

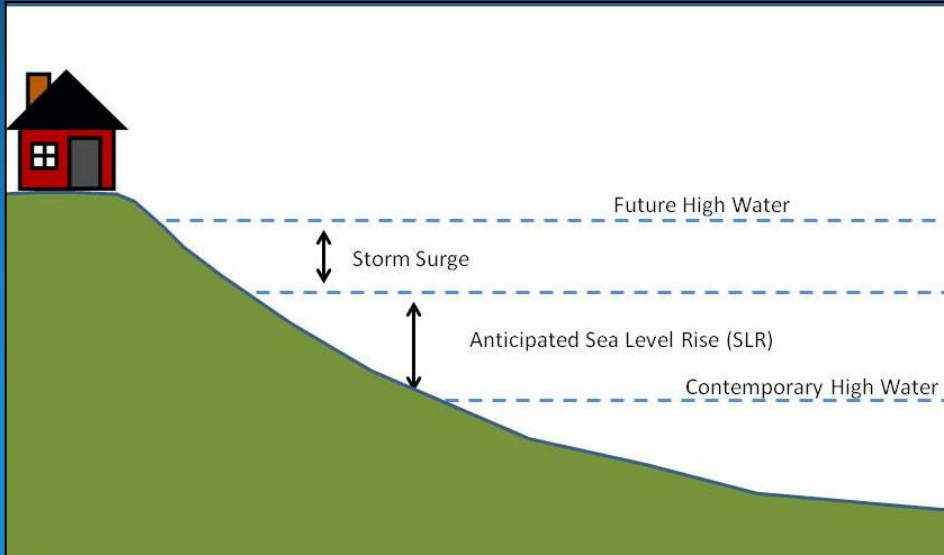
Sea Level Rise and Coastal Flooding

Why Waves Matter!



Jason D. Burtner
Massachusetts Office of Coastal Zone Management
South Shore Regional Coordinator

Sea Level Rise and Coastal Storm Damage and Flooding

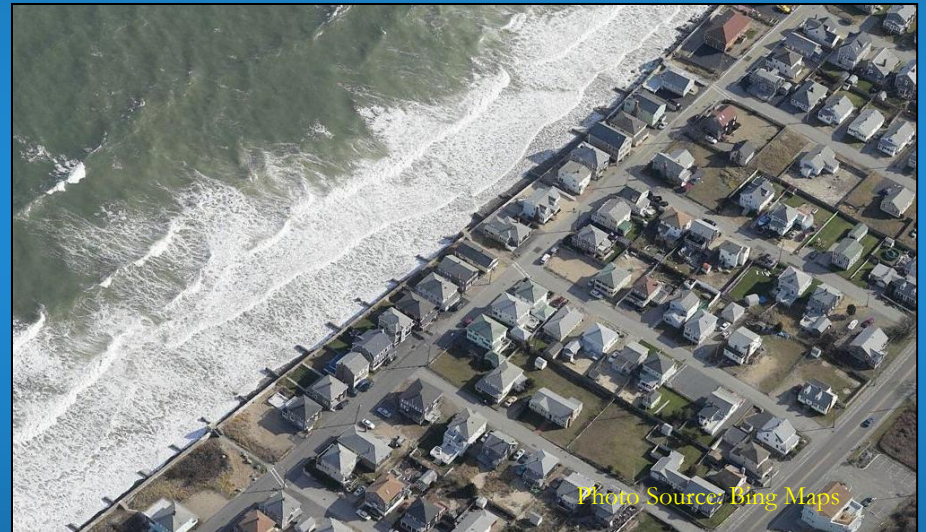
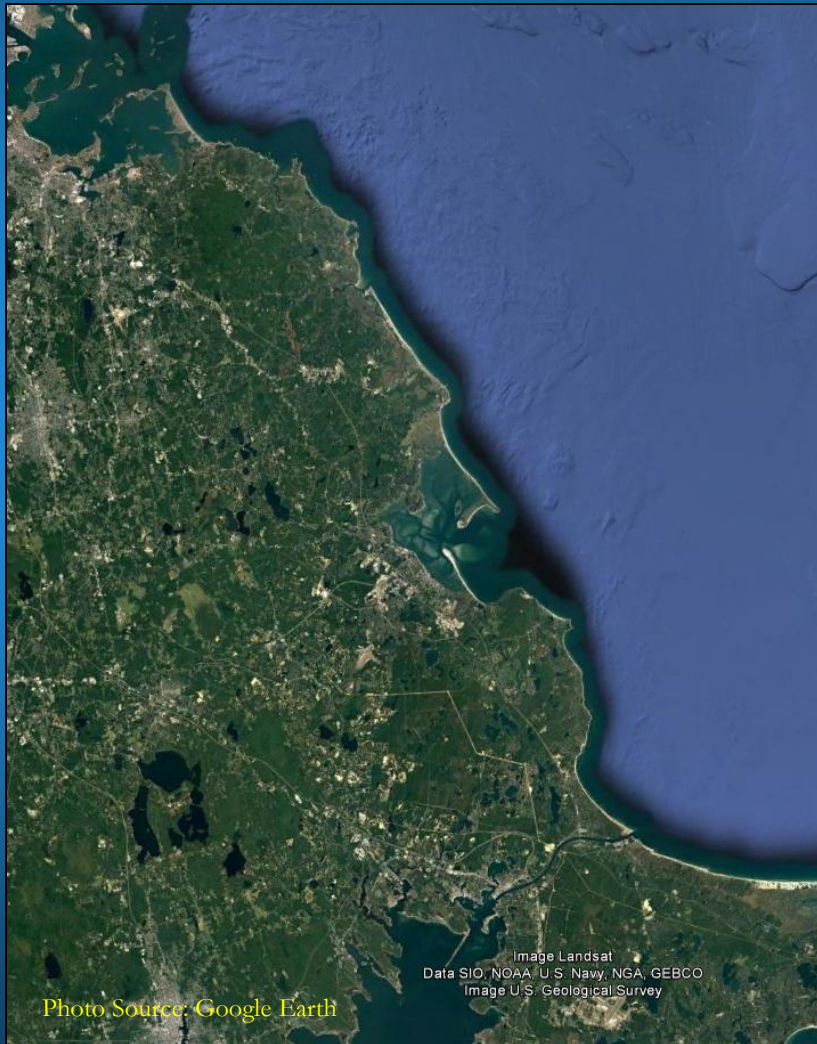


Most characterizations of SLR and associated impacts to coastal areas focus on increases in high water level and storm surge to depict a future high water condition.

But few depictions of impacts to coastal areas from SLR take into account flooding and storm damage associated with wind-driven waves.

- Contribution to flooding via overwash
- Wave battering to structures
- Scour and erosion of fronting dunes, beaches (and backshore areas too!)

The South Shore: Coastal Orientation and Patterns of Development



Nemo Storm - February 8-9, 2013

VOLUME 283
NUMBER 41
Suggested retail price
\$3.50
An Associated
Crested Book

Boston Sunday Globe

FEBRUARY 10, 2013

QUICK ON THE THAW
Snows mostly ending.
High 30-35. Low 18-25.
Monday Cloudy, with rain.
High 41-46. Low 30-35.
Tuesday 30-34 a.m. 12-27 p.m.
Snowing 6-87 p.m. 5-10
TUESDAY: PAGE B12

AN AWESOME POWER

Precautions limit tragedies, but vast storm's aftermath still claims 2
Waves blast over breakwalls, forcing hundreds of families to flee



DAVID L. BEAN/GLOBE STAFF

Water closed in on Andrea Giacomozzi and her daughter Gavin of Turner Road in Scituate as one of the most powerful storms in state history unleashed a torrent of winter misery.

In a flash, the ocean roared into homes of snow shovelers

By Kay Lazar

SALISBURY — It happened in seconds. Lynn and Angie Papetti were furiously shoveling a wall of snow deposited against their garage door by the rampaging nor'easter that struck New England on Friday and Saturday. Then, with scant warning, a cascade of water, broken decking, and siding creaked them. They were stranded, water rising fast. National Guard troops, equipped with a front-end loader, appeared. The Papettis and some neighbors — three at a time — clambered into the bucket of the loader, already coated with snow. Down North End Boulevard they went, to safety and waiting ambulances.

"We've had water come up to the building before, but the force of this water was scary," Lynn Papetti said several hours later as the couple waited with about 40 other residents who were evacuated to a makeshift shelter in this

SALISBURY, Page A17



ARAM BOHOSKIAN FOR THE BOSTON GLOBE

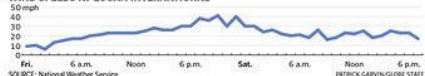
Zachary Lavalley, 4, relaxed at the Salisbury senior center, where many sought refuge.



JOHN TILMACK/GLOBE STAFF

Angus Meallister emerged with his snow brush from his vehicle on Beacon Hill.

WIND SPEEDS AT LOGAN INTERNATIONAL



2 killed by fumes

Quincy was hit hard by power outages, and residents struggled in the cold. 85.

Powerless in Quincy

The National Guard and paramedics helped deliver a baby in the midst of the storm. 85.

A child is born

The National Guard and paramedics helped deliver a baby in the midst of the storm. 85.

Travel resuming as Patrick lifts ban; but outages still a plague

By Brian MacQuarrie

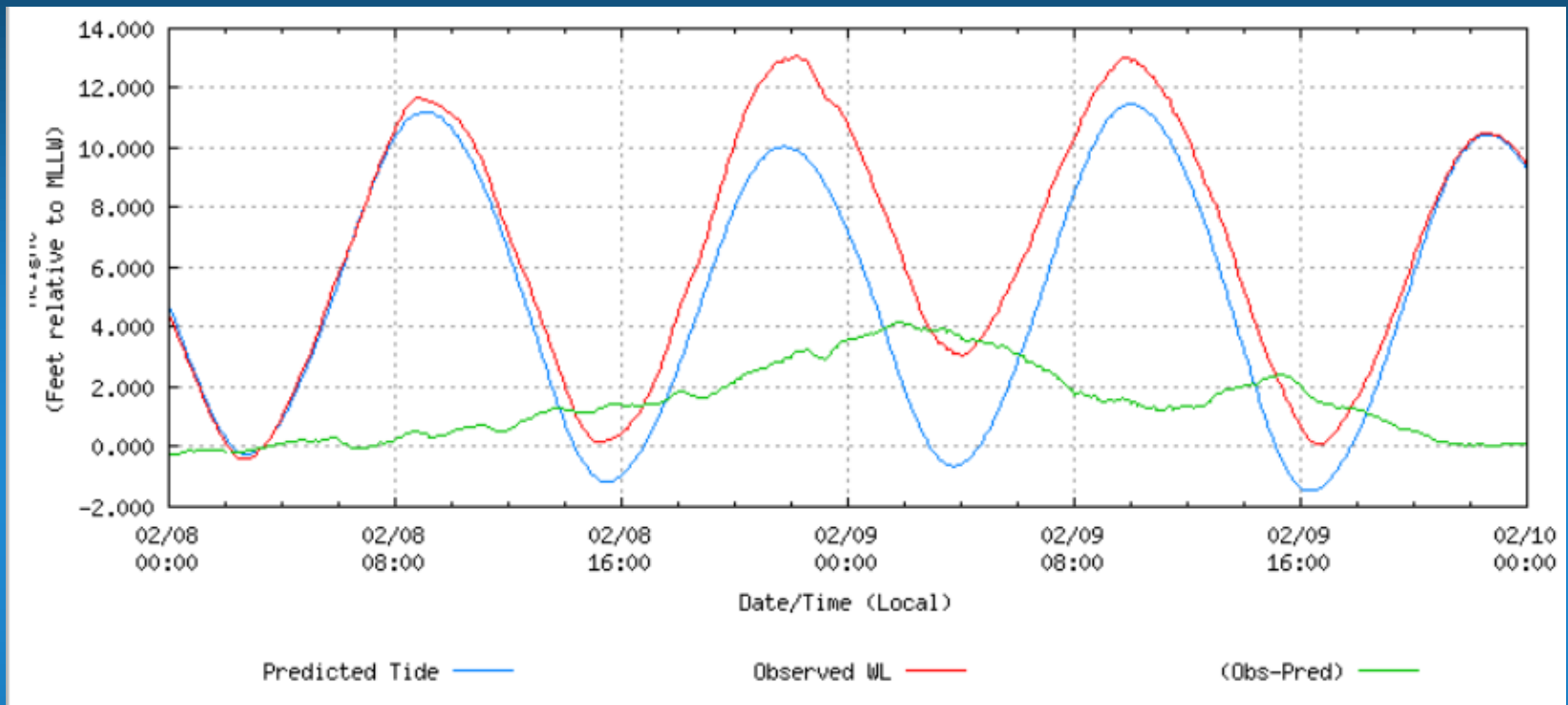
Pummeled by one of the worst winter storms in state history, much of Massachusetts spent Saturday digging out, waiting for power, and navigating a snow-shrouded landscape that proved both pristinely beautiful and savagely cruel. Two people died and two were injured in Boston because of carbon-monoxide poisoning linked to the storm, which dumped up to 30 inches of snow on the state. Hundreds of coastal residents were evacuated from the North Shore to Cape Cod, and more than 400,000 people in Massachusetts awoke without power Saturday.

Begrudgingly but steadily, conditions improved throughout the day as power slowly returned and traffic-free streets became cross-country ski tracks. Governor Deval Patrick lifted the statewide travel ban at 4 p.m., 24 hours after imposing the first such prohibition since the deadly Blizzard of '78.

BLIZZARD, Page A16

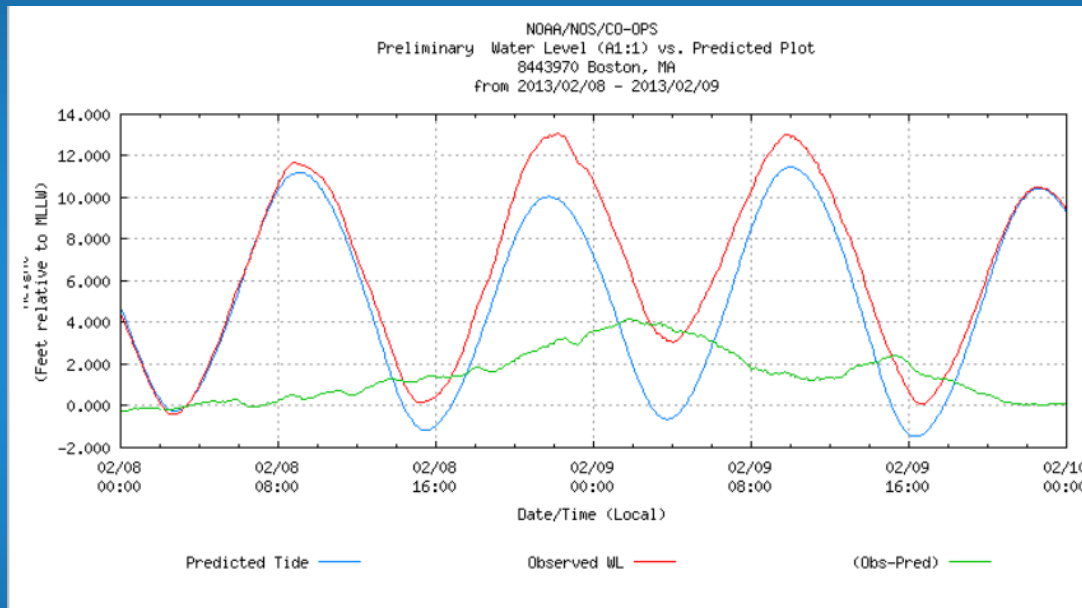


Nemo Storm - February 8-9, 2013



- Two sequential high tides of approximately 13 ft MLLW
- Only Minor to Moderate flooding and storm damage associated with the Feb 8th high tide.
- Moderate to Major flooding and storm damage associated with the Feb 9th high tide.
- Storm Surge Maximum of 4 feet occurred at 2:00 AM at the time of low tide.
- If Maximum storm surge occurred during the 10:00am tide on Feb 9th high tide the total storm surge would have been approximately 15.5 feet!!!

Nemo Storm - February 8-9, 2013



The difference in flooding and storm damage between two high tides:

Wave height!

- Waves at the time of the Feb 8th high tide were approximately 15-20 ft.
- Waves at the time of the Feb 9th high tide were approximately 25-30 ft.

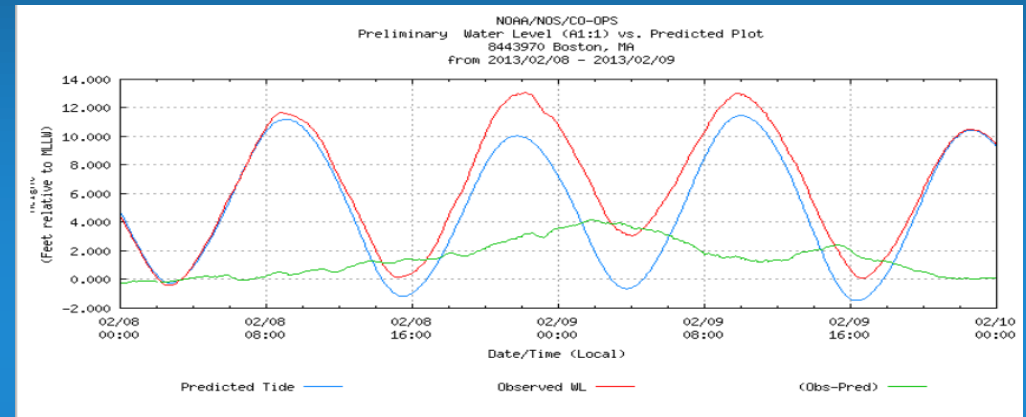
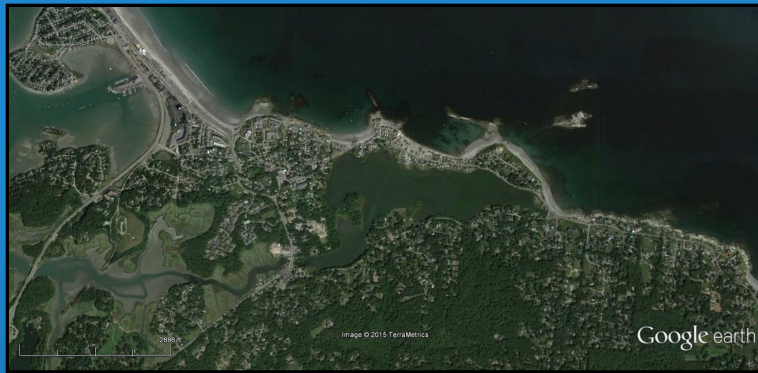
Nemo Storm February 8-9, 2013

Contribution to Flooding from Overwash

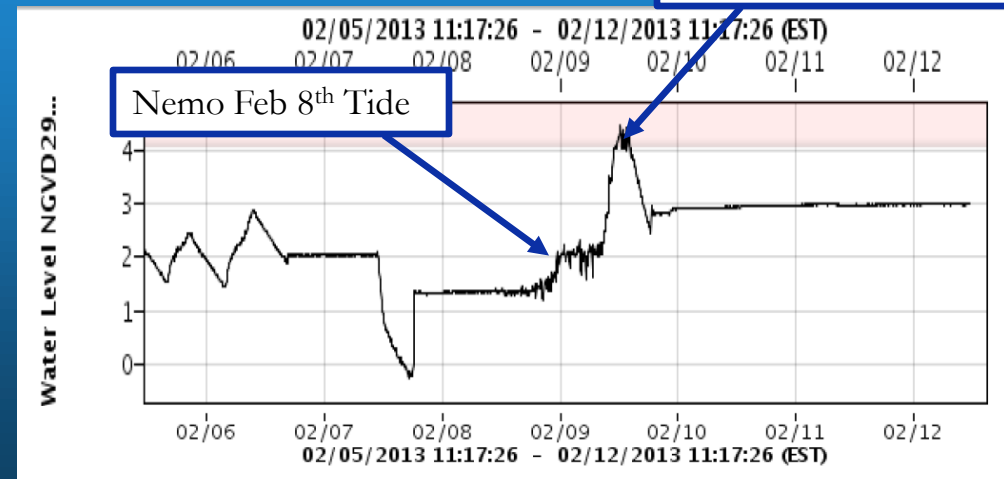


Nemo Storm February 8-9, 2013

Contribution to Flooding from Overwash

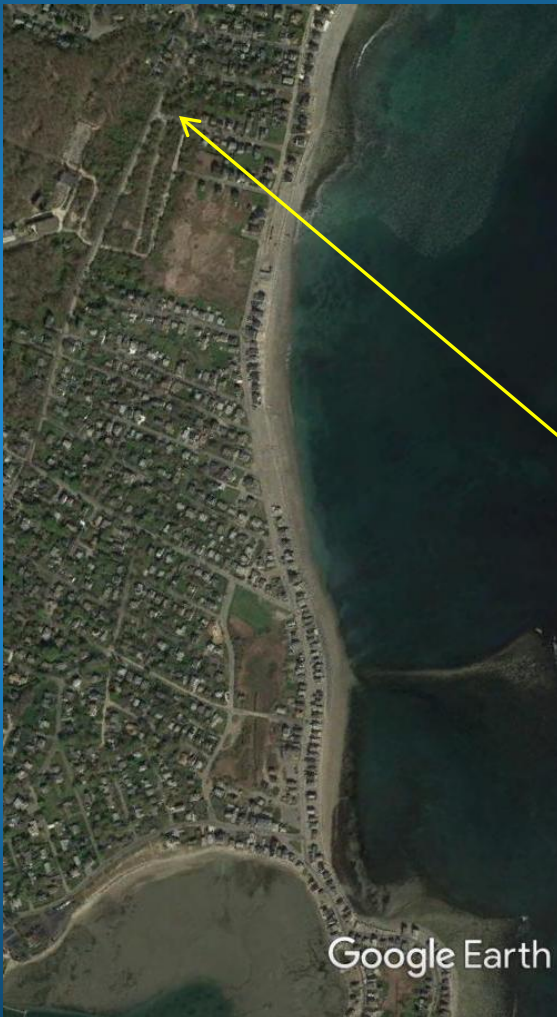


Nemo Feb 9th Tide



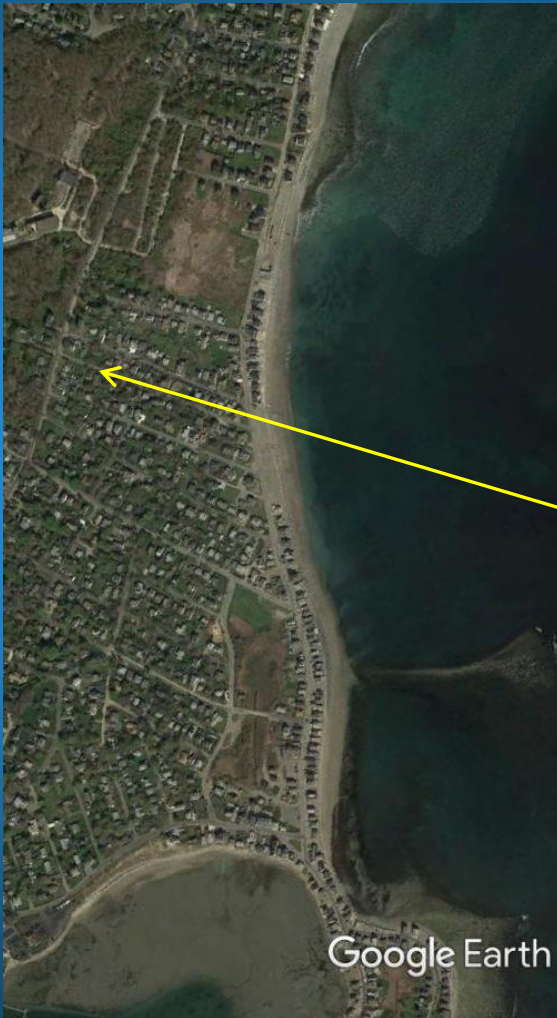
Why do waves matter?

- **Contribution to flooding via overwash**
- Wave battering to structures
- Scour and erosion of dunes and beaches



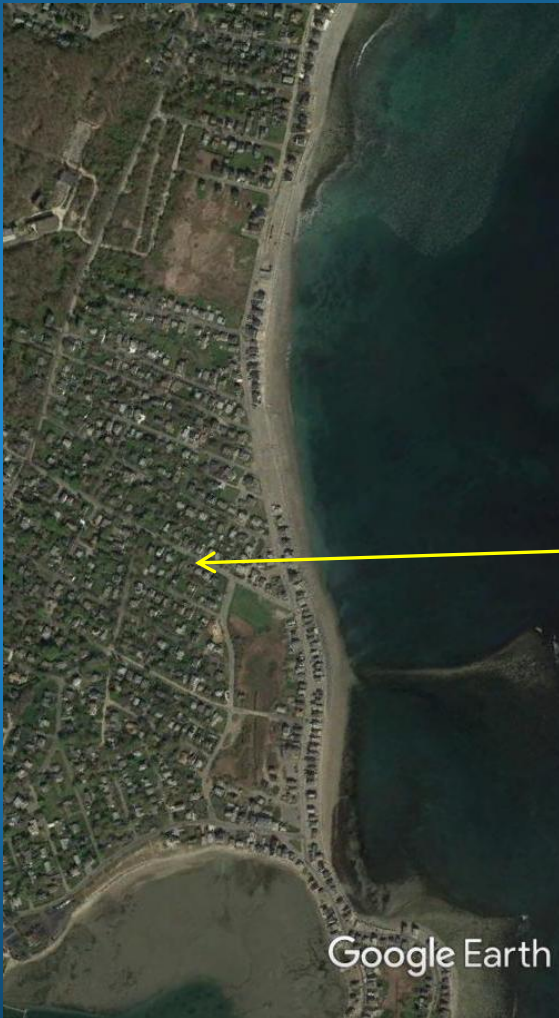
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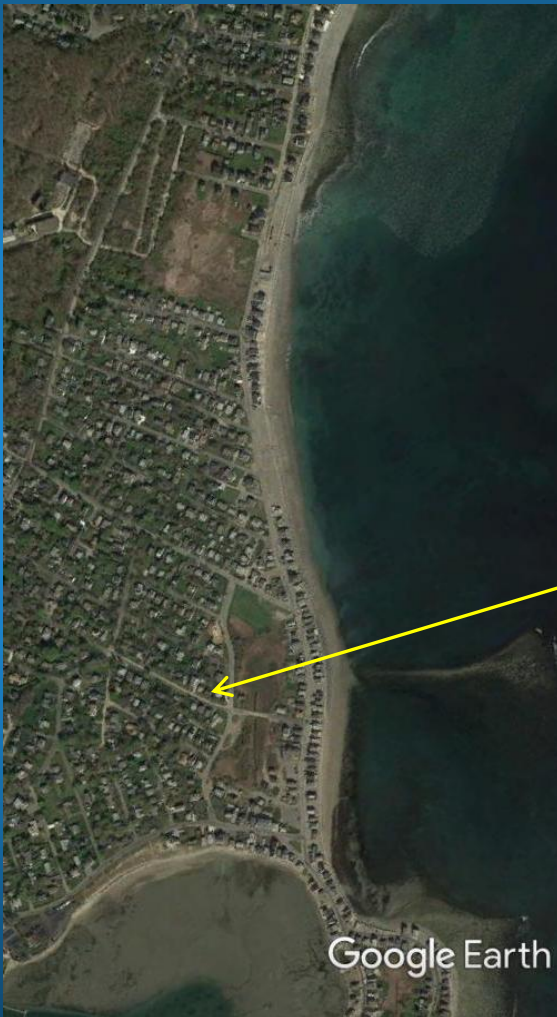
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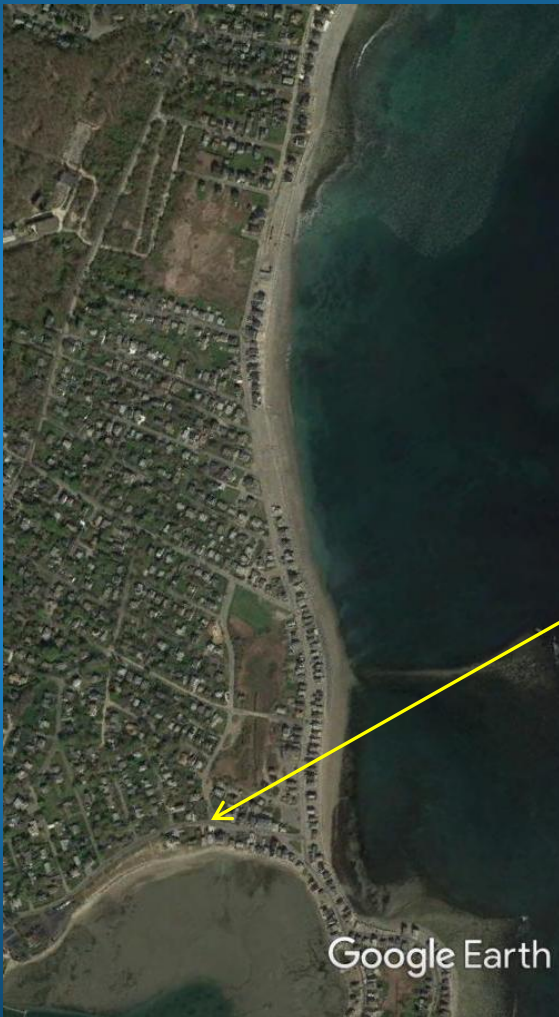
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- **Scour and erosion of dunes and beaches**



Photo Courtesy: MyCoast



Photo Courtesy: MyCoast

2013/03/08

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- Wave battery to structures
- **Scour and erosion of dunes and beaches**



Why do waves matter?

- Contribution to flooding via overwash
- Wave battering to structures
- **Scour and erosion of dunes and beaches**



Coastal Flood Definitions

Minor – Flooding of the most vulnerable shore road and/or basements due to height of storm or wave splashover. Majority of roads remain passable with only isolated closures. This is no significant threat to life and any impacts on property is minimal.

Moderate – Widespread flooding of vulnerable shore roads and/or basements due to height of storm and/or wave action. Numerous road closures are needed. Lives may be at risk for people who put themselves in harm's way. Isolated damage of very vulnerable structures such as docks or house decks/porches near the high tide line may be observed.

Major – Coastal flooding severe enough to cause at least scattered structural damage along with widespread flooding of vulnerable shore road and/or basements. Some vulnerable homes or businesses are severely damaged or destroyed. Numerous roads are impassable, some with washouts severe enough to be life threatening if one attempted to cross on foot or by vehicle. Some neighborhoods are isolated. Evacuation of some neighborhoods is necessary.



Coastal flood impacts are primarily a function of water level and waves

Secondary factors are wave direction, wave period, and duration of impact.

Storm Tide Level	Wave Height					
	10	15	20	25	30	35
9.5	-	-	-	-	Minor	Minor
10.0	-	-	-	Minor	Minor	Minor-Mdt
10.5	-	Minor	Minor	Minor	Minor-Mdt	Moderate
11.0	Minor	Minor	Minor	Minor-Mdt	Moderate	Mdt-Major
11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major
12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major
12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
14.0	Moderate	Mdt-Major	Major	Major	Major	Major
14.5	Mdt-Major	Major	Major	Major	Major	Major
15.0	Major	Major	Major	Major	Major	Major
15.5	Major	Major	Major	Major	Major	Major

Matrix of coastal flooding due to wave and tide level developed by National Weather Service (NWS) based on experience and assessment of local studies

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	10	15	20	25	30	35
9.5	-	-	-	-	Minor	Minor
10.0	-	-	-	Minor	Minor	Minor-Mdt
10.5	-	Minor	Minor	Minor	Minor	Moderate
11.0	Minor	Minor	Minor	Minor	Minor	Mdt-Major
11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major
12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major
12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
14.0	Moderate	Mdt-Major	Major	Major	Major	Major
14.5	Mdt-Major	Major	Major	Major	Major	Major
15.0	Major	Major	Major	Major	Major	Major
15.5	Major	Major	Major	Major	Major	Major

Nemo Feb 8th Tide

Nemo Feb 9th Tide

Matrix of coastal flooding due to wave and tide level developed by National Weather Service (NWS) based on experience and assessment of local studies

Coastal flood impacts are primarily a function of water level and waves

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Storm Tide Level	Wave Height					
	10	15	20	25	30	35
9.5	-	-	-	-	Minor	Minor
10.0	-	-	-	Minor	Minor	Minor-Mdt
10.5	-	Minor	Minor	Minor	Moderate	Moderate
11.0	Minor	Minor	Minor	Moderate	Moderate	Mdt-Major
11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major
12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major
12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
14.0	Moderate	Mdt-Major	Major	Major	Major	Major
14.5	Mdt-Major	Major	Major	Major	Major	Major
15.0	Major	Major	Major	Major	Major	Major
15.5	Major	Major	Major	Major	Major	Major

Nemo Feb 8th Tide

Nemo Feb 9th Tide

Blizzard of '78

“Perfect Storm” Oct. 91

Matrix of coastal flooding due to wave and tide level developed by National Weather Service (NWS) based on experience and assessment of local studies

Coastal flood impacts are primarily a function of water level and waves

Secondary factors are wave direction, wave period, and duration of impact.

Storm Tide Level	Sea Level Rise	Total Water Level	Wave Height					
			10	15	20	25	30	35
9.5	0	9.5	-	-	-	-	Minor	Minor
10.0	0	10.0	-	-	-	Minor	Minor	Minor-Mdt
10.5	0	10.5	-	Minor	Minor	Minor	Minor-Mdt	Moderate
11.0	0	11.0	Minor	Minor	Minor	Minor-Mdt	Moderate	Mdt-Major
11.5	0	11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major
12.0	0	12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major
12.5	0	12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
13.0	0	13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
13.5	0	13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
14.0	0	14.0	Moderate	Mdt-Major	Major	Major	Major	Major
14.5	0	14.5	Mdt-Major	Major	Major	Major	Major	Major
15.0	0	15.0	Major	Major	Major	Major	Major	Major
15.5	0	15.5	Major	Major	Major	Major	Major	Major

Extrapolate: extend the application of (a method or conclusion) to an unknown situation by assuming that existing trends will continue or similar methods will be applicable

Matrix developed by NWS with no additional Sea Level Rise Added

Coastal flood impacts are primarily a function of water level and waves

Secondary factors are wave direction, wave period, and duration of impact.

Storm Tide Level	Sea Level Rise	Total Water Level	Wave Height					
			10	15	20	25	30	35
9.5	1	10.5	-	Minor	Minor	Minor	Minor-Mdt	Moderate
10.0	1	11.0	Minor	Minor	Minor	Minor-Mdt	Moderate	Mdt-Major
10.5	1	11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major
11.0	1	12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major
11.5	1	12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
12.0	1	13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
12.5	1	13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
13.0	1	14.0	Moderate	Mdt-Major	Major	Major	Major	Major
13.5	1	14.5	Mdt-Major	Major	Major	Major	Major	Major
14.0	1	15.0	Major	Major	Major	Major	Major	Major
14.5	1	15.5	Major	Major	Major	Major	Major	Major
15.0	1	16.0	Major	Major	Major	Major	Major	Major
15.5	1	16.5	Major	Major	Major	Major	Major	Major

Matrix developed by NWS with additional 1 foot of Sea Level Rise Added

Coastal flood impacts are primarily a function of water level and waves

Secondary factors are wave direction, wave period, and duration of impact.

Storm Tide Level	Sea Level Rise	Total Water Level	Wave Height						
			10	15	20	25	30		
9.5	2	11.5	Minor	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	
10.0	2	12.0	Minor	Minor-Mdt	Moderate	Moderate	Mdt-Major	Major	
10.5	2	12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major	
11.0	2	13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major	
11.5	2	13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major	
12.0	2	14.0	Moderate	Mdt-Major	Major	Major	Major	Major	
12.5	2	14.5	Mdt-Major	Major	Major	Major	Major	Major	
13.0	2	15.0	Major	Major	Major	Major	Major	Major	
13.5	2	15.5	Major	Major	Major	Major	Major	Major	
14.0	2	16.0	Major	Major	Major	Major	Major	Major	
14.5	2	16.5	Major	Major	Major	Major	Major	Major	
15.0	2	17.0	Major	Major	Major	Major	Major	Major	
15.5	2	17.5	Major	Major	Major	Major	Major	Major	

Matrix developed by NWS with additional 2 foot of Sea Level Rise Added

Coastal flood impacts are primarily a function of water level and waves

Secondary factors are wave direction, wave period, and duration of impact.

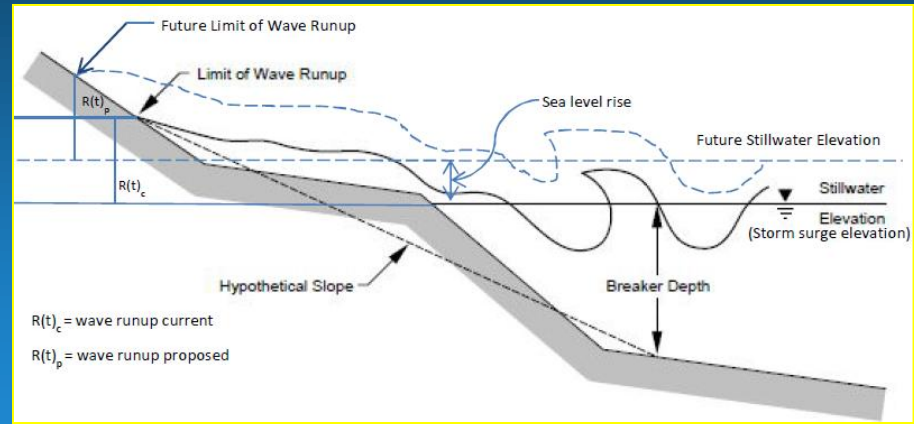
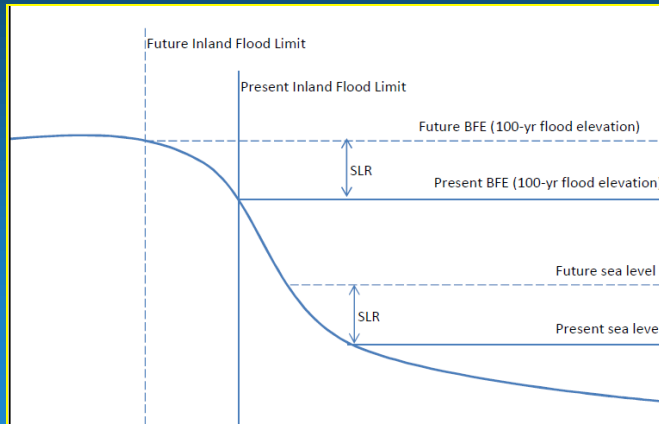
Storm Tide Level	Sea Level Rise	Total Water Level	Wave Height					
			10	15	20	25	30	35
9.5	3	12.5	Minor-Mdt	Moderate	Moderate	Moderate	Mdt-Major	Major
10.0	3	13.0	Moderate	Moderate	Moderate	Mdt-Major	Major	Major
10.5	3	13.5	Moderate	Moderate	Mdt-Major	Major	Major	Major
11.0	3	14.0	Moderate	Mdt-Major	Major	Major	Major	Major
11.5	3	14.5	Major	Major	Major	Major	Major	Major
12.0	3	15.0	Major	Major	Major	Major	Major	Major
12.5	3	15.5	Major	Major	Major	Major	Major	Major
13.0	3	16.0	Major	Major	Major	Major	Major	Major
13.5	3	16.5	Major	Major	Major	Major	Major	Major
14.0	3	17.0	Major	Major	Major	Major	Major	Major
14.5	3	17.5	Major	Major	Major	Major	Major	Major
15.0	3	18.0	Major	Major	Major	Major	Major	Major
15.5	3	18.5	Major	Major	Major	Major	Major	Major

Nemo Feb 8th Tide

Nemo Feb 9th Tide

Matrix developed by NWS with additional 3 foot of Sea Level Rise Added

Still Water “Storm Surge” Water Level Elevations

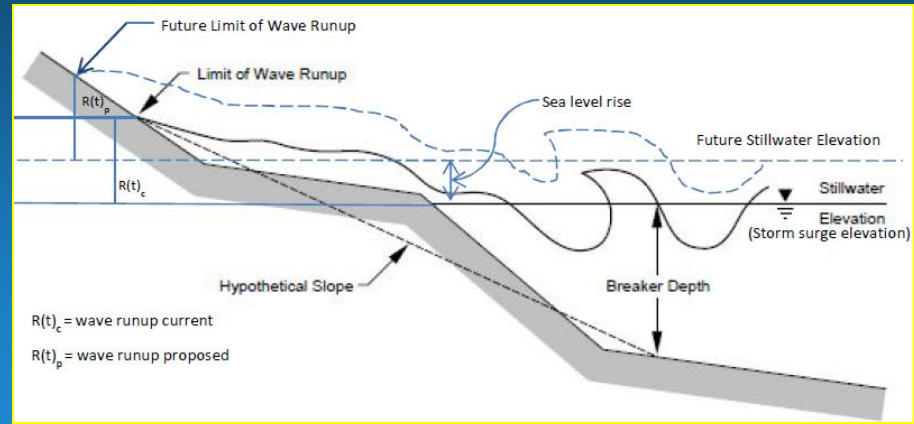
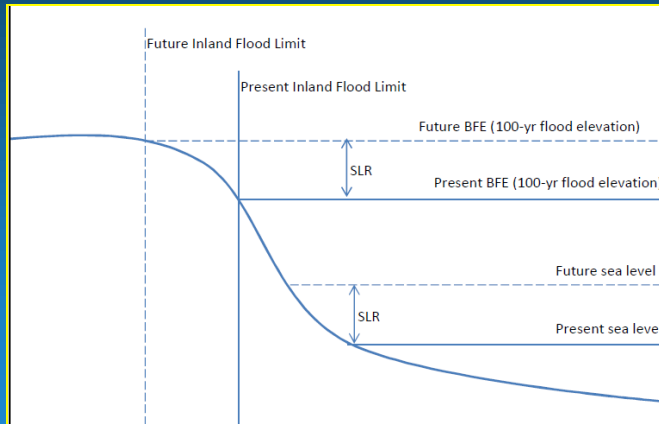


Source: Kleinfelder, 2013

Water Level Water Elevation
(Feet, NGVD88)

Mean Low Water	-5.2
Mean Sea Level	-0.3
Mean High Water	4.3
10% Storm Event	8.3
2% Storm Event	9.1
1% Storm Event	9.5
0.2% Storm Event	10.3

Still Water “Storm Surge” Water Level Elevations

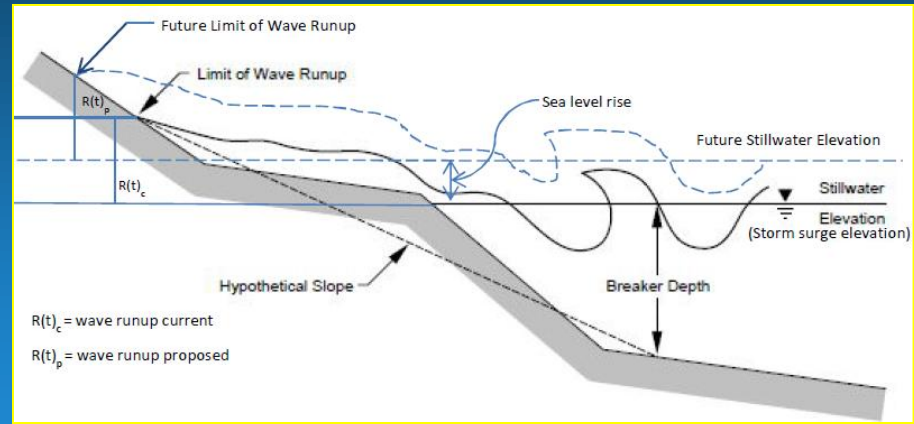
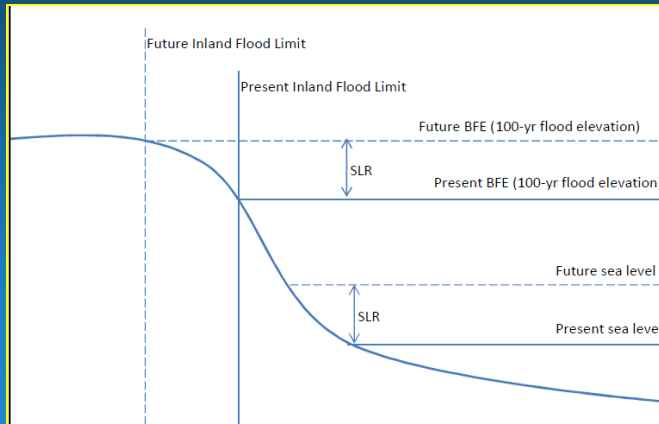


Source: Kleinfelder, 2013

Water Level Water Elevation 1 Ft. SLR
 (Feet, NGVD88)

Mean Low Water	-5.2	-4.2
Mean Sea Level	-0.3	0.3
Mean High Water	4.3	5.3
10% Storm Event	8.3	9.3
2% Storm Event	9.1	10.1
1% Storm Event	9.5	10.5
0.2% Storm Event	10.3	11.3

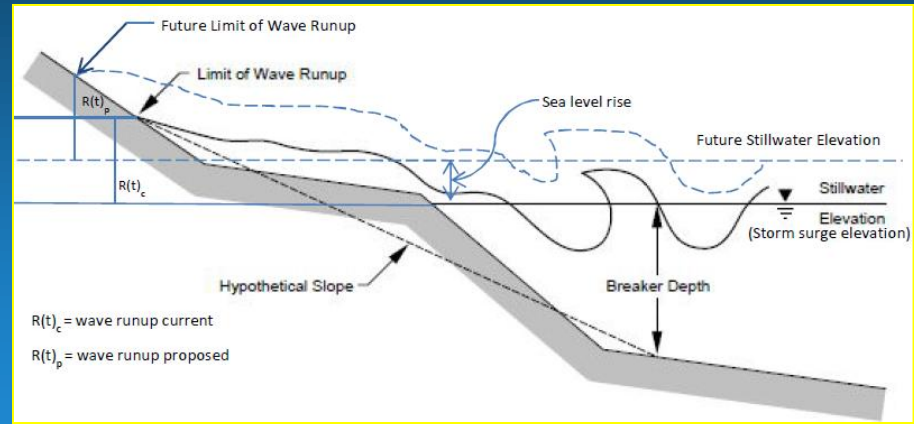
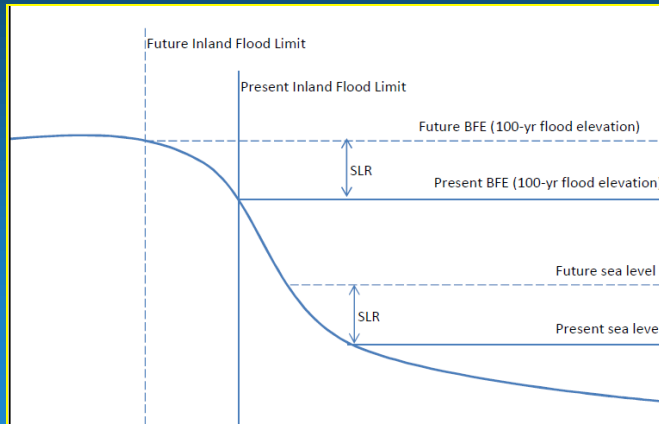
Still Water “Storm Surge” Water Level Elevations



Source: Kleinfelder, 2013

Water Level	Water Elevation (Feet, NGVD88)	1 Ft. SLR	2 Ft. SLR
Mean Low Water	-5.2	-4.2	-3.2
Mean Sea Level	-0.3	0.3	1.3
Mean High Water	4.3	5.3	6.3
10% Storm Event	8.3	9.3	10.3
2% Storm Event	9.1	10.1	11.1
1% Storm Event	9.5	10.5	11.5
0.2% Storm Event	10.3	11.3	12.5

Still Water “Storm Surge” Water Level Elevations



Source: Kleinfelder, 2013

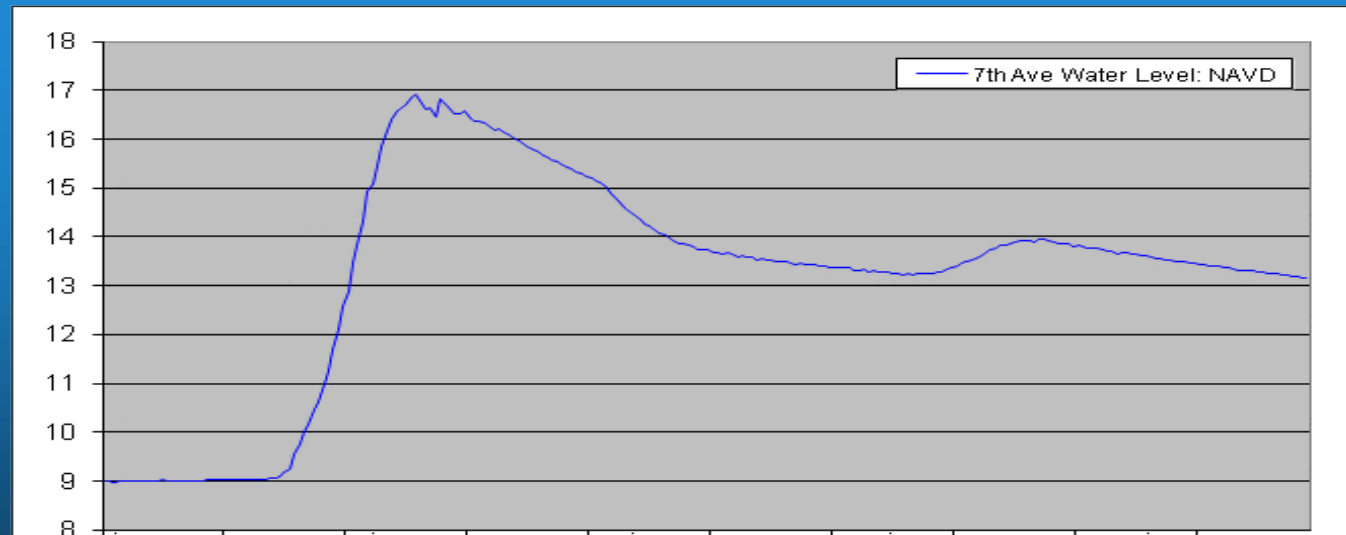
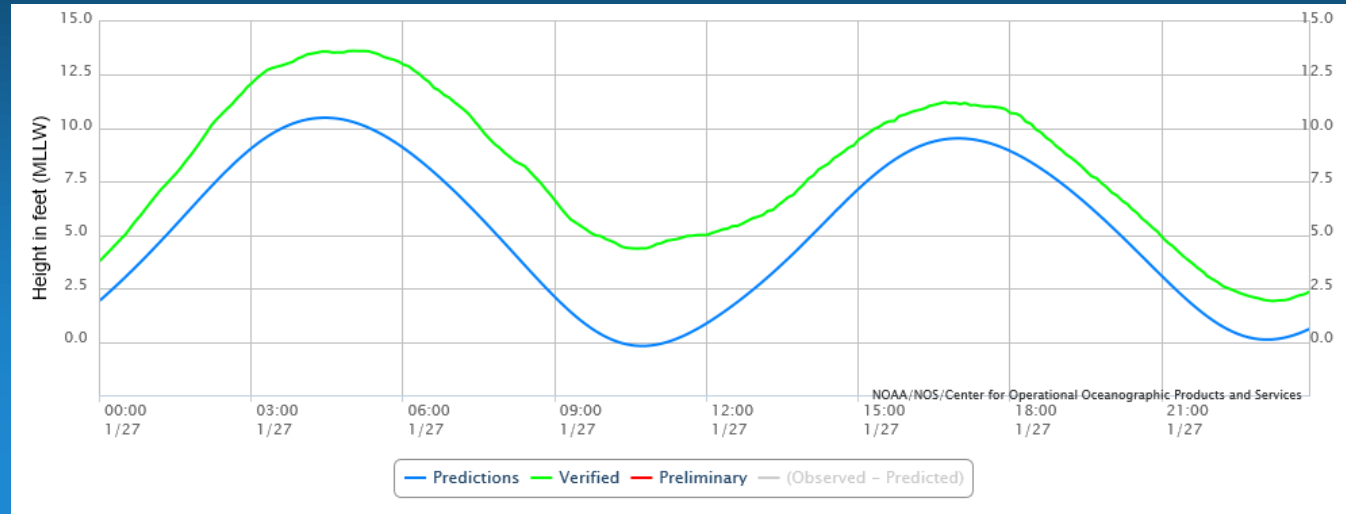
Water Level	Water Elevation (Feet, NGVD88)	1 Ft. SLR	2 Ft. SLR	3 FT SLR
Mean Low Water	-5.2	-4.2	-3.2	-2.2
Mean Sea Level	-0.3	0.3	1.3	2.3
Mean High Water	4.3	5.3	6.3	7.3
10% Storm Event	8.3	9.3	10.3	11.3
2% Storm Event	9.1	10.1	11.1	12.3
1% Storm Event	9.5	10.5	11.5	12.5
0.2% Storm Event	10.3	11.3	12.5	13.5

Contribution to Flooding via Overwash with SLR



Google Earth

Contribution to Flooding via Overwash with SLR



Jan. 27, 2015 00:00 to 23:59



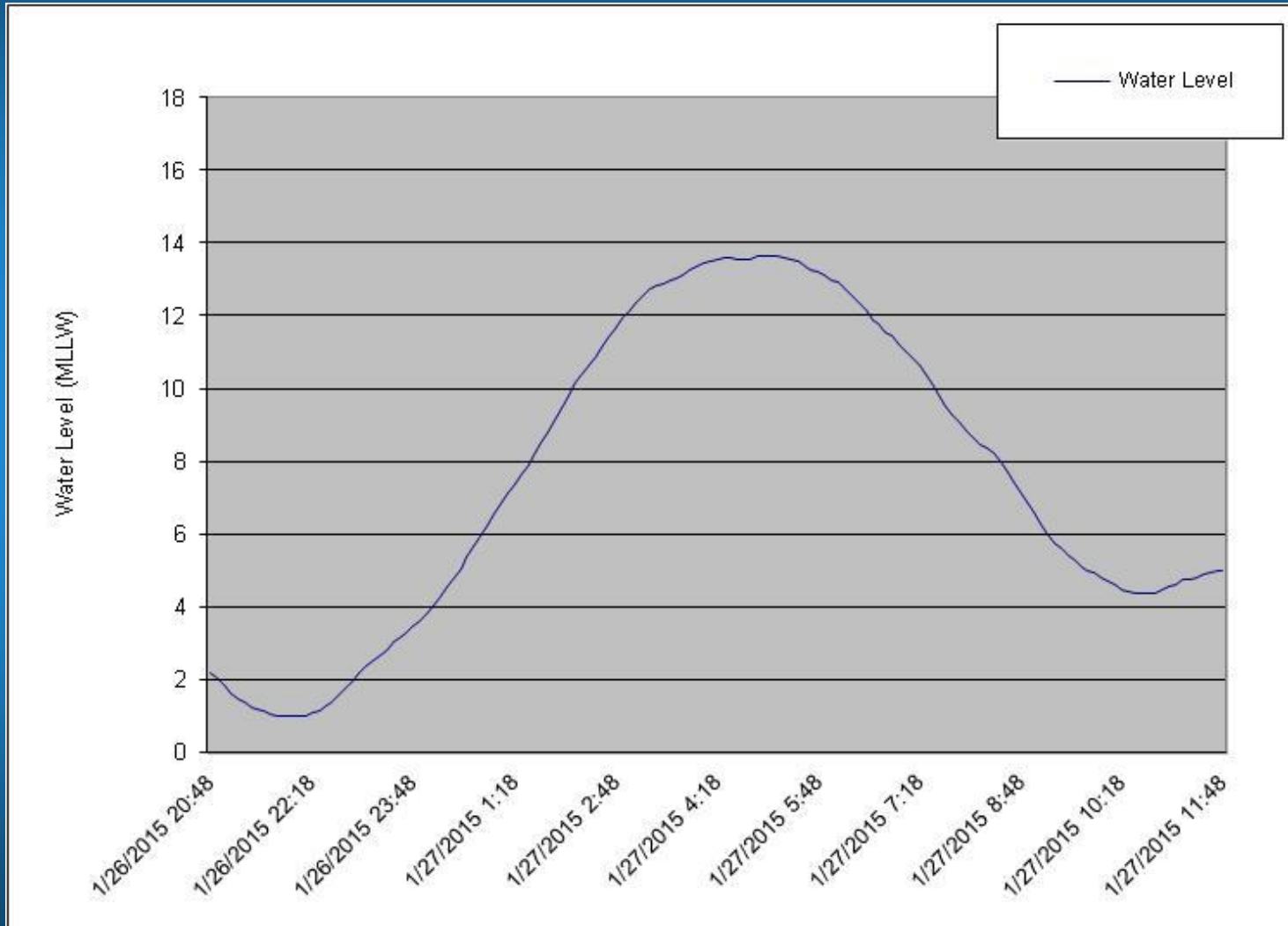


Storm photos courtesy of Dave Laroche

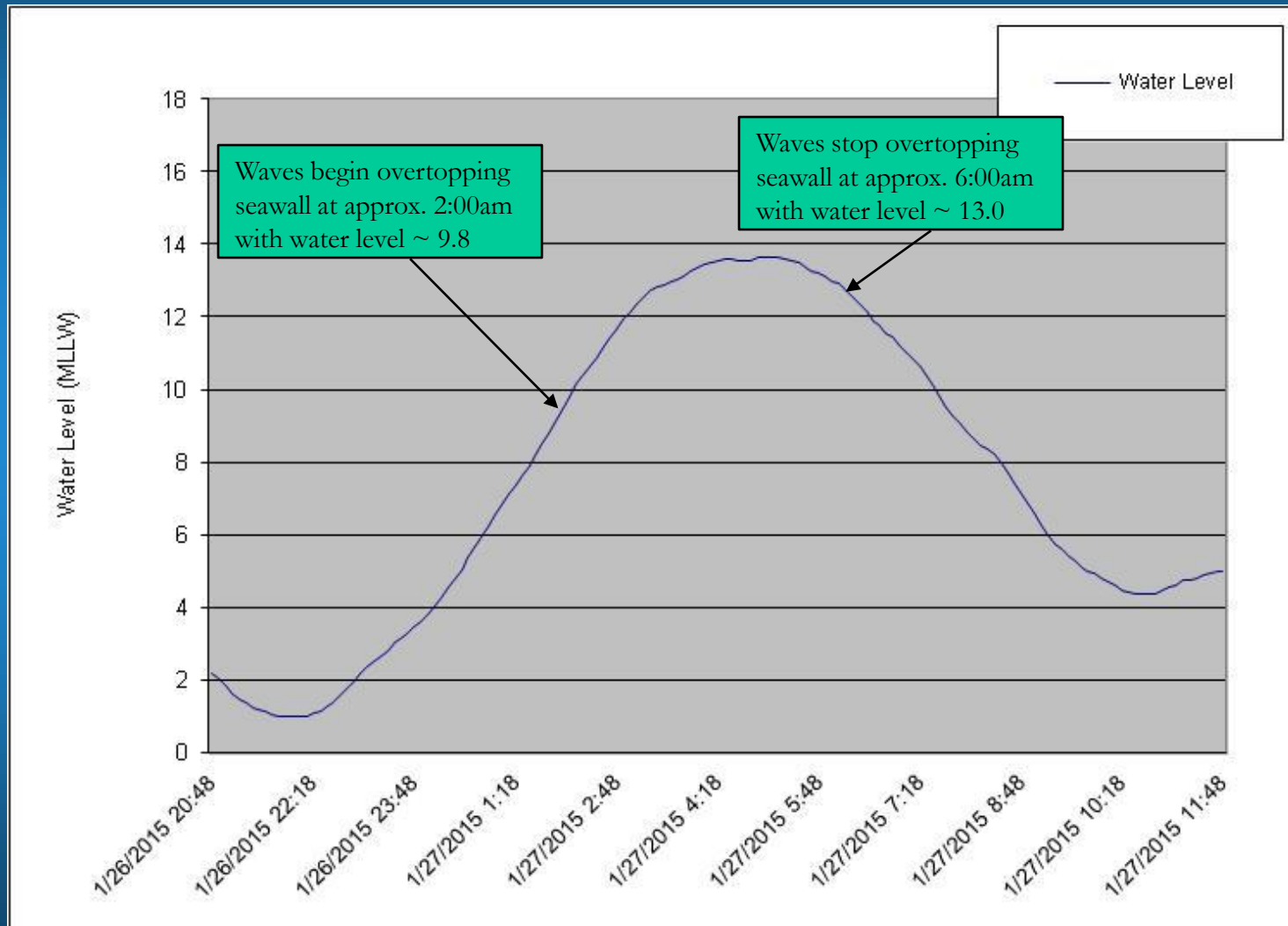
Contribution to Flooding via Overwash with SLR



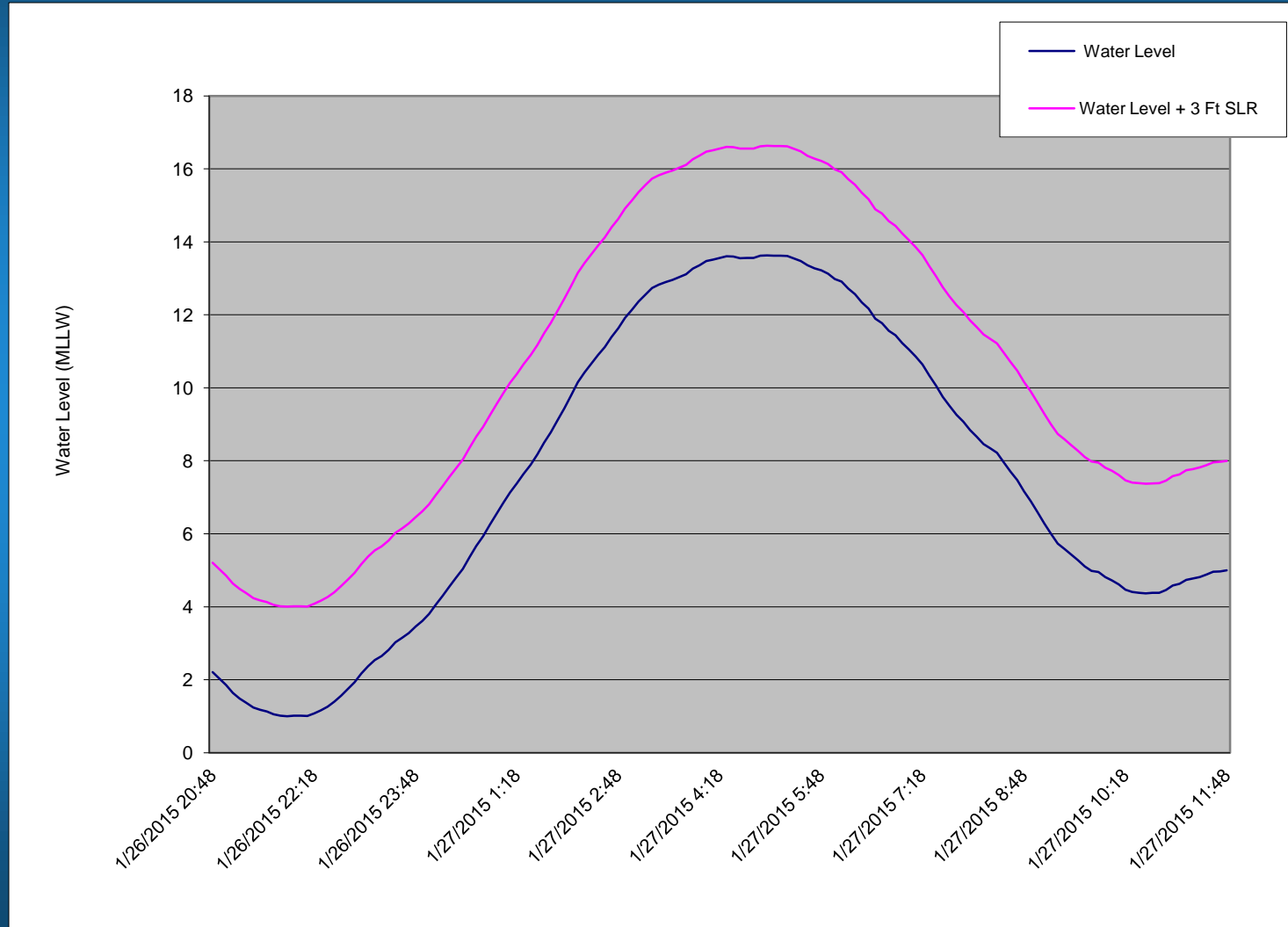
Contribution to Flooding via Overwash with SLR



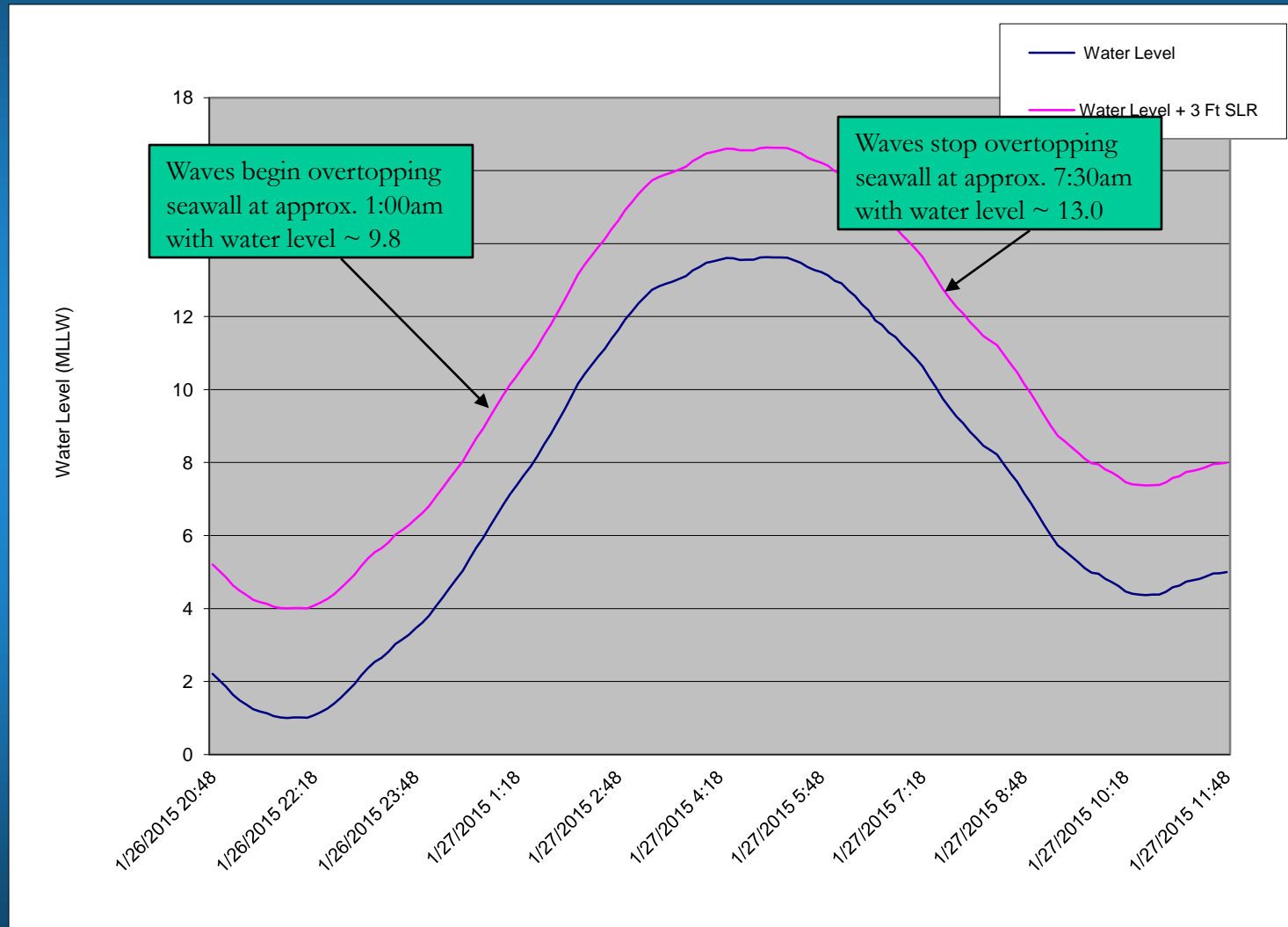
Contribution to Flooding via Overwash with SLR



Contribution to Flooding via Overwash with SLR



Contribution to Flooding via Overwash with SLR



Management, Policy, and Emergency Response Implications

- Greater flooding and storm damage for a given storm event (duration and degree).
- Increased frequency of flooding and storm damage events.
- Increased frequency and more challenging emergency response required.
- More frequent displacement of residents for longer duration.
- Increased strain and damage to shoreline protection structures.
- Increased erosion and scour of fronting beaches and backshore areas.
- Increased insurance payouts to property owners and disaster mitigation funds to municipalities to recover from storm damage.