# UNDERKEEL CLEARANCE IN NAVIGATION CHANNELS – RESULTS IN SW PASS

*COASTAL NAVIGATION PORTFOLIO MANAGEMENT*

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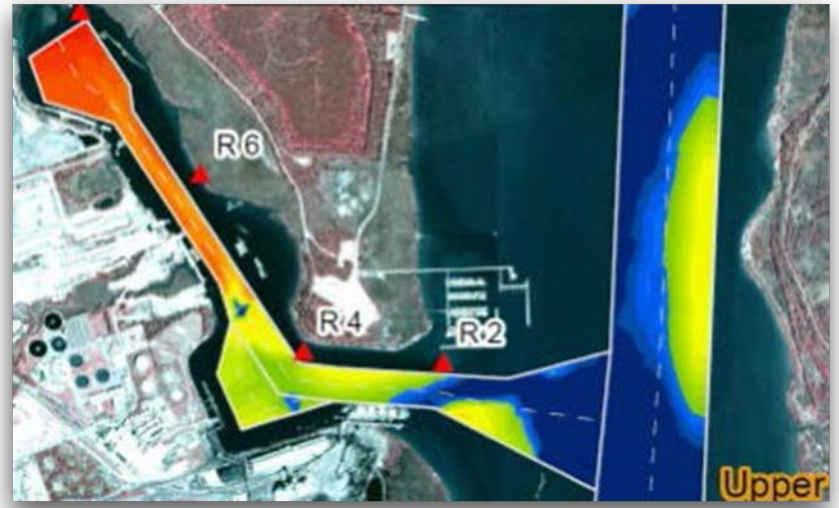
US Army Corps of Engineers®

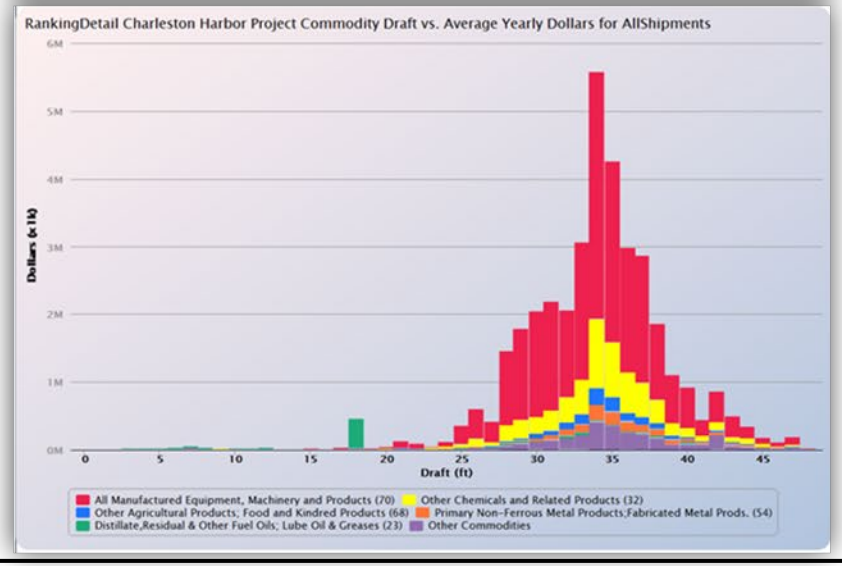
CHL COASTAL & HYDRAULICS LABORATORY

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

# Why this matters…

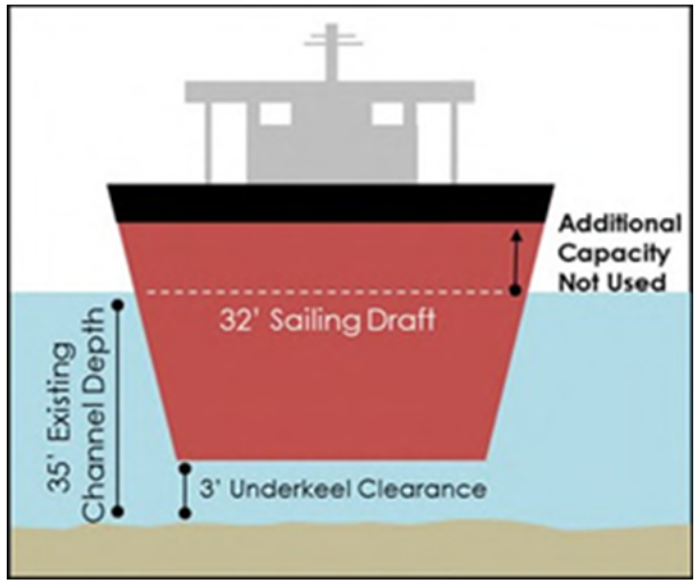
- USACE spends approximately $1B annually on dredging [6,7]
- USACE routinely reports low channel availability due to constrained maintenance funding [1,2,3]
- Increasing vessel size trends increases C, O&M dredging [4, 5, 7]
- Inadequate channel depth impacts the safety and efficiency of waterborne goods movement [7]
- Cargo tonnage and value used to prioritize maintenance dredging funds in ad hoc framework [3, 6, 7]
- Dredge reassignment has costly network implications in NAV and FRM BLs (WRDA 2020).
- Gains in vessel navigability from dredge activity are not measured.

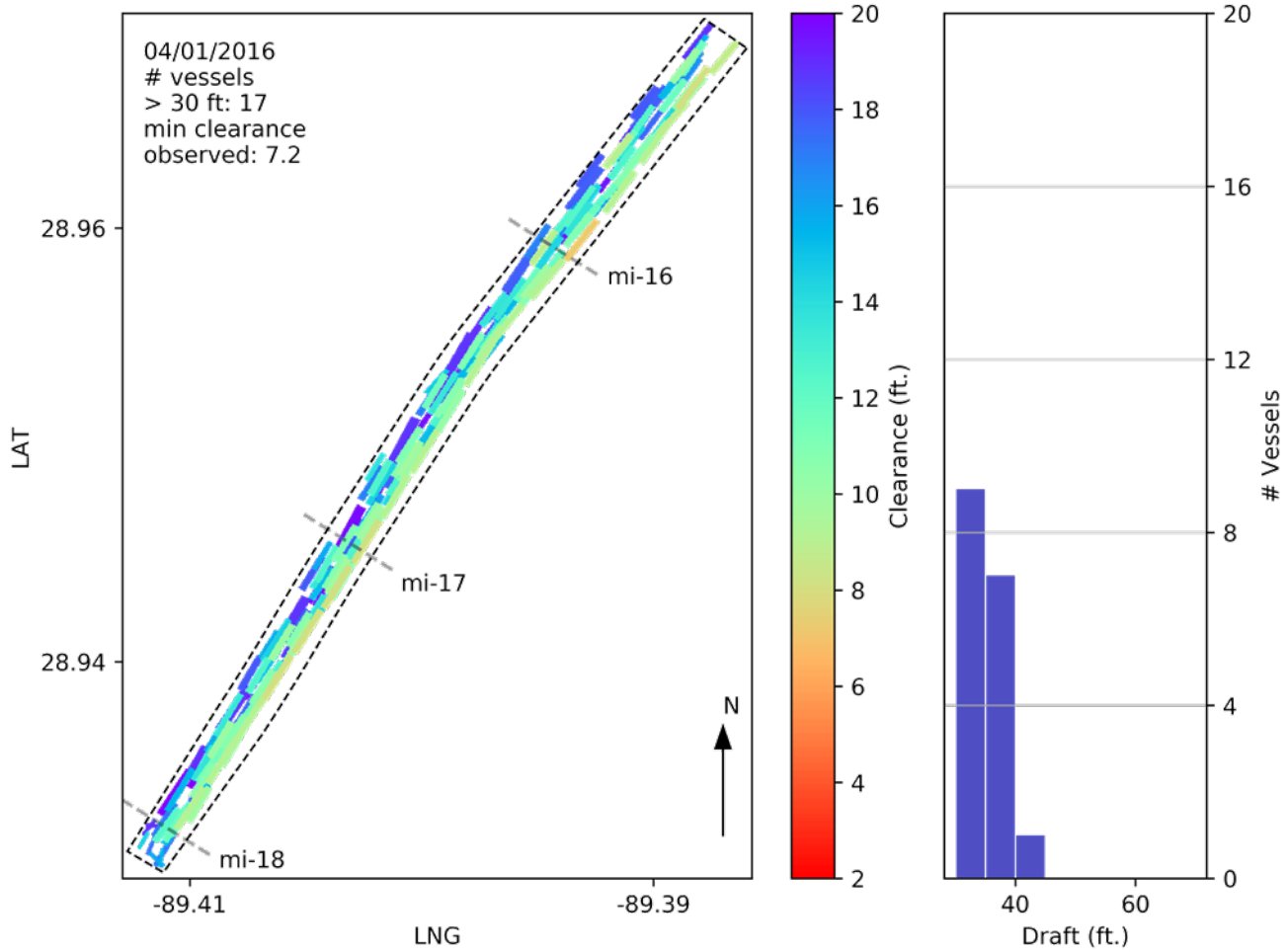


# Problem Statement

- **Existing performance metrics for coastal navigation channels allocate appx. $1B annually for dredging but indirectly describe channel performance.**
- **Vessel clearance can be estimated for nearly all transits made by commercial vessels in USACE managed waterways and will more adequately describe performance.**



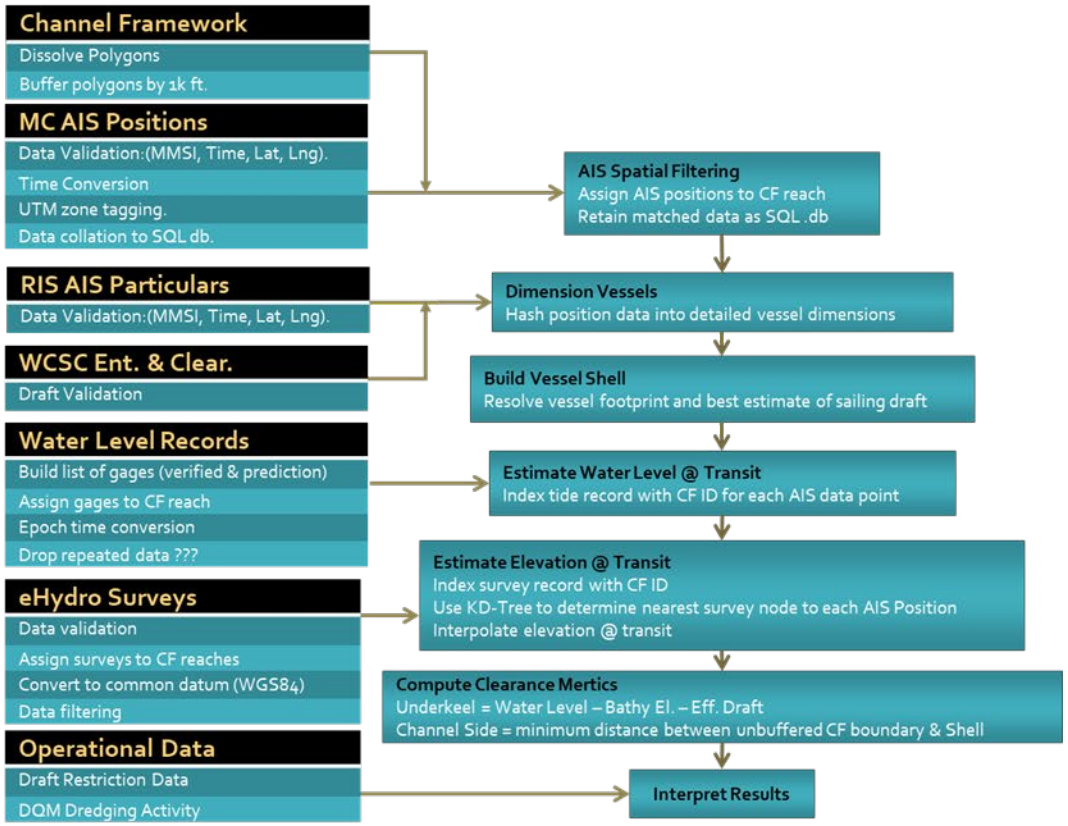




Underkeel clearance of vessels transiting through a dredged reach in the Southwest Pass of the Mississippi River.

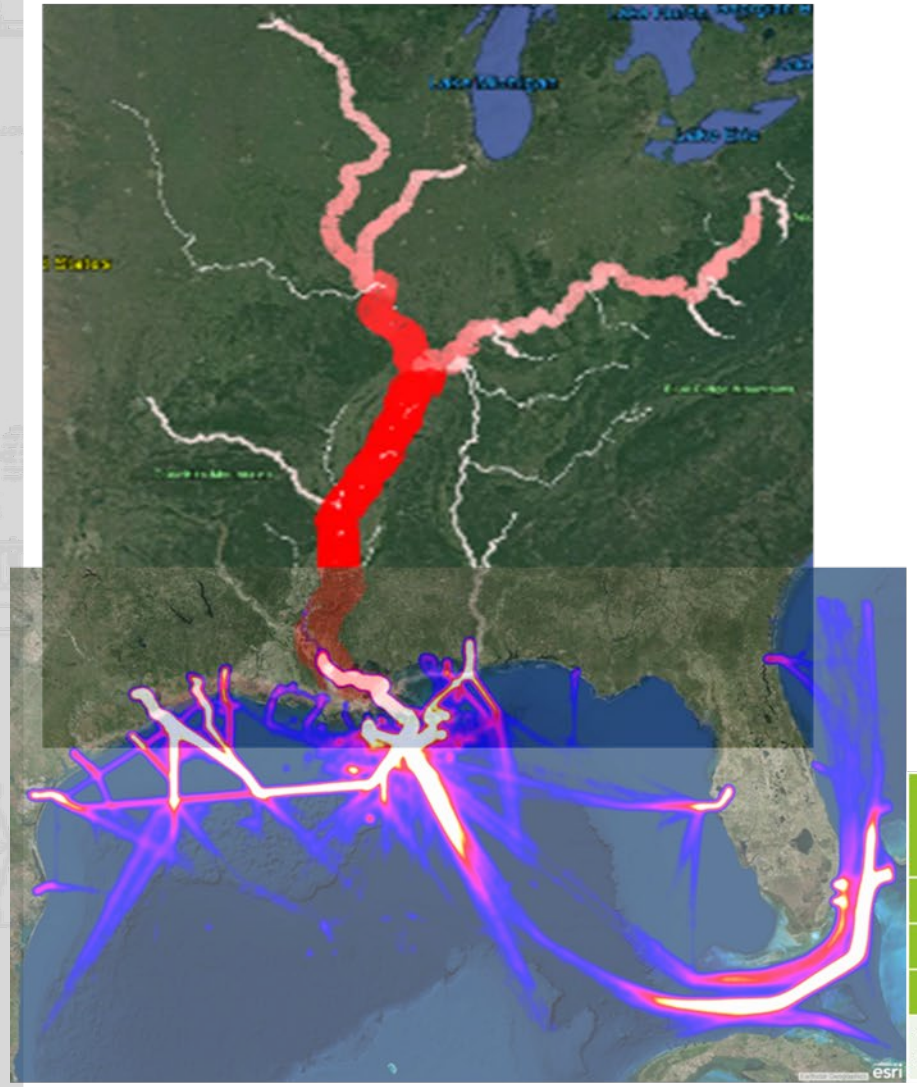
# Fusing Relevant Data

- **Archival vessel AIS data provides high resolution (space, time) missing from draft/tonnage and controlling depth.**
  - **AIS data is available in real time and far exceeds coverage of any other data source in space or time.**
    - **Relevant data sources are layered and cross-referenced to improve estimates.**
    - **Additional value extracted from existing data products generated by USACE and federal partners.**
  - **With further development AIS data may demonstrate shoal prediction capability**
    - **Potential to modify survey role from exploratory, e.g. "where is the shoal?" to descriptive, e.g. "how big is the shoal?"**
      - **Operational savings from targeted survey deployment.**

## HPC Data Modeling Approach



# Southwest Pass

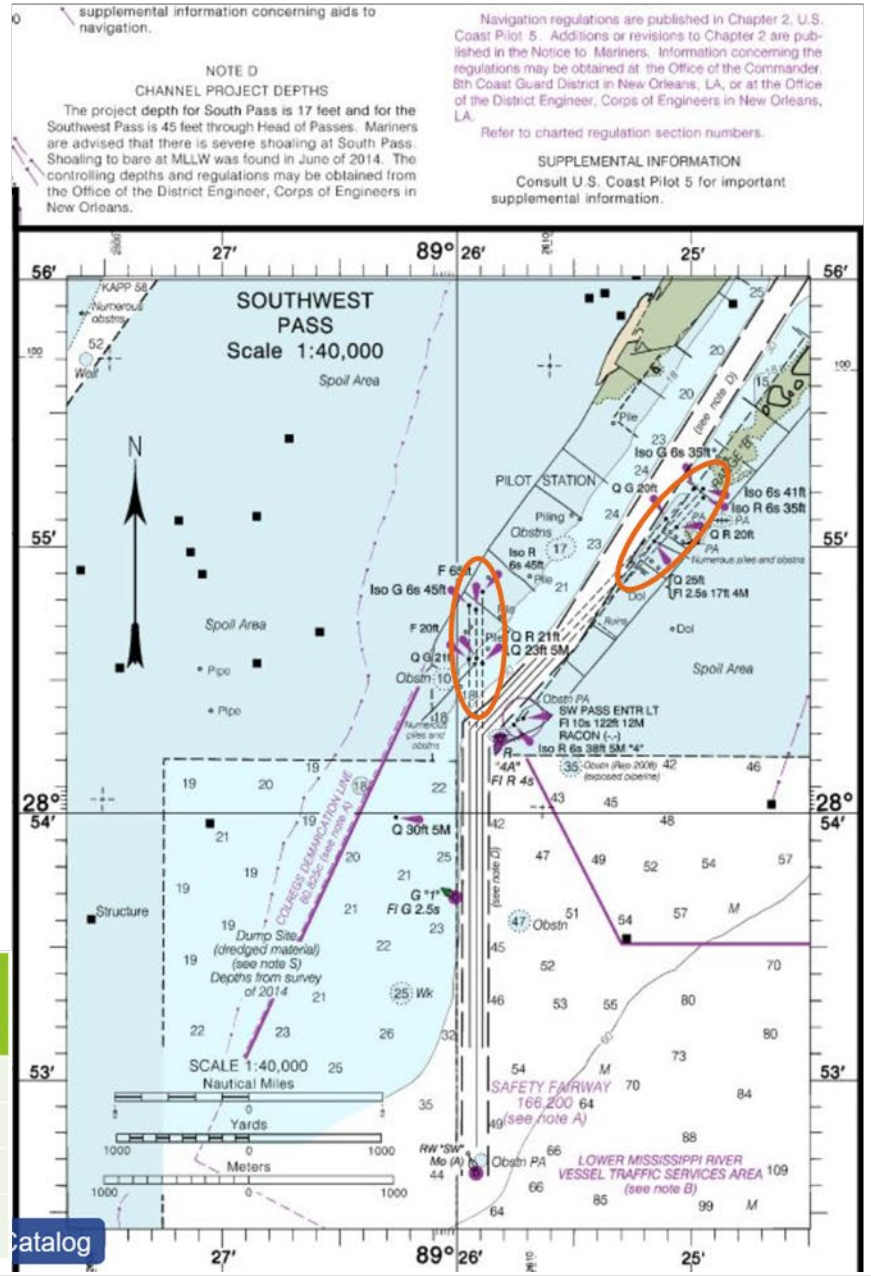


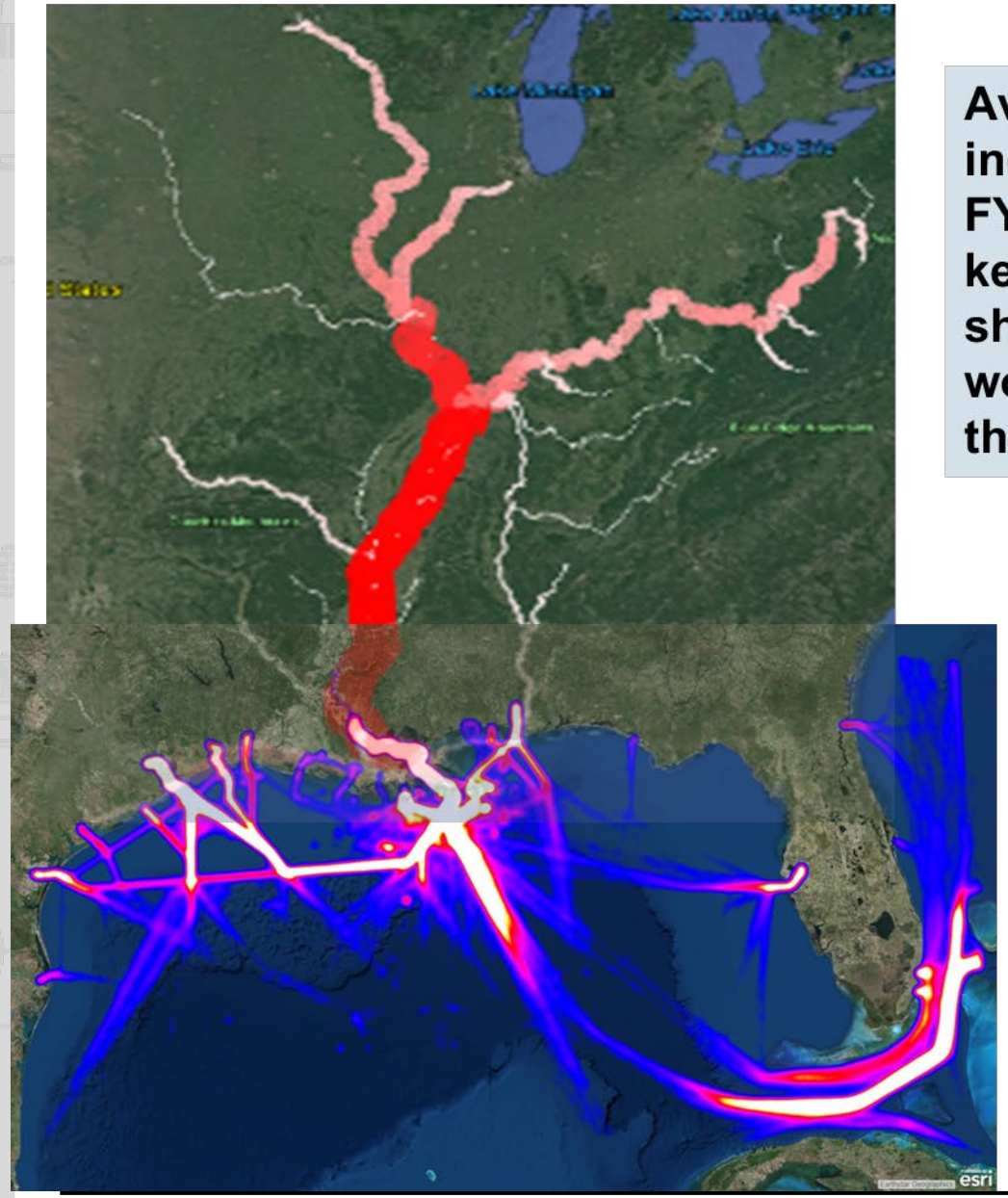
**"Controlling depths and regulations may be obtained from the Office of the District Engineer, Corps of Engineers in New Orleans."**

**Shoaling conditions are so dynamic that NOAA can't keep soundings up to date on Chart 11361.**

| Fiscal Year | Dollars ($M)[1] | Dredged Volume (million m³)[1] | Cargo Throughput (Megatonnes)[2] |
|---|---|---|---|
| 2015 | 66 | 14 | 216 |
| 2016 | 65 | 16 | 221 |
| 2017 | 62 | 17 | 236 |

1. Obtained from agency internal communication.
2. USACE B 2018






# Southwest Pass Draft Restrictions

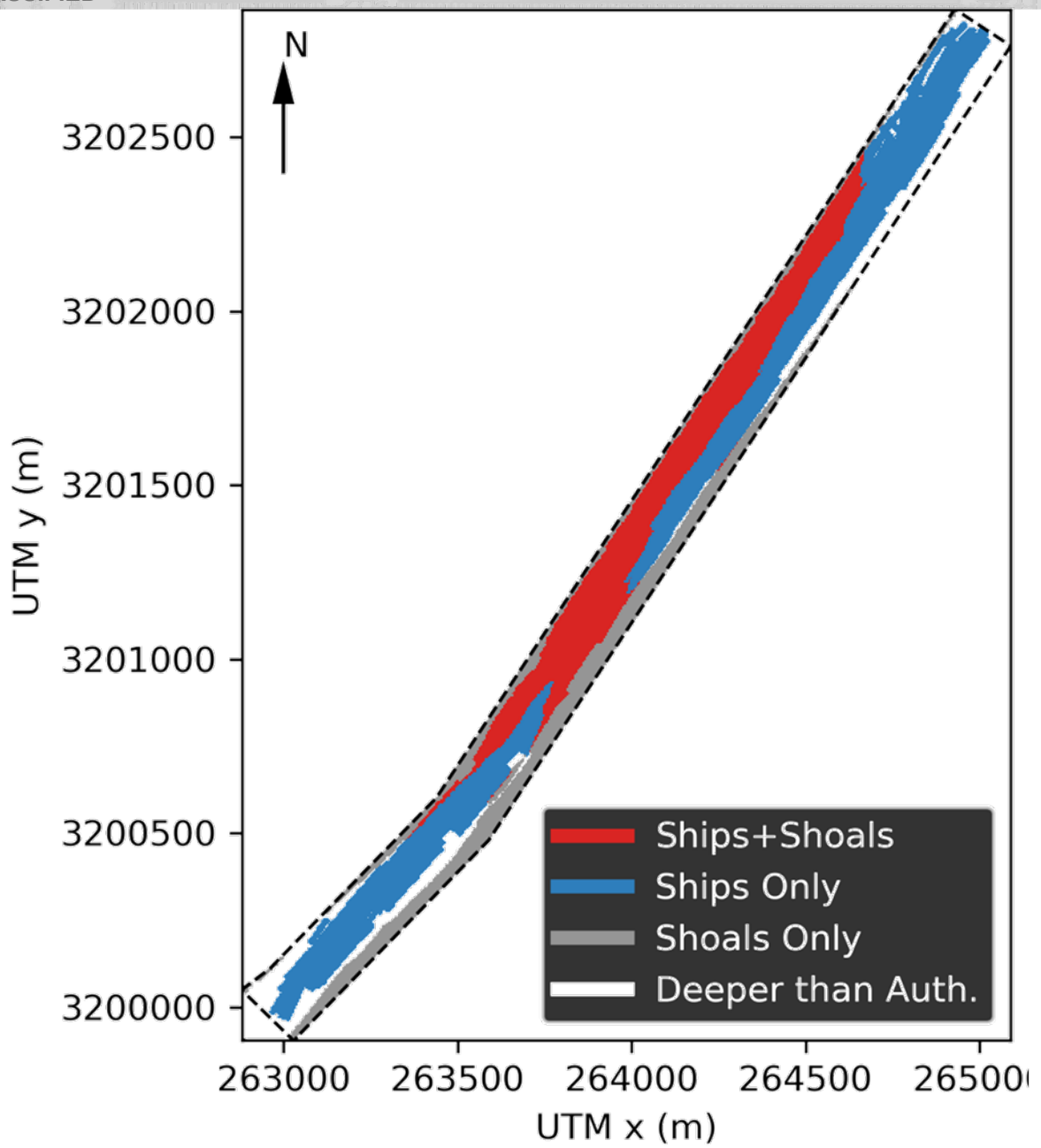
**Average channel condition of 42-ft since 18 NOV 2018 has incurred $73.2M in additional shipping costs as of 15 JUL 2019. FY19 dredging expenditures at Southwest Pass of $236M have kept channel conditions stable and prevented even higher shipping cost impacts. For example, a 38-ft draft restriction would have incurred $410M in additional shipping costs over the same time period.**

**Avg. annual # of trips per year by vessel sailing draft**

| Draft (ft) | Corpus Christi | Freeport | Houston-Galveston | Beaumont/Port Arthur | Lake Charles | Lower Miss. River | Pascagoula | Mobile | Tampa | Miami | Port Everglages | Jacksonville | Savannah | Charleston | Norfolk | Baltimore | Delaware River | New York-New Jersey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 106 | 40 | 616 | 442 | 98 | 1291 | 15 | 95 | 54 | 45 | 57 | 55 | 214 | 138 | 216 | 72 | 80 | 386 |
| 41 | 44 | 27 | 115 | 3 | 1 | 157 | 0 | 7 | 0 | 28 | 11 | 1 | 143 | 79 | 153 | 60 | 11 | 363 |
| 42 | 38 | 55 | 85 | 3 | 0 | 180 | 0 | 9 | 1 | 12 | 3 | 0 | 129 | 99 | 104 | 38 | 5 | 247 |
| 43 | 24 | 1 | 66 | 5 | 2 | 126 | 0 | 8 | 0 | 13 | 1 | 0 | 19 | 43 | 76 | 23 | 3 | 276 |
| 44 | 25 | 0 | 17 | 0 | 0 | 124 | 0 | 7 | 0 | 6 | 0 | 0 | 1 | 17 | 53 | 12 | 3 | 147 |
| 45 | 31 | 0 | 28 | 0 | 0 | 175 | 0 | 154 | 0 | 0 | 0 | 0 | 0 | 12 | 39 | 12 | 5 | 112 |
| 46 | 0 | 0 | 0 | 0 | 0 | 48 | 0 | 0 | 0 | 13 | 1 | 0 | 0 | 6 | 45 | 22 | 53 | 51 |
| 47 | 0 | 0 | 0 | 0 | 0 | 130 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 4 | 78 | 82 | 1 | 28 |
| 48 | 2 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 86 | 16 | 3 | 11 |
| 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 2 | 3 | 3 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 0 | 25 | 1 |

# Tagging Scheme

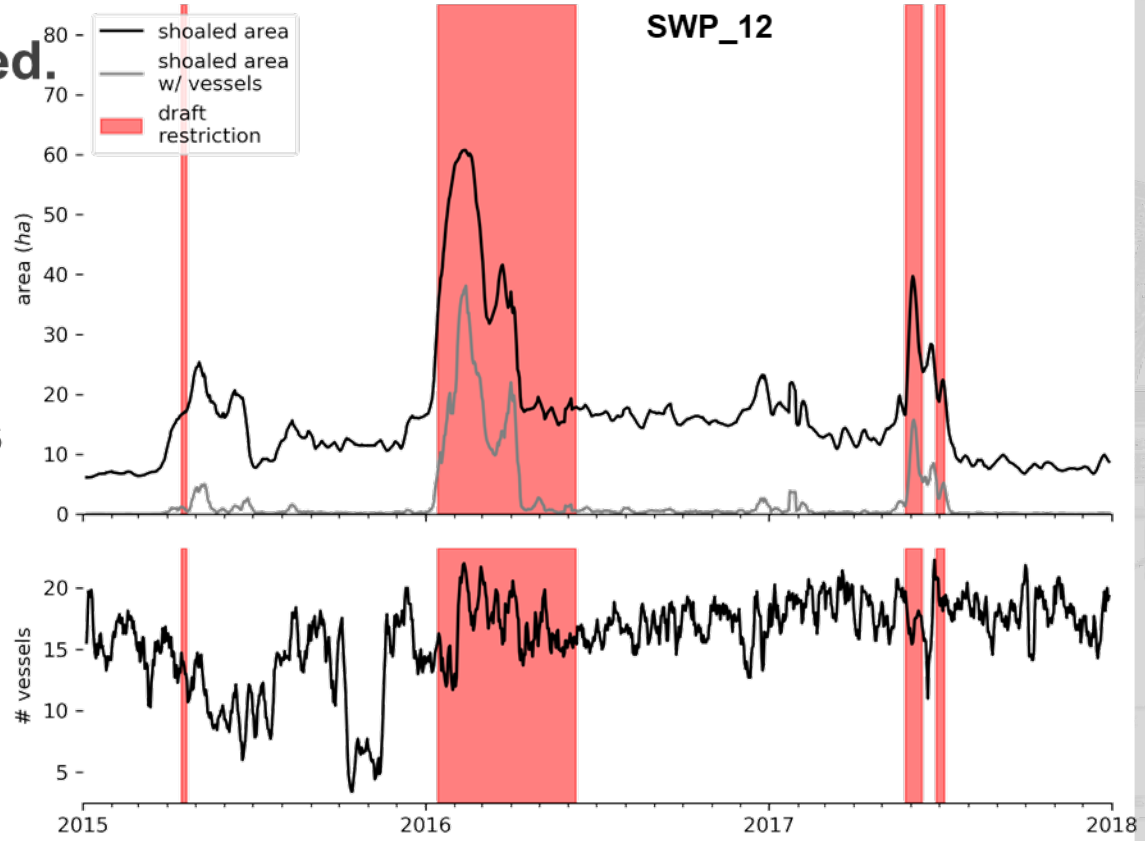
- Channel survey information represented as 5m x 5m grid.
- Grid cells tagged as “shoaled” if survey elevation < authorized depth (48.5 MLLW)
- Grid cells tagged as “ship” if centroid intersects vessel footprint resolved from AIS
- Ship+Shoals is {“shoaled”} ∩ {“ship”} cells
- The results computed daily for >30’ vessels
  - shoal area in swept path
  - shoal volume in swept path
  - UKC (gross)
  - UKC/Draft



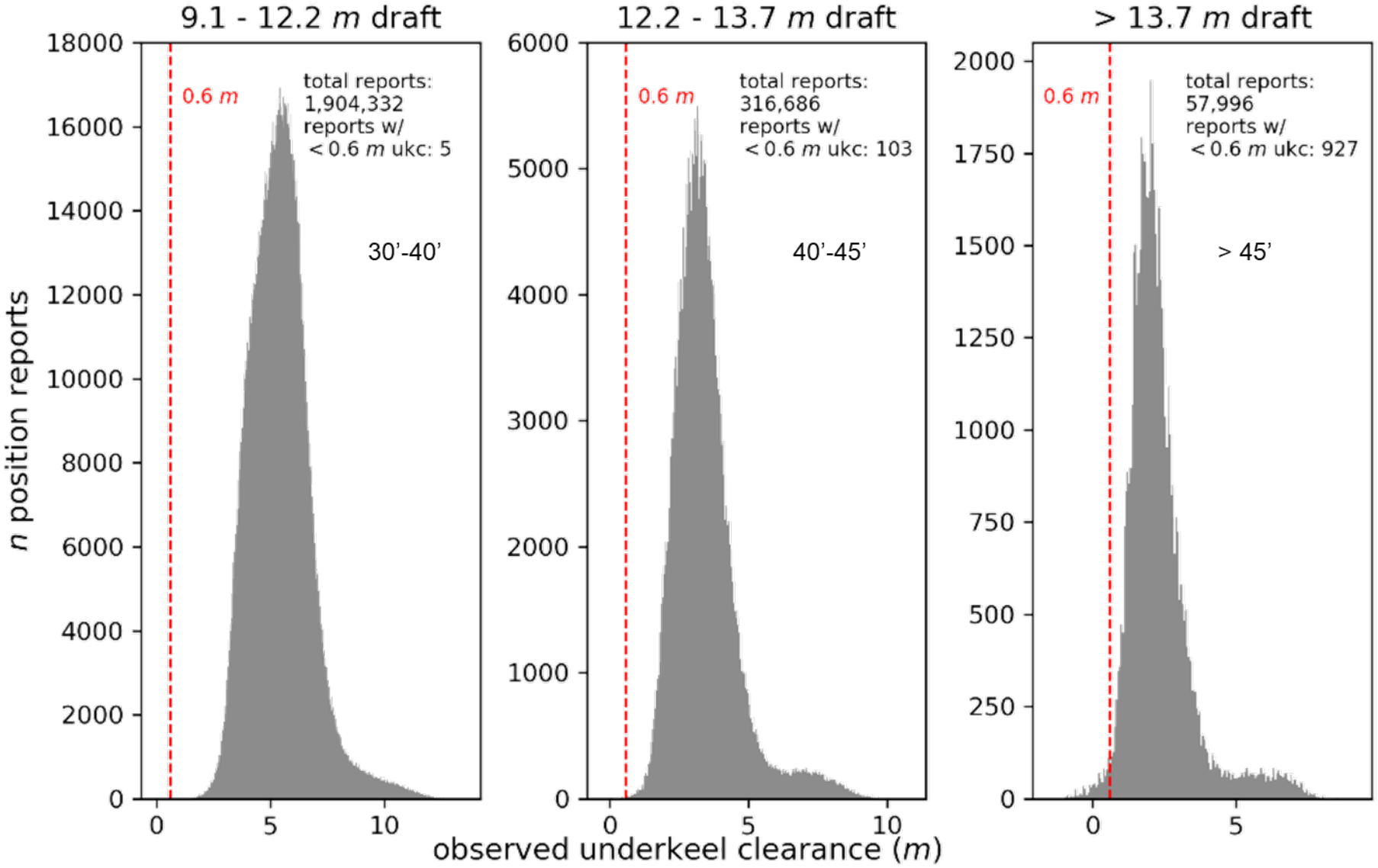
# Results: 2015-2017

- 586 million available depth calculations.
- 588 million accumulated sediment calculations.
- 2.5 million unique vessel position reports observed.
- 2.5 million UKC calculations.
- 96% of vessels had known dimensions.
- 89% of vessels matched in the Foreign Vessel Entrances and Clearances.
- +0.09m draft bias for FVEC matches, surprising.
- 0.045% of position reports calculated to have less than 0.6 m (2 ft) UKC.

| Channel Framework ID | Channel Area (ha) | Maximum observed shoaled area (ha) | Maximum observed shoaled volume ($10^5 m^3$) |
|---|---|---|---|
| SWP_02 | 112 | 3 | 0.1 |
| SWP_03 | 104 | 7 | 0.2 |
| SWP_04 | 113 | 62 | 3.3 |
| SWP_05 | 117 | 84 | 6.8 |
| SWP_06 | 107 | 41 | 2.6 |
| SWP_07 | 112 | 54 | 3.7 |
| SWP_08 | 109 | 50 | 4.0 |
| SWP_09 | 109 | 53 | 4.4 |
| SWP_10 | 109 | 67 | 4.4 |
| SWP_11 | 108 | 67 | 5.2 |
| SWP_12 | 68 | 61 | 7.5 |
| SWP_13 | 62 | 27 | 2.1 |

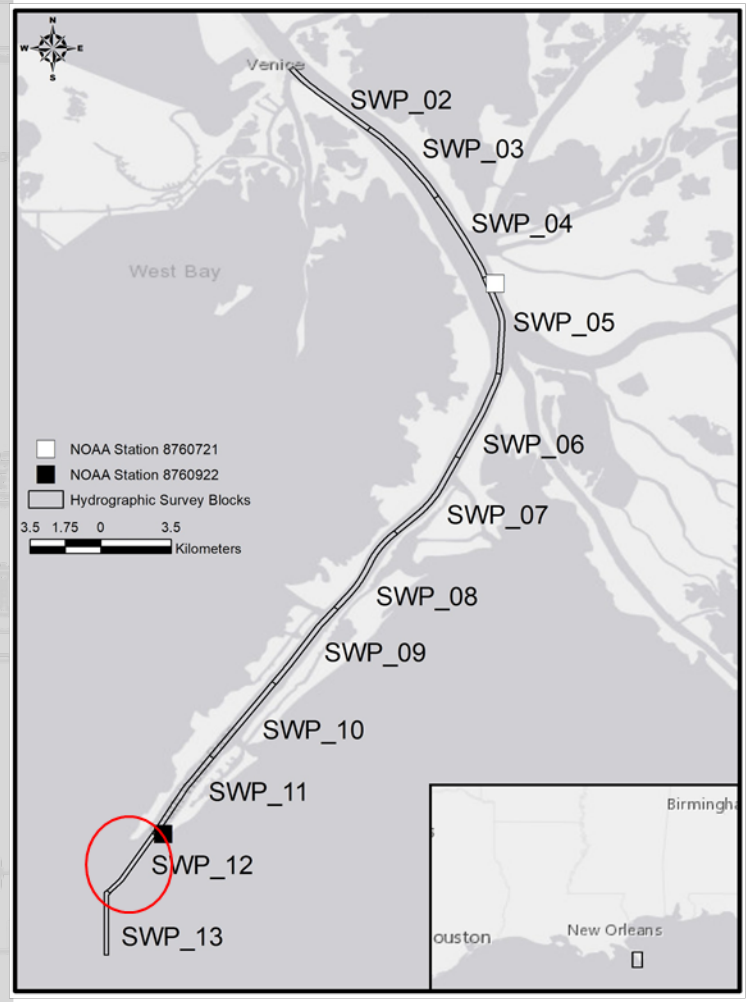


# Results: 2015 - 2017

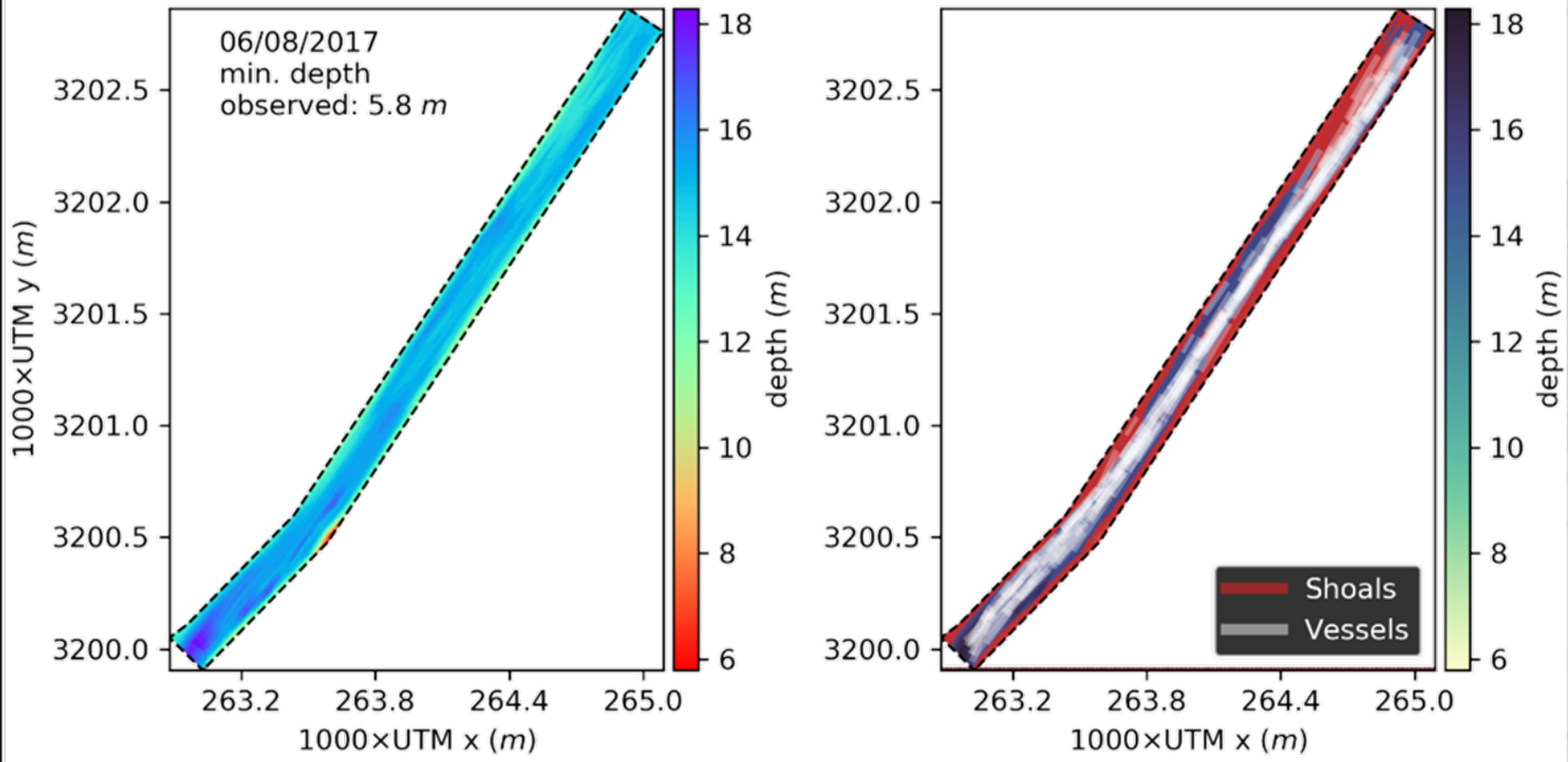



**Binned distributions for 2.5 million UKC observations.**

# Results: 2015 - 2017

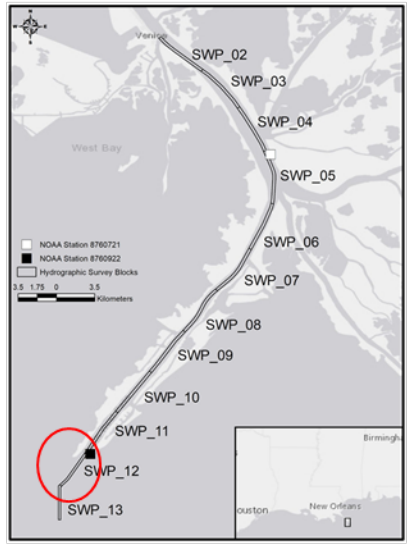



**Southwest Pass below Venice, Louisiana.**



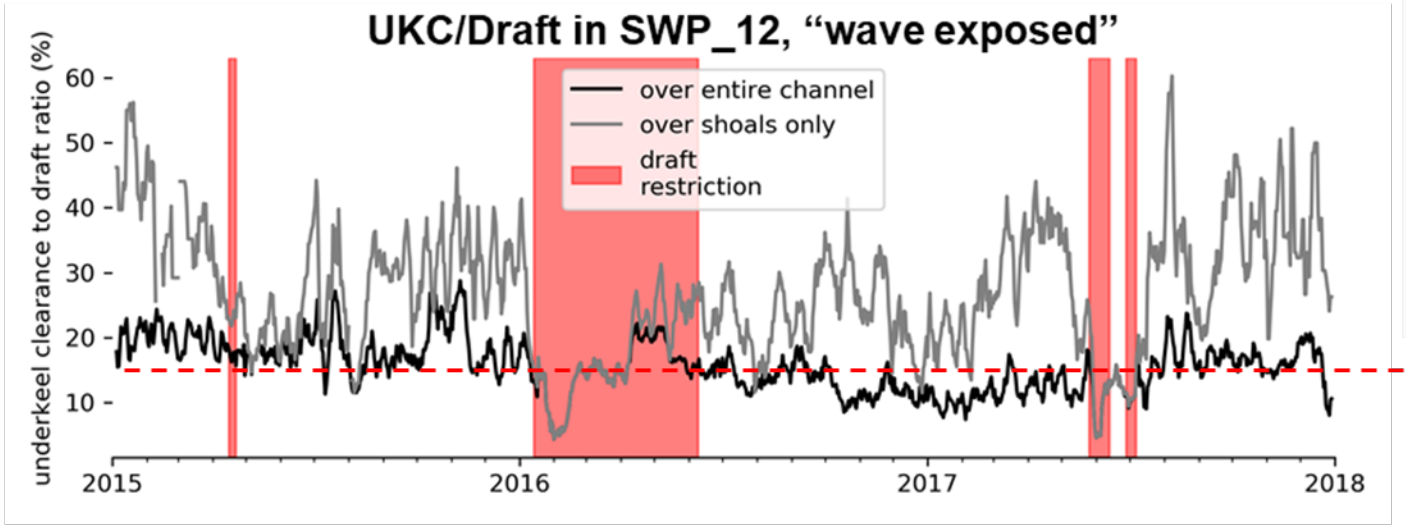

**Left: The shoalest depth of SWP_12 was 5.8 m (19 ft). Right: Vessel positions and shoal locations during peak shoaling do not overlap substantially.**

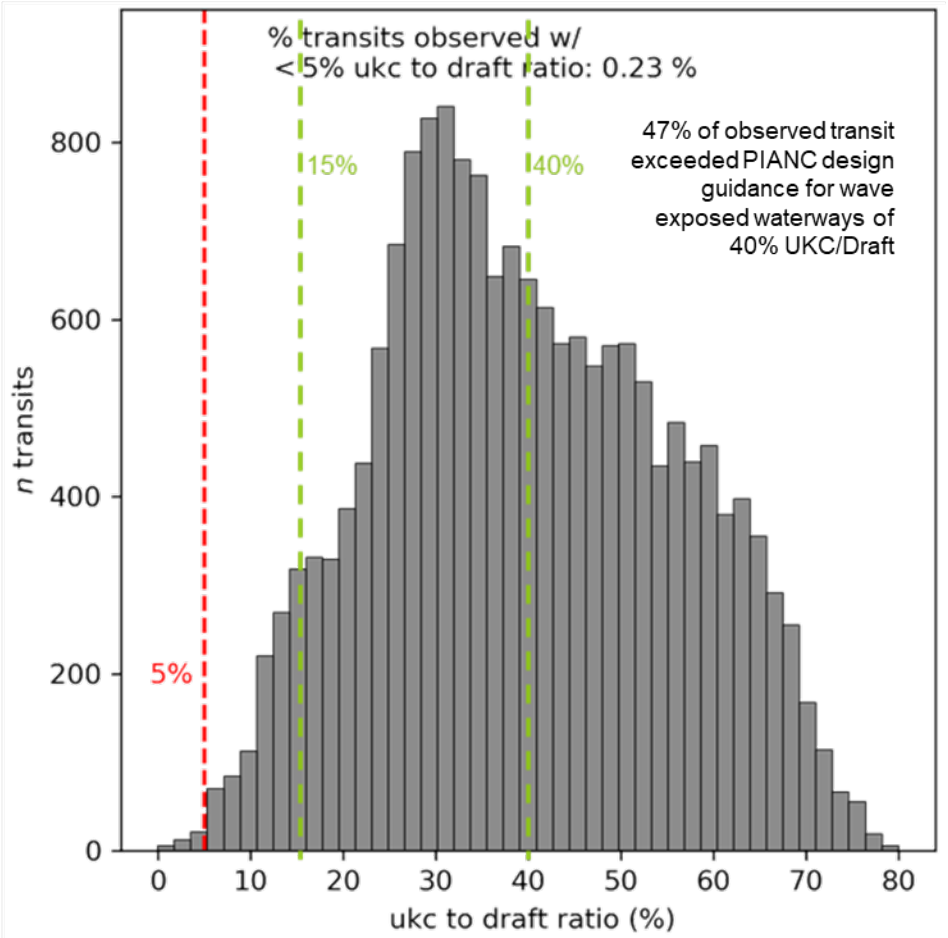
# Results: 2015 - 2017




Southwest Pass below Venice, Louisiana.

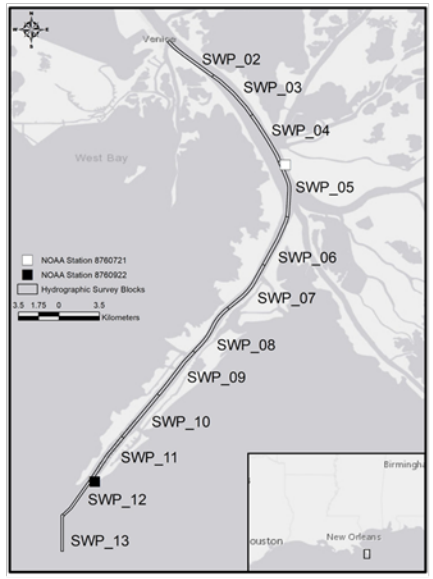
| Channel Framework ID | Maximum observed daily vessel count | Maximum % shoaled area under vessels | Maximum % shoaled volume under vessels | Min. UKC (m) entire channel | Min. UKC (m) over shoals |
|---|---|---|---|---|---|
| SWP_02 | 22 | 84.0 (2.5 ha) | 33.3 | 1.7 | 2.0 |
| SWP_03 | 21 | 68.3 | 93.8 (19k $m^3$) | 0.6 | 0.6 |
| SWP_04 | 22 | 62.9 | 53.0 | 0.7 | 0.8 |
| SWP_05 | 23 | 58.6 | 46.4 | 0.8 | 0.8 |
| SWP_06 | 23 | 38.3 | 31.2 | 1.1 | 1.1 |
| SWP_07 | 23 | 32.4 | 27.5 | 1.0 | 1.2 |
| SWP_08 | 22 | 27.0 | 20.1 | 0.8 | 0.8 |
| SWP_09 | 22 | 33.0 | 24.1 | 0.9 | 1.0 |
| SWP_10 | 23 | 43.4 | 19.2 | 0.9 | 1.0 |
| SWP_11 | 23 | 49.8 | 34.2 | 1.0 | 1.0 |
| SWP_12 | 22 | 62.7 (38 ha) | 49.6 (372k $m^3$) | 0.6 | 0.6 |
| SWP_13 | 20 | 31.9 | 17.3 | 1.2 | 1.4 |

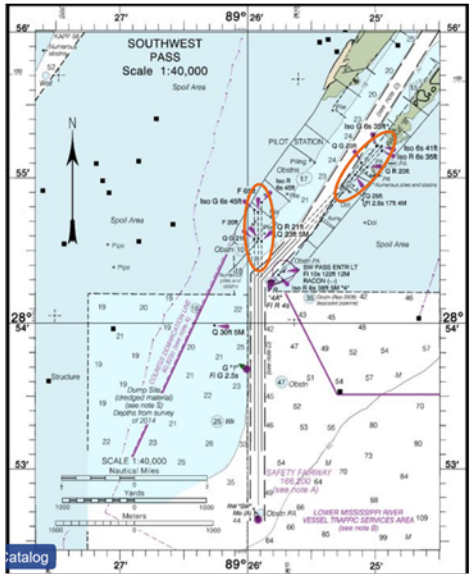


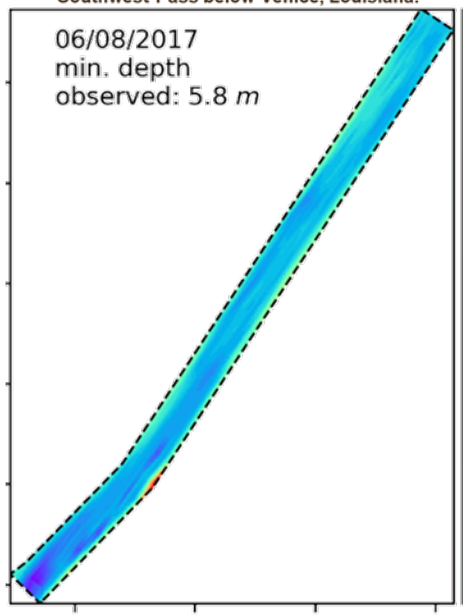

**Distribution of UKC to draft ratio in SWP_12 for 17,729 transits.**

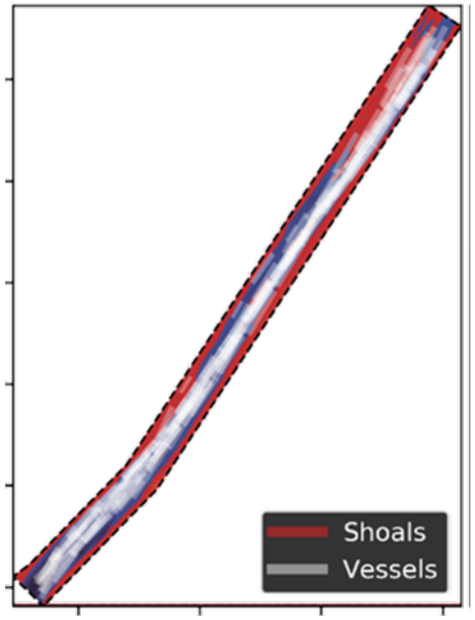
# Results: 2015 - 2017




Southwest Pass below Venice, Louisiana.

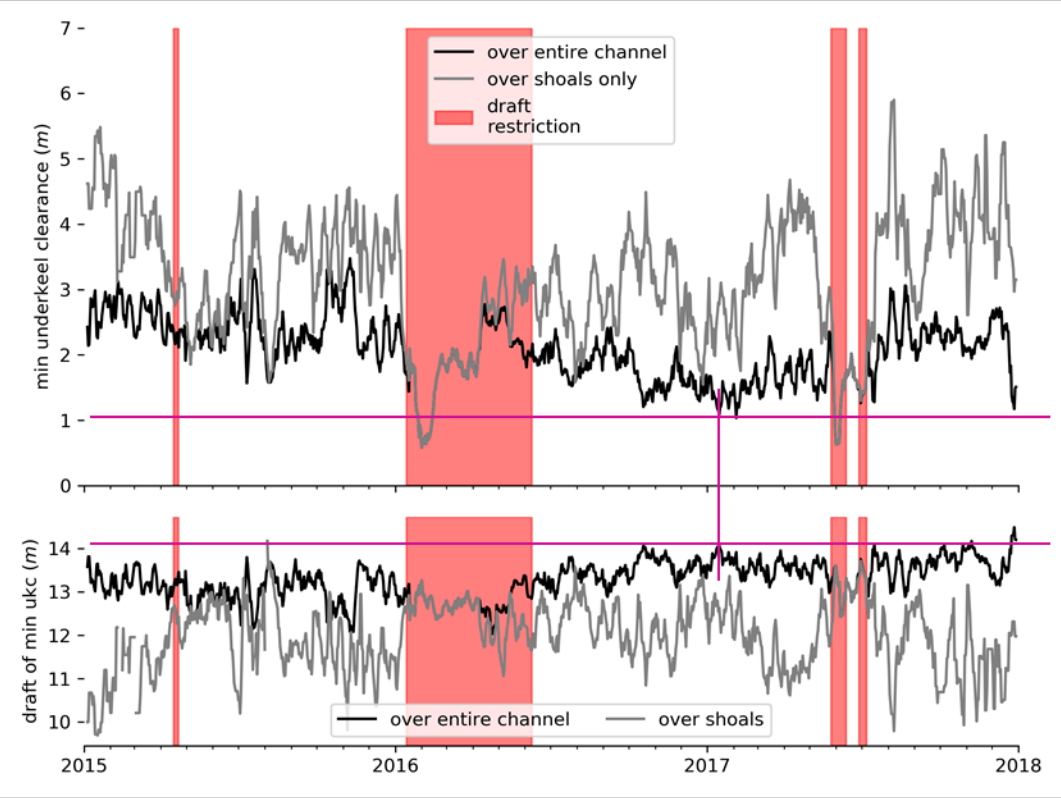


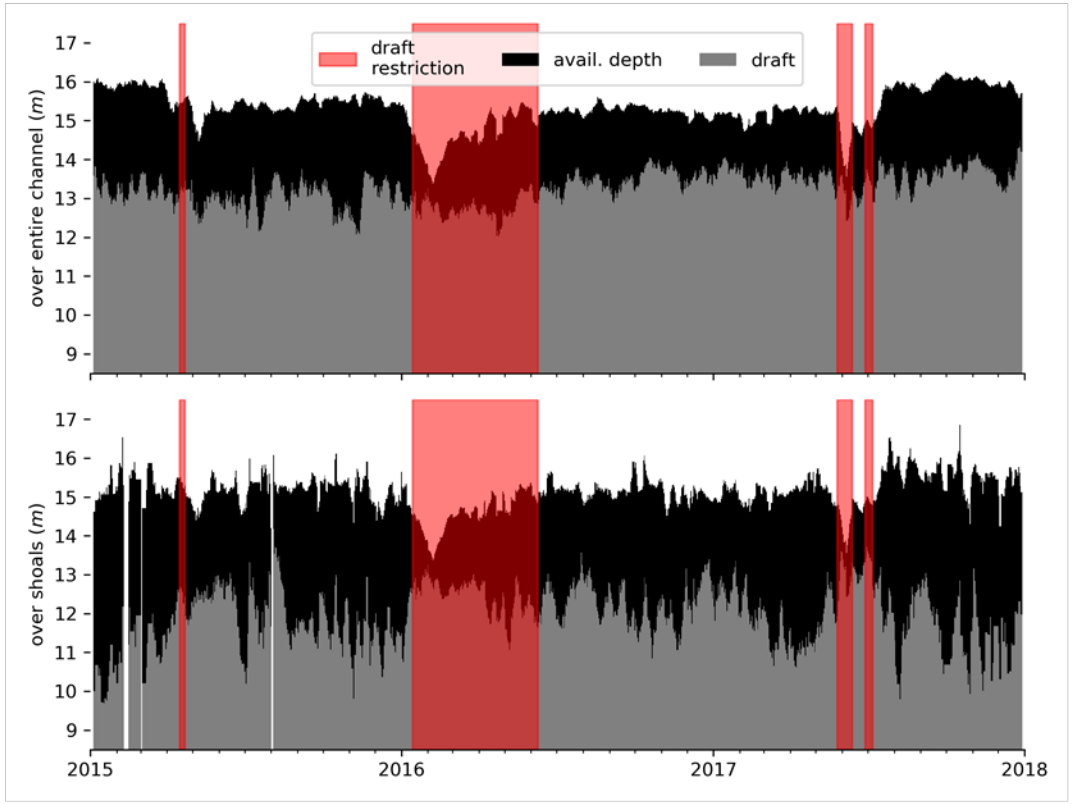

| | Vessel Drafts Exceeding -> | 9.1 M (30 ft) | 12.2 m (40 ft) | 13.7 m (45 ft) |
|---|---|---|---|---|
| SWP_02 | Max. Daily Vessel Count | 22 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 2.7 | 0.4 | 0.2 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.04 | 0.01 | 0.01 |
| SWP_03 | Max. Daily Vessel Count | 21 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 5.0 | 1.9 | 0.6 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.17 | 0.08 | 0.03 |
| SWP_04 | Max. Daily Vessel Count | 22 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 39.1 | 10.9 | 2.2 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 1.77 | 0.44 | 0.09 |
| SWP_05 | Max. Daily Vessel Count | 23 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 49.2 | 16.6 | 2.8 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 3.14 | 0.79 | 0.10 |
| SWP_06 | Max. Daily Vessel Count | 23 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 15.9 | 2.7 | 0.9 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.82 | 0.08 | 0.02 |
| SWP_07 | Max. Daily Vessel Count | 23 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 17.3 | 4.4 | 1.9 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 1.01 | 0.15 | 0.10 |
| SWP_08 | Max. Daily Vessel Count | 22 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 13.5 | 3.4 | 1.0 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.80 | 0.19 | 0.06 |
| SWP_09 | Max. Daily Vessel Count | 22 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 17.4 | 3.8 | 1.1 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 1.05 | 0.16 | 0.05 |
| SWP_10 | Max. Daily Vessel Count | 23 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 28.9 | 9.6 | 1.9 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.85 | 0.31 | 0.04 |
| SWP_11 | Max. Daily Vessel Count | 23 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 33.3 | 10.5 | 1.9 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 1.77 | 0.34 | 0.06 |
| SWP_12 | Max. Daily Vessel Count | 22 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 38.1 | 13.0 | 1.5 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 3.74 | 0.95 | 0.08 |
| SWP_13 | Max. Daily Vessel Count | 20 | 6 | 2 |
| | Shoal Area Below Vessels (ha) | 8.7 | 1.4 | 0.3 |
| | Shoal Volume Below Vessels ($10^5$ $m^3$) | 0.36 | 0.05 | 0.01 |

# Results: 2015-2017

**There is more variability in the draft of vessels than in the available depth resulting either from water level variation or bathymetric elevation.**




**Above, 7-day rolling average of minimum UKC in SWP_12. Below, 7-day rolling average of vessel draft incurring minimum UKC.**




**Available channel depth in terms minimum observed UKC and draft of vessel incurring minimum UKC over the entire channel (above) and over shoals (below).**

# Results: 2015-2017

## A traffic-informed way to think about dredging.

| Fiscal Year | Dollars ($M)[1] | Dredged Volume ($10^6$ $m^3$)[1] | $/$m^3$ | Cargo Throughput (Megatonnes) [2] | $/tonne | Encountered Shoaling ($10^3$ ha-days) | $/ha-day |
|---|---|---|---|---|---|---|---|
| **2015** | 66 | 14 | - | 216 | - | - | - |
| **2016** | 65 | 16 | $4.74 | 221 | $0.29 | 14.2 | $4,600 |
| **2017** | 62 | 17 | $4.06 | 236 | $0.26 | 7.4 | $8,900 |

1. Obtained from agency internal communication.
2. USACE 2018

**Hectare-day – Number of days where shoaling was observed in the swept path of vessels x the shoaled area (in hectares) within the swept path of vessels**

# Conclusions

- Larger vessels tend to have the smallest underkeel clearance.
- Underkeel clearance is generally influenced more by vessel draft than channel depth.
- Relatively small area/volumes of shoaling observed in the swept path of vessels
- Even smaller area/volumes of shoaling observed in the swept path of vessels drafting >40’ or >45’.
- Min. UKC over shoals > Min. UKC over unshoaled for 50% of reaches
- Vessels in unshoaled areas observed to maintain ~10-20% UKC/draft, ~40% UKC/draft in shoaled areas, mostly due to shallower draft (~13.5 m vs. ~11.5m respectively). This includes wave-exposed approaches where PIANC recommends 40% UKC/draft in design.
- Large vessels observed to transit with 0.6m UKC in unshoaled areas, concurs with PIANC Manoeuvrability Margin guidance.
- This is one data point.

# Next Steps, Thoughts, Opportunities

- NEXT: Scale to all ports (add data points)
  - JP: Multiport treatment of UKC for top 10 ports by tonnage.
- NEXT: Add in x,y clearance measurements

- Thought: Design is conservative (PIANC 2014, Vessel Simulator) due to limited available information. Vessel Simulator ~10's to 100's of runs in as-designed/constructed channel. ~10k's – 1M's of real-world runs in AIS.

- Opportunity to study vessel spatial distribution given shoaling conditions
- Opportunity to study vessel spatial distribution following dredging
  - Anecdotally, large vessels follow mid-channel aligned ranges (USCG Range Design Manual)
- Opportunity to study pre-post construction behavioral changes
- Opportunity to study Predicted (simulator) vs. Actual (AIS) to improve design efficiency.