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# Commercial Marine Emission Inventory Development

## Final Report

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## Final Report

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Environ International Corporation
EPA Contract No. 68-D-00-265
Work Assignment No. 1-11

# COMMERCIAL MARINE EMISSION INVENTORY DEVELOPMENT

## FINAL REPORT

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# EXECUTIVE SUMMARY

In this report, emissions were estimated for vessels propelled by Category 3 engines (those with cylinder displacements above 30 liters). Chapter 1 reviews the emissions data available for these types of engines and provides estimates of average emission factors to be used in later emission estimates. Chapter 2 details which ports were considered similar and matched to each of several ports for which detailed port call data was available from earlier EPA work (Arcadis, 1999a and 1999b) in order to estimate emissions for all ports. Chapter 3 provides a description of how the emission estimates near and at US ports were performed and summarizes results for all ports combined. Chapter 4 describes and summarizes emissions estimates for these type of vessels operating in US waters outside the area covered by the Chapter 3 estimates. Chapter 5 estimates future year emissions at US ports. Chapter 6 provides a sensitivity analysis for a number of assumptions and estimates used in the compilation of the Chapter 3 results.

In this analysis, the Category 3 engine emissions, shown below in Table ES-1, were considered to be the emissions from propulsion engines of merchant vessels (including passenger vessels but excluding barge carriers, fishing, supply vessels, and tug) and from auxiliary engines for passenger and reefer vessels only, while other vessel's propulsion and auxiliary engines were considered to be Category 2 or 1. Auxiliary loads were calculated for all merchant vessels, but evidence was discovered indicating that Category 3 engines were used only for auxiliary loads for two types of vessels (passenger and reefer) that have high electrical loads. The ports work was not able to distinguish between US and foreign flagged vessels from the data available. The "Between Port" estimates include transit between 25 nautical miles and 200 statute miles from US shores but may exclude some vessel traffic transit within 25 nautical miles of shore but not within 25 nautical miles of the next or last port of call.

**Table ES-1**. Emission estimates for Category 3 engines. (1,000 tons/year).

| Emission Estimate | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Chapter 3 Category 3* 1996 Near Ports | 5.2 | 11.5 | 101.0 | 9.2 | 68.2 |
| Chapter 4 Category 3* 1996 Between Ports | 2.1 | 4.2 | 88.8 | 7.8 | 58.9 |
| 1996 Total Emissions | 7.3 | 15.7 | 189.8 | 17.0 | 127.1 |

* Category 3 were summed as transit mode emissions of merchant vessels plus hotelling emissions for passenger and reefer vessels including steamships.

# 1. REVIEW OF EMISSION FACTORS

## INTRODUCTION

The purpose of this chapter is to provide an estimate of the emission factors for Category 3 engines for use in estimating emissions at US ports. EPA has defined 3 categories of marine engines as described in Table 1-1 (EPA, 1999b). Many previous reviews and emission studies [EPA (2000), Environment Canada (1997), Lloyds (1995), ETC (1997), BAH (1991), Environment Canada (1999), and TRC (1989)] have determined and reviewed emission estimates, but did not distinguished between these EPA-defined Categories. Based on these reviews and studies, this review seeks to determine appropriate emission factors for Category 3 engines specifically. Based on the Arcadis (1999a and 1999b) reports, activity information was available in units of engine power (kW) and hours of use, so emission factors in emissions per work units (g/kW-hr) were needed.

**Table 1-1.** EPA definition of engine categories.

| Category | Displacement (liters/cylinder) |
|---|---|
| Category 1 | <5.0 |
| Category 2 | 5.0 ≤ disp. <30 |
| Category 3 | ≥30 |

Historic EPA emission rate estimates include the official guidance for emission inventory preparation (EPA, 1992), which are found in BAH (1991), but support documents for recent rulemakings (1999a and 1999b) used different emission factors. Historic estimates were reviewed here for comparison with recommended emission factors for Category 3 engines.

Much of the data from which these official guidance EPA emission factors were derived was not referenced, and a number of studies [ETC (1997), Lloyds (1995), Environment Canada (1997), Lloyds (1997) or Environment Canada (1999)] determining emissions rates have been completed since the time of that guidance. Some of the more recent data has been incorporated into SIP emission inventories for the Houston-Galveston and California ports, which are currently used for ozone modeling and planning for attainment demonstration (Acurex, 1996; Starcrest, 2000). A review of the emissions data for Category 3 marine engines is presented here with a recommendation of the average values to use in emission inventory estimates.

## EPA EMISSION FACTORS GUIDANCE

Official EPA guidance for emission factors for large commercial vessels is shown in Table 1-2. (BAH, 1991 and EPA 1992) The guidance for emission factors did not distinguish between slow speed (direct-drive) and medium speed (geared or electric drive) engines and was limited in its consideration of engine displacement. This emission factor guidance did include estimates for steamships that represent a small number of aging steamships still operating in US waters powered by steam generated from boilers.

**Table 1-2.** EPA emission factors for large ships propulsion power(BAH, 1991).

| **Propulsion Type** | **NOx** (kg/tonne) | **HC** (kg/tonne) | **CO** (kg/tonne) | **PM** (kg/tonne) |
|---|---|---|---|---|
| Motorships | 69.6 | 3.0 | 7.7 | 4.2 |
| Steamships (full power) | 8.1 | 0.2 | 0.9 | 7.2 |
| Steamship (maneuvering) | 7.1 | 0.1 | 0.4 | 2.5 |

All emission estimates were converted from lb/1000 gallons units using 7.9 lb/gallon fuel density for heavy fuel oil.

For smaller vessels, such as push boats, tugs, ferries, and other similar sized work boats, EPA provided emission estimates ranked by size of engine as shown in Table 1-3. The data shown in Table 1-3 exhibited many inconsistencies from one power level to another that were not explained.

**Table 1-3.** EPA (1992) emission factors for small ship propulsion power.

| **Engine Size** | **Mode** | **NOx (kg/tonne** | **HC (kg/tonne)** | **CO (kg/tonne)** | **PM (kg/tonne)** |
|---|---|---|---|---|---|
| < 500 hp | Full | 38.7 | 3.0 | 8.2 | 2.4 |
| | Cruise | 54.8 | 7.2 | 6.7 | 2.4 |
| | Slow | 47.5 | 8.0 | 8.3 | 2.4 |
| 500-1000 hp | Full | 42.3 | 3.4 | 8.6 | 2.4 |
| | Cruise | 42.3 | 2.4 | 11.4 | 2.4 |
| | Slow | 23.5 | 2.4 | 8.8 | 2.4 |
| 1000-1500 hp | Full | 42.3 | 3.4 | 8.6 | 2.4 |
| | Cruise | 42.3 | 3.4 | 8.6 | 2.4 |
| | Slow | 42.3 | 3.4 | 8.6 | 2.4 |
| 1500-2000 | Full | 66.5 | 2.4 | 33.5 | 2.4 |
| | Cruise | 87.8 | 3.4 | 6.3 | 2.4 |
| | Slow | 52.3 | 3.4 | 17.2 | 2.4 |
| 2000+ hp | Full | 56.3 | 3.0 | 13.5 | 2.4 |
| | Cruise | 55.2 | 2.4 | 11.0 | 2.4 |
| | Slow | 59.1 | 3.2 | 8.4 | 2.4 |

All emission estimates were converted from lb/1000 gallons units using 7.1 lb/gallon fuel density for diesel fuel.

Estimates for auxiliary engines were also provided by engine size and are shown in Table 1-4.

This data also displayed many inconsistencies from one power level to another that were not explained. Auxiliary engines are primarily used to provide electric power for the ship while in dock, but may also be used for powering cranes, winches, pumps, bow thrusters, and other uses for the vessel. The larger ocean-going vessels have been reported to typically use 500 to 2,000 kW auxiliary engines for onboard electrical power while only smaller fishing or recreational boats would use engines at 40kW or below for similar purposes.

**Table 1-4.** EPA (1992) emission factors for auxiliary engine power.

| **Engine Power** | **NOx** (kg/tonne) | **HC** (kg/tonne) | **CO** (kg/tonne) | **PM** (kg/tonne) |
|---|---|---|---|---|
| 20 kW | 67.2 | 20.3 | 7.5 | 2.4 |
| 40 kW | 31.8 | 40.1 | 9.5 | 2.4 |
| 200 kW | 19.7 | 2.5 | 8.8 | 2.4 |
| 500+ kW | 41.3 | 11.5 | 6.8 | 2.4 |
| Steamship | 4.6 | 0.4 | 0.5 | 1.3 |

Emission estimates converted from lb/1000 gallons using 7.1 lb/gallon fuel density for diesel fuel.

In addition to auxiliary engines generating electricity, large vessels often maintain small heater boilers for a variety of reasons, such as to provide hot water, regardless of the propulsion engine type. EPA has no guidance for incorporating emissions from these boilers, though the steamship emissions rates in Table 1-4 would likely be appropriate because the boilers are likely to be of similar design and use similar fuels.

## PUBLISHED REVISED EPA EMISSION FACTORS

EPA has recently revised emission factor estimates in the Regulatory Impact Analysis (RIA) and published a rulemaking for commercial marine vessels. (EPA, 1999a &1999b) In the absence of a revised official EPA guidance for determining emissions from commercial marine vessels, the emission factors used in the EPA's RIA have been used as the best available information. (Starcrest, 2000)

In the RIA (EPA, 1999b), EPA estimated the emission factors in accordance with the defined engine categories. In Tables 1-5 and Table 1-6 are the EPA-estimated base emission factors for marine engines for each category of engine. These emission factors were applied to both propulsion and auxiliary engines.

**Table 1-5.** Baseline emission factors for category 1 marine engines (taken from Table 5-3, EPA 1999b).

| Power Range [kW] | HC [g/kW-hr] | NOx [g/kW-hr] | CO [g/kW-hr] | PM [g/kW-hr] |
|---|---|---|---|---|
| 37-75 | 0.27 | 11 | 2.0 | 0.90 |
| 75-130 | 0.27 | 10 | 1.7 | 0.40 |
| 130-225 | 0.27 | 10 | 1.5 | 0.40 |
| 225-450 | 0.27 | 10 | 1.5 | 0.30 |
| 450-560 | 0.27 | 10 | 1.5 | 0.30 |
| 560-1000 | 0.27 | 10 | 1.5 | 0.30 |
| 1000+ | 0.27 | 13 | 2.5 | 0.30 |

For Category 2 and 3 engines, EPA (1999b) estimated emission rates as shown in Table 1-6. For the Category 2 engines, the average values shown in Table 1-6 were those average values used to estimate the emissions reductions from the new emission standards. (Samulski, 1999) Category 2 engines have been either 2-stroke (GM-EMD or Fairbanks-Morse engines) or 4-stroke engine designs with rated speeds typically above 700 rpm using either geared or diesel-electric propulsion drives. For Category 3 engines, EPA relied on base emission estimates by Corbett and Fischbeck (1998) who in turn used emission factors determined from Lloyds (1995). In order to convert the Lloyds emission factors from kilogram per tonne of fuel consumed to gram per kilowatt-hr, the fuel consumption estimates in Lloyds (1995) of 195 (g/kW-hr) for “slow speed” and 210 (g/kW-hr) for “medium speed” engines were used. The term “slow speed” engine refers to engines that have rated speeds below 300 rpm and are exclusively 2-stroke engines directly driving the propeller. The term “medium speed” refers to Category 3 engines with rated speeds typically of 300 to 700 rpm that are typically 4-stroke engines either geared or diesel-electric driving the propeller.

**Table 1-6.** EPA (1999b) baseline emission factors for category 2 and 3 engines.

| Engine Category | HC [g/kW-hr] | NOx [g/kW-hr] | CO [g/kW-hr] | PM [g/kW-hr] |
|---|---|---|---|---|
| # 2 (5-30 l/cylinder) | 0.134 | 13.36 | 2.48 | 0.32 |
| # 3 Medium Speed (> 300 rpm) (> 30 l/cylinder) | 0.5* | 12* | 1.6* | Fuel sulfur dependence |
| # 3 Slow Speed (< 300 rpm) (> 30 l/cylinder) | 0.5* | 17* | 1.6* | Fuel sulfur dependence |

* Converted from kg/tonne units in Lloyds (1995) using the 195 (g/kW-hr) for “slow speed” and 210 (g/kW-hr) for “medium speed” engines.

Corbett and Fischbeck (1998) used one average emission factor for particulate determined from Lloyds, however Lloyds (1995) found the particulate emissions from marine engines are highly dependent on the fuel sulfur. In order to take advantage of this functional dependence, the Lloyds information was incorporated into an equation as shown in Figure 1-1 and converted to a useful unit (g/kW-hr) using the fuel consumption estimates above.

Also, vessels will use auxiliary boilers to provide steam and hot water. These emission sources are typically very small and insignificant sources of emissions. So only for the sake of completeness, the current emission factors for these boilers are shown in Table 1-7.

**Table 1-7.** Auxiliary boilers emission factors (EPA, 1992).

| Engine/Boiler Type | NOx (kg/tonne) | HC (kg/tonne) | CO (kg/tonne) | PM (kg/tonne) |
|---|---|---|---|---|
| Heavy Fuel | 4.6 | 0.4 | - | 1.3 |
| Distillate Fuel | 2.8 | 0.4 | 0.5 | 1.9 |

## REVIEW OF EMISSIONS STUDIES

The review of the available emission studies is presented here with an estimate of the average emission rate to be used in estimating the emissions inventory for Category 3 marine engines. More data are available for NOx emissions with some data on carbon monoxide (CO). In most cases, total hydrocarbon (THC) data was collected with grab samples, which are known to under represent the actual hydrocarbon emissions because of hydrocarbon losses to the walls of the bag or other collection container used to "grab" a sample, so very little data are available on THC emissions. Discussed in more detail below, data on particulate matter (PM) emissions are sensitive to the sulfur level of the fuel, so the range in emissions levels was found to be dependent on the quality of the fuel used during emission testing and an alternate recommended approach was suggested.

### EPA (2000)

EPA (2000) contracted a review of emission factors and fuel consumption for commercial marine vessels. The summary emission estimates relied exclusively on data from ETC (1997) and Lloyds (1995). Other studies available [Environment Canada (1997), Lloyds (1997) or Environment Canada (1999), TRC (1989)] were not considered because emission measurements would need to be converted from the measured units in kg/tonne to g/kW-hr units through a conversion with an estimated average fuel efficiency value. The EPA (2000) study did not attempt to distinguish emissions by the EPA-defined engine categories.

The emission estimates provided by EPA (2000) were not explicitly included because those estimates did not distinguish between engine categories, used a limited data set, and included no "slow speed" engines. EPA (2000) had included data only if the engine were tested over a range of operating loads to investigate the effect of load on emissions and fuel consumption. As discussed for the Lloyds (1995) data below, no “slow speed” engines were tested on multiple operating modes, so EPA (2000) included no slow speed engines in their analysis. The analysis in this report attempted to include as much data as possible, so the average emission rates were determined at one similar operating load level, the highest load for which data existed. However, as estimated by EPA (2000) for a consistent set of data including Category 1, 2, and 3 medium speed engines, one would expect that specific emissions (in units of g/kW-hr) would increase as the relative load (expressed as a percentage of full power) load decreases for slow speed engines as well as that demonstrated in EPA (2000) for medium speed engines.

**Lloyds (1995)**

In the EPA (2000) report, the contractors concluded that many of the emission measurements presented by Lloyds (1995) had inconsistent or unrealistic air fuel ratios making the results suspect. EPA provided the individual emission data points from Lloyds (1995) for which the contractors deemed the emission estimates to meet their quality assurance criteria. Data was supplied over a wide range of operating modes for some engines and only over few or single operating modes for the other engines. The engine specifications were not provided by Lloyds (1995) except for engine rated power and speed.

From a scan of engine specifications found in MER (2001), Category 3 engines are rarely found to have ratings less than 2,000 kW or rated speeds greater 750 rpm therefore Lloyds engines with less than 2,000 kW ratings were considered Category 2 engines for purposes of determining emission estimates. Using this definition to determine engine category and type and as shown in Table 1-8, the data from this study used in EPA (2000), which only used the data where vessels were tested over the full range of loads, was from medium speed (>300 rpm) Category 2 and 3 engines.

**Table 1-8.** Diesel engine specifications from Lloyds (1995) where emission values were considered accurate by EPA (2000) tested at single or multiple modes over the load range.

| Vessel | Load Range | Model Year | Speed (rpm) | # of Engines | Rated Power (kW) | Estimated Category* |
|---|---|---|---|---|---|---|
| B5 | Full | 1986 | 595 | 1 | 3963 | 3 |
| D1 | Full | 1975 | 600 | 1 | 3042 | 3 |
| R2port | Full | 1987 | 510 | 2 | 6545 | 3 |
| R3port | Full | 1978 | 512 | 2 | 4780 | 3 |
| R3stbd | Full | 1978 | 520 | 2 | 4780 | 3 |
| R4 | Full | 1978 | 570 | 1 | 4246 | 3 |
| R7gen | Full | 1987 | 1050 | 2 | 1400 | 2 |
| R7port | Full | 1987 | 510 | 2 | 7700 | 3 |
| TK3 | Full | 1978 | 450 | 1 | 3257 | 3 |
| TK5 | Full | 1979 | 750 | 1 | 745 | 2 |
| TG1push | Full | 1965 | 445 | 1 | 1350 | 2 |
| TG6push | Full | 1989 | 735 | 1 | 1270 | 2 |
| R2cent | Partial | 1987 | 510 | 2 | 6900 | 3 |
| R7cent | Partial | 1987 | 1050 | 2 | 1400 | 2 |

| Vessel | Load Range | Model Year | Speed (rpm) | # of Engines | Rated Power (kW) | Estimated Category* |
|---|---|---|---|---|---|---|
| TK1 | Partial | 1978 | 735 | 1 | 745 | 2 |
| TG3frun | Partial | 1969 | 600 | 1 | 1260 | 2 |
| R8port | One Point | 1980 | 155 | 2 | 5300 | 3 |
| R8stbd | One Point | 1980 | 155 | 2 | 5300 | 3 |
| R9port | One Point | 1980 | 153 | 2 | 5300 | 3 |
| R9stbd | One Point | 1980 | 155 | 2 | 5300 | 3 |
| TK6 | One Point | 1970 | 131 | 1 | 4297 | 3 |
| TK9 | One Point | 1977 | 110 | 1 | 13313 | 3 |

* This estimate made so that Category 2 engines are those with less than 2,000 kW ratings.

The data in Table 1-8 is a more complete listing of valid available data from Lloyds (1995) than was used in the EPA (2000), which had only used the data where the emissions tests were  tested over the full load range.

**ETC (1997)**

The ETC report determined emissions for a variety of engines found on Coast Guard vessels. From the engine models and specifications found in MER (2001), none of the engines tested could be considered Category 3 with the engines fitting either the Category 2 or Category 1 classification. Emissions data is complete for many operational modes for NOx and CO and partial data exists for PM emissions. THC emissions were taken with grab samples, which are expected to be underestimate emissions. Engines were tested at many different load points from cruise to idle.

Table 1-9 displays the engines sampled for emissions with the engine specifications gleaned from MER (2001). All engines were either Category 1 or 2 medium-speed engines or a turbine engine, which defies categorization. So coupled with Lloyds (1995) data described above, the EPA (2000) report relied on data from engines that do not fit the Category 3 classifications.

**Table 1-9.** Engine specifications from ETC (1997).

| Vessel | Engine | Engine Type | Rated Power (kW) | Vessel Type | Speed (rpm) | Bore (mm) | Stroke (mm) | Displacement (l/cylinder) | Category |
|---|---|---|---|---|---|---|---|---|---|
| Steadfast | Alco 16V-251-B | Diesel | 1864 | Cutter | 1000 | 229 | 267 | 11 | 2 |
| Sherman | Faibanks-Morse 3800 TD 8 1/8 | Diesel | 2610 | Cutter | 900 | 206 | 254 | 8 | 2 |
| Sherman | Pratt – Whitney | Turbine | 13423 | Cutter | - | - | - | - | - |
| Tybee | Paxman Type 16 RP 200M Valenta V-16 | Diesel | 2148 | Cutter | 1500 | 197 | 216 | 7 | 2 |
| Long Island | Caterpillar 3516 DITA V Type | Diesel | 2036 | Cutter | 1910 | 170 | 190 | 4 | 1 |
| Thetis | Alco V-18 251-C | Diesel | 2722 | Cutter | 1025 | 229 | 267 | 11 | 2 |
| 41 ft UTB | Cummins VT-903M | Diesel | 237 | Utility Boat | 2300 | 140 | 152 | 2 | 1 |

**Lloyds (1997); Environment Canada (1999)**

These two reports detailed the same emissions data, so the discussion here combines the two reports as one study. This study investigated emissions found on ferries but produced emission estimates only in units of kg/tonne for two operating modes (idle, and full power). As shown in Table 1-10, all three engine categories were included in the test program. Of the Category 3 engines, only medium speed engines were included.

**Table 1-10.** Diesel engine specifications from Lloyds (1997) from information supplied by Environment Canada (1999).

| Engine | Power (kW) | Type | Speed (rpm) | Bore (mm) | Stroke (mm) | Displacement (l/cylinder) | Category |
|---|---|---|---|---|---|---|---|
| MAK 12M551AK | 3430 | Ferry | 500 | 450 | 520 | 83 | 3 |
| Wartsilla 9R32D | 2535 | Ferry | 750 | 320 | 350 | 28 | 2 |
| MAK9MU551AK | 3024 | Ferry | 500 | 450 | 520 | 83 | 3 |
| Mirlees VSSM* | 2490 | Ferry | 381 | 457 | 320 | 52 | 3 |
| Mitsubishi S12R** | 800 | Ferry | 1534 | 160 | 180 | 4 | 1 |
| Bergen KRGB9 | 1800 | Ferry | 900 | 250 | 300 | 15 | 2 |
| Engine 1: Caterpillar 3412 | 242 | Ferry | 1600 | 137 | 152 | 2 | 1 |
| Engine 2: Caterpillar 3412 | 242 | Ferry | 1600 | 137 | 152 | 2 | 1 |
| MAN 6C40/54 | 2807 | Ferry | 550 | 400 | 540 | 68 | 3 |
| Waukesha F2896 | 242 | Auxiliary | 1020 | 216 | 216 | 8 | 2 |
| Mitsuibishi*** | 221 | Auxiliary | 1210 | 240 | 260 | 12 | 2 |
| Caterpillar 398 | 164 | Auxiliary | 1205 | 159 | 203 | 4 | 1 |

* Assumed to be the K Major design based on reported rated power and speed.
** Assumed to be the SM design based on reported rated power and speed.
*** Assumed to be the SU design based on reported rated power and speed.

**Environment Canada (1997)**

This study performed by Environment Canada investigated emissions measured on vessels producing emission estimates only in units of kg/tonne. The THC emissions were collected using grab samples using bags or other collection devices. This type of sampling is known to under represent average emission rates because the walls of the collection device allows heavier hydrocarbons to condense.

In Table 1-11 are the engine specifications determined from the engine model and MER (2001). This was a large data source for slow speed engines with some Category 3 medium-speed engines as well.

**Table 1-11.** Engine specifications for Environment Canada (1997).

| Engine | Year | Power (kW) | Type | Stroke | Bore (mm) | Stroke (mm) | Displacement (l/cylinder) | Category | Speed (rpm) |
|---|---|---|---|---|---|---|---|---|---|
| Sulzer 7RTA 52U | 1996 | 11066 | Cargo | 2 | 520 | 1800 | 382 | 3 | 98 - 135 |
| K MAN K7SZ70/125 | 1978 | 9918 | Cargo | 2 | 700 | 2674 | 1029 | 3 | 68 – 91 |
| M MAN 5S60MC | 1992 | 9508 | Cargo | 2 | 600 | 2292 | 648 | 3 | 79 - 105 |
| Sulzer RND90 | 1980 | 22371 | Cargo | 2 | 900 | 1900 | 1209 | 3 | 90 – 101 |
| Sulzer RND90 | 1980 | 22371 | Cargo | 2 | 900 | 1900 | 1209 | 3 | 90 – 101 |
| K MAN 10L90MC MKD | 1997 | 43699 | Container | 2 | 900 | 2916 | 1855 | 3 | 62 – 82 |
| K MAN 10L90MC MKD | 1997 | 43699 | Container | 2 | 900 | 2916 | 1855 | 3 | 62 – 82 |
| Sulzer 9RTA 84C | 1991 | 33557 | Container | 2 | 840 | 2400 | 1330 | 3 | 73 - 102 |
| B&W Mitsui 7K67GF* | 1978 | 9769 | Cargo | 2 | 670 | 1700 | 599 | 3 | 123 |
| DDC Series 149 t | 1986 | 895 | Tug | 4 | 146 | 146 | 2 | 1 | 1900 |
| MAK 12M551AK | 1976 | 4362 | Ferry | 4 | 450 | 520 | 83 | 3 | 500 |
| 3xMAN B&W 7L23/30H | | 922 | Auxiliary | 4 | 225 | 300 | 12 | 2 | 825 - 900 |
| 3xBergen KRG-6 | | 1074 | Auxiliary | 4 | 250 | 300 | 15 | 2 | 720 - 900 |
| Sulzer V12 12ZAV40 | 1995 | 8752 | Cruise** | 4 | 400 | 560 | 70 | 3 | 510 |
| 3xWaukesha F2896 | | 608 | Auxiliary | 4 | 216 | 216 | 8 | 2 | 600-1215 |
| Sulzer V12 12ZAV40 | 1991 | 8752 | Cruise** | 4 | 400 | 560 | 70 | 3 | 510 |

* Mitsui never produced a slow speed "67" model but B&W MAN did, so B&W MAN engine specifications are provided.

** These engines were listed as both propulsion and auxiliary engines, so presumably these vessels used diesel-electric drives.

### TRC (1989)

Data in this study included emission estimates only in kg/tonne for auxiliary engines with engine rating less than 2,000 kW. Data existed on steamship emission rates also in kg/tonne units for hotelling emissions from both auxiliary and main boilers. But no information about the engines was available other than rated powers, which were all under 2,000 kW, and therefore were considered Category 2 engines as described above for the Lloyds (1995). A table of the engine specifications therefore could not be created.

## EMISSION RATE RECOMMENDED AVERAGES

For recommending emission factors for Category 3 marine engines, the emissions data was separated into different categories by displacement (to distinguish between Category 2 and 3 engines) and by engine speed (above or below 300 rpm) for Category 3 engines before determining average emissions estimates. The reason for distinguishing these categories was that historical data (Lloyds, 1995) had demonstrated that slow speed engines produced higher NOx emissions than medium speed engines. Also, the purpose of this assignment was to review Category 3 engine emission factors separate of other engine types.

The intention of this work was to include as much of the available accurate data as possible in determining the average emission rates. Because the greatest number of engines were tested at the load of the service speed (i.e. during the cruise mode) of the vessel, this highest load point was used to compute an average emission rate for all similar types of engines. Emission rate averages were determined first in units of kg/tonne and converted with the average of the available information on fuel efficiency. Another reason for using the load point at the service speed was that EPA (2000) found that the emissions rates and fuel efficiency of engines becomes less (or not at all) a function of load for loads above about 20%, so the test point on one engine could be considered equivalent to another.

For slow speed engines, those under 300 rpm which are typically direct-drive, the average emission estimates are shown in Table 1-12. Of note here was the influence of the two K MAN engines with extraordinary NOx emission rates raising the average from 97.7 to 107.8 kg/tonne, but there was no reason determined to exclude this data. Also, these results compare with the reported average values from Lloyds (1995) for these types of engines of 87 (kg/tonne) of NOx converted to 17 (g/kW-hr) with a fuel efficiency of 0.195 (kg/kW-hr). The Lloyds (1995) estimate represents a lower range of a possible emission factor to be demonstrated in the sensitivity analysis in a later chapter.

**Table 1-12.** Summary data for category 3 slow speed engines at maximum operating point tested.

| Study | Vessel (Year) | Engine | Speed (rpm) | Percent Power* | BSFC (kg/kW-hr) | NOx (kg/tonne) | CO (kg/tonne) | PM (kg/tonne) |
|---|---|---|---|---|---|---|---|---|
| Lloyds (1995) | R8port (1980) | NA | 155 | | 0.221 | 105.6 | | |
| Lloyds (1995) | R8stbd (1980) | NA | 155 | | 0.221 | 110.2 | | |
| Lloyds (1995) | R9port (1980) | NA | 153 | | 0.225 | 86.4 | | |
| Lloyds (1995) | R9stbd (1980) | NA | 155 | | 0.194 | 115.9 | | |
| Lloyds (1995) | TK6 (1970) | NA | 131 | | 0.243 | 58.0 | | |
| Lloyds (1995) | TK9 (1977) | NA | 110 | | 0.208 | 123.2 | | |
| Env. C. (1997) | (1996) | Sulzer 7RTA 52U | 125 | 93% | | 84.8 | | 6.24 |
| Env. C. (1997) | (1978) | K MAN K7SZ70/125 | 135 | 93% | | 99.3 | 9.7 | 6.4 |
| Env. C. (1997) | (1992) | M MAN 5S60MC | 90 | 99% | | 51.7 | 5.02 | 7.43 |
| Env. C. (1997) | (1980) | Sulzer RND90 | 117 | 87% | | 83.6 | 1.45 | 1.04 |
| Env. C. (1997) | (1980) | Sulzer RND90 | 116 | 86% | | 120.1 | 6.7 | 10.49 |
| Env. C. (1997) | (1997) | K MAN 10L90MC MKD | 75 | 67% | | 178.9 | 5.51 | 16.32 |
| Env. C. (1997) | (1997) | K MAN 10L90MC MKD | 79 | 77% | | 168.1 | 4.72 | 11.84 |
| Env. C. (1997) | (1991) | Sulzer 9RTA 84C | 95 | 84% | | 119.5 | 3.5 | 8.03 |
| Env. C. (1997) | (1978) | B&W Mitsui 7K67GF | 122 | 70% | | 111.3 | 3.94 | 4.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Average** | **121** | **84%** | **0.219** | **107.8** | **5.1** | **8.1** |
| **Average (g/kW-hr)** | | | | **23.6** | **1.1** | **1.8** |

* Percent of rated power at cruise.

Trade literature and manufacturers claims of specific fuel consumption rate and emissions levels have been reported to be much lower than the data in Table 1-12 indicate. The trade journal The Motor Ship (1999) reported that a Wartsila NSD engine has fuel efficiency of ~165 g/kW-hr and produces NOx at 17 g/kW-hr while a MAN B&W engine has fuel efficiency of ~190 g/kW-hr and produces NOx at 18.6 g/kW-hr. These engines then both produce NOx at levels at about 100 kg/tonne or close to the average determined from the data shown above. The specific fuel consumption rate in the measured data reported specifically for those engine models shown above is significantly higher than that reported by the manufacturers as between 160 - 179 g/kW-hr (MER, 1999). Because the emissions data was measured in kg/tonne units, the specific fuel consumption was an important estimate in determining the specific emission rate. However for this work, the measured data was used to estimate specific emission rates rather than the manufacturer's reported estimates because the measured data was better understood. But further investigation is needed to reconcile this conflict in the fuel consumption rate estimates.

For medium speed Category 3 engines, the results are shown in Table 1-13. These results have higher emissions rates than the reported average values from Lloyds (1995) for these types of engines of 57 (kg/tonne) of NOx converted to 12 (g/kW-hr) with a fuel efficiency of 0.211 (kg/kW-hr). However, as described above, the Lloyds results did not distinguish between small and large displacement medium speed engines. Table 1-14 shows that the NOx emission results for Category 2 medium speed engines indicate a much closer correlation with the Lloyds (1995) averages indicating that the medium speed average reported by Lloyds (1995) was primarily influenced by smaller displacement engines. The difference between emission rates for Category 2 and 3 medium speed engines is considered sufficiently significant to recommend separate emission rates.

**Table 1-13.** Summary data for category 3 medium speed engines at maximum operating point tested.

| Study | Vessel (Year) | Engine | Speed (rpm) | BSFC (kg/kW-hr) | NOx (kg/tonne) | CO (kg/tonne) | PM (kg/tonne) |
|---|---|---|---|---|---|---|---|
| Lloyds (1995) | B5 (1986) | NA | 595 | 0.219 | 70.71 | | |
| Lloyds (1995) | D1 (1975) | NA | 600 | 0.200 | 65.32 | | |
| Lloyds (1995) | R2port (1987) | NA | 510 | 0.269 | 80.44 | | |
| Lloyds (1995) | R3port (1978) | NA | 512 | 0.224 | 71.97 | | |
| Lloyds (1995) | R3stbd (1978) | NA | 520 | 0.224 | 70.54 | | |
| Lloyds (1995) | R4 (1978) | NA | 570 | 0.233 | 55.11 | | |
| Lloyds (1995) | R7port (1987) | NA | 510 | 0.220 | 81.69 | | |
| Lloyds (1995) | TK3 (1978) | NA | 450 | 0.235 | 50.52 | | |
| Lloyds (1995) | R2cent (1987) | NA | 510 | 0.220 | 75.69 | | |
| Env. C. (1997) | (1976) | MaK 12M551AK | 500 | | 82.79 | | 6.64 |
| Env. C. (1997) | (1995) | Sulzer V12 12ZAV40 | 510 | | 86.22 | 4.07 | 0.65 |
| Env. C. (1997) | (1991) | Sulzer V12 12ZAV40 | 510 | | 76.28 | 3.04 | 5.53 |
| Env. C. (1999) | Not reported | MaK 12M551AK | 500 | 0.212 | 69.9 | 1.8 | 1.1 |
| Env. C. (1999) | Not reported | Wartsilla 9R32D* | 750* | 0.212 | 78.9 | 2.5 | 2.8 |

| Study | Vessel (Year) | Engine | Speed (rpm) | BSFC (kg/kW-hr) | NOx (kg/tonne) | CO (kg/tonne) | PM (kg/tonne) |
|---|---|---|---|---|---|---|---|
| Env. C. (1999) | Not reported | MaK9MU551AK | 500 | 0.244 | 104.3 | 4.2 | 0.9 |
| Env. C. (1999) | Not reported | Mirlees VSSM | 600 | 0.220 | 72.6 | 3.0 | 3.0 |
| Env. C. (1999) | Not reported | MAN 6C40/54 | 550 | 0.176 | 79.6 | 3.6 | 4.4 |
| **Average** | | | **540** | **0.222** | **74.9** | **3.2** | **3.1** |
| **Average (g/kW-hr)** | | | | | **16.6** | **0.7** | **0.7** |

* This engine has a displacement of 28 l/cylinder, close to Category 3 but technically a Category 2 engine.

The PM emission rates in the Tables 1-13 and 1-14 show considerable variability, which are probably explained by the fuel sulfur level during the test. Lloyds (1995) compared the PM emission rates for different fuel sulfur levels and are shown in Figure 1-1. For comparison to the data, the sulfate-related PM was calculated using equations found in EPA (1998) and shown as the dotted line in Figure 1-1. This calculated sulfate PM uses the estimate that 2.2% of the fuel sulfur directly converts in the engine to $H_2SO_4$:$7H_2O$, and explains much of the increased PM with higher fuel sulfur level fuels in the data. The fuel sulfur level needs to be specified in order to estimate the emission factor from commercial marine engines according to the best-fit estimate in Figure 1-1. While the best fit to the data indicates an exponential function with fuel sulfur, this nonlinear fit may be an artifact of the data set used to determine this fit.

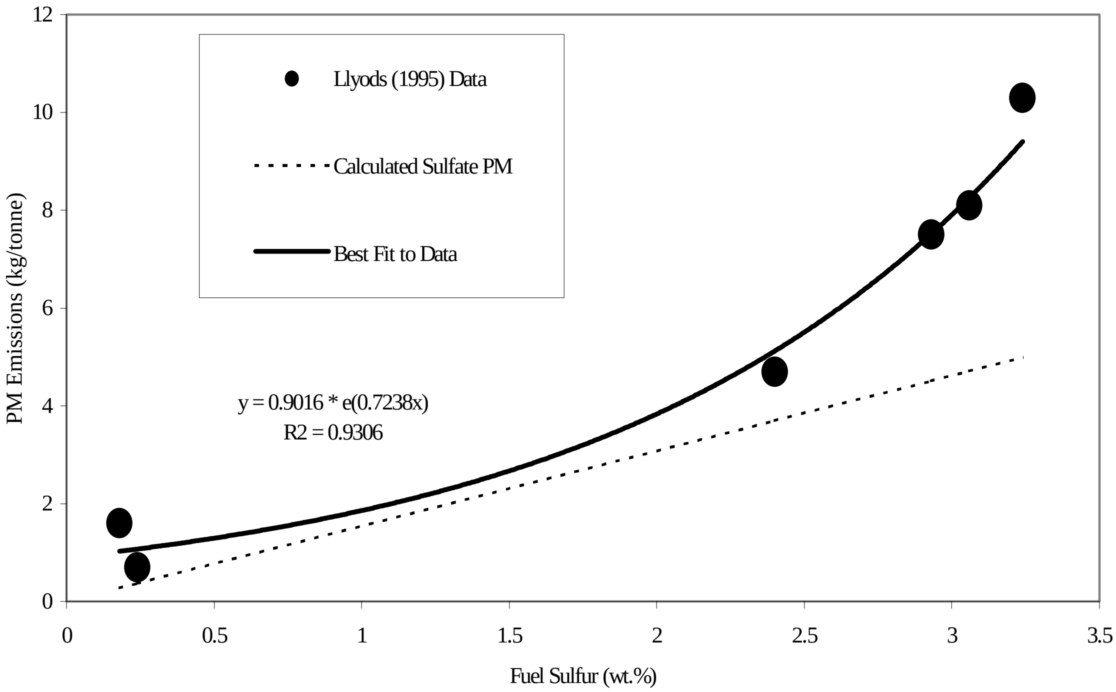


**Figure 1-1.** Effect of fuel sulfur on particulate emissions rates.

The available data for smaller engines, likely Category 2, were available for comparison with the Category 3 results. The Category 2 data shown in Table 1-14 was taken on 4-stroke medium and high speed engines and the average computed indicates that the Category 2 NOx emissions were found to be significantly lower than the Category 3 NOx emission rates in equivalent units.

**Table 1-14.** Summary data for category 2 medium speed engines.

| Study | Vessel | Engine | Use | NOx (kg/tonne) |
|---|---|---|---|---|
| Env. Canada (1999) | N/A | Bergen KRGB9 | Propulsion | 40.60 |
| Env. Canada (1999) | N/A | Engine 1: Caterpillar 3412 | Propulsion | 54.40 |
| Env. Canada (1999) | N/A | Engine 2: Caterpillar 3412 | Propulsion | 44.90 |
| Env. Canada (1999) | N/A | Waukesha F2896 | Auxiliary | 47.70 |
| Env. Canada (1999) | N/A | Mitsubishi | Auxiliary | 98.70 |
| Env. Canada (1997) | N/A | 3 x MAN B&W 7L23/30 H | Auxiliary | 24.44 |
| Env. Canada (1997) | N/A | 3 x Bergen KRG-6 | Auxiliary | 43.69 |
| Env. Canada (1997) | N/A | 3 x Waukesha F2896 DSIM | Auxiliary | 36.74 |
| ETC (1997) | Steadfast | Alco 16V-251-B (Starboard) | Propulsion | 81.51 |
| ETC (1997) | Steadfast | Alco 16V-251-B (Port) | Propulsion | 62.56 |
| ETC (1997) | Sherman | Faibanks-Morse 3800 TD 8 1/8, 12Cy (starboard) | Propulsion | 42.50 |

| Study | Vessel | Engine | Use | NOx (kg/tonne) |
|---|---|---|---|---|
| ETC (1997) | Sherman | Faibanks-Morse 3800 TD 8 1/8, 12Cy (Port) | Propulsion | 44.90 |
| ETC (1997) | Tybee | Paxman Type 16 RP 200M Valenta V-16 (starboard) | Propulsion | 39.01 |
| ETC (1997) | Tybee | Paxman Type 16 RP 200M Valenta V-16 (port) | Propulsion | 38.27 |
| ETC (1997) | Thetis | Alco V-18 251-C (starboard) | Propulsion | 48.58 |
| ETC (1997) | Thetis | Alco V-18 251-C (port) | Propulsion | 47.29 |
| TRC (1989) | President Adams | N/A | Auxiliary | 59.94 |
| TRC (1989) | President Adams | N/A | Auxiliary | 56.09 |
| TRC (1989) | Madame Butterfly | N/A | Auxiliary | 74.91 |
| TRC (1989) | Spring Bride | N/A | Auxiliary | 92.68 |
| TRC (1989) | Beltimber | N/A | Auxiliary | 44.97 |
| TRC (1989) | President Washington | N/A | Auxiliary | 35.54 |
| TRC (1989) | Hyundai Challenger | N/A | Auxiliary | 50.53 |
| TRC (1989) | California Jupiter | N/A | Auxiliary | 51.34 |
| TRC (1989) | Manhattan Bridge | N/A | Auxiliary | 72.27 |
| TRC (1989) | National Dignity | N/A | Auxiliary | 18.14 |
| TRC (1989) | Evergroup | N/A | Auxiliary | 36.05 |
| TRC (1989) | Sealand Explorer | N/A | Auxiliary | 79.25 |
| TRC (1989) | Aurora Ace | N/A | Auxiliary | 52.94 |
| TRC (1989) | Thorseggen | N/A | Auxiliary | 100.58 |
| TRC (1989) | Walter Jacob | N/A | Auxiliary | 64.37 |
| TRC (1989) | Star Esperanza | N/A | Auxiliary | 47.28 |
| TRC (1989) | Dynachem | N/A | Auxiliary | 42.17 |
| Lloyds (1995) | R7gen | N/A | Auxiliary | 52.88 |
| Lloyds (1995) | TK5 | N/A | Propulsion | 60.21 |
| Lloyds (1995) | TG1push | N/A | Propulsion | 56.96 |
| Lloyds (1995) | TG6push | N/A | Propulsion | 61.22 |
| Lloyds (1995) | R7cent | N/A | Propulsion | 52.88 |
| Lloyds (1995) | TK1 | N/A | Propulsion | 58.79 |
| Lloyds (1995) | TG3frun | N/A | Propulsion | 51.76 |
| **Average** | | | | **54.2** |

The THC emissions data was not well characterized in these studies, so the average emissions rate is recommended to be the Lloyds (1995) average, 2.4 (kg/tonne) converted to 0.53 g/kW-hr, where emissions were determined at the stack and did not rely on grab samples.

At loads below 20%, the relative emissions (in g/kW-hr units) and fuel consumption may be higher as indicated by EPA (2000), and slow and medium speed emission factors were adjusted as described here. At low loads there was evidence (EPA, 2000) described in Chapter 1 that specific emissions (in g/kW-hr units) at low loads could increase markedly compared with the high load emission rates used in this work. In order to estimate this effect, the ratio in emissions levels at 10% load (maneuvering load) compared to the loads used in the cruise emission rates 84% load for slow speed (the cruise speed average load) and 99% load for medium speed engines (cruise speed load especially with ferry engines) were determined from with results as shown in Table 1-15. As the load decreases, one expects specific (relative to shaft work in kW-hr) emissions to increase as parasitic loads (loads which do not produce shaft work) become a greater fraction of the engine work.

**Table 1-15.** Ratio of maneuvering emissions factors at 10% load to full load emission rates used in this sensitivity analysis.

| Pollutant | Slow Speed Engines | Medium Speed Engines |
|---|---|---|
| HC | 5.28 | 5.50 |
| CO | 8.52 | 7.41 |
| NOx | 1.36 | 1.36 |
| PM | 1.69 | 1.68 |
| SO2 | 1.57 | 1.55 |

## STEAMSHIP EMISSIONS

The data for steamship emissions was available only during hotelling operation, while emissions will be primarily calculated for transit operation. As shown in Table 1-16, the data and EPA guidance were similar, so the official EPA guidance is recommended for steamship emission rates.

**Table 1-16.** Hotelling emission factors for steamships.

| Engine/Boiler Type | NOx (kg/tonne) | HC (kg/tonne) | CO (kg/tonne) | PM (kg/tonne) |
|---|---|---|---|---|
| Main Boilers TRC (1989) | 9.8 | - | 0.4 | - |
| Smaller Boilers TRC (1989) | 12.3 | N/A | 4.6 | N/A |
| EPA Guidance (BAH, 1991) | 8.1 | 0.2 | 0.9 | 7.2 |
| | (2.8 g/kW-hr) | (0.07 g/kW-hr) | (0.3 g/kW-hr) | (2.5 g/kW-hr) |

* For emissions rates labeled N/A, EPA guidance was used.

In order to use the emission rates, the emission factor needs to be converted to units of g/kW-hr through a fuel efficiency estimate. BAH (1991) provides estimates of daily fuel consumption at full power and average power for steamships of dead weight tonnage (DWT) 50 – 75 kton and 75 – 100 kton. Using the BAH (1991) estimate that full power constitutes 80% of installed power, the calculated fuel efficiency for steamships was 0.350 and 0.334 (kg/kW-hr) for the two DWT ranges. Using the average fuel efficiency of 0.342 (kg/kW-hr), the recommended emission rates are shown in Table 1-16 for steamships. The steamships are being retired, so errors in this emission rate will have less effect on the overall emissions inventory with future year predictions.

# 2. PORT MATCHING

## INTRODUCTION

The purpose of this chapter is to describe the matching criteria used to associate ports that have detailed ship information (such as installed power, cruise speed, and hotelling hours per call) with those without such information. With the results of this work, it was possible to define the typical ship size and therefore the installed engine power for any port according to the procedure outlined in Arcadis (1999a and 1999b) and also described in Chapter 3. This procedure provides a method for using ratios in general vessel calls between like ports to estimate vessel activity at ports where only general vessel activity was available. Vessel characteristics were available for some detailed ports, which could be used at other ports matched to these ports. It was important to match the best estimate of detailed vessel characteristics to ports where such vessels would likely be operating. The detailed ports average vessel characteristics were then matched to other ports, with the total number of vessel calls by ship type determined by the ratio of overall vessel calls.

There were two criteria involved in port matching: regional differences and maximum vessel draft. The first cut used general geographical area to group the top ports into four regions: the Pacific Coast, the Atlantic Coast, the Gulf Coast, and the Great Lakes. This followed the assumption that the geographical area of a port was a primary influence on the characteristics (mainly size and installed power) of vessels calling these ports. The service for each of these regions was also likely unique in terms of the foreign or domestic previous and next ports of call, which is another factor affecting the type of vessel calling on each port in light of regional competition for business. In each of the four regions, there were at least two “typical ports” with detailed activity information in the EPA documents (Arcadis, 1999a and 1999b). The top deep sea and Great Lake ports without detailed activity information were then each matched to a typical port in the same region based on the maximum vessel draft of ships that entered the port during the given year (1996). Maximum vessel draft was assumed to correlate to the size of a vessel, and the size was considered to correspond to the horsepower of the vessel engines within each vessel type. In cases where more than one typical port in a given region had the same maximum vessel draft, geographical area was again the deciding factor for the ports that matched to that value. The port and its matched typical port were then assumed to have many of the same vessel activity patterns, including engine power breakdown by vessel type, vessel speed, and time in modes. Once matched, the number of vessel calls by vessel type were appropriately scaled for those ports without the specific call information using data that was gathered for the detailed ports.

## RESULTS

This work resulted in tables of matched ports by region based on the criteria described above. The port matching was executed for the top ports available in the 1996 and 1999 USACE (2001) data, which were not necessarily the same as the top ports provided in the Arcadis work (1999a and 1999b) based on 1995 vessel call information. But the 1995 vessel call information was used for determining the activity of the matched ports described in Chapter 3.

The available detailed deep-sea port information from Arcadis (1999a and 1999b) often included vessel calls for several ports combined. For the detailed ports constituted of several ports, average or typical characteristics were used to determine the matching described below. Shown below in Table 2-1 are the individual ports included in the deep-sea detailed ports and maximum drafts for vessels at those ports.

**Table 2-1.** Ports included in each detailed deep-sea port to be matched with other ports.

| Waterway | Port Name | Max Draft (ft) | Region * | Detailed Port |
|---|---|---|---|---|
| 0700 | Baltimore, MD | 48 | A | Maryland MEPA |
| 0398 | New York, NY and NJ | 48 | A | Port of New York MEPA |
| 0297 | Chester, PA | 43 | A | Philadelphia MEPA |
| 0298 | Penn Manor, PA | 43 | A | Philadelphia MEPA |
| 0299 | New Castle, DE | 43 | A | Philadelphia MEPA |
| 0552 | Philadelphia, PA | 43 | A | Philadelphia MEPA |
| 5251 | Marcus Hook, PA | 43 | A | Philadelphia MEPA |
| 5252 | Paulsboro, NJ | 43 | A | Philadelphia MEPA |
| 0551 | Camden, NJ | 41 | A | Philadelphia MEPA |
| 0554 | Wilmington, DE | 41 | A | Philadelphia MEPA |
| 2251 | New Orleans, LA | 48 | G | New Orleans MEPA |
| 2253 | South Louisiana, LA | 48 | G | New Orleans MEPA |
| 2255 | Plaquemine, LA | 48 | G | New Orleans MEPA |
| 2252 | Baton Rouge, LA | 43 | G | New Orleans MEPA |
| 2423 | Corpus Christi, TX | 45 | G | Corpus Christi MEPA |
| 2021 | Tampa, FL | 39 | G | Tampa MEPA |
| 4702 | Grays Harbor, WA | 36 | P | Puget Sound MEPA |
| 4708 | Port Angeles, WA | 52 | P | Puget Sound MEPA |
| 4730 | Anacortes, WA | 50 | P | Puget Sound MEPA |
| 4720 | Tacoma, WA | 45 | P | Puget Sound MEPA |
| 4725 | Everett, WA | 39 | P | Puget Sound MEPA |
| 4722 | Seattle, WA | 38 | P | Puget Sound MEPA |
| 4718 | Olympia, WA | 33 | P | Puget Sound MEPA |
| 4732 | Bellingham, WA | 33 | P | Puget Sound MEPA |
| 4660 | Coos Bay, OR | 38 | P | Columbia River MEPA |

* Key; A = Atlantic Coast, G = Gulf Coast, P = Pacific Coast

The summary of the matching for the Atlantic Coast ports is shown in Table 2-2 The detailed data from Philadelphia would be primarily used because the other detailed ports, Maryland and New York, represented the ability to receive greater vessel drafts. The maximum draft of the Philadelphia ports was 43 feet, an already larger vessel draft than many ports can receive. Thus, the ports with smaller draft, some as low as 15-foot draft, likely will be associated with larger vessels than could normally call on these ports. Other work might investigate whether the maximum draft can be associated with maximum dead-weight tonnage to avoid using oversized vessels in the emissions calculations for the lower draft ports. A remedy for this issue is to determine detailed vessel information for one or more smaller and shallow draft ports more similar to other smaller ports.

**Table 2-2.** Summary of the Atlantic Coast deep-sea ports and the matched detailed port.

| Waterway | Port Name | Max Draft (ft) | Region | Detailed Port Matched To |
|---|---|---|---|---|
| 0128 | Portland, ME | 46 | A | Port of New York MEPA |
| 0736 | Newport News, VA | 49 | A | Maryland MEPA |
| 0776 | Savannah, GA | 46 | A | Maryland MEPA |
| 5735 | Norfolk, VA | 50 | A | Maryland MEPA |
| 0110 | Bucksport, ME | 34 | A | Philadelphia MEPA |
| 0112 | Searsport, ME | 35 | A | Philadelphia MEPA |
| 0135 | Portsmouth, NH | 37 | A | Philadelphia MEPA |
| 0146 | Salem, MA | 35 | A | Philadelphia MEPA |
| 0149 | Boston, MA | 41 | A | Philadelphia MEPA |
| 0189 | Fall River, MA | 36 | A | Philadelphia MEPA |
| 0191 | Providence, RI | 39 | A | Philadelphia MEPA |
| 0311 | Bridgeport, CT | 38 | A | Philadelphia MEPA |
| 0317 | Stamford, CT | 15 | A | Philadelphia MEPA |
| 0522 | Port Jefferson, NY | 33 | A | Philadelphia MEPA |
| 0737 | Richmond, VA | 22 | A | Philadelphia MEPA |
| 0738 | Hopewell, VA | 27 | A | Philadelphia MEPA |
| 0764 | Morehead City, NC | 34 | A | Philadelphia MEPA |
| 0766 | Wilmington, NC | 38 | A | Philadelphia MEPA |
| 0772 | Georgetown, SC | 28 | A | Philadelphia MEPA |
| 0773 | Charleston, SC | 42 | A | Philadelphia MEPA |
| 0780 | Brunswick, GA | 35 | A | Philadelphia MEPA |
| 1507 | New Haven, CT | 38 | A | Philadelphia MEPA |
| 2017 | Jacksonville, FL | 40 | A | Philadelphia MEPA |
| 2136 | San Juan, PR | 41 | A | Philadelphia MEPA |
| 2160 | Canaveral, FL | 37 | A | Philadelphia MEPA |
| 2162 | Palm Beach, FL | 33 | A | Philadelphia MEPA |
| 2164 | Miami, FL | 41 | A | Philadelphia MEPA |
| 2139 | Fajardo, PR | 32 | A | Philadelphia MEPA |
| 2151 | Ponce, PR | 31 | A | Philadelphia MEPA |
| 3303 | Trenton, NJ | 20 | A | Philadelphia MEPA |

Table 2-3 shows the matched ports for the Gulf Coast. Again there is the potential problem with ports associated with the detailed port of Tampa, where the maximum draft was 39 feet. Tampa represents the available detailed port with the smallest maximum vessel draft, but its vessel sizes are still much larger than some other ports can realistically handle. Also noted here is that a detailed study of the Houston area ports (Starcrest, 2000) was used instead of the general methodology, so no port association was needed for those four ports covered by this work.

**Table 2-3.** Summary of the Gulf Coast deep-sea ports and the matched detailed port

| Waterway | Port Name | Max Draft (ft) | Region | Typical Port Matched To |
|---|---|---|---|---|
| 2002 | Biloxi, MS | 15 | G | Tampa MEPA |
| 2004 | Pascagoula, MS | 38 | G | Tampa MEPA |
| 2005 | Mobile, AL | 43 | G | Corpus Christi MEPA |
| 2007 | Pensacola, FL | 33 | G | Tampa MEPA |
| 2012 | Houston, TX | 44 | G | Starcrest (2000) |
| 2016 | Panama City, FL | 31 | G | Tampa MEPA |
| 2083 | Gulfport, MS | 32 | G | Tampa MEPA |
| 2163 | Port Everglades, FL | 47 | G | New Orleans MEPA |
| 2167 | Weedon Island, FL | 30 | G | Tampa MEPA |
| 2254 | Lake Charles, LA | 43 | G | Corpus Christi MEPA |
| 2395 | Beaumont, TX | 43 | G | Corpus Christi MEPA |
| 2404 | Texas City, TX | 44 | G | Starcrest (2000) |
| 2408 | Freeport, TX | 42 | G | Starcrest (2000) |
| 2410 | Matagorda Ship | 37 | G | Tampa MEPA |
| 2411 | Victoria, TX | 12 | G | Tampa MEPA |
| 2416 | Port Arthur, TX | 40 | G | Tampa MEPA |
| 2417 | Galveston, TX | 42 | G | Starcrest (2000) |
| 2420 | Brownsville, TX | 36 | G | Tampa MEPA |
| 2116 | Charlotte, FL | 28 | G | Tampa MEPA |

The California ports, for which the Air Resources Board produced emission estimates, dominate the Pacific Coast ports. Also, other work (Arcadis, 1999c) prepared vessel activity and emissions estimates for the Ports of Los Angeles and Long Beach, which may be included in the expected ARB data.

A concern for other port matching with following the strict criteria described was that the Puget Sound MEPA data was considered applicable only for maximum vessel drafts of 52 feet based on the draft at Port Angeles or 50 feet at the Port of Anacortes. This 52 feet maximum vessel draft for the Puget Sound MEPA data was considered unrepresentative of the typical vessels calling on the Puget Sound because the bulk of the vessels in the Puget Sound were those calling the Port of Seattle (~60% of vessel calls) with a vessel draft of 38 feet and the Port of Tacoma (~20% of vessel calls) with a vessel draft of 45 feet. The deep draft ports within the Puget Sound MEPA, Port Angeles and Anacortes, accounted for only a small fraction of all vessel calls (~12%) in the Puget Sound MEPA data. Therefore, it was determined that non-California Pacific Coast ports with vessel drafts greater than 38 feet, especially the Columbia River ports of Kalama, Longview, Vancouver, and Portland, be associated with the Puget Sound MEPA data rather than the port of Coos Bay. The Pacific Coast port matching is shown in Table 2-4.

**Table 2-4.** Summary of the Pacific Coast deep-sea ports and the matched detailed port

| WTWY | Port Name | Max Draft (ft) | Region | Typical Port Matched To |
|---|---|---|---|---|
| 4100 | San Diego, CA | 40 | P | Separate CARB-supplied Data |
| 4110 | Long Beach, CA | 58 | P | Separate CARB-supplied Data |
| 4120 | Los Angeles, CA | 51 | P | Separate CARB-supplied Data |
| 4150 | Port Hueneme, CA | 35 | P | Separate CARB-supplied Data |
| 4240 | Sacramento, CA | 33 | P | Separate CARB-supplied Data |
| 4270 | Stockton, CA | 32 | P | Separate CARB-supplied Data |
| 4335 | San Francisco, CA | 49 | P | Separate CARB-supplied Data |
| 4340 | Redwood City, CA | 33 | P | Separate CARB-supplied Data |
| 4345 | Oakland, CA | 38 | P | Separate CARB-supplied Data |
| 4350 | Richmond, CA | 49 | P | Separate CARB-supplied Data |
| 4375 | Humboldt, CA | 34 | P | Separate CARB-supplied Data |
| 4400 | Hilo, HI | 32 | P | Columbia River MEPA |
| 4405 | Kawaihae, HI | 19 | P | Columbia River MEPA |
| 4410 | Kahului, Maui, HI | 34 | P | Columbia River MEPA |
| 4420 | Honolulu, HI | 40 | P | Puget Sound MEPA |
| 4430 | Nawiliwili, Kauai, HI | 33 | P | Columbia River MEPA |
| 4457 | Barbers Point, HI | 55 | P | Puget Sound MEPA |
| 4622 | Longview, WA | 40 | P | Puget Sound MEPA |
| 4626 | Kalama, WA | 42 | P | Puget Sound MEPA |
| 4636 | Vancouver, WA | 40 | P | Puget Sound MEPA |
| 4644 | Portland, OR | 40 | P | Puget Sound MEPA |
| 4800 | Ketchikan, AK | 37 | P | Puget Sound MEPA |
| 4816 | Valdez, AK | 72 | P | Puget Sound MEPA |
| 4820 | Anchorage, AK | 36 | P | Columbia River MEPA |
| 4831 | Nikishka, AK | 39 | P | Columbia River MEPA |
| 4978 | Kivilina, AK | 20 | P | Columbia River MEPA |

The Great Lakes port matching shown in Table 2-5 was straight-forward using the criteria described though the maximum vessel draft for Burns Harbor (28 feet) and Cleveland (29 feet) are nearly indistinguishable (see Table 2-5).

**Table 2-5.** Summary of the Great Lakes ports and the matched detailed port

| Waterway | Port Name | Max Draft (ft) | Matched to 1996 Typical Port |
|---|---|---|---|
| 3924 | Duluth-Superior, MN & WI | 29 | Cleveland Harbor, OH |
| 3749 | Port of Chicago, IL | 28 | Burns Waterway Harbor, IN |
| 3738 | Indiana Harbor, IN | 31 | Cleveland Harbor, OH |
| 3321 | Port of Detroit, MI | 29 | Cleveland Harbor, OH |
| 3216 | Lorain Harbor, OH | 29 | Cleveland Harbor, OH |
| 3204 | Toledo Harbor, OH | 30 | Cleveland Harbor, OH |
| 3845 | Presque Isle Harbor, MI | 29 | Cleveland Harbor, OH |
| 3219 | Ashtabula Harbor, OH | 31 | Cleveland Harbor, OH |
| 3736 | Gary Harbor, IN | 29 | Cleveland Harbor, OH |
| 3929 | Taconite Harbor, MN | 29 | Cleveland Harbor, OH |
| 3795 | Escanaba, MI | 31 | Cleveland Harbor, OH |
| 3619 | Stoneport, MI | 28 | Burns Waterway Harbor, IN |
| 3620 | Calcite, MI | 28 | Burns Waterway Harbor, IN |
| 3926 | Two Harbors, MN | 29 | Cleveland Harbor, OH |
| 3501 | St. Clair, MI | 30 | Cleveland Harbor, OH |
| 3220 | Conneaut Harbor, OH | 30 | Cleveland Harbor, OH |
| 3803 | Port Inland, MI | 28 | Burns Waterway Harbor, IN |
| 3928 | Silver Bay, MN | 29 | Cleveland Harbor, OH |
| 3506 | MarineCity, MI | 29 | Cleveland Harbor, OH |
| 3213 | Sandusky Harbor, OH | 29 | Cleveland Harbor, OH |
| 3212 | Marblehead, OH | 26 | Burns Waterway Harbor, IN |
| 3756 | Milwaukee Harbor, WI | 28 | Burns Waterway Harbor, IN |
| 3627 | Port Dolomite, MI | 28 | Burns Waterway Harbor, IN |
| 3218 | Fairport Harbor, OH | 27 | Burns Waterway Harbor, IN |
| 3617 | Alpena Harbor, MI | 27 | Burns Waterway Harbor, IN |
| 3778 | Green Bay Harbor, WI | 26 | Burns Waterway Harbor, IN |
| 3202 | Monroe Harbor, MI | 28 | Burns Waterway Harbor, IN |
| 3230 | Port of Buffalo, NY | 27 | Burns Waterway Harbor, IN |
| 3725 | Muskegon Harbor, MI | 28 | Burns Waterway Harbor, IN |
| 3813 | Drummond Island, MI | 27 | Burns Waterway Harbor, IN |
| 3706 | Charlevoix Harbor, MI | 22 | Burns Waterway Harbor, IN |
| 3737 | Buffington Harbor, IN | 27 | Burns Waterway Harbor, IN |
| 3722 | Ludington Harbor, MI | 30 | Cleveland Harbor, OH |
| 3214 | Huron Harbor, OH | 28 | Burns Waterway Harbor, IN |
| 3221 | Erie Harbor, PA | 28 | Burns Waterway Harbor, IN |
| 3726 | Grand Haven Harbor, MI | 25 | Burns Waterway Harbor, IN |

# 3. 1996 EMISSIONS ESTIMATES AND CALCULATION PROCEDURE

## INTRODUCTION AND SUMMARY

This chapter describes estimates of the national emissions inventory for the US ports from activity of merchant vessels and other ships that use Category 3 engines. The emissions from the activity of merchant vessels in the United States were determined by ship type and by each of four modes of operation (cruise, reduced speed zone (RSZ), maneuvering, and hotelling). These four modes encompass merchant vessel activity out 25 nautical miles from ocean coasts and 10 nautical miles from Great Lakes' coasts. The propulsion power for these ships was supplied predominately by Category 3 2-stroke diesel engines with some Category 3 4-stroke and steamship engines, and auxiliary power was typically supplied by Category 2 or smaller 4-stroke diesel engines.

Summaries are provided in Tables 3-1 and 3-2 of all merchant vessels including those propelled by motor and steam ships excluding vessel types that likely use only smaller propulsion engines than Category 3, excluding vessels such as barge carriers, fishing, and supply vessels. The data used to determine vessel activity and vessel characteristics (overall engine power, vessel speed, hotelling times, etc.) was provided in earlier EPA contracted work (Arcadis, 1999a and 1999b).

**Table 3-1.** Summary of the US emission estimates by ship type (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier (BC) | 1,461 | 5,906 | 45,196 | 2,668 | 18,812 |
| Container Ship (CS) | 2,360 | 5,797 | 38,404 | 3,125 | 23,881 |
| General Cargo (GC) | 478 | 2,060 | 16,078 | 996 | 6,940 |
| Miscellaneous (OT) | 179 | 1,066 | 5,914 | 245 | 1,552 |
| Passenger (PA) | 344 | 879 | 6,143 | 747 | 5,804 |
| Reefer (RF) | 257 | 756 | 4,160 | 263 | 1,952 |
| Roll-on roll-off (RO) | 140 | 567 | 4,830 | 421 | 3,114 |
| Tanker (TA) | 1,175 | 3,950 | 32,022 | 3,048 | 22,507 |
| Vehicle Carrier (VC) | 259 | 570 | 3,732 | 293 | 2,247 |
| **Total** | **6,650** | **21,529** | **156,478** | **11,794** | **86,763** |

**Table 3-2.** Summary of the US emission estimates by mode (tons/year).

| Mode Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Cruise | 739 | 1,484 | 31,423 | 2,909 | 21,894 |
| RSZ | 2,587 | 4,635 | 58,707 | 5,215 | 39,936 |
| Maneuvering | 1,762 | 4,726 | 7,120 | 895 | 4,912 |
| Hotelling | 1,563 | 10,685 | 59,219 | 2,774 | 19,925 |
| **Total** | **6,650** | **21,529** | **156,478** | **11,794** | **86,763** |

The propulsion engines of the vessels included in the Arcadis (1999c) data were considered to be

Category 3 engines with the exception of the steamships. The auxiliary generator engines used during hotelling (also called dwelling or berthing) are not likely Category 3 engines except for some generators on specific types of vessels that require high electrical loads, such as some refrigerated cargo (reefers) and cruise ships. Because the Category 3 engines are used for propulsion, the transit (cruise, RSZ, and maneuvering) emission totals most closely represent the Category 3 emission estimates for vessels calling on US ports. The cruise, reduce speed zone (RSZ), maneuvering, and hotelling totals are shown by ship type in Tables 3-3 through 3-6. All transit emissions but only a small part of the hotelling should be considered as derived from Category 3 engines. While steamship emissions do not fit into the diesel engine categorization, ships that use steam propulsion systems will likely be retired, and vessels with diesel engines will be eventually nearly entirely replace steamships.

**Table 3-3.** Cruise (to and from 25 miles from coast) emissions by ship type (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 204 | 415 | 8,909 | 684 | 5,083 |
| Container Ship | 202 | 407 | 8,648 | 762 | 5,577 |
| General Cargo | 70 | 130 | 2,850 | 235 | 1,742 |
| Miscellaneous | 11 | 18 | 410 | 38 | 283 |
| Passenger | 46 | 88 | 1,771 | 266 | 2,048 |
| Reefer | 14 | 29 | 626 | 47 | 349 |
| Roro | 32 | 63 | 1,343 | 122 | 916 |
| Tanker | 142 | 300 | 6,116 | 697 | 5,329 |
| Vehicle Carrier | 18 | 34 | 749 | 58 | 430 |
| **Total** | **739** | **1,484** | **31,423** | **2,909** | **21,894** |

**Table 3-4.** Reduce Speed Zone (RSZ) emissions by ship type (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 553 | 1,026 | 15,424 | 1,223 | 9,276 |
| Container Ship | 942 | 1,644 | 16,996 | 1,513 | 11,945 |
| General Cargo | 185 | 334 | 5,386 | 442 | 3,249 |
| Miscellaneous | 51 | 86 | 773 | 68 | 527 |
| Passenger | 124 | 211 | 2,020 | 208 | 1,656 |
| Reefer | 97 | 164 | 1,405 | 123 | 991 |
| Roro | 48 | 93 | 1,468 | 145 | 1,116 |
| Tanker | 477 | 891 | 13,251 | 1,325 | 9,847 |
| Vehicle Carrier | 109 | 187 | 1,984 | 168 | 1,327 |
| **Total** | **2,587** | **4,635** | **58,707** | **5,215** | **39,936** |

**Table 3-5.** Maneuvering emissions by ship type (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 362 | 994 | 1,931 | 218 | 1,238 |
| Container Ship | 703 | 1,894 | 2,204 | 294 | 1,462 |
| General Cargo | 95 | 259 | 451 | 54 | 301 |
| Miscellaneous | 43 | 120 | 128 | 18 | 90 |
| Passenger | 97 | 236 | 362 | 54 | 315 |
| Reefer | 81 | 220 | 233 | 33 | 155 |
| Roro | 29 | 78 | 168 | 20 | 119 |
| Tanker | 275 | 728 | 1,404 | 183 | 1,116 |
| Vehicle Carrier | 80 | 218 | 241 | 33 | 161 |
| **Total** | **1,762** | **4,726** | **7,120** | **895** | **4,912** |

**Table 3-6.** Hotelling emissions by ship type (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 343 | 3,472 | 18,932 | 543 | 3,181 |
| Container Ship | 512 | 1,853 | 10,557 | 556 | 4,755 |
| General Cargo | 128 | 1,336 | 7,391 | 265 | 1,639 |
| Miscellaneous | 73 | 842 | 4,603 | 121 | 650 |
| Passenger | 77 | 344 | 1,991 | 220 | 1,774 |
| Reefer | 66 | 342 | 1,895 | 60 | 458 |
| Roro | 31 | 334 | 1,851 | 134 | 964 |
| Tanker | 281 | 2,031 | 11,247 | 842 | 6,180 |
| Vehicle Carrier | 52 | 130 | 753 | 32 | 325 |
| **Total** | **1,563** | **10,685** | **59,219** | **2,774** | **19,925** |

The emissions estimates were generated by determining the ratio of vessel activity for each port within the US by the vessel activity within one of several consolidated ports detailed by Arcadis (1999a and 1999b). Each port was matched according to criteria described in Chapter 2. A ratio between each port and the detailed port in terms of load and time in mode for the RSZ mode was also determined from information gathered on the speed and distance of the RSZ for each port. These ratios of port call activity and the RSZ load and time in mode were applied to the emission estimates of the detailed ports to calculate emissions by ship and mode type. The use of the ratio of vessel calls implies that the average vessel size by ship type at each port were identical to those of its matched consolidated ports.

Special information was available for the Houston area (Starcrest, 2000) and California (ARB, 2001) ports. The Houston area data may have been underestimated because the cruise mode did not appear to have been included in the emission estimates. The emission estimates in Houston were adjusted to reflect the emission factors estimated in this work. The California estimates were provided directly from ARB staff and were not adjusted for time, load, or emission factors. California data included transit emissions from the time a ship leaves a harbor till it enters the outer continental shelf area, while the Arcadis results included cruise time out to 25 miles into the open ocean. The California estimates were not adjusted for the emission factors estimates in Task 1 because the emission factors used by ARB were unknown. Documentation for the California estimates was not available, however the emissions provided were consistent with those provided to SCAQMD (Arcadis, 1999) for the San Pedro Bay ports.

This emission summary does not include emissions generated by ships within US waters that do not call on US ports or those emissions generated in transit to US ports but not within the cruise zone defined by Arcadis (1999). These estimates therefore do not include some transit emissions off the ocean coasts and within the Great Lakes that could affect air quality within the US.

## DETAILED PORTS ESTIMATES

In order to estimate the emissions at all ports, it was first necessary to estimate emissions at ports where detailed information about vessel activity and characteristics were available. The emission estimates for the detailed ports provided the basis for estimating emissions at all ports.

Arcadis (1999a and 1999b) provided estimates of the ocean-going vessel activity for several deep sea and Great Lakes ports. The activity estimates that were provided included vessel trips, vessel power, vessel cruise speed, vessel speed in mode, and time in mode where modes were defined as cruise, reduce speed zone (RSZ), maneuvering, and hotelling. The vessel calls were distinguished by vessel (e.g. container, tanker, general cargo, etc.) and propulsion engine type, either 2-stroke slow speed, 4-stroke medium speed, or steamship. The Arcadis reports provided all the required information to estimate emissions except the load and emission factors.

The emissions were calculated by associating and summing the product of the vessel trips or calls, vessel power, average load factor by mode of operation and time in mode for all modes of operation. The equation used for calculating emissions from vessels is shown below. The vessel and engine types were kept as distinct as possible to allow subtotals by vessel, mode, and engine type for each port.

*Emissions = Trips * Power * LF in mode * Time in mode * EF*

*Trips - number of trips or vessel calls by vessel and engine type*
*Power - rated power of propulsion engine by vessel and engine type*
*LF - load factor (fraction of rated power) by mode*
*Time - average time for each mode by vessel and engine type per call or trip*
*EF - emission factor in mode and by engine type*

The vessel power was assumed to have a load factor of 10% for hotelling and 80% at cruise, following the estimates provided in BAH (1991), which are official EPA guidance at this point. Data from Environment Canada indicated that the cruise mode averaged 84% load for their study. Also, Starcrest (2000) indicated that the hotelling load may be as low as 6% of the engine power. However, these reports indicate that the BAH (1991) values are reasonable average estimates.

For maneuvering and reduced speed zone modes, it was necessary to estimate the load at intermediate levels. In order to estimate the load at vessel speeds other than cruise, a cubic relationship was used and is shown in the equation below. This equation assumes that an auxiliary load of 10% is demanded at a minimum even when the vessel speed is zero. However, there is a question over whether the 10% load for auxiliary equipment is provided by the propulsion engine through a power take-off or from onboard generators. The actual speed of the vessels at each port was estimated from discussions with harbor pilots, while the cruise speed was provided by Arcadis (1999a and 1999b) by vessel type. The equation below demonstrates how the engine load was calculated for intermediate speeds.

$$\textit{Load Factor} = 0.1 + 0.7 * (\textit{Actual Speed} / \textit{Cruise Speed})^3$$

The maneuvering speed was estimated as 4 knots for all ports while the average RSZ speed varied for ports with an average used for the initial calculations shown in Table 3-7 for the detailed ports. The RSZ speed determined the load during this mode through the equation above using the cruise (also called service) speed of the individual vessel types also shown in Table 3-7.

**Table 3-7.** Average speed during RSZ and Cruise modes for detailed ports.

| Port | Indicator | RSZ Speed (knots) | Cruise Speed by Ship Type (knots) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BC | CS | GC | OT | PA | RF | RO | TA | VC |
| Lower Mississippi area | LM | 10 | 15 | 20 | 15 | 14 | 21 | 19 | 17 | 15 | 15 |
| New York area | NY | 10 | 15 | 21 | 16 | 14 | 21 | 22 | 18 | 15 | 18 |
| Delaware area | DE | 10 | 15 | 19 | 14 | 14 | 22 | 19 | 16 | 15 | 18 |
| Puget Sound area | PS | 13 | 14 | 21 | 16 | 14 | 19 | 16 | 23 | 16 | 18 |
| Corpus Christi | CC | 10 | 15 | 24 | 16 | 13 | - | - | - | 15 | - |
| Tampa | TA | 9 | 15 | 22 | 14 | 13 | 20 | 18 | 14 | 15 | 18 |
| Baltimore | BA | 14 | 15 | 20 | 15 | 15 | 21 | 19 | 18 | 15 | 18 |
| Coos Bay | CB | 7 | 14 | - | 15 | 15 | - | - | - | - | - |
| Cleveland * | CL | 9 | 14 (13) | 15 | 14 | - | - | - | - | 14 | - |
| Burns Harbor * | BH | 9 | 14 (14) | - | 13 | - | - | - | - | 14 | - |

* Vessels are labeled (Laker) or "Salty" referring to transit within the Great Lakes or out to sea.

The motor ship hotelling loads were assumed to be supplied by smaller auxiliary engines themselves operating at higher relative loads but at only 10% of the installed power (installed power was provided by Lloyds and averaged by Arcadis for the detailed ports) on the vessel.

The emission factors for the calculations, taken from Chapter 1 in Table 1-12 for slow speed propulsion, Table 1-13 for medium speed propulsion, Table 1-14 for medium speed auxiliary, and Table 1-15 for steamship power found in the emission factors chapter are summarized in Tables 3-8 and 3- 9. There remains a question about whether the emission factors are constant over the entire range of engine loads, however as demonstrated in EPA (2000) the emission factors (in g/hp-hr units) only increase for loads below about 10%.

**Table 3-8.** Emission factors (g/hp-hr) for transit modes.

| Engine Type | HC | CO | NOx | PM* | $SO_2$ |
|---|---|---|---|---|---|
| Slow Speed | 0.395 | 0.82 | 17.60 | 1.29 | 9.56 |
| Medium Speed | 0.395 | 0.52 | 12.38 | 1.31 | 9.69 |
| Steam Boiler | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 |

*Using an average fuel sulfur level of 3%.

**Table 3-9.** Emission factors (g/hp-hr) for hotelling modes (Category 2 medium speed engines except steam boilers).

| Propulsion Engine Type | HC | CO | NOx | PM* | $SO_2$ |
|---|---|---|---|---|---|
| Slow Speed | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 |
| Medium Speed | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 |
| Steam Boiler | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 |

* Using an average fuel sulfur level of 0.33% for engines and 3% sulfur for steam boilers.

The assumptions for fuel use in the emission rates shown above are that propulsion engines and steamships use high sulfur (3% by weight) fuel (an approximate average among a summary of bunker fuels found at http://www.marinelink.com/members/stats/), but lower sulfur (0.33%) fuel was assumed to be used at dock with auxiliary engines derived from the average nonroad diesel fuel sulfur level found in EPA (1998). However, steamships were assumed to have used high sulfur fuel while at dock though auxiliary diesel generators may supply the electric loads with the steamship boilers shut down.

There is confusion among several knowledgeable parties over the type of fuel used near ports. Some harbor pilots (Starcrest, 2000) have indicated that vessels use low sulfur diesel fuel at some point starting either during the Reduced Speed Zone or Maneuvering modes when the harbor pilots are in command. Once at dock, most vessels use smaller onboard generators running on low sulfur diesel fuel (Starcrest, 2000), so Category 2 medium-speed 4-stroke emission factors using low sulfur fuel were used for hotelling emissions on each vessel. Important for some ports was the estimate, based on information from TRC (1989), that steamship tankers burn heavy fuel oil during hotelling operations. On the other hand, Greg Rideout (2001) indicated that, during his work in the Puget Sound and Vancouver areas (Environment Canada, 1997), there was no evidence that lower sulfur fuels were used near ports in engines for either propulsion or electrical generation, and that on-board diesel generators appeared to run during transit as well as during hotelling modes. One Florida pilot (PCPA, 2001) estimated that only about 5-10% of ships are equipped with separate tanks to be able to switch to other fuels (either lighter weight and\or lower sulfur fuels) during transit modes.

The emissions results for each of the 10 detailed ports are shown in Appendix A by vessel and propulsion engine type and by mode of operation and for total emissions for all modes. The hotelling emissions for slow speed 2-stroke and medium speed 4-stroke propulsion engines are expected to be generated from Category 2 medium speed engines. Summary estimates are shown below in Table 3-10.

**Table 3-10.** Summary emission estimates for the detailed ports (tons/year).

| Consolidated Detailed Port | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Lower Mississippi | 437 | 2,560 | 23,204 | 1,337 | 9,243 |
| New York | 189 | 937 | 8,745 | 685 | 4,953 |
| Delaware River (Philadelphia et al.) | 124 | 674 | 6,284 | 403 | 2,837 |
| Puget Sound | 231 | 986 | 11,174 | 1,135 | 8,511 |
| Corpus Christi | 44 | 191 | 1,862 | 209 | 1,573 |
| Tampa | 41 | 241 | 2,055 | 140 | 987 |
| Baltimore | 160 | 586 | 7,444 | 530 | 3,844 |
| Coos Bay | 5 | 36 | 287 | 14 | 89 |
| Cleveland | 9 | 36 | 243 | 16 | 111 |
| Burns Harbor | 2 | 10 | 82 | 5 | 36 |

Relative emissions by mode differed between ports due to the geographic and operational differences between ports and by vessel type. The geographic differences were mainly observed in terms of the length of the RSZ and, to a lesser extent, the cruise mode lengths. At some ports, such as the Lower Mississippi and Puget Sound area ports, the RSZ's begin much further out from port in both distance and time than, for example, New York, Tampa, or Corpus Christi. Hotelling times were important and depended in large part on the prevalent type of vessel call, where, for instance, bulk carriers tend to spend longer in port than container ships.

Hotelling modes tended to be the largest source of NOx emissions for a port because of the length of this operational mode in comparison with the transit modes. The transit modes for cruise and RSZ tended to be of greater importance for PM emissions because of the high sulfur fuel assumed to be used during transit. Maneuvering modes tended be less important because the length of this mode was short and the engine load was low.

Some vessels in 1996 (the year for which the Arcadis, 1999a and 1999b data were valid) were still propelled by steamship boilers and turbines, with the relative number of steamships varied from port to port. The steamships are likely to be mostly replaced by Category 3 motorships because of the greater efficiency of these engines. The steamship NOx emission rates are significantly lower than those from motorships, so the NOx emissions will be higher in the future even without growth in activity of large merchant vessels. The fraction of vessels with steamship propulsion in 1996 for the detailed ports is summarized in Table 3-11. The transit emissions included emissions from steamships which do not fall under the description of Category 3 engines, but the steamship vessel activity will be mostly served by vessels with Category 3 engines in the future.

**Table 3-11.** Fraction of steamship calls at different ports in 1996.

| Port | Steamship Fraction of Tankers | Steamship Fraction of Total |
|---|---|---|
| Lower Mississippi | 1.2% | 3.2% |
| New York | 10.1% | 11.1% |
| Delaware River (Philadelphia and others) | 10.4% | 4.0% |
| Puget Sound | 59.9% | 20.3% |
| Corpus Christi | 40.3% | 34.5% |
| Tampa | 32.9% | 10.7% |
| Baltimore | 5.4% | 3.8% |
| Coos Bay | 0.0% | 0.0% |
| Cleveland | 0.0% | 6.2% |
| Burns Harbor | 0.0% | 4.8% |

## METHODOLOGY FOR MATCHED PORTS

These ports were matched to the detailed vessel characteristics for the ports described above as described in the Chapter 2 report using the procedure described by Arcadis (1999). The Arcadis report detailed a 12 step process (outlined below) for determining activity estimates for the matched (or Modeled) ports. In this work, the terminology "detailed" or "typical" ports refers to the ports where detailed vessel characteristics and activity were summarized in the Arcadis (1999) report. The term "matched" or "modeled" port refers to the ports where detailed activity and vessel characteristics were not available.

Step 1. Determine a Modeled Port and a Typical Port
Step 2. List USACE Port Codes Within the MEPA Area
Step 3. Total All Trips for the Ports in Step 2
Step 4. Determine Trips for the Typical Port
Step 5. Determining the Number of Calls for the Typical Port
Step 6. Determine the Distance to the Port/Waterway
Step 7. Determine the Distance from the Breakwater to the Typical Port
Step 8. Compute RSZ for the Typical Port
Step 9. Determine Trips for the Modeled Port
Step 10. Compute the Number of Calls for the Modeled Port
Step 11. Compute the revised reduced speed zone
Step 12. Allocation to Counties

For this work the steps described were generally followed with exceptions noted here below. In order to produce national estimates for all Category 3 vessels, a more straight-forward methodology was used compared to the Arcadis methodology.

Step 1 was provided in the Chapter 2 report. In our work, the 10 detailed ports provided by Arcadis (1999) will be used for the detailed (or also called typical) port designation, rather than using specific ports within the detailed port information as Arcadis (1999) described in their example using Bellingham (one of many Puget Sound ports) as the typical port.

Step 2 was simplified by using the entire detailed port vessel characteristics (e.g. all of the ports within the Puget Sound Marine Exchange and Port Authorities (MEPA)) rather than just Bellingham as given in the example described by Arcadis (1999)) as the basis for matched port vessels. In some cases, the detailed ports data set provided by Arcadis (1999) included vessel information from all ports within the MEPA area. Instead of extracting individual port information from the detailed data set, this work used the MEPA data in its entirety for port matching. Also, the ports within each MEPA area (Table 1-1 in Arcadis,1999) were excluded from the matched port list as the activity at all ports was assumed to be included in the totals for the detailed ports.

Steps 3 and 4 were followed for this work. The summary data for the detailed ports and the individual matched ports used the Arcadis-supplied United States Army Corps of Engineers (USACE) trip data for 1995 to determine relative activity by vessel type. Based on a review of several operators (e.g. Seabulk International, Crowley, and Foss), many types of vessels were not considered to have Category 3 engines onboard, including barge carriers (BA), dry cargo barges (BD), liquid barges (BL), supply vessels (SV) such as used for off-shore oil and gas production, and tugs (TUG) or fishing vessels. There were also unclassified vessels, which were mapped into the dry cargo vessels as described by Arcadis (1999). Matched ports may have trips recorded for vessel types that were not found in the detailed port data, so these vessel types were mapped into the OTHER or MISCELLANEOUS category characteristics for these vessels. This is demonstrated in Appendix B for the Texas ports.

Step 5 was handled much as described by Arcadis except that the total estimate for detailed ports (combination of the MEPA ports) was used instead of individual ports.

Steps 6 through 8 and Step 11 were handled differently and more directly than the described approach by contacting individual ports for information about average vessel speed and distance within each reduce speed zone (RSZ). This was done for each matched port except for Great Lakes ports, which were assumed to be similar for all modes of operation.

Steps 9 and 10 formed the basis for determining the large ocean-going vessels (OGV) counts at the matched ports using the Arcadis (1999) 1995 vessel trips data. An attempt was made to revise the trip data using USACE (2001) information for 1996 and 1999, but encountered difficulties in determining reasonable trip counts between certain ports. The trip data included vessel trips by 6 general types: Self-Propelled Dry Cargo, Self-Propelled Tanker, Towboat, Non-Self Propelled Dry Cargo, Non-Self Propelled Tanker, Other (undefined). Arcadis reported to have used a ratio of the 6 general types to map into the more detailed classifications. However, this procedure led to some unreasonable estimates of total trips for some ports, such as Seattle-Tacoma where self-propelled dry cargo trips increased by 10 to 20 times between 1995 and 1996. This increase in trips would have translated to an unreasonable increase from 1995 to 1996 for most vessel trips. Additional work would be needed to determine which method is most correct for determining vessel trips.

Step 12 was omitted in this work because county level emissions estimates were not requested.

In summary, the method used determined a ratio of the matched port to the detailed port summaries in terms of vessel calls by ship type to calculate emissions directly for cruise, maneuvering, and hotelling activity. The reduce speed zone (RSZ) load and time in mode was calculated specifically for each port based on the geography and discussions with harbor pilots or other officials. For other modes, each vessel call at the matched port is considered to be equivalent to that of the detailed port. The summary emission and RSZ speed and distance estimates by port are shown in Table 3-12 and were combined with the estimates for the detailed ports in Table 3-10 to provide national totals. The Houston-Galveston and California ports estimates were provided by the TNRCC and ARB and were not calculated in this work.

**Table 3-12.** Emission estimates and reduced speed zone parameters by port.

| Port | Matched Port* | Emissions (tons/year) | | | | | RSZ (knots and miles) | |
|---|---|---|---|---|---|---|---|---|
| | | HC | CO | NOx | PM | $SO_2$ | Speed | Distance |
| Brownsville, TX | TA | 12 | 85 | 644 | 34 | 227 | 8.8 | 18.5 |
| Gulfport Harbor, MS | TA | 5 | 49 | 322 | 13 | 81 | 10.0 | 17.0 |
| Matagorda Ship Channel, TX | TA | 6 | 34 | 284 | 20 | 143 | 7.3 | 24.0 |
| Orange, TX | TA | 1 | 2 | 25 | 2 | 11 | 7.0 | 53.5 |
| Panama City Harbor, FL | TA | 6 | 41 | 332 | 18 | 119 | 10.0 | 10.0 |
| Pascagoula Harbor, MS | TA | 19 | 111 | 937 | 66 | 465 | 10.0 | 17.0 |
| Pensacola Harbor, FL | TA | 2 | 17 | 129 | 7 | 45 | 12.0 | 12.0 |
| Port Arthur, TX | TA | 20 | 114 | 978 | 86 | 628 | 7.0 | 20.0 |
| Beaumont, TX | CC | 18 | 72 | 757 | 89 | 675 | 7.0 | 56.5 |
| Lake Charles, LA | CC | 23 | 110 | 1,007 | 103 | 767 | 6.0 | 24.0 |
| Mobile Harbor, AL | CC | 29 | 130 | 1,263 | 91 | 656 | 11.0 | 35.0 |
| Port Everglades Harbor, FL | LM | 138 | 1,304 | 8,601 | 465 | 3,086 | 7.5 | 2.0 |
| Houston-Galveston Area Ports | – | 209 | 867 | 8,810 | 573 | 3,437 estimated | 6 to 12 | 5 to 40 |
| Jacksonville Harbor, FL | DE | 41 | 255 | 2,122 | 118 | 802 | 10.0 | 15.0 |
| Port of Boston, MA | DE | 20 | 132 | 1,054 | 67 | 466 | 10.0 | 15.0 |
| Charleston Harbor, SC | DE | 38 | 222 | 1,899 | 111 | 764 | 12.0 | 17.0 |
| New Haven Harbor, CT | DE | 8 | 69 | 486 | 25 | 167 | 10.0 | 2.0 |
| Port of Wilmington, NC | DE | 26 | 156 | 1,318 | 77 | 529 | 10.0 | 28.0 |
| Providence, RI | DE | 8 | 58 | 445 | 26 | 179 | 9.0 | 22.0 |
| Morehead City Harbor, NC | DE | 6 | 43 | 346 | 19 | 132 | 10.0 | 28.0 |
| Bridgeport Harbor, CT | DE | 1 | 11 | 77 | 4 | 23 | 10.0 | 2.0 |
| Fall River Harbor, MA | DE | 3 | 24 | 185 | 9 | 59 | 9.0 | 22.0 |
| Palm Beach Harbor, FL | DE | 22 | 172 | 1,261 | 62 | 402 | 3.0 | 3.0 |
| Canaveral Harbor, FL | DE | 14 | 103 | 759 | 51 | 354 | 10.0 | 4.0 |
| Portsmouth Harbor, NH | DE | 2 | 17 | 121 | 7 | 48 | 10.0 | 2.0 |
| Port Jefferson Harbor, NY | DE | 0 | 0 | 2 | 0 | 1 | 10.0 | 2.0 |
| Brunswick Harbor, GA | DE | 11 | 58 | 545 | 31 | 215 | 13.0 | 45.5 |
| Searsport Harbor, ME | DE | 3 | 19 | 146 | 8 | 55 | 9.0 | 22.0 |
| Bucksport Harbor, ME | DE | 1 | 5 | 38 | 2 | 17 | 9.0 | 22.0 |

| Port | Matched Port* | Emissions (tons/year) | | | | | RSZ (knots and miles) | |
|---|---|---|---|---|---|---|---|---|
| | | HC | CO | NOx | PM | $SO_2$ | Speed | Distance |
| Georgetown Harbor, SC | DE | 3 | 26 | 199 | 9 | 61 | 12.0 | 17.0 |
| Port of Richmond, VA | DE | 27 | 132 | 1,311 | 79 | 550 | 10.0 | 100.0 |
| Port of Hopewell, VA | DE | 3 | 15 | 139 | 8 | 55 | 10.0 | 82.0 |
| Miami Harbor, FL | DE | 143 | 893 | 7,193 | 537 | 3,818 | 12.0 | 3.0 |
| Newport News, VA | BA | 25 | 154 | 1,328 | 83 | 579 | 14.0 | 22.0 |
| Savannah, GA | BA | 87 | 445 | 4,370 | 283 | 2,001 | 13.0 | 45.5 |
| Norfolk Harbor, VA | BA | 40 | 213 | 1,984 | 137 | 970 | 14.0 | 24.0 |
| Portland, ME | NY | 9 | 56 | 426 | 28 | 194 | 10.0 | 11.0 |
| Portland, OR | PS | 67 | 313 | 3,274 | 306 | 2,273 | 12.0 | 93.0 |
| Vancouver, WA | PS | 23 | 121 | 1,190 | 77 | 547 | 12.0 | 94.0 |
| Kalama, WA | PS | 13 | 80 | 720 | 43 | 303 | 12.0 | 69.0 |
| Longview, WA | PS | 19 | 120 | 1,054 | 61 | 420 | 12.0 | 59.0 |
| Honolulu, HI | PS | 25 | 175 | 1,374 | 123 | 900 | 4.0 | 7.0 |
| Barbers Point, HI | PS | 4 | 24 | 187 | 41 | 316 | 4.0 | 7.0 |
| Valdez, AK | PS | 19 | 94 | 812 | 228 | 1,798 | 10.0 | 27.0 |
| Ketchikan, AK | PS | 14 | 117 | 795 | 59 | 412 | 14.0 | 14.0 |
| Port of Astoria, OR | PS | 9 | 73 | 531 | 25 | 161 | 12.0 | 14.0 |
| Kahului, Maui, HI | CB | 1 | 5 | 43 | 2 | 13 | 4.0 | 7.0 |
| Hilo, HI | CB | 0 | 1 | 9 | 0 | 3 | 4.0 | 7.0 |
| Nawiliwili, Kauai, HI | CB | 0 | 3 | 20 | 1 | 6 | 4.0 | 7.0 |
| Nikiski, AK | CB | 0 | 1 | 15 | 1 | 6 | 14.5 | 84.0 |
| Anchorage, AK | CB | 1 | 5 | 64 | 4 | 30 | 14.5 | 144.0 |
| ALL California ports | – | 4,084 | 7,479 | 29,900 | 2,793 | 23,186 | - | - |
| Duluth-Superior, MN & WI | CL | 15 | 67 | 449 | 28 | 191 | - | - |
| Indiana Harbor, IN | CL | 5 | 20 | 139 | 10 | 68 | - | - |
| Port of Detroit, MI | CL | 6 | 24 | 168 | 12 | 79 | - | - |
| Lorain Harbor, OH | CL | 6 | 26 | 176 | 12 | 80 | - | - |
| Toledo Harbor, OH | CL | 7 | 31 | 209 | 13 | 90 | - | - |
| Presque Isle Harbor, MI | CL | 3 | 14 | 95 | 6 | 44 | - | - |
| Ashtabula Harbor, OH | CL | 4 | 17 | 114 | 8 | 53 | - | - |
| Gary Harbor, IN | CL | 2 | 8 | 54 | 4 | 26 | - | - |
| Taconite Harbor, MN | CL | 2 | 8 | 52 | 4 | 24 | - | - |
| Escanaba, MI | CL | 3 | 12 | 80 | 5 | 37 | - | - |
| Two Harbors, MN | CL | 2 | 7 | 48 | 3 | 23 | - | - |
| St. Clair, MI | CL | 2 | 11 | 75 | 5 | 31 | - | - |
| Conneaut Harbor, OH | CL | 2 | 12 | 78 | 5 | 31 | - | - |
| Silver Bay, MN | CL | 2 | 7 | 47 | 3 | 22 | - | - |
| Marine City, MI | CL | 1 | 4 | 25 | 2 | 12 | - | - |
| Sandusky Harbor, OH | CL | 4 | 18 | 121 | 8 | 52 | - | - |
| Ludington Harbor, MI | CL | 1 | 2 | 16 | 1 | 8 | - | - |
| Port of Chicago, IL | BH | 4 | 18 | 146 | 9 | 65 | - | - |
| Stoneport, MI | BH | 3 | 16 | 136 | 9 | 60 | - | - |
| Calcite, MI | BH | 3 | 17 | 138 | 9 | 61 | - | - |
| Port Inland, MI | BH | 2 | 10 | 87 | 6 | 38 | - | - |
| Marblehead, OH | BH | 2 | 8 | 69 | 4 | 31 | - | - |
| Milwaukee Harbor, WI | BH | 2 | 9 | 75 | 5 | 33 | - | - |
| Port Dolomite, MI | BH | 1 | 7 | 58 | 4 | 26 | - | - |
| Fairport Harbor, OH | BH | 3 | 19 | 136 | 7 | 46 | - | - |
| Alpena Harbor, MI | BH | 2 | 11 | 95 | 6 | 42 | - | - |
| Green Bay Harbor, WI | BH | 1 | 5 | 38 | 2 | 17 | - | - |
| Monroe Harbor, MI | BH | 1 | 3 | 23 | 1 | 10 | - | - |
| Port of Buffalo, NY | BH | 1 | 5 | 37 | 2 | 14 | - | - |
| Muskegon Harbor, MI | BH | 1 | 4 | 33 | 2 | 15 | - | - |
| Drummond Island, MI | BH | 1 | 3 | 27 | 2 | 12 | - | - |
| Charlevoix Harbor, MI | BH | 1 | 3 | 28 | 2 | 12 | - | - |
| Buffington Harbor, IN | BH | 0 | 2 | 16 | 1 | 7 | - | - |

| Port | Matched Port* | HC | CO | NOx | PM | $SO_2$ | Speed | Distance |
|---|---|---|---|---|---|---|---|---|
| | | Emissions (tons/year) | | | | | RSZ (knots and miles) | |
| Huron Harbor, OH | BH | 1 | 3 | 21 | 1 | 9 | - | - |
| Erie Harbor, PA | BH | 3 | 19 | 134 | 7 | 43 | - | - |
| Grand Haven Harbor, MI | BH | 1 | 3 | 25 | 2 | 11 | - | - |

* Legend for the matched ports is given in Table 3-7

# 4. BETWEEN PORT EMISSIONS

## INTRODUCTION

The method to determine between port emissions was described by Corbett and Fischbeck (2000) for emissions in the open ocean and Great Lakes by associating activity estimates from the USACE (2002) in terms of ton-miles of freight activity with emission rates in terms of ton-miles. Other methods were considered, such as tracking the domestic fleet through next and last port of call information from the Marine Exchange or Port Authority (MEPA), but were deemed unreliable for determining the routes of passage of vessels powered by Category 3 engines. Often next and last ports of call were unknown or indicated that foreign vessels were traveling between two US ports, which is illegal according to US cabotage law. The estimates using the USACE (2002) activity estimates appear to significantly underestimate emissions between ports however.

River traffic other than those vessels used in the open ocean were considered to be powered by Category 2 or smaller engines based on a review of many operators' fleets. Tow boats hauling freight by barge were considered to not operate outside of 25 nautical miles from ocean and 10 miles from Great Lakes shores.

Passenger vessels were not explicitly characterized by this approach such as cruise ships because freight tonnage was not a representative indicator of activity. The cruise vessel emissions were incorporated through the emission factor estimates by summing cruise vessel emissions along with the freight vessel emissions divided by the associated freight tonnage at each port.

## TOW AND PUSH BOAT TRAFFIC

In previous work (Corbett and Fischbeck, 1998), Category 3 engines were projected to produce emissions along river ways and near coasts. This section addresses whether Category 3 engines are used to provide power by tugs for much of the traffic along these inland waterways and near ocean coasts. Tugs (a term used here to indicate both tow and push boats) handle much (mostly domestic) freight traffic on ocean and river links. A search of the many operators (described below) indicated that most tugs are powered by engines not considered Category 3. Corbett and Fischbeck (1998) found rare instances where tugs were powered by Category 3 engines though these were few.

Except for river ports serving ocean-going traffic, all river traffic was assumed to be handled by push boats or other craft propelled by Category 1 or 2 engines. From BTS (1999) quoted below, it is clear that almost all of the river freight is handled by barges pushed by tugs.

> "In 1997, barges transported 96 percent of the tonnage that moved on inland waterways."

A review of the fleets of several tug operators showed that such tugs overwhelmingly use smaller displacement engines than Category 3. Large ocean-going tugs (up to 10,000 hp) and river pushboats (up to 8,000 hp) use US manufactured engines, all Category 2 or smaller engine types. Below are shown a variety of tugs and push boats operating in the U.S., and none of those shown use Category 3 engines.

Crosby Tugs; Golden Meadow, LA
http://www.crosbytugs.com/fleet.htm
**Examples of largest tugs**
M/V Crosby Duke - (2) Caterpillar 3516 DITA SCAC "B HD; 9,000 hp; #570147
M/V Crosby Star - (2) 3516 Caterpillar w/ 6:1 Reduction (Kort Nozzles); 6,000 hp; #1060046

Crowley Marine Services, Inc.; Seattle, WA
http://www.crowley.com/cms/vessel_specs_one.asp
**Examples of largest tugs**
Nanuq - 2 Caterpillar 3612-B; 10,192 hp; #1074361

Garvey Marine, Inc.;St. Charles, IL
http://www.garveyintl.com/marine/lemont.htm
**Examples of largest tugs**
Julie White, 1,900 hp (no Category 3 engines at this power level)

Hannah Marine Corporation; Lemont, IL
http://www.hannahmarine.com/equipment.htm
**Examples of largest tugs**
M/V SUSAN W.HANNAH; Two (2) EMD 12-645 E5; 4,350 hp; #582617

McDonough Marine Service; New Orleans, LA
http://www.mcdonoughmarine.com/
**Examples of largest tugs**
M/V CLAUDE R; (2) Detroit Diesel 8V-149 DDEC; 1,600 hp;

Riverway Company; Minneapolis, MN
http://www.riverway.com/bootsieb.htm
**Examples of largest tugs**
M/V BOOTSIE B; EMD 16 cylinder 710G7B; 8,000 hp;

Seabulk International
http://www.seabulkinternational.com/
**Examples of largest tugs**
Seabulk Montana; Alco 12-251; 5,600 hp
Seabulk Nevada; (2) EMD16-645-E5; 5,750 hp
Seabulk New Jersey; (2) Caterpillar 3606; 4,800 hp

For this work then, large ocean-going merchant vessels were considered the only vessel type that use Category 3 engines. Category 3 engine emissions on rivers were considered to be derived only from ocean-going vessels accessing river ports (such as Portland (OR), Vancouver (WA), Baton Rouge, New Orleans, Albany (NY)) and were included in the emission estimates for those ports serving ocean-going traffic. The emissions along the rivers were included in the reduced speed zone and maneuvering operating modes for these ports. Other river traffic, such as push boats and barges, was considered to be propelled by Category 1 and 2 engines.

## ACTIVITY ESTIMATES

In order to determine the activity of vessels powered by Category 3 engines operating to and from and between US ports, it was first determined that river traffic was handled by tugs powered by Category 1 or 2 engines as indicated above. River activity was therefore ignored except to the extent that large merchant ships, either ocean-going or Great Lakes, are involved in transport.

The method used by Corbett and Fischbeck (2000) was recreated in this report. For ocean and Great Lakes traffic, USACE (2002) provided activity estimates of total and domestic tonnage by waterway links. These estimates were converted to ton-miles estimates by multiplying tonnage by link distance to estimate overall activity. In order to make these estimates correspond to the previous method (Corbett and Fischbeck, 2000) and not double count the emissions estimated in Chapter 3, a criteria was used to determine the links and fractional links appropriate for estimating emissions. For ocean links, only links between 200 statute and 25 nautical miles from shore were used to determine emissions. For Great Lakes links, links outside of 10 nautical miles (7 miles of cruise and 3 miles of reduced speed activity) from shore were used to estimate emissions. Traffic within 25 nautical miles from the coast were considered to have been estimated in the by-port estimates in effect assuming that no transit emissions occur with 25 nautical miles from the coast other than vessels directly heading to and from ports.

The activity estimates were intended to be distinct from the port traffic by only applying the activity outside of 25 nautical miles from shore, however vessel activity may occur within the 25 mile limit but not within 25 miles from next or last port of call. Appendix C includes maps of all vessel links and maps of links within the 25 to 200 mile limits. Many coastal links are excluded because it was not possible to exclude, from the USACE (2002) data, barge traffic or near port activity captured under the estimates provided in Chapter 3. For reference, a comparison of the domestic ocean trip traffic from BTS (1999) and this work is provided in Appendix D indicating that the activity estimates in this work are potentially low.

Future year relative tonnage emission estimates were determined from the sum of the detailed ports tonnage estimates including the relative growth rates for container ship, tanker, and all other freight traffic as described in Chapter 5.

**Table 4-1.** Tonnage activity relative to 1996 base year.

| Link type | 2010 | 2020 | 2030 |
|---|---|---|---|
| Ocean | 1.52 | 2.05 | 2.82 |
| Great Lakes | 1.43 | 1.91 | 2.56 |

## EMISSION FACTORS

The emission factors were determined from the calculation of emissions for the cruise mode at each of the detailed ports described in Chapter 3. Cruise mode emissions were divided by the freight tonnage reported for these ports and 50 nautical miles assuming that each port call results in 50 miles of cruise (25 miles in and 25 miles out) for ocean traffic and 14 miles of cruise for Great Lakes traffic according to activity estimated by Arcadis (1999a and 1999b).

**Table 4-2.** 1996 emission factors (g/ton-nautical-mile) for Category 3 propulsion engines.

| | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| Baltimore MEPA | 0.0162 | 0.0330 | 0.7075 | 0.0564 | 0.4200 |
| Philadelphia MEPA | 0.0078 | 0.0155 | 0.3319 | 0.0275 | 0.2052 |
| New York MEPA | 0.0213 | 0.0434 | 0.9172 | 0.0836 | 0.6291 |
| New Orleans MEPA | 0.0090 | 0.0183 | 0.3924 | 0.0308 | 0.2294 |
| Corpus Christi | 0.0055 | 0.0118 | 0.2368 | 0.0292 | 0.2244 |
| Tampa | 0.0103 | 0.0198 | 0.4258 | 0.0389 | 0.2913 |
| Puget Sound MEPA | 0.0157 | 0.0337 | 0.6902 | 0.0737 | 0.5618 |
| Coos Bay | 0.0121 | 0.0251 | 0.5389 | 0.0396 | 0.2935 |
| **Avg. Ocean** | **0.0122** | **0.0251** | **0.5301** | **0.0475** | **0.3568** |
| Corbett and Fischbeck (2000)* Ocean | 0.0105 | 0.0323 | 0.3625 | 0.0295 | - |
| Cleveland | 0.0085 | 0.0164 | 0.3535 | 0.0309 | 0.2311 |
| Burns Harbor | 0.0058 | 0.0115 | 0.2486 | 0.0196 | 0.1459 |
| **Avg. Lakes** | **0.0071** | **0.0140** | **0.3101** | **0.0253** | **0.1885** |
| Corbett and Fischbeck (2000)* Lakes | 0.0087 | 0.0269 | 0.3021 | 0.0246 | - |

* Diesel engine emissions uncorrected for steamships; and emissions were assumed to have been given by Corbett and Fischbeck (2000) in terms of statute mile and converted here to like units.

The emission estimates per ton-mile in this work compared favorably with those of Corbett and Fischbeck (2000) as shown in Table 4-2. The primary difference in NOx and PM emission rates were that baseline emission factors in this work were higher (by about 38% for NOx and about 20% for PM for motorships) than those of Lloyds (1995), which were used by Corbett and Fischbeck (2000). Another difference is that steamship emission were not included by Corbett and Fischbeck (2000) estimates provided above, which would result in higher PM and lower

NOx emissions than those shown for Corbett and Fischbeck (2000).

Corbett and Fischbeck (2000) made a number of assumptions in deriving their estimates including average vessel characteristic and typical freight loading, while the estimates in this work used information on specific vessels and actual freight tonnage calling on the detailed ports. The fact that both estimates, having been derived by completely unique methods, yield emission rate estimates so similar provided confidence that these estimates were comparable.

Future year emission factors were determined using the same method described above but using emission and activity estimates from Chapter 5. These future year average estimates are shown in the Table 4-3. The change in emission factors from year to year is a combination of many factors including growth rates in traffic served by increasing vessel size, emission controls for NOx emissions, fraction of passenger ship activity, and lower fraction of steamship calls.

**Table 4-3.** Future year emission factors (g/ton-nautical-mile) for Category 3 propulsion engines.

| Estimate | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| **Avg. Ocean 2010** | 0.0133 | 0.0272 | 0.5047 | 0.0482 | 0.3605 |
| **Avg. Ocean 2020** | 0.0145 | 0.0295 | 0.4931 | 0.0508 | 0.3785 |
| **Avg. Ocean 2030** | 0.0160 | 0.0323 | 0.5124 | 0.0546 | 0.4062 |
| **Avg. Lakes 2010** | 0.0070 | 0.0139 | 0.2607 | 0.0242 | 0.1802 |
| **Avg. Lakes 2020** | 0.0068 | 0.0136 | 0.2293 | 0.0232 | 0.1727 |
| **Avg. Lakes 2030** | 0.0067 | 0.0134 | 0.2132 | 0.0225 | 0.1672 |

**RESULTS**

The emission factors were associated with the ton-miles estimates in the 25 nautical mile and 200 statute mile region. These emission estimates are shown in the Tables 4-4 through 4-7 for all and domestic-only traffic. The ‘domestic’ traffic label by USACE may have included freight US exports as well as between US port traffic, so it may have been carried by foreign flagged vessels.

**Table 4-4.** Transit emissions (tons per year) for **all** freight vessel traffic on ocean links.

| Estimate | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| Ocean 1996 | 1,580 | 3,251 | 68,705 | 6,152 | 46,248 |
| Ocean 2010 | 2,618 | 5,354 | 99,428 | 9,488 | 71,026 |
| Ocean 2020 | 3,850 | 7,832 | 131,015 | 13,487 | 100,575 |
| Ocean 2030 | 5,844 | 11,797 | 187,279 | 19,941 | 148,477 |

**Table 4-5.** Transit emissions (tons per year) for **domestic** freight vessel traffic on ocean links.

| Estimate | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| Ocean 1996 | 1,307 | 2,688 | 56,816 | 5,087 | 38,245 |
| Ocean 2010 | 2,165 | 4,428 | 82,223 | 7,847 | 58,735 |
| Ocean 2020 | 3,184 | 6,477 | 108,343 | 11,153 | 83,171 |
| Ocean 2030 | 4,832 | 9,755 | 154,872 | 16,490 | 122,784 |

**Table 4-6.** Transit emissions (tons per year) for **all** freight vessel traffic on Great Lakes links.

| Estimate | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| Lakes 1996 | 480 | 935 | 20,132 | 1,688 | 12,608 |
| Lakes 2010 | 677 | 1,327 | 24,203 | 2,309 | 17,235 |
| Lakes 2020 | 879 | 1,735 | 28,433 | 2,956 | 22,062 |
| Lakes 2030 | 1,161 | 2,291 | 35,434 | 3,843 | 28,629 |

**Table 4-7.** Transit emissions (tons per year) for **domestic** freight vessel traffic on Great Lakes links.

| Estimate | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| Lakes 1996 | 320 | 623 | 13,415 | 1,125 | 8,401 |
| Lakes 2010 | 451 | 884 | 16,127 | 1,538 | 11,484 |
| Lakes 2020 | 586 | 1,156 | 18,946 | 1,970 | 14,701 |
| Lakes 2030 | 773 | 1,526 | 23,610 | 2,561 | 19,076 |

Using this method, the total emissions for all vessels (sum of Table 4-4 and 4-6) in this zone, 25 nautical to 200 statute miles, is considerably lower than one would estimate extending the cruise mode in Chapter 3 out to 200 statute miles. For instance in Chapter 3, a total of 31,423 tons per year of NOx was found in cruise mode, such as 0 to 25 nautical miles from the ocean coasts, compared with 88,837 tons per year of NOx found here though much more transit occurs within this zone than the comparison indicates.

A comparison of the Corbett and Fischbeck (1998) and the results in this work (Chapter 3 and 4) is provided in Appendix E indicating similar results.

# 5. FUTURE YEAR PORT EMISSION ESTIMATES

## INTRODUCTION

In order to project emission estimates to future years, several factors were taken into account, including the overall activity growth, the type of vessel to be used to handle the demand growth, and the fleet turnover to estimate the effect of the MARPOL regulations. Overall growth trends relied on the freight demand forecasts to estimate the overall activity of vessels. In order to determine the impact on the fleet, an assumption was made that the increased freight traffic would be handled primarily by the largest ships (using slow speed engines), as ports and shipbuilders accommodate increasing ship sizes. The effect of fleet turnover on fleet emission factors was estimated using the MARPOL standards compared with the baseline emission rates distributed over a normal scrappage distribution and applied by vessel propulsion type.

## FREIGHT PROJECTIONS

The vessel activity demand was estimated using the freight forecasts described below. MARAD supplied estimates for freight forecasts for 1999 through 2004 for several types of vessels. These estimates were extrapolated using an exponential growth estimate and are comparable to other freight growth estimates through 2020 as shown in Table 5-1. The growth was projected from the 1996 base year for the initial emission estimates, so the historic freight growth from 1996 to 1999 was used and then projected beyond 1999 with the 1999-2004 projection. Growth to 2030 was extrapolated using the same exponential form as for the 2020 calculations with the understanding that such a long projection or extrapolation is uncertain.

**Table 5-1.** MARAD supplied estimates of US foreign demand growth from McGraw-Hill.

| Vessel Type | Annual Growth Rate (1999 - 2004) | Cumulative Growth (1996 - 2020) | Cumulative Growth (1996 - 2030) |
|---|---|---|---|
| Tankers (tonnes) | 2.2 % | 80 % | 124% |
| Other Bulk and General Cargo (tonnes) | 3.0 % | 97 % | 164% |
| Container Ships (TEU) | 6.2 % | 337 % | 700% |
| Cruise (passengers) | 6.6 % | 381 % | 810% |

FHWA (2001) provided overall freight projections, but the freight traffic presented by FHWA was dominated by truck traffic, so these projections may not be necessarily applicable to marine freight. This FHWA presentation showed the freight growth from 1998 through 2020 is expected to be 2.9% per year for domestic and 3.4% per year for international trade. Regionally, the freight growth in the western states is expected to be 3.2% overall and 2.7% in the northeast states, with midwest, gulf, and southeast Atlantic states at 2.9%. These overall freight projections provide justification for the MARAD estimates that were provided above and used for this work.

## INCORPORATION OF THE GROWTH IN THE EMISSION CALCULATIONS

In order to incorporate the growth into the emissions calculations, the overall dead weight tonnage (DWT) calling annually at ports was increased in proportion to the projected freight increases. While dead weight tonnage may not directly relate to freight, it was the only measure of size afforded by the 1996 activity data to relate to freight tonnage. The total DWT for the detailed ports was calculated by multiplying vessel calls by average dead weight tonnage for each of several categories of vessels. The additional vessel calls needed to accommodate the growth in activity were added to the largest DWT category of the vessels by type. This was estimated based on assessments by MARAD and BTS (1999) that predominately larger vessels are being built to handle replacement of old vessels and increased freight traffic, and that ports are accommodating larger vessels.

## EMISSION RATES INCLUDING FLEET TURNOVER

The proposed MARPOL regulations were developed under aegis of the International Maritime Organization (IMO). These regulations test the engine under three different loads and average the results to compare with an overall emission standard. The emission standard is related to the rated engine speed through the relationship shown below for new vessels constructed after January 1, 2000.

$$\text{Engine Speed} < 130 \text{ rpm};\ \ 17.0 \text{ g/kW-hr}$$
$$130 \text{ rpm} \le \text{Engine Speed} < 2{,}000 \text{ rpm};\ \ 45 * n^{-0.2} \text{ g/kW-hr}$$
$$\text{Engine Speed} \ge 2{,}000 \text{ rpm};\ \ 9.8 \text{ g/kW-hr}$$

*where "n" is the engine speed in rpm units*

In order to estimate the effect of the NOx emission standard on average emission rates, it was first necessary to estimate the in-use fleet age distribution. Data was available from BTS (1999) that estimated the average age of the in-use worldwide fleet at 13 years. Using an estimated growth rate and scrappage distribution, a median age at the time of vessel scrappage (or "median lifetime") was calculated to reflect the 13 year-old average age of the in-use fleet. The normal scrappage rate distribution shown in Table 5-2 was taken from the default input to the NONROAD model, which requires an estimate of the median (or average) age when vessels are scrapped. The scrappage rate was applied to the initial (new vessels in each year) relative population (demonstrate by example in Table 5-4 below where new vessels in each year progressively increase) of vessel by model year to determine the remaining fleet age distribution. This remaining fleet age distribution was then used to determine the average age of the in-use fleet to determine the age at the time of scrappage to produce a 13 year average age of the in-use fleet.

**Table 5-2.** Normal scrappage distribution.

| Normal Distribution | |
|---|---|
| **Relative Age** | **% Scrapped** |
| 0 | 0 |
| 0.06 | 1 |
| 0.12 | 2 |
| 0.17 | 3 |
| 0.22 | 4 |
| 0.24 | 4.5 |
| 0.26 | 5 |
| 0.3 | 6 |
| 0.4 | 8 |
| 0.45 | 10 |
| 0.5 | 11 |
| 0.55 | 13 |
| 0.6 | 14 |
| 0.65 | 15 |
| 0.7 | 18 |
| 0.75 | 19 |
| 0.8 | 21 |
| 0.85 | 24 |
| 0.9 | 25 |
| 0.95 | 31 |
| 1 | 50 |
| 1.05 | 69 |
| 1.1 | 75 |
| 1.15 | 76 |
| 1.2 | 79 |
| 1.25 | 81 |
| 1.3 | 82 |
| 1.35 | 85 |
| 1.4 | 86 |
| 1.45 | 87 |
| 1.5 | 89 |
| 1.55 | 90 |
| 1.6 | 92 |
| 1.7 | 94 |
| 1.72 | 95 |
| 1.74 | 95.5 |
| 1.78 | 96 |
| 1.83 | 97 |
| 1.88 | 98 |
| 1.94 | 99 |
| 2 | 100 |

The relative initial vessel population affected the calculated average age of the in-use fleet by skewing the fleet age distribution. So a historic growth rate of the vessel fleet of 2.0% per year was estimated from data provided by MARAD (2001) from McGraw-Hill and shown in Table 5-3.

**Table 5-3.** MARAD supplied estimates of historic fleet growth.

| Vessel Type | Growth per Year |
|---|---|
| Tankers | 1.2 % |
| Bulk Carriers | 2.1 % |
| Container Ships | 11.8 % |

Using an average 2.0% growth rate and the normal scrappage distribution, the median age at the time of scrappage (i.e. the median or average life of vessels) is 25 years in order to have the average age of the in-use fleet be 13 years. Using 0.0% growth, the median age of vessels at the time of scrappage was calculated to be 22 years, so the median age of scrapped vessels is not very sensitive to the estimated fleet growth rate. The 25 year estimate was consistent with the Corbett and Fishbeck (1998) information on the average age of broken up vessels. Shown in Table 5-4 is the age distribution in 2010 calculated with the assumptions detailed above.

**Table 5-4.** Age distribution of merchant vessels calculated for 2010.

| Model Year | Normalized Age | Initial Relative Population | Remaining Population | In-Use Distribution |
|---|---|---|---|---|
| 2010 | 0.00 | 132 | 132 | 0.0257 |
| 2009 | 0.04 | 259 | 259 | 0.0504 |
| 2008 | 0.08 | 254 | 251 | 0.0489 |
| 2007 | 0.12 | 249 | 244 | 0.0474 |
| 2006 | 0.16 | 244 | 239 | 0.0465 |
| 2005 | 0.20 | 239 | 232 | 0.0451 |
| 2004 | 0.24 | 234 | 224 | 0.0436 |
| 2003 | 0.28 | 230 | 218 | 0.0425 |
| 2002 | 0.32 | 225 | 212 | 0.0412 |
| 2001 | 0.36 | 221 | 208 | 0.0404 |
| 2000 | 0.40 | 216 | 199 | 0.0388 |
| 1999 | 0.44 | 212 | 195 | 0.0380 |
| 1998 | 0.48 | 208 | 187 | 0.0365 |
| 1997 | 0.52 | 204 | 182 | 0.0353 |
| 1996 | 0.56 | 200 | 174 | 0.0339 |
| 1995 | 0.60 | 196 | 169 | 0.0328 |
| 1994 | 0.64 | 192 | 165 | 0.0322 |
| 1993 | 0.68 | 188 | 160 | 0.0312 |
| 1992 | 0.72 | 185 | 152 | 0.0295 |
| 1991 | 0.76 | 181 | 147 | 0.0286 |
| 1990 | 0.80 | 178 | 140 | 0.0273 |
| 1989 | 0.84 | 174 | 138 | 0.0268 |
| 1988 | 0.88 | 171 | 130 | 0.0253 |
| 1987 | 0.92 | 167 | 126 | 0.0244 |
| 1986 | 0.96 | 164 | 113 | 0.0220 |
| 1985 | 1.00 | 161 | 80 | 0.0157 |

| Model Year | Normalized Age | Initial Relative Population | Remaining Population | In-Use Distribution |
|---|---|---|---|---|
| 1984 | 1.04 | 158 | 79 | 0.0154 |
| 1983 | 1.08 | 155 | 48 | 0.0093 |
| 1982 | 1.12 | 152 | 38 | 0.0074 |
| 1981 | 1.16 | 149 | 36 | 0.0069 |
| 1980 | 1.20 | 146 | 31 | 0.0060 |
| 1979 | 1.24 | 143 | 30 | 0.0058 |
| 1978 | 1.28 | 140 | 27 | 0.0052 |
| 1977 | 1.32 | 137 | 25 | 0.0048 |
| 1976 | 1.36 | 135 | 20 | 0.0039 |
| 1975 | 1.40 | 132 | 18 | 0.0036 |
| 1974 | 1.44 | 129 | 18 | 0.0035 |
| 1973 | 1.48 | 127 | 16 | 0.0032 |
| 1972 | 1.52 | 124 | 14 | 0.0027 |
| 1971 | 1.56 | 122 | 12 | 0.0024 |
| 1970 | 1.60 | 120 | 10 | 0.0019 |
| 1969 | 1.64 | 117 | 9 | 0.0018 |
| 1968 | 1.68 | 115 | 9 | 0.0018 |
| 1967 | 1.72 | 113 | 6 | 0.0011 |
| 1966 | 1.76 | 110 | 5 | 0.0010 |
| 1965 | 1.80 | 108 | 4 | 0.0008 |
| 1964 | 1.84 | 106 | 3 | 0.0006 |
| 1963 | 1.88 | 104 | 2 | 0.0004 |
| 1962 | 1.92 | 102 | 2 | 0.0004 |
| 1961 | 1.96 | 100 | 1 | 0.0002 |

The results of the emission reductions were determined from the age distribution shown above, projected for future years, and are shown in Table 5-5. For future year emission factor estimates, only a fraction of the vessels in operation would have been built after 2000 resulting in a partial emissions reduction associated with the emission standards beginning in 2000.

**Table 5-5.** NOx emission factors (g/hp-hr) and % reduction from baseline emissions with the implementation of the MARPOL standard and in **BOLD** adjusted by increasing future year engine emissions to 10% above the emission standards with the use of residual fuel.

| Engine Type | Baseline NOx | MARPOL NOx | % Reduction by 2010 | % Reduction by 2020 | % Reduction by 2030 |
|---|---|---|---|---|---|
| Slow Speed (~ 130 rpm) | 17.6 | 12.7<br>**13.9** | 13.1 %<br>**9.8%** | 22.2 %<br>**16.5%** | 26.6 %<br>**19.8%** |
| Medium Speed (~ 520 rpm) | 12.4 | 9.6<br>**10.6** | 10.6 %<br>**6.9%** | 17.9 %<br>**11.6%** | 21.6 %<br>**14.0%** |
| Auxiliary (Category 2 (~ 800 rpm) | 10.0 | 8.8 | 5.4 % | 9.2 % | 11.0 % |

**RESULTS**

Applying the growth estimate for DWT by adding port calls to the largest category slow speed vessels, an estimate of the overall activity at all ports was determined. By adjusting the NOx emission factors according to the expected effect from implementing the MARPOL standard, an estimate of the emissions for future years was made, as shown in Table 5-6. Because the States' of Texas and California estimates were used directly and not estimated in this work, the emission estimates for the Houston area and California ports were adjusted according to the average effect of the sensitivity analysis on all other ports.

**Table 5-6.** Ports emissions summary including activity growth.(tons/year)

| Ports | HC | CO | NOx | PM | SO2 |
|---|---|---|---|---|---|
| 1996 | 6,650 | 21,529 | 156,478 | 11,794 | 86,763 |
| 2010 | 10,581 | 33,745 | 229,307 | 17,386 | 125,979 |
| 2020 | 15,325 | 48,268 | 312,933 | 24,243 | 174,226 |
| 2030 | 23,169 | 71,958 | 456,772 | 35,692 | 254,950 |

Because of the large growth rate of container and passenger vessels, the significance of these types of vessels becomes much more important the further in the future that the projections are made. Tables 5-7 through 5-10 compare the 1996 baseline emission estimates with those for 2010, 2020 (the future year where growth projections were provided by reference), and 2030 (the furthest projected year estimated in this work).

**Table 5-7.** Summary of the US emission estimates by ship type for 1996 (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,461 | 5,906 | 45,196 | 2,668 | 18,812 |
| Container Ship | 2,360 | 5,797 | 38,404 | 3,125 | 23,881 |
| General Cargo | 478 | 2,060 | 16,078 | 996 | 6,940 |
| Miscellaneous | 179 | 1,066 | 5,914 | 245 | 1,552 |
| Passenger | 344 | 879 | 6,143 | 747 | 5,804 |
| Reefer | 257 | 756 | 4,160 | 263 | 1,952 |
| Roro | 140 | 567 | 4,830 | 421 | 3,114 |
| Tanker | 1,175 | 3,950 | 32,022 | 3,048 | 22,507 |
| Vehicle Carrier | 259 | 570 | 3,732 | 293 | 2,247 |
| **Total** | **6,650** | **21,529** | **156,478** | **11,794** | **86,763** |

**Table 5-8.** Summary of the US emission estimates by ship type for 2010 (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,985 | 8,051 | 57,170 | 3,617 | 25,441 |
| Container Ship | 5,288 | 12,937 | 80,251 | 6,339 | 47,191 |
| General Cargo | 578 | 2,451 | 17,876 | 1,184 | 8,237 |
| Miscellaneous | 253 | 1,579 | 8,244 | 348 | 2,183 |
| Passenger | 890 | 2,137 | 14,275 | 1,361 | 10,221 |
| Reefer | 363 | 1,056 | 5,385 | 373 | 2,769 |
| Roro | 187 | 737 | 5,919 | 517 | 3,794 |
| Tanker | 1,683 | 5,716 | 41,659 | 3,767 | 27,341 |
| Vehicle Carrier | 373 | 841 | 4,971 | 417 | 3,207 |
| **Total** | **10,581** | **33,745** | **229,307** | **17,386** | **125,979** |

**Table 5-9.** Summary of the US emission estimates by ship type for 2020 (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 2,543 | 10,333 | 69,366 | 4,627 | 32,494 |
| Container Ship | 9,497 | 23,193 | 135,672 | 10,964 | 80,734 |
| General Cargo | 685 | 2,867 | 19,934 | 1,385 | 9,617 |
| Miscellaneous | 332 | 2,116 | 10,592 | 456 | 2,854 |
| Passenger | 1,658 | 3,909 | 25,188 | 2,224 | 16,420 |
| Reefer | 475 | 1,375 | 6,620 | 489 | 3,638 |
| Roro | 238 | 918 | 7,042 | 620 | 4,518 |
| Tanker | 2,090 | 7,132 | 48,535 | 4,350 | 31,236 |
| Vehicle Carrier | 448 | 1,015 | 5,618 | 502 | 3,857 |
| **Total** | **15,325** | **48,268** | **312,933** | **24,243** | **174,226** |

**Table 5-10.** Summary of the US emission estimates by ship type for 2030 (tons/year).

| Ship Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 3,291 | 13,391 | 87,354 | 5,980 | 41,945 |
| Container Ship | 17,216 | 42,014 | 237,971 | 19,431 | 142,121 |
| General Cargo | 827 | 3,425 | 23,133 | 1,654 | 11,466 |
| Miscellaneous | 439 | 2,848 | 13,897 | 604 | 3,769 |
| Passenger | 3,114 | 7,274 | 44,857 | 3,861 | 28,188 |
| Reefer | 626 | 1,804 | 8,415 | 646 | 4,803 |
| Roro | 305 | 1,160 | 8,686 | 757 | 5,487 |
| Tanker | 2,604 | 8,926 | 58,369 | 5,091 | 36,176 |
| Vehicle Carrier | 602 | 1,377 | 7,289 | 670 | 5,150 |
| **Total** | **23,169** | **71,958** | **456,772** | **35,692** | **254,950** |

# 6. SENSITIVITY ANALYSIS

## INTRODUCTION

A sensitivity analysis was performed to demonstrate the effect of the uncertainty in the some of the estimates used to create the emissions inventory. The estimates tested and described below were adjusting the load estimates at intermediate speeds between stopped and cruise speeds, the emission factors of propulsion engines, the number of steamship port calls, the maximum and minimum load estimates for the cruise and auxiliary engine loads, and the emission factors during maneuvering modes only.

The emission estimates of each sensitivity analysis was compared with those estimates provided in Chapter 3 and also below in Tables 6-1 through 6-5. In each sensitivity case, we adjusted the assumptions used in the base emission estimates presented in Chapter 3 and carried them through the emissions calculations for the US ports. Because the States' of Texas and California estimates were used directly and not estimated in this work, the emission estimates for the Houston area and California ports were adjusted according to the average effect of the sensitivity analysis on all other ports.

**Table 6-1.** Baseline emission estimates for merchant vessels from Chapter 3 summed for all modes (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,461 | 5,906 | 45,196 | 2,668 | 18,812 |
| Container Ship | 2,360 | 5,797 | 38,404 | 3,125 | 23,881 |
| General Cargo | 478 | 2,060 | 16,078 | 996 | 6,940 |
| Miscellaneous | 179 | 1,066 | 5,914 | 245 | 1,552 |
| Passenger | 344 | 879 | 6,143 | 747 | 5,804 |
| Reefer | 257 | 756 | 4,160 | 263 | 1,952 |
| Roll-on Roll-off | 140 | 567 | 4,830 | 421 | 3,114 |
| Tanker | 1,175 | 3,950 | 32,022 | 3,048 | 22,507 |
| Vehicle Carrier | 259 | 570 | 3,732 | 293 | 2,247 |
| Total | **6,650** | **21,529** | **156,478** | **11,794** | **86,763** |

**Table 6-2.** Baseline emission estimates for merchant vessels from Chapter 3 for cruise speed emissions (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 204 | 415 | 8,909 | 684 | 5,083 |
| Container Ship | 202 | 407 | 8,648 | 762 | 5,577 |
| General Cargo | 70 | 130 | 2,850 | 235 | 1,742 |
| Miscellaneous | 11 | 18 | 410 | 38 | 283 |
| Passenger | 46 | 88 | 1,771 | 266 | 2,048 |
| Reefer | 14 | 29 | 626 | 47 | 349 |
| Roll-on Roll-off | 32 | 63 | 1,343 | 122 | 916 |
| Tanker | 142 | 300 | 6,116 | 697 | 5,329 |
| Vehicle Carrier | 18 | 34 | 749 | 58 | 430 |
| Total | 739 | 1,484 | 31,423 | 2,909 | 21,894 |

**Table 6-3.** Baseline emission estimates for merchant vessels from Chapter 3 for reduced speed zone (RSZ) emissions (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 553 | 1,026 | 15,424 | 1,223 | 9,276 |
| Container Ship | 942 | 1,644 | 16,996 | 1,513 | 11,945 |
| General Cargo | 185 | 334 | 5,386 | 442 | 3,249 |
| Miscellaneous | 51 | 86 | 773 | 68 | 527 |
| Passenger | 124 | 211 | 2,020 | 208 | 1,656 |
| Reefer | 97 | 164 | 1,405 | 123 | 991 |
| Roll-on Roll-off | 48 | 93 | 1,468 | 145 | 1,116 |
| Tanker | 477 | 891 | 13,251 | 1,325 | 9,847 |
| Vehicle Carrier | 109 | 187 | 1,984 | 169 | 1,327 |
| Total | 2,587 | 4,635 | 58,707 | 5,215 | 39,936 |

**Table 6-4.** Baseline emission estimates for merchant vessels from Chapter 3 for maneuvering emissions (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 362 | 994 | 1,931 | 218 | 1,238 |
| Container Ship | 703 | 1,894 | 2,204 | 294 | 1,462 |
| General Cargo | 95 | 259 | 451 | 54 | 301 |
| Miscellaneous | 43 | 120 | 128 | 18 | 90 |
| Passenger | 97 | 236 | 362 | 54 | 315 |
| Reefer | 81 | 220 | 233 | 33 | 155 |
| Roll-on Roll-off | 29 | 78 | 168 | 20 | 119 |
| Tanker | 275 | 728 | 1,404 | 183 | 1,116 |
| Vehicle Carrier | 80 | 218 | 241 | 33 | 161 |
| Total | 1,762 | 4,726 | 7,120 | 895 | 4,912 |

**Table 6-5.** Baseline emission estimates for merchant vessels from Chapter 3 for hotelling emissions (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 343 | 3,472 | 18,932 | 543 | 3,181 |
| Container Ship | 512 | 1,853 | 10,557 | 556 | 4,755 |
| General Cargo | 128 | 1,336 | 7,391 | 265 | 1,639 |
| Miscellaneous | 73 | 842 | 4,603 | 121 | 650 |
| Passenger | 77 | 344 | 1,991 | 220 | 1,774 |
| Reefer | 66 | 342 | 1,895 | 60 | 458 |
| Roll-on Roll-off | 31 | 334 | 1,851 | 134 | 964 |
| Tanker | 281 | 2,031 | 11,247 | 842 | 6,180 |
| Vehicle Carrier | 52 | 130 | 753 | 32 | 325 |
| Total | 1,563 | 10,685 | 59,219 | 2,774 | 19,925 |

## REDUCED SPEED ZONE AND MANEUVERING MODAL LOADS

In the course of interviewing knowledgeable sources (e.g. Rideout, 2001), we found it is possible or likely that on-board generator engines (mostly Category 2) run continuously in transit as well as at dock. In the equation for determining the engine load in the baseline emission estimates, an assumption was made that the propulsion power would have 10% load for auxiliary power and 80% total load at cruise speed (80% load at cruise is EPA guidance but that assumption is also supported by the Environment Canada data). Therefore, if auxiliary engines supply the 10% load for auxiliary power instead of the propulsion engines, then the load on the propulsion engines may be reduced for RSZ and maneuvering modes. So this sensitivity analysis provided emission estimates using the follow equation for loads at intermediate speeds;

$$\textit{Load Fraction} = 0.8 * (\textit{Speed/Cruise Speed})^3$$

instead of the baseline estimates using the following equation;

$$\textit{Load Fraction} = 0.1 + 0.7 * (\textit{Speed/Cruise Speed})^3$$

The auxiliary engine emissions increased because the 10% auxiliary load would occur during transit as well as hotelling modal operation to supply onboard electrical power. But the cruise emissions remained unchanged because the cruise load estimate of 80% was still used.

Not considered in this sensitivity analysis was that specific emission factors (in g/kW-hr units) at the lower load fractions (propulsion engine loads below 10% now occur at vessels speeds lower than about 7 knots for bulk carriers or about 11 knots for container ships for this sensitivity analysis) have been reported to increase significantly. The maneuvering mode was assumed (and confirmed by discussions with Harbor Pilots) to be 4 knots resulting in loads of 3% or less. This likely increase in the specific emission factors during maneuvering and some RSZ modes may cancel the effect of the reduced load calculated at slower vessel speeds.

The results shown in Tables 6-6 through 6-9 demonstrate that while overall emissions did not change significantly, RSZ and maneuvering modes emissions decreased, and auxiliary engine emissions increased. Cruise mode propulsion emissions were unchanged by this sensitivity analysis.

**Table 6-6.** Emissions with an alternative form of the load equation for all modes and ports (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,112 | 5,421 | 44,670 | 2,418 | 17,105 |
| Container Ship | 1,646 | 4,392 | 36,624 | 2,665 | 21,266 |
| General Cargo | 389 | 2,044 | 16,461 | 932 | 6,469 |
| Miscellaneous | 141 | 1,001 | 6,075 | 233 | 1,492 |
| Passenger | 257 | 788 | 6,363 | 784 | 6,233 |
| Reefer | 157 | 540 | 3,783 | 201 | 1,551 |
| Roll-on Roll-off | 114 | 594 | 5,046 | 407 | 2,995 |
| Tanker | 926 | 3,765 | 32,112 | 2,953 | 22,033 |
| Vehicle Carrier | 193 | 402 | 3,593 | 248 | 2,037 |
| Total | 4,903 | 18,948 | 154,876 | 10,934 | 81,891 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

**Table 6-7.** Emissions with an alternative form of the load equation for the RSZ mode of all ports (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 482 | 894 | 13,430 | 1,067 | 8,095 |
| Container Ship | 655 | 1,144 | 11,828 | 1,045 | 8,248 |
| General Cargo | 160 | 289 | 4,651 | 383 | 2,814 |
| Miscellaneous | 47 | 80 | 707 | 62 | 488 |
| Passenger | 82 | 138 | 1,330 | 131 | 1,042 |
| Reefer | 65 | 109 | 937 | 82 | 662 |
| Roll-on Roll-off | 39 | 74 | 1,177 | 111 | 848 |
| Tanker | 396 | 742 | 10,969 | 1,108 | 8,277 |
| Vehicle Carrier | 87 | 149 | 1,584 | 135 | 1,060 |
| Subtotal | 2,100 | 3,765 | 47,680 | 4,232 | 32,407 |
| *Baseline Subtotal* | *2,587* | *4,635* | *58,707* | *5,215* | *39,936* |

**Table 6-8.** Emissions with an alternative form of the load equation for maneuvering of all ports (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 27 | 71 | 286 | 30 | 180 |
| Container Ship | 12 | 26 | 112 | 13 | 72 |
| General Cargo | 6 | 15 | 59 | 6 | 38 |
| Miscellaneous | 2 | 4 | 17 | 2 | 11 |
| Passenger | 2 | 4 | 17 | 3 | 15 |
| Reefer | 2 | 3 | 14 | 2 | 9 |
| Roll-on Roll-off | 1 | 4 | 15 | 2 | 10 |
| Tanker | 16 | 42 | 173 | 22 | 138 |
| Vehicle Carrier | 2 | 4 | 15 | 2 | 10 |
| Subtotal | 77 | 186 | 777 | 89 | 518 |
| *Baseline Subtotal* | *1,762* | *4,726* | *7,120* | *895* | *4,912* |

**Table 6-9.** Emissions with an alternative form of the load equation for auxiliary engines at all ports (This now includes auxiliary engine emission during transit and hotelling modes.) (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 399 | 4,042 | 22,044 | 636 | 3,744 |
| Container Ship | 778 | 2,815 | 16,036 | 845 | 7,232 |
| General Cargo | 154 | 1,610 | 8,901 | 308 | 1,873 |
| Miscellaneous | 80 | 900 | 4,942 | 131 | 709 |
| Passenger | 127 | 558 | 3,245 | 384 | 3,127 |
| Reefer | 76 | 398 | 2,205 | 70 | 532 |
| Roll-on Roll-off | 41 | 453 | 2,511 | 172 | 1,222 |
| Tanker | 371 | 2,682 | 14,851 | 1,125 | 8,279 |
| Vehicle Carrier | 86 | 215 | 1,240 | 53 | 535 |
| Total | 1,986 | 13,514 | 74,990 | 3,703 | 27,055 |
| *Baseline Subtotal (Hotelling only)* | *1,563* | *10,685* | *59,219* | *2,774* | *19,925* |

## EMISSION FACTORS

There was considerable uncertainty in the specific NOx and PM emission factors (in units of g/kW-hr) estimates because of the fuel type and specific combustion efficiency estimate employed to convert fuel-based emission factors (in units of kg/tonne). The emission factors determined as described in Chapter 1 and used to produce the baseline emission estimates as described in Chapter 3 were generally higher for NOx and, depending upon fuel sulfur assumptions, either lower or higher in PM and $SO_2$ than previous comparable emission factors.

The NOx emission factors used in the baseline emissions estimates relied on the available data for specific fuel consumption in g/kW-hr units and emissions data in kg/tonne units. Therefore an error in either one will contribute to an error in the specific emissions rates in g/kW-hr units used in the emission estimates. For 2-stroke low speed Category 3 engines, the type most prevalent among merchant ships, manufacturers reported emission rates of 17 - 19 g/kW-hr though the test data indicated an average of 23.6 g/kW-hr. A value of 17 g/kW-hr reported by Lloyds (1995) was used for the sensitivity run as a lower limit for comparison purposes. For 4-stroke medium speed engines, Lloyds (1995) reported the NOx emission rate of 12 g/kW-hr instead of the value 16.6 g/kW-hr used in this study. If these lower Lloyds (1995) estimates are used, then no emission reductions can be expected for newer vessels meeting the MARPOL standard.

For PM the primary uncertainty is the sulfur level of the fuel used for propulsion and auxiliary engines. The sulfur level chosen for the heavy fuel used in the baseline estimates for propulsion engines was 3% by weight , while one report indicated that the sulfur can range from 0.8% to 3.92% worldwide with the US range from 1.8% to 3.9%. (Bunker fuel specifications found at http://www.marinelink.com/members/stats/) The PM emission rates were then recalculated based on the discussion in Chapter 1.

As expected, when the emission factors are changed, the overall emission estimates were proportionally affected as shown in Table 6-10. The emission changes primarily affect the transit emissions produced by propulsion engines, though steamships are thought to use residual fuel in the boilers while hotelling. Therefore a small portion of the PM and $SO_2$ emission increases were assumed to occur during hotelling, but the NOx decrease was assumed to occur only during transit modes.

**Table 6-10.** Effect of NOx emission factor and fuel sulfur assumptions on total port emissions (tons/year).

| Comparison | NOx | PM | $SO_2$ |
|---|---|---|---|
| Lower NOx Emission Rates | 129,794 | - | - |
| 1% Sulfur Fuel | - | 3,942 | 42,204 |
| 4% Sulfur Fuel | - | 23,240 | 109,043 |
| *Baseline* | *156,478* | *11,794* | *86,763* |

## STEAMSHIPS

It is likely that the current (1996 base year) numbers of steamships will dwindle as these older ships are retired because very few new steamships will be constructed. For instance, according to a report by the JIME (1999), only 4 out of 363 vessels constructed in Japan (the county that was the largest builder of merchant vessels in that year) in 1997 were steam turbine-powered.

A sensitivity analysis was run that converted the 1996 port calls of steamships entirely to diesel powered vessels of similar dead weight tonnage (DWT). As Table 6-11 shows, the emissions of NOx, HC, and CO were higher and PM and $SO_2$ were lower by supplanting steamships with diesel powered vessels according to the emission rates for steamships compared to motorships.

**Table 6-11.** 1996 emissions with steamships replaced by diesel motor ships (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,489 | 6,015 | 46,025 | 2,608 | 18,177 |
| Container Ship | 2,550 | 6,290 | 41,738 | 2,706 | 19,431 |
| General Cargo | 479 | 2,072 | 16,152 | 902 | 6,103 |
| Miscellaneous | 188 | 1,134 | 6,297 | 252 | 1,577 |
| Passenger | 465 | 1,167 | 8,165 | 510 | 3,620 |
| Reefer | 257 | 756 | 4,160 | 263 | 1,952 |
| Roll-on Roll-off | 141 | 567 | 4,894 | 285 | 1,976 |
| Tanker | 1,516 | 4,971 | 39,510 | 2,276 | 15,546 |
| Vehicle Carrier | 259 | 570 | 3,732 | 293 | 2,247 |
| Total | 7,377 | 23,642 | 171,022 | 10,109 | 70,240 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

## LOAD ASSUMPTIONS

Besides the issue of the which engines supply auxiliary load during transit is the uncertainty in the 10% auxiliary and 80% cruise load estimates. The 80% load at cruise is the historic EPA guidance but Environment Canada measured this load at anywhere from 70% to 99%.

The relative auxiliary load was based on the fraction of installed power as supplied by Lloyds registry data, so is highly uncertain given that ships with large propulsion engines may require not much more auxiliary power than smaller ships. A range of 5 to 15% auxiliary load is suggested for a sensitivity analysis. Also this load may be supplied only by Category 2 engines, so the sensitivity analysis of auxiliary load may not be relevant to Category 3 engine emissions.

Four sensitivity runs were performed using the load equations shown below.

(1) An assumption for the cruise load of 100% and hotelling load of 10% was made and affected the cruise, RSZ, and maneuvering modal emissions through the equation shown below with results shown in Table 6-12.

$$\textit{Load Fraction} = 0.1 + 0.9 * (\textit{Speed/Cruise Speed})^3$$

**Table 6-12.** Case of 100% cruise load (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,641 | 6,262 | 50,693 | 3,102 | 22,059 |
| Container Ship | 2,583 | 6,211 | 43,527 | 3,578 | 27,372 |
| General Cargo | 537 | 2,171 | 17,921 | 1,147 | 8,053 |
| Miscellaneous | 191 | 1,088 | 6,135 | 266 | 1,707 |
| Passenger | 374 | 932 | 6,858 | 843 | 6,544 |
| Reefer | 279 | 794 | 4,553 | 296 | 2,206 |
| Roll-on Roll-off | 159 | 602 | 5,459 | 479 | 3,555 |
| Tanker | 1,311 | 4,220 | 36,142 | 3,482 | 25,758 |
| Vehicle Carrier | 286 | 620 | 4,320 | 341 | 2,622 |
| Total | 7,388 | 22,939 | 175,868 | 13,545 | 100,014 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

(2) An assumption for the cruise load of 70% and hotelling load of 10% was made and affected the cruise, RSZ, and maneuvering modal emissions through the equation shown below with results shown in Table 6-13.

$$Load\ Fraction = 0.1 + 0.6 * (Speed/Cruise\ Speed)^3$$

**Table 6-13.** Case of 70% cruise load (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,371 | 5,728 | 42,448 | 2,451 | 17,188 |
| Container Ship | 2,248 | 5,590 | 35,843 | 2,898 | 22,136 |
| General Cargo | 448 | 2,005 | 15,157 | 920 | 6,383 |
| Miscellaneous | 173 | 1,056 | 5,804 | 235 | 1,474 |
| Passenger | 329 | 852 | 5,785 | 700 | 5,434 |
| Reefer | 247 | 736 | 3,964 | 247 | 1,826 |
| Roll-on Roll-off | 131 | 549 | 4,515 | 392 | 2,894 |
| Tanker | 1,107 | 3,815 | 29,962 | 2,832 | 20,881 |
| Vehicle Carrier | 245 | 545 | 3,438 | 268 | 2,059 |
| Total | 6,282 | 20,824 | 146,783 | 10,919 | 80,137 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

(3) An assumption of the cruise load of 80% and auxiliary load of 15% was made and affected the RSZ, maneuvering, and hotelling modal emissions through the equation shown below with results shown in Table 6-14.

$$Load\ Fraction = 0.15 + 0.65 * (Speed/Cruise\ Speed)^3$$

**Table 6-14.** Case of 15% auxiliary load (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,820 | 8,126 | 56,470 | 3,109 | 21,527 |
| Container Ship | 3,090 | 7,863 | 47,301 | 3,775 | 28,796 |
| General Cargo | 595 | 2,862 | 20,334 | 1,181 | 8,109 |
| Miscellaneous | 236 | 1,541 | 8,302 | 316 | 1,935 |
| Passenger | 450 | 1,199 | 7,654 | 921 | 7,152 |
| Reefer | 344 | 1,056 | 5,450 | 329 | 2,418 |
| Roll-on Roll-off | 173 | 778 | 5,977 | 514 | 3,784 |
| Tanker | 1,475 | 5,355 | 39,394 | 3,657 | 26,879 |
| Vehicle Carrier | 332 | 755 | 4,420 | 341 | 2,617 |
| Total | 8,447 | 29,377 | 194,722 | 14,066 | 102,690 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

(4) An assumption of the cruise load of 80% and auxiliary load of 5% was made and affected the RSZ, maneuvering, and hotelling modal emissions through the equation shown below with results shown in Table 6-15.

$$\textit{Load Fraction} = 0.05 + 0.75 * (\textit{Speed/Cruise Speed})^3$$

**Table 6-15.** Case of 5% auxiliary load (tons/year).

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Bulk Carrier | 1,102 | 3,687 | 33,922 | 2,227 | 16,097 |
| Container Ship | 1,630 | 3,732 | 29,508 | 2,475 | 18,966 |
| General Cargo | 361 | 1,258 | 11,822 | 810 | 5,770 |
| Miscellaneous | 122 | 592 | 3,526 | 174 | 1,169 |
| Passenger | 239 | 559 | 4,631 | 574 | 4,455 |
| Reefer | 171 | 455 | 2,870 | 197 | 1,487 |
| Roll-on Roll-off | 107 | 355 | 3,683 | 328 | 2,444 |
| Tanker | 875 | 2,545 | 24,649 | 2,439 | 18,135 |
| Vehicle Carrier | 185 | 386 | 3,044 | 244 | 1,876 |
| Total | 4,854 | 13,682 | 118,234 | 9,522 | 70,836 |
| *Baseline Total* | *6,650* | *21,529* | *156,478* | *11,794* | *86,763* |

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# APPENDIX A

## Detailed Ports Emissions

File Name
DetailedPortsEmissions03 with SO2.xls

**EMISSION FACTORS**

| **Cruise** | Load | 0.8 | | | |
|---|---|---|---|---|---|
| g/hp-hr | HC | CO | NOx | PM | SO2 |
| 2 | 0.395 | 0.82 | 17.6 | 1.29 | 9.56 |
| 4 | 0.395 | 0.52 | 12.38 | 1.31 | 9.69 |
| Steam | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 |

| **RSZ** | | | | | |
|---|---|---|---|---|---|
| g/hp-hr | HC | CO | NOx | PM | SO2 |
| 2 | 0.395 | 0.82 | 17.6 | 1.29 | 9.56 |
| 4 | 0.395 | 0.52 | 12.38 | 1.31 | 9.69 |
| Steam | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 |
| Speed | 6.5 | knots | | | |

| **Maneuver** |
|---|
| g/hp-hr |
| 2 |
| 4 |
| Steam |
| Speed |

For SO2 calcs:

| | BSFC (g/hp-hr) | |
|---|---|---|
| 2-stroke | 253.7893025 | 163.3 |
| 4-stroke | 260.1601133 | 165.5 |
| Steam | 255 | 255 |

Maneuverir

slow

medium

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Hotel** | Load | | 0.1 | | | | **All Modes** |
| HC | CO | NOx | PM | SO2 | g/hp-hr | HC | CO | NOx | PM | SO2 | | |
| 2.085717 | 6.072741 | 23.9113 | 2.168337 | 23.02 | 2 | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 | | |
| 2.172732 | 4.432346 | 16.87605 | 2.216072 | 23.87 | 4 | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 | | |
| 0.05 | 0.22 | 2.09 | 1.86 | 15.0 | Steam | 0.05 | 0.22 | 2.09 | 1.86 | 1.65 | | |
| 4 | knots | | | | | | | | | | | |

ng Adjustment

| **HC** | **CO** | **NOx** | **PM** | **CO2** |
|---|---|---|---|---|
| **5.28** | **7.41** | **1.36** | **1.68** | **1.55** |
| 5.500588 | 8.523742 | 1.36317 | 1.691658 | 1.571964 |

**Lower Mississippi River Ports Emissions by Vessel Type (TPY)**

| | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| BARGE CARRIER | 1 | 1 | 26 | 4 | 28 | 1 | 2 | 44 | 7 | 51 | 0 | 1 | 3 | 0 | 4 | 1 | 12 |
| BULK CARRIER | 68 | 139 | 2992 | 223 | 1651 | 93 | 192 | 4113 | 309 | 2289 | 24 | 69 | 271 | 25 | 266 | 70 | 1280 |
| CONTAINER SHIP | 5 | 10 | 206 | 25 | 194 | 6 | 13 | 255 | 32 | 247 | 2 | 6 | 24 | 3 | 31 | 3 | 43 |
| GENERAL CARGO | 8 | 14 | 313 | 25 | 185 | 18 | 35 | 761 | 60 | 446 | 4 | 10 | 38 | 4 | 39 | 8 | 155 |
| MISCELLANEOUS | 0 | 0 | 5 | 0 | 3 | 0 | 0 | 9 | 1 | 5 | 0 | 0 | 1 | 0 | 1 | 1 | 10 |
| PASSENGER | 3 | 6 | 114 | 13 | 102 | 4 | 9 | 182 | 22 | 169 | 1 | 3 | 12 | 2 | 15 | 1 | 14 |
| REEFER | 0 | 0 | 7 | 1 | 4 | 0 | 1 | 12 | 1 | 7 | 0 | 0 | 1 | 0 | 1 | 1 | 12 |
| RORO | 2 | 3 | 71 | 5 | 40 | 3 | 7 | 142 | 11 | 79 | 1 | 2 | 8 | 1 | 8 | 1 | 19 |
| TANKER | 21 | 43 | 930 | 72 | 532 | 61 | 124 | 2668 | 205 | 1525 | 12 | 33 | 129 | 12 | 129 | 17 | 307 |
| VEHICLE CARRIER | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Grand Total** | **107** | **218** | **4665** | **368** | **2741** | **188** | **382** | **8190** | **648** | **4820** | **43** | **123** | **487** | **47** | **495** | **101** | **1853** |

**Lower Mississippi River Ports Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 99 | 206 | 4421 | 324 | 2401 | 172 | 358 | 7676 | 563 | 4169 | 40 | 116 | 457 | 41 | 440 | 91 | 1688 |
| 4-stroke | 7 | 9 | 204 | 22 | 160 | 14 | 18 | 439 | 46 | 343 | 3 | 7 | 25 | 3 | 36 | 8 | 144 |
| Steam Engine | 1 | 2 | 24 | 21 | 169 | 1 | 4 | 40 | 36 | 289 | 0 | 0 | 2 | 2 | 17 | 2 | 7 |
| **Grand Total** | **107** | **218** | **4665** | **368** | **2741** | **188** | **382** | **8190** | **648** | **4820** | **43** | **123** | **487** | **47** | **495** | **101** | **1853** |

**New York Ports Emissions by Vessel Type (TPY)**

| | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| BARGE CARRIER | 0 | 0 | 1 | 1 | 6 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| BULK CARRIER | 5 | 10 | 215 | 17 | 128 | 6 | 12 | 249 | 19 | 143 | 3 | 8 | 32 | 3 | 32 | 6 | 110 |
| CONTAINER SHIP | 38 | 80 | 1683 | 155 | 1171 | 15 | 32 | 660 | 61 | 461 | 13 | 36 | 144 | 15 | 155 | 12 | 210 |
| GENERAL CARGO | 3 | 7 | 149 | 12 | 89 | 2 | 5 | 98 | 8 | 58 | 1 | 4 | 15 | 1 | 15 | 3 | 38 |
| MISCELLANEOUS | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| PASSENGER | 5 | 8 | 164 | 24 | 181 | 2 | 4 | 82 | 12 | 94 | 2 | 4 | 17 | 3 | 27 | 1 | 12 |
| REEFER | 1 | 2 | 38 | 3 | 21 | 0 | 1 | 15 | 1 | 8 | 0 | 1 | 3 | 0 | 3 | 0 | 8 |
| RORO | 4 | 8 | 182 | 14 | 101 | 2 | 4 | 87 | 6 | 48 | 2 | 6 | 24 | 2 | 24 | 2 | 31 |
| TANKER | 16 | 33 | 703 | 64 | 479 | 11 | 23 | 484 | 44 | 333 | 13 | 36 | 143 | 15 | 153 | 9 | 165 |
| VEHICLES CARRIER | 5 | 9 | 188 | 15 | 109 | 2 | 4 | 91 | 7 | 53 | 2 | 6 | 25 | 2 | 26 | 1 | 19 |
| **Grand Total** | **77** | **157** | **3325** | **304** | **2286** | **41** | **84** | **1769** | **160** | **1201** | **36** | **102** | **404** | **42** | **436** | **34** | **595** |

**New York Ports Emissions by Engine Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| 2-stroke | 67 | 139 | 2983 | 219 | 1620 | 36 | 74 | 1592 | 117 | 865 | 32 | 93 | 365 | 33 | 351 | 28 | 519 |
| 4-stroke | 9 | 12 | 280 | 30 | 219 | 5 | 6 | 146 | 15 | 114 | 4 | 9 | 33 | 4 | 47 | 3 | 63 |
| Steam Engine | 1 | 7 | 62 | 56 | 447 | 1 | 3 | 31 | 28 | 222 | 0 | 1 | 5 | 5 | 38 | 3 | 13 |
| **Grand Total** | **77** | **157** | **3325** | **304** | **2286** | **41** | **84** | **1769** | **160** | **1201** | **36** | **102** | **404** | **42** | **436** | **34** | **595** |

**Delaware River Ports Emissions by Vessel Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vessel Type | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| BULK CARRIER | 5 | 11 | 238 | 18 | 131 | 10 | 20 | 420 | 31 | 231 | 2 | 6 | 23 | 2 | 23 | 5 | 90 |
| CONTAINER SHIP | 6 | 11 | 235 | 19 | 138 | 6 | 12 | 268 | 21 | 157 | 2 | 5 | 18 | 2 | 19 | 2 | 43 |
| GENERAL CARGO | 3 | 6 | 127 | 10 | 77 | 5 | 10 | 215 | 17 | 129 | 1 | 3 | 12 | 1 | 13 | 3 | 50 |
| MISCELLANEOUS | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PASSENGER | 0 | 0 | 9 | 2 | 18 | 0 | 0 | 8 | 2 | 20 | 0 | 0 | 1 | 0 | 2 | 0 | 1 |
| REEFER | 3 | 6 | 136 | 10 | 76 | 4 | 7 | 155 | 12 | 86 | 1 | 3 | 13 | 1 | 13 | 2 | 42 |
| RORO | 1 | 1 | 21 | 2 | 14 | 1 | 1 | 30 | 3 | 19 | 0 | 0 | 1 | 0 | 2 | 0 | 6 |
| TANKER | 14 | 29 | 607 | 53 | 397 | 24 | 51 | 1071 | 94 | 702 | 8 | 23 | 89 | 9 | 93 | 13 | 227 |
| VEHICLE CARRIER | 1 | 2 | 39 | 3 | 22 | 1 | 1 | 31 | 2 | 18 | 0 | 1 | 3 | 0 | 3 | 0 | 4 |
| **Grand Total** | **33** | **66** | **1413** | **117** | **873** | **51** | **103** | **2200** | **183** | **1363** | **14** | **41** | **161** | **16** | **168** | **26** | **465** |

**Delaware River Ports Emissions by Engine Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| 2-stroke | 28 | 59 | 1267 | 93 | 688 | 45 | 93 | 1999 | 147 | 1086 | 13 | 37 | 148 | 13 | 142 | 23 | 417 |
| 4-stroke | 4 | 6 | 135 | 14 | 105 | 6 | 8 | 182 | 19 | 142 | 2 | 3 | 12 | 2 | 17 | 2 | 44 |
| Steam Engine | 0 | 1 | 11 | 10 | 80 | 0 | 2 | 19 | 17 | 135 | 0 | 0 | 1 | 1 | 9 | 1 | 3 |
| **Grand Total** | **33** | **66** | **1413** | **117** | **873** | **51** | **103** | **2200** | **183** | **1363** | **14** | **41** | **161** | **16** | **168** | **26** | **465** |

**Puget Sound Ports Emissions by Vessel Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vessel Type | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 10 | 21 | 452 | 34 | 256 | 0 | 36 | 75 | 1605 | 124 | 925 | 4 | 11 | 43 | 4 | 43 | 11 | 208 |
| CONTAINER SHIP | 27 | 57 | 1194 | 112 | 845 | 0 | 62 | 132 | 2747 | 255 | 1927 | 7 | 21 | 85 | 9 | 91 | 12 | 203 |
| FISHING | 1 | 1 | 17 | 2 | 17 | 0 | 2 | 3 | 65 | 9 | 67 | 0 | 1 | 4 | 1 | 6 | 3 | 50 |
| GENERAL CARGO | 3 | 7 | 142 | 11 | 84 | 0 | 11 | 21 | 466 | 38 | 280 | 1 | 3 | 12 | 1 | 13 | 3 | 46 |
| MISCELANEOUS | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 1 | 11 | 1 | 11 | 0 | 0 | 0 | 0 | 0 | 1 | 14 |
| PASSENGER | 0 | 0 | 10 | 1 | 8 | 0 | 1 | 1 | 24 | 3 | 20 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| REEFER | 0 | 1 | 16 | 1 | 9 | 0 | 1 | 2 | 50 | 4 | 29 | 0 | 1 | 3 | 0 | 3 | 1 | 15 |
| RORO | 1 | 3 | 39 | 14 | 109 | 0 | 2 | 6 | 79 | 33 | 260 | 0 | 0 | 3 | 1 | 10 | 2 | 9 |
| TANKER | 4 | 11 | 190 | 47 | 370 | 0 | 13 | 34 | 575 | 145 | 1143 | 4 | 11 | 47 | 11 | 100 | 4 | 45 |
| VEHICLES CARRIER | 2 | 4 | 77 | 6 | 44 | 0 | 6 | 11 | 233 | 18 | 135 | 1 | 2 | 6 | 1 | 6 | 0 | 8 |
| **Grand Total** | **49** | **104** | **2140** | **229** | **1745** | | **134** | **285** | **5857** | **629** | **4796** | **17** | **50** | **204** | **28** | **273** | **37** | **600** |

**Puget Sound Ports Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **EMISSIONS ESTIMATES** | | | | | |
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 44 | 92 | 1980 | 145 | 1075 | | 120 | 250 | 5367 | 393 | 2915 | 16 | 46 | 183 | 17 | 176 | 27 | 496 |
| 4-stroke | 2 | 3 | 75 | 8 | 59 | | 8 | 11 | 256 | 27 | 200 | 1 | 3 | 10 | 1 | 14 | 4 | 79 |
| Steam Engine | 2 | 9 | 85 | 76 | 611 | | 6 | 25 | 235 | 209 | 1681 | 0 | 1 | 12 | 10 | 84 | 6 | 25 |
| **Grand Total** | **49** | **104** | **2140** | **229** | **1745** | | **134** | **285** | **5857** | **629** | **4796** | **17** | **50** | **204** | **28** | **273** | **37** | **600** |

**Port of Corpus Christi Emissions by Vessel Type (TPY)**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **EMISSIONS ESTIMATES** | | | | | |
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| BARGE CARRIER | 0 | 0 | 0 | 0 | 2 | # | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BULK CARRIER | 3 | 6 | 139 | 10 | 77 | 0 | 2 | 4 | 90 | 7 | 50 | 2 | 6 | 24 | 2 | 23 | 1 | 26 |
| CONTAINER SHIP | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| TANKER | 13 | 29 | 574 | 78 | 600 | 0 | 8 | 18 | 355 | 47 | 364 | 8 | 24 | 98 | 13 | 125 | 5 | 75 |
| GENERAL CARGO | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| MISCELLANEOUS | 0 | 0 | 1 | 0 | 1 | # | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Grand Total** | **17** | **36** | **720** | **89** | **684** | | **10** | **22** | **449** | **54** | **418** | **11** | **31** | **123** | **15** | **150** | **6** | **103** |

**Port of Corpus Christi Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **EMISSIONS ESTIMATES** | | | | | |
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 14 | 30 | 634 | 47 | 345 | | 9 | 19 | 400 | 29 | 217 | 10 | 28 | 112 | 10 | 108 | 5 | 87 |
| 4-stroke | 1 | 2 | 43 | 5 | 33 | | 1 | 1 | 24 | 3 | 19 | 1 | 2 | 6 | 1 | 9 | 1 | 11 |
| Steam Engine | 1 | 4 | 43 | 38 | 306 | | 1 | 3 | 25 | 23 | 181 | 0 | 0 | 5 | 4 | 33 | 1 | 5 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grand Total** | **17** | **36** | **720** | **89** | **684** | | **10** | **22** | **449** | **54** | **418** | | **11** | **31** | **123** | **15** | **150** | | **6** | **103** |

**Port of Tampa Emissions by Vessel Type (TPY)**

| | | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| BULK CARRIER | 7 | 14 | 299 | 24 | 175 | 0 | 4 | 7 | 155 | 12 | 90 | | 4 | 10 | 41 | 4 | 41 | | 5 | 90 |
| CONTAINER SHIP | 0 | 0 | 4 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | | 0 | 0 | 1 | 0 | 1 | | 0 | 3 |
| GENERAL CARGO | 2 | 3 | 70 | 6 | 46 | 0 | 1 | 2 | 39 | 3 | 26 | | 1 | 1 | 5 | 1 | 6 | | 1 | 20 |
| PASSENGER | 3 | 6 | 127 | 10 | 73 | 0 | 1 | 3 | 63 | 5 | 36 | | 1 | 2 | 9 | 1 | 9 | | 1 | 21 |
| REEFER | 0 | 1 | 20 | 1 | 11 | | 0 | 0 | 7 | 0 | 4 | | 0 | 1 | 2 | 0 | 2 | | 0 | 9 |
| RORO | 0 | 0 | 5 | 0 | 3 | | 0 | 0 | 3 | 0 | 2 | | 0 | 0 | 1 | 0 | 1 | | 0 | 3 |
| TANKER | 4 | 8 | 157 | 20 | 157 | | 2 | 4 | 83 | 11 | 82 | | 1 | 3 | 12 | 2 | 17 | | 1 | 21 |
| TUG | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| VEHICLES CARRIER | 0 | 0 | 1 | 0 | 1 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 1 |
| BARGE DRY CARGO | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| BARGE TANKER | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| MISCELLANEOUS | 0 | 0 | 2 | 0 | 2 | | 0 | 0 | 1 | 0 | 1 | | 0 | 0 | 0 | 0 | 0 | | 0 | 6 |
| UNSPECIFIED MOTOR | 0 | 0 | 0 | 0 | 0 | # | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| **Grand Total** | **17** | **32** | **685** | **63** | **469** | | **9** | **16** | **353** | **32** | **241** | | **7** | **18** | **71** | **7** | **77** | | **10** | **174** |

**Port of Tampa Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 9 | 19 | 403 | 30 | 219 | | 5 | 10 | 208 | 15 | 113 | | 4 | 12 | 49 | 4 | 47 | | 5 | 94 |
| 4-stroke | 1 | 1 | 23 | 2 | 18 | | 0 | 0 | 11 | 1 | 9 | | 0 | 0 | 2 | 0 | 3 | | 1 | 16 |
| Steam Engine | 0 | 1 | 10 | 9 | 72 | | 0 | 1 | 5 | 5 | 37 | | 0 | 0 | 1 | 1 | 5 | | 0 | 2 |
| **Grand Total** | **17** | **32** | **685** | **63** | **469** | | **9** | **16** | **353** | **32** | **241** | | **7** | **18** | **71** | **7** | **77** | | **10** | **174** |

**Port of Baltimore by Vessel Type (TPY)**

| | | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| BULK CARRIER | 7 | 14 | 302 | 24 | 182 | | 31 | 64 | 1354 | 108 | 809 | | 2 | 6 | 25 | 2 | 25 | | 6 | 111 |
| CONTAINER SHIP | 11 | 24 | 510 | 40 | 299 | | 31 | 66 | 1397 | 110 | 817 | | 4 | 13 | 50 | 5 | 49 | | 3 | 52 |
| GENERAL CARGO | 2 | 4 | 85 | 7 | 52 | | 9 | 17 | 363 | 30 | 225 | | 1 | 2 | 8 | 1 | 8 | | 2 | 35 |
| MISCELLANEOUS | 0 | 0 | 3 | 0 | 2 | | 0 | 1 | 16 | 2 | 11 | | 0 | 0 | 0 | 0 | 0 | | 1 | 13 |
| PASSENGER | 0 | 0 | 9 | 2 | 12 | | 1 | 1 | 20 | 4 | 29 | | 0 | 0 | 1 | 0 | 1 | | 0 | 5 |
| REEFER | 0 | 0 | 1 | 0 | 1 | | 0 | 0 | 2 | 0 | 1 | | 0 | 0 | 0 | 0 | 0 | | 0 | 3 |

| | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuvering SO2 | Hotelling HC | Hotelling CO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RORO | 4 | 9 | 186 | 14 | 101 | 13 | 27 | 586 | 43 | 320 | 2 | 5 | 19 | 2 | 19 | 2 | 32 |
| TANKER | 2 | 3 | 70 | 6 | 45 | 7 | 14 | 291 | 25 | 191 | 1 | 2 | 6 | 1 | 7 | 1 | 13 |
| VEHICLES CARRIER | 4 | 7 | 155 | 12 | 90 | 10 | 20 | 434 | 34 | 253 | 2 | 5 | 19 | 2 | 20 | 1 | 19 |
| **Grand Total** | **30** | **62** | **1321** | **105** | **784** | **102** | **209** | **4463** | **356** | **2656** | **11** | **33** | **129** | **12** | **130** | **16** | **283** |

**Port of Baltimore Emissions by Engine Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| 2-stroke | 28 | 58 | 1248 | 91 | 678 | 95 | 196 | 4217 | 309 | 2290 | 11 | 31 | 122 | 11 | 117 | 13 | 244 |
| 4-stroke | 2 | 3 | 65 | 7 | 51 | 7 | 9 | 219 | 23 | 171 | 1 | 2 | 6 | 1 | 9 | 2 | 37 |
| Steam Engine | 0 | 1 | 8 | 7 | 55 | 1 | 3 | 27 | 24 | 194 | 0 | 0 | 1 | 0 | 4 | 1 | 2 |
| **Grand Total** | **30** | **62** | **1321** | **105** | **784** | **102** | **209** | **4463** | **356** | **2656** | **11** | **33** | **129** | **12** | **130** | **16** | **283** |

**Coos Bay Emissions by Vessel Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vessel Type | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| BULK CARRIER | 2 | 4 | 76 | 6 | 41 | 0 | 1 | 16 | 1 | 9 | 0 | 1 | 3 | 0 | 2 | 1 | 21 |
| GENERAL CARGO | 1 | 1 | 30 | 2 | 16 | 0 | 0 | 6 | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 8 |
| MISCELLANEOUS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Grand Total** | **2** | **5** | **106** | **8** | **58** | **1** | **1** | **23** | **2** | **12** | **0** | **1** | **4** | **0** | **3** | **2** | **29** |

**Coos Bay Emissions by Engine Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| 2-stroke | 2 | 5 | 106 | 8 | 57 | 1 | 1 | 23 | 2 | 12 | 0 | 1 | 4 | 0 | 3 | 2 | 28 |
| 4-stroke | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Steam Engine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Grand Total** | **2** | **5** | **106** | **8** | **58** | **1** | **1** | **23** | **2** | **12** | **0** | **1** | **4** | **0** | **3** | **2** | **29** |

**Port of Cleveland Emissions by Vessel Type (TPY)**

| | EMISSIONS ESTIMATES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vessel Type | Cruise HC | Cruise CO | Cruise NOx | Cruise PM | Cruise SO2 | RSZ HC | RSZ CO | RSZ NOx | RSZ PM | RSZ SO2 | Maneuvering HC | Maneuvering CO | Maneuvering NOx | Maneuvering PM | Maneuviring SO2 | Hotelling HC | Hotelling CO |
| BULK CARRIER, SALTY | 0 | 1 | 16 | 1 | 9 | 0 | 0 | 3 | 0 | 2 | 0 | 1 | 5 | 0 | 5 | 1 | 15 |
| BULK CARRIER, LAKER | 1 | 3 | 60 | 5 | 41 | 0 | 1 | 15 | 1 | 10 | 5 | 13 | 51 | 5 | 55 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CONTAINER SHIP, SALTY | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| EXCURSION VESSEL | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 12 | 1 | 9 | | 0 | 0 | 1 | 0 | 1 | | 0 | 0 |
| GENERAL CARGO, SALTY | 0 | 0 | 1 | 0 | 1 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 1 |
| TANKER, SALTY | 0 | 0 | 1 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| **Grand Total** | **2** | **4** | **77** | **7** | **50** | | **1** | **1** | **31** | **3** | **22** | | **5** | **15** | **58** | **6** | **62** | | **1** | **17** |

**Port of Cleveland Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 1 | 3 | 63 | 5 | 34 | | 0 | 1 | 15 | 1 | 8 | | 4 | 12 | 47 | 4 | 45 | | 1 | 16 |
| 4-stroke | 0 | 1 | 13 | 1 | 10 | | 0 | 1 | 15 | 2 | 12 | | 1 | 3 | 11 | 1 | 15 | | 0 | 1 |
| Steam Engine | 0 | 0 | 1 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | | 0 | 0 | 0 | 0 | 2 | | 0 | 0 |
| **Grand Total** | **2** | **4** | **77** | **7** | **50** | **0** | **1** | **1** | **31** | **3** | **22** | | **5** | **15** | **58** | **6** | **62** | | **1** | **17** |

**Burns Waterway Harbor Emissions by Vessel Type (TPY)**

| | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| BULK CARRIER, SALTY | 0 | 0 | 10 | 1 | 6 | | 0 | 0 | 2 | 0 | 1 | | 0 | 1 | 3 | 0 | 3 | | 0 | 5 |
| BULK CARRIER, LAKER | 1 | 1 | 23 | 2 | 14 | | 0 | 0 | 5 | 0 | 3 | | 1 | 1 | 5 | 1 | 6 | | 0 | 1 |
| GENERAL CARGO, SALTY | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| TANKER, SALTY | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| **Grand Total** | **1** | **2** | **34** | **3** | **20** | | **0** | **0** | **8** | **1** | **5** | | **1** | **2** | **9** | **1** | **9** | | **0** | **6** |

**Burns Waterway Harbor Emissions by Engine Type (TPY)**

| | | | | | | | | | | | | | | EMISSIONS ESTIMATES | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cruise HC** | **Cruise CO** | **Cruise NOx** | **Cruise PM** | **Cruise SO2** | | **RSZ HC** | **RSZ CO** | **RSZ NOx** | **RSZ PM** | **RSZ SO2** | | **Maneuvering HC** | **Maneuvering CO** | **Maneuvering NOx** | **Maneuvering PM** | **Maneuviring SO2** | | **Hotelling HC** | **Hotelling CO** |
| 2-stroke | 1 | 1 | 31 | 2 | 17 | | 0 | 0 | 7 | 1 | 4 | | 1 | 2 | 8 | 1 | 8 | | 0 | 6 |
| 4-stroke | 0 | 0 | 3 | 0 | 2 | | 0 | 0 | 1 | 0 | 1 | | 0 | 0 | 1 | 0 | 1 | | 0 | 0 |
| Steam Engine | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| **Grand Total** | **1** | **2** | **34** | **3** | **20** | **0** | **0** | **0** | **8** | **1** | **5** | | **1** | **2** | **9** | **1** | **9** | | **0** | **6** |

**Lower Mississippi River F**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | 68 | 11 | 86 | 3 | 16 | 140 | 22 | 170 |
| BULK CARRIER | 6901 | 181 | 865 | 254 | 1680 | 14277 | 737 | 5071 |
| CONTAINER SHIP | 240 | 23 | 170 | 16 | 72 | 724 | 84 | 643 |
| GENERAL CARGO | 838 | 22 | 108 | 38 | 214 | 1950 | 111 | 778 |
| MISCELLANEOUS | 54 | 1 | 6 | 1 | 11 | 68 | 3 | 15 |
| PASSENGER | 78 | 7 | 52 | 9 | 32 | 386 | 44 | 338 |
| REEFER | 65 | 2 | 7 | 1 | 13 | 85 | 3 | 18 |
| RORO | 102 | 2 | 11 | 7 | 31 | 323 | 19 | 138 |
| TANKER | 1654 | 45 | 222 | 111 | 506 | 5381 | 334 | 2408 |
| VEHICLE CARRIER | 4 | 0 | 0 | 0 | 1 | 10 | 1 | 4 |
| **Grand Total** | **10002** | **296** | **1527** | **439** | **2576** | **23344** | **1358** | **9583** |

**Lower Mississippi River F**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 9089 | 218 | 974 | 403 | 2368 | 21642 | 1146 | 7983 |
| 4-stroke | 774 | 19 | 83 | 32 | 178 | 1443 | 90 | 622 |
| Steam Engine | 64 | 57 | 462 | 3 | 14 | 131 | 116 | 937 |
| **Grand Total** | **10002** | **296** | **1527** | **439** | **2576** | **23344** | **1358** | **9583** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 311 | 680 | 12,553 | 928 | 7,009 | Slow |
| | 24 | 34 | 669 | 71 | 539 | Medium |
| | 3 | 14 | 131 | 116 | 937 | Steamship |
| | 99 | 1,832 | 9,863 | 237 | 1,057 | **category 2** |
| total | 437 | 2,559 | 23,215 | 1,352 | 9,543 | |

**New York Ports Emission**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | 9 | 8 | 65 | 0 | 1 | 10 | 9 | 73 |
| BULK CARRIER | 594 | 16 | 79 | 19 | 140 | 1091 | 56 | 381 |
| CONTAINER SHIP | 1150 | 68 | 454 | 78 | 358 | 3636 | 300 | 2241 |
| GENERAL CARGO | 217 | 33 | 252 | 10 | 53 | 479 | 54 | 414 |
| MISCELLANEOUS | 5 | 0 | 1 | 0 | 1 | 11 | 1 | 5 |
| PASSENGER | 69 | 6 | 41 | 10 | 28 | 332 | 45 | 343 |
| REEFER | 42 | 1 | 4 | 2 | 11 | 98 | 5 | 36 |
| RORO | 170 | 14 | 96 | 10 | 49 | 463 | 36 | 269 |
| TANKER | 898 | 40 | 243 | 49 | 258 | 2228 | 162 | 1208 |
| VEHICLES CARRIER | 102 | 2 | 11 | 10 | 38 | 406 | 27 | 199 |
| **Grand Total** | **3257** | **188** | **1246** | **189** | **938** | **8755** | **694** | **5170** |

**New York Ports Emission**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 2793 | 67 | 299 | 163 | 825 | 7733 | 435 | 3136 |
| 4-stroke | 337 | 8 | 36 | 21 | 89 | 796 | 58 | 416 |
| Steam Engine | 127 | 113 | 911 | 5 | 24 | 225 | 201 | 1618 |
| **Grand Total** | **3257** | **188** | **1246** | **189** | **938** | **8755** | **694** | **5170** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 135 | 306 | 4,940 | 368 | 2,836 | Slow |
| | 18 | 27 | 459 | 49 | 380 | Medium |
| | 5 | 24 | 225 | 201 | 1,618 | Steamship |
| | 31 | 581 | 3,130 | 75 | 336 | **category 2** |
| total | 189 | 938 | 8,755 | 694 | 5,170 | |

**Delaware River Ports Emi**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 484 | 12 | 53 | 22 | 127 | 1166 | 63 | 437 |
| CONTAINER SHIP | 233 | 6 | 25 | 16 | 71 | 754 | 47 | 339 |
| GENERAL CARGO | 270 | 6 | 29 | 12 | 69 | 623 | 35 | 247 |
| MISCELLANEOUS | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 2 |
| PASSENGER | 8 | 2 | 16 | 1 | 2 | 25 | 7 | 56 |
| REEFER | 228 | 5 | 24 | 10 | 59 | 531 | 29 | 199 |
| RORO | 33 | 1 | 4 | 2 | 9 | 86 | 5 | 38 |
| TANKER | 1234 | 55 | 339 | 59 | 329 | 3002 | 210 | 1532 |
| VEHICLE CARRIER | 24 | 1 | 3 | 2 | 8 | 96 | 6 | 45 |
| **Grand Total** | **2515** | **88** | **493** | **124** | **674** | **6288** | **403** | **2896** |

**Delaware River Ports Emi**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 2244 | 54 | 241 | 109 | 606 | 5658 | 307 | 2156 |
| 4-stroke | 239 | 6 | 26 | 14 | 61 | 568 | 41 | 291 |
| Steam Engine | 32 | 28 | 226 | 2 | 7 | 63 | 56 | 449 |
| **Grand Total** | **2515** | **88** | **493** | **124** | **674** | **6288** | **403** | **2896** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 86 | 190 | 3,414 | 253 | 1,916 | Slow |
| | 12 | 16 | 329 | 35 | 265 | Medium |
| | 2 | 7 | 63 | 56 | 449 | Steamship |
| | 25 | 461 | 2,483 | 60 | 266 | **category 2** |
| total | 124 | 674 | 6,288 | 403 | 2,896 | |

**Puget Sound Ports Emiss**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 1122 | 30 | 142 | 62 | 315 | 3223 | 192 | 1366 |
| CONTAINER SHIP | 1115 | 70 | 474 | 108 | 413 | 5141 | 446 | 3336 |
| FISHING | 275 | 23 | 161 | 6 | 54 | 361 | 34 | 252 |
| GENERAL CARGO | 249 | 6 | 31 | 19 | 77 | 869 | 57 | 408 |
| MISCELANEOUS | 73 | 2 | 10 | 1 | 14 | 87 | 4 | 23 |
| PASSENGER | 16 | 1 | 7 | 1 | 5 | 50 | 5 | 36 |
| REEFER | 79 | 2 | 8 | 3 | 18 | 149 | 7 | 50 |
| RORO | 76 | 55 | 440 | 4 | 18 | 197 | 102 | 819 |
| TANKER | 285 | 93 | 737 | 25 | 101 | 1098 | 296 | 2349 |
| VEHICLES CARRIER | 44 | 1 | 5 | 8 | 24 | 360 | 26 | 190 |
| **Grand Total** | **3334** | **283** | **2015** | **237** | **1041** | **11535** | **1170** | **8830** |

**Puget Sound Ports Emiss**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 2672 | 64 | 286 | 208 | 885 | 10201 | 619 | 4453 |
| 4-stroke | 428 | 10 | 46 | 16 | 96 | 768 | 46 | 318 |
| Steam Engine | 234 | 209 | 1683 | 14 | 60 | 566 | 504 | 4059 |
| **Grand Total** | **3334** | **283** | **2015** | **237** | **1041** | **11535** | **1170** | **8830** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 181 | 389 | 7,530 | 555 | 4,166 | Slow |
| | 12 | 16 | 340 | 36 | 272 | Medium |
| | 14 | 60 | 566 | 504 | 4,059 | Steamship |
| | 31 | 576 | 3,100 | 74 | 332 | **category 2** |
| total | 237 | 1,041 | 11,535 | 1,170 | 8,830 | |

**Port of Corpus Christi Em**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | 1 | 1 | 7 | 0 | 0 | 1 | 1 | 10 |
| BULK CARRIER | 138 | 3 | 15 | 9 | 42 | 391 | 23 | 166 |
| CONTAINER SHIP | 4 | 0 | 0 | 0 | 1 | 7 | 0 | 3 |
| TANKER | 423 | 47 | 350 | 35 | 146 | 1450 | 185 | 1439 |
| GENERAL CARGO | 4 | 0 | 1 | 0 | 1 | 10 | 1 | 6 |
| MISCELLANEOUS | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 1 |
| **Grand Total** | **571** | **52** | **373** | **44** | **191** | **1863** | **210** | **1624** |

**Port of Corpus Christi Em**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 469 | 11 | 50 | 38 | 164 | 1615 | 97 | 720 |
| 4-stroke | 58 | 1 | 6 | 4 | 15 | 131 | 9 | 68 |
| Steam Engine | 44 | 39 | 317 | 3 | 12 | 117 | 104 | 837 |

| Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|
| 33 | 77 | 1,146 | 86 | 669 | Slow |
| 3 | 5 | 74 | 8 | 62 | Medium |
| 3 | 12 | 117 | 104 | 837 | Steamship |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Grand Total** | **571** | **52** | **373** | | **44** | **191** | **1863** | **210** | **1624** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 98 | 527 | 13 | 57 | **category 2** |
| total | 44 | 191 | 1,863 | 210 | 1,624 | |

**Port of Tampa Emissions**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 487 | 12 | 57 | | 20 | 122 | 981 | 52 | 363 |
| CONTAINER SHIP | 17 | 0 | 2 | | 0 | 4 | 24 | 1 | 6 |
| GENERAL CARGO | 107 | 3 | 15 | | 4 | 26 | 222 | 13 | 93 |
| PASSENGER | 115 | 3 | 12 | | 6 | 32 | 314 | 18 | 130 |
| REEFER | 46 | 1 | 6 | | 1 | 10 | 75 | 3 | 23 |
| RORO | 16 | 0 | 2 | | 0 | 3 | 25 | 1 | 8 |
| TANKER | 121 | 17 | 127 | | 8 | 36 | 373 | 50 | 383 |
| TUG | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| VEHICLES CARRIER | 5 | 0 | 1 | | 0 | 1 | 7 | 0 | 1 |
| BARGE DRY CARGO | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| BARGE TANKER | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| MISCELLANEOUS | 32 | 1 | 3 | | 0 | 6 | 36 | 1 | 6 |
| UNSPECIFIED MOTOR | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| **Grand Total** | **946** | **38** | **225** | | **41** | **241** | **2055** | **140** | **1013** |

**Port of Tampa Emissions**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|---|
| 2-stroke | 503 | 12 | 54 | | 23 | 134 | 1164 | 61 | 433 |
| 4-stroke | 89 | 2 | 10 | | 2 | 18 | 125 | 6 | 40 |
| Steam Engine | 17 | 15 | 125 | | 1 | 4 | 33 | 30 | 239 |
| **Grand Total** | **946** | **38** | **225** | | **41** | **241** | **2055** | **140** | **1013** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 18 | 41 | 660 | 49 | 379 | Slow |
| | 1 | 2 | 36 | 4 | 30 | Medium |
| | 1 | 4 | 33 | 30 | 239 | Steamship |
| | 6 | 110 | 592 | 14 | 64 | **category 2** |
| total | 26 | 156 | 1,322 | 97 | 713 | |

**Port of Baltimore by Vess**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 600 | 18 | 91 | | 46 | 195 | 2281 | 153 | 1107 |
| CONTAINER SHIP | 281 | 10 | 53 | | 50 | 154 | 2238 | 164 | 1219 |
| GENERAL CARGO | 192 | 11 | 69 | | 13 | 58 | 648 | 49 | 354 |
| MISCELLANEOUS | 68 | 2 | 7 | | 1 | 14 | 88 | 4 | 22 |
| PASSENGER | 31 | 7 | 54 | | 1 | 7 | 61 | 12 | 96 |
| REEFER | 15 | 0 | 2 | | 0 | 3 | 19 | 1 | 3 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| RORO | 174 | 4 | 19 | 21 | 73 | 966 | 63 | 458 |
| TANKER | 68 | 2 | 14 | 10 | 31 | 436 | 35 | 257 |
| VEHICLES CARRIER | 101 | 2 | 11 | 17 | 51 | 709 | 51 | 373 |
| **Grand Total** | **1532** | **56** | **320** | **160** | **586** | **7444** | **530** | **3889** |

**Port of Baltimore Emissio**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 | | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-stroke | 1311 | 31 | 141 | 146 | 529 | 6898 | 443 | 3226 | | 133 | 285 | 5,586 | 412 | 3,085 | Slow |
| 4-stroke | 199 | 5 | 21 | 12 | 51 | 490 | 36 | 253 | | 10 | 14 | 291 | 31 | 232 | Medium |
| Steam Engine | 22 | 20 | 158 | 1 | 6 | 57 | 51 | 410 | | 1 | 6 | 57 | 51 | 410 | Steamship |
| **Grand Total** | **1532** | **56** | **320** | **160** | **586** | **7444** | **530** | **3889** | | 15 | 280 | 1,510 | 36 | 162 | **category 2** |
| | | | | | | | | | total | 160 | 586 | 7,444 | 530 | 3,889 | |

**Coos Bay Emissions by V**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 110 | 3 | 12 | 3 | 25 | 205 | 10 | 65 |
| GENERAL CARGO | 42 | 1 | 5 | 1 | 10 | 79 | 4 | 25 |
| MISCELLANEOUS | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| **Grand Total** | **154** | **4** | **16** | **5** | **36** | **287** | **14** | **90** |

**Coos Bay Emissions by E**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 | | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-stroke | 152 | 4 | 16 | 5 | 35 | 284 | 13 | 89 | | 3 | 7 | 132 | 10 | 73 | Slow |
| 4-stroke | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | | 0 | 0 | 1 | 0 | 1 | Medium |
| Steam Engine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | Steamship |
| **Grand Total** | **154** | **4** | **16** | **5** | **36** | **287** | **14** | **90** | | 2 | 29 | 154 | 4 | 16 | **category 2** |
| | | | | | | | | | total | 5 | 36 | 287 | 14 | 90 | |

**Port of Cleveland Emissic**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BULK CARRIER, SALTY | 82 | 2 | 9 | 2 | 17 | 106 | 4 | 24 |
| BULK CARRIER, LAKER | 0 | 0 | 0 | 7 | 16 | 126 | 12 | 106 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CONTAINER SHIP, SALTY | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| EXCURSION VESSEL | 0 | 0 | 0 | 0 | 1 | 13 | 1 | 11 |
| GENERAL CARGO, SALTY | 7 | 0 | 1 | 0 | 1 | 8 | 0 | 2 |
| TANKER, SALTY | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| **Grand Total** | **90** | **2** | **10** | **9** | **36** | **255** | **18** | **143** |

**Port of Cleveland Emissio**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 87 | 2 | 9 | 7 | 32 | 212 | 12 | 97 |
| 4-stroke | 3 | 0 | 0 | 2 | 5 | 42 | 4 | 38 |
| Steam Engine | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9 |
| **Grand Total** | **90** | **2** | **10** | **9** | **36** | **255** | **18** | **143** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 6 | 15 | 125 | 10 | 87 | Slow |
| | 2 | 4 | 39 | 4 | 37 | Medium |
| | 0 | 0 | 1 | 1 | 9 | Steamship |
| | 1 | 17 | 90 | 2 | 10 | **category 2** |
| total | 9 | 36 | 255 | 18 | 143 | |

**Burns Waterway Harbor E**

| Vessel Type | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| BULK CARRIER, SALTY | 27 | 1 | 5 | 1 | 6 | 43 | 2 | 15 |
| BULK CARRIER, LAKER | 3 | 0 | 1 | 1 | 3 | 37 | 3 | 23 |
| GENERAL CARGO, SALTY | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| TANKER, SALTY | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| **Grand Total** | **32** | **1** | **6** | **2** | **10** | **82** | **5** | **39** |

**Burns Waterway Harbor E**

| | Hotelling NOx | Hotelling PM | Hotelling SO2 | All Modes HC | All Modes CO | All Modes NOx | All Modes PM | All Modes SO2 |
|---|---|---|---|---|---|---|---|---|
| 2-stroke | 30 | 1 | 3 | 2 | 9 | 76 | 4 | 32 |
| 4-stroke | 1 | 0 | 0 | 0 | 1 | 6 | 0 | 4 |
| Steam Engine | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 4 |
| **Grand Total** | **32** | **1** | **6** | **2** | **10** | **82** | **5** | **39** |

| | Transit Modes HC | Transit Modes CO | Transit Modes NOx | Transit Modes PM | Transit Modes SO2 | |
|---|---|---|---|---|---|---|
| | 2 | 4 | 46 | 4 | 28 | Slow |
| | 0 | 0 | 4 | 0 | 4 | Medium |
| | 0 | 0 | 1 | 0 | 4 | Steamship |
| | 0 | 6 | 31 | 1 | 3 | **category 2** |
| total | 2 | 10 | 82 | 5 | 39 | |

**Lower Mississippi River F**

| |
|---|
| **Vessel Type** |
| BARGE CARRIER |
| BULK CARRIER |
| CONTAINER SHIP |
| GENERAL CARGO |
| MISCELLANEOUS |
| PASSENGER |
| REEFER |
| RORO |
| TANKER |
| VEHICLE CARRIER |
| **Grand Total** |

**Lower Mississippi River F**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**New York Ports Emission**

| |
|---|
| **Vessel Type** |
| BARGE CARRIER |
| BULK CARRIER |
| CONTAINER SHIP |
| GENERAL CARGO |
| MISCELLANEOUS |
| PASSENGER |
| REEFER |
| RORO |
| TANKER |
| VEHICLES CARRIER |
| **Grand Total** |

**New York Ports Emission**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Delaware River Ports Emi**

| |
|---|
| **Vessel Type** |
| BULK CARRIER |
| CONTAINER SHIP |
| GENERAL CARGO |
| MISCELLANEOUS |
| PASSENGER |
| REEFER |
| RORO |
| TANKER |
| VEHICLE CARRIER |
| **Grand Total** |

**Delaware River Ports Emi**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Puget Sound Ports Emiss**

| |
|---|
| **Vessel Type** |

| |
|---|
| BULK CARRIER |
| CONTAINER SHIP |
| FISHING |
| GENERAL CARGO |
| MISCELANEOUS |
| PASSENGER |
| REEFER |
| RORO |
| TANKER |
| VEHICLES CARRIER |
| **Grand Total** |

**Puget Sound Ports Emiss**

| |
|---|
| |
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Port of Corpus Christi Em**

| |
|---|
| |
| **Vessel Type** |
| BARGE CARRIER |
| BULK CARRIER |
| CONTAINER SHIP |
| TANKER |
| GENERAL CARGO |
| MISCELLANEOUS |
| **Grand Total** |

**Port of Corpus Christi Em**

| |
|---|
| |
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |

| |
|---|
| **Grand Total** |

**Port of Tampa Emissions**

| |
|---|
| |
| **Vessel Type** |
| BULK CARRIER |
| CONTAINER SHIP |
| GENERAL CARGO |
| PASSENGER |
| REEFER |
| RORO |
| TANKER |
| TUG |
| VEHICLES CARRIER |
| BARGE DRY CARGO |
| BARGE TANKER |
| MISCELLANEOUS |
| UNSPECIFIED MOTOR |
| **Grand Total** |

**Port of Tampa Emissions**

| |
|---|
| |
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Port of Baltimore by Vess**

| |
|---|
| |
| **Vessel Type** |
| BULK CARRIER |
| CONTAINER SHIP |
| GENERAL CARGO |
| MISCELLANEOUS |
| PASSENGER |
| REEFER |

| |
|---|
| RORO |
| TANKER |
| VEHICLES CARRIER |
| **Grand Total** |

**Port of Baltimore Emissio**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Coos Bay Emissions by V**

| |
|---|
| **Vessel Type** |
| BULK CARRIER |
| GENERAL CARGO |
| MISCELLANEOUS |
| **Grand Total** |

**Coos Bay Emissions by E**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Port of Cleveland Emissic**

| |
|---|
| **Vessel Type** |
| BULK CARRIER, SALTY |
| BULK CARRIER, LAKER |

| |
|---|
| CONTAINER SHIP, SALTY |
| EXCURSION VESSEL |
| GENERAL CARGO, SALTY |
| TANKER, SALTY |
| **Grand Total** |

**Port of Cleveland Emissio**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

**Burns Waterway Harbor E**

| |
|---|
| |
| **Vessel Type** |
| BULK CARRIER, SALTY |
| BULK CARRIER, LAKER |
| GENERAL CARGO, SALTY |
| TANKER, SALTY |
| **Grand Total** |

**Burns Waterway Harbor E**

| |
|---|
| |
| 2-stroke |
| 4-stroke |
| Steam Engine |
| **Grand Total** |

## Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

| Ship Type | Engine Type | DWT Range | Calls | DWT (Tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | 2 | 35,000 - 45,000 | 9 | 44,799 | 26,100 | 18 | ND | ND | 1972 | 2.8 | 18.3 | 1.7 | 80.1 |
| BARGE CARRIER | 2 | > 45,000 | 10 | 49,835 | 26,000 | 18 | ND | ND | 1969 | 2.8 | 18.6 | 1.6 | 81.4 |
| BARGE CARRIER | ST | 35,000 - 45,000 | 10 | 41,578 | 31,565 | 22 | ND | ND | 1974 | 2.3 | 18.2 | 1.8 | 107.7 |
| BARGE CARRIER | ST | > 45,000 | 6 | 47,036 | 31,565 | 22 | ND | ND | 1975 | 2.3 | 18.8 | 1.9 | 76.7 |
| BARGE CARRIER | 0 | 0 | 3 | 45,701 | 28,570 | 20 | ND | ND | 1972 | 2.3 | 19.9 | 2.5 | 134.0 |
| **BARGE CARRIER Total** | | | **38** | **45,701** | **28,570** | **20** | **#N/A** | **#N/A** | **1972** | **2.5** | **18.6** | **1.8** | **91.4** |
| BULK CARRIER | 2 | <25,000 | 438 | 18,138 | 8,060 | 15 | 140 | 39% | 1979 | 3.4 | 20.7 | 2.4 | 144.7 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 717 | 29,492 | 10,768 | 15 | 132 | 51% | 1978 | 3.3 | 19.9 | 2.5 | 172.9 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 507 | 39,596 | 11,266 | 15 | 114 | 15% | 1982 | 3.4 | 20.8 | 2.5 | 153.8 |
| BULK CARRIER | 2 | > 45,000 | 1,183 | 72,142 | 14,501 | 15 | 98 | 0% | 1984 | 7.8 | 18.4 | 2.7 | 195.2 |
| BULK CARRIER | 4 | <25,000 | 70 | 15,614 | 6,606 | 14 | 479 | 100% | 1975 | 3.5 | 21.7 | 2.4 | 124.7 |
| BULK CARRIER | 4 | 25,000 - 35,000 | 13 | 27,092 | 9,528 | 14 | 278 | 100% | 1987 | 3.5 | 21.5 | 2.6 | 193.2 |
| BULK CARRIER | 4 | 35,000 - 45,000 | 10 | 38,731 | 12,650 | 16 | 464 | 100% | 1981 | 3.3 | 21.6 | 2.7 | 252.9 |
| BULK CARRIER | 4 | > 45,000 | 26 | 63,419 | 13,531 | 14 | 342 | 73% | 1983 | 3.5 | 16.9 | 2.8 | 200.2 |
| BULK CARRIER | ST | <25,000 | 5 | 18,314 | 8,384 | 15 | 123 | 21% | 1975 | 5.0 | 14.1 | 1.9 | 81.7 |
| BULK CARRIER | ST | 25,000 - 35,000 | 1 | 33,373 | 11,837 | 15 | 123 | 21% | 1983 | 3.3 | 35.1 | 2.5 | 38.7 |
| BULK CARRIER | ST | > 45,000 | 21 | 54,624 | 17,614 | 18 | 123 | 21% | 1970 | 2.9 | 16.2 | 2.7 | 198.4 |
| BULK CARRIER | 0 | 0 | 10 | 46,560 | 11,904 | 15 | 123 | 21% | 1981 | 3.7 | 20.4 | 2.5 | 206.7 |
| **BULK CARRIER Total** | | | **3,001** | **46,560** | **11,904** | **15** | **123** | **21%** | **1981** | **5.1** | **19.6** | **2.6** | **173.9** |
| CONTAINER SHIP | 2 | <25,000 | 120 | 18,707 | 15,717 | 19 | 117 | 27% | 1987 | 2.7 | 14.6 | 1.7 | 58.4 |
| CONTAINER SHIP | 2 | 25,000 - 35,000 | 6 | 28,019 | 19,411 | 19 | 111 | 0% | 1984 | 2.8 | 14.5 | 2.0 | 66.6 |
| CONTAINER SHIP | 2 | 35,000 - 45,000 | 66 | 38,743 | 27,387 | 21 | 91 | 0% | 1987 | 2.5 | 12.9 | 1.8 | 25.5 |
| CONTAINER SHIP | 2 | > 45,000 | 4 | 53,726 | 28,845 | 19 | 97 | 0% | 1985 | 3.1 | 13.1 | 1.8 | 30.0 |
| CONTAINER SHIP | 4 | <25,000 | 84 | 10,063 | 12,157 | 17 | 425 | 100% | 1991 | 2.8 | 12.8 | 1.6 | 20.5 |
| CONTAINER SHIP | ST | <25,000 | 58 | 21,711 | 25,280 | 22 | 242 | 53% | 1974 | 2.3 | 12.4 | 1.7 | 28.7 |
| CONTAINER SHIP | ST | 25,000 - 35,000 | 37 | 26,803 | 32,787 | 22 | 242 | 53% | 1974 | 2.3 | 12.8 | 1.6 | 31.8 |
| CONTAINER SHIP | ST | 35,000 - 45,000 | 1 | 38,656 | 31,565 | 21 | 242 | 53% | 1971 | 2.3 | 18.5 | 1.5 | 250.8 |
| CONTAINER SHIP | 0 | 0 | 3 | 22,127 | 20,366 | 20 | 242 | 53% | 1984 | 3.5 | 12.7 | 2.8 | 190.0 |
| **CONTAINER SHIP Total** | | | **379** | **22,127** | **20,366** | **20** | **242** | **53%** | **1984** | **2.6** | **13.4** | **1.7** | **38.6** |
| GENERAL CARGO | 2 | <15,000 | 247 | 9,246 | 6,166 | 15 | 178 | 91% | 1981 | 3.5 | 19.9 | 2.2 | 141.7 |
| GENERAL CARGO | 2 | 15,000 - 30,000 | 265 | 20,223 | 11,344 | 16 | 134 | 30% | 1982 | 3.1 | 19.0 | 2.0 | 88.4 |
| GENERAL CARGO | 2 | 30,000 - 45,000 | 41 | 40,358 | 12,943 | 15 | 97 | 0% | 1983 | 3.3 | 22.9 | 2.2 | 84.2 |
| GENERAL CARGO | 2 | > 45,000 | 4 | 46,648 | 14,313 | 17 | 105 | 0% | 1995 | 3.0 | 13.9 | 1.9 | 32.8 |
| GENERAL CARGO | 4 | <15,000 | 308 | 5,180 | 3,047 | 12 | 493 | 100% | 1979 | 4.1 | 20.2 | 2.2 | 193.2 |
| GENERAL CARGO | 4 | 15,000 - 30,000 | 43 | 18,775 | 8,922 | 15 | 460 | 100% | 1979 | 3.3 | 21.1 | 2.2 | 138.1 |
| GENERAL CARGO | ST | 15,000 - 30,000 | 2 | 22,536 | 23,673 | 21 | 212 | 64% | 1969 | 3.0 | 16.8 | 3.0 | 230.8 |

## Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

| Ship Type | Engine Type | DWT Range | Calls | DWT (Tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GENERAL CARGO | 0 | 0 | 1 | 13,112 | 7,128 | 15 | 212 | 64% | 1980 | 3.6 | 15.2 | 2.5 | 24.9 |
| **GENERAL CARGO Total** | | | **911** | **13,112** | **7,128** | **15** | **212** | **64%** | **1980** | **3.6** | **19.9** | **2.1** | **140.4** |
| MISCELLANEOUS | 2 | <1500 | 1 | 879 | 3,000 | 12 | ND | ND | 1978 | 4.2 | 36.8 | 2.5 | 1276.3 |
| MISCELLANEOUS | 2 | > 4,500 | 1 | 9,360 | 10,330 | 18 | ND | ND | 1980 | 2.8 | 19.7 | 1.5 | 1072.3 |
| MISCELLANEOUS | 4 | <1500 | 11 | 878 | 3,478 | 14 | ND | ND | 1980 | 3.9 | 11.4 | 2.0 | 502.4 |
| MISCELLANEOUS | 4 | > 4,500 | 1 | 9,950 | 13,800 | 15 | ND | ND | 1982 | 3.3 | 13.0 | 1.5 | 234.7 |
| MISCELLANEOUS | 0 | 0 | 7 | 2,132 | 4,670 | 14 | ND | ND | 1980 | 5.0 | 17.2 | 2.7 | 355.5 |
| **MISCELLANEOUS Total** | | | **21** | **2,132** | **4,670** | **14** | **#N/A** | **#N/A** | **1980** | **4.2** | **14.9** | **2.2** | **512.1** |
| PASSENGER | 2 | <5,000 | 26 | 4,217 | 29,370 | 21 | 363 | 53% | 1983 | 2.4 | 18.7 | 1.7 | 25.5 |
| PASSENGER | 2 | 5,000 - 10,000 | 54 | 6,473 | 30,083 | 19 | 363 | 53% | 1985 | 2.6 | 18.7 | 1.5 | 16.9 |
| PASSENGER | 2 | > 15,000 | 9 | 19,830 | 14,726 | 18 | 102 | 0% | 1988 | 2.8 | 11.5 | 1.6 | 36.1 |
| PASSENGER | 4 | <5,000 | 4 | 1,358 | 9,167 | 17 | 750 | 100% | 1967 | 3.1 | 18.5 | 1.9 | 188.5 |
| PASSENGER | 4 | 5,000 - 10,000 | 7 | 6,620 | 36,706 | 20 | 533 | 100% | 1991 | 2.6 | 18.7 | 1.6 | 26.7 |
| PASSENGER | ST | 5,000 - 10,000 | 52 | 8,721 | 25,504 | 23 | 363 | 53% | 1958 | 2.4 | 18.5 | 1.5 | 20.3 |
| **PASSENGER Total** | | | **152** | **7,519** | **27,240** | **21** | **363** | **53%** | **1976** | **2.5** | **18.2** | **1.6** | **25.7** |
| REEFER | 2 | 5,000 - 10,000 | 5 | 8,467 | 10,440 | 18 | 141 | 50% | 1982 | 2.9 | 16.3 | 1.9 | 251.1 |
| REEFER | 2 | 10,000 - 15,000 | 8 | 11,457 | 14,812 | 20 | 123 | 0% | 1980 | 2.6 | 18.1 | 1.6 | 383.5 |
| REEFER | 4 | <5,000 | 1 | 4,196 | 4,400 | 15 | 128 | 14% | 1981 | 3.3 | 10.9 | 3.0 | 186.9 |
| **REEFER Total** | | | **14** | **9,871** | **12,507** | **19** | **128** | **14%** | **1980** | **2.8** | **17.0** | **1.8** | **322.2** |
| RORO | 2 | <5,000 | 4 | 4,613 | 6,100 | 17 | 451 | 86% | 1979 | 3.0 | 19.4 | 1.5 | 89.4 |
| RORO | 2 | 5,000 - 10,000 | 7 | 6,521 | 7,014 | 17 | 451 | 86% | 1983 | 3.0 | 19.2 | 1.9 | 120.7 |
| RORO | 2 | 10,000 - 15,000 | 10 | 12,777 | 11,512 | 17 | 157 | 100% | 1989 | 3.0 | 16.6 | 2.1 | 192.2 |
| RORO | 2 | > 15,000 | 45 | 37,027 | 27,881 | 19 | 102 | 0% | 1982 | 2.8 | 19.7 | 1.8 | 44.9 |
| RORO | 4 | <5,000 | 8 | 3,262 | 3,336 | 12 | 1800 | 100% | 1980 | 4.0 | 18.4 | 2.2 | 101.7 |
| RORO | 4 | 5,000 - 10,000 | 26 | 9,883 | 5,998 | 14 | 500 | 100% | 1984 | 3.4 | 13.0 | 1.8 | 25.5 |
| **RORO Total** | | | **100** | **21,412** | **16,259** | **17** | **451** | **86%** | **1983** | **3.1** | **17.5** | **1.8** | **66.2** |
| TANKER | 2 | <30,000 | 314 | 16,943 | 7,930 | 15 | 168 | 76% | 1984 | 3.4 | 25.9 | 2.5 | 81.8 |
| TANKER | 2 | 30,000 - 60,000 | 304 | 40,559 | 12,593 | 15 | 111 | 2% | 1984 | 3.3 | 21.7 | 2.5 | 91.6 |
| TANKER | 2 | 60,000 - 90,000 | 303 | 77,606 | 15,455 | 15 | 97 | 0% | 1984 | 3.4 | 27.0 | 2.4 | 71.0 |
| TANKER | 2 | 90,000 - 120,000 | 287 | 97,851 | 15,067 | 15 | 95 | 0% | 1990 | 3.4 | 27.5 | 2.4 | 66.6 |
| TANKER | 2 | 120,000 - 150,000 | 49 | 134,806 | 23,453 | 15 | 99 | 0% | 1983 | 3.3 | 10.4 | 1.9 | 76.3 |
| TANKER | 2 | > 150,000 | 4 | 157,345 | 19,605 | 14 | 85 | 0% | 1992 | 3.5 | 19.8 | 2.5 | 107.7 |
| TANKER | 4 | <30,000 | 103 | 9,575 | 5,240 | 14 | 414 | 74% | 1981 | 3.7 | 23.1 | 2.6 | 79.8 |
| TANKER | 4 | 30,000 - 60,000 | 19 | 46,237 | 15,072 | 16 | 132 | 20% | 1979 | 3.2 | 25.2 | 2.6 | 454.9 |
| TANKER | 4 | 60,000 - 90,000 | 53 | 81,275 | 14,394 | 15 | 296 | 58% | 1982 | 3.4 | 25.3 | 2.4 | 66.2 |
| TANKER | ST | 30,000 - 60,000 | 10 | 40,102 | 15,190 | 16 | 132 | 20% | 1967 | 3.2 | 25.7 | 2.7 | 96.0 |
| TANKER | ST | 60,000 - 90,000 | 3 | 71,694 | 19,728 | 16 | 132 | 20% | 1971 | 3.1 | 14.0 | 2.3 | 73.9 |
| TANKER | ST | 90,000 - 120,000 | 3 | 92,809 | 24,167 | 16 | 132 | 20% | 1977 | 3.0 | 26.6 | 2.7 | 73.1 |
| TANKER | ST | 120,000 - 150,000 | 1 | 122,249 | 25,647 | 16 | 132 | 20% | 1973 | 3.1 | 29.0 | 2.5 | 134.5 |
| TANKER | 0 | 0 | 5 | 57,586 | 12,699 | 15 | 132 | 20% | 1985 | 3.4 | 16.5 | 2.5 | 143.7 |
| **TANKER Total** | | | **1,458** | **57,586** | **12,699** | **15** | **132** | **20%** | **1985** | **3.4** | **24.7** | **2.4** | **83.0** |
| TUG | 2 | < 1,000 | 3 | 669 | 6,717 | 15 | ND | ND | 1978 | 3.4 | 18.4 | 2.2 | 280.2 |
| TUG | 2 | < 500 | 28 | 6 | 3,631 | 12 | ND | ND | 1970 | 4.3 | 18.7 | 2.5 | 558.6 |
| TUG | 4 | < 500 | 4 | 0 | 3,628 | 13 | ND | ND | 1966 | 3.9 | 17.7 | 2.8 | 1420.6 |
| TUG | 0 | 0 | 44 | 62 | 3,895 | 13 | ND | ND | 1970 | 4.0 | 14.1 | 2.6 | 847.7 |
| **TUG Total** | | | **79** | **62** | **3,895** | **13** | **#N/A** | **#N/A** | **1970** | **4.1** | **16.1** | **2.6** | **752.7** |
| VEHICLE CARRIER | 2 | > 35,000 | 2 | 40,999 | 14,000 | 15 | ND | ND | ND | 3.3 | 26.4 | 2.5 | 117.3 |
| **VEHICLE CARRIER Total** | | | **2** | **40,999** | **14,000** | **15** | **#N/A** | **#N/A** | **#N/A** | **3.3** | **26.4** | **2.5** | **117.3** |

## Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

| Ship Type | Engine Type | DWT Range | Calls | DWT (Tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grand Total** | | | **6,155** | **40,829** | **12,393** | **15** | **154** | **30%** | **1982** | **4.2** | **20.3** | **2.4** | **142.1** |

## Table 7-5: Summary of 1996 Deep-Sea Vessel Data for the Consolidated Port of New York and Ports on the Hudson River

| Ship Type | Stroke | DWT Category | Calls | DWT (tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr) | Man. (hr) | Hotel (hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | ST | 35,000 - 45,000 | 6 | 46,153 | 31,541 | 22 | ND | ND | 1974 | 2.3 | 3.4 | 1.6 | 209.4 |
| **BARGE CARRIER Total** | | | **6** | **46,153** | **31,541** | **22** | **ND** | **ND** | **1974** | **2.3** | **3.4** | **1.6** | **209.4** |
| BULK CARRIER | 2 | <25,000 | 69 | 19,957 | 8,666 | 15 | 152 | 62% | 1982 | 3.3 | 14.3 | 2.2 | 120.0 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 85 | 29,401 | 10,766 | 15 | 130 | 63% | 1979 | 3.3 | 11.6 | 2.6 | 184.6 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 64 | 39,241 | 10,891 | 15 | 118 | 10% | 1982 | 3.4 | 14.8 | 2.4 | 102.0 |
| BULK CARRIER | 2 | > 45,000 | 122 | 71,583 | 14,107 | 14 | 102 | 0% | 1986 | 3.5 | 5.9 | 2.9 | 115.6 |
| BULK CARRIER | 4 | <25,000 | 16 | 18,260 | 6,523 | 15 | 573 | 100% | 1979 | 3.4 | 7.3 | 2.7 | 219.2 |
| BULK CARRIER | 4 | 25,000 - 35,000 | 1 | 25,739 | 8,200 | 14 | 157 | 100% | 1992 | 3.6 | 4.9 | 1.3 | 104.4 |
| BULK CARRIER | 4 | 35,000 - 45,000 | 1 | 41,513 | 10,000 | 14 | ND | ND | 1982 | 3.6 | 2.4 | 5.0 | 226.2 |
| BULK CARRIER | 4 | > 45,000 | 4 | 70,719 | 12,075 | 14 | ND | ND | 1980 | 3.6 | 4.6 | 2.5 | 83.1 |
| BULK CARRIER | ST | <25,000 | 28 | 18,314 | 8,378 | 15 | ND | ND | 1975 | 3.3 | 5.6 | 1.3 | 39.9 |
| **BULK CARRIER Total** | | | **390** | **41,733** | **11,119** | **15** | **132** | **24%** | **1982** | **3.4** | **10.1** | **2.5** | **127.5** |
| CONTAINER SHIP | 2 | <25,000 | 396 | 20,258 | 16,922 | 19 | 117 | 10% | 1987 | 2.7 | 4.2 | 1.2 | 24.9 |
| CONTAINER SHIP | 2 | 25,000 - 35,000 | 167 | 30,162 | 22,994 | 20 | 102 | 0% | 1984 | 2.6 | 4.1 | 1.2 | 22.3 |
| CONTAINER SHIP | 2 | 35,000 - 45,000 | 348 | 40,772 | 40,589 | 23 | 99 | 0% | 1982 | 2.2 | 4.2 | 1.1 | 19.7 |
| CONTAINER SHIP | 2 | > 45,000 | 491 | 51,853 | 38,622 | 22 | 95 | 0% | 1988 | 2.3 | 4.2 | 1.1 | 22.2 |
| CONTAINER SHIP | 4 | <25,000 | 92 | 9,833 | 8,018 | 17 | 481 | 100% | 1989 | 3.0 | 4.2 | 1.1 | 22.1 |
| CONTAINER SHIP | 4 | 25,000 - 35,000 | 5 | 27,396 | 15,962 | 18 | 386 | 100% | 1980 | 2.7 | 4.0 | 1.4 | 16.0 |
| CONTAINER SHIP | 4 | > 45,000 | 24 | 62,685 | 50,235 | 24 | 99 | 0% | 1993 | 2.1 | 4.2 | 1.1 | 31.0 |
| CONTAINER SHIP | ST | <25,000 | 234 | 20,521 | 25,642 | 22 | ND | ND | 1971 | 2.3 | 4.1 | 1.1 | 25.5 |
| CONTAINER SHIP | ST | 25,000 - 35,000 | 33 | 26,207 | 31,541 | 22 | ND | ND | 1973 | 2.3 | 4.2 | 1.1 | 20.5 |
| CONTAINER SHIP | ST | 35,000 - 45,000 | 14 | 39,433 | 35,483 | 25 | ND | ND | 1976 | 2.0 | 4.1 | 1.1 | 15.7 |
| CONTAINER SHIP | ST | > 45,000 | 16 | 47,864 | 79,967 | 23 | ND | ND | 1973 | 2.2 | 4.2 | 1.1 | 16.2 |
| **CONTAINER SHIP Total** | | | **1,820** | **34,197** | **29,929** | **21** | **131** | **10%** | **1984** | **2.4** | **4.2** | **1.1** | **22.7** |
| GENERAL CARGO | 2 | <15,000 | 49 | 11,029 | 7,586 | 16 | 146 | 25% | 1986 | 3.2 | 4.3 | 1.9 | 70.3 |
| GENERAL CARGO | 2 | 15,000 - 30,000 | 122 | 20,397 | 13,611 | 17 | 132 | 32% | 1982 | 2.9 | 6.5 | 1.7 | 54.6 |
| GENERAL CARGO | 2 | 30,000 - 45,000 | 54 | 39,365 | 13,689 | 15 | ND | ND | 1981 | 3.2 | 4.7 | 1.5 | 21.1 |
| GENERAL CARGO | 2 | > 45,000 | 2 | 46,865 | 10,345 | 15 | 111 | 0% | 1993 | 3.3 | 4.5 | 2.1 | 29.7 |
| GENERAL CARGO | 4 | <15,000 | 79 | 5,539 | 3,765 | 13 | 616 | 100% | 1987 | 3.9 | 7.0 | 1.7 | 78.9 |
| GENERAL CARGO | 4 | 15,000 - 30,000 | 11 | 19,019 | 8,896 | 17 | ND | ND | 1982 | 3.0 | 7.6 | 1.9 | 124.3 |
| GENERAL CARGO | ST | <15,000 | 9 | 12,931 | 14,746 | 19 | ND | ND | 1962 | 2.6 | 4.0 | 1.3 | 1060.7 |
| **GENERAL CARGO Total** | | | **326** | **18,440** | **10,184** | **16** | **336** | **58%** | **1983** | **3.3** | **5.9** | **1.7** | **81.4** |
| MISCELLANEOUS | 2 | <1500 | 2 | 24,713 | 2,200 | 12 | ND | ND | 1968 | 4.2 | 21.1 | 4.3 | 146.4 |
| MISCELLANEOUS | 2 | > 4,500 | 2 | 23,945 | 9,000 | 16 | ND | ND | 1987 | 3.1 | 5.2 | 2.3 | 77.6 |
| MISCELLANEOUS | 4 | <1500 | 18 | 11,783 | 2,320 | 14 | ND | ND | 1987 | 3.6 | 4.7 | 1.6 | 53.7 |
| MISCELLANEOUS | 4 | > 4,500 | 1 | 5,009 | 13,581 | 14 | 720 | 100% | 1992 | 3.6 | 2.3 | 0.5 | 1.5 |
| **MISCELLANEOUS Total** | | | **23** | **13,670** | **5,860** | **14** | **720** | **100%** | **1985** | **3.6** | **6.1** | **1.9** | **61.5** |
| PASSENGER | 2 | <5,000 | 26 | 4,300 | 29,370 | 21 | ND | ND | 1984 | 2.4 | 5.2 | 1.3 | 6.3 |
| PASSENGER | 2 | 5,000 - 10,000 | 4 | 5,830 | 19,500 | 19 | ND | ND | 1971 | 2.7 | 5.2 | 1.3 | 15.6 |
| PASSENGER | 4 | <5,000 | 22 | 1,896 | 15,080 | 18 | 646 | 100% | 1987 | 2.9 | 6.0 | 1.5 | 24.1 |
| PASSENGER | 4 | 5,000 - 10,000 | 97 | 6,467 | 21,809 | 19 | 588 | 100% | 1974 | 2.7 | 5.2 | 1.4 | 8.8 |
| PASSENGER | 4 | 10,000 - 15,000 | 1 | 8,600 | 86,140 | 18 | 514 | 100% | 1996 | 2.8 | 5.2 | 1.3 | 72.1 |
| PASSENGER | 4 | > 15,000 | 19 | 15,521 | 130,005 | 28 | ND | ND | 1969 | 1.8 | 5.2 | 1.3 | 8.1 |
| PASSENGER | ST | 5,000 - 10,000 | 14 | 9,102 | 41,479 | 25 | ND | ND | 1963 | 2.0 | 5.2 | 1.3 | 10.5 |
| PASSENGER | ST | 10,000 - 15,000 | 1 | 13,960 | 40,177 | 18 | ND | ND | 1961 | 2.8 | 5.2 | 1.3 | 6.2 |
| PASSENGER | ST | > 15,000 | 43 | 16,604 | 43,369 | 24 | ND | ND | 1961 | 2.1 | 5.1 | 1.3 | 7.8 |
| **PASSENGER Total** | | | **227** | **8,648** | **36,700** | **21** | **600** | **100%** | **1973** | **2.4** | **5.2** | **1.4** | **10.2** |
| REEFER | 2 | 5,000 - 10,000 | 3 | 9,864 | 14,865 | 22 | ND | ND | 1980 | 2.3 | 4.7 | 0.8 | 24.9 |
| REEFER | 2 | 10,000 - 15,000 | 60 | 11,757 | 16,661 | 22 | 114 | 0% | 1988 | 2.3 | 4.4 | 1.2 | 36.9 |
| REEFER | 2 | > 15,000 | 1 | 15,100 | 20,500 | 22 | ND | ND | 1979 | 2.3 | 4.7 | 0.5 | 8.2 |
| **REEFER Total** | | | **64** | **11,721** | **16,637** | **22** | **114** | **0%** | **1987** | **2.3** | **4.4** | **1.1** | **35.8** |

## Table 7-5: Summary of 1996 Deep-Sea Vessel Data for the Consolidated Port of New York and Ports on the Hudson River

| Ship Type | Stroke | DWT Category | Calls | DWT (tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr) | Man. (hr) | Hotel (hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RORO | 2 | <10,000 | 73 | 16,968 | 11,478 | 17 | 97 | 0% | 1981 | 3.0 | 4.4 | 1.8 | 28.2 |
| RORO | 2 | 10,000 - 20,000 | 13 | 15,302 | 11,338 | 16 | 159 | 100% | 1990 | 3.1 | 4.5 | 1.7 | 25.5 |
| RORO | 2 | 20,000 - 30,000 | 3 | 23,242 | 20,271 | 19 | ND | ND | 1981 | 2.6 | 4.2 | 4.1 | 277.1 |
| RORO | 2 | > 30,000 | 119 | 46,217 | 25,750 | 19 | 97 | 0% | 1983 | 2.7 | 4.7 | 2.1 | 17.0 |
| RORO | 4 | <10,000 | 14 | 5,979 | 7,851 | 15 | 425 | 100% | 1977 | 3.3 | 7.5 | 2.0 | 93.7 |
| RORO | 4 | 20,000 - 30,000 | 1 | 20,303 | 25,920 | 19 | ND | ND | 1971 | 2.6 | 4.0 | 1.3 | 1490.5 |
| RORO | ST | 10,000 - 20,000 | 1 | 15,946 | 29,570 | 24 | ND | ND | 1970 | 2.1 | 3.2 | 3.2 | 1625.7 |
| **RORO Total** | | | **224** | **31,817** | **19,088** | **18** | **104** | **3%** | **1982** | **2.9** | **4.7** | **2.0** | **43.2** |
| TANKER | 2 | <30,000 | 202 | 22,271 | 8,766 | 15 | 135 | 27% | 1985 | 3.4 | 6.1 | 3.4 | 45.6 |
| TANKER | 2 | 30,000 - 60,000 | 489 | 34,820 | 12,546 | 15 | 117 | 7% | 1985 | 3.4 | 6.3 | 3.9 | 61.6 |
| TANKER | 2 | 60,000 - 90,000 | 155 | 74,752 | 15,612 | 15 | 101 | 0% | 1984 | 3.3 | 5.8 | 3.6 | 64.5 |
| TANKER | 2 | 90,000 - 120,000 | 81 | 95,769 | 13,993 | 14 | 98 | 0% | 1991 | 3.5 | 6.1 | 3.2 | 62.6 |
| TANKER | 2 | 120,000 - 150,000 | 31 | 140,266 | 20,709 | 15 | 86 | 0% | 1987 | 3.4 | 4.4 | 2.7 | 72.3 |
| TANKER | 2 | > 150,000 | 9 | 137,489 | 20,940 | 14 | 85 | 0% | 1991 | 3.6 | 6.3 | 3.2 | 72.2 |
| TANKER | 4 | <30,000 | 65 | 15,402 | 7,551 | 15 | 351 | 65% | 1984 | 3.4 | 5.6 | 3.1 | 29.5 |
| TANKER | 4 | 30,000 - 60,000 | 21 | 43,052 | 14,917 | 16 | ND | ND | 1979 | 3.2 | 5.5 | 3.3 | 57.0 |
| TANKER | 4 | 60,000 - 90,000 | 29 | 71,780 | 13,598 | 14 | 256 | 39% | 1985 | 3.5 | 6.2 | 3.7 | 58.8 |
| TANKER | ST | <30,000 | 14 | 26,459 | 14,784 | 18 | ND | ND | 1964 | 2.8 | 5.4 | 3.2 | 26.4 |
| TANKER | ST | 30,000 - 60,000 | 82 | 36,889 | 15,108 | 16 | ND | ND | 1964 | 3.1 | 6.1 | 3.6 | 50.1 |
| TANKER | ST | 60,000 - 90,000 | 2 | 63,000 | 19,713 | 16 | ND | ND | 1971 | 3.1 | 5.6 | 3.9 | 85.4 |
| TANKER | ST | > 150,000 | 23 | 35,605 | 35,293 | 16 | ND | ND | 1975 | 3.1 | 5.5 | 2.6 | 23.8 |
| **TANKER Total** | | | **1,203** | **45,538** | **13,120** | **15** | **128** | **12%** | **1983** | **3.4** | **6.0** | **3.6** | **56.0** |
| VEHICLES CARRIER | 2 | <12,500 | 76 | 11,461 | 11,243 | 18 | 119 | 6% | 1982 | 2.8 | 5.1 | 1.6 | 13.9 |
| VEHICLES CARRIER | 2 | 12,500 - 15,000 | 73 | 13,788 | 13,961 | 19 | 107 | 0% | 1986 | 2.7 | 4.9 | 1.9 | 17.7 |
| VEHICLES CARRIER | 2 | 15,000 - 17,500 | 72 | 17,041 | 13,984 | 18 | 113 | 0% | 1985 | 2.7 | 4.8 | 1.9 | 15.7 |
| VEHICLES CARRIER | 2 | > 17,500 | 54 | 22,727 | 16,382 | 19 | 106 | 0% | 1985 | 2.6 | 4.9 | 2.3 | 22.9 |
| VEHICLES CARRIER | 4 | <12,500 | 51 | 10,566 | 13,240 | 18 | 518 | 100% | 1980 | 2.7 | 5.0 | 2.2 | 30.0 |
| VEHICLES CARRIER | 4 | 12,500 - 15,000 | 19 | 13,498 | 14,287 | 18 | 520 | 100% | 1980 | 2.9 | 4.9 | 1.9 | 24.7 |
| VEHICLES CARRIER | 4 | 15,000 - 17,500 | 2 | 15,396 | 12,555 | 18 | ND | ND | 1982 | 2.8 | 4.9 | 1.3 | 6.1 |
| VEHICLES CARRIER | 4 | > 17,500 | 2 | 19,422 | 16,880 | 18 | ND | ND | 1981 | 2.8 | 5.1 | 2.1 | 6.8 |
| **VEHICLES CARRIER Total** | | | **349** | **14,890** | **13,670** | **18** | **178** | **18%** | **1984** | **2.7** | **4.9** | **2.0** | **19.3** |
| **Grand Total** | | | **4,632** | **33,449** | **20,932** | **18** | **162** | **18%** | **1983** | **2.8** | **5.4** | **2.0** | **45.0** |

## Table 8-5: Summary of 1996 Deep-Sea Vessel Data for the Delaware River Ports Including Philadelphia, PA

| Ship Type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 2 | <25,000 | 109 | 18,365 | 9,665 | 14 | 144 | 68% | 1981 | 3.5 | 14.9 | 1.8 | 81.0 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 126 | 29,721 | 9,696 | 15 | 126 | 52% | 1982 | 3.4 | 14.7 | 1.7 | 100.8 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 77 | 38,659 | 10,320 | 14 | 113 | 11% | 1983 | 3.5 | 15.2 | 1.8 | 95.1 |
| BULK CARRIER | 2 | > 45,000 | 81 | 79,616 | 16,328 | 15 | 113 | 0% | 1983 | 3.4 | 15.3 | 1.7 | 110.9 |
| BULK CARRIER | 4 | <25,000 | 17 | 13,853 | 7,504 | 15 | 473 | 100% | 1977 | 3.3 | 14.4 | 1.6 | 86.3 |
| BULK CARRIER | ST | <25,000 | 1 | 18,314 | 8,300 | 15 | 131 | 36% | 1975 | 3.3 | 12.3 | 1.5 | 64.3 |
| **BULK CARRIER Total** | | | **411** | **40,274** | **11,018** | **15** | **131** | **36%** | **1982** | **3.4** | **14.9** | **1.7** | **95.8** |
| CONTAINER SHIP | 2 | <25,000 | 242 | 18,425 | 17,757 | 19 | 106 | 0% | 1987 | 2.6 | 11.4 | 1.2 | 37.4 |
| CONTAINER SHIP | 2 | 25,000 - 35,000 | 27 | 27,503 | 16,327 | 18 | 229 | 38% | 1977 | 2.8 | 12.9 | 1.0 | 35.7 |
| CONTAINER SHIP | 4 | <25,000 | 129 | 12,143 | 10,898 | 18 | 429 | 100% | 1989 | 2.8 | 12.5 | 1.2 | 25.8 |
| **CONTAINER SHIP Total** | | | **398** | **18,208** | **15,383** | **19** | **229** | **38%** | **1987** | **2.7** | **11.9** | **1.1** | **33.5** |
| GENERAL CARGO | 2 | <15,000 | 132 | 6,833 | 5,784 | 14 | 437 | 89% | 1985 | 3.7 | 13.3 | 1.4 | 63.0 |
| GENERAL CARGO | 2 | 15,000 - 30,000 | 90 | 18,918 | 10,456 | 16 | 140 | 63% | 1980 | 3.2 | 14.6 | 2.0 | 119.3 |
| GENERAL CARGO | 2 | 30,000 - 45,000 | 8 | 38,907 | 12,876 | 14 | 96 | 0% | 1981 | 3.5 | 12.3 | 1.2 | 62.3 |
| GENERAL CARGO | 2 | > 45,000 | 1 | 46,956 | 12,170 | 14 | 117 | 0% | 1992 | 3.6 | 12.4 | 1.0 | 33.0 |
| GENERAL CARGO | 4 | <15,000 | 166 | 5,316 | 3,944 | 14 | 743 | 100% | 1988 | 3.7 | 12.9 | 1.6 | 98.1 |
| GENERAL CARGO | 4 | 15,000 - 30,000 | 16 | 18,775 | 7,536 | 15 | 561 | 90% | 1981 | 3.4 | 15.1 | 1.7 | 122.6 |
| GENERAL CARGO | ST | <15,000 | 1 | 10,538 | 6,284 | 14 | 561 | 90% | 1918 | 3.6 | 14.2 | 1.0 | 18.1 |
| **GENERAL CARGO Total** | | | **414** | **10,538** | **6,284** | **14** | **561** | **90%** | **1985** | **3.6** | **13.4** | **1.6** | **91.3** |
| MISCELLANEOUS | 2 | < 1,000 | 8 | 0 | 2,400 | 14 | ND | ND | 1943 | 3.6 | 10.9 | 1.2 | 45.4 |
| MISCELLANEOUS | 4 | < 1,000 | 4 | 448 | 1,293 | 14 | ND | ND | 1978 | 3.6 | 12.4 | 1.4 | 41.1 |
| **MISCELLANEOUS Total** | | | **12** | **149** | **2,031** | **14** | **#N/A** | **#N/A** | **1955** | **3.6** | **11.4** | **1.3** | **44.0** |
| PASSENGER | 4 | <5,000 | 6 | 1,332 | 16,108 | 18 | 532 | 100% | 1983 | 2.9 | 11.4 | 1.0 | 24.3 |
| PASSENGER | 4 | 5,000 - 10,000 | 6 | 7,257 | 20,776 | 18 | 616 | 100% | 1966 | 2.7 | 11.4 | 1.0 | 23.4 |
| PASSENGER | ST | 5,000 - 10,000 | 9 | 9,076 | 40,649 | 26 | 582 | 100% | 1964 | 2.0 | 12.6 | 1.0 | 15.9 |
| PASSENGER | ST | 10,000 - 15,000 | 1 | 13,016 | 169,708 | 30 | 582 | 100% | 1952 | 1.7 | 5.5 | 3.5 | 20.5 |
| **PASSENGER Total** | | | **22** | **7,828** | **34,403** | **22** | **582** | **100%** | **1969** | **2.4** | **11.6** | **1.1** | **20.5** |
| REEFER | 2 | <5,000 | 28 | 4,988 | 9,553 | 18 | 146 | 65% | 1984 | 2.7 | 10.7 | 1.6 | 51.4 |
| REEFER | 2 | 5,000 - 10,000 | 87 | 7,667 | 9,706 | 18 | 141 | 59% | 1988 | 2.7 | 10.7 | 1.3 | 56.8 |
| REEFER | 2 | 10,000 - 15,000 | 153 | 11,833 | 12,500 | 19 | 116 | 0% | 1987 | 2.6 | 12.2 | 1.4 | 64.8 |
| REEFER | 2 | > 15,000 | 3 | 15,696 | 18,467 | 20 | 155 | 41% | 1979 | 2.6 | 11.4 | 1.3 | 33.6 |

## Table 8-5: Summary of 1996 Deep-Sea Vessel Data for the Delaware River Ports Including Philadelphia, PA

| Ship Type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REEFER | 4 | <5,000 | 16 | 4,880 | 7,048 | 16 | 202 | 100% | 1992 | 3.1 | 13.6 | 2.5 | 87.8 |
| REEFER | 4 | 5,000 - 10,000 | 15 | 6,555 | 6,837 | 17 | 402 | 100% | 1989 | 3.0 | 13.0 | 1.9 | 81.7 |
| REEFER | 4 | 10,000 - 15,000 | 3 | 11,087 | 15,672 | 22 | 428 | 100% | 1992 | 2.3 | 11.2 | 1.0 | 54.0 |
| **REEFER Total** | | | **305** | **10,137** | **10,958** | **19** | **155** | **41%** | **1987** | **2.7** | **11.7** | **1.5** | **63.0** |
| RORO | 2 | <15,000 | 26 | 7,074 | 8,280 | 17 | 242 | 100% | 1981 | 2.9 | 13.2 | 1.2 | 67.1 |
| RORO | 2 | 15,000 - 30,000 | 5 | 22,845 | 12,852 | 18 | 102 | 0% | 1988 | 2.8 | 8.8 | 1.0 | 43.0 |
| RORO | 4 | <15,000 | 26 | 7,601 | 8,553 | 14 | 720 | 100% | 1981 | 3.7 | 13.3 | 1.2 | 57.7 |
| **RORO Total** | | | **57** | **9,142** | **8,805** | **16** | **456** | **69%** | **1982** | **3.3** | **12.9** | **1.2** | **60.7** |
| TANKER | 2 | <30,000 | 237 | 13,261 | 10,008 | 14 | 132 | 30% | 1984 | 3.6 | 14.4 | 2.1 | 72.3 |
| TANKER | 2 | 30,000 - 60,000 | 78 | 43,461 | 12,616 | 15 | 125 | 41% | 1982 | 3.4 | 14.2 | 2.4 | 62.8 |
| TANKER | 2 | 60,000 - 90,000 | 111 | 77,375 | 16,026 | 15 | 95 | 0% | 1983 | 3.3 | 14.9 | 2.2 | 70.8 |
| TANKER | 2 | 90,000 - 120,000 | 91 | 98,373 | 15,451 | 15 | 97 | 0% | 1991 | 3.4 | 13.8 | 2.4 | 83.0 |
| TANKER | 2 | 120,000 - 150,000 | 150 | 137,083 | 23,046 | 15 | 93 | 0% | 1982 | 3.4 | 16.5 | 3.2 | 137.4 |
| TANKER | 2 | > 150,000 | 32 | 155,676 | 25,559 | 15 | 85 | 0% | 1983 | 3.3 | 16.3 | 3.2 | 122.6 |
| TANKER | 4 | <30,000 | 57 | 15,655 | 7,077 | 14 | 413 | 89% | 1981 | 3.7 | 14.0 | 2.0 | 61.6 |
| TANKER | 4 | 30,000 - 60,000 | 5 | 44,153 | 15,360 | 15 | 133 | 19% | 1980 | 3.3 | 15.7 | 2.8 | 63.9 |
| TANKER | 4 | 60,000 - 90,000 | 17 | 80,320 | 14,305 | 15 | 416 | 75% | 1981 | 3.4 | 14.7 | 2.6 | 77.3 |
| TANKER | ST | <30,000 | 24 | 26,755 | 14,646 | 16 | 133 | 19% | 1959 | 3.1 | 14.0 | 2.3 | 88.4 |
| TANKER | ST | 30,000 - 60,000 | 54 | 35,574 | 15,498 | 16 | 133 | 19% | 1962 | 3.1 | 13.8 | 2.0 | 65.8 |
| TANKER | ST | 90,000 - 120,000 | 2 | 92,760 | 23,923 | 16 | 133 | 19% | 1976 | 3.1 | 14.6 | 2.3 | 70.2 |
| TANKER | ST | > 150,000 | 10 | 276,808 | 36,324 | 16 | 133 | 19% | 1973 | 3.2 | 15.4 | 3.0 | 104.1 |
| **TANKER Total** | | | **868** | **74,084** | **15,137** | **15** | **133** | **19%** | **1982** | **3.4** | **14.8** | **2.4** | **85.1** |
| VEHICLE CARRIER | 2 | <12,500 | 39 | 12,115 | 11,877 | 18 | 117 | 0% | 1982 | 2.8 | 7.6 | 1.2 | 17.7 |
| VEHICLE CARRIER | 2 | 12,500 - 15,000 | 5 | 13,813 | 12,859 | 18 | 111 | 0% | 1986 | 2.7 | 10.1 | 1.3 | 27.2 |
| VEHICLE CARRIER | 2 | 15,000 - 17,500 | 7 | 16,209 | 13,911 | 18 | 111 | 0% | 1984 | 2.7 | 9.0 | 1.0 | 23.9 |
| VEHICLE CARRIER | 2 | > 17,500 | 13 | 18,558 | 15,224 | 19 | 101 | 0% | 1987 | 2.7 | 6.9 | 1.0 | 25.2 |
| VEHICLE CARRIER | 4 | <12,500 | 8 | 10,382 | 13,150 | 18 | 527 | 100% | 1977 | 2.8 | 13.2 | 1.4 | 39.9 |
| VEHICLE CARRIER | 4 | 12,500 - 15,000 | 1 | 14,501 | 14,770 | 18 | 143 | 8% | 1983 | 2.7 | 9.5 | 1.0 | 18.0 |
| **VEHICLE CARRIER Total** | | | **73** | **13,678** | **12,914** | **18** | **143** | **8%** | **1983** | **2.7** | **8.4** | **1.2** | **22.7** |
| **Grand Total** | | | **2,560** | **38,991** | **12,476** | **16** | **236** | **0** | **1984** | **3.2** | **13.5** | **1.8** | **74.1** |


| Ship Type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

## Table 9-5: Summary of 1996 Deep-Sea Vessel Data for Puget Sound Area Ports Including Seattle, WA

| Ship Type - Manip | Stroke type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 2 | <25,000 | 165 | 22,130 | 7,073 | 14 | 150 | 94% | 1990 | 3.6 | 15.4 | 1.4 | 70.6 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 306 | 27,887 | 8,155 | 14 | 124 | 32% | 1988 | 3.5 | 16.5 | 1.5 | 128.1 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 167 | 40,489 | 10,752 | 15 | 107 | 3% | 1985 | 3.4 | 16.3 | 1.6 | 88.1 |
| BULK CARRIER | 2 | > 45,000 | 216 | 66,419 | 12,646 | 15 | 98 | 0% | 1987 | 3.5 | 15.8 | 2.0 | 154.1 |
| BULK CARRIER | 4 | <25,000 | 8 | 6,436 | 3,625 | 13 | ND | ND | 1977 | 4.0 | 17.7 | 5.1 | 84.4 |
| BULK CARRIER | 4 | 25,000 - 35,000 | 2 | 32,019 | 10,400 | 15 | 518 | 100% | 1983 | 3.5 | 14.6 | 1.4 | 96.8 |
| BULK CARRIER | 4 | 35,000 - 45,000 | 2 | 41,642 | 10,943 | 14 | 117 | 0% | 1989 | 3.6 | 13.4 | 0.9 | 64.3 |
| BULK CARRIER | 4 | > 45,000 | 13 | 63,029 | 14,806 | 15 | 400 | 100% | 1983 | 3.4 | 16.6 | 2.1 | 177.9 |
| BULK CARRIER | ST | > 45,000 | 13 | 82,035 | 17,111 | 16 | ND | ND | 1968 | 3.1 | 21.5 | 1.4 | 58.8 |
| **BULK CARRIER Total** | | | **892** | **39,661** | **9,727** | **14** | **123** | **34%** | **1987** | **3.5** | **16.2** | **1.7** | **115.4** |
| CONTAINER SHIP | 2 | <25,000 | 184 | 19,019 | 18,365 | 19 | 135 | 77% | 1985 | 2.7 | 17.9 | 1.0 | 34.3 |
| CONTAINER SHIP | 2 | 25,000 - 35,000 | 135 | 31,480 | 26,364 | 20 | 101 | 0% | 1984 | 2.5 | 16.6 | 0.9 | 25.9 |
| CONTAINER SHIP | 2 | 35,000 - 45,000 | 363 | 40,261 | 31,808 | 22 | 93 | 0% | 1987 | 2.3 | 16.4 | 1.0 | 30.9 |
| CONTAINER SHIP | 2 | > 45,000 | 276 | 56,958 | 51,033 | 23 | 95 | 0% | 1992 | 2.2 | 16.0 | 0.9 | 28.4 |
| CONTAINER SHIP | 4 | <25,000 | 8 | 19,987 | 12,405 | 19 | 428 | 100% | 1988 | 2.7 | 16.0 | 1.1 | 59.5 |
| CONTAINER SHIP | ST | <25,000 | 3 | 19,800 | 26,797 | 21 | ND | ND | 1980 | 2.4 | 18.2 | 1.5 | 138.7 |
| CONTAINER SHIP | ST | 25,000 - 35,000 | 93 | 28,628 | 30,080 | 20 | ND | ND | 1973 | 2.5 | 16.5 | 0.9 | 40.4 |
| CONTAINER SHIP | ST | 35,000 - 45,000 | 64 | 38,988 | 31,565 | 21 | ND | ND | 1973 | 2.4 | 15.5 | 0.9 | 17.8 |
| CONTAINER SHIP | ST | > 45,000 | 24 | 47,851 | 80,006 | 23 | ND | ND | 1972 | 2.2 | 16.2 | 0.9 | 30.3 |
| **CONTAINER SHIP Total** | | | **1,150** | **38,791** | **34,337** | **21** | **98** | **5%** | **1985** | **2.4** | **16.5** | **0.9** | **30.8** |
| FISHING | 2 | <1500 | 12 | 789 | 1,897 | 12 | ND | ND | 1973 | 4.3 | 21.1 | 5.9 | 1291.8 |
| FISHING | 2 | 1,500 - 3,000 | 3 | 1,883 | 3,626 | 14 | 150 | 100% | 1987 | 3.5 | 15.9 | 1.8 | 33.4 |
| FISHING | 2 | 3,000 - 4,500 | 1 | 4,500 | 10,768 | 18 | 660 | 100% | 1996 | 2.8 | 16.7 | 0.9 | 1432.0 |
| FISHING | 2 | > 4,500 | 2 | 9,360 | 10,331 | 18 | ND | ND | 1984 | 2.8 | 16.0 | 3.7 | 654.3 |
| FISHING | 4 | <1500 | 20 | 698 | 1,702 | 12 | 773 | 100% | 1983 | 4.3 | 20.1 | 4.3 | 915.6 |
| FISHING | 4 | 1,500 - 3,000 | 10 | 1,861 | 5,159 | 16 | 720 | 100% | 1978 | 3.1 | 13.2 | 1.8 | 321.5 |
| FISHING | 4 | 3,000 - 4,500 | 2 | 3,372 | 14,398 | 15 | 500 | 100% | 1991 | 3.3 | 16.3 | 7.9 | 1405.4 |
| FISHING | 4 | > 4,500 | 27 | 5,805 | 8,048 | 14 | 720 | 100% | 1993 | 3.6 | 14.8 | 4.3 | 399.2 |
| FISHING | ST | > 4,500 | 4 | 19,286 | 37,976 | 20 | ND | ND | 1964 | 2.5 | 13.0 | 4.1 | 534.6 |
| **FISHING Total** | | | **81** | **3,846** | **6,774** | **14** | **686** | **100%** | **1984** | **3.7** | **16.9** | **4.2** | **686.4** |
| GENERAL CARGO | 2 | <15,000 | 7 | 3,540 | 3,647 | 12 | 200 | 100% | 1987 | 4.3 | 17.9 | 2.8 | 65.2 |
| GENERAL CARGO | 2 | 15,000 - 30,000 | 73 | 21,745 | 11,495 | 16 | 130 | 29% | 1981 | 3.1 | 18.4 | 1.5 | 52.4 |
| GENERAL CARGO | 2 | 30,000 - 45,000 | 52 | 41,323 | 12,006 | 15 | 104 | 5% | 1984 | 3.3 | 13.3 | 1.0 | 32.0 |
| GENERAL CARGO | 2 | > 45,000 | 77 | 45,539 | 10,164 | 15 | 98 | 0% | 1988 | 3.3 | 16.2 | 1.1 | 23.2 |
| GENERAL CARGO | 4 | <15,000 | 21 | 9,063 | 9,493 | 15 | 278 | 100% | 1982 | 3.5 | 17.9 | 2.1 | 353.6 |
| GENERAL CARGO | 4 | 15,000 - 30,000 | 32 | 20,039 | 20,164 | 18 | ND | ND | 1985 | 2.9 | 17.6 | 2.1 | 112.5 |
| GENERAL CARGO | ST | <15,000 | 1 | 14,897 | 15,289 | 19 | ND | ND | 1966 | 2.6 | 18.3 | 0.9 | 163.9 |
| **GENERAL CARGO Total** | | | **263** | **30,851** | **11,907** | **16** | **122** | **17%** | **1984** | **3.2** | **16.6** | **1.4** | **71.9** |
| MISCELANEOUS | 2 | (blank) | 3 | 7,900 | 9,387 | 14 | ND | ND | 1991 | 3.6 | 19.3 | 2.4 | 2189.6 |
| MISCELANEOUS | 2 | (blank) | 1 | 1,200 | 1,860 | 12 | ND | ND | 1990 | 4.2 | 22.4 | 0.9 | 472.8 |
| MISCELANEOUS | 4 | (blank) | 4 | 761 | 3,486 | 13 | 1225 | 100% | 1986 | 3.8 | 16.1 | 3.2 | 300.1 |
| MISCELANEOUS | ST | (blank) | 3 | 3,988 | 8,483 | 15 | ND | ND | 1940 | 3.3 | 15.4 | 0.9 | 49.0 |
| **MISCELANEOUS Total** | | | **11** | **3,548** | **5,827** | **14** | **1225** | **100%** | **1983** | **3.7** | **17.3** | **2.1** | **762.6** |
| PASSENGER | 2 | <5,000 | 3 | 4,226 | 29,370 | 21 | ND | ND | 1983 | 2.4 | 14.5 | 1.4 | 67.1 |
| PASSENGER | 2 | 5,000 - 10,000 | 1 | 5,340 | 32,350 | 19 | ND | ND | 1986 | 2.6 | 17.5 | 0.9 | 7.7 |
| PASSENGER | 4 | <5,000 | 4 | 850 | 9,906 | 16 | 788 | 100% | 1983 | 3.2 | 17.1 | 0.9 | 9.5 |
| PASSENGER | 4 | 5,000 - 10,000 | 3 | 7,089 | 45,589 | 21 | 514 | 100% | 1993 | 2.4 | 16.2 | 0.9 | 54.6 |

## Table 9-5: Summary of 1996 Deep-Sea Vessel Data for Puget Sound Area Ports Including Seattle, WA

| Ship Type - Manip | Stroke type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PASSENGER | ST | 5,000 - 10,000 | 2 | 8,706 | 25,154 | 23 | ND | ND | 1958 | 2.2 | 17.6 | 0.9 | 67.5 |
| **PASSENGER Total** | | | **13** | **4,623** | **26,704** | **19** | **670** | **100%** | **1982** | **2.6** | **16.4** | **1.0** | **42.0** |
| REEFER | 2 | <5,000 | 17 | 3,307 | 4,767 | 15 | 155 | 100% | 1986 | 3.3 | 15.6 | 3.9 | 315.7 |
| REEFER | 2 | 5,000 - 10,000 | 21 | 6,642 | 6,945 | 17 | 163 | 100% | 1988 | 3.0 | 14.1 | 3.4 | 163.2 |
| REEFER | 2 | 10,000 - 15,000 | 7 | 11,746 | 11,969 | 20 | 115 | 0% | 1988 | 2.6 | 15.6 | 2.4 | 201.5 |
| REEFER | 4 | <5,000 | 7 | 2,004 | 1,730 | 11 | 230 | 100% | 1970 | 4.7 | 22.1 | 1.5 | 259.8 |
| REEFER | 4 | 5,000 - 10,000 | 8 | 5,804 | 5,676 | 16 | 634 | 100% | 1991 | 3.1 | 16.7 | 1.0 | 51.5 |
| **REEFER Total** | | | **60** | **5,640** | **6,136** | **16** | **272** | **88%** | **1986** | **3.3** | **16.0** | **2.9** | **207.3** |
| RORO | 2 | <10,000 | 11 | 7,976 | 6,738 | 16 | 174 | 75% | 1988 | 3.3 | 22.1 | 1.3 | 30.1 |
| RORO | 2 | 10,000 - 20,000 | 16 | 11,346 | 8,004 | 16 | 162 | 81% | 1992 | 3.3 | 19.9 | 0.9 | 24.4 |
| RORO | 2 | 20,000 - 30,000 | 16 | 26,787 | 18,649 | 19 | ND | ND | 1983 | 2.6 | 17.9 | 0.9 | 25.0 |
| RORO | 2 | > 30,000 | 4 | 41,856 | 15,136 | 14 | ND | ND | 1981 | 3.5 | 14.2 | 0.9 | 10.3 |
| RORO | ST | 10,000 - 20,000 | 121 | 17,084 | 29,764 | 25 | ND | ND | 1976 | 2.0 | 17.0 | 1.4 | 73.8 |
| **RORO Total** | | | **168** | **17,455** | **24,777** | **23** | **166** | **79%** | **1979** | **2.3** | **17.6** | **1.3** | **60.1** |
| TANKER | 2 | <30,000 | 66 | 19,629 | 9,104 | 15 | 176 | 79% | 1986 | 3.5 | 19.0 | 4.3 | 43.7 |
| TANKER | 2 | 30,000 - 60,000 | 79 | 46,934 | 12,451 | 15 | 107 | 0% | 1984 | 3.4 | 15.9 | 4.0 | 67.6 |
| TANKER | 2 | 60,000 - 90,000 | 18 | 71,315 | 15,262 | 15 | 89 | 0% | 1984 | 3.3 | 16.0 | 3.3 | 45.2 |
| TANKER | 2 | 90,000 - 120,000 | 20 | 100,679 | 14,738 | 14 | 94 | 0% | 1991 | 3.5 | 15.8 | 2.6 | 64.0 |
| TANKER | 2 | 120,000 - 150,000 | 26 | 123,742 | 26,146 | 16 | ND | ND | 1974 | 3.1 | 14.5 | 7.2 | 63.9 |
| TANKER | 4 | <30,000 | 12 | 10,056 | 4,864 | 13 | 245 | 33% | 1976 | 4.0 | 15.6 | 0.9 | 16.2 |
| TANKER | 4 | 30,000 - 60,000 | 1 | 37,350 | 11,700 | 14 | 520 | 100% | 1981 | 3.6 | 17.0 | 4.2 | 84.7 |
| TANKER | ST | <30,000 | 18 | 19,992 | 14,795 | 18 | ND | ND | 1964 | 2.8 | 14.4 | 3.8 | 59.7 |
| TANKER | ST | 30,000 - 60,000 | 35 | 39,541 | 13,809 | 16 | ND | ND | 1969 | 3.1 | 15.4 | 3.5 | 45.3 |
| TANKER | ST | 60,000 - 90,000 | 125 | 71,997 | 19,286 | 17 | ND | ND | 1970 | 3.0 | 16.6 | 3.4 | 62.4 |
| TANKER | ST | 90,000 - 120,000 | 29 | 91,915 | 23,095 | 16 | ND | ND | 1977 | 3.2 | 15.9 | 5.3 | 52.1 |
| TANKER | ST | 120,000 - 150,000 | 119 | 122,732 | 26,360 | 16 | ND | ND | 1974 | 3.1 | 14.7 | 6.2 | 62.8 |
| TANKER | ST | > 150,000 | 5 | 189,978 | 27,620 | 14 | ND | ND | 1978 | 3.5 | 11.1 | 1.9 | 103.4 |
| **TANKER Total** | | | **553** | **73,490** | **18,099** | **16** | **129** | **22%** | **1977** | **3.2** | **16.0** | **4.4** | **58.3** |
| VEHICLES CARRIER | 2 | <12,500 | 27 | 10,286 | 10,289 | 17 | 158 | 82% | 1983 | 3.0 | 20.0 | 0.9 | 32.2 |
| VEHICLES CARRIER | 2 | 12,500 - 15,000 | 33 | 13,709 | 14,049 | 18 | 109 | 9% | 1985 | 2.7 | 18.6 | 1.2 | 19.0 |
| VEHICLES CARRIER | 2 | 15,000 - 17,500 | 49 | 16,272 | 14,023 | 18 | 120 | 0% | 1984 | 2.8 | 17.3 | 1.5 | 19.6 |
| VEHICLES CARRIER | 2 | > 17,500 | 7 | 19,783 | 15,501 | 18 | 98 | 0% | 1985 | 2.7 | 18.4 | 1.7 | 19.9 |
| VEHICLES CARRIER | 4 | <12,500 | 19 | 10,981 | 13,118 | 18 | ND | ND | 1981 | 2.7 | 20.2 | 0.9 | 20.2 |
| VEHICLES CARRIER | 4 | 12,500 - 15,000 | 4 | 12,917 | 13,600 | 19 | ND | ND | 1980 | 2.6 | 20.2 | 0.9 | 13.5 |
| VEHICLES CARRIER | 4 | 15,000 - 17,500 | 2 | 17,224 | 16,880 | 19 | 450 | 100% | 1978 | 2.6 | 18.9 | 0.9 | 22.0 |
| VEHICLES CARRIER | 4 | > 17,500 | 1 | 19,712 | 16,880 | 18 | ND | ND | 1981 | 2.8 | 19.4 | 3.1 | 21.1 |
| **VEHICLES CARRIER Total** | | | **142** | **13,946** | **13,319** | **18** | **137** | **22%** | **1984** | **2.8** | **18.7** | **1.2** | **21.8** |
| **Grand Total** | | | **3,333** | **40,347** | **20,617** | **18** | **139** | **25%** | **1984** | **2.9** | **16.5** | **1.9** | **83.9** |

## Table 10-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Corpus Christi, TX

**Port of Corpus Christ, TX**

SOURCE: EPA document *Commercial Marine Activity of Deep Sea Ports* , Table 10-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Corpus Christi, TX

| Ship Type Manip | Stroke type | DWT Category | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BARGE CARRIER | ST | 2 | 25,000 - 35,000 | 2 | 30,298 | 31,564 | 22 | ND | ND | 1972 | 2.3 | 5.0 |
| **BARGE CARRIER Total** | | | | **2** | **30,298** | **31,564** | **22** | **ND** | **ND** | **1972** | **2.3** | **5.0** |
| BULK CARRIER | 2 | 1 | < 25,000 | 38 | 14,322 | 6,448 | 13 | 151 | 67% | 1974 | 3.9 | 5.0 |
| BULK CARRIER | 2 | 2 | 25,000 - 35,000 | 35 | 28,117 | 11,029 | 15 | 150 | 100% | 1977 | 3.3 | 5.0 |
| BULK CARRIER | 2 | 3 | 35,000 - 45,000 | 21 | 39,326 | 11,298 | 15 | 108 | 17% | 1981 | 3.3 | 5.0 |
| BULK CARRIER | 2 | 4 | 45,000 - 90,000 | 60 | 68,076 | 14,830 | 15 | 93 | 0% | 1982 | 3.4 | 5.0 |
| BULK CARRIER | 2 | 5 | > 90,000 | 36 | 133,928 | 19,693 | 15 | 91 | 0% | 1989 | 3.4 | 6.6 |
| BULK CARRIER | 4 | 1 | < 25,000 | 5 | 18,600 | 8,100 | 15 | ND | ND | 1978 | 3.3 | 5.0 |
| BULK CARRIER | 4 | 2 | 25,000 - 35,000 | 6 | 29,485 | 11,036 | 14 | 460 | 100% | 1979 | 3.6 | 5.0 |
| BULK CARRIER | 4 | 3 | 35,000 - 45,000 | 1 | 36,414 | 15,600 | 17 | ND | ND | 1981 | 2.9 | 5.0 |
| BULK CARRIER | 4 | 4 | 45,000 - 90,000 | 7 | 70,656 | 12,057 | 14 | 440 | 100% | 1981 | 3.6 | 5.0 |
| **BULK CARRIER Total** | | | | **209** | **57,708** | **12,793** | **15** | **162** | **28%** | **1981** | **3.5** | **5.3** |
| CONTAINER SHIP | 2 | 4 | > 45,000 | 1 | 65,642 | 66,398 | 24 | 100 | 0% | 1996 | 2.1 | 5.0 |
| **CONTAINER SHIP Total** | | | | **1** | **65,642** | **66,398** | **24** | **100** | **0%** | **1996** | **2.1** | **5.0** |
| TANKER | 2 | 1 | <30,000 | 66 | 19,231 | 8,852 | 15 | 183 | 88% | 1983 | 3.4 | 5.0 |
| TANKER | 2 | 2 | 30,000 - 60,000 | 276 | 44,487 | 11,085 | 15 | 123 | 44% | 1984 | 3.4 | 5.0 |
| TANKER | 2 | 3 | 60,000 - 90,000 | 161 | 76,375 | 15,241 | 15 | 99 | 0% | 1984 | 3.3 | 5.0 |
| TANKER | 2 | 4 | 90,000 - 120,000 | 171 | 98,320 | 15,403 | 15 | 89 | 0% | 1991 | 3.4 | 6.6 |
| TANKER | 2 | 5 | 120,000 - 150,000 | 31 | 139,846 | 21,270 | 15 | 85 | 0% | 1987 | 3.4 | 6.6 |
| TANKER | 2 | 6 | above 150,000 | 5 | 155,042 | 20,124 | 14 | 85 | 0% | 1991 | 3.5 | 6.6 |
| TANKER | 4 | 1 | <30,000 | 34 | 8,311 | 4,828 | 14 | 532 | 78% | 1984 | 3.7 | 5.0 |
| TANKER | 4 | 2 | 30,000 - 60,000 | 24 | 43,869 | 15,369 | 16 | ND | ND | 1975 | 3.2 | 5.0 |
| TANKER | 4 | 3 | 60,000 - 90,000 | 27 | 77,584 | 14,563 | 15 | 275 | 50% | 1983 | 3.4 | 5.0 |
| TANKER | ST | 1 | <30,000 | 2 | 25,943 | 10,968 | 16 | ND | ND | 1954 | 3.2 | 5.0 |
| TANKER | ST | 2 | 30,000 - 60,000 | 522 | 37,414 | 13,060 | 16 | ND | ND | 1957 | 3.2 | 5.0 |
| TANKER | ST | 3 | 60,000 - 90,000 | 4 | 63,000 | 19,727 | 16 | ND | ND | 1971 | 3.1 | 5.0 |
| TANKER | ST | 4 | 90,000 - 120,000 | 9 | 91,898 | 24,166 | 16 | ND | ND | 1977 | 3.1 | 6.6 |
| **TANKER Total** | | | | **1,332** | **53,948** | **13,178** | **15** | **128** | **24%** | **1974** | **3.3** | **5.3** |
| GENERAL CARGO | 2 | 1 | < 25,000 | 6 | 9,861 | 5,483 | 15 | 200 | 100% | 1319 | 3.4 | 5.0 |

## Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

**Tampa Harbor, FL**

SOURCE: EPA document *Commercial Marine Activity of Deep Sea Ports* , Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

| Ship-type | Engine Type | DWT CAT | DWT RANGE | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | % RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 2 | 1 | <25,000 | 52 | 18,828 | 8,478 | 15 | 158 | 56% | 1979 | 3.4 | 5.6 |
| BULK CARRIER | 2 | 2 | 25,000 - 35,000 | 82 | 29,575 | 9,367 | 15 | 125 | 32% | 1983 | 3.4 | 5.5 |
| BULK CARRIER | 2 | 3 | 35,000 - 45,000 | 66 | 39,389 | 10,670 | 15 | 114 | 14% | 1983 | 3.4 | 5.4 |
| BULK CARRIER | 2 | 4 | > 45,000 | 117 | 57,952 | 13,451 | 15 | 110 | 0% | 1979 | 3.4 | 5.4 |
| BULK CARRIER | 4 | 1 | <25,000 | 8 | 15,900 | 6,581 | 14 | 124 | 23% | 1975 | 3.5 | 5.5 |
| BULK CARRIER | 4 | 2 | 25,000 - 35,000 | 2 | 29,089 | 8,198 | 14 | 157 | 100% | 1995 | 3.6 | 5.4 |
| BULK CARRIER | 4 | 3 | 35,000 - 45,000 | 1 | 41,455 | 11,336 | 14 | 117 | 0% | 1995 | 3.6 | 5.3 |
| BULK CARRIER | ST | 4 | > 45,000 | 1 | 92,854 | 10,876 | 16 | 124 | 23% | 1975 | 3.1 | 5.3 |
| BULK CARRIER | 0 | 0 | 0 | 229 | 39,830 | 10,876 | 15 | 124 | 23% | 1981 | 3.4 | 5.4 |
| **BULK CARRIER Total** | | | | **558** | **39,830** | **10,876** | **15** | **124** | **23%** | **1981** | **3.4** | **5.4** |
| CONTAINER SHIP | 2 | 3 | 35,000 - 45,000 | 2 | 36,750 | 23,945 | 21 | 259 | 50% | 1986 | 2.4 | 5.7 |
| CONTAINER SHIP | 2 | 4 | > 45,000 | 1 | 60,639 | 51,920 | 24 | 90 | 0% | 1990 | 2.1 | 5.3 |
| CONTAINER SHIP | 4 | 1 | <25,000 | 1 | 21,540 | 16,993 | 20 | 428 | 100% | 1993 | 2.5 | 4.4 |
| **CONTAINER SHIP Total** | | | | **4** | **38,920** | **29,201** | **22** | **259** | **50%** | **1989** | **2.3** | **5.3** |
| GENERAL CARGO | 2 | 1 | <15,000 | 37 | 6,769 | 4,048 | 14 | 197 | 100% | 1979 | 3.7 | 5.5 |
| GENERAL CARGO | 2 | 2 | 15,000 - 30,000 | 22 | 21,512 | 9,736 | 16 | 130 | 50% | 1982 | 3.2 | 5.8 |
| GENERAL CARGO | 2 | 3 | 30,000 - 45,000 | 2 | 34,336 | 10,300 | 15 | 95 | 0% | 1980 | 3.5 | 5.7 |
| GENERAL CARGO | 2 | 4 | > 45,000 | 1 | 46,641 | 8,950 | 15 | 105 | 0% | 1995 | 3.3 | 5.3 |
| GENERAL CARGO | 4 | 1 | <15,000 | 70 | 3,158 | 2,322 | 13 | 554 | 100% | 1978 | 3.9 | 5.8 |
| GENERAL CARGO | 4 | 2 | 15,000 - 30,000 | 5 | 19,880 | 10,120 | 15 | 280 | 86% | 1981 | 3.5 | 5.9 |
| GENERAL CARGO | ST | 1 | <15,000 | 14 | 14,897 | 4,428 | 19 | 280 | 86% | 1966 | 2.6 | 5.4 |
| GENERAL CARGO | 0 | 0 | 0 | 191 | 9,060 | 4,428 | 14 | 280 | 86% | 1978 | 3.6 | 5.8 |
| **GENERAL CARGO Total** | | | | **342** | **9,060** | **4,428** | **14** | **280** | **86%** | **1978** | **3.6** | **5.8** |
| PASSENGER | 2 | 1 | <5,000 | 26 | 4,243 | 29,370 | 21 | 559 | 75% | 1984 | 2.4 | 6.0 |
| PASSENGER | 2 | 2 | 5,000 - 10,000 | 55 | 6,456 | 29,961 | 19 | 120 | 0% | 1984 | 2.6 | 6.0 |
| PASSENGER | 4 | 1 | <5,000 | 5 | 1,254 | 9,313 | 17 | 769 | 100% | 1979 | 3.0 | 6.0 |
| PASSENGER | 4 | 2 | 5,000 - 10,000 | 2 | 5,500 | 20,934 | 18 | 580 | 100% | 1987 | 2.8 | 6.0 |
| PASSENGER | 0 | 0 | 0 | 32 | 5,485 | 28,408 | 20 | 559 | 75% | 1984 | 2.5 | 6.0 |
| **PASSENGER Total** | | | | **120** | **5,485** | **28,408** | **20** | **559** | **75%** | **1984** | **2.5** | **6.0** |
| REEFER | 2 | 2 | 5,000 - 10,000 | 46 | 6,417 | 8,160 | 18 | 158 | 70% | 1986 | 2.8 | 4.0 |

## Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

**Tampa Harbor, FL**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REEFER | 2 | 3 | 10,000 - 15,000 | 6 | 11,054 | 12,983 | 20 | 120 | 0% | 1976 | 2.6 | 3.5 |
| REEFER | 4 | 1 | <5,000 | 1 | 3,536 | 3,002 | 14 | 600 | 100% | 1978 | 3.6 | 3.5 |
| REEFER | 4 | 2 | 5,000 - 10,000 | 1 | 6,502 | 6,933 | 16 | 168 | 100% | 1995 | 3.1 | 3.5 |
| **REEFER Total** | | | | **54** | **6,880** | **8,578** | **18** | **168** | **70%** | **1985** | **2.8** | **3.9** |
| RORO | 2 | 1 | <5,000 | 30 | 872 | 1,948 | 14 | 650 | 100% | 1959 | 3.6 | 5.6 |
| RORO | 4 | 1 | <5,000 | 12 | 2,697 | 2,849 | 13 | 750 | 100% | 1977 | 3.9 | 6.0 |
| RORO | 4 | 2 | 5,000 - 10,000 | 2 | 7,440 | 9,000 | 15 | 600 | 100% | 1993 | 3.3 | 6.0 |
| **RORO Total** | | | | **44** | **1,668** | **2,514** | **14** | **650** | **100%** | **1966** | **3.7** | **5.8** |
| TANKER | 2 | 1 | <30,000 | 111 | 19,007 | 11,871 | 16 | 136 | 47% | 1978 | 3.1 | 5.5 |
| TANKER | 2 | 2 | 30,000 - 60,000 | 17 | 39,778 | 16,976 | 17 | 122 | 0% | 1977 | 3.0 | 5.5 |
| TANKER | 4 | 1 | <30,000 | 45 | 3,121 | 1,542 | 11 | 459 | 100% | 1972 | 4.5 | 5.6 |
| TANKER | 4 | 2 | 30,000 - 60,000 | 3 | 37,874 | 16,000 | 16 | 150 | 44% | 1971 | 3.1 | 5.4 |
| TANKER | ST | 1 | <30,000 | 37 | 24,854 | 9,794 | 14 | 150 | 44% | 1947 | 3.5 | 5.7 |
| TANKER | ST | 2 | 30,000 - 60,000 | 121 | 37,075 | 9,794 | 15 | 150 | 44% | 1955 | 3.3 | 5.4 |
| TANKER | ST | 6 | > 150,000 | 1 | 228,274 | 9,794 | 17 | 150 | 44% | 1977 | 2.9 | 6.0 |
| TANKER | 0 | 0 | 0 | 148 | 25,893 | 9,794 | 15 | 150 | 44% | 1966 | 3.4 | 5.4 |
| **TANKER Total** | | | | **483** | **25,893** | **9,794** | **15** | **150** | **44%** | **1966** | **3.4** | **5.5** |
| TUG | 2 | 0 | 0 | 701 | 75 | 4,905 | 12 | ND | ND | 1976 | 4.3 | 5.4 |
| TUG | 4 | 0 | 0 | 166 | 157 | 9,206 | 14 | ND | ND | 1978 | 3.7 | 5.6 |
| TUG | 0 | 0 | 0 | 459 | 91 | 5,768 | 13 | ND | ND | 1976 | 4.2 | 5.5 |
| **TUG Total** | | | | **1,326** | **91** | **5,768** | **13** | **#N/A** | **#N/A** | **1976** | **4.2** | **5.4** |
| VEHICLES CARRIER | 2 | 2 | 12,500 - 15,000 | 2 | 13,208 | 11,500 | 18 | 111 | 0% | 1984 | 2.8 | 5.7 |
| **VEHICLES CARRIER Total** | | | | **2** | **13,208** | **11,500** | **18** | **111** | **0%** | **1984** | **2.8** | **5.7** |
| BARGE DRY CARGO | 0 | 0 | 0 | 525 | ND | ND | ND | ND | ND | ND | ND | 5.4 |
| **BARGE DRY CARGO Total** | | | | **525** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **5.4** |
| BARGE TANKER | 0 | 0 | 0 | 852 | ND | ND | ND | ND | ND | ND | ND | 5.5 |
| **BARGE TANKER Total** | | | | **852** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **5.5** |
| MISCELLANEOUS | 2 | 1 | <1,000 | 4 | 113 | 895 | 12 | 430 | 100% | 1977 | 4.2 | 5.9 |
| MISCELLANEOUS | 2 | 3 | 5,000 - 10,000 | 1 | 9,360 | 10,332 | 18 | 430 | 100% | 1984 | 2.8 | 3.5 |

## Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

| Man. (hr/call) | Hotel (hr/call) |
|---|---|
| 1.9 | 76.2 |
| 2.8 | 87.4 |
| 2.7 | 96.1 |
| 3.4 | 71.9 |
| 1.4 | 346.8 |
| 3.3 | 64.6 |
| 3.0 | 223.2 |
| 9.0 | 265.3 |
| 1.5 | 56.3 |
| **2.3** | **75.6** |
| 3.3 | 276.3 |
| 1.0 | 7.1 |
| 3.0 | 125.9 |
| **2.6** | **171.4** |
| 1.8 | 46.2 |
| 1.4 | 80.8 |
| 1.0 | 43.5 |
| 5.7 | 120.8 |
| 1.2 | 98.7 |
| 1.7 | 51.4 |
| 1.2 | 35.7 |
| 1.2 | 62.3 |
| **1.3** | **68.0** |
| 1.1 | 15.1 |
| 1.0 | 10.2 |
| 1.8 | 224.3 |
| 1.0 | 9.5 |
| 1.0 | 71.8 |
| **1.0** | **36.6** |
| 1.0 | 38.8 |

## Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

| | |
|---|---|
| 5.0 | 352.4 |
| 1.0 | 86.2 |
| 1.0 | 81.8 |
| **1.5** | **75.3** |
| 2.0 | 60.3 |
| 1.5 | 216.1 |
| 1.5 | 199.9 |
| **1.9** | **110.3** |
| 1.3 | 34.3 |
| 1.7 | 37.0 |
| 1.4 | 86.0 |
| 1.8 | 35.9 |
| 1.1 | 21.1 |
| 1.9 | 47.7 |
| 2.4 | 640.7 |
| 1.2 | 21.9 |
| **1.4** | **39.0** |
| 2.1 | 55.7 |
| 2.1 | 64.9 |
| 1.6 | 49.6 |
| **1.9** | **54.7** |
| 1.3 | 203.3 |
| **1.3** | **203.3** |
| 1.8 | 91.8 |
| **1.8** | **91.8** |
| 2.0 | 149.6 |
| **2.0** | **149.6** |
| 1.1 | 83.5 |
| 1.0 | 319.7 |

## Table 12-5: Summary of 1996 Deep-Sea Vessel Data for Baltimore Harbor, MD

| Ship Type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Biuld | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 2 | < 25,000 | 50 | 18,690 | 8,707 | 15 | 146 | 63% | 1981 | 3.4 | 16.0 | 1.5 | 113.5 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 85 | 29,958 | 10,618 | 15 | 131 | 61% | 1982 | 3.3 | 16.7 | 1.5 | 167.7 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 73 | 39,143 | 10,435 | 15 | 109 | 5% | 1984 | 3.4 | 16.6 | 1.6 | 133.1 |
| BULK CARRIER | 2 | 45,000 - 90,000 | 144 | 68,715 | 13,970 | 14 | 100 | 3% | 1986 | 3.5 | 17.4 | 1.5 | 79.1 |
| BULK CARRIER | 2 | > 90,000 | 76 | 133,223 | 18,241 | 14 | 86 | 0% | 1985 | 3.5 | 18.9 | 1.4 | 49.5 |
| BULK CARRIER | 4 | < 25,000 | 10 | 12,466 | 5,700 | 14 | ND | ND | 1974 | 3.7 | 14.7 | 1.5 | 63.6 |
| BULK CARRIER | 4 | 25,000 - 35,000 | 3 | 32,322 | 8,602 | 13 | 157 | 100% | 1984 | 4.0 | 20.1 | 1.3 | 181.8 |
| BULK CARRIER | 4 | 45,000 - 90,000 | 3 | 89,127 | 12,600 | 14 | 404 | 100% | 1982 | 3.6 | 17.5 | 1.3 | 91.0 |
| BULK CARRIER | 4 | > 90,000 | 2 | 158,526 | 17,850 | 14 | 399 | 100% | 1986 | 3.6 | 17.2 | 2.5 | 64.7 |
| BULK CARRIER | ST | < 25,000 | 29 | 18,232 | 9,115 | 15 | ND | ND | 1975 | 3.3 | 14.2 | 1.3 | 30.3 |
| BULK CARRIER | ST | 25,000 - 35,000 | 1 | 33,373 | 11,837 | 15 | ND | ND | 1983 | 3.3 | 10.7 | 1.3 | 1.2 |
| BULK CARRIER | ST | > 90,000 | 5 | 159,743 | 27,126 | 16 | ND | ND | 1970 | 3.1 | 17.2 | 1.3 | 61.4 |
| **BULK CARRIER Total** | | | **481** | **59,304** | **12,611** | **15** | **111** | **16%** | **1983** | **3.4** | **17.0** | **1.5** | **98.8** |
| CONTAINER SHIP | 2 | < 25,000 | 247 | 21,107 | 18,352 | 19 | 118 | 16% | 1987 | 2.6 | 14.1 | 1.3 | 23.7 |
| CONTAINER SHIP | 2 | 25,000 - 35,000 | 96 | 29,065 | 16,979 | 19 | 102 | 0% | 1984 | 2.7 | 14.5 | 1.3 | 17.2 |
| CONTAINER SHIP | 2 | 35,000 - 45,000 | 92 | 39,319 | 46,221 | 23 | 105 | 0% | 1979 | 2.2 | 16.9 | 1.4 | 16.1 |
| CONTAINER SHIP | 2 | 45,000 - 90,000 | 72 | 55,730 | 41,379 | 22 | 94 | 0% | 1988 | 2.2 | 17.1 | 1.3 | 13.7 |
| CONTAINER SHIP | 4 | < 25,000 | 13 | 8,793 | 6,508 | 16 | 475 | 100% | 1984 | 3.2 | 13.4 | 1.3 | 105.4 |
| CONTAINER SHIP | ST | < 25,000 | 3 | 18,832 | 28,112 | 23 | ND | ND | 1973 | 2.2 | 14.1 | 1.3 | 12.7 |
| CONTAINER SHIP | ST | 25,000 - 35,000 | 18 | 26,826 | 35,181 | 20 | ND | ND | 1973 | 2.5 | 15.5 | 1.3 | 20.7 |
| **CONTAINER SHIP Total** | | | **541** | **30,106** | **26,242** | **20** | **117** | **10%** | **1985** | **2.5** | **15.1** | **1.3** | **21.7** |
| GENERAL CARGO | 2 | < 25,000 | 114 | 16,545 | 10,516 | 16 | 154 | 55% | 1982 | 3.1 | 16.7 | 1.5 | 108.3 |
| GENERAL CARGO | 2 | 25,000 - 35,000 | 13 | 30,370 | 10,302 | 15 | 108 | 0% | 1984 | 3.3 | 16.5 | 2.0 | 96.8 |
| GENERAL CARGO | 2 | 35,000 - 45,000 | 9 | 41,141 | 13,058 | 16 | ND | ND | 1984 | 3.1 | 14.3 | 1.3 | 29.8 |
| GENERAL CARGO | 2 | 45,000 - 90,000 | 1 | 45,000 | 12,300 | 16 | 93 | 0% | 1994 | 3.1 | 17.4 | 1.3 | 180.0 |
| GENERAL CARGO | 4 | < 25,000 | 80 | 5,301 | 3,469 | 13 | 642 | 100% | 1988 | 3.8 | 19.0 | 1.4 | 55.7 |
| GENERAL CARGO | 4 | 25,000 - 35,000 | 4 | 29,719 | 12,000 | 14 | ND | ND | 1974 | 3.6 | 18.0 | 2.1 | 107.2 |
| GENERAL CARGO | ST | < 25,000 | 5 | 13,264 | 16,709 | 20 | ND | ND | 1962 | 2.6 | 17.4 | 1.3 | 358.9 |
| **GENERAL CARGO Total** | | | **226** | **14,626** | **8,281** | **15** | **435** | **78%** | **1984** | **3.4** | **17.4** | **1.5** | **91.7** |
| Miscellaneous | 2 | < 10,000 | 4 | 6,450 | 3,500 | 15 | ND | ND | 1982 | 3.3 | 15.9 | 2.0 | 509.1 |

## Table 12-5: Summary of 1996 Deep-Sea Vessel Data for Baltimore Harbor, MD

| Ship Type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Biuld | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Miscellaneous | 4 | < 10,000 | 6 | 7,053 | 11,671 | 14 | 720 | 100% | 1990 | 3.5 | 18.3 | 1.8 | 790.1 |
| **Miscellaneous Total** | | | **10** | **6,812** | **10,503** | **15** | **720** | **100%** | **1987** | **3.4** | **17.3** | **1.9** | **677.7** |
| PASSENGER | 2 | <10,000 | 3 | 6,291 | 22,000 | 20 | ND | ND | 1976 | 2.5 | 15.1 | 1.3 | 81.9 |
| PASSENGER | 4 | <10,000 | 6 | 5,478 | 32,171 | 20 | 524 | 100% | 1986 | 2.6 | 15.1 | 1.3 | 85.7 |
| PASSENGER | ST | <10,000 | 6 | 7,942 | 35,363 | 24 | ND | ND | 1961 | 2.1 | 16.1 | 1.3 | 146.7 |
| **PASSENGER Total** | | | **15** | **6,626** | **31,413** | **21** | **524** | **100%** | **1974** | **2.4** | **15.5** | **1.3** | **109.4** |
| REEFER | 2 | 10,000 - 20,000 | 2 | 11,560 | 13,100 | 19 | 117 | 0% | 1987 | 2.6 | 10.9 | 1.6 | 531.4 |
| **REEFER Total** | | | **2** | **11,560** | **13,100** | **19** | **117** | **0%** | **1987** | **2.6** | **10.9** | **1.6** | **531.4** |
| RORO | 2 | <10,000 | 66 | 5,420 | 9,650 | 16 | 96 | 0% | 1981 | 3.1 | 17.1 | 1.5 | 47.8 |
| RORO | 2 | 10,000 - 20,000 | 46 | 15,272 | 14,935 | 19 | 98 | 0% | 1985 | 2.7 | 15.1 | 2.0 | 30.3 |
| RORO | 2 | 20,000 - 30,000 | 51 | 26,522 | 16,952 | 20 | 102 | 0% | 1984 | 2.6 | 14.6 | 1.9 | 32.6 |
| RORO | 2 | > 30,000 | 83 | 45,016 | 26,562 | 19 | 98 | 0% | 1983 | 2.7 | 17.4 | 1.3 | 19.8 |
| RORO | 4 | <10,000 | 3 | 8,903 | 10,332 | 15 | 425 | 100% | 1979 | 3.3 | 15.8 | 1.3 | 33.6 |
| RORO | 4 | 20,000 - 30,000 | 1 | 24,106 | 27,000 | 22 | ND | ND | 1972 | 2.3 | 16.2 | 1.3 | 1301.3 |
| **RORO Total** | | | **250** | **24,800** | **17,805** | **18** | **107** | **3%** | **1983** | **2.8** | **16.3** | **1.6** | **37.0** |
| TANKER | 2 | <30,000 | 53 | 19,174 | 8,165 | 14 | 157 | 52% | 1984 | 3.5 | 15.6 | 1.6 | 34.3 |
| TANKER | 2 | 30,000 - 60,000 | 42 | 37,543 | 12,008 | 15 | 113 | 7% | 1982 | 3.3 | 16.5 | 1.7 | 51.5 |
| TANKER | 2 | 60,000 - 90,000 | 13 | 64,867 | 14,170 | 15 | 108 | 0% | 1985 | 3.3 | 15.9 | 1.4 | 34.3 |
| TANKER | 2 | 90,000 - 120,000 | 1 | 95,628 | 16,600 | 14 | 94 | 0% | 1993 | 3.6 | 17.5 | 1.3 | 242.4 |
| TANKER | 2 | > 150,000 | 1 | 281,559 | 29,460 | 15 | 75 | 0% | 1995 | 3.3 | 17.2 | 2.3 | 93.3 |
| TANKER | 4 | <30,000 | 22 | 8,330 | 5,354 | 14 | 486 | 100% | 1989 | 3.5 | 14.5 | 1.5 | 29.1 |
| TANKER | 4 | 30,000 - 60,000 | 7 | 36,753 | 14,760 | 16 | ND | ND | 1983 | 3.2 | 16.8 | 1.7 | 39.0 |
| TANKER | ST | 30,000 - 60,000 | 8 | 44,388 | 16,275 | 15 | ND | ND | 1958 | 3.3 | 18.1 | 1.3 | 30.9 |
| **TANKER Total** | | | **147** | **31,354** | **10,331** | **15** | **222** | **46%** | **1983** | **3.4** | **15.9** | **1.6** | **40.3** |
| TUG | 2 | <10,000 | 15 | 177 | 4,713 | 13 | 900 | 100% | 1975 | 4.0 | 16.6 | 1.3 | 52.9 |
| TUG | 4 | <10,000 | 27 | 430 | 15,252 | 16 | 750 | 100% | 1978 | 3.2 | 14.9 | 1.4 | 29.3 |
| **TUG Total** | | | **42** | **340** | **11,488** | **15** | **825** | **100%** | **1977** | **3.4** | **15.5** | **1.4** | **37.8** |
| VEHICLES CARRIER | 2 | <10,000 | 3 | 9,352 | 10,978 | 18 | 124 | 33% | 1984 | 2.8 | 16.1 | 2.9 | 35.4 |
| VEHICLES CARRIER | 2 | 10,000 - 20,000 | 225 | 14,660 | 13,308 | 18 | 110 | 0% | 1985 | 2.7 | 14.7 | 1.8 | 22.8 |
| VEHICLES CARRIER | 2 | 20,000 - 30,000 | 3 | 26,342 | 13,963 | 19 | 101 | 0% | 1990 | 2.7 | 17.0 | 1.7 | 17.0 |
| VEHICLES CARRIER | 4 | <10,000 | 12 | 8,246 | 11,830 | 18 | 530 | 100% | 1980 | 2.8 | 14.2 | 1.5 | 21.7 |
| VEHICLES CARRIER | 4 | 10,000 - 20,000 | 50 | 12,863 | 13,649 | 18 | 502 | 100% | 1981 | 2.8 | 15.5 | 1.9 | 28.1 |
| **VEHICLES CARRIER Total** | | | **293** | **14,156** | **13,289** | **18** | **173** | **17%** | **1984** | **2.7** | **14.9** | **1.8** | **23.7** |
| **Grand Total** | | | **2,007** | **31,529** | **16,493** | **17** | **172** | **23%** | **1984** | **3.0** | **16.0** | **1.5** | **56.4** |

## Table 13-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Coos Bay, OR

| Ship-type | Engine Type | DWT Range | Calls | DWT (tonnes) | Power (HP) | Vessel Speed (knots) | Engine Speed (RPM) | %RPM >130 | Date of Build | Cruise (hr/call) | RSZ (hr/call) | Maneuver (hr/call) | Hotel (hr/call) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER | 2 | < 25,000 | 26 | 22,978 | 7,007 | 14 | 149 | 96% | 1993 | 3.6 | 3.6 | 0.6 | 64.0 |
| BULK CARRIER | 2 | 25,000 - 35,000 | 39 | 30,108 | 9,756 | 15 | 127 | 13% | 1983 | 3.4 | 3.4 | 0.6 | 69.4 |
| BULK CARRIER | 2 | 35,000 - 45,000 | 60 | 42,436 | 9,136 | 14 | 105 | 6% | 1987 | 3.5 | 3.0 | 0.6 | 58.9 |
| BULK CARRIER | 2 | > 45,000 | 28 | 46,825 | 10,249 | 14 | 106 | 0% | 1990 | 3.5 | 3.5 | 0.6 | 94.8 |
| BULK CARRIER | 2 | (blank) | 2 | 36,790 | 9,136 | 14 | 117 | 24% | 1987 | 3.5 | 4.0 | 0.3 | 179.7 |
| **BULK CARRIER Total** | | | **155** | **36,790** | **9,136** | **14** | **117** | **24%** | **1987** | **3** | **3.3** | **0.6** | **70.4** |
| GENERAL CARGO | 2 | < 25,000 | 10 | 20,800 | 11,770 | 16 | 103 | 0% | 1980 | 3.1 | 3.6 | 0.6 | 65.3 |
| GENERAL CARGO | 2 | 25,000 - 35,000 | 18 | 30,068 | 8,040 | 14 | 95 | 0% | 1984 | 3.5 | 3.6 | 0.6 | 52.5 |
| GENERAL CARGO | 2 | 35,000 - 45,000 | 20 | 42,857 | 13,010 | 15 | 119 | 0% | 1982 | 3.2 | 2.7 | 0.6 | 56.5 |
| GENERAL CARGO | 2 | > 45,000 | 5 | 46,547 | 12,300 | 16 | 93 | 0% | 1994 | 3.1 | 4.0 | 0.6 | 128.5 |
| GENERAL CARGO | 4 | < 25,000 | 1 | 23,168 | 7,800 | 15 | 103 | 0% | 1978 | 3.3 | 3.0 | 0.6 | 67.4 |
| **GENERAL CARGO Total** | | | **54** | **34,486** | **10,962** | **15** | **103** | **0%** | **1983** | **3** | **3.3** | **0.6** | **63.7** |
| MISCELLANEOUS | 4 | (blank) | 1 | 36,189 | 9,612 | 15 | ND | ND | ND | 3.4 | 4.0 | 0.3 | 128.7 |
| **MISCELLANEOUS Total** | | | **1** | **#N/A** | **#N/A** | **15** | **#N/A** | **#N/A** | **#N/A** | **#N/A** | **4.0** | **0.3** | **128.7** |
| **Grand Total** | | | **210** | **36,189** | **9,612** | **15** | **116** | **21%** | **1986** | **3** | **3.3** | **0.6** | **69.0** |

**Cleveland Harbor, OH**

SOURCE: EPA document *Commercial Marine Activity for Lake and Riv*

| Ship Type | Engine Type | DWT Category | Trips | Year Build | DWT (tonnes) |
|---|---|---|---|---|---|
| BULK CARRIER, SALTY | 2 | < 10,00 | 2 | ND | 8,186 |
| BULK CARRIER, SALTY | 2 | 10,000 - 20,0 | 23 | ND | 15,866 |
| BULK CARRIER, SALTY | 2 | 20,000 - 30,0 | 134 | 1984 | 27,225 |
| BULK CARRIER, SALTY | 2 | > 30,00 | 60 | 1981 | 35,125 |
| **BULK CARRIER, SALTY Total** | | | **219** | **1983** | **28,022** |
| BULK CARRIER, LAKER | 2 | 10,000 - 20,0 | 39 | 1943 | 17,500 |
| BULK CARRIER, LAKER | 2 | 20,000 - 30,0 | 717 | 1977 | 26,830 |
| BULK CARRIER, LAKER | 2 | 30,000 - 40,0 | 55 | 1974 | 37,107 |
| BULK CARRIER, LAKER | 2 | > 40,00 | 37 | 1980 | 50,800 |
| BULK CARRIER, LAKER | 4 | < 10,00 | 56 | 1959 | 7,686 |
| BULK CARRIER, LAKER | 4 | 10,000 - 20,0 | 350 | 1951 | 17,000 |
| BULK CARRIER, LAKER | 4 | 20,000 - 30,0 | 70 | 1973 | 21,303 |
| BULK CARRIER, LAKER | 4 | 30,000 - 40,0 | 16 | 1980 | 33,205 |
| BULK CARRIER, LAKER | ST | 10,000 - 20,0 | 106 | 1943 | 15,047 |
| **BULK CARRIER, LAKER Total** | | | **1446** | **1967** | **23,445** |
| CONTAINER SHIP, SALTY | 2 | < 10,00 | 4 | ND | 8,229 |
| CONTAINER SHIP, SALTY | 4 | 10,000 - 20,0 | 2 | 1995 | 10,187 |
| **CONTAINER SHIP, SALTY Total** | | | **6** | **1995** | **8,882** |
| EXCURSION VESSEL | 4 | 450 | 572 | 1981 | ND |
| EXCURSION VESSEL | 4 | 1000 | 748 | 1990 | ND |
| **EXCURSION VESSEL Total** | | | **1320** | **1986** | **ND** |
| GENERAL CARGO, SALTY | 2 | < 10,00 | 2 | ND | 7,805 |
| GENERAL CARGO, SALTY | 2 | 10,000 - 20,0 | 6 | 1980 | 15,658 |
| GENERAL CARGO, SALTY | 4 | < 10,00 | 8 | 1963 | 7,251 |
| GENERAL CARGO, SALTY | 4 | 10,000 - 20,0 | 2 | ND | 17,154 |
| GENERAL CARGO, SALTY | 4 | 20,000 - 30,0 | 2 | ND | 23,000 |
| **GENERAL CARGO, SALTY Total** | | | **20** | **1972** | **12,394** |
| TANKER, SALTY | 2 | < 10,00 | 5 | 1974 | 8,000 |
| TANKER, SALTY | 4 | 10,000 - 20,0 | 12 | 1978 | 11,420 |
| **TANKER, SALTY Total** | | | **17** | **1976** | **10,280** |
| Grand Total | | | 1665 | 1968 | 23,678 |

a ST refers to steam turbine

b Category is dead weight tonnes for all ship-types c Hotelling times are found in Table 3-7

Table 3-7. Average hotelling times by ship-type for calls on Port of Cleveland in 1996

| Ship-type | Category a | Calls | Hotelling (hrs/call) |
|---|---|---|---|
| BULK CARRIER, SALTY | 10,000 - 2( | 11 | 41.3 |
| | 20,000 - 3( | 75 | 69.3 |
| | > 30, | 45 | 49.1 |
| BULK CARRIER, SALTY Total | | 131 | 60 |
| BULK CARRIER, LAKER | 20,000 - 3( | 1 | 7.8 |
| | > 30, | 1 | 7 |
| BULK CARRIER, LAKER Total | | 2 | 7.4 |
| CONTAINER SHIP, SALTY | < 10, | 1 | 24.7 |
| | 10,000 - 2( | 1 | 111.5 |
| CONTAINER SHIP, SALTY Total | | 2 | 68.1 |
| GENERAL CARGO, SALTY | < 10, | 9 | 55.1 |
| | 10,000 - 2( | 6 | 78.9 |
| GENERAL CARGO, SALTY Total | | 15 | 64.6 |
| PASSENGER, SALTY | all | 2 | 30.5 |
| TANKER, SALTY | all | 1 | 29 |
| Grand Total | | 153 | 59.3 |

*ver Ports* , Table 3-4. Summary of trips for the Port of Cleveland for 1996

| | | | | | | | | EMISSION FAC |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Cruise**<br>g/hp-hr<br>2<br>4<br>Steam |
| **Power (hp)** | **Vessel Speed (knots)** | **Engine Speed (RPM)** | **Cruise (hr/trip)** | **RSZ (hr/trip)** | **Maneuver (hr/trip)** | **Calls** | **Hotel (hr/call)** | |
| 6,200 | 14 | ND | 0.5 | 0.3 | 0.8 | | | |
| 6,996 | 14 | 113 | 0.5 | 0.3 | 0.8 | 11 | 41.3 | |
| 9,116 | 15 | 110 | 0.5 | 0.3 | 0.8 | 75 | 69.3 | |
| 10,909 | 14 | 100 | 0.5 | 0.3 | 0.8 | 45 | 49.1 | |
| **9,358** | **14** | **109** | **0.5** | **0.3** | **0.8** | | | |
| 4,500 | 13 | ND | 0.5 | 0.3 | 0.8 | | | |
| 7,098 | 13 | 750 | 0.5 | 0.3 | 2.4 | 0.911055 | 7.8 | |
| 7,087 | 13 | ND | 0.5 | 0.4 | 1 | 0.774648 | 7 | |
| 8,538 | 13 | ND | 0.5 | 0.3 | 0.9 | | | |
| 4,303 | 14 | ND | 0.5 | 0.3 | 0.9 | | | |
| 4,236 | 13 | ND | 0.5 | 0.3 | 2 | | | |
| 5,503 | 14 | ND | 0.5 | 0.3 | 2.5 | 0.088945 | 7.8 | |
| 9,601 | 12 | ND | 0.6 | 0.4 | 0.8 | 0.225352 | 7 | |
| 8,269 | 15 | ND | 0.5 | 0.3 | 0.9 | | | |
| **6,308** | **13** | **750** | **0.5** | **0.3** | **2** | | | |
| 5,950 | 15 | ND | 0.5 | 0.3 | 0.8 | 1 | 24.7 | |
| 7,382 | 16 | 500 | 0.4 | 0.3 | 0.8 | 1 | 111.5 | |
| **6,427** | **15** | **500** | **0.5** | **0.3** | **0.8** | | | |
| 460 | 10 | ND | 0 | 2 | 0.4 | 0.866667 | 30.5 | |
| 850 | 12 | ND | 0 | 2 | 0.4 | 1.133333 | 30.5 | |
| **655** | **11** | **ND** | **0** | **2** | **0.4** | | | |
| 5,400 | 15 | 225 | 0.5 | 0.3 | 0.8 | 1.8 | 55.1 | |
| 10,600 | 16 | ND | 0.4 | 0.3 | 0.8 | 4.5 | 78.9 | |
| 3,391 | 12 | 550 | 0.6 | 0.4 | 0.8 | 7.2 | 55.1 | |
| 6,000 | 14 | ND | 0.5 | 0.3 | 0.8 | 1.5 | 78.9 | |
| 7,800 | 13 | ND | 0.5 | 0.4 | 0.8 | | | |
| **6,456** | **14** | **442** | **0.5** | **0.3** | **0.8** | | | |
| 2,950 | 12 | 750 | 0.5 | 0.3 | 2.6 | 0.294118 | 29 | |
| 6,253 | 15 | 117 | 0.5 | 0.3 | 0.8 | 0.705882 | 29 | |
| **5,152** | **14** | **328** | **0.5** | **0.3** | **1.4** | | | |
| 6,664 | 13 | 519 | 0.5 | 0.3 | 1.8 | | | Total Grams per Year |
| | | | | | | | | 2-stroke Tons per Year |
| | | | | | | | | 4-stroke Tons per Year |

| |
|---|
| Steam Engine Tons per Year |
| **Total Tons per Year** |

| Load | | 0.8 | | | **RSZ** | | |
|---|---|---|---|---|---|---|---|
| HC | CO | NOx | PM | SO2 | g/hp-hr | HC | |
| 0.395 | 0.82 | 17.6 | 1.29 | 9.56 | | 2 | 0.395 |
| 0.395 | 0.52 | 12.38 | 1.31 | 9.69 | | 4 | 0.395 |
| 0.05 | 0.22 | 2.09 | 1.86 | 15.0 | Steam | | 0.05 |
| | | | | | Speed | | 9 |

| **Cruise HC g/yr** | **Cruise CO g/yr** | **Cruise NOx g/yr** | **Cruise PM g/yr** | **Cruise SO2 g/yr** | **RSZ Load** | **RSZ HC g/yr** |
|---|---|---|---|---|---|---|
| 1959 | 4067 | 87296 | 6398 | 47411 | | 420 |
| 25423 | 52778 | 1132792 | 83029 | 615231 | | 5453 |
| 193004 | 400666 | 8599670 | 630317 | 4670571 | | 41395 |
| 103417 | 214689 | 4607962 | 337743 | 2502632 | | 22181 |
| **323804** | **672201** | **14427720** | **1057486** | **7835845** | **0.29** | **69449** |
| 27729 | 57564 | 1235520 | 90558 | 671024 | | 6910 |
| 804104 | 1669279 | 35828433 | 2626061 | 19458796 | | 200386 |
| 61586 | 127849 | 2744086 | 201129 | 1490342 | | 20463 |
| 49913 | 103617 | 2223978 | 163007 | 1207866 | | 12439 |
| 38073 | 50121 | 1193274 | 126267 | 933784 | | 9488 |
| 234251 | 308381 | 7341835 | 776882 | 5745277 | | 58376 |
| 60863 | 80124 | 1907560 | 201850 | 1492741 | | 15167 |
| 29126 | 38343 | 912848 | 96594 | 714339 | | 8065 |
| 17530 | 77133 | 732064 | 652126 | 5245200 | | 4369 |
| **1323175.00** | **2512411.51** | **54119598.15** | **4934475.64** | **36959369.04** | **0.33** | **335662.07** |
| 3760 | 7806 | 167552 | 12281 | 90999 | | 708 |
| 1866 | 2457 | 58489 | 6189 | 45770 | | 439 |
| **5627** | **10263** | **226041** | **18470** | **136769** | **0.25** | **1148** |
| 0 | 0 | 0 | 0 | 0 | | 100481 |
| 0 | 0 | 0 | 0 | 0 | | 242801 |
| **0** | **0** | **0** | **0** | **0** | **0.48** | **343282** |
| 1706 | 3542 | 76032 | 5573 | 41294 | | 366 |
| 8039 | 16689 | 358195 | 26254 | 194540 | | 2155 |
| 5143 | 6771 | 161205 | 17058 | 126150 | | 1226 |
| 1896 | 2496 | 59424 | 6288 | 46502 | | 407 |
| 2465 | 3245 | 77251 | 8174 | 60452 | | 705 |
| **19250** | **32743** | **732108** | **63347** | **468937** | **0.29** | **4858** |
| 2331 | 4838 | 103840 | 7611 | 56397 | | 500 |
| 11856 | 15607 | 371578 | 39319 | 290775 | | 2543 |
| **14186** | **20445** | **475418** | **46930** | **347171** | **0.29** | **3043** |
| 1686041.41 | 3248063.69 | 69980884.99 | 6120709.01 | 45748091.69 | | 757441.67 |
| 1.41 | 2.93 | 62.88 | 4.61 | 34.15 | | 0.34 |
| 0.42 | 0.56 | 13.29 | 1.41 | 10.40 | | 0.48 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.02 | 0.08 | 0.81 | 0.72 | 5.77 | | 0.00 |
| **1.85** | **3.57** | **76.98** | **6.73** | **50.32** | | **0.83** |

| | | | | Maneuver | |
|---|---|---|---|---|---|
| CO | NOx | PM | SO2 | g/hp-hr | HC |
| 0.82 | 17.6 | 1.29 | 9.56 | 2 | 2.085717156 |
| 0.52 | 12.38 | 1.31 | 9.69 | 4 | 2.172732372 |
| 0.22 | 2.09 | 1.86 | 15.0 | Steam | 0.05 |
| knots | | | | Speed | 4 |

**EMISSIO**

| RSZ CO g/yr | RSZ NOx g/yr | RSZ PM g/yr | RSZ SO2 g/yr | Maneuvering Load | Maneuvering HC g/yr |
|---|---|---|---|---|---|
| 872 | 18723 | 1372 | 10169 | | 2407 |
| 11320 | 242958 | 17808 | 131953 | | 31232 |
| 85934 | 1844432 | 135188 | 1001730 | | 237101 |
| 46046 | 988302 | 72438 | 536757 | | 127046 |
| **144172** | **3094415** | **226807** | **1680609** | **0.12** | **397786** |
| 14345 | 307896 | 22567 | 167221 | | 35255 |
| 415990 | 8928569 | 654424 | 4849199 | | 3067026 |
| 42481 | 911781 | 66829 | 495198 | | 97876 |
| 25822 | 554223 | 40622 | 301004 | | 71392 |
| 12490 | 297368 | 31466 | 232702 | | 56729 |
| 76850 | 1829611 | 193602 | 1431743 | | 775632 |
| 19967 | 475371 | 50302 | 371996 | | 251907 |
| 10617 | 252761 | 26746 | 197795 | | 32146 |
| 19222 | 182433 | 162512 | 1307122 | | 4749 |
| **637783.49** | **13740012.44** | **1249070.36** | **9353981.62** | **0.12** | **4392711.14** |
| 1471 | 31567 | 2314 | 17144 | | 4498 |
| 579 | 13774 | 1458 | 10779 | | 2907 |
| **2049** | **45341** | **3771** | **27923** | **0.11** | **7405** |
| 132279 | 3149253 | 333241 | 2464415 | | 30565 |
| 319637 | 7609816 | 805239 | 5954982 | | 73856 |
| **451916** | **10759069** | **1138480** | **8419397** | **0.13** | **104420** |
| 760 | 16307 | 1195 | 8857 | | 2096 |
| 4474 | 96031 | 7039 | 52155 | | 12345 |
| 1614 | 38417 | 4065 | 30062 | | 5485 |
| 535 | 12745 | 1349 | 9974 | | 2426 |
| 928 | 22091 | 2338 | 17287 | | 3154 |
| **8311** | **185591** | **15985** | **118335** | **0.12** | **25507** |
| 1038 | 22271 | 1632 | 12096 | | 9305 |
| 3347 | 79695 | 8433 | 62364 | | 15172 |
| **4385** | **101966** | **10065** | **74460** | **0.12** | **24477** |
| 1248615.90 | 27926394.13 | 2644178.51 | 19674706.43 | | 4952306.03 |
| 0.72 | 15.36 | 1.13 | 8.34 | | 4.07 |
| 0.64 | 15.16 | 1.60 | 11.86 | | 1.37 |

| | | | | | |
|---|---|---|---|---|---|
| 0.02 | 0.20 | 0.18 | 1.44 | | 0.01 |
| **1.37** | **30.72** | **2.91** | **21.64** | | **5.45** |

| CO | NOx | PM | SO2 | **Hotel** g/hp-hr | Load HC | |
|---|---|---|---|---|---|---|
| 6.072740558 | 23.91129555 | 2.168336646 | 23.02 | 2 | | 0.1 |
| 4.432346073 | 16.87604551 | 2.216072174 | 23.87 | 4 | | 0.1 |
| 0.22 | 2.09 | 1.86 | 15.0 | Steam | | 0.05 |
| knots | | | | | | |

**NS ESTIMATES**

| **Maneuvering CO g/yr** | **Maneuvering NOx g/yr** | **Maneuvering PM g/yr** | **Maneuvering SO2 g/yr** | | **Hotelling HC g/yr** |
|---|---|---|---|---|---|
| 7008 | 27593 | 2502 | 26564 | | |
| 90935 | 358055 | 32469 | 344701 | | 31783 |
| 690339 | 2718197 | 246493 | 2616820 | | 473804 |
| 369905 | 1456492 | 132078 | 1402171 | | 241034 |
| **1158187** | **4560337** | **413543** | **4390255** | | **746621** |
| 102647 | 404172 | 36651 | 389098 | | |
| 8929903 | 35161316 | 3188517 | 33849944 | | 504 |
| 284974 | 1122080 | 101753 | 1080231 | | 384 |
| 207865 | 818463 | 74220 | 787938 | | |
| 115726 | 440624 | 57860 | 623168 | | |
| 1582280 | 6024490 | 791104 | 8520351 | | |
| 513886 | 1956608 | 256931 | 2767203 | | 38 |
| 65578 | 249685 | 32787 | 353126 | | 151 |
| 20894 | 198302 | 176648 | 1420824 | | |
| **11823752.51** | **46375740.40** | **4716472.97** | **49791883.47** | | **1078.33** |
| 13097 | 51570 | 4677 | 49647 | | 1470 |
| 5930 | 22579 | 2965 | 31932 | | 8231 |
| **19027** | **74149** | **7641** | **81580** | | **9701** |
| 62351 | 237401 | 31174 | 335753 | | 122 |
| 150665 | 573653 | 75329 | 811309 | | 294 |
| **213016** | **811054** | **106503** | **1147062** | | **415** |
| 6103 | 24032 | 2179 | 23136 | | 5356 |
| 35943 | 141524 | 12834 | 136245 | | 37635 |
| 11190 | 42605 | 5595 | 60255 | | 13453 |
| 4950 | 18846 | 2475 | 26654 | | 7101 |
| 6435 | 24500 | 3217 | 34650 | | |
| **64620** | **251507** | **26300** | **280940** | | **63545** |
| 27091 | 106671 | 9673 | 102693 | | 252 |
| 30951 | 117844 | 15475 | 166666 | | 1280 |
| **58042** | **224516** | **25148** | **269359** | | **1532** |
| 13336645.03 | 52297301.95 | 5295608.01 | 55961078.44 | | 822892.04 |
| 11.84 | 46.63 | 4.23 | 44.89 | | 0.87 |
| 2.80 | 10.68 | 1.40 | 15.10 | | 0.03 |

| | | | | | |
|---|---|---|---|---|---|
| 0.02 | 0.22 | 0.19 | 1.56 | | 0.00 |
| **14.67** | **57.53** | **5.83** | **61.56** | | **0.91** |

| 0.1 | | | | All modes |
|---|---|---|---|---|
| CO | NOx | PM | SO2 | |
| 1.85 | 9.96 | 0.239 | 1.07 | |
| 1.85 | 9.96 | 0.239 | 1.07 | |
| 0.22 | 2.09 | 1.86 | 15.00 | |

| **Hotelling CO g/yr** | **Hotelling NOx g/yr** | **Hotelling PM g/yr** | **Hotelling SO2 g/yr** | **All Modes HC g/yr** | **All Modes CO g/yr** | **All Modes NOx g/yr** |
|---|---|---|---|---|---|---|
| | | | | 4786.24 | 11947.22 | 133611.65 |
| 587982 | 3165570 | 75961 | 339316 | 93891.19 | 743014.79 | 4899374.74 |
| 8765376 | 47190888 | 1132392 | 5058377 | 945303.92 | 9942315.34 | 60353187.19 |
| 4459136 | 24007022 | 576072 | 2573305 | 493678.13 | 5089775.13 | 31059777.19 |
| **13812494** | **74363480** | **1784425** | **7970999** | 1537659.47 | 15787052.48 | 96445950.77 |
| | | | | 69893.95 | 174556.43 | 1947587.50 |
| 9331 | 50238 | 1206 | 5385 | 4072019.70 | 11024503.77 | 79968556.07 |
| 7109 | 38276 | 918 | 4103 | 180309.58 | 462413.80 | 4816223.36 |
| | | | | 133743.98 | 337303.62 | 3596664.42 |
| | | | | 104289.67 | 178337.82 | 1931265.47 |
| | | | | 1068259.14 | 1967510.12 | 15195936.08 |
| 706 | 3803 | 91 | 408 | 327975.20 | 614683.15 | 4343341.21 |
| 2802 | 15085 | 362 | 1617 | 69487.81 | 117338.83 | 1430378.44 |
| | | | | 26647.50 | 117249.01 | 1112799.67 |
| **19949.03** | **107401.25** | **2577.20** | **11512.31** | 6052626.54 | 14993896.54 | 114342752.23 |
| 27189 | 146377 | 3512 | 15690 | 10436.86 | 49562.96 | 397066.35 |
| 152272 | 819801 | 19672 | 87874 | 13443.49 | 161237.54 | 914642.37 |
| **179461** | **966178** | **23184** | **103564** | 23880.34 | 210800.51 | 1311708.72 |
| 2249 | 12111 | 291 | 1298 | 131167.14 | 196879.55 | 3398764.27 |
| 5436 | 29264 | 702 | 3137 | 316950.70 | 475737.37 | 8212733.07 |
| **7685** | **41375** | **993** | **4435** | 448117.85 | 672616.92 | 11611497.34 |
| 99081 | 533430 | 12800 | 57178 | 9524.38 | 109486.46 | 649801.15 |
| 696253 | 3748476 | 89948 | 401798 | 60174.30 | 753358.55 | 4344225.53 |
| 248876 | 1339896 | 32152 | 143623 | 25307.18 | 268450.85 | 1582123.02 |
| 131369 | 707260 | 16971 | 75811 | 11830.01 | 139349.59 | 798274.75 |
| | | | | 6323.93 | 10607.39 | 123842.56 |
| **1175579** | **6329062** | **151872** | **678410** | 113159.80 | 1281252.84 | 7498267.01 |
| 4655 | 25061 | 601 | 2686 | 12386.60 | 37621.81 | 257843.63 |
| 23680 | 127491 | 3059 | 13666 | 30850.55 | 73586.23 | 696608.31 |
| **28335** | **152552** | **3661** | **16352** | 43237.15 | 111208.04 | 954451.94 |
| 15223502.69 | 81960046.94 | 1966711.97 | 8785272.74 | 8218681.15 | 33056827.31 | 232164628.01 |
| 16.12 | 86.80 | 2.08 | 9.30 | 6.69 | 31.61 | 211.67 |
| 0.62 | 3.36 | 0.08 | 0.36 | 2.32 | 4.62 | 42.49 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.13 | 1.22 |
| **16.75** | **90.16** | **2.16** | **9.66** | **9.04** | **36.36** | **255.38** |
| | | | | 8.55 | 35.62 | 242.61 |

| All Modes PM g/yr | All Modes SO2 g/yr |
| --- | --- |
| 10272.88 | 84143.59 |
| 209266.51 | 1431201.65 |
| 2144389.96 | 13347497.64 |
| 1118331.15 | 7014865.42 |
| 3482260.51 | 21877708.30 |
| 149776.67 | 1227343.00 |
| 6470207.21 | 58163324.86 |
| 370629.99 | 3069873.75 |
| 277849.83 | 2296808.00 |
| 215593.86 | 1789654.26 |
| 1761588.06 | 15697370.60 |
| 509174.35 | 4632348.27 |
| 156489.14 | 1266878.00 |
| 991287.07 | 7973145.70 |
| 10902596.17 | 96116746.44 |
| 22783.50 | 173480.67 |
| 30283.41 | 176355.49 |
| 53066.91 | 349836.16 |
| 364705.62 | 2801465.77 |
| 881270.27 | 6769428.15 |
| 1245975.89 | 9570893.92 |
| 21747.52 | 130464.52 |
| 136074.79 | 784738.29 |
| 58869.91 | 360090.35 |
| 27082.79 | 158939.83 |
| 13729.22 | 112389.42 |
| 257504.23 | 1546622.40 |
| 19517.97 | 173871.48 |
| 66285.82 | 533470.61 |
| 85803.79 | 707342.09 |
| 16027207.49 | 130169149.31 |
| 12.05 | 96.69 |
| 4.49 | 37.73 |

| | |
|---|---|
| 1.09 | 8.77 |
| **17.63** | **143.19** |

16.26 132.66

**Burns Waterway Harbor, IN**

SOURCE: EPA document *Commercial Marine Activity for Lake and River Ports,* Table 3-12. Summary of trips for Burns Waterway Harbor for 1996

| Ship Type | Engine Type | DWT Category | Trips | Year Build | DWT (tonnes) | Power (hp) | Vessel Speed (knots) | Engine Speed (RPM g/yr) | Cruise (hr/trip) | RSZ (hr/trip) | Maneuver (hr/trip) | Calls |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK CARRIER, LAKER | 2 | 20,000 - 30,0 | 9 | 1973 | 24,827 | 8,531 | 13 | 750 | 0.5 | 0.4 | 0.7 | 2.423077 |
| BULK CARRIER, LAKER | 2 | 30,000 - 40,0 | 37 | 1974 | 34,925 | 7,108 | 13 | ND | 0.5 | 0.4 | 0.6 | 1.146018 |
| BULK CARRIER, LAKER | 2 | > 40,000 | 162 | 1975 | 67,695 | 14,376 | 14 | ND | 0.5 | 0.3 | 0.6 | 5.017699 |
| BULK CARRIER, LAKER | 4 | 10,000 - 20,0 | 14 | 1952 | 17,978 | 4,800 | 13 | ND | 0.5 | 0.4 | 0.7 | 7 |
| BULK CARRIER, LAKER | 4 | 20,000 - 30,0 | 6 | 1971 | 22,491 | 6,600 | 15 | ND | 0.5 | 0.3 | 0.7 | 1.615385 |
| BULK CARRIER, LAKER | 4 | 30,000 - 40,0 | 27 | 1979 | 32,908 | 9,541 | 12 | ND | 0.6 | 0.4 | 0.7 | 0.836283 |
| BULK CARRIER, LAKER | ST | 20,000 - 30,0 | 11 | 1953 | 23,627 | 8,886 | 16 | ND | 0.4 | 0.3 | 0.6 | 2.961538 |
| **BULK CARRIER, LAKER Total** | | | **266** | **1973** | **52,630** | **11,753** | **14** | **750** | **0.5** | **0.3** | **0.6** | |
| BULK CARRIER, SALTY | 2 | 10,000 - 20,0 | 4 | 1976 | 14,631 | 6,700 | 14 | ND | 0.5 | 0.3 | 0.7 | 4 |
| BULK CARRIER, SALTY | 2 | 20,000 - 30,0 | 99 | 1973 | 27,329 | 8,839 | 13 | 219 | 0.5 | 0.3 | 0.7 | 35.77311 |
| BULK CARRIER, SALTY | 2 | 30,000 - 40,0 | 42 | 1982 | 32,449 | 10,132 | 14 | 105 | 0.5 | 0.3 | 0.7 | 19 |
| BULK CARRIER, SALTY | ST | 20,000 - 30,0 | 20 | 1961 | 26,175 | 3,551 | 16 | ND | 0.4 | 0.3 | 0.7 | 7.226891 |
| **BULK CARRIER, SALTY Total** | | | **165** | **1974** | **28,185** | **8,476** | **14** | **193** | **0.5** | **0.3** | **0.7** | |
| GENERAL CARGO, SALTY | 2 | < 10,000 | 8 | 1962 | 8,395 | 4,100 | 14 | ND | 0.5 | 0.3 | 0.7 | 5.714286 |
| GENERAL CARGO, SALTY | 2 | 10,000 - 20,0 | 1 | 1982 | 16,467 | 11,200 | 16 | 150 | 0.4 | 0.3 | 0.7 | 1 |
| GENERAL CARGO, SALTY | 4 | < 10,000 | 6 | 1979 | 5,785 | 3,667 | 12 | ND | 0.6 | 0.4 | 0.7 | 4.285714 |
| **GENERAL CARGO, SALTY Total** | | | **15** | **1970** | **7,889** | **4,400** | **13** | **150** | **0.5** | **0.3** | **0.7** | |
| TANKER, SALTY | 4 | < 10,000 | 200 | 1973 | 7,500 | 400 | 14 | 720 | 0.5 | 0.3 | 0.6 | |
| **TANKER, SALTY Total** | | **< 10,000** | **200** | **1973** | **7500** | **400** | **14** | **720** | **0.5** | **0.3** | **0.6** | |
| Grand Total | | | 646 | 1973 | 40,342 | 9,792 | 14 | 596 | 0.5 | 0.3 | 0.7 | |

a ST refers to steam turbine

b Category is dead weight tonnes for all ship-types

c Hotelling times are found in Table 3-15

Table 3-15. Average hotelling times by ship-type for calls on Burns Waterway Harbor

| Ship-type | Category a | Calls | Hotelling (hrs/call) |
|---|---|---|---|
| BULK CARRIER, LAKER | 10,000 - 20,000 | 7 | 13.5 |
| | 20,000 - 30,000 | 7 | 17.9 |
| | > 30,000 | 7 | 18.7 |
| BULK CARRIER, LAKER Total | | 21 | 16.6 |
| BULK CARRIER, SALTY | 10,000 - 20,000 | 4 | 61 |
| | 20,000 - 30,000 | 43 | 43.2 |
| | > 30,000 | 19 | 48 |
| BULK CARRIER, SALTY Total | | 66 | 45.8 |
| GENERAL CARGO, SALTY | < 10,000 | 10 | 26.3 |
| | 20,000 - 30,000 | 1 | 23.9 |
| GENERAL CARGO Total | | 11 | 26 |
| DRY-CARGO BARGE | < 2000 | 446 | 46.8 |
| LIQUID CARGO BARGE | < 2000 | 23 | 52.9 |
| | 2000 - 5000 | 27 | 29.7 |
| LIQUID CARGO BARGE Total | | 50 | 40.3 |
| Grand Total | | 594 | 44.4 |

a Category is in dead weight tonnes.

**EMISSION FAC**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cruise** | Load | 0.8 | | | | **RSZ** | | | | | | **Maneuver** | |
| g/hp-hr | HC | CO | NOx | PM | SO2 | g/hp-hr | HC | CO | NOx | PM | SO2 | g/hp-hr | HC |
| 2 | 0.395 | 0.82 | 17.6 | 1.29 | 9.56 | 2 | 0.395 | 0.82 | 17.6 | 1.29 | 9.56 | 2 | 2.085717156 |
| 4 | 0.395 | 0.52 | 12.38 | 1.31 | 9.69 | 4 | 0.395 | 0.52 | 12.38 | 1.31 | 9.69 | 4 | 2.172732372 |
| Steam | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 | Steam | 0.05 | 0.22 | 2.09 | 1.86 | 15.0 | Steam | 0.05 |
| | | | | | | Speed | 9 | knots | | | | Speed | 4 |

| **Hotel (hr/call)** | | **Cruise HC g/yr** | **Cruise CO g/yr** | **Cruise NOx g/yr** | **Cruise PM g/yr** | **Cruise SO2 g/yr** | **RSZ Load** | **RSZ HC g/yr** | **RSZ CO g/yr** | **RSZ NOx g/yr** | **RSZ PM g/yr** | **RSZ SO2 g/yr** | **Maneuvering Load** | **Maneuvering HC g/yr** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17.9 | | 12131 | 25184 | 540524 | 39618 | 293564 | | 3469 | 7202 | 154573 | 11330 | 83950 | | 13040 |
| 18.7 | | 41553 | 86263 | 1851492 | 135706 | 1005565 | | 11883 | 24668 | 529470 | 38808 | 287561 | | 38286 |
| 18.7 | | 367968 | 763883 | 16395540 | 1201719 | 8904589 | | 78921 | 163835 | 3516467 | 257741 | 1909830 | | 339030 |
| 13.5 | | 10618 | 13978 | 332774 | 35213 | 260409 | | 3036 | 3997 | 95163 | 10070 | 74469 | | 11889 |
| 17.9 | | 6257 | 8237 | 196099 | 20750 | 153455 | | 1342 | 1767 | 42059 | 4450 | 32913 | | 7006 |
| 18.7 | | 48842 | 64299 | 1530804 | 161983 | 1197915 | | 11639 | 15323 | 364803 | 38602 | 285472 | | 45576 |
| 17.9 | | 1564 | 6881 | 65310 | 58178 | 467942 | | 419 | 1845 | 17509 | 15597 | 125454 | | 341 |
| | | **488933** | **968724** | **20912544** | **1653167** | **12283440** | **0.29** | **110710** | **218637** | **4720044** | **376598** | **2799649** | **0.12** | **455169** |
| 61 | | 4234 | 8790 | 188672 | 13829 | 102470 | | 908 | 1885 | 40466 | 2966 | 21977 | | 4552 |
| 43.2 | | 138260 | 287020 | 6160429 | 451531 | 3345794 | | 29654 | 61559 | 1321271 | 96843 | 717596 | | 148618 |
| 48 | | 67236 | 139578 | 2995830 | 219581 | 1627066 | | 14421 | 29936 | 642537 | 47095 | 348968 | | 72273 |
| 43.2 | | 1136 | 5000 | 47453 | 42271 | 339996 | | 305 | 1340 | 12722 | 11333 | 91152 | | 289 |
| | | **210866** | **440389** | **9392384** | **727212** | **5415326** | **0.29** | **45287** | **94721** | **2016995** | **158237** | **1179693** | **0.12** | **225732** |
| 26.3 | | 5182 | 10758 | 230912 | 16925 | 125411 | | 1291 | 2681 | 57544 | 4218 | 31253 | | 5765 |
| 23.9 | | 1416 | 2939 | 63078 | 4623 | 34259 | | 441 | 915 | 19649 | 1440 | 10672 | | 1969 |
| 26.3 | | 4172 | 5492 | 130745 | 13835 | 102313 | | 1155 | 1521 | 36202 | 3831 | 28330 | | 4029 |
| | | **10770** | **19189** | **424735** | **35383** | **261982** | **0.33** | **2888** | **5117** | **113396** | **9489** | **70254** | **0.12** | **11763** |
| | | 12640 | 16640 | 396160 | 41920 | 310011 | | 2711 | 3569 | 84967 | 8991 | 66490 | | 12132 |
| | | **12640** | **16640** | **396160** | **41920** | **310011** | **0.29** | **2711** | **3569** | **84967** | **8991** | **66490** | **0.12** | **12132** |
| | Total Grams per Year | 723209 | 1444941 | 31125823 | 2457682 | 18270759 | | 161595 | 322044 | 6935402 | 553314 | 4116087 | | 704795 |
| | 2-stroke Tons per Year | 0.70 | 1.46 | 31.27 | 2.29 | 16.98 | | 0.16 | 0.32 | 6.91 | 0.51 | 3.75 | | 0.69 |
| | 4-stroke Tons per Year | 0.09 | 0.12 | 2.85 | 0.30 | 2.23 | | 0.02 | 0.03 | 0.69 | 0.07 | 0.54 | | 0.09 |
| | Steam Engine Tons per Year | 0.00 | 0.01 | 0.12 | 0.11 | 0.89 | | 0.00 | 0.00 | 0.03 | 0.03 | 0.24 | | 0.00 |
| | **Total Tons per Year** | **0.80** | **1.59** | **34.24** | **2.70** | **20.10** | | **0.18** | **0.35** | **7.63** | **0.61** | **4.53** | | **0.78** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Hotel** | Load | 0.1 | | | | **All modes** |
| CO | NOx | PM | SO2 | g/hp-hr | HC | CO | NOx | PM | SO2 | |
| 6.072740558 | 23.91129555 | 2.168336646 | 23.02 | 2 | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 | |
| 4.432346073 | 16.87604551 | 2.216072174 | 23.87 | 4 | 0.1 | 1.85 | 9.96 | 0.239 | 1.07 | |
| 0.22 | 2.09 | 1.86 | 15.0 | Steam | 0.05 | 0.22 | 2.09 | 1.86 | 15.00 | |
| knots | | | | | | | | | | |

**EMISSIONS ESTIMATES**

| **Maneuvering CO g/yr** | **Maneuvering NOx g/yr** | **Maneuvering PM g/yr** | **Maneuvering SO2 g/yr** | | **Hotelling HC g/yr** | **Hotelling CO g/yr** | **Hotelling NOx g/yr** | **Hotelling PM g/yr** | **Hotelling SO2 g/yr** | **All Modes HC g/yr** | **All Modes CO g/yr** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 37967 | 149494 | 13556 | 143918 | | 3700 | 68453 | 368536 | 8843 | 39503 | 32340 | 138805 |
| 111472 | 438917 | 39802 | 422547 | | 1523 | 28181 | 151719 | 3641 | 16263 | 93245 | 250583 |
| 987115 | 3886746 | 352460 | 3741787 | | 13489 | 249549 | 1343518 | 32239 | 144011 | 799408 | 2164383 |
| 24254 | 92346 | 12126 | 130603 | | 4536 | 83916 | 451786 | 10841 | 48427 | 30079 | 126145 |
| 14292 | 54418 | 7146 | 76963 | | 1908 | 35306 | 190078 | 4561 | 20374 | 16513 | 59602 |
| 92975 | 354002 | 46486 | 500659 | | 1492 | 27603 | 148610 | 3566 | 15929 | 107550 | 200200 |
| 1501 | 14245 | 12689 | 102064 | | 2355 | 10363 | 98357 | 87617 | 706591 | 4680 | 20590 |
| **1269576** | **4990167** | **484266** | **5118541** | | **29004** | **503371** | **2752604** | **151309** | **991099** | **1083816** | **2960308** |
| 13252 | 52181 | 4732 | 50235 | | 16348 | 302438 | 1628261 | 39072 | 174533 | 26042 | 326366 |
| 432713 | 1703799 | 154505 | 1640254 | | 136598 | 2527059 | 13605137 | 326469 | 1458330 | 453129 | 3308351 |
| 210429 | 828561 | 75136 | 797659 | | 92404 | 1709471 | 9203422 | 220845 | 986512 | 246333 | 2089415 |
| 1272 | 12075 | 10756 | 86517 | | 5543 | 24390 | 231482 | 206205 | 1662942 | 7273 | 32002 |
| **657667** | **2596616** | **245129** | **2574665** | | **250893** | **4563357** | **24668301** | **792590** | **4282318** | **732778** | **5756134** |
| 16786 | 66095 | 5994 | 63630 | | 6162 | 113992 | 613707 | 14726 | 65783 | 18401 | 144217 |
| 5732 | 22569 | 2047 | 21727 | | 2677 | 49521 | 266609 | 6398 | 28578 | 6502 | 59107 |
| 8218 | 31292 | 4109 | 44255 | | 4133 | 76465 | 411670 | 9878 | 44127 | 13489 | 91696 |
| **30737** | **119956** | **12149** | **129613** | | **12972** | **239977** | **1291986** | **31002** | **138488** | **38392** | **295020** |
| 24749 | 94230 | 12374 | 133269 | | | | | | | 27483 | 44958 |
| **24749** | **94230** | **12374** | **133269** | | **0** | **0** | **0** | **0** | **0** | **27483** | **44958** |
| 1982728 | 7800969 | 753918 | 7956087 | | 292869 | 5306706 | 28712892 | 974901 | 5411904 | 1882468 | 9056420 |
| 2.00 | 7.86 | 0.71 | 7.57 | | 0.30 | 5.55 | 29.90 | 0.72 | 3.20 | 1.84 | 9.33 |
| 0.18 | 0.69 | 0.09 | 0.97 | | 0.01 | 0.25 | 1.32 | 0.03 | 0.14 | 0.21 | 0.57 |
| 0.00 | 0.03 | 0.03 | 0.21 | | 0.01 | 0.04 | 0.36 | 0.32 | 2.61 | 0.01 | 0.06 |
| **2.18** | **8.58** | **0.83** | **8.75** | | **0.32** | **5.84** | **31.58** | **1.07** | **5.95** | **2.07** | **9.96** |

| All Modes NOx g/yr | All Modes PM g/yr | All Modes SO2 g/yr |
|---|---|---|
| 1213127 | 73347 | 560936 |
| 2971598 | 217956 | 1731935 |
| 25142272 | 1844159 | 14700218 |
| 972069 | 68250 | 513908 |
| 482654 | 36908 | 283705 |
| 2398218 | 250637 | 1999976 |
| 195422 | 174083 | 1402050 |
| **33375359** | **2665340** | **21192728** |
| 1909580 | 60598 | 349215 |
| 22790635 | 1029348 | 7161974 |
| 13670350 | 562657 | 3760206 |
| 303731 | 270565 | 2180607 |
| **38674296** | **1923168** | **13452002** |
| 968258 | 41863 | 286077 |
| 371906 | 14508 | 95235 |
| 609908 | 31653 | 219025 |
| **1950073** | **88024** | **600337** |
| 575358 | 63285 | 509770 |
| **575358** | **63285** | **509770** |
| 74575086 | 4739816 | 35754836 |
| 75.94 | 4.23 | 31.51 |
| 5.54 | 0.50 | 3.88 |
| 0.55 | 0.49 | 3.94 |
| **82.03** | **5.21** | **39.33** |

# APPENDIX B

## Texas Ports Example Calculations

## Matched Texas Port Example

From the draft Task 2 report, Beaumont was associated with the Port of Corpus Christi and the ports in Port Arthur, Matagorda, and Brownsville were associated with the Port of Tampa based on the similar vessel drafts of ships for Gulf Coast ports. Table B-1 shows the 1995 vessel trips by vessel type reported by Arcadis (1999). Tables B-2a and 2b show the 1996 and 1999 vessel trips by type of vessel for the detailed ports (Corpus Christi and Tampa) and the 1999 trips for the matched Texas ports with the total trips by vessel with Category 3 engines summed. Although the 1996 and 1999 vessel trips for these ports does not appear extraordinary, other ports show extraordinary differences between the 1995 and 1996 and 1999 vessel trip data.

**Table B-1.** 1995 Vessel trips for matched ports (Arcadis, 1999)**.**

| PORTNAME | BA | BC | BD | BL | CS | GC | OT | PA | RF | RO | SV | TA | TUG | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corpus Christi, TX | 2 | 407 | 1,030 | 7,590 | 7 | 27 | - | 125 | - | 10 | 2,702 | 1,921 | 4,716 | 98 | - | **2,594** |
| Tampa, FL | - | 958 | 1,134 | 1,312 | 32 | 229 | 17 | 96 | 238 | 64 | - | 974 | 2,369 | 534 | 2 | **3,144** |
| Beaumont, TX | - | 78 | 1,846 | 7,837 | 6 | 13 | - | 2 | 2 | 24 | 357 | 719 | 7,268 | 49 | - | **892** |
| Port Arthur, TX | - | 321 | 1,398 | 4,202 | 24 | 126 | 20 | 10 | 2 | 16 | 95 | 1,220 | 5,430 | 189 | - | **1,929** |
| Matagorda Ship Channel, TX | - | 205 | 1,435 | 1,412 | 2 | 34 | 1 | - | - | - | 6 | 173 | 1,265 | 51 | - | **466** |
| Brownsville, TX | - | 120 | 330 | 507 | 30 | 25 | 8 | 2 | - | 6 | 6 | 88 | 509 | 617 | 2 | **898** |

**Table B-2a.** 1996 Vessel trips for detailed ports (USACE, 2001).

| PORTNAME | BA | BC | BD | BL | CS | GC | OT | PA | RF | RO | SV | TA | TUG | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corpus Christi, TX | 6 | 592 | 1,392 | 10,255 | 10 | 39 | 4 | 182 | - | 14 | 3,933 | 2,142 | 14,245 | 142 | - | **3,126** |
| Tampa, FL | - | 1,588 | 1,370 | 1,584 | 53 | 380 | 40 | 160 | 394 | 106 | - | 1,015 | 3,308 | 884 | 4 | **4,624** |

**Table B-2b.** 1999 Vessel trips for matched ports (USACE, 2001)**.**

| PORTNAME | BA | BC | BD | BL | CS | GC | OT | PA | RF | RO | SV | TA | TUG | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corpus Christi, TX | 6 | 707 | 1,396 | 10,284 | 12 | 47 | 1 | 217 | - | 17 | 4,693 | 1,992 | 13,940 | 169 | - | **3,162** |
| Beaumont, TX | - | 45 | 2,035 | 8,641 | 3 | 7 | 1 | 1 | 1 | 14 | 205 | 2,186 | 10,387 | 28 | - | **2,287** |
| Port Arthur, TX | - | 369 | 1,616 | 4,856 | 28 | 145 | 21 | 12 | 2 | 19 | 109 | 266 | 4,736 | 218 | - | **1,079** |
| Matagorda Ship Channel, TX | - | 292 | 1,453 | 1,429 | 3 | 48 | 2 | - | - | - | 9 | 267 | 1,319 | 73 | - | **685** |
| Brownsville, TX | - | 50 | 485 | 744 | 13 | 10 | 2 | 1 | - | 3 | 3 | 77 | 669 | 259 | 1 | **415** |

BA = Barge Carrier
BC = Bulk Cargo Carrier
BD = Dry-cargo Barge
BL = Liquid Cargo (Tanker) Barge
CS = Container Ship
GC = General Cargo
OT = Other, Unknown, or Undefined
PA = Passenger, Cruise and Excursion
RF = Reefer
RO = RORO and Ferry
SV = Supply Vessel and Support Vessel
TA = Tanker
TUG = Tugboat and Pushboat
UC = Unidentified Dry-cargo

VC = Vehicle Carrier

Arcadis (1999) recommended that unclassified (UC) vessels be reclassified according to the proportion of dry cargo vessels (i.e. all those Category 3 vessels other than tankers (TA) at the port of interest. This procedure was followed for the detailed and matched port trip totals with the result shown in Tables B-3 and B-4. Based on a review of the engines of such vessels, barge carriers (BA), dry cargo barges (BD), liquid barges (BL), supply vessels (SV) such as used for off-shore oil and gas production, and tugs (TUG) were not considered to have Category 3 engines onboard.

**Table B-3.** 1995 Detailed ports' Category 3 trips modified for unclassified vessels**.**

| PORT NAME | BC | CS | GC | OT | PA | RF | RO | TA | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Corpus Christi, TX | 476 | 8 | 31 | - | 146 | - | 12 | 1,921 | 0 | 0 | **2,594** |
| Tampa, FL | 1,270 | 42 | 304 | 23 | 128 | 315 | 85 | 974 | 0 | 3 | **3,144** |

**Table B-4.** 1995 Matched ports' Category 3 trips modified for unclassified vessels**.**

| PORT NAME | BC | CS | GC | OT | PA | RF | RO | TA | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaumont, TX | 108 | 8 | 18 | - | 3 | 3 | 33 | 719 | | - | **892** |
| Port Arthur, TX | 438 | 33 | 172 | 27 | 14 | 3 | 22 | 1,220 | | - | **1,929** |
| Matagorda Ship Channel, TX | 248 | 2 | 41 | 1 | - | - | - | 173 | | - | **466** |
| Brownsville, TX | 505 | 125 | 104 | 34 | 8 | - | 26 | 88 | | 9 | **898** |

The detailed port data may have fewer vessel types than were expected based on the USACE (2001) data, so all vessel types not explicitly categorized in the detailed data were assumed to be equivalent to the other or miscellaneous category. For Corpus Christi and the port matched to Corpus Christi (Beaumont), vessel trips associated with passenger (PA) and reefer (RF), roll on-roll off (RO), and vehicle carrier (VC) vessels were lumped with the other (OT) vessel types to conform to the detailed vessel data available for Corpus Christi. Detailed data for Tampa included all vessel types, so no adjustment was necessary for ports matched to Tampa. The results are shown in Tables B-5 and B-6.

**Table B-5.** 1995 detailed ports' Category 3 trips modified to match Marine Exchange vessel types**.**

| PORT NAME | BC | CS | GC | OT | PA | RF | RO | TA | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Corpus Christi, TX | 476 | 8 | 31 | 158 | - | - | - | 1,921 | 0 | - | **2,594** |
| Tampa, FL | 1,270 | 42 | 304 | 23 | 128 | 315 | 85 | 974 | 0 | 3 | **3,144** |

**Table B-6.** 1995 matched ports' Category 3 trips modified to match Marine Exchange vessel types.

| PORT NAME | BC | CS | GC | OT | PA | RF | RO | TA | UC | VC | Cat. 3 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaumont, TX | 108 | 8 | 18 | 39 | - | - | - | 719 | 0 | - | **892** |
| Port Arthur, TX | 438 | 33 | 172 | 27 | 14 | 3 | 22 | 1,220 | 0 | 0 | **1,929** |
| Matagorda Ship Channel, TX | 248 | 2 | 41 | 1 | 0 | 0 | 0 | 173 | 0 | 0 | **466** |
| Brownsville, TX | 505 | 125 | 104 | 34 | 8 | 0 | 26 | 88 | 0 | 9 | **898** |

For the Texas ports, the ratio of the vessel trips by type of vessel were calculated and are shown in Table B-7 for the typical (or like) detailed ports of Corpus Christi and Tampa.

**Table B-7.** Ratio of the 1995 matched to the detailed ports' trips.

| Like Port | Port | BC | CS | GC | OT | PA | RF | RO | TA | VC |
|---|---|---|---|---|---|---|---|---|---|---|
| CC | Beaumont, TX | 0.23 | 1.03 | 0.57 | 0.25 | - | - | - | 0.37 | - |
| TM | Port Arthur, TX | 0.35 | 0.78 | 0.57 | 1.21 | 0.11 | 0.01 | 0.26 | 1.25 | 0.00 |
| TM | Matagorda Ship Channel, TX | 0.20 | 0.06 | 0.14 | 0.05 | 0.00 | 0.00 | 0.00 | 0.18 | 0.00 |
| TM | Brownsville, TX | 0.40 | 2.98 | 0.34 | 1.49 | 0.07 | 0.00 | 0.30 | 0.09 | 2.74 |

CC - Corpus Christi; TM - Tampa

For each port the RSZ speed and distance were needed to calculate the time and load in the RSZ mode, as summarized in Table B-8 based on discussions with the local pilots (Beaumont-Port Arthur, Brazos-Port Isabel, Matagorda Pilots (2001)). The speed was used to calculate the average load using the equation described below where the cruise speed was supplied by vessel type for each detailed port. The distance divided by the speed represents the time in mode for the RSZ mode.

$$\textit{Load Factor} = 0.1 + 0.7 * (\textit{Actual Speed} / \textit{Cruise Speed})^3$$

**Table B-8.** Estimates of the Reduce Speed Zone (RSZ) trips by port.

| Port | Distance | Speed (knots) |
|---|---|---|
| Corpus Christi, TX | 25 | 10 |
| Tampa, FL | 24 | 9 |
| Beaumont, TX | 56.5 | 7 |
| Port Arthur, TX | 20 | 7 |
| Matagorda Ship Channel, TX | 24 | 7.25 |
| Brownsville, TX | 18.5 | 8.75 |

The emission estimates were then calculated by applying the vessel call ratio to the detailed port emission estimates by vessel type provided in Appendix A. RSZ mode emissions were adjusted for time and load in mode based on the specific conditions within each port and compared by ship type with the detailed port information shown in Table B-9.

**Table B-9.** Average vessel speed and Reduced Speed Zone load by ship type.

| | Corpus Christi | | Tampa | |
|---|---|---|---|---|
| **Ship Type** | **Cruise Speed (knots)** | **RSZ Load** | **Cruise Speed (knots)** | **RSZ Load** |
| Bulk Carrier | 14.5 | 0.33 | 14.7 | 0.26 |
| Container Ship | 24.0 | 0.15 | 21.5 | 0.15 |
| General Cargo | 15.6 | 0.29 | 14.3 | 0.27 |
| Passenger | - | - | 19.7 | 0.17 |
| Reefer | - | - | 17.8 | 0.19 |
| Roro | - | - | 13.8 | 0.30 |
| Tanker | 15.1 | 0.30 | 15.0 | 0.25 |
| Vehicles Carrier | - | - | 18.0 | 0.19 |
| Miscellaneous | 12.5 | 0.46 | 13.0 | 0.33 |

The emission totals are provided below and reflect the 1996 emission estimates because the Marine Exchange data for the detailed ports was based on 1996 activity. The 1995 vessel trip data was used to determine the relative activity between ports and applied to the 1996 activity data.

**1996 Corpus Christi Emission Totals (Tons/year)**

| **Vessel Type** | **HC** | **CO** | **NOx** | **PM** | **$SO_2$** |
|---|---|---|---|---|---|
| BULK CARRIER Total | 7 | 37 | 385 | 22 | 152 |
| CONTAINER SHIP Total | 0 | 1 | 7 | 0 | 2 |
| TANKER Total | 28 | 126 | 1426 | 182 | 1109 |
| GENERAL CARGO Total | 0 | 1 | 10 | 1 | 5 |
| MISCELLANEOUS Total | 0 | 0 | 3 | 0 | 1 |
| **TOTAL** | **35** | **165** | **1831** | **205** | **1270** |
| *Transit* | *29* | *63* | *1260* | *154* | *1179* |
| *Hotelling* | *6* | *102* | *570* | *51* | *91* |

**1996 Beaumont Emission Totals (Tons/year)**

| **Vessel Type** | **HC** | **CO** | **NOx** | **PM** | **$SO_2$** |
|---|---|---|---|---|---|
| BULK CARRIER Total | 2 | 9 | 101 | 6 | 42 |
| CONTAINER SHIP Total | 0 | 1 | 9 | 0 | 3 |
| TANKER Total | 13 | 52 | 629 | 81 | 616 |
| GENERAL CARGO Total | 0 | 1 | 7 | 1 | 4 |
| MISCELLANEOUS Total | 0 | 0 | 1 | 0 | 0 |
| **TOTAL** | **15** | **63** | **746** | **88** | **666** |
| *Transit* | *13* | *27* | *550* | *69* | *531* |
| *Hotelling* | *2* | *35* | *196* | *19* | *135* |

1996 Tampa Emission Totals (Tons/year)

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| BULK CARRIER Total | 16 | 113 | 970 | 50 | 339 |
| CONTAINER SHIP Total | 0 | 3 | 23 | 1 | 5 |
| GENERAL CARGO Total | 4 | 25 | 220 | 13 | 90 |
| PASSENGER Total | 6 | 30 | 311 | 18 | 125 |
| REEFER Total | 1 | 10 | 74 | 3 | 21 |
| RORO Total | 0 | 3 | 25 | 1 | 7 |
| TANKER Total | 8 | 33 | 370 | 49 | 376 |
| VEHICLES CARRIER Total | 0 | 1 | 7 | 0 | 1 |
| MISCELLANEOUS Total | 0 | 6 | 36 | 1 | 6 |
| **Total** | **36** | **225** | **2036** | **137** | **971** |
| *Transit* | *26* | *51* | *1090* | *99* | *746* |
| *Hotelling* | *10* | *174* | *946* | *38* | *225* |

**1996 Port Arthur Emission Totals (Tons/year)**

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| BULK CARRIER Total | 5 | 38 | 319 | 16 | 108 |
| CONTAINER SHIP Total | 0 | 3 | 18 | 1 | 4 |
| GENERAL CARGO Total | 2 | 14 | 117 | 7 | 46 |
| PASSENGER Total | 1 | 3 | 32 | 2 | 12 |
| REEFER Total | 0 | 0 | 1 | 0 | 0 |
| RORO Total | 0 | 1 | 6 | 0 | 2 |
| TANKER Total | 9 | 40 | 433 | 58 | 441 |
| VEHICLES CARRIER Total | 0 | 0 | 0 | 0 | 0 |
| MISCELLANEOUS Total | 1 | 7 | 43 | 1 | 7 |
| **Total** | **17** | **107** | **969** | **85** | **620** |
| *Transit* | *13* | *25* | *520* | *56* | *425* |
| *Hotelling* | *5* | *82* | *449* | *29* | *195* |

**1996 Matagorda Ship Channel Emission Totals (Tons/year)**

| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| BULK CARRIER Total | 3 | 22 | 185 | 10 | 64 |
| CONTAINER SHIP Total | 0 | 0 | 1 | 0 | 0 |
| GENERAL CARGO Total | 1 | 3 | 29 | 2 | 11 |
| PASSENGER Total | 0 | 0 | 0 | 0 | 0 |
| REEFER Total | 0 | 0 | 0 | 0 | 0 |
| RORO Total | 0 | 0 | 0 | 0 | 0 |
| TANKER Total | 1 | 6 | 64 | 8 | 65 |
| VEHICLES CARRIER Total | 0 | 0 | 0 | 0 | 0 |
| MISCELLANEOUS Total | 0 | 0 | 2 | 0 | 0 |
| **Total** | **5** | **31** | **281** | **20** | **141** |
| *Transit* | *4* | *7* | *147* | *14* | *105* |
| *Hotelling* | *1* | *25* | *134* | *6* | *36* |

**1996 Brownsville Emission Totals (Tons/year)**

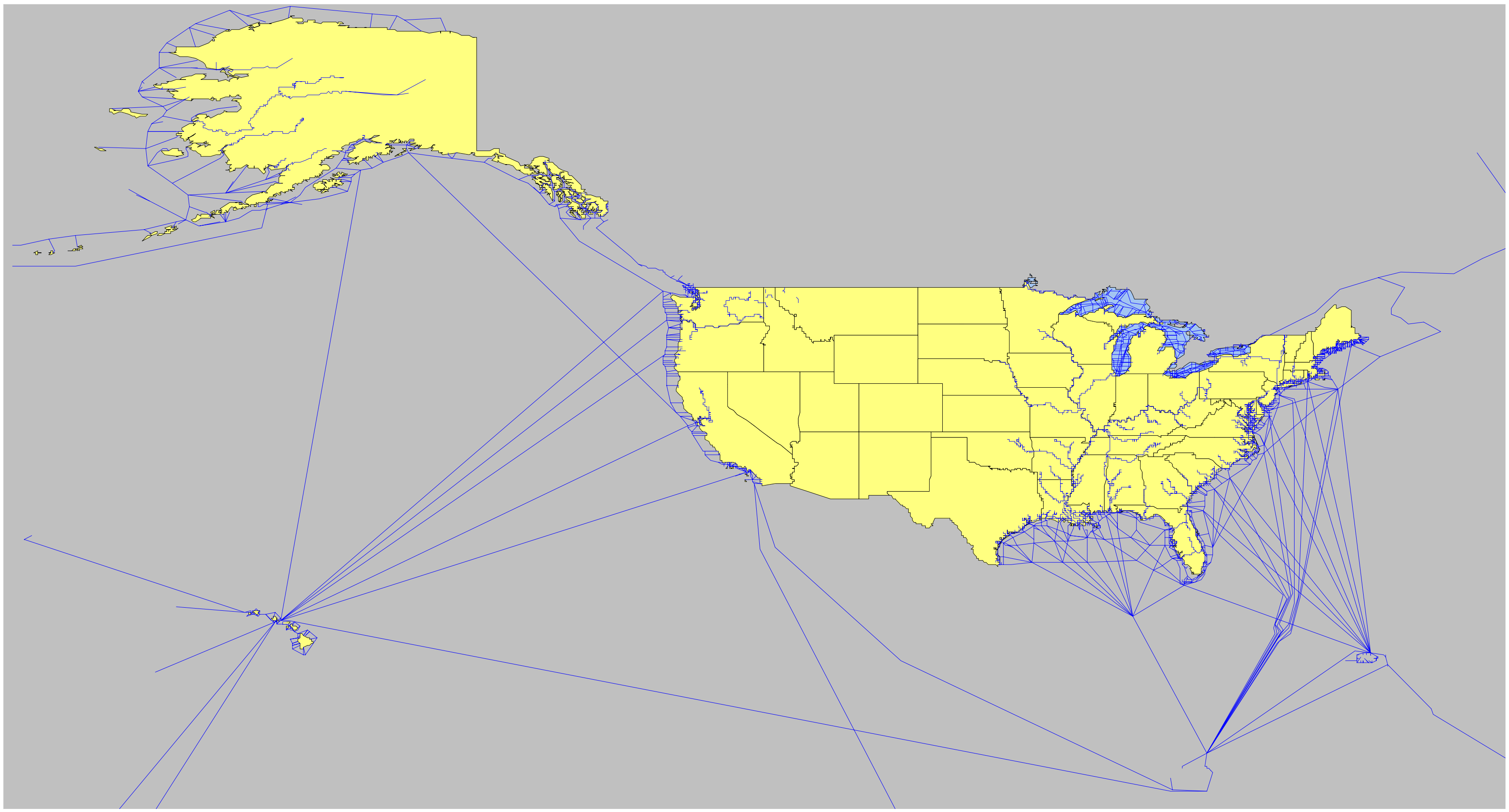
| Vessel Type | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| BULK CARRIER Total | 6 | 44 | 370 | 19 | 125 |
| CONTAINER SHIP Total | 1 | 10 | 69 | 3 | 15 |
| GENERAL CARGO Total | 1 | 8 | 71 | 4 | 28 |
| PASSENGER Total | 0 | 2 | 19 | 1 | 7 |
| REEFER Total | 0 | 0 | 0 | 0 | 0 |
| RORO Total | 0 | 1 | 7 | 0 | 2 |
| TANKER Total | 1 | 3 | 31 | 4 | 32 |
| VEHICLES CARRIER Total | 0 | 3 | 18 | 1 | 4 |
| MISCELLANEOUS Total | 1 | 9 | 53 | 2 | 8 |
| **Total** | **10** | **80** | **638** | **33** | **222** |
| *Transit* | *7* | *12* | *271* | *23* | *169* |
| *Hotelling* | *4* | *68* | *367* | *10* | *53* |

# APPENDIX C

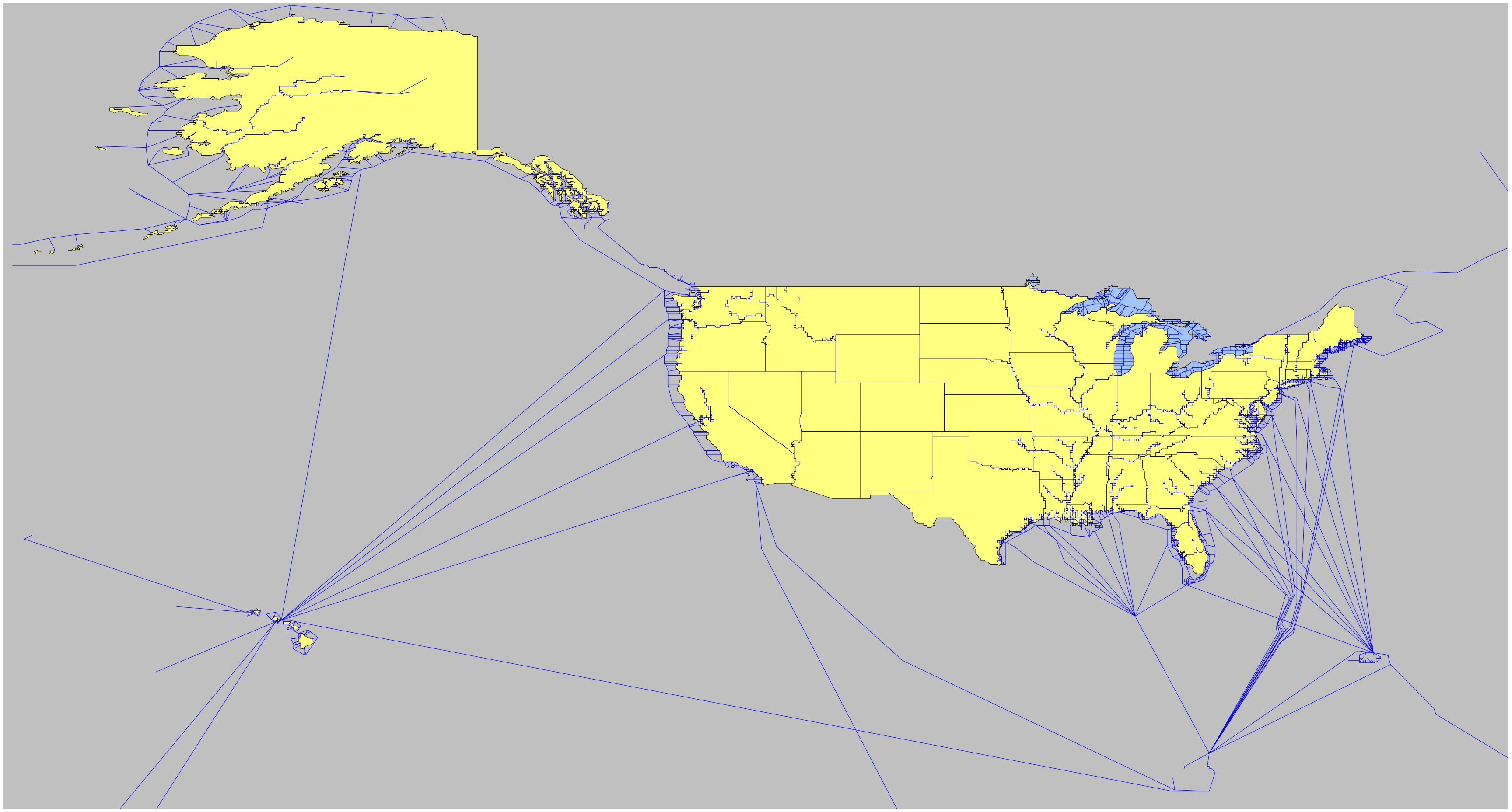
## Maps USACE Waterway Link Network

**MAPS USACE WATERWAY LINK NETWORK**

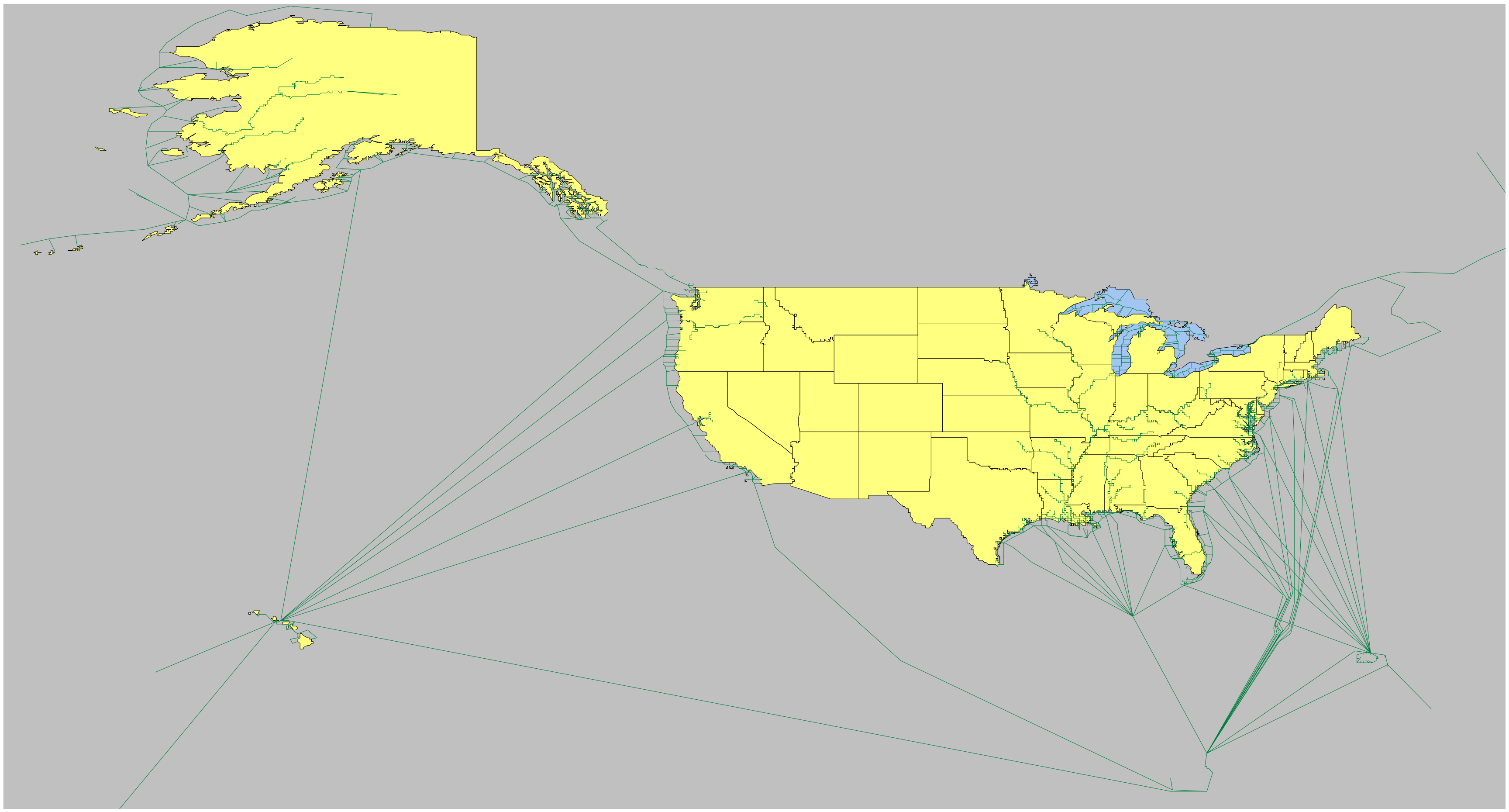
# National Waterway Network (NWN)



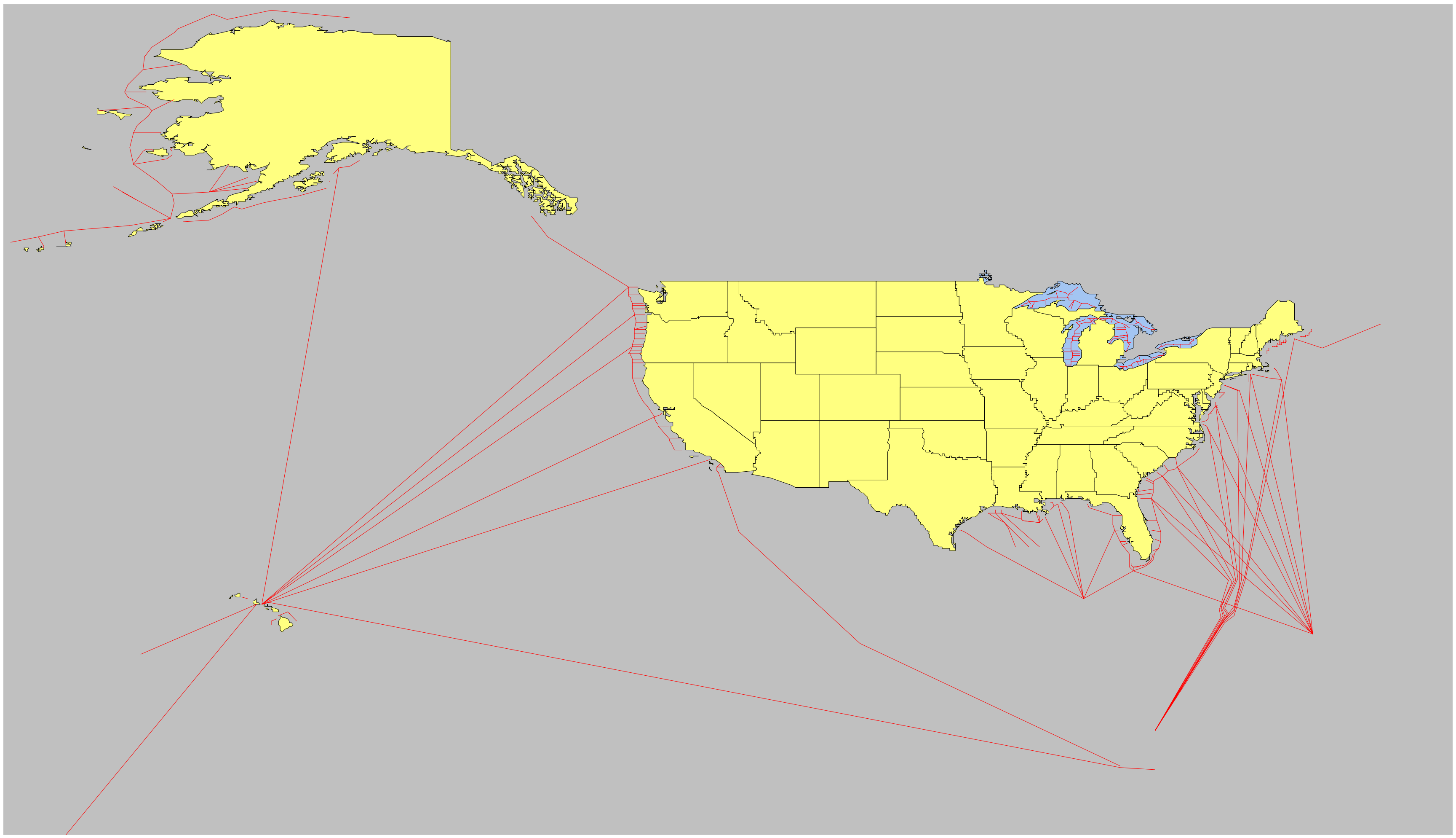
# USACE Waterway Link Network



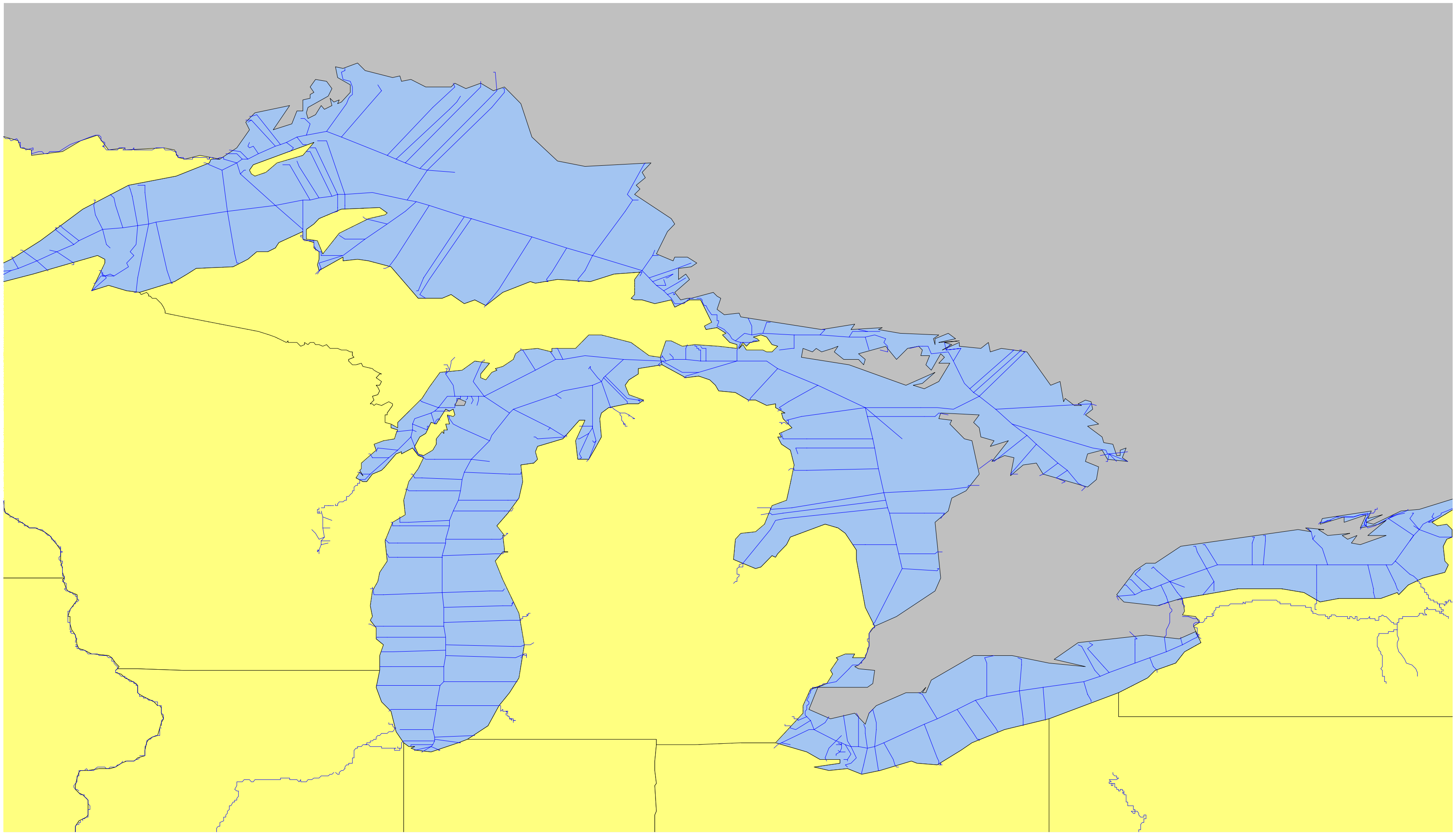
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data



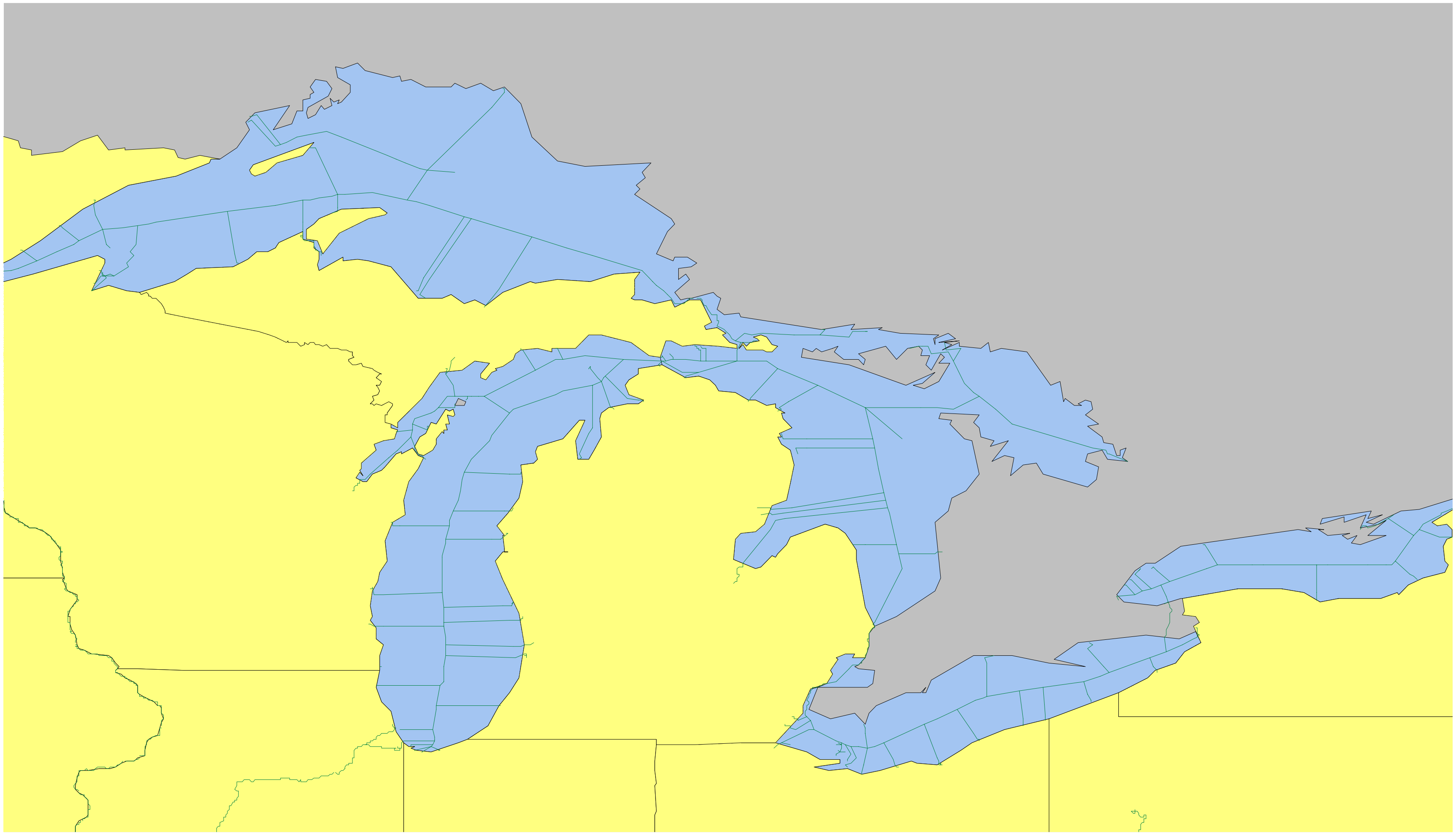
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for ocean-going, >10mi from shore for Great Lakes)



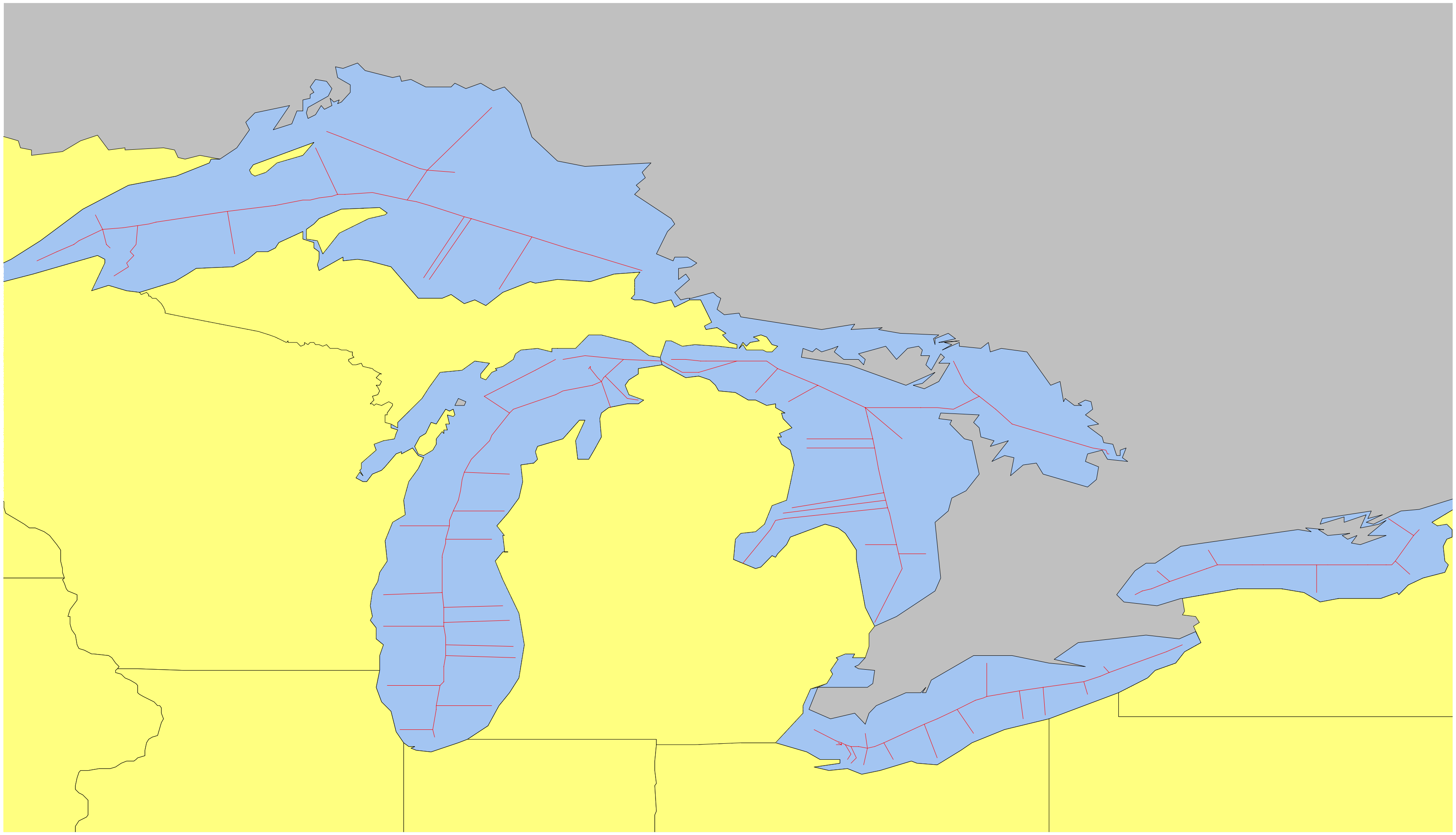
# USACE Waterway Link Network (Great Lakes)



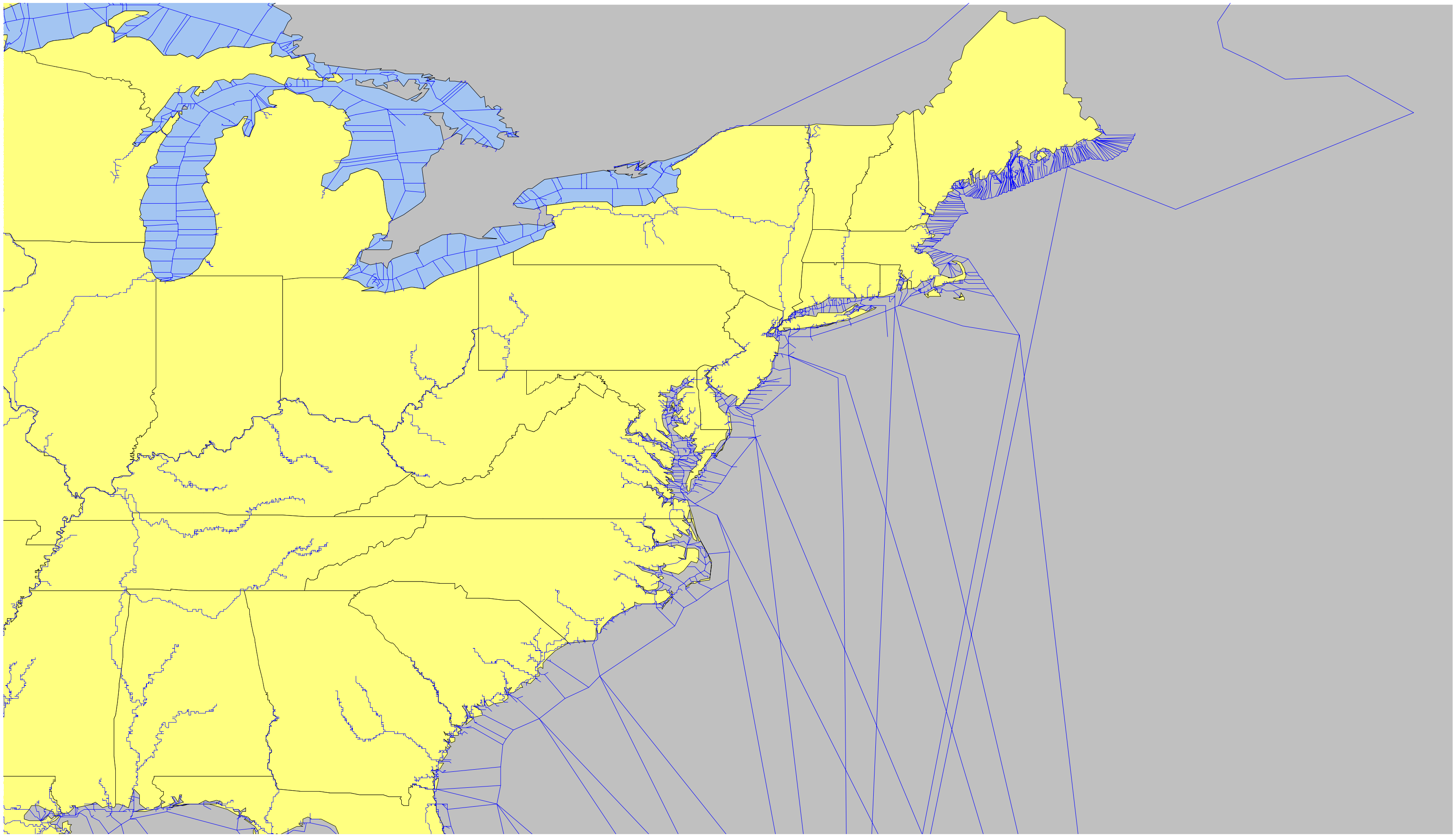
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Great Lakes)



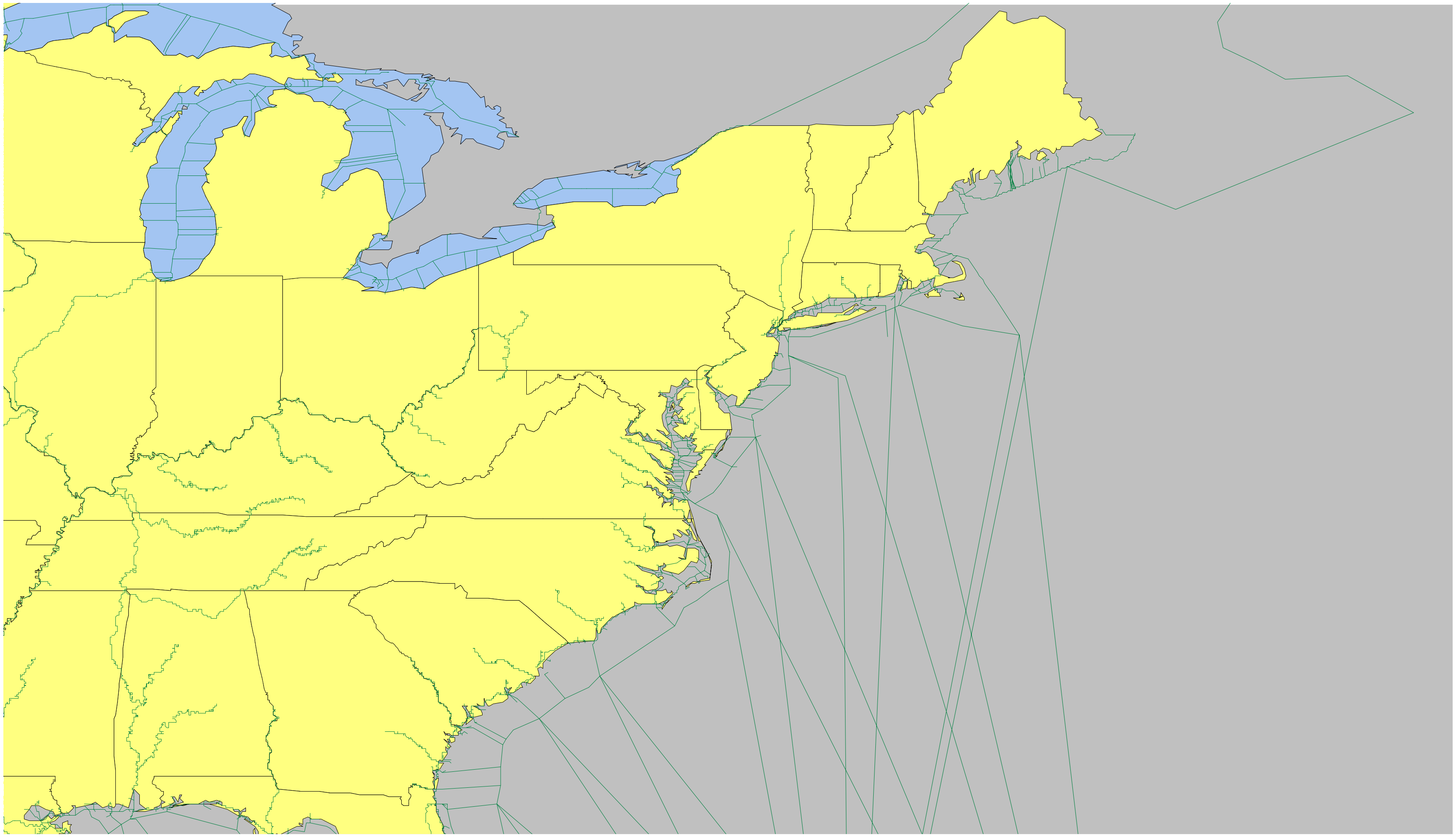
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>10mi from shore for Great Lakes)



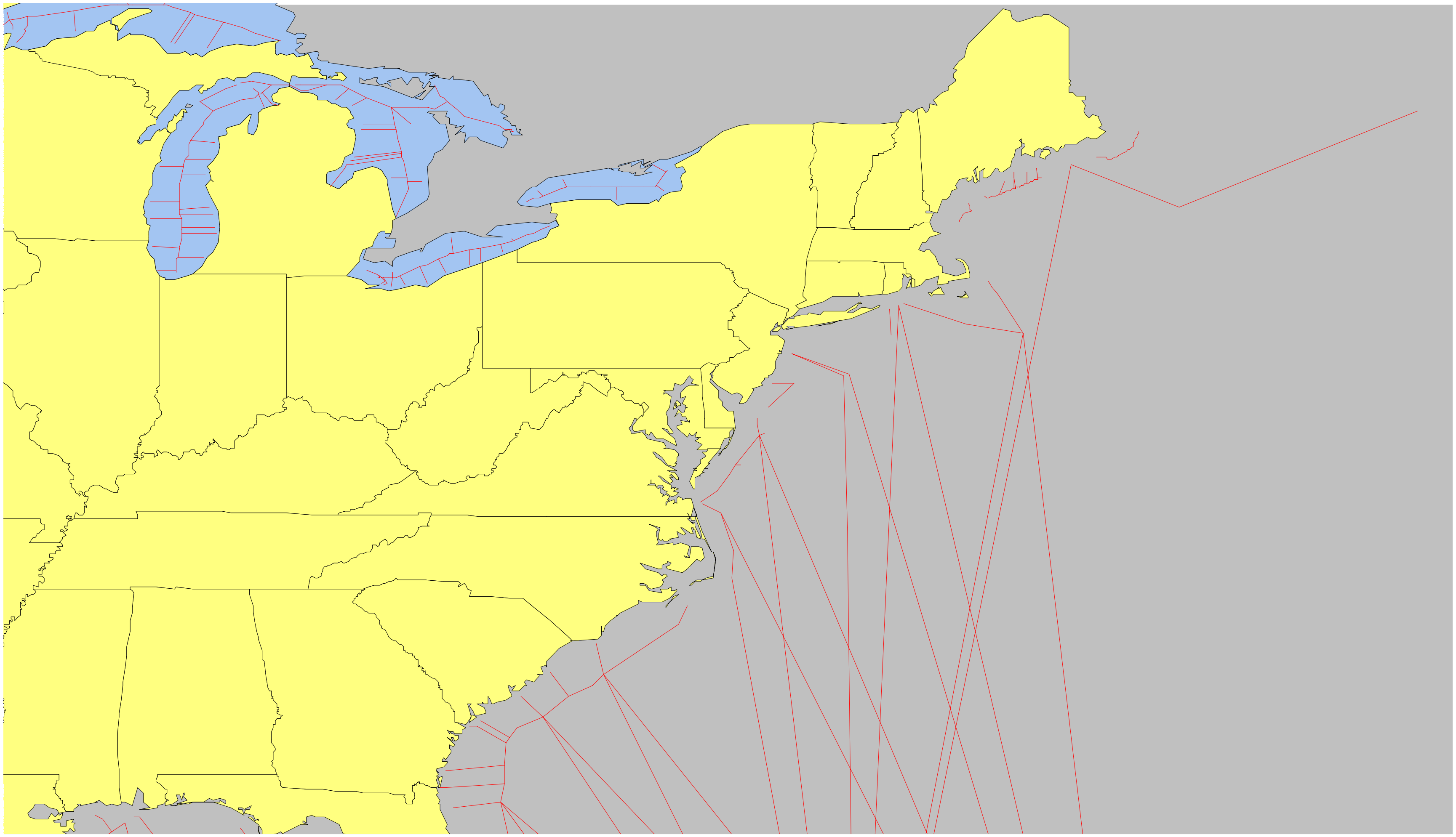
# USACE Waterway Link Network (East Coast)



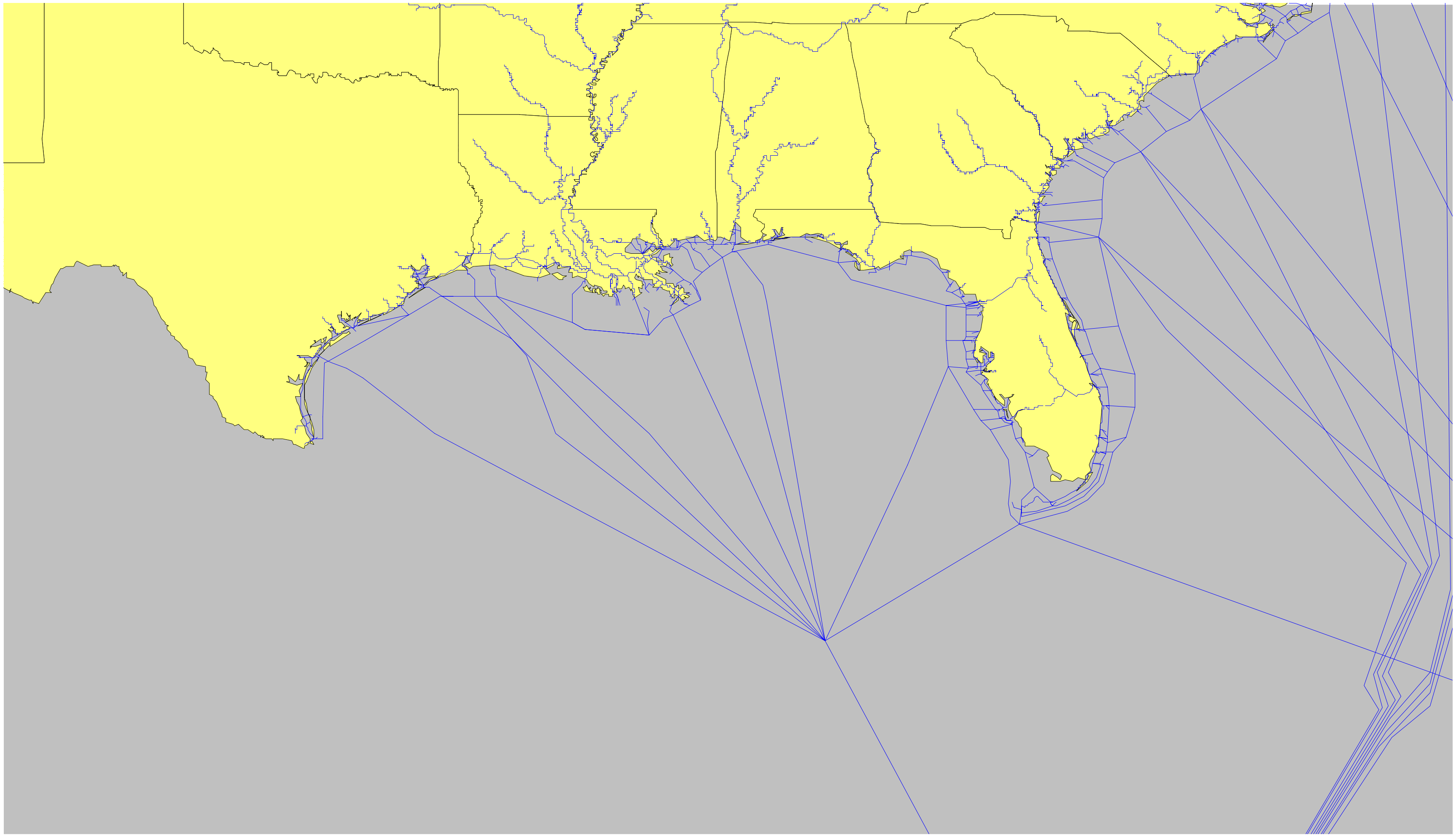
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (East Coast)



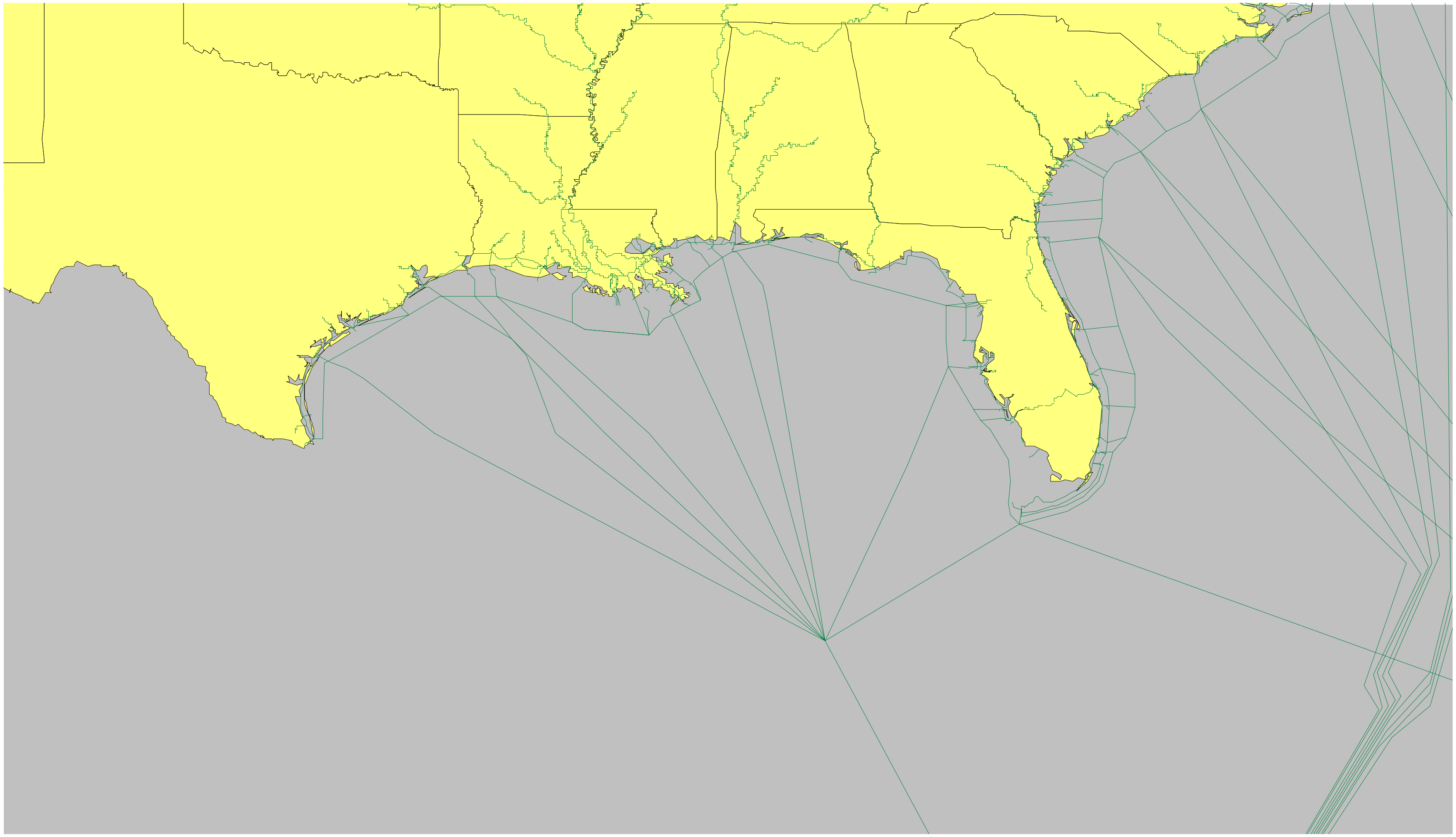
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for East Coast)



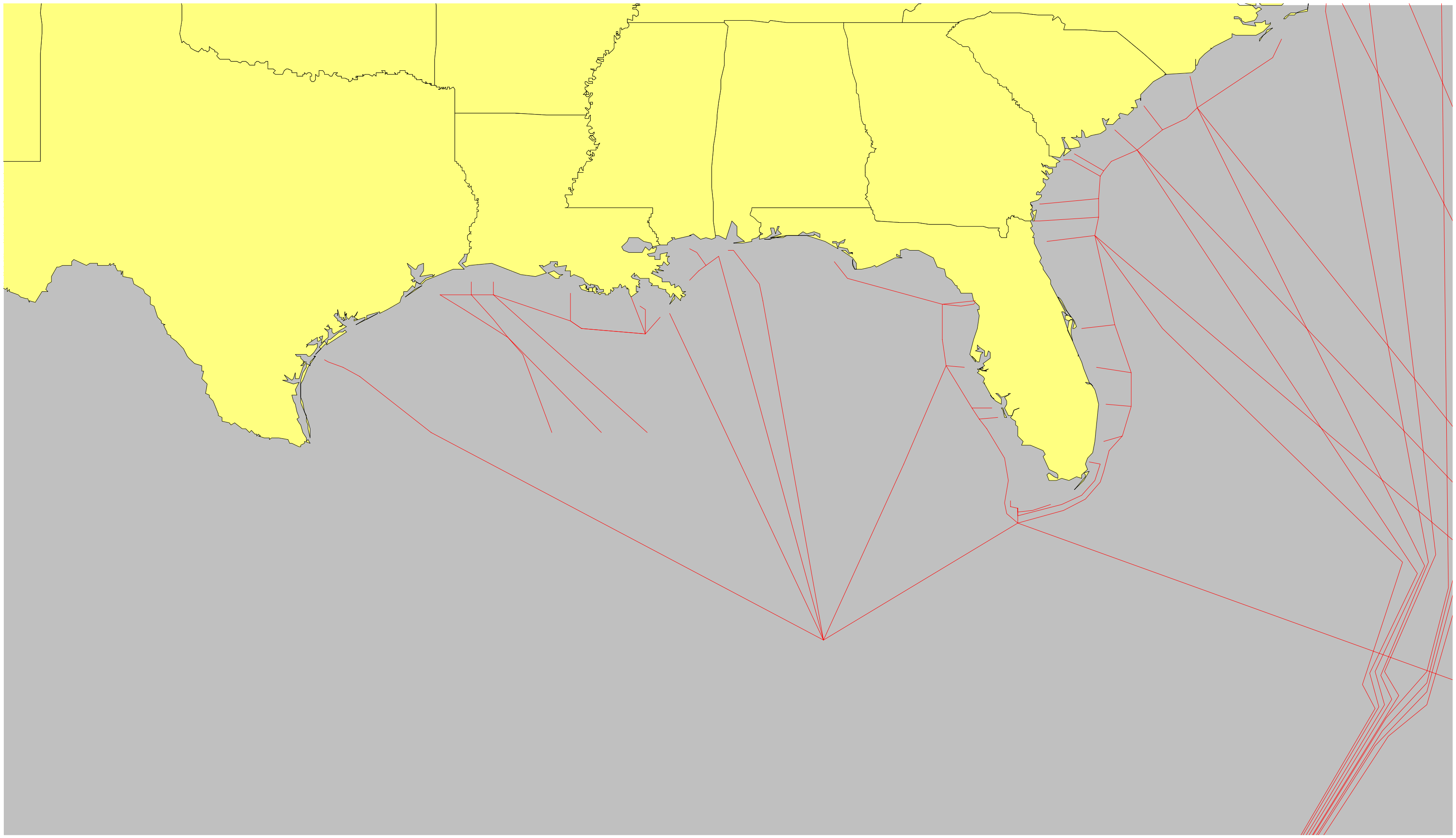
# USACE Waterway Link Network (Gulf Coast)



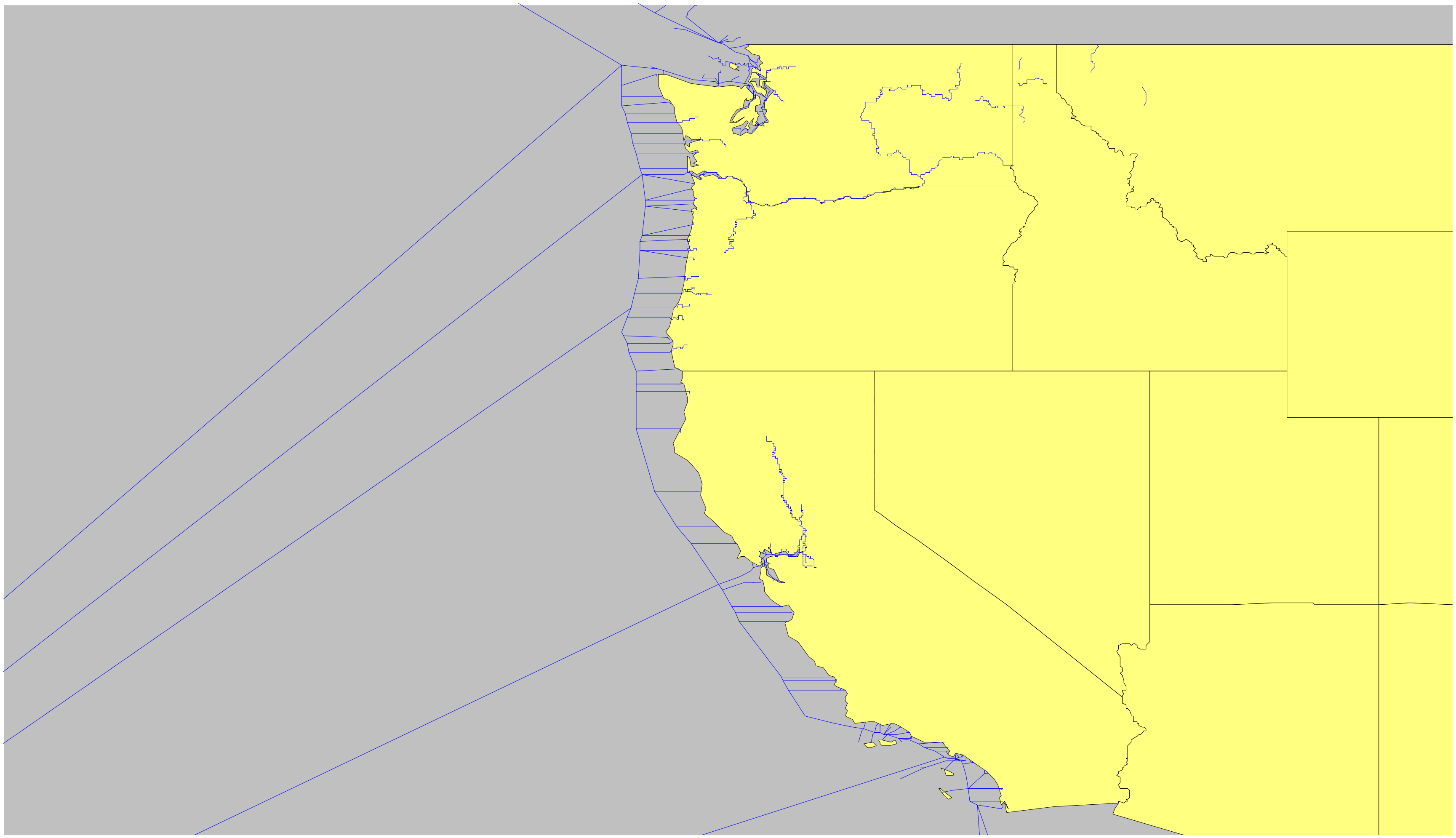
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Gulf Coast)



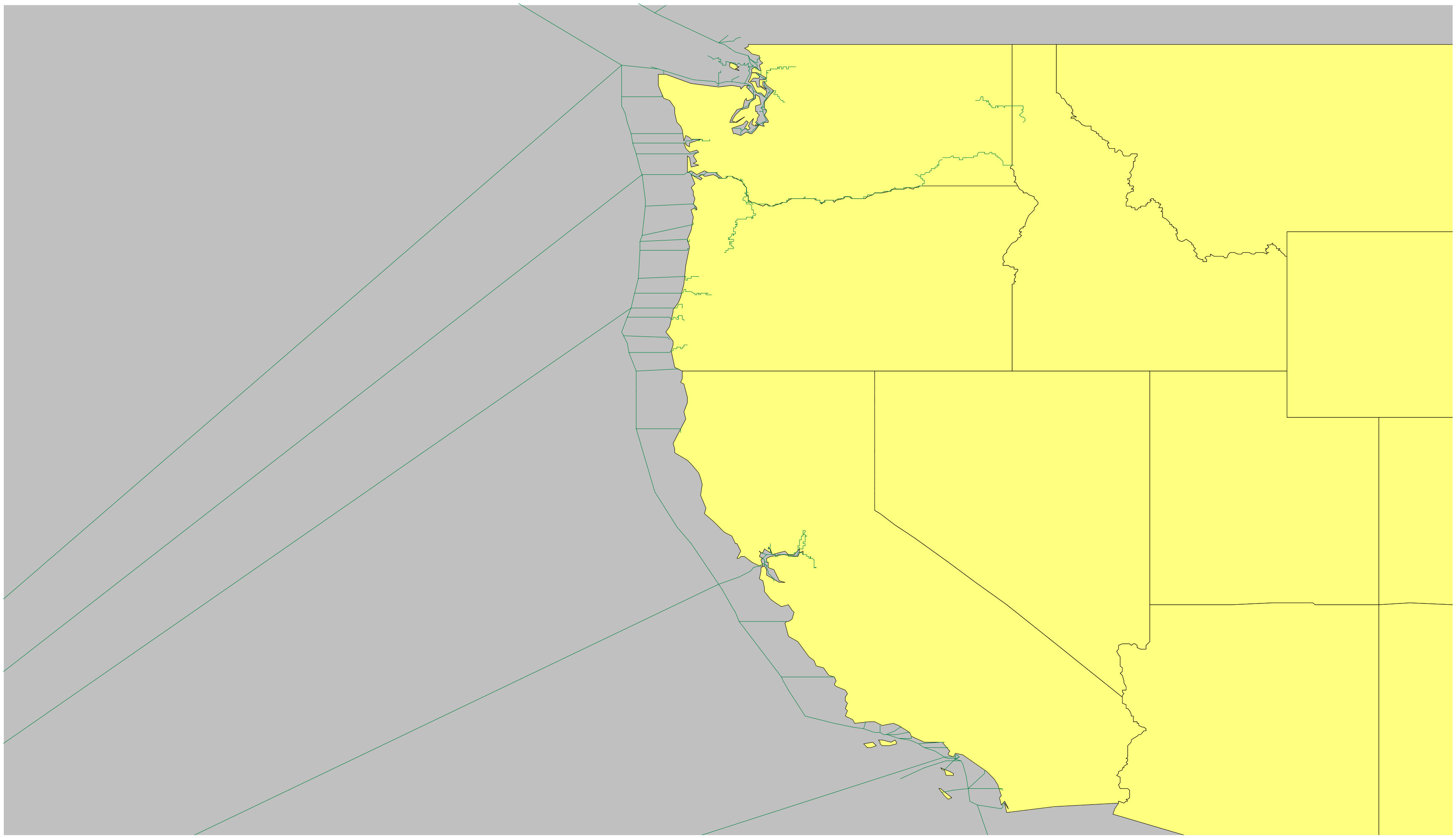
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for Gulf Coast)



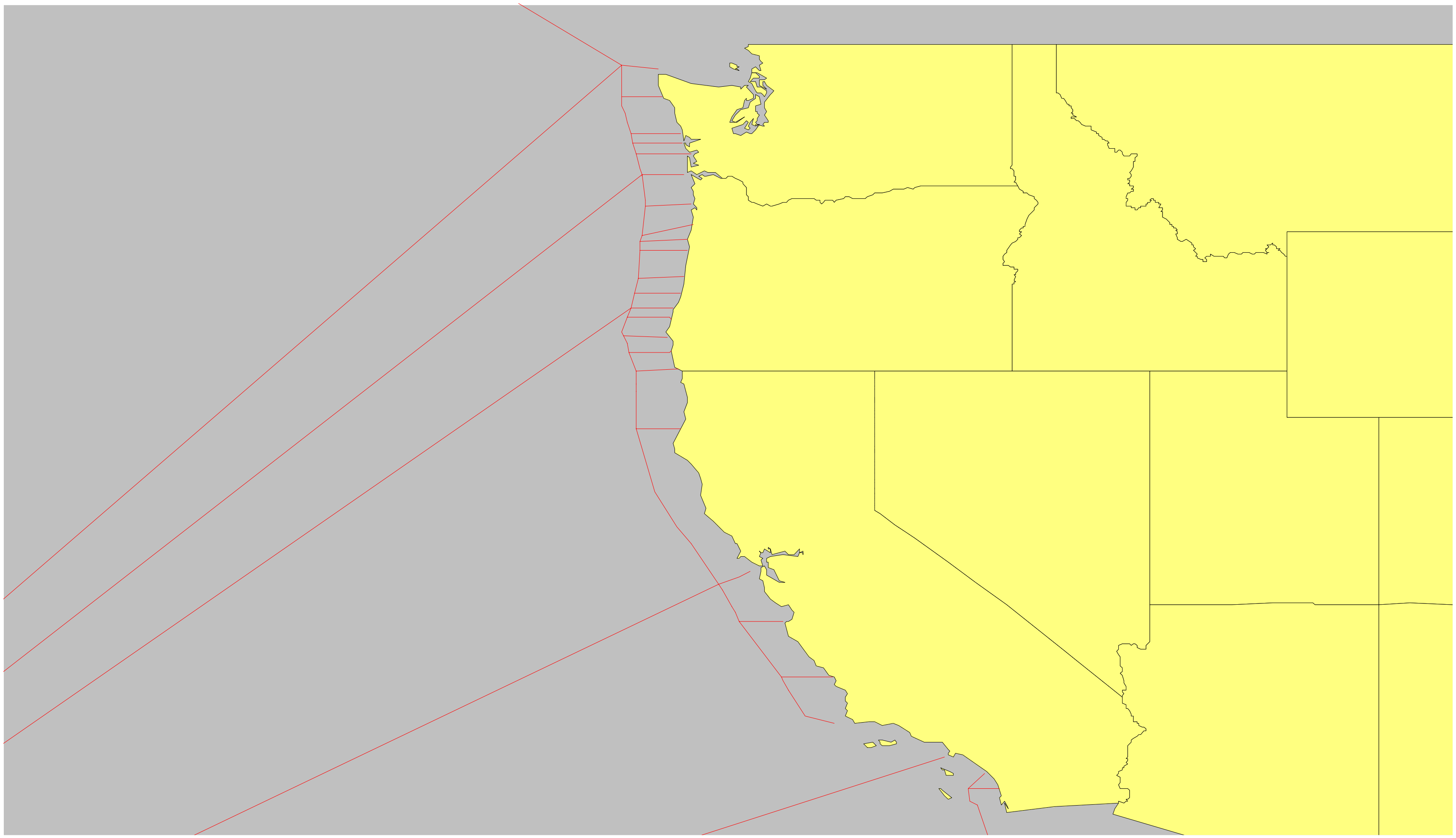
# USACE Waterway Link Network (West Coast)



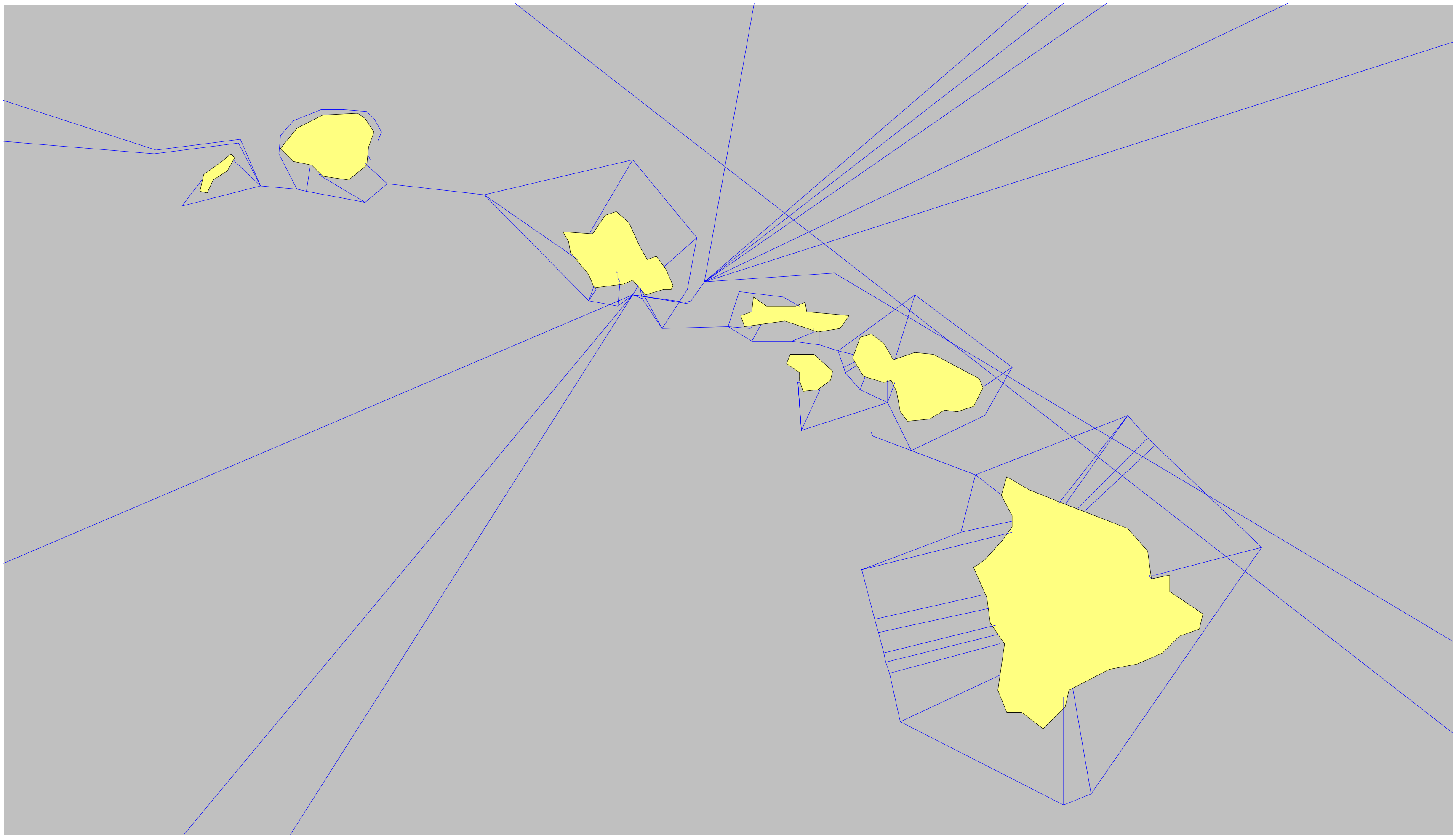
## USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (West Coast)



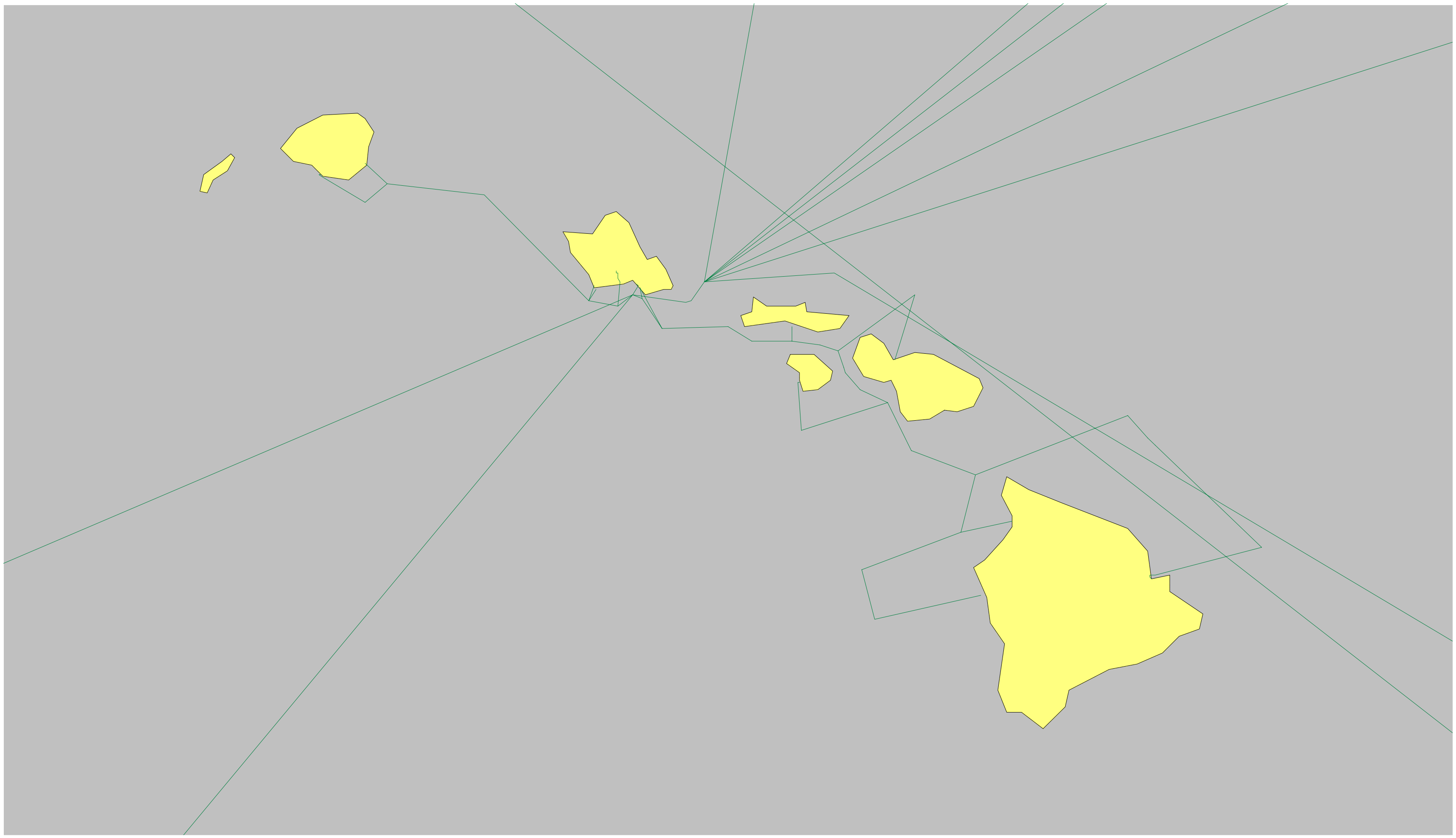
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for West Coast)



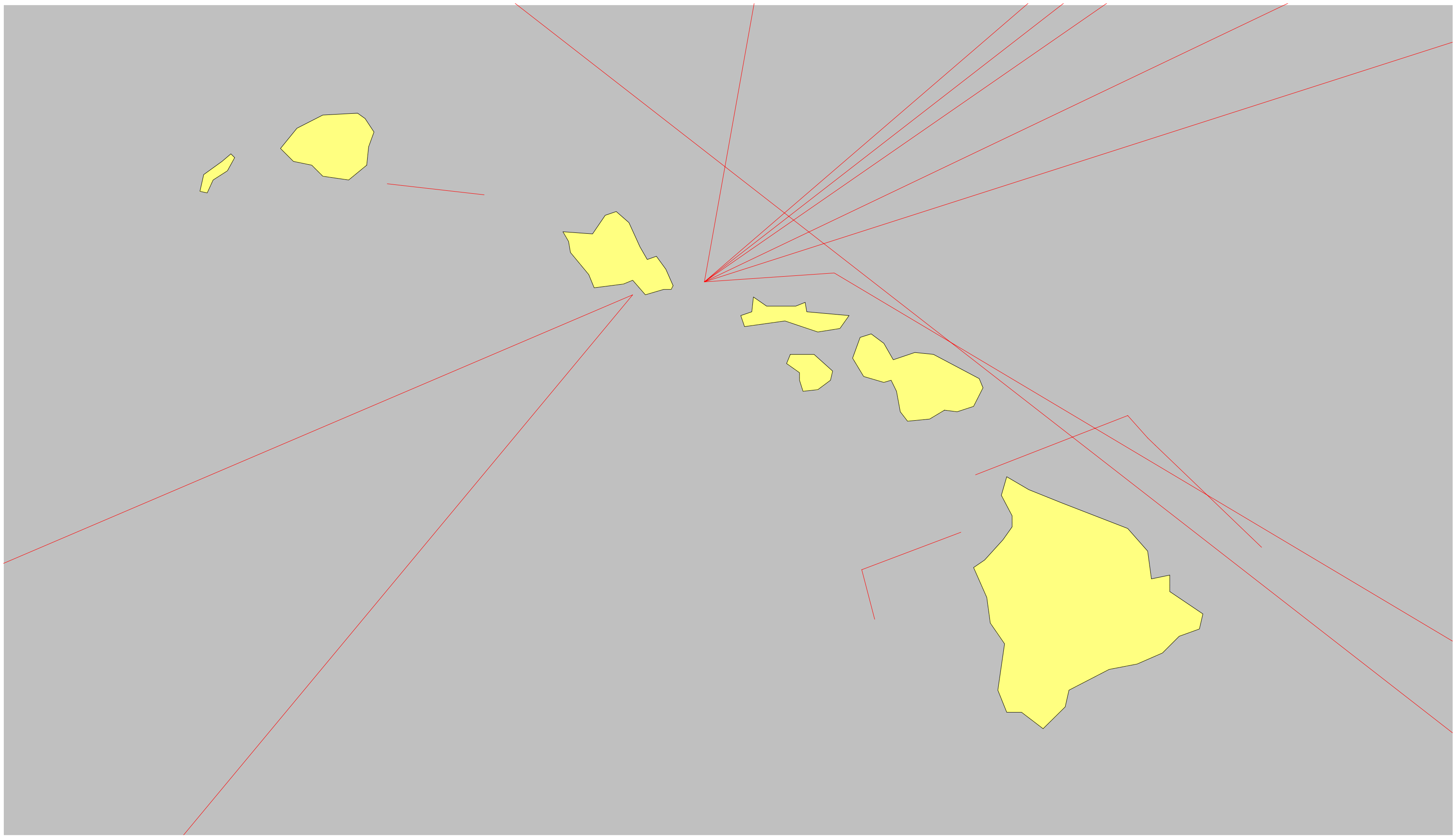
# USACE Waterway Link Network (Hawaii)



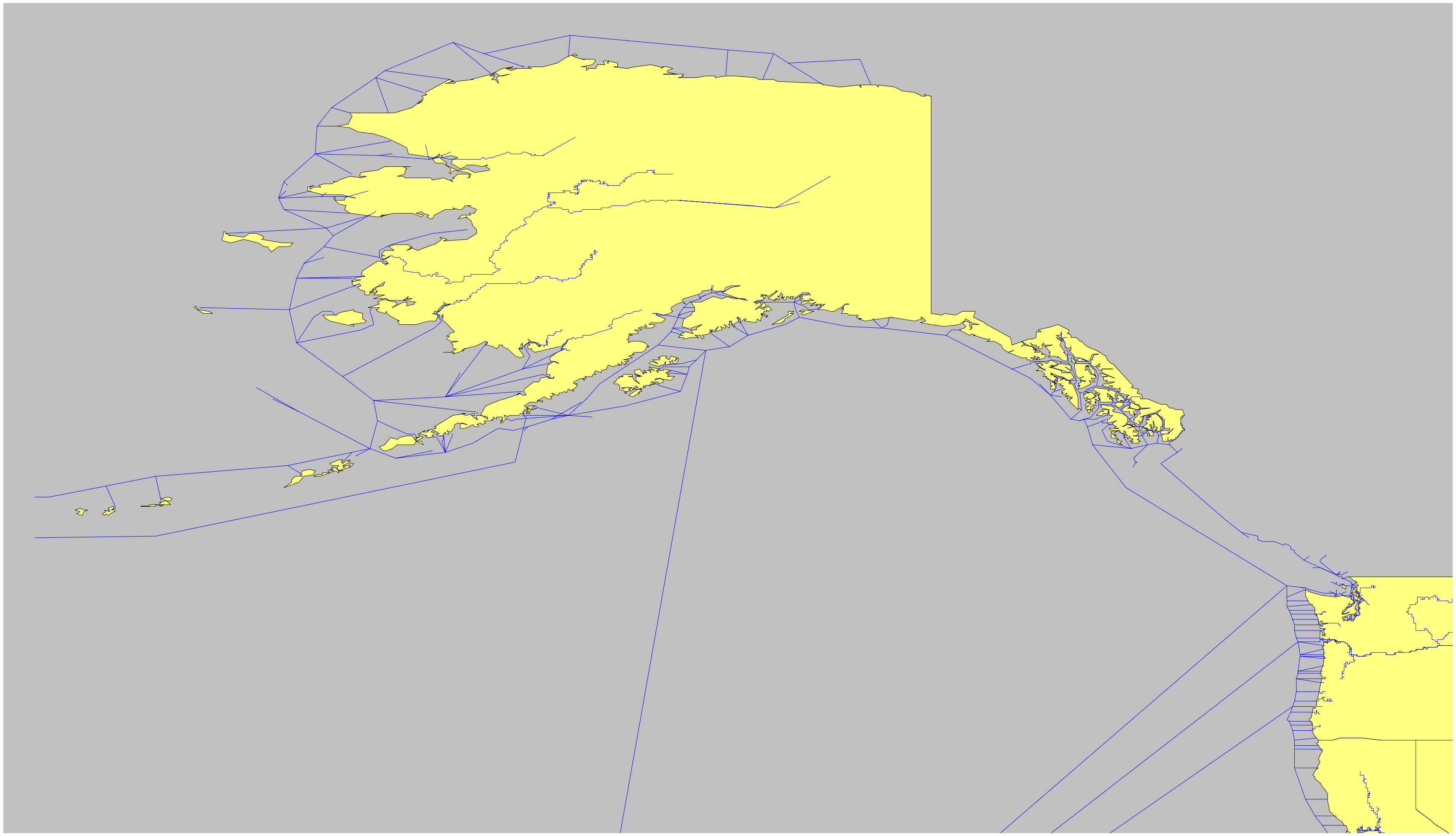
## USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Hawaii)



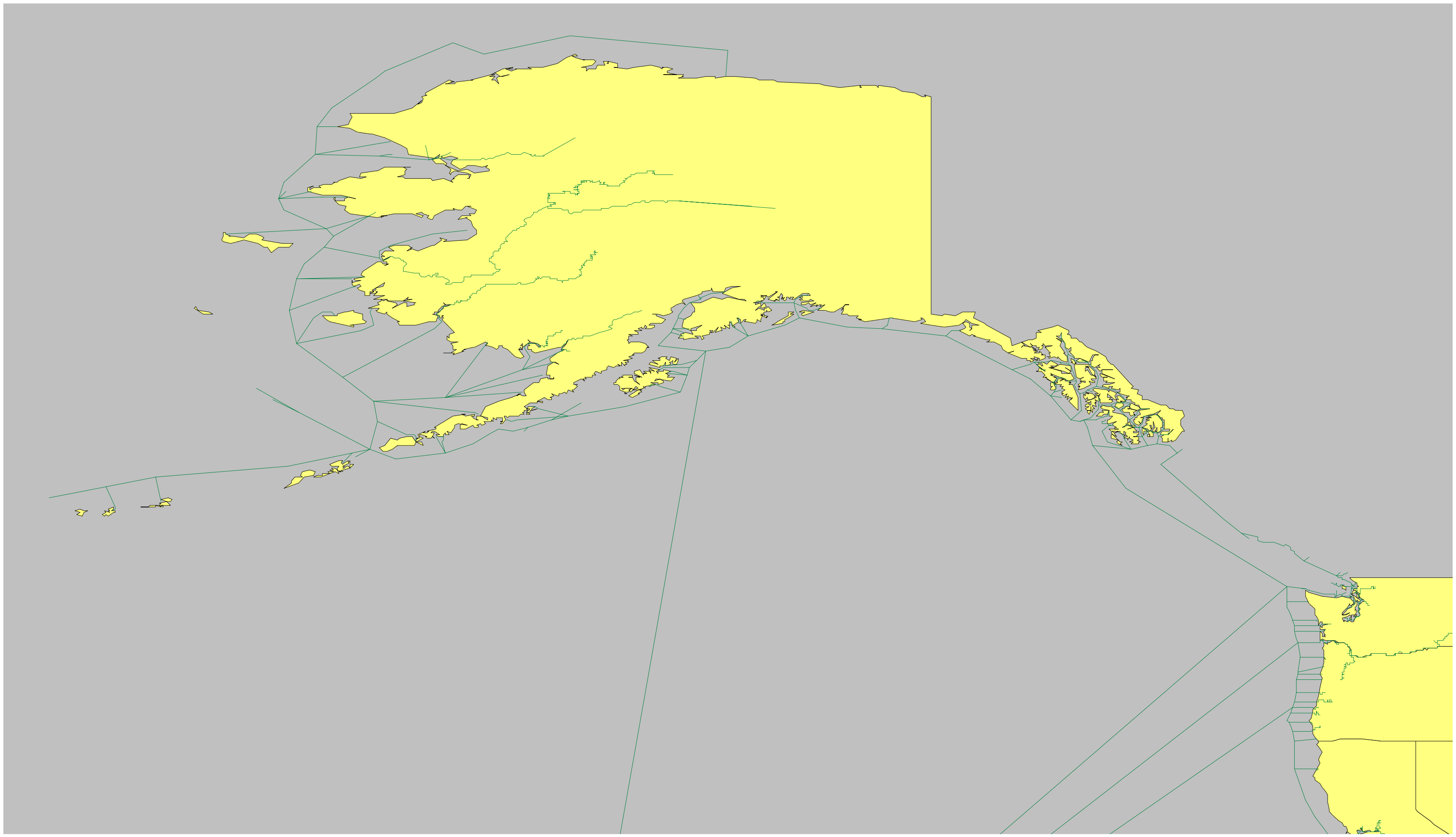
# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for Hawaii)



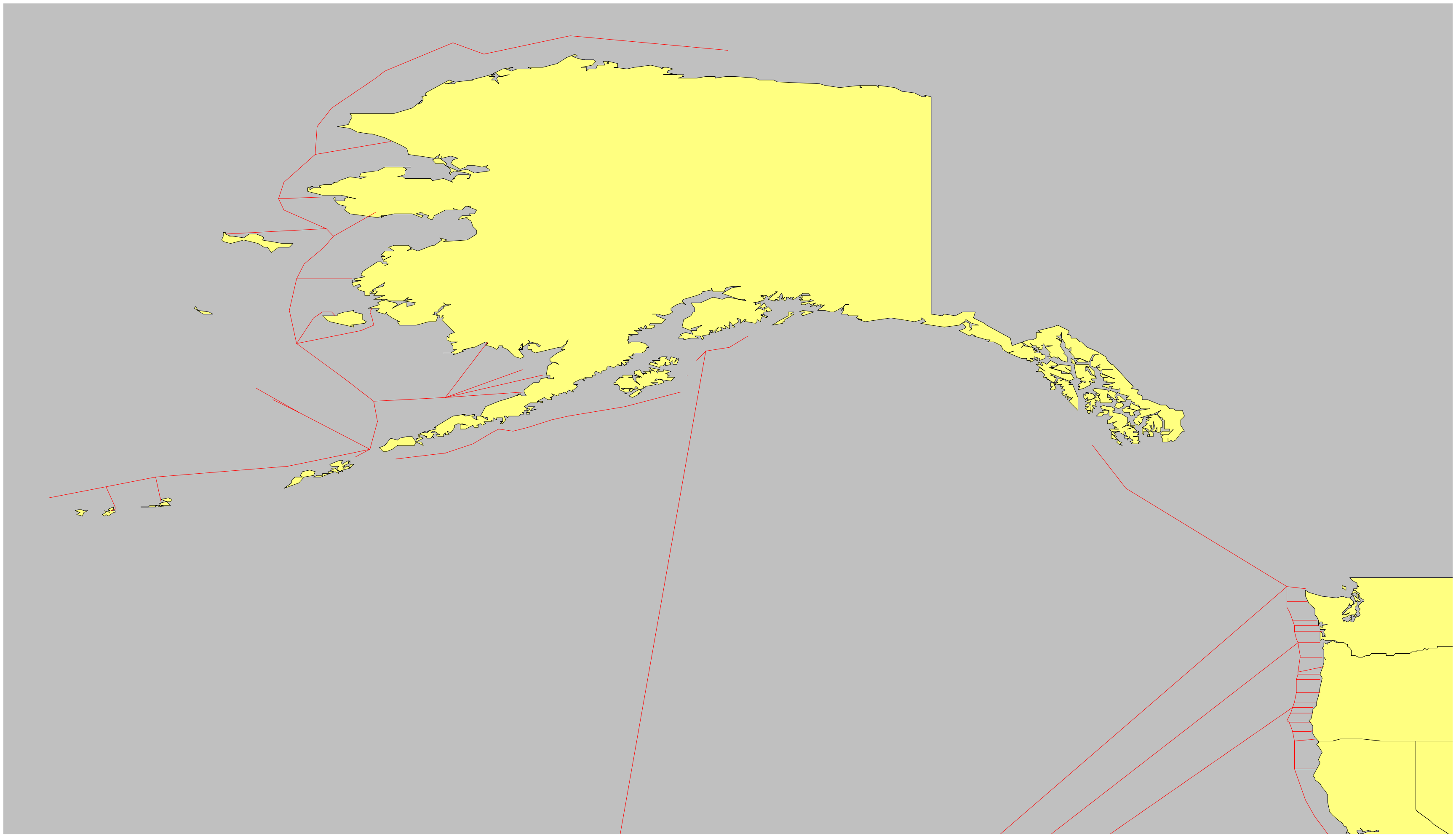
# USACE Waterway Link Network (Alaska)



# USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Alaska)



## USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for Alaska)



# APPENDIX D

## Domestic Fleet Traffic

**DOMESTIC FLEET TRAFFIC**

The difficulty with the domestic fleet was that some of the ocean and lake traffic could be served by either tow boats (using Category 1 or 2 engines) or larger vessels (using Category 3 engines). The domestic fleet comprises a relatively small number of vessels from the BTS (1999) review quoted below.

> "The fleet serving U.S. domestic deep-sea trades in 1997 included 39 dry-cargo vessels (800,000 dwt), 122 tankers (8.2 million dwt), 3,393 dry-cargo barges (4.8 million DWT) and 669 tank barges (3.4 million dwt). Barges carried 86 percent of deep-sea cargoes moved less than 500 miles, while self-propelled vessels carried 91 percent of the metric tons moved in trades greater than 1,500 miles."

The Table C-1 describes the domestic sea trade tonnage by length of voyage demonstrating that most of the traffic traveling over 1,000 miles was handled by vessels, considered in this work to be powered by Category 3 propulsion engines. Applying the average trip length to the tonnage by vessel from Table D-1 indicates that domestic ton-miles would be estimated to be $223 \times 10^9$ for all traffic compared with the $112 \times 10^9$ estimate in this work for ocean trip traffic in the 25 - 200 mile range.

**Table D-1.** Domestic Deep-Sea Trade, Self-Propelled Vessel v. Barge, by Length of Haul, 1997 (Million metric tons) (Table 1-18, BTS, 1999)

| Miles | Barge | Vessel | Total | Percent (barge) |
|---|---|---|---|---|
| < 500 | 55.6 | 9.2 | 64.8 | 85.8 |
| 500-1,000 | 32.7 | 12 | 44.7 | 73.1 |
| 1,001-1,500 | 11.7 | 42 | 53.7 | 21.8 |
| 1,501-2,000 | 3.7 | 35.3 | 39 | 9.4 |
| > 2,000 | 3.6 | 38.4 | 42 | 8.6 |
| **Total** | **107.3** | **137** | **244.3** | **43.9** |

# APPENDIX E

## Comparison with Corbett and Fischbeck (1998)

## EMISSION TOTAL COMPARISONS

A comparison of the emission results from this work with those previously estimated for Corbett and Fischbeck (1998). The comparison shows that the emission totals are similar for all vessels together though somewhat smaller for the comparable in-use year of 1996.

**Table E-1**. Comparison of Category 3 results between Corbett and Fischbeck (1998). (1,000 tons/year).

| Emission Estimate | HC | CO | NOx | PM | $SO_2$ |
|---|---|---|---|---|---|
| Corbett (1998) (Table 2) 1996 Category 3 US Flag | 3.4 | 10.6 | 118.8 | 9.6 | - |
| Corbett (1998) (Table 2) 1996 Category 3 Foreign Flag | 3.6 | 11.0 | 116.9 | 8.7 | - |
| Corbett (1998) (Table 2) 1996 Category 3 Total | 7.0 | 21.6 | 235.7 | 18.3 | - |
| Corbett (1998) (Table 3) 1993 Category 3 US Flag | 1.3 | 4.4 | 57.1 | 4.1 | - |
| Corbett (1998) (Table 3) 1993 Category 3 Foreign Flag | 3.6 | 11.0 | 117.0 | 8.7 | - |
| Corbett (1998) (Table 3) 1993 Category 3 Total | 4.9 | 15.4 | 174.0 | 12.8 | - |
| Chapter 3 Category 3* 1996 Near Ports | 5.2 | 11.5 | 101.0 | 9.2 | 68.2 |
| Chapter 4 Category 3* 1996 Between Ports | 2.1 | 4.2 | 88.8 | 7.8 | 58.9 |
| 1996 Total Emissions | 7.3 | 15.7 | 189.8 | 17.0 | 127.1 |

* Category 3 were summed as transit mode emissions of merchant vessels plus hotelling emissions for passenger and reefer vessels including steamships.