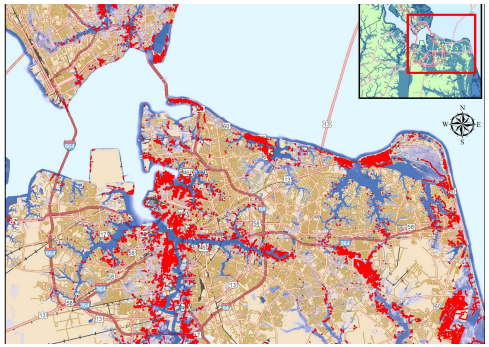
SAND2017-6407PE



Development of an Urban Resilience Analysis Framework

Application to Norfolk, VA and New Oreans, LA

Robert Jeffers and Bill Rhodes

Presentation to 100 Resilient Cities, July 06 2016

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Agenda

1. **Who are we, what do we do?**
2. **The need: effective resilience-enhancing investments**
3. **Norfolk, VA: application of an urban resilience analysis process**
4. **New Orleans, LA: improving urban resilience through grid resilience**
5. **Discussion**

Sandia Addresses National Security Challenges

Sandia National Laboratories

1950s	1960s	1970s	1980s	1990s	2000s	2010s
Nuclear weapons	Development engineering	Multiprogram laboratory	Missile defense work	Post–Cold War transition	START Post 9/11	LEPs Cyber, biosecurity proliferation
Production and manufacturing engineering	Vietnam conflict	Energy crisis	Cold War	Stockpile stewardship	National security	Evolving national security challenges

National Infrastructure Simulation and Analysis Center

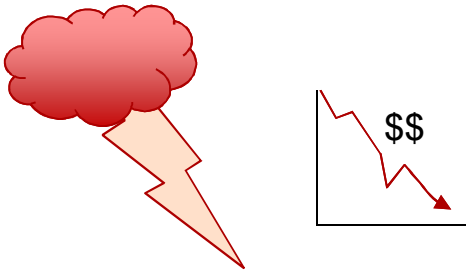
Provide new modeling and simulation capabilities for the analysis of critical infrastructures, their interdependencies, vulnerabilities, and complexities.

NISAC

Aid decision makers in

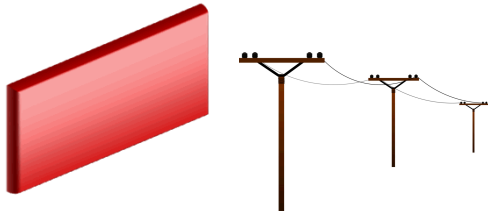
- Policy assessment,
- Mitigation planning,
- Education and training, and
- Near real-time assistance to crisis response organizations.

The need for cities



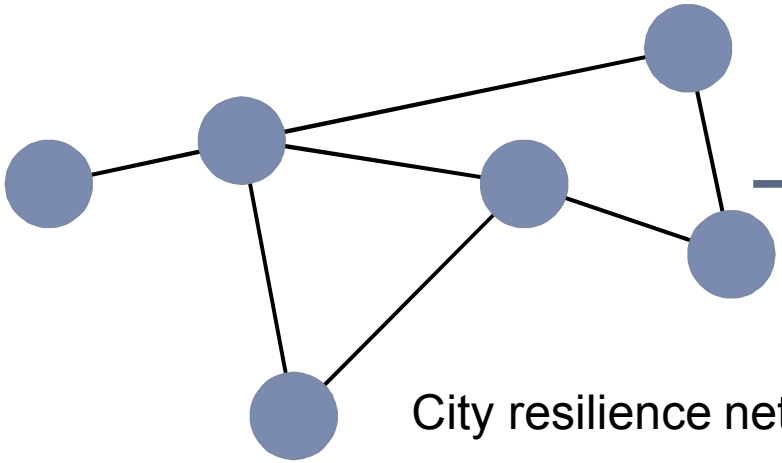
Shocks and stresses

Urban Resilience Analysis Process



Prioritized resilience improvements

The need for the nation



City resilience networks

Targeted Investment

National Security

Urban resilience analysis process

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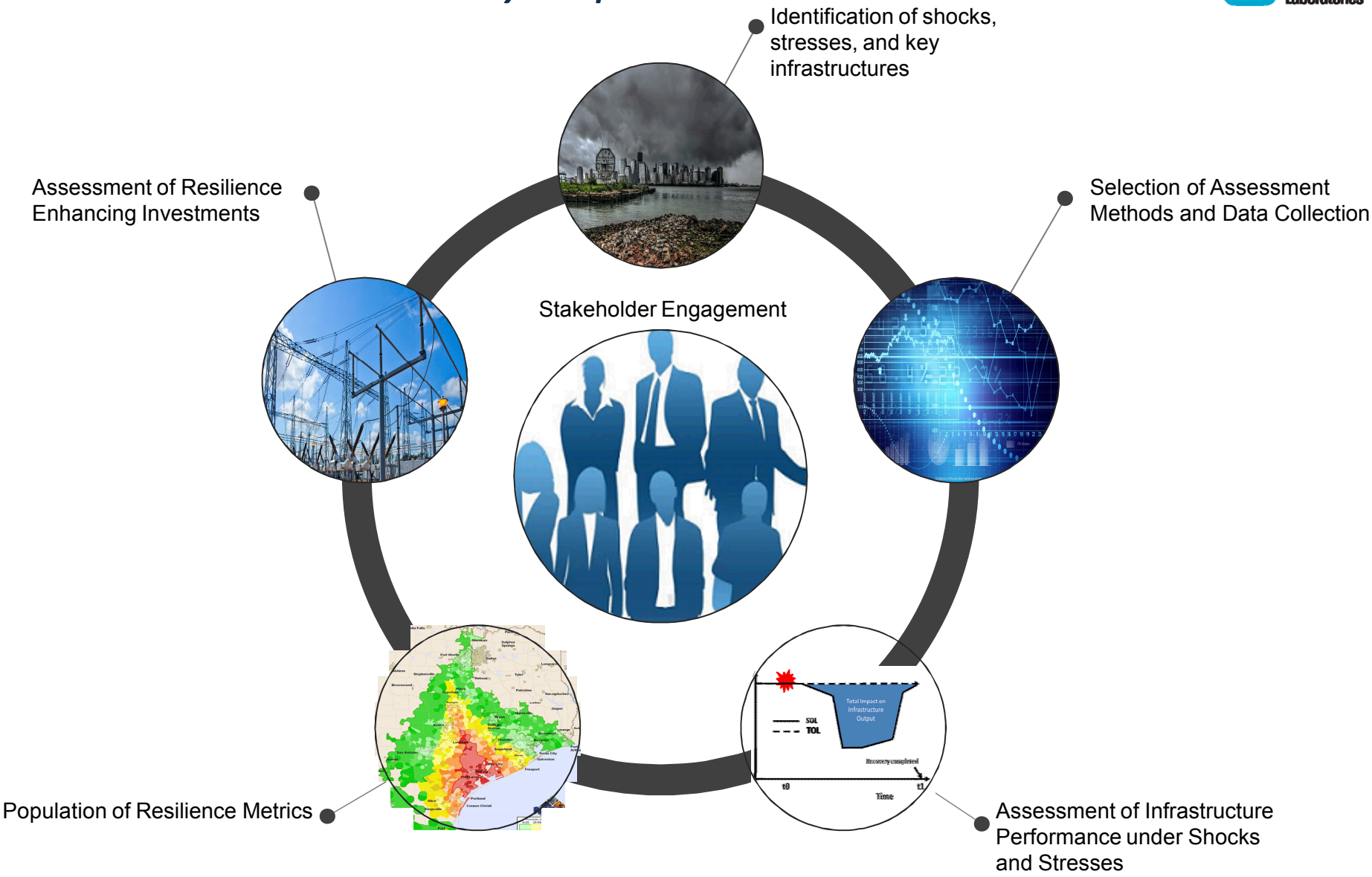
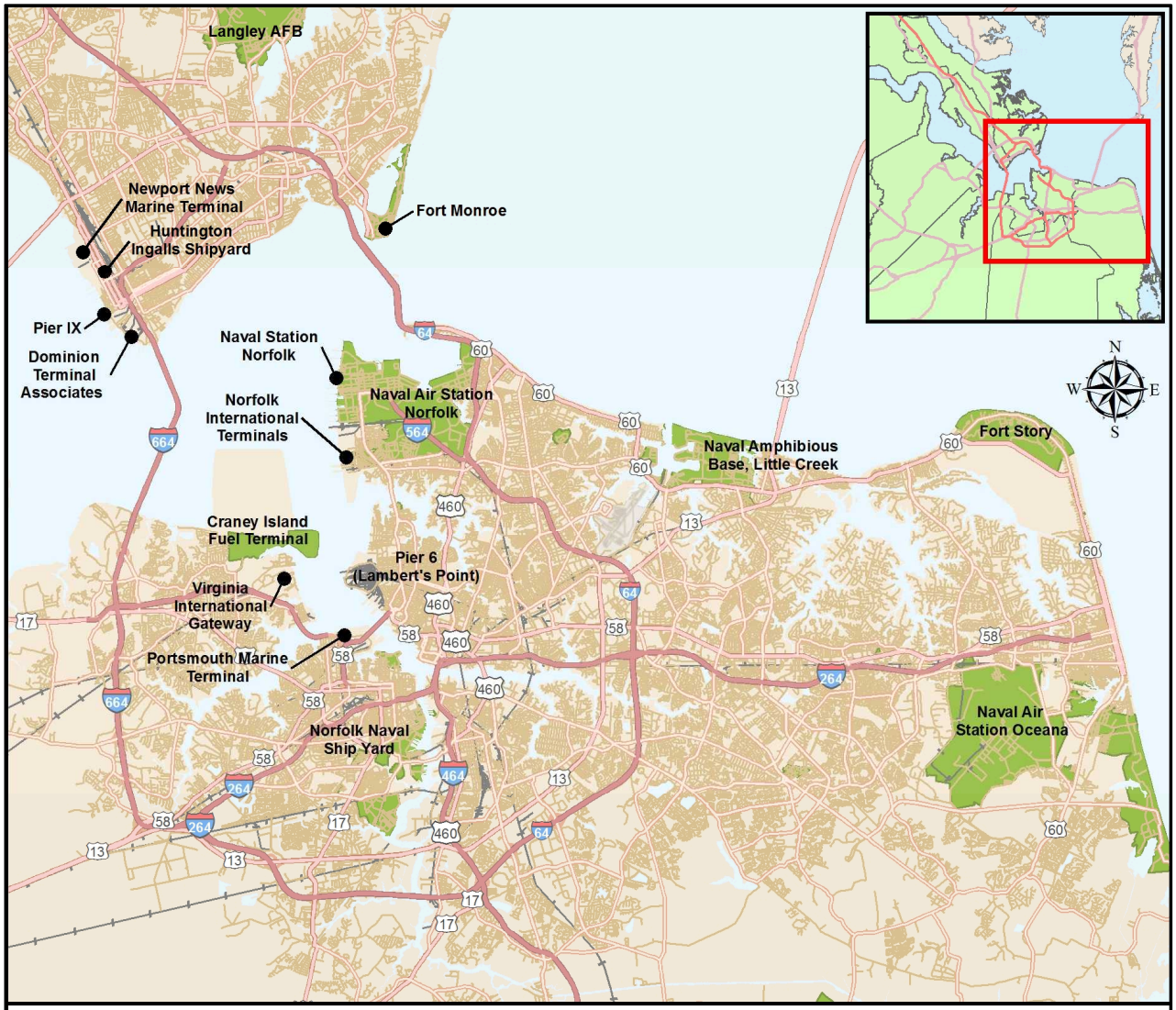
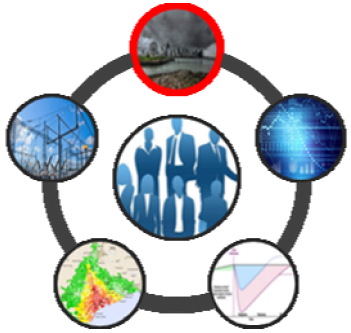


Norfolk, VA – shocks and stresses



Region of Study with Major Facilities of Interest



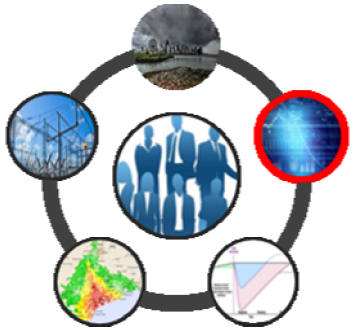
Norfolk, VA: "When we experience flooding, how are the region, nation, and world impacted?"

Economic Productivity

Global Security

Four critical infrastructures:

- *Electric power, Voice communications, Transportation, Petroleum fuels*



Selection of analysis tools:

Calculate flood depths

Analyze infrastructure performance

Analyze asset performance

Calculate economic impacts

Project national and global impacts

Available data

FIRMs

HSIP freedom

City data

US Census Trade

Generated data

EP and Comms

Application of GIS analysis for three 100-year flood scenarios: +0ft, +1.5ft, +3ft of net sea level rise

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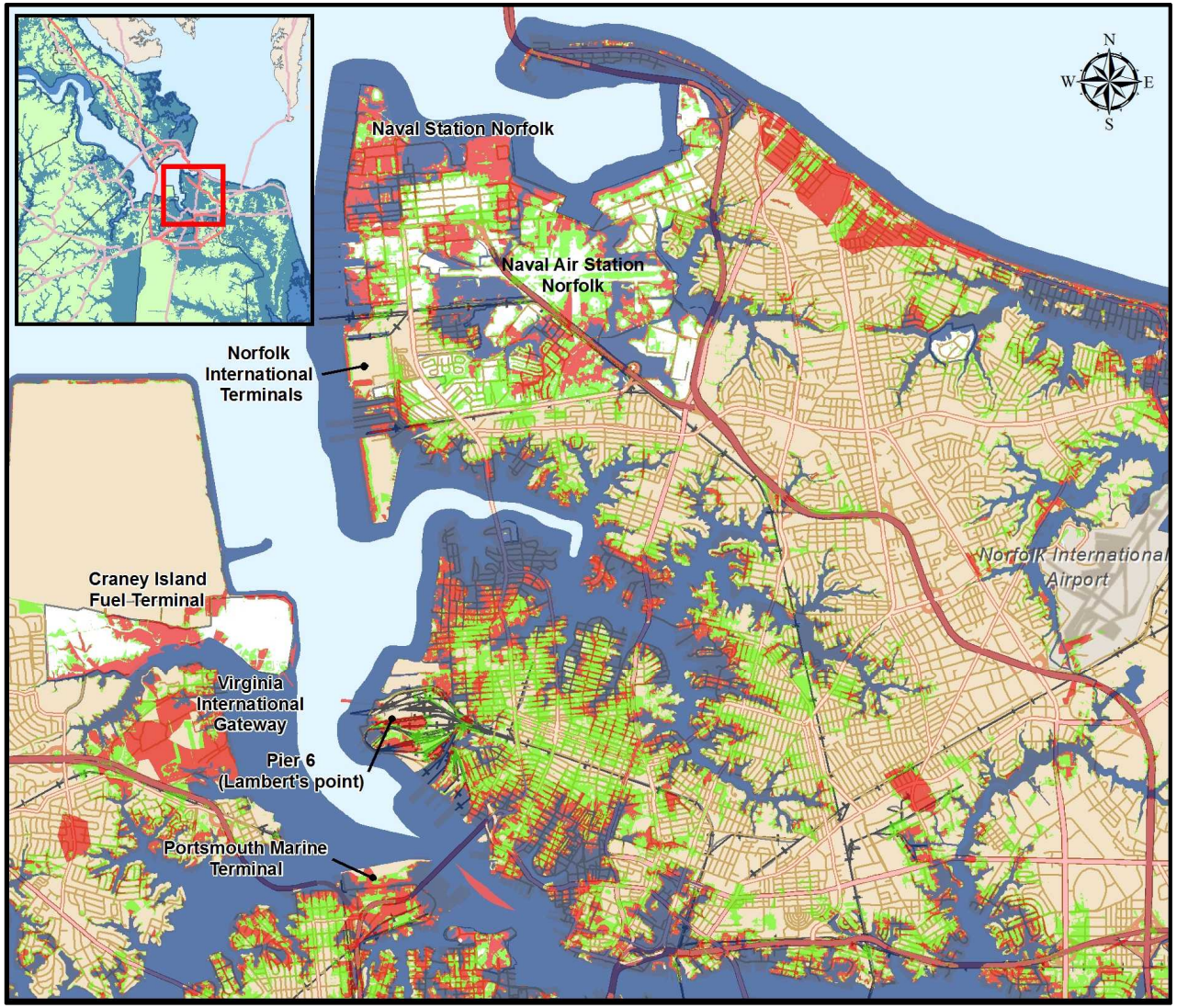

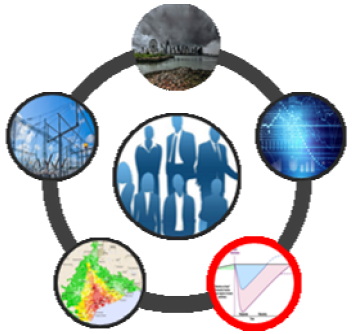

Projection of infrastructure performance and asset performance

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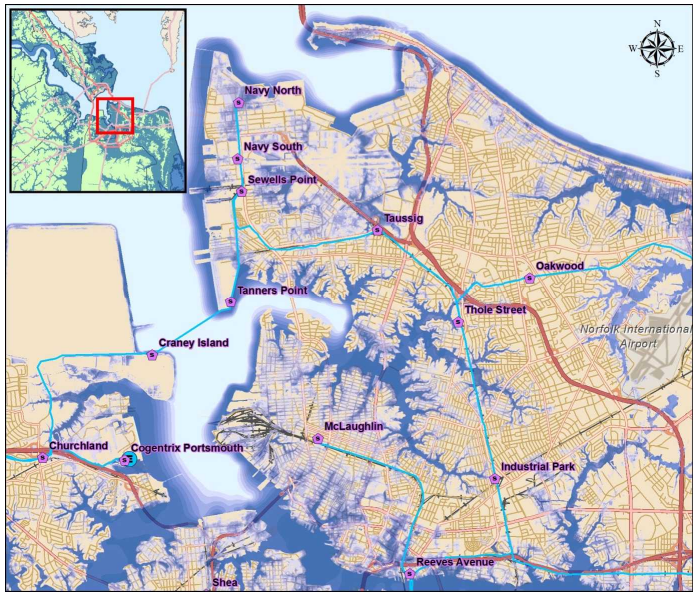

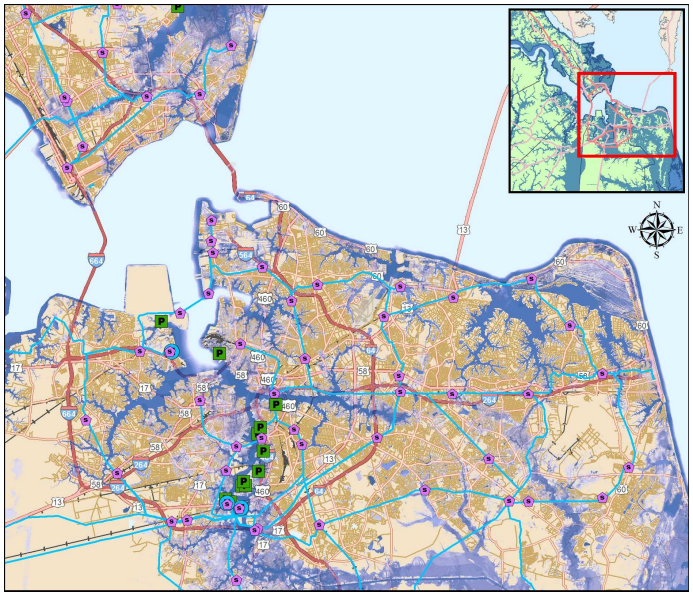

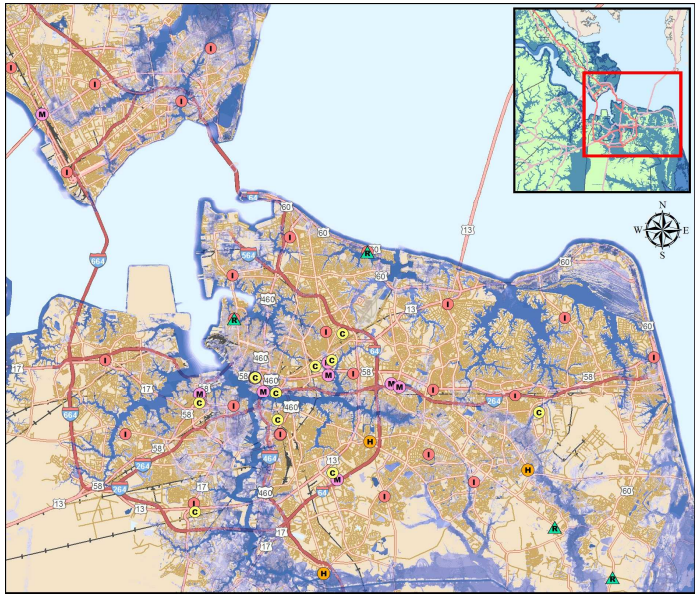

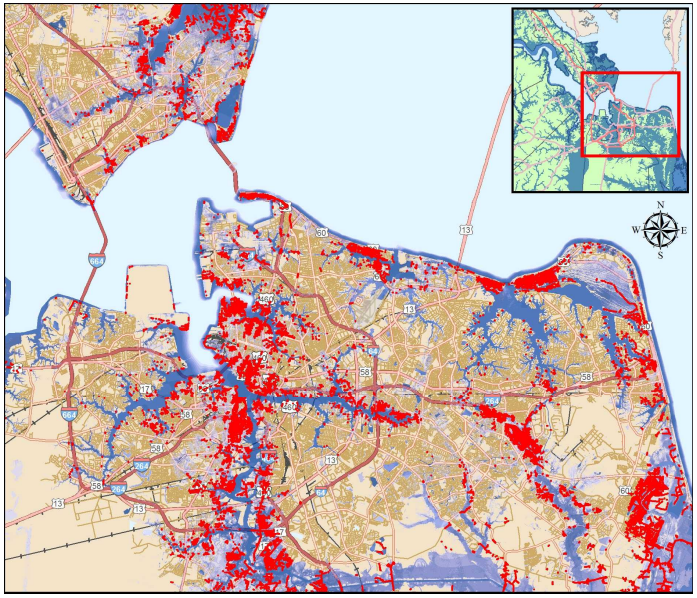

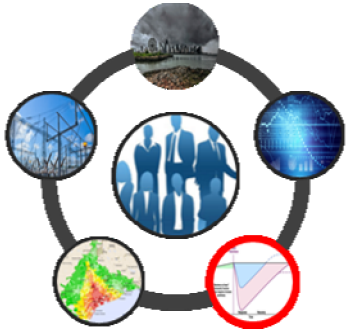

Open Data Sources:

Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Telecommunications data from: http://www.sandman.com/cosearch.asp https://telcodata.us/, http://www.co-buildings.com/va/757/

Electric Power Infrastructure: https://www.openstreetmap.org/, https://www.dom.com/residential/dominion-virginia-power http://www.pjm.com/about-pjm.aspx, http://www.eia.gov/electricity/annual/, http://www.eia.gov/maps/layer_info-m.cfm
Fuels Infrastructure: http://www.eia.gov/maps/layer_info-m.cfm, https://www.tankterminals.com/index_auth.php

Economic impacts calculated by REAcct

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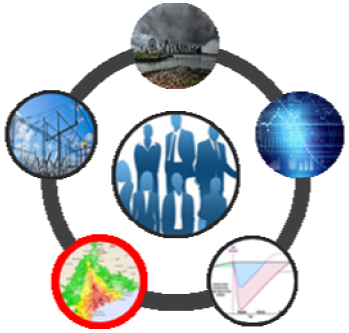
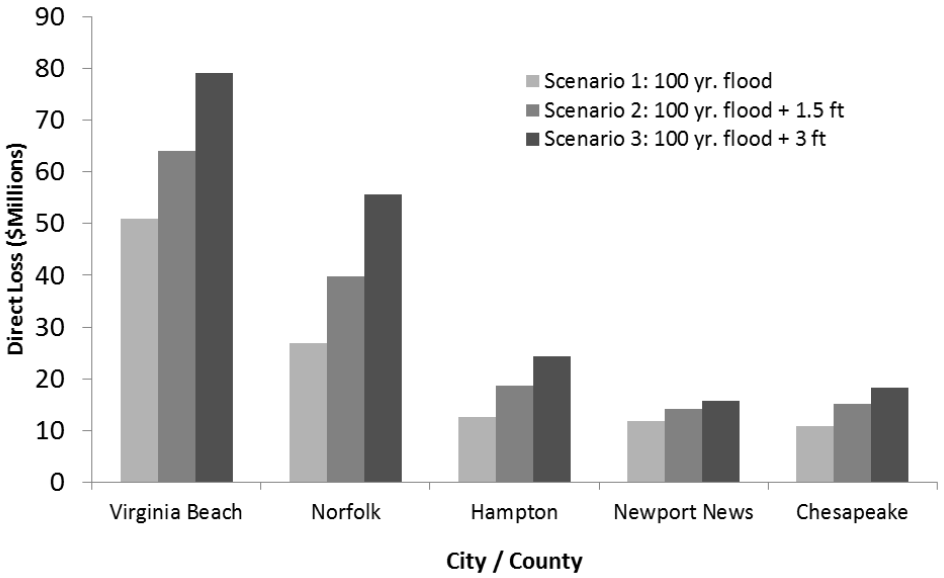


Top 5 cities or counties ranked by four day direct losses



Norfolk and Hampton increase disproportionately from the +0ft to +3ft scenarios compared to other cities and counties. (carry color through) *do this with graphics

Summary of four day direct and indirect losses for three flooding scenarios

	Scenario 1	Scenario 2	Scenario 3
Annual Direct Losses	$135 M	$182.3 M	$230.9 M
Annual Indirect Losses	$219 M	$296.3 M	$375.5 M
Total	$354 M	$478.7 M	$606.4 M

Cascading economic impacts due to container transportation disruption

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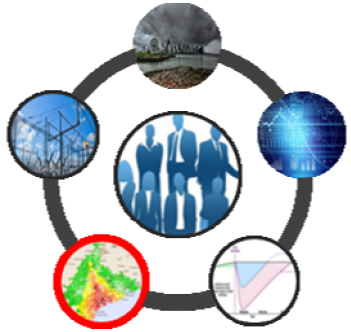

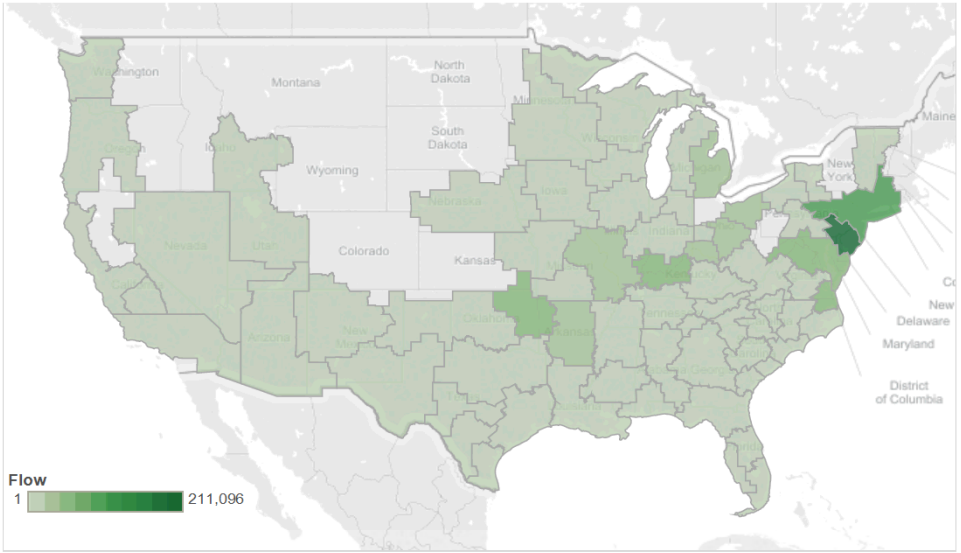

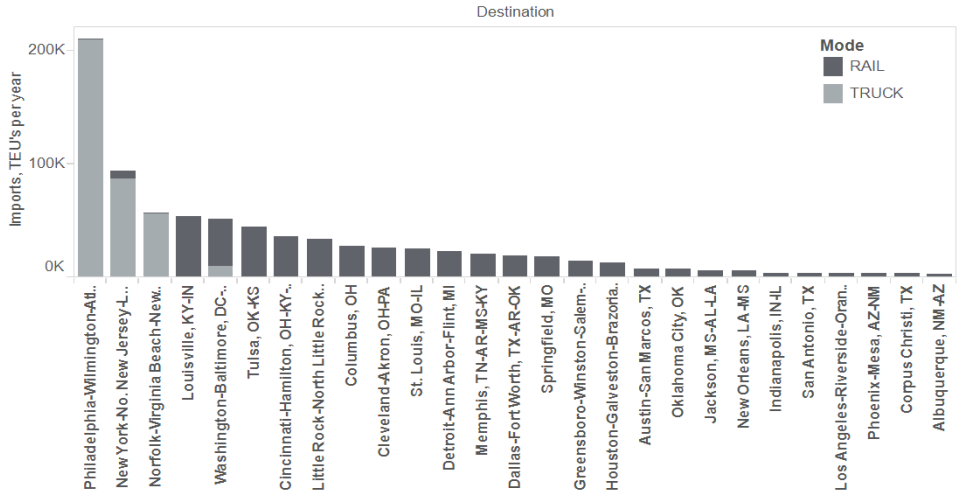

1. Jones, D. et al. (2009) SIERRA: System for Import/Export Routing and Recovery Analysis

2. American Association of Port Authorities, 2010. "North American Port Container Traffic, 2007," accessed online at www.aapa-ports.org, 6/9/2010

Insight into global impacts of loss of Hampton Roads ports

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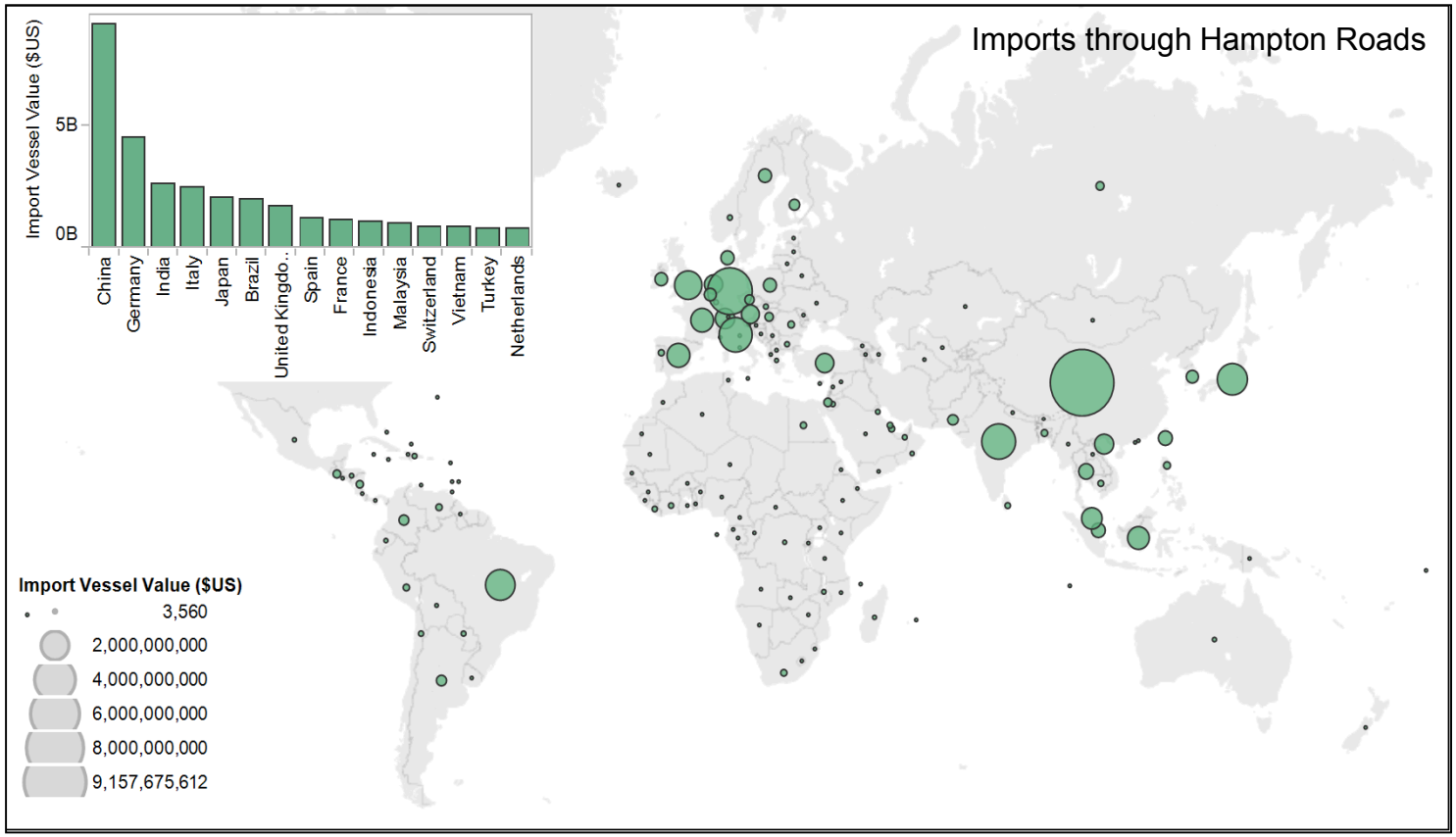
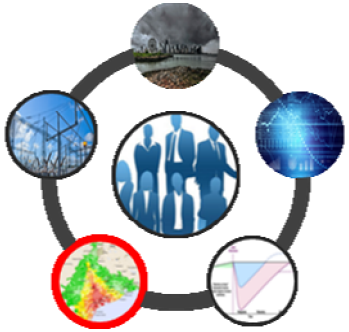
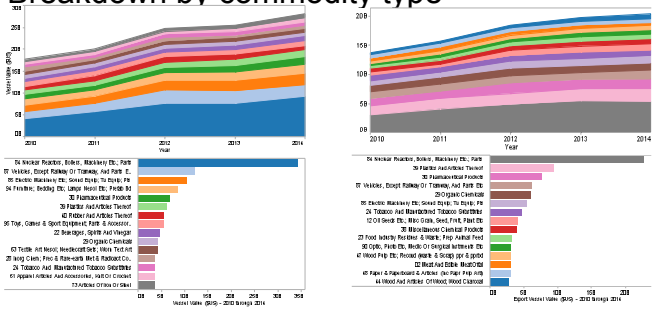


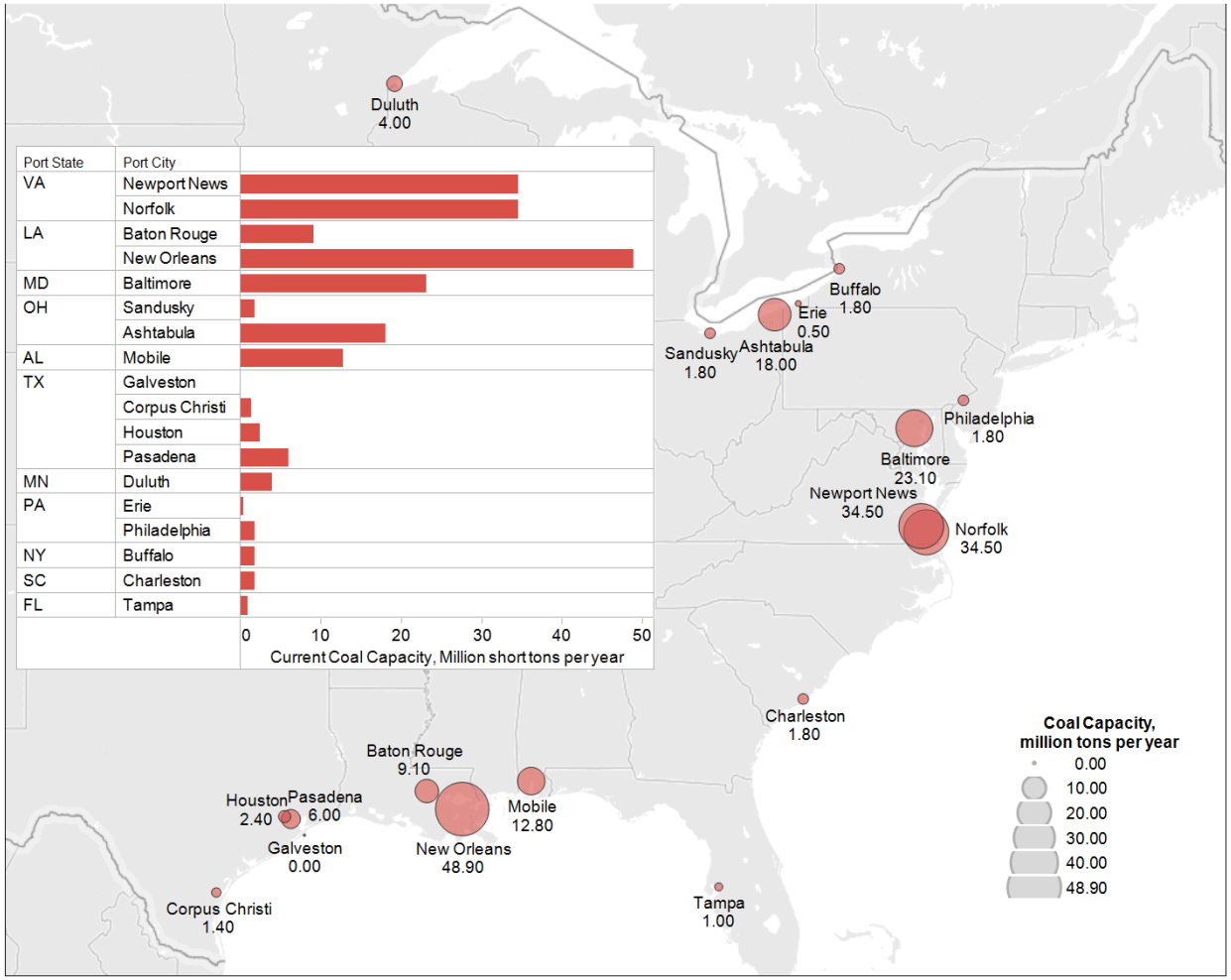


Exports through Hampton Roads

Breakdown by commodity type



Lambert's Point is a globally-critical coal export facility



Source: US Coal Exports Existing and Proposed Coal Infrastructure, Accessed July 2015: http://www.uscoalexports.org/data/Coal-Port-Capacity-and-Projections.pdf

Global reliance on Hampton Roads for coal shipments

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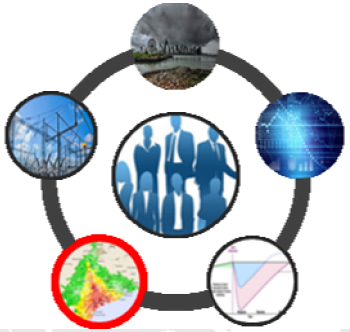
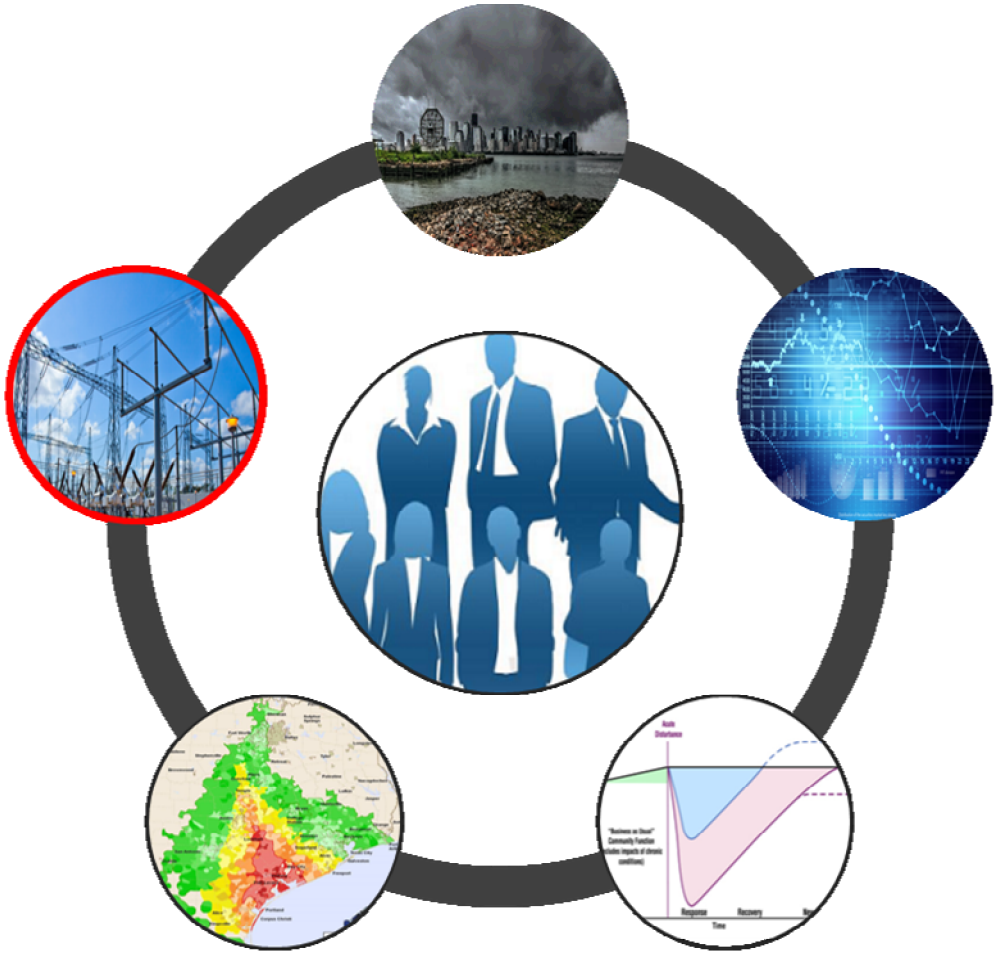


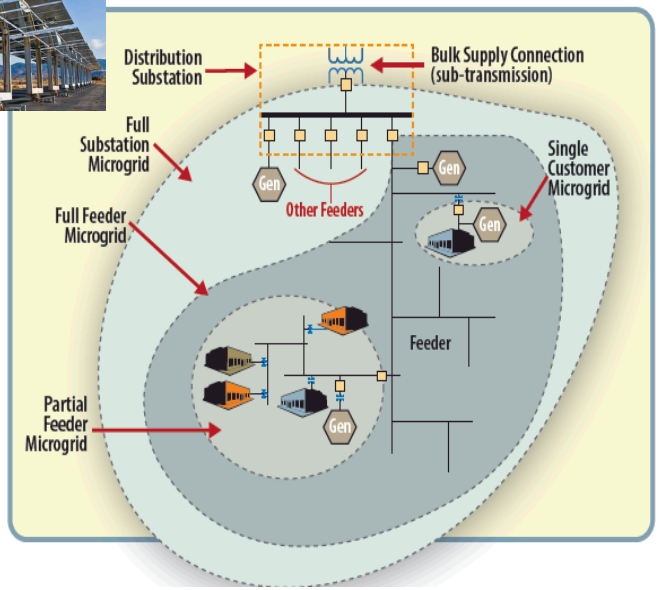
US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

Closing the loop: analyzing the benefits of resilience-enhancing investments



New Orleans, LA

GRID MODERNIZATION LAB CONSORTIUM



Selecting, socializing, and designing grid improvements that improve NOLA's holistic resilience

Engaged partners:

City of New Orleans
- Sewerage and Water Board
- Homeland Security and Emergency Preparedness

US Army Corps of Engineers

Entergy New Orleans

New Orleans, LA

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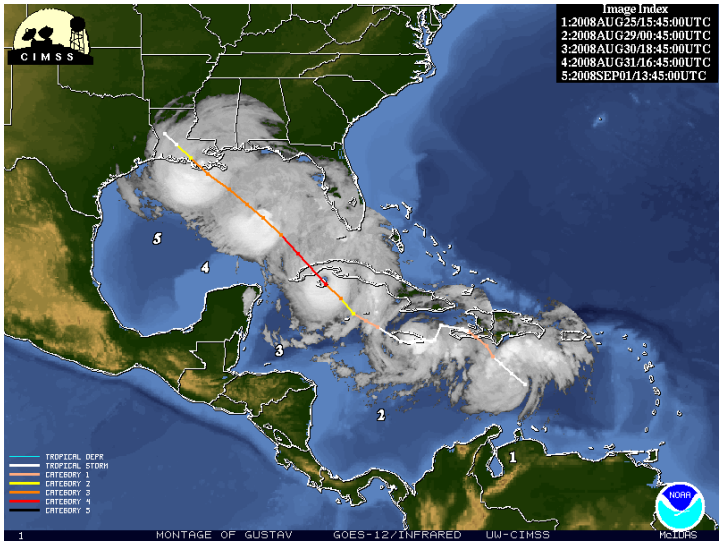
Hurricane Simulation → Infrastructure Analysis → Consequence Estimation

Hurricane Simulation	Infrastructure Analysis	Consequence Estimation
Wind speed	Damaged infrastructure	Citizens without infrastructure services
Inundation	Infrastructure services through time	



Pathway Katrina followed before and after Katrina hit land. Picture from NOAA. (http://www.vos.noaa.gov/MWL/apr_06/katrina.shtml)

Montage of Gustav. Picture from NOAA. (http://http://www.srh.noaa.gov/lix/?n=gustav2008

BACKUP

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Norfolk has regional, national, and global significance

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Global security

- Naval Station Norfolk
  - US Atlantic Fleet
  - NATO Allied Command Transformation
  - Military Sealift Command HQ
- Norfolk Shipbuilding and Drydock Co.

World Trade

- Norfolk International Terminal (containers)
- Lambert's Point (coal), Norfolk Southern

Regional Partner

- Newport News Marine Terminal (bulk, RO-RO)
- Pier IX (coal)
- Dominion Terminal Associates (coal)
- Huntington Ingalls (shipyard)
- Norfolk Naval Shipyard

Norfolk is experiencing increasing flood risk

Increasing probability and impact of flood

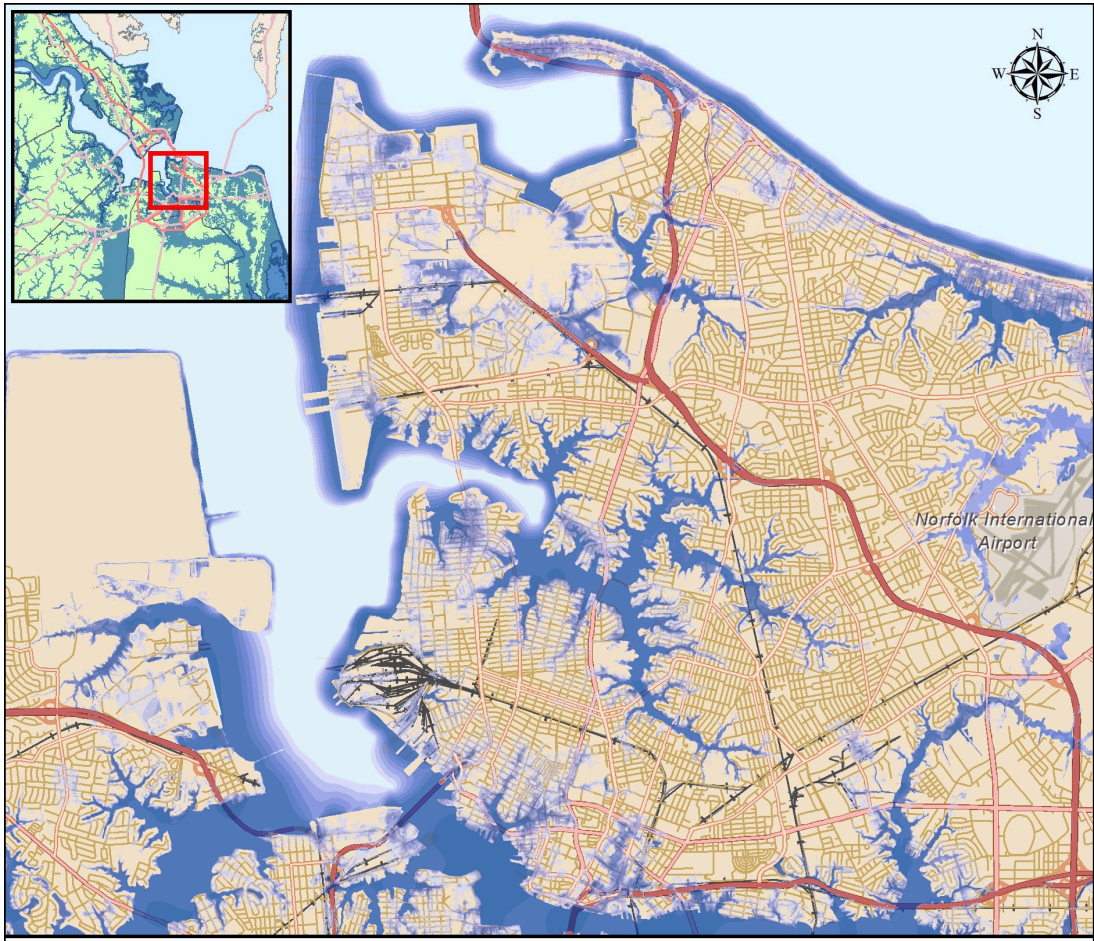
- Frequency and magnitude of storms[1]
- Thermohaline current change[1]
- Sea level rise[2]
- Subsidence[1]
- Glacial isostatic adjustment[3]

1. VIMS recurrent flooding study: http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf
2. Fugro Atlantic Citywide Coastal Flooding Eval. May 2012.
3. USGS, Land Subsidence and Relative Sea Level Rise in the Southern Chesapeake Bay Region. 2013: http://pubs.usgs.gov/circ/1392/pdf/circ1392.pdf

What does a likely worst case flood event look like?

100 year flood with three variations of net sea level rise

- +0 ft, +1.5 ft, +3 ft
- Assumed the nor'easter event
- Did not analyze impacts of wind (e.g. hurricane)
  - Indication that high-wind hurricanes are not coincident with 100yr flood hurricanes



Flood Inundation - (FEMA 100yr Flood with 1.5 ft. of Sea Level Rise)

Flood Depth (feet)

0 - 1	4 - 5
1 - 2	5 - 6
2 - 3	6 - 10
3 - 4	> 10

Miles

0 0.5 1 1.5 2

Data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal

What does a likely worst case flood event look like?

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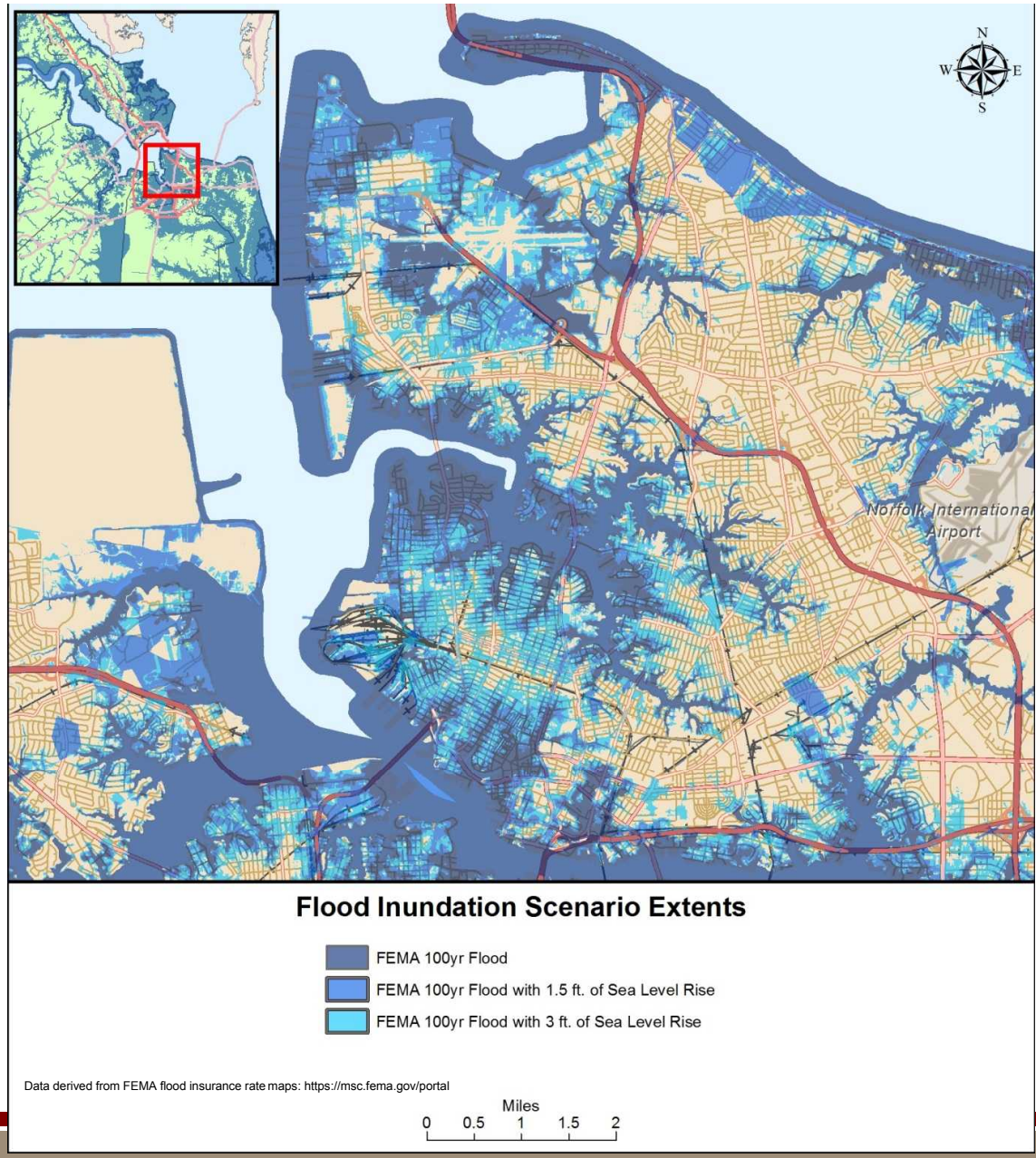
100 year flood with three variations of net sea level rise

- Extent of flooding increases considerably with +3ft scenario
- Norfolk peninsula between Lafayette and Elizabeth Rivers becomes more inundated than not



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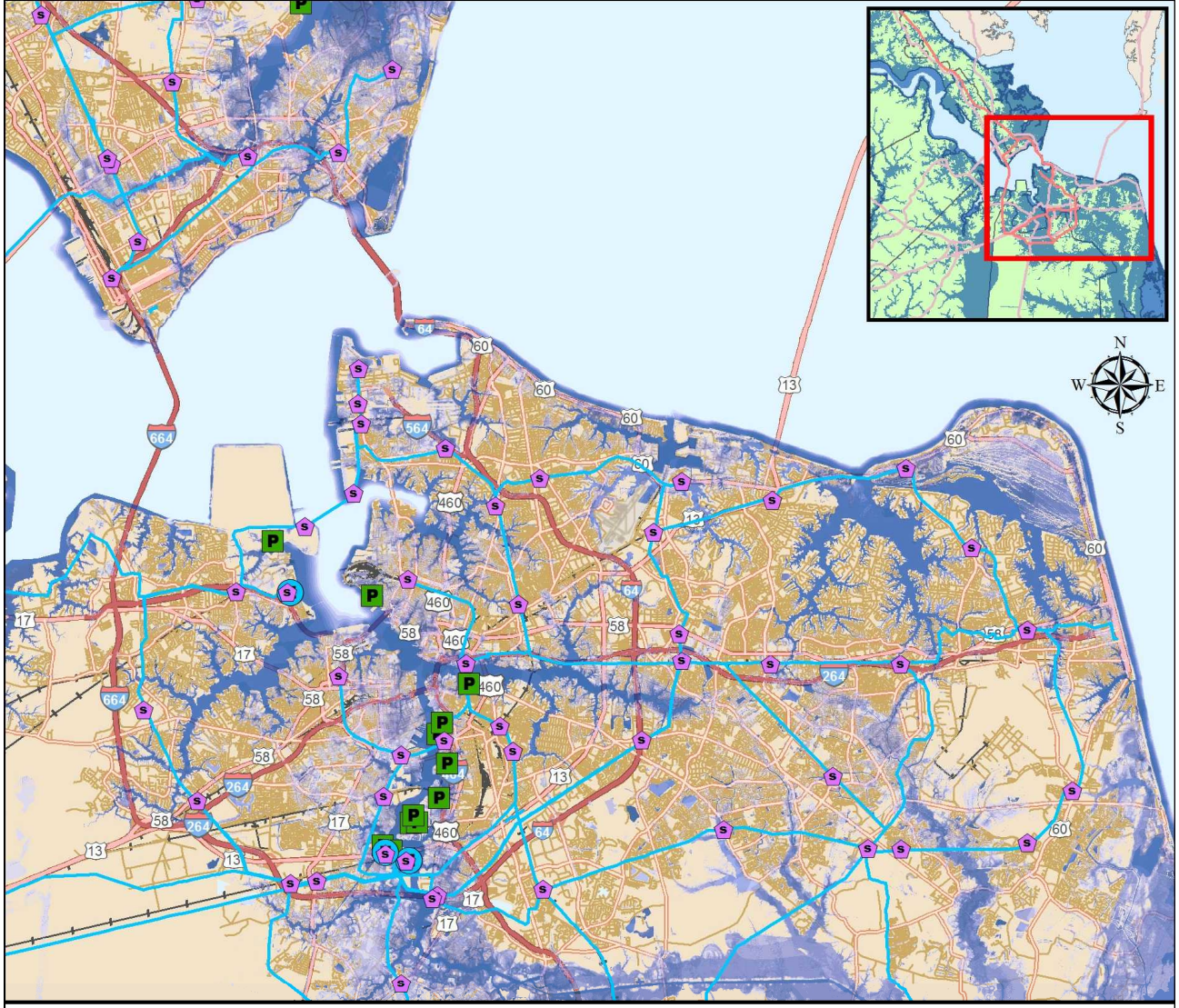


Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Electric Power & Petroleum Terminal Assets

- Electric Power Substation
- Petroleum Product Terminal
- Electric Power Plant
- Electric Transmission Line

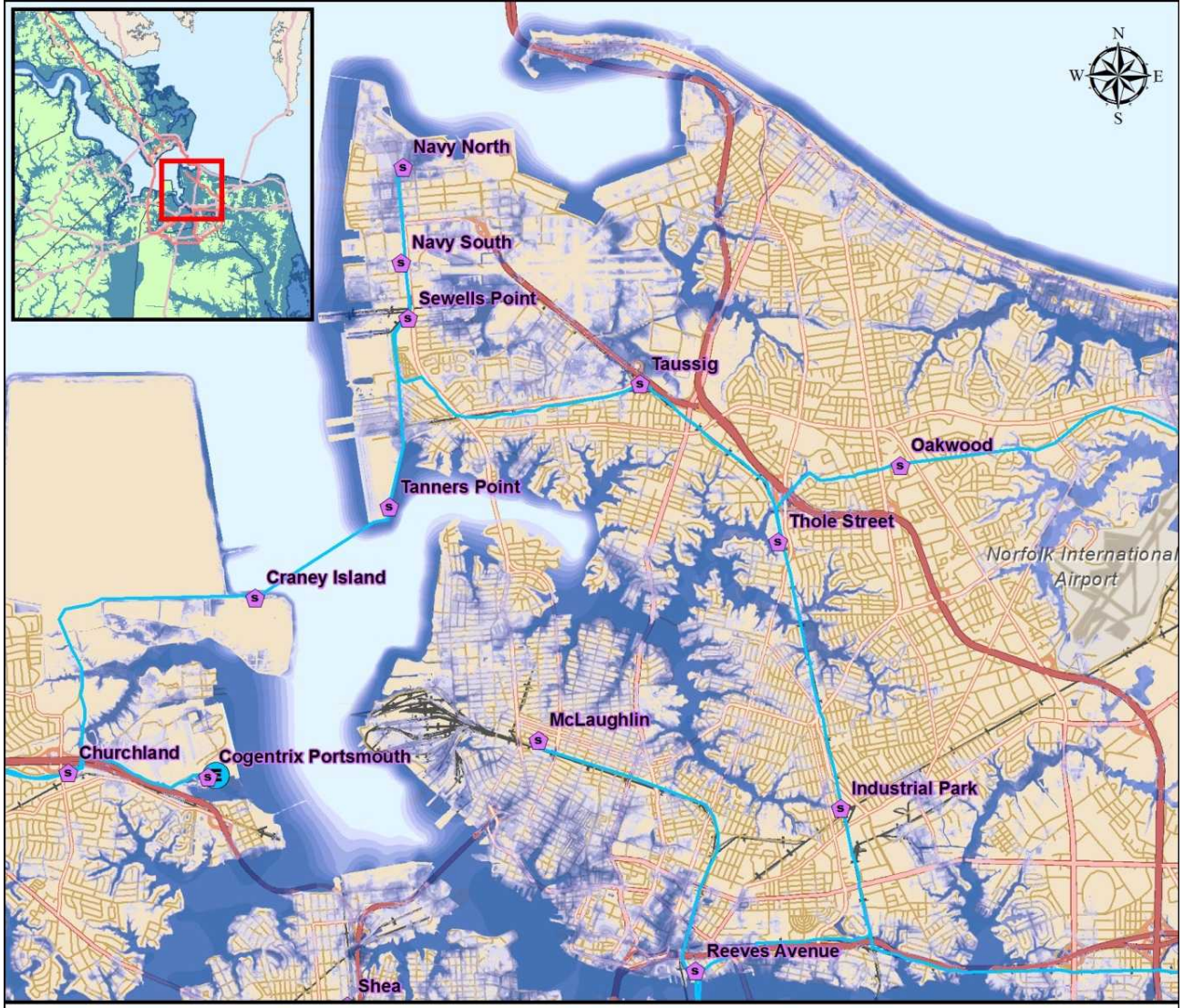
Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Electric Power Infrastructure: https://www.openstreetmap.org/,
https://www.dom.com/residential/dominion-virginia-power
http://www.pjm.com/about-pjm.aspx, http://www.eia.gov/electricity/annual/,
http://www.eia.gov/maps/layer_info-m.cfm
Fuels Infrastructure: http://www.eia.gov/maps/layer_info-m.cfm,
https://www.tankterminals.com/index_auth.php

- Major Highway
- Highway
- Major Road
- Street
- Rail Line

Flood Depth (feet)

0 - 1	4 - 5
1 - 2	5 - 6
2 - 3	6 - 10
3 - 4	> 10

Miles
0 2 4 6 8 10



Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Electric Power Assets

- Electric Power Substation
- Electric Transmission Line
- Electric Power Plant

Flood Depth (feet)

0 - 1	4 - 5
1 - 2	5 - 6
2 - 3	6 - 10
3 - 4	> 10

Miles: 0 1 2 3 4

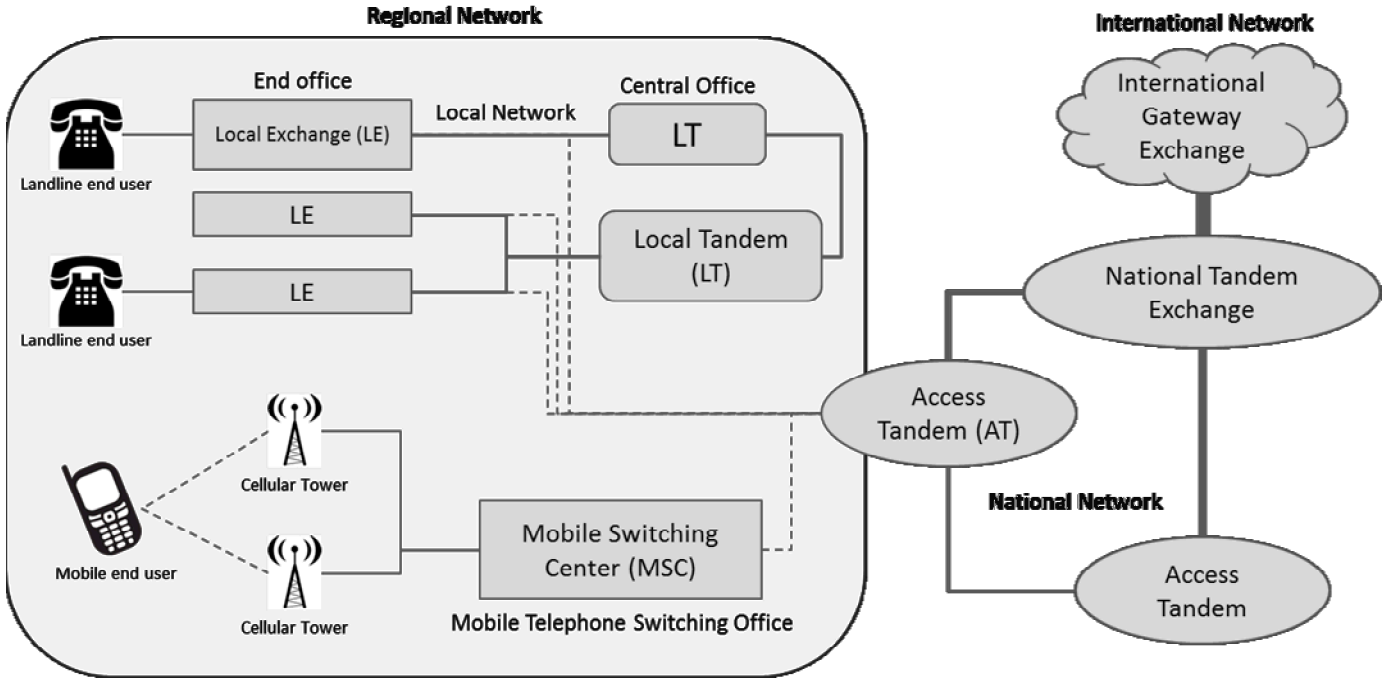
Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Electric Power Infrastructure: https://www.openstreetmap.org/,
https://www.dom.com/residential/dominion-virginia-power
http://www.pjm.com/about-pjm.aspx, http://www.eia.gov/electricity/annual/,
http://www.eia.gov/maps/layer_info-m.cfm

Substations under more than 1ft of maximum flood inundation in the +3ft scenario, with depths of greater than 2 ft. highlighted in bold.

Substation Name	City/County	Max depth +0ft	Max depth +1.5ft	Max depth +3ft
Dozier	Chesapeake, VA	**2.71**	**3.71**	**4.71**
Gosport	Chesapeake, VA	0.44	1.05	**2.05**
Greenwich	Chesapeake, VA	0.00	1.24	1.58
Huntsman Chemical	Chesapeake, VA	1.10	**2.10**	**2.10**
Industrial Park	Norfolk, VA	0.00	1.48	**2.48**
Long Creek	Virginia Beach, VA	**2.17**	**2.17**	**3.17**
Berkley	Chesapeake, VA	0.89	1.89	**2.26**
Bloxoms Corner	Hampton, VA	**3.01**	**4.01**	**5.01**
Chesapeake	Chesapeake, VA	1.13	1.54	**2.35**
Churchland	Portsmouth, VA	0.00	0.00	1.39
Cradock	Chesapeake, VA	1.08	1.77	**2.77**
Navy North	Hampton, VA	0.00	0.86	1.91
Reeves Avenue	Norfolk, VA	1.23	**2.23**	**3.23**
Shea	Portsmouth, VA	0.00	0.00	1.06
Shellbank	Hampton, VA	**2.81**	**3.81**	**4.55**
Tanners Point	Norfolk, VA	0.12	**2.64**	**2.78**
Thole Street	Norfolk, VA	**2.13**	**3.01**	**4.13**
Union Carbide	Poquoson, VA	0.00	1.27	1.81
Whealton	Newport News, VA	0.00	0.00	1.08

Note Industrial Park, Reeves Avenue, Tanners Point, and Thole Street

Generic voice switching diagram for routing of landline and cellular communications.



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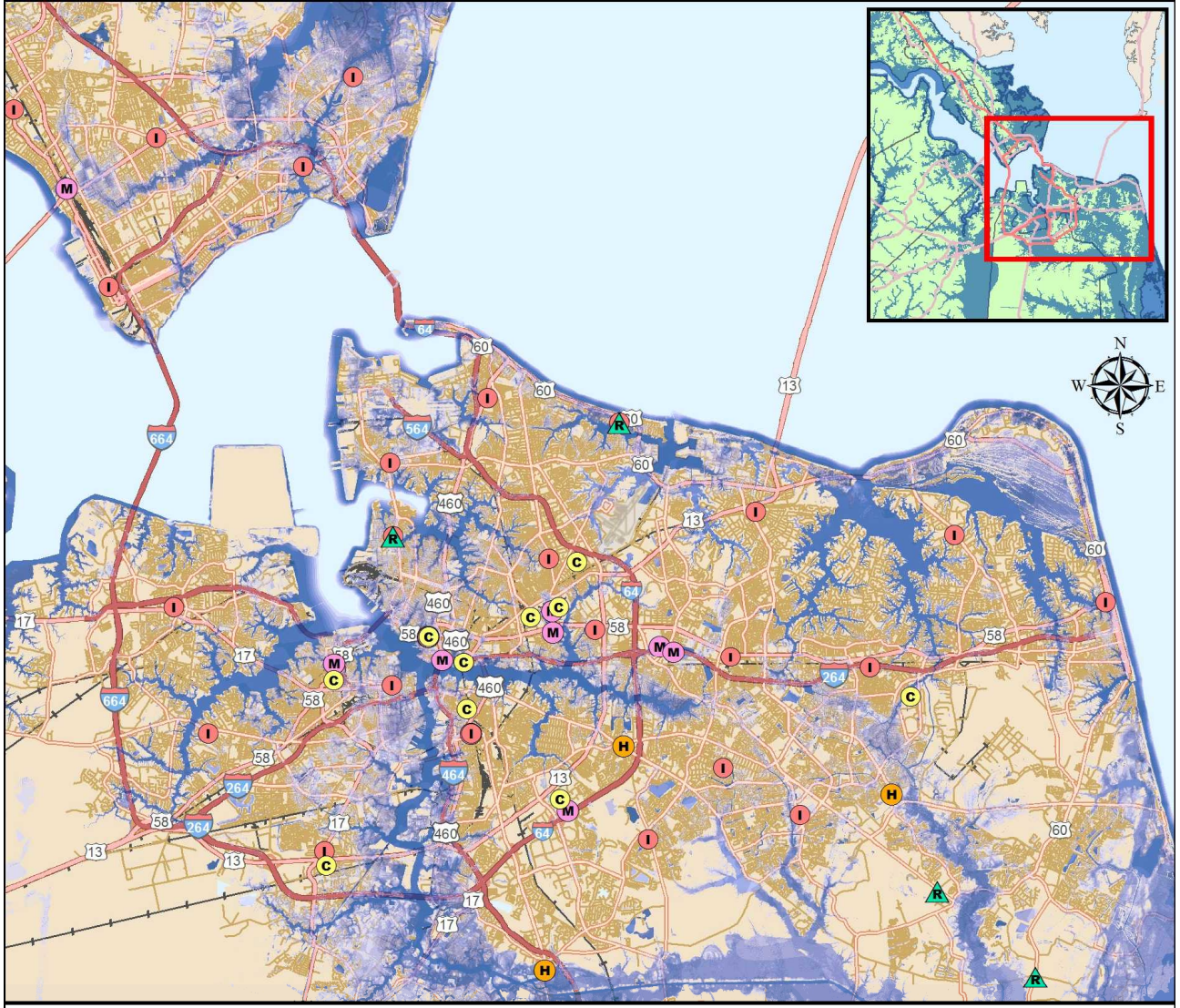


Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Telecom Assets

- C — Competitive Wire Center
- I — Incumbent Wire Center
- M — Mobile Switching Center
- H — Hosting Wire Center
- R — Remote Wire Center

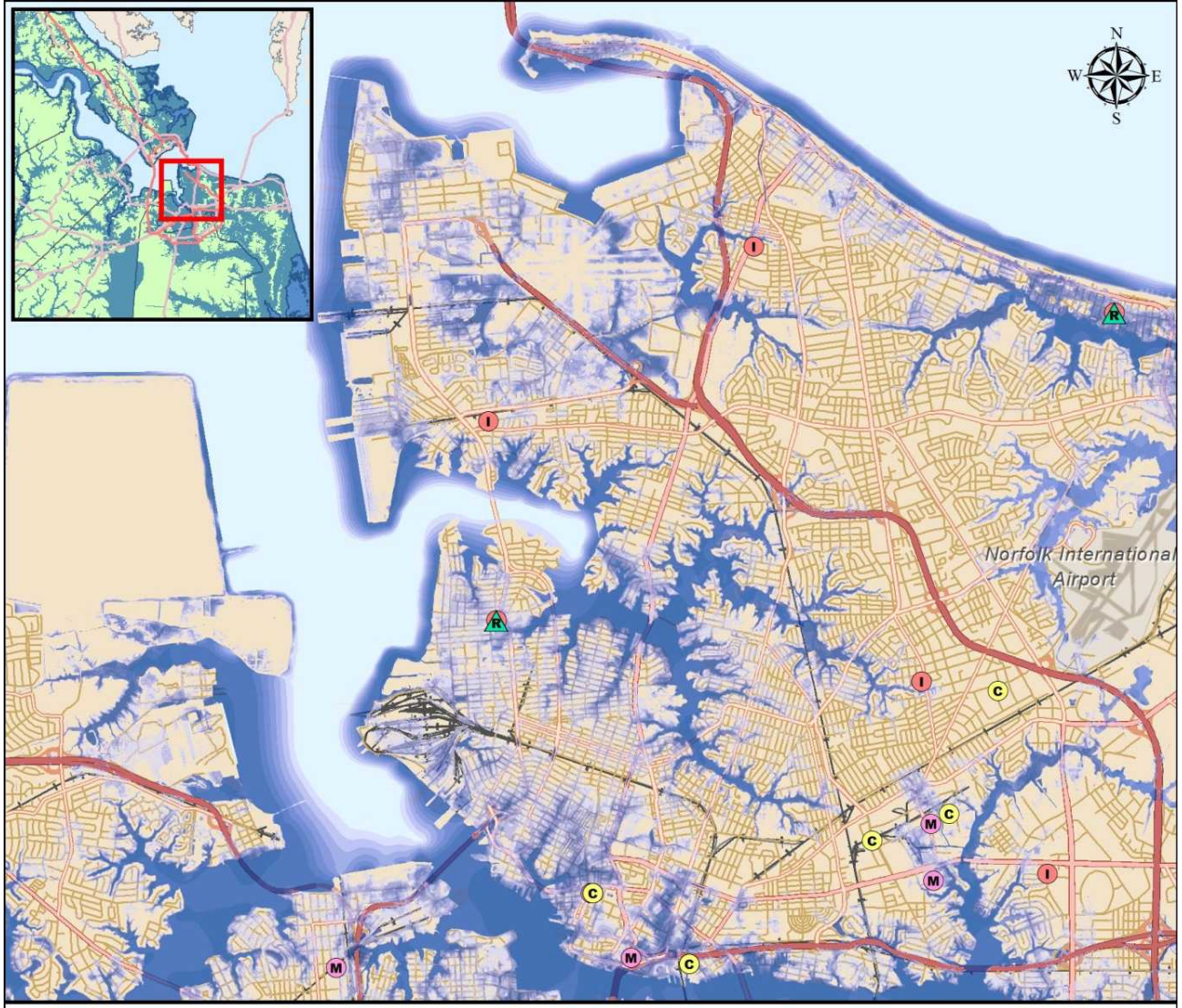
- Major Highway
- Highway
- Major Road
- Street
- Rail Line

Flood Depth (feet)

0 - 1	4 - 5
1 - 2	5 - 6
2 - 3	6 - 10
3 - 4	> 10

Miles: 0 2 4 6 8 10

Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Telecommunications data from: http://www.sandman.com/cosearch.asp
https://telcodata.us/, http://www.co-buildings.com/va/757/



Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Telecom Assets

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Miles: 0 1 2 3 4

Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Telecommunications data from: http://www.sandman.com/cosearch.asp
https://telcodata.us/, http://www.co-buildings.com/va/757/

Wire centers under more than 1ft of maximum flood inundation in the +3ft scenario, with depths of greater than 2 ft. highlighted in bold.

Wire Center Code	No. Switches	City/County	Max depth +0ft	Max depth +1.5ft	Max depth +3ft
GRBRVAXA	2	Chesapeake, VA	0.00	0.67	1.67
NRFLVA06	1	Norfolk, VA	0.00	0.07	1.07
NRFLVAOD	1	Norfolk, VA	0.00	0.14	1.14
NRFLVAOV	1	Norfolk, VA	1.45	**2.45**	**3.45**
HMPNVAQN	1	Hampton, VA	0.16	0.16	1.16

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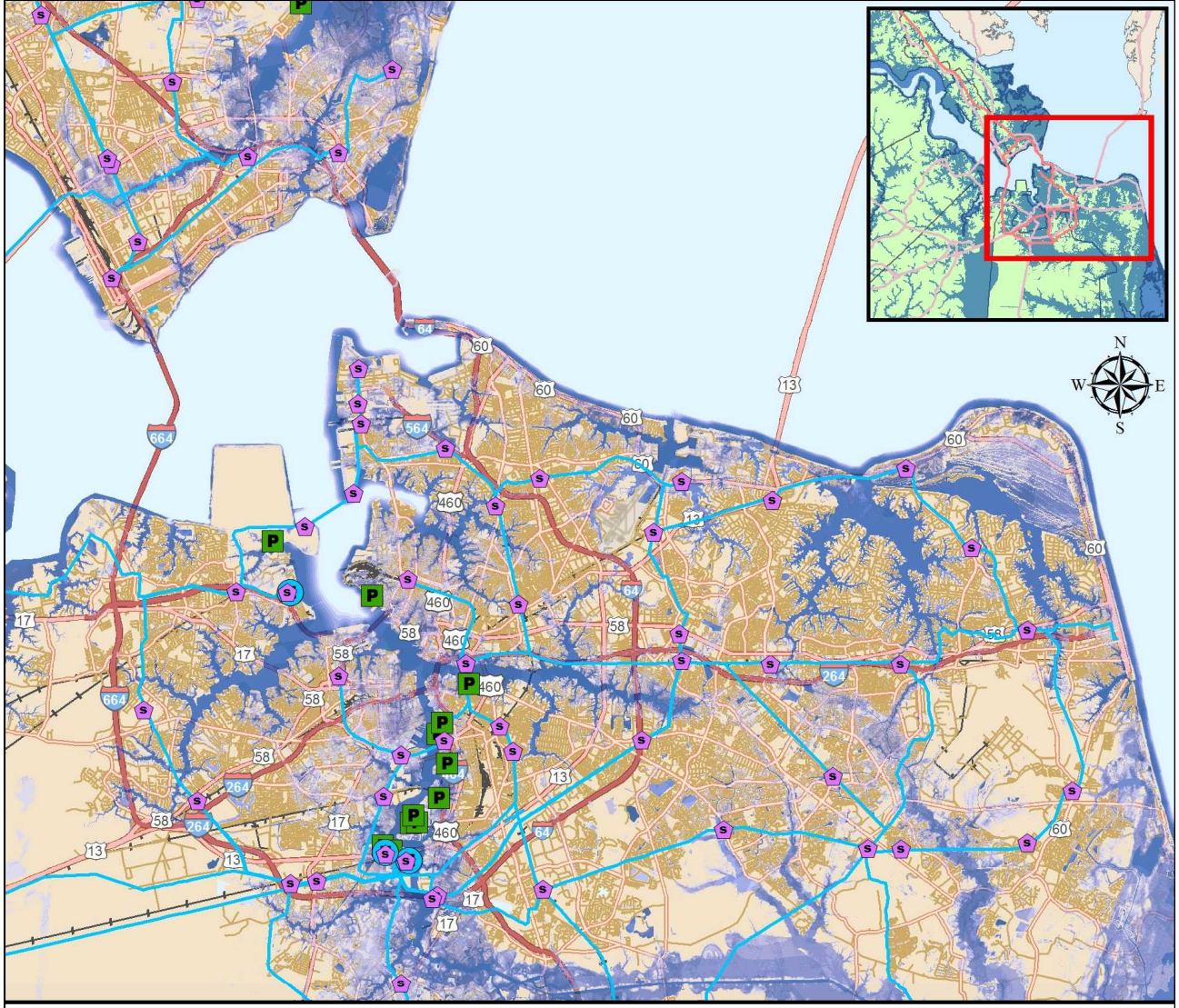

Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Electric Power & Petroleum Terminal Assets

- Electric Power Substation
- Petroleum Product Terminal
- Electric Power Plant
- Electric Transmission Line

Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal
Electric Power Infrastructure: https://www.openstreetmap.org/,
https://www.dom.com/residential/dominion-virginia-power
http://www.pjm.com/about-pjm.aspx, http://www.eia.gov/electricity/annual/,
http://www.eia.gov/maps/layer_info-m.cfm
Fuels Infrastructure: http://www.eia.gov/maps/layer_info-m.cfm,
https://www.tankterminals.com/index_auth.php

- Major Highway
- Highway
- Major Road
- Street
- Rail Line

Flood Depth (feet)

0 - 1	4 - 5
1 - 2	5 - 6
2 - 3	6 - 10
3 - 4	> 10

Miles
0 2 4 6 8 10

Sandia National Laboratories

Fuel terminals under more than 1ft of maximum flood inundation in the +3ft scenario, with depths of greater than 2 ft. highlighted in bold.[2]

Terminal Name	City/County	Capacity (bbl)	Max depth +0ft	Max depth +1.5ft	Max depth +3ft
DCP Midstream Partners	Chesapeake, VA	480,000	**10.171**	**9.738**	**9.738**
International Matex Tank	Chesapeake, VA	963,000	**4.772**	**5.357**	**5.357**
Buckeye	Chesapeake, VA	980,000	**3.421**	**4.394**	**5.394**
Kinder Morgan Southeast	Chesapeake, VA	375,000	**3.417**	**3.417**	**3.417**
CITGO Petroleum	Chesapeake, VA	347,286	**4.646**	**4.287**	**5.287**
Kinder Morgan Liquids	Chesapeake, VA	1,400,000	**5.719**	**7.923**	**7.005**
Center Point	Chesapeake, VA	567,930	**4.077**	**4.067**	**4.176**
Trans Montaigne Product Services	Chesapeake, VA	1,337,703	**9.232**	**11.232**	**12.232**
ARC Petroleum	Chesapeake, VA	199,756	**10.953**	**9.953**	**10.953**
Kinder Morgan Liquids	Norfolk, VA	420,000	**10.927**	**10.953**	**10.953**
Norfolk Oil Transit	Norfolk, VA	73,331	**3.817**	**4.817**	**3.583**
Naval Station Norfolk - Carney Island	Portsmouth, VA	---[1]	**7.016**	**9.713**	**10.569**
Langley AFB	Hampton, VA	---	0.000	1.992	**2.218**

1. Fuel terminal capacity for military terminals not available at time of study
2. Fuels Infrastructure: http://www.eia.gov/maps/layer_info-m.cfm, https://www.tankterminals.com/index_auth.php

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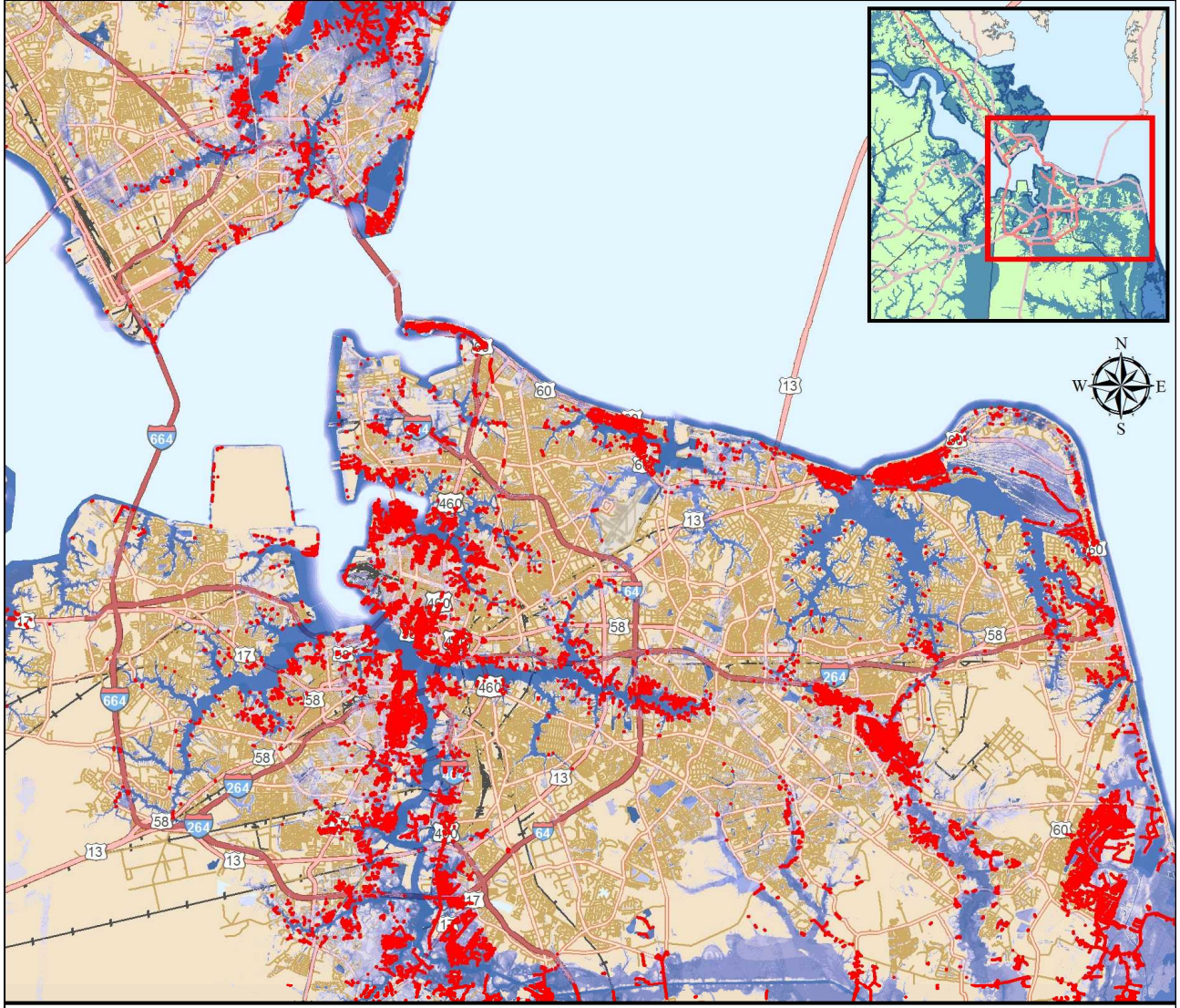


Flood Inundation - (FEMA 100yr Flood with 3 ft. of Sea Level Rise)

Potentially Inundation Transporation Route

Affected Road Segment

Major Highway
Highway
Major Road
Street
Rail Line

Flood Depth (feet)

0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 10
> 10

Miles
0 2 4 6 8 10

Flood data derived from FEMA flood insurance rate maps: https://msc.fema.gov/portal

Inundated Roadways Data: HRTPO (2013) Hampton Roads Military Transportation Needs Study: Roadways Serving the Military and Sea Level Rise/Storm Surge.

Estimation of infrastructure impacts

Sandia National Laboratories

Telecommunications

- Lambert's Point: High likelihood of loss of landline and wireless comms in +3ft scenario, medium likelihood in +0ft and +1.5ft
- NIT and NAVSTA Norfolk: low likelihood of loss of landline comms, indeterminate likelihood of loss of wireless comms, all scenarios

Electric Power

- Lambert's Point: Connected via overhead distribution lines to the transmission backbone. A heavily impacted area. High likelihood of loss of utility service in +3ft, medium to low in +1.5ft and +0ft.
- NIT: Tanner's point substation of concern – recommend assessing which of Tanner's Point and Sewell's Point substations serve NIT. Medium likelihood of loss of power in +3ft, low in +1.5ft and +0ft
- NAVSTA Norfolk: Heavily connected to transmission system. Navy North substation of concern, but likely to have adequate backup systems. Low likelihood of loss of service in all scenarios.

Estimation of infrastructure impacts

Sandia National Laboratories

Fuels

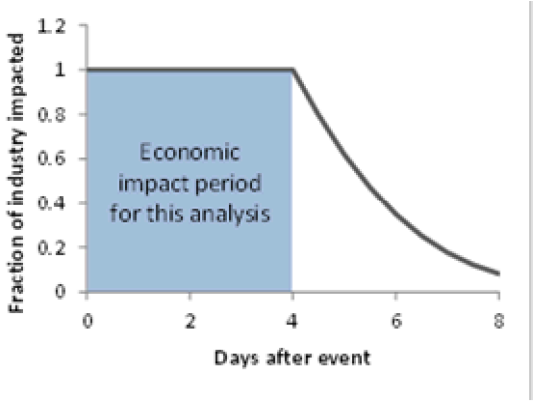
- No crude processing – only refined product in Hampton Roads.
- The Colonial Pipeline spur from the Richmond Area may undergo loss of service due to power outage.
- Many fuel storage terminals are located in Chesapeake along the southern Elizabeth River.
  - These terminals are likely to experience significant damage due to their buoyancy under inundation.
- Although much of the region's storage is impacted, supply via the Colonial Pipeline is expected to resume once power is restored.

Transportation

- Both bridge tunnels across Hampton Roads harbor have high likelihood of closure
  - Approximately 9% of NAVSTA Norfolk workforce live on Virginia Peninsula
- The Norfolk peninsula between Elizabeth and Lafayette rivers combines large population with transportation choke points
- Lambert's point heavily impacted by transportation access problems
- NIT and NAVSTA Norfolk maintain strong connection to I-64

Econ Impact Analysis

Pattern of economic impacts during mitigation and recovery periods.



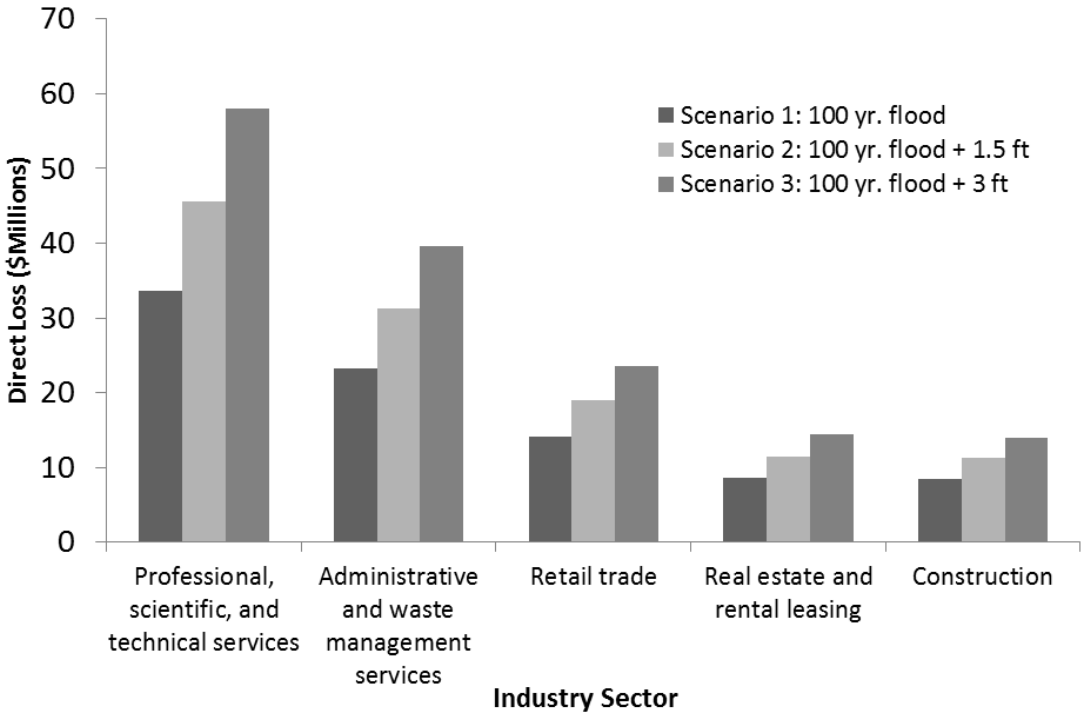
Sandia employed the Regional Economic Accounting Tool (REAcct) to estimate regional and national impacts to economic activity during the flooding period.[1]

1. Vargas, V., Ehlen, M. (2013) REAcct: a scenario analysis tool for rapidly estimating economic impacts of major natural and man-made hazards. Environment Systems & Decisions, 33, 1, 76-88.

Econ Impact Analysis

These direct economic impacts are defined as the economic activity lost because of firm closures or loss of production directly due to the flood.

Top 5 Industries ranked by four day direct losses

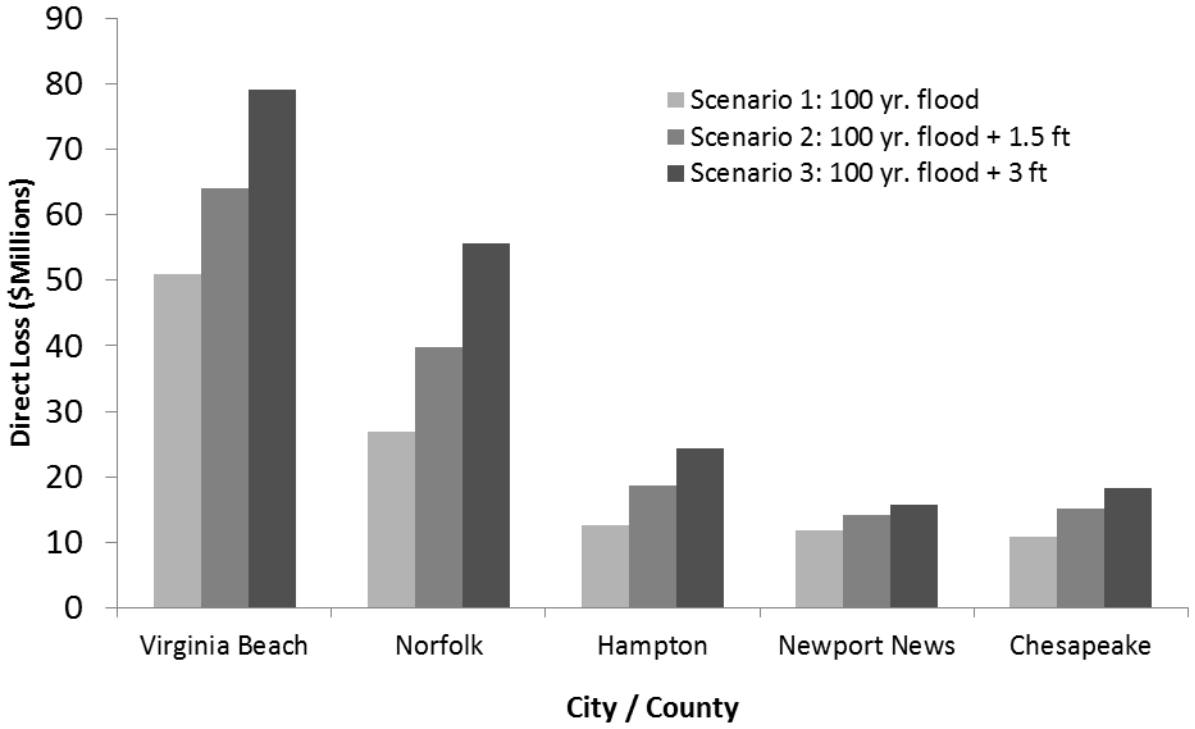


Industry	Annual Direct Losses ($Millions)		
	Scenario 1	Scenario 2	Scenario 3
Professional, scientific, and technical services	33.68	45.56	57.96
Administrative and waste management services	23.31	31.24	39.55
Retail trade	14.19	18.94	23.65
Real estate and rental leasing	8.68	11.48	14.44
Construction	8.41	11.23	14.03

Econ Impact Analysis

Note Norfolk and Hampton increase disproportionately from the +0ft to +3ft scenarios compared to other cities and counties.

Top 5 cities or counties ranked by four day direct losses

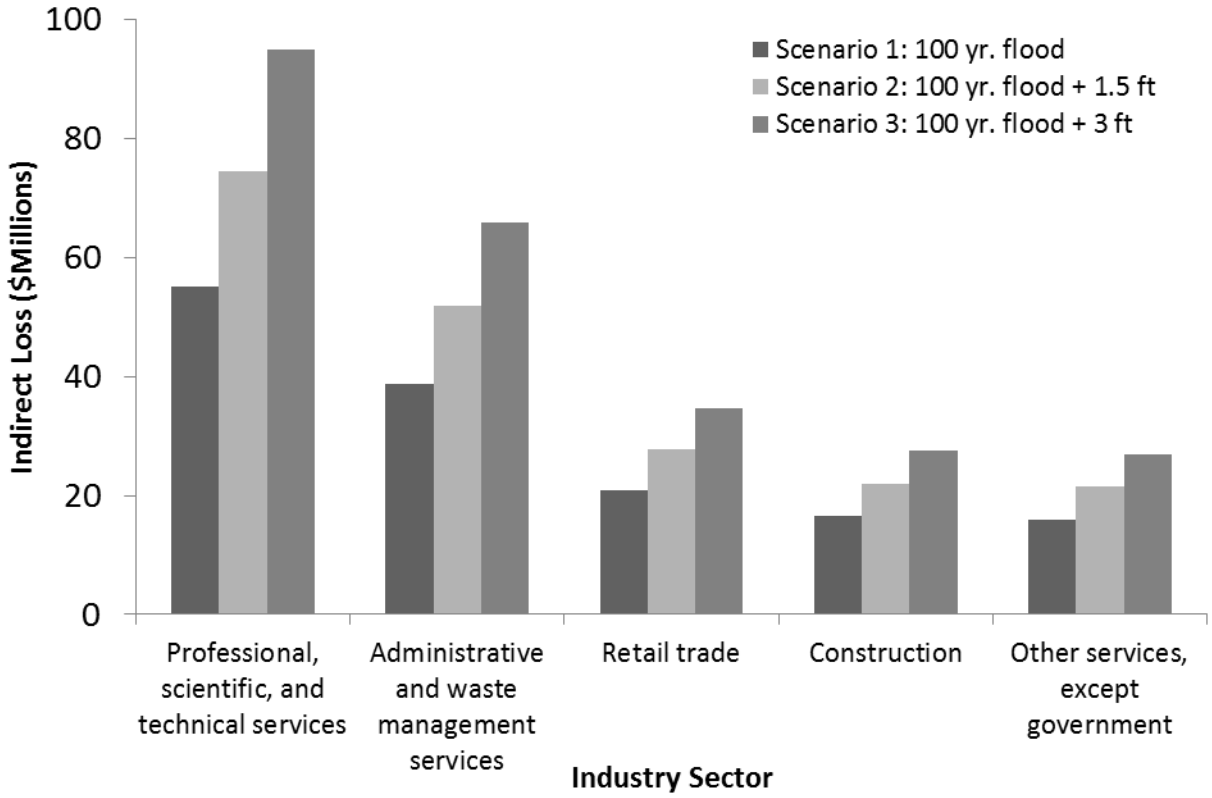


City/County	Annual Direct Losses ($Millions)		
	Scenario 1	Scenario 2	Scenario 3
Virginia Beach	50.90	64.08	79.02
Norfolk	26.92	39.71	55.60
Hampton	12.59	18.66	24.39
Newport News	11.75	14.07	15.73
Chesapeake	10.83	15.22	18.33

Econ Impact Analysis

Indirect impacts are defined as economic losses that are compounded through supply chain disruptions and other production dependencies.

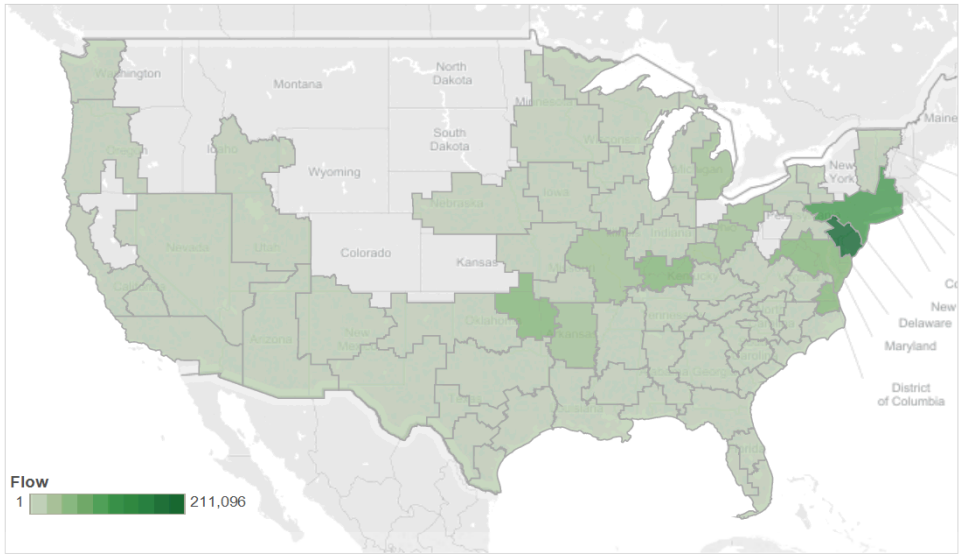
Top 5 Industries ranked by four day indirect losses

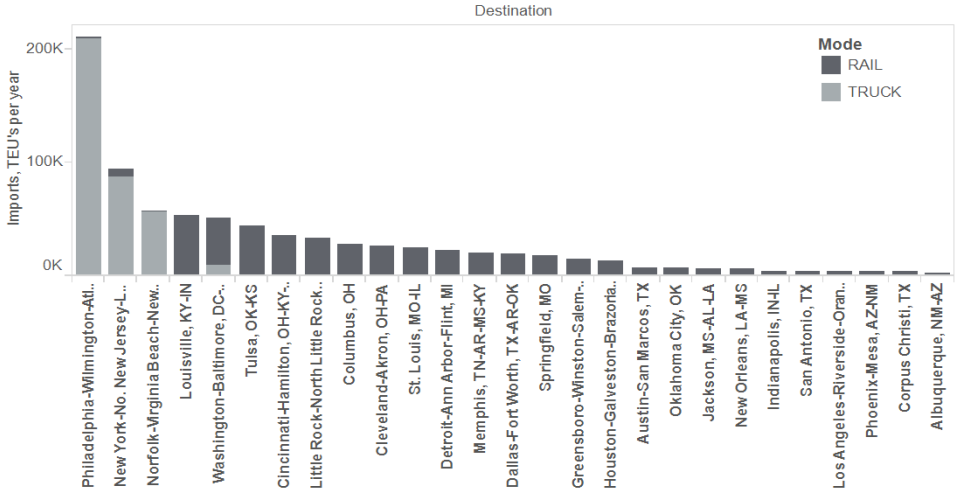


Summary of four day direct and indirect losses for three flooding scenarios

	Scenario 1	Scenario 2	Scenario 3
Annual Direct Losses	$135.1 M	$182.3 M	$230.9 M
Annual Indirect Losses	$219.4 M	$296.3 M	$375.5 M
Total	$354.5 M	$478.7 M	$606.4 M

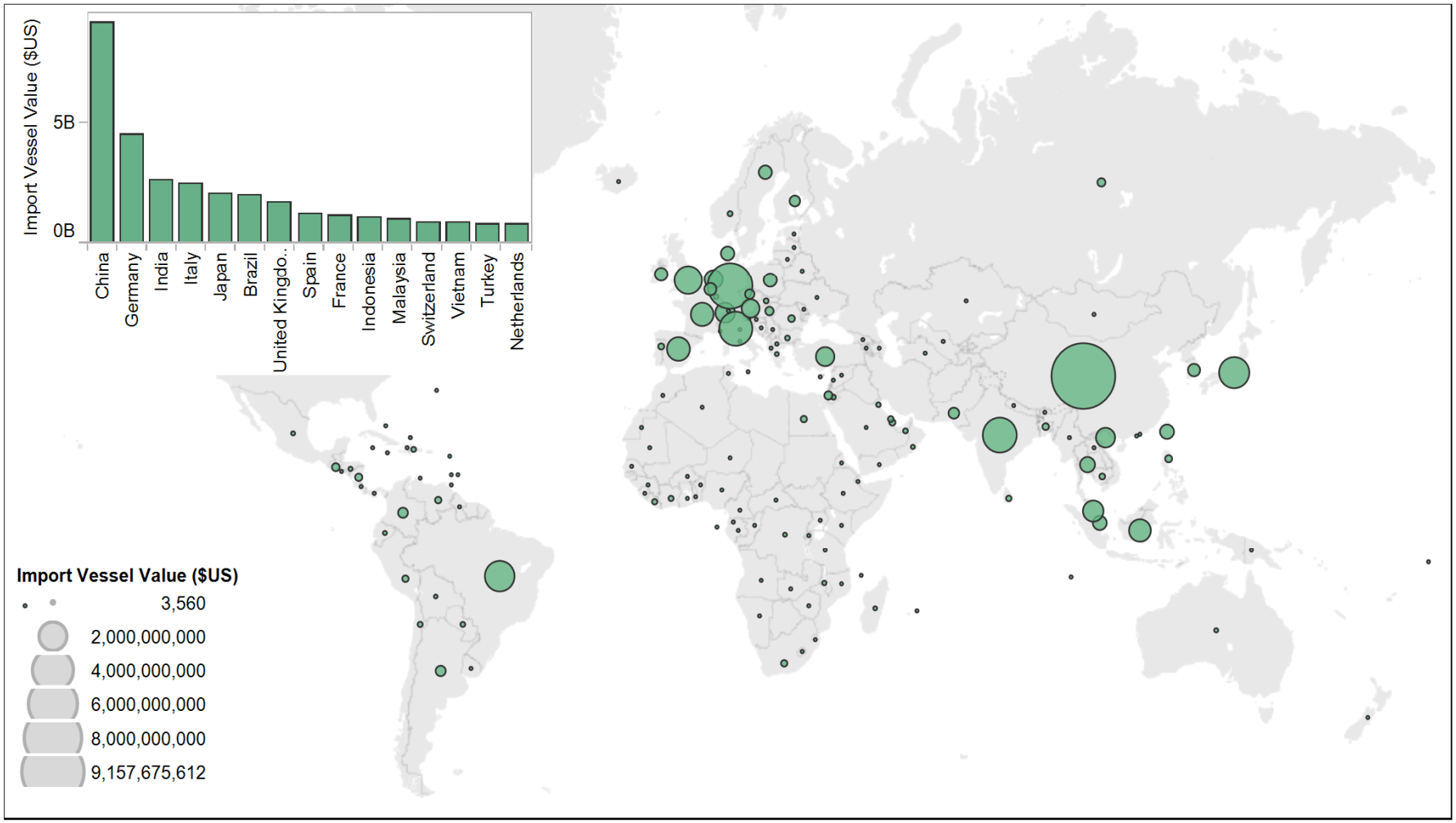
Which US Regions are Impacted by a Loss of Hampton Roads Import Capacity?





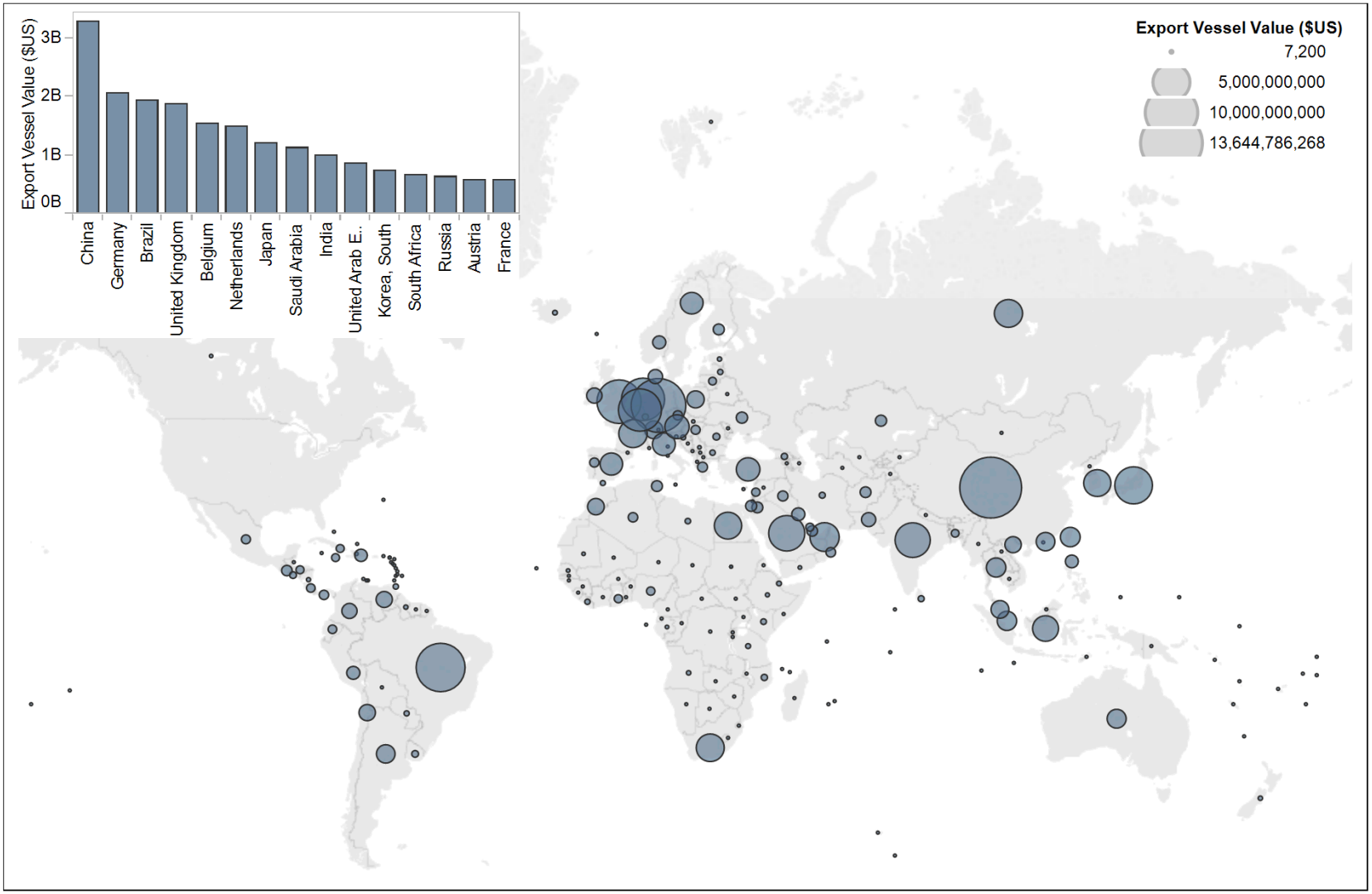
1. Jones, D. et al. (2009) SIERRA: System for Import/Export Routing and Recovery Analysis
2. American Association of Port Authorities, 2010. "North American Port Container Traffic, 2007," accessed online at www.aapa-ports.org, 6/9/2010

International imports through Norfolk



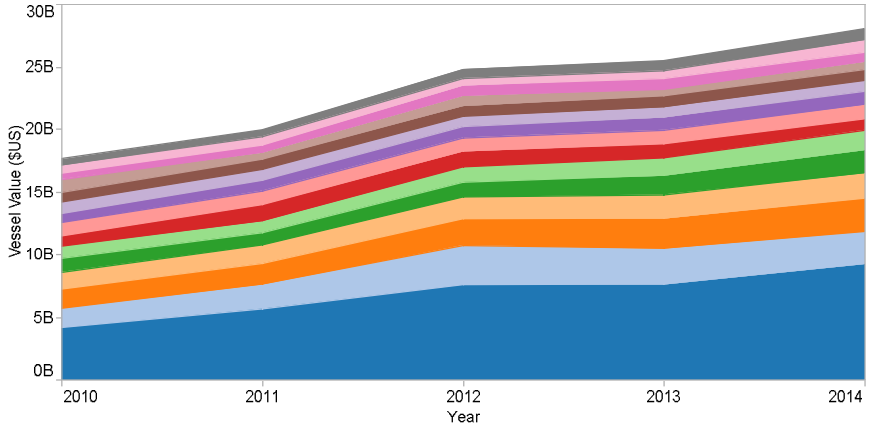
US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

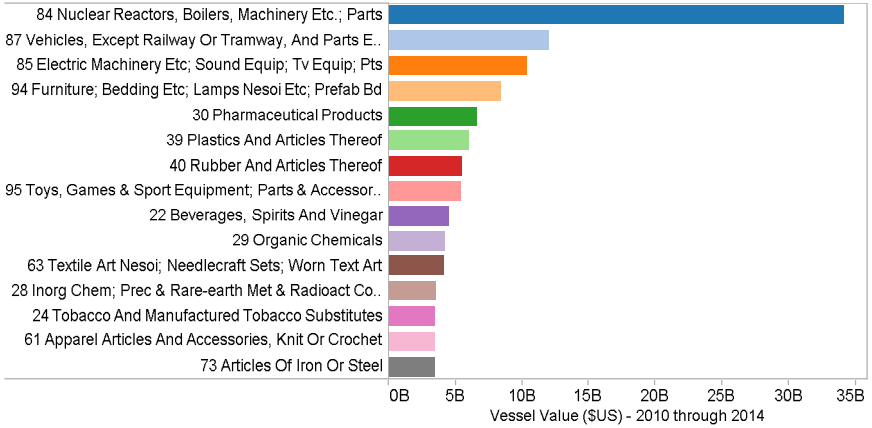
International exports through Norfolk



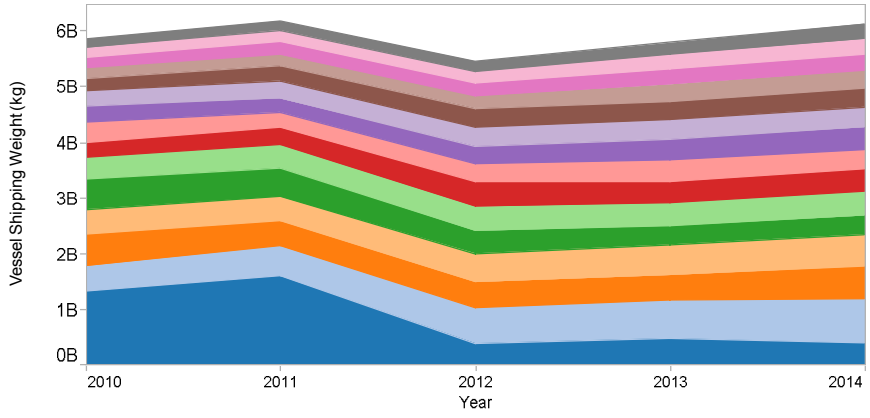
US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

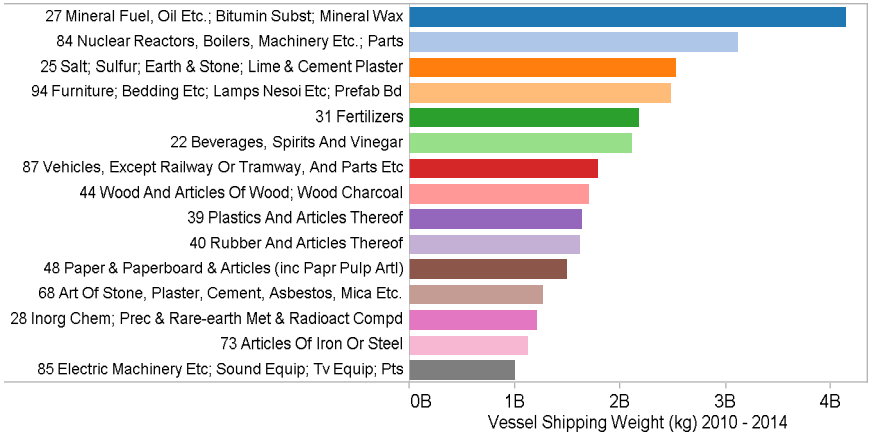
Commodity types imported (value and weight)





Trends and ranking by value of commodities imported through Hampton Roads.

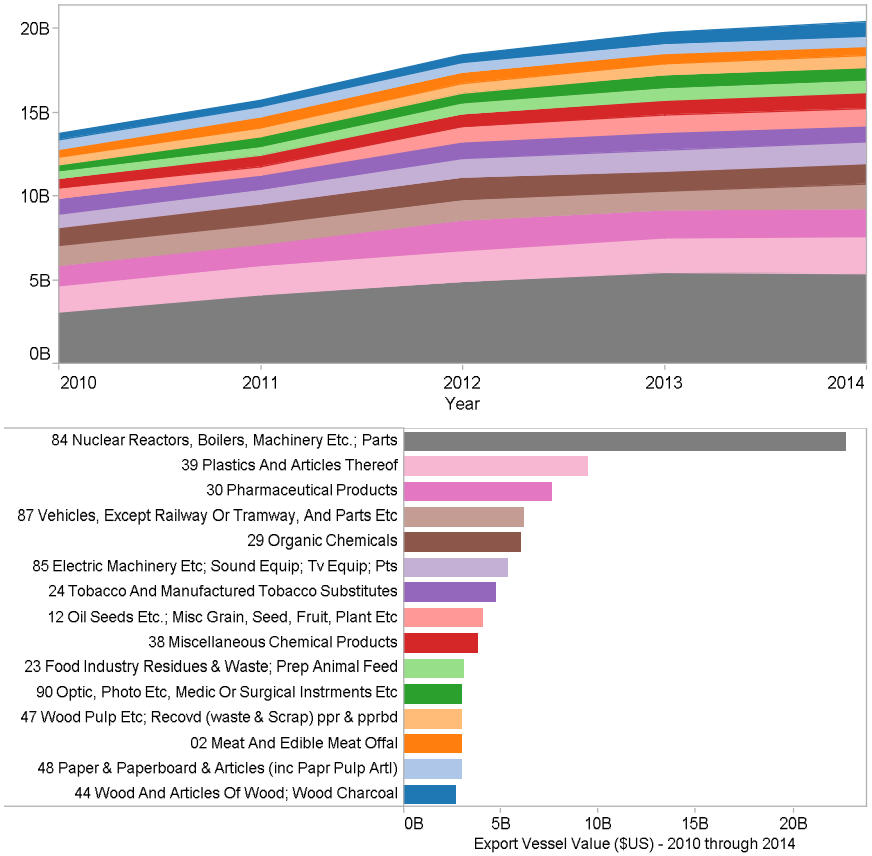




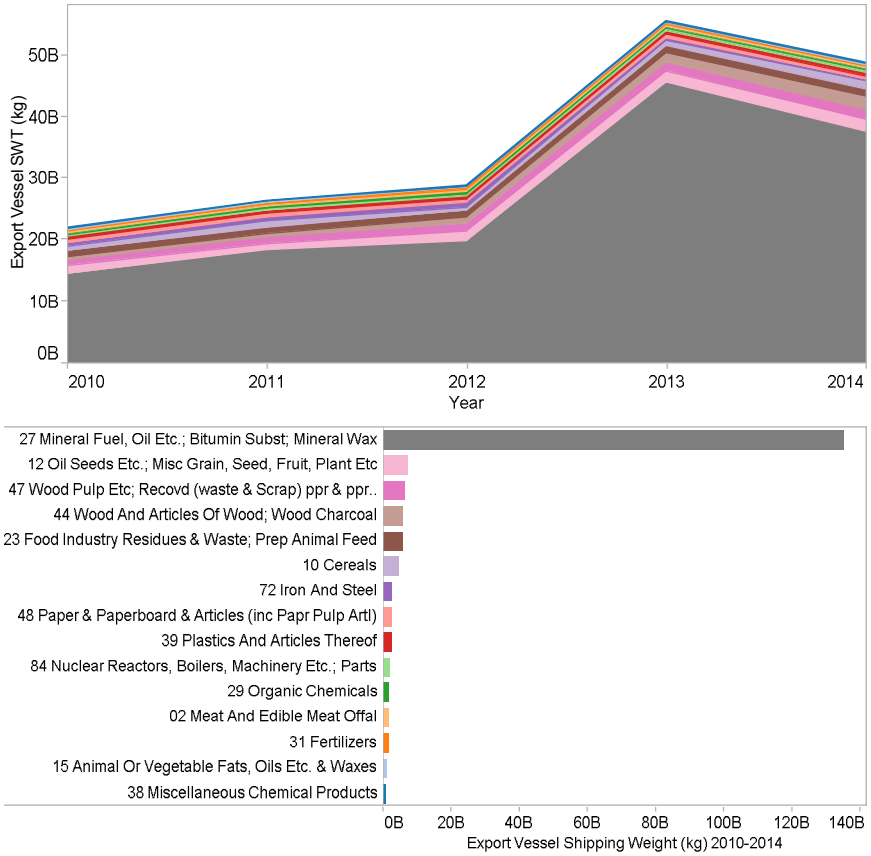
Trends and ranking by weight of commodities imported through Hampton Roads.

Source: US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

Commodity types exported (value and weight)



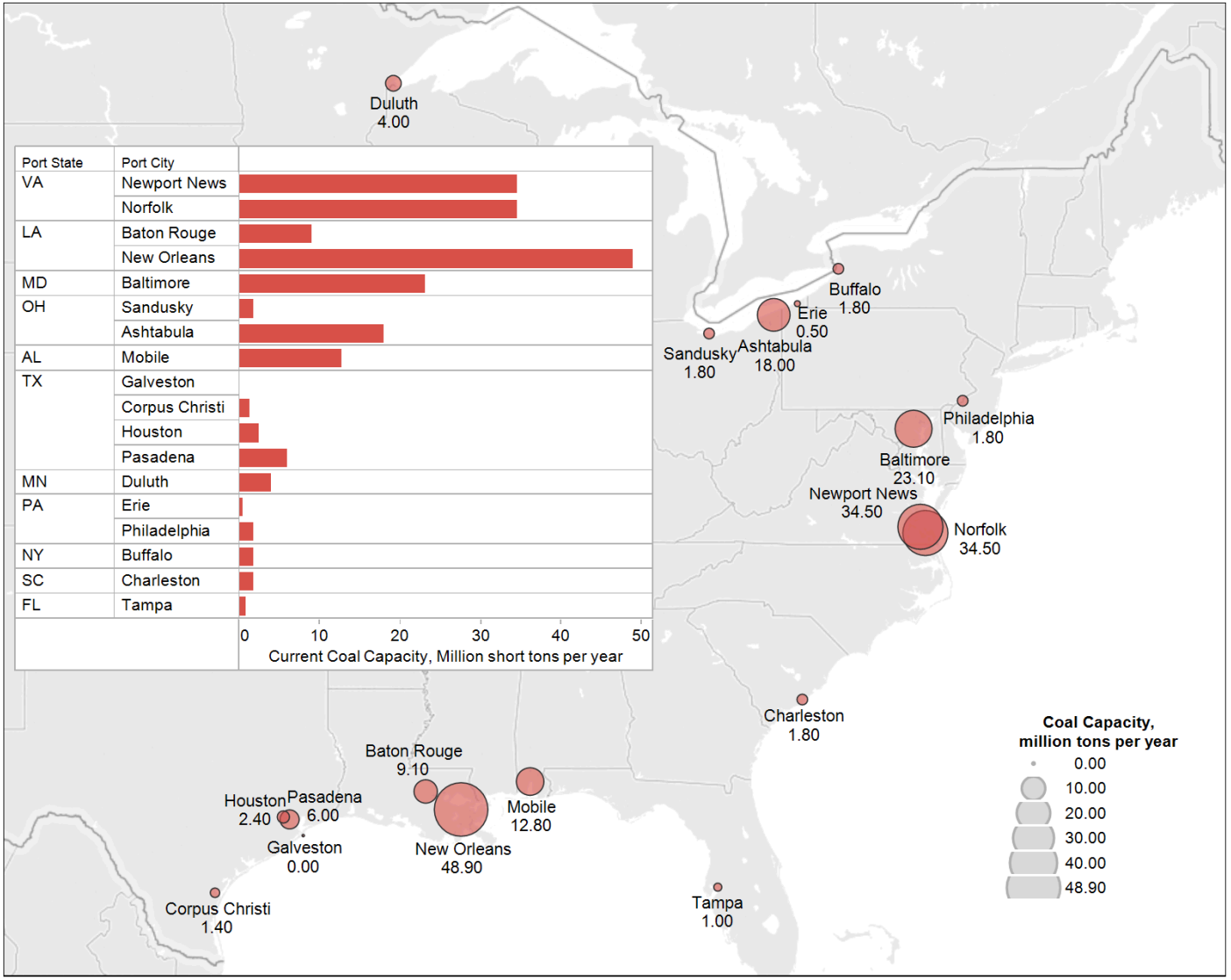
Trends and ranking by value of commodities exported through Hampton Roads.



Trends and ranking by weight of commodities exported through Hampton Roads.

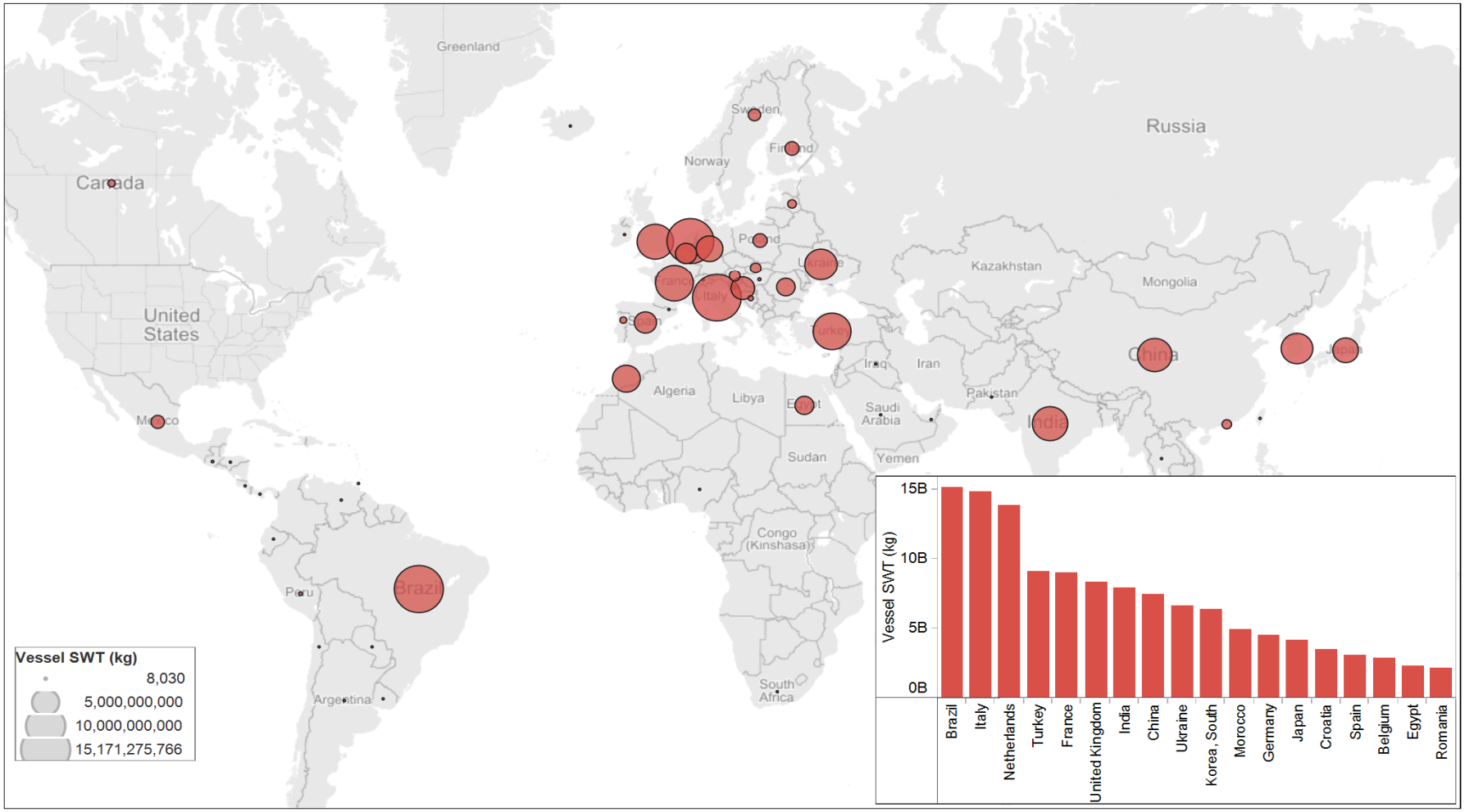
Source: US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

Atlantic coal shipment capacities:



Source: US Coal Exports Existing and Proposed Coal Infrastructure, Accessed July 2015: http://www.uscoalexports.org/data/Coal-Port-Capacity-and-Projections.pdf

Countries of destination for coal exports through Hampton Roads



US Census (2015) USA Trade Online, Accessed July 2015: https://usatrade.census.gov/

Econ Impact Analysis, Summary

- Norfolk operates as a cog among the Hampton Roads port machine. Because of this, protecting Norfolk from flooding will protect about half of Hampton Roads' coal shipping capacity, all of its container shipping capacity through NIT, but none of the bulk commodity or roll-on-roll-off capacity of NNMT.

- Norfolk is innately intertwined with successful operation of NAVSTA Norfolk and supporting facilities. Norfolk's flooding resilience will have an impact to the individuals that work and serve at these facilities, as well as the facilities themselves.

- Changes in global trade will also change Norfolk's impact to outside entities. The decrease in coal imports and spike in coal exports that occurred between 2011 and 2013 are examples of shifts in Norfolk's role in global supply chains.

- Changes in high-value items, such as machinery, define much of the economic value of trade through Norfolk and Hampton Roads, and these changes have happened relatively slowly. Coal actually has very little impact on the dollar value of exports through Hampton Roads. Other commodities such as *oil seeds and grain* and *plastics* register as high-volume, relatively high-value traded commodities. The relative value of these commodities has changed little in the past five years, while Norfolk has increased in overall value of imports and exports during this time.

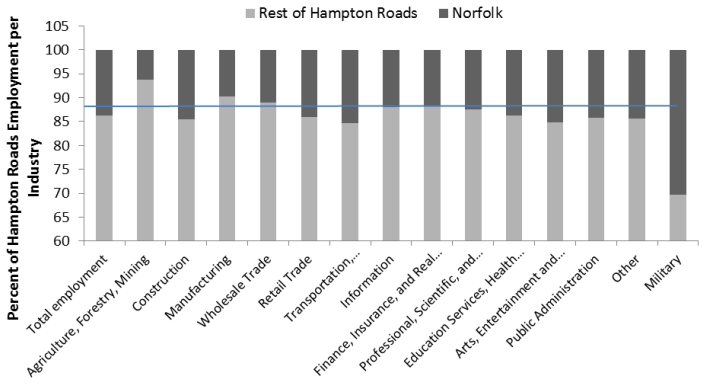
DOD Impact Analysis, Summary

- Much of the cost of ensuring mission readiness will be related to ensuring missions are served from remote locations. For instance, the NAVSTA Norfolk population includes over 80,000 active duty personnel, 112,000 family members and 30,000 civilians. If 80 percent of this population were to evacuate, the cost of reimbursing travel expenses, per diem, and lodging to these families is on the order of $13-37 million per day.[1] The remaining 20 percent of this population is likely to be housed on the sortied carrier groups themselves or retained on base as essential personnel, which will not incur a significantly higher operational cost than normal. There are times when an impact to NAVSTA Norfolk may be more costly, such as immediately before a major deployment or during an exercise.
- NAVSTA Norfolk is expected to maintain electric utility service from the Navy South substation, but potentially lose service from the Navy North substation in all scenarios. Depending on the configuration of the distribution grid on NAVSTA Norfolk, this may or may not cause loss of utility service at the northern section of the base.
- For buildings served by this infrastructure, the cost of maintaining and operating backup generation is a major component of the cost of serving the mission during such an event. This cost could be mitigated by ensuring the protection of Navy North and the NAVSTA Norfolk distribution system to flood depths shown in Figure 15. Potential actions the city of Norfolk could consider include hardening the Tanner's Point substation to the projected flooding of up to 2.78 feet, which would improve reliability of service to the NAVSTA Norfolk substations.
- The impact of damage to the Craney Island Fuel Terminal may result in a major recovery cost to the Navy after the 100-year flood. This terminal undergoes significant flooding in all scenarios. Operational costs are not expected to be highly dependent on loss of fuel storage at Craney Island, however.

1. Based on an assumption of the range of lodging allowances, meals and incidental expenses for average military family size of 2.4 persons from http://www.gsa.gov/portal and http://www.prb.org/pdf11/segal-military-families-presentation.pdf and www.defensetravel.dod.mil/Docs/perdiem/JTR.pdf

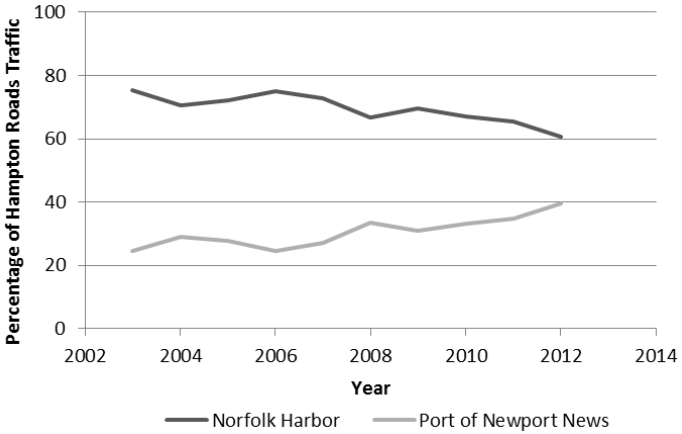
Norfolk as a global connector for Hampton Roads

1. Norfolk has a high share of Hampton Roads military jobs



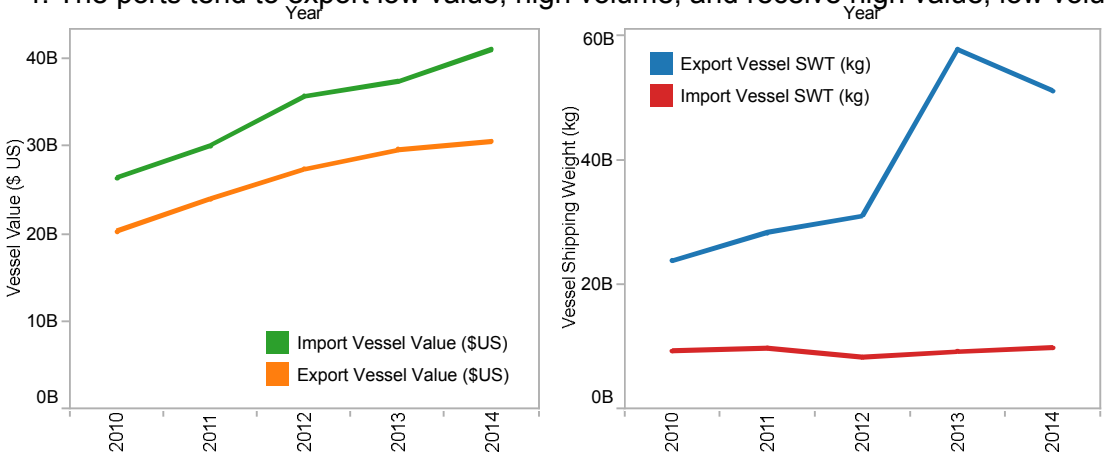
Source: US Census Virginia quick facts, http://quickfacts.census.gov/qfd/states/51/51710lk.html

2. The NIT's share of Hampton Roads traffic is declining



Source: US Army Corps of Engineers Navigation Data Center, http://www.navigationdatacenter.us/wcsc/pdf/wcusatl13.pdf

3. Overall value of commodities shipped through Hampton Roads is increasing.
4. The ports tend to export low value, high volume, and receive high value, low volume commodities



Source: US Census, USA Trade Online, https://usatrade.census.gov/