Storm Sewer Infrastructure Planning with Climate Change Risk: A Case Study from Alexandria VA

Laurens van der Tak, PE, D.WRE

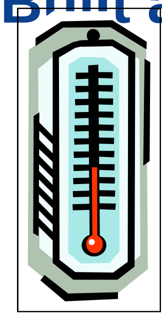
MWCOG Climate Impacts Symposium
May 21, 2012

CH2MHILL®

Presentation Topics

- Overview of City of Alexandria Storm Sewer Capacity Analysis Study
- Climate change case study:
  - Precipitation intensity, duration and frequency
  - Sea level rise

How does Climate Change Impact Management of Built and Natural Environments?

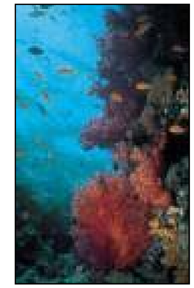


Temp Increase

Droughts and Floods

More Frequent Storm Events

Rising Sea Level



Ocean Acidification

Impacts on…

Source Water

- Regional drought
- Intake elevations
- WQ Issues
- Evaporation
- Groundwater depletion
- Seawater Intrusion

Stormwater

- Localized flooding
- Regional flooding
- Increased CSOs
- Other WQ issues
- Drainage system management

Water Treatment

- Siting elevations
- Sedimentation
- Additional treatment requirements
- WQ issues: algae

Wastewater

- Siting elevations
- Outfall elevations
- Temp-dependent processes
- Receiving WQ

Agriculture

- Evapotranspiration
- Crop yields
- Irrigation demands
- Growing season

Ecosystems

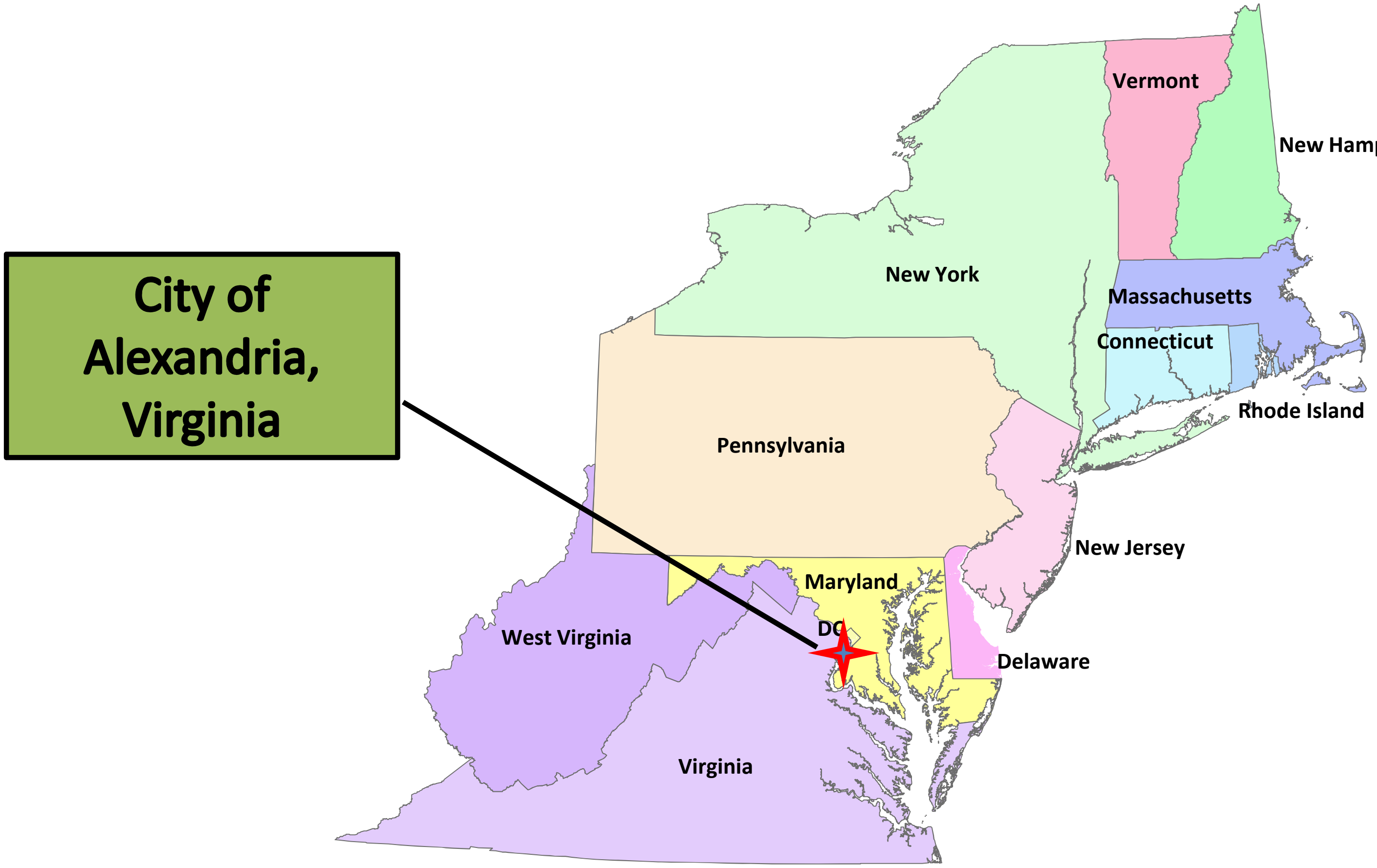
- Marine, freshwater ecosystem collapse
- Widespread species extinctions

Storm Sewer Infrastructure Planning with Climate Change Risk - A Case Study

- The City of Alexandria, Virginia, has experienced repeated and increasingly frequent flooding events
- Review of design criteria and potential impacts of climate change

Hurricane Isabel flooding, September 2003
Photo Credit: Courtesy Mark Young/The Journal Newspapers

City of Alexandria, Virginia, is on the tidal Potomac River, across from Washington DC



Project Overview – City of Alexandria Storm Sewer Capacity Analysis

Task 1
Evaluate City of Alexandria rainfall data and hydrographs

Task 2
Hydrologic and Hydraulic Modeling

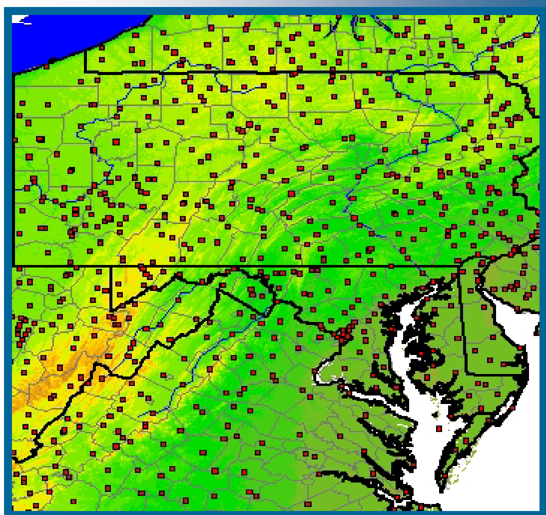
Task 3
Field Verification

Task 4
Identify Problem Areas and Suggest Solutions

Task 5
Coordination Meetings and Public Involvement

Project Overview –
City of Alexandria Storm Sewer Capacity

NOAA Atlas 14 climate stations used for IDF analysis (2004)



Task 1
Evaluate City of Alexandria rainfall data and hydrographs

Task 2
Hydrologic and Hydraulic Modeling

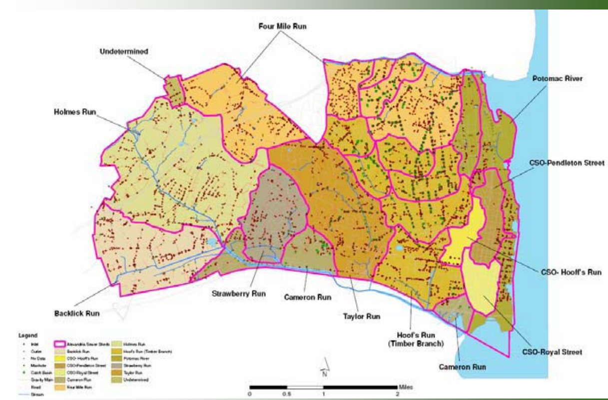
Task 3
Field Verification

Task 4
Identify Problem Areas and Suggest Solutions

Task 5
Coordination Meetings and Public Involvement

Project Overview –
City of Alexandria Storm Sewer Capacity

Hydrologic and hydraulic modeling will maximize use of the City of Alexandria's existing GIS for the seven storm sewer sheds outside the CSO area. Pilot testing of procedures will be done in one area selected together with the City.



Task 1
Evaluate City of Alexandria rainfall data and hydrographs

Task 2
Hydrologic and Hydraulic Modeling

Task 3
Field Verification

Task 4
Identify Problem Areas and Suggest Solutions

Task 5
Coordination Meetings and Public Involvement

Project Overview – City of Alexandria Storm Sewer Capacity

Task 1
Evaluate City of Alexandria rainfall data and hydrographs

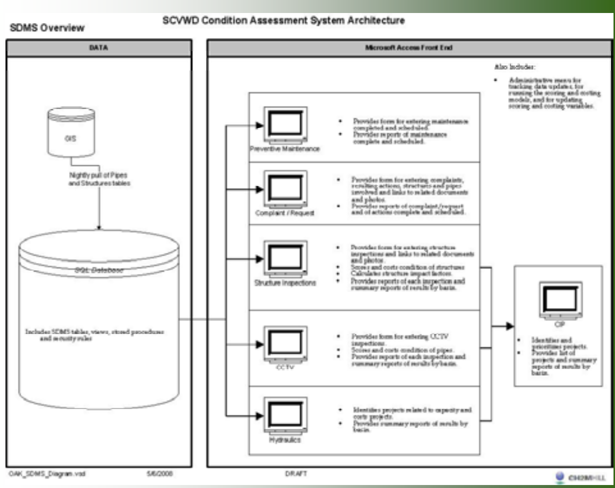
Task 2
Hydrologic and Hydraulic Modeling

Task 3
Field Verification

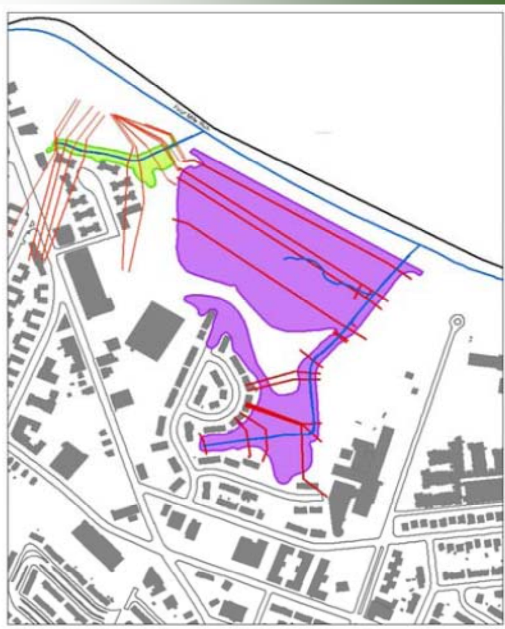
Task 4
Identify Problem Areas and Suggest Solutions

Task 5
Coordination Meetings and Public Involvement

CH2M HILL will develop a technical memorandum that presents the overall database architecture and data flow for how data from the field verification tasks are stored and then linked into or used to update the City's existing GIS. A similar architecture was used to successfully update the City of Oakland's GIS for their Storm Drainage Master Plan project.



Project Overview –
City of Alexandria Storm Sewer Capacity



Updated Four Mile Run flood boundaries come close to high-rise apartments in Alexandria.

Task 1
Evaluate City of Alexandria rainfall data and hydrographs

Task 2
Hydrologic and Hydraulic Modeling

Task 3
Field Verification

Task 4
Identify Problem Areas and Suggest Solutions

Task 5
Coordination Meetings and Public Involvement

Project Overview – City of Alexandria Storm Sewer Capacity

Congressman Jim Moran, Vice Mayor Del Pepper and others take part in a ribbon-cutting ceremony marking the unanimous acceptance of the Four Mile Run Restoration Master Plan by all agencies.

Task 1
Evaluate City of Alexandria rainfall data and hydrographs

Task 2
Hydrologic and Hydraulic Modeling

Task 3
Field Verification

Task 4
Identify Problem Areas and Suggest Solutions

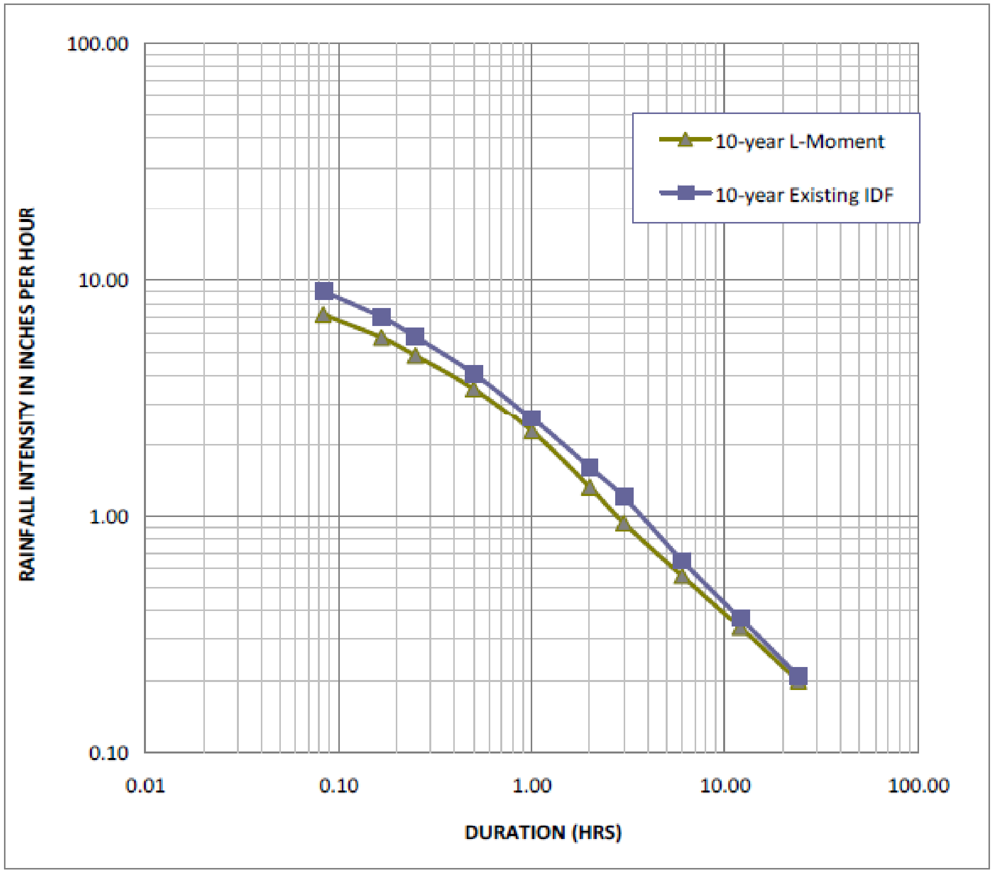
Task 5
Coordination Meetings and Public Involvement

Task 1 Summary:
Effects of Climate Change on Rainfall Design Criteria

- Review and propose revisions to the City's stormwater design criteria
- Update existing precipitation frequency information with 30 additional years of observed data
- Using climate change projections for 2050 and 2100 investigate:
  - Projected changes in intensity, duration, and frequency (IDF)
  - Projected changes in sea level

Rainfall Intensity-Duration-Frequency (IDF) Curve 10-year Return Period Analysis of Historic Data, and Comparison to Existing Curves

- Original IDF analysis used 1941-1969 dataset and TP-40 distribution analysis
- Updated analysis used 1948-2008 dataset and L-MOMENTS distribution analysis (similar to NOAA Atlas 14 updates)
- Existing IDF curves (48-69) are conservative for shorter durations and return frequencies



Climate Change Risk Assessment

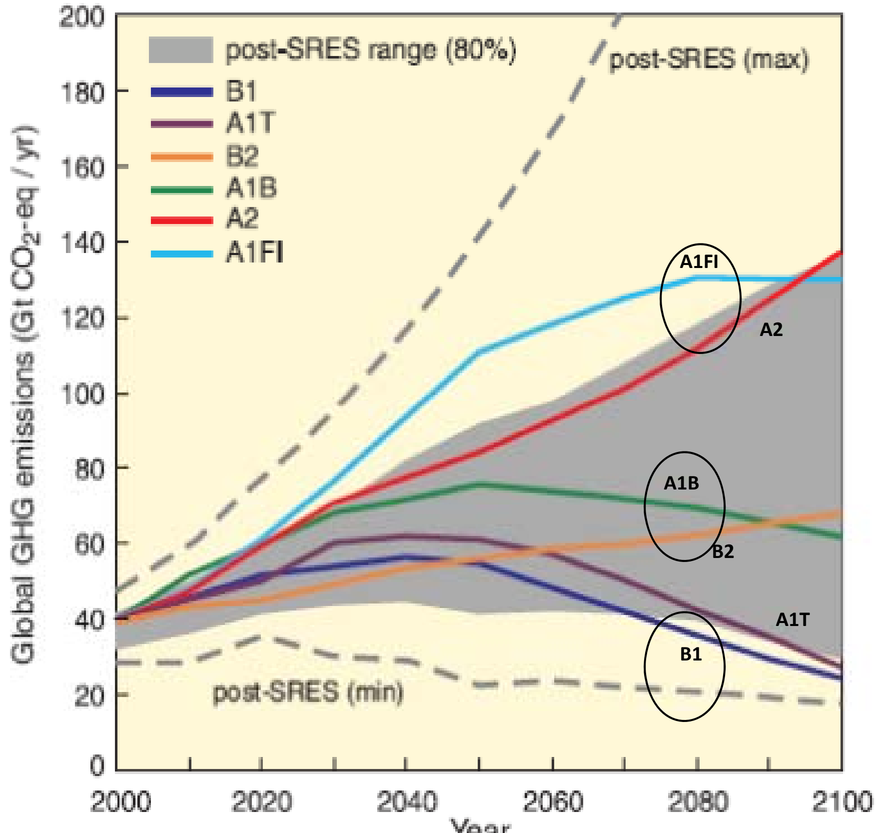
What Climate Data and Tools are Needed?

- Observed data
  - Daily precipitation for Reagan National AP (1948-2008) and daily tide data (1931-2008)
- Climate change projections
  - Global Circulation Model (GCM)
  - Greenhouse Gas (GHG) emission scenarios
- Analysis tools
  - Turn data into information to assess risk and vulnerability using historical data and GCM projections

Selected a Range of Low to High Greenhouse Gas (GHG) Emission Scenarios from Intergovernmental Panel on Climate Change (IPCC)

"Scenario Family"	Description
A1 – Rapid Growth A1FI - Fossil Intensive A1T - Non-fossil A1B – Balanced	Second Highest Greenhouse Emissions
A2 – Heterogeneous High Population Growth Slow Economic and Technology Change	Highest Greenhouse Emissions
B1 – Convergent World Same Population as A1, more service and information technology.	Lowest Greenhouse Emissions
B2 – Intermediate Population growth, local solutions.	Second Lowest Greenhouse Emission

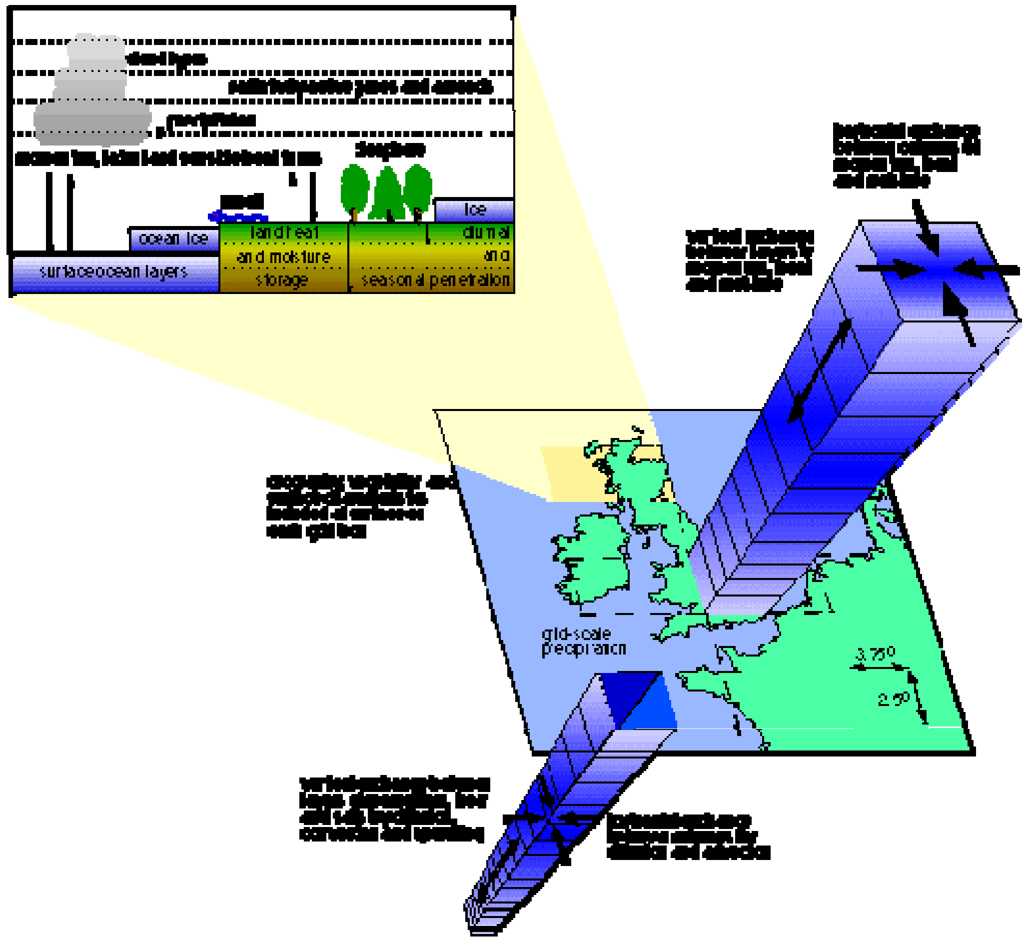
SRES (Special Report on Emission Scenarios, IPCC 2000)



Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies.

Global Circulation Models (GCM)

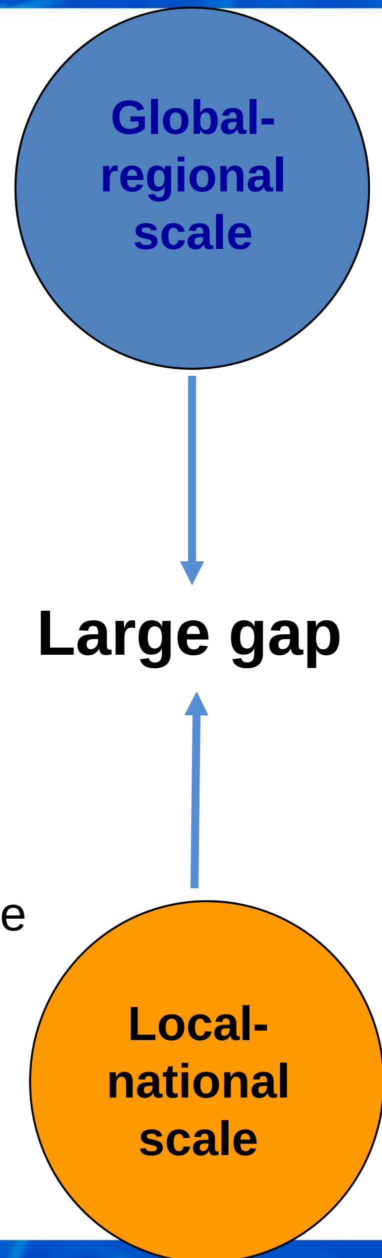
- Five GCMs selected initially based on ability to reproduce historical precipitation patterns
- Later updated to include ensemble of all 12 daily GCMs from AR4
- Studies show taking ensemble is better than using a single GCM (Knuti, et al., IPCC, Jan.2010)



GCM components (Hadley Center)

- Climate science
- Global climate models
- Scenarios of change
- Bio-physical impact assessment

e.g. IPCC assessment

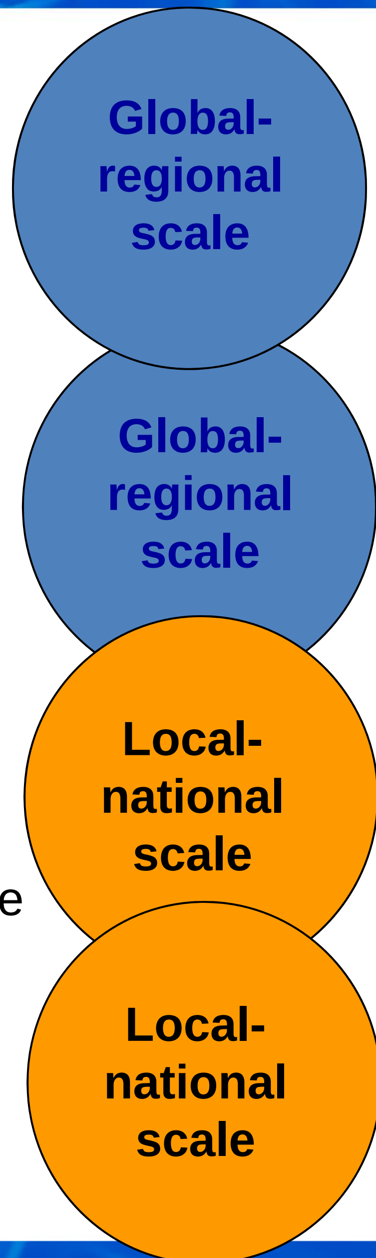


- Vulnerability and resilience
- Adaptation
- Sustainable development
- Risk-based assessments

e.g. "climate-proofing" community water supply

- Climate science
- Global climate models
- Scenarios of change
- Bio-physical impact assessment

e.g. IPCC assessment



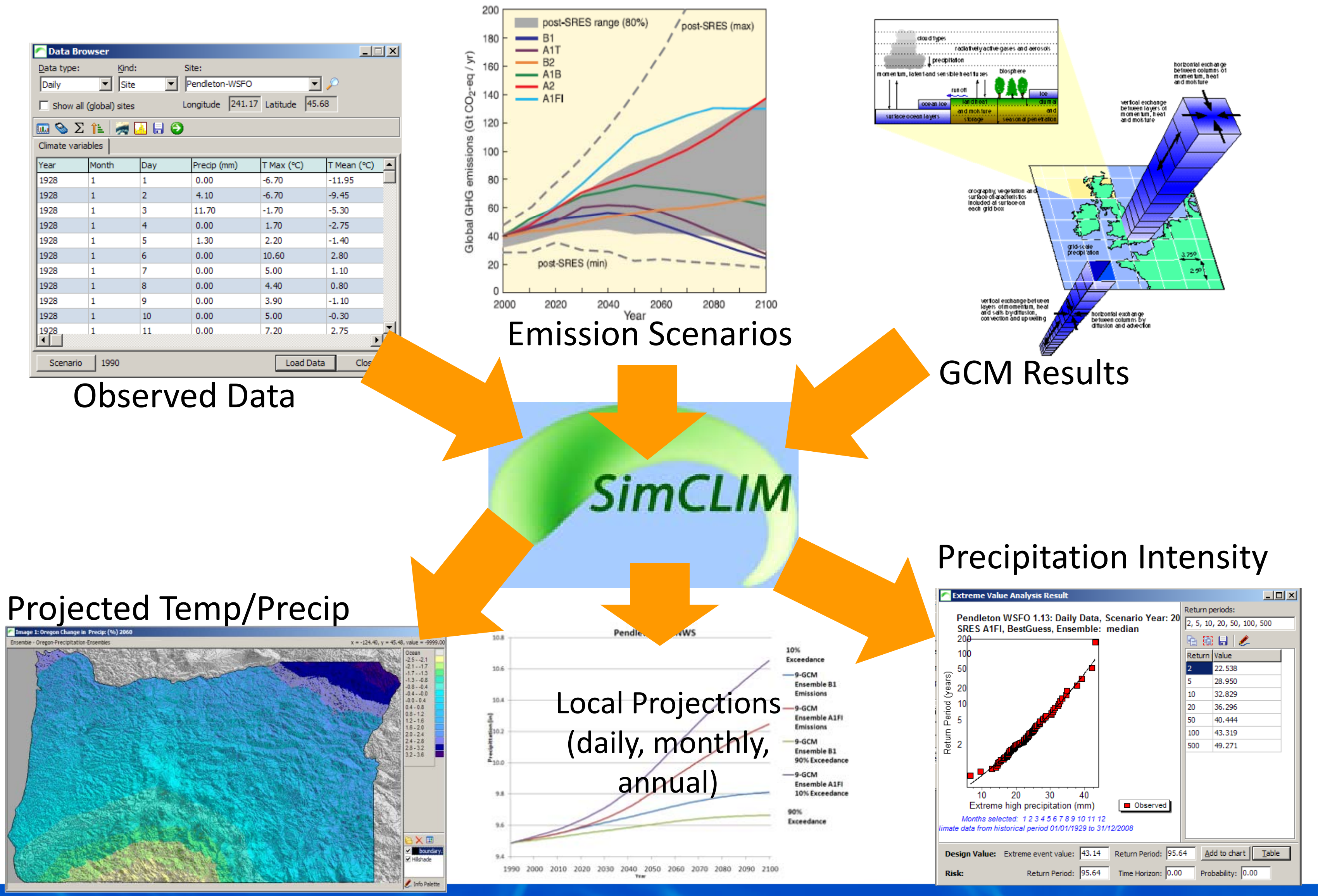
Bridging the gap: integrated assessment models and tools

e.g. the SimCLIM modeling system

- Vulnerability and resilience
- Adaptation
- Sustainable development
- Risk-based assessments

e.g. “climate-proofing” community water supply

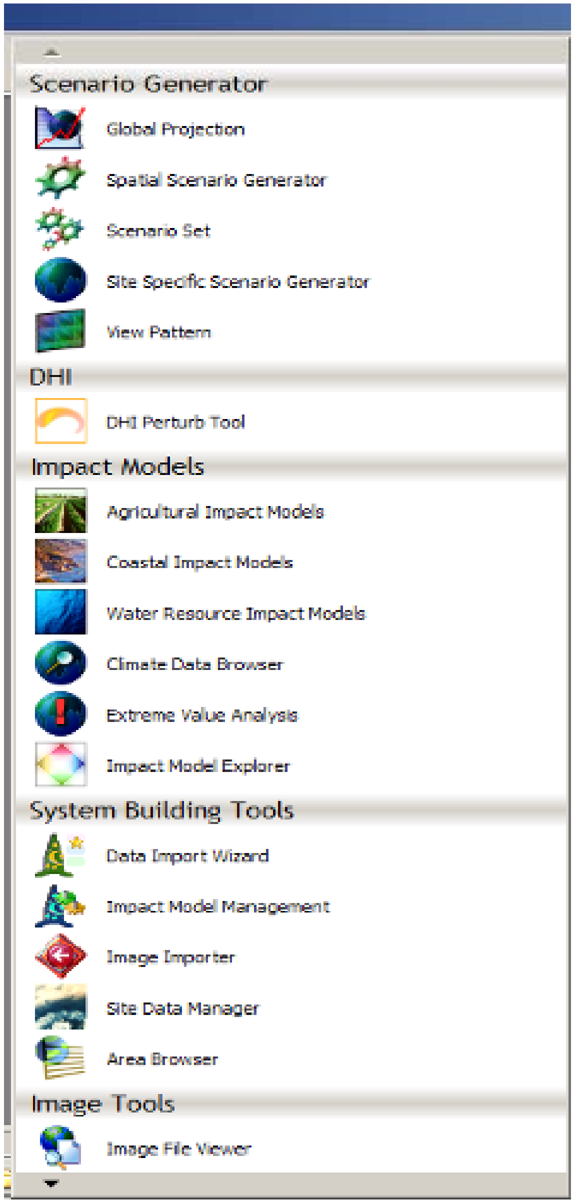
SimCLIM Input and Output



SimCLIM Technology*

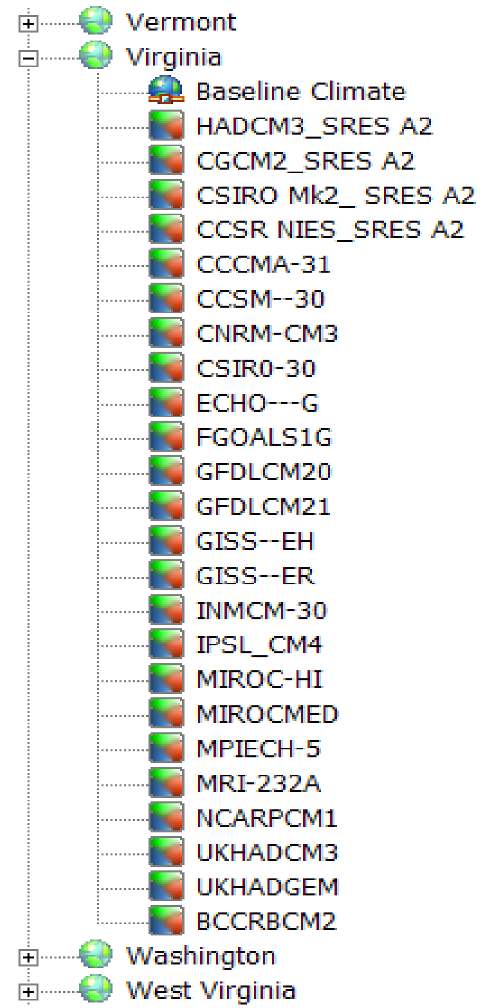
*CLIMsystems Ltd, New Zealand

- SimCLIM
  - PC-based technology that manages observed data and GCM results
  - Seamless selection of emissions and GCM results to create temperature, precipitation, and sea level rise scenarios
  - Generates daily time series of baseline and future temperature and precipitation, rainfall return frequencies and amounts
  - Results exported into Voyage, GoldSIM, WEAP, REF-ET, Excel, and Arc GIS formats



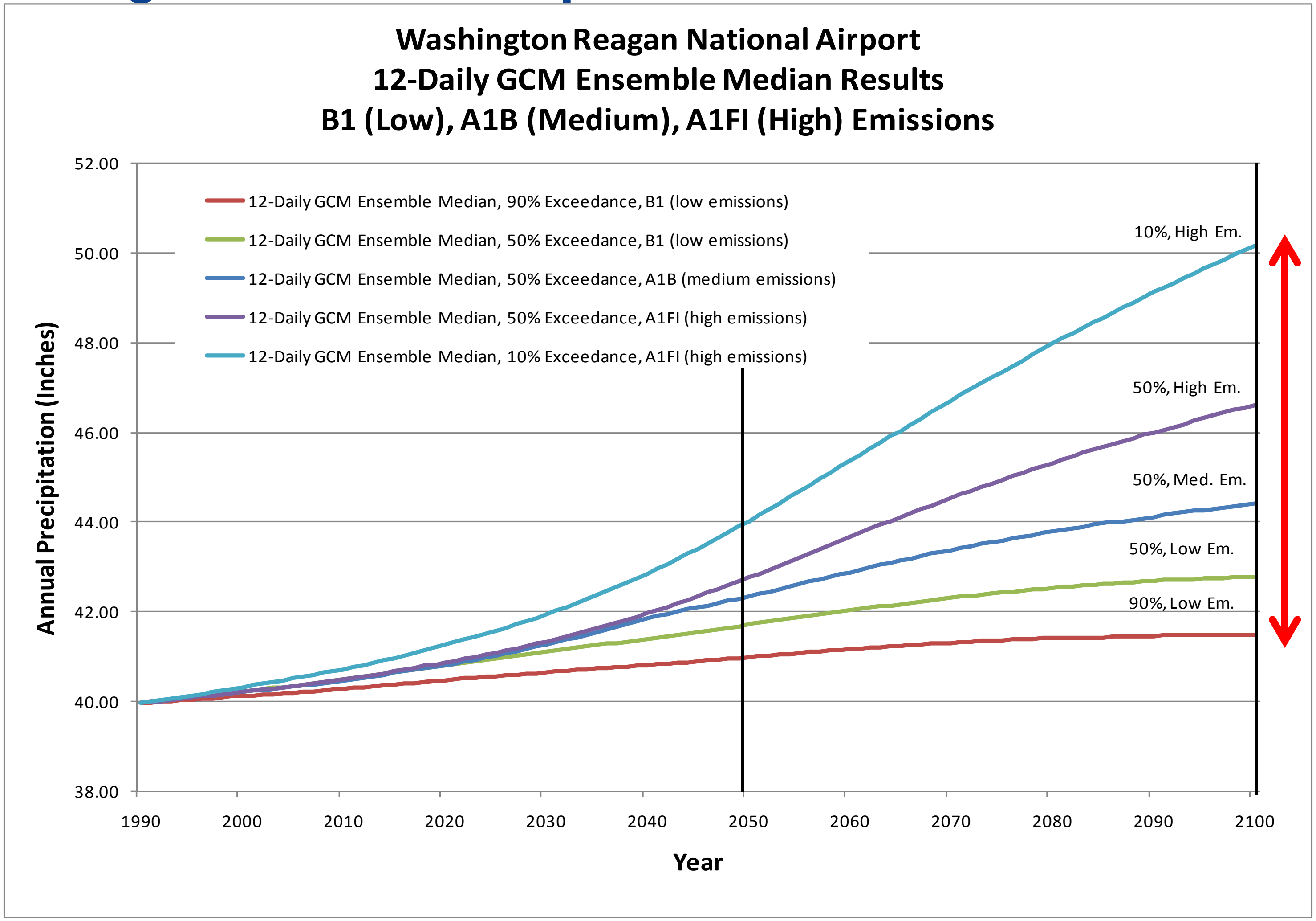
GCM Availability

- GCMS must be well documented and sanctioned by the IPCC
- 24 GCM results available
- Models ranked high for annual precipitation simulation by University Center for Atmospheric Research include:
  - CCCMA3 (Canada)
  - MRI-232A (Japan)
  - ECHO-G (Germany/Korea)
  - HadCM3 (United Kingdom)
  - GFDLCM20 (United States)
- All models are available for use in this project using the SimCLIM modeling application



GCM models available from the SimCLIM climate change modeling application

Projected Annual Precipitation
Reagan National Airport, DC

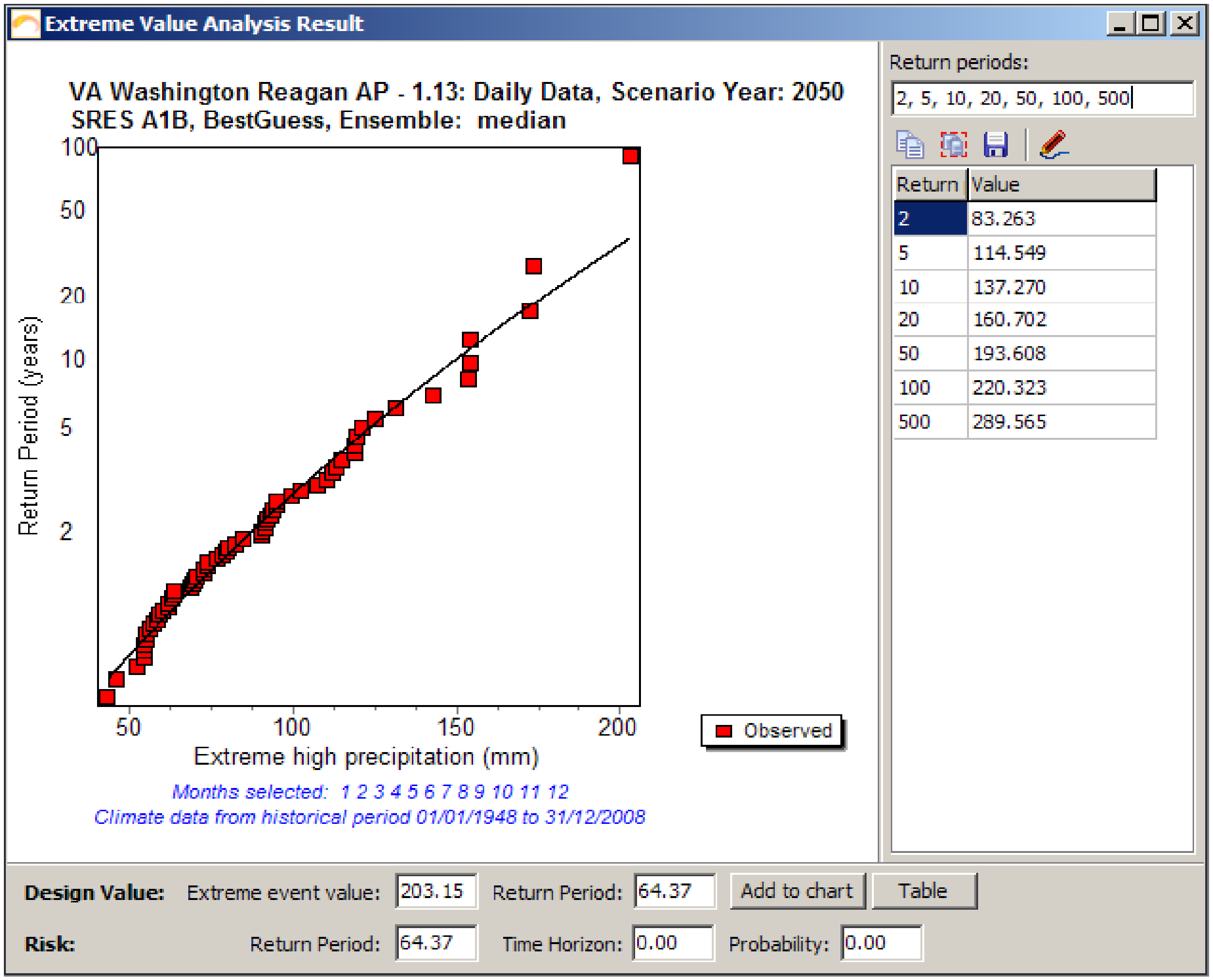


4 to 25% increase in annual precipitation by 2100

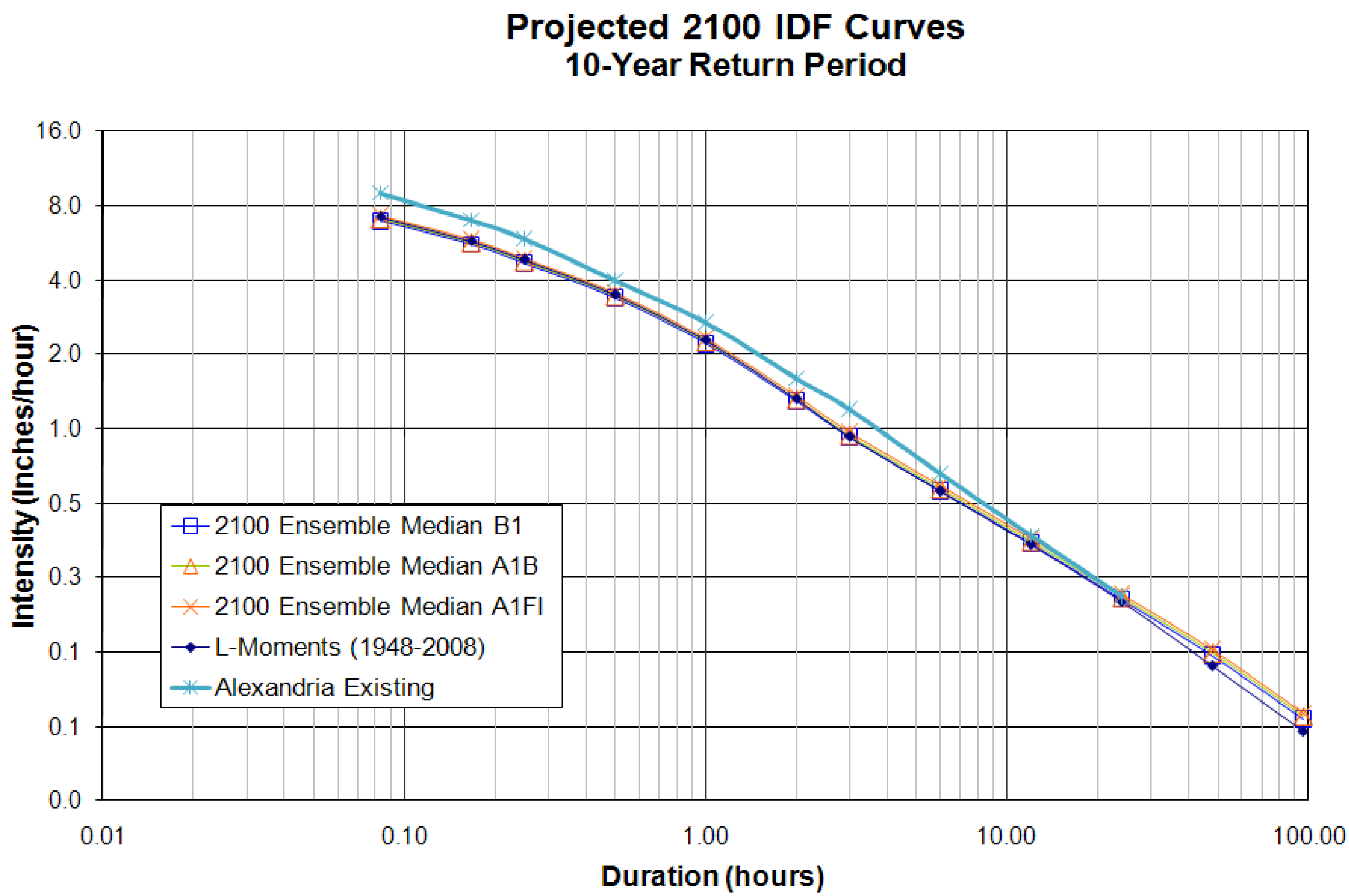
Merging Historical Data Record and GCM Results to Create Climate Change IDFs

1. Analyze observed hourly and daily data to obtain historical IDF for 60-minutes to 96-hours (1948-2008)
2. Obtain 5, 10, 15, and 30 minute durations by applying a ratio to the 60-minute estimates using NOAA Atlas-14
3. Calculate the ratio of the observed 24-hour value to 1, 2, 3, 6, 12-hour durations
4. Generate projections of daily precipitation from 12 GCM runs and 3 emissions scenarios for 2050 and 2100
5. Calculate the differences between the projected daily values at target dates and the historical averages (1948-2008)
6. Apply the prorated percent daily difference to the observed daily data for the selected analysis period and run the GEV analysis
7. Adjust the 24-hour GEV value by the historical ratios for durations ranging from 5-minutes to 12-hours

Merging Historical Data Record and GCM Results to Create Climate Change IDFs

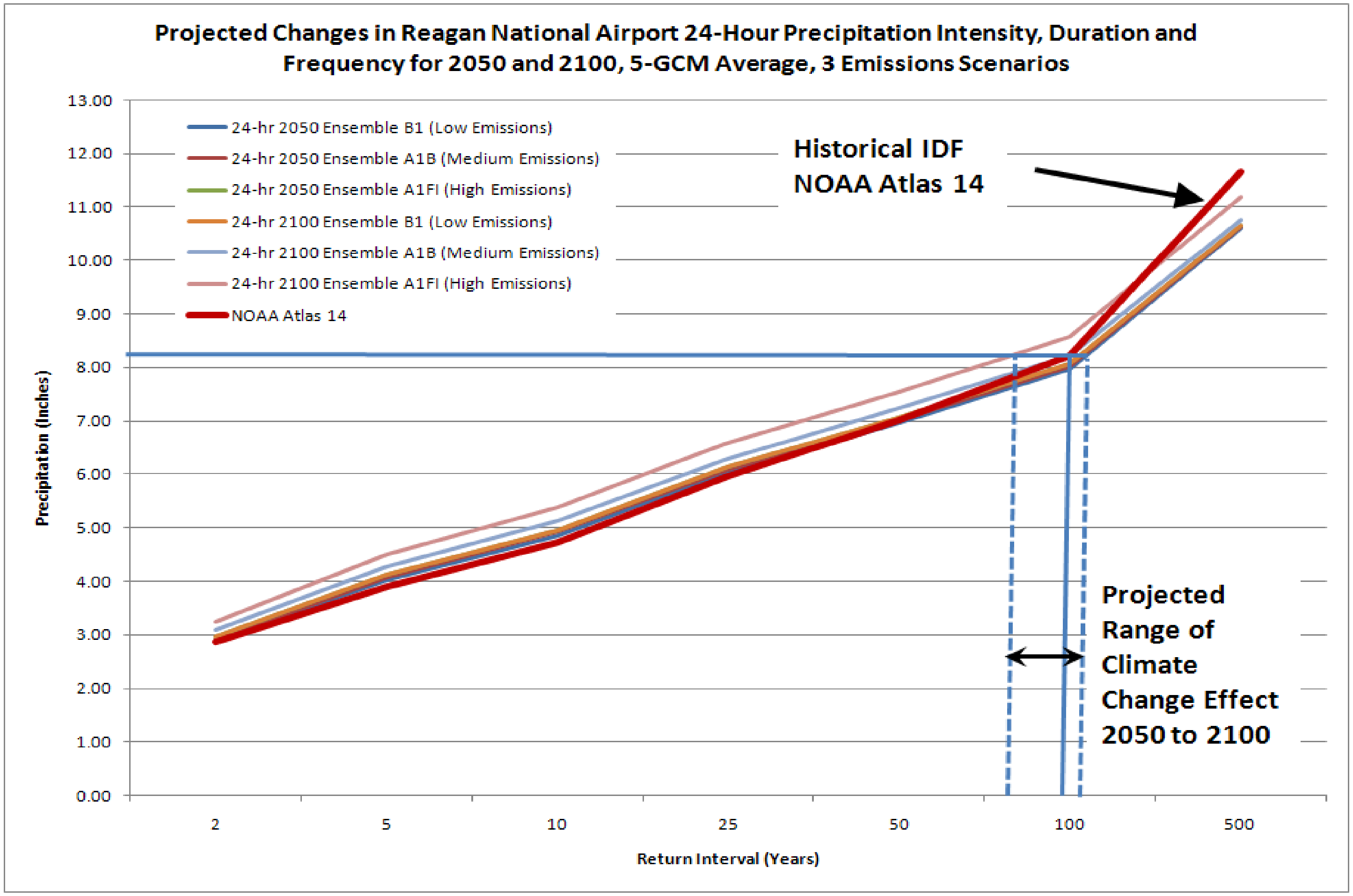


10-year IDF Projections in 2100 Reagan National Airport



- Existing Alexandria intensities more conservative for durations of 5 minutes to 24 hours
- Slight increase in climate change projected intensities from 24 to 96 hours.

Projected Changes in Precipitation Intensity, Duration, Frequency, Reagan National AP, DC



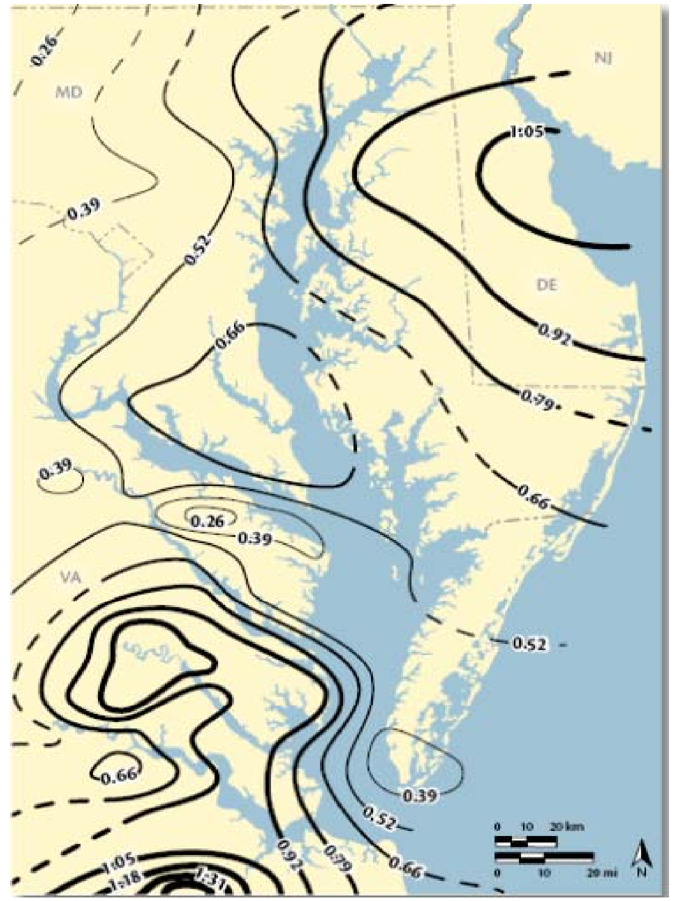
Sea Level Rise Risk Assessment

- Provide the City of Alexandria with a range of potential sea level rise (SLR) based on appropriate climate change scenarios.
- Analyzes historical records for trends and uses the GCM derived sea level rise projections to quantitatively determine specific sea level rise in the Chesapeake Bay and the Potomac River near Alexandria.

Rates of SLR (ft/century) for the Chesapeake and Delaware Bays Region.
Data from tide gages and data record shown in parenthesis.
Source: The Maryland Commission Climate Change

Sea Level Rise Risk Assessment

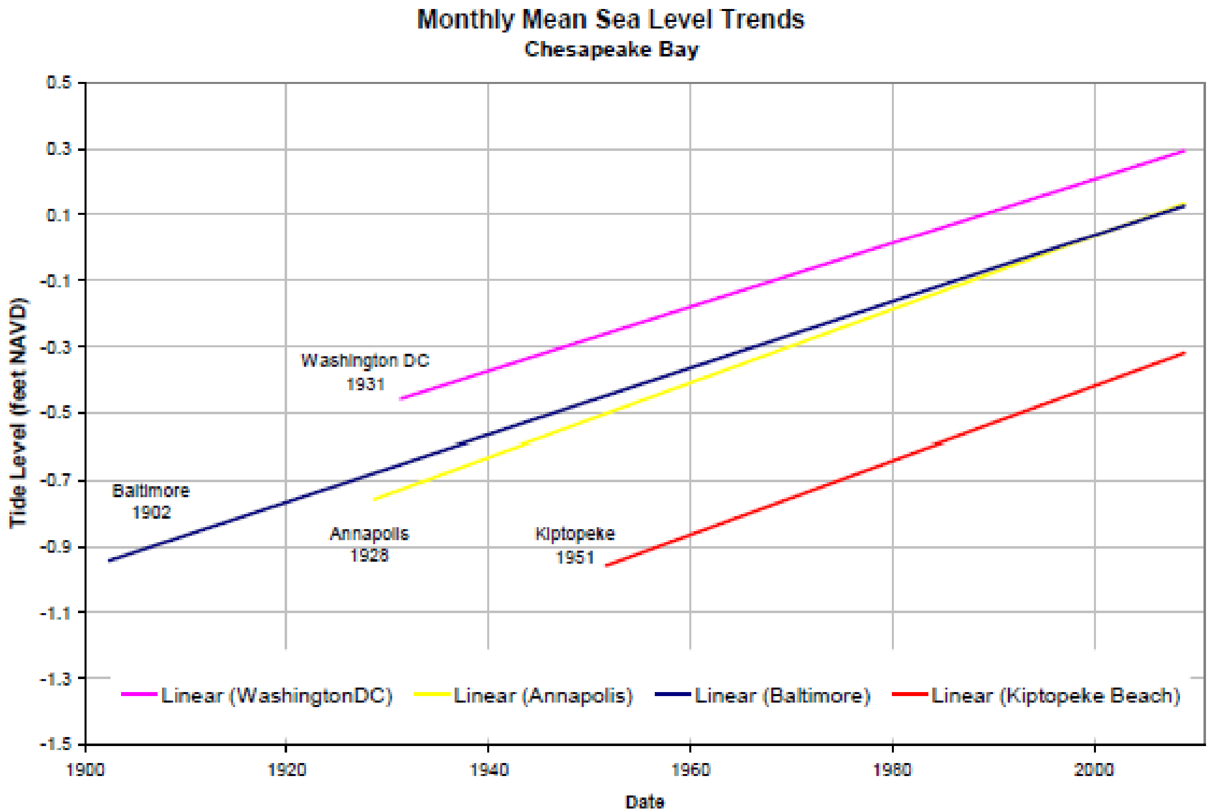
- Sea Level Rise elements
  - "Steric rise" is an increase in ocean volume without a change in mass, primarily through changes in temperature (thermal expansion) and salinity (freshening)
  - "Eustatic rise" is an increase in the mass of water from increased runoff from terrestrial regions, including glaciers and ice sheets
  - Land subsidence, Alexandria area is experiencing land subsidence of 1.37 mm/year
  - Storm surge winds from hurricanes
  - Planetary-driven daily tides



Rates of land subsidence (ft/century) Rates of land subsidence in the Chesapeake Bay region. Subsidence in this region is mostly a result of postglacial rebound or readjustment (sinking) of land elevations since the retreat of the glaciers at the end of the last ice age. Lines are dashed where values are inferred. Source: The Maryland Commission Climate Change

Chesapeake Bay Sea Level Trends

- Similar long-term sea level trends for 4 area stations
- Washington DC rise of .76' (9.1") from 1931 - 2008
- Data source NOAA



Historical Highest Tides Analysis for Washington, DC

Date	Highest Tide Level (feet NAVD 88)	Event
10/1/1942	9.65	Rainfall, 10" to 12"
3/1/1936	9.15	"The Great Spring Flood"
9/1/2003	8.87	Hurricane Isabel
8/1/1933	8.76	Chesapeake-Potomac Hurricane
4/1/1937	7.35	Heavy, Non-Hurricane Rainfall
6/21/1972	7.25	Tropical Storm Agnes
9/1/1996	6.76	Hurricane Fran
11/1/1985	6.74	Hurricane Juan
1/20/1996	6.70	Rapid snow-melt and rainfall

Observed highest tide levels

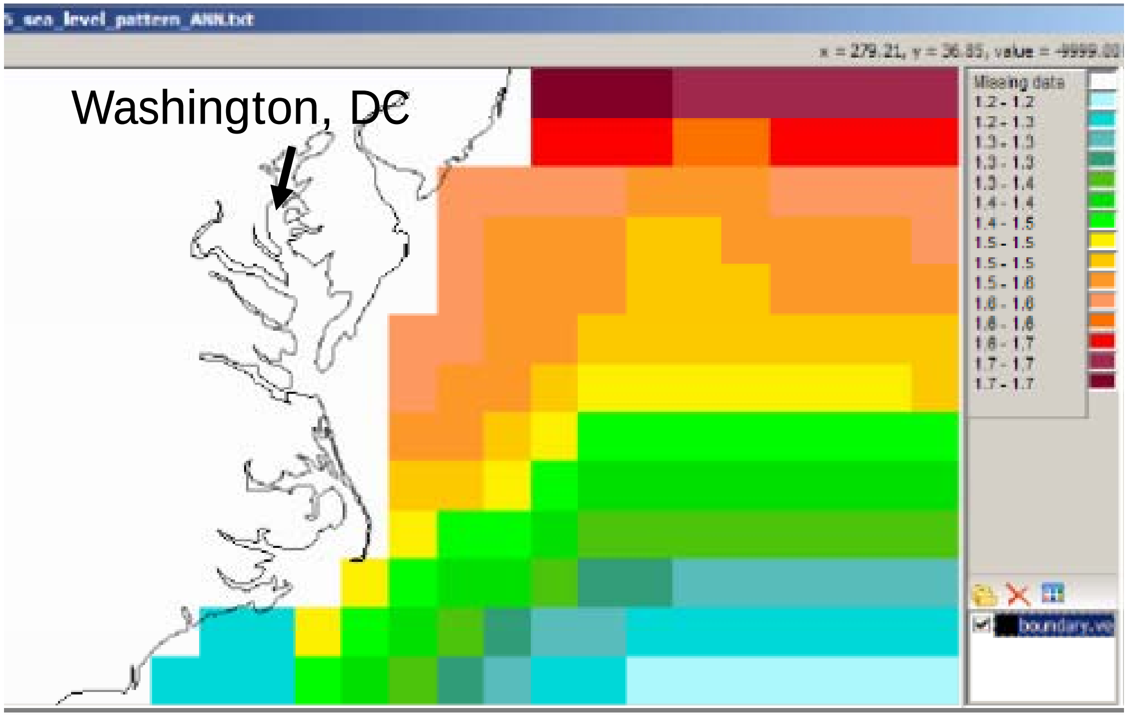
GEV analysis of 30 years of observed high tides (1979-2008)

Return Interval (Year)	Water Level Elevation (feet)
2	3.703
5	4.595
10	5.410
20	6.418
50	8.156
100	9.879
500	15.880

Datum: NAVD 1988

Sea Level Rise GCM Patterns

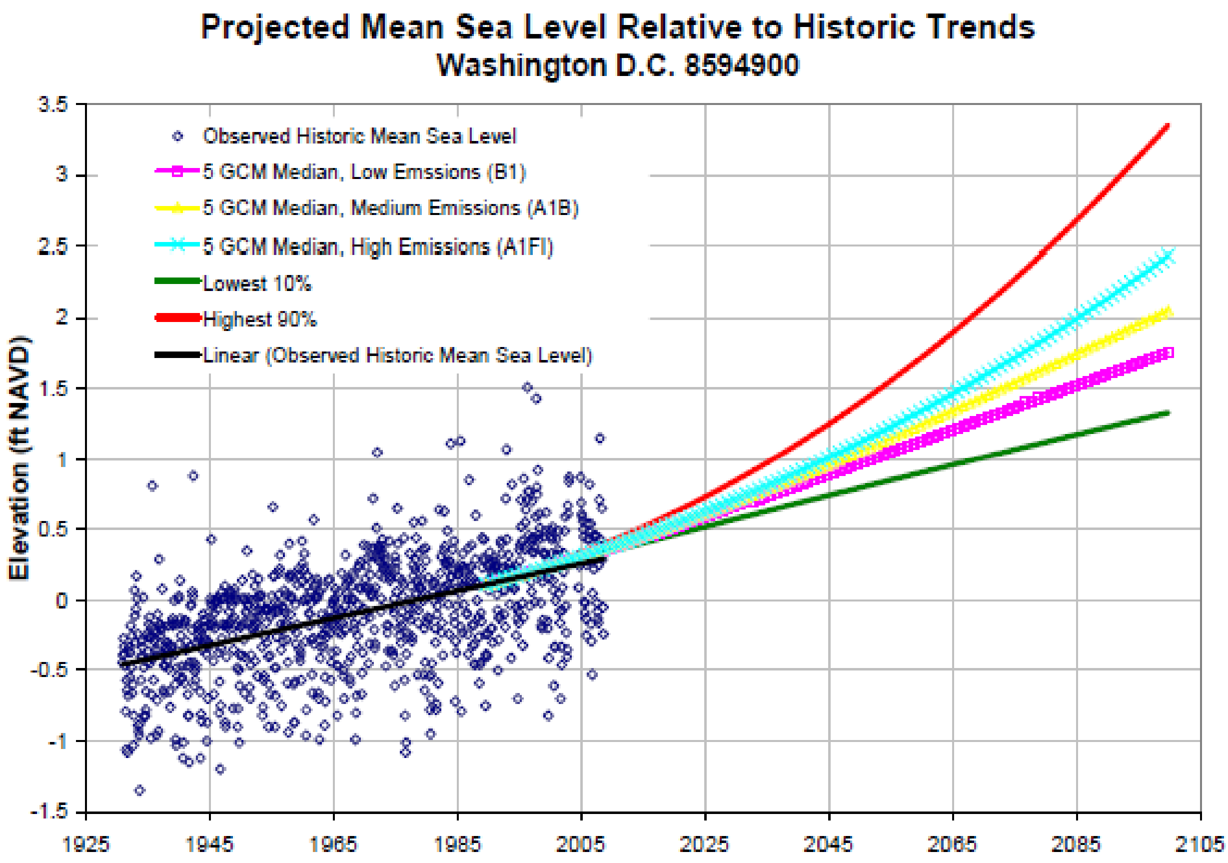
- Typical output from one of the five GCM models and low, medium, high emissions scenarios
- Median values calculated for years 1990 to 2100



Excludes ice melt projections per Vermeer and Rahmstorf (2009) because not yet adopted by IPCC, but expected in AR5.

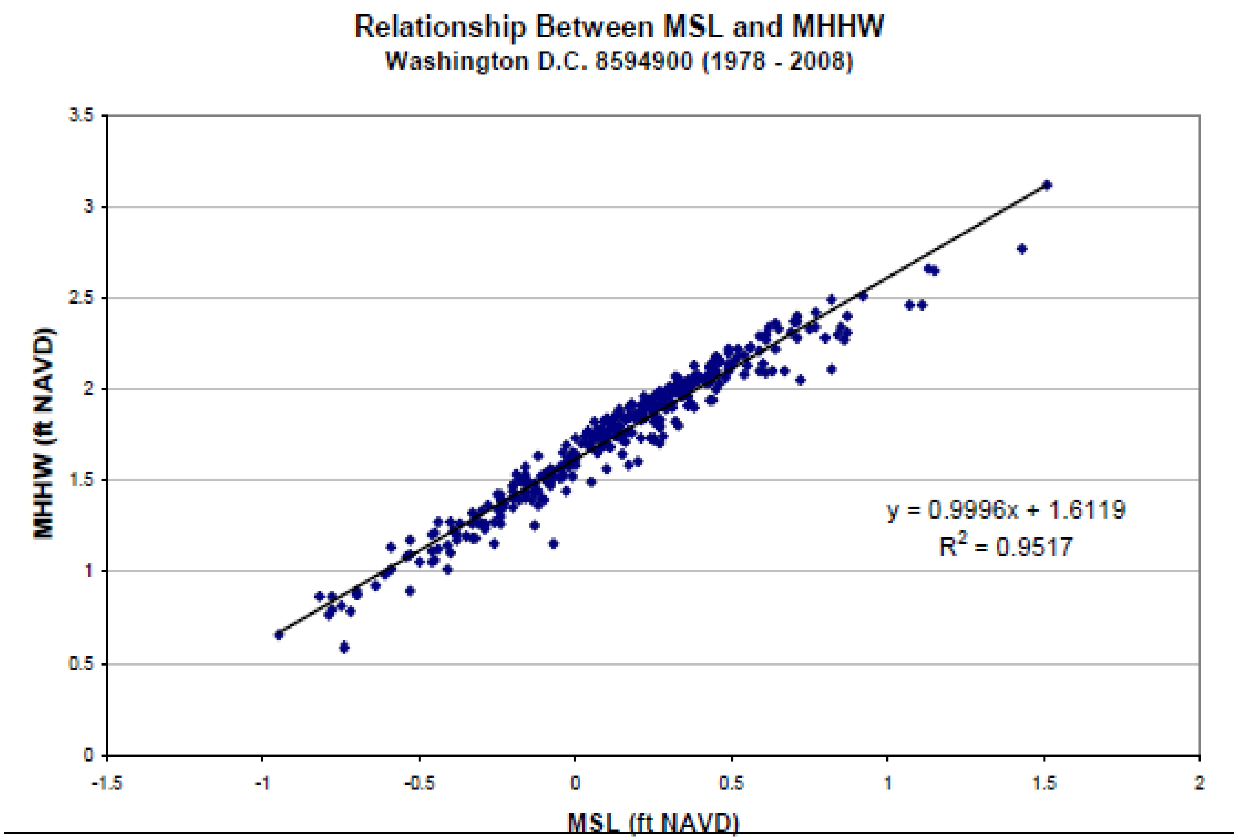
Projected Mean Sea Level Rise Washington, DC

- Observed monthly sea level
- Median of 5 GCMs and 3 emission scenarios
- Merged at the 1990 GCM start date
- Range from 1.8' to 2.4' by 2100



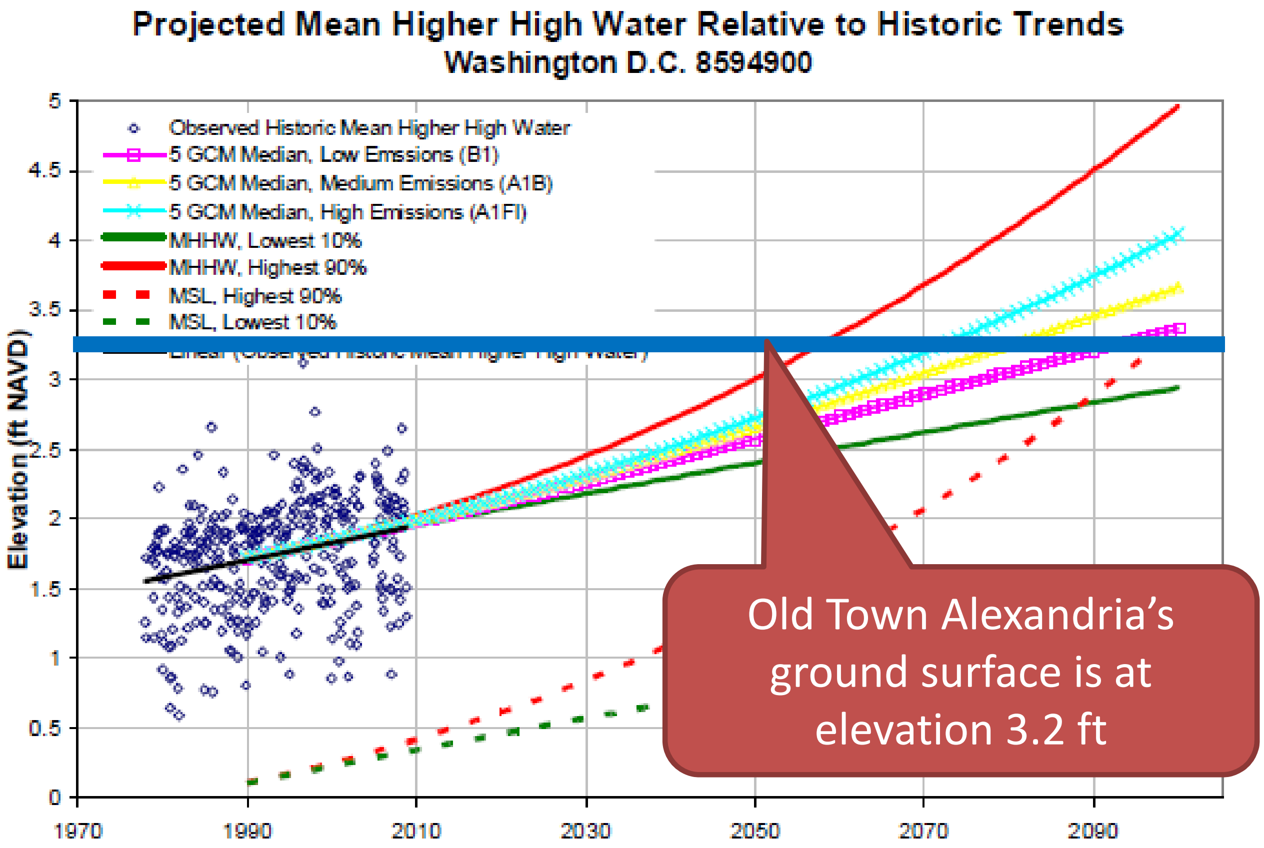
Relationship Between Mean Tide and High Tide for Washington, DC

- Need to determine impacts on daily tides
- MHHW is the average of the higher high water height of each tidal day
- Relationship between MSL and MHHW developed



Projected Mean High Higher Water (MHHW) Level for Washington, DC

- MSL/MHHW relationship used to adjust MSL projections
- Projected MHHW range is between 3.35' and 4.05' by 2100



Excludes ice melt projections per Vermeer and Rahmstorf (2009) because not yet adopted by IPCC, but expected in AR5.

Next Steps

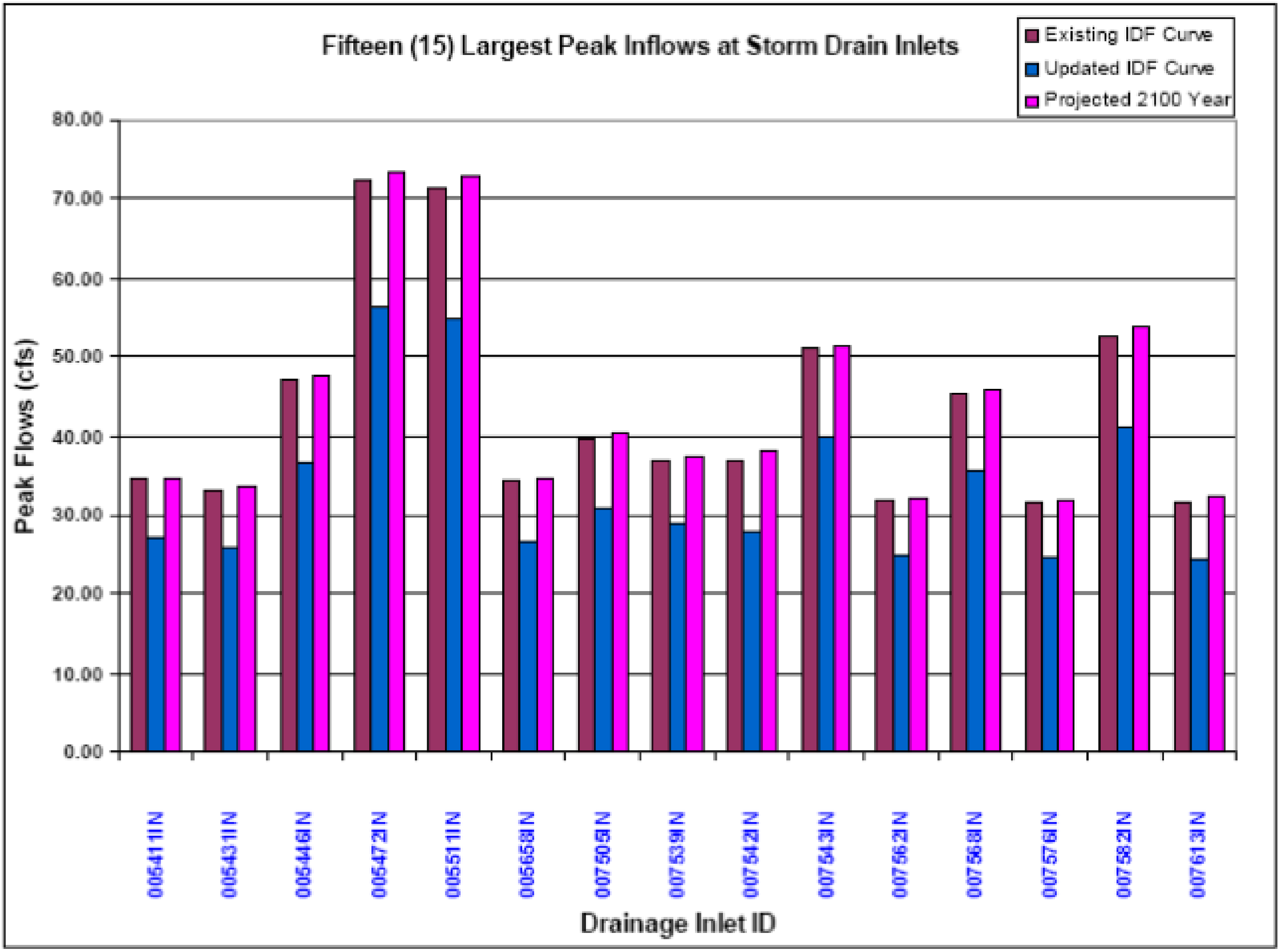
- Evaluate and benchmark City design criteria for stormwater management facilities
- Run models with 10-year 24-hr design storm from existing IDF, NOAA Atlas 14 IDF, and year 2100 projected IDF
- Conduct cost-benefit evaluation to changing design criteria to reflect climate change and updated IDF curve

Possible New Design Criteria Rainfall Hyetographs (Intensity Distribution)

- **Existing IDF Curve -** period of record (1941-1969)
- **Updated IDF Curve -** L-Moment analysis based on all available historical data (1948-2008)
- **Projected Year 2100 -** based on ensemble average of 12 global change models and 3 greenhouse gas emission scenarios

DRAFT

Hydrologic Modeling Results



Summary

- Significant research is now available that describes projected changes in global climate
- Methods exist to use climate change projections to estimate changes in rainfall intensity-duration-frequency (IDF) curves, sea level rise and other impacts on natural resources at community scales
- Knowing the boundaries of projected climate change impacts on water resource and other projects is an important component of any long-term infrastructure planning

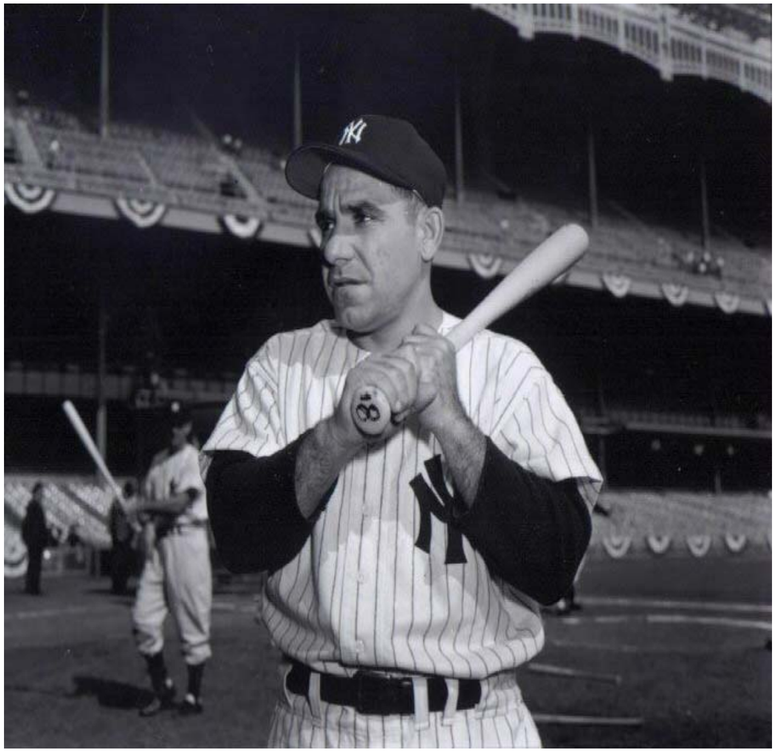
Yogi Berra On Climate

Climate Stationarity

"The future ain't what it used to be."

Future Climate

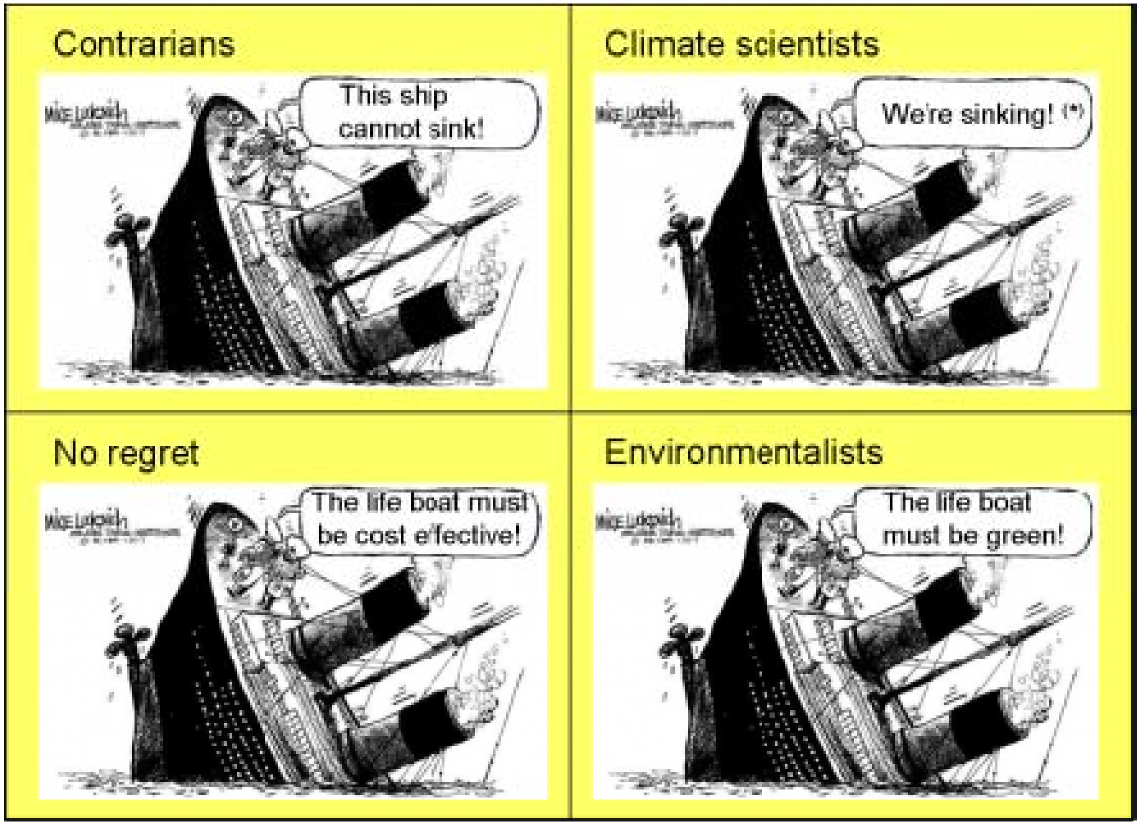
"I wish I had an answer to that because I'm tired of answering that question."



Yogi Berra

Bridging the Gap for Adaptation Action

- Climatic risks are increasing
- Adaptation will be required to reduce the risks
- Governance and institutional concerns must be addressed



http://ourchangingclimate.wordpress.com/2011/05/16/different-approaches-to-climate-problem/