Town of Cape Elizabeth: A summary of some of the latest sea level rise science and storm surge data to help guide municipal ordinance changes

May 29, 2014

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http://www.maine.gov/doc/nrimc/mgs/mgs.htm

Why does sea level change?

Global Sea Levels…

Thermal Expansion (the ocean heats up/expands as atmosphere warms)

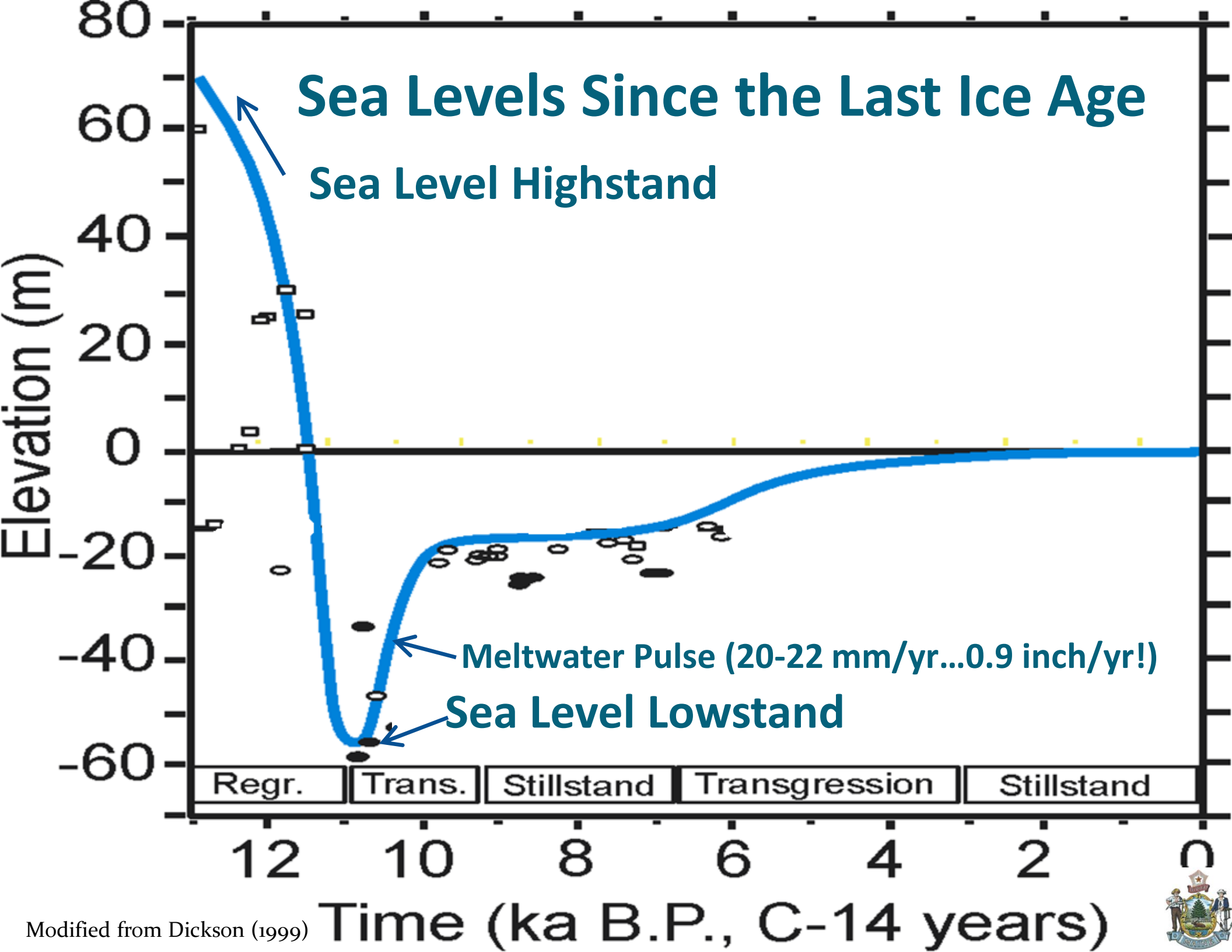
Volumetric Increase (volume increases with water from melting glaciers and land-based ice sheets)

Global climate variation (impacts of ENSO, El Nino/La Niña warming and cooling patterns in the Pacific Ocean)

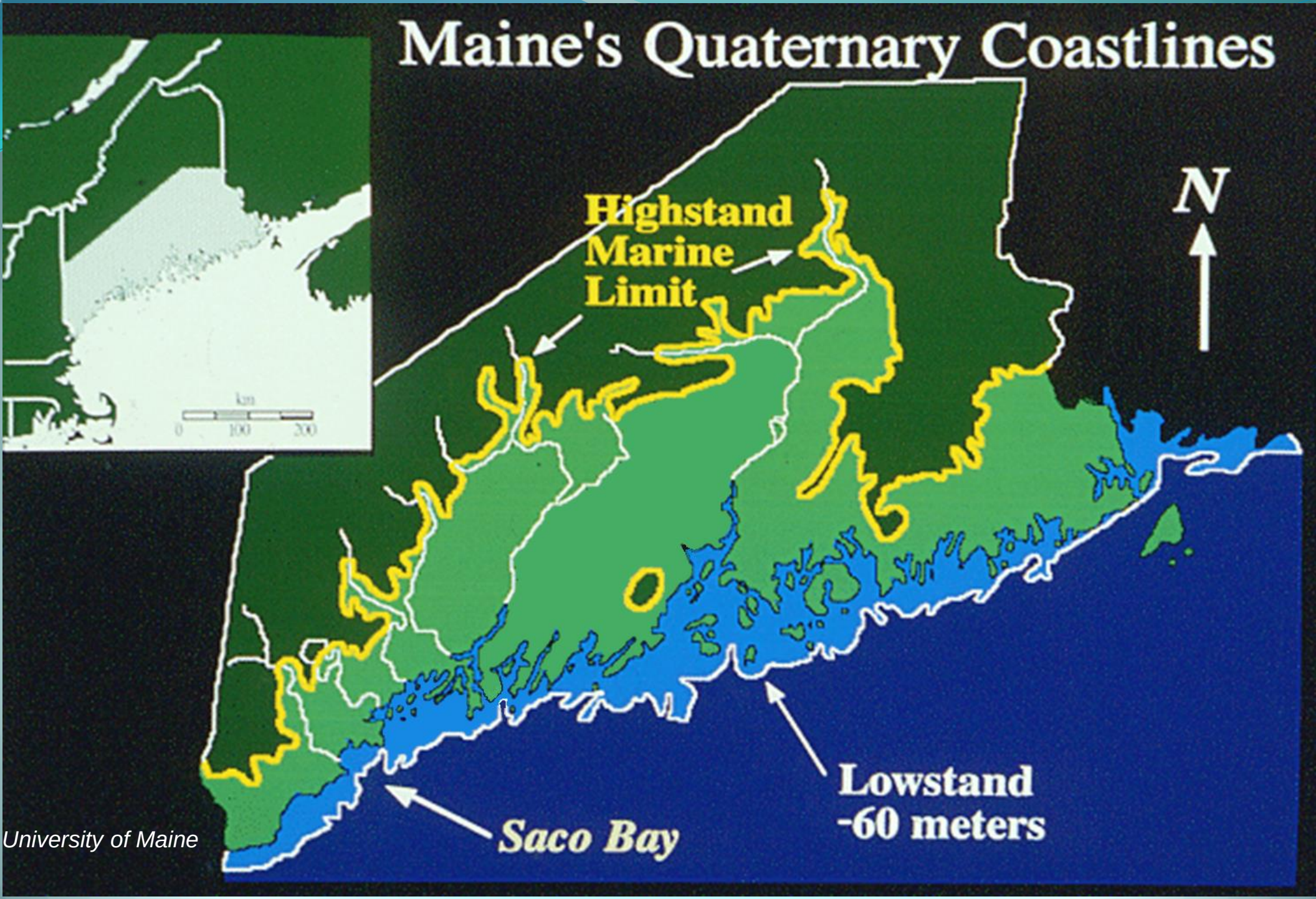
Relative (or "Local") Sea levels…

Isostatic rebound (response of the crust to glaciation) ***– this has been a key factor in Maine historically since the last ice age due to glaciation, but not today.***

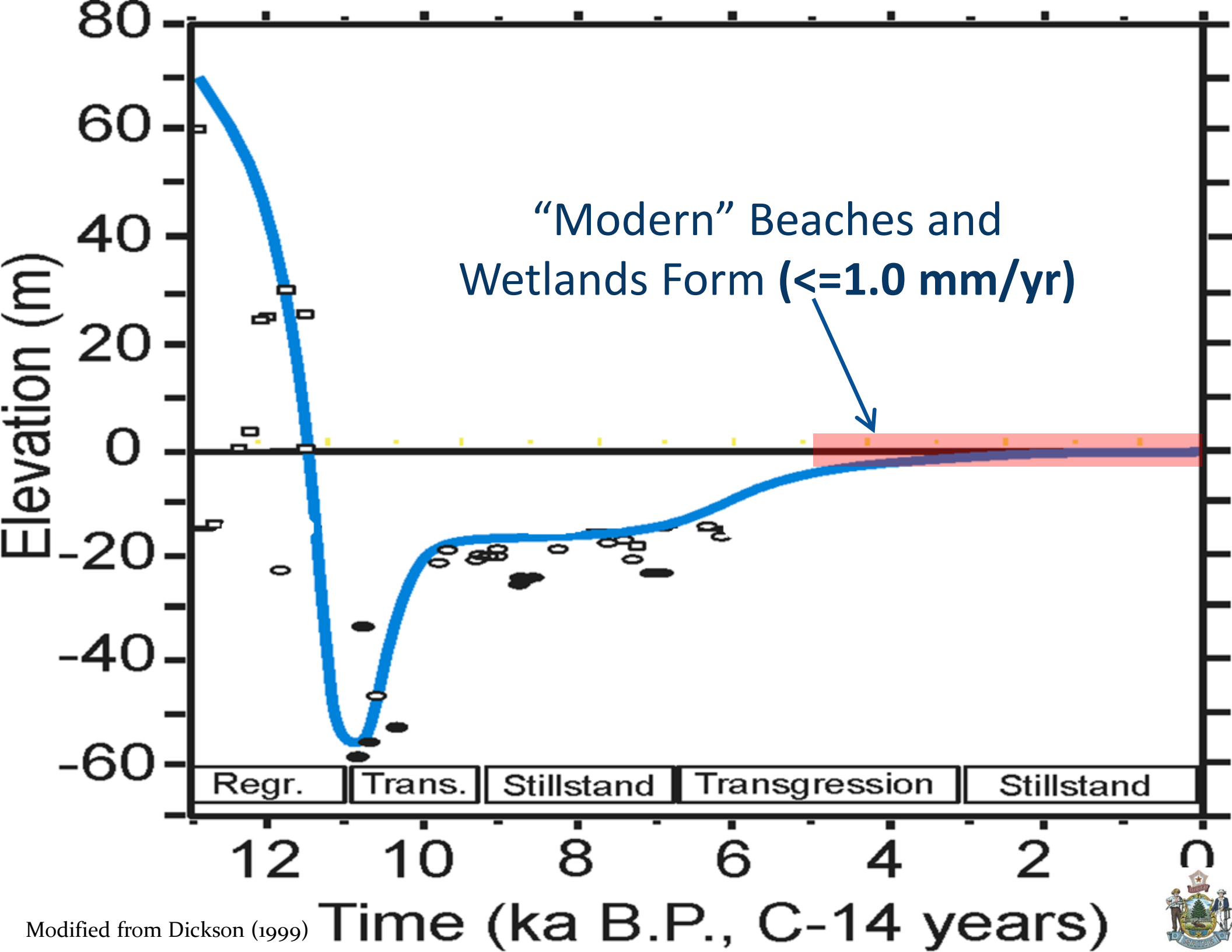
Subsidence (sinking of the land due to other factors than isostasy)



Modified from Dickson (1999)

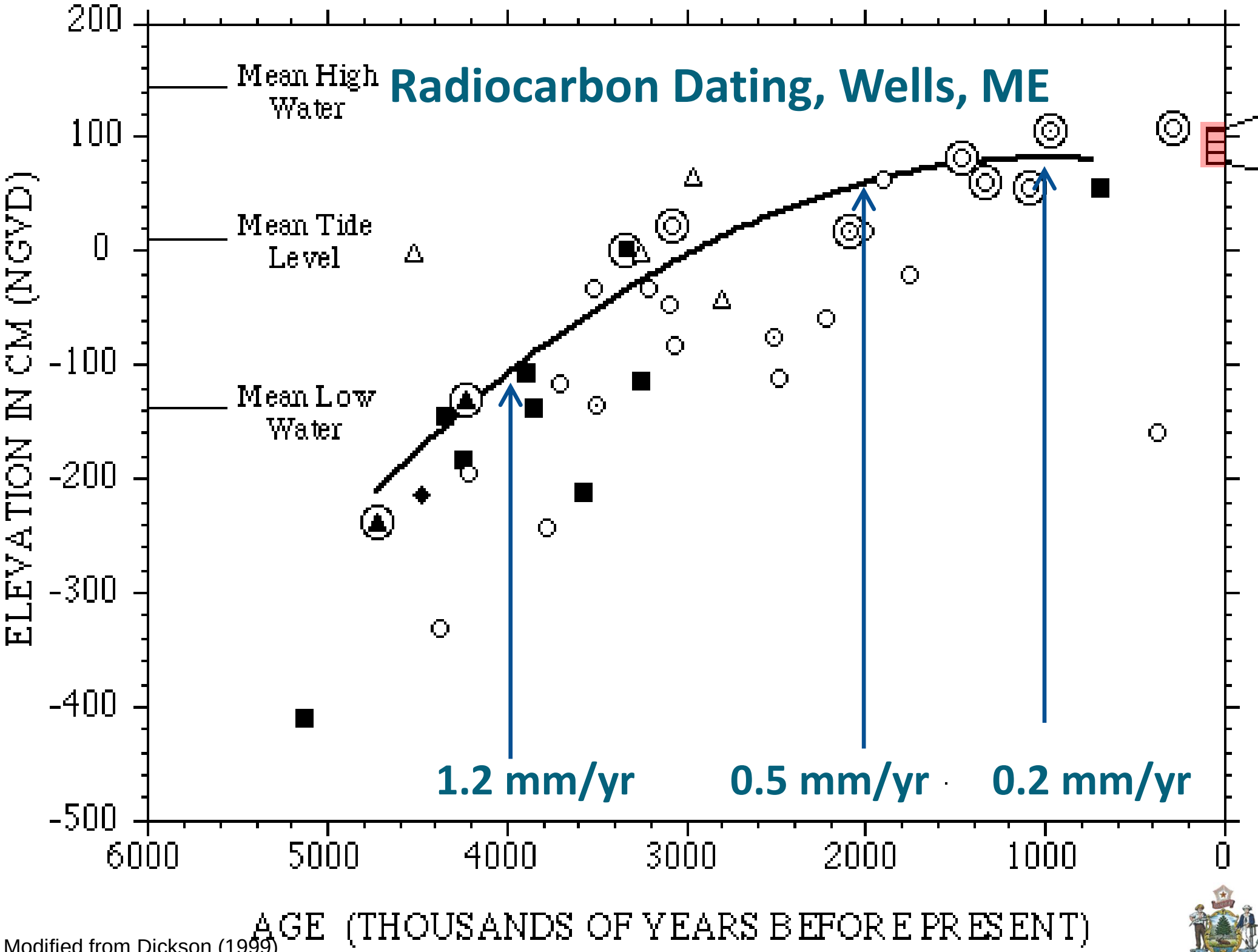


Massive adjustments in response to glaciation drove much of Maine's sea level changes…



Modified from Dickson (1999)

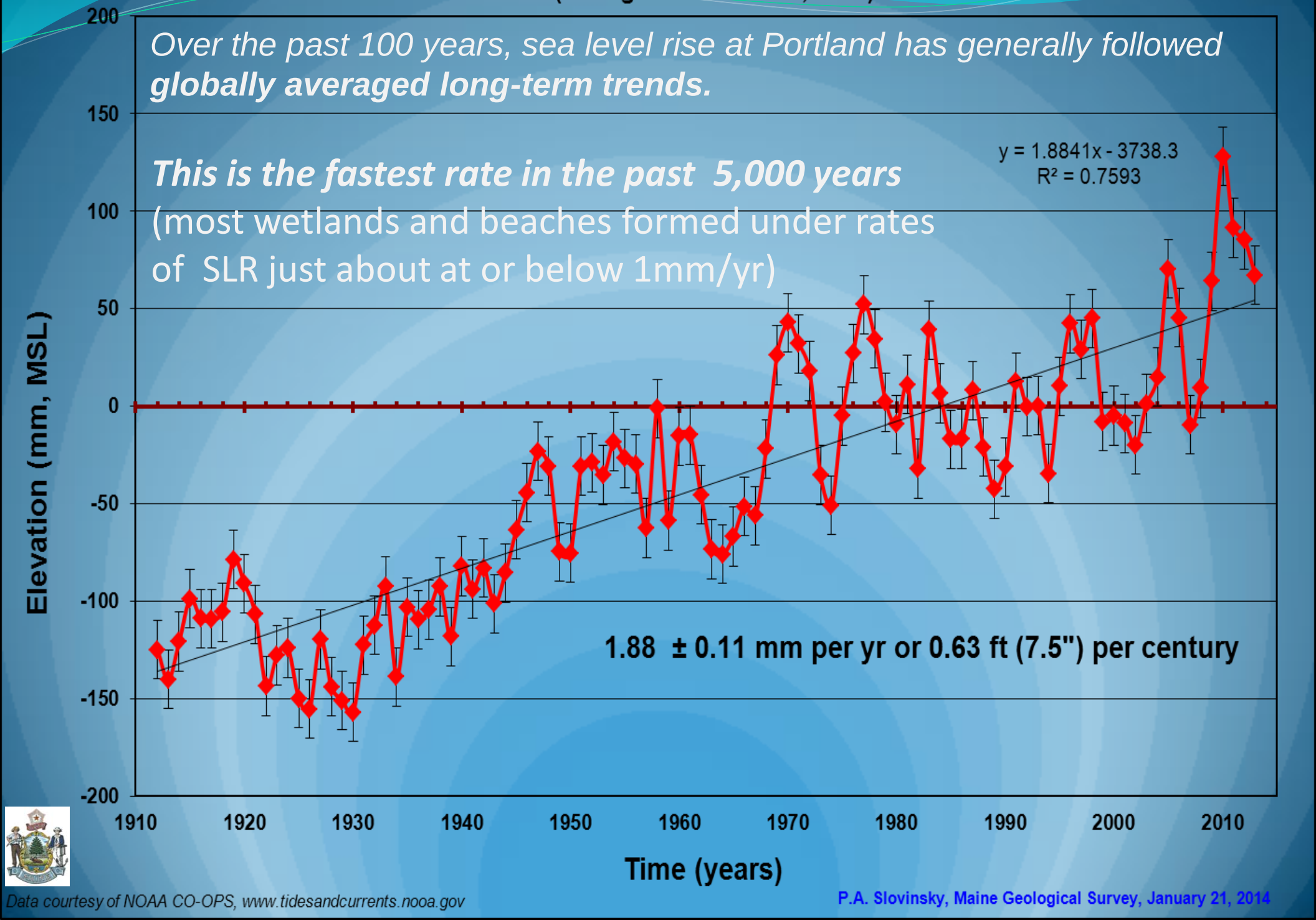
Radiocarbon Dating, Wells, ME



Modified from Dickson (1999)

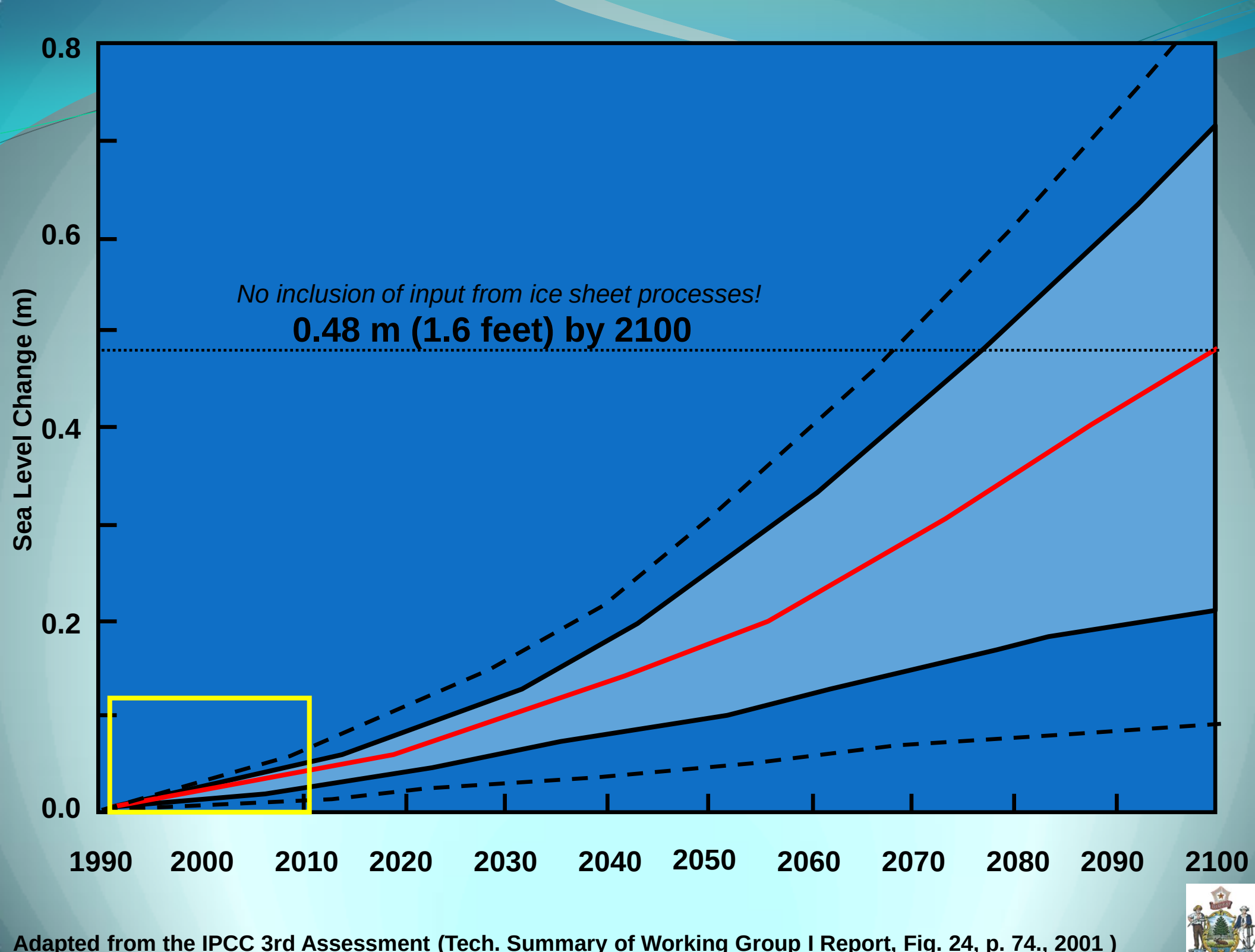
Sea Level, Portland, Maine

1912-2013 (through December 31, 2013)

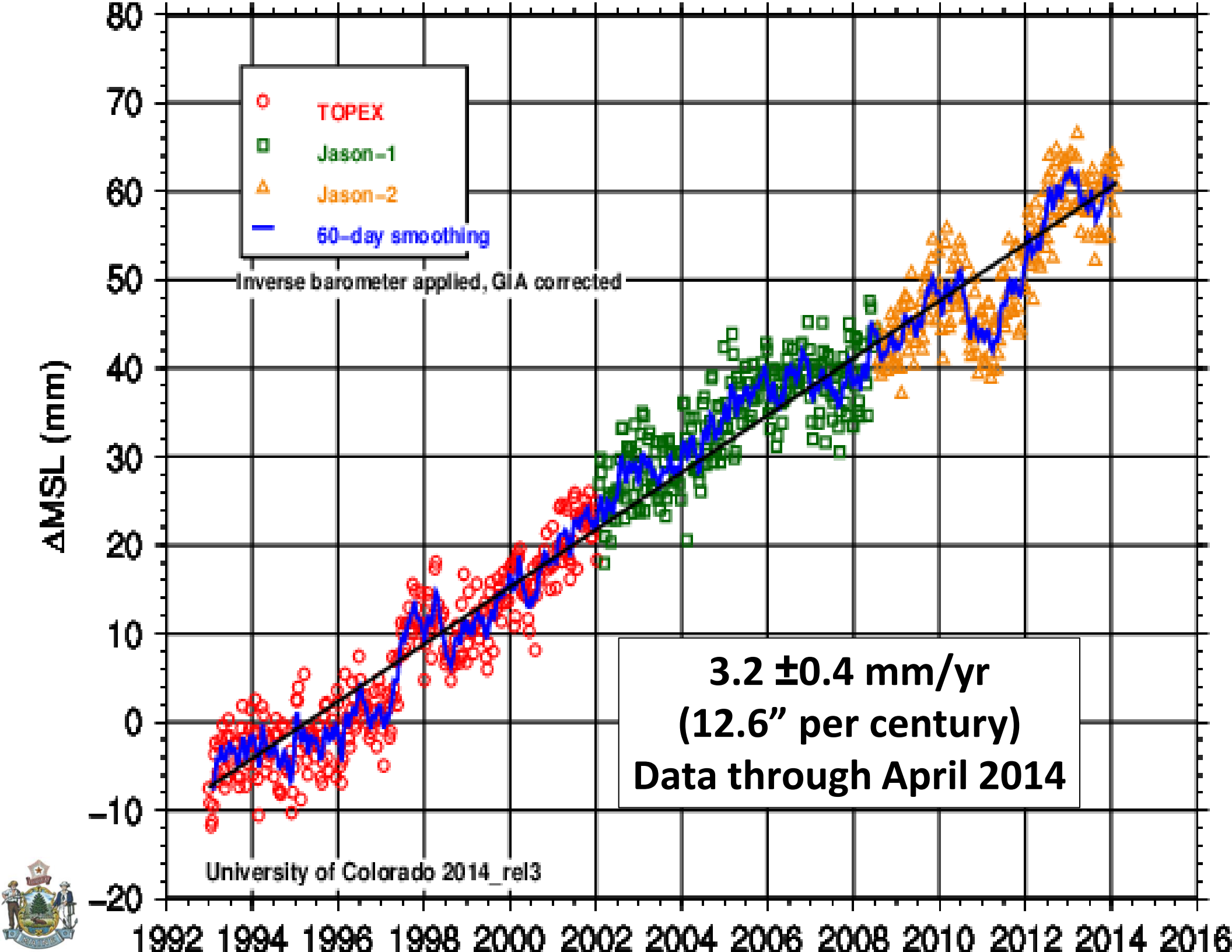


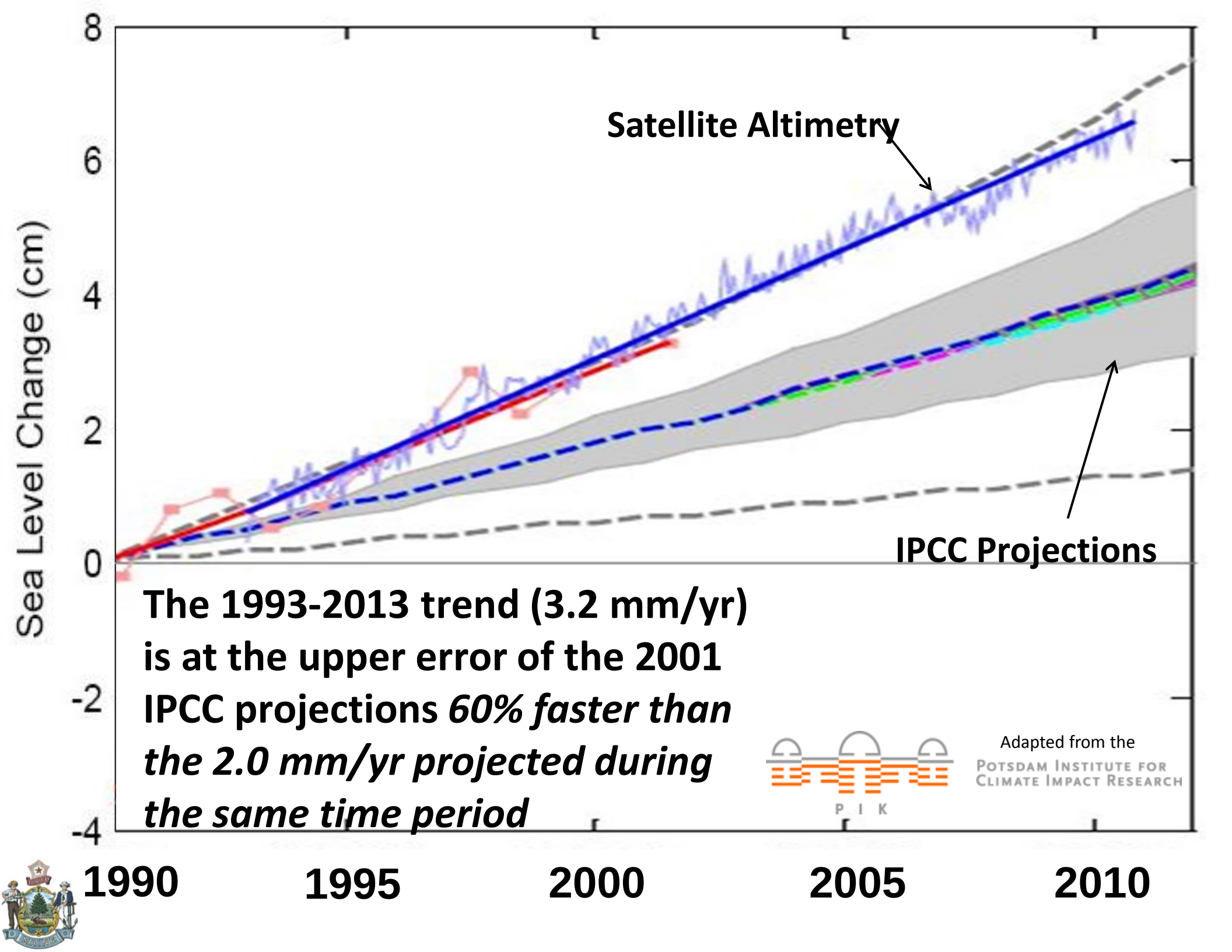
Data courtesy of NOAA CO-OPS, www.tidesandcurrents.nooa.gov

P.A. Slovinsky, Maine Geological Survey, January 21, 2014



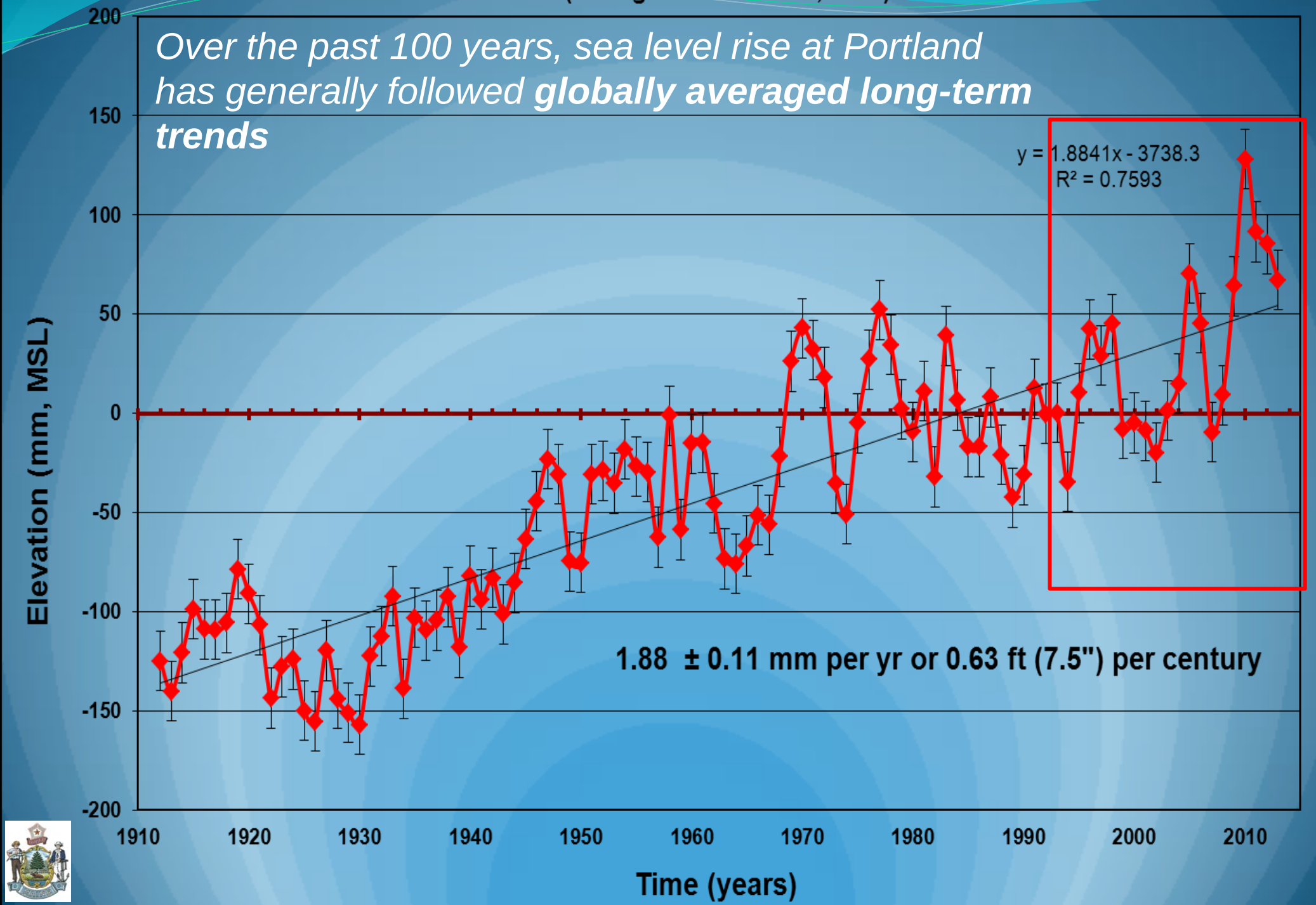
Adapted from the IPCC 3rd Assessment (Tech. Summary of Working Group I Report, Fig. 24, p. 74., 2001)


TOPEX
Jason-1
Jason-2
60-day smoothing
Inverse barometer applied, GIA corrected
ΔMSL (mm)
80
70
60
50
40
30
20
10
0
-10
-20
1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
3.2 ±0.4 mm/yr
(12.6” per century)
Data through April 2014
University of Colorado 2014_rel3


Satellite Altimetry
IPCC Projections
Sea Level Change (cm)
8
6
4
2
0
-2
-4
1990
1995
2000
2005
2010
The 1993-2013 trend (3.2 mm/yr) is at the upper error of the 2001 IPCC projections *60% faster than the 2.0 mm/yr projected during the same time period*
Adapted from the
Potsdam Institute for Climate Impact Research
P I K

Sea Level, Portland, Maine

1912-2013 (through December 31, 2013)

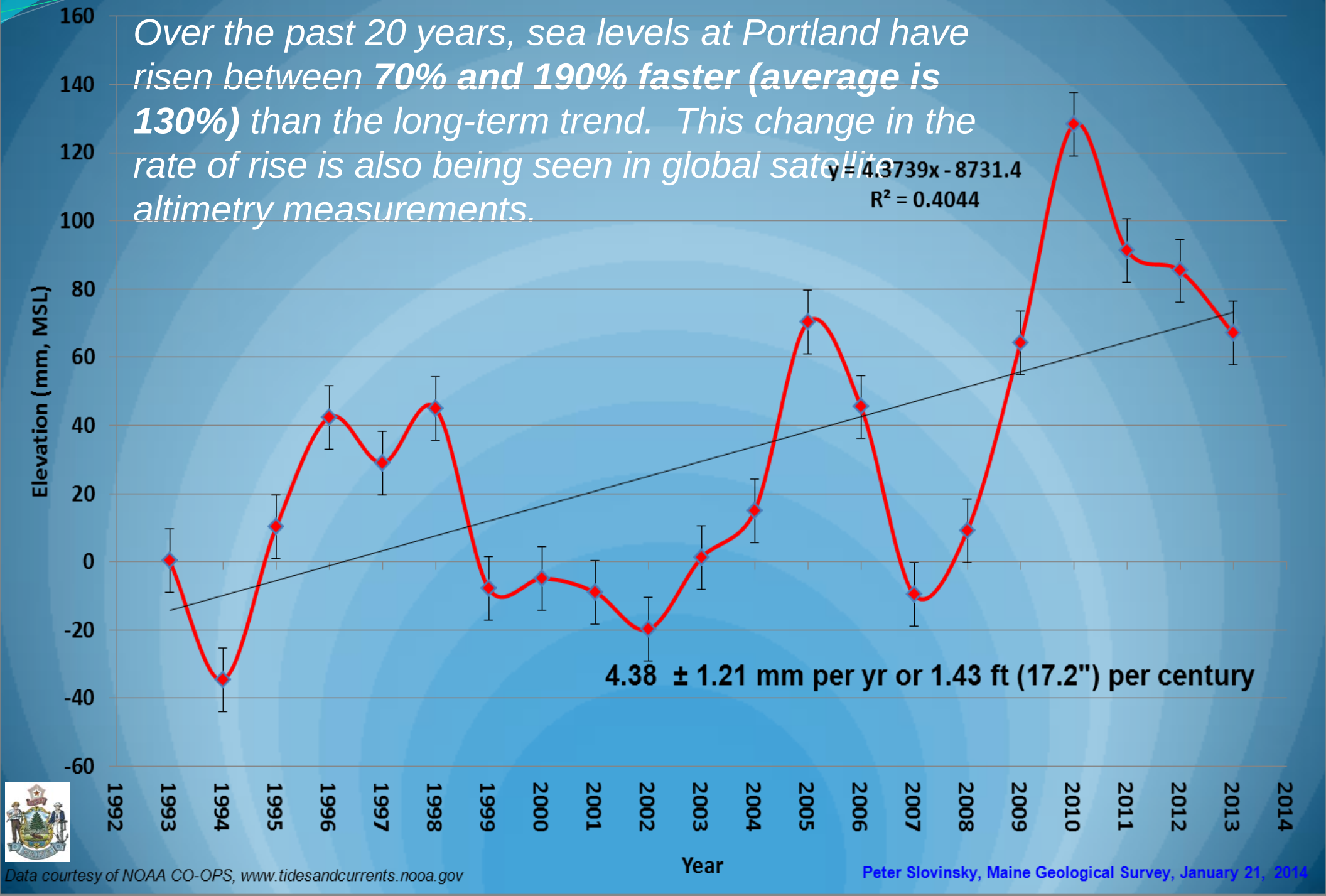


Data courtesy of NOAA CO-OPS, www.tidesandcurrents.nooa.gov

P.A. Slovinsky, Maine Geological Survey, January 21, 2014

Sea Level, Portland, Maine

1993-2013 (through December 2013)



Data courtesy of NOAA CO-OPS, www.tidesandcurrents.nooa.gov

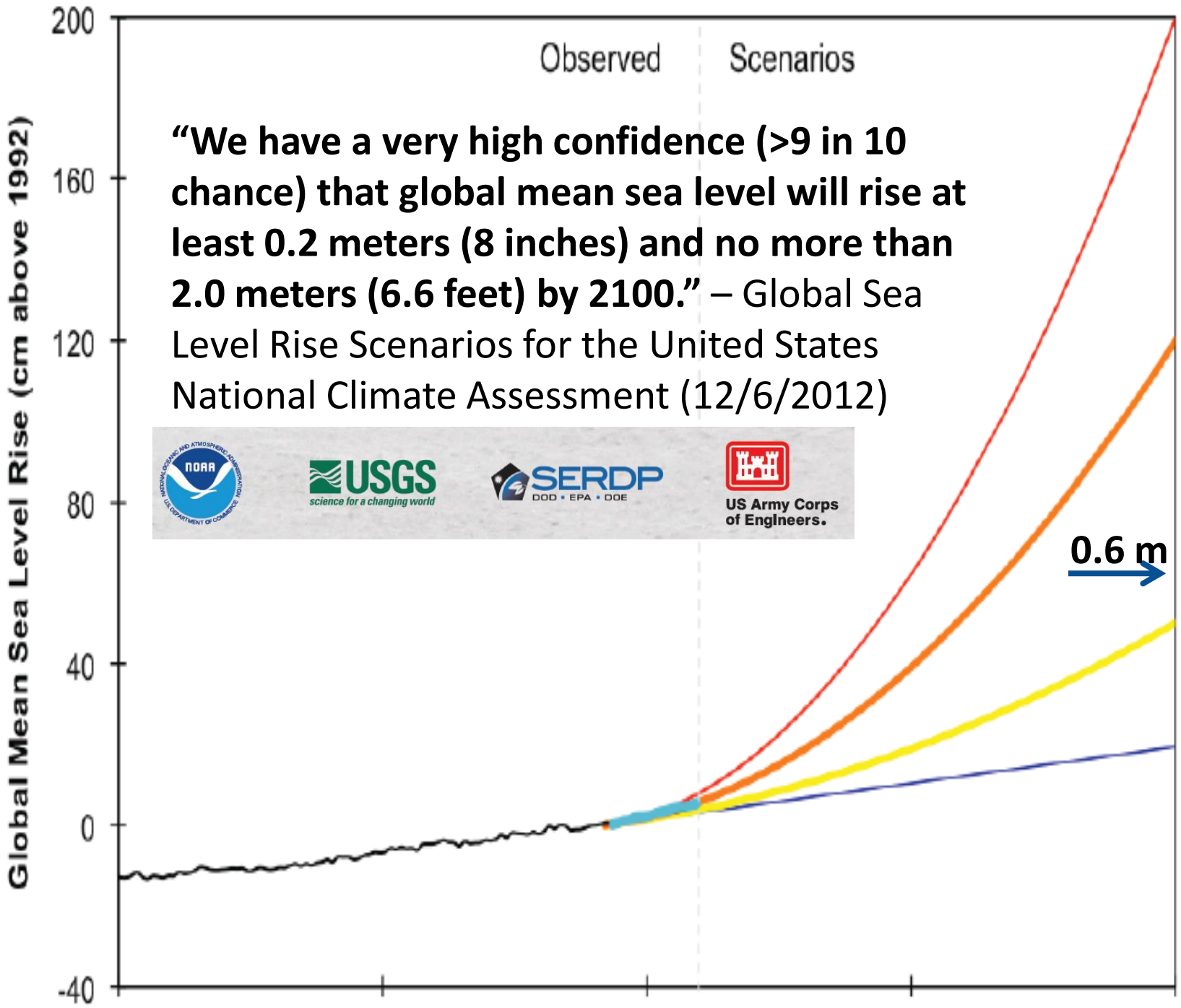
Peter Slovinsky, Maine Geological Survey, January 21, 2014

…if current [Antarctic and Greenland] ice sheet melting rates continue for the next four decades, their cumulative loss could raise sea level by 15 centimeters (5.9 inches) by 2050. When this is added to the predicted sea level contribution of 8 centimeters (3.1 inches) from glacial ice caps and 9 centimeters (3.5 inches) from ocean thermal expansion, total sea level rise could reach 32 centimeters **(12.6 inches) by the year 2050**.

Rignot and others, March 2011

http://www.agu.org/news/press/pr_archives/2011/2011-09.shtml

Image from www.swisseduc.ch



"We have a very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100." – Global Sea Level Rise Scenarios for the United States National Climate Assessment (12/6/2012)

NOAA · USGS science for a changing world · SERDP DOD • EPA • DOE · US Army Corps of Engineers.

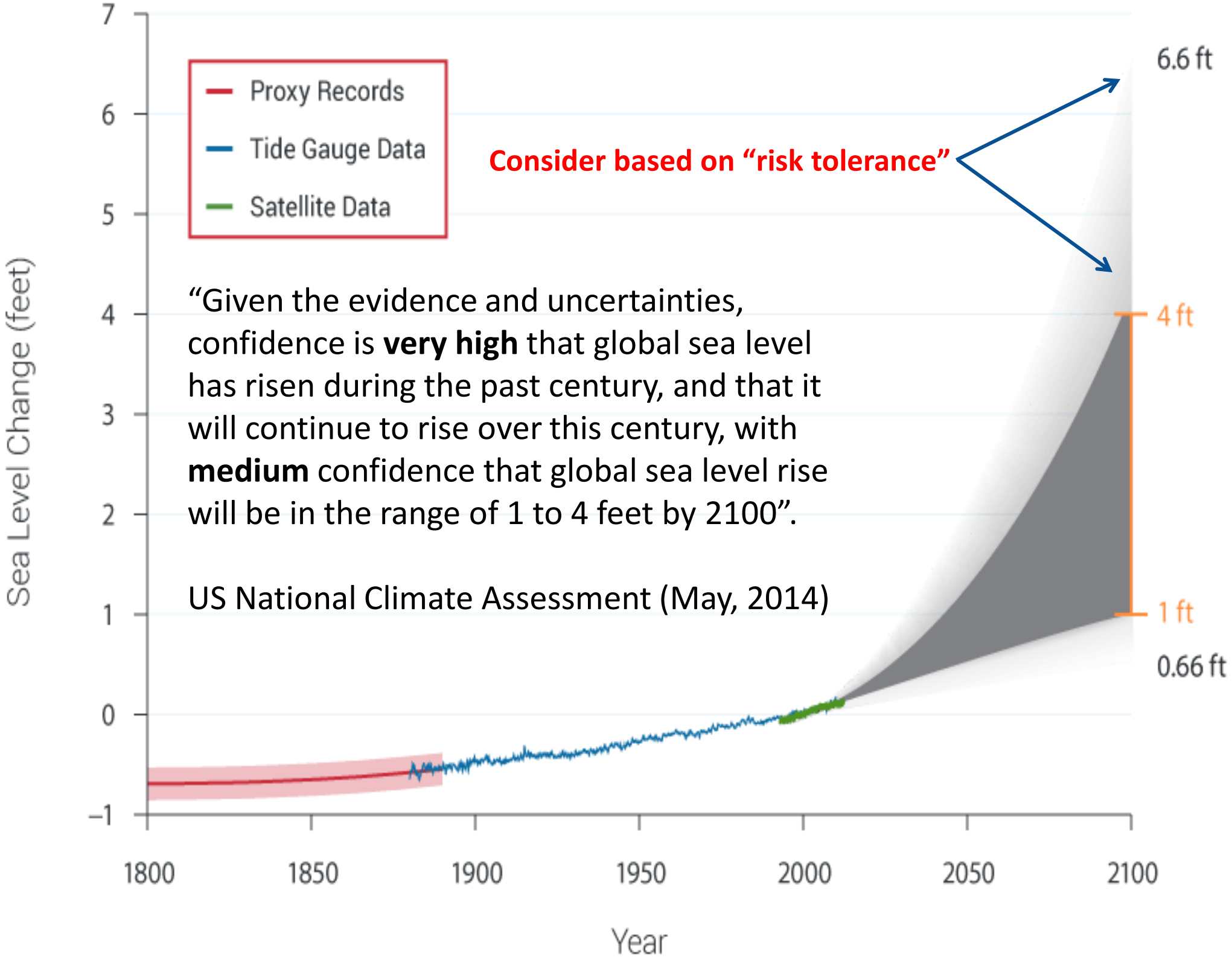
Highest
(2.0 m, 6.6 ft)
***Combines maximum warming, thermal expansion, and possible ice sheet loss from semi-empirical models.**

Intermediate-High
(1.2 m, 3.9 ft)
***Average of high end global predictions, combines recent ice sheet loss and thermal expansion**

Intermediate-Low
(0.5 m, 1.6 ft)
***Includes only thermal expansion from warming from IPCC AR4.**

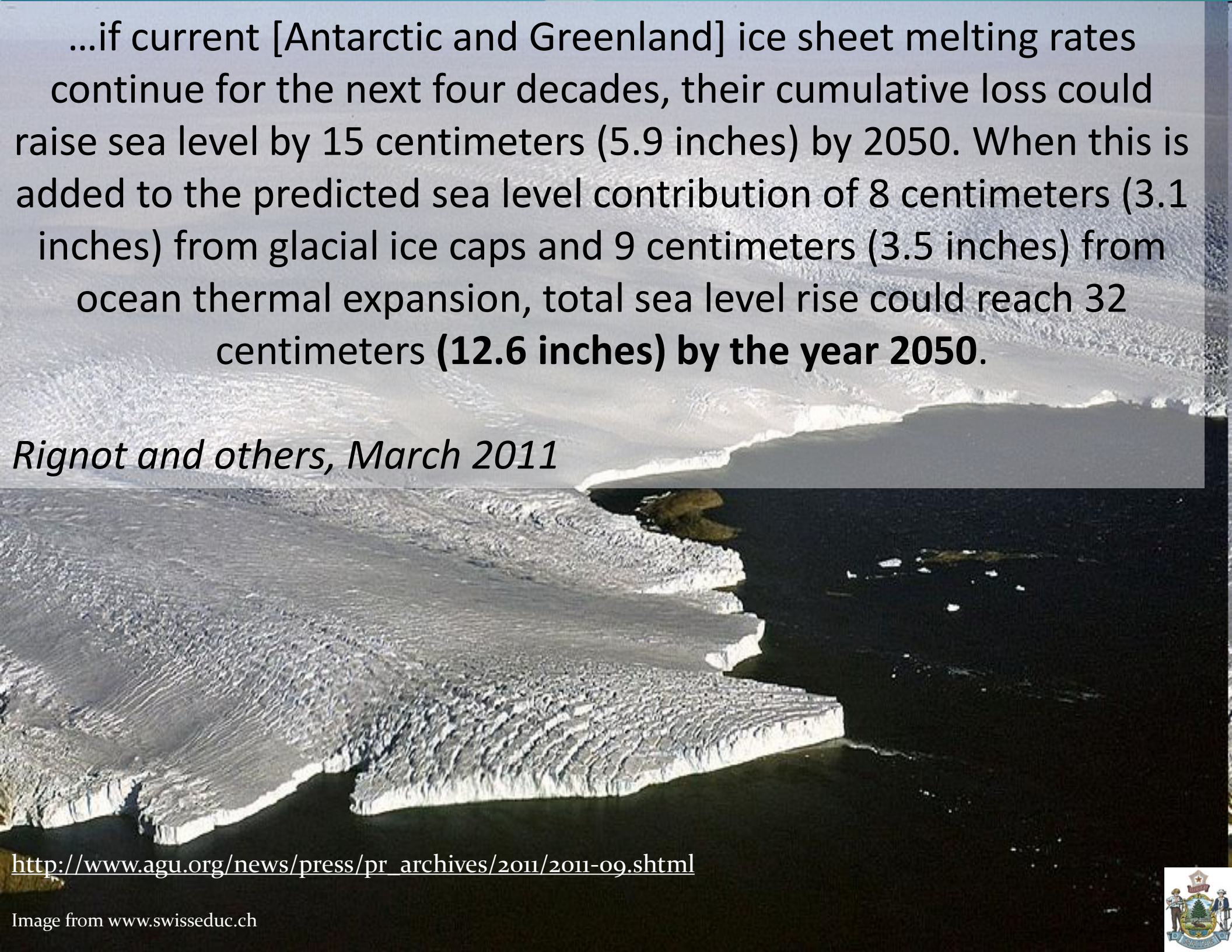
Lowest
(0.2 m, 0.7 ft)
*** Historical trend continued; no additional thermal expansion from warming**

Recommend using a "Scenario" Based Approach


Proxy Records
Tide Gauge Data
Satellite Data
Consider based on "risk tolerance"
6.6 ft
4 ft
1 ft
0.66 ft
"Given the evidence and uncertainties, confidence is **very high** that global sea level has risen during the past century, and that it will continue to rise over this century, with **medium** confidence that global sea level rise will be in the range of 1 to 4 feet by 2100".
US National Climate Assessment (May, 2014)
Sea Level Change (feet)
7
6
5
4
3
2
1
0
–1
1800
1850
1900
1950
2000
2050
2100
Year

…if current [Antarctic and Greenland] ice sheet melting rates continue for the next four decades, their cumulative loss could raise sea level by 15 centimeters (5.9 inches) by 2050. When this is added to the predicted sea level contribution of 8 centimeters (3.1 inches) from glacial ice caps and 9 centimeters (3.5 inches) from ocean thermal expansion, total sea level rise could reach 32 centimeters **(12.6 inches) by the year 2050**.

Rignot and others, March 2011



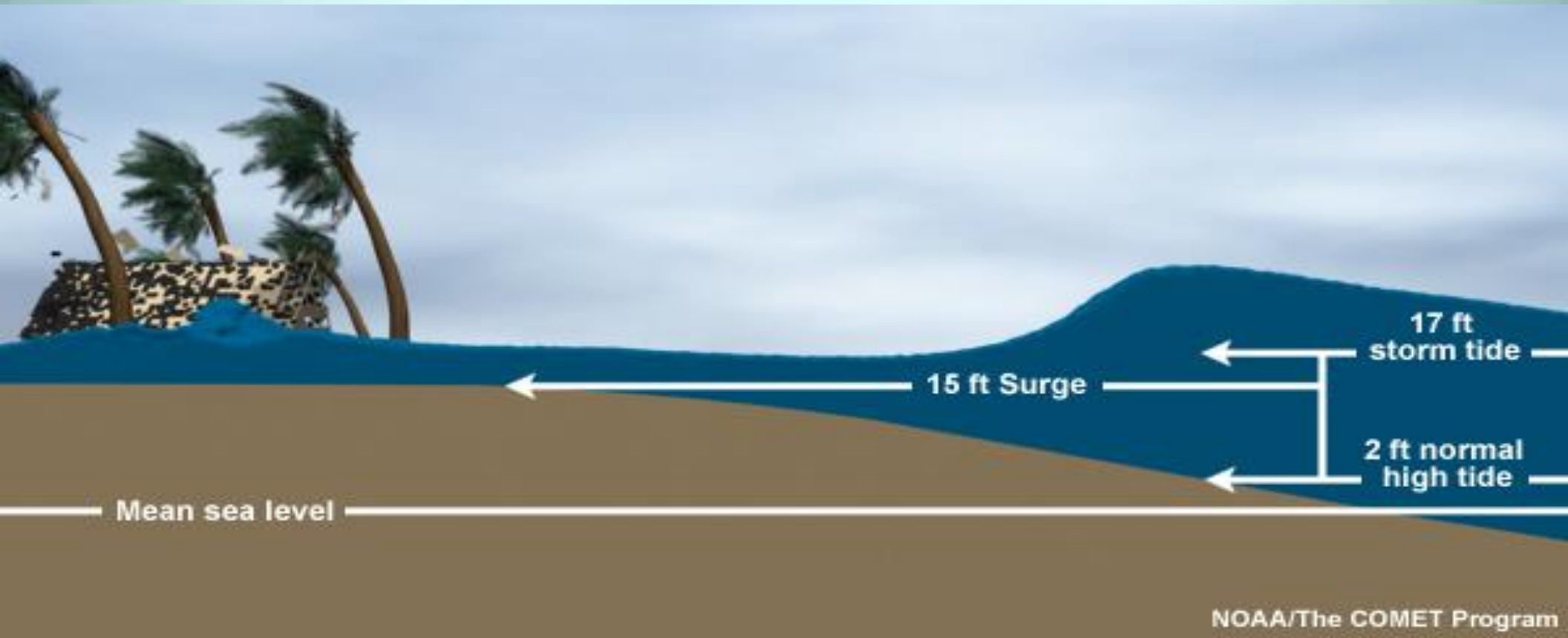
http://www.agu.org/news/press/pr_archives/2011/2011-09.shtml

Image from www.swisseduc.ch

What about storm tides and storm surges?

So what is storm surge?

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide, which is defined as the water level rise due to the combination of storm surge and the astronomical tide (National Hurricane Center)

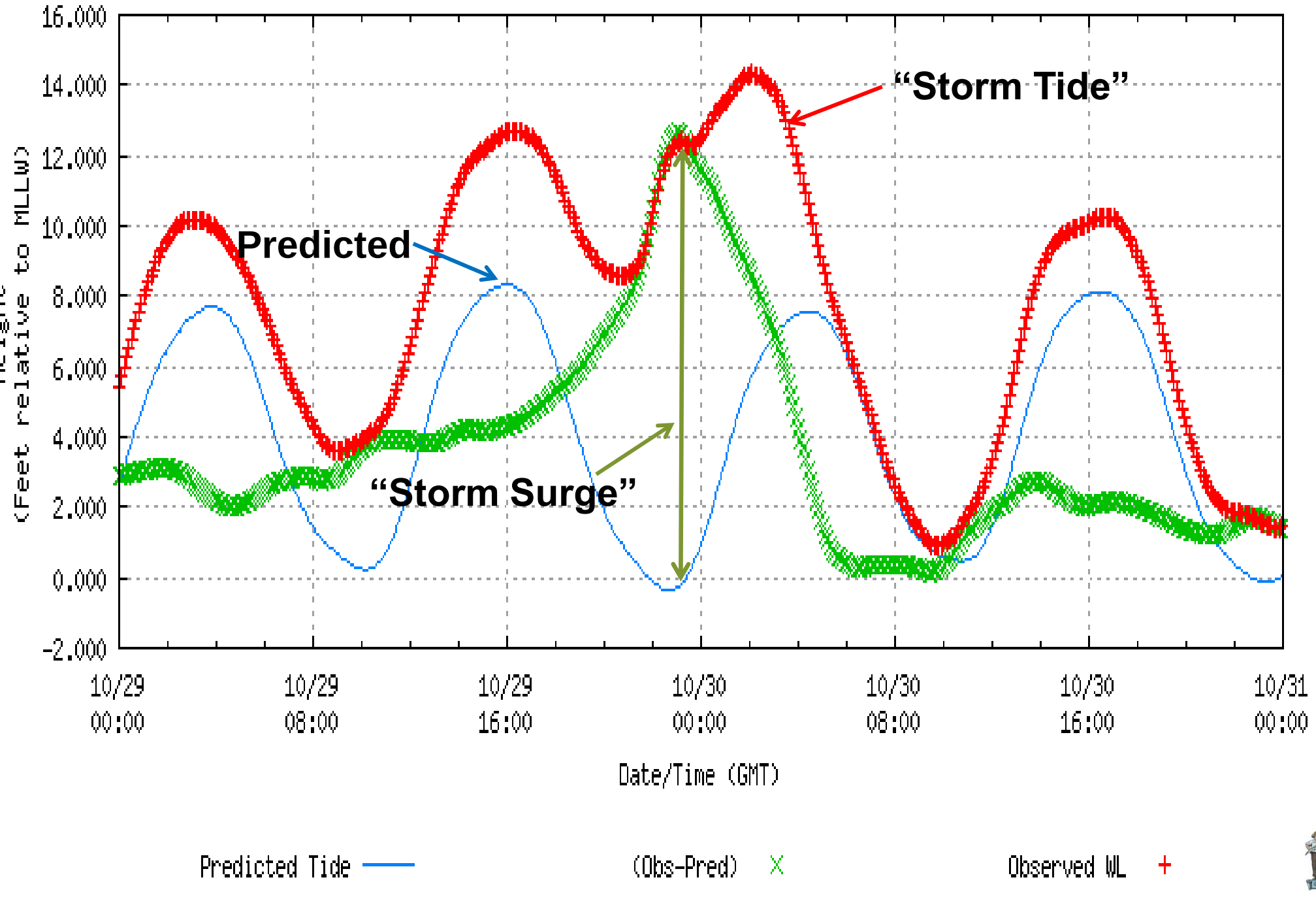


Storm Surge

"Superstorm Sandy"

NOAA/NOS/CO-OPS
Verified Water Level vs. Predicted Plot
8516945 Kings Point, NY
from 2012/10/29 - 2012/10/30

Kings Point, NY
10/29-10/30/2012

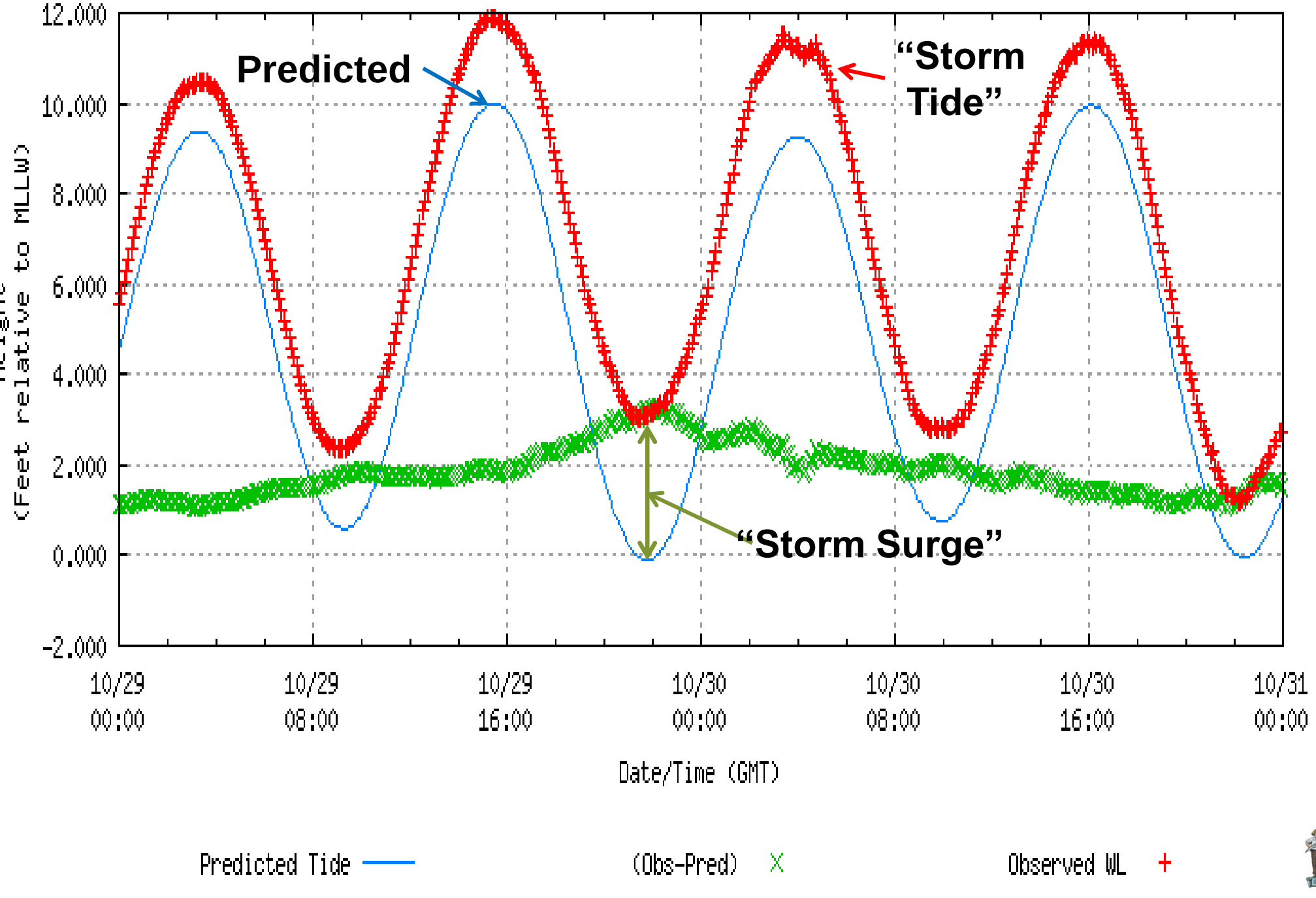


Storm Surge

"Superstorm Sandy"

NOAA/NOS/CO-OPS
Verified Water Level vs. Predicted Plot
8418150 Portland, ME
from 2012/10/29 - 2012/10/30

Portland, ME
10/29-10/30/2012



Portland Storm Surges, any tide (1912-2012)

Time Interval (years)		Surge Height (feet)
1	(100 %)	1.8
2	(50%)	2.4
5	(20%)	3.3
10	(10 %)	4.0
20	(5%)	4.7
25	(4 %)	4.9
50	(2 %)	5.6
75	(1.3 %)	6.0
100	(1%)	6.3

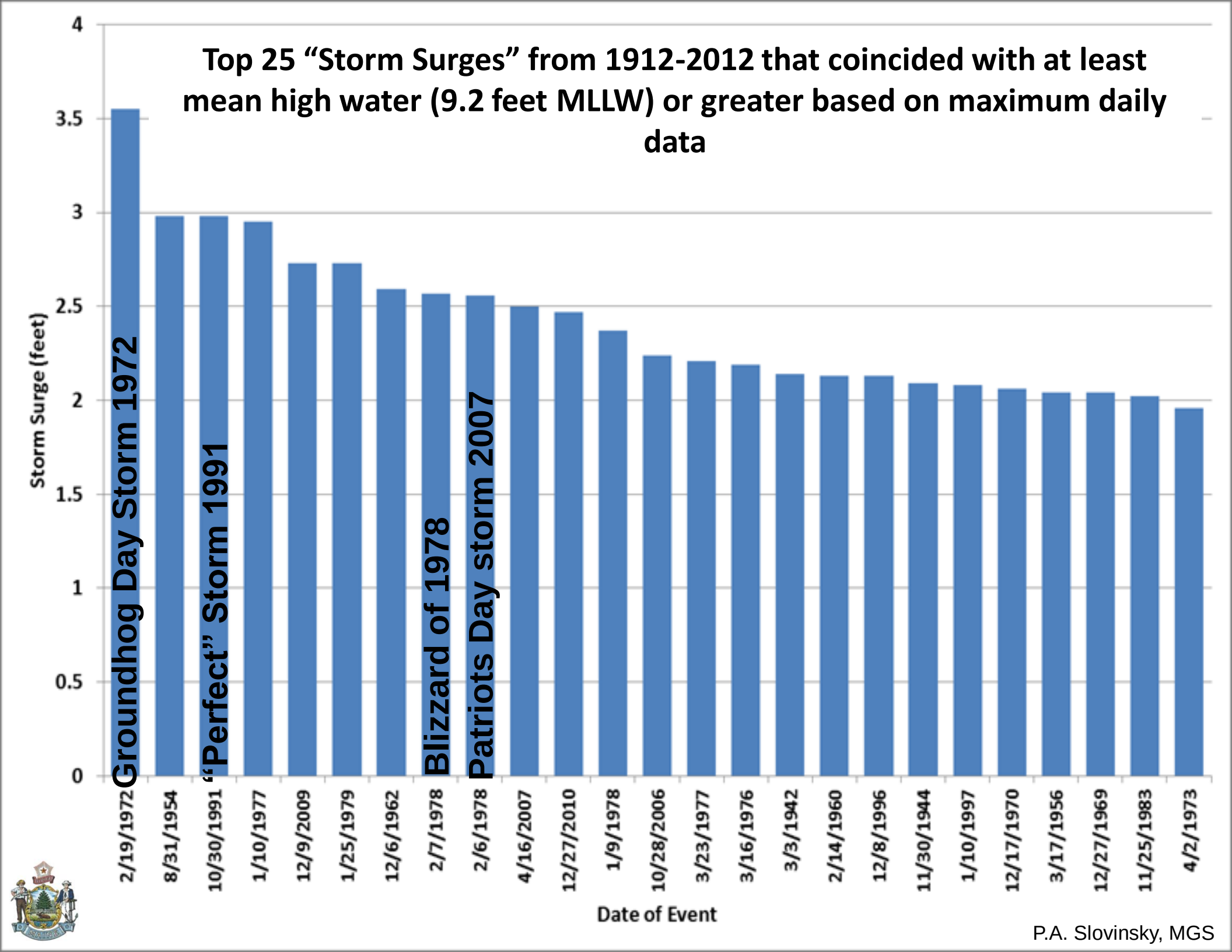
These numbers correlate relatively well with overall longer term sea level rise planning!

P.A. Slovinsky, MGS

Because of Maine's tidal variation, it's *the combination of astronomical tide and "storm surge" that are of concern* (NHC calls this overall water level the **"storm tide"**)

Portland Storm Surges, 1912-2012 (coinciding with mean high water or greater)

Interval (yrs)	Surge at MHW (ft)
1 (100 %)	1.1
5 (20%)	2
10 (10 %)	2.4
25 (4 %)	2.9
50 (2 %)	3.3
100 (1 %)	3.7


Top 25 "Storm Surges" from 1912-2012 that coincided with at least mean high water (9.2 feet MLLW) or greater based on maximum daily data
Storm Surge (feet)
4
3.5
3
2.5
2
1.5
1
0.5
0
Groundhog Day Storm 1972
"Perfect" Storm 1991
Blizzard of 1978
Patriots Day storm 2007
2/19/1972
8/31/1954
10/30/1991
1/10/1977
12/9/2009
1/25/1979
12/6/1962
2/7/1978
2/6/1978
4/16/2007
12/27/2010
1/9/1978
10/28/2006
3/23/1977
3/16/1976
3/3/1942
2/14/1960
12/8/1996
11/30/1944
1/10/1997
12/17/1970
3/17/1956
12/27/1969
11/25/1983
4/2/1973
Date of Event
P.A. Slovinsky, MGS

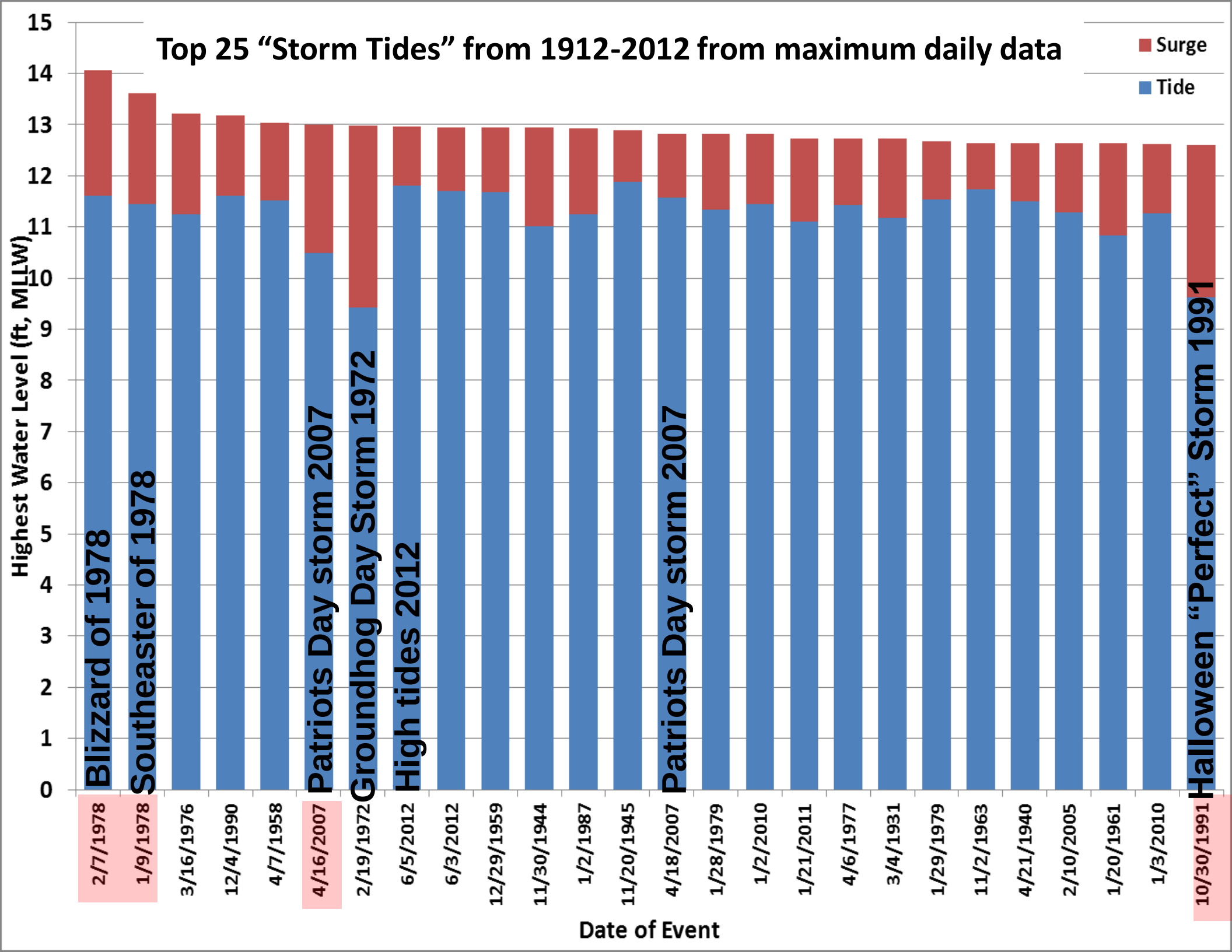
Portland "Storm Tides", 1912-2012

Interval (yrs)	"Storm Tide" Level (ft, MLLW)
1 (100 %)	11.7
5 (20%)	12.6
10 (10 %)	12.9
25 (4 %)	13.4
50 (2 %)	13.7
100 (1 %)	14.1

Portland "Storm Tides", 1912-2012

Interval (yrs)	"Storm Tide" Level (ft, MLLW)
1 (100 %)	11.7
5 (20%)	12.6
10 (10 %)	12.9
25 (4 %)	13.4
50 (2 %)	13.7
100 (1 %)	14.1

1 foot difference!

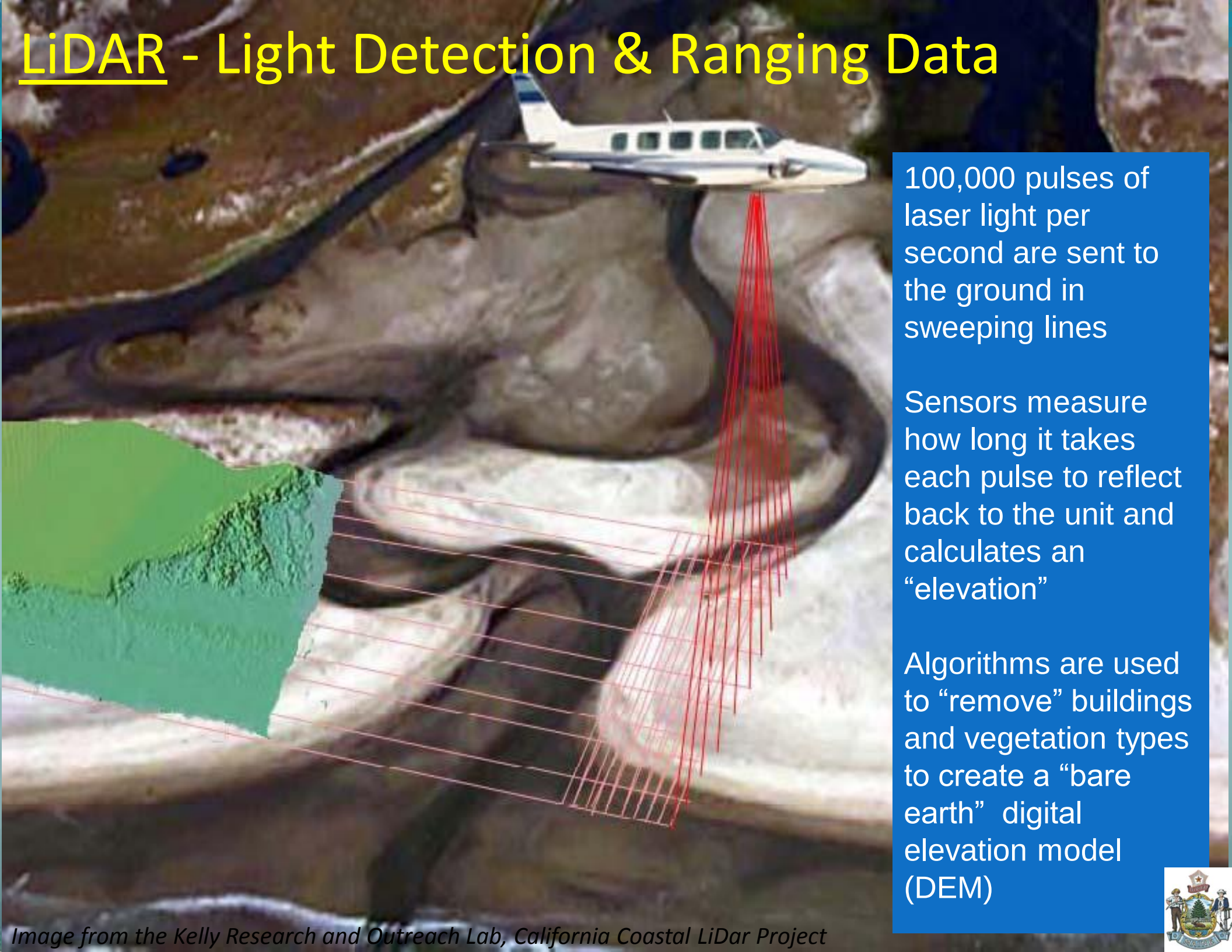

Top 25 "Storm Tides" from 1912-2012 from maximum daily data
Surge
Tide
Highest Water Level (ft, MLLW)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Blizzard of 1978
Southeaster of 1978
Patriots Day storm 2007
Groundhog Day Storm 1972
High tides 2012
Patriots Day storm 2007
Halloween "Perfect" Storm 1991
2/7/1978
1/9/1978
3/16/1976
12/4/1990
4/7/1958
4/16/2007
2/19/1972
6/5/2012
6/3/2012
12/29/1959
11/30/1944
1/2/1987
11/20/1945
4/18/2007
1/28/1979
1/2/2010
1/21/2011
4/6/1977
3/4/1931
1/29/1979
11/2/1963
4/21/1940
2/10/2005
1/20/1961
1/3/2010
10/30/1991
Date of Event

Sea Level and Storm Surge Summaries

- Latest scientific predictions for SLR: 1 ft 2050, 2-3 ft *but potentially more* by 2100; the **State of Maine has adopted 2 feet as a middle of the road prediction by the year 2100 for areas with regulated Coastal Sand Dunes – Cape Elizabeth has this**.
- There is only about a one foot difference between the "10 year" event and the "100 year" event ; thus, **a one-foot rise in sea level by 2050 would cause the "100 year" event to come about every 10 years because sea level rise significantly lowers the recurrence interval of storms.**
- For Coastal Hazard Resiliency Projects with partner communities, we typically suggest **examining scenarios of 1 foot, 2 feet, 3.3 feet, and 6 feet on top of the highest annual tide (HAT). These scenarios relate to the National Climate Assessment, and also correspond well with evaluating *potential impacts from storm surges that may coincide with higher tides today.***

So how do we use this data to complete "Vulnerability Assessments" for the natural and built environments to sea level rise and storms?

LiDAR - Light Detection & Ranging Data



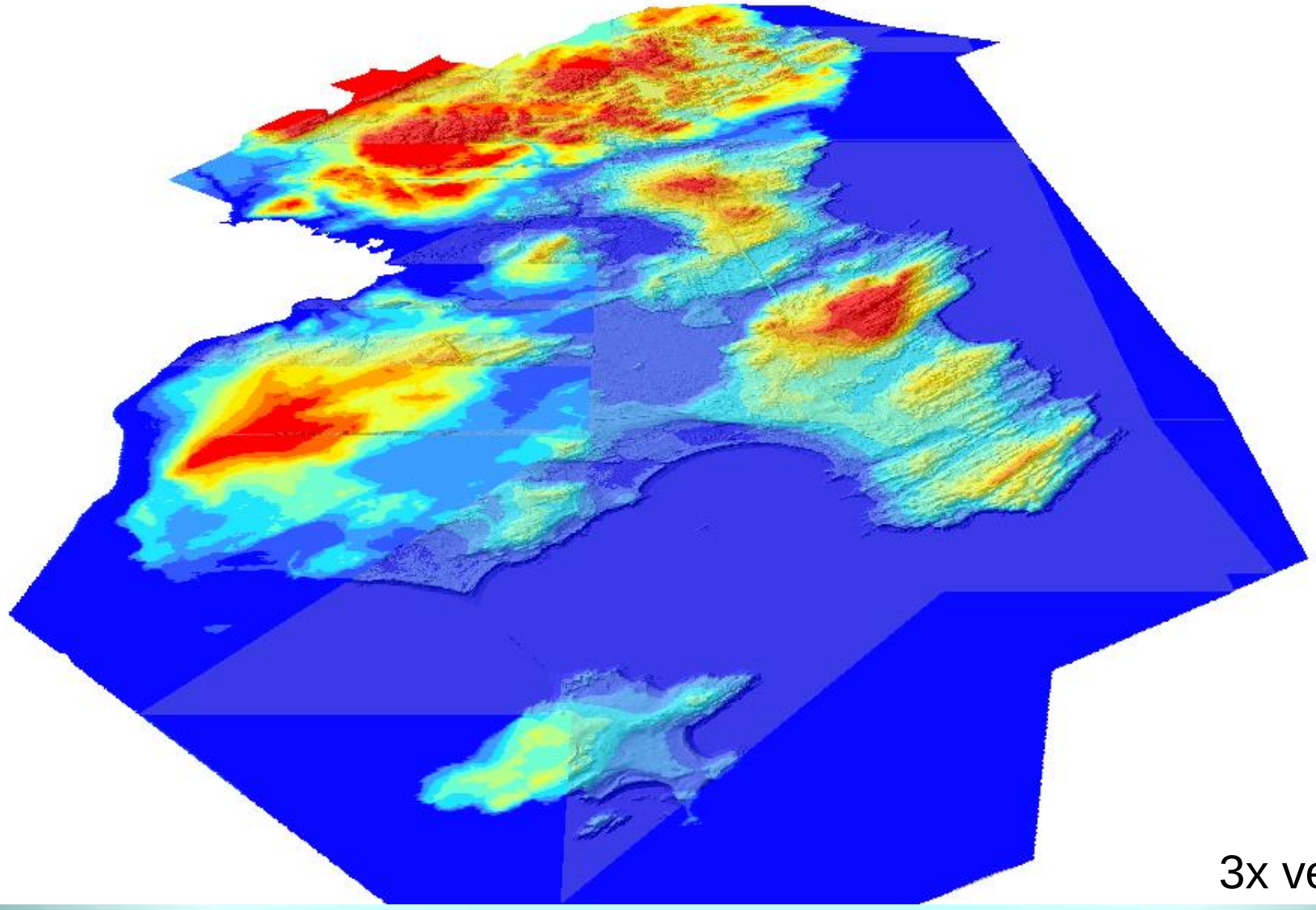
100,000 pulses of laser light per second are sent to the ground in sweeping lines

Sensors measure how long it takes each pulse to reflect back to the unit and calculates an “elevation”

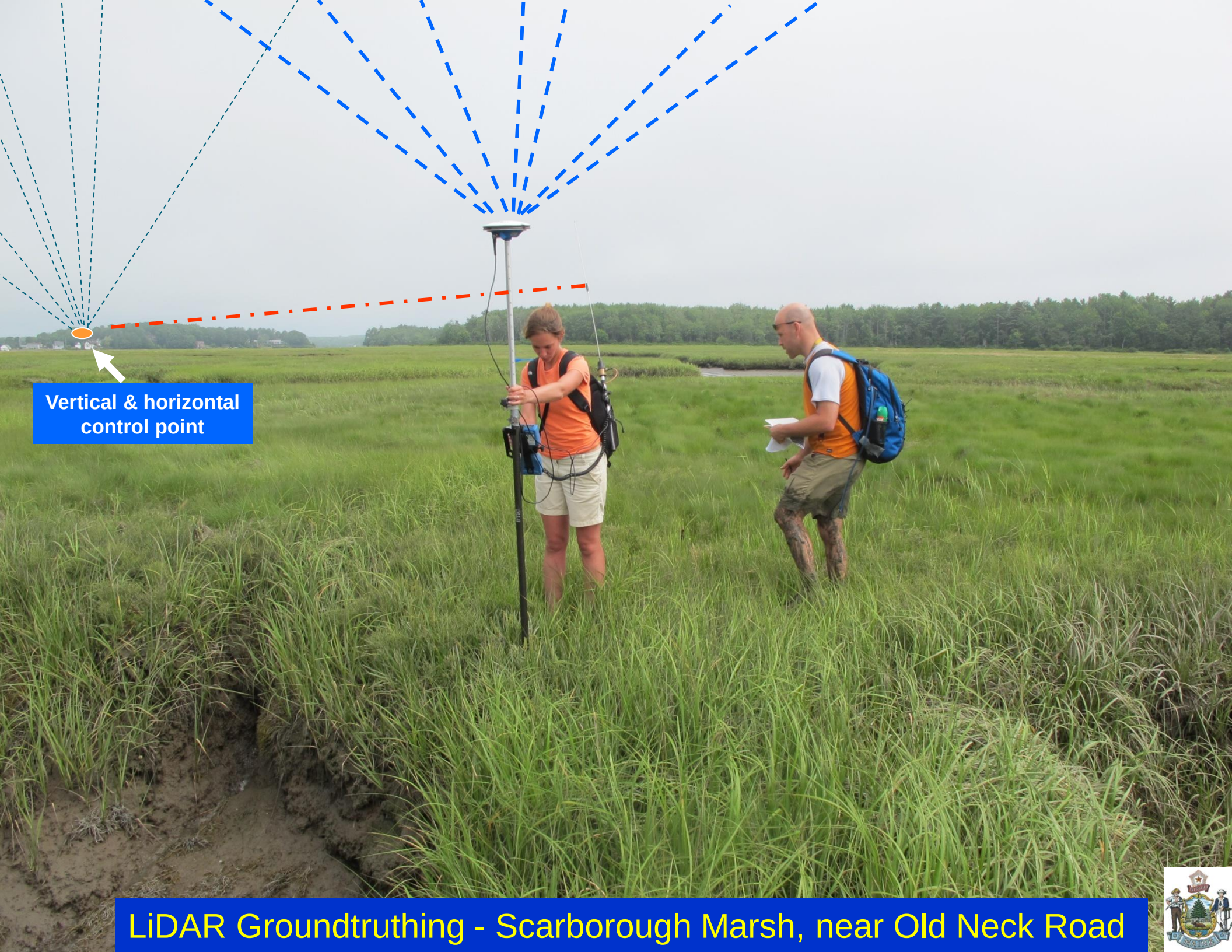
Algorithms are used to “remove” buildings and vegetation types to create a “bare earth” digital elevation model (DEM)

Image from the Kelly Research and Outreach Lab, California Coastal LiDar Project

LiDAR Digital Elevation Model (DEM) for Cape Elizabeth, ME

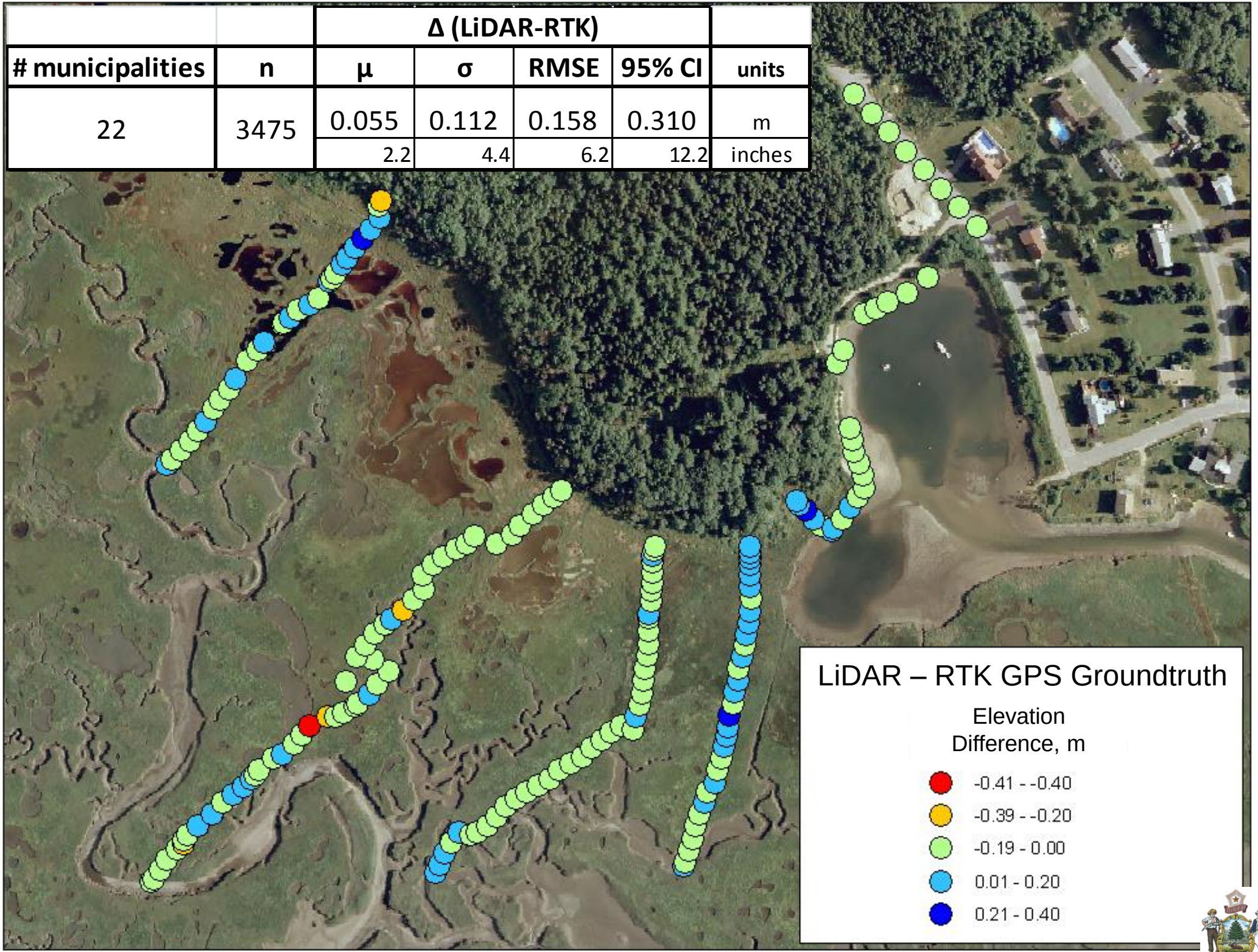


3x vertical



LiDAR Groundtruthing - Scarborough Marsh, near Old Neck Road

		Δ (LiDAR-RTK)				
# municipalities	n	μ	σ	RMSE	95% CI	units
22	3475	0.055	0.112	0.158	0.310	m
		2.2	4.4	6.2	12.2	inches



How can we use LiDAR to help more accurately define the Shoreland Zone in Maine?

Maine's Shoreland Zone

The Mandatory Shoreland Zoning Act (MSZA) requires municipalities to adopt, administer, and enforce local ordinances that regulate land use activities in the shoreland zone. **The shoreland zone is comprised of all land areas within 250 feet, horizontal distance, of the**

- ***normal high-water line of any great pond or river***;
- ***upland edge of a coastal wetland, including all areas affected by tidal action, and***
- upland edge of defined freshwater wetlands; and
- all land areas within 75 feet, horizontal distance, of the normal high-water line of certain streams.

Cape Elizabeth's language…

Normal High Water Line of Coastal Waters: That line on the shore of tidal waters which is the apparent extreme limit of the effect of the tides, ***i.e. the top of the bank, cliff or beach above high tide***

The Shoreland Performance Overlay District applies to **all land within two hundred fifty (250) feet**, horizontal distance, of the:

- normal high-water line of any great pond and the Spurwink River;
- ***upland edge of a coastal wetland, including all areas affected by tidal action such as cobble and sand beaches, mudflats, and rocky ledges;***
- upland edge of a freshwater wetland

Coastal wetlands

"Coastal wetlands" means all tidal and subtidal lands; all areas with vegetation present that is tolerant of salt water and occurs primarily in salt water or estuarine habitat; and any swamp, marsh, bog, beach, flat or other contiguous lowland that is subject to tidal action during the **highest tide level for each year** in which an activity is proposed as identified in tide tables published by the National Ocean Service. Coastal wetlands may include portions of coastal sand dunes.

Required in Maine's Municipal Shoreland Zoning

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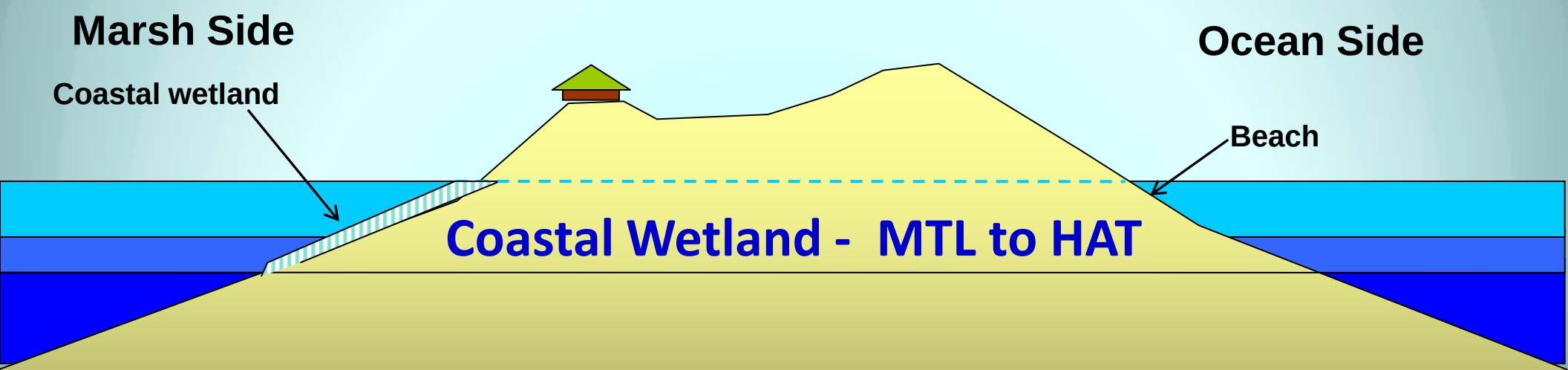
Using Tidal Elevations as Proxies Coastal Wetlands

Highest Annual Tide (HAT) - "spring" tide, the highest predicted water level for any given year but is reached within several inches numerous tides a year

Mean Tide Level (MTL) = average height of the ocean's surface (between mean high and mean low tide).



This is what is currently used in Maine's shoreland zoning regulations.

Tidal elevations are determined from nearby applicable NOAA National Ocean Service/CO-OPs tidal prediction stations (Old Orchard Beach)
http://tidesandcurrents.noaa.gov

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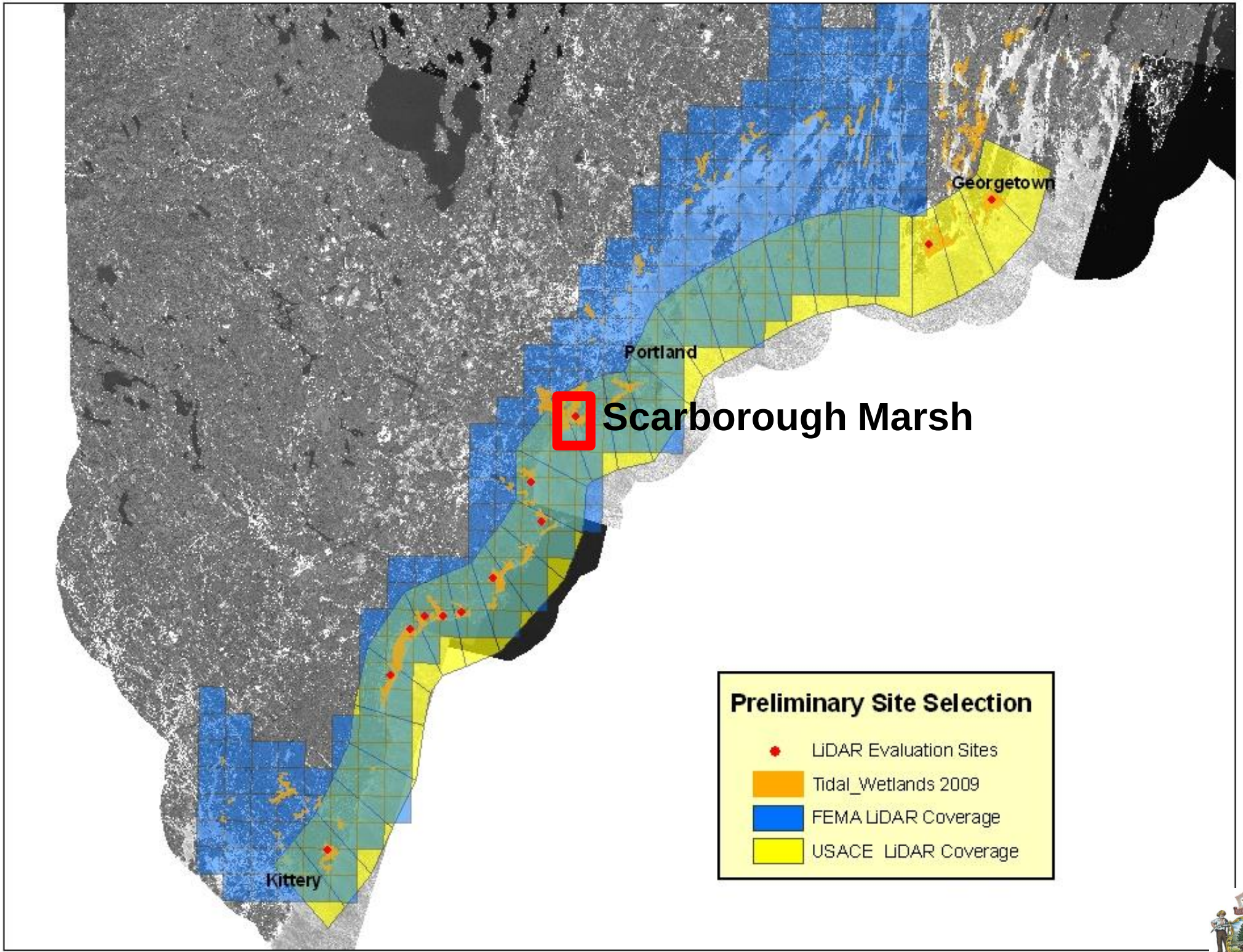
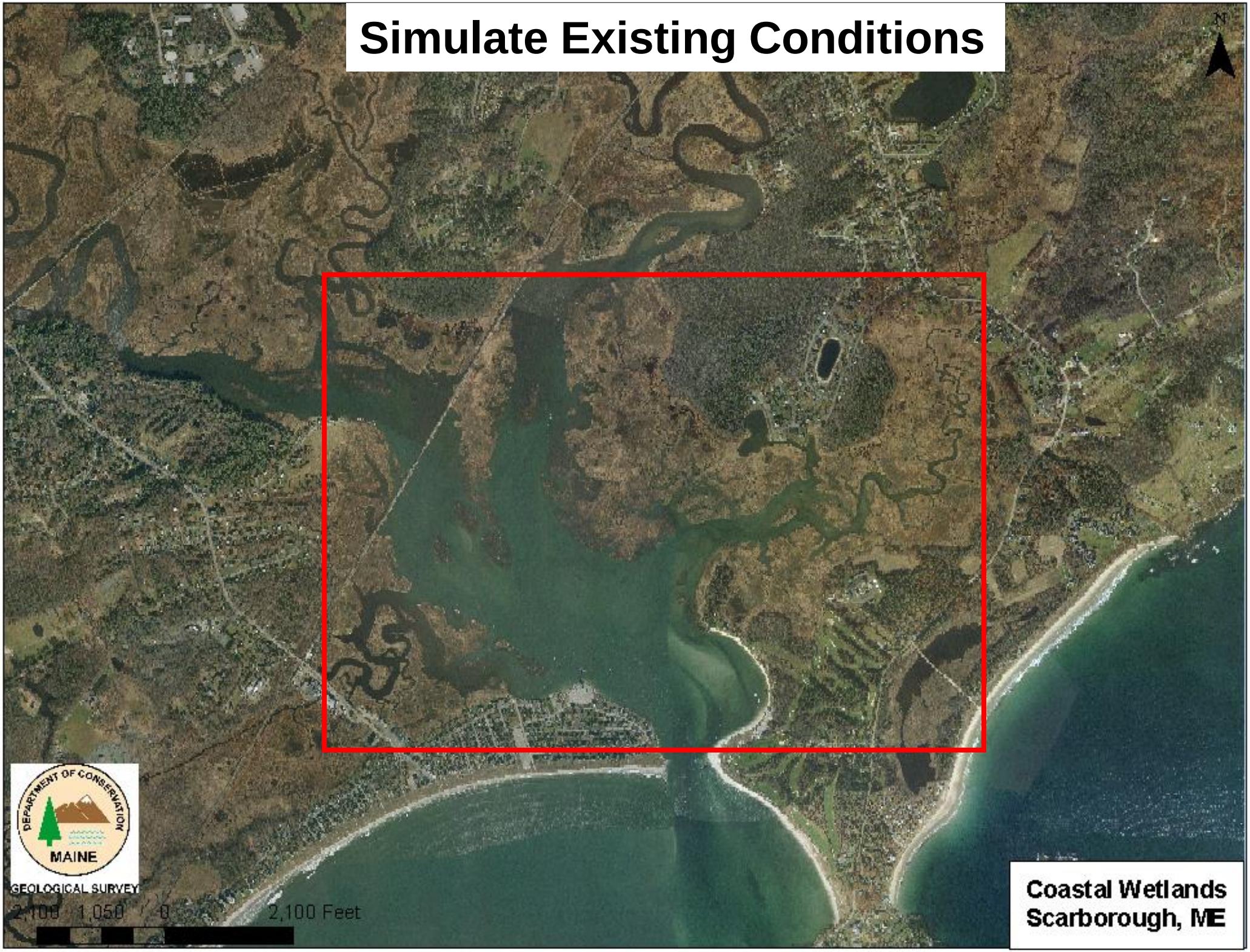
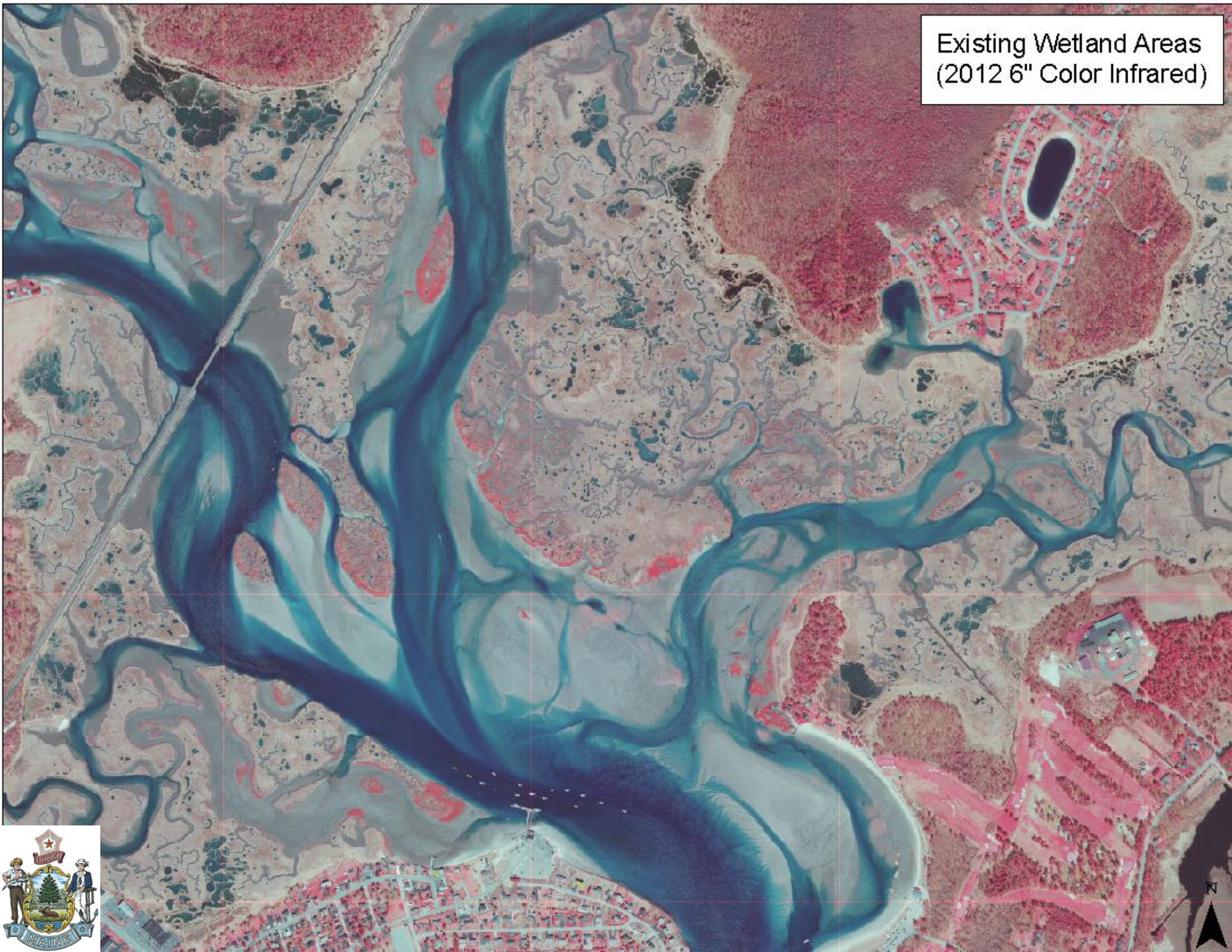
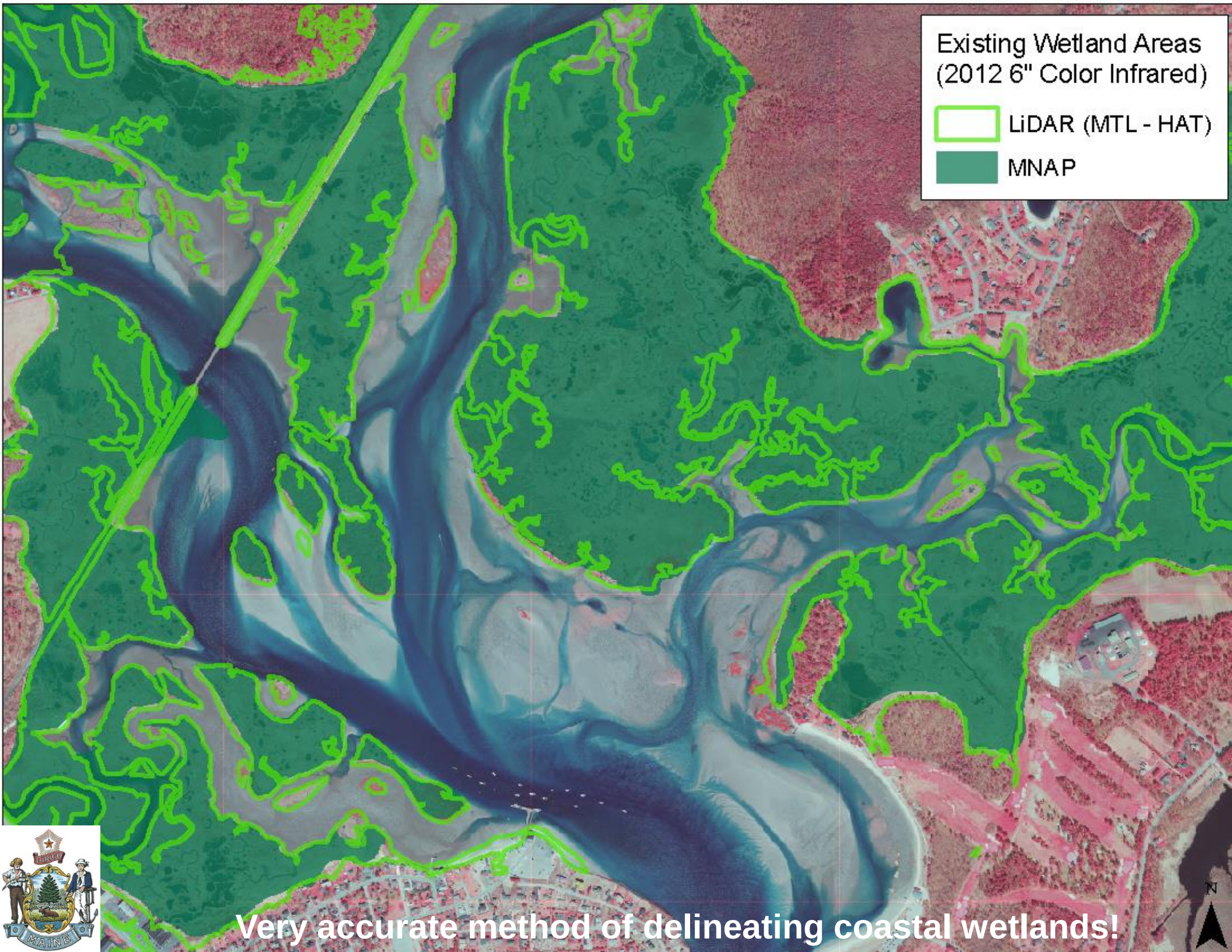

Georgetown
Portland
Scarborough Marsh
Kittery
Preliminary Site Selection
LiDAR Evaluation Sites
Tidal_Wetlands 2009
FEMA LiDAR Coverage
USACE LiDAR Coverage

Simulate Existing Conditions




Existing Wetland Areas
(2012 6" Color Infrared)
N


Existing Wetland Areas
(2012 6" Color Infrared)
MNAP
N


Existing Wetland Areas
(2012 6" Color Infrared)
LiDAR (MTL - HAT)
MNAP
N
Very accurate method of delineating coastal wetlands!

Maine DEP

Highest Annual Tide (HAT) Levels for Year 2013

Maine Coast from Eastport to Portsmouth, NH

Location	2013 HAT (Tide Table- ft.)	HAT (NGVD29) (elev. feet)	HAT (NAVD88) (elev. feet)	Ref. Station
Vaill Island	11.6	7.2	6.5	Portland
Long Island	11.9	7.4	6.6	Portland
Cow Island	11.9	7.4	6.6	Portland
Presumpscot River Bridge	12.0	7.4	6.6	Portland
Back Cove	11.5	7.0	6.3	Portland
Great Diamond Island	11.9	7.4	6.6	Portland
Peak Island	11.8	7.3	6.6	Portland
Cushing Island	11.8	7.3	6.5	Portland
PORTLAND	11.9	7.4	6.6	Portland
Fore River	11.9	7.3	6.6	Portland
Portland Head Light	11.5	7.1	6.4	Portland
MAINE, outer coast				
Old Orchard Beach	11.5	7.2	6.5	Portland
Camp Ellis, Saco River Entrance	11.5	7.1	6.4	Portland
Biddeford, Saco River	11.8	7.3	6.5	Portland
Cape Porpoise	11.3	7.0	6.2	Portland
Kennebunkport	11.5	7.1	6.4	Portland
Wells, Webhannet River	11.4	7.1	6.3	Portland
Cape Neddick	11.3	7.0	6.2	Portland
York Harbor	11.3	7.1	6.3	Portland
Fort Point, York Harbor	11.3	7.0	6.3	Portland
Seapoint, Cutts Island	11.4	7.1	6.3	Portland
MAINE and NEW HAMPSHIRE				
Portsmouth Harbor				
Jaffrey Point	11.3	7.0	6.2	Portland
Gerrish Island	11.3	7.0	6.2	Portland
Fort Point	11.2	6.9	6.2	Portland
Kittery Point	11.4	7.1	6.3	Portland
Seavey Island	10.6	6.6	5.8	Portland
Portsmouth	10.2	6.4	5.7	Portland
Piscataqua River				
Atlantic Heights	9.7	6.1	5.4	Portland
Dover Point	8.3	5.3	4.6	Portland
Dover, Cocheco River	9.1	5.7	5.0	Portland
Salmon Falls River	8.9	5.7	5.0	Portland

Problem with using annual HAT is that the **value slightly changes each year**. MGS creates tide table predictions for the Maine DEP and the general public to help determine what the effective highest tide level is for each year at locations along the Maine coast using NOAA NOS data.

Recommendation to MeDEP:

For Shoreland Zoning Purposes, instead of using the predicted **Highest Annual Tide** (which changes each year), consider using the ***Highest Astronomical Tide***, which is the highest measured tide level for the effective 19 year National Tidal Datum Epoch (1983 – 2001, made effective in April 2003). This occurs during the spring tide when the sun and moon are closest to the earth during an 18.6 year tidal cycle ***and accounts for all significant variations in moon and earth orbits.*** *The NTDE is recalculated every 20-25 years.*

"The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the National Tidal Datum Epoch."

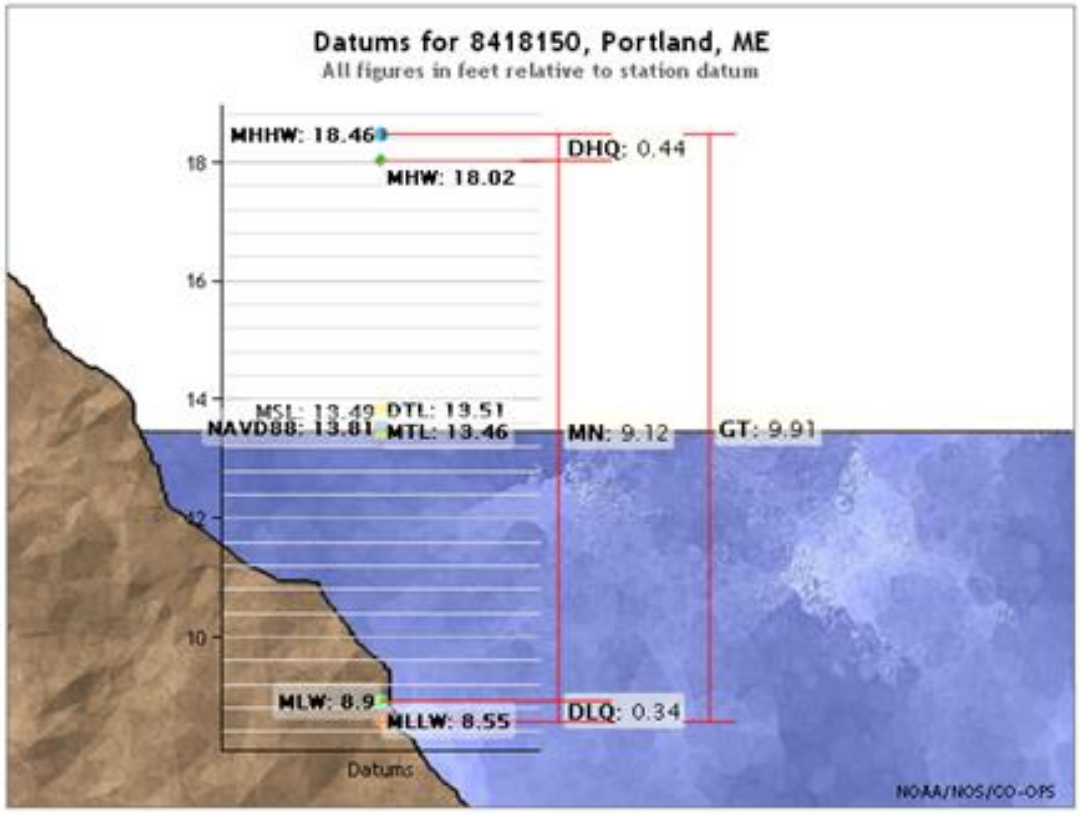
http://tidesandcurrents.noaa.gov/datum_options.html#HAT

Determining the Highest Astronomical Tide Value Using the effective NTDE (for Portland)

Elevations on Station Datum

Station: 8418150, Portland, ME **T.M.:** 75 W
Status: Accepted (Apr 17 2003) **Epoch:** 1983-2001
Units: Feet **Datum:** STND

Datum	Value	Description
MHHW	18.46	Mean Higher-High Water
MHW	18.02	Mean High Water
MTL	13.46	Mean Tide Level
MSL	13.49	Mean Sea Level
DTL	13.51	Mean Diurnal Tide Level
MLW	8.90	Mean Low Water
MLLW	8.55	Mean Lower-Low Water
NAVD88	13.81	North American Vertical Datum of 1988
STND	0.00	Station Datum
GT	9.91	Great Diurnal Range
MN	9.12	Mean Range of Tide
DHQ	0.44	Mean Diurnal High Water Inequality
DLQ	0.34	Mean Diurnal Low Water Inequality
HWI	3.59	Greenwich High Water Interval (in hours)
LWI	9.75	Greenwich Low Water Interval (in hours)
Maximum	22.68	Highest Observed Water Level
Max Date & Time	02/07/1978 10:30	Highest Observed Water Level Date and Time
Minimum	5.10	Lowest Observed Water Level
Min Date & Time	11/30/1955 17:18	Lowest Observed Water Level Date and Time
HAT	20.50	Highest Astronomical Tide
HAT Date & Time	05/17/1999 04:42	HAT Date and Time
LAT	6.43	Lowest Astronomical Tide



HAT in station datum = 20.50 ft

MLLW in station datum = 8.55 ft

The Highest Astronomical Tide is…

20.50 – 8.55 = 11.95 ft MLLW

Cape Elizabeth's proposed DRAFT Zoning Ordinance
Normal High Water Line Zoning Amendments

SEC. 19-1-3. DEFINITIONS
Highest Astronomical Tide: The elevation of the highest predicted astronomical tide, referenced to Mean Lower Low Water (MLLW) at Portland Head Light tide prediction station. This prediction is based on an adjustment from the Portland tidal station. The highest astronomical tide is based on the most recent National Tidal Datum Epoch (NTDE) as determined from time to time by the National Ocean Service, an office within the U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Normal High Water Line: …Adjacent to tidal waters, the normal high water line shall be the topographic line located at the Highest Astronomical Tide, **plus three (3) vertical feet upland**.

Comparing 2013 and 2014 Highest Annual Tide (HAT) with Highest Astronomical Tide (HAsT)

Water Level	Portland	Portland Head Light#^			
	MLLW (ft)	MLLW (ft)	1 ft SLR	2 ft SLR	3 ft SLR
HAT 2013*	11.9	11.5	12.5	13.5	14.5
HAT 2014**	11.8	11.4	12.4	13.4	14.4
HAsT***	12.0	11.6	12.6	13.6	14.6

** taken from 6/25/2013 tidal predictions for Portland at tides.noaa.gov*

*** taken from 1/2/2014 tidal predictions for Portland at tides.noaa.gov*

**** derived from Portland Tidal Station benchmark sheet for current NTDE (1983-2001), 5/17/1999*

*# adjusted from Portland Tide Station to Portland Head Light using *0.97 at MLLW*

^ the value can be adjusted from MLLW to NAVD88 using VDATUM software

Comparing Highest Astronomical Tide (HAsT) + 3 feet with other numbers…

Water Level (feet, MLLW)					
Existing HAsT	**HAsT+3 ft SLR**	10% (10 yr) SWL*	2% (50 yr) SWL*	1% (100 yr) SWL*	0.2% (500 yr) SWL*
11.6	**14.6**	12.6	13.2	13.5	14.2

**from 11/5/2013 preliminary FEMA Flood Insurance Study*

conversions from NAVD to MLLW using Portland Head Light location and NOAA's VDATUM tool

Visualizing Highest Astronomical Tides in Cape Elizabeth

Wikimedia commons

Some Assumptions and Limitations

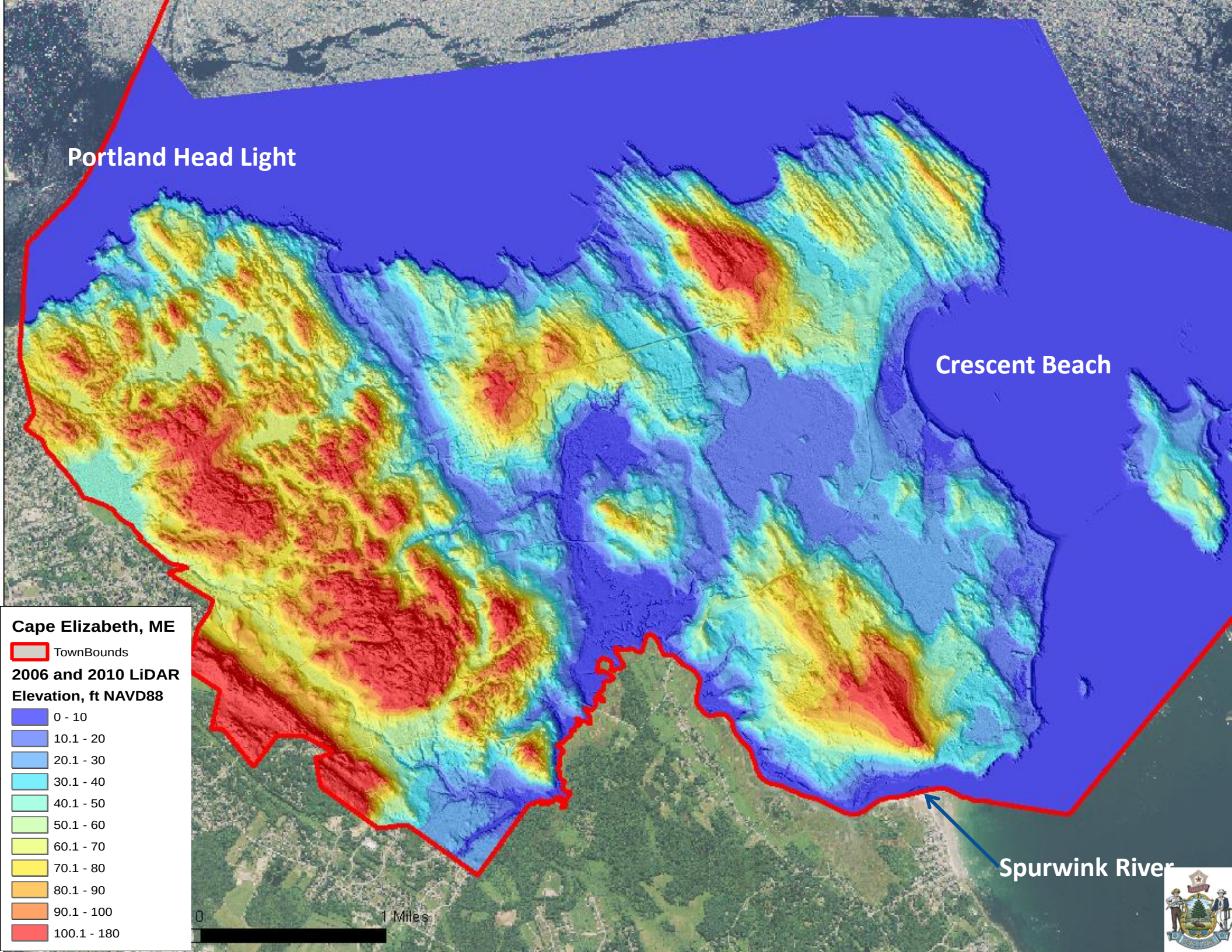
- We use a “bare earth” LiDAR DEM that represents a “snapshot” of topography that **may have changed since the data was captured**.

- Simulations use a **bathtub approach that assumes that the topography stays the same**, i.e., it doesn’t account for erosion, sedimentation, tidal restrictions, *or dynamic processes like waves*.

- We use a tool, NOAA’s VDATUM, to convert from MLLW to NAVD88 elevations and to translate elevations across water surfaces. This helps adjust tidal predictions, but also **adds additional vertical error (up to a published 13.2 cm per NOAA)** to our datasets.

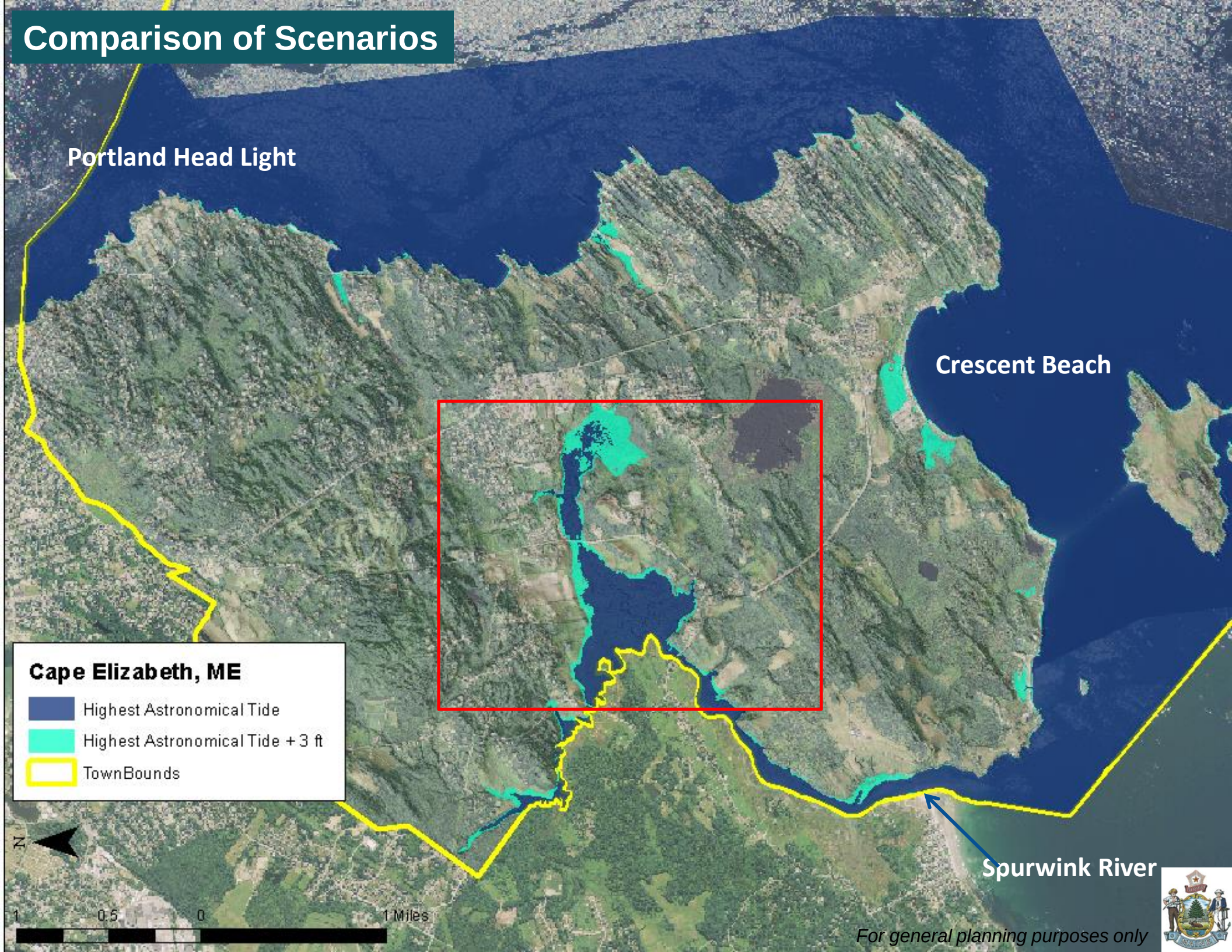
- Although data is quite accurate, lines and boundaries drawn on the following maps should be used ***for planning purposes only.***


Portland Head Light
Crescent Beach
Spurwink River
N
1
0.5
0
1 Miles


Portland Head Light
Crescent Beach
Spurwink River
Cape Elizabeth, ME
TownBounds
2006 and 2010 LiDAR
Elevation, ft NAVD88
0 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
100.1 - 180
0
1 Miles

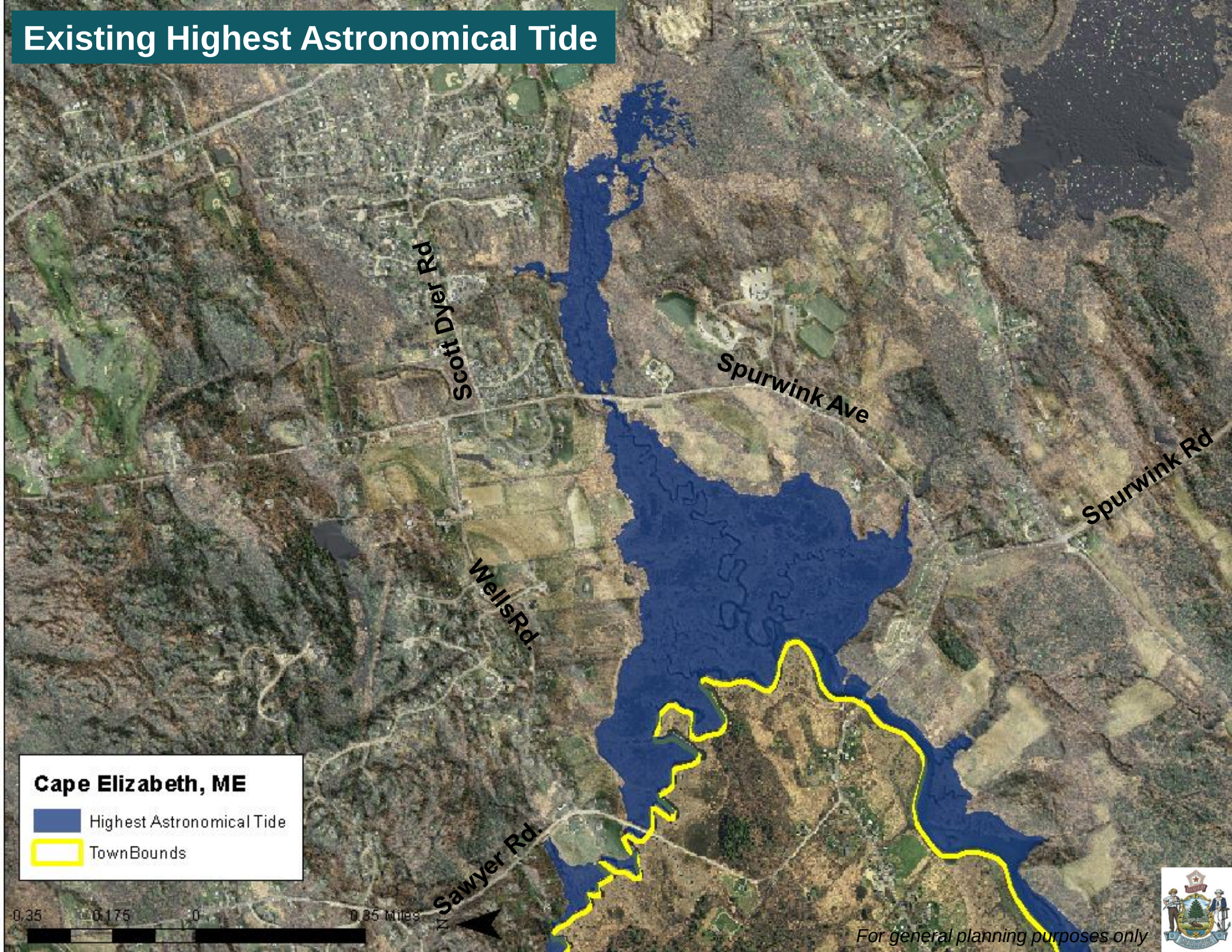
Existing Highest Astronomical Tide

Comparison of Scenarios

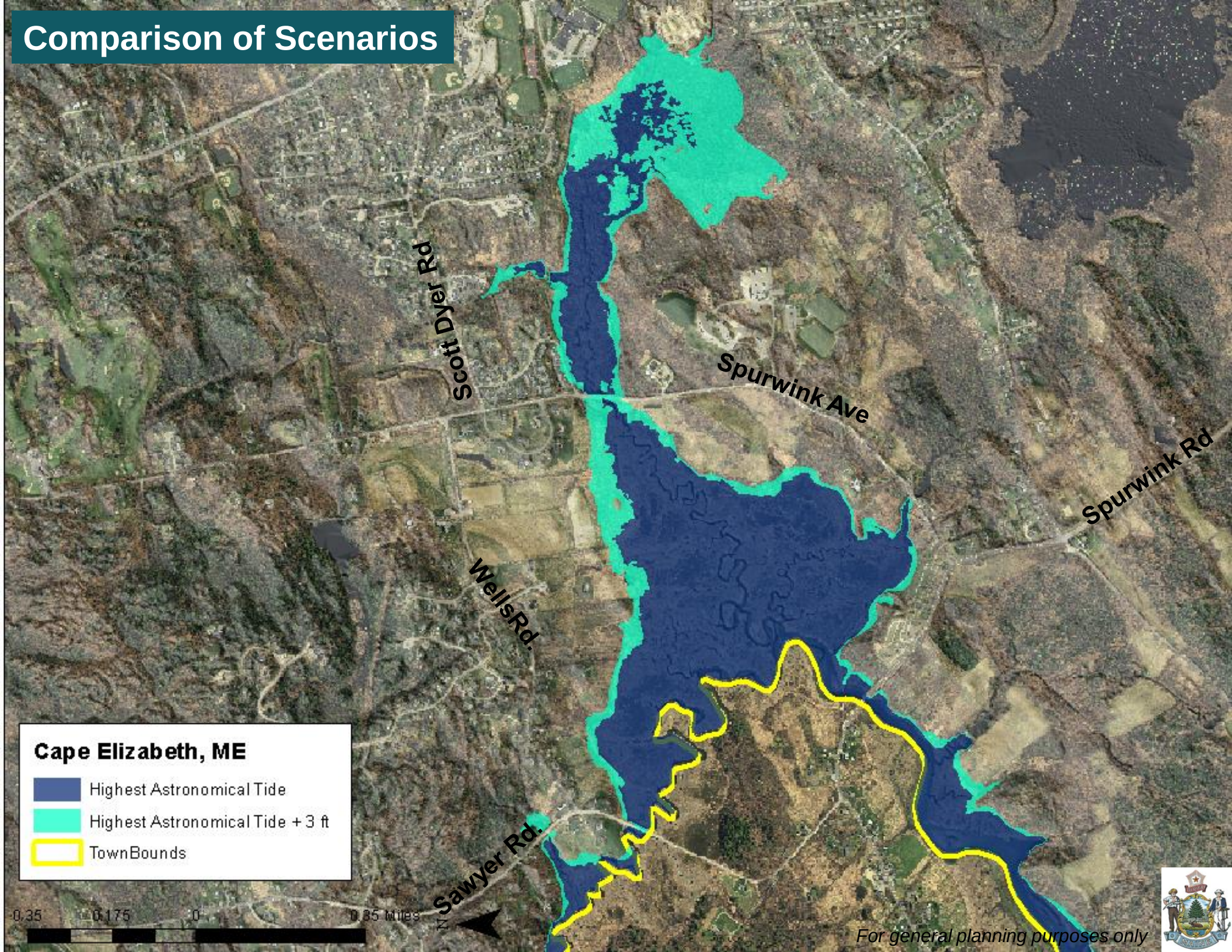


For general planning purposes only

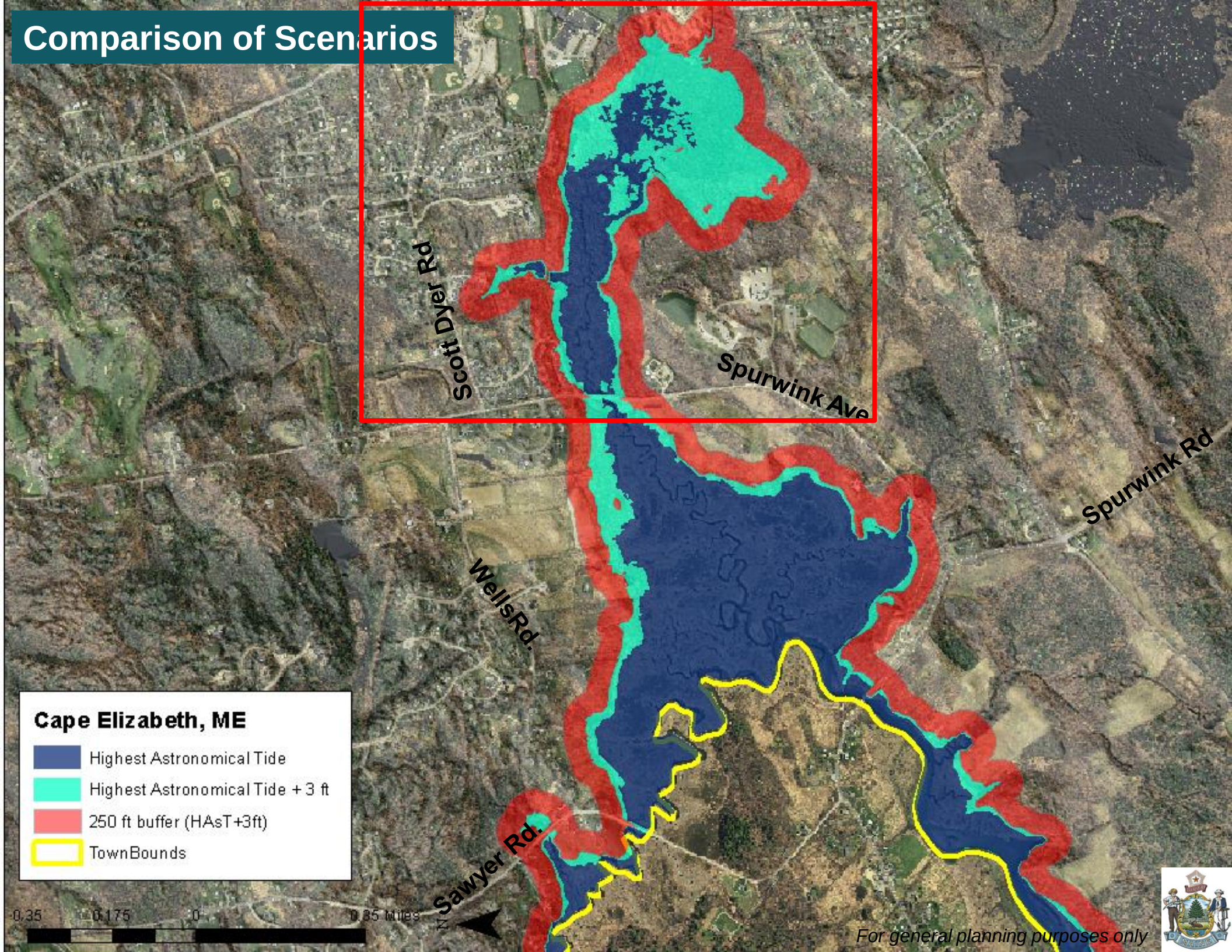
Existing Highest Astronomical Tide



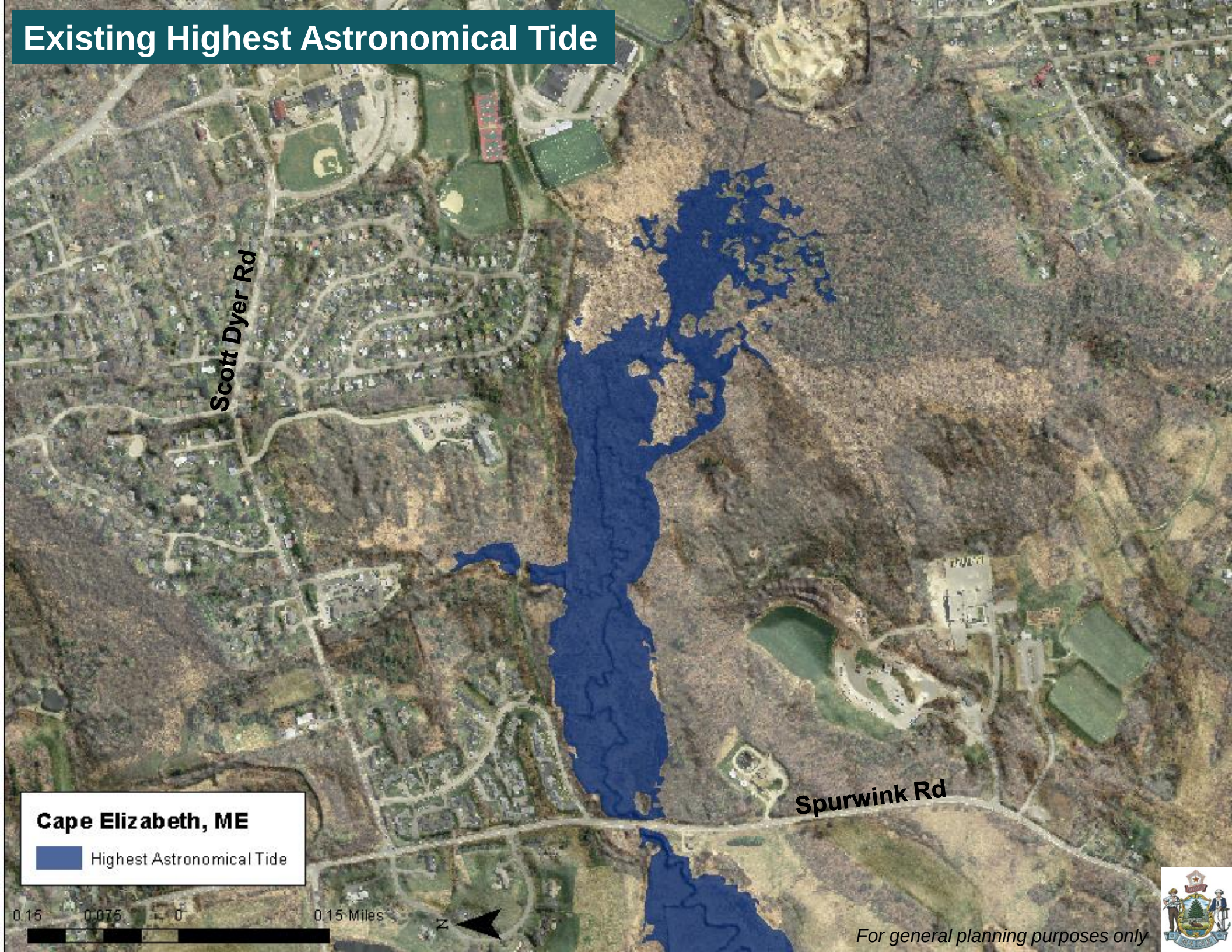
Comparison of Scenarios



Comparison of Scenarios



Existing Highest Astronomical Tide



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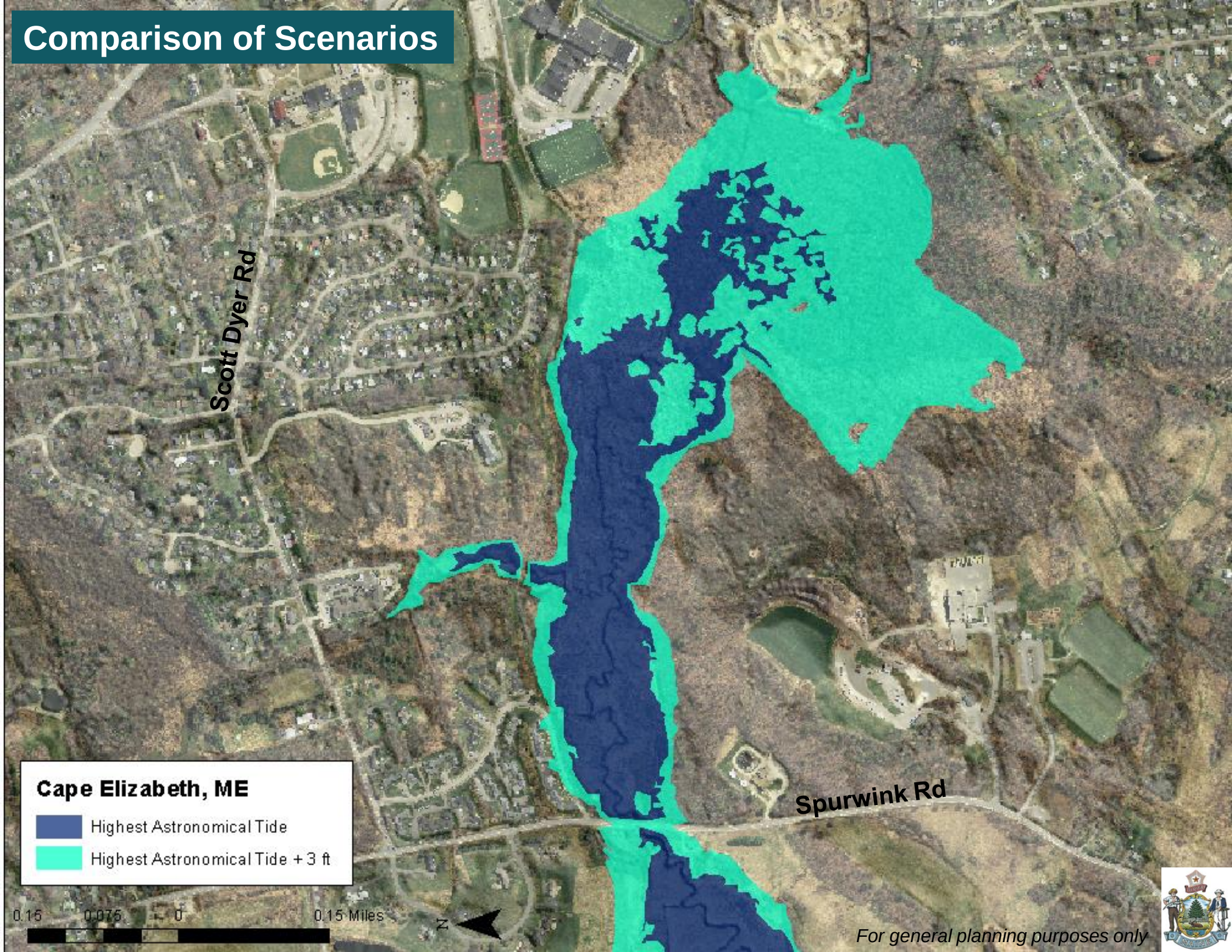
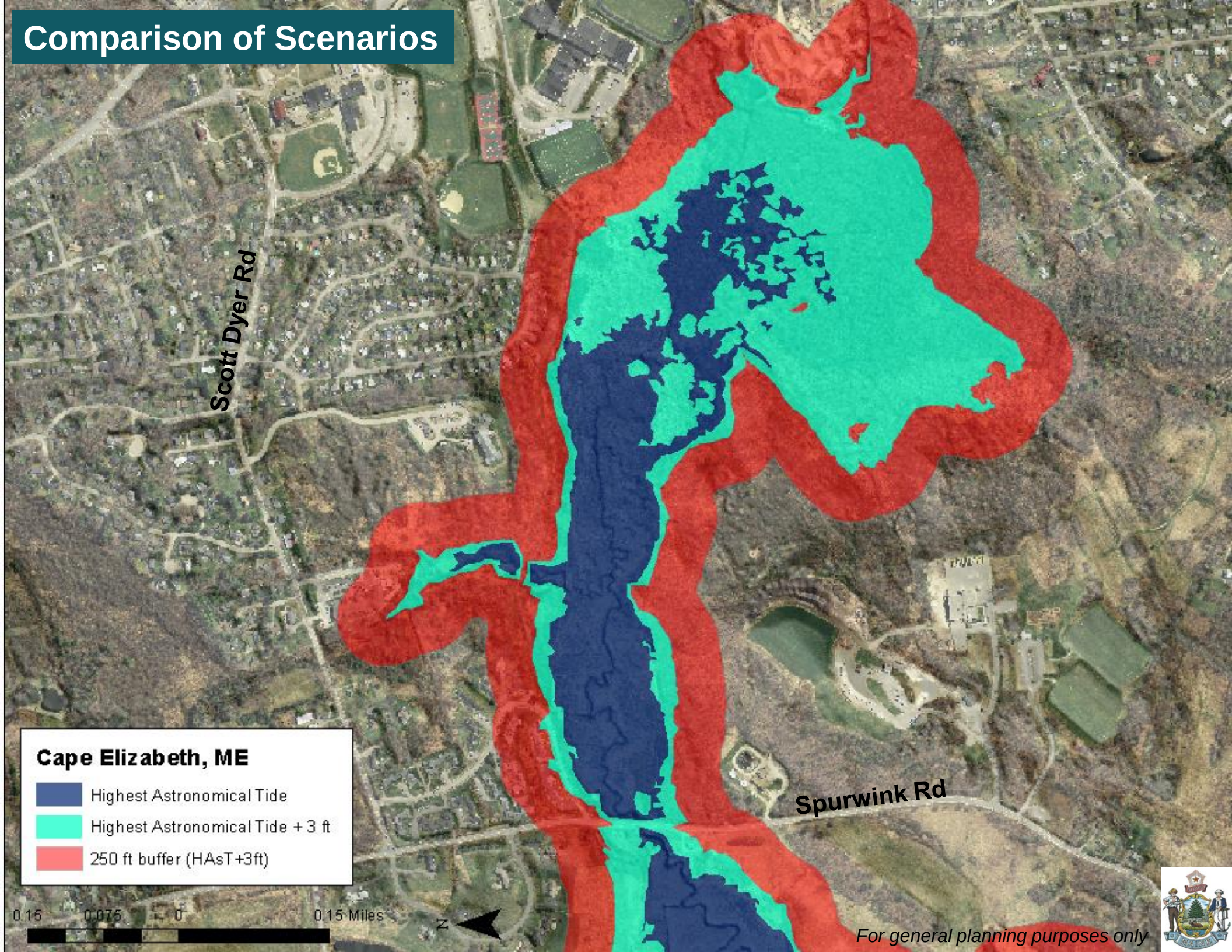


Comparison of Scenarios



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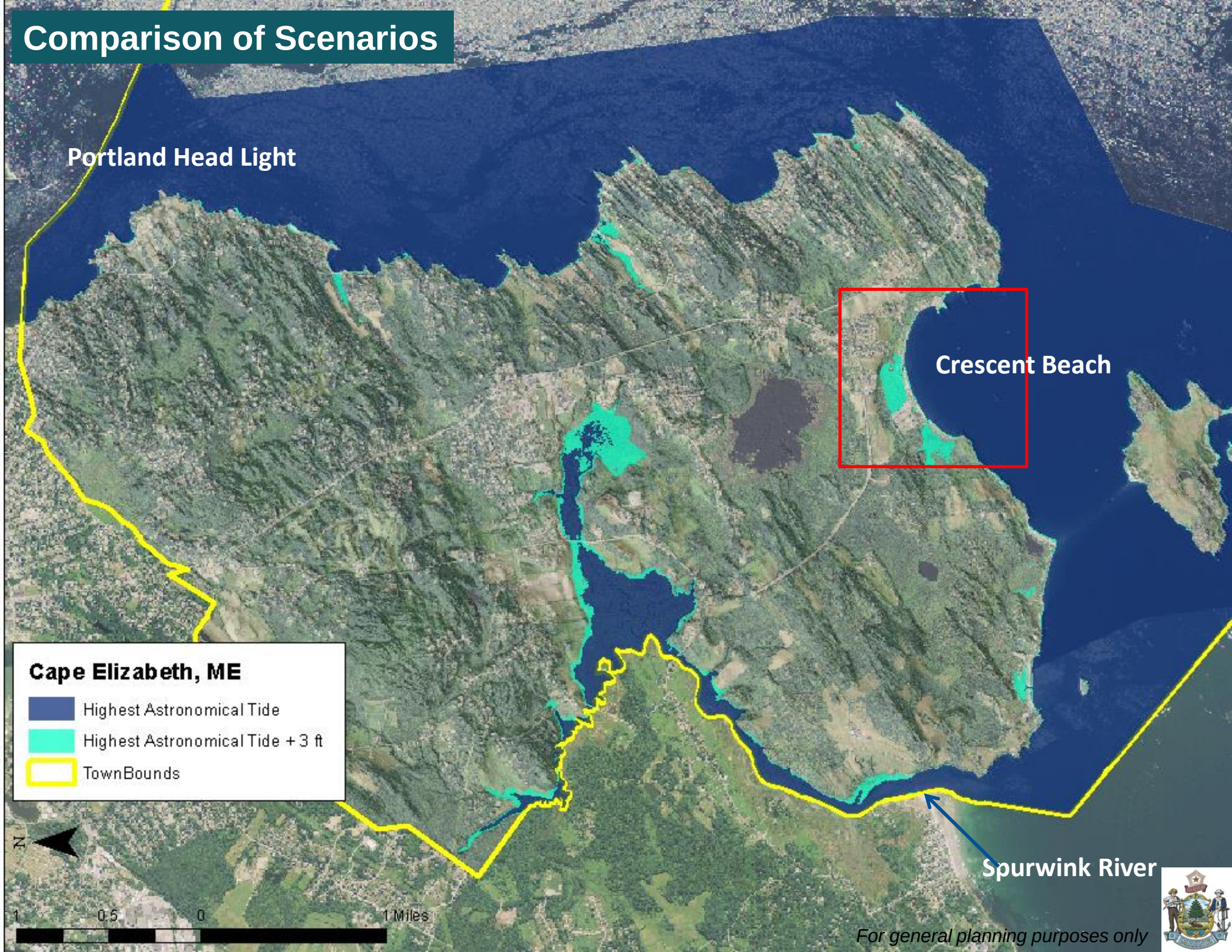
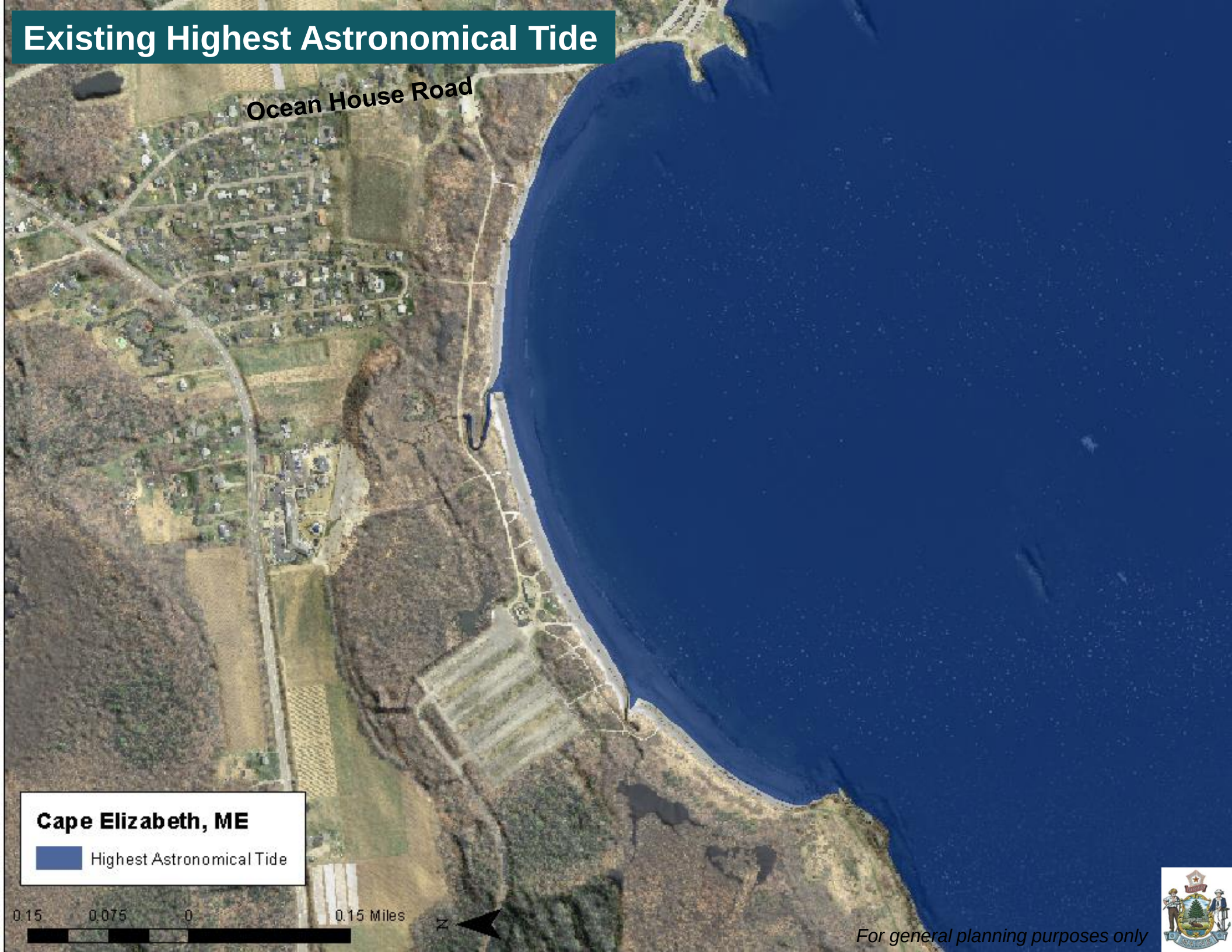
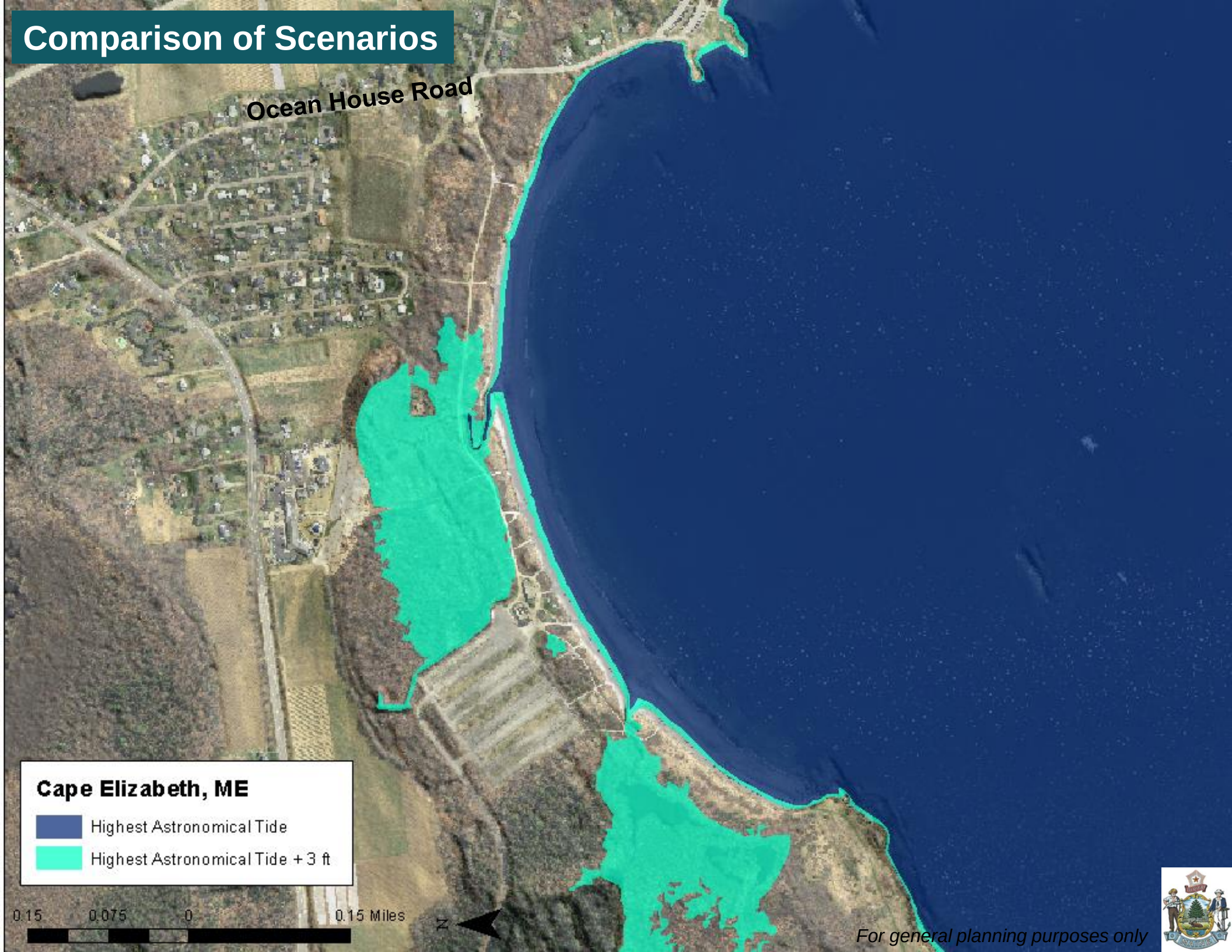


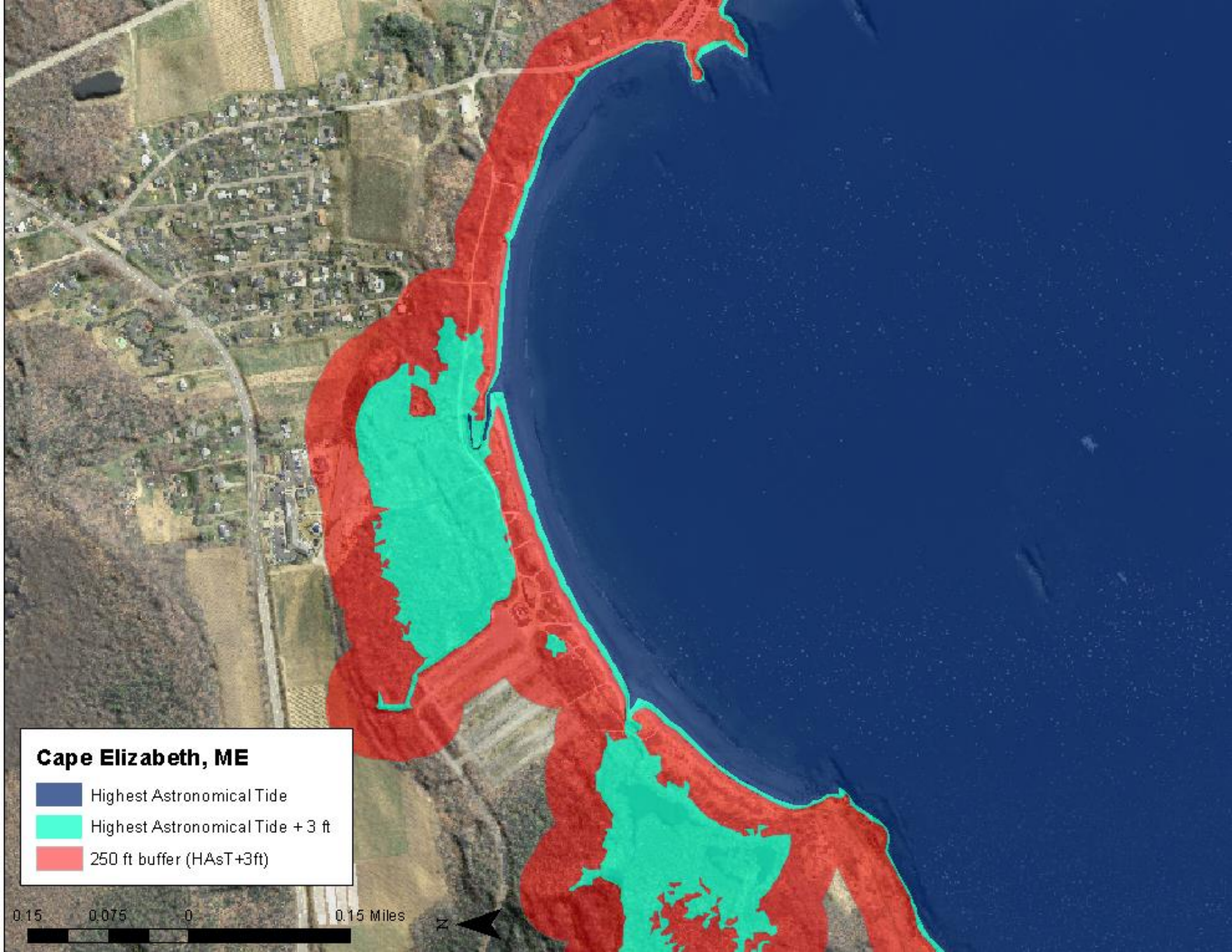
Existing Highest Astronomical Tide



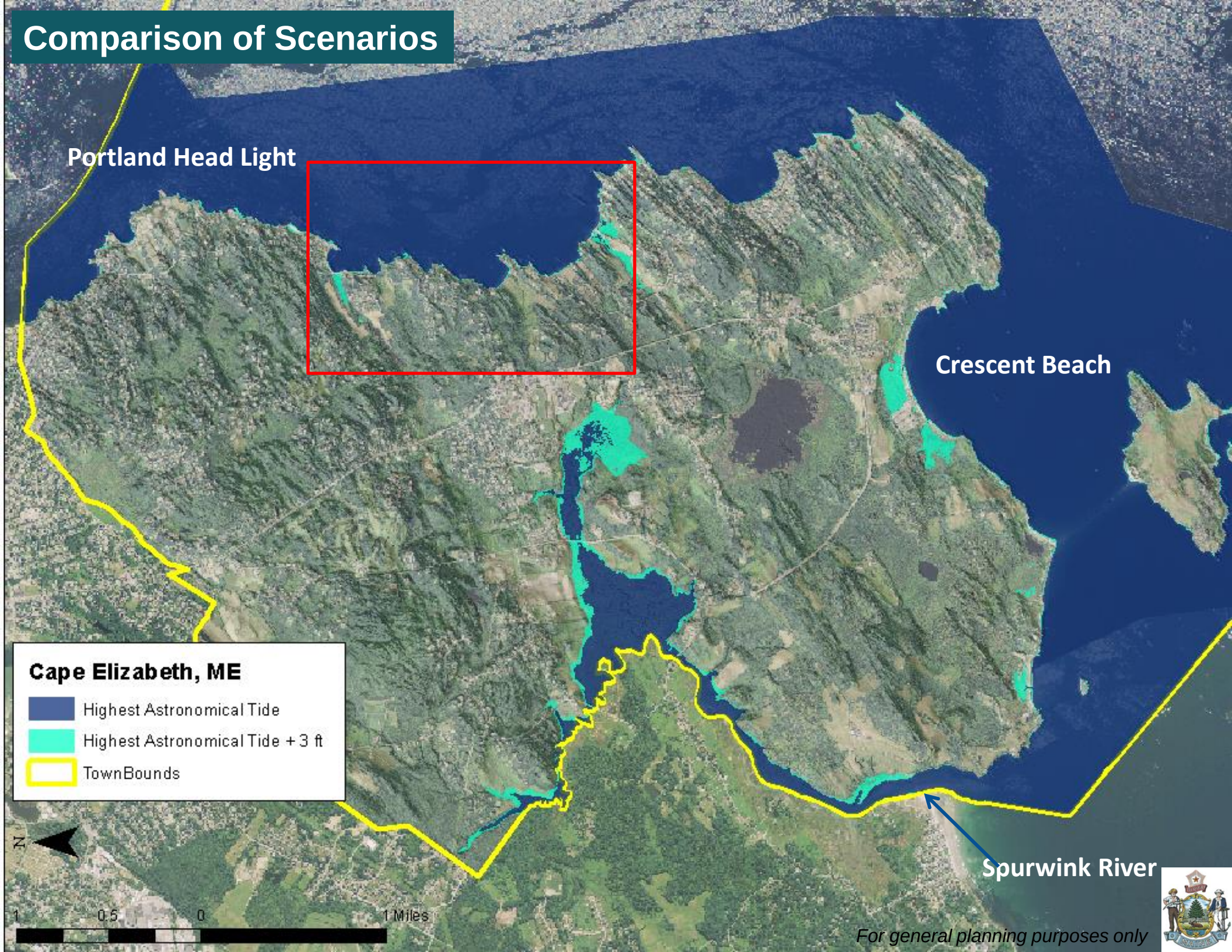
For general planning purposes only

Comparison of Scenarios



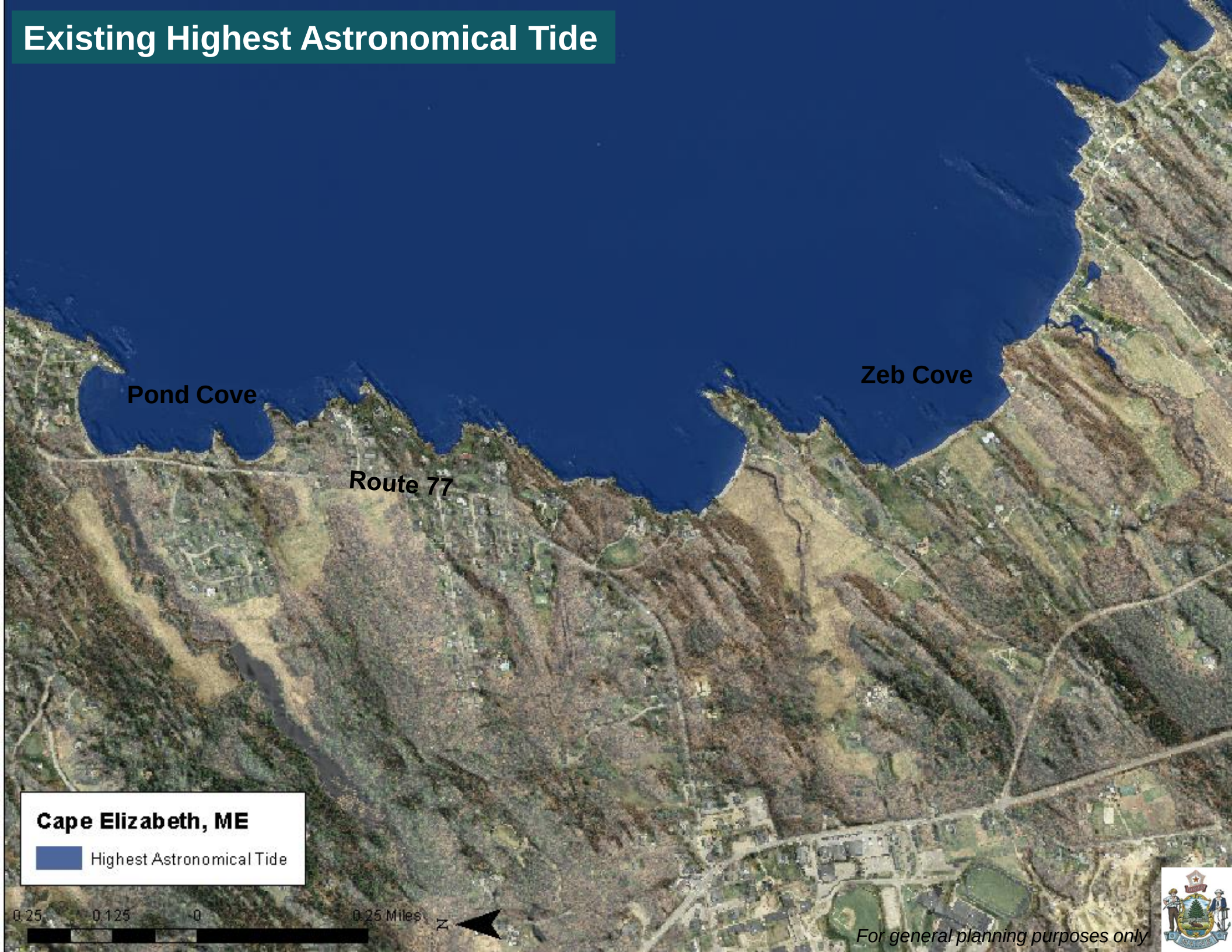

Cape Elizabeth, ME
Highest Astronomical Tide
Highest Astronomical Tide + 3 ft
250 ft buffer (HAsT+3ft)
0.15
0.075
0
0.15 Miles
N

Comparison of Scenarios



For general planning purposes only

Existing Highest Astronomical Tide



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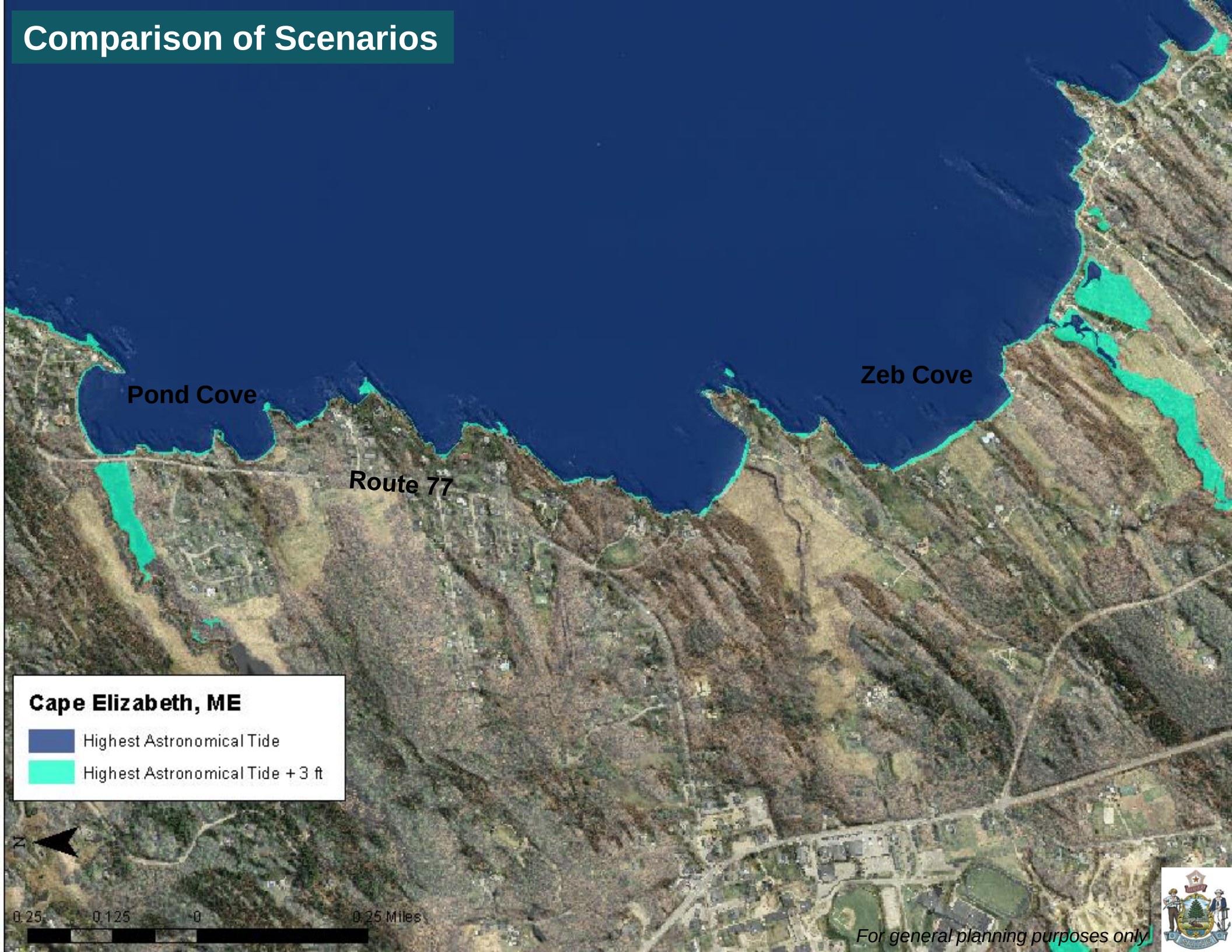
Comparison of Scenarios



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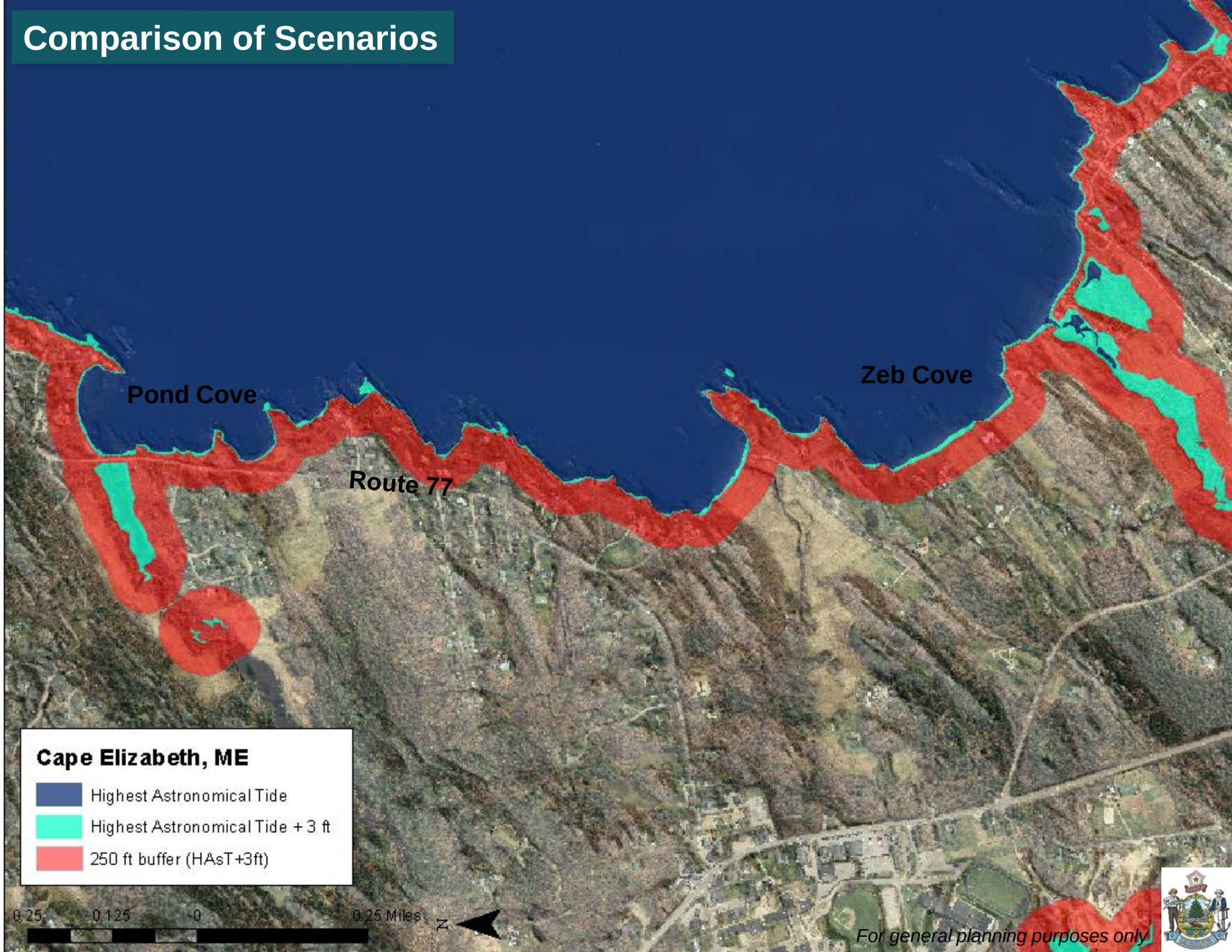

How are other communities incorporating sea level rise into their ordinances or planning process?

Creating Regional Working Groups – SLAWG

Biddeford, Saco, Old Orchard Beach, Scarborough

Using LiDAR to better define the Shoreland Zone

Old Orchard Beach, Saco

Incorporating sea level rise language into Comprehensive Plans

South Portland, York, Bowdoinham

working on it… Kittery, Kennebunk, and Old Orchard

Incorporating increased freeboard into Floodplain Management

Saco, Berwick

Conducting vulnerability assessments for built/natural areas

Too many to count

Thank you!

Town of Cape Elizabeth:
A summary of some of the latest sea level rise science and storm surge data to help guide municipal ordinance changes

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Department of Agriculture, Conservation, and Forestry
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