Developing Sea-Level Change Policy for the Corps of Engineers

NOAA Restoration Center
Sea Level Rise and Marsh Restoration Workshop
14 September 2010

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US Army Cold Regions Research and Engineering Laboratory
Engineer Research and Development Center
Hanover, NH

Outline

- USACE climate and sea-level rise activities
  - Climate change research
  - Past sea-level rise policies
- Why develop a new policy for sea-level rise?
- Considerations and concept for the new policy
- Writing
- Implementation
- Example

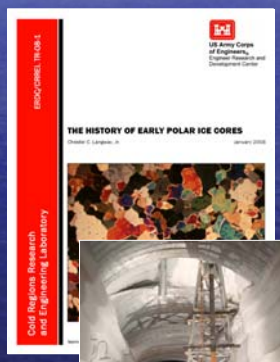
Definitions

- RSLR = Relative Sea-Level Rise
- RSLR = f(Δ sea level + Δ land surface elevation)
- Δ Sea height = f(eustacy, steric effects, gravity, etc.)
- Δ Land height = f(subsidence, deposition, erosion, etc.)

Corps of Engineers interest in climate change and sea-level change

First, a little history……

- 1941: Defense of Greenland
- 1950-1990: USACE drilling polar ice cores in Greenland and Antarctica
- 1952-1955: USACE exploration of Greenland for Air Force
- Ice cores led to other proxies for climate change: tree rings, sediment cores, glacier lengths, others

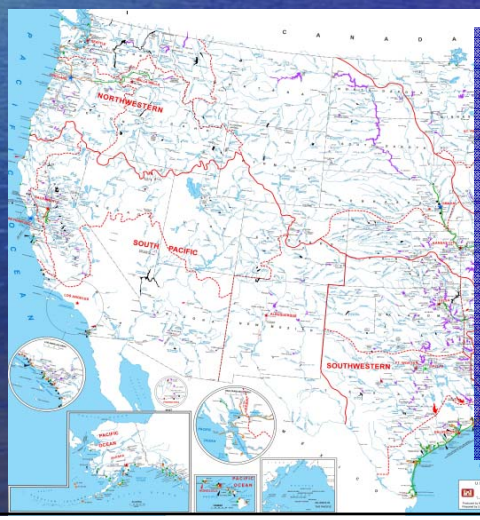


Camp Century Greenland 1964

http://www.crrel.usace.army.mil/library/technicalreports/ERDC-CRREL-TR-08-1.pdf

Climate Change and USACE

- The entire portfolio of USACE Civil Works water resources infrastructure and programs, including regulatory program, is potentially affected



~ 12 million acres of land and water resources

- **~ $2T infrastructure**
- **>600 dams, >1000 coastal structures, >250 locks, >300 major seaports, >600 smaller harbors**
- **2nd largest number of recreational users**

75 major hydropower projects, (>20.72 GW, ~24% of US hydropower)

USACE Sea-Level Change Policy
History

- **1986**
  Memo from HQUSACE
- **1990**
  - ER 1105-2-100, Planning Guidance Notebook
  - Addresses the risk and uncertainty associated with both historically determined and future estimates for sea level rise rates.
  - Applies to "every coastal and estuarine (as far inland as the new head of tide) feasibility study that the Corps undertakes."
- **2000**
  Similar to 1990 policy

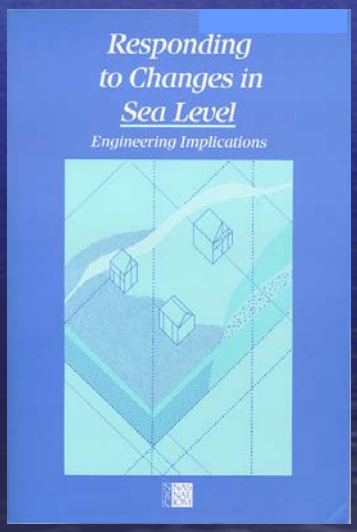
1990 & 2000 Policy

Future Projections of Sea-Level Rise
NRC Estimates

National Research Council, 1987.

Responding to Changes in Sea Level: Engineering Implications.

National Academy Press.

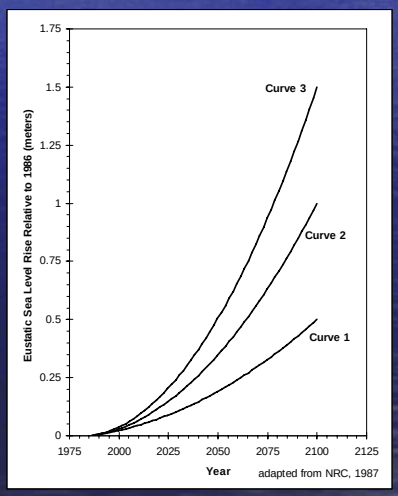


Future Projections of Sea-Level Rise
NRC Estimates

Two Scenarios

Low – extrapolation of historic trend

High – NRC "Curve 3"



Why Develop a New Policy?

Why Develop a New Policy?

- Rarely used
- Very few people were aware of the policy
- Buried in a very large document
  - ER 1105-2-100
    - 712 pages
    - Appendix E, Section 24, Sub-section k
    - Page E-142

Developing the New Policy

Developing the New Policy

- What should the new policy be?
- How should the old policy be updated?

ideas developed

IPCC input

comments from multiple sources, including USGS, EPA, and NOS

NRC input

extensive literature review

ideas discarded

NCAR input

numerous meetings/discussions

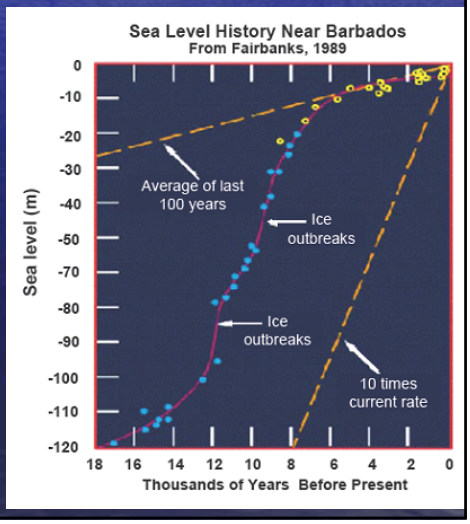
Developing the New Policy
Historic Trends

Why consider the historic trend?

- Low rate
- Political benefit

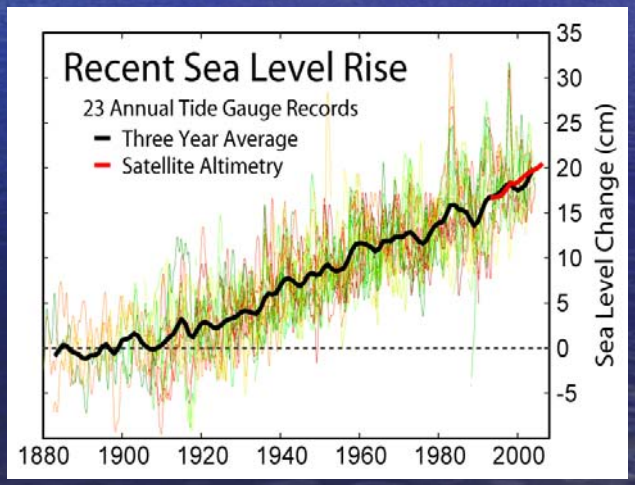
Developing the New Policy
Historic Trends

- sea level has risen ~120 m since the last glacial maximum (~20,000 years b.p.)
- 15,000-6,000 b.p. - peak rate ~ 10 mm/yr
- past 3000 years - 0.1 to 2.0 mm/yr (depending on source)
- past 100-450 years - 1.0 to 2.0mm/yr
- past ~15 years – 3.4 mm/yr? (ask about this later!)



Developing the New Policy
Historic Trends

- Sea-level measurements from 23 long-term tide gauge records in geologically stable environments show a rise of approximately 18 centimeters per century (~ 1.8 mm/year).
- Source: IPCC 2007
- Updated values from Church and others



Developing the New Policy
Future Projections of Sea-Level Change

- Contributing factors
- NRC estimates
- IPCC methods & details
- IPCC TAR (2001)
- IPCC AR4 (2007)
- Other considerations?

Developing the New Policy
Contributing Factors for Future Projections

- Global (eustatic) ocean water mass changes
  - glaciers and ice sheets
  - terrestrial water storage
- Steric effects
  - thermo
  - halo
- Local effects (often not included in projections)
  - subsidence (fluid withdrawal, consolidation/ compaction of Holocene strata)
  - tectonic movement and faulting
  - isostatic adjustments
- "Other" (gravity, etc.)

Developing the New Policy
Contributing Factors for Future Projections

"In the preparation of this document USACE has relied entirely on climate change science performed and published by agencies and entities external to USACE. The conduct of science as to the causes, predicted scenarios, and consequences of climate change is not within the USACE mission. The USACE is a user of the currently accepted community consensus on the state of climate science knowledge and applicable USACE policies will be periodically reviewed and revised as the accepted consensus changes."

Developing the New Policy

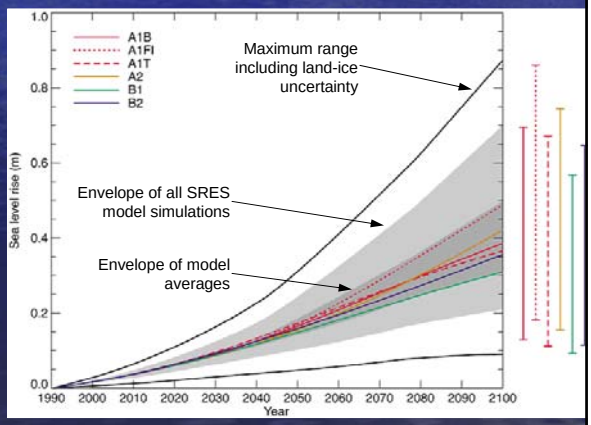
Initial Thought: Use IPCC results

Developing the New Policy

Future projections: IPCC TAR (2001)

IPCC global SLR by 2100
(all units are m)

- **Overall**
  - range = 0.09 – 0.88
  - central value = 0.48
- **Contributions**
  - thermal = 0.11-.043
  - glacial = 0.01-0.23
  - Greenland = -0.02-0.09
  - Antarctic = -0.17 - +0.02



IPCC, 2001

Developing the New Policy

Future projections: IPCC AR4 (2007)

mean central value = 0.343 m range = 0.18 m – 0.59 m

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulaion Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

IPCC, 2007

Developing the New Policy

IPCC interviews and input

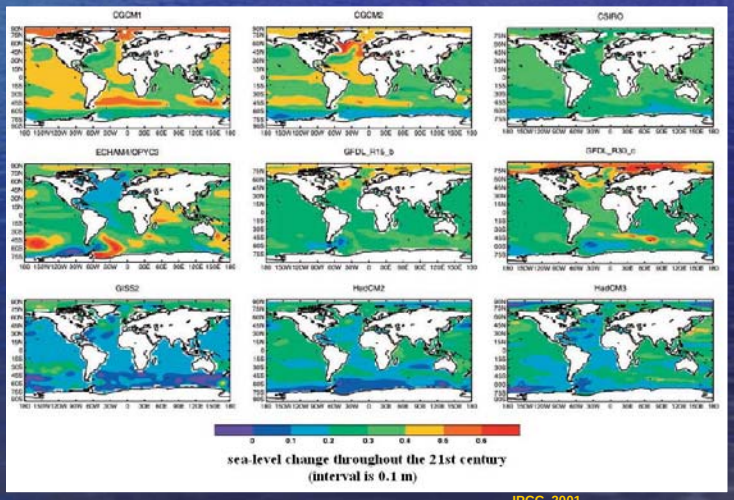
- 2001 (TAR) IPCC team
- TAR models and results
- 2007 (AR4) IPCC team
- AR4 models and results

Developing the New Policy

Understanding IPCC Modeling

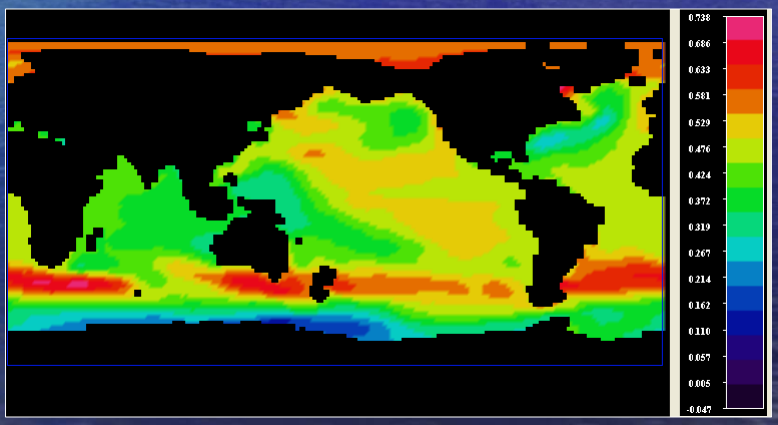
Developing the New Policy

Understanding IPCC modeling



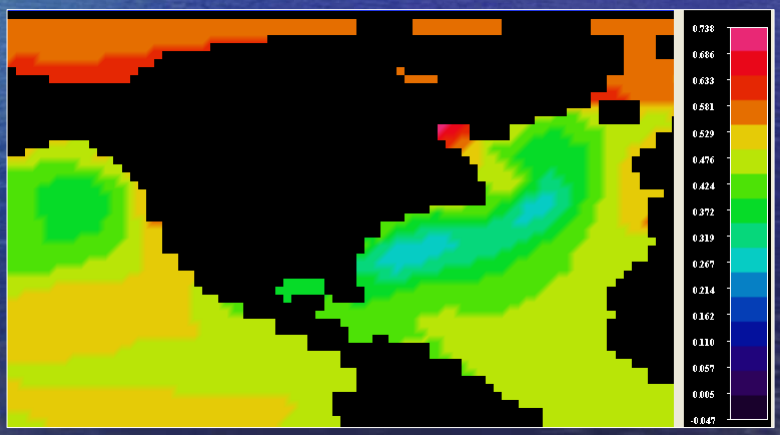
IPCC, 2001

Developing the New Policy
Understanding IPCC modeling



CGCM1_GS: Canadian Center for Climate Modeling and Analysis

Developing the New Policy
Understanding IPCC modeling



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Developing the New Policy

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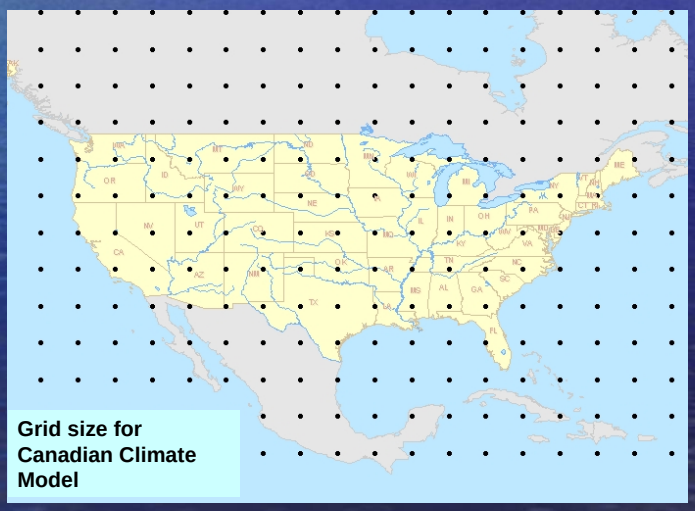

Developing the New Policy

Other Considerations

- Greenland and Antarctica
- Global means
- Regional variations
  - Netherlands work: Katzman (KNMI)
  - British work: Foresight
- Uncertainty (model suite and ???)

"Education is the path from cocky ignorance to miserable uncertainty"

Mark Twain

Developing the New Policy

So, what do we do?

Developing the New Policy
So, what do we do?

NRC report provides reasonable guidance on how to consider sea-level rise in project planning, design, and operation . . . but it's old.

Developing the New Policy
What ***specific*** values should be used?

- Multi-scenario approach
- Use a range of values that bracket what is reasonably possible:
  - Low rate = extrapolation of historic trend
  - High rate = 1.5 meters by 2100
  - "acceptable"* rate (?) = IPCC AR4

    mean central value = 0.343m

    range = 0.18m – 0.59m

** "acceptable" refers to a rate that is commonly accepted and quoted by a large number of people and for which there is a strong scientific basis.*

Developing the New Policy

What *specific* values should be used?

- IPCC AR4 rate = what?
  - 0.343m?
  - 0.18m?
  - 0.59m?

- "Congressionally mandated complication"

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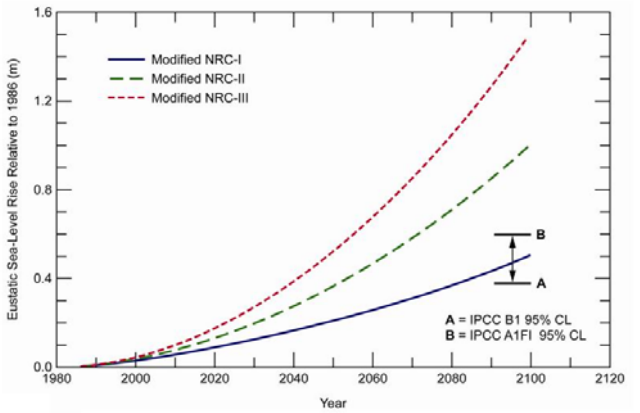
vs

Need values to calculate economic damages and benefits at multiple stages in the project's "economic" or design life

Developing the New Policy

So, what do we do (again)?

Use NRC curves and equations closest to IPCC estimate



Modified NRC (1987) eustatic sea-level rise scenarios and the IPCC (2007)

Developing the New Policy
Writing and adding details

- Include some scientific background, but not too much (at this point)
- Include some rationale, particularly in areas where problems can be expected
- Step-by-step approach

Developing the New Policy
Writing and adding details

Data analysis for determining historic trend

Period of record ≥ 40 yrs

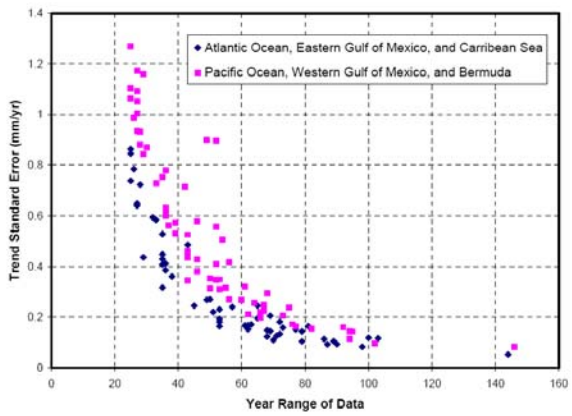
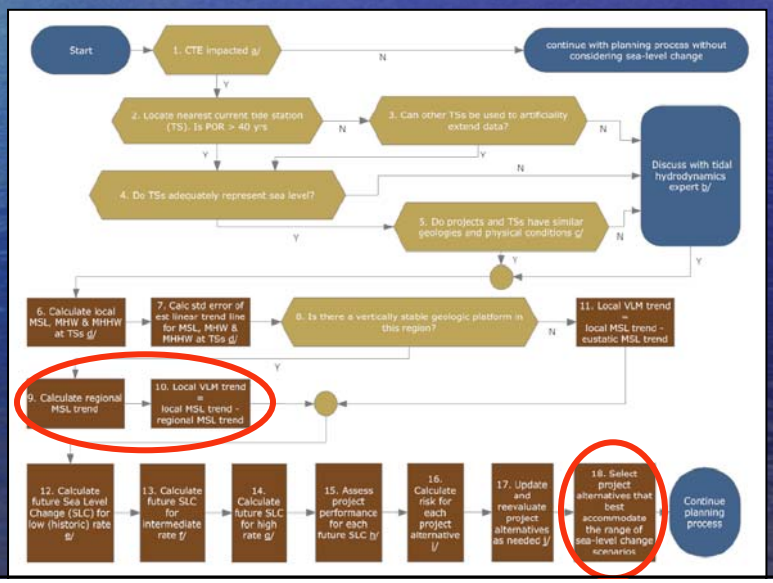


Figure B-2. Standard Error of Linear Trend of Sea-level rise vs. Period of Record, U.S. Tide Stations.

Developing the New Policy

Writing and adding details



Developing the New Policy

Basic design method

- Three methods to incorporate SLR into CoE projects
  - Adaptive management
  - Facilitating future modifications
  - Design for the future
- Method used depends upon type of project

Developing the New Policy
Basic design method

plan for uncertainty

Q: which method is most appropriate for tidal wetlands?

Developing the New Policy
two rounds of external review

USACE (field, lab, HQ), ASA, NOAA, USGS, EPA, FHA, ASFPM, CSO, Academia, England, ~Australia

- Modified NRC equations and curves
  - USGS comment
  - Received "approval" from team that developed initial NRC curves and equations
- Added additional explanation

Developing the New Policy
final equation/curves

Calculating sea-level values for specific years

$$E(t) = 0.0017t + bt^2$$

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

modified NRC "b" values:

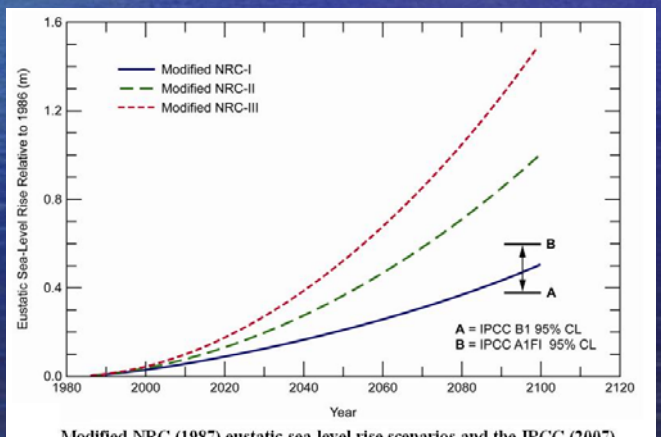
I – 2.36E-5

II – 6.20E-5

III – 1.005E-4

NOTE: These values will NOT include local land elevation changes, which must be added to determine RELATIVE sea-level change

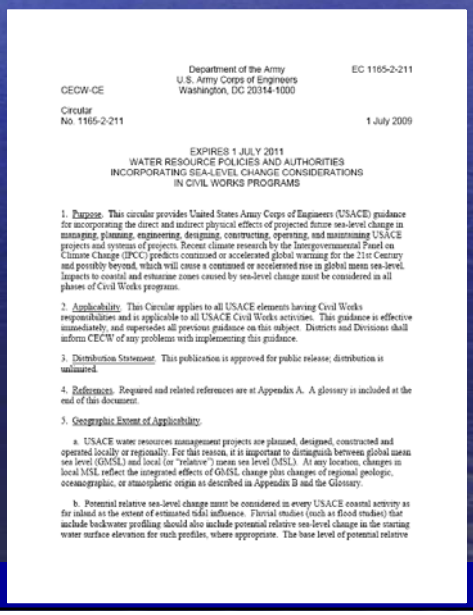
Developing the New Policy
final equation/curves



Modified NRC (1987) eustatic sea-level rise scenarios and the IPCC (2007)

New Policy

- Effective July 2009
- **EC 1165-2-211**
- Implementation guidance



Department of the Army
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EC 1165-2-211

CECW-CE

Circular
No. 1165-2-211

1 July 2009

EXPIRES 1 JULY 2011
WATER RESOURCE POLICIES AND AUTHORITIES
INCORPORATING SEA-LEVEL CHANGE CONSIDERATIONS
IN CIVIL WORKS PROGRAMS

1. Purpose. This circular provides United States Army Corps of Engineers (USACE) guidance for incorporating the direct and indirect physical effects of projected future sea-level change in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects. Recent climate research by the Intergovernmental Panel on Climate Change (IPCC) predicts continued or accelerated global warming for the 21st Century and possibly beyond, which will cause a continued or accelerated rise in global mean sea-level. Impacts to coastal and estuarine zones caused by sea-level change must be considered in all phases of Civil Works programs.

2. Applicability. This Circular applies to all USACE elements having Civil Works responsibilities and is applicable to all USACE Civil Works activities. This guidance is effective immediately, and supersedes all previous guidance on this subject. Districts and Divisions shall inform CECW of any problems with implementing this guidance.

3. Distribution Statement. This publication is approved for public release; distribution is unlimited.

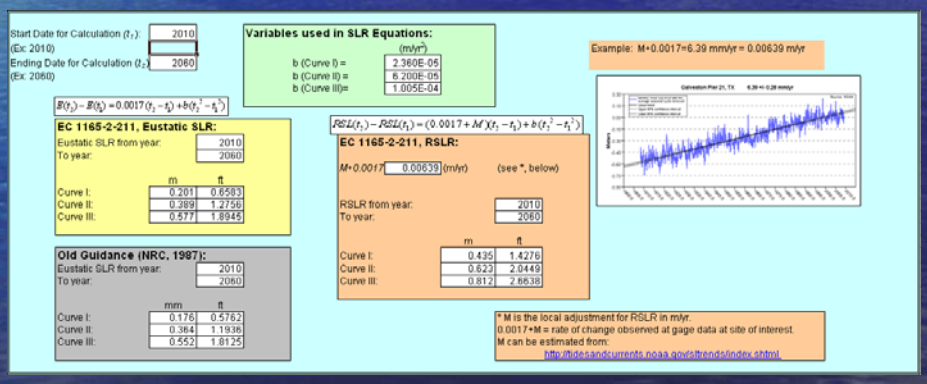
4. References. Required and related references are at Appendix A. A glossary is included at the end of this document.

5. Geographic Extent of Applicability.

a. USACE water resources management projects are planned, designed, constructed and operated locally or regionally. For this reason, it is important to distinguish between global mean sea level (GMSL) and local (or "relative") mean sea level (MSL). At any location, changes in local MSL reflect the integrated effects of GMSL change plus changes of regional geologic, oceanographic, or atmospheric origin as described in Appendix B and the Glossary.

b. Potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. Fluvial studies (such as flood studies) that include backwater profiling should also include potential relative sea-level change in the starting water surface elevation for such profiles, where appropriate. The base level of potential relative

Calculating Sea-Level Change
spreadsheet tool



Start Date for Calculation (t_1): 2010
(Ex: 2010)
Ending Date for Calculation (t_2): 2060
(Ex: 2060)

Variables used in SLR Equations:

	(m/yr²)
b (Curve I) =	2.360E-05
b (Curve II) =	6.200E-05
b (Curve III)=	1.005E-04

$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$

EC 1165-2-211, Eustatic SLR:

Eustatic SLR from year: 2010
To year: 2060

	m	ft
Curve I:	0.201	0.6583
Curve II:	0.389	1.2756
Curve III:	0.577	1.8945

Old Guidance (NRC, 1987):

Eustatic SLR from year: 2010
To year: 2060

	mm	ft
Curve I:	0.176	0.5762
Curve II:	0.364	1.1936
Curve III:	0.552	1.8125

$RSL(t_2) - RSL(t_1) = (0.0017 + M)(t_2 - t_1) + b(t_2^2 - t_1^2)$

EC 1165-2-211, RSLR:

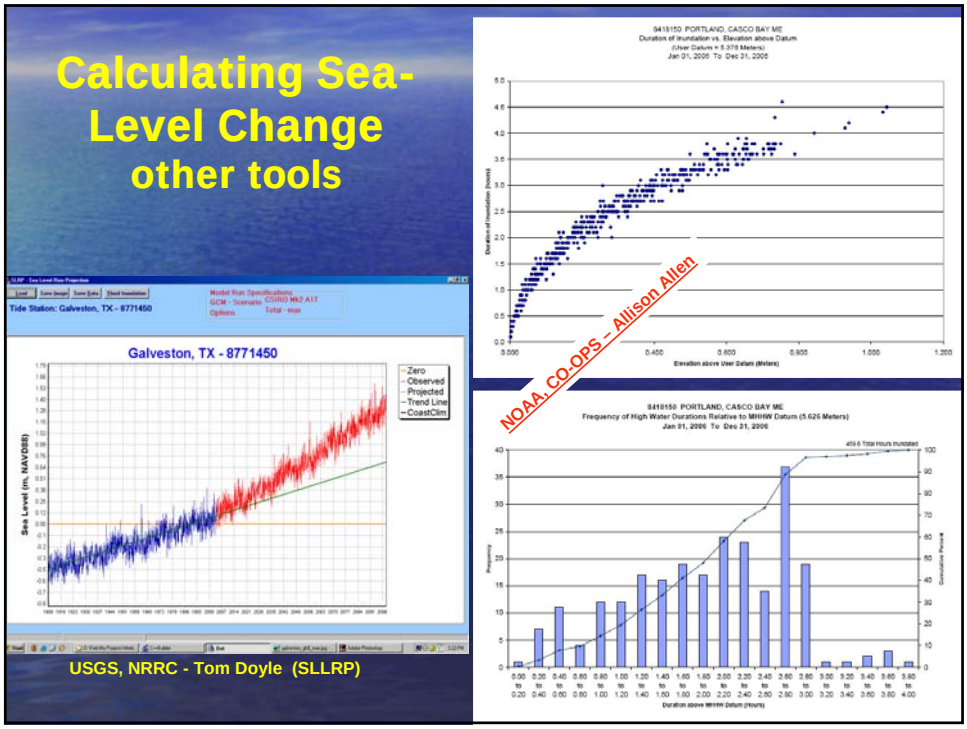
M+0.0017: 0.00639 (m/yr) (see *, below)

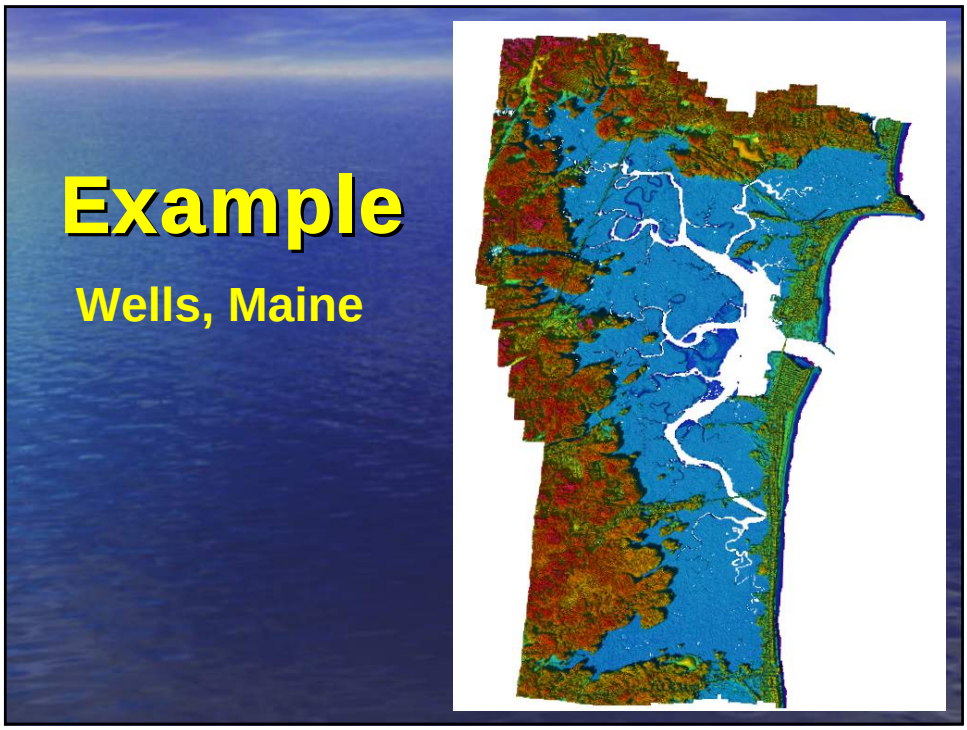
RSLR from year: 2010
To year: 2060

	m	ft
Curve I:	0.435	1.4276
Curve II:	0.623	2.0449
Curve III:	0.812	2.6638

Example: M+0.0017=6.39 mm/yr = 0.00639 m/yr

* M is the local adjustment for RSLR in m/yr.
0.0017+M = rate of change observed at gage data at site of interest.
M can be estimated from:
http://tidesandcurrents.noaa.gov/sltrends/index.shtml

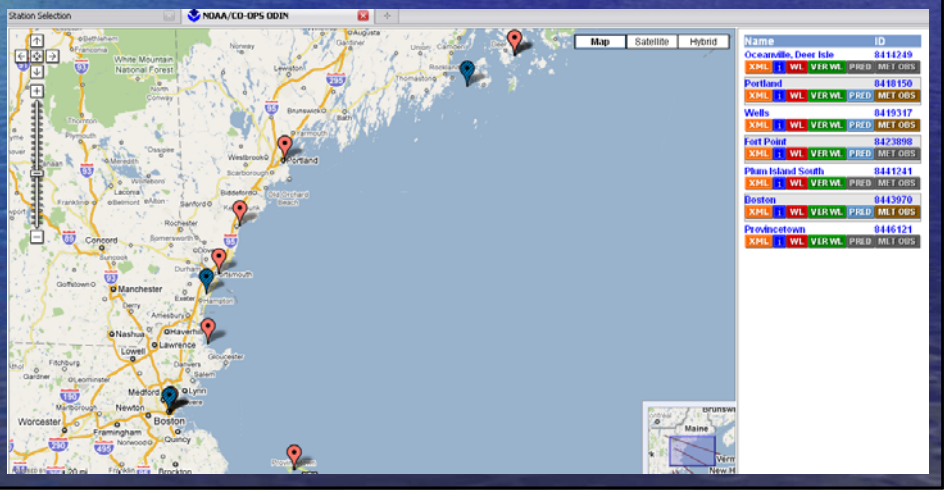

Calculating Sea-Level Change other tools
Tide Station: Galveston, TX - 8771450
Galveston, TX - 8771450
Sea Level (m, NAVD88)
Zero
Observed
Projected
Trend Line
CoastClim
USGS, NRRC - Tom Doyle (SLLRP)
8418150 PORTLAND, CASCO BAY ME
Duration of Inundation vs. Elevation above Datum
Jan 01, 2006 To Dec 31, 2006
Elevation above User Datum (Meters)
NOAA, CO-OPS – Allison Allen
8418150 PORTLAND, CASCO BAY ME
Frequency of High Water Durations Relative to MHHW Datum (5.626 Meters)
Jan 01, 2006 To Dec 31, 2006
Duration above MHHW Datum (Hours)


Example
Wells, Maine

Example Project - Wells, Maine

Historic sea-level rise rate

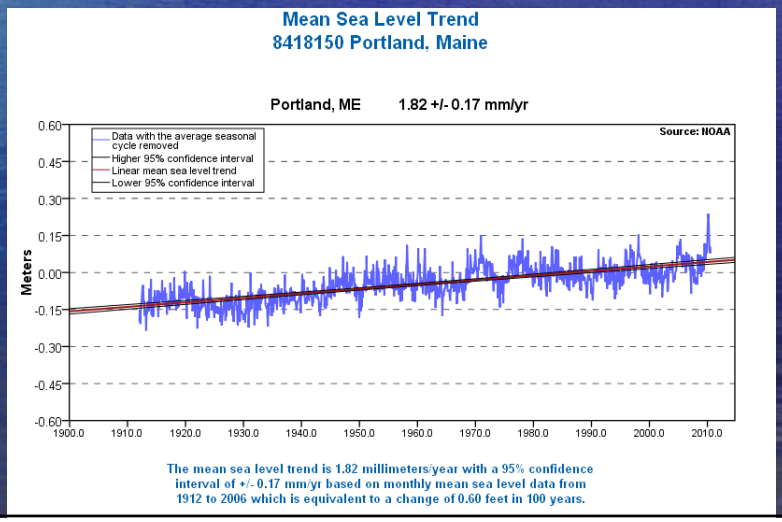
Q: local long-term (≥40 years) tide gauge?



Example Project - Wells, Maine

Historic sea-level rise rate

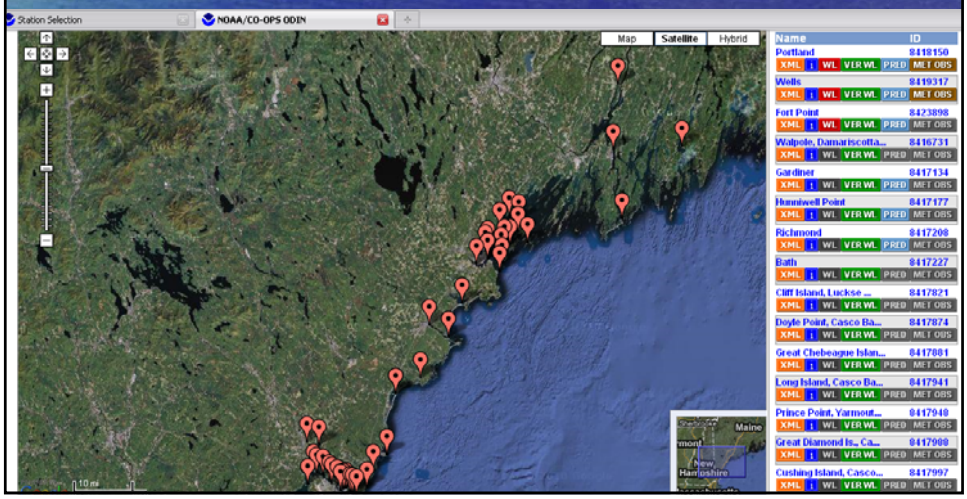
Q: sea-level rise trend from closest long-term (≥40 yrs) tide gauge?



Example Project - Wells, Maine

Historic sea-level rise rate

Q: historic gauges near project site?

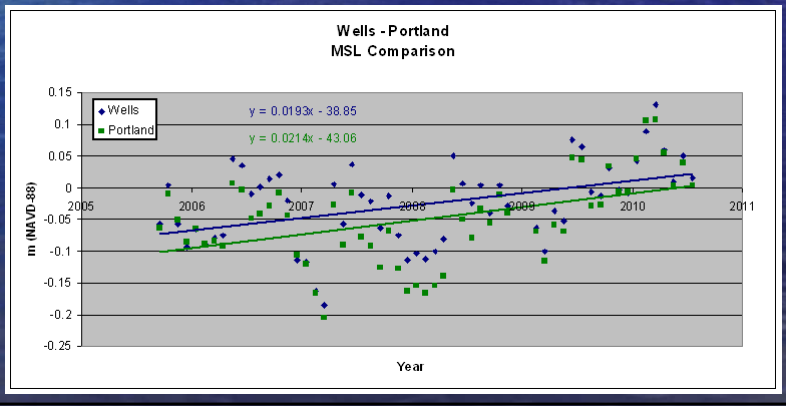


Example Project - Wells, Maine

Historic sea-level rise rate

Q: is the rate from the closest long-term (≥40 yrs) tide gauge representative for the project site?

(a quick/crude check is relatively easy)



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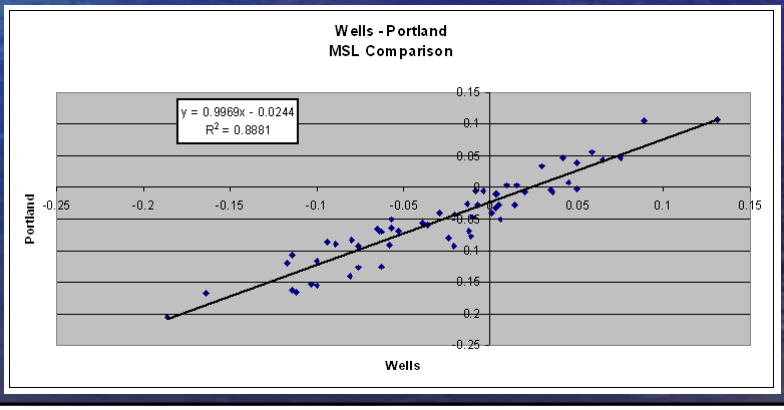


Example Project - Wells, Maine

Historic sea-level rise rate

Q: is the rate from the closest long-term (≥40 yrs) tide gauge representative for the project site?

(a quick/crude check is relatively easy)

NOTE: you must consider both tidal hydrodynamics AND local geology to determine if the closest long-term tide gauge can provide a sea-level rise trend that can be used at the project site. Consult with the appropriate experts.

Example Project - Wells, Maine
Historic sea-level rise rate

Q: vertical land motion at project site?

A1: Global rate (1.7 mm/yr) – local rate (1.8 mm/yr) = 0.1 mm/yr

Q: What does this mean?

Portland gauge trend ~ 1.82 mm/yr ± 0.17 mm/yr so local rate is essentially equal to global rate and gauge data does not indicate vertical land movement of any statistical significance

Portland historic rate = 1.8 mm/yr with no significant vertical land movement

Wells historic rate ~ 1.8 mm/yr with no significant vertical land movement (BUT CHECK LOCAL GEOLOGY AND OTHER INFORMATION SOURCES!!!)

Example Project - Wells, Maine
Historic sea-level rise rate

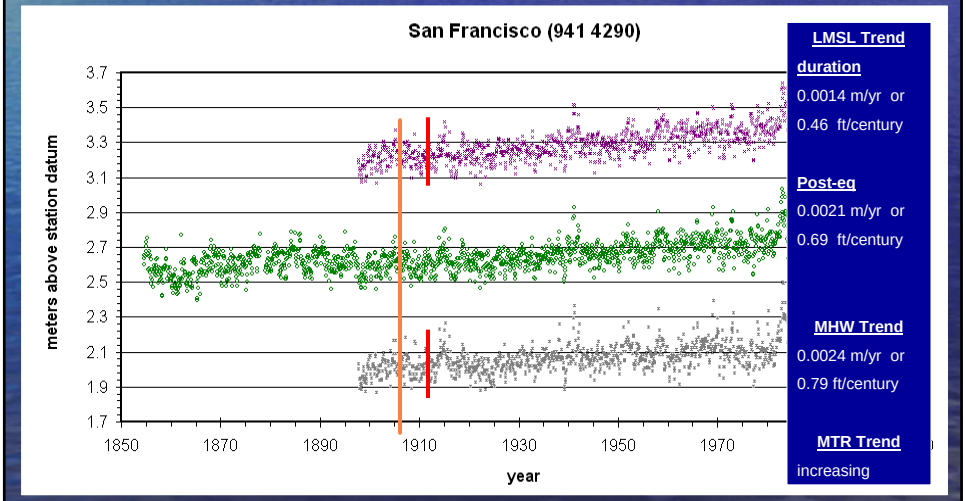
CHECK: are there any other significant tidal datum trends for Portland gauge?

Check trends for MLLW, MLW, MHW, MHHW, if applicable

Example Project - Wells, Maine

Variations in Tidal Datum Trends from San Francisco Bay

(do similar analysis for local gauge (Portland, ME))



Example Project - Wells, Maine

Multiple Scenarios

Low rate: 1.8 mm/yr

Intermediate rate: IPCC approximation → modified NRC curve I

High rate: modified NRC curve III

NO SIGNIFICANT SUBSIDENCE OR UPLIFT TO CONSIDER

Example Project - Wells, Maine

Multiple Scenarios

Project start date	2010	b1 = 2.36E-05
Local sea-level trend	1.8 mm/yr	b3 = 1.01E-04
subsidendce/uplift rate	0 mm/yr	t1 = 2010-1986 = 24

E(t2) – E(t1) = 0.0017(t2 – t1) + b(t2^2 - t1^2)

	SLR in meters				SLR in feet		
year	Low (historic)	Intermediate (~IPCC)	High (modified curve III)	t2=(year-1986)	Low (historic)	Intermediate (~IPCC)	High (modified curve III)
2010	0.00	0.00	0.00	24	0.0	0.0	0.0
2020	0.02	0.03	0.08	34	0.1	0.1	0.2
2030	0.04	0.07	0.17	44	0.1	0.2	0.6
2040	0.05	0.11	0.29	54	0.2	0.3	0.9
2050	0.07	0.15	0.42	64	0.2	0.5	1.4
2060	0.09	0.20	0.58	74	0.3	0.7	1.9
2070	0.11	0.25	0.75	84	0.4	0.8	2.5
2080	0.13	0.31	0.95	94	0.4	1.0	3.1
2090	0.14	0.38	1.17	104	0.5	1.2	3.8
2100	0.16	0.45	1.40	114	0.5	1.5	4.6

FOR a tidal wetland project, it is important to also calculate these values for the applicable tidal datums, if the datum trends are different, due to plant species habitat zones being so strongly affected by frequency and duration of tidal inundation (approximated by tidal datums).

NOTE: tidal datum relationships may change as sea-level rises and are probably likely to do so for many sites. This will create a significant amount of uncertainty in sustainability of tidal wetlands.

Example Project - Wells, Maine

Multiple Scenarios

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Q: What is the range of rates you can reasonably expect for marsh surface accretion? Can the wetland naturally keep up with the rate of sea-level rise and thus be naturally sustainable?

NOTE: This can vary significantly between locations due to suspended sediment load in water, upland sediment sources that contribute to the wetland, climate, potential for organic matter accumulation, etc. Have there been any local measurements? Ask an expert or someone with local knowledge.

Example Project - Wells, Maine

Multiple Scenarios

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A necessary question to ask yourself when working on wetland projects and considering sea-level rise is . . .

Q: What year or what time period are you targeting to achieve a specific mix of habitat zones?

QUESTIONS?