Game of Inches: Nuisance Flooding and the King Tide Phenomenon

Prof. Dave Kriebel, PhD, PE
Ocean Engineering Program
United States Naval Academy
kriebel@usna.edu
**Nuisance flooding** - flooding which causes public inconveniences such as frequent road closures, overwhelmed storm drains and compromised infrastructure (NOAA)

**King tide** - a colloquial term for an especially high tide, such as a perigean spring tide. "King tide" is not a scientific term, nor is it used in a scientific context. (Wikipedia)
Venice Illustrates the Problem

- Venice, Italy “Acqua Alta” events flooding city center at an increasing rate
- Events increasing with increasing mean sea level
- Flood events caused by minor storm surge superimposed on high tides
South Florida Illustrates the Problem

Flooded streets of Miami Beach, Collins Ave and 30th Street, during a King Tide on Sept. 28, 2015. (Miami Herald)

A flooded street in Miami Beach during the high tide on Sept. 29, 2015. (NOAA)

Las Olas Isles, Fort Lauderdale, Oct. 17, 2016. (Joe Cavaretta/Orlando Sentinel via AP)
Annapolis Illustrates the Problem

City Dock area, 12-21-12, 9:00 am Photo by Chris Trumbauer

Sept 30, 2016
Photo: Alderman Joe Budge
Courtesy: John Englander

Dec 2012
The Weather Channel
The Naval Academy Illustrates the Problem

Nuisance Flooding
US Naval Academy
Sept 7, 2016
Photos: D. Kriebel
Annapolis Tide Data
September 2016
Flooding of McNair Road, US Naval Academy

What Are Causes?
Not strongly correlated to Perigean spring tide
Strongly influenced by long term and seasonal mean sea level
Strongly influenced by minor meteorological events
Relative Sea Level Rise since 1992 (not accounted for in tide prediction)

Seasonal increase in mean sea level (not accounted for in tide prediction)
Annapolis, MD
High Tide Peaks above thresholds:
(1) MHHW=0.66 ft NAVD
(2) McNair Rd=1.98 ft NAVD

Note:
Data not detrended so sea level rise trend included
Annapolis, MD
Number of High Tide Flood Events as a Function of Threshold

Some Problematic Threshold elevations in Annapolis:

1. USNA McNair Rd 1.89 ft
2. Dock St Storm Drain 1.90 ft
3. City Dock Storm Drain 1.71 ft
4. Compromise St Storm Drain 1.67 ft
5. Newman Street Storm Drain 1.44 ft
6. Public Landing Storm Drain 2.09 ft
Key West, FL
High Tide Peaks above thresholds:
(1) +2.00 ft NGVD
(2) +2.25 ft NGVD
(3) +2.50 ft NGVD
Virginia Key, FL
High Tide Peaks above thresholds:
(1) +1.25 ft NAVD
(2) +1.50 ft NAVD
(3) +1.75 ft NAVD
Key West, FL
Little correlation to Proxigean Spring Tides
Strong correlation to fall seasonal mean sea level
Nuisance Flooding Projections with Future Sea Level Rise

- Hourly water levels from NOAA tide
  - Annapolis and Virginia Key 1996 to 2016
- Detrend to remove mean and long term linear sea level trend
  - Retain normal astronomical tides, meteorological events, seasonal mean sea level, and decadal sea level anomalies
- Identify high tide peaks – high tide amplitudes
  - Relative to “flat” mean sea level

Sample detrended data summer-fall 2016 Virginia Key
Both can be approximated by Normal or Gaussian Distribution
• Adopt future Global sea level rise scenario
• Add Vertical Land Movement
• Shift high tide probability curve by amount of future SLR
• Apply flood threshold
• Determine probability of flooding
  • Convert to number per year, etc
Statistics of High Tide Amplitudes
Shifted to NAVD88 Datum
With 0.5, 1.0, 1.5, and 2.0 ft sea level rise

Annapolis, MD

Virginia Key, FL
Apply Threshold Elevations

Annapolis, MD
Threshold = 1.98 ft NAVD

Virginia Key, FL
Threshold = 1.75 ft NAVD
Number of Flood Events with Future Sea Level Rise

Annapolis, MD
Threshold = 1.98 ft NAVD

Virginia Key, FL
Threshold = 1.75 ft NAVD
Statistics of Flood Depth Over Threshold
With 0, 0.5, 1.0, and 1.5 ft Sea Level Rise

**Annapolis, MD**
Threshold = 1.98 ft NAVD

**Virginia Key, FL**
Threshold = 1.75 ft NAVD
Number of Flood Events with Future Sea Level Rise Scenarios

Annapolis, MD
Threshold = 1.98 ft NAVD

- 5.0 ft (1.5m) +VLM by 2100
- 3.3 ft (1.0m) +VLM by 2100
- 1.6 ft (0.5m) +VLM by 2100
- 1 ft (0.3m) +VLM by 2100

Existing Trend
- 0.5 ft (0.15m) +VLM by 2100

Virginia Key, FL
Threshold = 1.75 ft NAVD

- 5.0 ft (1.5m) +VLM by 2100
- 3.3 ft (1.0m) +VLM by 2100
- 1.6 ft (0.5m) +VLM by 2100
- 1 ft (0.3m) +VLM by 2100

Existing Trend
- 0.5 ft (0.15m) +VLM by 2100
Effect of Raising Streets in Miami Beach

Streets in Sunset Harbor area
Old elevation 1.5 to 2.0 ft NAVD
New elevation 3.2 ft NAVD

Photo of Miami Beach City Engineer Dr. Bruce Mowry in Sunset Harbor (Miami Herald)
Conclusions

- **Nuisance Flooding and King Tides**
  - Need more precise definitions, but nuisance flood depths less than about 1 ft
  - Strong effect of long-term and seasonal (fall) increase in mean sea level
  - Strong effect of low-level meteorological events
  - Not uniquely related to perigean spring tides

- **Game of Inches**
  - Number of flood events changes dramatically as flood threshold, mean sea level, or both change by a few inches

- **Projections with Future Sea Level Rise**
  - Large increase in flood events expected even with current sea level trend
  - Dramatic increase under accelerated sea level scenarios
  - Can evaluate effect of adaptation actions