Strong PS focus
Joe will be talking about broader coastal management issues next week.
Overview

• Sea Level Rise
  – Global and regional context
  – Projections and role of ice sheets

• Shoreline response to rising sea level
  – Different impacts in different places
  – Response depends on rate of SLR, ability to migrate, and sediment availability

• Implications of higher water levels
  – Impacts will be associated with infrequent high water events
  – Higher water levels lead to increased flooding and erosion
  – Application and limitations of inundation maps

• Adaptation to sea level rise
  – Adaptation Strategies
  – Human response is likely to be drive by events
  – Hardened shorelines
  – Restoration and resilience
For 6K, from 14K to 8K, sea level rose 90m. About 1.5 cm/yr, or 1.5m/century, maybe like the next few hundred years? Distinct leveling out around 6000 years ago. Other factors, but change less rapid.
2mm/yr, most recently a little over 3mm/yr.
Seattle record.
Vertical Land Movements

- Glacial Rebound
- Tectonics
- Local Subsidence

Sea Level at Neah Bay Tide Gauge

Relative sea level is falling!
Global sea level: estimates of emissions, models of climate response, models of ocean response, models of water level response. Best guesses, but much unknown. Dynamic ice effects.

CONSIDER ADDING GREENLAND OR WAP GRAPHIC…
Glacial Melting

- Mountain Glaciers
- Greenland
- West Antarctica
Historic, current, and projected – Source Nicholls and Cazenave, 2010
Clairfy what color bars represent...
Red 32: Rahmstorf, 2007
Blue 33: Vermeer and Rahmstorf, 2009
Green 34: Grinsted et al, 2009
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We have steep coastline. Isolated low-lying areas.

Geomorphologist – interested in this variety. Recognition that these are shaped by a different suite of processes. Different response to sea level. But they’ve emerged during a period of gradual sea level rise.
### Geomorphic Setting

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>RESPONSE</th>
<th>IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocky (21%)</td>
<td>Bedrock, resistant to erosion Residential, undeveloped</td>
<td>Minimal erosion or change</td>
<td>Limited erosion and inundation</td>
</tr>
<tr>
<td>Bluffs (38%)</td>
<td>Erodible, elevated Residential, undeveloped</td>
<td>Accelerated erosion, mass-wasting, accelerated bluff retreat</td>
<td>Landslides and erosion, modified bluff habitats</td>
</tr>
<tr>
<td>Barrier Beaches (11%)</td>
<td>Low lying spits and barriers. Dunes. Often back-barrier wetlands Residential, parks, undeveloped</td>
<td>Erosion, overwash, migration Breaching, shifting tidal inlets</td>
<td>Erosion, flooding, storm damage, altered backshore habitat</td>
</tr>
<tr>
<td>Estuaries and Lagoons (13%)</td>
<td>Small, sheltered estuaries and lagoons. Stream mouths.</td>
<td>Tidal prism change, altered inlet dynamics, marsh erosion/accretion</td>
<td>Marsh/habitat loss, shoreline erosion</td>
</tr>
<tr>
<td>Delta (8%)</td>
<td>Broad, low elevation alluvial features at river mouths Agricultural and urban/</td>
<td>Sedimentation patterns change, altered riverine influences, marsh erosion/accretion, inundation.</td>
<td>Increased flood vulnerability, damage to dikes and levees, vegetation shifts, difficult drainage</td>
</tr>
<tr>
<td>Artificial (10%)</td>
<td>Engineered, fill, hardened usually low elevation Urban/industrial/</td>
<td>Limited change</td>
<td>Storm damage, flooding</td>
</tr>
</tbody>
</table>

Landform percentages for Puget Sound approximate (preliminary data PSNERP)

Beaches are approximately 50% of our shoreline.
Go through rows
Go through columns
Simple. Often steep. Unlikely to be a major issue unless water levels go up enormously. Also, little “response” to higher water levels. They change little, if at all.
Coastal Bluffs

- Erosion and retreat
- Scale and type of landsliding
- Sediment supply
- Morphology
- Vegetation

Bluffs – erosion rates, form of bluffs, vegetation on bluffs, large-scale landsliding
Coastal Bluffs

- Increased erosion rates and landsliding
- Escalating damage to seawalls, need for larger, more expensive measures over time
- Beach habitats squeezed out where shorelines armored
- Shift from forested bluffs to unstable bare slopes
- Changes in bluff erosion may impact beaches elsewhere along shoreline

Gig Harbor
A total of 33% of bluff backed beaches and 27% of barrier beaches have been armored in Puget Sound.
Importance of available sediment
Increased frequency and severity of flooding and storm damage
- Rapid erosion and potential for breaching
- Failure of septic systems; threat to water supply and utilities
- Loss of beaches where shoreline is armored
- Loss of associated wetland and estuarine habitats
Small Estuaries and Marsh accretion
Marsh erosion
Tidal prism
Marsh migration
Inlet Dynamics

Kala Point, Port Townsend
River Deltas

Loss of nearshore habitats seaward of dikes

Significant influence on long-term decisions regarding agricultural use or ecological restoration

Increased costs of repairing and maintaining dikes and levees

Increased flooding, soil saturation, drainage problems

Increased intrusion of saltwater into estuary

Inundation because low-lying, low gradient.
Changes restoration costs/benefits, long term prognoses.
Agricultural lands
Need to raise and strengthen dikes and levees. Cost of maintaining dikes and levees increases.

May reinforce efforts to acquire lowest lying agricultural lands and allow shoreline to shift landward. Ties into restoration.
Geomorphic Response of: Beaches, Estuaries, Marshes, Deltas

*Depends on:*  
- Rate of sea level rise  
- Ability to migrate landward  
- Sediment availability

Rates: at some point, can't keep up. Existing system has evolved in response to rising sea levels  
Migrate: move landward – human or natural contraints  
Sediment availability: Builds elevation, allows lateral movement, allows marshes to accrete vertically
Built shorelines.
These are shorelines that are engineered. Geomorphic response is less relevant. Might think of as a ROCKY shoreline. But unlike most naturally rocky shores – underground is filled with steel pipes and elevation is just above maximum water level.

Little geomorphic response. But significant human investment/vulnerability.

Issues: Erosion, damage, flooding (storms, wave overtopping, drainage, pumping, rainfall or marine), infrastructure – salt water corrosion.
Urban Waterfronts

- Increased risks to infrastructure
  - Treatment Plants
  - Transportation Corridors
  - Commercial and Industrial Waterfronts
  - Parks
- Storm drainage systems require expensive fixes
- Increasingly steep public costs to maintain, protect, and repair public facilities and property
- Redevelopment opportunities

Damage to infrastructure
- Treatment plants, coastal transportation corridors, bridges, parks
Need to protect or elevate low-lying areas.
Increased pumping.
Increased damage, closure following severe storms.
Redevelopment opportunities
May impact contaminated, or remediated sites. Increased corrosion of underground tanks and pipes.
Increased leaching of contaminated soils?
Higher costs to local governments
Storm drainage infrastructure more expensive
Port facilities. Docks and piers. Container facilities.
Ports

- Increasing storm damage to piers and seawalls
- Need to reconfigure or elevate freight handling yards and rail lines
- Increased corrosion of tanks and pipes; increased leaching of contaminated soils
- Opportunity to adapt during major facility updates

Ports typically have heavily engineered shorelines. Freight handling requires extensive rail yards near water level. Associated industrial areas may contain currently or historically contaminated sites.

Port of Tacoma example
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Water level variability

- Sea level varies at daily, seasonal, annual, and decadal scales.

- Impact of higher sea level will ... at highest water levels, which are episodic and infrequent.

Add bullets with important points....
In any time series, larger events tend to occur less frequently.

Check actual numbers – don’t perpetuate the 10x figure!
If nothing else, add some wiggle language or caveats.
Sea level was almost 2’ higher than normal throughout the third week of January, 2010.
**Practicing for future sea level rise...**

During strong El Ninos, sea level in the Salish Sea can rise more than 15–20 cm, resulting in more frequent extreme high tides.

|--------------|--------------|

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<th>Annual frequency of Seattle tides &gt;13.0' MLLW</th>
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<td>MHHW = 11.35'</td>
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During El Ninos, sea level is slightly higher, (sort of a dress rehearsal for climate change) and the result is many more events....
Storms and Coastal Flooding

- Extreme high water levels will increase over time
  - Longer flood durations
  - Drainage of low-lying areas more difficult

- Severity and frequency of storms may or may not increase

- Flood events of any given magnitude will become more frequent

- Damaging storms will occur more frequently, because they will occur at higher water levels
Erosion and Landslides

• Erosion rates likely to increase in most locations
• Landslides more frequent and possibly larger
• Patterns of sediment transport on beaches will be altered, leading to complex, perhaps rapid shoreline changes

Ledgewood Beach, Whidbey Island
Inundation Maps

- Emphasize large, low-lying areas, subject to flooding, but tend to miss beaches and steep bluffs subject to erosion and more developed areas subject to severe storm damage and costly infrastructure
- Assumes static landscape with no geomorphic, or human, response to rising sea level over the next 100 or more years
- Limited incorporation of engineered shorelines such as dikes and levees

DEM + GIS + SLR = inundation maps

Why so readily available: GIS, DEMs

Example/Map: regional PS, CISP flooded picnic shelter?, Or Useless Bay colony sign. Uses, that we can learn from them

Limitations

2' (red) indicates areas potentially subject to tidal inundation – approximate IPCC 0.7 m

20’ (yellow) indicates areas potentially subject to tidal inundation under a much more extreme scenario
Scale matters
Local inundation maps

Olympia

Port Townsend

SYMBOL KEY
- Tsunami Hazard Zones
- Outside the Hazard Zones
- Evacuation Routes
- Community Center
- Hospital
- Assembly Area
- Police Station
- Fire Station
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Adaptation

Protect

Retreat

Accommodate
Human Response

- Response to sea level rise will be driven by events (natural disasters)
- Storm events will continue to be seen as capricious events – "acts of god"
- Pressure to rebuild and to defend, often with associated will see events as flukes (unusual and unfair), will defend and rebuild, try to hold the line. Reclaim lost property, lost security. Natural response will be to build dikes and seawalls
“In the next century, the majority of America's publicly owned tidal shorelines could be replaced by a wall, not because anyone decided that this should happen but because no one decided that it should not.”

Titus, JG 1998

- Hardening shorelines will be a natural and logical response to increasing erosion and storm damage
- Result will be “coastal squeeze,” causing loss of beaches and coastal wetlands
Managed Retreat, French, Cooper  -- make sure you can clearly explain the main points.
1. SPACE: opportunistic – human landscape, not naturally best locations...
2. TIME: Rates of inundation – fast versus gradual … chemical response in marshes, sediment response on beaches
Accelerated sea level rise underscores existing coastal management challenges:

- Planning: Guide shoreline development, beware coastal sprawl, identify where you will protect/accommodate/retreat, adopt longer time horizons.
- Hazards: Anticipate and avoid, don't just react and rebuild.
- Setbacks: from dynamic coastal features – bluffs, beaches, marshes. Reduce hazards AND foster resilience.
- Armoring: Decide where you want it, and where you don't, or you'll get it everywhere!
- Restoration: Build resilience by

Make sure it's clear what each of these bullets means …
Human civilization has developed under relatively static sea levels – maybe because of them. Rapid changes will completely change the way we interact with our coastline – will put coastal management in entirely different context. Easy to say some areas we will protect; some areas we will allow to respond naturally. BUT, real impact will be a fundamentally different relationship with our coast??

We don’t face same issues as everyone else. Probably less serious than some. Localized. But, impacts in other places will have big effect on how we adapt here – both good and bad. Awareness, budget priorities, etc.
Story line. Burning of fossil fuels leads to more frequent damaging flood events.

Stuff to still incorporate: storm damage, changed biota, beach loss
Resilience and adaptation: restoration, retreat, armoring