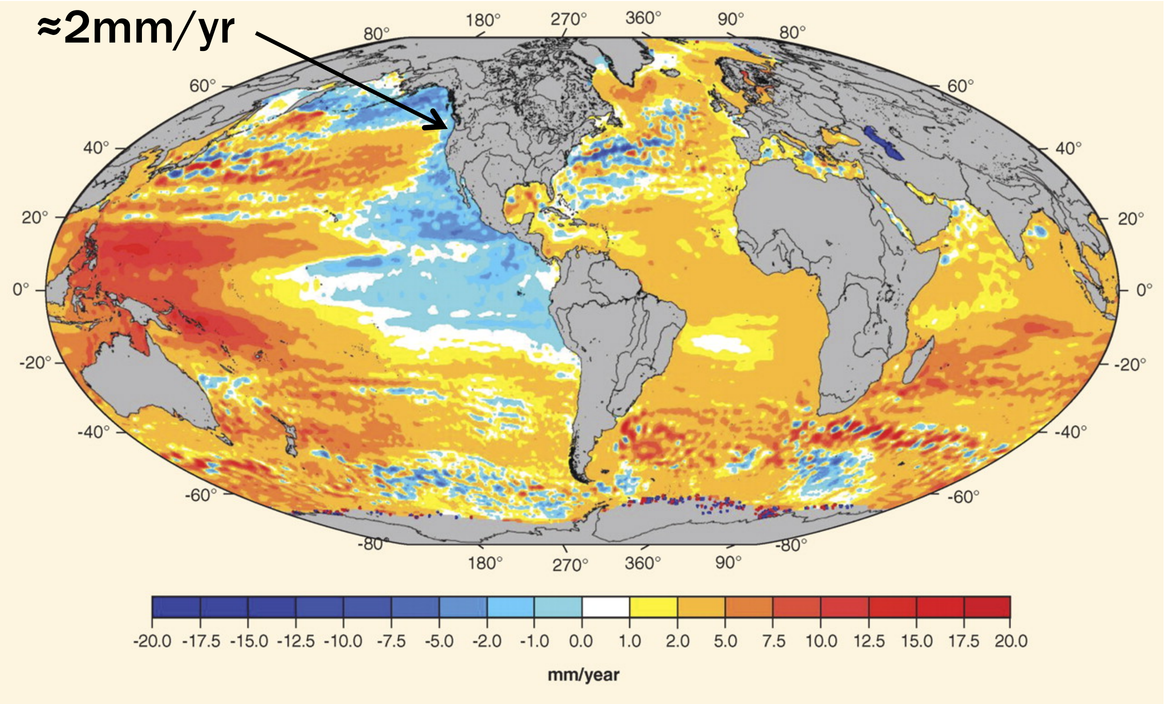
PUGET SOUND SEA LEVEL RISE

- Puget Sound SLR rate adjusted for vertical land movement is 1.8-2.2 mm/year.
- Recent trends in Puget Sound MSL are smaller than 20year global average of 3.26 mm/ year.



GLOBAL SEA LEVEL RISE

Sea-Level Trends from Satellite Altimetry, 1992 -2009



- Heterogeneous global SLR
- Observed trends in Eastern Pacific sea level are negative over past 20 years
- Likely due to large scale wind patterns
- It is unclear how long this pattern will persist

Source: Nicholls and Cazenave, 2010

PROJECTIONS OF GLOBAL SEA LEVEL RISE

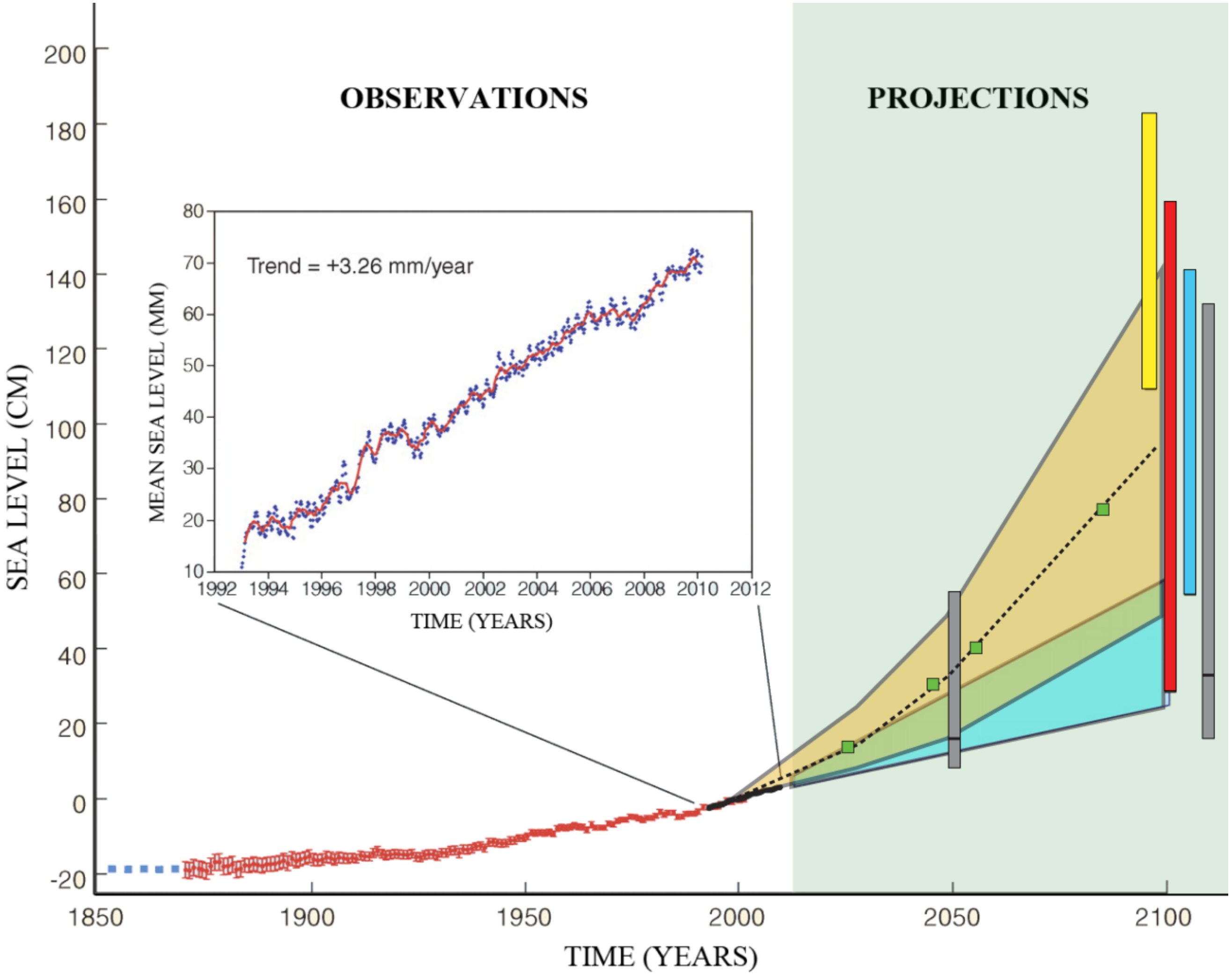
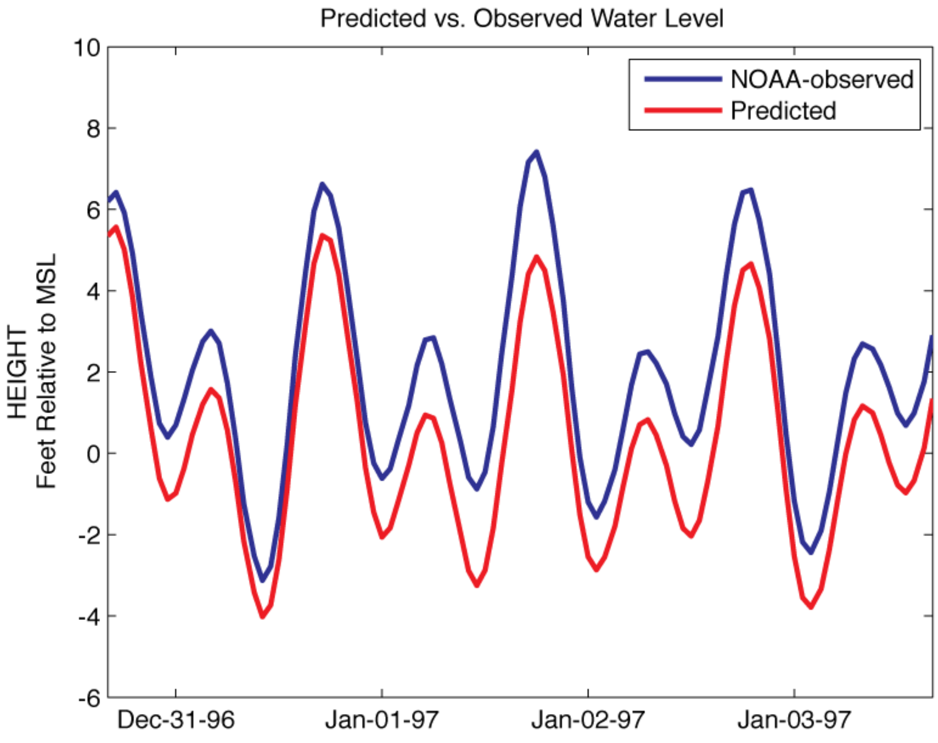


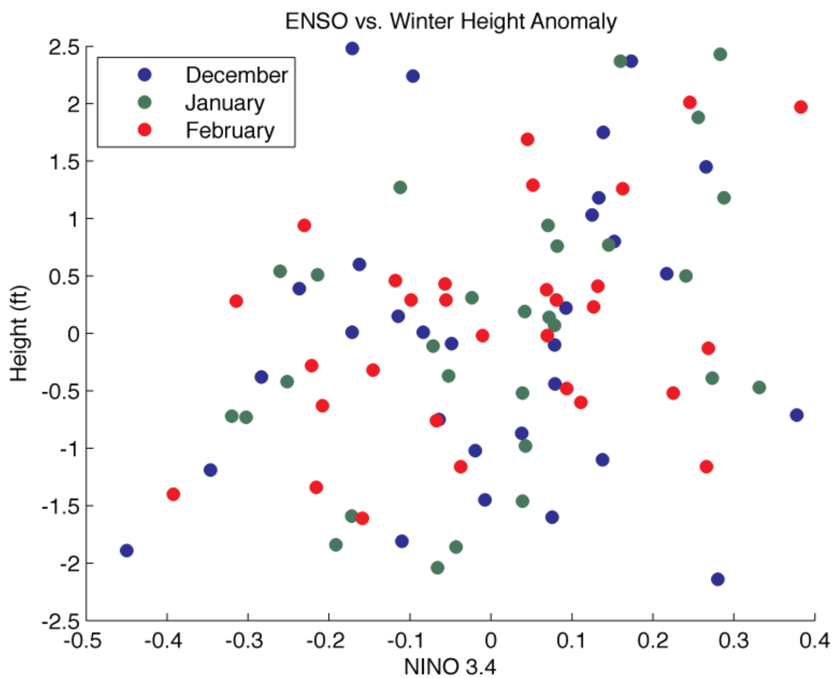
Figure adapted from Nicholls and Cazenave (2010)

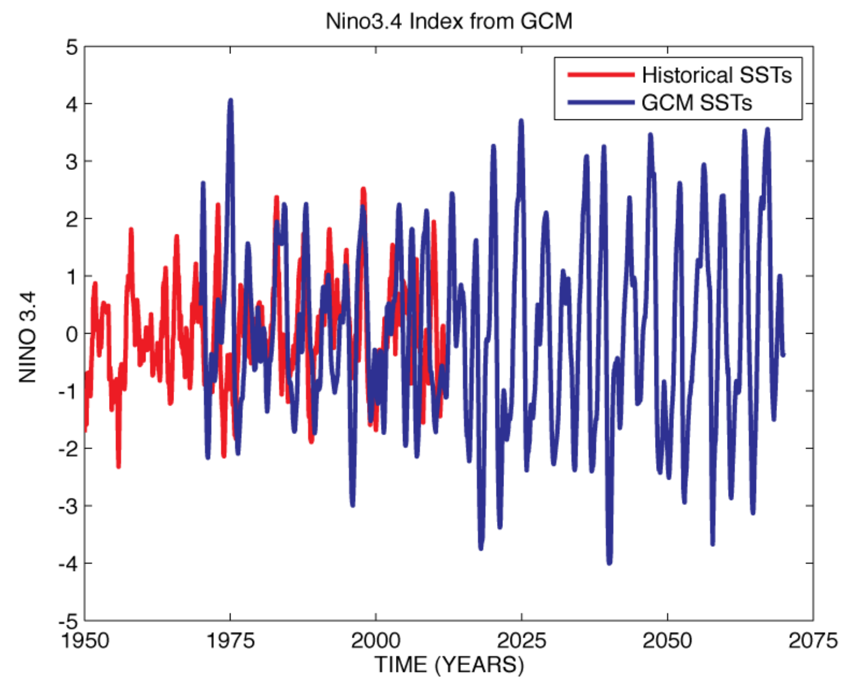
STORM SURGE
LINEAR REGRESSION APPROACH

1. Calculate anomalies and sort by month
2. Anomaly = f (Pressure, Pressure Patterns, ENSO)
   - Training Data: WRF-Reanalysis, observed ENSO
   - Forecast Data: WRF-ECHAM5 and ECHAM5 SSTs
3. Add forecasted anomalies and SLR to hourly tide projections



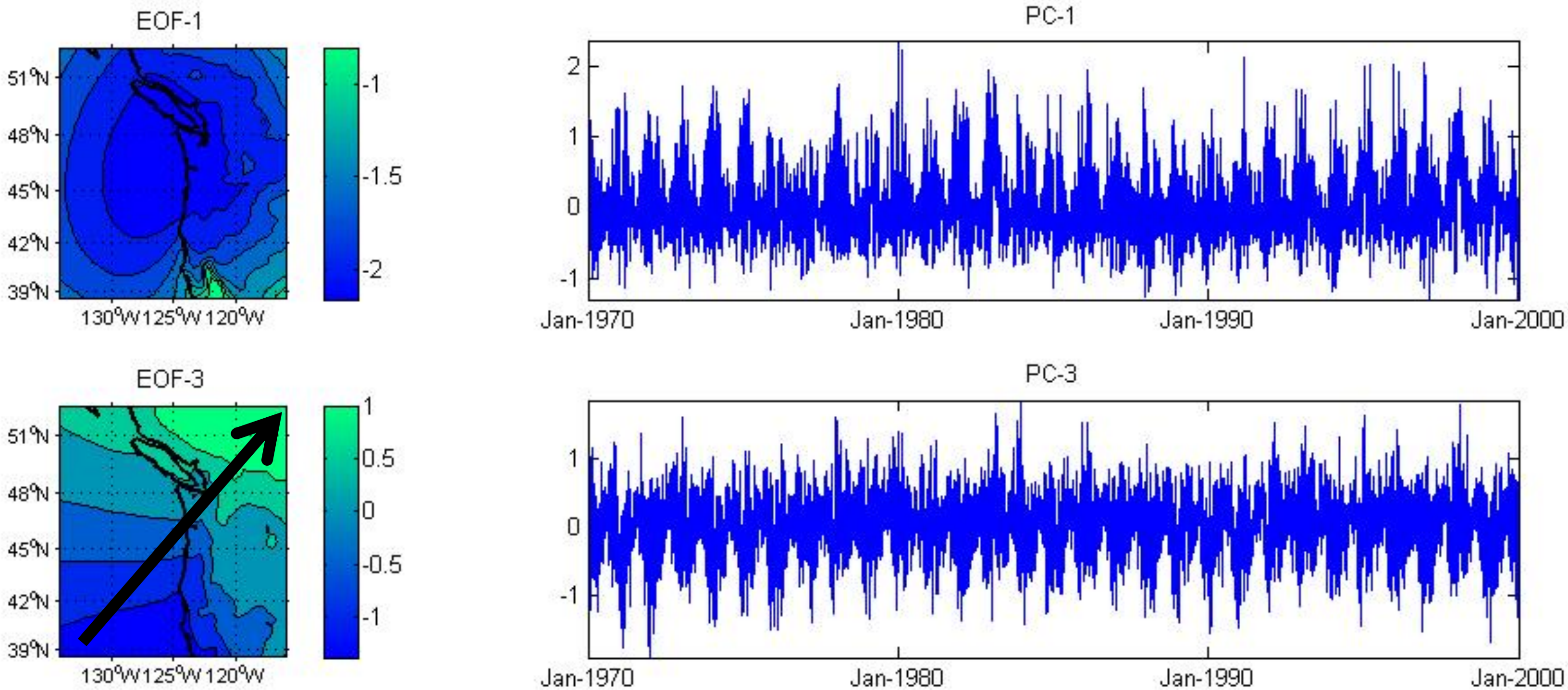
STORM SURGE
EL NINO SOUTHERN OSCILLATION





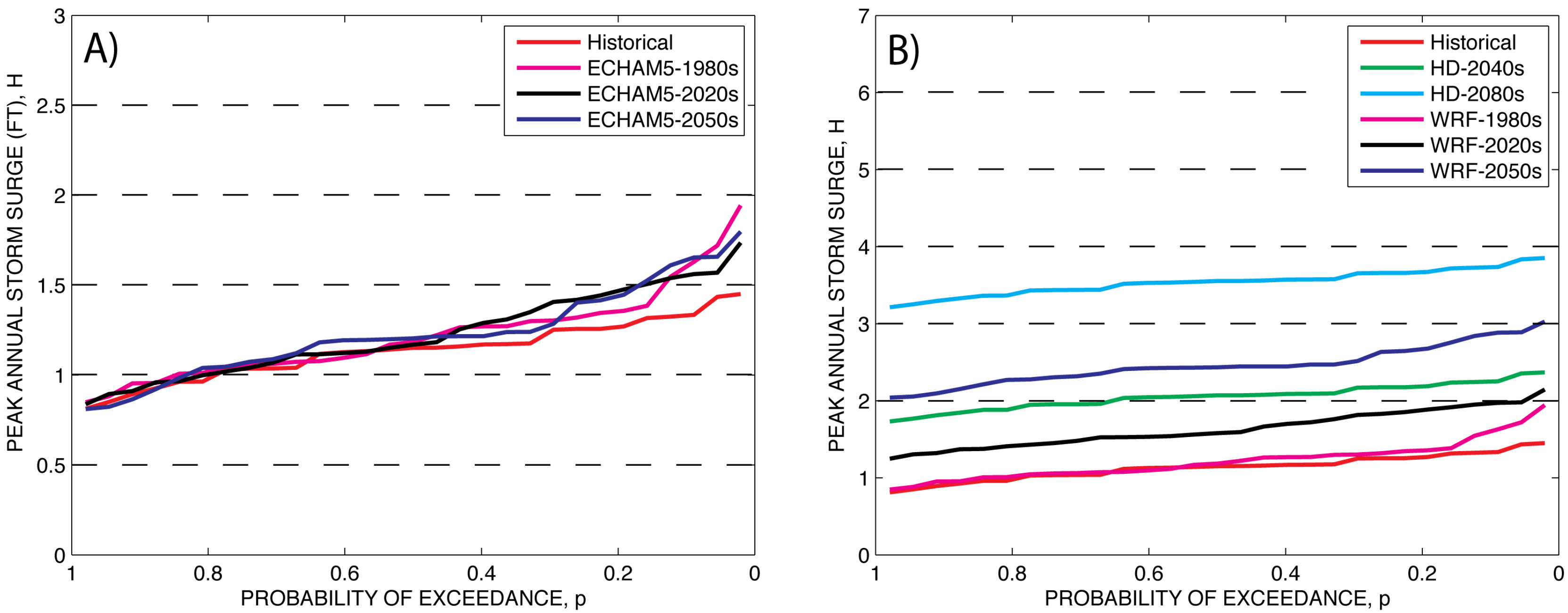
- Linear relationship between ENSO and Winter height anomaly
- Extracted Nino3.4 from GCM SSTs

STORM SURGE PRESSURE PATTERNS



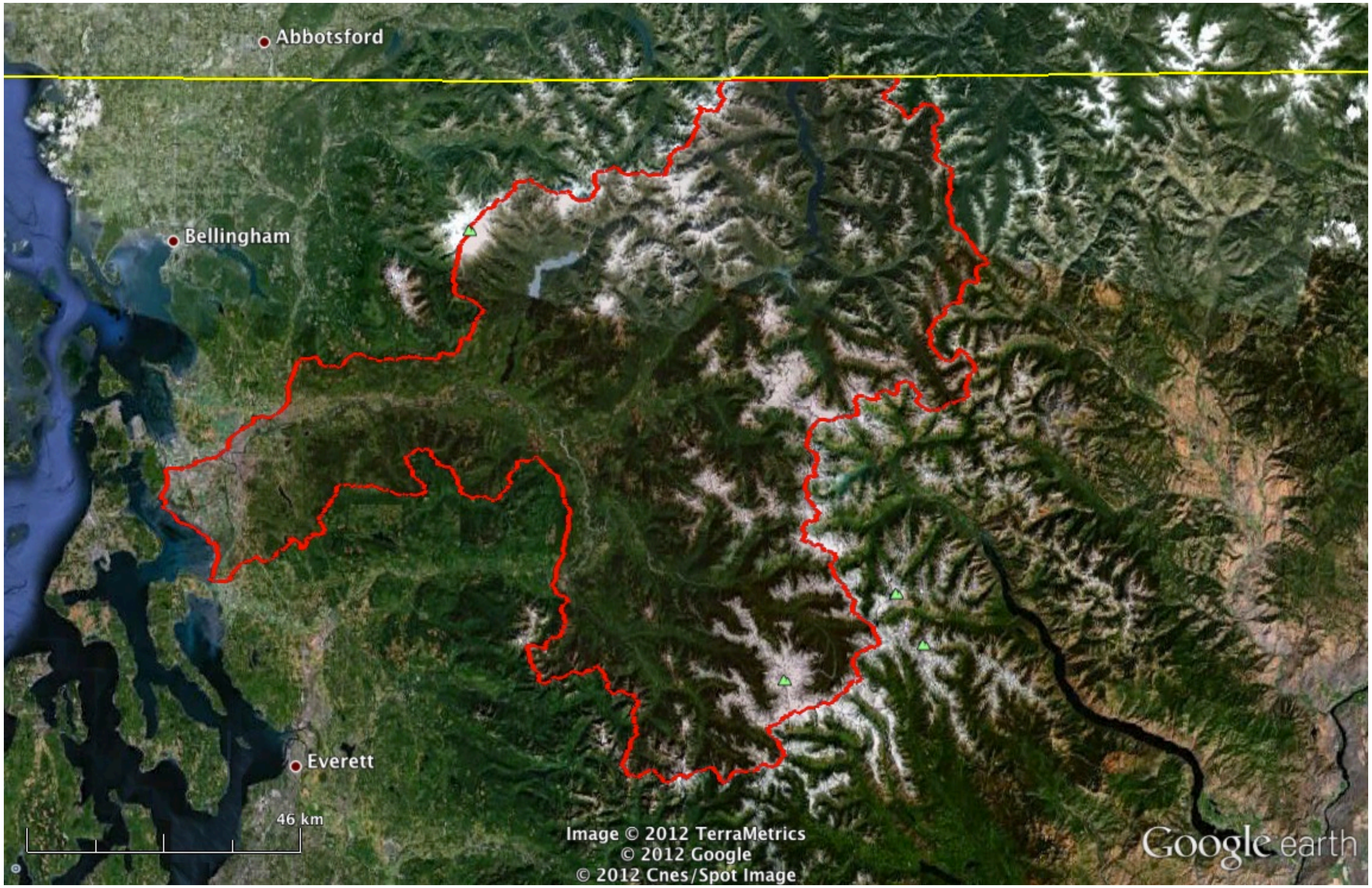
- Used singular value decomposition (SVD) to isolate important regional pressure patterns
- These time series represent the key modes of pressure variability that explain storm surge anomalies

STORM SURGE AND SLR

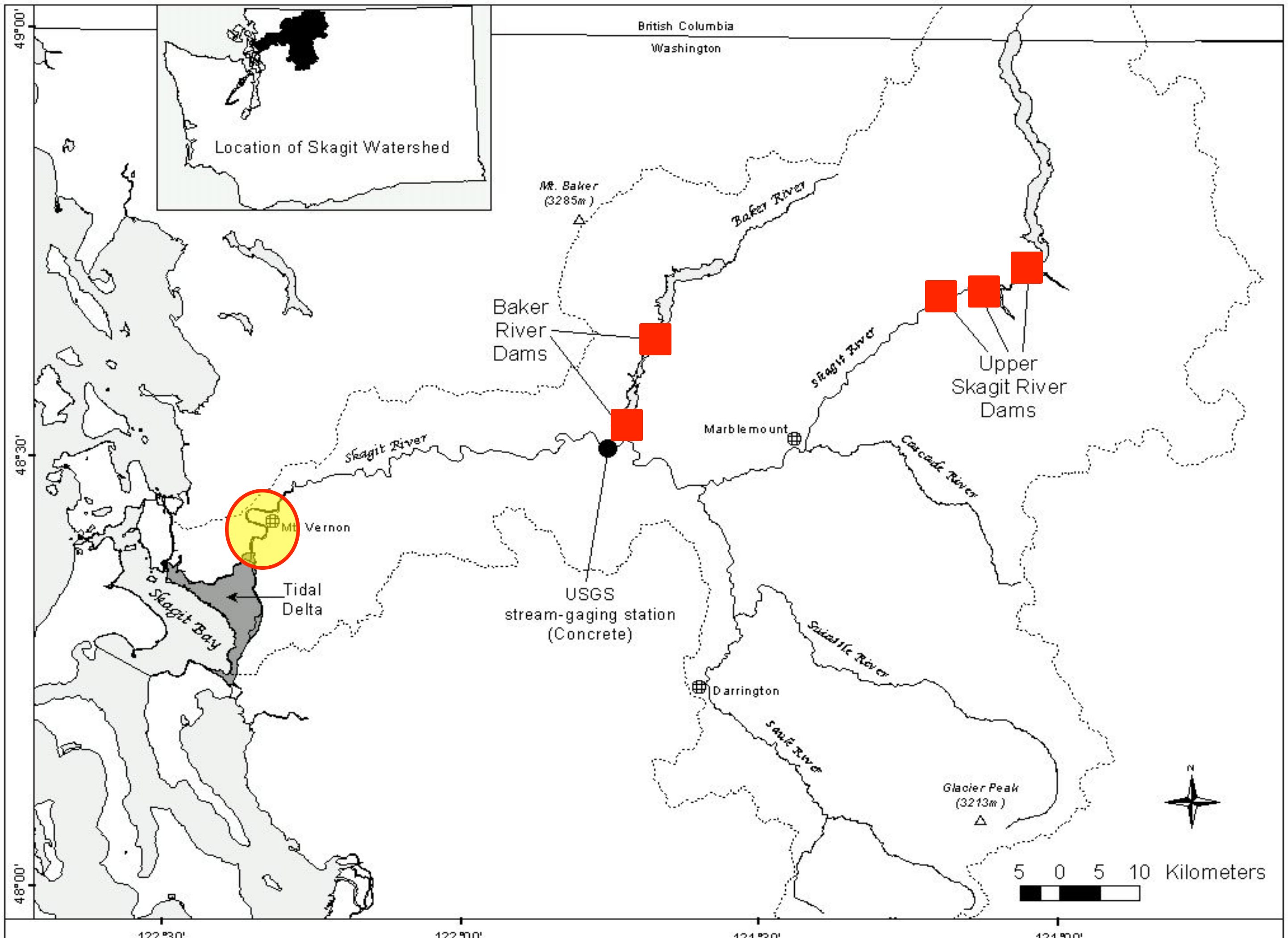


- No change in the storm surge CDFs between RCM time periods
- SLR, by comparison, drastically changes the CDFs by shifting them each upward

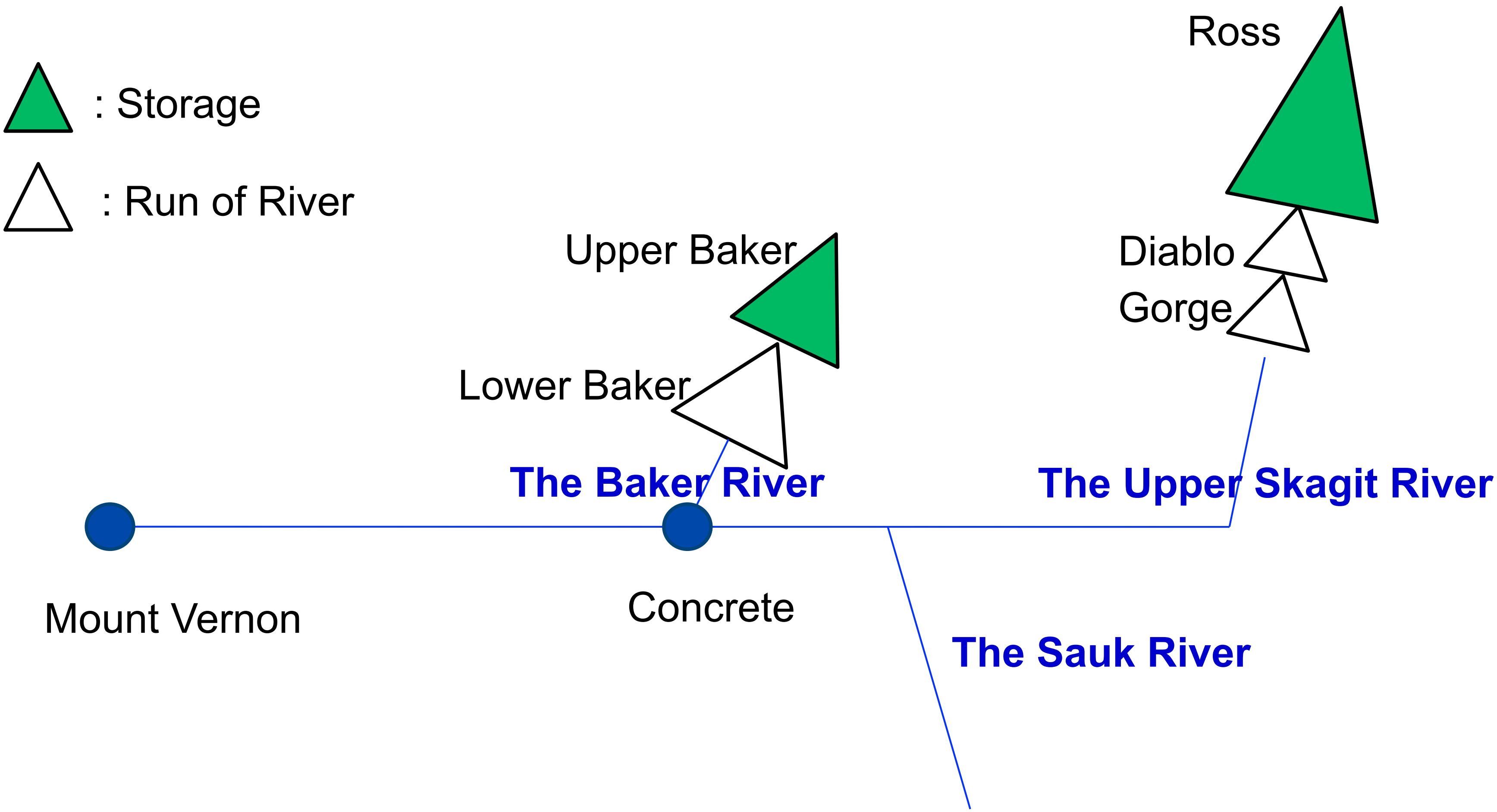
SKAGIT RIVER BASIN



SKAGIT RIVER BASIN

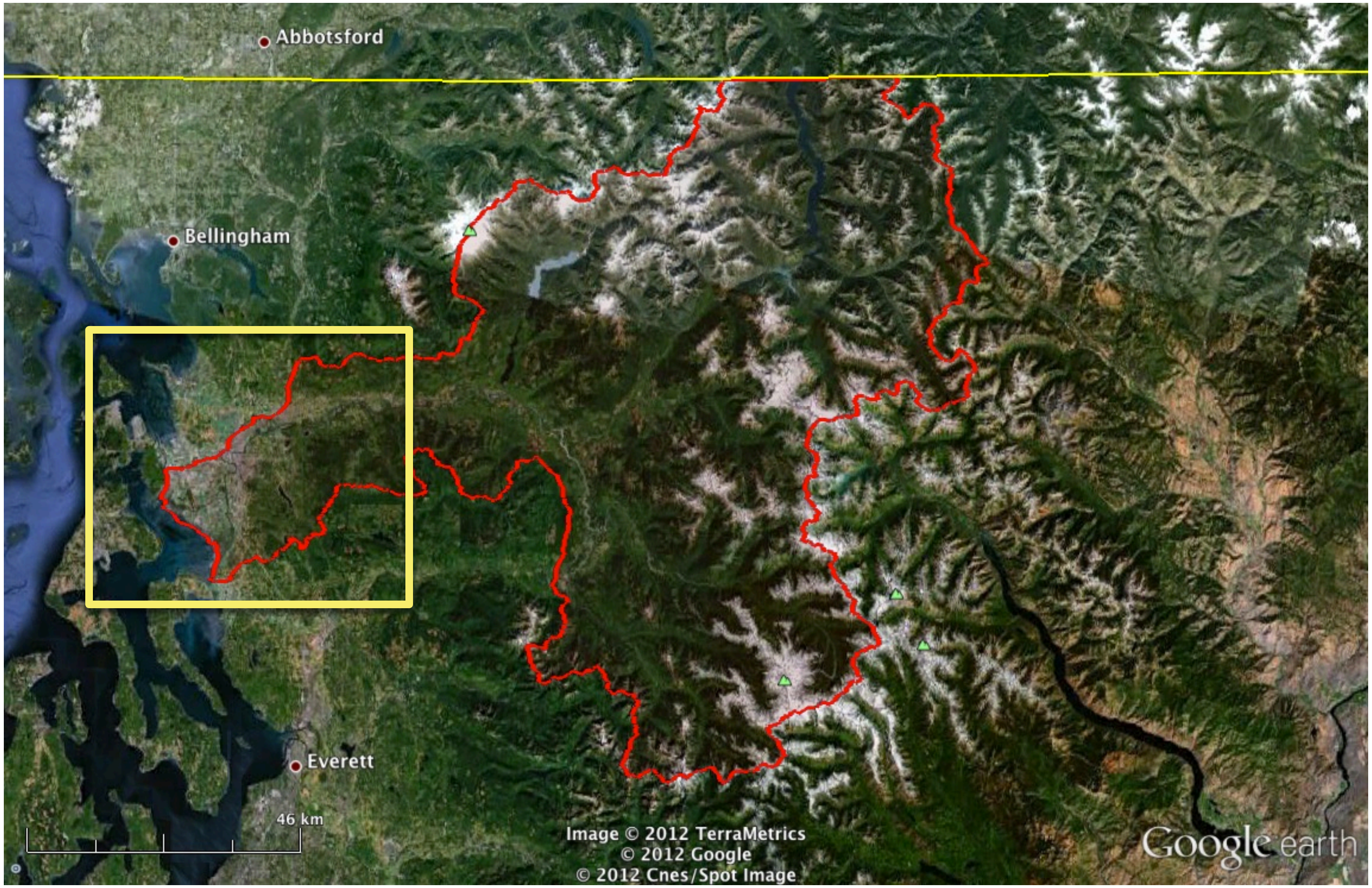


THE SKAGIT RIVER RESERVOIRS

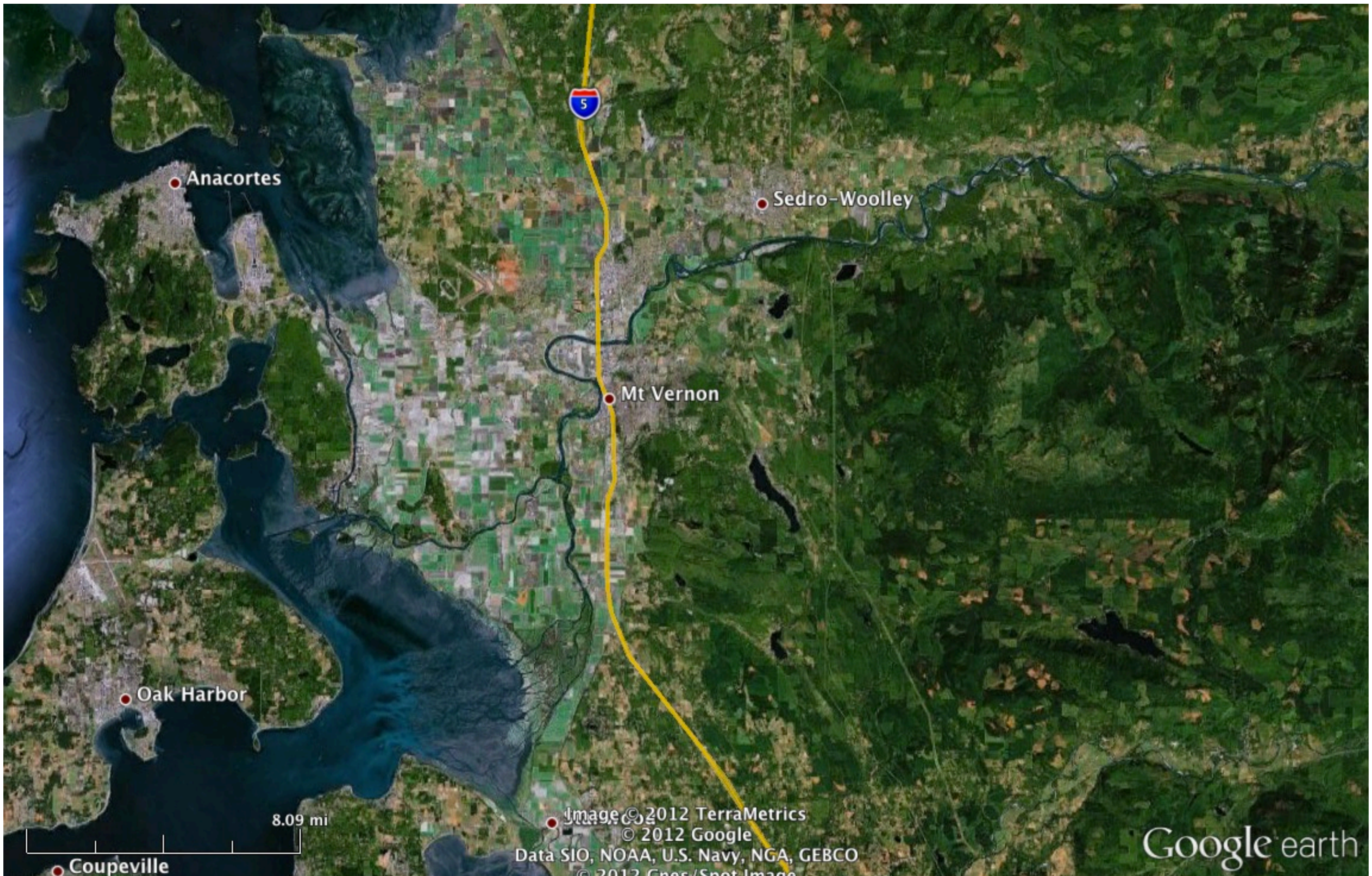


Source: Se-Yeun Lee

LOWE SKAGIT RIVER BASIN



LOWER SKAGIT RIVER BASIN

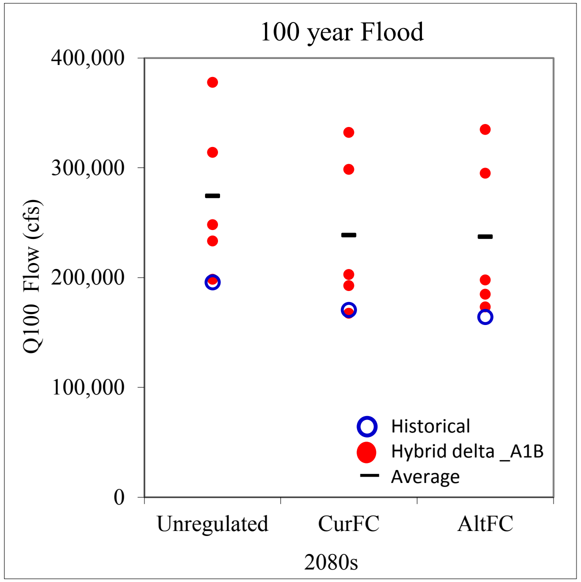


FLOODING IN THE SKAGIT RIVER BASIN

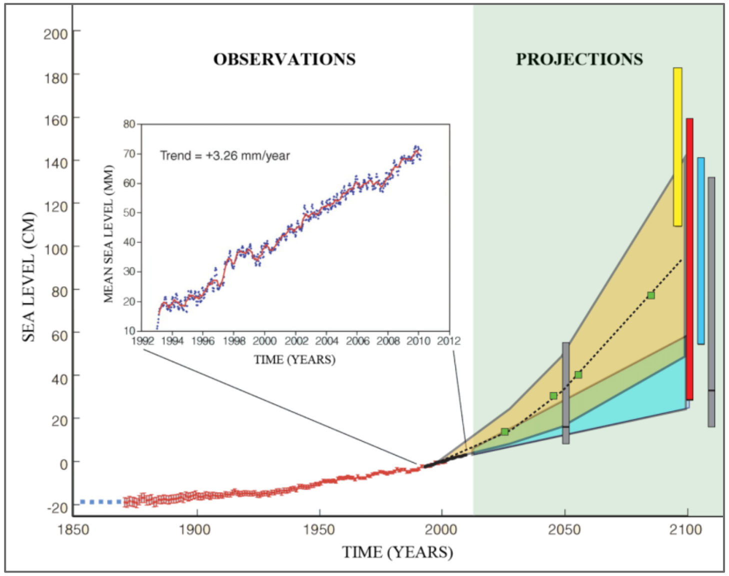
- Organizations involved:
  - US Army Corps of Engineers – Flood Control Operations
  - FEMA – Flood Mapping and Flood Insurance (NFIP)
  - Puget Sound Energy – Baker River Reservoirs
  - Seattle City Light – Skagit River Reservoirs
  - Skagit County – Coordination and Development
  - Local Governments

LOCAL IMPACTS

- How do we combine what we know about flooding and SLR in the Skagit River to plan for the future?



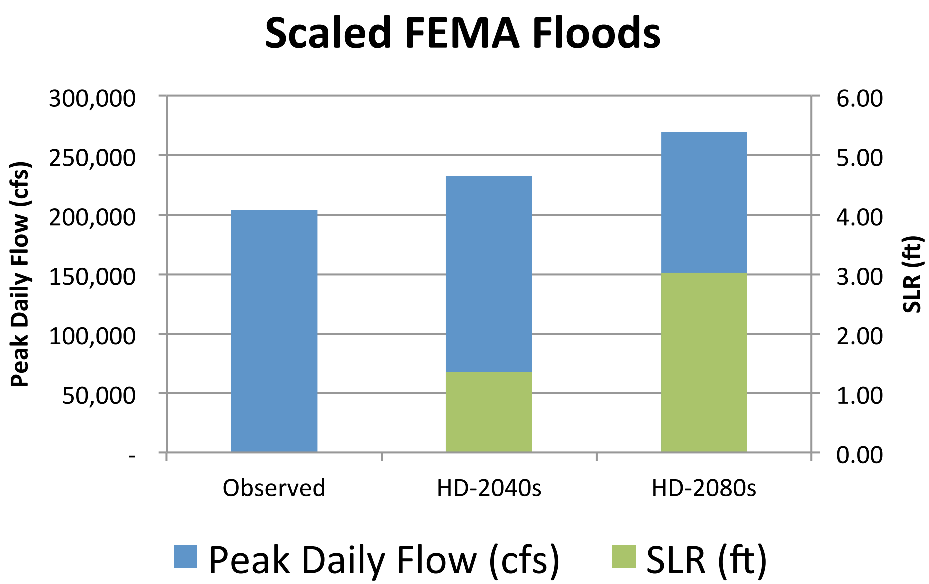
+

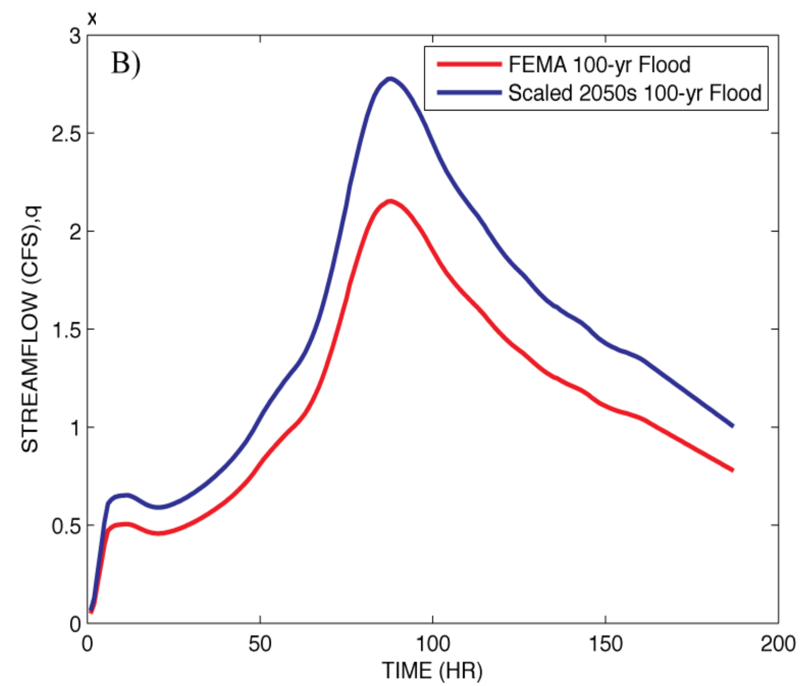


METHODS
100-YEAR FLOOD MAPPING

- 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)

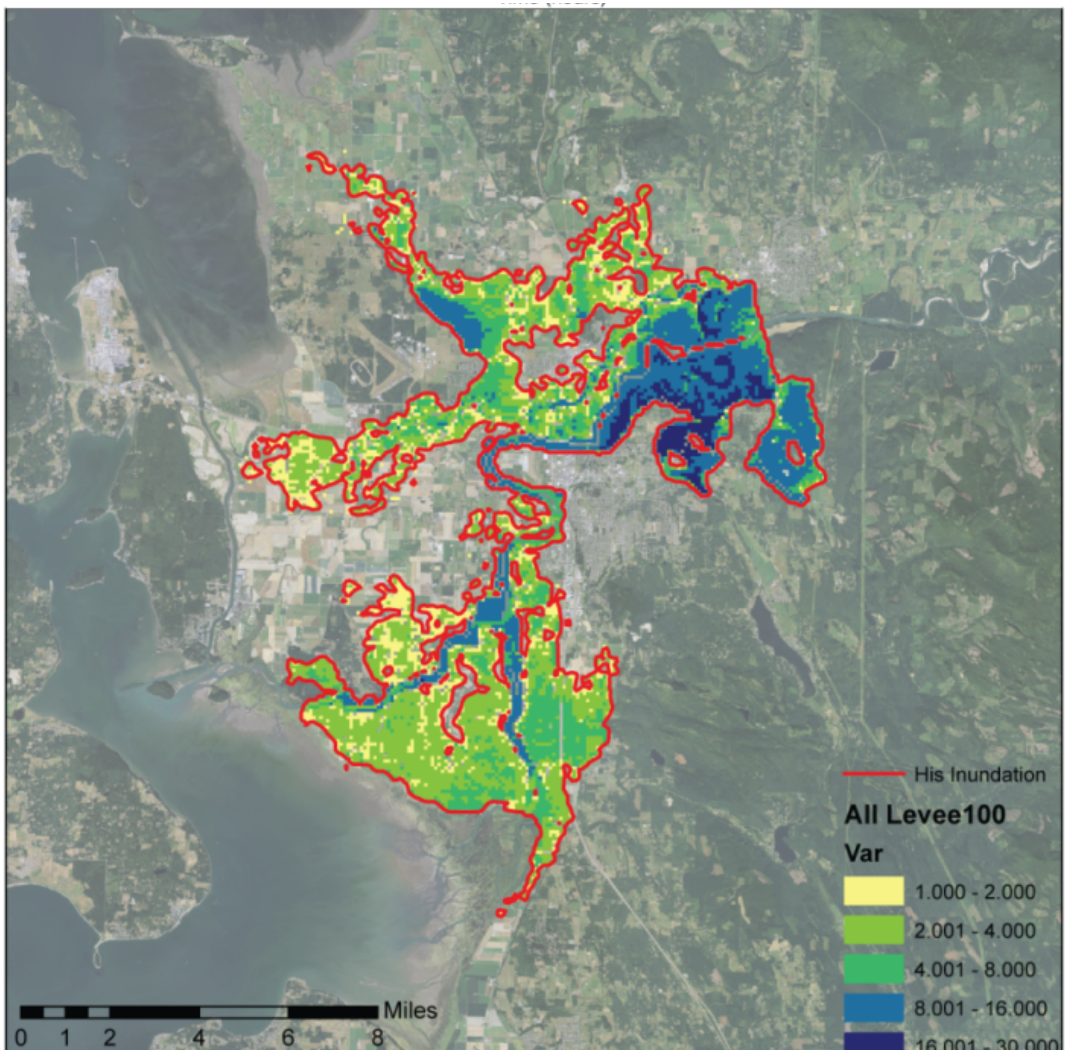
$$FEMA_{2040s} = FEMA \times \frac{100yrHD_{2040s}}{100yrHis}$$





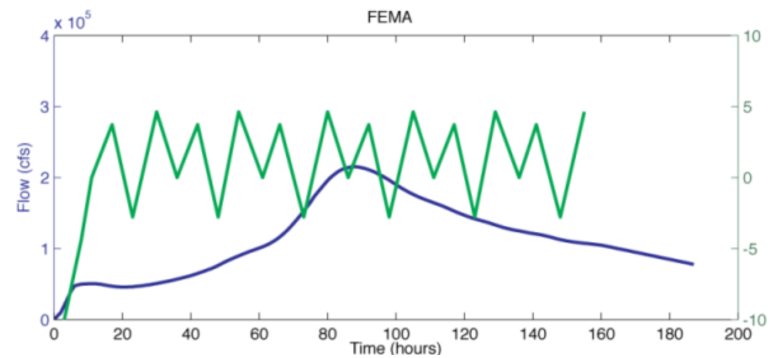
HISTORICAL 100-YEAR FLOOD

ALL LEVEES INTACT



Inputs:

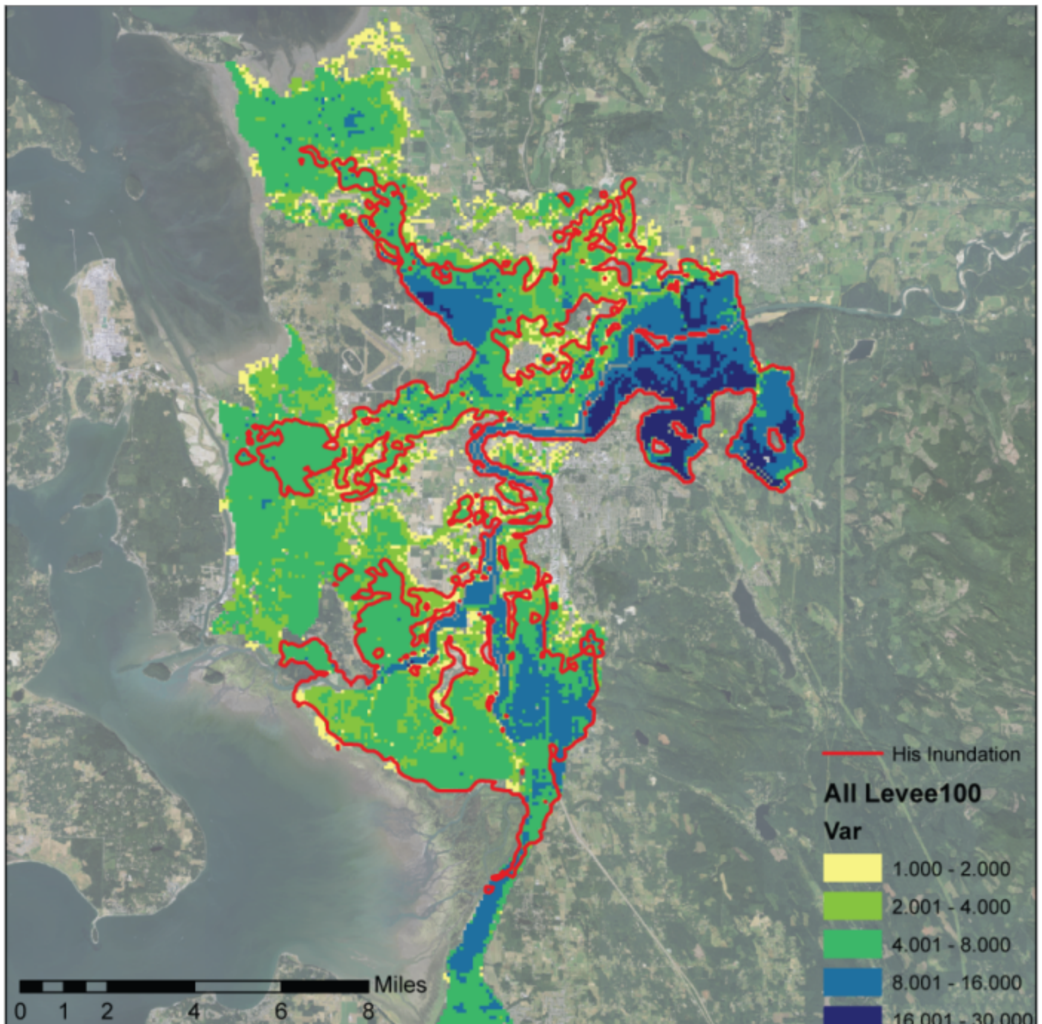
- Hydrograph: Historical 100yr
- Sea Level Rise: 0.00 feet



Area Flooded: 42,266 acres

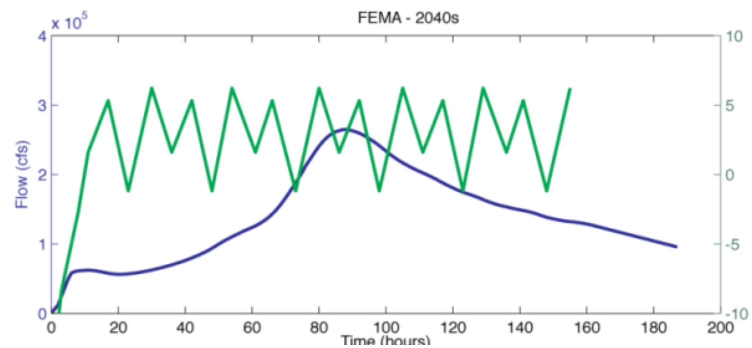
2040S 100-YEAR FLOOD

ALL LEVEES INTACT



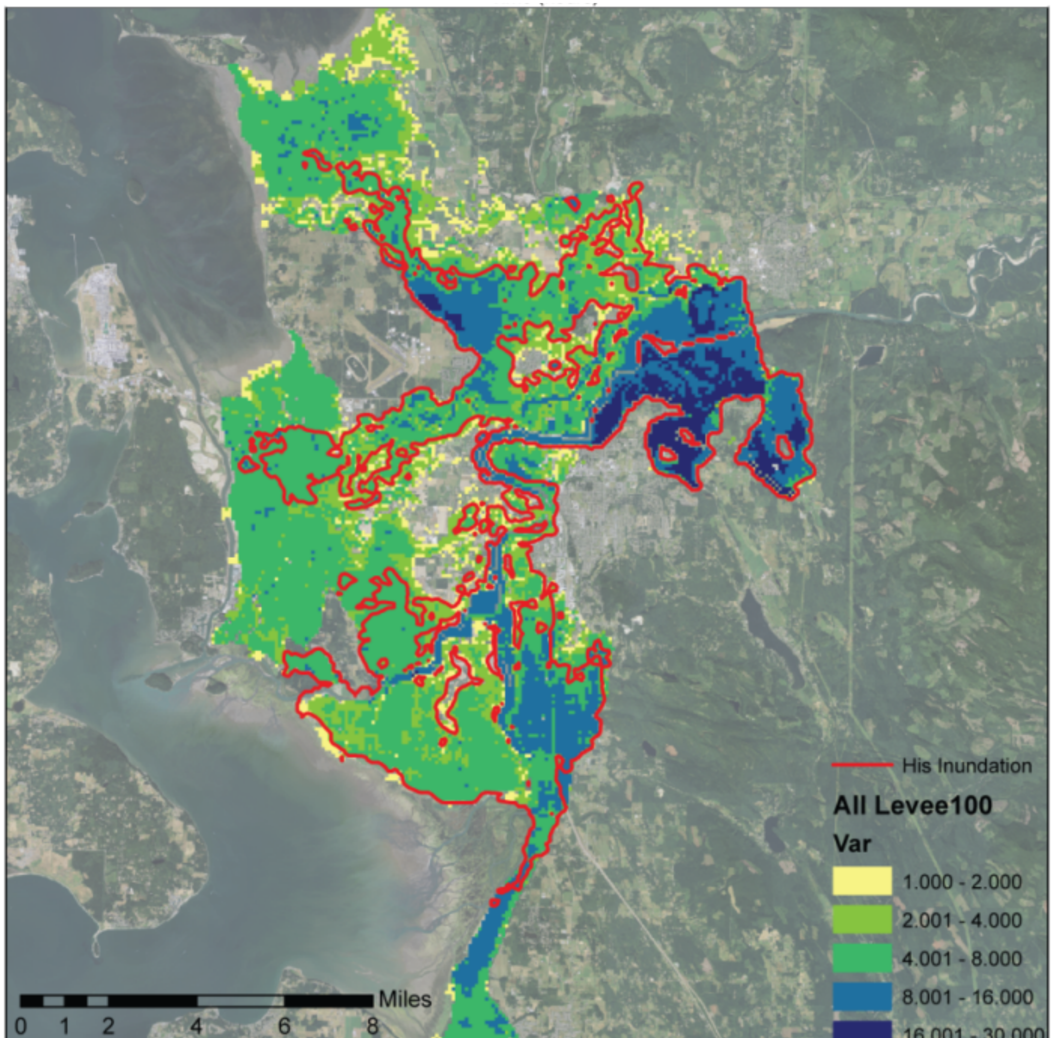
Inputs:

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

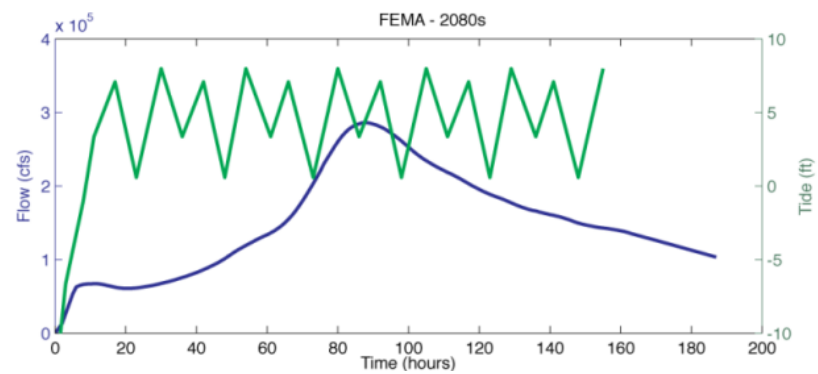


Area Flooded: 66,248 acres (+57%)

2080S 100-YEAR FLOOD
ALL LEVEES INTACT

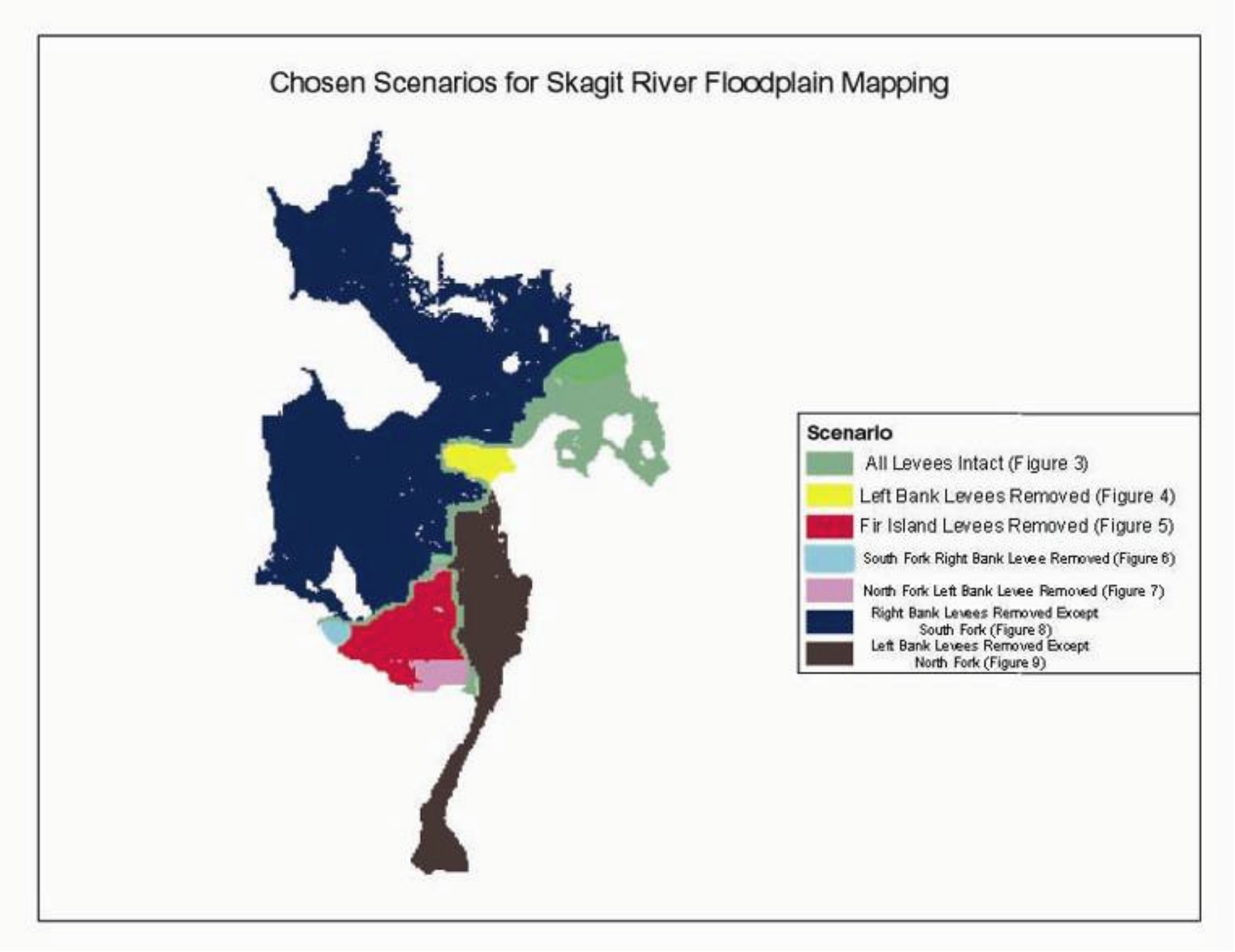


Inputs:
- Hydrograph: 1.32 x (His 100yr)
- Sea Level Rise: 3.02 feet

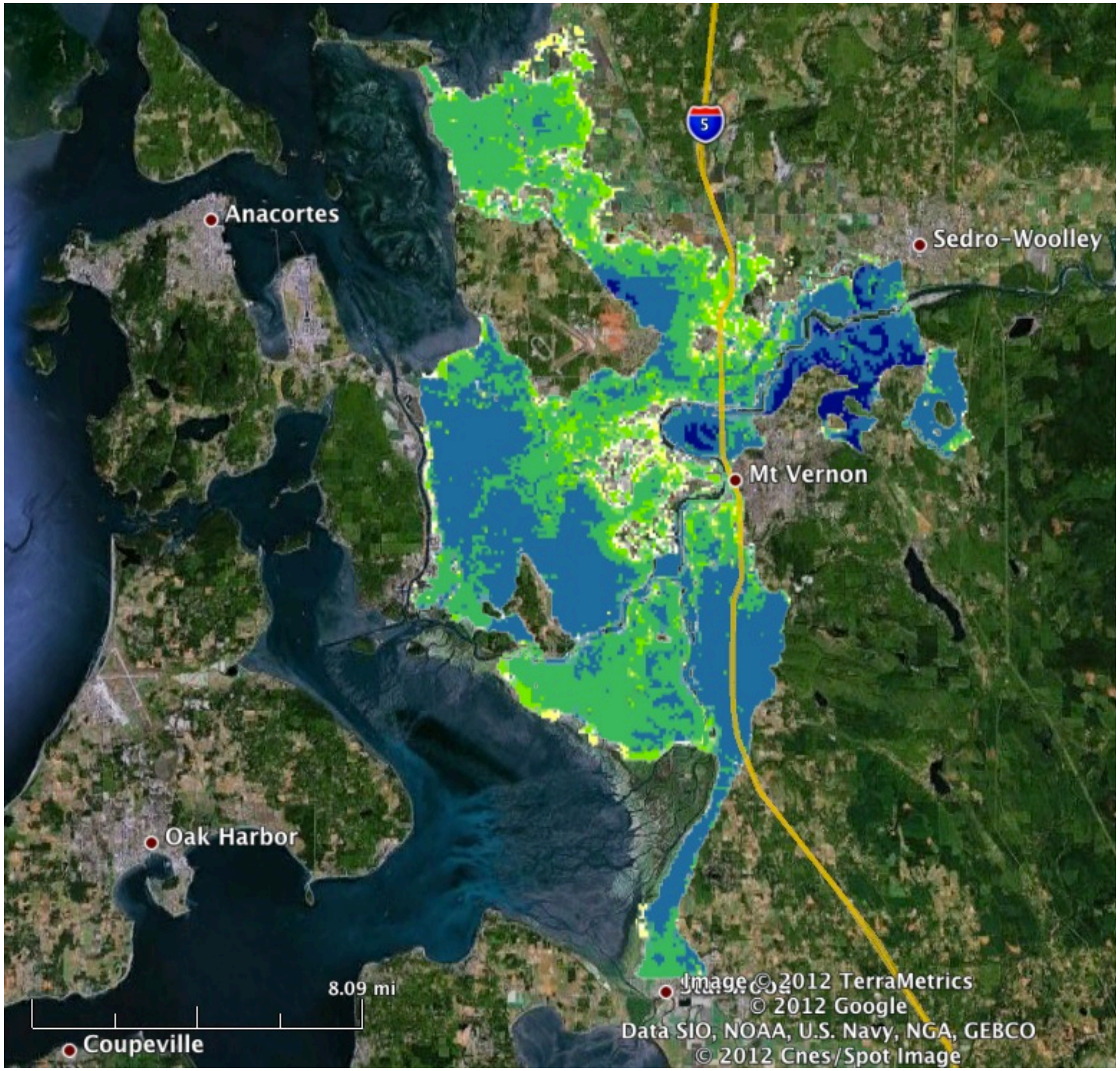


Area Flooded: 73,594 acres (+74%)

COMPOSITE FLOOD MAPS
7 LEVEE FAILURE SCENARIOS



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

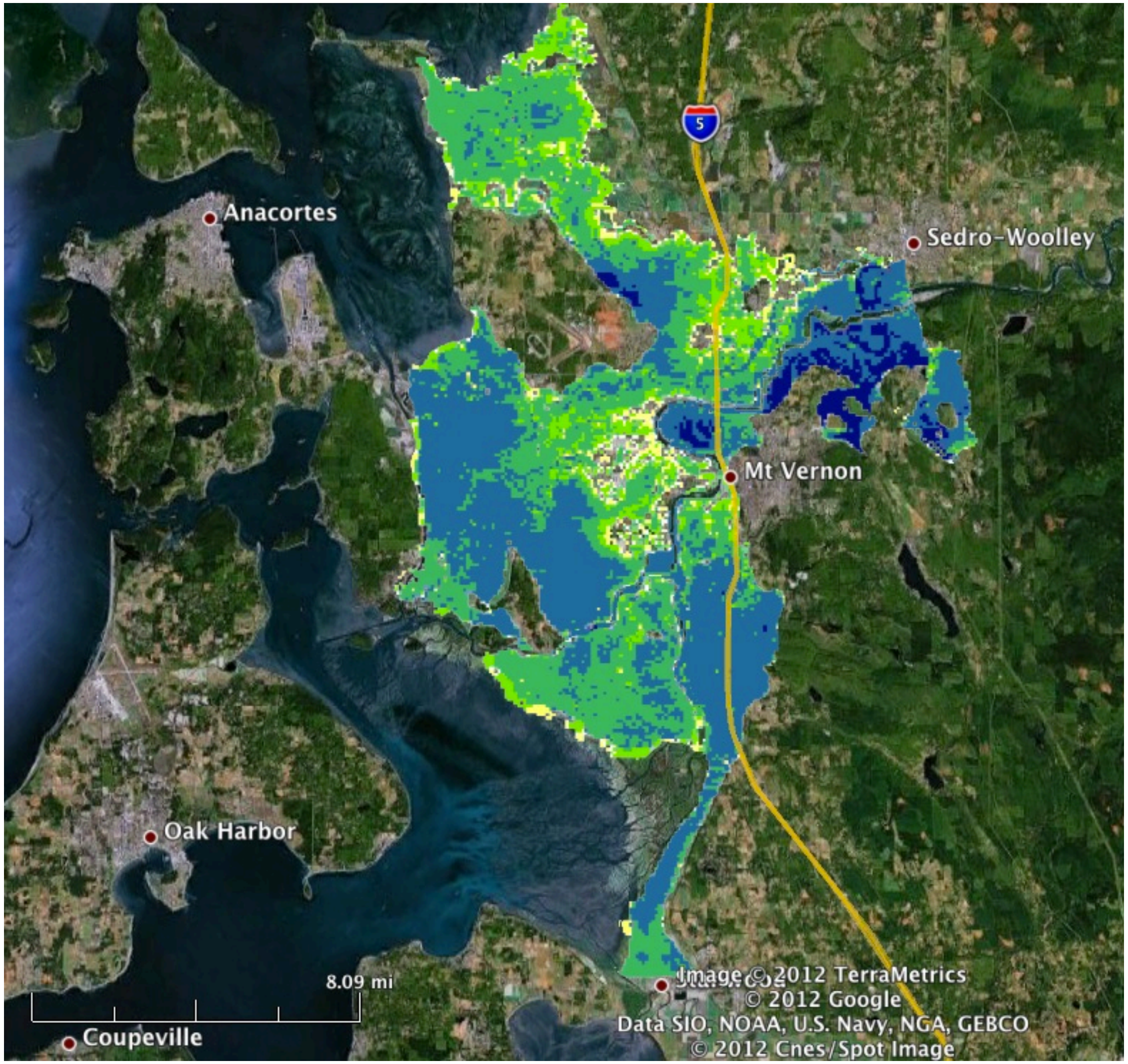
2.001 - 4.000

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

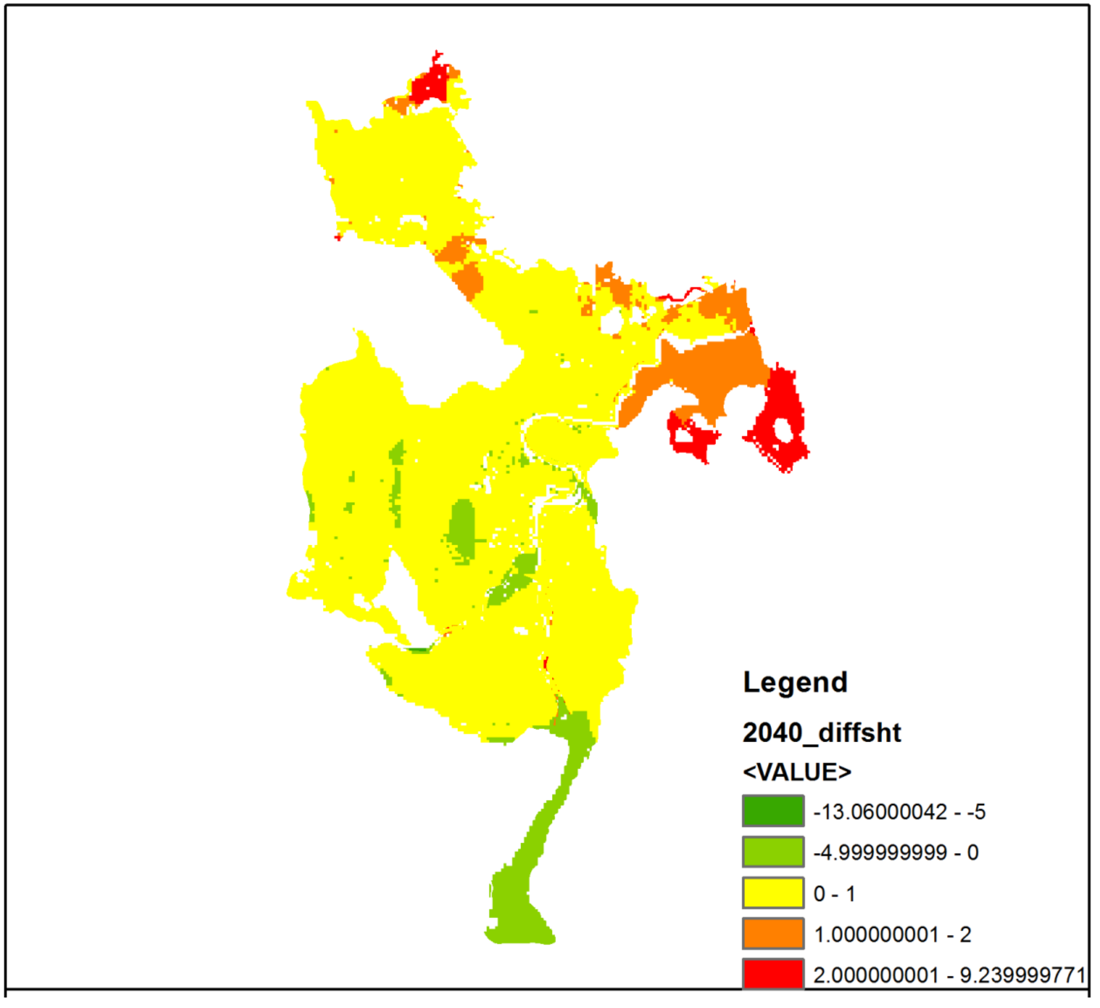
Area Flooded: 72,206 acres (+1%)

Avg Depth: 7.46 feet (+5 inches)

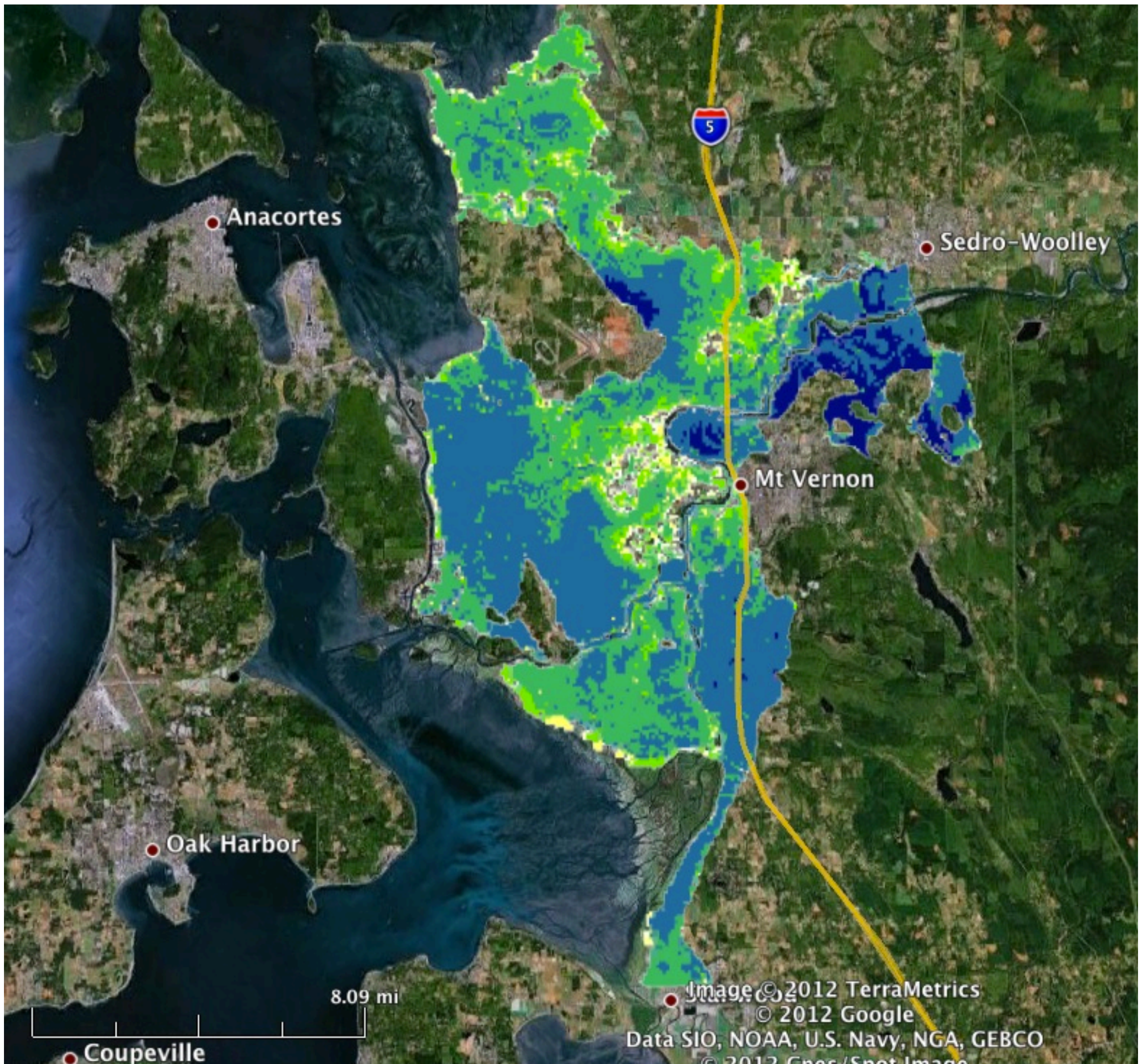
Yellow	1.000 - 2.000
Light green	2.001 - 4.000
Green	4.001 - 8.000
Blue	8.001 - 16.000
Dark blue	16.001 - 30.000

COMPOSITE FLOOD MAPS

2040S



COMPOSITE FLOOD MAPS
2080S



Inputs:

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

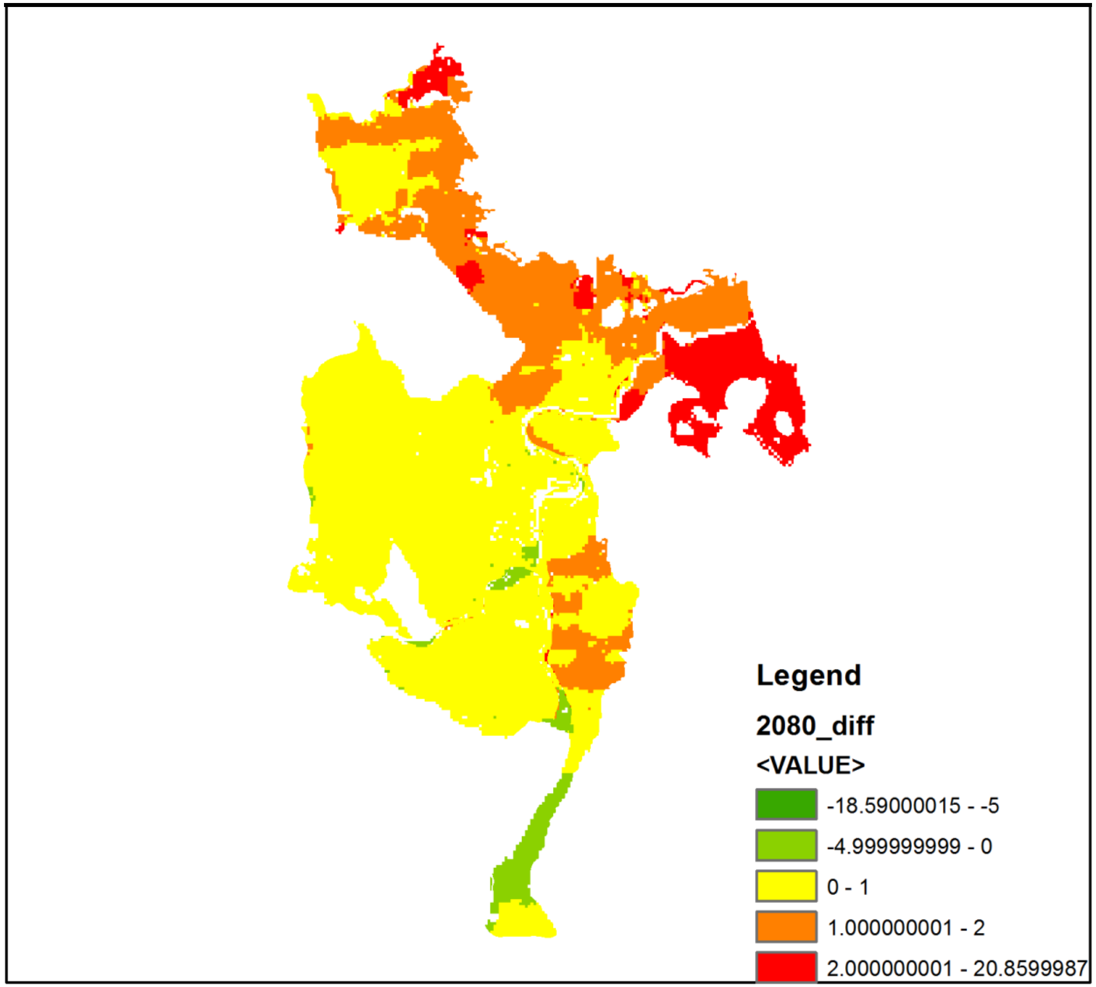
Area Flooded: 72,768 acres (+2%)

Avg Depth: 7.46 feet (+10 inches)

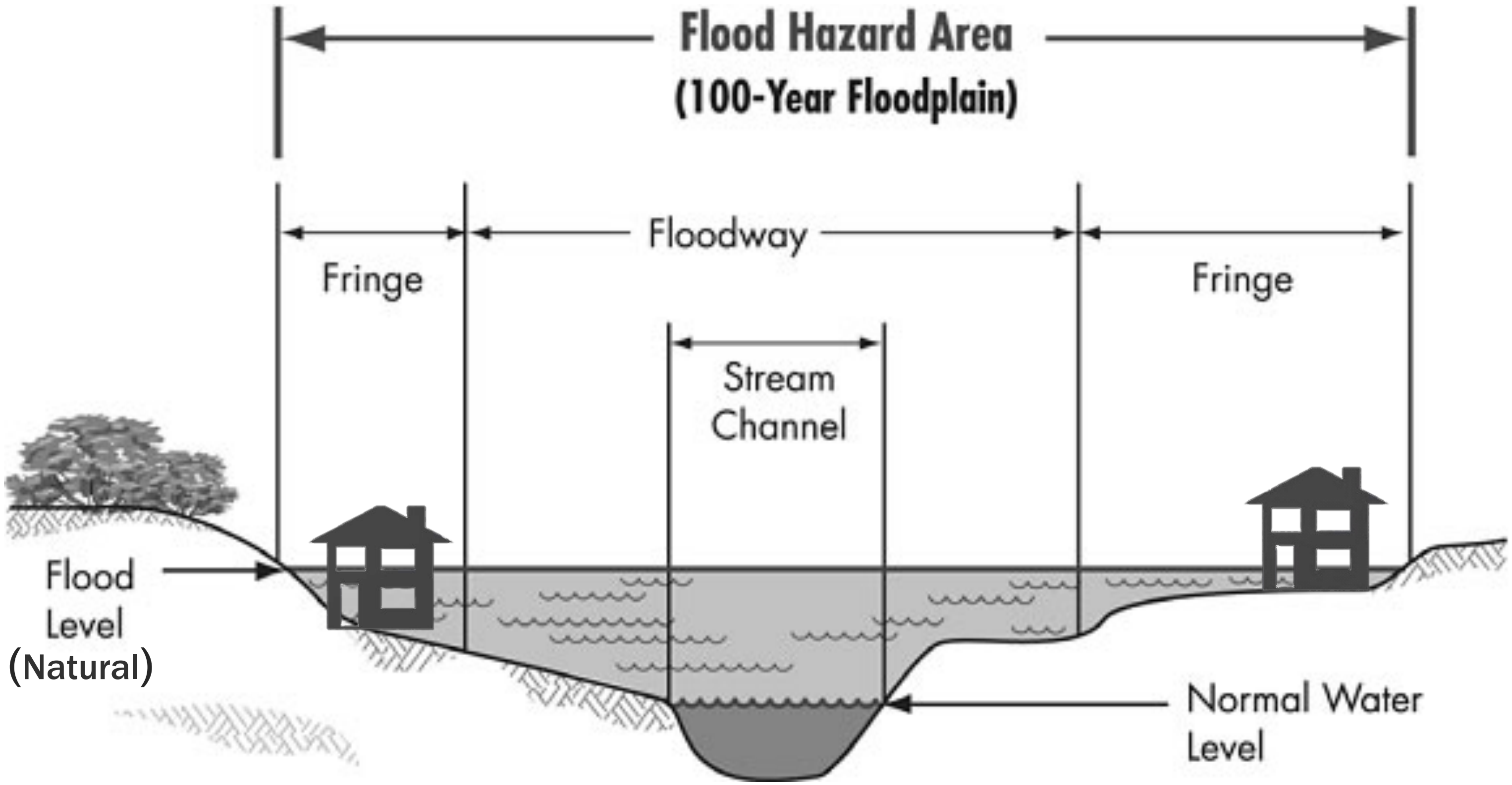
- 1.000 - 2.000
- 2.001 - 4.000
- 4.001 - 8.000
- 8.001 - 16.000
- 16.001 - 30.000

COMPOSITE FLOOD MAPS

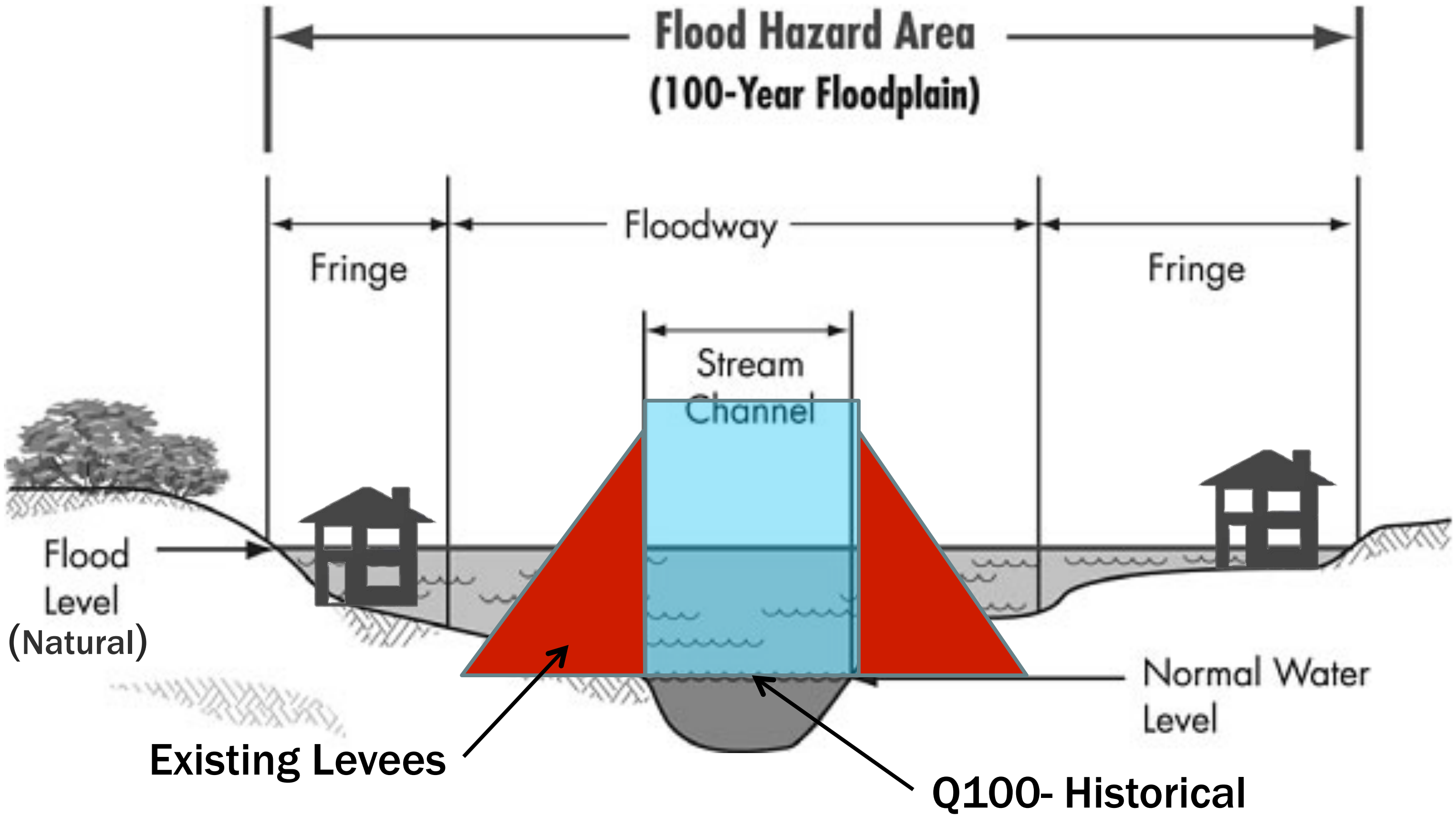
2080S



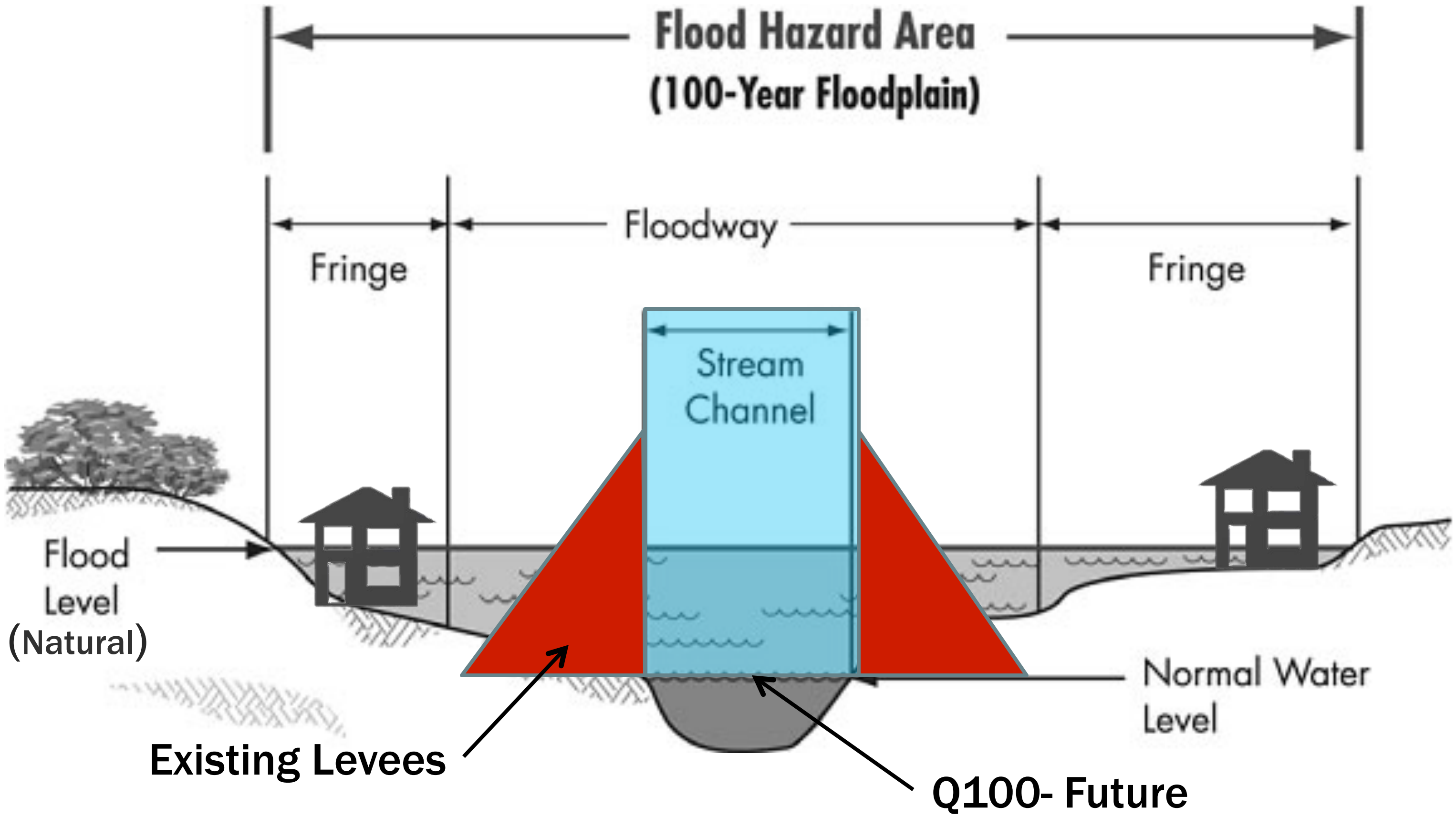
NATURAL RIVER CONDITIONS



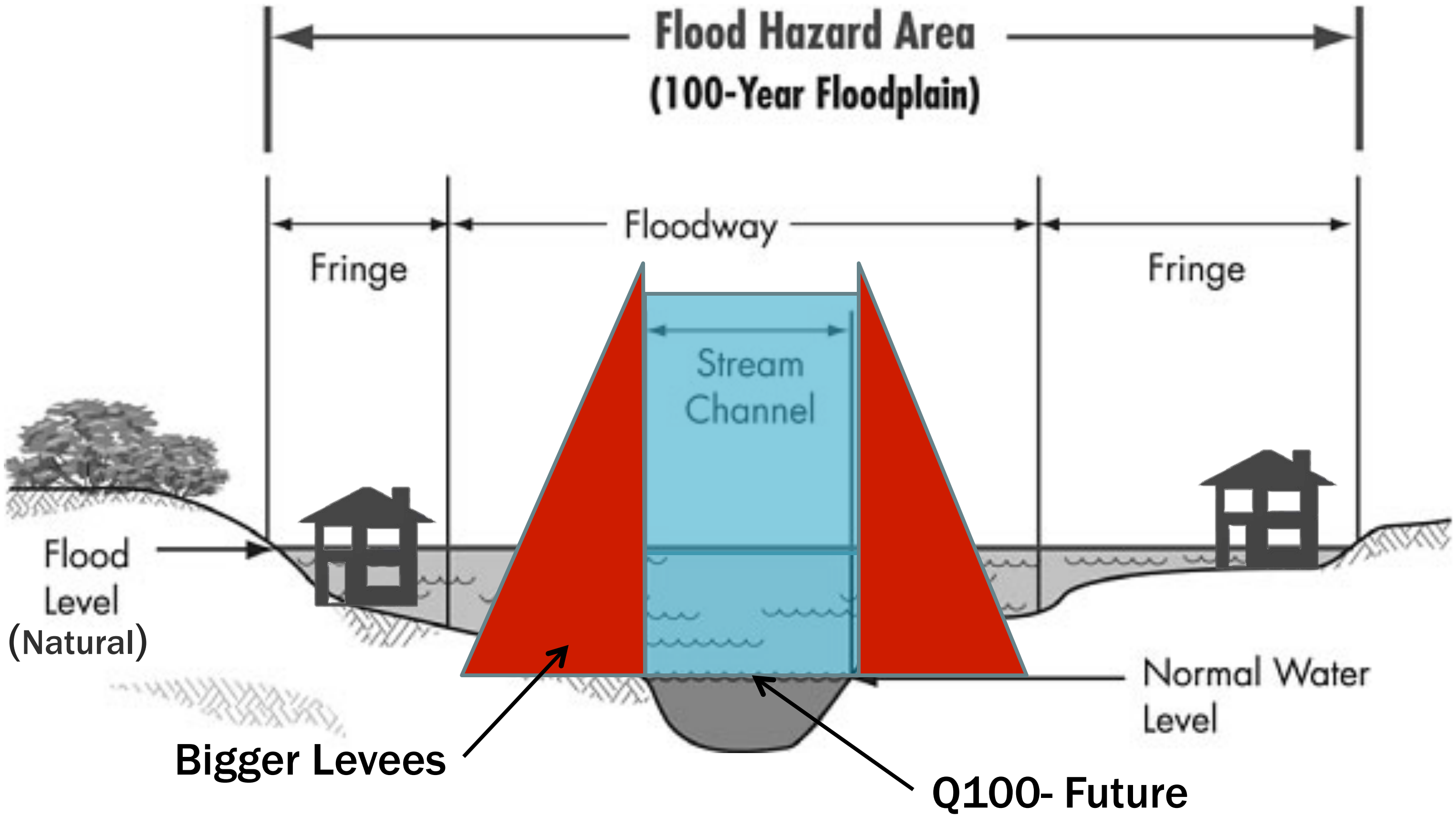
CONSTRAINED CHANNEL CONDITIONS



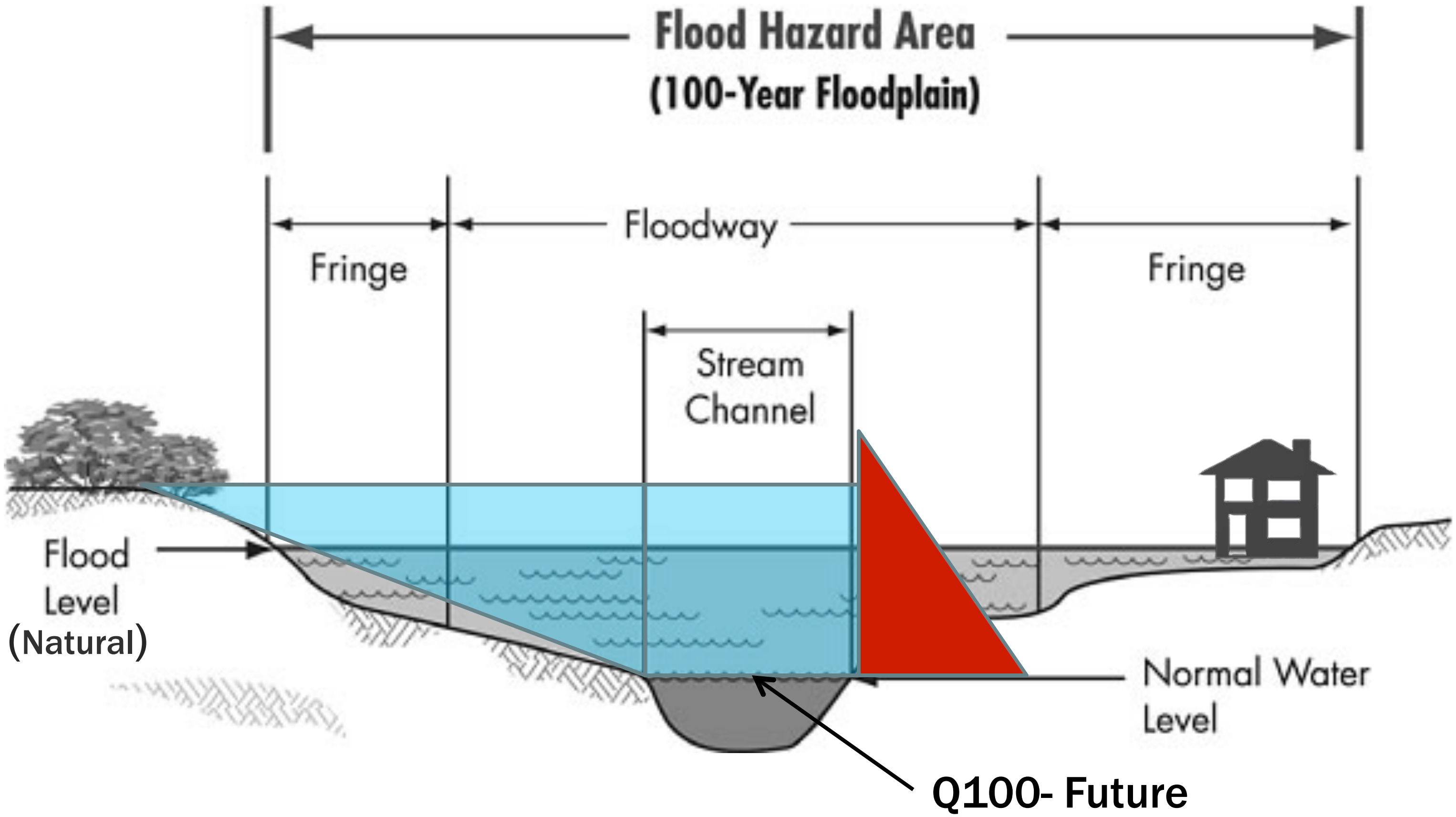
CONSTRAINED CHANNEL CONDITIONS



CONSTRAINED CHANNEL CONDITIONS



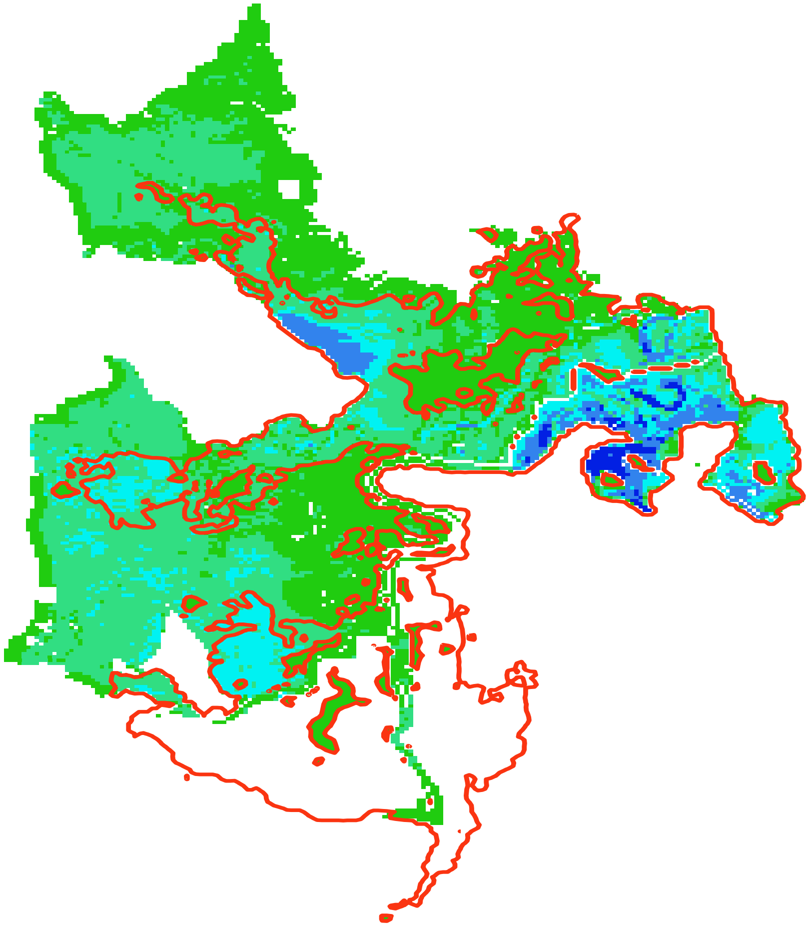
PARTIALLY CONSTRAINED CONDITIONS



RIGHT LEVEES REMOVED (EXAMPLE)

- 2080s
  - 1.32xHistorical
  - 75% area flooded relative to the “All Levees Intact” Scenario

- Similar process could be completed for other levee removal and setback scenarios



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.
- Modifying levee positions is a way to offset the increases in flood risk.

QUESTIONS?

Acknowledgments

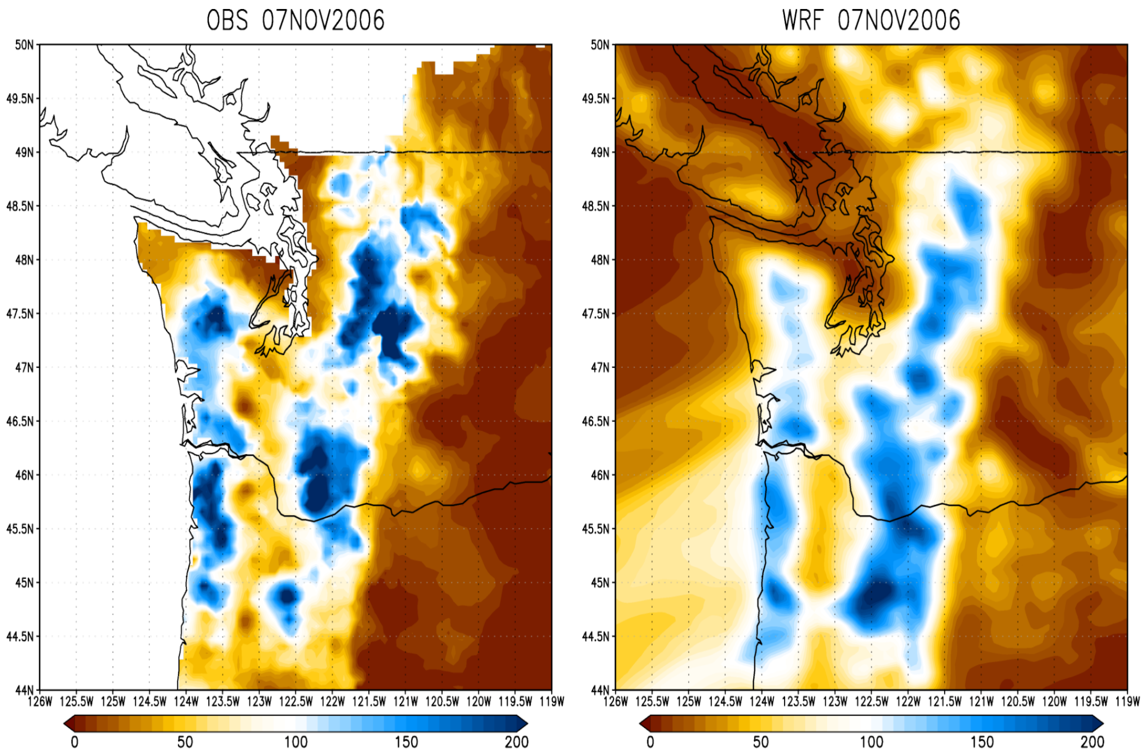
- Alan Hamlet
- Contributors
  - Se-Yuen Lee
  - Matt Stumbaugh
  - Eric Salathé
- EPA Funding
  - Roger Fuller
  - Eric Grossman

EXTRAS

RESOURCES

- Skagit County HAZUS - http://www.skagitcounty.net/Common/asp/default.asp?d=PlanningAndPermit&c=General&p=FEMAfloodstudy/femafloodstudy2010.htm
- Skagit County Flood Study – http://www.skagitcounty.net/Common/asp/default.asp?d=PlanningAndPermit&c=General&p=FEMAfloodstudy.htm
- Envision Skagit 2060 - http://www.skagitcounty.net/Common/asp/default.asp?d=EnvisionSkagit&c=General&P=reports.htm
- Climate Impacts Group, 2860 project - http://www.hydro.washington.edu/2860/

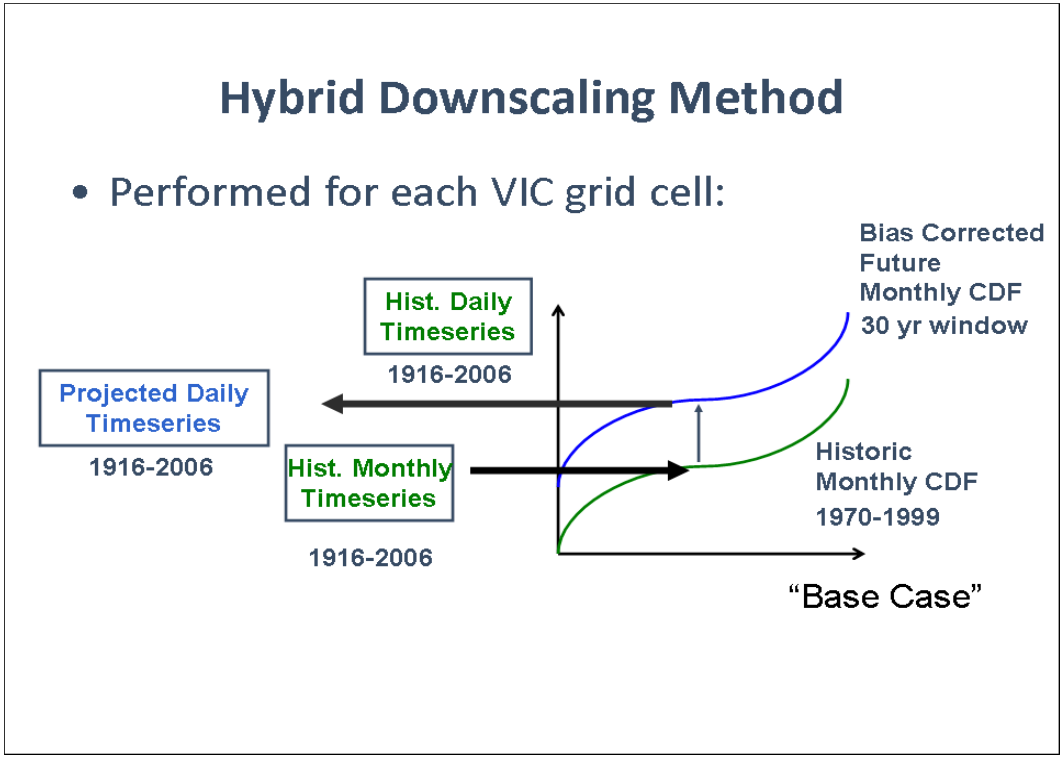
DYNAMIC DOWNSCALING



- 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

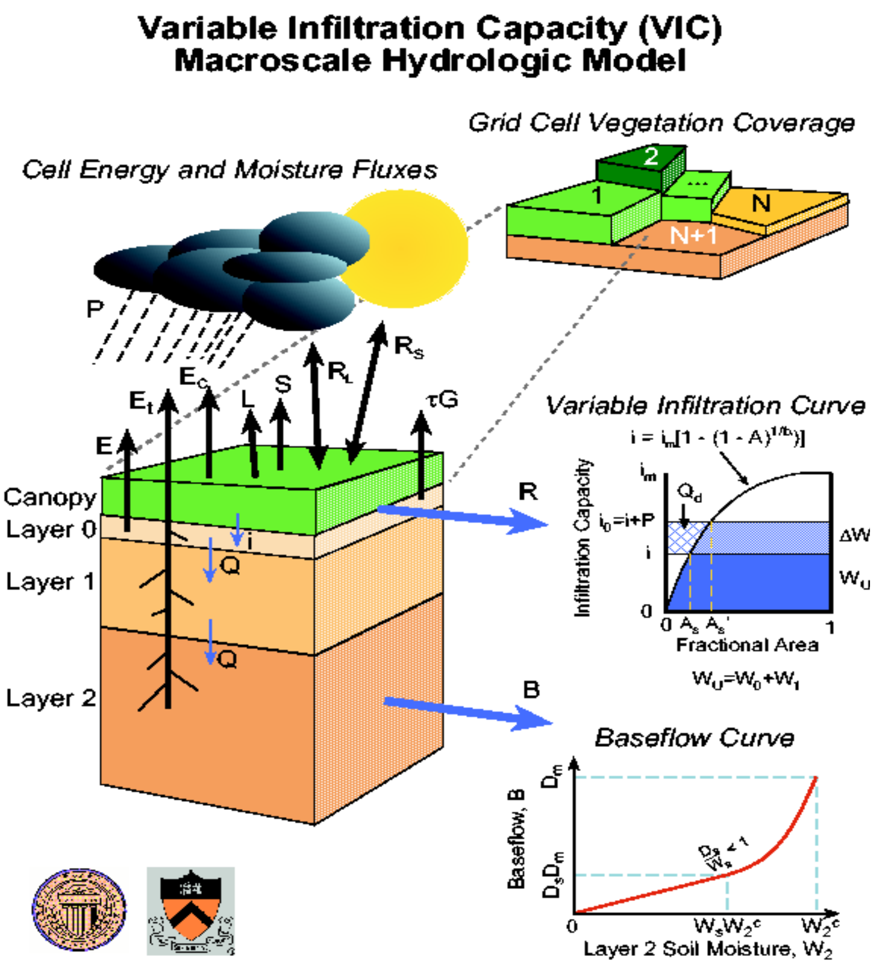
- Three 30-year time periods
  - 1980s, 2020s and 2050s

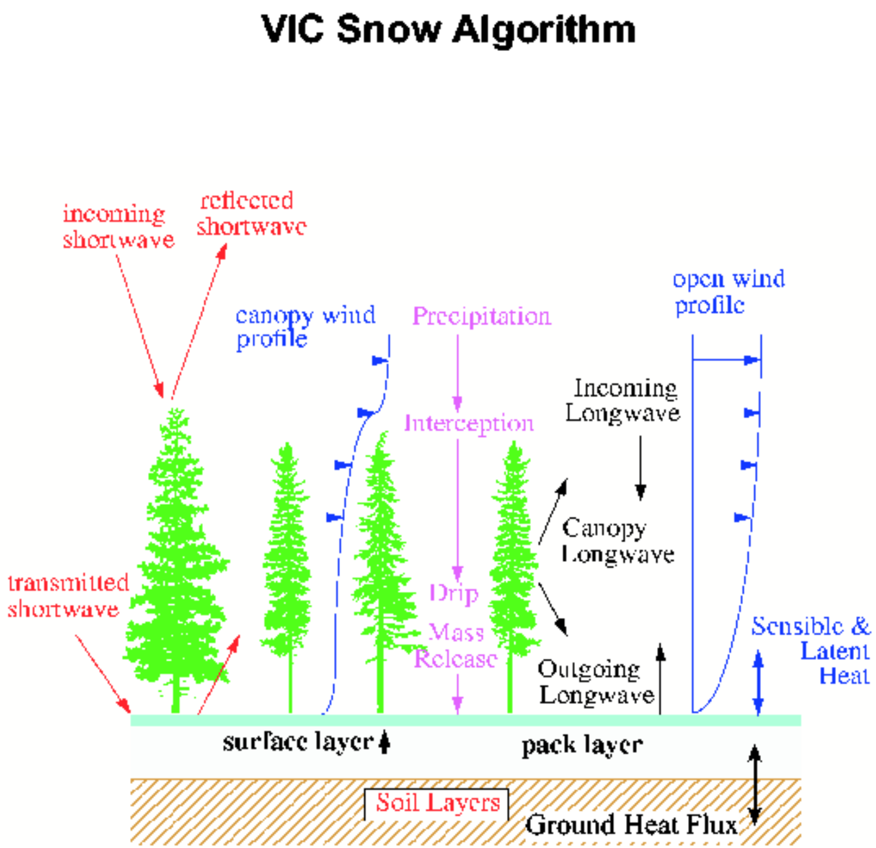
STATISTICAL DOWNSCALING



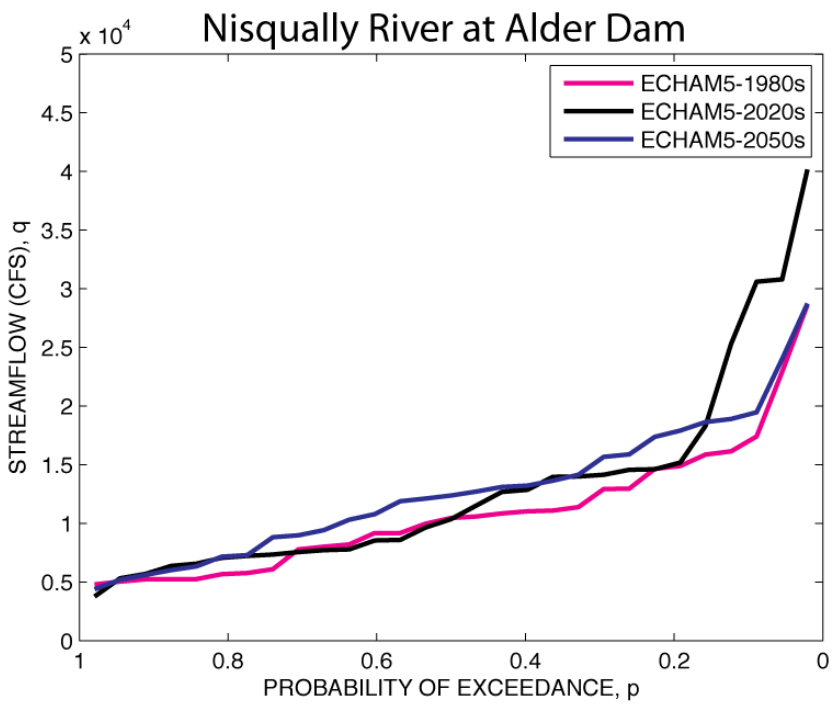
- Adjusts historic monthly timeseries to match CDF of GCM at each grid cell
- Forces historic daily timeseries to fit new monthly values
- Preserves most of the historical time series behavior
  - Storm size, storm location, interarrival, seasonality, time, etc.
- Two30-year time periods
  - 2040s and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

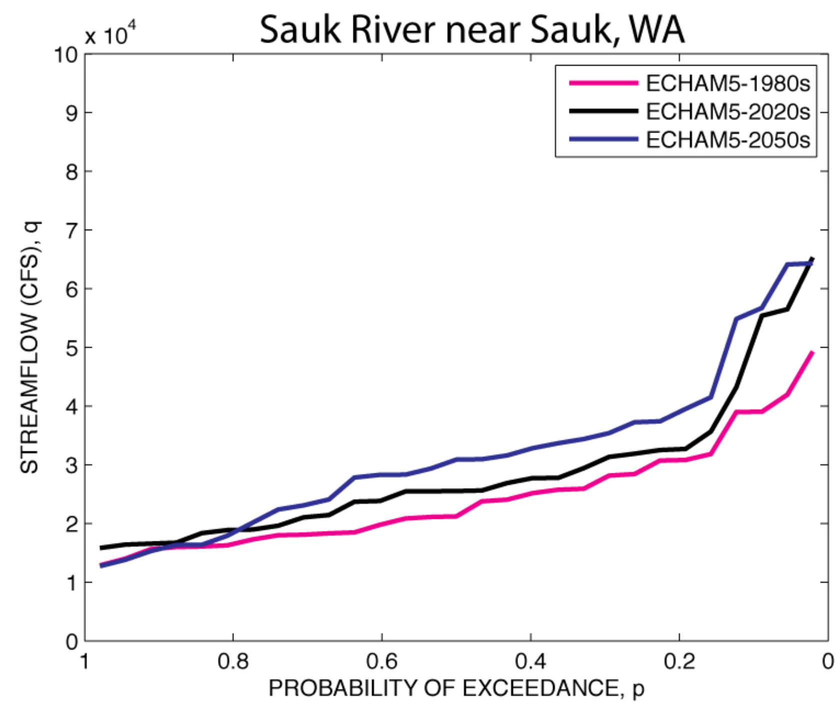
HYDROLOGIC MODELING





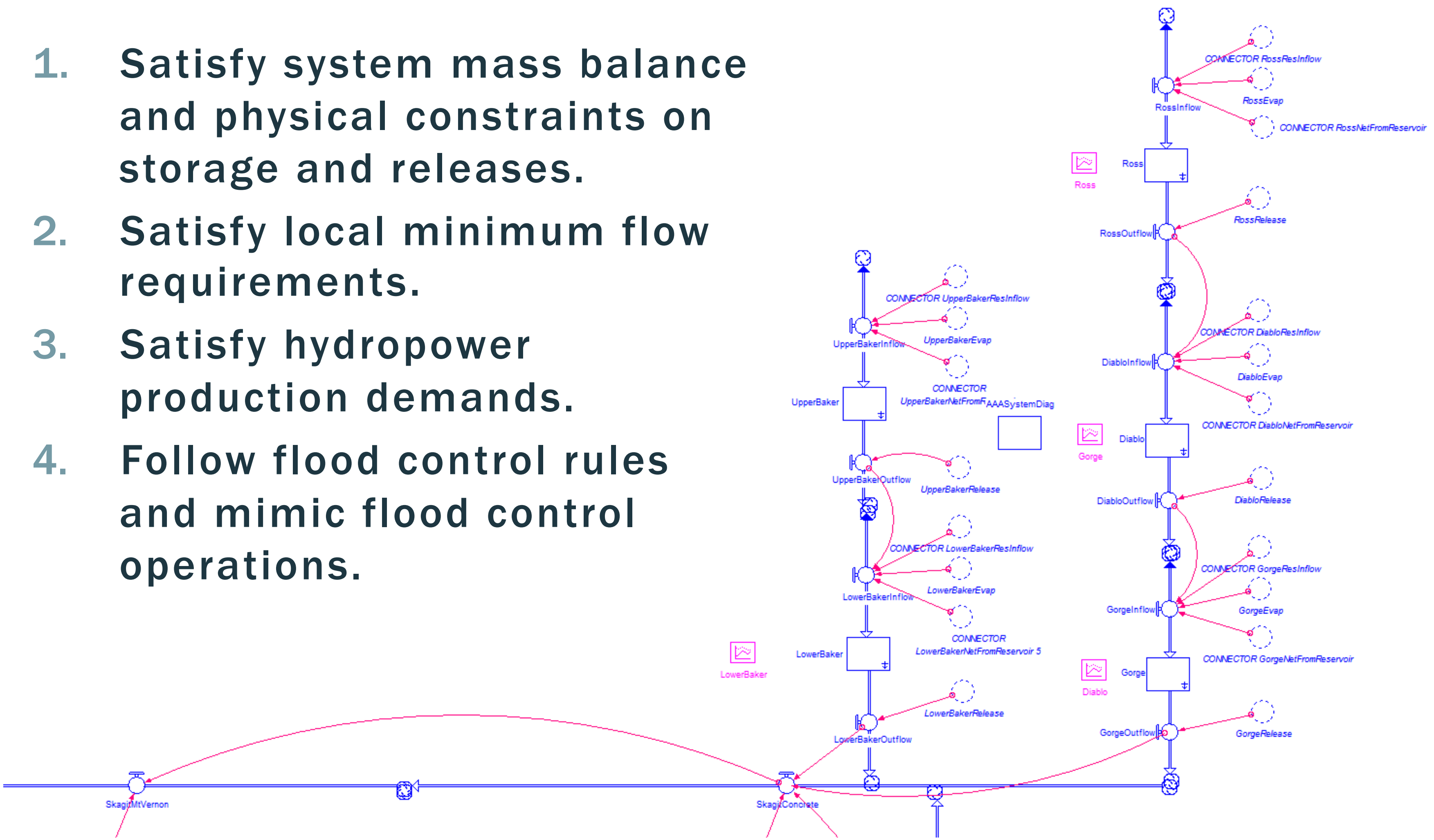
UNREGULATED HYDROLOGY



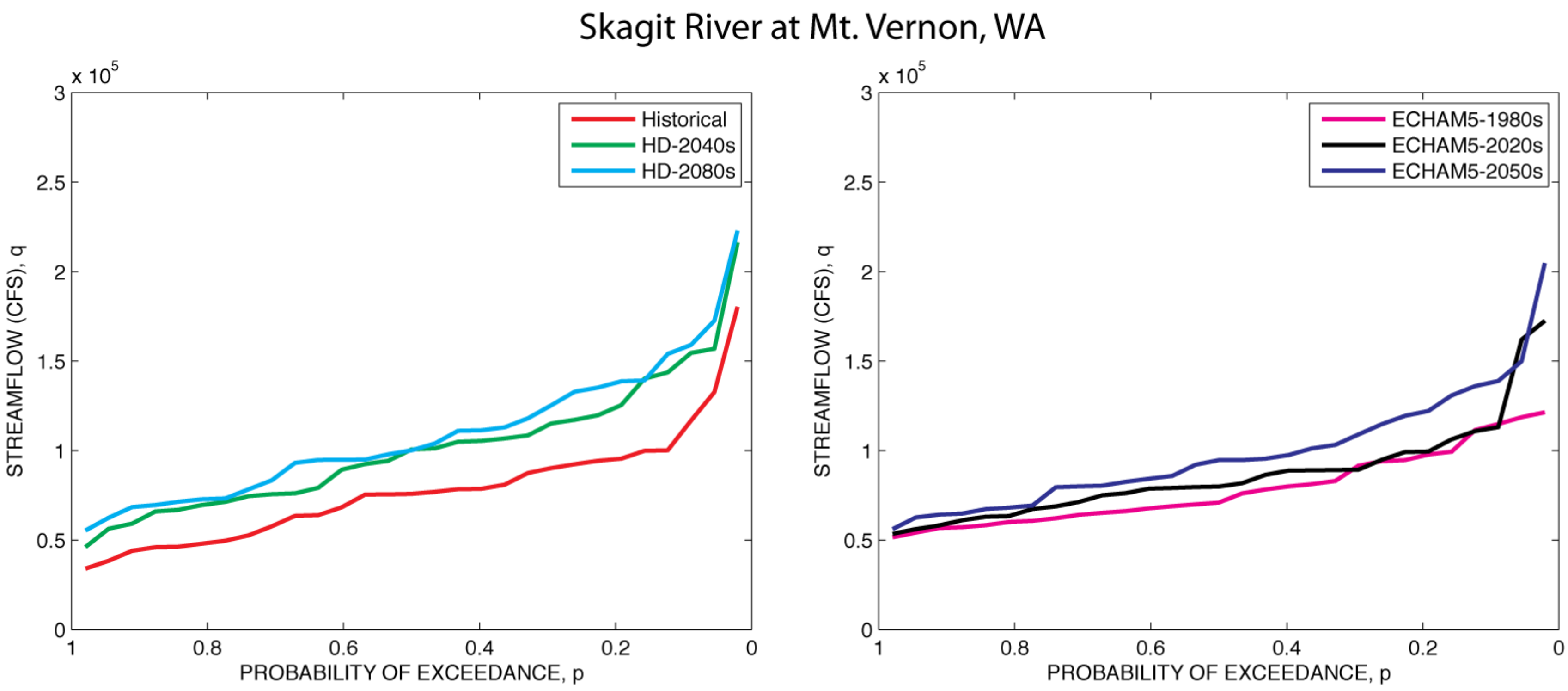


RESERVOIR MODELING

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.

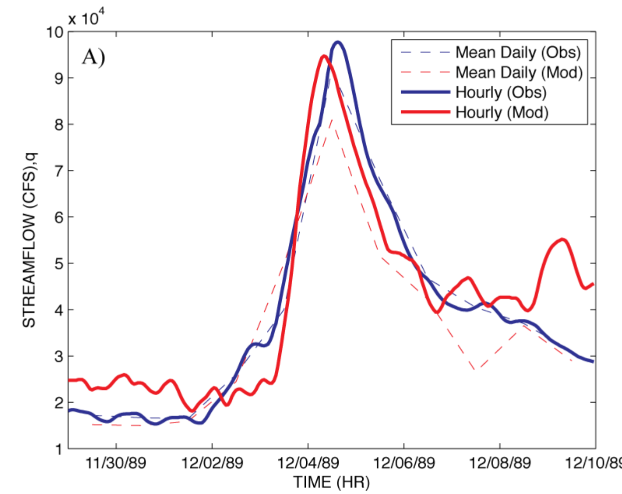


REGULATED PEAK FLOWS



HOURLY DISAGGREGATION

- WRF storms
  - **Goal**: Assess dynamics of flooding under completely different conditions (storm surge, SLR, hydrograph)
  - ***Approach***: *Steepness Index Unit Volume Flood Hydrograph Approach for Sub-Daily Flow Disaggregation*



- Scaled FEMA storms
  - **Goal**: Compare flood extents and depths between different time periods (e.g. Historical and 2050s)
  - ***Approach***: Scale by relative increase in 100-yr flood based on GEVD fit to each 30-yr time period