Delaware River Recreation Safety Study

An Assessment from the Commodore Barry Bridge to the Tacony-Palmyra Bridge

June 2023

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Section 1 Introduction

The objective of this Safety Study is to identify maritime, hydraulic and shoreline hazards in the urbanized reach of the Delaware and tidal Schuylkill Rivers and to detail safety concerns that may arise from primary contact recreation activities taking place in a location with such hazards. Primary contact recreation activities included in this study are swimming, wading, kayaking, paddleboarding, canoeing and jet skiing.

The Pennsylvania Department of Environmental Protection (PADEP) presently excludes primary contact recreation from the designated uses in the Delaware River from the Commodore Barry Bridge to the Tacony-Palmyra Bridge and the tidal Schuylkill River from the Delaware River confluence to the Fairmount Dam. This exclusion is due to the continuing significant impacts from combined sewer overflows and hazards associated with commercial shipping and navigation (Pennsylvania Bulletin, 2020).

The Study Area encompasses the Delaware River from the Commodore Barry Bridge to the Tacony-Palmyra Bridge (Zone 3 and upper Zone 4, River Miles 108.4–81.8) and the tidal Schuylkill River from the Delaware River confluence to Fairmount Dam. For mapping purposes, the main text of this report will depict the full extent of the Study Area, Figure 1.1. Additional detailed maps of the Study Area divided into upper, lower and middle reaches are presented in Appendix A.

This Safety Study is intended to reach a broad audience of regulatory agencies, regulated entities, environmental advocacy organizations, rescue and security organizations, the general public, the maritime community and the recreation community. Information within this report may help inform recreation decisions at the regional, state, municipal and individual levels. The context within which the Safety Study may provide support to regulatory agencies is detailed at the end of the report in Section 11.

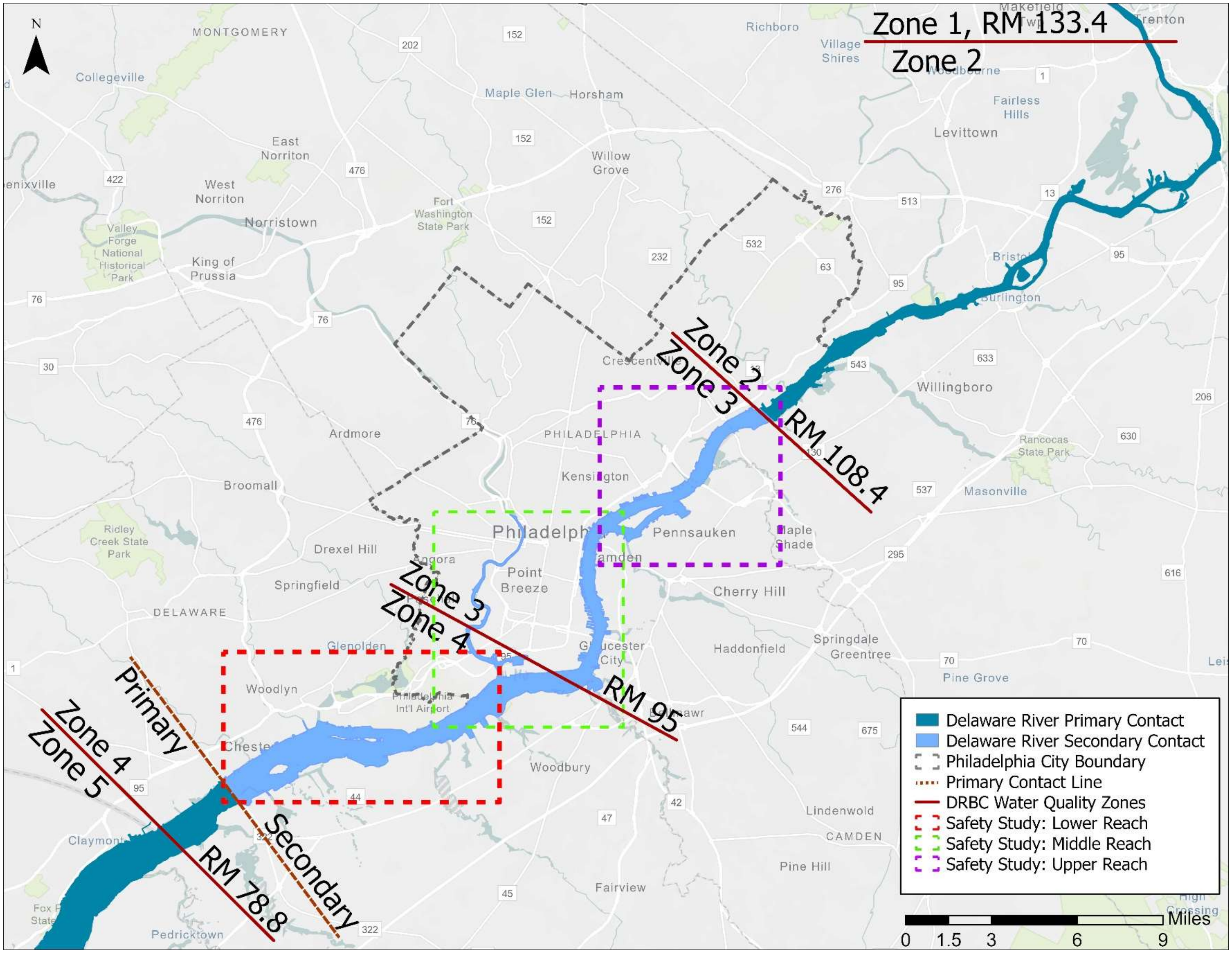


Figure 1.1 Study Area of this Safety Study

1.1. Report Structure

Section 1 Introduction

Introduces the Safety Study and the location of the Study Area.

Section 2 Water Safety Regulations and Enforcement

Discussions of the enforcement role, safety guidance and concerns of the entities responsible for rescue, recovery and security in the Study Area.

Section 3 Commercial Shipping and Navigation Activities

Documentation of commercial vessel traffic for two recent years in the Study Area and during the recreation season, analysis of vessel traffic density and economic impacts of maritime industry.

Section 4 Hydraulic and Shoreline Modifications

Documentation of navigation channel, dredging, active and inactive shoreline infrastructure.

Section 5 Hydraulic Hazards

Analysis of water depth, river width, current velocity and wind-generated waves in the Study Area.

Section 6 Shoreline and Other Hazards

Analysis of debris and hazards from active and inactive shoreline infrastructure.

Section 7 Maritime Hazards

Analysis of hazards from commercial shipping and supporting vessels, ship navigation and visibility limitations.

Section 8 Primary Contact Recreation Activities

Detailed documentation and discussion of the characteristics of each recreational activity reviewed and establishment of recommended safety criteria.

Section 9 Primary Contact Recreation Hazard Assessment

Discussion comparing each hydraulic, shoreline and maritime hazard with safety recommendations developed for each recreational activity within the Study Area.

Section 10 Summary of Findings and Conclusions

Summary of assessment and conclusions.

Section 11 Safety in the Use Attainability Analysis Context

Overview of recreational use evaluations conducted within and outside of the Study Area and discussion of UAA findings for the Delaware River Recreation Safety Study.

Section 2 Water Safety Regulations and Enforcement

Multiple municipal, state and federal agencies are responsible for responding to water emergencies, conducting rescue and recovery missions and enforcing boating and homeland security regulations in the Study Area. The Philadelphia Water Department (PWD) interviewed officials from the Philadelphia Police Department Marine Unit, New Jersey State Police Marine Services Bureau, Pennsylvania Fish and Boat Commission, and U.S. Coast Guard Sector Delaware Bay to document roles, jurisdiction, regulations, and safety concerns for primary contact recreational activities in the Study Area.

2.1. Philadelphia Police Department Marine Unit

The Police Marine Unit (PMU) extends and supplements the patrol force of the Philadelphia Police Department (PPD). It is part of the Domestic Preparedness and Response Division of the PPD's Homeland Security Bureau. The PMU mission is to respond to all water-related emergencies and to conduct rescues and recoveries of persons and properties from the water. It also works to deter crime, encourage safe boating and promote water safety.

2.1.1. Philadelphia Patrol and Enforcement

The PMU's area of responsibility consists of 42 miles of navigable waterways, including the Delaware and Schuylkill Rivers, as well as numerous creeks and streams located within or adjacent to Philadelphia County. It is a "shore-to-shore" operation, extending eastward to the western coast of New Jersey. PMU boats conduct random patrols of the Delaware River (Figure 2.1), but it is not budgeted to patrol the Schuylkill River unless specifically requested to assist, such as for a regatta. When on patrol, officers will attempt to remove swimmers from the water when possible, but they have little to no interaction with kayakers and paddleboarders. The PMU does not patrol continuously in the Study Area, and response time is limited by the proximity of assets to the location of an incident.

Figure 2.1 Philadelphia Police Department Marine Unit Patrol Boat near Ben Franklin Bridge

PMU Public Safety Dive Specialists operate throughout the area when needed. Divers respond to emergencies 24 hours a day, 7 days a week. They dive in the middle of the night, during inclement weather, in zero visibility "black water" and in waters polluted by chemicals and biohazards. Public Safety Dive Specialists also support numerous other federal, state and municipal law enforcement agencies on request. These include the U.S. Coast Guard, U.S. Customs & Border Protection, the Secret Service, the Navy, the FBI and the State of New Jersey.

2.1.2. Police Marine Unit Safety Guidance

A core mission of the PMU is to promote water safety in waterbodies located within or adjacent to Philadelphia County. On July 24, 2020 the PPD Twitter account posted a five-minute public service announcement video in which PMU Lt. Andrew Napoli discussed the dangers of swimming in local waterbodies, particularly the tidal Delaware and tidal Schuylkill Rivers (Figure 2.2).

Figure 2.2 Philadelphia Police Department July 24, 2020 Video on the Dangers of Swimming in Philadelphia County Waterways

Lt. Napoli stressed that even the best swimmers cannot swim against the tidal currents in the Delaware and Schuylkill Rivers and that drowning is a serious threat as strong currents can pull swimmers underwater. He also discussed the overabundance of submerged debris that is not visible and can easily snag or injure swimmers. For these reasons, the PPD strongly encourages the public to utilize neighborhood pools and spraygrounds rather than trying to swim in Philadelphia County waterways (Philadelphia Police Department, 2020).

2.1.3. Police Marine Unit Concerns

The PMU is concerned about hazards to swimming, paddling and jet skiing in the Study Area. People tend to want to return to the shoreline where they entered the water; however, this is often not possible because it is very difficult to swim against strong currents. The risk of drowning increases markedly as swimmers become tired trying to fight the current. The PMU particularly noted the lack of safe swimming access points in Philadelphia County and explained that legacy submerged infrastructure, rubbish, scrap metal and debris make diving and jumping in the water completely unsafe in the Study Area.

The PMU recognizes that everyone raises concerns about river safety after a tragedy, yet interest in discussing these hazards diminishes significantly as time passes. Officials stressed that PMU officers are not lifeguards and do not have the resources to patrol continuously for safety risks to swimmers, paddlers and jet skiers (Philadelphia Police Department Marine Unit, personal communication, July 8, 2021).

2.2. New Jersey State Police Marine Services Bureau

The New Jersey Marine Services Bureau (NJMSB) provides law enforcement services for all New Jersey waterways. Its mission is to protect and serve the New Jersey boating community and to preserve the state's natural resources by utilizing general law enforcement concepts and training and education, as well as by enforcing all laws fairly and without bias. The NJMSB also provides a preventive level of homeland security through intelligent, vigilant and highly visible patrol measures.

2.2.1. New Jersey Patrol and Enforcement

The NJMSB is responsible for patrolling all waterways within and adjacent to the State of New Jersey. The Bureau is composed of ten stations; while these stations are strategically located throughout the state to help the NJMSB meet its far-ranging mission, none is located directly within the Study Area (Figure 2.3).

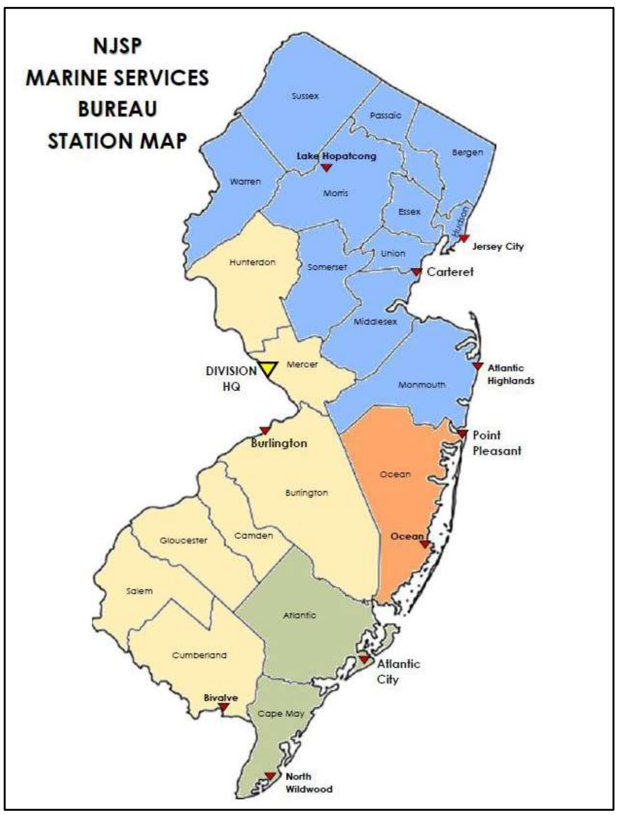


Figure 2.3 NJSP Marine Services Bureau Station Locations

The Burlington and Bivalve Stations are responsible for the western New Jersey coast, from Cape May north to Hunterdon County.

Troopers assigned to the Burlington and Bivalve Stations are 24-four hours a day, 7 days a week, including weekends and holidays. Troopers patrol the Delaware River two times a day.

Troopers are expected to be proactive about enforcing regulations for kayakers, paddleboarders and jet skiers. However, they generally interact only with swimmers who are affecting commercial and recreational boating.

NJMSB does not patrol continuously in the Study Area, and response times are limited by the location of officers and response vessels.

2.2.2. New Jersey Marine Services Bureau Regulations

The New Jersey State Police Boating Safety Manual references regulations that apply to swimming and jet skiing in the Study Area (Figure 2.4). The purpose of the manual is to educate boaters about applicable laws and regulations and to reduce the risk of loss of life, injury and property damage associated with the use of New Jersey waterways. Most notably, New Jersey regulations state that no person may swim in a shipping channel, under a bridge or impede, obstruct, or interfere with passage of watercraft therein (New Jersey State Police, 2013).

Skin Diving

- No person may swim or dive in a narrow, confined or improved channel or in a marked fairway, under a bridge or impede, obstruct or interfere with passage of watercraft therein.

Personal Watercraft

- A person shall not operate a personal watercraft above the minimum headway speed within 100 feet of:
    - Buoys or signs that mark the boundaries of a swimming area
    - The shoreline
    - Any person in the water
    - Residential dwelling units

Figure 2.4 NJ State Police Boating Safety Manual - Swimming and Jet Skiing Regulations

2.2.3. New Jersey Marine Services Bureau Concerns

The NJMSB is concerned about hazards to swimming, paddling and jet skiing in the Study Area, emphasizing that the public should be informed about the inherent safety risks and hazards before engaging in these activities. Officials stressed that unlike patrol cars, police boats are not stationed at all locations along the Delaware River. This means response times to swimmers, paddlers and jet skiers in distress are dependent on officer and response boat locations when incidents are reported. For instance, a patrol boat in Trenton, New Jersey could be a one-hour ride away from responding to an incident in Camden, New Jersey (New Jersey State Police Marine Unit, personal communication, July 8, 2021).

2.3. Pennsylvania Fish and Boat Commission

The Pennsylvania Fish and Boat Commission (PAFBC) Waterways Conservation Officers are responsible for enforcing boating laws and regulations in Pennsylvania. Waterways Conservation Officers are certified boating safety instructors and specially trained in all aspects of watercraft safety.

2.3.1. Pennsylvania Patrol and Enforcement

PAFBC Waterways Conservation Officers patrol the tidal Delaware and the tidal Schuylkill Rivers. Three officers have shared jurisdiction in the Study Area, though each officer has discretion as to where to patrol and when. More patrols occur between Memorial Day and Labor Day, when temperatures are warmer and a greater number of people uses the Delaware River. PAFBC does not patrol continuously in the Study Area, and response time is limited by the location of officers and response vessels.

PAFBC Waterways Conservation Officers are also responsible for enforcing U.S. Coast Guard homeland security regulations. An officer observing a violation will direct the person(s) to move out of the restricted area. In the event of non-compliance, the officer will contact the Coast Guard and assist in moving the person(s) out of the restricted area.

2.3.2. Pennsylvania Fish and Boat Commission Regulations

The PAFBC *Pennsylvania Boating Handbook* provides boaters with information necessary for operating watercraft on Pennsylvania waterways, including a review of state and federal boating regulations. The PAFBC included Homeland security requirements in the boating handbook at the request of the U.S. Coast Guard following the September 11, 2001 terrorist attacks and the earlier attack on the USS COLE in Aden Harbor, Yemen (Figure 2.5). Homeland security requirements apply to all watercraft, including kayaks, canoes and paddleboards. Regulations require all watercraft to stay at least 100 yards from all military, cruise line or commercial shipping vessels (Pennsylvania Fish and Boat Commission, 2021).

Homeland Security

Strict regulations have been issued relating to waterways for national security. Boaters must follow these regulations or be exposed to serious penalties. Our mutual security, in part, depends on your diligence in reporting suspicious activities that you may encounter on the water.

REQUIREMENTS FOR ALL WATERCRAFT:

- Stay at least 100 yards from all military, cruise line, or commercial shipping vessels. Violating the Naval Vessel Protection Zone is a felony offense, punishable by up to six years imprisonment and/or up to $250,000 in fines.
- You must operate at slow, no-wake speed within 500 yards of U.S. Naval vessels.
- Check with local authorities and refer to current charts to identify and stay away from security zones and port operation areas.
- Generally, stay at least 100 yards from military areas, cruise lines, and petroleum facilities. Also, stay away from dams and power plants.

At the request of the Captain of the Port, or District Commander, an area may also be designated a Security Zone. This zone may be highlighted in magenta (pink-red coloration) on charts to better stand out and warn the public to stay clear. Unauthorized vessels, without specific permission to enter, must stay out of these marked areas. Armed military, harbor police, or civilian authorities, securing these areas, will confront violators.

GUIDELINES:

- Do not stop or anchor beneath bridges or in a channel. If you do stop, be prepared to be boarded by patrolling authorities.
- Be observant and report any suspicious activity to USCG or local authorities.
- Always secure and lock your boat when not on board.

Figure 2.5 *Pennsylvania Boating Handbook* - Homeland Security Legal Requirements

2.3.3. Pennsylvania Fish and Boat Commission Guidance

In 2007 the PAFBC published an article about the dangers of wakes in its "Pennsylvania Angler & Boater Magazine." The article identified the Delaware Estuary as a dangerous place in Pennsylvania for wake damage from large commercial ships, such as freighters, tankers, and barges. It explained that the wakes these vessels create can easily buffet even large recreational craft and discussed their ability to swamp smaller boats. The article reminded readers that in the Delaware Estuary, within which the Study Area is located, commercial vessels have the right of way, so boaters must stay well out of their way and remain alert for commercial traffic (Pennsylvania Fish and Boat Commission, 2007).

In 2010, the PAFBC and other agencies developed safety guidance for paddling and boating the Tidal Delaware River Water Trail, one of Pennsylvania's 27 designated water trails (Pennsylvania Fish and Boat Commission, 2010). The guidance listed in Figure 2.6 was developed for the Philadelphia section of the tidal Delaware River and is therefore applicable to the Study Area. The area between the Walt Whitman and Ben Franklin bridges, where the shipping channel is not marked, was noted as having particularly heavy ship traffic and numerous anchorages, terminals, and piers. The guidance also discussed hazards from commercial vessel traffic, tugboat wakes, tides, currents, floating debris, and river walls.

Floating the River

- Large commercial boats traverse the shipping lane that runs the length of the tidal river (lane marked by green and red buoys). These ships can be fast-moving and cannot stop or slow down easily. In addition to avoiding ships, recreational boaters need to be alert for the large wakes generated by ships.
- Kayakers can paddle the main-stem tidal Delaware, but a high level of expertise is required to negotiate wakes, including those churned by maneuvering tugboats. In addition to large ships and wakes, boaters must contend with river hazards such as tides and currents, boat traffic both large and small, floating debris, river walls, piers and bridge abutments.
- The tidal surge up the Delaware River is so powerful that the river changes direction four times daily. Boaters, particularly those in human-powered craft, must consider the changing tides.
- The area between the Walt Whitman and Ben Franklin bridges has particularly heavy ship traffic, anchorages, terminals, and piers, and along this stretch the shipping lane is not marked. Stay alert and aware and stay in the shallowest water possible when moving through this area.
- Look out for floating debris, especially after heavy rain.
- Much of the river is urbanized with ports and industry. River walls and piers may present obstacles.
- Homeland security is an issue around bridges, ports, pipelines, and other facilities. Keep clear of security risk areas, and be prepared to communicate with Coast Guard, marine police and other security personnel.

Figure 2.6 Tidal Delaware River Water Trail Map and Guide, Philadelphia Section, River Miles 113-90 - Paddling Safety

2.3.4. Pennsylvania Fish and Boat Commission Concerns

PAFBC officials are concerned about hazards to swimming, paddling and jet skiing in the Study Area. Officials stressed that tidal currents are very strong in this stretch of the Delaware River, making swimming very challenging. The PAFBC finds that people often overestimate their swimming abilities, particularly in open water where conditions are much different than in pools. Visibility is a significant concern because wakes and choppy water make it very difficult for large vessels, recreational boats and jet skiers to see swimmers in the Delaware River. They noted that swimming is often a group activity, and those who encourage swimming place a group of people at risk for injuries and drownings. In addition, the limited access points to the tidal Delaware River can lead to issues with swimmers impeding boat launches. While the PAFBC promotes paddling and boating in Pennsylvania waterways, officials indicated that an increase in the number of people paddling and swimming in the Study Area would create challenges for agencies responsible for water safety like the PAFBC (Pennsylvania Fish and Boat Commission, personal communication, October 8, 2021).

2.4. United States Coast Guard

The U.S. Coast Guard is responsible for maritime safety, security and environmental stewardship within U.S. ports and waterways. It is a multi-functional agency, including roles as a military service, law enforcement, a regulatory agency, a first responder and a member of the intelligence community.

2.4.1. Coast Guard Patrol and Enforcement

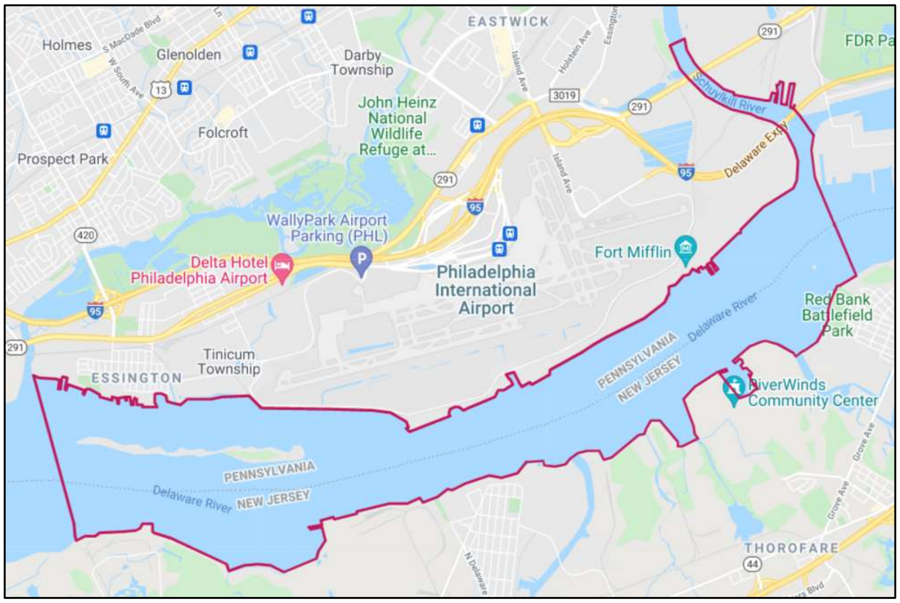
The Coast Guard Sector Delaware Bay has a tristate area of responsibility that encompasses portions of Pennsylvania, New Jersey and Delaware and includes the busy commercial ports of Philadelphia, Camden and Wilmington (Figure 2.7). It is comprised of approximately 800 active duty, reserve and civilian members and more than 1,700 volunteer auxiliary members. The Sector has two Aids to Navigation teams that maintain more than 800 navigational aids for recreational and commercial vessels. Sector Delaware Bay is headquartered in Philadelphia, Pennsylvania on the Delaware River at Washington Street.

The Coast Guard prevents marine casualties and property losses while also protecting the marine environment by developing and enforcing federal regulations and conducting safety inspections. The Coast Guard investigates accidents on the water involving commercial vessels, injuries or pollution and seeks to determine what went wrong and how to prevent similar incidents in the future.

Figure 2.7 U.S. Coast Guard Sector Delaware Bay Area of Responsibility

2.4.2. Coast Guard Regulations

The Coast Guard has multiple regulations establishing safety protocols in the Study Area, which include recreational exclusionary zones and navigation rules to prevent the interference of recreational vessels in the shipping channel.



33 CFR § 165.558 identifies a Security Zone for the tidal Delaware and tidal Schuylkill Rivers. No person may swim upon or below the surface of the water of this security zone unless authorized by the U.S. Coast Guard Captain of the Port or a designated representative. This zone is enforced when it is "necessary for the protection of VIPs" who may be utilizing the airport (C.F.R., 2018).

Figure 2.8 U.S. Coast Guard Security Zone Adjacent to Philadelphia International Airport

33 CFR § 165.558 identifies a Safety Zone for the tidal Schuylkill River adjacent to the former Philadelphia Energy Solutions facility in Philadelphia, PA (Figure 2.9).

This regulation is enforced when a barge having a beam (width) of up to 80 feet is moored at the Deloach dock of Philadelphia Energy Solutions.

The regulation states that no person or vessel may enter or remain in a safety zone without the permission of the U.S. Coast Guard Captain of the Port or a designated representative (C.F.R., 2020).

Figure 2.9 U.S. Coast Guard Safety Zone Tidal Schuylkill River

Philadelphia Energy Solutions closed in July 2019 following an explosion and fire. The refinery has since been demolished, and the site is slated for redevelopment. It is unclear at the time of this report whether the Coast Guard will amend the regulation delineating the Safety Zone for the tidal Schuylkill River due to barge traffic at the site. For the purposes of this report, the tidal Schuylkill River Safety Zone is considered still in effect.

Coast Guard rules under 33 CFR § 165.2025 are designed to protect U.S. naval vessels (Figure 2.10). Regulations state that no vessel or person is allowed within 100 yards of a large U.S. naval vessel unless authorized by the Coast Guard, the senior naval officer present in command or official patrol (C.F.R., 2002). Violating the Naval Vessel Protection Zone is a felony offense, punishable by up to six years in prison and/or up to $250,000 in fines (U.S. Coast Guard, 2010).

Subpart G - Protection of Naval Vessels
§ 165.2025 Atlantic Area.

b) A naval vessel protection zone exists around U.S. naval vessels greater than 100 feet in length overall at all times in the navigable waters of the United States, whether the large U.S. naval vessel is underway, anchored, moored, or within a floating drydock, except when the large naval vessel is moored or anchored within a restricted area or within a naval defensive sea area.
c) The Navigation Rules shall apply at all times within a naval vessel protection zone.
d) When within a naval vessel protection zone, all vessels shall operate at the minimum speed necessary to maintain a safe course, unless required to maintain speed by the Navigation Rules, and shall proceed as directed by the Coast Guard, the senior naval officer present in command, or the official patrol. When within a naval vessel protection zone, no vessel or person is allowed within 100 yards of a large U.S. naval vessel unless authorized by the Coast Guard, the senior naval officer present in command, or official patrol.

Figure 2.10 U.S. Coast Guard Regulations 33 CFR § 165.2025 - Protection of Naval Vessels

The navigation of recreational vessels near the regulated shipping channel is addressed in 33 CFR § 83.09 (Figure 2.11). The regulation states that vessels less than 20 meters in length should not impede the passage of a vessel that can safely navigate only within a specified shipping channel (C.F.R., 2017).

Part 83 - Navigation Rules
§ 83.09 Narrow channels (Rule 9).

b) A vessel of less than 20 meters in length or a sailing vessel shall not impede the passage of a vessel that can safely navigate only within a narrow channel or fairway.
d) A vessel must not cross a narrow channel or fairway if such crossing impedes the passage of a vessel which can safely navigate only within such channel or fairway.

Figure 2.11 U.S. Coast Guard Regulations 33 CFR § 83.09 - Navigational Rules

2.4.3. Coast Guard Guidance

Operation Clear Channel is a U.S. Coast Guard initiative to keep shipping channels clear for commercial traffic. This operation also includes educational outreach to inform recreational boaters of their responsibility to not impede commercial traffic. Through Operation Clear Channel, the U.S. Coast Guard Sector Delaware Bay published an educational pamphlet that applies to recreational vessels in the Delaware River and Bay (Figure 2.12). Among other guidance, the pamphlet states that all recreational vessels should stay at least 200 yards from all commercial traffic. The Coast Guard also stresses that large ships and tugs present significant danger to recreational boaters, noting visibility from the control stations of large ships is extremely limited, large ships can take miles to come to a stop and it is virtually impossible for large ships to steer around recreational vessels (U.S. Coast Guard Sector Delaware Bay, 2021).

Operation Clear Channel Stay Clear Stay Alive!

- Large ships must remain in the shipping channels due to their deep draft and they must maintain speed to be able to steer. This can be a deadly combination for a small recreational boat that gets in their way. Stay out of these channels and give large ships plenty of room – at least 200 yards – for them to transit safely.
- Commercial Vessels are huge, they are much faster than you think (upwards of 20 mph!) tipping the laws of physics against you and your vessel.
- Even in the best of circumstances visibility from the control station of large ships is extremely limited – especially in front and just to the sides of the vessel.
- Boats don't have brakes! That is especially true for large ships. In some cases it can take miles for a ship to come to a stop!
- Large ships are hard to turn and must stay in their channel or risk running aground. Steering around your small vessel is virtually impossible.
- If you must cross a shipping channel, do so quickly and maintain a lookout all around – including behind you!
- Stay at least 200 yards away from all commercial traffic!
- Large ships and tugs present significant danger to recreational boaters.
- Stay out of the channel. Leave the deep water for the vessels that need it. Never anchor in the channel.
- Get out of the way! If an approaching ship is within 2 miles, take early and positive action to avoid collision and move out of the channel if possible. Ships and tugs move much faster than you think!
- Never cut off a ship. Wait for the ship to pass. If it's a tugboat, watch out for a tow behind it.

Figure 2.12 U.S. Coast Guard Sector Delaware Bay - Operation Clear Channel

In 2010 the U.S. Coast Guard published "A Boater's Guide to the Federal Requirements for Recreational Boats" (Figure 2.13). In addition to explaining regulations about Naval Vessel Protection Zones, the guide directs recreational boaters to avoid commercial port operations, military, nuclear and petroleum facilities. It also states that recreational vessels should not stop or anchor beneath bridges or in shipping channels (U.S. Coast Guard, 2010).

A Boater's Guide to the Federal Requirements for Recreational Boats and Safety Tips

Naval Vessel Protection Zones

- Do not approach within 100 yards, and slow to minimum speed within 500 yards, of any U.S. Naval vessel.

Commercial Shipping Safety Zones

- In addition to the Naval Vessel Protection Zone requirements, you must also avoid operating your vessel near all military vessels, cruise liners, and certain commercial vessels.
- Observe and avoid all security zones and commercial port operations.
- Areas that have large marine facilities – including military, commercial/cruise, or petroleum facilities – should be avoided. There are also restrictions near most dams, power plants, and other facilities located near water.

Bridges and Shipping Channels

- Do not stop or anchor beneath bridges or in shipping channels. If you do, you can expect to be asked to move and/or be boarded by law enforcement officials.

Figure 2.13 U.S. Coast Guard Boater's Guide to Federal Requirements

2.4.4. Coast Guard Concerns

Coast Guard Sector Delaware Bay personnel are concerned about hazards to swimming, paddling and jet skiing in the Study Area. Coast Guard officials identified the following potential hazards associated with large ships, tug, barge, and dredge boats, Table 2.1.

Table 2.1 Hazards to Recreation Identified by U.S. Coast Guard Sector Delaware Bay

Hazard	Risk
Collisions	There is a high risk of collision with kayakers and paddleboarders because they do not have AIS (automatic identification system—real-time vessel positioning and tracking software) or position transmitting capabilities to deep-draft vessels, tug and tow operators or large pleasure craft. Additionally because small craft have little to no radar reflection, they are extremely hard to detect, especially at night or during restricted visibility situations.
Allisions	Currents and wind in the Study Area can increase the chance of a kayak, paddleboard, etc. allision with a dock, bridge or other structure in the waterway. Further, debris allisions are possible for all types of boaters.
Groundings	It is possible that a ship will alter course in order to avoid recreational water activity, potentially leading to a grounding. This type of incident could result in injury to onboard personnel, loss of cargo, oil spill or mechanical failure, which in turn could make the ship itself become a hazard to navigation.
Large wake	The federal channel does not have mandatory no-wake zones. Vessels are required to transit at safe speeds to adequately maintain maneuverability; hence large wakes are probable, creating a major safety hazard for primary contact water users if they were to come into the channel or within an unsafe distance to it.
Deep channels	Current is often funneled through deep channels, creating potentially turbulent waters where swimmers, kayakers and paddleboarders might not expect it.
Adrift vessels (i.e., barges)	Due to the limited speed of most paddlecraft, avoiding an adrift vessel, especially during a max current or high-wind scenario, would be difficult, significantly increasing the chances for an incident.
Legacy infrastructure (pilings, sunken ships, abandoned docks and piers)	Old or aging infrastructure can produce hazardous situations if not regarded carefully.

U.S. Coast Guard Sector Delaware Bay, personal communication, May 4, 2021

2.5. Summary of Safety Agency Roles and Concerns

A strong presence of municipal, state and federal agencies promotes and enforces waterway safety in the Study Area. These agencies work together to respond to all water-related emergencies, conduct rescue and recoveries of persons from the water and enforce safe boating and homeland security regulations (Table 2.2). They share numerous concerns about the safety of primary contact activities in the Study Area, including:

- Swimmers and paddlers may not be aware of strong tidal currents and can tire easily before reaching the shore.
- Choppy water, wakes and visibility limitations on commercial vessels make seeing swimmers and paddlers in the water very difficult, increasing the risk of collision.
- Wakes from ships and tugboats can cause paddlesports and jet skis to capsize or become swamped with water.
- Floating, submerged and legacy debris inherent to an industrial waterfront can harm swimmers, paddlers and jet skiers.
- Swimming, paddling and jet skiing in the shipping channel or near marine terminals are extremely dangerous due to the heavy presence of commercial ship traffic.
- There is no continuous patrol in the Study Area. Response time to swimmers, paddlers and jet skiers in distress is limited by the location of personnel and response vessels in relation to the location of the incident.

Table 2.2 Safety Agency Jurisdiction, Roles, and Safety Concerns in the Study Area

Name	Jurisdiction in Study Area	Roles	Safety Concerns
PPD Marine Unit	• Tidal Delaware River • Tidal Schuylkill River • Tidal Creeks (Philadelphia)	• Patrol • Rescue & Recovery • Homeland Security • Water Safety Education	• Swimming, paddling and jet skiing
NJSP Marine Services Bureau	• Tidal Delaware River • Tidal Cooper River • Tidal Creeks (New Jersey)	• Patrol • Rescue & Recovery • Regulation Enforcement • Homeland Security • Boater Education • Environmental Stewardship	• Swimming, paddling and jet skiing
Pennsylvania Fish & Boat Commission	• Tidal Delaware River • Tidal Schuylkill River • Tidal Creeks (Pennsylvania)	• Patrol • Rescue & Recovery • Regulation Enforcement • Homeland Security • Boater Education • Environmental Stewardship	• Swimming, paddling and jet skiing
U.S. Coast Guard Sector Delaware Bay	• Tidal Delaware River • Tidal Schuylkill & Cooper Rivers • Tidal Creeks (Delaware, New Jersey and Pennsylvania)	• Patrol • Rescue & Recovery • Regulation Enforcement • Military • Homeland Security • Maritime Safety • Boater Education • Environmental Stewardship	• Swimming, paddling and jet skiing

2.6. Summary of Safety Regulations and Guidance

The U.S. Coast Guard, New Jersey State Police and Pennsylvania Fish and Boat Commission promulgated safety regulations and developed guidance that apply to swimming, paddling and jet skiing in the Study Area. Table 2.3 summarizes these regulations and guidance.

Table 2.3 Swimming, Paddling, and Jet Skiing Safety Regulations in the Study Area

Marine Category	Safety Regulations and Guidance
U.S. Naval Vessels	• Do not approach within 100 yards, slow to minimum speed within 500 yards of any U.S. Naval vessel.
Commercial Vessels	• Stay at least 200 yards away from all commercial traffic.
Commercial Port Operations	• Observe and avoid all security zones and commercial port operations.
Military Areas and Petroleum Facilities	• Stay at least 100 yards from military areas and petroleum facilities.
Shipping Channel	• Swimming is forbidden in shipping channels. • A vessel of less than 20 meters in length shall not impede the passage of a vessel that can safely navigate only within a narrow channel or fairway.
Bridges	• Swimming is forbidden under bridges. • Stopping or anchoring vessels beneath bridges is forbidden.

Section 3 Commercial Shipping and Navigation Activities

The Maritime Exchange for the Delaware River and Bay (Maritime Exchange) and independent companies collect extensive information on cargo ship, passenger vessel, tugboat and barge activity in the Study Area. An analysis of vessel movement, traffic and density data provides an understanding of the frequency and magnitude of commercial shipping and navigation activities in the Study Area.

3.1. Commercial Vessel Transits 2018-2019

The section presents and analyzes commercial vessel transit data in the Study Area between January 1, 2018 and December 31, 2019. Ship arrivals at maritime facilities originate from the Maritime Exchange Ship Reporting System (Maritime On-Line®), and vessel transit data are obtained from passenger, tug and barge companies operating in the Study Area. A reported arrival at a maritime facility within or immediately north of the Study Area is counted as one transit. A single voyage through or within the Study Area by a passenger vessel, tugboat and barge is recorded as one transit.

3.1.1. Maritime Facility Activity

Maritime facilities include wharves, warehouses, piers, anchorages and other terminal and transportation structures used in connection with the transport, storage, or distribution of commercial goods. The Study Area includes 31 maritime facilities, and four facilities are located north of the Study Area. This analysis considered the northern maritime facilities as commercial vessels must pass through the Study Area on their way to and from these locations. A total of 1,823 and 1,920 vessels arrived at these 35 facilities in 2018 and 2019, respectively (Table 3.1). Cargo ships, including container ships, tankers, bulk carriers and others, are the predominant vessel type arriving at these facilities. A reported arrival at a maritime facility in the Study Area is counted as one transit.

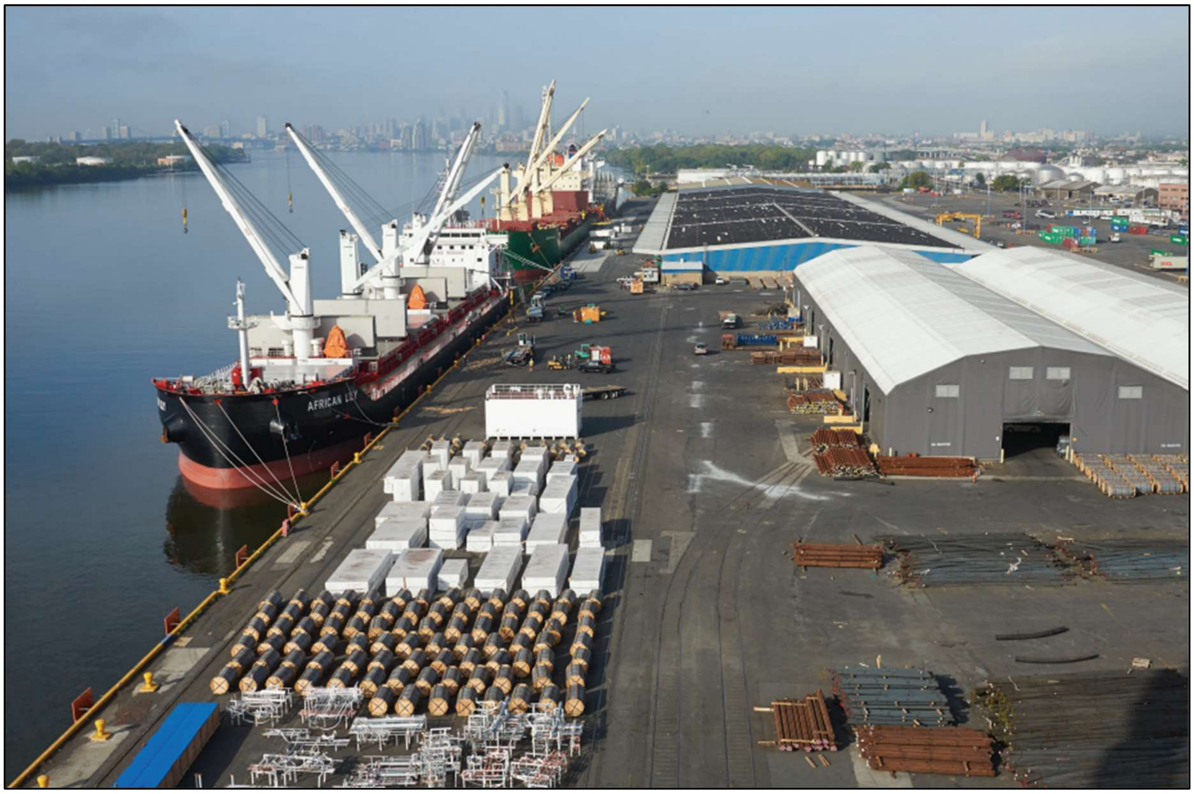


Figure 3.1 Cargo Ships Docked at PhilaPort's Tioga Marine Terminal

Table 3.1 Ship Arrivals at Maritime Facilities in the Study Area (2018-2019)

Maritime Facility	State	Waterway	Vessel Type	Material Type	2018 Vessels	2019 Vessels
Balzano Marine Terminal	NJ	Delaware	Cargo Ship	Steel	68	69
Broadway Terminal 1	NJ	Delaware	Cargo Ship	Plywood, Salt, Slag, Steel	30	22
Broadway Terminal 5	NJ	Delaware	Cargo Ship	Fruit	0	3
Buckeye Energy	NJ	Delaware	Cargo Ship	Fuel Oil	26	18
BWC	PA	Delaware	Cargo Ship	Chemicals	56	60
CPI Operations	NJ	Delaware	Cargo Ship	Asphalt, Gasoline, Fuel Oil, Oil	53	26
City Dock	PA	Schuylkill	Tug and Barge		N/A	N/A
Eagle Point Terminal	NJ	Delaware	Cargo Ship	Diesel, Fuel Oil, Gasoline Oil	59	61
Fort Mifflin	PA	Delaware	Cargo Ship	Crude, VGO	110	29
Georgia Pacific	NJ	Delaware	Tug and Barge	Gypsum	N/A	N/A
Girard Point	PA	Schuylkill	Cargo Ship	Diesel, Fuel Oil, Oil	10	12
Gloucester Marine Terminal	NJ	Delaware	Cargo Ship	Containers, Fruit, Steel, Sugar	176	166
Hog Island	PA	Delaware	Cargo Ship	Chemicals, Gases, Naphtha, Oil	1	10
Navy Yard	PA	Schuylkill	Cargo Ship	Layberth	2	5
Packer Avenue Marine Terminal	PA	Delaware	Cargo Ship	Containers, Fruit, Project, Steel	451	473
Paulsboro Marine Terminal	NJ	Delaware	Cargo Ship	Containers, Steel	29	22
Paulsboro Refinery	NJ	Delaware	Cargo Ship	Asphalt, Chemicals, Diesel, Lubes	166	134
PBF Logistics Paulsboro	NJ	Delaware	Cargo Ship	Diesel, Fuel Oil, Gasoline, Naphtha	18	15
PBF Logistics Philadelphia	PA	Schuylkill	Cargo Ship	Asphalt, Oil	0	4
PECO	PA	Schuylkill	Tug and Barge	Fuel Oil	25	252
Penn Terminals	PA	Delaware	Cargo Ship	Containers, Fruit, Steel	145	161

Maritime Facility	State	Waterway	Vessel Type	Material Type	2018 Vessels	2019 Vessels
Penn's Landing	PA	Delaware	Yachts, Tall Ships, Military		13	8
Philadelphia Forest Products Center (Pier 38-40)	PA	Delaware	Cargo Ship	Paper	1	0
Philadelphia Forest Products Center (Pier 80)	PA	Delaware	Cargo Ship	Paper	53	51
Pier 82	PA	Delaware	Cargo Ship	Containers, Fruit	18	1
Pier 84	PA	Delaware	Cargo Ship	Cocoa	11	6
Pier 122	PA	Delaware	Cargo Ship	Autos	52	74
Repauno	NJ	Delaware	Cargo Ship	Gases	Opened 2021	
Southport Auto Terminal	PA	Delaware	Cargo Ship	Ro/Ro (Roll On-Roll Off) Cargo Ships	Opened 2019, started taking ships in 2021	
Tioga Liquid Bulk Term. (179 N)	PA	Delaware	Cargo Ship	Chemicals	59	57
Tioga Marine Terminals	PA	Delaware	Cargo Ship	Fruit, Steel, Wood Pulp	71	78
Fairless Hills Terminal*	PA	Delaware	Cargo Ship	Coal, Fertilizer, Salt, Sand, Steel, Sugar	53	53
National Gypsum*	NJ	Delaware	Cargo Ship	Gypsum	11	9
Riverside*	PA	Delaware	Cargo Ship	Cement, Gypsum, Salt	19	15
Waste Mgmt. (PCI Fairless)*	PA	Delaware	Cargo Ship, Tug & Barge	Scrap	37	26
				Total	**1,823**	**1,920**

*Facilities Located Above the Study Area

3.1.2. Tug and Barge Activity

Tug and barge companies move goods via barge, assist vessels with docking and undocking, serve as vessel escorts, and bring supplies to vessels. Since no mandatory reporting systems exist for tracking tug and barge movements, vessel transit data was solicited from tug and barge companies operating in the Study Area in 2018 and 2019.

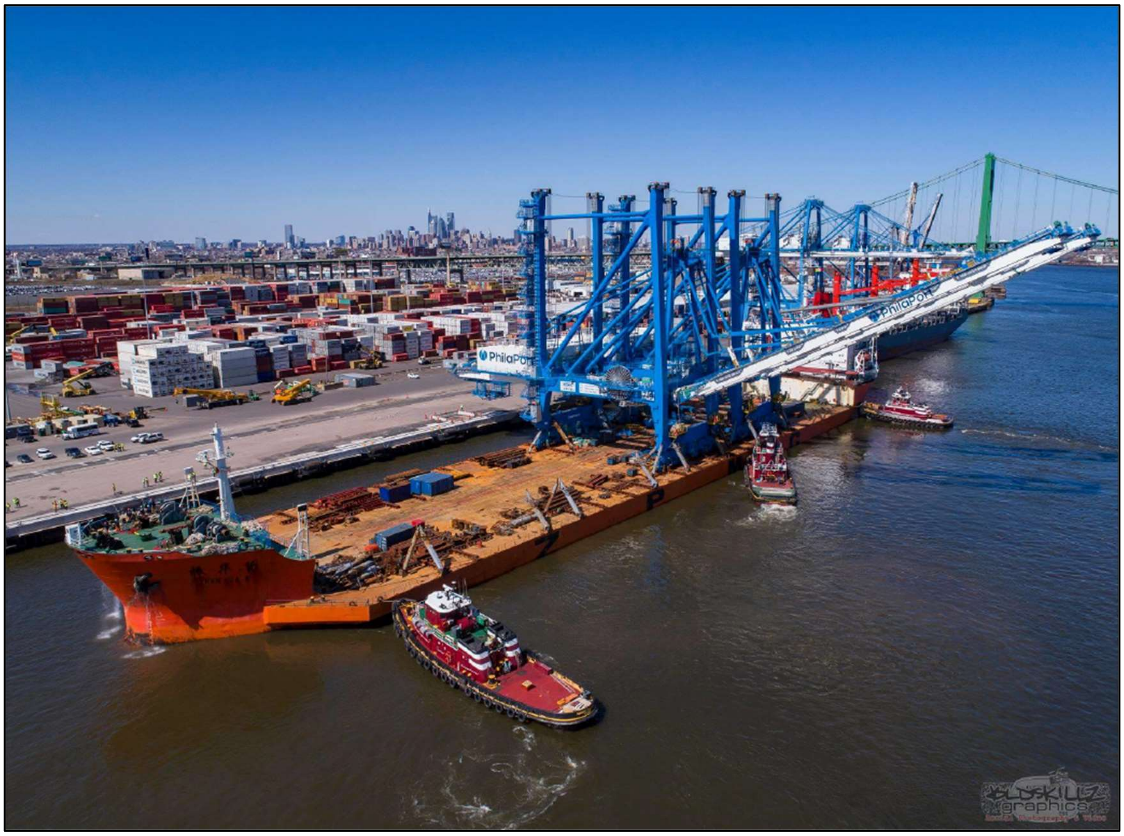


Figure 3.2 Tugboats Assisting a Cargo Ship at Packer Avenue Marine Terminal

A single voyage through or within the Study Area was recorded as one transit. Five companies provided transit data specific to the Study Area, and one of these (Moran Towing) provided transit data for the entire Delaware River. The five companies providing transit data in the Study Area accounted for 12,402 and 13,285 vessel transits in 2018 and 2019, respectively (Table 3.2).

However, it should be noted that not all tug/barge operators responded to the data request. As a result, the values in Table 3.2 reflect a minimum of activity, not total activity.

Table 3.2 Tug and Barge Transits in the Study Area (2018-2019)

Tug and Barge Companies	2018 Vessel Transits	2019 Vessel Transits
Express Marine	48	28
McAllister Towing	3,160	3,832
Moran Towing	9,408*	8,274*
River Services	566	541
Vane Brothers	4,448	4,914
Wilmington Tug	4,180	3,970
Total (excluding Moran Towing)	**12,402**	**13,285**
Total (including Moran Towing)	**21,810**	**21,559**

**Moran Towing vessel transits represent all the Delaware River, not just the Study Area*

3.1.3. Passenger Vessel Activity

Passenger vessels provide public transportation, dinner cruises, sightseeing cruises and private function cruises. A single voyage through or within the Study Area was recorded as one transit. Passenger vessels accounted for 3,978 and 3,722 transits in Study Area in 2018 and 2019, respectively (Table 3.3).

Table 3.3 Passenger Vessel Transits in the Study Area (2018-2019)

Passenger Services	2018 Vessel Transits	2019 Vessel Transits
RiverLink Ferry	3,126	2,870
City Experiences (Hornblower)	562	547
Ben Franklin Yacht	290	305
Total	**3,978**	**3,722**

Figure 3.3 RiverLink Ferry

The most active passenger vessel in the Study Area is the Riverlink Ferry, which provides transportation services between Penn's Landing in Philadelphia, Pennsylvania and Wiggins Waterfront in Camden, New Jersey.

The ferry moves passengers between the many activities and attractions on either side of the Delaware River in this popular location.

3.1.4. Summary of Commercial Vessel Transits 2018-2020

Transit data from cargo ships, passenger vessels, tugboats and barges show heavy activity, more than 18,000 transits per year within the Study Area.

Figure 3.4 Tugboat Assisting a Containership at Packer Avenue Marine Terminal

Tug boats are nearly ten times more active in the Study Area than cargo vessels. In total, commercial vessels accounted for 18,203 and 18,927 transits in the Study Area in 2018 and 2019, respectively.

Table 3.4 Summary of Commercial Vessel Activity in the Study Area (2018-2019)

Commercial Vessel Activity	2018 Vessel Transits	2019 Vessel Transits
Maritime Facilities	1,823	1,920
Tug and Barge	12,402	13,285
Passenger Vessels	3,978	3,722
Total	**18,203**	**18,927**

3.2. Marine Traffic Analysis During 2021 Recreation Season

An automatic identification system (AIS), a digital positional awareness system, allows vessel movements to be broadcasted, tracked and recorded in real time. AIS data are separated into two classes (A and B), with class A required for commercial vessels operating on navigable waters. Recreational motorboats are not required by law to operate AIS transceivers, however many such vessels transmit via class B devices voluntarily.

AIS data show vessel traffic in the Study Area between May 1, 2021 and September 30, 2021. Pennsylvania Water Quality Standards refer to May 1 through September 30 as the “swimming season,” as the public is more likely to engage in primary contact recreation activities when air and water temperatures are warmer (Pennsylvania Code, 2020).

For this analysis, the Study Area is divided into five AIS zones, each of which automatically generates and counts the alerts when an AIS-equipped vessel enters or leaves the zone. The results include AIS data from commercial cargo ships, tugboats, fishing craft, passenger vessels and recreational motorboats.

Table 3.5 Count of AIS Vessel Alerts in the Study Area, May 1, 2021-Sept. 30, 2021

Zone	Waterway	Northern Boundary	Southern Boundary	Vessel Count	Percentage
A	Delaware	Tacony-Palmyra Bridge	Betsy Ross Bridge	2,756	1
B	Delaware	Betsy Ross Bridge	Ben Franklin Bridge	8,313	3
C	Delaware	Ben Franklin Bridge	Walt Whitman Bridge	185,252	59
D	Delaware	Walt Whitman Bridge	Commodore Barry Bridge	48,226	15
E	Schuylkill	Fairmount Dam	Delaware River Confluence	67,734	22
			Total	**312,281**	**100**

Collectively the five zones generated 312,281 vessel alerts between May 1, 2021 and September 30, 2021. Zone C (Delaware River, Ben Franklin Bridge to Walt Whitman Bridge) had the most vessel traffic with 185,252 alerts, representing nearly 60% of the total. Zone D (Delaware River, Walt Whitman Bridge to Commodore Barry Bridge) and Zone E (tidal Schuylkill River to Fairmount Dam) accounted for 48,226 and 67,734 vessel alerts, respectively.

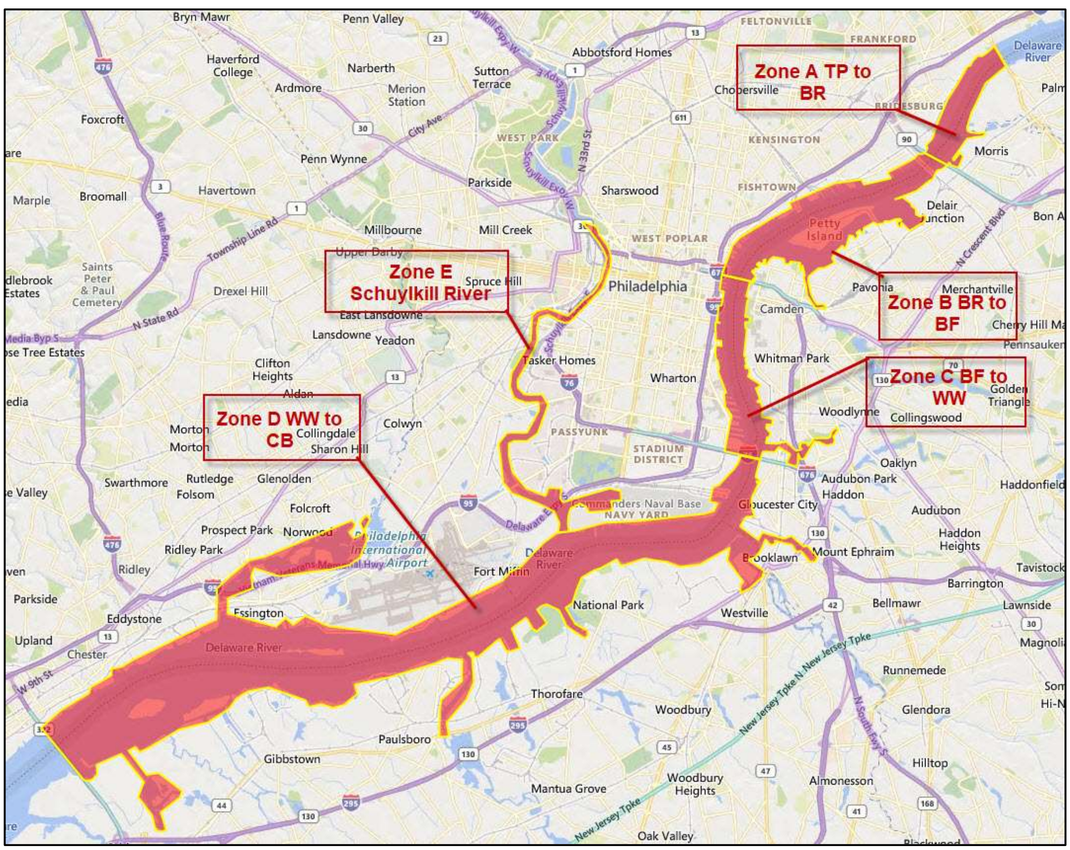


Figure 3.5 AIS Zones Created to Determine 2021 Vessel Movements in the Study Area

3.3. Vessel Density (2019-2020)

Vessel density maps for the Study Area use AIS data collected in 2019 and 2020. A vessel density map shows the distribution of ships based on the instantaneous number of vessels per unit area.

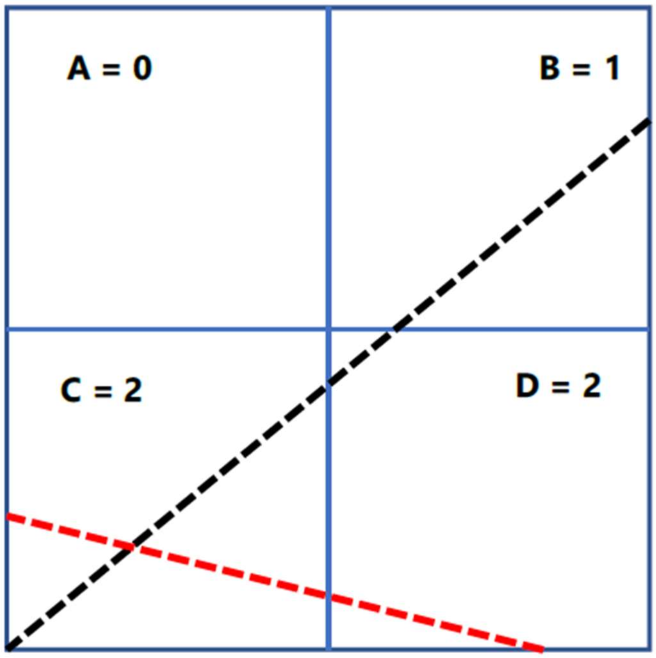


Figure 3.6 presents the development of vessel density maps. First a grid of the desired area is created. Next, AIS positions are used to generate ship travel lines.

The AIS travel lines are then intersected with the grid, and a program is able to count the number of trips through each grid to make a vessel density map in a given time interval (European Marine Observation and Data Network, 2019).

This methodology enabled the calculation of vessel density in the Study Area for 2019 and 2020.

Figure 3.6 Calculating Vessel Density Based on the Number of Ship Tracks in a Unit Area

The results of the vessel density maps are presented in Figure 3.7 and Figure 3.8. These maps present the distribution of vessels in the Study Area based on the instantaneous number of vessels per 100 square meter grid tile in 2019 and 2020, respectively.

Higher vessel densities in the Study Area correspond to the federally regulated navigation areas in the Delaware River and the tidal Schuylkill River. Large vessels like containerships must remain in these shipping channels due to their deep drafts. In 2019 and 2020, vessel density was highest in the Delaware River between the Betsy Ross and the Commodore Barry Bridges and the tidal Schuylkill River between the Passyunk Avenue bridge and the confluence with the Delaware River.

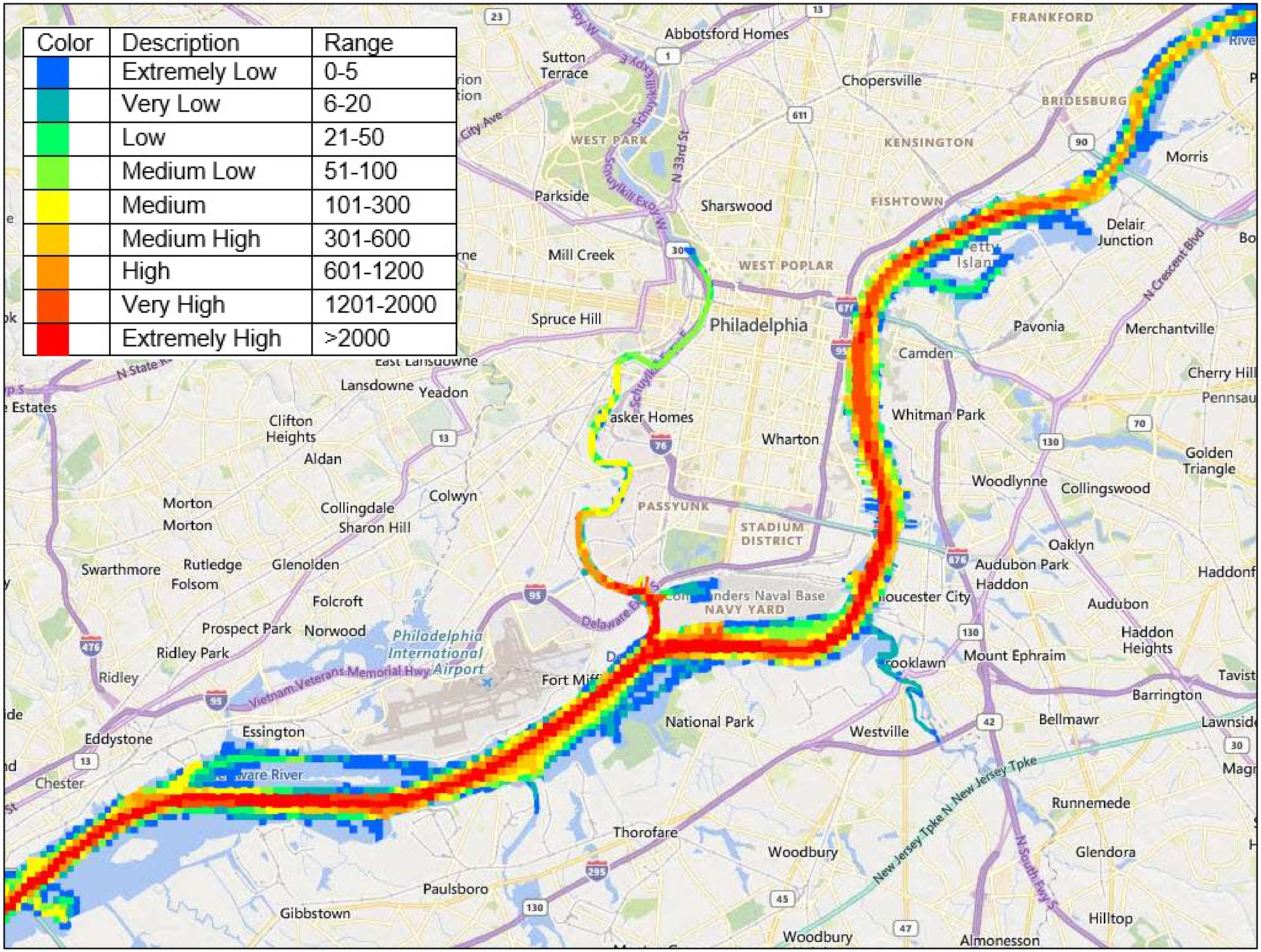


Figure 3.7 Vessel Density in the Study Area between January 1, 2019 and December 31, 2019

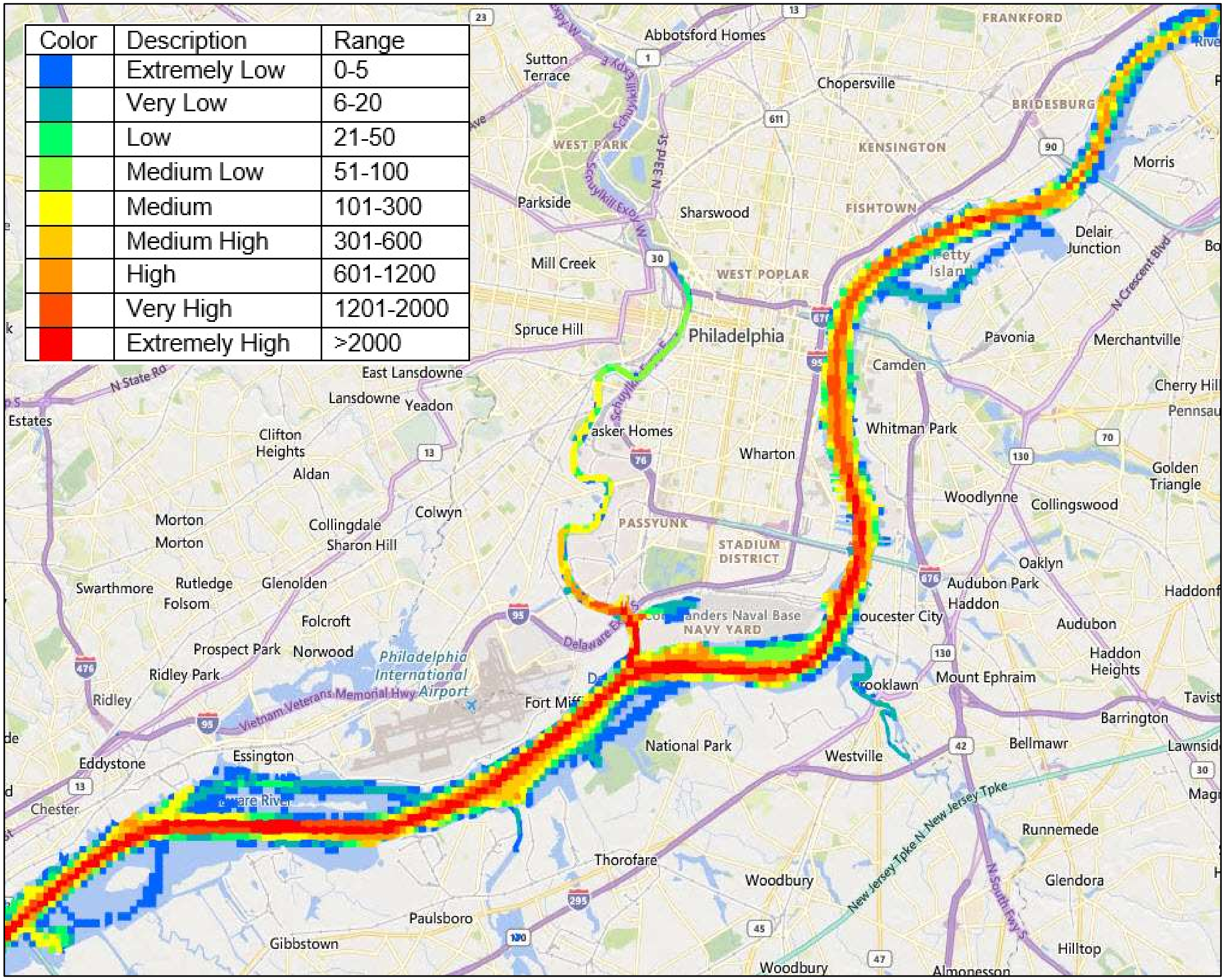


Figure 3.8 Vessel Density in the Study Area between January 1, 2020 and December 31, 2020

3.4. Summary of Commercial Shipping and Navigation Activities

By any measure, commercial shipping and navigation activities are prevalent throughout the Study Area. With over 30 maritime facilities and more than 18,000 commercial vessel transits per year, the Study Area is critical to the movement of goods in and out of the Delaware Valley region. Tugboats are the most active commercial vessels in the Study Area, traveling up, down and across the Delaware River and the tidal Schuylkill River to move goods via barge, assist vessels with docking and undocking, serve as escorts and deliver supplies. Commercial vessel traffic in the Study Area is exceptionally heavy between May and September, a period when the public is most likely to engage in primary contact recreation activities.

3.5. Economic Significance of Maritime Activity on the Delaware River

Cargo activity and associated vessel operations at the deepwater marine terminals along the Delaware River contribute to the local, regional and national economies by providing employment and income to individuals, tax revenues to local and state governments and revenue to businesses engaged in handling, shipping and receiving cargo via the terminals.

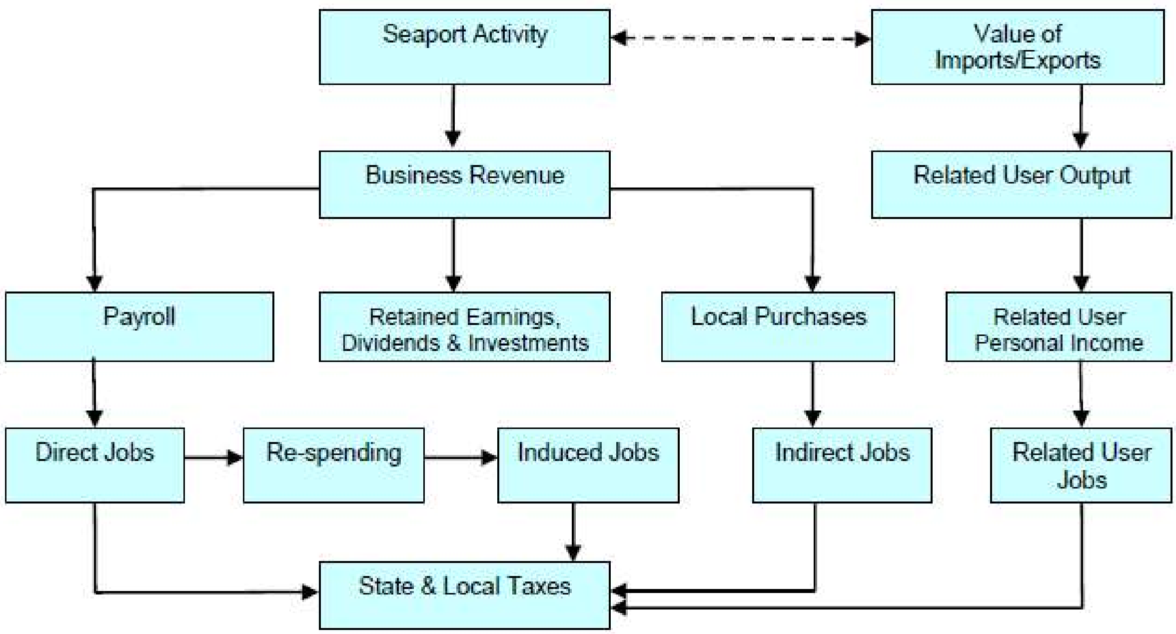


Figure 3.9 Flow of Economic Impacts of Maritime Activity on the Delaware River

Source: (Martin Associates, 2018)

The Maritime Exchange commissioned Martin Associates to measure the local and regional economic impacts generated by the movement of cargo at the Delaware River marine terminals in the year 2017. Economic impact assessments included jobs, personal earnings, business revenue and state and local taxes (Martin Associates, 2018).

In 2017, 90.4 million tons of cargo moved through the Delaware River marine terminals. The total economic value of this cargo activity, including the revenue and value added at each stage of moving an export to or an import from the marine terminals, was estimated at $77.6 billion.

At the time of the study, an estimated 190,436 total jobs were directly or indirectly generated by cargo activity at the marine terminals. Of that number, 20,798 jobs were directly generated by cargo activity, including jobs in trucking, terminal operations and maritime services (Table 3.6). An additional 25,240 induced jobs are supported by the purchases of goods and services by individuals holding direct jobs. Another 9,221 indirect jobs are generated as the result of local purchases by businesses dependent upon the marine terminals for the shipment and receipt of cargo. Lastly, 135,178 related user jobs are held throughout the states of Pennsylvania, New Jersey and Delaware with manufacturing and wholesale and retail distribution businesses using the marine terminals for the shipment and receipt of cargo.

Table 3.6 Direct Jobs Generated by Cargo and Vessel Activity on the Delaware River

Direct Jobs Category	Number of Jobs	Percent of Total Jobs
Truck	6,293	30%
Rail	197	1%
Terminal Operators	7,449	36%
Longshoremen/Dockworkers	2,062	10%
Maritime Services	1,874	9%
Government	834	4%
Warehousing	820	4%
Forwarders	366	2%
Towing	186	1%
Agents	98	0%
Linehaul Barge	95	0%
Dependent Shippers/Consignees	71	0%
Public Port Authority	454	2%
Total	**20,798**	**100%**

The distribution of the direct jobs by place of residence is a useful measure of the geographic importance of the marine terminals to the local economy. Nearly 21% of all direct job holders reside in Philadelphia County, reflecting cargo activity at PhilaPort and nearby terminals. Over 42% of direct job holders reside in Pennsylvania, compared to 31% and 22% residing in Delaware and New Jersey, respectively (Table 3.7).

It is estimated that activity at the marine terminals along the Delaware River in 2017 generated $2.6 billion in state and local taxes. Over $655 million is attributed to direct, induced and indirect jobs, and $2.0 billion is attributed to related user jobs.

The economic impact analysis by Martin Associates clearly demonstrates that cargo activity and associated vessel operations at Delaware River marine terminals have a significant impact on the local, regional and national economies.

Table 3.7 Distribution of Direct Jobs by Place of Residence

County	State	Total Direct Jobs	Percent of Total Jobs
Bucks	Pennsylvania	966	4.6%
Chester	Pennsylvania	914	4.4%
Delaware	Pennsylvania	823	4.0%
Montgomery	Pennsylvania	111	0.5%
Philadelphia	Pennsylvania	4,276	20.6%
Other PA Counties	Pennsylvania	1,813	8.7%
	PA Subtotal	**8,903**	**42.8%**
Atlantic	New Jersey	12	0.1%
Burlington	New Jersey	138	0.7%
Camden	New Jersey	2,082	10.0%
Cumberland	New Jersey	204	1.0%
Gloucester	New Jersey	921	4.4%
Mercer	New Jersey	20	0.1%
Salem	New Jersey	27	0.1%
Other NJ Counties	New Jersey	1,230	5.9%
	NJ Subtotal	**4,634**	**22.3%**
Kent	Delaware	302	1.5%
New Castle	Delaware	6,212	29.9%
Sussex	Delaware	15	0.1%
	DE Subtotal	**6,529**	**31.4%**
Other U.S. States		732	3.5%
	Total	**20,798**	**100.0%**

Section 4 Hydraulic and Shoreline Modifications

Research into channel deepening and maintenance dredging, intake and discharge structures, stormwater and combined sewer outfalls and maritime points of interest within the Study Area informs this discussion of hydraulic and shoreline modifications.

4.1. Channel Deepening and Maintenance Dredging

The federal navigation channel in the Study Area is located on the Delaware River between the Commodore Barry Bridge and the Tacony-Palmyra Bridge and the tidal Schuylkill River between the Delaware River confluence and the University Avenue Bridge in Philadelphia, Pennsylvania.

Prior to the late 1800s, the Delaware River federal navigation channel was maintained at a depth of 18 feet (U.S. Army Corps of Engineers, 2012). Over the last 125 years, the navigation channel has been deepened in the Study Area to accommodate increasingly larger, deeper draft ships. Presently the Delaware River federal navigation channel has an authorized depth of 45 feet from the Commodore Barry Bridge to the Ben Franklin Bridge and 40 feet to the Tacony-Palmyra Bridge (U.S. Army Corps of Engineers, 2022). The tidal Schuylkill River federal navigation channel presently has an authorized depth of 33 feet from the Delaware River confluence to the Passyunk Avenue Bridge, 26 feet to Bartram's Garden and 22 feet to the University Avenue Bridge (NOAA, 2022).

The U.S. Army Corps of Engineers (USACE) Philadelphia District is responsible for maintaining the authorized widths and depths for the federal navigation channels in the Study Area. Maintenance dredging is required every year to remove sediment that reaccumulates in the channel. Maintenance dredging is critical to ensuring that sediment does not impede navigational safety and efficiency (Figure 4.1). In 2019, there were 17 days when the USACE performed dredging on the Delaware River between the Commodore Barry and Tacony-Palmyra bridges, and another 38 days where the dredging vessel was transiting through the Study Area either on the way to/from the dredge site or heading to Fort Mifflin to discharge dredged material (U.S. Army Corps of Engineers Philadelphia District, personal communication, April 15, 2021). These numbers only represent USACE dredge activity and do not represent the dredge activity of vessels under contract to with USACE to perform maintenance dredging. The federal navigation channel, periodic deepening and maintenance dredging are significant hydraulic modifications that run the full length of the Study Area.

Figure 4.1 Dredging of the Federal Navigation Channel Adjacent to Camden, New Jersey (USACE)

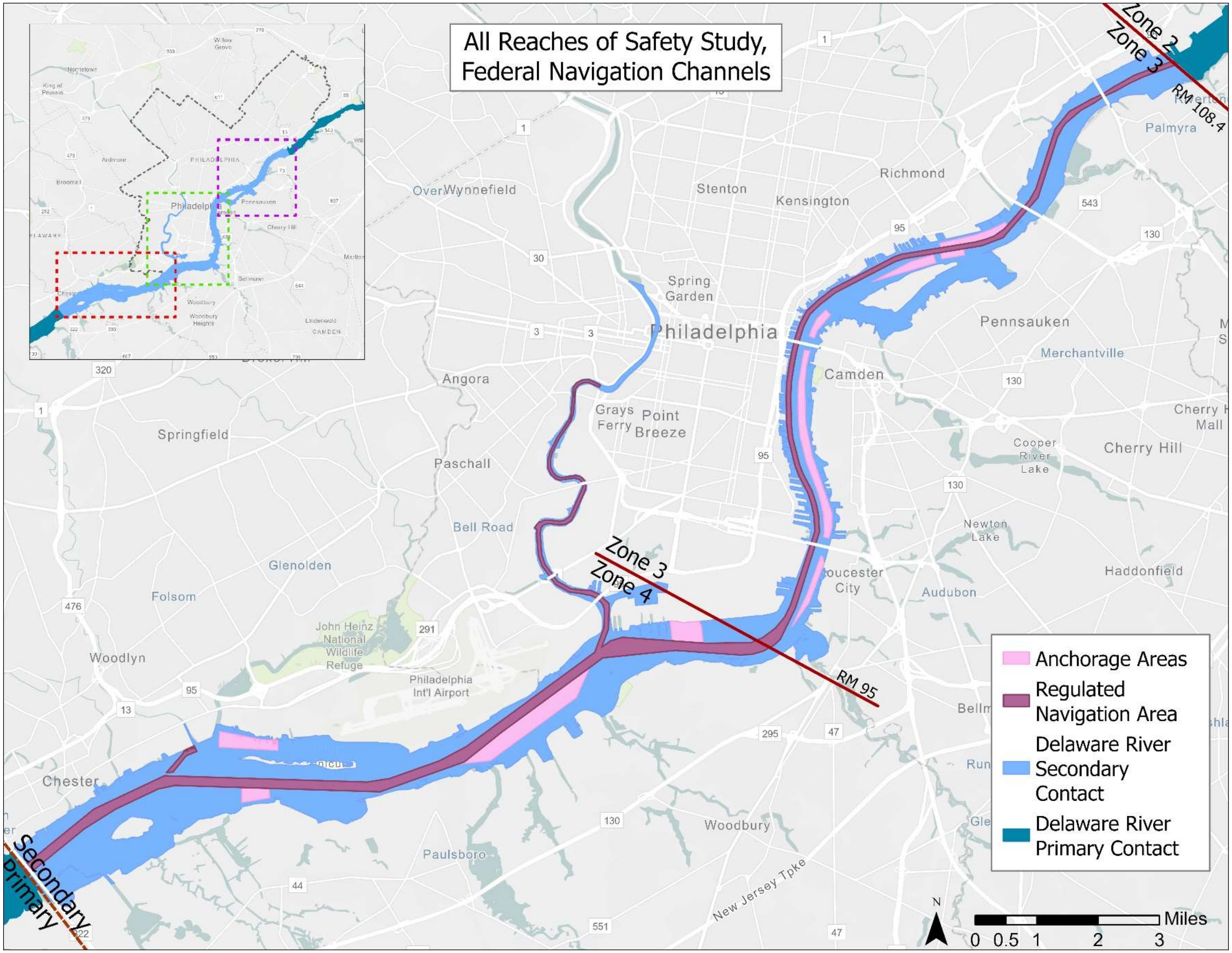


Figure 4.2 Federal Navigational Channels in the Study Area

4.2. Intake and Discharge Structures

Intake structures collect surface water to be conveyed to drinking water treatment plants and industrial facilities. Within the Study Area are 11 intake structures, 1 municipal and 10 belonging to industrial facilities. Discharge structures release effluent treated wastewater from municipal and industrial facilities into surface waters. The Study Area includes 94 discharge structures, 16 belonging to municipal wastewater plants and 78 to industrial facilities (Figure 4.4).

4.3. Stormwater and CSO Outfalls

Stormwater outfalls discharge rainwater runoff from streets, houses and businesses into nearby surface waters. Approximately 662 stormwater outfalls are located in the Study Area. Combined sewer systems are designed to collect rainwater runoff, domestic sewage and industrial wastewater in the same pipe. Under dry conditions, all the wastewater collected in a combined sewer system is transported to a sewage treatment plant, however during periods of rainfall, the capacity of a combined sewer system and treatment plant may be exceeded. When this occurs, combined sewer outfalls are designed to discharge excess flow directly into surface waters (Figure 4.3). Approximately 146 combined sewer outfalls are located in the Study Area (Figure 4.5).

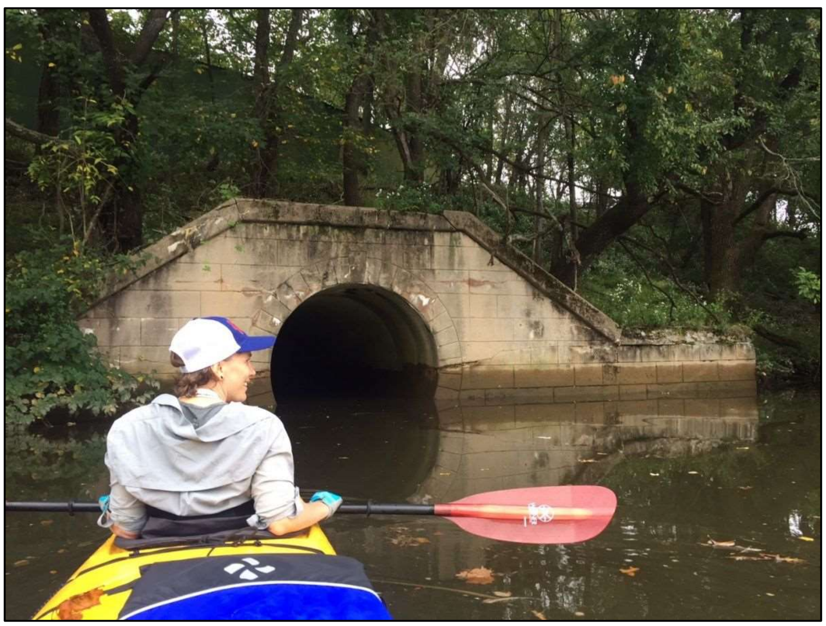


Figure 4.3 Kayaker Near a Combined Sewer Outfall (2018. William Penn Foundation. *25,000 Miles of Safe Swimming and Great Fishing*.)

Outfall counts were determined using publicly available GIS data from Philadelphia Water Department (2021 dataset), New Jersey Department of Environmental Protection (2016, 2017 and 2022 datasets) and Pennsylvania Department of Environmental Protection (2022 dataset). Combined sewer outfall counts also included GIS data from the Delaware County Regional Water Quality Control Authority (2021 dataset). Only outfalls adjacent to the study area were counted and included in this analysis.

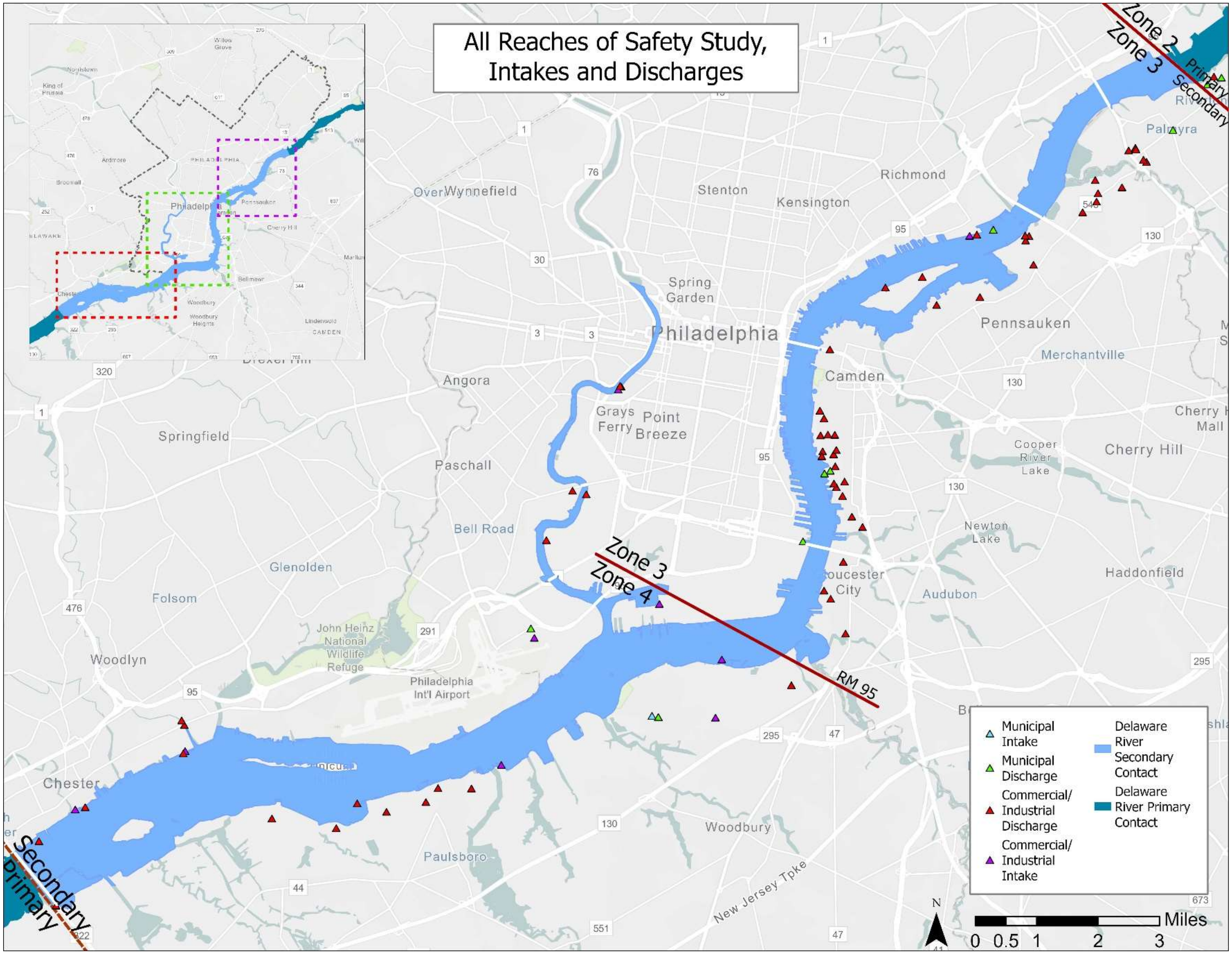


Figure 4.4 Intake and Discharge Structures in the Study Area

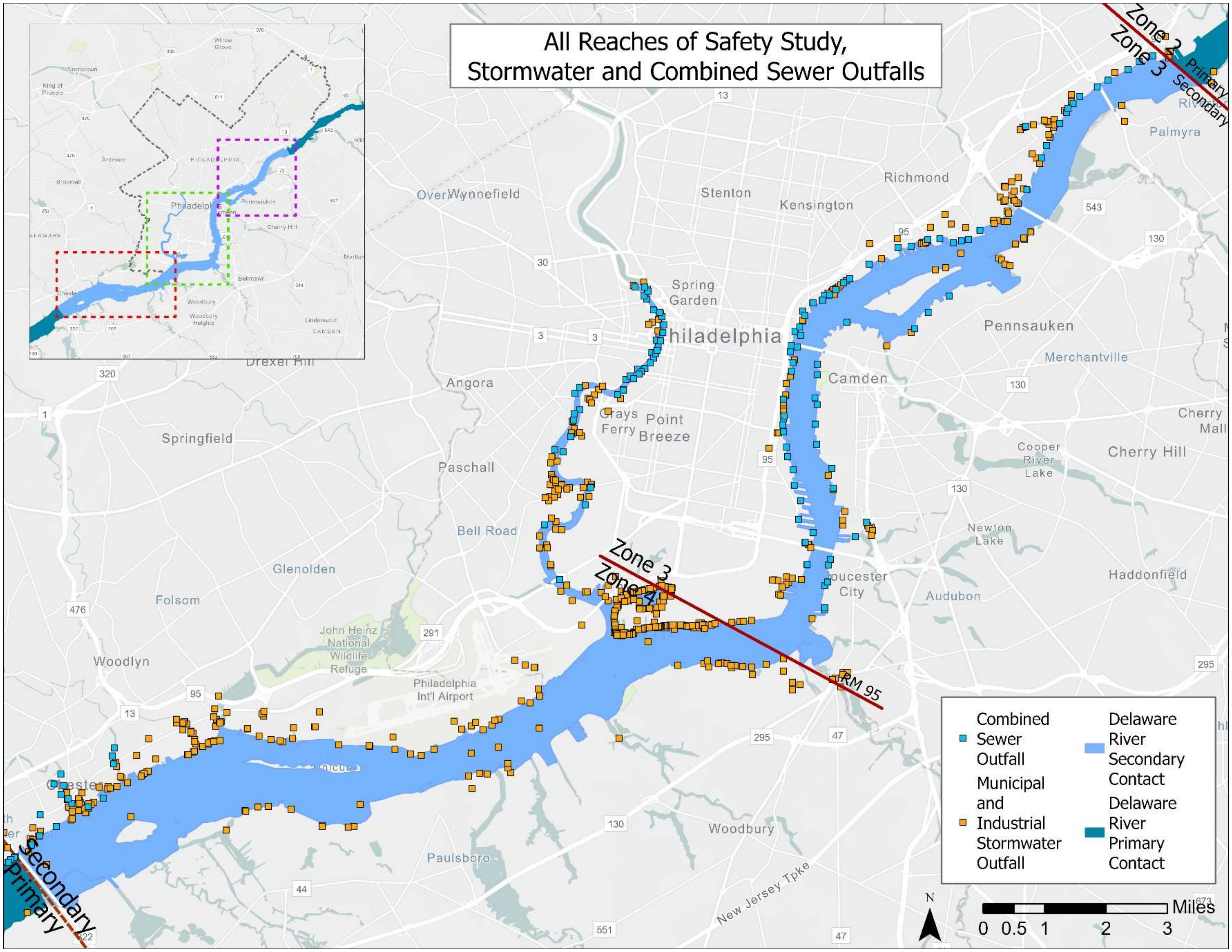


Figure 4.5 Stormwater and Combined Sewer Outfalls in the Study Area

4.4. Maritime Points of Interest

Maritime points of interest include commercial ports and terminals, boat ramps and launches, boat clubs and marinas, docks and piers (Figure 4.6). There are approximately 63 maritime points of interest in the Study Area (Figure 4.7), which include 28 cargo ship facilities, 3 tug and barge ports, 2 security ports, 21 boat clubs and marinas and 9 boat ramps and launches.

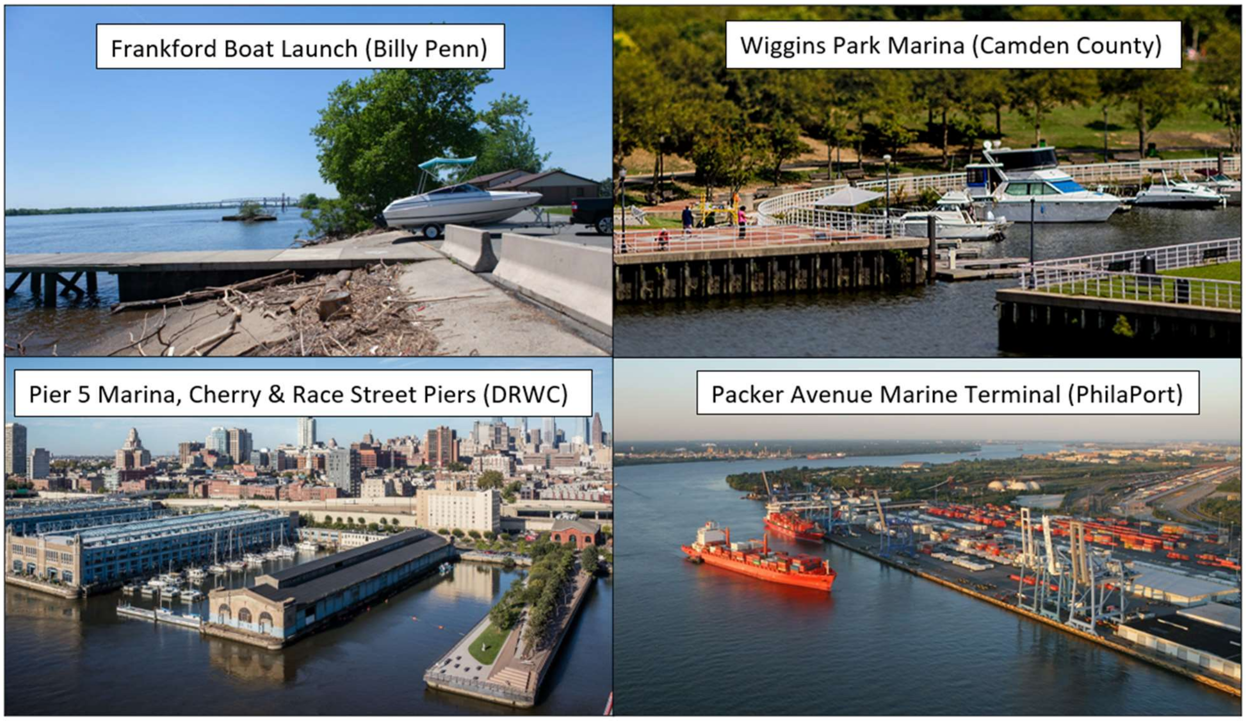


Figure 4.6 Examples of Maritime Points of Interest in the Study Area

4.5. Legacy Infrastructure and Shipwrecks

The Delaware River within the Study Area has been a working river for hundreds of years. The legacy of intensive commercial use fills the Study Area shoreline with abandoned infrastructure that has become dilapidated, either partially or wholly submerged. The Study Area also includes a large number of shipwrecks as documented by NOAA in its navigation charts as a warning to mariners. The Study Area contains 63 shipwrecks, 554 pieces of legacy infrastructure (e.g., abandoned docks and piers) and 20 obstructions reported by NOAA.

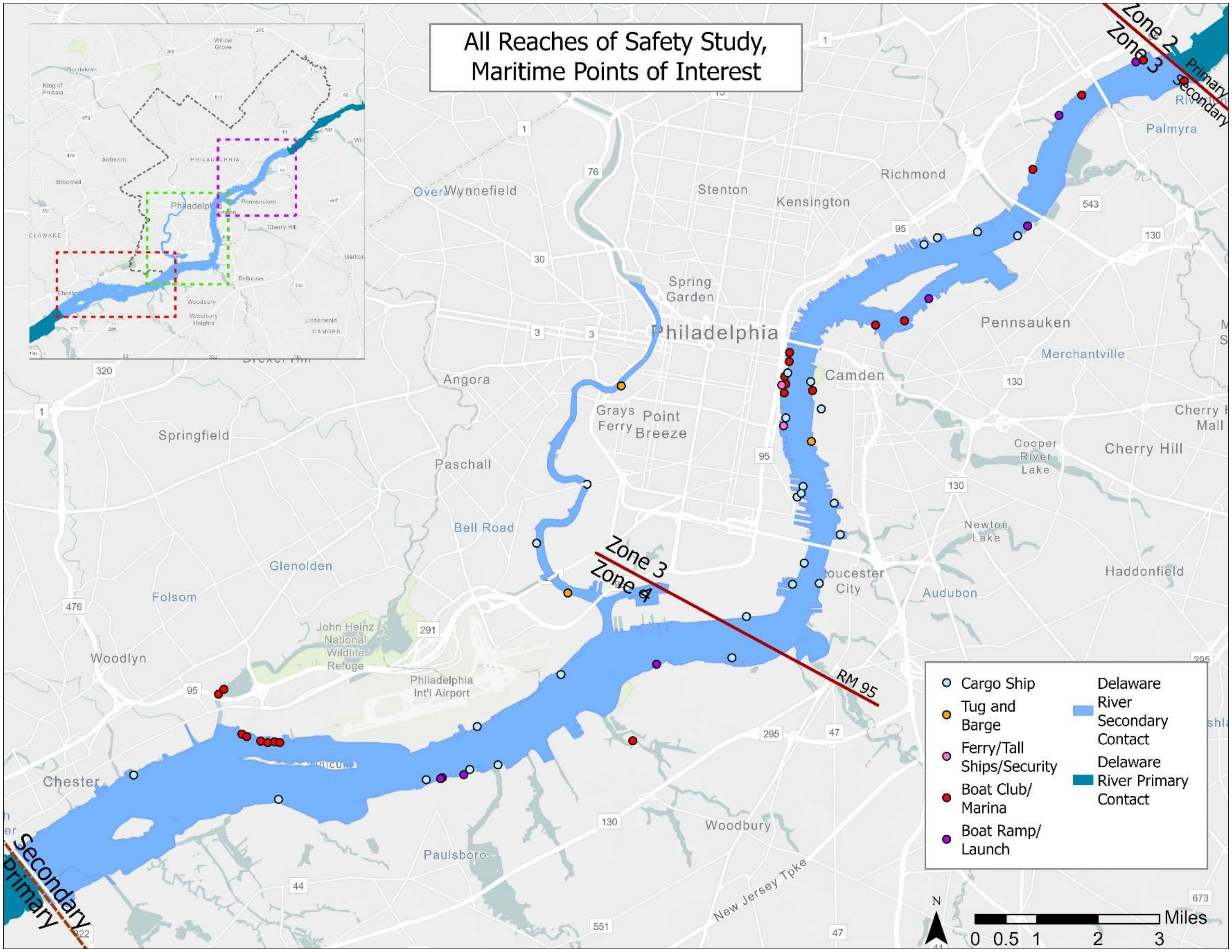


Figure 4.7 Maritime Points of Interest in the Study Area

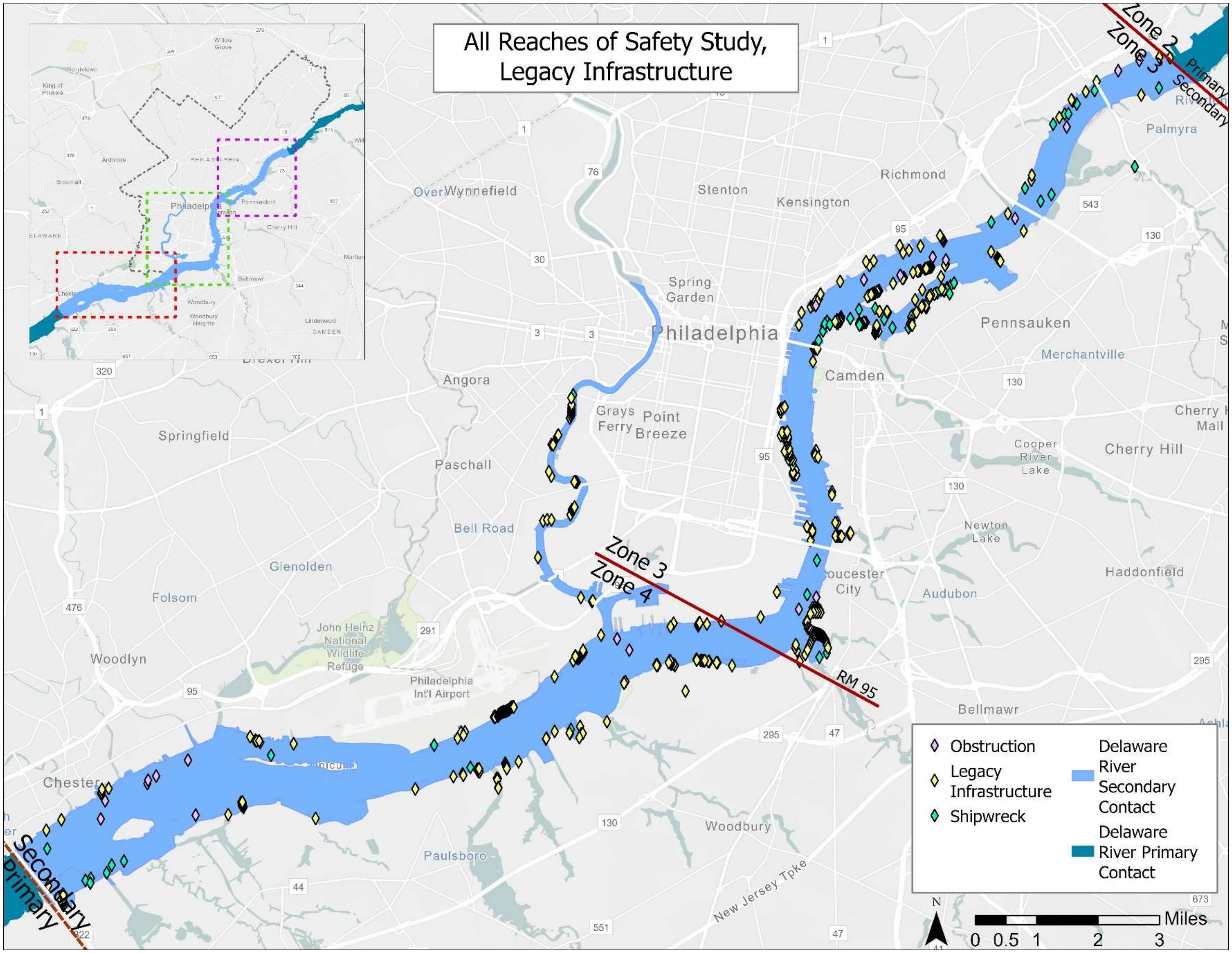


Figure 4.8 Legacy Infrastructure, Shipwrecks, and Obstructions in the Study Area

4.6. Summary of Hydraulic and Shoreline Modifications

The shoreline and hydraulics in the Study Area have been extensively modified to accommodate urban areas, industry, commercial shipping and navigation. Table 4.1 details these modifications, and the information is also presented in a summary map in Figure 4.9.

Table 4.1 Total Hydraulic and Shoreline Modifications

Modification	Number	Modification	Number
Municipal Intakes	1	Security Ports	2
Municipals Discharges	16	Boat Clubs/Marinas	21
Commercial/Industrial Intakes	10	Boat Ramps/Launches	9
Commercial/Industrial Discharges	78	Shipwrecks	63
Stormwater Outfalls	662	Legacy Infrastructure	1163
Combined Sewer Outfalls	146	Navigation Channel	1
Cargo Ship Ports/Terminals	28	Anchorage Areas	10
Tug and Barge Ports	3	Obstructions	20
Total Modifications	**2,216**		

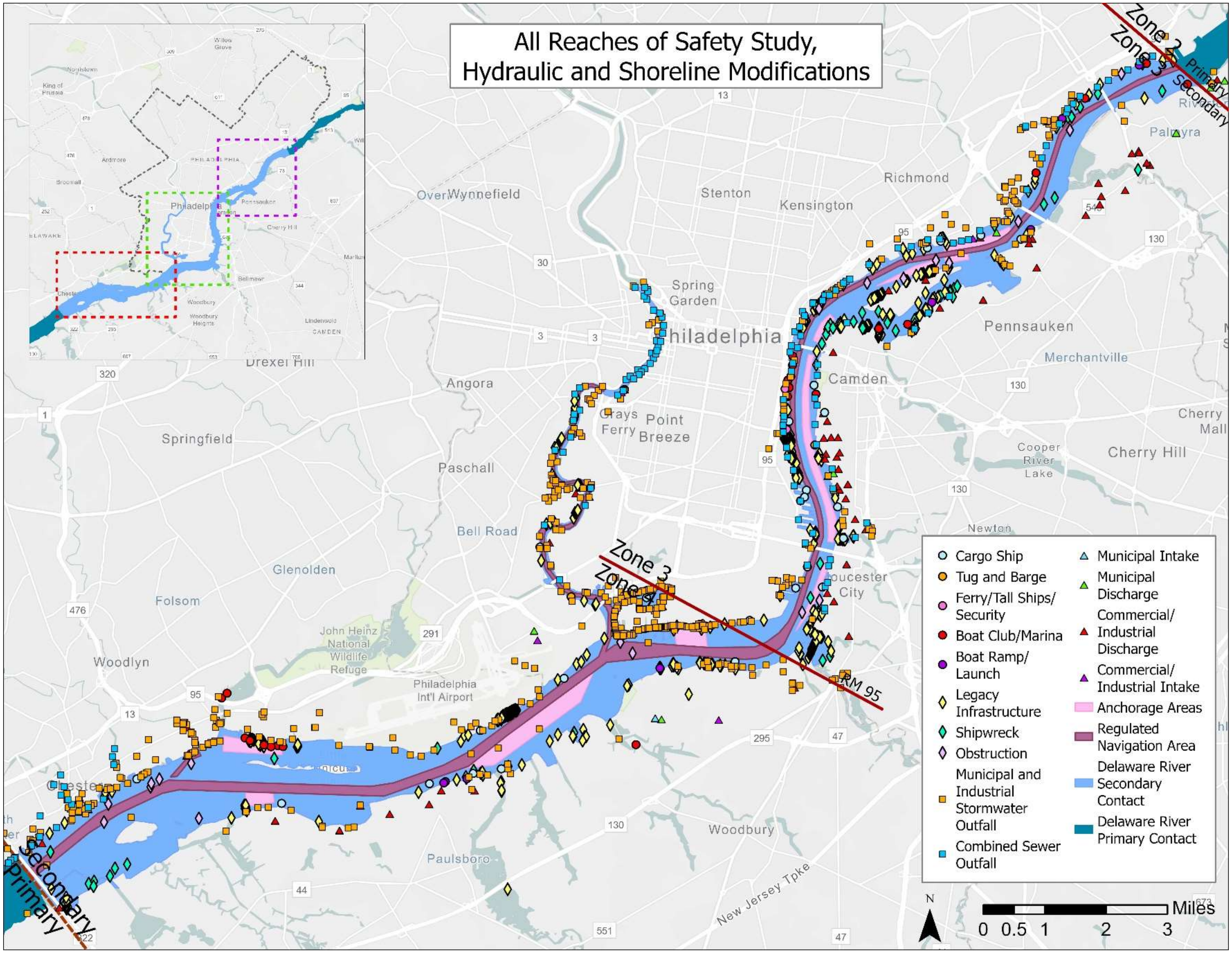


Figure 4.9 Total Hydraulic and Shoreline Modifications in the Study Area

Section 5 Hydraulic Hazards

This section discusses hydraulic characteristics that can potentially pose hazards for various types of recreation. These characteristics include water depth, river width, current velocity and wind-generated waves.

5.1. Water Depth

It is important to note the influence that tides have on water levels, and corresponding total water depths, within the Study Area. Two high tides and two low tides occur each day in the Study Area. The NOAA Philadelphia Station (8545240) records water level data and provides statistics on the tidal range and the changes in water level due to tides observed within the Study Area. According to NOAA data, the mean range of tide (MN) at Philadelphia is 6.1 feet (Figure 5.1, Table 5.1). This means that during the day there is, on average, a 6.1 foot difference between high tide and low tide. In more rare conditions, which can be driven by astronomical or meteorological forces, the tidal range can reach 6.69 feet. This is defined as the great diurnal tidal range.

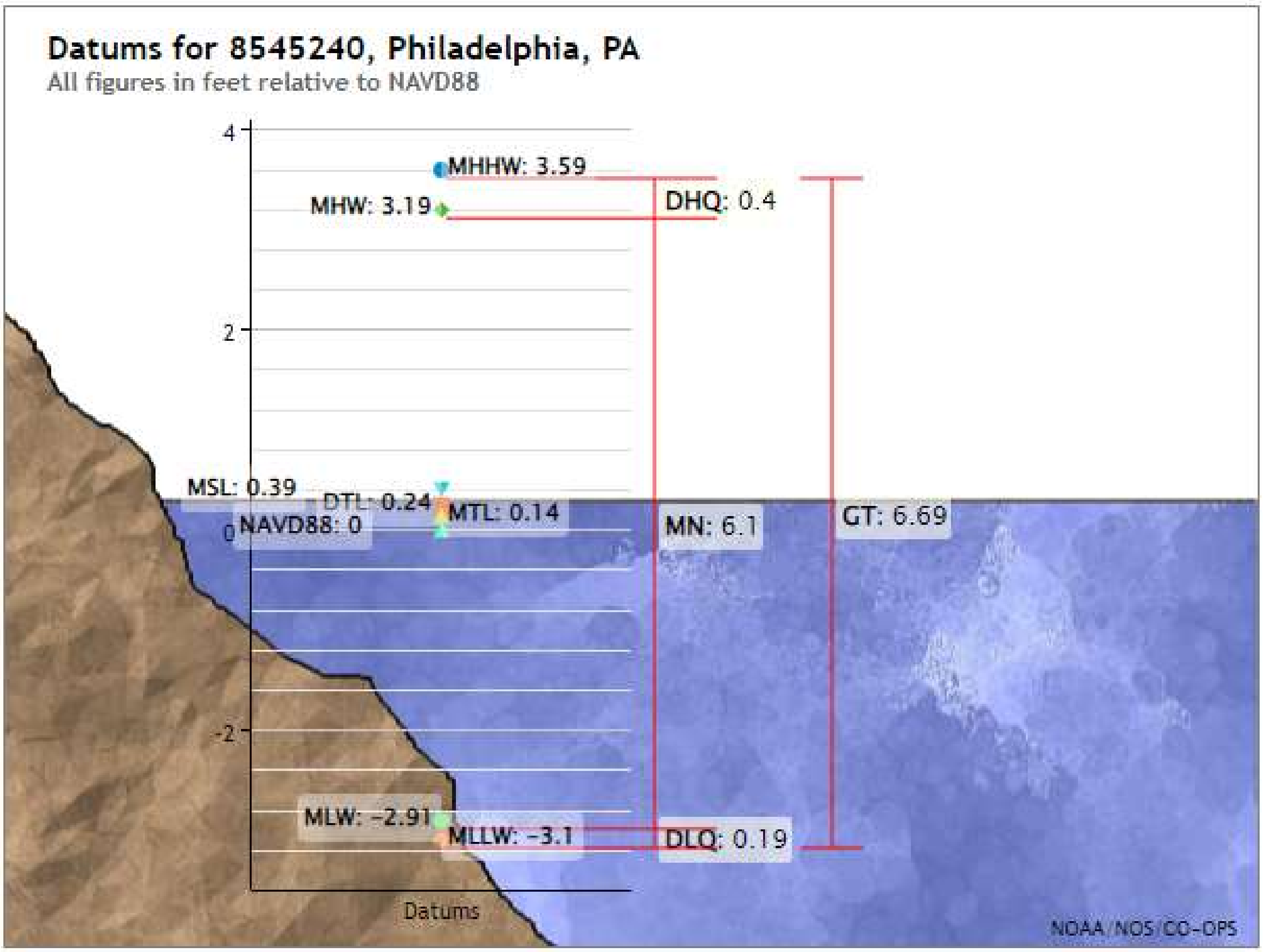


Figure 5.1 NOAA Philadelphia Station 8545240 Tidal Range Statistics, https://tidesandcurrents.noaa.gov/stationhome.html?id=8545240

Table 5.1 NOAA Philadelphia Stations 8545240 Acronym Definitions

Datum	Description
MHHW	Mean Higher-High Water
MHW	Mean High Water
MTL	Mean Tide Level
MSL	Mean Sea Level
DTL	Mean Diurnal Tide Level
MLW	Mean Low Water
MLLW	Mean Lower-Low Water
NAVD88	N. Am. Vertical Datum of 1988
GT	Great Diurnal Range
MN	Mean Range of Tide
DHQ	Mean Diurnal High Water Inequality
DLQ	Mean Diurnal Low Water Inequality

Detailed riverbed bathymetry data for the Study Area is available from NOAA for 2005 and the Army Corps of Engineers (USACE) through 2016. The Corps regularly updates the bathymetry data based on maintenance of the navigation channel. The Philadelphia Water Department has also conducted bathymetry surveys in some areas, mostly in and around the mouths of tributaries to the Delaware River. The vertical distance between surface water level and riverbed bathymetry is the total water depth. The mean water surface level and available bathymetry data sources are combined to create the total water depth contours of the Study Area presented in Figure 5.2. The depths calculated in this way represent water depths in the middle of a tidal cycle, or mean depth.

The depth of the Delaware River within the Study Area varies from 0-20 meters (0–65.6 ft). This wide variation in depth can be observed from shore to shore, with the shallower areas along the shores and the deepest areas within the shipping channel. The New Jersey side of the Study Area has more shallow stretches of shoreline, 0-2 meters (0-6.6 ft), than the Pennsylvania side. On the Pennsylvania shoreline, the only shallow stretch of the shoreline is adjacent to the Philadelphia International Airport. Along Philadelphia County the water is deep, with a shoreline depth mostly from 2-5 meters (6.6-16.4 ft), though deeper in many locations. The tidal Schuylkill River is also deep, with shoreline depths ranging from 2-10 meters (6.6-32.8 ft) and total depth ranging from 2-15 meters (6.6–49.2 ft).

Water depth can be hazardous to swimmers when exceeding the depth at which the swimmer can safely stand on the bottom to breathe and rest. Additionally, the changing tidal levels throughout the day can put swimmers at risk given the difference between high and low tides of 6.1 feet within the Study Area. Deep water at the shorelines also compounds safety risks to other recreators who may need to exit the water and must try to do so from deep areas surrounding piers, docks, sea walls and other impediments to safe egress. In the Study Area, the deepest waters in the shipping channel are also noted for having the fastest current velocities, which are hazardous to non-motorized recreational craft such as kayaks, paddleboards and canoes.

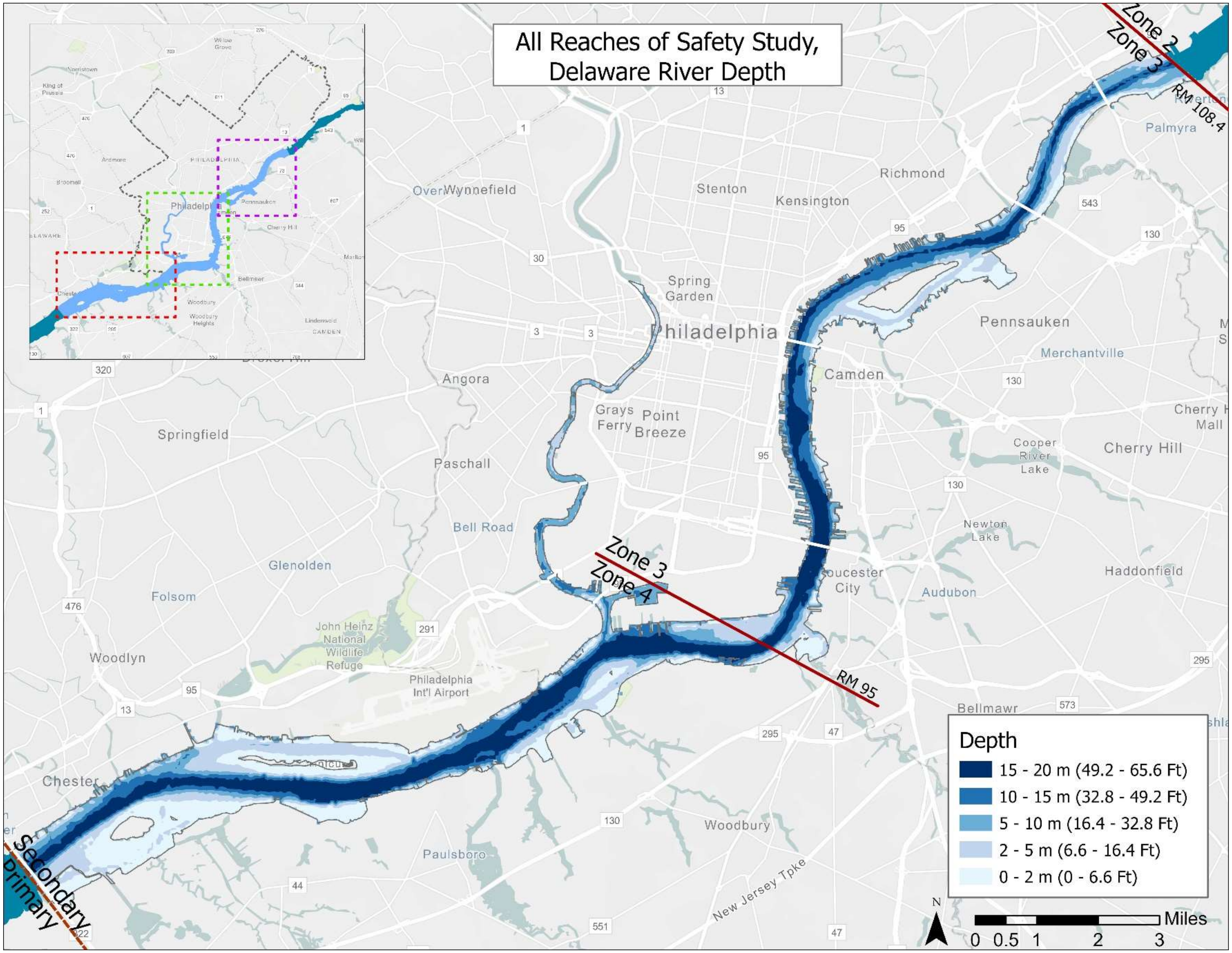


Figure 5.2 Mean Tidal Depth – Full Extent of the Safety Study Area

5.2. Distance from Shore

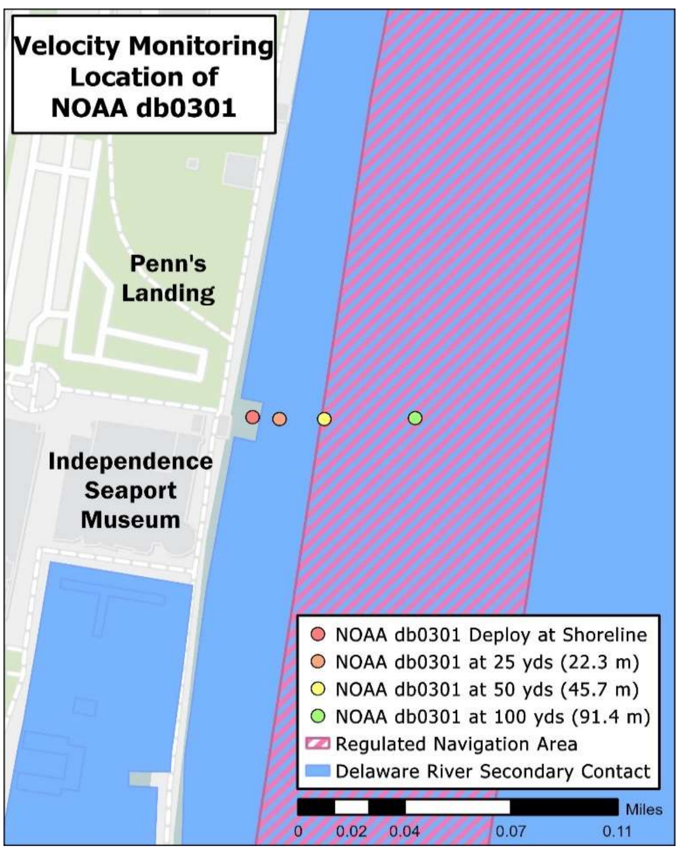
The width of the Delaware and tidal Schuylkill Rivers within the Study Area may be calculated using geographic information systems or other freely available web-based resources. Figure 5.4 presents seven transects measuring river width across multiple locations within the Study Area. The width of the Delaware River within the Study Area is highly variable, ranging from 0.55 kilometers (0.34 miles) to 2.15 kilometers (1.33 miles). The width of the tidal Schuylkill River ranges from 0.11 kilometers (0.07 miles) to 0.27 kilometers (0.17 miles).

Distance from shore is an important hydraulic parameter for evaluating swimming safety (Section 9.2) as well as kayaking, canoeing and paddleboarding safety (Section 9.3). Given the tidal range of the Study Area, recreators may safely launch and egress under high tide conditions but have trouble returning to shore in some locations under low tide conditions.

5.3. Current Velocity

The tidal Delaware River is known for its fast currents. A detailed description of the spatial distribution of currents and their fluctuation over the course of tidal cycles is important to understanding their potential hazards to recreational activities in the Study Area.

Limited observed velocity data is available within the Study Area. NOAA hosts a tidal velocity monitoring station (db0301, Figure 5.3) located at Penn's Landing, and the PWD temporarily deployed monitoring buoys, managed by Woods Hole Group, near the mouth of the Schuylkill River (Buoy B) and just below the downstream boundary of the Study Area near Claymont, Delaware (Buoy C). These monitoring locations are presented in Figure 5.5.



PWD has performed additional short-term buoy deployments to measure velocity, but the longest ranges of overlapping data, which are most useful to describe velocity for this report, are among db0301, Buoy B and Buoy C. Buoys B and C measure velocity over a range of depths, however this report will discuss only surface velocities.

In addition to measuring surface velocity, db0301 is a "side looker," meaning that it measures velocities from where it is mounted out across the river a specific distance.

With db0301 data, velocities within different distances from shore may be measured and interpreted. Figure 5.4 shows locations in the river corresponding to velocity measurements used in this study.

Figure 5.3 NOAA Station db0301 Current Velocity Monitoring Location

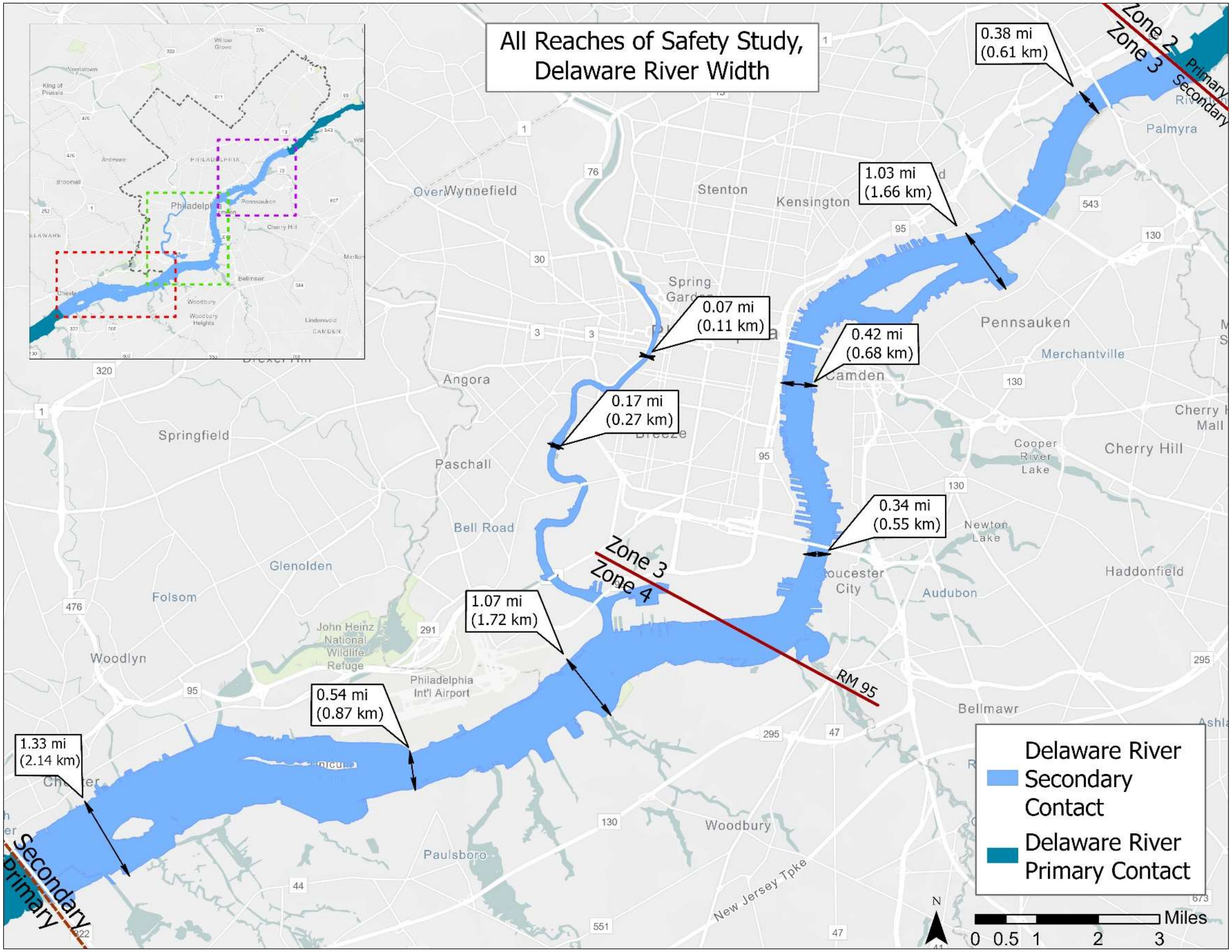


Figure 5.4 Distance from Shore – Full Extent of Study Area

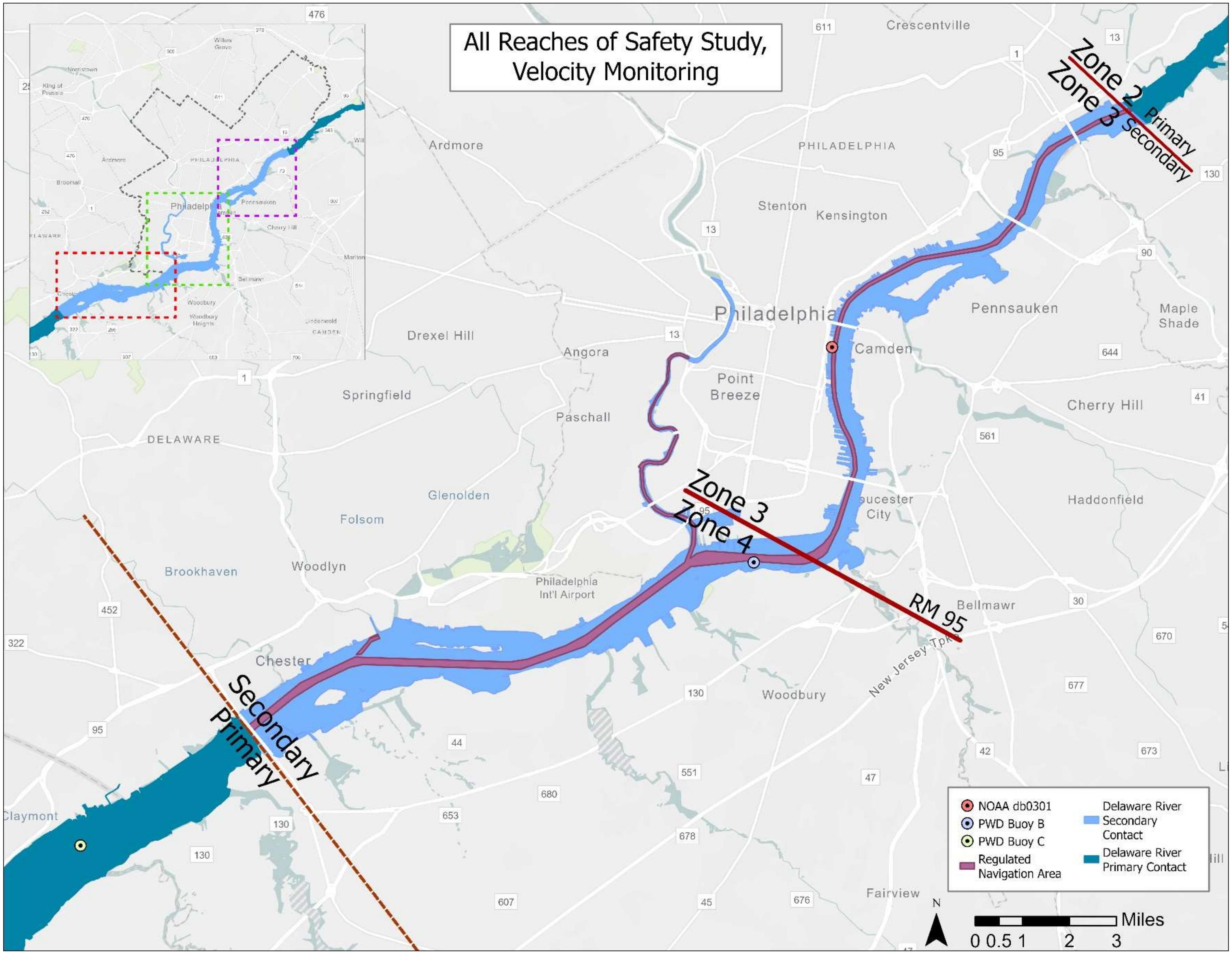


Figure 5.5 Current Velocity – Observed Data Stations Full Extent of Study Area

Figure 5.6 presents NOAA db0301 velocity data and nearby NOAA Philadelphia water level data for the 4th of July in 2014. The graph shows both the current velocity and the water level increasing and decreasing due to tidal action. Velocities are positive when water is moving upstream on a flood tide and are negative when water is moving downstream on an ebb tide.

In simple estuaries, the high/low water levels and peak velocities align so that maximum water levels occur when the water velocity is zero. This is called "slack tide," as the water is not moving very fast while it changes direction from flood to ebb. Similarly, at low water levels the velocity is also zero (or at slack tide) because the velocity is transitioning from an ebb tide to a flood. However, most estuaries are not simple, and the Delaware River is no exception. The discrepancy between a simple estuary's water level-velocity alignment and the observed alignment is called a "phase lag." Note the approximate three- to five-hour phase lag between slack velocity and high/low water level or tide. Due to this phase lag, as shown in Figure 5.6, current velocities are not necessarily zero at low and high tides and can be as swift as 1.5 ft/s.

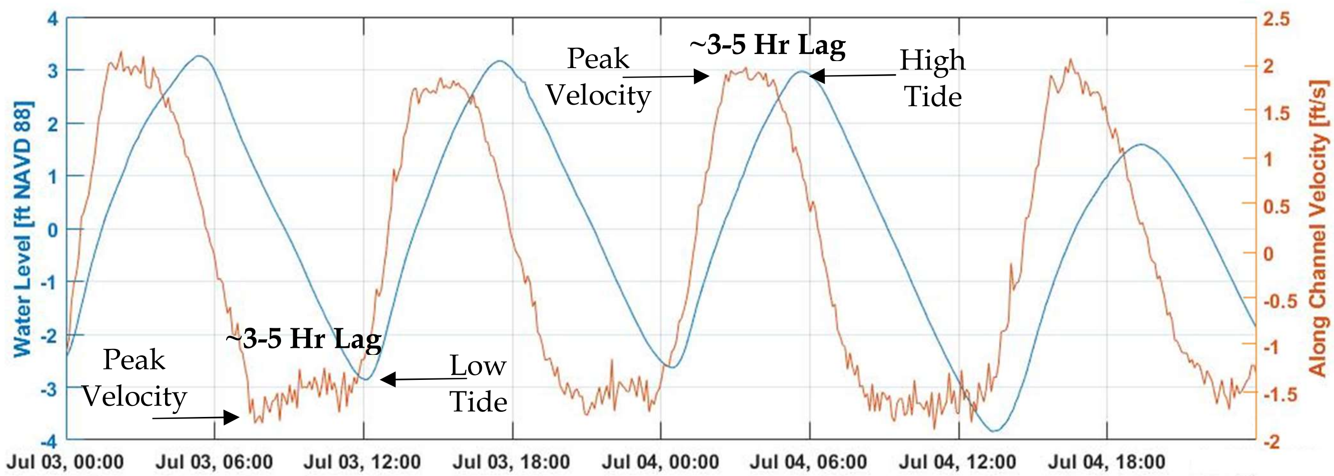


Figure 5.6 NOAA db0301 25-50 Yards Offshore and NOAA Philadelphia Water Level 2014

The figure above presents current velocities in their upstream and downstream directions (positive or negative). Absolute velocity may also be analyzed to study the current speeds observed regardless of whether the current is moving upstream or downstream. One of the most practical ways to do this is to create a cumulative distribution plot of the data, which helps identify the percent of time the current exceeds a certain velocity. Figure 5.7 shows the cumulative distributions of three observed velocity data sources in or adjacent to the Study Area plotted together. The distribution plots reflect a time of year when recreation is likely to take place (May 1 through September 30). The year 2014 is used because of data availability at all data sources during this time.

Figure 5.7 allows for observations of the frequency of specific velocities in the Study Area. Velocities in the Study Area range from 0.1 to 3.5 ft/s with a 50% exceedance ranging from 1-2.5 ft/s. Data at station db0301 show that velocities 0-25 yards from shore are slower than those 25-50 yards from shore, which are slower yet than velocities 50-100 yards from shore. As they move from shore towards the channel, water velocities increase rapidly. Buoys B, C and db0301 at 25-50 yards from shore are representative of velocities along the edge of the shipping channel. Measurements taken from db0301 at 50 to 100 yards from shore are within the shipping channel. These four locations have the fastest currents compared to the near-shore db0301 observations at a location 0-25 yards from shore.

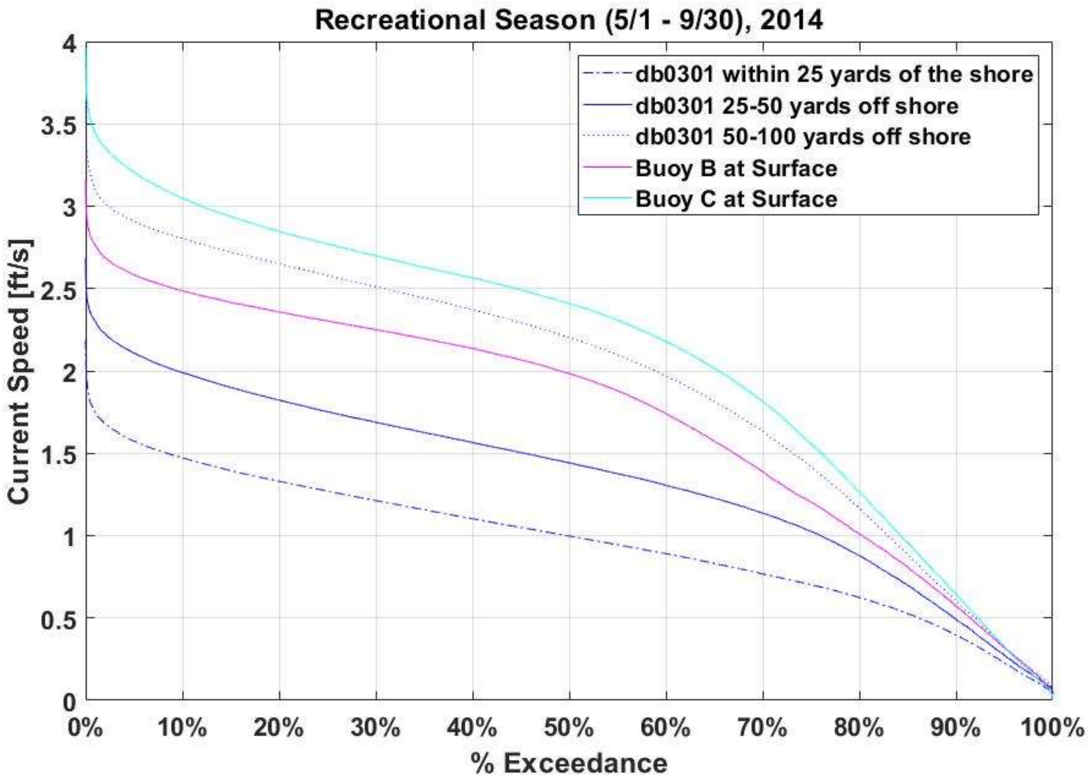


Figure 5.7 Cumulative Distribution of Study Area Velocity May–Sept. 2014

A new current velocity monitoring station was established by the USGS during the production of this report. In the future, USGS station 01467200 at Penn's Landing may provide additional current velocity information.

5.4. Wind-Generated Waves

Surface water waves can result from many causes; they can propagate into an estuary like the tidal Delaware River from the ocean, and they can also be generated locally, often from wind blowing over the water surface. Local events, such as boats leaving wakes, can also generate waves. This wave height estimation focuses on locally wind-generated waves. The estuary is far enough from ocean influences that only wave signals as energetic as the tides themselves can propagate into the Study Area with significant frequency.

This section summarizes a method for estimating expected locally generated wind waves in the Study Area. The wave heights estimated using this method are approximate and are not as accurate as a wave model or buoy observations would be. However, estimations are sufficient for identifying whether wind-generated waves may create a hazard to recreational activities in the Study Area.

Wind wave generation results from wind acting in a single direction over a long stretch of water. This allows the energy transferred from the wind to the water to build, and the total length over which energy can build is called a fetch length. Three representative stretches of the river that could result in wave generation were identified, designated the "upper," "central" and "lower" reaches (Figure 5.9). Table 5.2 includes the fetch length associated with each reach and the approximate wind directions that could result in wave generation over the reach.

Table 5.2 Fetch Length and Wind Directions for Wave Height Estimation

River Reach	Extent	Fetch Length, Miles	Approximate Wind Directions of Concern, Degrees	Percent of Wind Record in this Alignment
Upper	Ben Franklin Bridge to Betsy Ross	4.7	45-64 °, 225-245 °	16%
Middle	Brooklawn to shoreline north of the Ben Franklin Bridge	4.9	355-15 °, 175-195 °	10%
Lower	Fort Mifflin to Gloucester City	4.3	65-85 °, 245-265 °	12%

This study evaluated the wind record within the wind directions associated with the fetch length for each reach to identify the likelihood and size of wind-generated waves within the Study Area. It specifically considers the wind record from the Philadelphia International Airport from 6:00 a.m. through 8:00 p.m. for May 1 through September 30, 2018 and 2019. The data are presented as a wind rose generated by the Northeast Regional Climate Center.

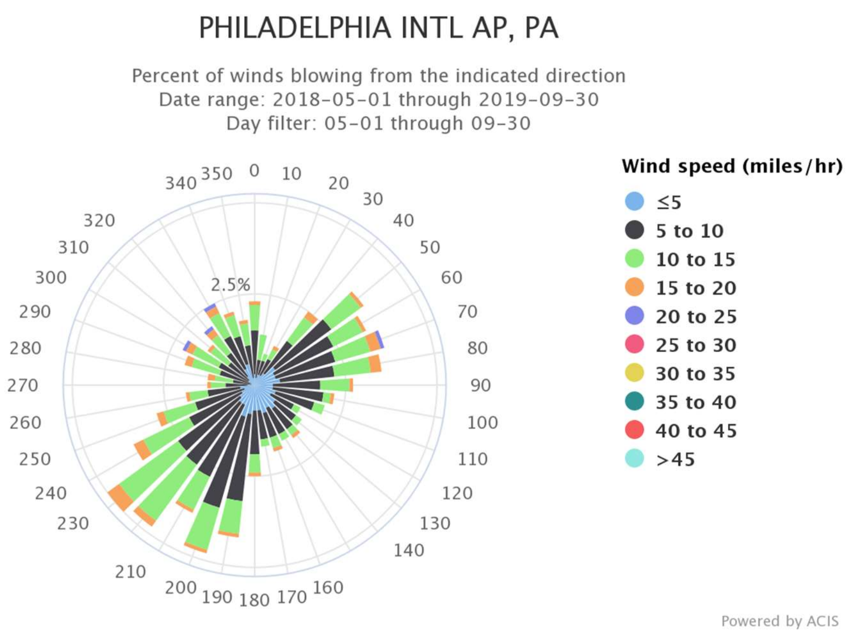


Figure 5.8 Wind Rose from Philadelphia Airport (Northeast Regional Climate Center)

For each reach, the fetch length is used to estimate the expected wave height associated with the various wind speeds observed at the airport. As wind energy builds along a fetch length, wave heights can also increase. For this reason, wave heights identified in this analysis are only likely to occur in localized areas rather than along the entire length of a fetch. For wind to generate waves, the wind direction must align with the fetch direction. The river turns and bends in the Study Area, leaving only a few long reaches where the fetch length supports wave propagation. To estimate wind-generated wave height, the USACE methodology is followed and detailed within the reference (U.S. Army Corps of Engineers, 1984). Results appear in the following graphs.

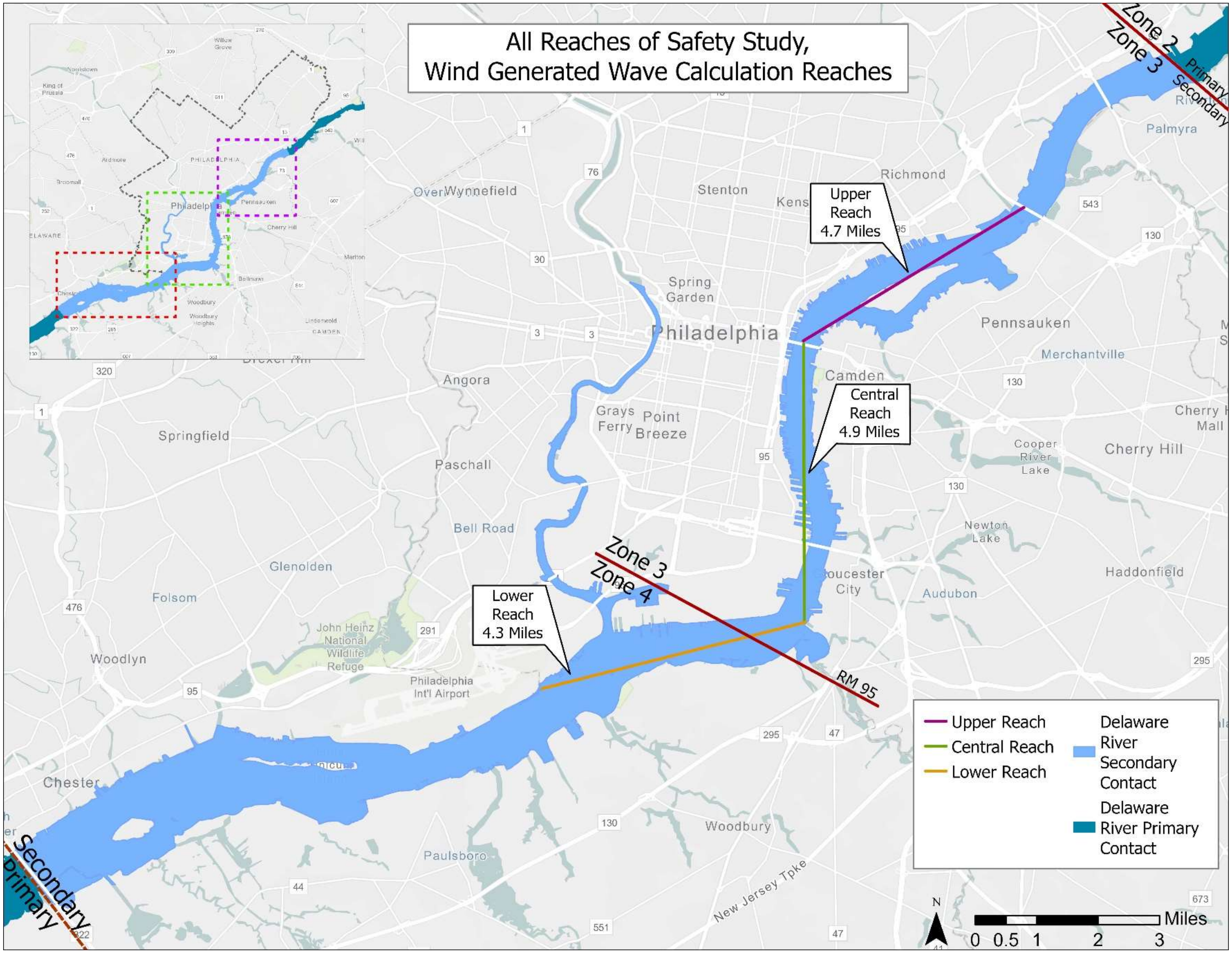


Figure 5.9 Map of Reaches Used to Estimate Wave Height

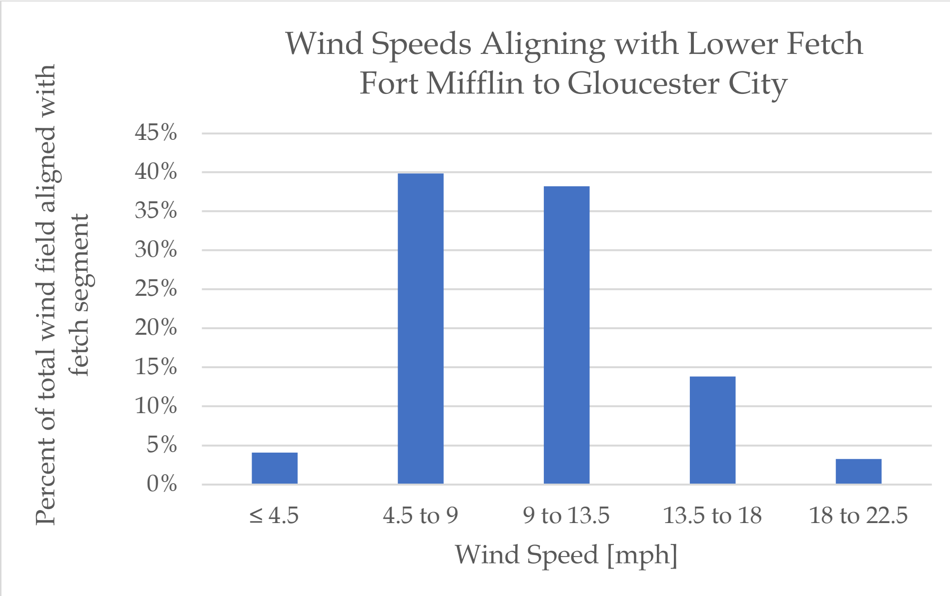


Figure 5.10 Winds Speeds Aligning with Lower Fetch

In the 4.3-mile lower reach used to estimate expected wave heights, 77% of the winds that aligned with the river stretch had wind speeds from 4.5–13.5 miles per hour. The highest observed wind speeds aligning with the stretch were between 18 and 22.5 miles per hour. These wind speeds and fetch alignments result in waves that range from <0.8-2 feet.

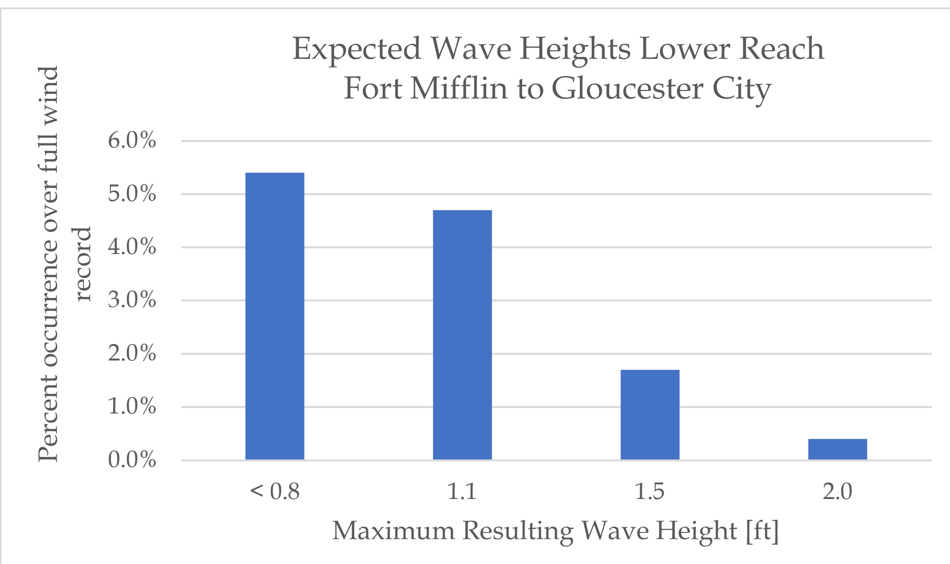


Figure 5.11 Expected Wave Heights in Lower Reach

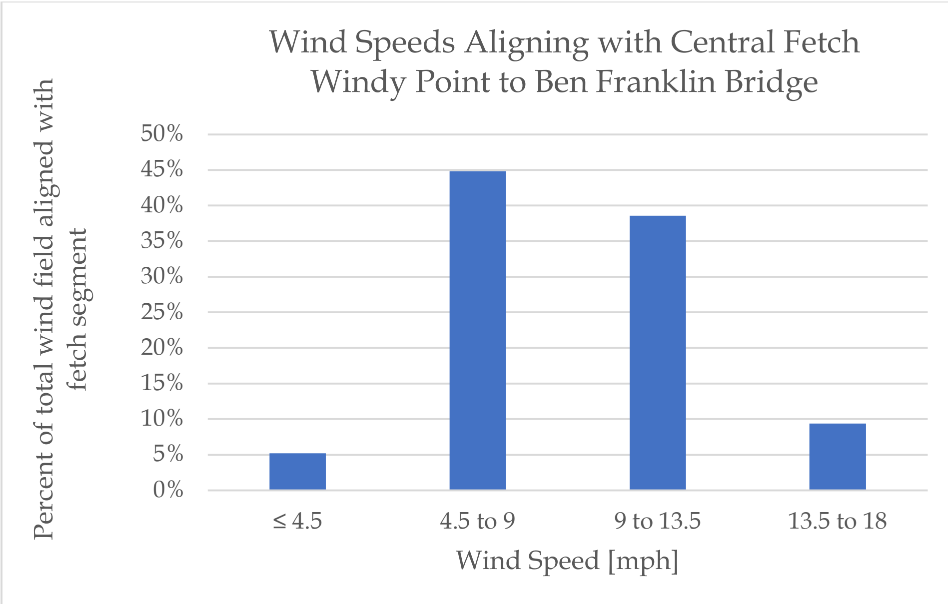


Figure 5.12 Winds Speeds Aligning with Central Fetch

In the 4.9-mile central reach used to estimate expected wave heights, 84% of the winds that aligned with the river stretch had wind speeds from 4.5–13.5 miles per hour. No observed winds above 18 miles per hour align with the central reach. Ten percent of the winds aligning with this river stretch had observed wind speeds from 13.5-18 miles per hour. These wind speeds and fetch alignments result in waves that range from <0.8–1.6 feet.

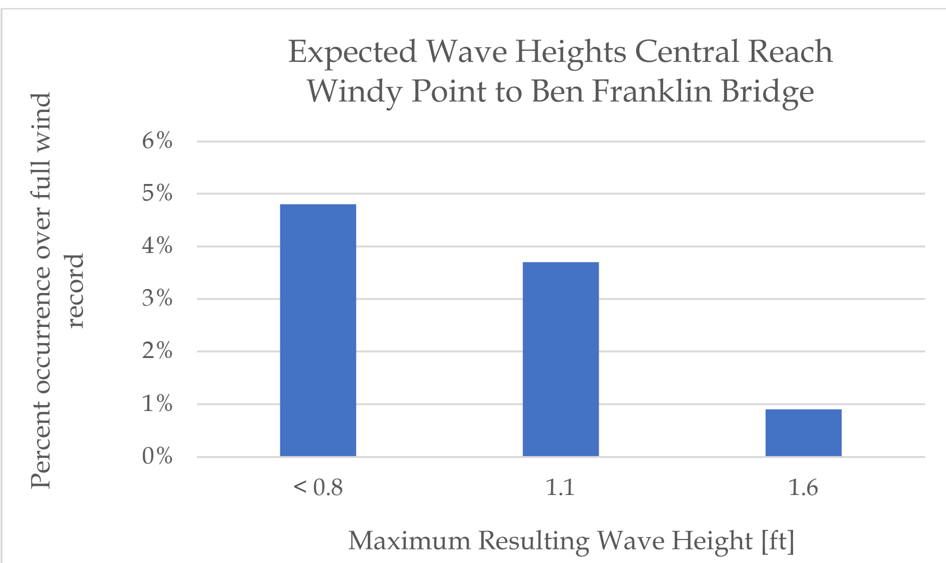


Figure 5.13 Expected Wave Heights in Central Reach

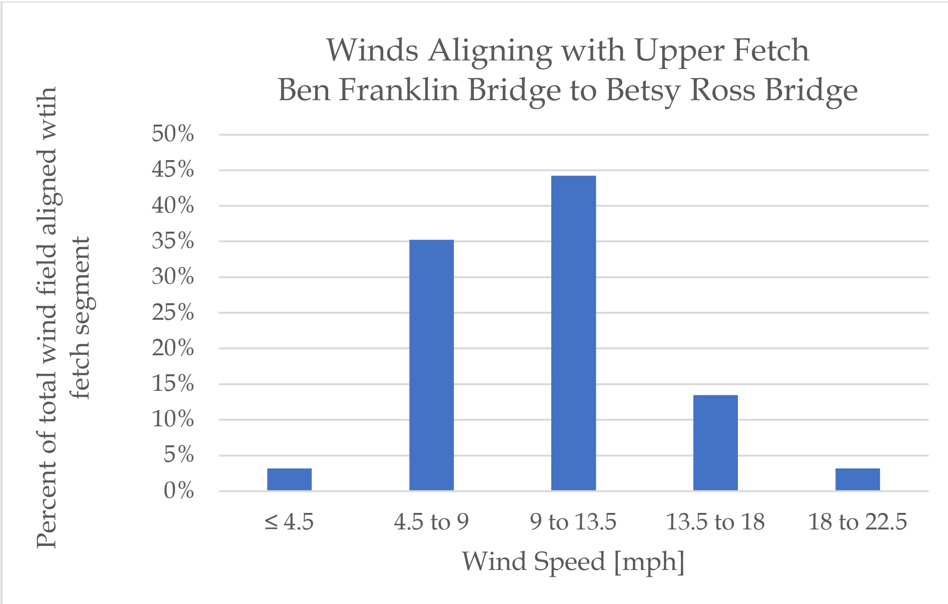


Figure 5.14 Winds Speeds Aligning with Upper Fetch

In the 4.7-mile upper reach used to estimate expected wave heights, 79% of the winds that aligned with the river stretch had wind speeds from 4.5–13.5 miles per hour. The highest observed wind speeds aligning with the fetch were 18-22.5 miles per hour. These wind speeds and fetch alignments result in waves that range from <0.8–2.1 feet.

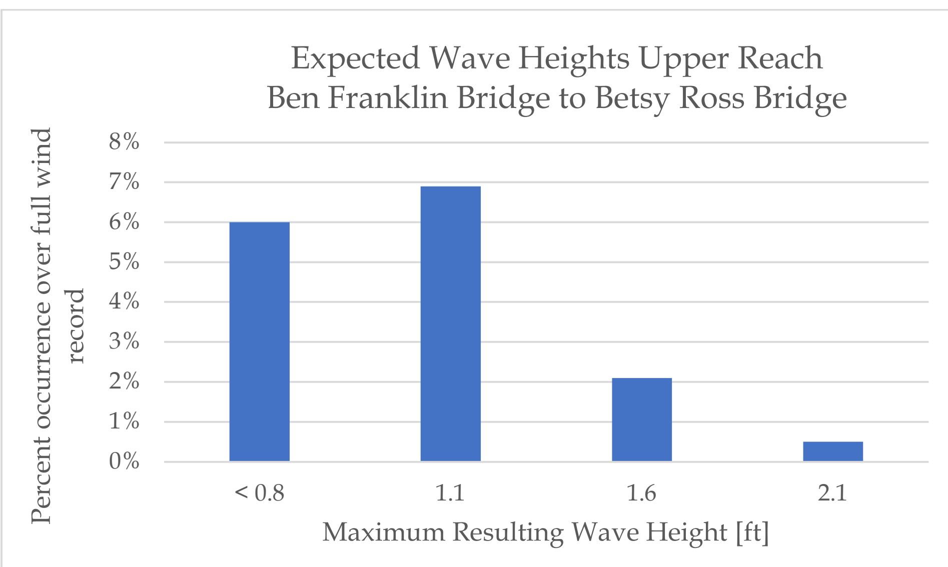


Figure 5.15 Expected Wave Heights in Upper Reach

Table 5.3 below summarizes wind-generated wave estimations per reach. The analysis identifies that wind-generated waves based on estimations from the wind record could occur at heights over one foot in the Study Area. In the upper reach, wind-generated waves above one foot have the potential to occur 10% of the time, 5% of the time in the central reach and 7% of the time in the lower reach.

Table 5.3 Wind-Generated Wave Estimated Results

River Reach	Extent	Fetch Length, Miles	Approximate Wind Directions of Concern, Degrees	% of Wind Record in this Alignment	% of Winds Aligned with Stretch Resulting in Waves above 1 ft	% of Winds Overall Resulting in Waves above 1 ft
Upper	Betsy Ross to Ben Franklin Bridges	4.7	45-64 °, 225-245 °	16%	61%	10%
Central	Ben Franklin Bridge to Windy Point	4.9	355-15 °, 175-195 °	10%	48%	5%
Lower	Fort Mifflin to Gloucester City	4.3	65-85 °, 245-265 °	12%	55%	7%

Note this estimate assumes that winds coming from directions outside the directions identified for fetch analysis would result in negligible wave heights.

Wind-generated waves have the potential to create hazards to recreators depending upon the activity. Section 8 explores the safety concerns related to wind-generated waves in more detail for each recreational activity.

Section 6 Shoreline and Other Hazards

This section considers debris, security zones, legacy infrastructure, active infrastructure and electrical shock drowning in the Study Area in a discussion of shoreline hazards. A number of resources are available, including river debris cleanup data, U.S. Coast Guard guidance and satellite imagery to document shoreline hazards in the Study Area.

6.1. Debris

Floating and submerged debris, including wood (fallen trees and branches) and man-made materials such as tires, mattresses, steel drums, and shopping carts can interfere with the recreational use and navigability of a waterway. Downed tree limbs and other debris can disorient or snag swimmers and capsize kayakers, canoers, paddleboarders and jet skiers, causing injury or drowning (American Canoe Association, 2004).

In 2018, the U.S. Coast Guard hosted a Ports and Waterways Safety Assessment workshop to evaluate navigational safety on the tidal Delaware River from Middletown, Delaware to the Betsy Ross Bridge in Philadelphia, Pennsylvania. The final report from this workshop offers information on both the quantity of debris and associated hazards in the Study Area (U.S. Coast Guard, 2019). Heavy concentrations of debris and floating obstructions are noted throughout the tidal Schuylkill River and the Delaware River between the Schuylkill River confluence and Penn's Landing Marina. Debris that naturally accumulates in the Delaware River's Horseshoe Bend, for example, includes not just small logs but entire trees and pier sections (Figure 6.1). Heavy rain events can dramatically increase the quantity of debris flowing down the tidal Schuylkill and Delaware Rivers. The report emphasizes that obstructions such as fallen trees, railroad ties and drums can be an irritant to larger commercial vessels but pose a major hazard for recreational boats, jet skis, and small craft such as kayaks, canoes and paddleboards.

Debris and litter cleanups in the Study Area offer information on the quantity and types of debris found in the tidal Schuylkill and Delaware Rivers. Living Lands and Waters, an Illinois-based nonprofit dedicated to cleaning America's rivers, hosted 20 Delaware River cleanups within or immediately north of the Study Area in 2015 (Philadelphia Water Department, 2015). The cleanups removed 16.4 tons of garbage, including 308 tires, from the Delaware River and its shorelines. The cleanup also revealed debris such as mattresses, wooden pallets, plastic crates and steel drums (Figure 6.2).

Debris traveling with the currents is often difficult to see or is below the water surface. Given the hazards and visibility issues with debris, any swimming, kayaking, canoeing, paddle-boarding and jet skiing recreation requires keeping a watchful eye for and staying away from debris in the water.

Figure 6.1 Horseshoe Bend (outlined in red) is a Natural Collection Point for Debris (Imagery @2023 Maxar Technologies, U.S. Geological Survey, USDA/FPAC/GEO, Map data @2023)

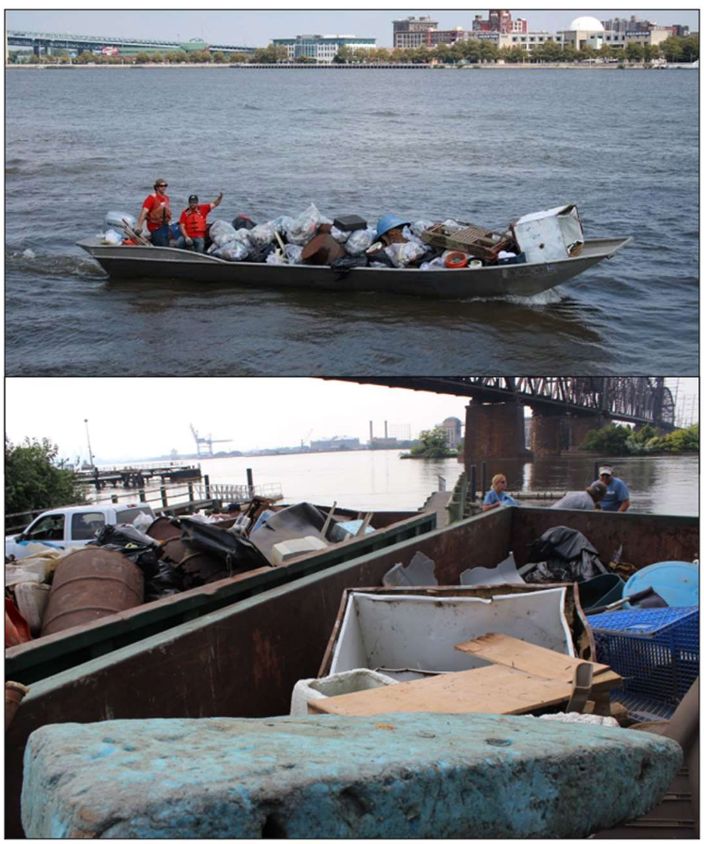


Figure 6.2 Living Lands and Waters Delaware River Cleanups Aug. 20-Sept. 2, 2015 (Billy Penn)

6.2. Security and Exclusion Zones

Security and exclusion zones, whether enforced or unenforced, exist around industrial, military and commercial shipping facilities in the Study Area. These facilities may summon municipal police, state police and the U.S. Coast Guard Sector Delaware Bay if a person is swimming, wading, kayaking, canoeing, paddleboarding or jet skiing too close to sensitive infrastructure such as intake structures, discharge pipes, terminals, piers and docks.

The Philadelphia Marine Police Unit and the U.S. Coast Guard Sector Delaware Bay work closely together to keep the Port of Philadelphia secure and safe (Figure 6.3). The agencies reside together in the same building at One Washington Avenue in Philadelphia, allowing constant communication when situations arise. The Philadelphia Marine Police Unit is instrumental when the Port of Philadelphia offloads military cargo, sending divers underwater and scanning the pier for threats (U.S. Coast Guard, 2009). The Pennsylvania Fish and Boat Commission and the New Jersey Marine Services Bureau also share the responsibility of enforcing U.S. Coast Guard homeland security regulations in the Study Area, assisting as needed when patrol boats are near an incident (Pennsylvania Fish and Boat Commission, personal communication, October 8, 2021).

Figure 6.3 U.S. Coast Guard and Philadelphia Marine Police Unit (U.S. Coast Guard)

A strong presence of municipal, state and federal agencies enforces security in the Study Area. These agencies work collaboratively to respond to security concerns and enforce homeland security regulations. Table 6.1 includes security zone guidance that applies to swimming, wading, kayaking, canoeing, paddleboarding and jet skiing activities in the Study Area.

Table 6.1 Security Zone Guidance Applying to the Study Area

Agency	Security Zone Guidance
U.S. Coast Guard	• Observe and avoid all security zones and commercial port operations. Avoid areas that have large marine facilities—including military, commercial/cruise or petroleum facilities. Restrictions are also in place near most dams, power plants and other facilities located near water. • Do not stop or anchor beneath bridges or in shipping channels. Anyone doing so can expect to be asked to move and/or boarded by law enforcement officials.
PA Fish & Boat Commission	• Check with local authorities and refer to current charts to identify and stay away from security zones and port operation areas. • Generally, stay at least 100 yards from military areas, cruise lines and petroleum facilities. Also stay away from dams and power plants.

Sources: (U.S. Coast Guard, 2010) and (Pennsylvania Fish and Boat Commission, 2021)

For security, and therefore safety purposes, recreational activities should remain a minimum of 100 yards from marine facilities, power plants, military areas, cruise lines and petroleum facilities.

6.3. Legacy Infrastructure

Legacy infrastructure includes derelict docks, piers, terminals, piles, outfalls, intakes, pipelines, bridges and vessels in a waterway detailed in Section 4 and depicted in Figure 4.8. Currents, wind and boat wakes can increase the chance of a swimmer, kayaker, canoer or paddleboarder alliding with legacy infrastructure in the Study Area, causing injury or drowning (U.S. Coast Guard Sector Delaware Bay, personal communication, May 4, 2021).

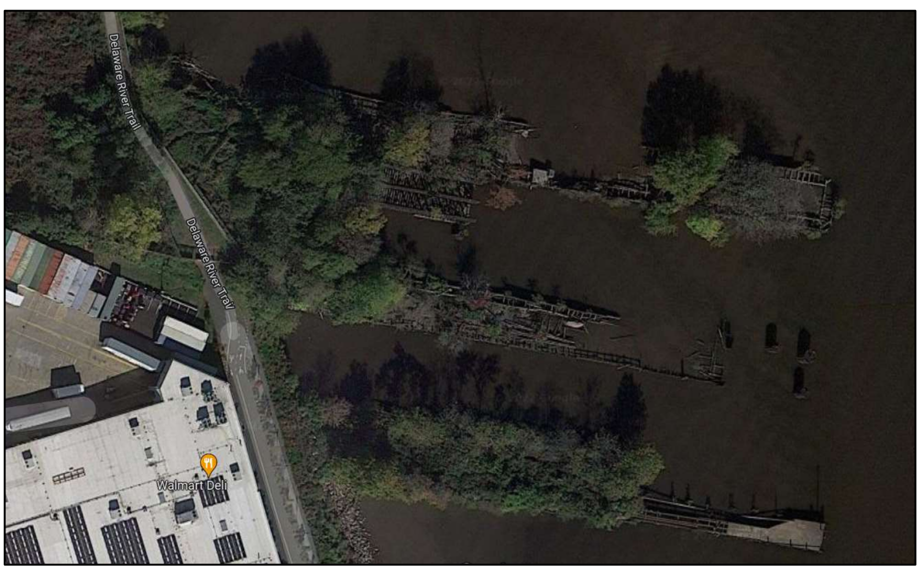


Figure 6.4 Abandoned Structures in the Study Area, Southeast Philadelphia (Google Maps)

The decaying conditions typically associated with legacy infrastructure make swimming, wading, paddling and jet skiing near these structures dangerous. Figure 6.5 shows a kayak was pierced by exposed rebar from a bridge. Upon seeing an oncoming wake from a motorboat, the kayaker attempted to hold onto the side of the bridge to steady the kayak; however, the wake filled the kayak with water, pushing it under a sharp piece of rebar.

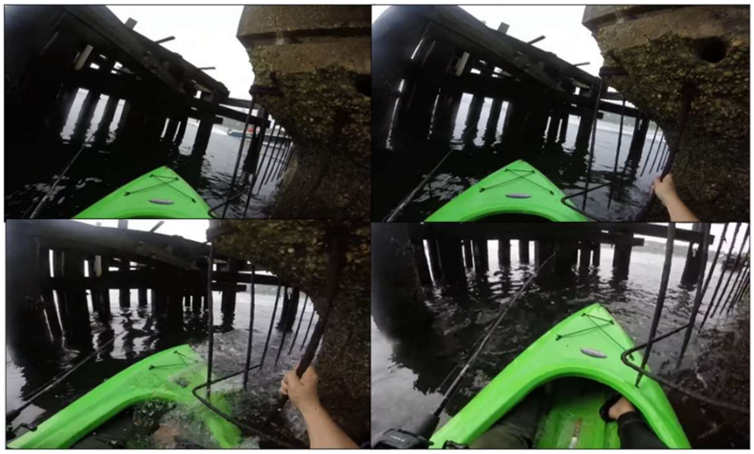


Figure 6.5 Kayak Pierced by Exposed Rebar from Bridge (Youtube, That Fishing Guy)

Guidance from other waterways with legacy infrastructure is available to help determine unsafe distances around legacy infrastructure in the Study Area. For example, Kiptopeke State Park along the Chesapeake Bay has partially sunken concrete ships that draw in kayakers, canoers, paddleboarders and jet skiers. To protect the public from exposed rebar and other hazards on these ships, the park posts signs warning users to maintain a minimum distance of 50 feet from each concrete ship (Chesapeake Bay Media, 2019).

For this study, the safe distance for swimming, wading, kayaking, canoeing, paddleboarding and jet skiing is at least 50 feet away from legacy infrastructure.

6.4. Active Infrastructure

Active infrastructure in the Study Area includes intake structures, discharge structures, stormwater and combined sewer outfalls detailed in Section 4, Figure 4.9. The general public may not be aware of these structures or understand the safety risks associated with swimming, wading, kayaking, canoeing, paddleboarding and jet skiing near them.

Intake structures pump surface water to industrial facilities and drinking-water treatment plants, exerting a localized suction effect as they do so. The suction and resulting current into an intake pipe can be strong enough to pull and impinge a person, causing injury or drowning (Royal Life Saving Society – Australia, 2021).

Discharge structures release treated wastewater from municipal and industrial facilities into surface waters at a high volume, high velocity, and in some cases high temperature. High-velocity and turbulent currents produced by discharge structures are dangerous to swimmers, kayaks, canoes and paddleboards.

Stormwater and combined sewer outfalls discharge during and after rain events. Flow exiting these outfalls can increase very rapidly, catching swimmers, waders, kayakers, canoers and paddleboarders off guard, causing injury or drowning. If there is no flow from an outfall and no rain in the immediate area, people may feel a false sense of security that they are safe near an outfall; however, conditions can quickly change if rain is occurring nearby. In a 2018 example, a woman photographing the inside of a stormwater outfall in Philadelphia, Pennsylvania was swept away when a flash flood caused a sudden rush of water to flow through the outfall. After extensive search efforts, the Philadelphia Police Marine Unit recovered the victim from the Pennypack Creek (6ABC Action News Philadelphia, 2018). The victim's body was found pinned under a piece of discarded furniture in the creek (Figure 6.6).

Figure 6.6 Philadelphia Police Marine Unit Searching Pennypack Creek for Victim Swept Away by the Current from a Stormwater Outfall in Philadelphia, Pennsylvania (6ABC News)

For this study, the safe distance for swimming, wading, kayaking, canoeing, paddleboarding and jet skiing is at least 50 feet away from active infrastructure.

6.5. Electrical Shock Drowning

Electrical Shock Drowning (ESD) is a drowning resulting from paralysis caused by electrical currents in the water. ESD occurs when dock, marina or boat electrical system leaks electric current into the water (Figure 6.7). Faulty wiring, the use of damaged electrical cords and other devices not approved as marine rated can cause the surrounding water source to become energized from electricity leakage (National Fire Protection Association, 2022).

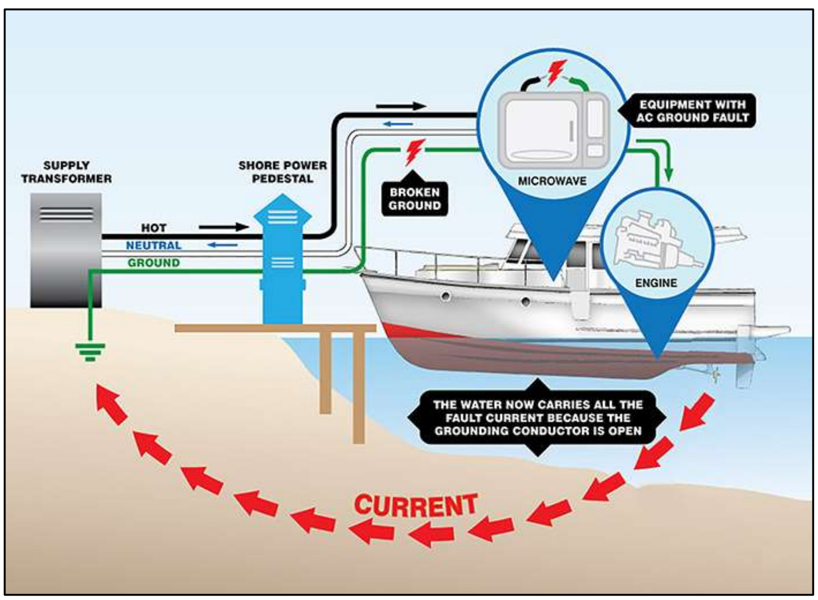


Figure 6.7 How Electrical Current can Leak into the Water (Boat U.S.)

In freshwater environments, the human body is much more conductive than the water itself, making ESD a significant hazard near freshwater docks and marinas with electric power. In a 2017 interview, Penn's Landing Marina Dockmaster Jim Picuri discussed the need to prevent electrical shock drowning (6ABC Action News Philadelphia, 2017). A portion of the report is provided for informational purposes (Figure 6.8).

Reporter Bob Brooks "Also this weekend in Ohio at the famous Put-in-Bay, a 19-year-old was electrocuted and died at a marina near his family's boat. That's why the policy here at Penn's Landing Marina is no one in the water ever."

Dock Master Jim Picuri "We don't allow anybody in the water, whether they be tubing or row boating, you can't sit on the dock and dangle your feet in the water."

Reporter Bob Brooks "He says here nothing electrical is exposed and there are routine checks for that daily. He said the main thing to focus on here is the electrical connection to the boats."

Figure 6.8 Penn's Landing Marina Dockmaster on Electrical Shock Drowning (6ABC News)

To prevent ESD, the Electrical Shock Drowning Prevention Association recommends that people do not swim within 50 yards of any electrically powered docks (Electrical Shock Drowning Prevention Association, 2015). Due to the potential to make contact with electrical currents in the water, the safe distance from docks and marinas due to the threat of electrical shock drowning for swimming, wading, kayaking, canoeing, paddleboarding and jet skiing is a minimum of 50 yards.

6.6. Summary of Shoreline Hazards

Debris, security zones, legacy and active infrastructure and electrical shock drowning collectively contribute to shoreline hazards in the Study Area. The comprehensive mapping in Section 4 detailing shoreline modifications provides locations of the shoreline hazards discussed in this section. Table 6.2 provides a summary of the numerical and narrative criteria identified for the shoreline hazards evaluated in the Study Area.

Table 6.2 Summary of Shoreline Hazards Criteria

Shoreline Hazard	Safety Criteria
Debris	Avoid visible and exposed and submerged debris where possible
Security Zones	At least 100 yards from all marine facilities, power plants, military areas, cruise lines and petroleum facilities
Legacy Infrastructure	At least 50 feet from all legacy infrastructure
Active Infrastructure	At least 50 feet from all active infrastructure
Electrical Shock Drowning	At least 50 yards from all electrically powered docks and marinas

Section 7 Maritime Hazards

Maritime hazards research informs identification and documentation of objective criteria to review for compatibility with swimming, wading, kayaking, canoeing, paddleboarding and jet skiing within the Study Area. Guidance from local professional mariners such as the U.S. Coast Guard, Pennsylvania Fish and Boat Commission, Mariners' Advisory Committee (harbor safety committee) and the Pilots' Association for the Bay and River Delaware assisted in identifying, describing and establishing safety criteria for each maritime hazard.

Numerous maritime hazards exist due to the large maritime economy—which utilizes various sizes and configurations of commercial vessels, supporting vessels like tugboats and tank vessels such as barges—within the Study Area. The maritime hazards reviewed in this section include propeller wash, bow and stern thruster wash, tow lines, oncoming ships, ship stopping distance, ship suction, visibility limitations, wakes and marine traffic areas.

7.1. Propeller Wash

Propeller wash is a strong underwater current generated by a vessel's propeller. Commercial vessels produce powerful wash currents that can result in severe turbulence hundreds of yards behind a vessel (American Waterway Operators, 2002). Propeller wash from tugboats can be especially dangerous because the current can quickly change direction due to powerful propellers which can swiftly rotate 360 degrees (Figure 7.1).

Propeller wash from commercial vessels can cause smaller watercraft like kayaks, canoes, paddleboards and jet skis to capsize and pull occupants underwater (Cuyahoga River Safety Task Force, 2017). In 2012, a kayaker maneuvering behind a passenger vessel in the San Francisco Bay was pulled down by propeller wash and fatally injured (National Transportation Safety Board, 2017). Propeller wash from commercial vessels can also pull swimmers underwater, especially when turning or reversing near the shoreline in the course of regular operations.

Figure 7.1 Propeller Wash Generated by Tugboats

A distance of 200 yards (182.9 m) behind all commercial vessels, including tugboats, is established as propeller wash safety criteria for all primary contact recreation within this Study Area.

7.2. Bow and Stern Thruster Wash

A thruster is a propeller located in a ship's bow (front) and sometimes at the stern (rear) which provides lateral propulsion and enhances maneuverability, particularly at lower speeds when turning and docking in narrow harbors (Figure 7.2). The thrusters on commercial vessels can produce turbulent underwater currents that can capsize smaller watercraft, pulling occupants and swimmers underwater (Cuyahoga River Safety Task Force, 2017).

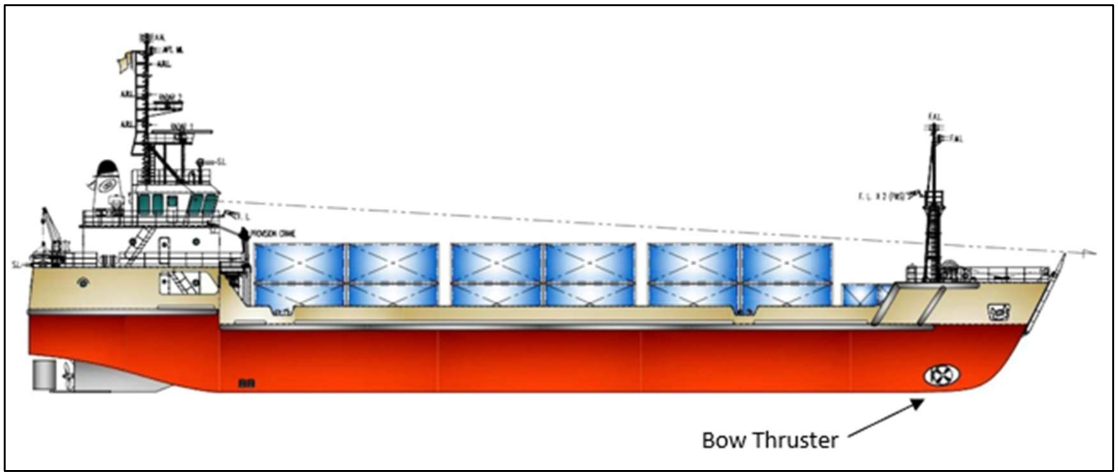


Figure 7.2 Diagram Showing a Bow Thruster on a Container Ship (Baird Maritime)

The force of bow and stern thruster wash can also push smaller watercraft against hazards like bulkheads and river walls (Figure 7.3). Officials from the Port of Green Bay advise that smaller watercraft should stay at least 100 yards away from commercial vessels and do not get alongside them because bow thrusters can create a dangerous situation (WTAQ, 2021).

For this study, the bow and stern thruster wash from commercial vessels can affect the safety of primary contact activities occurring less than 100 yards (91.4 meters) away.

Figure 7.3 Bow Thruster Wash on the Cuyahoga River in Cleveland, Ohio (Share the River)

7.3. Tow Lines

Tugboats use towlines, either above or below the water surface, when operating alongside a ship in the push-pull mode or when towing a ship by its bow or stern. Towlines are also used by recreational boaters to pull water skiers.

Figure 7.4 Towlines Located Above the Water Surface

Figure 7.4 shows pictures of visible tow lines located above the water surface. The cover picture of this report shows the Crowley barge being pulled with a towline below the water surface. Towlines are a hazard to primary contact activities, particularly jet skiing where individuals may intentionally try to jump a commercial vessel's wake and not realize a towline is attached to stern of the vessel. In 1985, a 13-year-old aboard a jet ski was decapitated by a water skier's tow line after trying to jump the wake behind a recreational motorboat (AP News, 1985).

Towlines located above and below the water surface can affect the safety of primary contact activities. Given that recreators may not be able to see the towlines, they should maintain at least a 100 yards (91.4 meters) distance away from tugs and barges in all directions.

7.4. Oncoming Ships

The speed of an oncoming commercial vessel is influenced by multiple factors, such as its size, channel width, currents, wind velocity and boat traffic. The average speed for commercial vessels in the Study Area is 8-12 knots or 9.2-13.8 miles per hour (Pilots' Association for the Bay and River Delaware, personal communication, November 18, 2021). Recreators may be unable to accurately ascertain the speed at which an oncoming commercial vessel is traveling. For example, if a commercial vessel is traveling at a speed of 10 knots, and a kayak has capsized 1,000 feet in front of that vessel, the kayaker has less than one minute to get out of the vessel's way (American Waterway Operators, 2002). Oncoming ships are a hazard to primary contact activities because collisions with commercial vessels can result in injury or death.

For this study, the assumed average speed of an oncoming commercial vessel is 10 knots (514 cm/s).

Figure 7.5 Tanker Ship on the Delaware River by Penn's Landing, Philadelphia (PENNDOT)

7.5. Ship Stopping Distance

Commercial vessels do not have brakes like automobiles and must maintain speed to be able to steer. To initiate a stop, the ship's master or pilot must cut back on the engine while at the same time accounting for winds, currents, the shipping channel and boat traffic. A commercial vessel traveling at a speed of 10 knots can take two to three miles to reach a complete stop (Pilots' Association for the Bay and River Delaware, personal communication, November 18, 2021). The U.S. Coast Guard advises operators of all recreational watercraft (including kayaks, paddleboards, canoes and jet skis) to take early and positive action to avoid a collision if an approaching commercial vessel is within two miles (U.S. Coast Guard Sector Delaware Bay, 2021).

For this study, two miles (3.2 km) will be the assumed distance required for a commercial vessel to reach a complete stop.

7.6. Water Displacement and Suction

As large commercial ships move through the water, they displace an amount of water equal to the volume of the vessel below the surface. This displaced water is pushed away, leading to temporarily increased water levels in front and to the sides of an oncoming commercial vessel. Conversely, a suction effect is created as water rushes towards the stern to fill the void of displaced water created by the moving ship. As seen in Figure 7.6, a high-pressure zone exists on both sides of the ship's bow as water is displaced, causing fast moving and turbulent water to flow outwards and along the sides of the ship until reaching the lower pressure zone near the stern. A ship's suction can draw nearby vessels and smaller craft such as canoes, kayaks, and paddleboards toward its stern (Lone Star Harbor Safety Committee, 2020).

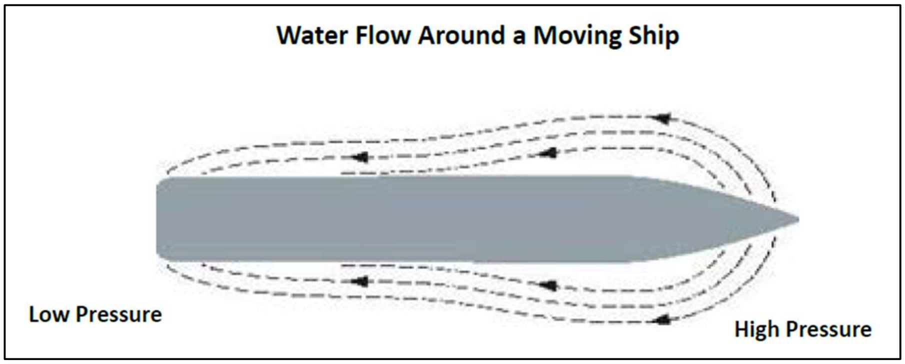
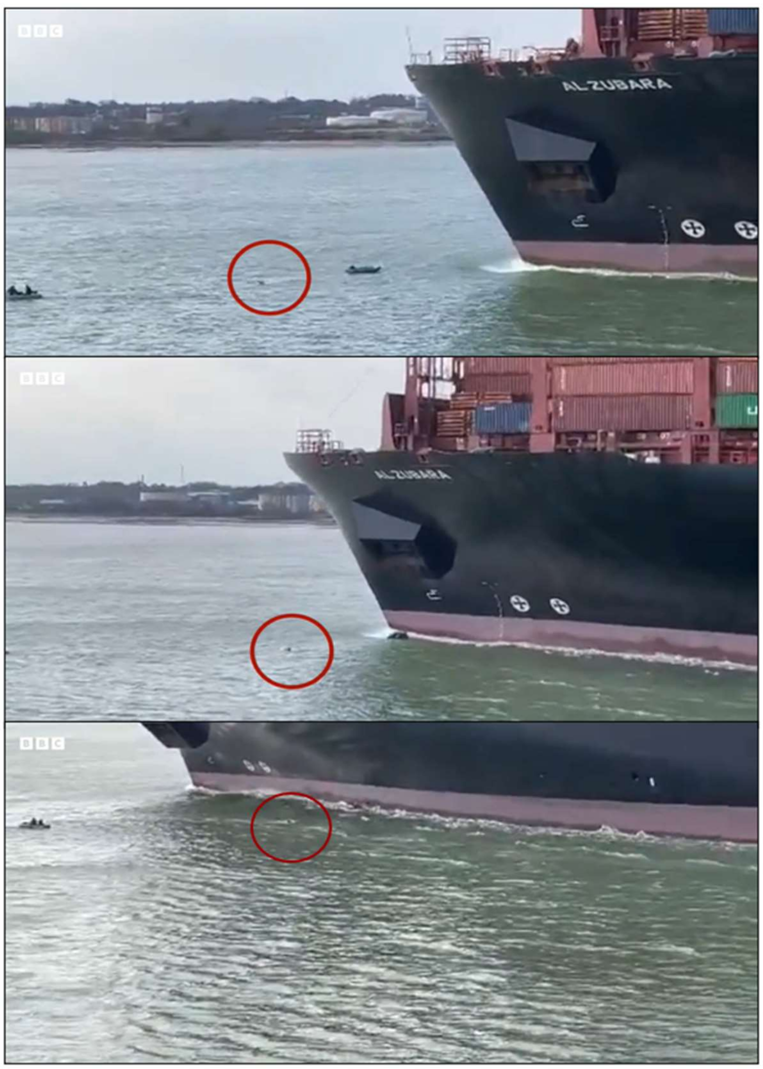


Figure 7.6 Suction and Displacement (Lone Star Harbor Safety Committee)



This powerful suction effect is known to pull swimmers, kayakers, paddleboarders, canoers and jet skiers towards the sides and stern of commercial vessels, potentially leading to injury or death.

In March 2022, a person attempted to swim away from a large container ship in the English Channel after jumping overboard from a dinghy boat that had engine failure. As seen in Figure 7.7 *(left),* the individual tried to swim away from the container ship but was pulled toward its side as it passed (BBC, 2022). The disabled dinghy, also visible in the photos, was also pulled into the hull of the ship.

Figure 7.7 Container Ship Suction and Person Trying to Swim Away After Jumping from Dinghy (BBC)

Even motorized vessels, such as jet skis, can have significant trouble evading passing commercial ships due to the suction effect. Figure 7.8 shows a jet ski that collided with the side of a container ship after being pulled in by the ship's suction. The jet ski's engine could not overcome the suction effect of the container ship.

Figure 7.8 A Jet Ski Capsizing from Container Ship Suction (YouTube, Ross 218)

Propellers on commercial vessels exert their own suction effects, independent of a vessel moving. A swimmer or a person dislodged from a kayak, canoe, paddleboard, or jet ski can be sucked through the large propellers of a commercial vessel (American Waterway Operators, 2002). Figure 7.9 shows the suction from the propellers of a stationary oil tanker causing a passing outrigger canoe to collide with the tanker and capsize. One of the canoers later wrote, "[W]e had no idea that an anchored ship would have its engine running with the propeller turning. As we were riding along the back of the ship it created a suction toward the boat, so our canoe started getting sucked into the side of the ship and I was unable to steer it away which ultimately caused us to crash into the side of the ship. Once in the water we felt our bodies being suck toward the ship's side," (Yahoo News Network, 2015).

Figure 7.9 An Outrigger Canoe Capsizing from Suction of a Stationary Oil Tanker (Yahoo)

Suction is also a hazard for people wading in shallow areas, walking in mudflats or temporarily mooring recreational boats close to the shipping channel. As a commercial vessel passes the shallow area, it sucks in water and then pushes it back towards the shoreline at very fast and turbulent speeds that have the potential to knock people over and unmoor boats. The Pilots' Association for the Bay and River Delaware noted that other than blaring a warning horn, there is nothing they can do to try to protect people who are wading, walking in mud flats or mooring boats too close to the shipping channel (Pilots' Association for the Bay and River Delaware, personal communication, November 18, 2021). Figure 7.10 shows water displacement on the Columbia River caused by a passing freight ship creating a hazardous situation for people wading near the shoreline.

Figure 7.10 Water Displacement on the Columbia River from a Passing Ship (YouTube, Lewis Mason)

For this study, the water displacement and suction from commercial vessels can affect the safety of primary contact activities occurring less than 200 yards (182.9 m) away.

7.7. Blind Spots and Visibility

A commercial vessel's configuration and cargo affect the pilot's line of sight from the bridge of a ship. As shown in Figure 7.11, the blind spot ahead of the bow can be a few hundred feet or extend thousands of feet in the case of deep-draft container ships (Lone Star Harbor Safety Committee, 2020).

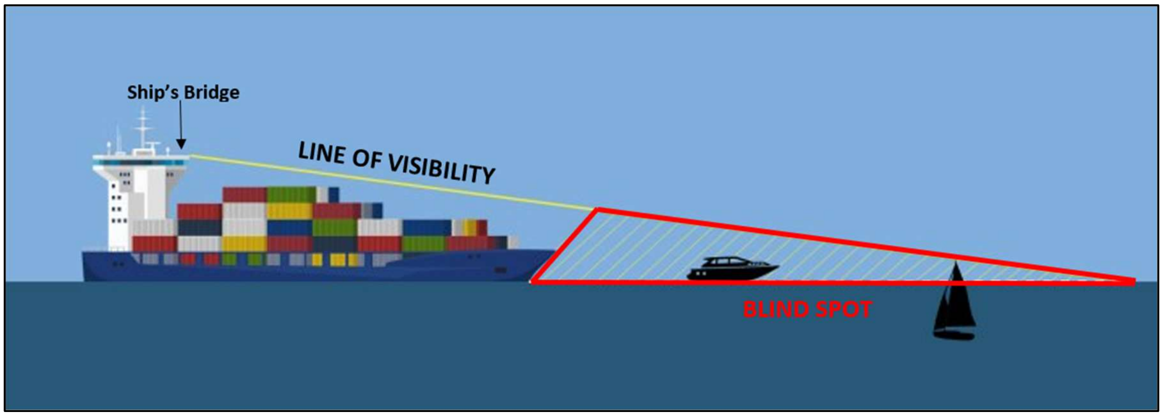


Figure 7.11 Blind Spot Ahead of the Bow Extends Hundreds of Feet (The Chart Room)

Delaware River pilots noted that from the bridge of container ships, they cannot see 200 feet ahead of the foremast located at the bow (Pilots' Association for the Bay and River Delaware, personal communication, November 18, 2021). Figure 7.12 shows a pilot's view from the bridge of a container ship.

For this study, less than 200 feet (70 m) is the distance in front of large cargo ship within which a pilot cannot see a kayaker, canoer, paddleboarder, jet skier or swimmer.

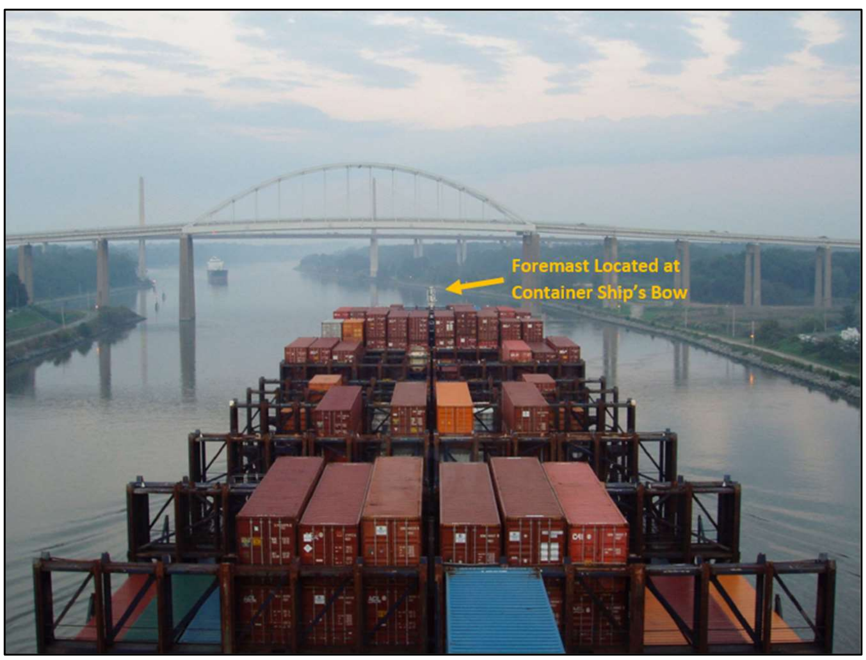


Figure 7.12 View from Bridge of Container Ship (Pilots' Association for the Bay and River Delaware)

A tugboat pilot's blind spot can extend for hundreds of feet when pushing barges (American Waterway Operators, 2002). Figure 7.13 shows the blind spot created when a tugboat is pushing a barge.

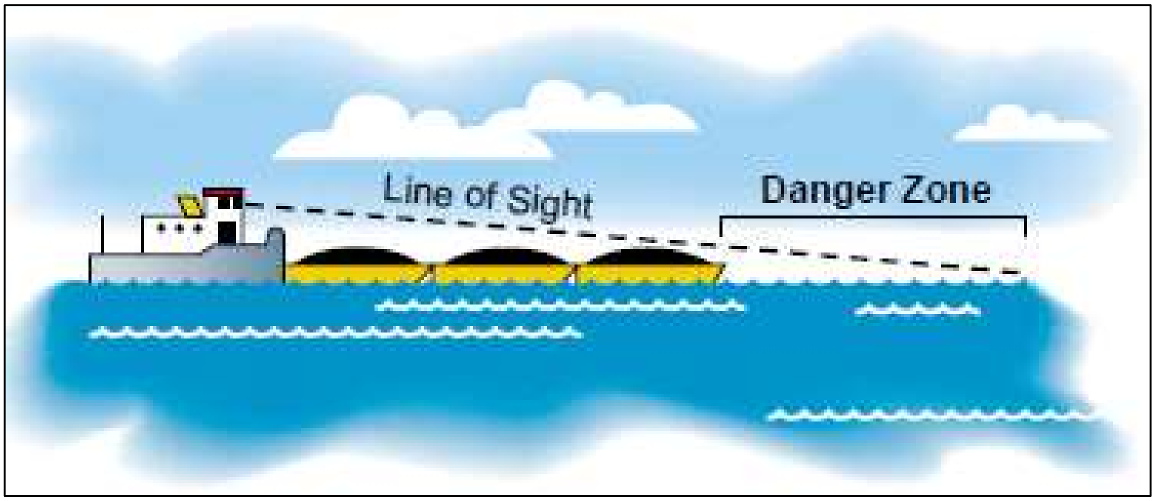


Figure 7.13 Tugboat Blind Spot Extends Hundreds of Feet (American Waterways Operators)

Blind spot distances can increase when moving empty barges because these barges ride higher in the water, presenting more of an obstruction for tugboat captains (U.S. Coast Guard, 2003). Figure 7.14 shows how empty barges can increase blind spot distances.

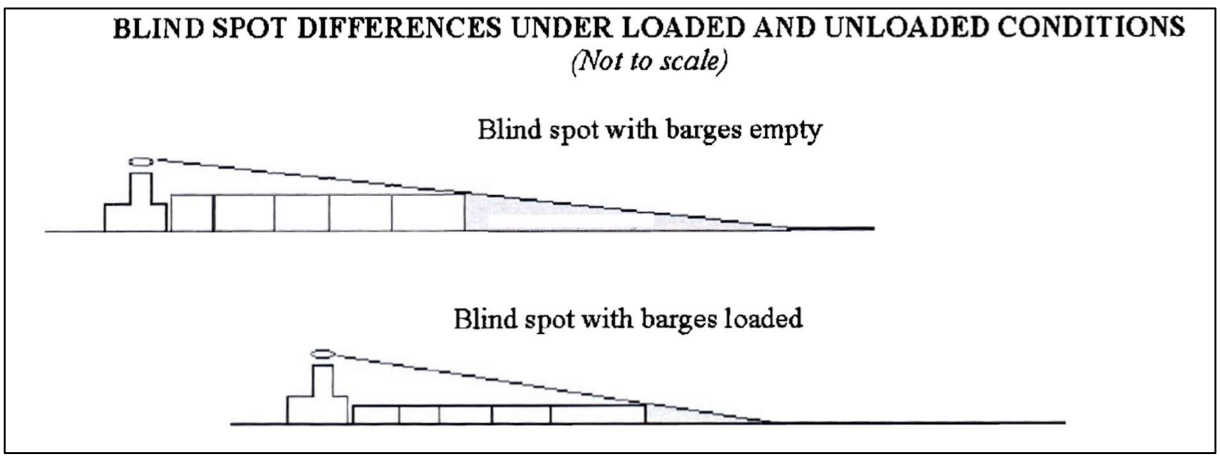


Figure 7.14 Blind Spot Distances for Tugboats (U.S. Coast Guard)

For this study, less than 100 feet (30.5 m) is the distance in front of a barge in which a tugboat pilot cannot see a kayaker, canoer, paddleboarder, jet skier or swimmer.

Weather conditions like fog and sun glare present additional visibility challenges for commercial vessel pilots, making it harder to see nearby kayakers, canoers, paddleboarders, jet skiers and swimmers. The Lone Star Harbor Safety Committee advises smaller watercraft to always "exercise extreme caution in vicinity of ships and tows due to their limited sightlines and maneuvering capabilities; especially so in conditions of hazardous weather and restricted visibility," (Lone Star Harbor Safety Committee, 2020).

At approximately 6:00 p.m. on August 30, 2016, a passenger ferry traveling 18-19 knots collided with a guided kayak tour on the Hudson River near Pier 79 in New York City. According to a

Coast Guard Incident Investigation Report, at the time of the collision the kayaks were operating close to the middle of the shipping channel in a busy ferry traffic area. The sun was starting to set over the Hudson River, creating a glare that blocked the ferry captain's ability to see the water in front of him. The kayak guide saw the ferry approaching and attempted to get the crew's attention by waving his arms. Of the group of 10 kayakers, two were seriously injured: one suffered a broken rib and a dislocated shoulder and the other had severe lacerations to the arm that required multiple surgeries. The Coast Guard concluded that the ferry captain was unable to see the kayakers because of the sun glare. The Coast Guard also concluded that while the kayaks were in good condition, no defense would have enabled the kayak to go fast enough to avoid collision with a vessel that was going those speeds and no defense would protect the rider when the kayak is involved in a collision with a motor vessel (U.S. Coast Guard, 2017). Figure 7.15 shows the sun glare from the view of the ferry's bow moments before the collision with the kayakers (National Transportation Safety Board, 2017). Figure 7.16 shows the New York Police Department rescue operation after the collision.

Figure 7.15 Bow Video before Colliding with Kayakers on the Hudson River (NTSB)

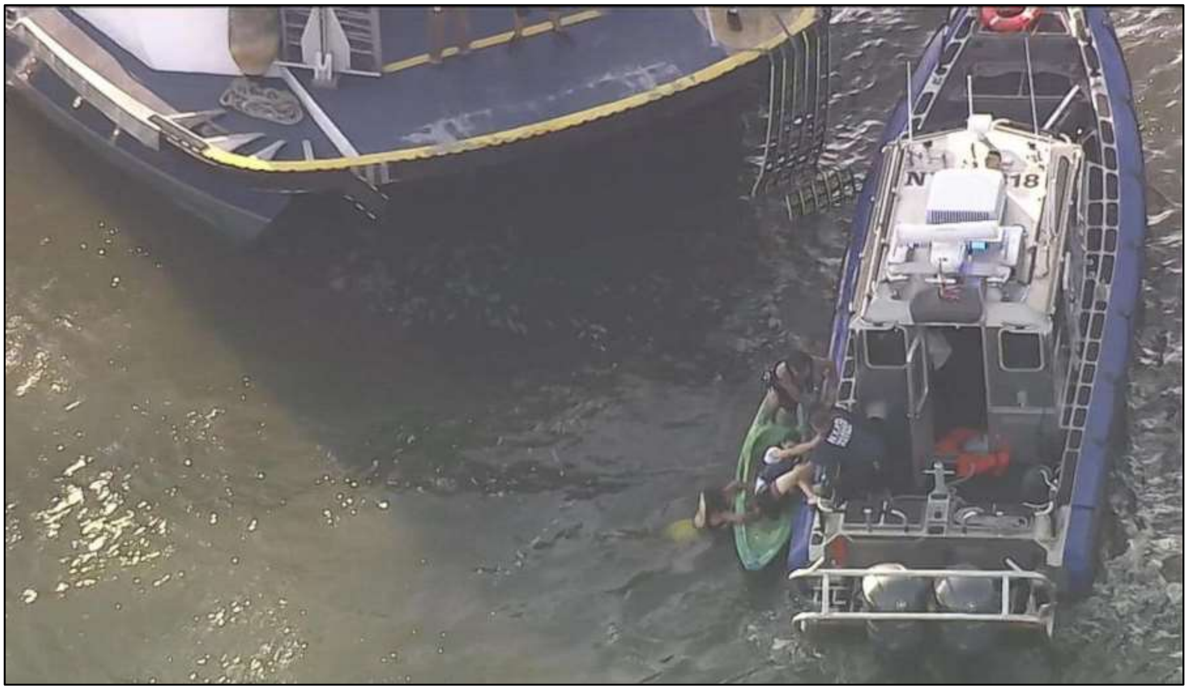


Figure 7.16 NYPD Rescue from the Hudson River after Collision with Kayak Tour (ABC News)

7.7.1. Marine Radar

Commercial vessels utilize marine radar as a navigation and collision-avoidance tool. The design and construction material of a target object affects how well it will show up on a radar screen. Larger vessels made from steel more readily reflect radar wave energy compared to smaller, lower profile vessels made of plastic, fiberglass, or wood (Springuel, 2005). A marine U.S. Coast Guard safety alert emphasized that wood and fiberglass are particularly poor radar reflecting materials and produce weak radar signatures (U.S. Coast Guard, 1997).

Fiberglass and plastic are the primary construction materials for kayaks, canoes, paddleboards and jet skis, thus commercial vessels operators cannot easily detect these small watercraft on their radar screens. The Pilots' Association for the Bay and River Delaware confirmed that kayaks, canoes and paddleboards do not show up on their radar displays (Pilots' Association for the Bay and River Delaware, personal communication, November 18, 2021).

Blind spots, inclement weather, sun glare, and limited radar return limit visibility of small recreational craft, like kayaks, from commercial vessels.

7.8. Wakes

A wake is the wave generated when a vessel moves through water. As shown in Figure 7.17, diverging wakes are formed at a vessel's bow and transverse wakes are formed at the stern. Typically wake height is greater in diverging wakes than in transverse wakes. Wake height is likely to increase when vessel speed increases, water depth decreases, distance from sailing line decreases, hull shape becomes less streamlined and waterway cross sectional area is reduced (Ausenco Engineering Canada Inc., 2015).

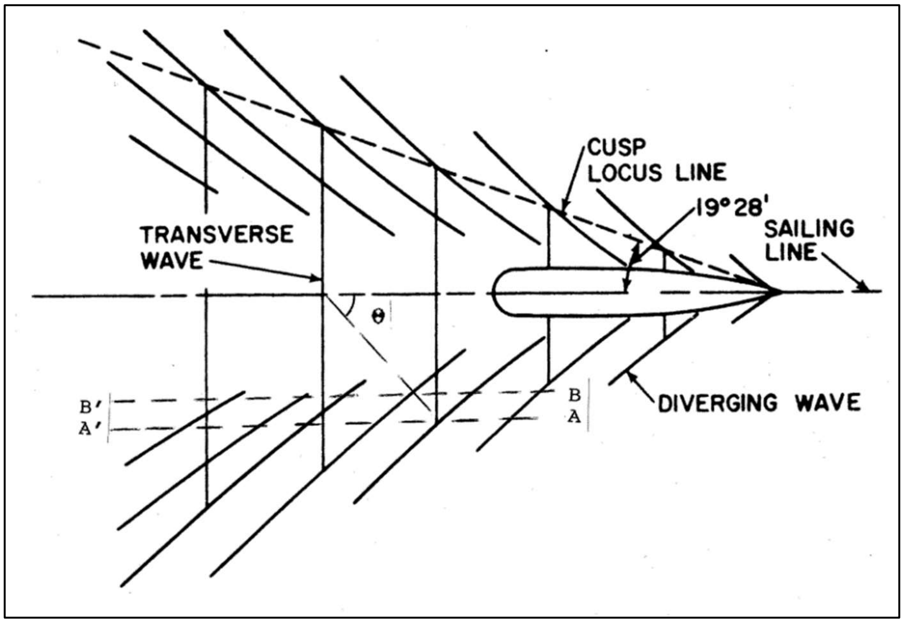
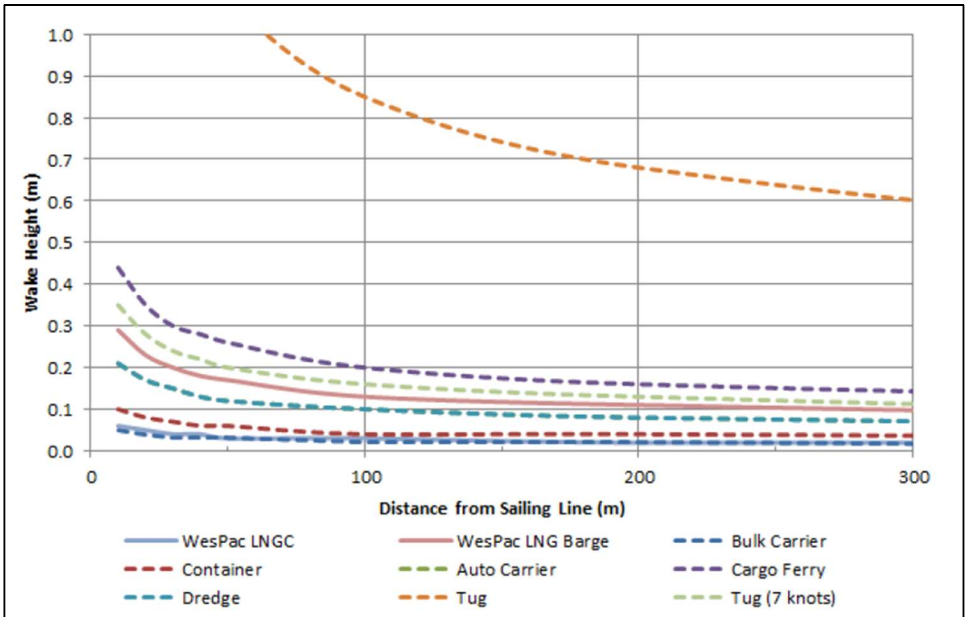


Figure 7.17 Vessel Wake Pattern (Robert M. Sorensen)

The Pennsylvania Fish and Boat Commission warns that commercial vessels can create large wakes that can easily swamp and capsize small watercraft like kayaks, canoes, paddleboards and jet skis (Pennsylvania Fish and Boat Commission, 2007). Figure 7.18 shows a touring kayak that capsized after encountering wakes from a cargo ship on the Cape Fear River in North Carolina. The PFBC also cautions that bulkheads and river walls act as mirrors for wakes, creating multiple high-frequency surges and cross-chops that do not lessen in strength while they reflect the wake back in the direction it originated. In addition to capsizing small watercraft, commercial wakes can disorient swimmers and knock over people who are wading.

Figure 7.18 Kayak Capsized from Cargo Ship Wake, Cape Fear River (YouTube, The Deitz)

A 2015 study estimated wake height as a function of vessel speed and distance from the sailing line for commercial vessels operating on the Fraser River in British Columbia. Wake height was compared to the distance from the sailing line for vessels traveling at a speed of 10 knots (11.5 mph) and a channel width of 49.2 feet (15 m). As shown in Figure 7.19, wake height for a tugboat traveling at a speed of 10 knots (11.5 mph) was significantly higher than other types of commercial vessels traveling at this same speed (Ausenco Engineering Canada Inc., 2015).



Wake height estimates are plotted for different commercial vessels traveling at a speed of 10 knots, except for the tugboat which was plotted at 7 and 10 knots.

Figure 7.19 Wake Heights for Commercial Vessels (Ausenco Engineering Canada Inc., 2015)

Table 7.1 lists measured wake heights for commercial vessels and recreational motorboats. When wakes were measured 30 meters (98.4 ft) and 150 meters (492.1 ft) away from a tugboat traveling at a speed of 10 knots (11.5 mph), the maximum wake heights were 0.5 meters (1.6 ft) and 0.3 meters (1.0 ft), respectively.

Table 7.1 Measured Wake Heights for Commercial Vessels and Recreational Boats (Bilkovica, 2019)

Boat type	Distance from sailing line (m)	Speed of boat travel (knots ((km hr^{-1}))	Max wave height (m)
26' (8 m) Recreational boat:	100	10 (19)	0.41
Uniflight*	100	26 (48)	0.29
	150	10 (19)	0.37
	150	27 (50)	0.21
16' (5 m) Recreational boat:	50	10 (19)	0.22
Boston Whaler*	50	24 (44)	0.13
	150	12 (22)	0.14
	150	27 (50)	0.07
45' (14 m) Commercial boat:	30	6 (11)	0.2
Tugboat**	30	10 (19)	0.5
	150	6 (11)	0.1
	150	10 (19)	0.3
263' (80 m) Commercial	150	10 (19)	0.2
boat: Barge**	300	10 (19)	0.1

Table 7.2, modified from (Pullar & Single, 2009) lists measured wake heights for container ships and oil tankers operating in the Lower Otago Harbour in New Zealand. For the 14 vessels observed, the average speed was 10 knots (11.5 mph), and the average wake height was 194 millimeters (7.6 in). Tugboats have the potential to produce the largest wakes due to their design and powerful propellers.

Figure 7.20 Tugboats Can Produce Large Wakes

Table 7.2 Wake Height Measurements in Lower Otago Harbour (Pullar & Single, 2009)

Date	Vessel Name	Vessel Trade	Wake Height (mm)	Vessel Speed (knots)
18/08/09	Kakariki	Oil tanker	200	7.6
20/08/09	Maersk Damascus	4100 Container	140	11.3
18/08/09	MSC Kiwi	Container	150	8.2
07/09/09	Vega Gotland	Container	100	10.9
14/09/09	Maersk Radford	Container	200	8
25/09/09	Maersk Duffield	4100 Container	220	10.2
28/09/09	Torea	Oil tanker	150	11.3
01/10/09	Maersk Dunafare	4100 Container	350	9.6
05/10/09	Maersk Radford	Container	150	10.9
08/10/09	Maersk Denton	4100 Container	500	11.1
13/10/09	Maersk Fukuoka	Container	150	11.3
16/10/09	Maersk Damascus	4100 Container	200	8.1
19/10/09	Vega Gotland	Container	100	11.9
19/10/09	MSC Sardinia	Container	100	9.3
		Minimum	**100**	7.6
		Maximum	**500**	11.9
		Range	**100-500**	**7.6-11.9**
		Average	**194**	**10**

The information in Table 7.1 and Table 7.2 provide wake height estimates for tugboats and commercial vessels traveling at 10 knots. At 10 knots, the average speed of an oncoming commercial vessel within the Study Area (Section 7.4), the assumed average wake height for tugboats is 1.6 feet (0.5 m) and 0.65 feet (0.2 m) for non-tugboat commercial vessels.

7.9. Marine Traffic Areas

Marine traffic refers to the passage of vessels along a water route in a particular area. It is important to note that a marine traffic area includes but does not only refer to the formal boundaries of a dredged shipping channel. Unlike roads where cars are restricted to directional lanes, commercial vessels must move outside of established shipping lanes to arrive and depart maritime facilities such as piers and terminals located on the shoreline and to enter, remain in and depart anchorages.

As shown in Figure 7.21, the movement, docking/undocking and anchoring of commercial vessels contributes to marine traffic outside of the shipping channel in the Study Area. The U.S. Coast Guard advises all recreational watercraft operators (including kayakers, paddleboarders, canoers and jet skiers) to stay at least 200 yards from all commercial traffic because these larger vessels present a significant danger to small watercraft (U.S. Coast Guard Sector Delaware Bay, 2021).

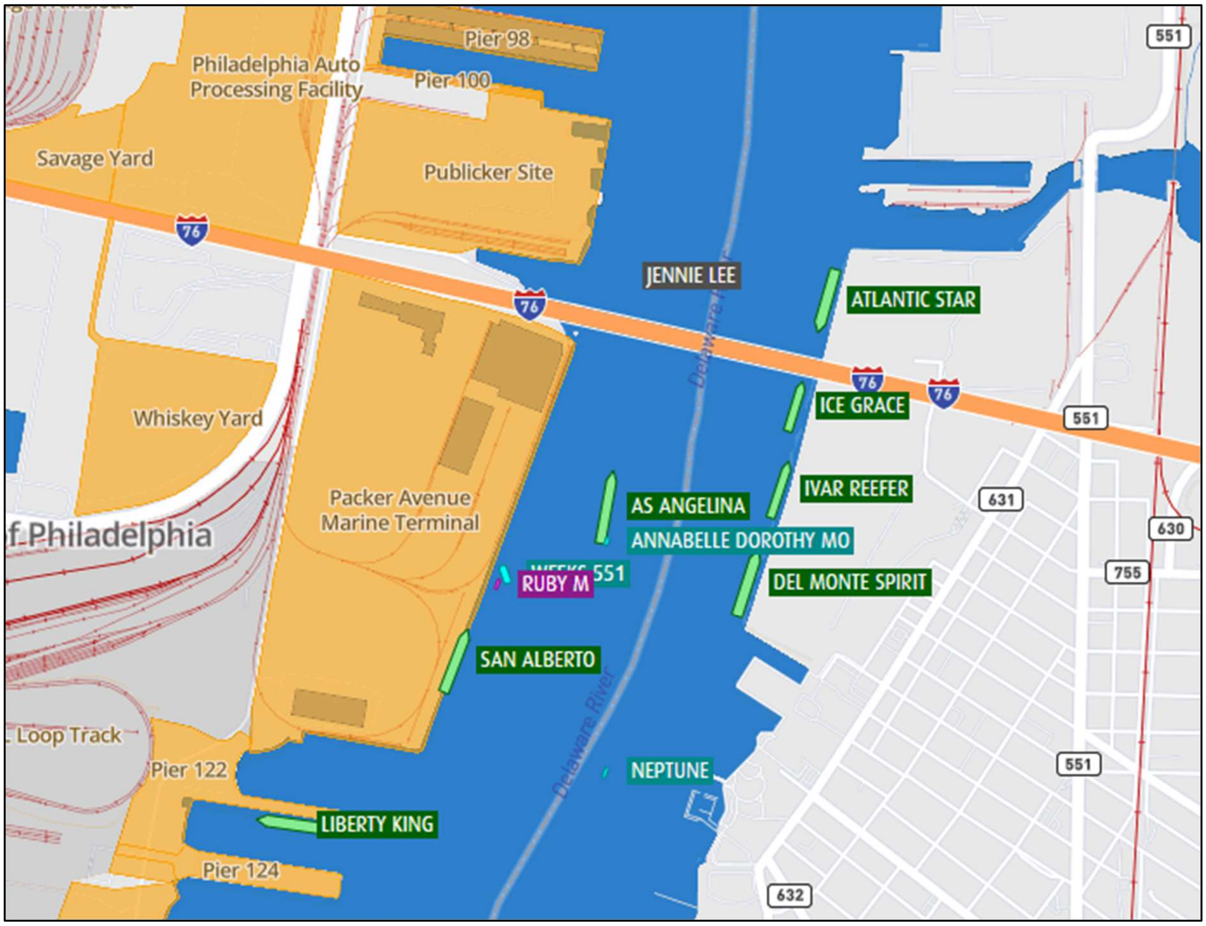


Figure 7.21 PhilaPort Live Vessel Map Marine Traffic (Screenshot 2/28/22 10:18 am)

For this study, as noted by the U.S. Coast Guard, the safety of primary contact activities can be affected when marine traffic is less than 200 yards (183 m) away. The following maritime traffic areas map presents a 200-yard buffer around the navigation channel, ports, terminals and waters connecting the ports and terminals to the navigation channel.

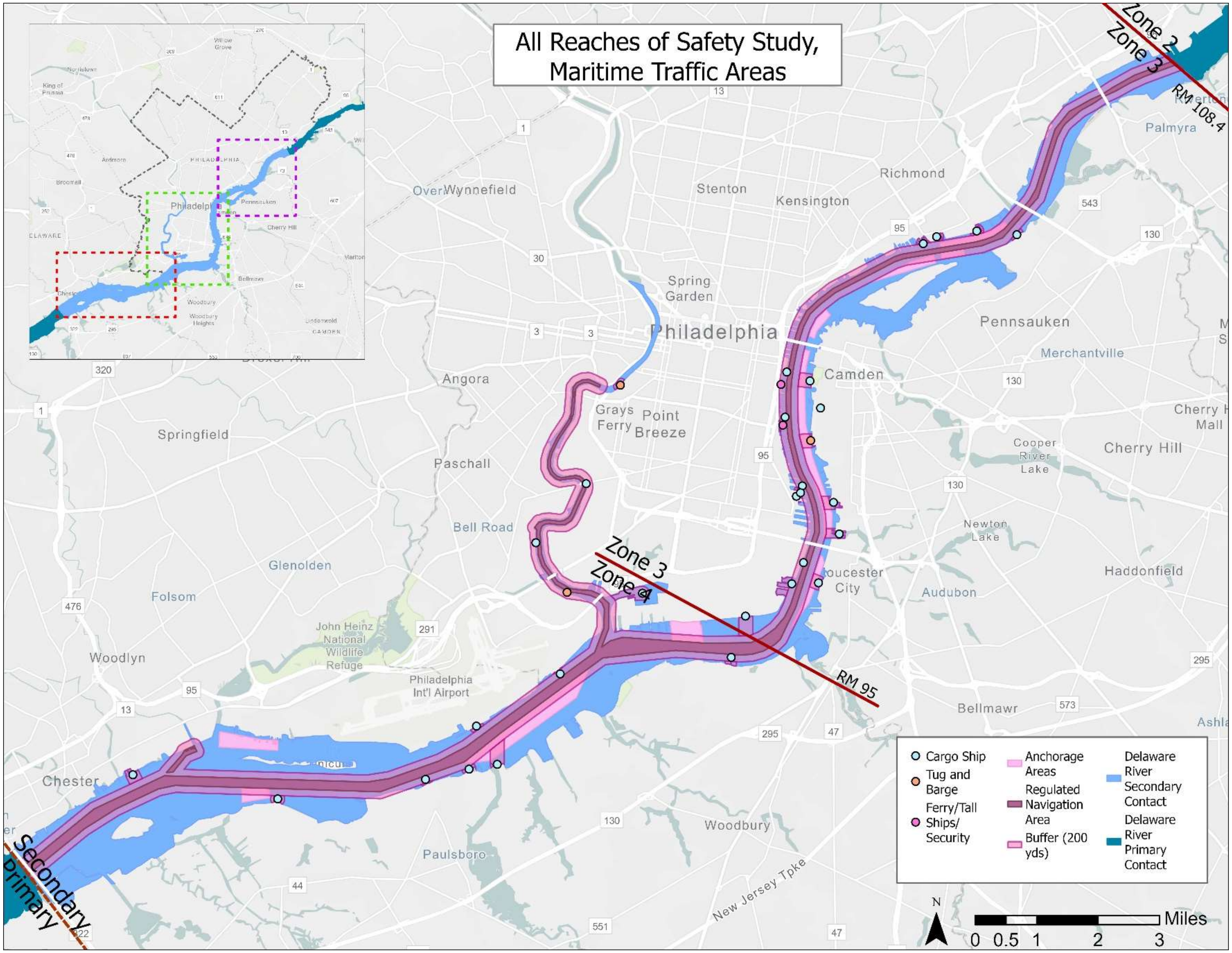


Figure 7.22 Maritime Traffic Areas

7.10. Summary of Maritime Hazards Criteria

The criteria identified for maritime hazards evaluated in the Study Area are summarized in Table 7.3.

Table 7.3 Summary of Maritime Hazards Criteria

Maritime Hazard	**Safety Criteria**	**Large Commercial Vessel** (Cargo ship, Oil Tanker)	**Medium Commercial Vessel** (Tugboat)
Propeller Wash	Unsafe Distance from the Propeller Wash of Commercial Vessels	< 200 yds (182.9 m) behind vessel	< 200 yds (182.9 m)
Bow and Stern Thruster Wash	Unsafe Distance from the Bow and Stern Wash of Commercial Vessels	< 100 yds (91.4 m) all around vessel	< 100 yds (91.4 m)
Tow Lines and Barges	Unsafe Distance from a Barge	< 100 yds (91.4 m)	< 100 yds (91.4 m)
Oncoming Ship	Average Speed of an Oncoming Commercial Vessel	10 knots (514 cm/s)	10 knots (514 cm/s)
Ship Stopping Distance	Average Distance for Commercial Vessel to Come to a Complete Stop	2 mi (3.2 km)	2 mi (3.2 km)
Water Displacement and Suction	Unsafe Distance from the Displacement and Suction of Commercial Vessels	< 200 yds (182.9 m)	< 200 yds (182.9 m)
Visibility	Blind Spot Distance in Front of Commercial Vessels	< 200 ft (70 m)	*When pushing a barge*: < 100 ft (30.5 m)
Wakes	Average Wake Height from a Vessel	0.65 ft (0.2 m)	1.6 ft (0.5 m)
Marine Traffic Area	Unsafe Distance from Marine Traffic Areas	< 200 yds (182.9 m)	< 200 yds (182.9 m)

Section 8 Primary Contact Recreation Activities

This study researched swimming, wading, kayaking, paddleboarding, canoeing and jet skiing to compare primary contact recreational activities against hydraulic, shoreline and maritime hazards in the Study Area. This analysis includes multiple criteria relevant to each primary contact activity based on extensive research and detailed in this section.

8.1. Swimming

Inherent differences exist between swimming in a pool and in open water (e.g., streams, rivers, lakes and oceans). The tidal Delaware and Schuylkill Rivers in the Study Area are open water that present safety challenges swimmers would not find in pools, such as tides, currents, limited visibility, commercial vessel traffic, shoreline modifications, debris and sudden changes in depth. Open-water swimming has no easily reachable walls, ladders, steps or other boundaries to safely rest or exit onto dry land.

Figure 8.1 Swimming in the Hudson River upstream of NYC (*New York Times*)

To better understand potential risks to the general public from open-water swimming and to develop protective swimming safety criteria for the Study Area, the research for the present study included reviewing a national study that detailed drownings across the U.S. from 2007-2016.

Safe Kids Worldwide, a nonprofit organization working to help families and communities keep children safe from injuries, published a report in 2018 on open-water drowning and the risks to U.S. children ages 0-19 (Safe Kids Worldwide, 2018). The report examined fatal open-water drownings for U.S. children between 2007 and 2016, considering age and gender, race and ethnicity, activity at time of drowning, location and waterbody type. It stated that open water was the most common setting for fatal child drownings in the United States in 2016.

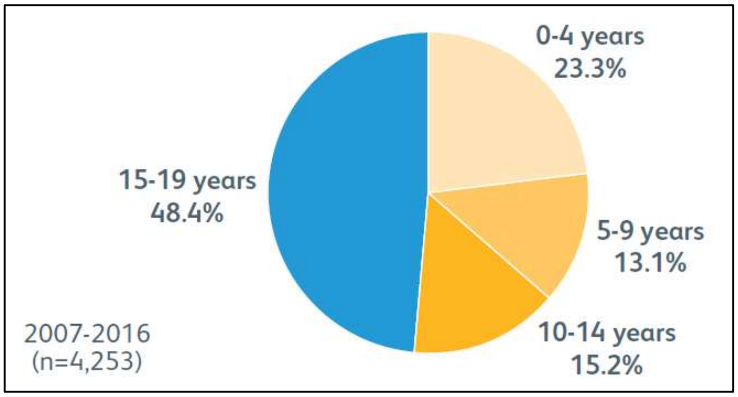


Figure 8.2 Ages of Children Who Fatally Drowned in the U.S., 2007-2016 (Safe Kids Worldwide)

Teens aged 15-19 years accounted for 48% of the fatal open-water drowning victims, the most of any age group (Figure 8.2). At the time of drowning, over 75% of victims were already playing or swimming in open water, suggesting that most children who drown in open water intend to have contact with the water (Figure 8.3).

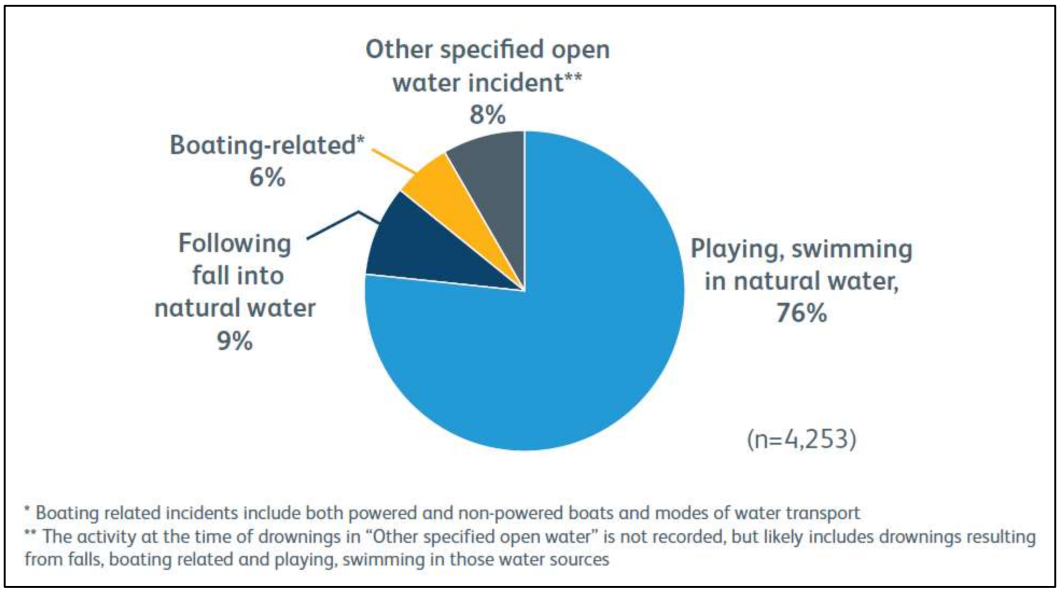


Figure 8.3 Activity at Time of Open-Water Drowning in the U.S. 2007-2016 (Safe Kids Worldwide)

The report also examined the type of open water involved in fatal drownings in U.S. children ages 0-17 years from 2005 to 2014, finding nearly 24% of the drownings occurred in rivers and 20% occurred in creeks (Figure 8.4). The Safe Kids Worldwide study found that between 2005 and 2014, rivers and creeks accounted for a combined 44% of the fatal open-water drownings of children.

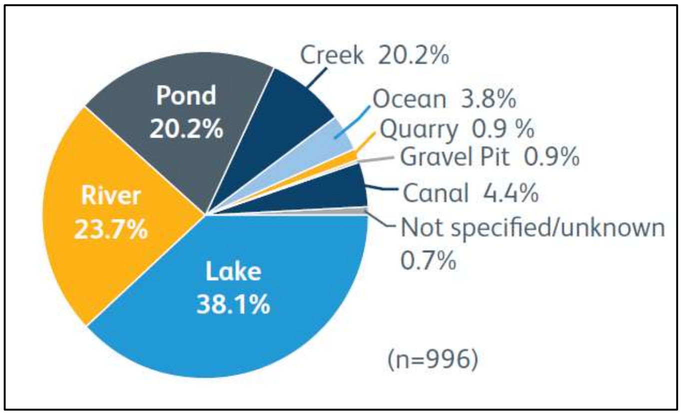


Figure 8.4 Open Water where Drownings Occurred in the U.S. 2005-2014 (Safe Kids Worldwide)

The report suggested that the presence of lifeguards at ocean beaches may be the reason oceans only accounted for 4% of fatal open-water drownings of children during this period. There are no lifeguards or public-sanctioned swimming beaches in the Study Area, meaning the chances of a drowning fatality are significantly higher than a guarded pool or beach. Additionally, no components of the Clean Water Act require lifeguards for waters designated as "swimmable" for primary contact recreation use.

Nearly 40% of the children who fatally drowned across the United States in open water between 2007 and 2016 were from large urban centers with populations greater than 1,000,000, and 11% were from small urban centers with populations of less than 250,000 (Figure 8.5). Adjacent to the Delaware River within the Study Area, Philadelphia is a large urban center while Camden, New Jersey and Chester, Pennsylvania are smaller urban centers.

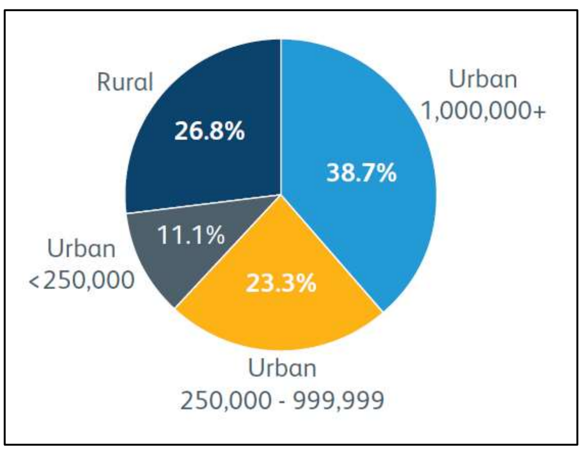


Figure 8.5 Setting of Open Water Drownings in the U.S. 2007-2016 (Safe Kids Worldwide)

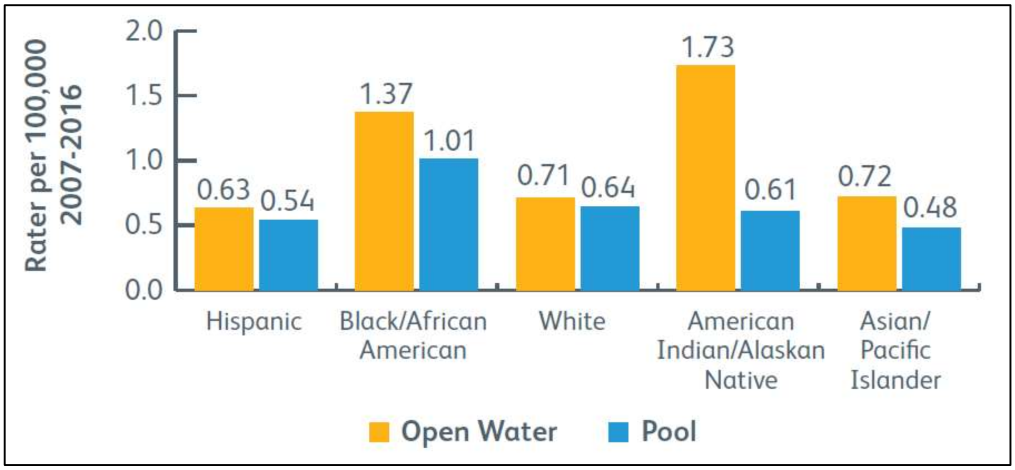


Figure 8.6 Risk of Open-Water Drownings by Race and Ethnicity in the U.S., 2007-2016 (Safe Kids Worldwide)

When race and ethnicity were considered, Black/African American and American Indian/Alaskan Native children were at a greater risk for fatal open-water drowning than White, Asian/Pacific Islander and Hispanic children (Figure 8.6). When race, ethnicity, age, and gender were considered, the highest rate of fatal open-water drowning occurred in Black/African American males ages 15-19 (Figure 8.7).

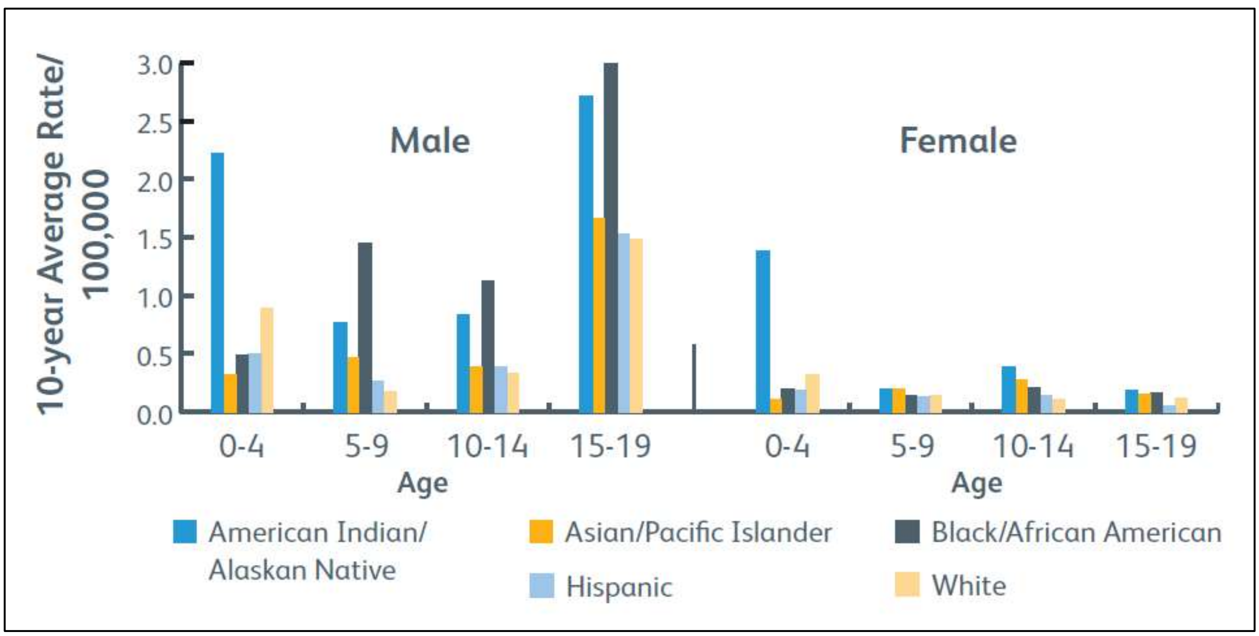


Figure 8.7 Risk of Open-Water Drownings by Race/Ethnicity/Age/Gender in the U.S. 2007-2016 (Safe Kids Worldwide)

Findings from the 2018 Safe Kids Worldwide report are relevant to the communities along the Study Area. Nearly 40% of the children who fatally drowned across the United States in open water between 2007 and 2016 were from large urban centers with populations greater than 1,000,000; Philadelphia meets this criterion as a large urban center. The report also found that Black/African American children were at a greater risk for fatal open-water drowning than White, Asian/Pacific Islander, and Hispanic children. According to the 2020 Decennial Census presented in Table 8.1, Black/African Americans comprise the majorities of Philadelphia, Pennsylvania (39%), Chester, Pennsylvania (71%) and Camden, New Jersey (42%).

Table 8.1 2020 Census Population Demographics of Major Cities Adjacent to the Study Area

Demographics	Philadelphia, PA	Chester, PA	Camden, NJ	United States
Total Population, Census April 1, 2020	**1,603,797**	**32,605**	**71,791**	**331,449,281**
White alone	36%	15%	10%	62%
Black or African American alone	39%	71%	42%	12%
American Indian and Alaskan Native alone	0%	0%	1%	1%
Asian alone	8%	1%	2%	6%
Native Hawaiian and other Pacific Isl. alone	0%	0%	0%	0%
Other race alone	9%	7%	33%	8%
Two or more races	7%	6%	12%	10%
Total Percent	**100%**	**100%**	**100%**	**100%**

Source: United States Census Bureau, April 1, 2020 Decennial Census

Given the findings of the 2018 Safe Kids Worldwide report related to open-water swimming and urban areas, it is important to be conservative and err on the side of public health when identifying safety criteria for swimming in the open waters of the Study Area. Further, because the research presents a high rate of drownings associated with open-water swimming in large urban areas, it is reasonable to assume for the purposes of this safety study that the proficiency of swimmers in these areas is not above average. As ascertaining the swimming proficiency of potential swimmers within the Study Area is not feasible, formulating a reasonable assumption is necessary. To establish swimming safety criteria protective of a broad range of potential swimmers in the Study Area, it is therefore assumed that the criteria for swimming speeds and distances as well as wave and wake tolerances are associated with below-average swimmers.

8.1.1. Swimming Criteria

The specific swimming safety criteria researched and identified include swimming distance and speed for adults and children, maximum swimming depth for adults and children and maximum tolerable wave and wake height for adult and child swimmers. For these criteria, the adult category includes individuals over the age of 18, and the children category individuals ranging in age from 6 to 10.

8.1.1.1. Swimming Distance - Adults

The American Red Cross (ARC) is widely acknowledged and respected across the U.S. for its focus on water safety, which includes drowning prevention outreach, basic resuscitation training, lifeguard certification and guidance for teaching swimming skills. At pools, clubs and private organizations across the country, the ARC Water Safety Instructors Manual is used to teach swimming to children and adults according to its Learn to Swim approach. This teaching approach breaks water skills down into Learn to Swim Levels 1-6, ranging from introductory skills such as being able to simply immerse one's face and blow bubbles to fitness skills such as swimming specific strokes for specific distances.

The ARC Learn to Swim Level 4–Stroke Improvement is selected to inform the criteria that identifies an appropriate minimum distance that a below-average adult swimmer should be able to traverse. Swim Level 4 includes improving forward crawl, backstroke and breaststroke as well as treading water and survival floating for small increments of time.

According to ARC Swim Level 4, the swimmer should be able to swim at least 25 yards using forward crawl without stopping (American Red Cross, 2019). For this study, 25 yards (22.9 m) is the swimming distance criteria for adults; this distance represents one length of a common-sized (non-Olympic) swimming pool.

8.1.1.2. Swimming Distance - Children

The lower levels of the ARC Learn to Swim program focus on building water proficiency skills one step at a time, giving children the opportunity to increase water safety skills prior to learning multiple strokes or swimming long distances. ARC Swim Level 3–Stroke Development teaches stroke fundamentals for front crawl and backstroke. This safety study assumes that children swimming may know stroke basics but not be proficient enough to swim the length of a pool without stopping. The skills taught and expectations of a swimmer at ARC Swim Level 3 most align with this assumption.

According to ARC Swim Level 3, the swimmer should be able to swim at least 15 yards using forward crawl without stopping (American Red Cross, 2019). For this safety study, 15 yards (13.7 m) is swimming distance criteria for children ages 6-10 years.

8.1.1.3. Swimming Speed - Adults

Research did not uncover available swimming speed information that aligned with the ARC Swim Level 4. An additional reference, the Cooper 12-minute swimming test, was identified to inform the potential swimming speed of a below-average proficiency adult.

The Cooper 12-minute swimming test requires a person to swim the greatest distance possible in a pool in 12 minutes, resting when needed and using whatever stroke is preferred (American Red Cross, 2014). The test allows for rating a person's cardiorespiratory endurance by factoring age and gender with the distance covered (Figure 8.8). It should be noted that in the Cooper 12-minute test, swimmers are asked to swim longer distances than the minimum expectations within the ARC Swim Level 4 (25 yards). This is because in the Cooper test swimmers are able to take as many breaks as needed while they try to traverse as many laps of the pool possible within 12 minutes. The distance traveled within 12 minutes allows for the calculation of the swimmer's speed.

	Age (Years)					
Fitness Category	13–19	20–29	30–39	40–49	50–59	>60
I. Very poor						
Men	<500	<400	<350	<300	<250	<250
Women	<400	<300	<250	<200	<150	<150
II. Poor						
Men	500–599	400–499	350–449	300–399	250–349	250–299
Women	400–499	300–399	250–349	200–299	150–249	150–199
III. Fair						
Men	600–699	500–599	450–549	400–499	350–449	300–399
Women	500–599	400–499	350–449	300–399	250–349	200–299
IV. Good						
Men	700–799	600–699	550–649	500–599	450–549	400–499
Women	600–699	500–599	450–549	400–499	350–449	300–399
V. Excellent						
Men	>800	>700	>650	>600	>550	>500
Women	>700	>600	>550	>500	>450	>400
< means "less than"; > means "more than."						
From Cooper K. H.: *The Aerobics Program for Total Well-Being*, New York: Bantam Books, 1982.						

Figure 8.8 Yards Covered in the Cooper 12-Minute Swimming Test (American Red Cross)

Figure 8.8 presents the expected swimming yards within 12 minutes by age and fitness category according to the Cooper 12-minute swimming test. Selecting a number from this table to be used to calculate adult (>18 yrs) swimming-speed criteria for this safety study can be informed by the Safe Kids Worldwide 2018 report. The report found males aged 15-19 years as having the most swimming fatalities compared to females in the comparable age group (Figure 8.7). At a minimum, the swimming speed safety criteria for this safety study should be protective of this vulnerable group.

The swimming speed safety criteria are intended to represent a minimum expected speed of a swimmer within the Study Area. The criteria should also be broadly protective of public health, especially male teenagers as per the research findings. With these considerations, the distance of 400 yards from the Cooper 12-minute swimming test is selected to calculate the swimming speed safety criteria for this safety study. According to Figure 8.8, males and females with poor to very poor swimming fitness and within the 13-29 age group should be able to swim 400 yards within 12 minutes, given adequate rest as needed. Additionally, males and females ages 30-49 with fair swimming fitness may be able to swim 400 yards within 12-minutes, given adequate rest as needed. Swimming 400 yards in 12 minutes equates to a speed of 1.7 feet per second (51.8 cm/s).

It is worth repeating that these distances are calculated in a pool with adequate rest provided, not open water. Therefore, the distances with rest are greater than the minimum distance expected *without* rest, which is the definition of the criteria for minimum swimming distance defined in Section 8.1.1.1. Given the lack of specific information available from credible sources and the widespread use of the Cooper 12-minute swimming test by the ARC, the Cooper 12-minute swimming test was selected as the reference to infer swimming speed criteria for this study.

8.1.1.4. Swimming Speed - Children

The Cooper 12-minute swimming test only presents findings for teenagers (13-19 years) and does not include information for swimmers aged 6-10, defined as children in this safety study. Another resource available through USA Swimming documents swimming speeds for children age 10 and under, but careful assumptions are necessary to interpret these data and to identify swimming speed criteria appropriate for children within the Study Area.

USA Swimming, the national governing body for the sport of swimming in the United States, publishes age group motivational times for competitive racing every four years. It provides motivational times for five categories, with AAAA Min representing the top 2% of swimmers for a particular age group, gender, stroke and distance (USA Swimming, 2020). The most recent USA Swimming motivational times for ages 10 and under are presented in Table 8.2.

Table 8.2 USA Swimming 2021-2024 Motivational Times, 10 & Under Boys

	AAAA Min	AAA Min	AA Min	A Min	BB Min	B Min
10 & under Boys						
50 M Free	31.39	32.79	34.09	35.49	39.49	43.59
100 M Free	1:09.49	1:12.89 *	1:16.39 *	1:19.79 *	1:30.19 *	1:40.59 *
200 M Free	2:29.49	2:36.59	2:43.69	2:50.79	3:12.09	3:33.49
400 M Free	5:14.59 *	5:29.59 *	5:44.49 *	5:59.49 *	6:44.49 *	7:29.39 *

Given that AAAA Min represents the fastest of competitive swimmers, this category is an available starting place to develop swimming speed criteria for children ages 6-10 in the Study Area. It is important to note that not all children are competitive swimmers, and that not all competitive swimmers are as fast as the AAAA Min swimmers. Therefore, it would be protective of children within the Study Area to assume they are not competitive swimmers and that their swimming speeds are far less than the AAAA Min speeds that can be calculated from Table 8.2.

An assumption is made that children in the Study Area swim three times slower than the average AAAA Min motivational times for the 100-, 200-, and 400-meter freestyle for boys 10 and under. Because the 50-meter distance is considered a sprint for competitive swimmers, it is excluded from this assumption. As shown in Table 8.3, the average pace for 10 and under boys swimming three times slower than the AAAA Min motivational time is 1 mile per hour, or 1.47 feet per second. For this study, 1.47 feet per second (44.7 cm/s) will be the swimming speed criteria for children ages 6-10 years.

Table 8.3 Predicted Swimming Speed Based on USA Swimming 2021-2024 Motivational Times

Category	Standard	100 meter Freestyle		200 meter Freestyle		400 meter Freestyle		Average Speed (mph)
		Time (mm:ss)	Speed (mph)	Time (mm:ss)	Speed (mph)	Time (mm:ss)	Speed (mph)	
10 & Under Boys	AAAA Min	01:09.5	3.2	02:29.5	3	05:14.6	2.8	**3**
	3x slower than AAAA Min	03:28.5	1.1	07:28.5	1	15:43.8	0.9	**1**

The swimming criteria identified for this safety study are based on the best information available and reasonable assumptions given the lack of specific information available from credible sources on below-average swimming proficiency speeds for children ages 6-10.

8.1.1.5. Swimming Depth – Adults

Open waters do not have the gradual depth changes commonly found in swimming pools. Water depth in open waters can quickly change due to uneven bottoms, dredging and the tidal cycle. The U.S. National Park Service advises that depths in open water above chin level can be dangerous, especially for inexperienced or non-swimmers who are unable to keep their heads above water or swim back to shore (U.S. National Park Service, 2022).

The U.S. Centers for Disease Control and Prevention (CDC) identifies 69.0 and 63.5 inches as the average standing height for adult men and women, respectively (U.S. Centers for Disease Control and Prevention, 2022). For this study, unsafe swimming depths for adults will be greater than or equal to 66.3 inches (1.7 m).

8.1.1.6. Swimming Depth – Children

Children ages 6-10 are more vulnerable to depth changes in open water because their standing height is less than that of adults. In 2021, the CDC published a report containing anthropometric reference data for children and adults from 2015 to 2018 (U.S. Centers for Disease Control and Prevention, 2021). The report included height measurements for children and adolescents ages 2-19 years, as shown in Table 8.4.

As summarized in Table 8.5, the 50th percentile height for children ages 6-10 is 51.4 inches. For this study, unsafe swimming depths for children ages 6-10 years old will be greater than or equal to 51.4 inches (1.3 m).

Table 8.4 CDC Standing Height for Children, 2015-2018

Sex and age[1]	Number of examined persons	Mean	Standard error of the mean	Percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
Male		Inches										
2 years	208	36.0	0.10	33.2	33.7	34.2	34.8	35.8	37.1	37.8	38.2	38.8
3 years	181	39.0	0.17	35.9	36.7	37.1	37.8	39.1	40.2	40.8	41.3	†
4 years	178	41.7	0.16	38.3	39.5	39.8	40.4	41.5	42.9	43.8	44.1	45.1
5 years	180	44.4	0.24	40.4	41.5	41.9	42.8	44.3	45.8	46.7	47.3	48.3
6 years	168	46.8	0.19	43.1	43.9	44.4	45.2	46.5	48.0	49.5	50.0	50.6
7 years	193	49.7	0.21	45.9	46.5	47.3	48.2	49.6	51.1	52.1	52.9	53.7
8 years	217	52.0	0.23	47.7	48.9	49.6	50.3	51.9	53.7	54.7	55.7	56.5
9 years	195	53.5	0.27	48.3	49.5	50.5	51.6	53.7	55.2	55.9	56.9	†
10 years	185	55.8	0.23	51.5	52.0	53.0	54.1	55.5	57.6	58.4	59.0	59.7
11 years	172	58.8	0.33	53.7	55.0	55.6	56.4	58.4	60.5	62.0	62.9	64.1
12 years	157	60.7	0.34	55.2	55.7	57.2	58.3	60.6	62.6	64.5	65.6	66.7
13 years	163	64.0	0.26	58.8	59.7	60.3	61.8	64.4	66.0	67.0	67.6	68.0
14 years	166	66.6	0.30	60.9	61.6	62.3	64.2	66.9	69.0	70.3	70.7	†
15 years	165	67.8	0.26	63.0	63.7	64.4	65.9	68.0	69.4	70.9	71.5	†
16 years	152	68.3	0.26	63.0	64.3	64.7	65.9	67.9	70.7	71.8	72.8	73.2
17 years	156	69.0	0.23	64.4	65.9	66.4	67.0	68.9	70.8	71.5	72.8	73.7
18 years	129	69.0	0.29	64.5	65.6	66.3	67.3	69.1	70.8	71.2	71.7	†
19 years	132	68.9	0.28	64.0	65.0	66.3	67.2	69.3	70.6	71.6	72.4	†
Female												
2 years	214	35.3	0.13	32.9	33.4	33.7	34.2	35.3	36.5	37.0	37.3	37.7
3 years	154	38.4	0.17	†	36.2	36.6	37.3	38.2	39.4	40.3	40.9	41.7
4 years	189	41.3	0.23	38.2	38.7	39.1	40.2	41.2	42.7	43.6	44.0	44.6
5 years	190	44.1	0.29	40.1	40.7	41.9	42.5	44.1	45.5	46.1	46.6	48.2
6 years	180	46.8	0.19	43.0	43.8	44.3	45.0	47.0	48.3	48.7	49.2	50.0
7 years	190	48.9	0.22	45.2	45.9	46.4	47.2	48.7	50.3	51.2	51.8	52.6
8 years	186	51.1	0.27	47.3	47.6	48.2	49.6	51.1	52.7	54.1	54.5	55.8
9 years	215	53.9	0.26	49.7	50.5	51.0	51.9	53.8	56.1	57.2	57.5	58.0
10 years	186	56.3	0.21	51.2	52.5	53.3	54.7	56.0	58.4	59.1	60.0	60.9
11 years	205	59.2	0.31	53.8	55.2	55.9	57.1	59.4	61.5	62.5	63.0	64.1
12 years	154	60.9	0.27	55.9	57.2	58.1	59.8	60.8	62.5	63.5	64.8	†
13 years	138	62.2	0.27	57.1	59.2	59.6	60.7	62.1	64.1	64.7	64.9	65.5
14 years	169	63.7	0.29	59.2	59.8	60.7	61.8	63.5	65.6	66.8	67.2	†
15 years	129	63.4	0.30	59.6	60.3	60.9	61.4	63.0	65.1	66.4	67.4	†
16 years	170	63.7	0.25	59.8	60.7	61.5	62.0	63.7	65.3	66.3	66.7	68.0
17 years	146	64.2	0.30	60.1	61.1	61.5	62.1	64.0	65.8	67.1	67.7	†
18 years	141	63.8	0.26	59.0	59.9	60.9	62.7	63.9	65.5	66.0	66.4	67.3
19 years	114	63.9	0.31	60.3	60.8	61.2	62.3	63.4	65.1	66.0	67.1	†

† Estimate not shown because the standard error could not be computed due to small sample size.
[1]Age at time of examination.

Source: U.S. Centers for Disease Control and Prevention, 2021

Table 8.5 Child Swimming Depth Criteria

Category	Age Group	Standing Height (50th Percentile)	Unsafe Swimming Depth
Boys	6 years	46.5 in	≥ 51.4 in (1.3 m)
	7 years	49.6 in	
	8 years	51.9 in	
	9 years	53.7 in	
	10 years	55.5 in	
Girls	6 years	47.0 in	
	7 years	48.7 in	
	8 years	51.1 in	
	9 years	53.8 in	
	10 years	56.0 in	

8.1.1.7. Safe Swimming with Waves and Wakes

Swimmers within the Study Area are expected to experience periodic exposure to wind-generated waves and boat wakes. Therefore, understanding how waves, either wind or wake generated, may influence swimming performance is paramount. Studies are available comparing swimming performance in pools to open water, providing information on the effects of waves on swimming performance.

A 2013 study examined swimming performance among 11-year-old Norwegian schoolchildren in calm and unsteady water conditions. Learn-to-swim lessons are compulsory in the Norwegian school system, and all students are expected to be able to swim by age 11. The study asked the 66 student participants to swim 200 meters in a pool with calm water (no waves) and unsteady water (11.8-15.7 in waves). The results showed an 8% decrement in performance between calm and unsteady water conditions for students who completed the 200-meter distance. For weaker swimmers who completed only 50 meters of the 200-meter test distance, the performance decrement increased to 14%. The study concluded that 11-year-olds should not be expected to reproduce swimming skills they have performed in calm water with the same proficiency in unsteady conditions (Kjendlie, 2013).

A 2008 study examined swimming performance among beach lifeguards in a pool, calm sea and surf sea. Thirty-five lifeguards with surf swimming experience (SE) and 30 lifeguards with no surf swimming experience (NSE) completed a best-effort 200-meter swim in a 25-meter pool (zero m wave height), a calm sea (zero m wave height) and surf sea (1-1.5 m wave height). In both lifeguard groups, swim times were fastest in the pool and slowest in the surf sea. As shown in Figure 8.9, swim times in the calm sea test did not differ significantly between the two lifeguard groups, but the lifeguards without surf experience were on average 49 seconds slower in the 200-meter surf sea swim test (Tipton, 2008).

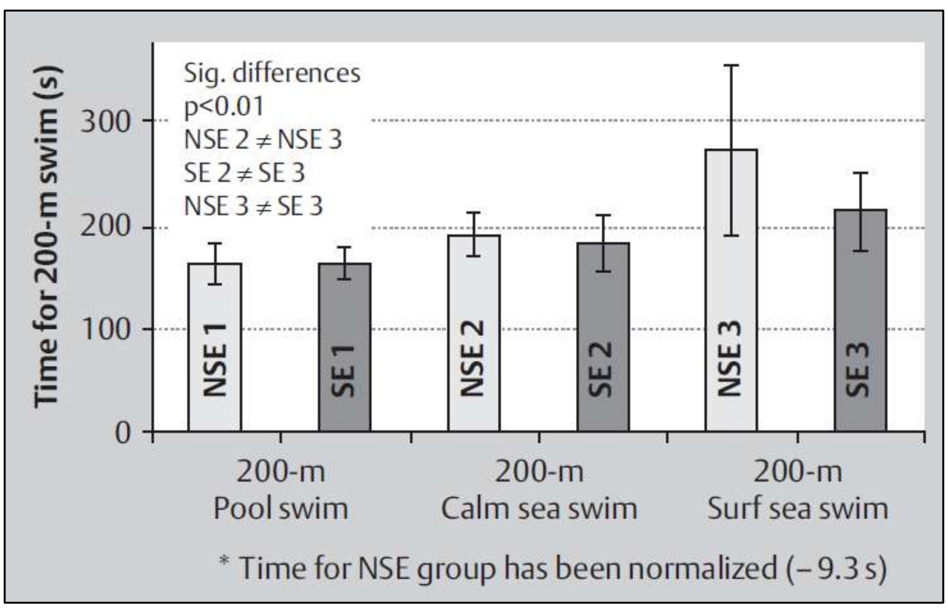


Figure 8.9 Average Swims for Lifeguards with Surf Experience (SE) and No Surf Experience (NSE) (Tipton, 2008).

Both studies demonstrate that waves, which in the case of the Study Area are expected from wind and boat wakes, make open-water swimming more challenging than calm water swimming and increase the time and energy needed to swim a particular distance. It is reasonable to assume that below-average swimmers will be more vulnerable to the effects of wind-generated waves and boat wakes. Therefore, this study assumes there is no safe wave height swimming criteria for both adults and children.

8.1.1.8. Summary of Swimming Criteria

A summary of the swimming criteria to be compared against hazards within the Study Area is presented below in Table 8.6

Table 8.6 Swimming Criteria to be Examined in the Safety Study

Category	Subcategory	Criteria
Swimming Distance	Adult (> 18 years)	25 yds (22.9 m)
	Child (6-10 years)	15 yds (13.7 m)
Swimming Speed	Adult (> 18 years)	1.7 ft/s (51.8 cm/s)
	Child (6-10 years)	1.47 ft/s (44.7 cm/s)
Water Depth	Adult (> 18 years)	66.3 in (1.7 m)
	Child (6-10 years)	51.4 in (1.3 m)
Safe Swimming Wave Height	Adult (> 18 years)	0 in
	Child (6-10 years)	0 in

8.2. Wading

Wading is an activity that involves walking in or through water, using one's feet to make contact with the floor of a waterbody.

8.2.1. Wading Criteria

Adult and child knee heights and safe wading velocities are researched to identify objective criteria that could be used to compare the activity of wading against hydraulic, shoreline and maritime hazards.

8.2.1.1. Wading Depth - Adults

This safety study assumes that water depths at or less than an average-height person's knee level would be appropriate for wading in the Study Area. It is further assumed that people would feel less comfortable wading in the Study Area at depths closer to their waists than their knees due to currents, depth changes and water turbidity.

In 1965, the U.S. Department of Health, Education, and Welfare published a report on anthropometric measurements of U.S. adults (U.S. Department of Health, Education, and Welfare, 1965). The report included knee height measurements for adult men and women ages 18-79 years (Table 8.7).

Table 8.7 Knee Height of United States Adults by Gender and Age, 1960-1962

Average height and percentile	Total, 18-79 years	18-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65-74 years	75-79 years
	Height in inches							
MEN								
Average height--	21.3	21.4	21.6	21.4	21.3	21.1	21.0	20.6
Percentile[1]								
99-------------	24.1	23.9	24.6	24.4	23.9	24.0	23.7	23.3
95-------------	23.4	23.4	23.7	23.4	23.3	23.1	22.9	22.7
90-------------	22.9	22.9	23.3	22.9	22.8	22.8	22.5	22.2
80-------------	22.4	22.5	22.7	22.5	22.4	22.2	21.9	21.7
70-------------	22.0	22.1	22.2	22.1	22.0	21.8	21.6	21.4
60-------------	21.7	21.8	21.9	21.8	21.7	21.4	21.3	21.0
50-------------	21.4	21.5	21.6	21.5	21.4	21.1	21.0	20.7
40-------------	21.1	21.2	21.3	21.2	21.1	20.8	20.7	20.4
30-------------	20.7	20.8	21.1	20.8	20.7	20.5	20.5	20.0
20-------------	20.4	20.5	20.6	20.4	20.3	20.2	20.2	19.6
10-------------	20.0	20.1	20.2	20.0	19.9	19.6	19.9	19.2
5--------------	19.3	19.4	19.8	19.4	19.3	19.1	19.2	19.0
1--------------	18.3	18.3	19.0	18.4	18.2	18.1	18.2	18.0
WOMEN								
Average height--	19.6	19.7	19.7	19.7	19.5	19.4	19.3	19.4
Percentile[1]								
99-------------	22.4	22.7	22.5	22.4	22.5	21.9	22.0	21.5
95-------------	21.5	21.6	21.6	21.5	21.6	21.4	21.0	20.9
90-------------	21.0	21.0	21.0	21.0	21.0	20.9	20.7	20.7
80-------------	20.5	20.6	20.6	20.6	20.5	20.4	20.1	20.2
70-------------	20.1	20.3	20.3	20.2	20.1	20.0	19.8	19.9
60-------------	19.8	20.0	20.0	19.9	19.8	19.7	19.5	19.6
50-------------	19.6	19.7	19.7	19.6	19.5	19.5	19.2	19.4
40-------------	19.3	19.5	19.4	19.4	19.2	19.2	19.0	19.2
30-------------	19.1	19.2	19.2	19.1	19.0	19.0	18.7	18.9
20-------------	18.6	18.9	18.8	18.8	18.5	18.6	18.4	18.4
10-------------	18.2	18.4	18.3	18.3	18.1	18.2	18.1	18.0
5--------------	17.9	18.1	18.0	18.0	17.6	17.8	17.8	17.3
1--------------	17.1	17.3	17.2	17.2	17.1	16.6	17.1	16.3

[1]Measurement below which the indicated percent of persons in the given age group fall.

Source: U.S. Department of Health, 1965

As summarized in Table 8.8, the average knee height for adult men and women ages 18-79 is 21.3 and 19.6 inches, respectively. For this study, unsafe wading depth for adults is greater than or equal to 21 inches (53 cm).

Table 8.8 Adult Wading Depth Criteria

Category	Age Group	Knee Height (Average)	Unsafe Adults Wading Depth
Men	> 18 years	21.3 in (54.1 cm)	≥ 21 in (53.3 cm)
Women	> 18 years	19.6 in (49.8 cm)	

8.2.1.2. Wading Depth - Children

In 1973, the U.S. Department of Health, Education, and Welfare published a report on anthropometric measurements of U.S. children ages 6 to 11 (U.S. Department of Health, Education, and Welfare, 1973). The report included knee height measurements for children ages 6 to 11 (Table 8.9).

Table 8.9 Knee Height of U.S. Children by Gender and Age at Last Birthday, 1963-1965

Sex and age	n	N	$\bar{X}$	s	$s_{\bar{x}}$	Percentile						
						5th	10th	25th	50th	75th	90th	95th
Boys			In centimeters									
6 years-------	575	2,082	36.1	2.03	0.079	32.9	33.5	34.6	35.9	37.4	38.8	39.7
7 years-------	632	2,074	38.2	2.17	0.112	34.8	35.5	36.7	38.2	39.6	41.3	42.2
8 years-------	618	2,026	40.2	2.25	0.109	36.3	37.3	38.6	40.2	41.7	42.9	43.8
9 years-------	603	2,012	42.4	2.65	0.140	38.1	39.1	40.7	42.4	43.8	45.6	46.7
10 years------	576	1,963	44.2	2.64	0.114	39.7	40.7	42.4	44.3	45.9	47.5	48.6
11 years------	628	1,924	46.3	2.73	0.104	41.7	42.8	44.4	46.3	48.2	49.8	50.9
Girls												
6 years-------	536	2,016	35.9	2.18	0.103	32.4	33.1	34.5	35.9	37.3	38.7	39.7
7 years-------	609	2,010	37.9	2.22	0.074	34.3	35.2	36.5	37.8	39.5	40.7	41.6
8 years-------	613	1,960	40.2	2.40	0.091	36.3	37.2	38.5	40.1	41.8	43.3	44.3
9 years-------	581	1,945	42.5	2.79	0.131	38.2	39.1	40.5	42.3	44.4	46.1	47.3
10 years------	584	1,904	44.4	2.88	0.118	39.6	40.7	42.4	44.4	46.4	47.8	49.3
11 years------	564	1,868	46.6	2.83	0.113	42.1	43.0	44.8	46.6	48.3	50.3	51.2

Source: U.S. Department of Health, 1973

As summarized in Table 8.10, the 50th percentile knee height for children ages 6 is 14 inches. For this study, unsafe wading depths for a 6-year-old child is greater than or equal to 14 inches.

Table 8.10 Child Wading Depth Criteria

Category	Age Group	Knee Height (50th Percentile)	Unsafe Child Wading Depth
Boys	6 years	14.1 in (35.9 cm)	≥ 14 in (35.6 cm)
Girls	6 years	14.1 in (35.9 cm)	

Figure 8.10 Children Wading in the Leigh River Confluence (The Morning Call)

Demonstrated in Figure 8.10, the safe wading depth of children may be highly variable. An older child may be able to wade and have water to the knees, yet a younger sibling may try to wade and have water to the upper thighs. An attempt to identify a safe wading depth for children ages 6-10 does not capture safe wading depth for children of all ages or height percentiles.

8.2.1.3. Wading Velocity - Adults

Wading safety in any moving body of water depends upon the height, weight and experience of the individual. Studies identifying instream velocity criteria provide data to evaluate safe wading conditions for adults.

In 1978, the U.S. Fish and Wildlife Service, Environmental Protection Agency and other agencies prepared a report presenting recreational criteria developed to quantify instream water requirements for recreation. The report identified 2.5 feet per second (76.2 cm/s) as the maximum velocity for safe wading conditions (Cooperative Instream Flow Service Group, 1978).

As described in a 1995 Federal Energy Regulatory Commission report, three power generation companies based in Idaho submitted a study to determine the ramping rate (the rate of change of water flow) for a permitted project under FERC regulations. Kayaking, rafting and wading criteria were examined to determine whether any changes in ramping rate regimes would adversely affect the suitability of these recreational activities. The study also used an instream velocity of less than 2.5 feet per second (76.2 cm/s) as part of its criteria for evaluating safe wading conditions (Federal Energy Regulatory Commission, 1995).

For this study, unsafe wading velocities for adults is greater than or equal to 2.5 feet per second (76.2 cm/s).

8.2.1.4. Wading Velocity - Children

Research was not able to identify any recent or historical criteria for safe wading conditions for children. Given that children are typically shorter and weigh less than adults, it is assumed that safe wading velocities would be lower for children than for adults. This study assumes that the unsafe wading velocity for a child is half that of an adult, or greater than or equal to 1.25 feet per second (38.1 cm/sec).

8.2.1.5. Summary of Wading Criteria

The results of researched adult and child knee heights as well as safe wading velocities, with reasonable assumptions, were used to identify the wading criteria shown in Table 8.11.

Table 8.11 Wading Criteria for Adults and Children

Category	Subcategory	Safety Criteria
Unsafe Wading Depth	Adult (> 18 years)	≥ 21 in (53 cm)
	Child - 6 years old	≥ 14 in (35.6 cm)
Unsafe Wading Velocity	Adult (> 18 years)	≥ 2.5 ft/s (76.2 cm/sec)
	Child - 6 years old	≥ 1.25 ft/s (38.1 cm/sec)

8.3. Kayaking

Kayaking involves moving through water in a light, narrow watercraft propelled by a double-bladed paddle. There are two main categories of kayaks: flatwater and whitewater. Flatwater kayaks include recreational, sit-on-top, touring, pedal and inflatable (Figure 8.11). Only flatwater kayaks will be evaluated in this study. Safety criteria to be determined for beginner use of flatwater kayaks include kayaking speed, distance, height above water and unsafe wave height.

Figure 8.11 Types of Flatwater Kayaks: 1. Recreational (Sun Dolphin Boats); 2. Sit-On-Top (Ocean Kayak); 3. Touring (Riot Kayaks); 4. Pedal (Ocean Kayak); and 5. Inflatable (Sea Eagle Boats, Inc.)

8.3.1. Kayaking Criteria

Kayaking speeds, travel distances, depth dimensions and associated wave and wake challenges are researched to identify objective criteria that could be used to compare the activity of kayaking against hydraulic, shoreline and maritime hazards in the Study Area.

8.3.1.1. Kayaking Speed

Kayaking guidebooks are an available resource to determine typical travel speeds for beginner, intermediate and advanced kayakers. The guidebook *Basic Illustrated Sea Kayaking* explains that in calm water with little wind or current, the typical speed for a beginner kayaker is 2.3-2.9 miles per hour (Schumann, 2016). This safety study assumes the average of this range is representative of the average speed for a kayaker, 2.6 miles per hour (116.2 cm/s).

8.3.1.2. Kayaking Distance

Kayak tours in the Study Area were reviewed to identify the average paddle distances for beginner kayakers. The Independence Seaport Museum, operating at Penn's Landing Marina in Philadelphia, offers guided kayak tours on the Delaware River for beginner, intermediate and advanced paddlers (Independence Seaport Museum, 2022). Hidden River Outfitters, operating from the Walnut Street Dock, offers guided kayak tours on the tidal Schuylkill River for beginner, intermediate and advanced paddlers (Hidden River Outfitters, 2022). As shown in Table 8.12, beginner kayak tours in the Study Area range from two to three miles in distance. For this study, the average distance for a kayaker will be 2.5 miles (4.0 km). Information in Table 8.12 was sourced from the outfitters' websites, including paddling experience difficulty and corresponding trip distance.

Table 8.12 Beginner, Intermediate, and Advanced Kayak Tours in the Study Area

Kayaking Outfitter	Tour Name	River	Distance, Miles	Paddling Experience	Itinerary
Independence Seaport Museum	Three Sisters Shipwreck	Delaware	3	Beginner	• Starts and ends at Penn's Landing Marina • Paddle to Three Sisters Shipwreck (near Pier 68)
	Graffiti Pier	Delaware	6	Intermediate to Advanced	• Starts and ends at Penn's Landing Marina • Paddle to Graffiti Pier and Penn Treaty Park
	Petty's Island	Delaware	10	Advanced	• Starts and ends at Penn's Landing Marina • Paddle to Petty's Island and Pyne Point Park
Hidden River Outfitters	Fairmount Water Works	Tidal Schuylkill	2	Beginner	• Starts and ends at Walnut Street Dock • Paddle to Fairmount Water Works
	Bartram's Garden	Tidal Schuylkill	4.5	Intermediate to Advanced	• Starts and ends at Walnut Street Dock • Paddle to Bartram's Garden

8.3.1.3. Kayak Height Above Water

Depth dimensions for flatwater kayaks are researched to determine the average height that a kayak sits above the waterline when occupied by at least one person. Depth of recreational kayaks is measured by the thickest part of the boat, whereas in touring kayaks depth is measured between the floor and top of the cockpit (Figure 8.12).

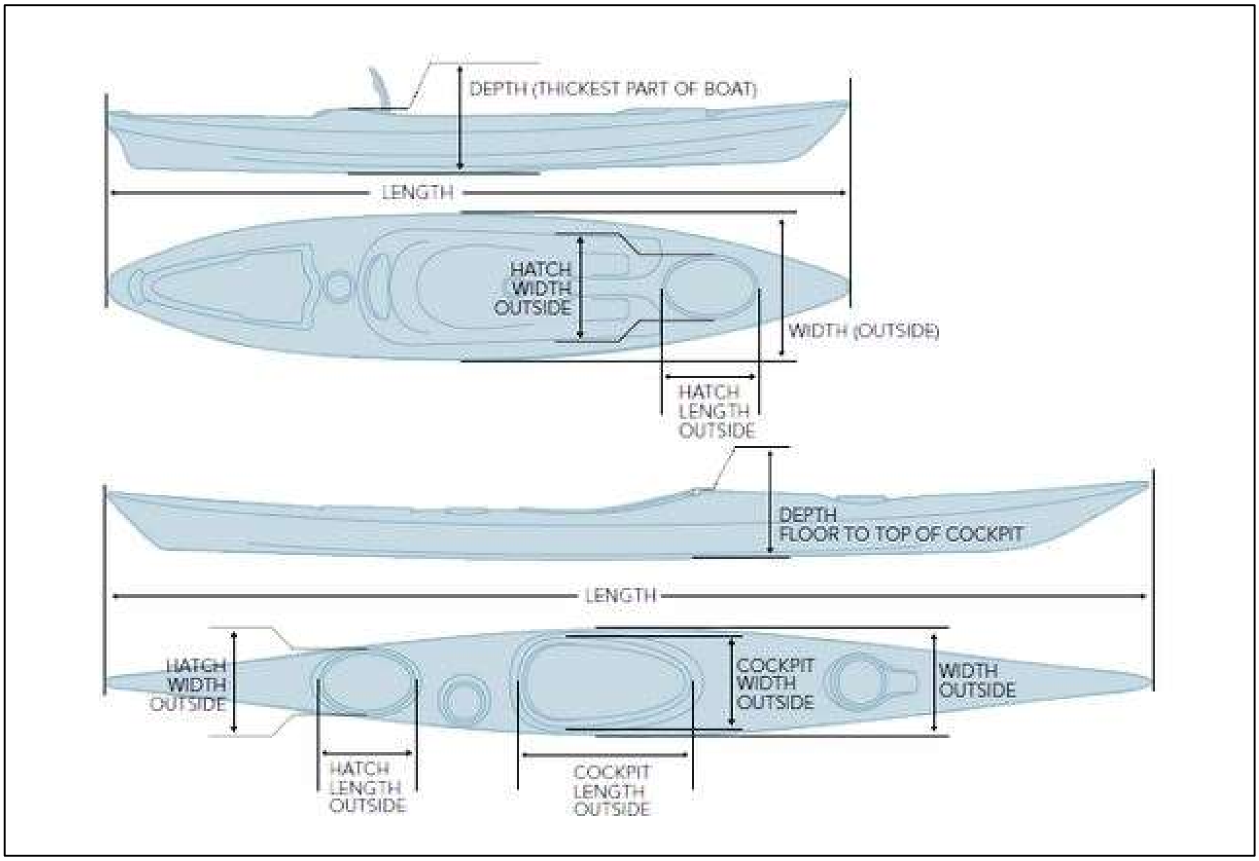


Figure 8.12 Depth Measurements in Recreational and Touring Kayaks (Perception Kayaks)

Flatwater kayak depth dimensions range from 11-16 inches (Table 8.13). As seen in Figure 8.13, the height at which a kayak sits above water is influenced by several factors, including the design and weight of the kayak, the weight of the person(s) sitting in it and associated gear. For this study, the height at which a kayak sits above water is 10 inches (25.4 cm).

Table 8.13 Depth of Various Flatwater Kayak Models

Kayak Type	Model	Company	Seats	Depth
Touring	Solstice GT	Current Designs	1	14 in (35.6 cm)
	Squall GTS	Current Designs	1	13 in (33.0 cm)
	Unity	Current Designs	2	13 in (33.0 cm)
	Libra XT	Current Designs	1	15.75 in (40 cm)
Sit-On-Top	Pescador Pro 10.0	Perception Kayaks	1	14 in (35.6 cm)
	Rambler 9.5	Perception Kayaks	1	13.1 in (33.3 cm)
Recreational	Pamlico 135T	Wilderness Systems	2	14 in (35.6 cm)
	Trailblazer 100 NXT	Pelican	1	14 in (35.6 cm)
	Drift 9.5	Perception Kayaks	1	11 in (27.9 cm)
	JoyRide 10.0	Perception Kayaks	1	15.25 in (38.7 cm)

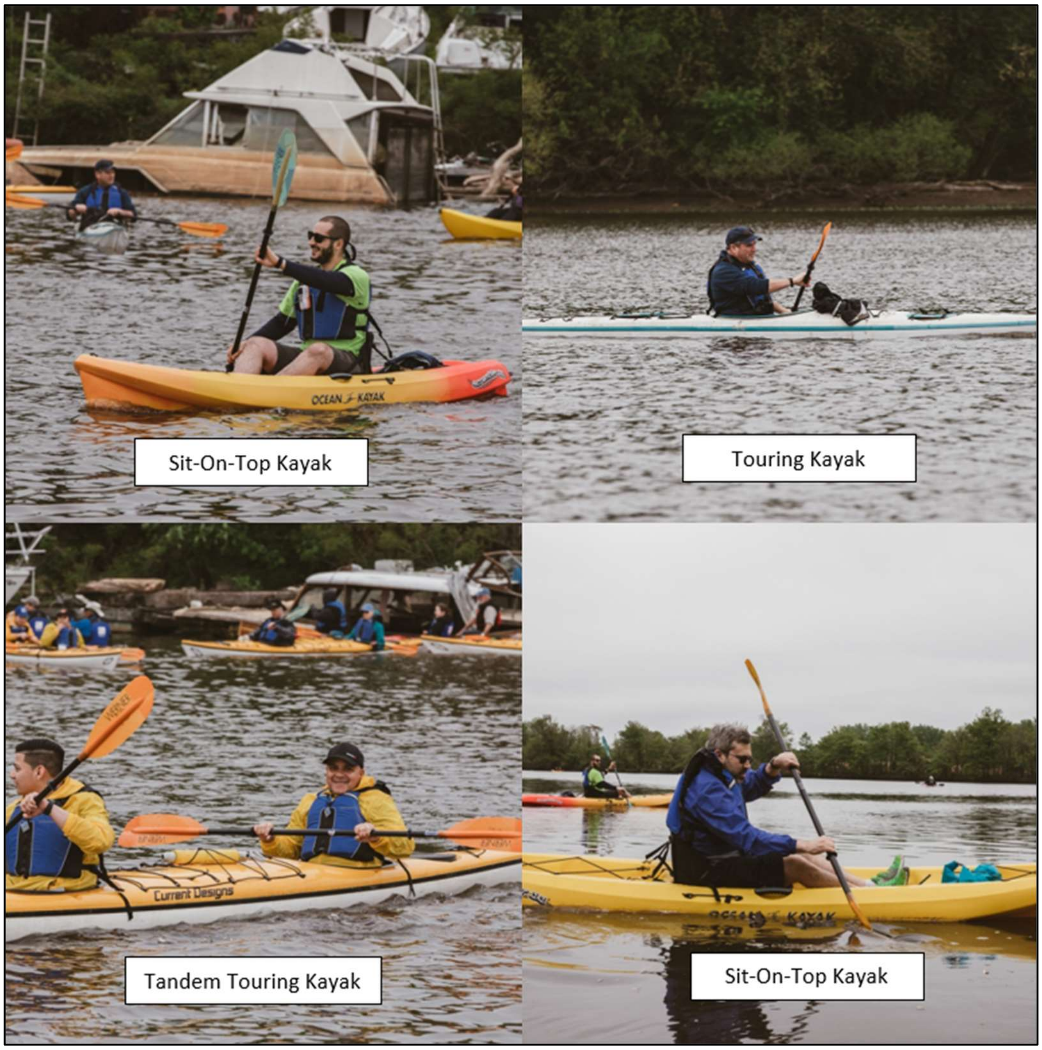


Figure 8.13 Kayak Types and Different Heights above Water (Upstream Alliance)

8.3.1.4. Wave and Wake Height

Skill assessment courses developed by the American Canoe Association (ACA) are available to determine the height at which waves and wakes are considered unsafe for beginner kayakers (American Canoe Association, 2022). As seen in Table 8.14, beginner ACA kayak assessment courses require locations where the water is calm and waves are less than 1 foot (0.3 m). For this study, wave and wake heights greater than 1 foot (0.3 m) are considered unsafe for kayaking.

Table 8.14 American Canoe Association Kayaking Skills Assessment Courses

Organization	Skills Assessment Course	Description of Course Location/Venue
American Canoe Association	Level 1: Introduction to Kayaking	Flat water, protected from wind, waves and outside boat traffic, with current less than 0.5 knots and within swimming distance of shore.
	Level 2: Essentials of Kayak Touring	Calm, protected water with constant access to safe landing and within 0.5 nautical miles from shore: • Winds less than 10 knots • Waves less than 1 ft (0.3 m) • Current less than 1 knot • No surf-shore break less than 1 ft (0.3 m)
	Level 2: Essentials of Sit-On-Top Kayaking	Calm, protected water with constant access to safe landing and within 0.5 nautical miles from shore: • Winds less than 10 knots • Waves less than 1 ft (0.3 meters) • Current less than 1 knot • No surf-shore break less than 1 ft (0.3 m)

8.3.1.5. Summary of Kayaking Criteria

This study researched kayaking speeds, travel distances, depth dimensions and wave and wake heights to identify the kayaking criteria shown in Table 8.15.

Table 8.15 Kayaking Criteria

Category	Safety Criteria
Average Kayaker Speed	2.6 mph (116.2 cm/s)
Average Kayaker Distance	2.5 mi (4.0 km)
Average Height that Kayak Sits Above Water	10 in (25.4 cm)
Unsafe Wave/Wake Height for Average Kayaker	> 1 ft (0.3 m)

8.4. Paddleboarding

Paddleboarding involves standing or kneeling on a paddleboard and propelling oneself through the water with a paddle or one's hands (Figure 8.14). Stand up paddleboards can be differentiated by construction methods and materials, which include epoxy, composite and inflatable. There are four main categories of stand up paddleboards: recreational, surfing, touring and racing. Safety criteria to be determined for beginner use of paddleboards include paddleboarding speed, distance, height above water and unsafe wave height.

Figure 8.14 Stand Up Paddleboarding (Sea Trek)

8.4.1. Paddleboard Criteria

Research is available for paddleboarding speeds, travel distances, depth dimensions and associated wave and wake challenges to identify objective criteria that could be used to compare the activity of paddleboarding against hydraulic, shoreline and maritime hazards in the Study Area.

8.4.1.1. Paddleboarding Speed

Paddleboarding guidebooks are available resources to determine travel speeds for beginner, intermediate and advanced paddleboarders. *Stand Up Paddleboarding A Beginner's Guide* explains that the top paddleboard speed for a beginner is between 2.3-3.5 miles per hour (Bassett, 2019). Given that not all beginners will reach the top speed, this study uses an average of this range of 2.9 miles per hour (129.6 cm/s).

8.4.1.2. Paddleboarding Distance

Information about paddleboarding tours inside the Study Area is available to identify the average distance traveled by beginner paddleboarders. Standup Philly was a stand up paddleboard rental and tour business that operated at the Bartram's Garden Community Boathouse in 2015 and 2016, offering tours on the tidal Schuylkill River between Bartram's Garden and Center City Philadelphia. Most participants would reach the South Street or Walnut Street Bridges before paddling back to Bartram's Garden (Graham, 2016). Aqua Vida offers stand up paddleboard tours in the Delaware River at the Penn's Landing Marina (Aqua Vida, 2022). As shown in Table 8.16, beginner paddleboard tours in the Study Area range from 1-4 miles in distance. For this study, the average paddleboarding distance is 2.5 miles (4.0 km).

Table 8.16 Stand Up Paddleboarding Tours in the Study Area

Outfitter	Status	Tour Name	River	Distance, Miles	Experience Level	Itinerary
Standup Philly	Closed in 2016	Center City	Tidal Schuylkill	3-4	Beginner	• Start and end at Bartram's Community Boathouse • Paddle to South Street or Walnut Street Bridge
Aqua Vida	Active	Paddleboard Old City Philadelphia	Delaware	< 1	Beginner	• Start at end at Spruce Street Harbor Park • Paddle through Penn's Landing Marina

8.4.1.3. Paddleboard Height Above Water

Depth dimensions for paddleboards are researched to determine the average height a paddleboard sits above the waterline when holding a person. The depth of a paddleboard is measured at its absolute thickest part, usually by the stringer and belly of the board. Most recreational, touring and racing paddleboards are 4.5-6 inches thick, while surf paddleboards are between 3-4.5 inches (Figure 8.15).

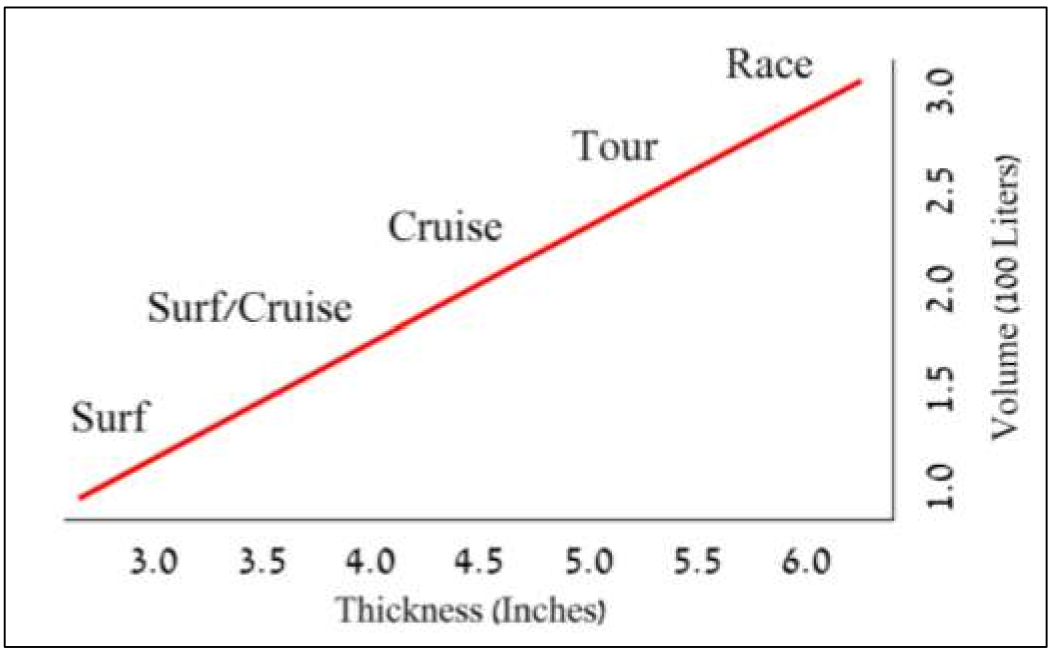


Figure 8.15 Paddleboard Thickness by Activity (Blue Planet Surf)

Considering that most paddleboarders in the study would use a recreational or touring paddleboard, five inches will serve to delineate an average thickness. Given that a paddleboard sits a few inches below the water when a person is standing or kneeling on it, the average height at which a paddleboard sits above the waterline would be approximately three inches (Figure 8.16). For this study, the height at which a paddleboard sits above water is 3 inches (7.6 cm).

Figure 8.16 Paddleboards on the Tidal Schuylkill River (Standup Philly)

8.4.1.4. Wake and Wave Height

Skill assessment courses developed by the ACA are available to determine the height at which waves and wakes are considered unsafe for beginner paddleboarders (American Canoe Association, 2022). As seen in Table 8.17, beginner ACA paddleboarding assessment courses require locations where the water is flat and waves are less than one foot in height. For this study, wave and wake heights greater than 1 foot (0.3 m) are considered unsafe for the average paddleboarder.

Table 8.17 American Canoe Association Paddleboarding Skills Assessment Courses

Organization	Skills Assessment Course	Description of Course Location/Venue
American Canoe Association	Level 1: Introduction to Stand Up Paddleboarding	Flat water, protected from wind, waves and outside boat traffic, with current less than 0.5 knots, and within swimming distance of shore.
	Level 2: Stand Up Paddleboarding	Flat water with less than 10-knot wind, 1-ft waves or smaller, or 1-2-knot current

8.4.1.5. Summary of Paddleboarding Criteria

Researched paddleboarding speeds, travel distances, depth dimensions, wave and wake heights and reasonable assumptions are used to identify the paddleboarding criteria shown in Table 8.18.

Table 8.18 Paddleboarding Criteria

Category	Safety Criteria
Average Paddleboarder Speed	2.9 mph (129.6 cm/s)
Average Paddleboarder Distance	2.5 mi (4.0 km)
Average Height that Paddleboard Sits Above Water	3 in (7.6 cm)
Unsafe Wave/Wake Height for Average Paddleboarder	> 1 ft (0.3 m)

8.5. Canoeing

Canoeing involves moving through water in a light, narrow boat propelled by a single-bladed paddle (Figure 8.17). There are four main categories of canoes: whitewater, recreational, touring and racing.

Figure 8.17 Canoeing (Old Town Canoe)

8.5.1. Canoeing Criteria

Canoe speeds, travel distances, depth dimensions and associated wave and wake challenges are researched to identify objective criteria that could be used to compare the activity of canoeing against hydraulic, shoreline and maritime hazards in the Study Area.

8.5.1.1. Canoeing Speed

Canoeing guidebooks are an available resource to determine travel speeds for beginner, intermediate and advanced canoers. The guidebook *Canoe Country Camping* explains that the typical speed for out-of-shape to average canoers is one to four miles per hour (Furtman, 2002). This safety study assumes that the average of this range is representative of the average speed for a canoer, 2.6 miles per hour (116.2 cm/s).

8.5.1.2. Canoeing Distance

Since no organized canoe tours are available in the Study Area, research into canoe trips in nearby waterways helps identify the average paddle distances for beginner canoers. Northbrook Canoe Company offers canoe trips on the West Branch Brandywine Creek ranging from 2-5.25 miles in length (Northbrook Canoe Company, 2022). Wilderness Canoe Trips Inc. offers canoe trips on the Brandywine River ranging from 6-12 miles in length (Wilderness Canoe Trips Inc., 2022). As shown in Table 8.19, beginner canoe trips range from 2-6 miles in length. For this study, the average canoeing distance will be 2.5 miles (4.0 km).

Table 8.19 Beginner, Intermediate, and Advanced Canoe Trips Outside Study Area

Kayaking Outfitter	Trip Name	Waterbody	Distance, Miles	Estimated Time	Experience Level
Northbrook Canoe Company	Embreeville to Northbrook	West Branch Brandywine Creek	2	1 hr	Beginner
	Corcoran's Br. to Northbrook	West Branch Brandywine Creek	2.75	1.5 hrs	Beginner
	Harvey's Br. to Northbrook	West Branch Brandywine Creek	5.25	2.25 hrs	Intermediate
Wilderness Canoe Trips Inc.	Brandywine River Museum to Thompson's Br.	Brandywine River	6	2 hrs	Beginner to Intermediate
	Lenape Access to Thompson's Br.	Brandywine River	12	4 hrs	Intermediate to Advanced

8.5.1.3. Canoe Height Above Water

This study researched depth dimensions for recreational and touring canoes to determine the height that a canoe sits above the water when occupied by at least one person. In canoes, center depth is the measurement from the center of the canoe at the keel line, straight up to the gunwales (Figure 8.18).

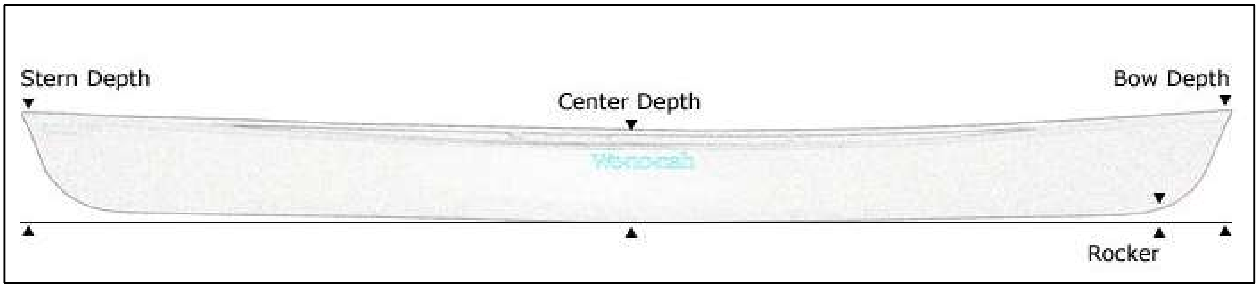


Figure 8.18 Center Depth Measurement in Canoes (Wenonah Canoe)

Recreational and touring canoe center depth dimensions range from 11-15 inches (Table 8.20). Several factors influence the height at which a canoe sits above water versus below it, including the design and weight of the canoe, the weight of the person(s) sitting in it and associated gear. For this study, the height at which a canoe sits above water is 10 inches (25.4 cm).

Table 8.20 Center Depth of Various Recreational and Touring Canoe Models

Canoe Type	Model	Company	Seats	Center Depth
Touring	Heron	Wenonah Canoe	2	13 in (33.0 cm)
	Seneca	Wenonah Canoe	3	14 in (35.6 cm)
	Spirit II	Wenonah Canoe	2	14 in (35.6 cm)
	Keewaydin 17	Swift Canoe & Kayak	2	14 in (35.6 cm)
	Keewaydin 16	Swift Canoe & Kayak	2	13 in (33.0 cm)
Recreational	Discovery 133	Old Town Canoe	3	14 in (35.6 cm)
	Next	Old Town Canoe	1	11.5 in (29.2 cm)
	Saranac 146	Old Town Canoe	2	13.25 in (33.7 cm)
	Discovery Sport 15	Old Town Canoe	3	15 in (38.1 cm)
	Prospector 15	Swift Canoe & Kayak	2	13 in (33.0 cm)

8.5.1.4. Wake and Wave Height

This study reviewed skill assessment courses developed by the ACA to determine the height at which waves and wakes are considered unsafe for beginner canoers (American Canoe Association, 2022). As shown in Table 8.21, beginner ACA canoeing assessment courses require locations where the water is flat and waves are less than 1 foot (0.3 m).

Table 8.21 American Canoe Association Canoeing Skills Assessment Courses

Skills Assessment Course	Description of Course Location/Venue
Level 1: Introduction to Canoeing	Flat water, protected from wind, waves and outside boat traffic, with current less than 0.5 knots, and within swimming distance of shore.
Level 2: Essentials of Canoe Touring	Protected water near shore with winds up to 10 knots, waves up to 1 foot (0.3 meters) or current up to 1 knot

For this study, wave and wake heights greater than 1 foot (0.3 m) are considered unsafe for the average canoer.

8.5.1.5. Summary of Canoeing Criteria

Researched canoeing speeds, travel distances, depth dimensions, wave and wake heights and reasonable assumptions are used to identify the canoeing criteria shown in Table 8.22.

Table 8.22 Canoeing Criteria to be Examined in Safety Study

Category	Criteria
Average Canoer Speed	2.6 mph (116.2 cm/s)
Average Canoer Distance	2.5 miles (4.0 km)
Average Height that Canoe Sits Above Water	10 inches (25.4 cm)
Unsafe Wave/Wake Height for Average Canoer	> 1 foot (0.3 m)

8.6. Jet Skiing

Jet skiing is an activity that involves sitting, standing, or kneeling on a jet-propelled watercraft that skims across the surface of water at high speeds (Figure 8.19). Jet skis, formally called personal watercraft, are boats less than 16 feet in length powered by jet pumps, not propellers. Jet skis can reach fast speeds and are designed to be very maneuverable. The two categories of jet skis are sit down and stand up. This study will evaluate only sit-down jet skis.

Figure 8.19 Jet Skiing (SEA-DOO)

8.6.1. Jet Skiing Criteria

Research into jet ski dimensions, drafts and depth requirements identified objective criteria that can be used to compare the activity of jet skiing against hydraulic, shoreline and maritime hazards in the Study Area.

8.6.1.1. Jet Ski Draft

A vessel's draft is the depth of water needed to float it. The draft of a jet ski is measured between the deepest point of the hull and the waterline (Figure 8.20). A jet ski has a shallower draft (4-9 inches) than other motorized boats (NOAA, 2022).

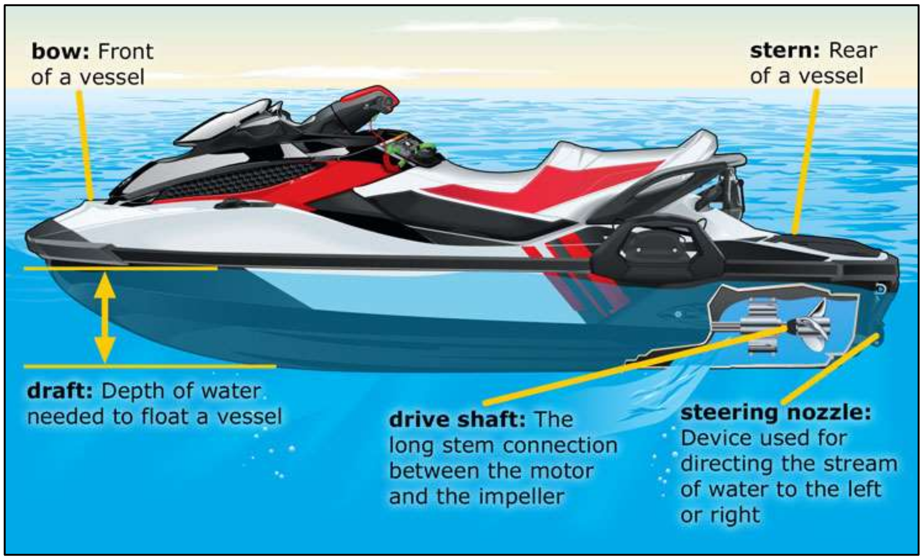


Figure 8.20 The Draft of a Jet Ski (Boat-ed.com)

8.6.1.2. Jet Ski Operating Depth

Reviews of owner's manuals from jet ski manufacturers identified the minimum water depth required to safely operate a jet ski. As shown in Table 8.23, the minimum water depth needed to safely operate a jet ski ranges from 2.5-3.5 feet. Jet ski manufacturers caution users against operating in shallow waters because sand, weeds and debris can get sucked into the jet pump, damage the pump and impeller and possibly clog cooling lines (Kawasaki, 2022).

Table 8.23 Minimum Depth Requirements for Safe Jet Ski Operation (Kawasaki, SEA-DOO, Yamaha)

Manufacturer	Model Year	Minimum Depth Requirements for Safe Jet Ski Operation
Kawasaki	2022	≥ 2.6 ft (0.8 m) of water
SEA-DOO	2022	≥ 3 ft (0.9 m) of water from the bottom of the watercraft
Yamaha	2022	≥ 2 ft (0.6 m) from the bottom of the watercraft

For this study, depths less than or equal to 3 feet (0.9 m) are considered unsafe for operating a jet ski.

8.6.1.3. Summary of Jet Skiing Criteria

Research into jet ski dimensions, draft, and depth requirements identified the jet skiing criterion shown in Table 8.24.

Table 8.24 Jet Skiing Criterion to be Examined in Safety Study

Category	Criteria
Unsafe Jet Ski Operating Depth	≤ 3 feet (0.9 m)

8.6.1.4. Safety Concerns for Jet Skiing

Jet skis can capsize and experience propeller damage from striking floating and submerged debris, such as downed tree limbs. As seen in Figure 8.21, floating and submerged debris in the Study Area can increase following heavy rain events. Jet skiers in the Study Area also must contend with changing water depths caused by incoming and outgoing tides. Figure 8.22

shows depth changes in the tidal Delaware River near Washington Avenue Green in Philadelphia, Pennsylvania. These safety concerns will be discussed in greater detail when recreational activities are compared against hydraulic, shoreline and maritime hazards.

Figure 8.21 Debris in the Tidal Schuylkill following Tropical Storm Isaias, 2020 (Billy Penn)

Figure 8.22 Water Depth Changes in the Delaware River at Washington Avenue Green (DRBC)

8.7. Summary of Primary Contact Recreation Activities Criteria

A summary of the criteria identified for the recreational activities that will be evaluated in this study is provided below.

Table 8.25 Summary of Recreational Activity Criteria

Recreational Activity	Recreational Criteria						
	Age Group	Average Speed	Average Distance	Unsafe Depth	Unsafe Velocity	Average Height of Watercraft Above Waterline	Unsafe Wave & Wake Height
Swimming	Child 6-10 years	1.47 ft/s	15 yds	51.4 in			>0
	Adult >18 years	1.7 ft/s	25 yds	66.3 in			>0
Wading	Child 6 years			≥ 14 in	≥ 1.25 ft/s		
	Adult >18 years			≥ 21 in	≥ 2.5 ft/s		
Kayaking	Adult >18 years	2.6 mph	2.5 mi			10 in	> 1 ft
Paddleboarding	Adult >18 years	2.9 mph	2.5 mi			3 in	> 1 ft
Canoeing	Adult >18 years	2.6 mph	2.5 mi			10 in	> 1 ft
Jet Skiing	Adult >18 years			≤ 3 ft			

Section 9 Activity and Hazard Safety Assessment

9.1. Introduction

The assessment presented in this section compares the safety criteria identified for each recreational activity in Section 8 to the hydraulic and shoreline hazards detailed in Section 6 and the maritime hazards detailed in Section 7. The goal of this assessment is to determine whether hazards and activities may overlap within the Study Area, whether the recreational safety criteria are exceeded when hazards and activities overlap, and where such overlap may occur.

The assessment first compares each recreational activity to each hazard and determines whether the hazard has the ability to impact the recreational activity. It is important to note that not all recreational activities are exposed to all hazards. For example, water depth is not relevant to recreational activities that use watercraft such as kayaks but is relevant to a depth-dependent activity like wading. Table 9.1, Table 9.2, and Table 9.3 include results of this screening by using blue-shaded cells to indicate which activities have the potential to be impacted by a specific hazard. Activities and hazards that are not expected to impact one another are not shaded blue. Only the shaded activity vs. hazard combinations are assessed in this section.

Overlapping activities and hazards are assessed in four ways: by narrative comparison, numerical comparison, a calculated scenario, and geographic extent. Activities and hazards may be assessed by one or more of these methods.

Narrative Comparison – This describes how a hazard may impact a recreational activity were they to intersect in the Study Area.

Numerical Comparison – A recreational safety criteria is compared against a hazard safety criteria.

Calculated Scenario – A calculation is required to describe a scenario where a hazard may impact a recreational activity or safety criteria in the Study Area.

Geographic Extent – An examination of the Study Area geography, with results presented in maps.

The safety assessments are organized by recreational activity and subdivided by hydraulic, shoreline, other and maritime hazards. Kayaking, canoeing and paddleboarding are discussed within the same section given the similarities in safety criteria for distance, speed and wave or wake height tolerance among these non-motorized watercraft.

Table 9.1 Hydraulic Hazard Safety Considerations for Recreational Activities

Hydraulic Hazards	Recreational Activities							
	Swimming		Wading		Kayaking	Paddle-boarding	Canoeing	Jet Skiing
	Adult	Child	Adult	Child				
Depth								
Distance to Shore								
Currents								
Wind-Generated Waves								

Table 9.2 Shoreline and other Hazard Safety Considerations for Recreational Activities

Shoreline and Other Hazards	Recreational Activities							
	Swimming		Wading		Kayaking	Paddle-boarding	Canoeing	Jet Skiing
	Adult	Child	Adult	Child				
Debris								
Security and Exclusions								
Legacy Infrastructure								
Active Infrastructure								
Electrical Shock Drowning								

Table 9.3 Maritime Hazard Safety Considerations for Recreational Activities

Maritime Hazards	Recreational Activities							
	Swimming		Wading		Kayaking	Paddle-boarding	Canoeing	Jet Skiing
	Adult	Child	Adult	Child				
Propeller Wash								
Bow/Stern Thruster Wash								
Tow Lines								
Oncoming Ships								
Ship Stopping Distance								
Water Displacement/Suction								
Blind Spots and Visibility								
Wakes								
Maritime Traffic Areas								

9.2. Swimming

9.2.1. Swimming and Hydraulic Hazards

Swimming is susceptible to four hydraulic hazards: depth, distance to shore, currents, and wind-generated wave height. The safety assessment methods for each of these combinations are presented below in Table 9.4. The comparison of swimming safety criteria against hydraulic hazards is made using the recreational activities characterization in Section 8 and includes further analysis where necessary.

Table 9.4 Method of Assessment of Hydraulic Hazard Safety Considerations for Swimming

Hydraulic Hazards	Safety Criteria	Swimming Assessment Method	
		Adult	Child
Depth	Safe Swimming Depth	Numerical, Geographic	Numerical, Geographic
Distance from Shore	Safe Swimming Distance from Shore	Numerical, Calculated Scenario	Numerical, Calculated Scenario
Currents	Swimming Current Velocity	Numerical, Calculated Scenario	Numerical, Calculated Scenario
Wind-Generated Waves	Safe Swimming Wave Height	Numerical, Calculated Scenario	Numerical, Calculated Scenario

9.2.1.1. Swimming and Water Depth

In order to assess where in the Study Area swimmers may be able to swim without reaching water over their heads, a numerical comparison between swimming depth and water depth can be made. Safe swimming research presented in Section 8.1 identifies the safe swimming depth for an adult is below 66.3 inches (1.7 m) and below 51.4 inches (1.3 m) for a child, Table 9.5.

Table 9.5 Swimming Water Depth Criteria

Swimming Criteria	Adult (>18 years)	Child (6-10 years)
Swimming Depth	66.3 in (1.7 m)	51.4 in (1.3 m)

To identify where in the Study Area depths below these safe swimming criteria may occur, the bathymetry of the Study Area (detailed in Section 5.1) is reviewed. Locations identified by mapping that indicate where the depth is below the adult and child safe swimming water depth criteria are presented in Figure 9.1. It is important to note that the bathymetry mapped represents the approximate mean depth; high tide is approximately three feet above and low tide is approximately three feet below the mean tidal water level.

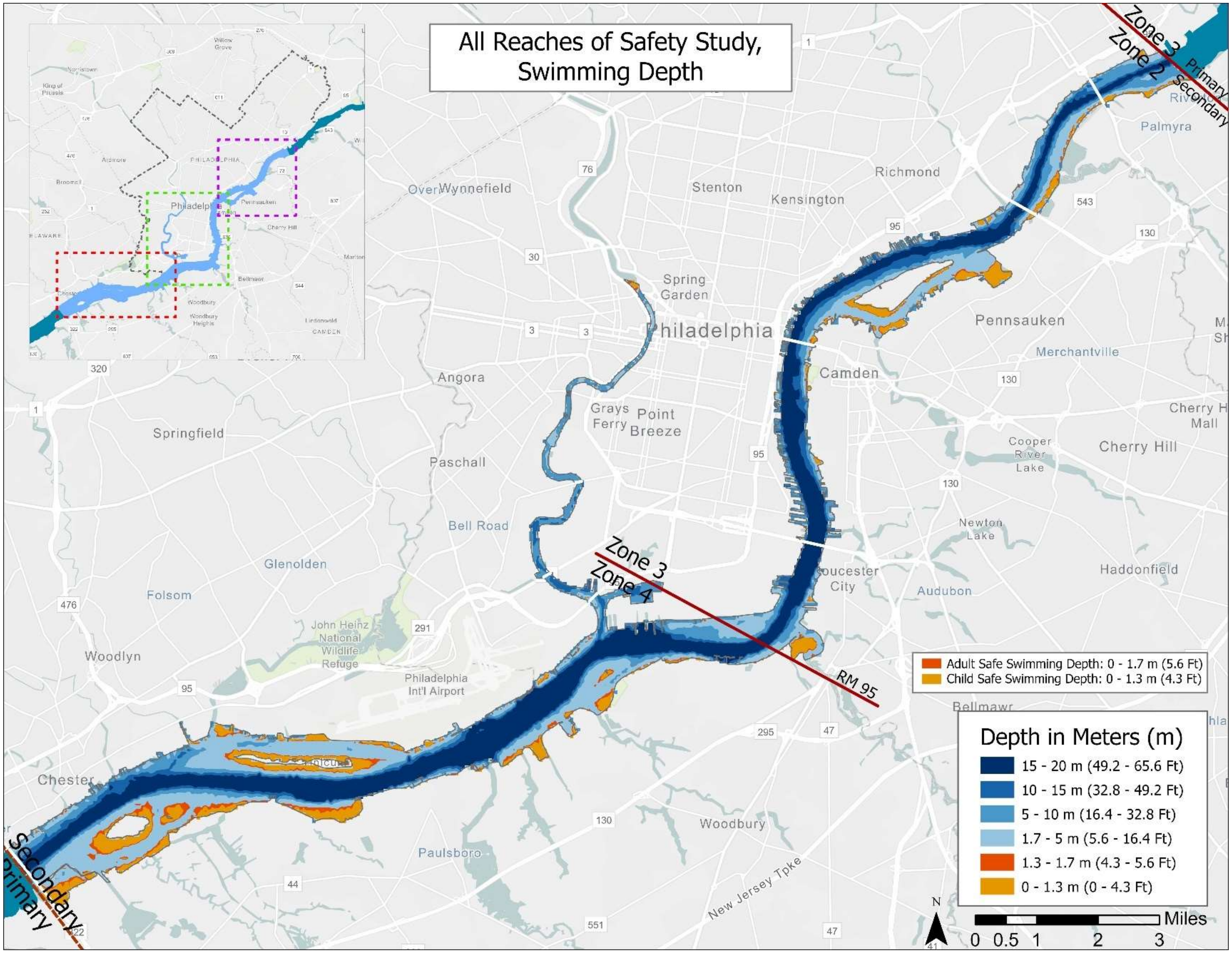


Figure 9.1 Swimming Safety Criteria and Approximate Mean Tidal Depth

The map identifies some areas, primarily in New Jersey, where the adult and child safe swimming depth is present at mean tide depth. However, it is critical to note that during high tide the depth of these areas would exceed the safe adult and child swimming depth by approximately three feet. At low tide, swimmers may not be able to reach the deeper water easily, requiring walking on foot across tidal mud. Changing water level due to tides will substantially expand and contract swimming areas available hourly, even during a swim, creating complex hazards to swimmers from water depth.

9.2.1.2. Swimming and Distance from Shore

The width from the Pennsylvania shoreline to the New Jersey shoreline of the Delaware River in the Study Area ranges from approximately 0.4–1.2 miles (0.7-2 km). According to information presented in Section 5.2, even at the narrowest locations within the Study Area, the width of the Delaware River exceeds the safe swimming distance for adults and children, 25 yards and 15 yards respectively. Based on distance alone, ignoring other hydraulic hazards, the Delaware River is too wide for non-competitive recreational swimmers to swim from the Pennsylvania shoreline to the New Jersey shoreline, or vice versa.

Swimming in the Delaware River is considered open water, meaning there is no pool wall on which swimmers can rest. In open water, a swimmer would need to swim out from the shore and swim back to the point of entry on the shore. In this scenario, it is assumed that the combined out-and-back distance equals the safe swimming distance criteria. This makes half the safe swimming distance criteria the turnaround distance from the shore so that the swimmer can make it back, Table 9.6.

Table 9.6 Safe Swimming Distances

Swimming Criteria	Adult (>18 years)	Child (6-10 years)
Safe Swimming Distance	25 yards (22.9 m)	15 yards (13.7 m)
Safe Turnaround Distance from Shore	12.5 yards (11.45 m)	7.5 yards (6.8 m)

In open water, such as the Study Area, swimmers would have to know to change their swimming direction and turn back toward shore before depleting their energy. Knowing when to turn around to maintain sufficient energy to reach shore requires skill and experience as a swimmer. Further considerations must be made to accommodate how the tides can change the location of the suitable-depth water relative to the shoreline. At low tide, swimmers may need to walk across mud flats to reach water of a swimmable depth. At high tide, the water depth may be approximately three feet deeper at a given location than presented in Figure 9.1. The tidal variation in water level throughout the day compounds the hazards of swimming in the Study Area and complicates delineating safe swimming areas based on depth and safe swimming distance from shore.

9.2.1.3. Swimming and Currents

As discussed in Section 5.3, the tidal currents within the Study Area change direction four times per 24 hours, and range in velocity from 0.1-3.5 feet per second (3.05-106.7 cm/s). Careful consideration must be given to the effect that current velocity will have on swimming in the Study Area.

Research regarding swimming speed, used to identify the average swimming speeds for adults and children, was available from analyses of swimmers in pools, not open water with currents.

The average swimming speeds for adults and children developed in Section 8.1 need to be adapted to swimming in tidal open water with currents; therefore safe swimming current velocity criteria are needed to compare against observed safety Study Area current velocities.

As discussed in the previous section, a swimmer in the Study Area could originate from the shoreline, proceed to the safe turnaround distance, then return to the shoreline. A swimmer may also swim out a distance, get displaced by the currents, then have to swim against the current to return to the starting location. A conservative approach to interpreting the influence of currents on open-water swimming in all possible scenarios is needed because *even trying to remain in one place while swimming in water with currents will expend energy*, regardless of whether the swimmer is trying to traverse a distance. With no identified research that articulates the speed of currents unsafe for open-water swimming or how long or far a swimmer may be able to last in currents of a certain speed, an assumption must be made.

It is assumed that currents that would slow swimmers to less than half of their average swimming speed are unsafe. With this assumption, a swimmer moving 1.7 feet per second against a 0.85 feet-per-second current would be able to maintain a speed of 0.85 feet per second moving forward and overcome the current. It is important that the assumption includes a current that may be overcome by the swimmer, so the swimmer can make it back to shore. A swimmer's half speed is used to determine the safe swimming current velocity criteria from the average swimming speeds for adults and children researched in Section 8.1.

Table 9.7 Safe Swimming Velocity Criteria

Swimming Criteria	Adult (>18 years)	Child (6-10 years)
Average Swimming Speed	1.7 ft/s (51.8 cm/s)	1.47 ft/s (44.7 cm/s)
Safe Swimming Current Velocity	< 0.85 ft/s (25.9 cm/s)	< 0.74 ft/s (22.3 cm/s)

The safe swimming current velocity criteria for adults and children, Table 9.7, indicate that velocities above 0.85 feet per second (25.9 cm/s) are unsafe for adult swimmers, and velocities above 0.74 feet per second (22.3 cm/s) are unsafe for child swimmers. The velocity characterization of the Study Area presented in Section 5.3 may be used to understand the frequency with which the safe swimming current velocity criteria may be exceeded in the Study Area. The cumulative distribution of observed velocity within the Study Area during a likely recreation time period in 2014 is reproduced in Figure 9.2, with child and adult safe swimming velocity criteria overlain.

When overlaying the safe swimming velocity criteria on the observed velocity cumulative distribution, the intersection of the criteria and distributions allows interpretation of the percent of time that velocities above or below the criteria may be observed within the Study Area. Most critically, the observed velocity data show that approximately 63% of the time near-shore (0-25 yds) currents are above the adult safe swimming velocity, and approximately 71% of the time near-shore currents are above the child safe swimming velocity. As tidal action changes current direction and current speed throughout each day, identifying when currents may be below the safe swimming velocity criteria would be extremely difficult for recreators. Velocities will likely change during the time period of a swim, potentially increasing above the safety threshold the longer a swimmer is in the water.

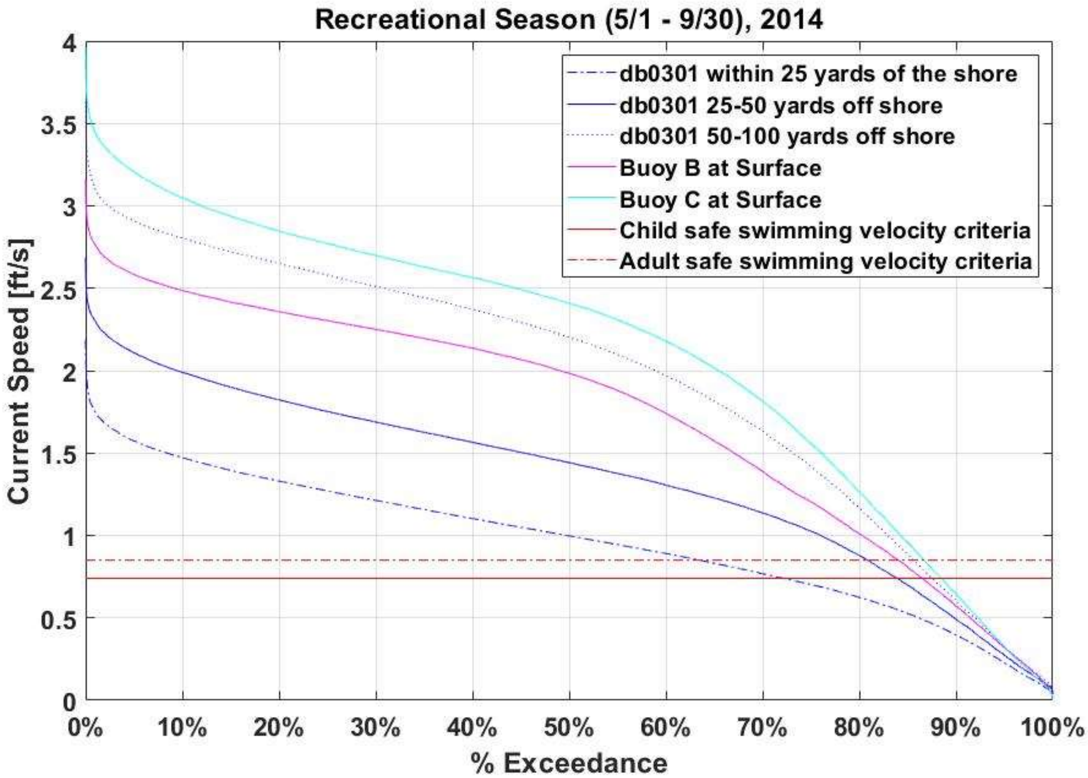


Figure 9.2 Percent Exceedance of Adult and Child Safe Swimming Velocity Criteria

While any swimming in the Study Area may reasonably be expected to occur close to shore, the farther from shore swimmers go, the more they are exposed to velocities above the safe swimming velocity criteria. The observed data taken along the edge of the shipping channel (Buoys B & C and db0301, 25-50 yds) show that the adult safe swimming velocity criteria is exceeded approximately 75-80% of the time and the child safe swimming velocity criteria is exceeded approximately 83-86% of the time. The data further demonstrate that any swimming in the Study Area should take place close to shore and not even approach the edge of the navigation channel.

The currents within the Study Area create a serious threat to swimmers when compared against safe swimming velocity criteria and from a predictability standpoint. The currents are hazardous from a predictability standpoint given that high tide, low tide, and the periods where velocities may be below the safe swimming current velocity criteria do not occur at the same time each day. For potential swimmers, this means that velocity conditions that may occur in the afternoon one weekend will be different another weekend at that same time. For individuals and families who may plan a swim around their daily or weekend activities but do not consider specific tidal velocity and depth conditions that change hourly, this situation would be extremely confusing and dangerous.

9.2.1.4. Swimming and Wind-Generated Waves

As discussed in Section 8.1, wave action makes for a more hazardous swimming environment than calm conditions. In the Study Area, waves can be generated by wind or boat wakes. Wind-generated waves can produce very choppy water conditions and white caps, which are different than breaking waves typically experienced when swimming at a beach. As presented in Table 9.8, there is no safe wave height for swimming in the Study Area.

Table 9.8 Swimming Wave Height Criteria

Swimming Criteria	Adult (>18 years)	Child (6-10 years)
Safe Wave/Wake Height	0 feet	0 feet

The analysis of wind-generated waves presented in Section 5.4 and excerpted in Table 9.9, indicates that wind can generate waves that are higher than the safe swimming wave height of 0 feet 5-10% of the time in small locations in the Study Area where a large fetch exists.

Table 9.9 Average Wind-Generated Wave Height within Study Area

Wind Generated Wave Height	% of Overall Winds Resulting in Waves > 1 Ft
Upper Reach	10%
Central Reach	5%
Lower Reach	7%

The presence of wind-generated waves above the safe wave height in the Study Area are hazardous to potential swimmers. Even with these waves estimated to occur just 5-10 % of the time, wind-generated waves will compound risk to swimmers already dealing with variable tidal water depths and current velocities.

9.2.2. Swimming and Shoreline and Other Hazards

Swimming is susceptible to five shoreline and other hazards: debris, security and exclusions, legacy infrastructure, active infrastructure, and electrical shock drowning. The safety assessment methods for each of these combinations is presented below in Table 9.10. Maps presented in this section depict safe swimming water depths as well as the locations of shoreline and other hazards.

Table 9.10 Method of Assessment of Shoreline and Other Hazard Safety Considerations for Swimming

Shoreline and Other Hazards	Safety Criteria	Swimming Assessment Method	
		Adult	Child
Debris	General Activity Caution	Narrative	Narrative
Security and Exclusions	100-yd Safety Buffer	Narrative, Geographic	Narrative, Geographic
Legacy Infrastructure	50-ft Safety Buffer	Narrative, Geographic	Narrative, Geographic
Active Infrastructure	50-ft Safety Buffer	Numerical, Geographic	Numerical Geographic
Electrical Shock Drowning	50-yd Safety Buffer	Narrative	Narrative

9.2.2.1. Swimming and Debris

As detailed in Section 6.1, local river cleanup events and the U.S. Coast Guard have documented river debris in the Study Area comprised of trees and branches, trash, and larger items such as railroad ties, shopping carts, tires and mattresses. Debris moving with the river currents poses a hazard to swimmers who may be struck, lacerated or become entangled. The debris may not be visible from the surface, giving a swimmer little warning to take evasive action. The presence of submerged and difficult-to-see debris creates a safety hazard for swimmers in the Study Area.

9.2.2.2. Swimming and Security and Exclusions

The U.S. Coast Guard enforces a security zone when needed around the Philadelphia International Airport that excludes recreation, and specifically swimming, when activated. The tidal Schuylkill also has a large security zone enforced by the U.S. Coast Guard when specific sized barges are moored at the Deloach dock near the former Philadelphia Energy Solutions site (Section 2.4). While these recreational activity exclusions are not active every hour of every day, the need for such exclusions implies the presence of security sensitivities at these locations that all recreators, including swimmers, should avoid. On the Pennsylvania shoreline of the Study Area, the majority of the shallow water areas below the swimming-safe depth criteria are located adjacent to the Philadelphia International Airport, Figure 9.1.

The U.S. Coast Guard and the Pennsylvania Fish and Boat Commission have issued guidance for recreational boating that similarly recommends staying at least 100 yards away from marine facilities, power plants, military areas, cruise lines and petroleum facilities (Section 6.2). While the recreational boating guidance does not explicitly include swimming, these critical safety and emergency response agencies are highlighting hazards from which swimmers should also remain at least 100 yards away. If a facility or location is hazardous to a motorboat, it is likely as hazardous, or more, to a swimmer.

It is recommended that swimmers should remain 100 yards away from marine facilities, power plants, military areas, cruise lines and petroleum facilities because they are mentioned in guidance by the U.S. Coast Guard and Pennsylvania Fish and Boat Commission for security and recreational exclusions in the Study Area. These types of locations typically have active infrastructure and are included in Figure 9.3 and Figure 9.4 that depict legacy and active infrastructure and safe swimming depth. These types of locations are also included in Figure 9.5 that presents safe swimming depth and maritime traffic areas.

9.2.2.3. Swimming and Legacy Infrastructure

There are 1163 pieces of legacy infrastructure in the Study Area, including piers, docks and pilings. The legacy infrastructure is no longer in use, abandoned in place, dilapidated, and wholly or partially submerged. Additionally, many pieces of legacy infrastructure may be more or less visible from the water surface depending on the tidal cycle. While swimmers may see these locations as a point of interest, they are at risk of being entangled, lacerated or otherwise hurt trying to climb onto or jump from legacy infrastructure. The abundance of legacy infrastructure in the Study Area also blocks safe egress from the water along the shoreline.

Table 9.11 Legacy Infrastructure Identified in Areas Below Safe Swimming Depth

Location Below Safe Swimming Depth	Legacy Infrastructure		Shipwrecks		Total Study Area	
	NJ Shoreline	PA Shoreline	NJ Shoreline	PA Shoreline	Legacy Infrastructure	Ship-wrecks
Child Swimming Depth	129	3	11	2	132	13
Adult Swimming Depth	77	28	5	1	105	6
Total Study Area	**206**	**31**	**16**	**3**	**237**	**19**

Table 9.11 presents the total pieces of legacy infrastructure and shipwrecks identified within areas below the child and adult safe swimming depths. Along the New Jersey shoreline, 206 pieces of legacy infrastructure are identified, and along the Pennsylvania shoreline, 31 pieces of legacy infrastructure are identified in the areas where depth may support swimming. According to this analysis, legacy infrastructure is abundant in areas where depth has indicated swimming may be possible, creating a critical hazard to swimmers. It is recommended that swimmers remain at least 50 feet away from legacy infrastructure, which may not even be possible in some locations given the abundance of legacy infrastructure in the shallow depths that may support swimming in the Study Area.

9.2.2.4. Swimming and Active Infrastructure

The Study Area shoreline is heavily populated with active infrastructure representative of an urban industrial maritime corridor. There are 987 pieces of active infrastructure in the Study Area, which include 11 water intakes, 94 municipal and industrial discharges, 662 stormwater outfalls and 220 combined sewer outfalls. The intakes and discharges may be active around the clock or intermittently when facilities need to make specific withdrawals or releases. Swimmers should not be near intakes to avoid having to swim against the suction. Swimmers also should not be near discharges due to the potential for a high rate of flow and unknown water quality or temperature of the release. Stormwater and combined sewer outfalls are active during a precipitation event and in the days following a precipitation event. These outfalls release very large amounts of water very fast, can create powerful localized currents and bring swimmers into contact with untreated stormwater and sewage. The abundance of active infrastructure in the Study Area also blocks safe egress from the water along the shoreline.

Table 9.12 Active Infrastructure Identified in Areas Below Safe Swimming Depth

Location Below Safe Swimming Depth	Outfalls		Discharges		CSOs		Total Study Area
	NJ Shoreline	PA Shoreline	NJ Shoreline	PA Shoreline	NJ Shoreline	PA Shoreline	
Child Swimming Depth	11	11	1	2	3	3	**31**
Adult Swimming Depth	6	8	0	0	2	1	**17**
Total Study Area	**17**	**19**	**1**	**2**	**5**	**4**	**48**

Within the Study Area where mean water depth is below the adult and child safe swimming criteria are 48 pieces of active infrastructure, including 9 CSOs and 36 stormwater outfalls, Table 9.12.

The public health impacts of swimming in the presence of stormwater outfalls and CSOs are outside the scope of this analysis. The intersections between active infrastructure and water depths below the safe swimming criteria are presented in Figure 9.4.

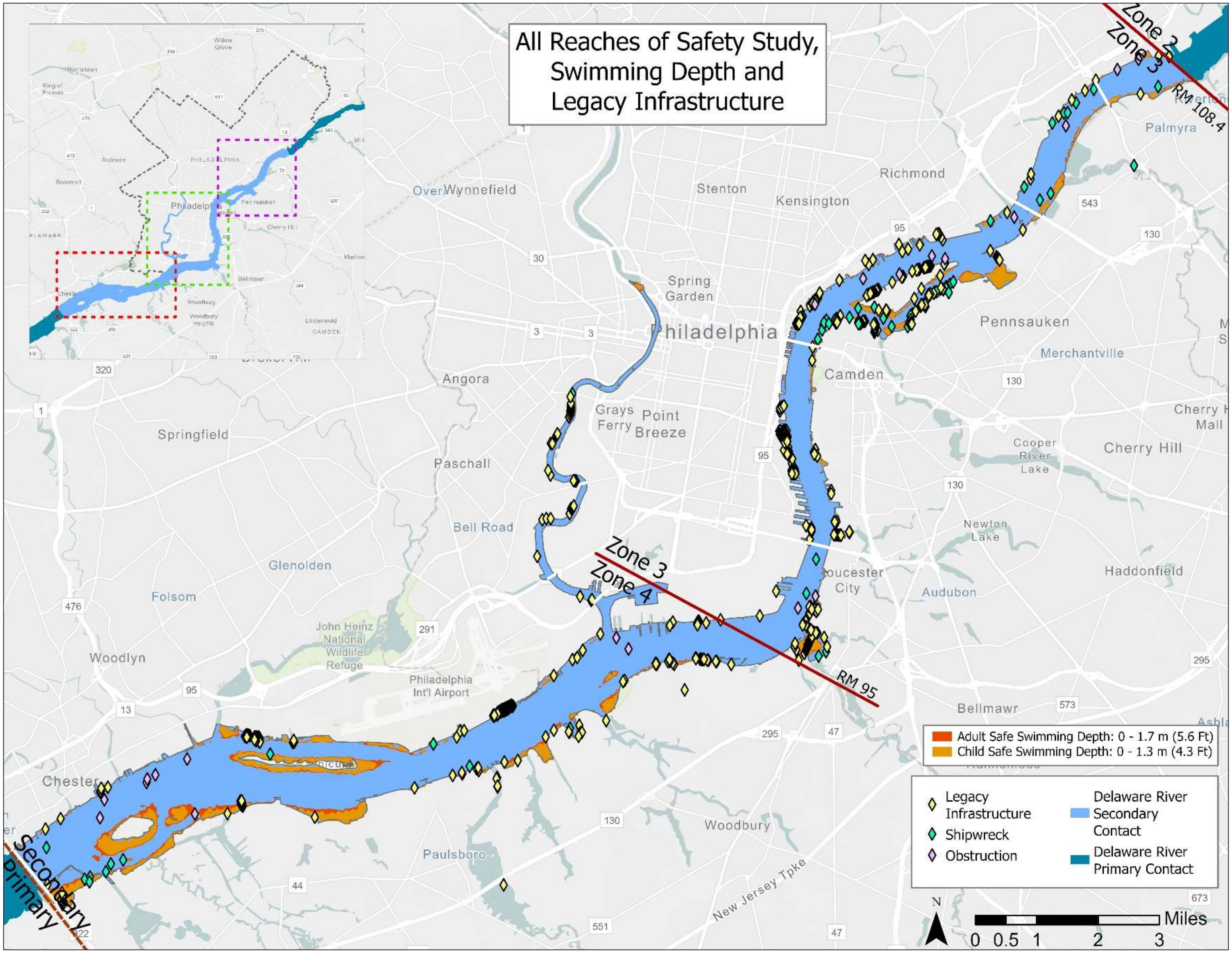


Figure 9.3 Legacy Infrastructure and Safe Swimming Depth

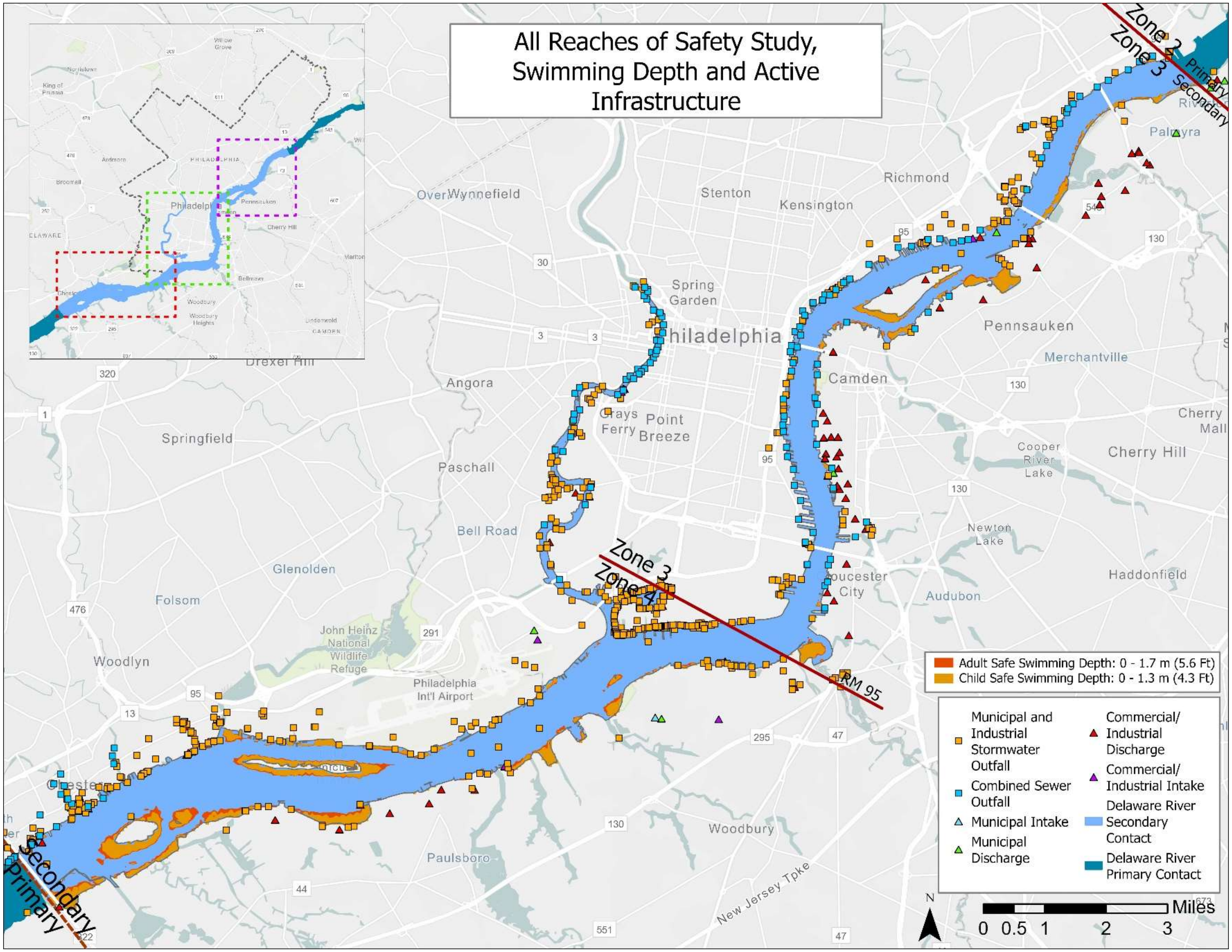


Figure 9.4 Active Infrastructure and Safe Swimming Depth

9.2.2.5. Swimming and Electrical Shock Drowning

Electrical shock drowning may occur when a person's body is in contact with the water, typically near a marina, and electric current leaks into the water. This may happen when boats docked at the marina are plugged into the shoreline electrical supply. As discussed in Section 6.5, marinas are aware of this threat and do not allow swimming from their properties. However, swimmers in the vicinity may not be aware of this threat, which is why swimmers are recommended to stay 50 yards away from all docks and marinas.

In the Study Area are 21 marinas and 9 boat ramps. It is not known whether electrical plugs are available at all of these locations. Within the Study Area where mean water depth is below the adult safe swimming criteria (1.7 meters), there are eight boat club/marinas and four boat ramp/launches, Table 9.13. Within the Study Area where mean water depth is below the child safe swimming criteria (1.3 meters) is one boat club/marina; no boat ramps/launches are extant in these areas.

Table 9.13 Boat Clubs/Marinas and Ramps/Launches Identified in Areas Below Safe Swimming Depth

Location Below Safe Swimming Depth	Boat Club/Marina		Ramp/Launch		Total Study Area	
	NJ Shoreline	PA Shoreline	NJ Shoreline	PA Shoreline	Boat Club/ Marina	Ramp/ Launch
Child Swimming Depth	1	0	0	0	**1**	**0**
Adult Swimming Depth	2	6	3	1	**8**	**4**
Total Study Area	**3**	**6**	**3**	**1**	**9**	**4**

9.2.3. Swimming and Maritime Hazards

Swimming is susceptible to six maritime hazards: propeller wash, bow and stern thruster wash, water displacement and suction, blind spots and low visibility, wakes and marine traffic areas. The safety assessment methods for each of these combinations are presented below in Table 9.14. Swimming safety criteria compared to maritime hazards are taken directly from the maritime hazards summarized in Section 7.10 or the swimming characterization in Section 8.1.

Table 9.14 Method of Assessment of Hydraulic Hazard Safety Considerations for Swimming

Maritime Hazards	Safety Criteria	Swimming Assessment Method	
		Adult	Child
Propeller Wash	200-yd Safety Buffer	Narrative	Narrative
Bow/Stern Thruster Wash	100-yd Safety Buffer	Narrative	Narrative
Water Displacement/Suction	200-yd Safety Buffer	Narrative	Narrative
Blind Spots and Visibility	200-ft Safety Buffer	Narrative	Narrative
Wakes	Safe Swimming Wave Height	Numerical	Numerical
Maritime Traffic Areas	200-yd Safety Buffer	Narrative, Geographic	Narrative, Geographic

Many assessments of the impact of maritime hazards on swimming within this section are narrative comparisons. While section 9.2.1 identifies locations where hydraulic conditions may accommodate safe swimming, the potential for maritime hazards to influence those locations exists but is unknown, and the potential for swimmers to stray outside of hydraulically safe swimming locations exists but is unknown. It is the known and unknown overlaps between swimming location and maritime hazards that lead to swimming being potentially impacted by so many maritime hazards. Critically, many maritime hazards generate strong turbulent currents or waves, which as previously discussed lead to unsafe swimming conditions in open water. It is generally recommended that swimmers remain 200 yards from marine traffic areas, including the navigation channel, all maritime facilities, and the waters directly between maritime facilities and the navigation channel (Figure 9.5).

9.2.3.1. Swimming and Propeller Wash

Section 6.1 describes propeller wash as the strong underwater current generated by a vessel's propeller and notes that such currents can trail hundreds of yards behind a vessel. This is why a propeller wash safety distance of 200 yards behind all commercial vessels and tugboats is recommended as a safety criterion. If swimmers were to get within 200 yards of the propeller wash of commercial vessels or tugboats, they could experience severe turbulence and strong currents that may exhaust their available energy and prevent them from safely exiting the water. To prevent swimmers from potentially getting caught in propellor wash, they should remain a minimum of 200 yards away from marine traffic areas.

9.2.3.2. Swimming and Bow/Stern Thruster Wash

Section 6.2 describes bow and stern thruster wash as currents that move perpendicularly away from the vessel. Vessels typically use bow and stern thrusters when maneuvering at slow speeds for turning and docking. The currents extend from the sides of the vessel; swimmers looking for currents generated behind the vessel may not notice the sideward wash. Section 6.2 recommends that the minimum safe distance from bow and stern thruster wash is 100 yards. Similar to propeller wash, swimmers are vulnerable to the currents generated by bow and stern thrusters and should remain a minimum of 200 yards away from maritime traffic areas.

9.2.3.3. Swimming and Water Displacement/Suction

Detailed in Section 6.6, water displacement and suction occur when large vessels move through water. As a ship moves forward, it first displaces (pushes) water out of its way, which rapidly raises water levels in front of and alongside the moving ship. Swimmers could be quickly exposed to water depths over their heads and to strong currents as the moving ship displaces water. Water displaced away from the front of the vessel rushes aft to fill in the displaced volume, creating currents that pull water toward the back of the ship and the propeller. This suction effect toward the back of the boat is extremely dangerous for swimmers who may find themselves suddenly fighting a powerful current pulling them towards a moving ship. Given the displacement and suction effects of commercial vessels, swimmers should remain a minimum of 200 yards away from marine traffic areas.

9.2.3.4. Swimming, Blind Spots and Visibility

Large commercial vessels have blind spots and visibility limitations as detailed in Section 6.7. The direct blind spot in front of a large commercial vessel can extend approximately 200 feet ahead. Tugboats pushing barges also have blind spots extending approximately 100 feet in front of the barges. These blind spots leave little time for navigators to take evasive action to avoid a swimmer or small vessel in the blind spot. In addition to blind spots, navigators must contend with visibility limitations caused by fog and sun glare. To avoid the chance of a swimmer crossing into a vessel's blind spot, it is recommended that swimmers should remain a minimum of 200 yards away from marine traffic areas.

9.2.3.5. Swimming and Wakes

As discussed in Section 8.1.1.7, wave action makes for a more hazardous swimming environment than calm conditions. In the Study Area, both wind and boat wakes can generate waves. Boat wake-generated waves radiate away from the sides and stern of moving vessels. The size and speed of the vessel as well as the depth of the water all influence the wave height and velocity of boat wakes.

As presented in Table 8.6, no safe wave height for swimming exists in the Study Area. Section 7.8 presents an analysis of vessel size, speed and wake height. Research indicated that large commercial vessels and tugboats traveling at 10 knots produce different wake heights, as illustrated in Table 9.15.

Table 9.15 Average Boat Wake Wave Height within Study Area

Maritime Hazard	Wake Height
Large Commercial Vessel Wake Height	0.65 ft (0.2 m)
Medium Commercial Vessel (Tugboat) Wake Height	1.6 ft (0.5 m)

Boat wake-generated waves are higher than the safe swimming wave height of 0 inches, creating unsafe conditions for swimming in the Study Area.

9.2.3.6. Swimming and Maritime Traffic Areas

Swimming in maritime traffic areas would expose recreators to the most numerous and dangerous hydraulic and maritime hazards. The marine traffic areas have the fastest current velocities in the Study Area as well as the deepest water. Marine traffic areas are also where commercial vessels are traversing and docking/undocking and tugboats are assisting ships or moving barges. As a result, swimmers would be susceptible to the dangerous currents and wakes produced by vessels as well as visibility limitations. Maritime traffic areas and the recommended 200-yard buffer are presented in Figure 9.5, along with the Study Area locations with water depth below the safe swimming criteria. Maritime traffic areas, including marinas, the shipping channel and anchorages, are adjacent to the limited areas along the Pennsylvania shoreline of the Study Area where depth is below the safe swimming criteria. The New Jersey shoreline includes some locations where water depth is below the safe swimming criteria that are not adjacent to maritime traffic areas.

As noted in the discussion about tidal influence on water depth (Section 9.2.1.1), the data used to generate the maps represent mean water depth and the locations where mean water depth may be below the safe swimming criteria. These locations during high tide and low tide may be different from the mapped locations due to the approximately six-foot difference between high tide and low tide in the Study Area. It is possible that swimmers could move beyond areas identified as having water depths below the safe swimming criteria, putting themselves closer to maritime traffic areas than depicted.

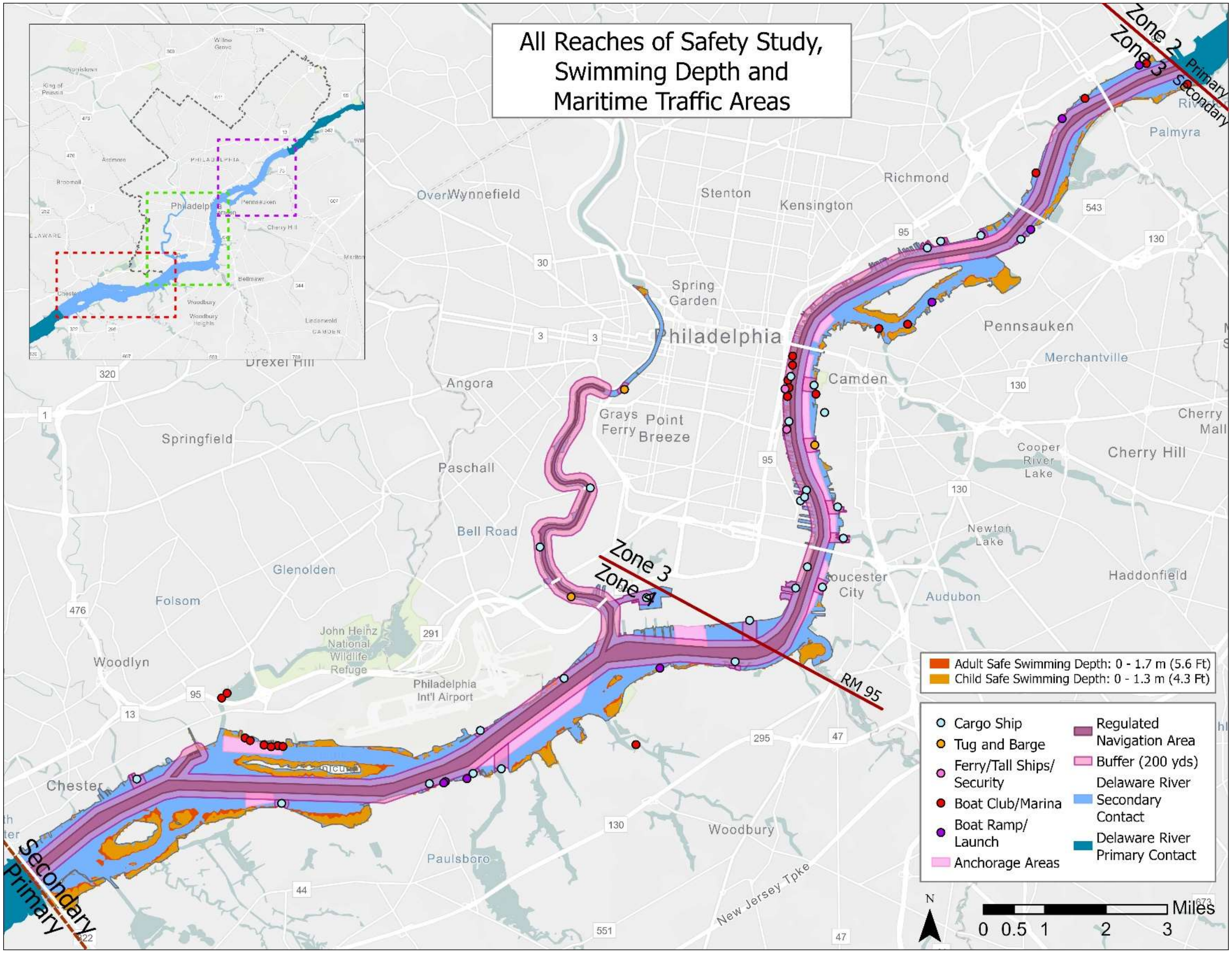


Figure 9.5 Maritime Traffic Areas and Safe Swimming Depth

9.2.4. Summary of Hazards to Swimming in Study Area

Following is a summary from the preceding discussion of the assessment of hazards to swimming in the Study Area.

Summary of Swimming and Hydraulic Hazards

- The Study Area is very deep, and in a few areas, primarily in New Jersey, the water is *shallow enough* to swim without reaching over the heads of adults and children.
- Changing water level due to tides, approximately 6 feet twice each day, will substantially expand and contract swimming areas available hourly, even during a swim, creating complex hazards to swimmers from water depth.
- The Delaware River in the Study Area is too wide for an average swimmer to swim from Pennsylvania to New Jersey.
- In open water such as the Study Area, with no pool wall for a resting space, swimmers would have to know to change their swimming directions and turn back toward shore. Knowing when to turn to maintain enough energy to reach the shore requires advanced swimming skill and experience.
- At low tide, swimmers may need to walk across mud flats to reach water of a swimmable depth, bringing the swimmers closer to where the deeper, higher-velocity water is located.
- Observed velocity data show that approximately 63% of the time near-shore (0-25 yards) currents are above the adult safe swimming velocity and approximately 71% of the time near-shore currents are above the child safe swimming velocity.
- Tidal action changes current direction and speed multiple times each day; therefore identifying when currents may be below the safe swimming velocity criteria would be extremely difficult for recreators.
- Velocities will likely change during an individual swim, potentially rising above the safety threshold the longer a swimmer is in the water.
- The farther from shore swimmers go, the more they are exposed to velocities above the safe swimming velocity criteria.
- Wind-generated waves above the safe wave height are estimated to occur 5-10 % of the time, compounding risk to swimmers already facing variable tidal water depths and current velocities.

Summary of Swimming and Shoreline and Other Hazards

- Local river cleanup events and the U.S. Coast Guard have documented river debris in the Study Area comprised of trees and branches, trash, and larger items such as railroad ties, shopping carts, tires and mattresses.
- Debris, which may not be visible from the surface, is moving with the river currents and poses a hazard to swimmers who may be struck, lacerated or become entangled.
- On the Pennsylvania shoreline of the Study Area, the majority of the shallow water areas below the swimming safe depth criteria are located adjacent to the Philadelphia International Airport.
- In areas where depth may support swimming, along the New Jersey shoreline are 206 pieces of legacy infrastructure and along the Pennsylvania shoreline are 31 pieces of legacy infrastructure.
- In areas where depth may support swimming are 36 stormwater outfalls, 3 discharges and 9 combined sewer outfalls.

- The abundance of legacy infrastructure in the Study Area blocks safe egress from the water along the shoreline.
- Electrical shock drowning may occur when a person's body is in contact with the water, typically near a marina, and electric current leaks into the water. Nine boat clubs and marinas are identified in areas where water depth may support swimming.

Summary of Swimming and Maritime Hazards

- While depth is used to identify locations where hydraulic conditions may accommodate safe swimming, the potential for maritime hazards to influence those locations exists but is unknown, and the potential for swimmers to stray outside of swimming locations exists but is unknown.
- The known and unknown overlaps between swimming location and maritime hazards lead to the proliferation of maritime hazards potentially affecting swimming.
- Critically, many maritime hazards generate strong, turbulent currents or waves, which as previously discussed lead to unsafe swimming conditions in open water.
- Swimmers are very vulnerable to strong propeller wash and bow/stern thruster wash currents and should stay a minimum of 200 yards away from maritime traffic areas.
- The suction toward the stern of a cargo ship, created by the ship's movement, is extremely dangerous for swimmers who may find themselves suddenly fighting a powerful current pulling them towards a moving ship.
- A swimmer cannot be seen in the water in front of moving commercial vessels.
- Boat wakes are higher than the safe swimming wave height of 0 inches.
- Swimming in maritime traffic areas would expose recreators to the most numerous and dangerous hydraulic and maritime hazards.
- The marine traffic areas have the fastest current velocities and the deepest water in the Study Area.

9.3. Wading

9.3.1. Wading and Hydraulic Hazards

Wading is susceptible to two hydraulic hazards: depth and currents. Table 9.16 presents the safety assessment methods for each of these combinations. The comparison of wading safety criteria against hydraulic hazards uses results of the hydraulic hazards characterization in Section 5 and the recreational activities characterization in Section 8.

Table 9.16 Method of Assessment of Hydraulic Hazard Safety Considerations for Wading

Maritime Hazards	Safety Criteria	Wading Assessment Method	
		Adult	Child
Water Depth	Safe Wading Depth	Numerical, Geographic	Numerical, Geographic
Currents	Safe Wading Velocity	Numerical	Numerical

9.3.1.1. Wading and Water Depth

Safe wading depths for children (<u><</u>14 in) and adults (<u><</u>21 in) are identified in Section 8.2.1. According to an analysis of approximate mean tidal depth, only a few small areas with depths below the safe wading depths for children or adults have been identified on the Pennsylvania shoreline of the Study Area; these are adjacent to the Philadelphia Airport. Slightly more areas exist along the New Jersey shoreline of the Study Area that have mean tidal depths below the adult safe wading depth criteria near Camden and Pennsauken, as shown in Figure 9.6. An analysis of mean tidal depth shows that water shallow enough for wading is extremely limited in the Study Area.

The tidal water cycle will heavily influence the location of areas seemingly available for wading, especially at low tide. Low tide will extend the wadable area, and high tide will decrease the wadable area. Traversing river sediments or mud flats while attempting to reach wadable depths at low tide creates additional hazards from decreased mobility due to sinking, exposure to sediments of unknown quality and lacerations from materials submerged within the sediments.

9.3.1.2. Wading and Currents

Sections 8.2.1.3 and 8.2.1.4 identify wading safety velocity criteria, below which wading is assumed to be safe for children and adults. The child safe wading velocity criteria is $\leq$1.25 feet per second, and the adult safe wading velocity criteria is $\leq$2.5 feet per second. Current velocity tolerance for wading is very different than swimming. Waders are able to tolerate slightly faster currents than swimmers as the wading depth is assumed to reach the knees or below and feet are touching the streambed. A wader may be able to safely traverse the same current velocity that would be challenging for a swimmer as long as the wading depth is approximately at knee height or below. Wading quickly becomes unsafe as depth increases above the knees.

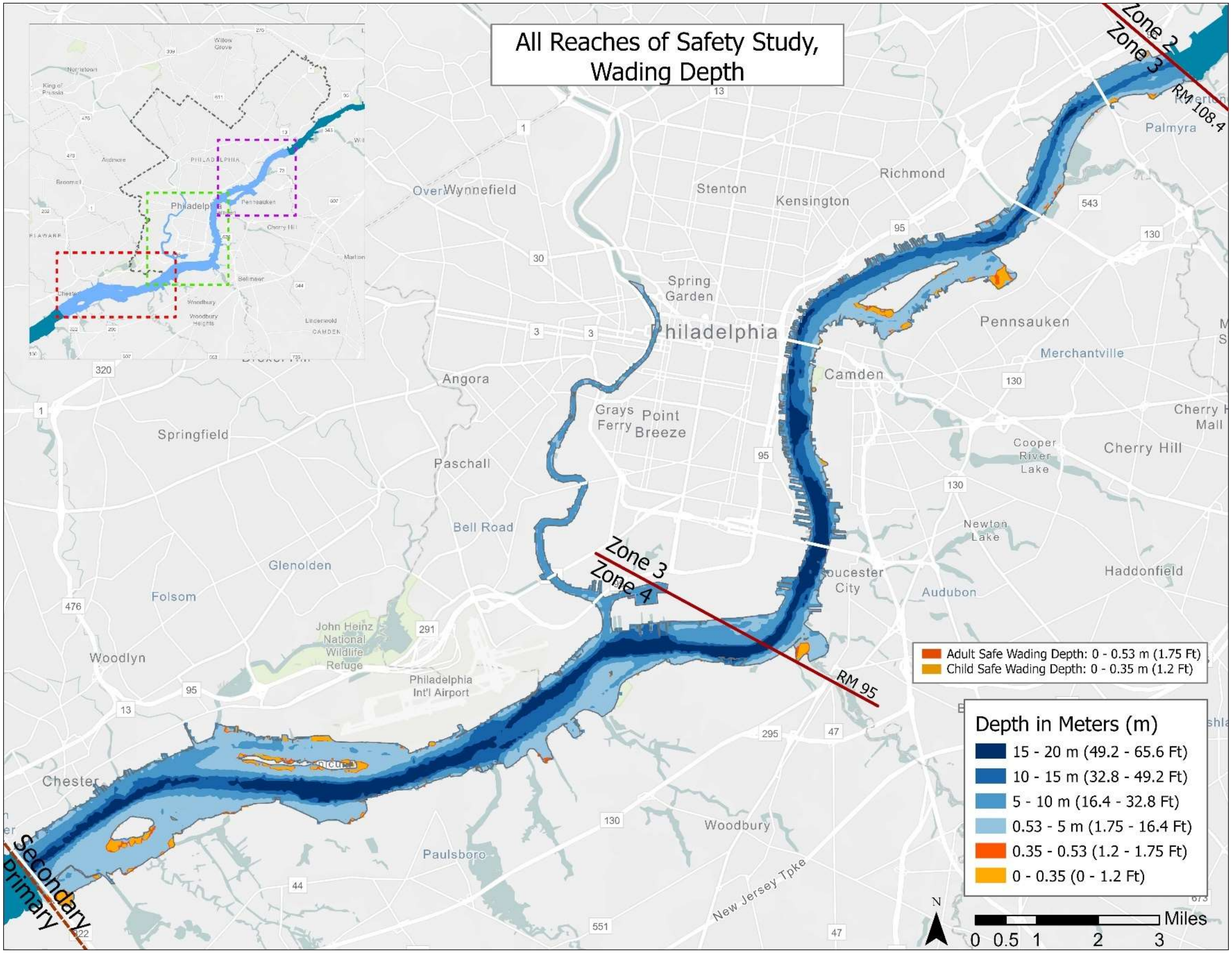


Figure 9.6 Mean Tidal Depth and Safe Wading Depth

Section 5.3 presents current velocity data for the Study Area at different distances from the shoreline and in the center channel during May to September 2014. From the available near-shore velocity data, the adult safe wading velocity criteria is not exceeded within 25 yards of the shoreline, and the child safe velocity criteria is exceeded within 25 yards of the shoreline approximately 10% of the time. Available near-shore velocity data identify safe wading velocities present in the Study Area. Yet, wading safety cannot be defined independently from water depth, assumed to be at or below the knees, and such depths are present in a very limited capacity in the Study Area on the New Jersey shoreline.

9.3.2. Wading and Shoreline and Other Hazards

Wading is susceptible to all of the shoreline and other hazards in locations where wading is possible due to suitable water depths. The safety assessment methods for each of these combinations is presented below in Table 9.17.

Table 9.17 Method of Assessment of Shoreline and other Hazard Safety Considerations for Wading

Shoreline and Other Hazards	Safety Criteria	Wading Assessment Method	
		Adult	Child
Debris	General Activity Caution	Narrative	Narrative
Security and Exclusions	100-yd Safety Buffer	Narrative	Narrative
Legacy Infrastructure	50-ft Safety Buffer	Narrative	Narrative
Active Infrastructure	50-ft Safety Buffer	Narrative	Narrative
Electric Shock Drowning	50-yd Safety Buffer	Narrative	Narrative

9.3.2.1. Wading and Debris

Debris poses a different hazard to waders than to swimmers, kayakers, canoers, paddleboarders and jet skiers. Since wading takes place in very shallow water, waders are unlikely to be exposed to large debris moving with the current, such as trees, pallets, tires, and other large trash items. Waders are, however, more likely to be exposed to small pieces of debris in the current and the possibility of encountering large pieces of debris stuck in the river sediments and mud.

9.3.2.2. Wading and Security and Exclusions

Given that wading is a depth-limited activity and that locations with low enough depths to support wading are few in the Study Area, waders should remain 100 yards from any marine facilities, power plants, military areas, cruise lines and petroleum facilities. Wading near such facilities is unlikely because they require water depths that support mooring, docking and anchoring, which are too deep for wading.

9.3.2.3. Wading and Legacy Infrastructure

Legacy infrastructure poses many of the same risks to waders as it does to swimmers. Legacy infrastructure may appear to be more numerous and visible at low tides when depths may support wading. While these abandoned piers and docks may appear to be points of interest, waders risk becoming entangled, lacerated or otherwise hurt trying to climb onto or jump from legacy infrastructure. The abundance of legacy infrastructure in the Study Area also blocks safe egress from the water along the shoreline. Waders should stay at least 50 feet away from legacy infrastructure.

9.3.2.4. Wading and Active Infrastructure

Active infrastructure, including stormwater and combined sewer outfalls, discharges and intakes, are located throughout the Study Area shorelines. Some of this infrastructure may be configured such that it would be out of reach to a wader, such as a submerged discharge. However, much active infrastructure, primarily outfalls, may be accessible to waders depending upon the water depth. Deep plunge pools exist directly in front of many outfalls that are not visible at the surface, a result of scouring the streambed from discharging at high velocities. Outfalls can also start flowing rapidly with no perceptible warning to the wader. Waders should not approach active infrastructure and remain at least 50 feet away.

9.3.2.5. Wading and Electrical Shock Drowning

As discussed in Section 6.5 and Section 9.2.2.5, swimmers and anyone directly in contact with the water near marinas with electrical systems risk electrocution. Electrical shock drowning poses a similar hazard to waders as it does swimmers. While marinas tend to be deep enough to support mooring boats, which is too deep for wading, waders considering entering the water near a marina should remain at least 50 yards away.

9.3.3. Wading and Maritime Hazards

Wading is susceptible to water displacement and suction caused by commercial ship movement in locations where wading is possible due to suitable water depths. Table 9.18 below presents the safety assessment method for this comparison of recreational activity to maritime hazard.

Table 9.18 Method of Assessment of Maritime Hazard Safety Considerations for Wading

Maritime Hazards	Safety Criteria	Wading Assessment Method	
		Adult	Child
Water Displacement/Suction	200-yd Safety Buffer	Narrative	Narrative

9.3.3.1. Wading and Water Displacement and Suction

Commercial ships that create water displacement and suction effects as they pass through the water require deep water. However, the water displacement and suction effects themselves can extend away from the shipping lane towards the shorelines where potential waders may be. Water displacement may create unsafe conditions for waders as it can lead to a rapid increase in water depth. Conversely, the suction effect of a ship passing can pull water away from the shoreline, creating temporary shallow water and extended mudflats that may appear safe for wading but will become inundated again once the ship has passed. Thus, the rapid changes in water depth created by the displacement and suction effects of passing commercial ships are a hazard to waders. It is recommended that waders remain 200 yards away from passing ships to avoid the effects of water displacement and suction.

9.3.4. Summary of Wading Hazards

Below is a summary of the assessment of hazards to wading in the Study Area based on the preceding discussion.

Summary of Wading and Hydraulic Hazards

- According to analysis of mean tidal depth, water shallow enough for wading is extremely limited in the Study Area
- Only a few small areas with depths below the safe wading depths for children or adults have been identified on the Pennsylvania shoreline of the Study Area adjacent to the Philadelphia Airport.
- Slightly more areas exist along the New Jersey shoreline of the Study Area that have mean tidal depth below the adult safe wading depth criteria, near Camden and Pennsauken.
- The tidal water cycle will heavily influence the location of areas seemingly available for wading. Low tide will extend the wadable area, and high tide will decrease the wadable area.
- Traversing river sediments or mud flats while attempting to reach wadable depths at low tide creates additional hazards from decreased mobility due to sinking, exposure to sediments of unknown quality and lacerations from materials submerged within the sediments.
- A wader may be able to safely traverse the same current velocity that would be challenging for a swimmer as long as the wading depth is approximately at knee height or below. Wading quickly becomes unsafe as depth increases above the knees.
- From the available near-shore velocity data, the adult safe wading velocity criteria of $\leq$1.25 feet per second is not exceeded within 25 yards of the shoreline, and the child safe velocity criteria is exceeded approximately 10% of the time within 25 yards of the shoreline.
- Wading safety cannot be defined independently from water depth, assumed to be at or below the knees, and such depths are present in a very limited capacity in the Study Area.

Summary of Wading and Shoreline and Other Hazards

- Waders are more likely to be exposed to small, rather than large, pieces of debris in the current and the possibility of encountering large pieces of debris stuck in the river sediments and mud.
- Wading near secure facilities is unlikely because they require water depths that support mooring, docking and anchoring which are too deep for wading.
- Legacy infrastructure poses many of the same risks to waders as it does to swimmers.
- While abandoned piers and docks may appear to be points of interest, waders may risk getting entangled, lacerated or otherwise hurt trying to climb onto or jump from legacy infrastructure.
- The abundance of legacy infrastructure in the Study Area blocks safe egress from the water along the shoreline.
- Much active infrastructure, primarily stormwater and combined sewer outfalls, may be accessible to waders depending upon the water depth.
- Deep plunge pools exist directly in front of many outfalls that are not visible at the surface, a result of scouring the streambed from discharging at high velocities.
- Outfalls can start flowing rapidly with no perceptible warning to waders.

Summary of Wading and Maritime Hazards

- Commercial ships that create water displacement and suction effects as they pass through the water require deep water. However, the water displacement and suction effects themselves can extend away from the shipping lane towards the shorelines where potential waders may be.

9.4. Paddlesports – Kayaking, Paddleboarding, Canoeing

Section 8 presents characteristics of three paddlesports: kayaking, paddleboarding and canoeing. The research used to develop safety criteria for average speed, distance and unsafe wave and wake height for each of the three activities indicated similar safety criteria. The average speed of paddleboarding is 2.9 mph, which is slightly faster than the 2.6 mph of kayaking and canoeing. All three activities have the same average distance and unsafe wave and wake height criteria. These similarities are intuitive because kayaking, paddleboarding and canoeing all require manual paddling, typically with one or two passengers.

Kayaking, paddleboarding and canoeing will be combined into one category, paddlesports, for the assessment of hydraulic, maritime, shoreline and other hazards. Table 9.19 presents the summary of safety criteria from Section 8.7 for kayaking, canoeing and paddleboarding with the criteria for paddlesports that will be used, where necessary, in this hazard assessment.

Table 9.19 Paddlesports Safety Criteria

Recreational Activity	Age Group	Average Speed, mph	Average Distance, miles	Average Trip Time, hours	Unsafe Wave & Wake Height, ft
Kayaking	Adult >18 Years	2.6	2.5	1	>1
Paddleboarding	Adult >18 Years	2.9	2.5	1.2	>1
Canoeing	Adult >18 Years	2.6	2.5	1	>1
Paddlesports	**Adult >18 Years**	**2.6**	**2.5**	**1**	**>1**

9.4.1. Paddlesports and Hydraulic Hazards

Three hydraulic hazards affect paddlesports: distance to shore, currents and wind-generated waves. Table 9.20 presents the safety assessment methods for each of these combinations.

Table 9.20 Method of Assessment of Hydraulic Hazard Safety Considerations for Paddlesports

Hydraulic Hazards	Safety Criteria	Paddlesport Assessment Method
Distance to Shore	Average distance	Numerical
Currents	Average speed	Numerical, Calculated Scenario
Wind-Generated Waves	Unsafe wave height	Numerical

9.4.1.1. Paddling and Distance to Shore

The width from the Pennsylvania shoreline to the New Jersey shoreline of the Delaware River in the Study Area ranges from approximately 0.4–1.2 miles (0.7–2 km). As identified in Table 9.19, the average travel distance for a recreator enjoying paddlesports in one outing is 2.5 miles. The width of the Study Area from shoreline to shoreline is well below the average distance for paddlesports for traveling in a single direction. However, paddling across the Study Area from shoreline to shoreline will introduce the paddler to multiple maritime hazards discussed in Section 9.4.3. It is important to note that the paddler will not finish at a location directly across from the starting location and will be displaced on the opposite shoreline relative to the direction and velocity of the currents at the time of the activity, as shown in Figure 9.7.

The displacement of a paddler during a one-way paddling trip across the Study Area will be calculated in the following section. Paddlers planning a one-way trip in the Study Area need to plan for the displacement. The Study Area shorelines are developed urban areas and lined with active and legacy infrastructure, maritime facilities, sea walls, bulkheads and private property. Accordingly, paddlers should not assume safe egress is widely available. While the width of the Study Area is well below the average distance a paddler can travel, displacement of paddlers due to the currents on a one-way trip further confounds safe egress along developed urban shorelines.

9.4.1.2. Paddling and Currents

River currents can be a help and a hindrance to paddlesports. Paddlers moving with the current can travel farther without additional effort. Paddlers moving against the current may struggle to maintain their pace or overcome the current to make forward progress. In order to demonstrate the relationship between river currents in the Study Area and paddlesports, three activity scenarios will be calculated and discussed: a one-way trip to the opposite shoreline, a round trip to the opposite shoreline and back and a trip along the shoreline.

Currents included in these analyses are described in detail in Section 5.3. For these analyses, the data from NOAA monitoring station db0301 and PWD Buoy B provide three velocity distributions at different locations in the Study Area, as seen in Table 9.21.

Table 9.21 Distribution of Observed Velocities in the Study Area May-Sept. 2014

Velocity Exceedances	Observed Velocity Locations, ft/s		
	Near-Shore Penn's Landing db0301 25-50 yds	Shipping Channel Penn's Landing db0301 50-100 yds	Near Schuylkill Confluence Buoy B
10%	1.99	2.8	2.49
25%	1.75	2.58	2.3
50%	1.44	2.2	1.98
75%	1.03	1.42	1.2
90%	0.49	0.61	0.57

The velocity exceedances in Table 9.21 describe the range of current speeds, not the direction, in the Study Area. These current speeds may occur in the upstream and downstream directions. One example from the data indicates that at Penn's Landing along the shoreline, the current velocity exceeds 1.99 feet per second 10% of the time.

For the calculated scenarios, the safety criteria for speed, distance and trip time are used as assumptions, as shown in Table 9.22.

Table 9.22 Paddlesport Safety Criteria for Average Speed, Distance Traveled, and Trip Time

Paddlesport Safety Criteria	
Average speed	2.6 mph
Average distance	2.5 miles
Average trip time	1 hour

Two locations in the Study Area are chosen for the paddlesport-calculated scenarios, Penn's Landing and Fort Mifflin. As shown in Table 9.23, Penn's Landing is located in a very narrow section of the Study Area, and Fort Mifflin is located in a wide section of the Study Area.

Table 9.23 Width of Delaware River at Penn's Landing and Fort Mifflin

Location	River Width, Miles
Penn's Landing	0.41
Fort Mifflin	1.03

These calculated scenarios aim to identify whether paddlers would be able to return to their starting locations given the average speed, distance and trip time identified in Section 8. The scenarios also look to approximate the effect the currents will have on trip time and displacement. These scenarios do not address the maritime hazards paddlers would confront by entering maritime traffic areas or the shoreline and other hazards. These are addressed in Sections 9.4.2 and 9.4.3.

One-Way Trip to the Opposite Shoreline

A paddler taking a one-way trip to the opposite shoreline, for example from Pennsylvania to New Jersey, would set out from one shoreline and arrive at the other. Due to the current direction and speed, paddlers would arrive at locations not directly across from where they entered the water on the Pennsylvania side, as shown in Figure 9.7.

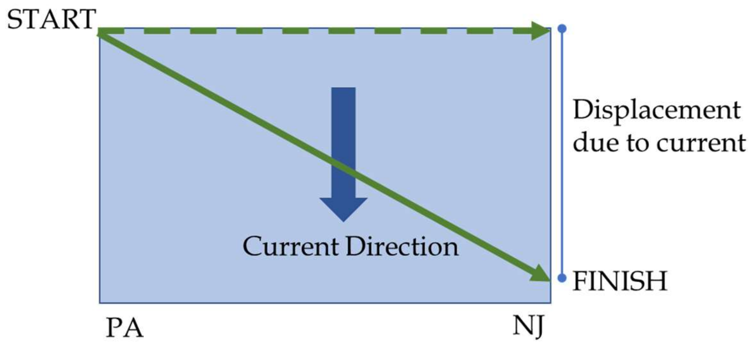


Figure 9.7 Example of Displacement due to Currents on One-Way Paddling Trip from PA to NJ

The dotted line in Figure 9.7 represents the distance from Pennsylvania to New Jersey a recreator would paddle at the average speed of 2.6 mph. From Penn's Landing, this distance is 0.41 miles, and from Fort Mifflin it is 1.03 miles. The solid green line in Figure 9.7 represents the relative distance the paddler would travel due to the river current pushing the watercraft while underway. The displacement is the difference in location along the opposite shore between the location the paddler would reach with no current and the location the paddler would reach with current. Table 9.24 below lists the length of the displacement due to multiple current speeds for the Penn's Landing and Fort Mifflin examples.

Table 9.24 Displacement Calculated for One-Way Paddling Trip from PA to NJ

Penn's Landing One-Way Scenario				Fort Mifflin One-Way Scenario		
Velocity Exceedances	**NOAA db0301 50-100 yds, ft/s**	**Displacement due to current, miles**		**Velocity Exceedances**	**PWD Buoy B, ft/s**	**Displacement due to current, miles**
10%	2.80	0.30		10%	2.49	0.67
25%	2.58	0.28		25%	2.30	0.62
50%	2.20	0.23		50%	1.98	0.53
75%	1.42	0.15		75%	1.20	0.32
90%	0.61	0.07		90%	0.57	0.15

Table 9.24 displacement calculations show that with faster current speeds, or lower exceedances, the displacement of the paddler is greater than with slower current speeds. In the Penn's Landing example, the trip across the river is 0.41 miles, but at the 50% exceedance the displacement is 0.23 miles. Thus, paddlers leaving Penn's Landing would arrive after 10 minutes of paddling nearly a quarter mile downstream from where they left on the opposite shoreline in New Jersey. In the Ft. Mifflin example, the displacement distance is larger because the river is wider. At the 50% exceedance velocity, after leaving Fort Mifflin and paddling for 24 minutes, paddlers would reach New Jersey over a half mile downstream from their departure position.

In the one-way trip scenarios from Penn's Landing and Fort Mifflin, the paddler does not exceed the maximum trip distance criteria of 2.5 miles or the maximum trip time of one hour. However, these scenarios identify displacement on the opposite shoreline in the current direction ranging from 14%-73% of the total trip distance. This range of displacement is approximated from the example calculated and demonstrates the influence current has on paddlers traveling from shoreline to shoreline. A paddler may not know the exact river velocity when traveling from one shore to the other and would not know how to estimate displacement. Displacement due to river currents and the disorientation a paddler may face when arriving along the opposite shoreline could lead to challenges identifying safe egress, especially along the developed shorelines within the Study Area.

Round Trip to the Opposite Shoreline and Back

A scenario in which a paddler makes a round trip from the Pennsylvania shoreline to the New Jersey shoreline and back builds on the discussion of river currents and displacement presented during the one-way trip scenario. Figure 9.8 depicts the displacement of a paddler attempting a round trip. The displacement in a round trip is double that in a one-way trip because it occurs when paddlers first move from Pennsylvania to New Jersey and again when they return.

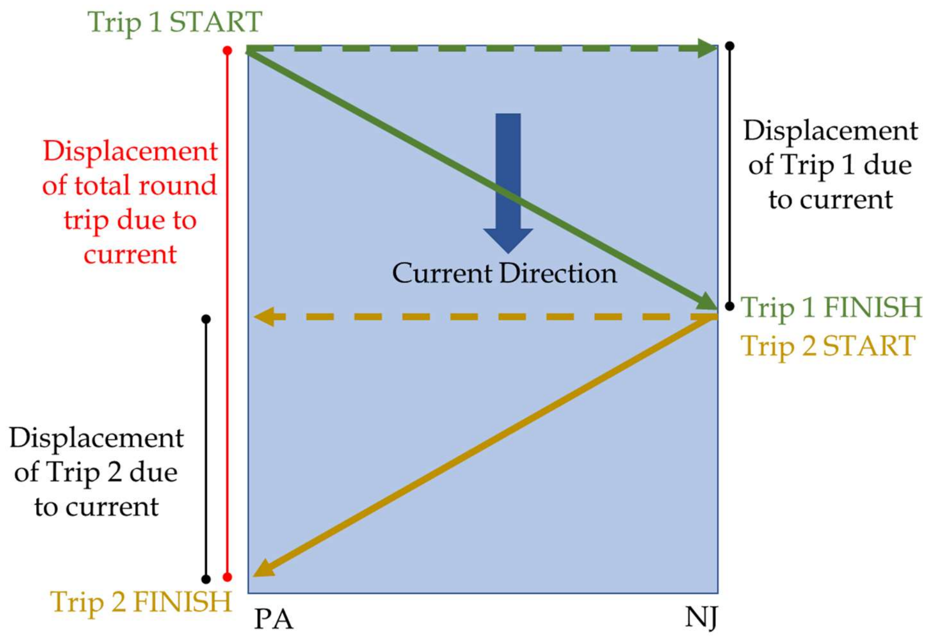


Figure 9.8 Example of Displacement due to Currents on Round Trip from PA to NJ

Additionally, in the round-trip scenario, the paddler must overcome the total displacement (red line in Figure 9.8) and paddle along the shoreline against the current to arrive back where the trip began. Figure 9.9 below depicts the three different trips that a paddler must make to complete a round-trip.

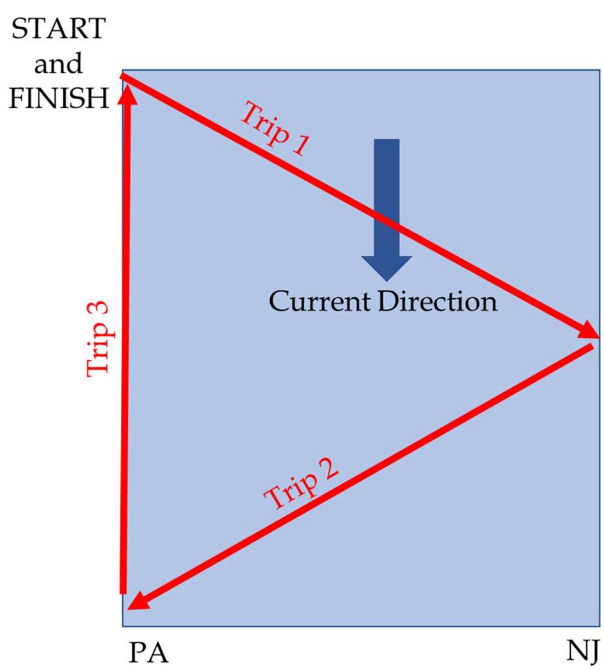


Figure 9.9 Summary of Distances in Round-Trip Paddle from PA to NJ

From the observed data available, measurements recorded in locations adjacent to the shipping channel are used to calculate displacement traveling shoreline to shoreline, similar to the one-way trip scenario. For the final trip along the shoreline, to complete the round-trip scenario, observed data recorded from along the shoreline are used. The results for total displacement, total trip distance and total trip time for the Penn's Landing and Fort Mifflin round-trip scenarios are presented below in Table 9.25 and Table 9.26.

Table 9.25 Displacement Calculated for Round-Trip Scenario from PA to NJ at Penn's Landing

Penn's Landing Round-Trip Scenario					
Velocity Exceedances	**NOAA db0301 25-50 yds, ft/s**	**NOAA db0301 50-100 yds, ft/s**	**Displacement due to current, miles**	**Total Trip Distance, miles**	**Total Trip Time, hours**
10%	1.99	2.8	0.60	1.41	1.30
25%	1.75	2.58	0.56	1.37	0.97
50%	1.44	2.20	0.46	1.27	0.71
75%	1.03	1.42	0.30	1.11	0.50
90%	0.49	0.61	0.14	0.95	0.38

Table 9.25 round-trip calculations approximate that a paddler will be displaced from the starting location of Penn's Landing, in the direction of the current, by 0.14 to 0.6 miles. The paddler will then have to paddle the displaced distance *against* the current to return to the starting location. At the slower current velocities that represent conditions approximately 25% of the time (>75% exceedance) a round trip from Penn's Landing may take 23-30 minutes. As velocity increases, the total trip time increases. Currents above the 50% exceedance, which occur on average half of the time, will create round-trip times from 43–78 minutes when leaving from Penn's Landing. It is important to note that at an average paddling speed of 2.6 mph, a paddler takes an estimated 20 minutes to get across to New Jersey and back to the Pennsylvania shoreline. The remainder of the trip time is spent paddling against the current to return to the starting location. From Penn's Landing, the total trip time exceeds the one-hour trip-time safety criteria for paddling 25% of the time. This means paddlers will be exerting against the current for over 40 minutes. The ability of beginner paddlers, on which the safety criteria is based, to maintain their pace against a current for over 40 minutes in order to return to the starting location is unknown. If paddlers get fatigued and cannot make it back to Penn's Landing or choose to not paddle against the current, they would have to identify a safe egress location along an urban shoreline over a half mile from where they started. If a similar situation occurred in the Fort Mifflin scenario, paddlers who chose to not try to fight the current would find themselves trying to exit the river over a mile from where they started.

Table 9.26 Displacement Calculated for Round-Trip Scenario from PA to NJ at Fort Mifflin

Fort Mifflin Round-Trip Scenario					
Velocity Exceedances	**NOAA db0301 25-50 yds, ft/s**	**PWD Buoy B, ft/s**	**Displacement due to current, miles**	**Total Trip Distance, miles**	**Total Trip Time, hours**
10%	1.99	2.49	1.35	3.40	2.99
25%	1.75	2.3	1.24	3.30	2.25
50%	1.44	1.98	1.06	3.12	1.71
75%	1.03	1.2	0.64	2.70	1.20
90%	0.49	0.57	0.30	2.36	0.93

Table 9.26 displacement calculations for a round-trip from Fort Mifflin identify that paddlers will exceed the total trip-time safety criteria of one hour 75% of the time. The river is more than twice as wide at Fort Mifflin than at Penn's Landing. Differences in river width throughout the Study Area influence total displacement due to the current, increase the distance a recreator would have to paddle against the current and increase the overall round-trip time to exceed the safe paddling criteria.

Along-Shoreline Trip

In a trip along the shoreline, a paddler will travel one distance with the current, turn around, and then paddle the same distance against the current to return to the starting location. An along-shoreline paddling trip scenario is similar to the round-trip example in that the paddler will be working *against* the current in one direction. Complicating the along-shoreline trip scenario is that a paddler will also be paddling *with* the current. In this scenario, the paddler is traversing the same distance along the shoreline and the same distance back to the starting location. However, the time spent paddling one distance with the current will be less than the time spent traversing the same distance against the current. While paddling with the current appears helpful, this can be disorienting because the paddler must know when to turn around to have enough energy to paddle against the current back to the starting location. Figure 9.10 depicts an along-shoreline paddling trip with equal distance downstream and upstream trips and a turn around.

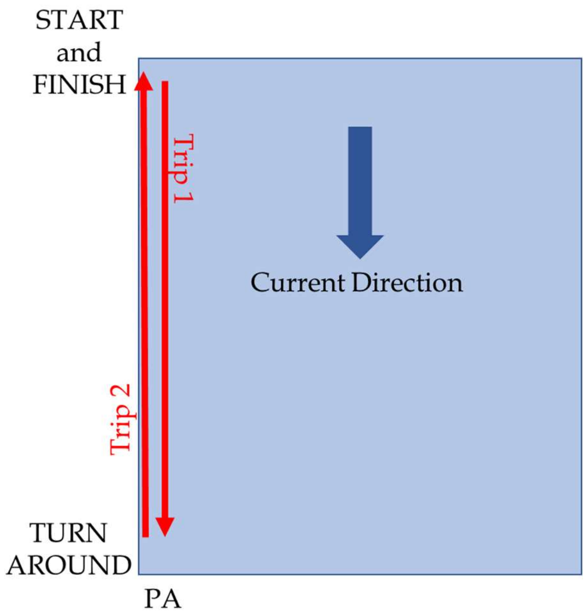


Figure 9.10 Example of Along-Shoreline Paddling Trip

In this example, the current is moving downstream, and the paddler is setting out in the direction of the current first. Were the current direction and the starting direction reversed in this scenario, a similar turnaround time would result.

The goal of calculating this scenario is to understand how much time would elapse before a paddler would have to turn around and paddle back in the opposite direction to reach the starting location. In this example, the paddler is traveling downstream with the current, turning around, then traveling upstream against the current for a total time of one hour, the average trip-time safety criteria.

Table 9.27 Calculation of Turnaround Time in Along Shoreline Paddling Trip Scenario

Velocity Exceedances	NOAA db0301 25-50 yds, ft/s	Downstream Trip		Upstream Trip		Total Trip	
		Turnaround Time, min.	Distance, miles	Time, min.	Distance, miles	Distance, miles	Time, hour
10%	1.99	14.3	0.95	45.7	0.95	1.89	1
25%	1.75	16.2	1.03	43.8	1.03	2.05	1
50%	1.44	18.7	1.11	41.3	1.11	2.23	1
75%	1.03	21.9	1.21	38.1	1.21	2.41	1
90%	0.49	26.1	1.28	33.9	1.28	2.56	1

Table 9.27 presents the calculations for turnaround time (downstream trip) and time spent paddling against the current (upstream trip). The trip distance decreases as velocity increases because the paddler must spend the majority of the one-hour trip overcoming the current on the return trip. In this scenario, 50% of the time a paddler would have to turn around 14.3-18.7 minutes into the trip and at 18.7-26.1 minutes into the trip the remaining 50% of the time. Under faster and slower currents, the paddler spends the majority of the one-hour trip paddling

against the current. In the fastest currents that occur less than 25 percent of the time, a paddler would have to spend over 44 minutes fighting the current to get back to the starting location.

In the calculated round-trip and along shoreline scenarios, the average speed of the paddler is faster than the velocity, meaning the paddler can make forward progress. Locations may be present within the Study Area shoreline where currents are faster than those used in this example; there may also be paddlers who cannot perform at the 2.5 mph average kayaking speed assumption. With faster currents or a slower paddling speed, a paddler may not be able to overcome the current to return to the starting location. In both the round-trip and along-shoreline scenarios, a paddler lacking the energy to overcome the current would have to find safe egress at a distance that could exceed a mile from the starting point, an extremely disorienting and potentially hazardous outcome. The paddler and the watercraft would then have to get back to the return location on land or otherwise acquire transportation.

While research into beginner skillsets identified specific paddlesports characteristics and safety criteria, maintaining those criteria against river currents may be unattainable to a beginner. In such conditions, the criteria may be more representative of an advanced skillset. While potentially having the strength to overcome river currents, experienced paddlers also know the currents may displace them and will maintain their heading on their destination to avoid displacement. These scenarios may seem overly simplistic to an advanced-skillset paddler, however, this Safety Study identifies the interactions between hazards within the Study Area and recreators with beginning skillsets in order to identify safety considerations for the widest range of recreators possible. A broad assumption in these scenarios is that a beginner can maintain their average speed against the current. While this assumption may hold for *some* beginning paddlers, it may not hold for all beginners.

A realistic hypothetical example of these scenarios involves a family of beginning paddlers with adults and teenagers who may have previously paddled together in a lake or reservoir. Paddling in the Study Area may be their first time facing river currents; some may be able to maintain speed against the current and some may not. Such a real-life situation could quickly become hazardous when the currents separate the family by ability. A tired paddler may need, but be unable, to find other egress along the developed shoreline of the Study Area. These calculated scenarios are intended to provide examples of the relationships between assumed beginner paddler ability and river currents. Considering the outcome of the calculated scenarios and the reality that beginning paddlers represent a range of skills, the river currents of the Study Area pose an incontrovertible hydraulic hazard to paddlesports.

9.4.1.3. Paddling and Wind Generated Waves

As discussed in Sections 8.3, 8.4 and 8.5, kayaks, paddleboards and canoes are all vulnerable to capsizing from waves. Research indicated a safe wave height of <1 foot for these watercraft, which will be used as the paddlesport safe wave height criteria, as shown in Table 9.28.

Table 9.28 Paddlesport Safe Wave Height Criteria

Paddlesports Safety Criteria	Adult (>18 years)
Safe Wave Height	<1 ft

The analysis of wind-generated waves presented in Section 5.4 and excerpted in Table 9.29 indicates that wind can generate waves over the safe wave height of one foot 5-10% of the time in small sections of the Study Area where a large fetch exists.

Table 9.29 Average Wind-Generated Wave Height Within Study Area

Wind-Generated Wave Height	% of Overall Winds Resulting in Waves > 1 Ft
Upper Reach	10%
Central Reach	5%
Lower Reach	7%

The presence of wind-generated waves above the safe wave height in the Study Area creates a hydraulic hazard to paddlesports. Even with wind-generated waves estimated to occur just 5-10% of the time, the waves will compound risk to paddlers already dealing with variable tidal current velocities.

9.4.2. Paddlesports and Shoreline and Other Hazards

Paddlesports are susceptible to five shoreline and other hazards: debris, security zones and exclusions, legacy infrastructure, active infrastructure and electrical shock drowning. In contrast to swimming and wading, paddlesports are not depth limited and thus are assumed to be possible in the entire Study Area. Maps from Section 9.2.2 may inform the locations of shoreline and other hazards within the Study Area. Table 9.30 presents the method of assessing shoreline and other hazards to paddlesports.

Table 9.30 Method of Assessment of Shoreline and other Hazard Safety Considerations for Paddlesports

Shoreline and Other Hazards	Safety Criteria	Assessment Method
Debris	General Activity Caution	Narrative
Security Zones and Exclusions	100-yd Safety Buffer	Narrative
Legacy Infrastructure	50-ft Safety Buffer	Narrative
Active Infrastructure	50-ft Safety Buffer	Narrative
Electrical Shock Drowning	50-yd Safety Buffer	Narrative

9.4.2.1. Paddlesports and Debris

Similar to swimming and wading, debris creates a hazard to paddlesports. Floating and submerged debris is prevalent within the Study Area (Section 6.1). Debris moving at or just below the water surface may capsize kayaks and canoes or cause a paddleboarder to lose balance and fall into the water. While the large obstructions such as trees, railroad ties and drums may not be a threat to large commercial vessels, they may pose a major hazard to paddlesports.

9.4.2.2. Paddlesports and Security Zones and Exclusions

The discussion in Section 9.2.2.2 of swimming and security zones and exclusion zones applies to paddlesports. It is recommended that paddlers remain 100 yards away from marine facilities, power plants, military areas, cruise lines and petroleum facilities because they are mentioned in guidance by the U.S. Coast Guard and Pennsylvania Fish and Boat Commission for security and recreational exclusions in the Study Area.

9.4.2.3. Paddlesports and Legacy Infrastructure

As discussed in Sections 4.5 and 6.3, the Study Area contains 63 shipwrecks, 554 pieces of legacy infrastructure and 20 obstructions. While these may seem like attractive points of interest to paddlers, legacy infrastructure has characteristics that are particularly hazardous to paddlers. Much legacy infrastructure in the Study Area are old, abandoned pilings of various heights that may be submerged near the water surface and more or less visible depending upon the tide. These wood or cement pilings are often located in rows or clusters, with their former decking gone or collapsed in the water nearby. Weaving through old pilings may seem to be a low-risk activity, but compounded with waves from wind and wakes from traveling boats and commercial vessels, a paddler could be pushed into the pilings and capsize, or the integrity of the watercraft could be compromised. As depicted previously in Figure 6.5, a paddler weaving through old pilings was pushed up into dangling rebar by a wake, piercing the kayak. It is recommended that paddlers remain at least fifty feet away from legacy infrastructure. The Study Area shorelines, where abandoned legacy infrastructure is prevalent, are a hazard to paddlesports.

9.4.2.4. Paddlesports and Active Infrastructure

As mentioned in the discussion of active infrastructure and swimming, 987 pieces of active infrastructure are located in the Study Area: 11 water intakes, 94 municipal and industrial discharges, 662 stormwater outfalls and 220 combined sewer outfalls. Paddlers are equally as susceptible as swimmers to the hazards of high-velocity water coming from the discharges and outfalls as well as discharged water being splashed onto the paddler or into the watercraft. It is recommended that paddlers remain at least 50 feet away from active infrastructure. The Study Area shorelines, full of active infrastructure, are a hazard to paddlesports.

9.4.2.5. Paddlesports and Electrical Shock Drowning

Electrical shock drowning requires a person to be in the water when an electrical leak occurs. While paddlers may be protected by their watercraft from this risk, the potential exists for kayaks and canoes to overturn and paddleboarders to fall into the water. Those who become separated from their watercraft near electrified marinas are at risk of electrical shock.

9.4.3. Paddlesports and Maritime Hazards

Paddlers are more likely to encounter maritime hazards than swimmers or waders because the locations paddlers can reach are neither confined to the shoreline nor limited by depth. Paddlers are capable of reaching the shipping channel and maritime traffic areas where tugboats and commercial vessels are active.

Table 9.31 Method of Assessment of Maritime Hazard Safety Considerations for Paddlesports

Maritime Hazards	Safety Criteria	Paddlesport Assessment Method
Propeller Wash	200-yd Safety Buffer	Narrative
Bow/Stern Thruster Wash	100-yd Safety Buffer	Narrative
Tow Lines	100-yd Safety Buffer	Narrative
Oncoming Ships	Average Speed	Numerical, Calculated Scenario
Ship Stopping Distance	2-mi Buffer	Numerical, Calculated Scenario
Water Displacement/Suction	200-yd Safety Buffer	Narrative
Blind Spots and Visibility	200-ft Buffer	Narrative
Wakes	Safe Wake Height	Numerical
Maritime Traffic Areas	200-yd Safety Buffer	Narrative

9.4.3.1. Paddlesports and Propeller Wash

Detailed in Section 7.1, propeller wash is a hazard to paddlesports because the strong underwater currents are not visible and extend behind commercial vessels. Propeller wash is different from the more commonly recognized boat wake as these currents are underwater and not typically as visible from the surface. The turbulence created by these currents may exhaust a paddler's energy, capsize kayaks or canoes and cause a paddleboarder to lose balance and become separated from their board.

The Study Area includes over 30 maritime facilities and more than 18,000 commercial vessel transits per year (Section 3). Tugboats are a known source of propeller wash and are the most prevalent commercial vessels in the Study Area. The vessel density maps presented in Section 3.3 indicate that the shipping channel and waters directly adjacent to it support a total density of >2,000 vessels per 100 square meters per year. The area with the second greatest vessel density is the tidal Schuylkill downstream of the Passyunk Bridge. In the shipping channel and tidal Schuylkill River, tugboats are very active moving barges, assisting vessels with docking and undocking, and escorting vessels. While large commercial vessels require a deep draft to operate, tugboats do not and therefore operate both within and outside of the shipping channel. Additionally, propeller wash from tugboats may extend from the shipping channel to the shoreline. This is possible where the 200-yard safety buffer from the shipping channel overlaps with the shoreline, which includes nearly the entire Delaware River shoreline of Philadelphia County, Pennsylvania; Paulsboro, Gloucester City, and parts of Pennsauken and Palmyra, New Jersey; and both Schuylkill River shorelines south of Gray's Ferry in Philadelphia County (Figure 9.11, Figure 9.12 and Figure 9.13).

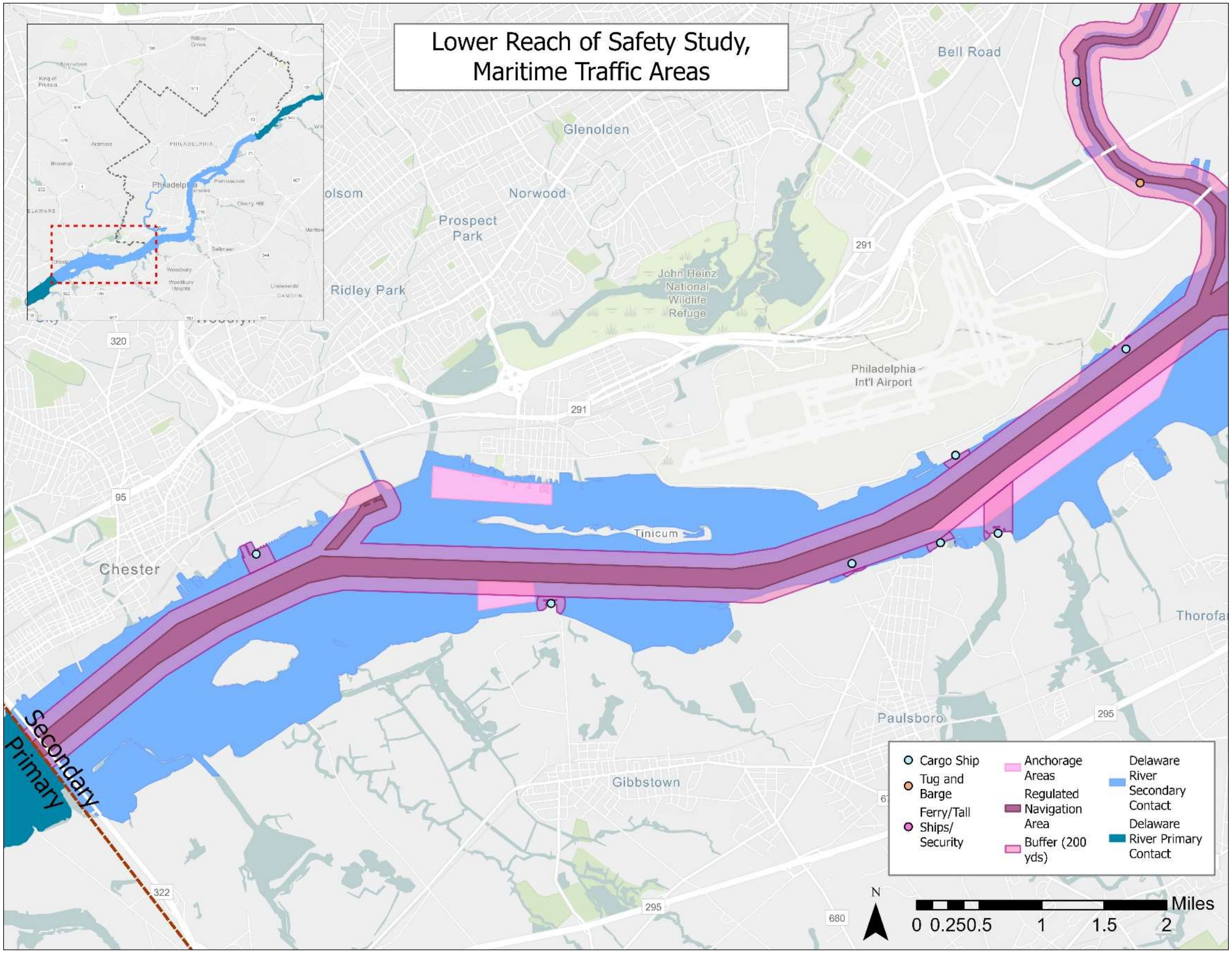


Figure 9.11 Close-up of Navigation Channel Buffer and Maritime Facilities Buffer, Lower Reach of Study Area

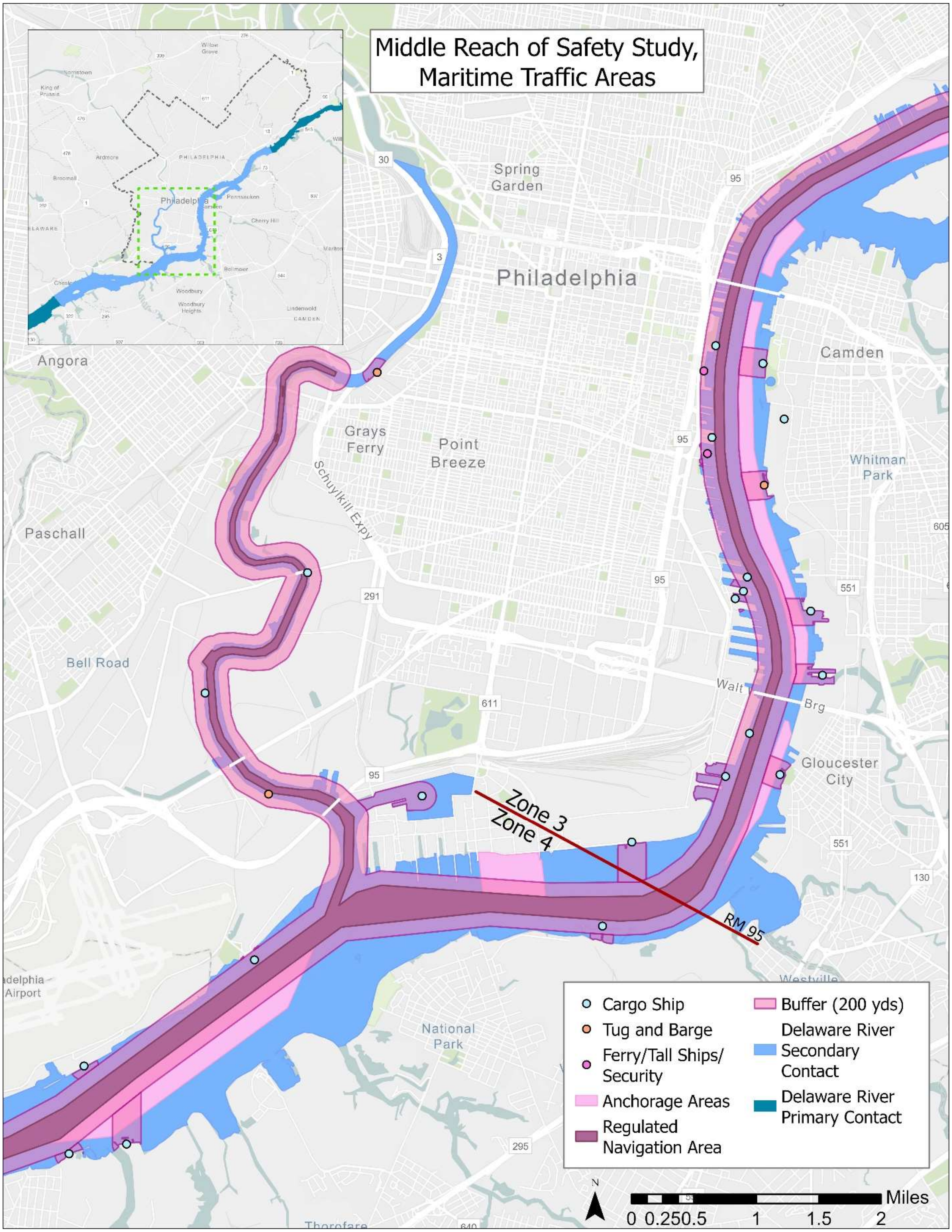


Figure 9.12 Close-up of Navigation Channel Buffer and Maritime Facilities Buffer, Middle Reach of Study Area

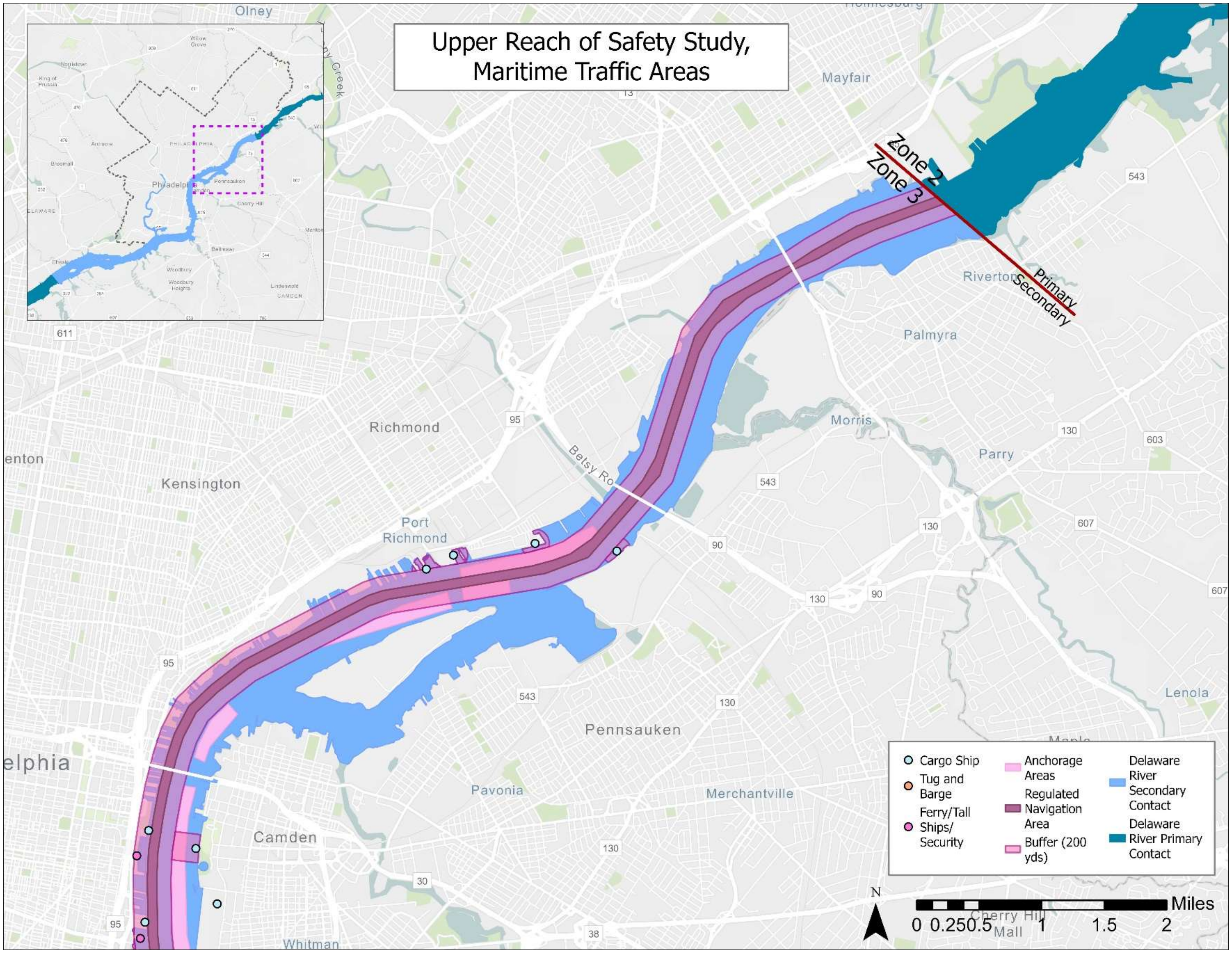


Figure 9.13 Close-up of Navigation Channel Buffer and Maritime Facilities Buffer, Upper Reach of Study Area

With such a high density of commercial vessels and tugboats in the Study Area producing low-visibility hazardous currents, recreators attempting paddlesports in the Study Area should stay at least 200 yards away from the shipping channel and avoid areas where that safety buffer overlaps with the shoreline.

9.4.3.2. Paddlesports and Bow/Stern Thruster Wash

Hazards to paddlesports from propeller wash extend to bow/stern thruster wash. Bow/stern thruster wash currents come from the sides of commercial vessels and move perpendicular to the vessels, rather than behind the vessels like propeller wash. As discussed in Section 7.2, bow thrusters can push paddlers, possibly into hazards or other active and legacy infrastructure along the shoreline. These powerful currents may capsize a kayak/canoe and cause a paddleboarder to lose balance and become separated from their board. Within the Study Area, bow/stern thruster wash may be found in similar areas to propeller wash, which includes the navigation channel, within the 200-yard buffer around the navigation channel and within the 200-yard buffers around cargo, tug, barge and ferry ports and terminals. These areas are depicted in the maps in Figure 9.11, Figure 9.12, and Figure 9.13.

9.4.3.3. Paddlesports and Tow Lines

The towlines between tugboats and barges or other vessels can be very hard to see. The cover of this report pictures a barge being towed by a towline below the water surface. Figure 7.4 includes other images of towlines above the water surface. A paddler is unlikely to move fast enough to get between two moving vessels to encounter a towline, however towlines are considered a hazard to paddlers. This is because a stationary barge may seem like a point of interest, but it may have a connected towline that could be pulled without warning. The Study Area contains a high density of vessel traffic, and paddlers should stay at least 100 yards away from tugs and barges in all directions to avoid towlines.

9.4.3.4. Paddlesports and Oncoming Ships

With high-density ship traffic in the Study Area and the ability of paddlers to access the shipping channel, it is important to assess whether a paddler may be able to evade an oncoming ship. A scenario is established and calculated to perform this assessment.

Section 7.4 defines the average speed of a ship traveling in the Study Area as 10 knots (11.5 mph). The river current will have no effect on the ship speed in this scenario because it assumes the vessel engine will maintain 10 knots. The average speed of a paddler is 2.6 mph. If a paddler were in the center of the shipping channel, attempted to exit the channel and then paddle the recommended 200-yard safety buffer away from the channel, the paddler would traverse 300 yards (0.17 miles). This scenario assumes the shipping channel is 200 yards wide (600 feet). A schematic of this scenario is presented in Figure 9.14.

This scenario is not to calculate a collision, but rather to quantify how far away a ship has to be to give the kayaker sufficient time to move out of the way—defined as moving 200 yards away from the shipping channel, the recommended safety buffer.

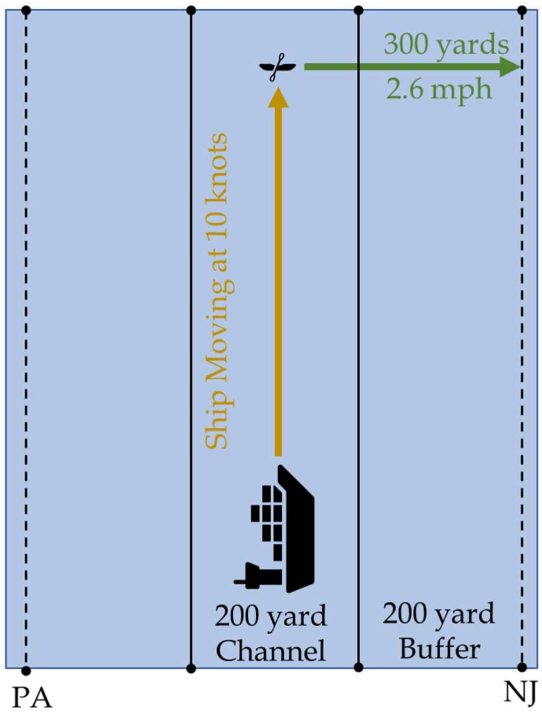


Figure 9.14 Scenario of Paddler Exiting Channel and Safety Buffer due to Oncoming Ship

Based on the speed of the paddler (2.6 mph) and the distance the paddler must traverse (300 yards), 3.9 minutes is needed to paddle from the center of the navigation channel and through the safety buffer. For the paddler to move a safe distance away in 3.9 minutes, the ship has to be over 0.75 miles away (Table 9.32).

Table 9.32 Calculation of Ship Distance Traveled at 10 Knots (11.5 mph)

Ship Distance from Paddler		Ship Travel Time to Paddler, Minutes
Miles	Yards	
0.17	300	0.9
0.25	440	1.3
0.50	880	2.6
0.75	1,320	3.9
1.00	1,760	5.2
1.25	2,200	6.5

The ship is moving at a speed over four times faster than the paddler. While most paddlers may see oncoming ships, they may not realize the ships can reach them in *minutes*. The current will not affect ship speed, yet it will displace paddlers as demonstrated in previous examples. If the current is moving towards the ship, the paddler will be displaced towards the ship while the ship is traveling towards the paddler. This could be a very dangerous situation given the compounded hazards of water displacement and suction, wakes and current generated from thrusters and propellers.

This calculated scenario estimates that if a ship is over 0.75 miles from the paddler, the paddler will be able to move to safety. However, the reality of this scenario is more complicated and hazardous to the paddler. The impacts from a moving ship to a paddler extend in front of, alongside and behind the ship while it is moving. Judging distance on water is notoriously difficult and disorienting. If a paddler assumes a ship is a quarter of a mile farther away than it really is, the paddler may not get out of the way in time. If a paddler does not immediately begin paddling out of the way when first noticing the ship, the paddler may not get out of the way in time. Oncoming ships pose a critical hazard to paddlers recreating within or near the federal navigation channel.

9.4.3.5. Paddlesports and Ship Stopping Distance

This section builds on the discussion of hazards to paddlers from oncoming ships. If a paddler gets stuck in the shipping channel, the oncoming ship cannot stop quickly. Paddlers could fall out of their watercraft, lose oars/paddles, be otherwise immobilized, not be paying attention or not be aware of the hazards of oncoming ships. Section 7.5 discusses ship-stopping distance and notes that a ship traveling 10 knots takes approximately two miles to stop. Pilots and captains can begin to slow the ship and take evasive action, but there is no equivalent to pushing the brake pedal or pulling an emergency brake to stop commercial cargo ships. The long distance needed to stop a ship is a critical hazard to paddlers recreating within or near the federal navigation channel.

9.4.3.6. Paddlesports and Water Displacement/Suction

As Section 3.1 determined, more than 18,000 vessels transit per year within the 26.6 mile length of the Study Area. These vessels may transit the entire length of the Study Area through to terminals upstream or only enter a portion of the Study Area. Among those vessel transits are nearly 2,000 container, bulk carrier and tanker cargo ships. This means that approximately five to six cargo ships transit into the Study Area each day. Once cargo processing is complete, the ships will transit out of the Study Area while newly arrived ships continue to enter the Study Area. This high traffic volume means that large cargo ships are regularly traversing the Study Area simultaneously in the upstream and downstream directions.

The high volume of cargo ship traffic in the Study Area is a round-the-clock source of water displacement and suction hazards to paddlesports. The previous discussion of an oncoming ship revealed a paddler has just minutes to get at least 200 yards from the shipping channel to safety when an approaching cargo ship is visible. The reason for that safety buffer, and why simply exiting the channel is not sufficient, is due to the powerful and far-reaching effects of water displacement and suction. Section 7.6 includes multiple examples of paddlesports, and even a jet ski, being pulled towards a cargo ship and capsized due to the powerful suction effect. The water displacement and suction that occurs when a cargo ship travels through the water and the high traffic of such ships in the Study Area pose a critical hazard to paddlesports.

9.4.3.7. Paddlesports and Blind Spots and Visibility

Section 7.7 details the many blind spot and visibility challenges to mariners in the Study Area. Paddlesports, as opposed to recreational motorboats, are especially vulnerable to these challenges because they are low on the water and small in size. Inclement weather, fog and sun glare are noted visibility challenges within the Study Area. Commercial radar may not detect paddlecraft due to their construction materials. Section 7.7 also details the blind spots that extend up to 200 feet in front of a cargo ship and 100 feet in front of a barge. The hazards to paddlers from attempting to avoid oncoming ships, lack of ability to stop ships quickly, water displacement and suction are already noted. Blind spot and visibility challenges exacerbate these existing hazards to paddlesports because though the paddler may see the oncoming ship, the oncoming ship may not see the paddler.

9.4.3.8. Paddlesports and Wakes

Through research discussed in Section 8, a safe wake height of ≤1 foot is recommended for paddlesports. Boat wakes can radiate from the front, sides and back of vessels. The height and speed of wakes are determined by the size of the ship, speed of the ship and depth of the water. In the Study Area, ships were determined to travel at an average speed of 10 knots. Table 9.15 noted that while traveling at 10 knots, large commercial vessels have an average wake height of 0.65 feet (0.2 meters) and medium commercial vessels (tugboats) have an average wake height of 1.6 feet (0.5 meters). With the high volume of cargo ship and tugboat traffic in the Study Area, boat wakes are common.

The safe wake height for paddlesports is exceeded by the average wake of tugboats. Section 3 estimates that tugboats make from 12,000 to 18,000 transits per year within the Study Area. Tugboats are active night and day moving barges, assisting cargo vessels and performing other tasks. While tugboat wake may be a visible hazard to paddlers, caution should also be taken near tugboats to avoid less visible hazards from propeller wash and bow/stern thruster wash.

The safe wake height for paddlesports is not exceeded by the average wake height of large cargo ships. However, in isolation this comparison is not a reason for paddlers to consider being directly behind a cargo ship a safe location. Areas behind cargo ships put paddlers at risk of propeller wash, thruster wash and suction hazards.

9.4.3.9. Paddlesports and Maritime Traffic Areas

Maritime traffic areas in the Study Area include the federal navigation channel, a 200-yard safety buffer from the navigation channel, anchorage areas, a 200-yard buffer around port facilities and marine terminals and the waters between the navigation channel and port facilities and marine terminals. These areas are depicted in Figure 9.11, Figure 9.12 and Figure 9.13. In maritime traffic areas, hazards to paddlers include propeller wash, bow/stern thruster wash, tow lines, oncoming ships, ships that take two miles to stop, water displacement and suction effects, blind spots and visibility limitations of large ships seeing small craft and boat wakes.

Paddlers can easily access maritime traffic in the Study Area. The hazards to paddlesports cannot be overstated given the extent of maritime traffic through the whole length of the Study Area, the high volume of maritime traffic and the ability of maritime hazards to compound. Compared to swimming and wading, paddlers face all the maritime hazards identified in the Study Area.

9.4.4. Summary of Paddlesport Hazards

Below is a summary of hazards to paddlesports in the Study Area from the preceding discussion.

Summary of Paddlesports and Hydraulic Hazards

- Kayaking, paddleboarding and canoeing are combined into one category, paddlesports, for the assessment of hydraulic, maritime, shoreline and other hazards.

- While the width of the Study Area is well below the average distance a paddler can travel, displacement of paddlers due to the currents on a one-way trip confounds safe egress along developed urban shorelines.
- Paddling across the Study Area from shoreline to shoreline will introduce the paddler to multiple maritime hazards.
- River currents can help and hinder paddlesports. Paddlers moving with the current can travel farther without additional effort. Paddlers moving against the current may struggle to maintain their pace or to overcome the current to make forward progress.
- Due to the current direction and speed, paddlers departing Pennsylvania would arrive at a location in New Jersey that is not directly across from where they entered the water.
  - For example, a paddler leaving Penn's Landing, after 10 minutes of paddling, would arrive on the opposite shoreline in New Jersey nearly a quarter mile downstream from the departure point.
  - A paddler leaving Ft. Mifflin would arrive, after 24 minutes of paddling, in New Jersey a half mile downstream from the departure point.
  - These examples identify displacement on the opposite shoreline in the current direction ranging from 14%-73% of the total trip distance.
- A paddler may not know the exact river velocity when traveling from shoreline to shoreline and would not know how to estimate displacement and plan for safe egress.
- Round-trip calculations approximate that a paddler going from Penn's Landing to New Jersey, and from New Jersey back to Pennsylvania will be displaced from the starting location of Penn's Landing, in the direction of the current, by 0.14 to 0.6 miles. The paddler will then have to paddle the displaced distance *against* the current to return to the starting location.
  - This means that for over 40 minutes paddlers will be exerting against the current.
- The ability of a beginner paddler, on which the safety criteria are based, to maintain pace against a current for over 40 minutes in order to return to the starting location is unknown.
- A paddler going from Philadelphia to NJ who becomes fatigued and cannot complete the round-trip back to Penn's Landing or chooses to not paddle against the current would have to identify a safe egress location along an urban shoreline over a half mile from the starting point. If a similar situation occurred in the Fort Mifflin scenario, a paddler would need to exit the river over a mile from the starting point.
- Differences in river width throughout the Study Area influence total displacement due to the current, increase the distance a recreator would have to paddle against the current and increase the overall round-trip time to exceed the safe paddling criteria of a one-hour trip time.
- Paddling along the shoreline with the direction of the current can be disorienting because the paddler must know when to turn around so as to retain enough energy to paddle against the current back to the starting location.
- The distance of an along-shoreline paddling trip decreases as velocity increases because the paddler has to turn around and spend the majority of the one-hour trip overcoming the current on the return trip.
- In the along-shoreline trip example, with faster currents *and* slower currents, the paddler spends the majority of a one-hour trip paddling against the current. In the fastest currents, that occur less than 25% of the time, a paddler would have to spend over 44 minutes (out of one hour) fighting the current to get back to the starting location.

- While research into beginner skillsets identified specific paddlesports characteristics and safety criteria, maintaining those criteria against river currents may be unattainable to a beginner.
- In the examples of a one-way, round-trip and along-shoreline trip, a broad assumption is made that a beginner can maintain average speed against the current. While this assumption may hold for *some* beginning paddlers, it may not hold for all beginners.
- Considering the outcome of the calculated scenarios and the reality that paddlers represent a range of skills, the river currents of the Study Area pose an incontrovertible hydraulic hazard to paddlesports.
- Even with wind-generated waves exceeding the safe wave height in the Study Area estimated to occur just 5-10% of the time, the waves will compound risk to paddlers already encountering variable tidal current velocities.

Summary of Paddlesports and Shoreline and Other Hazards

- Debris moving at or just below the water surface may capsize kayaks and canoes or cause a paddleboarder to lose balance and separate from their board. While large obstructions such as trees, railroad ties and drums may not be a threat to motorized and commercial vessels, they may pose a major hazard to paddlesports.
- Weaving through legacy infrastructure such as old pilings may seem to be a low-risk activity, but compounded with waves from wind and wakes from traveling boats and commercial vessels, a paddler could be pushed into the pilings and capsize or have the integrity of the watercraft compromised.
- Paddlers are as susceptible as swimmers to the hazards of high-velocity water from discharges and outfalls. Discharged water may also splash onto the paddler or into the watercraft.

Summary of Paddlesports and Maritime Hazards

- Paddlers are more likely to encounter maritime hazards than swimmers or waders because the locations a paddler can reach are not confined to the shoreline and not limited by depth. Paddlers are capable of reaching the shipping channel and maritime traffic areas where tugboats and commercial vessels are active.
- The Study Area has over 30 maritime facilities and more than 18,000 commercial vessel transits per year. Tugboats are a known source of propeller wash and are the most active commercial vessels in the Study Area.
- The shipping channel and waters directly adjacent to it have a total density of >2,000 vessels per 100 square meters per year. The area with the second greatest vessel density is the tidal Schuylkill to the Passyunk Bridge.
- Propeller wash, bow/stern thruster wash, boat wakes, water displacement and suction may extend from the shipping channel to the shoreline. This is possible where the 200-yard safety buffer from the shipping channel overlaps with the shoreline, which includes nearly the entire Delaware River shoreline of Philadelphia County, Pennsylvania; Paulsboro, Gloucester City, and parts of Pennsauken and Palmyra, New Jersey; and, both Schuylkill River shorelines south of Gray's Ferry in Philadelphia County.
- With such a high density of commercial vessels and tugboats in the Study Area producing low-visibility hazardous currents, paddlers in the Study Area should stay at least 200 yards away from the shipping channel and avoid areas where that safety buffer overlaps with the shoreline.

- A paddler is unlikely to move fast enough to get between two moving vessels to encounter the towline. However, towlines are considered a hazard to paddlers because a stationary barge may seem like a point of interest but have a towline already connected that could be pulled without warning.
- Getting out of the way of an oncoming ship is defined as getting 200 yards away from the shipping channel, the recommended safety buffer.
- For a paddler to have time to get a safe distance away from an oncoming ship, the ship has to be over 0.75 miles away. A paddler takes 3.9 minutes to traverse 300 yards, and it takes the ship 3.9 minutes to traverse three-quarters of a mile (1,320 yards).
- Ships move at a speed over four times faster than paddlers do. While paddlers may see the ships, they may not realize that the ships could reach them in *minutes.*
- If the current is moving towards the ship, the paddler will be displaced towards the ship while the ship is traveling towards the paddler. This could be a very dangerous situation given the compounded hazards of water displacement and suction, wakes and current generated from thrusters and propellers.
- Judging distance on water is notoriously difficult and disorienting. If a paddler assumes a ship is one-quarter of a mile farther away than it really is, the paddler may not get out of the way in time. If a paddler does not immediately begin paddling out of the way when the first noticing a ship, the paddler may not get out of the way in time.
- Oncoming ships pose a critical hazard to paddlers recreating within or near the federal navigation channel.
- If the paddler gets stuck in the shipping channel, the oncoming ship cannot stop quickly. The long distance needed to stop a ship is a critical hazard to paddlers recreating within or near the federal navigation channel.
- Nearly 2,000 container, bulk carrier and tanker cargo ships transit the Study Area each year, approximately five to six cargo ships transiting daily. Once cargo processing is complete, the ships transit out of the Study Area while newly arrived ships continue to enter the Study Area. This high traffic volume means that large cargo ships are regularly traversing the Study Area simultaneously in the upstream and downstream directions.
- The high volume of cargo ship traffic in the Study Area is a round-the-clock source of water displacement and suction hazards to paddlesports.
- A paddler has just minutes to get at least 300 yards from the shipping channel to safety when an approaching cargo ship is visible. The reason for that safety buffer, and why simply exiting the channel is not far enough, is due to the powerful and far-reaching effects of water displacement and suction.
- Paddlesports are vulnerable to commercial vessel blind spot and visibility challenges because they are low on the water and small in size. Inclement weather, fog and sun glare are noted visibility challenges within the Study Area. Paddlesports are not even detected by commercial radar due to the construction material of the vessel.
- The safe wake height for paddlesports is exceeded by the average wake of tugboats. It is estimated that tugboats make from 12,000 to 18,000 transits per year in the Study Area. Tugboats are active night and day moving barges, assisting cargo vessels and other tasks.
- Paddlers can easily access maritime traffic in the Study Area. The hazards to paddlesports cannot be overstated given the extent of maritime traffic through the length of the Study Area, the high volume of maritime traffic, and the ability of maritime hazards to compound.

9.5. Jet Skiing

9.5.1. Jet Skiing and Hydraulic Hazards

Jet skis are the only powered watercraft included in the safety study. The powerful engine in a jet ski is capable of producing high rates of speed across the Study Area. Distance from shore, river currents and wind-generated waves are not hydraulic hazards to jet skis given their speed and maneuverability. The only hydraulic hazard examined in the safety study relevant to jet skiing is water depth, as depicted in Table 9.33.

Table 9.33 Method of Assessment of Hydraulic Hazard Safety Considerations for Jet Skiing

Hydraulic Hazard	Jet Skiing Safety Criteria	Assessment Method
Depth	Minimum Safe Depth >3 feet	Numerical, Geographic

9.5.1.1. Jet Skiing and Water Depth

After a comparison of the manuals of multiple jet ski makes and models, Section 8.6 identified a minimum water depth of three feet to operate a jet ski. When jet skis are operated in water below this minimum recommended depth, mud and vegetation can become entangled in the jet pump and cause damage. Within the Study Area are very few locations where mean tidal depth is less than three feet, as per Figure 9.15. Jet skiers would need to exercise caution if attempting to launch, egress or traverse these areas to avoid damage to the jet pump and engine.

9.5.2. Jet Skiing and Shoreline and Other Hazards

Jet skiing is susceptible to five shoreline hazards: debris, security and exclusions, legacy infrastructure, active infrastructure and electrical shock drowning. The safety assessment methods for each of these combinations is presented in Table 9.34.

Table 9.34 Method of Assessment of Shoreline and other Hazard Safety Considerations for Jet Skiing

Shoreline and Other Hazards	Safety Criteria	Jet Skiing Assessment Method
Debris	General Activity Caution	Narrative
Security and Exclusions	100-yd Safety Buffer	Narrative
Legacy Infrastructure	50-ft Safety Buffer	Narrative
Active Infrastructure	50-ft Safety Buffer	Narrative
Electrical Shock Drowning	50-yd Safety Buffer	Narrative

9.5.2.1. Jet Skiing and Debris

Similar to swimming, wading and paddlesports, debris creates a hazard to jet skiing. Floating and submerged debris is prevalent within the Study Area (Section 6.1). Debris moving at or just below the water surface may capsize a jet ski, clog the jet pump, or cause the jet skier to lose control and become separated from the craft. While the large obstructions such as trees, railroad ties and drums may not be a threat to large commercial vessels, they may pose a major hazard to jet skis.

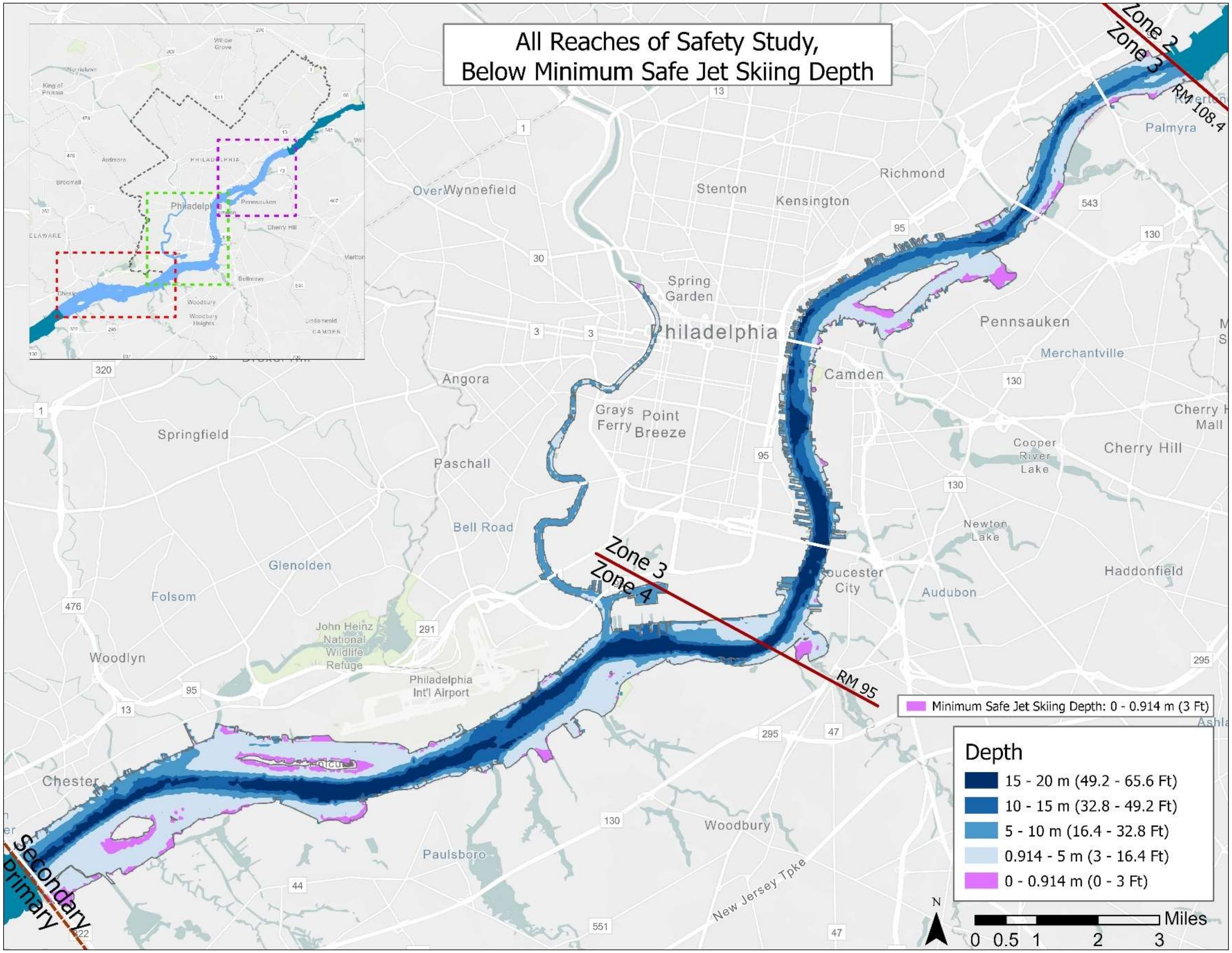


Figure 9.15 Areas below Minimum Safe Jet Skiing Depth in Study Area

9.5.2.2. Jet Skiing and Security and Exclusions

It is recommended that jet skiers remain 100 yards away from marine facilities, power plants, military areas, cruise lines and petroleum facilities because they are mentioned in guidance by the U.S. Coast Guard and Pennsylvania Fish and Boat Commission for security and recreational exclusions in the Study Area.

9.5.2.3. Jet Skiing and Legacy Infrastructure

As discussed in Section 4.5 and Section 6.3, the Study Area contains 63 shipwrecks, 554 pieces of legacy infrastructure and 20 obstructions. While these may seem like attractive points of interest, legacy infrastructure has characteristics that are particularly hazardous to jet skiers. Legacy infrastructure in the Study Area includes many old, abandoned pilings of various heights, which may be submerged and more or less visible depending upon the tide. These wood or cement pilings are often located in rows or clusters, with their former decking gone or collapsed in the water nearby. A jet skier moving at a high rate of speed may not see some of this infrastructure and could collide with submerged legacy infrastructure that may not extend above the surface. It is recommended that jet skiers remain at least fifty feet away from legacy infrastructure. Operators may avoid many pieces of legacy infrastructure located directly along the shoreline in the Study Area by staying in water deep enough for the jet ski.

9.5.2.4. Jet Skiing and Active Infrastructure

As mentioned in the discussion of active infrastructure and swimming, 987 pieces of active infrastructure are located in the Study Area: 11 water intakes, 94 municipal and industrial discharges, 662 stormwater outfalls and 220 combined sewer outfalls. Jet skiers are not as susceptible as swimmers and paddlers to the hazards of high velocity water coming from the discharges and outfalls as they can more easily move away from such discharges. However, they are still susceptible to being splashed from any water exiting this infrastructure. It is recommended that jet skiers remain at least 50 feet away from active infrastructure.

9.5.2.5. Jet Skiing and Electrical Shock Drowning

Electrical shock drowning requires a person to be submerged in the water when an electrical leak occurs. While jet skiers may be protected by their watercraft from this risk, the potential exists for the jet ski to overturn or the operators to become unseated. Jet skiers who become separated from their watercraft near an electrified marina are at risk of electrical shock.

9.5.3. Jet Skiing and Maritime Hazards

Jet skiing is susceptible to all maritime hazards even though jet skis have engines and are not manually propelled like paddlesports. Jet skis can reach speeds up to 65 mph, are not confined to the shoreline or shallow areas and can easily reach the federal navigation channel. Given that jet skis have engines, maritime hazards will affect them differently than paddlesports.

Table 9.35 Method of Assessment of Maritime Hazard Safety Considerations for Jet Skiing

Maritime Hazards	Safety Criteria	Jet Ski Assessment Method
Propeller Wash	200-yd Safety Buffer	Narrative
Bow/Stern Thruster Wash	100-yd Safety Buffer	Narrative
Tow Lines	100-yd Safety Buffer	Narrative
Oncoming Ships	Average Speed	Narrative
Ship Stopping Distance	2-mi Buffer	Narrative
Water Displacement/Suction	200-yd Safety Buffer	Narrative
Blind Spots and Visibility	200-ft Buffer	Narrative
Wakes	Safe Wake Height	Narrative
Maritime Traffic Areas	200-yd Safety Buffer	Narrative

9.5.3.1. Jet Skiing and Propeller Wash

Jet skis may be exposed to propeller wash while jumping wakes or crossing too closely behind cargo ships and tugboats. As a jet skier lands a jump, balancing the watercraft may become difficult given the strong and turbulent currents generated by propellers. Jet skis are known to be top heavy, and the operator may roll the jet ski, becoming separated from the watercraft in and among these currents. Section 7.1 recommends a safety buffer of 200 yards behind all commercial ships and tugboats to avoid propeller wash.

9.5.3.2. Jet Skiing and Bow/Stern Thruster Wash

Similar to propeller wash, bow/stern thruster wash is a hazard to jet skiers jumping wakes or traveling too close to commercial vessels and tugboats. Bow/stern thruster wash may cause a jet skier to lose balance and roll or otherwise become separated from the watercraft. Section 7.2 recommends a safety buffer of 100 yards alongside all commercial ships and tugboats to avoid bow/stern thruster wash.

9.5.3.3. Jet Skiing and Tow Lines

An estimated 12,000 to 18,000 tugboat transits occur per year in the Study Area. While not all these tugs are towing barges, and though tow lines are not used for all barge trips, the sheer volume of such movements presents ample opportunity for casualty. Tow lines pose a greater hazard to jet skis than to paddlesports. Jet skis are fast enough to get between a moving tugboat and a barge or other vessel being towed. Jet skiers may also be attracted to the back of tugboats in order to jump the high wakes generated. This combination of ability and attraction makes tow lines a very particular hazard to jet skiers. The jet ski operator may not see the tow line, because lines can be both above and below the waterline. Colliding at speed with a tow line could separate the operator from the watercraft, causing great bodily harm or even death.

9.5.3.4. Jet Skiing and Oncoming Ships

Due to the powerful engines on jet skis, they are able to quickly move out of the way of an oncoming ship. Oncoming ships present a hazard to jet skiers in the event the operators become separated from the watercraft or it breaks down in the navigation channel.

9.5.3.5. Jet Skiing and Ship Stopping Distance

The two-mile stopping distance associated with large cargo ships is a hazard to jet skis in the event that the operator becomes separated from the watercraft or it breaks down in the navigation channel. Large cargo ships are unable to stop quickly, unlike cars and trucks, and would need to take evasive action to avoid a disabled jet ski in the navigation channel.

9.5.3.6. Jet Skiing and Water Displacement/Suction

The effects of water displacement and suction from moving cargo ships are hazardous to all recreational activities examined in the safety study, including jet skis. Even though jet skis have motors, the suction effect of a passing ship can pull a jet ski towards the ship. Section 7.6 presents an example of a jet ski being pulled next to a cargo ship, even touching the hull, then having difficulty getting away and ultimately capsizing.

9.5.3.7. Jet Skiing and Blind Spots and Visibility

Jet skiers are capable of reaching and traveling in the blind spots of large cargo ships and barges. Jet skiers are exposed to the same hazards as paddlers from cargo ship blind spots and visibility limitations. Detailed in Section 7.7, the blind spots in front of cargo ships may extend up to 200 feet and 100 feet in front of barges. Similar to paddlesports, radar systems used in commercial navigation may not detect jet skis.

9.5.3.8. Jet Skiing and Wakes

Jet skis are designed for jumping waves, and boat wakes are a type of wave. Jet skis can easily jump the average wakes generated by ships in the Study Area, and boat wakes are attractive to jet skiers. However, jumping boat wakes introduces the jet skier to multiple maritime hazards. The boat wakes, and their locations to the side and back of ships, are not isolated from the effects of propeller wash, bow/stern thruster wash or water displacement and suction. A jet skier jumping wakes may land into very turbulent currents that may be disorienting, cause the jet skier to lose balance or even cause the jet ski to roll over and become separated from the operator. While wakes are not hazardous to jet skis in the same way they are hazardous to swimmers and paddlers, jet skiers should avoid jumping boat wakes due to the other hazards associated with ship transit in the Study Area.

9.5.3.9. Jet Skiing and Maritime Traffic Areas

Jet skis are able to move fast and can be easily steered to maintain a safe distance from maritime facilities, cargo ships and tugboats in order to minimize the hazards associated with maritime traffic areas. Maritime traffic areas are hazardous to jet skiers when operators may recklessly jump boat wakes, motor too close to cargo ships and tugboats, encounter tow lines or when operators become separated from their watercraft.

9.5.4. Summary of Jet Skiing Hazards

The assessment of hazards to jet skiing in the Study Area is summarized from the preceding discussion.

Summary of Jet Skiing and Hydraulic Hazards

- The recommended minimum water depth to operate a jet ski is three feet. When jet skis are operated in water below this minimum recommended depth, mud and vegetation can become entangled in the jet pump and cause damage.
- Within the Study Area are very few locations where mean tidal depth is less than three feet. Jet skiers would need to exercise caution if attempting to launch, egress, or traverse these areas to avoid damage to the jet pump and engine.

Summary of Jet Skiing and Shoreline and Other Hazards

- Debris moving at or just below the water surface may capsize a jet ski, clog the jet pump or cause the jet skier to lose control and become unseated. Large obstructions such as trees, railroad ties and drums may pose a major hazard to jet skis.
- A jet skier moving at a high rate of speed could allide with submerged legacy infrastructure that may not extend above the surface, depending upon the tide.
- Jet skiers are not as susceptible as swimmers and paddlers to the hazards of high velocity water coming from the discharges and outfalls. Jet skiers can more easily move away from such discharges, but they are still susceptible to being splashed from any water exiting this infrastructure.

Summary of Jet Skiing and Maritime Hazards

- Jet skis can reach speeds up to 65 mph, are not confined to the shoreline or shallow areas and can easily reach the federal navigation channel. Given that jet skis have engines, the maritime hazards will affect jet skis differently than paddlesports.
- Jet skis may be exposed to propeller wash or bow/stern thruster wash while jumping wakes or crossing too closely behind cargo ships and tugboats. As a jet skier lands a jump, balancing the watercraft may become difficult given the strong and turbulent currents generated by propellers. Jet skis are known to be top heavy, and the operator may roll the jet ski, becoming separated from the watercraft in and among these currents.
- Tow lines pose a greater hazard to jet skis than to paddlesports. Colliding at speed with a towline could separate the operator from the watercraft, causing great bodily harm or even death.
- Jet skiers may be attracted to the back of tugboats in order to jump the high wakes. This combination of ability and attraction makes tow lines a very particular hazard to jet skiers.
- Even though jet skis have motors, the suction effect of a passing ship can pull a jet ski towards the ship.
- Due to the powerful engines on jet skis, they are able to quickly move out of the way of an oncoming ship. An oncoming ship is a hazard to a jet skier if that operator becomes separated from the watercraft or it breaks down in the navigation channel.
- While wakes are not hazardous to jet skis in the same way they are hazardous to swimmers and paddlers, jet skiers should avoid jumping boat wakes due to the other hazards associated with ship transit in the Study Area.

Section 10 Conclusions

The highly developed urban shoreline, thriving maritime industry and deep tidal river that comprise the Study Area are permanent features that create many safety concerns for the recreational activities examined. The safety study presents detailed information characterizing the hydraulic, maritime, shoreline and other hazards within the Study Area. Hazards are assessed against the characteristics of swimming, wading, paddlesports, and jet skiing, as outlined in Table 10.1.

Table 10.1 Summary of Recreational Activities Compared Against Hazards

Hazard	Hazard Category	Recreational Activities			
		Swimming	Wading	Paddlesports	Jet Skiing
Depth	Hydraulic Hazards	X	X		X
Distance to Shore		X		X	
Currents		X	X	X	
Wind Generated Waves		X		X	
Debris	Shoreline and Other Hazards	X	X	X	X
Security and Exclusions		X	X	X	X
Legacy Infrastructure		X	X	X	X
Active Infrastructure		X	X	X	X
Electrical Shock Drowning		X	X	X	X
Propeller Wash	Maritime Hazards	X		X	X
Bow/Stern Thruster Wash		X		X	X
Tow Lines				X	X
Oncoming Ships				X	X
Ship Stopping Distance				X	X
Water Displacement/Suction		X	X	X	X
Blind Spots and Visibility		X		X	X
Wakes		X		X	X
Maritime Traffic Areas		X		X	X
"X" indicates a recreational activity was compared against a specific hazard					

This analysis thoroughly researched the characteristics of recreational activities to establish a definition of a beginner skillset and evaluate the ways in which a beginner skillset may interact with hazards in the Study Area. Examining the Study Area through the characteristics of a beginner skillset is a conservative approach to assessing safety, including to the extent possible the broadest range of skills.

The conclusions presented here highlight the uniqueness of the Study Area, the potential for exposure to multiple hazards at once, the ubiquity of maritime traffic, the numerous shoreline hazards and safety study findings in the use attainability context.

The Study Area is Unique

The Study Area is part of a tidal estuary bounded by an urban waterfront with a thriving maritime industry. It experiences two tides per day during which the water level rises and falls approximately six feet between high tide and low tide, and the current direction changes upstream or downstream with the incoming and outgoing tides. The Study Area is deep, with the Pennsylvania shoreline almost entirely devoid of shallow areas less than 5.5 feet mean tidal depth. The Study Area has fast currents, which within 25 yards of the shoreline are too strong for an adult swimmer 63% of the time and too strong for a child swimmer 71% of the time. Currents 100 yards from shore are twice as fast as those 25 yards from shore, a rapid increase in speed moving a small distance from the shoreline. The shorelines of the Study Area are fully developed urban areas lined with seawalls, active discharges, active intakes, active outfalls, active ports and terminals and abandoned piers and pilings. Maritime traffic, deep water, fast currents, daily tidal fluctuations in water depth and current direction and an urban shoreline cluttered with active and legacy infrastructure are the unique, irretrievable conditions of the Study Area. These conditions make the Study Area unique when compared to the non-tidal sections of the Delaware River where commercial vessel traffic is not present, depths are shallower, and legacy and active infrastructure is far less abundant.

Compounding Effects of Hazards in the Study Area

This study assessed hazards to recreation within the Study Area individually. However, given that a recreator may encounter more than one hazard, it is reasonable to also consider compounding safety concerns from multiple hazards acting together. For example, in one trip a paddler may confront high wakes from a passing ship, have to paddle against strong currents, and face challenges finding a safe place to disembark and lift the watercraft out of the water along a shoreline cluttered with active outfalls, abandoned pilings and seawalls. Similarly, a swimmer may begin a swim close to the shoreline, try to avoid submerged debris moving with the current, fall prey to fast currents depositing the swimmer far from the point of ingress and attempt to climb up a seawall and walk back rather than swim into the current to return to the starting location. Hazards within hydraulic, shoreline and maritime categories of hazards can compound, such as currents and wind acting on a paddler at the same time. Categories of hazards can also compound with each other, such as the force of a passing ship's wake pushing a swimmer or paddler against an abandoned pier.

Maritime Traffic is Ubiquitous

The Study Area has an active, robust maritime industry, importing and exporting domestic and international food, energy products, raw materials, and consumer goods. In 2017, the value of this industry was estimated at $77.6 billion, with over 190,000 jobs directly and indirectly generated by marine cargo activity. The Study Area includes 28 cargo ship ports and terminals and three tug and barge ports, as shown in Figure 10.1. These facilities handle more than 18,000 vessel transits per year, which include scheduled cargo ship arrivals, tugboat and barge trips. Such dense maritime traffic shifts continuously as tugboats move to accompany and provide service to the ships and as vessels move into the Study Area, reach their locations then exit the Study Area. Some maritime traffic moves to ports upstream of the Study Area and reenters the Study Area to exit to the Delaware Bay and Atlantic Ocean. The total density of cargo vessel movements per year exceeds 2,000 vessels per 100 square meters in the federal navigation channel and in waters adjacent to ports and terminals. The hazards to recreation generated by maritime traffic are inexorable side effects of large, powerful vessels moving through water. Maritime traffic is an irretrievable condition of the Study Area.

Shoreline Hazards are Numerous

The Study Area shorelines are almost fully developed, with far-reaching urban development on the Pennsylvania and New Jersey sides of the Delaware River. The city of Philadelphia, the

Philadelphia International Airport, Essington, and Chester comprise the 27-mile Pennsylvania shoreline in the Study Area. The New Jersey side of the Study Area contains five miles of undeveloped riverfront downstream of the Paulsboro Refinery and a mile undeveloped north of Paulsboro; it is fully developed for the remaining 21 miles of the Study Area. These urban shorelines have 16 municipal discharges, 78 industrial discharges, 11 intakes, 662 stormwater outfalls, 220 combined sewer outfalls and over 554 pieces of abandoned dilapidated legacy infrastructure. The Study Area shoreline contains large stretches of industrial property, such as the airport, refineries, manufacturing facilities and cargo terminals. For example, the riverfront of the Philadelphia International Airport property is approximately four miles long, and the Paulsboro Refinery is approximately three miles long. Recreators may be able to access the water, but if they are unable to return to their starting locations due to the currents or other hydraulic and maritime hazards, they may find themselves trying to exit the water along a property that is inaccessible from the water. The shoreline is so developed, it is largely inaccessible *from the water* to safely disembark or for safe egress to the land due to fenced off private property, sea walls, bulkheads, legacy and active infrastructure, as in Figure 10.1. These shoreline hazards are an irretrievable condition of the Study Area.

Swimming Hazards are Numerous

Adult and child swimming criteria are compared against 15 hazards to detail safety concerns that may arise from swimming in the Study Area. An analysis of mean tidal depth reveals only a few locations in the Study Area, primarily in New Jersey, where the water is sufficiently shallow without exceeding the heights of adult and child swimmers. Twice each day, the water depth rises and falls by six feet, and the currents change direction with the incoming and outgoing tides. An analysis of observed velocity data in the Study Area shows that currents located within 25 yards of the shoreline exceed adult and child safe swimming velocities 63% and 71% of the time, respectively. Along the shoreline, currents in the Study Area are frequently too fast for safe swimming. Such currents can easily move swimmers from their starting locations and would be too strong to overcome as swimmers attempt to return to return to their points of ingress.

Swimmers in the Study Area face a highly developed urban shoreline that is cluttered with active and legacy infrastructure, bulkheads, sea walls, abandoned piers and fenced off industrial property. These conditions make safe egress from the water very challenging, particularly when currents move swimmers away from their points of entry into the water. Large concentrations of debris and floating obstructions moving with the current also pose a hazard to swimmers who may be struck, lacerated or become entangled. The heavy density of marine traffic and the proximity of the federal navigation channel to the shoreline creates situations in which swimmers may encounter propeller wash, bow and stern thruster wash, wakes, water displacement and suction from commercial vessels operating nearby.

While this study identified criteria that reflect the characteristics and abilities of beginner adult and child swimmers, ascertaining the way an individual, whether a beginner or experienced swimmer, may react when faced with actual hydraulic, maritime, shoreline and other hazards in the Study Area is impossible. Those who consider themselves proficient swimmers in a state park lake or a guarded ocean beach may be unfamiliar with conditions in the Study Area, which are very different than those found in lakes and oceans. This study objectively identifies at least 15 hazards that can negatively affect safe swimming conditions in the Study Area.

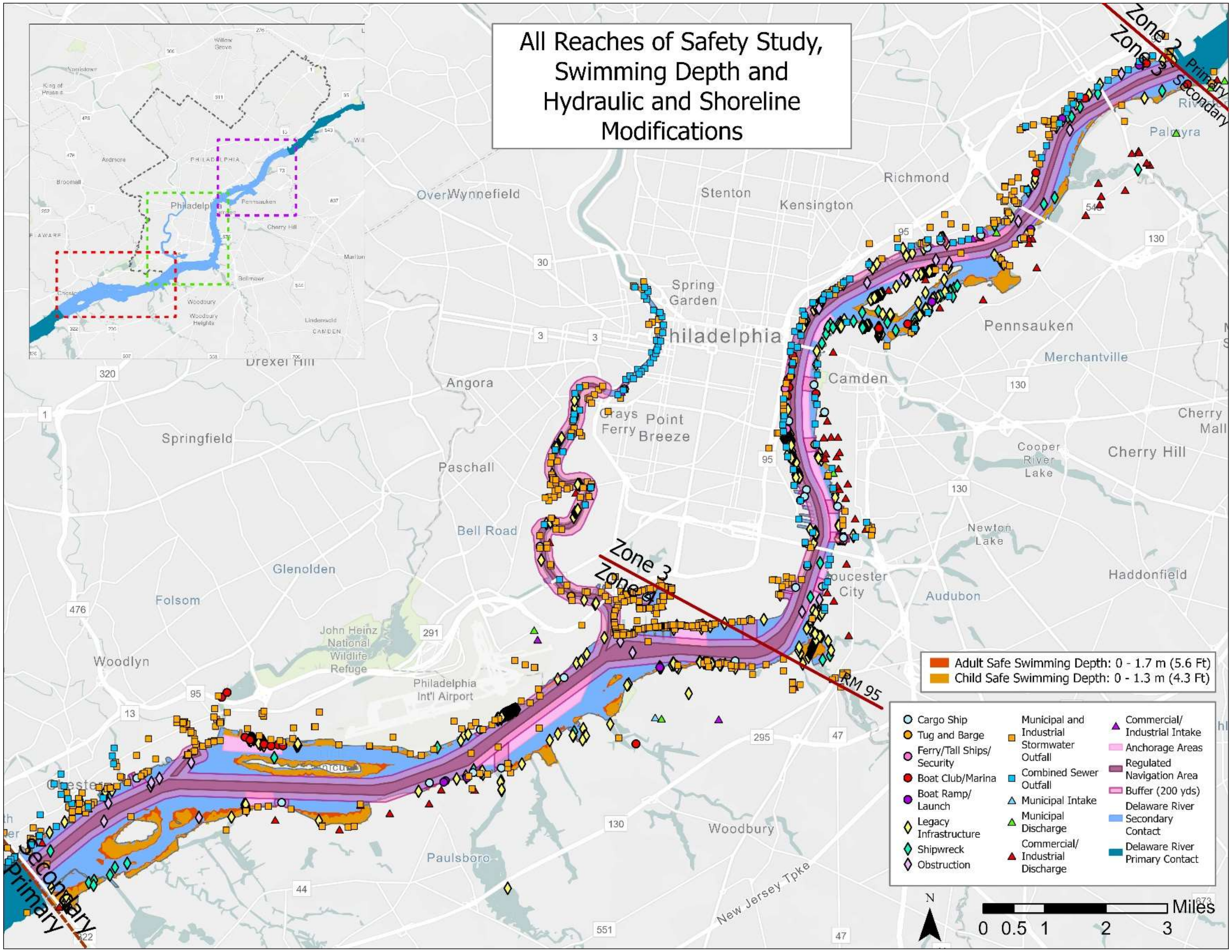


Figure 10.1 Swimming Depth, Hydraulic and Shoreline Modifications for all Reaches of the Study Area

Wading Opportunities are Limited and Hazards are Numerous

Adult and child wading criteria are compared against eight hazards to detail safety concerns that may arise from wading in the Study Area. The biggest factor limiting safe wading in the Study Area is depth. An analysis of depth in the Study Area indicates that at mean tide only a few areas along the Pennsylvania shoreline have safe wading depths (knee height or below) for children or adults, with slightly more areas along the New Jersey shoreline. This is significant because the lack of shallow areas means a wader could encounter sudden drop offs in water depth that would inadvertently change the activity from wading to swimming, exposing the wader to additional hydraulic and maritime hazards. The tidal water cycle heavily influences the location of areas seemingly available for wading in the Study Area, especially at low tide. Traversing river sediments or mud flats while attempting to reach wadable depths at low tide creates additional hazards from decreased mobility due to sinking and lacerations from materials submerged within the sediments. Waders may also risk getting entangled, lacerated or otherwise hurt trying to climb onto, climb over or jump from the legacy infrastructure prevalent along the shoreline of the Study Area. Waders may also encounter low-visibility plunge pools and high-velocity flows from active infrastructure, such as discharges or outfalls.

Paddlesport Hazards are Numerous

Kayaking, canoeing, and paddleboarding criteria are compared against 17 hazards to detail safety concerns that may arise from paddlesports in the Study Area. Paddlecraft are manually powered, relying on the strength and endurance of the paddler and especially vulnerable to compounding hydraulic, shoreline and maritime hazards. Nearly the entire Philadelphia shoreline is less than the recommended 200-yard safety buffer away from maritime traffic areas, leaving few areas available where paddlers can safely distance themselves from the omnipresent maritime traffic in the Study Area on the Pennsylvania shoreline. Both the Pennsylvania and New Jersey shorelines in the Study Area are extensively developed with active ports and terminals, active commercial industrial activity, active infrastructure and legacy infrastructure blocking safe disembarkment, portage and egress from the water.

Hydraulic, shoreline and maritime hazards in the Study Area create a setting for paddlesports very different from other regional paddling experiences. Paddling in the undeveloped areas of the Delaware River typically start at one location and end at another downstream as paddlers move with the current, have multiple opportunities to disembark on the undeveloped shorelines to take a break, then receive transportation to their starting locations. As lake and pond settings do not have currents like rivers, paddlers can often see their starting locations and travel as near or far as desired. The Study Area differs greatly from these typical paddling settings, requiring knowledge and experience to avoid shoreline and maritime hazards, power and skill to escape maritime hazards when interactions occur and endurance to overcome strong currents to return to a designated location to disembark. The Study Area shoreline is so developed with active and legacy infrastructure and industrial property, that areas to safely disembark are extremely limited. Given shoreline access limitations, paddling trips in the Study Area would likely to be round trips, which require paddling against the currents in one leg of the journey.

Section 9.4.1.2 provided three scenarios to demonstrate the relationship between river currents in the Study Area and paddlesports: a one-way trip to the opposite shoreline, a round trip to the opposite shoreline and back, and an along-shoreline trip. While the width of the Study Area from shoreline to shoreline is well below the average distance for a paddler to travel, the paddler may be displaced on the opposite shoreline relative to the direction and velocity of the currents. Displacement is a critical factor because safe egress from the water, especially while portaging a kayak or canoe, is not widely available along the highly developed urban shorelines in the Study Area. For a round trip to the opposite shoreline and back, a paddler will have to travel the displaced distance against the current or try to identify a safe egress location to bring the watercraft to shore. The lack of suitable wading depth along the shoreline in the Study Area limits the ability of the paddler to "walk" the watercraft back to the starting point. Displacement can be over a mile from the starting location. Likewise, paddling along the shoreline with the direction of the current can be disorienting because the paddler must know when to turn around so as to have sufficient energy to paddle against the current back to the starting location. It cannot be assumed that all paddlers, particularly beginners, know the exact river velocity at the time of the activity or understand the tidal cycle in the Study Area. It also cannot be assumed that all paddlers in the Study Area have access to supervised guided tours that coordinate their trips around the schedule of the tidal cycle to reduce paddling against the current. Taking into consideration the outcome of the calculated scenarios and the reality that paddlers represent a range of skills and experience, the river currents of the Study Area pose an incontrovertible hydraulic hazard to paddlesports.

Heavy concentrations of debris and floating obstructions occur throughout the tidal Schuylkill River and the Delaware River between the Schuylkill River confluence and Penn's Landing Marina. Large obstructions, such as trees, drums and railroad ties moving at or just below the water surface pose a major hazard to paddlesports due to risk of kayaks and canoes capsizing and paddleboarders losing balance and falling into the water. The abundance of legacy infrastructure within the Study Area poses a safety risk to paddlesports, particularly when compounded with currents, wind-generated waves and wakes from traveling boats and commercial vessels. These hydraulic and maritime hazards can push kayaks, canoes and paddleboards into legacy infrastructure, causing paddlecraft to capsize or become compromised.

Paddlers are more likely to encounter maritime hazards than swimmers or waders because the locations a paddler can reach are neither confined to the shoreline nor limited by depth. Paddlers can reach the shipping channel and maritime traffic areas where tugboats and commercial vessels are active. The Study Area has 31 maritime facilities and supports more than 18,000 commercial vessel transits per year. A major maritime hazard in the Study Area is propeller wash, particularly from tugboats which can swiftly rotate 360 degrees and produce turbulent currents that can exhaust a paddler's energy, capsize paddlecraft and cause a paddleboarder to lose balance and become separated from their board. While large commercial vessels require deep draft to operate, tugboats do not and are therefore not exclusively found in the shipping channel. With high-density ship traffic in the Study Area and the ability of paddlers to access the shipping channel, oncoming ships pose a critical hazard to paddlers recreating within or near the federal navigation channel.

Section 9.4.3.4 provided an example scenario that calculated the time it would take an oncoming ship to reach a kayak in the center of the navigation channel. The critical finding is that if a commercial ship is 0.75 miles away, a kayaker has *less than five minutes* to paddle out of the navigation channel and clear the 200-yard buffer to reach a distance far enough away from the effects of a ship's propeller wash, bow and stern thruster wash, wake, water displacement and suction. Individuals react and perform differently in real-life situations, and there is no certainty that a paddler will react quickly to an oncoming vessel, know to get as far away as possible from an oncoming vessel, or even see an oncoming vessel at a distance of 0.75 miles or more, particularly when visibility is limited by weather conditions or the time of day. It cannot be assumed that all paddlers know the boundaries of the navigational channel or can anticipate where a commercial vessel is going, particularly shallow draft vessels such as tugboats that operate in and outside of the channel. Many areas of the Study Area are too narrow to provide a 200-yard distance from the federal navigation channel to avoid these hazards. Maritime hazards are an irretrievable condition of the Study Area, and paddlesports are especially susceptible and exposed to these hazards in the Study Area.

Jet Skiing

Jet skiing criteria are compared against 15 hazards to detail safety concerns that may arise from the Study Area. Jet skis are powerful motorized watercraft and are not affected by the deep water and fast currents in the same ways that swimming, wading and paddlesports are. However, despite being motorized and fast, jet skis are vulnerable to maritime, shoreline and other hazards, such as floating and submerged debris. Contact with debris may flip the jet ski, clog the jet pump, or cause the jet skier to lose control and fall into the water. A jet skier moving at a high rate of speed in the Study Area could allide with legacy infrastructure that is more or less visible depending on the changing water depth due to tides.

Jet skis can reach speeds up to 65 mph, are not confined to the shoreline or shallow areas and can easily reach the federal navigation channel. The capabilities of a jet ski may create a false sense of security for the operator. Jet skis can get close to commercial vessels and are susceptible to all eight maritime hazards evaluated in this study. Tow lines pose the greatest hazard to jet skis, compared to other recreational activities, because jet skis are fast enough to get between a moving tugboat and a barge or other vessel being towed. Jet skiers can collide with tow lines located above or below the waterline, separating the operator from the watercraft and causing great bodily harm or even death. Despite being capable of reaching high speeds, jet skis are still susceptible to the hazard of water displacement and suction from moving cargo ships. Jet skiers may be exposed to propeller wash while intentionally jumping wakes or crossing too closely behind cargo ships and tugboats. Even though jet skis have engines, they are susceptible to shoreline and maritime hazards in the Study Area.

Use Attainability Context

In the context of a Use Attainability Analysis (UAA), attaining primary contact recreation in the Study Area is not feasible due to human-caused conditions and hydrologic modifications, Factors 3 and 4. Human-caused conditions relevant to Factor 3 include commercial shipping and navigation activities, maritime traffic density, active infrastructure, legacy infrastructure, and restricted shoreline access due to urban, commercial and industrial development. Hydrologic modifications relevant to Factor 4 include the federal navigation channel, channel dredging, active infrastructure and legacy infrastructure. Removing these hazards is not feasible; they are permanent conditions of the Study Area. The shoreline has been developed over hundreds of years and includes a mix of abandoned and active infrastructure associated with major metropolitan areas, manufacturing facilities, refineries and shipping terminals. The established maritime industry in the Study Area is a major source of food, energy, and raw materials for the eastern United States and into the heartland. The federal navigation channel that runs through the Study Area has been deepened over the years to accommodate ever-growing cargo ships and is currently maintained at 45 feet. The Study Area is so *narrow*, including the majority of the Philadelphia shoreline, that the recommended 200-yard safety buffer from the navigation channel extends onto the shoreline. Without the ability to maintain a safe distance from the federal navigation channel, swimmers and paddlers are especially vulnerable to maritime hazards. Restricting or limiting maritime traffic in the Study Area to mitigate the many safety risks maritime hazards pose to primary contact recreation activities is neither feasible nor practical. Dense maritime traffic and developed hazardous shorelines are irretrievable conditions of the Study Area.

Table 10.2 Safety Study Conclusions in a Use Attainability Context

Study Name	Year	**UAA Factor 3 Reasoning** *Non-attainment of primary contact use*	**UAA Factor 4 Reasoning** *Non-attainment of primary contact use*
Delaware River Recreation Safety Study	2022	**Human caused conditions** including commercial shipping and navigation activities, maritime traffic density, active infrastructure, legacy infrastructure, and restricted shoreline access due to urban, commercial and industrial development	**Hydrologic modifications** including the federal navigation channel, channel deepening and dredging, active infrastructure, and legacy infrastructure

While consideration of physical conditions, Factor 5, may preclude attainment of aquatic life protections, the uniqueness of the Study Area makes ignoring the hydraulic hazards to safe primary contact recreation difficult. Deep water, tidal fluctuations in water depth and current direction, current velocity and wind-generated waves are hazards to swimming, wading, and paddlesports as detailed in Section 9. At the very least, the hydraulic hazards in the Study Area exacerbate the safety concerns created by human-caused conditions and hydrologic modifications, Factors 3 and 4. A more detailed discussion of this Safety Study in the use attainability context may be found in Section 11.

In Conclusion

The research and analyses outlined in this study clearly describe permanent conditions of the Study Area that make swimming, wading, and paddlesports hazardous activities. The hydraulic characteristics of the Study Area which include deep water, tidally fluctuating depth, and fast currents are hazardous to non-motorized recreational activities such as swimming, wading and paddlesports. The developed shoreline, with active and legacy infrastructure, and dense maritime traffic are irretrievable conditions of the Study Area that pose numerous hazards to swimming, wading and paddlesports.

Section 11 Safety and Use Attainability Analysis Context

A use attainability analysis (UAA) is a structured scientific assessment of the factors affecting the attainment of uses specified in Section 101(a)(2) of the Clean Water Act, commonly referred to as the swimmable and fishable uses (U.S. Environmental Protection Agency, 2021). As shown in Figure 1.2, the six factors that may be considered in such an analysis include the chemical, physical and economic criteria described in 40 CFR 131.10(g).

A UAA must be conducted to designate uses below the fishable/swimmable goals of the Clean Water Act. In order to raise a designated use to the fishable/swimmable goals of the Clean Water Act, a state is not required to conduct a UAA but may choose to do so to justify the use change (40 CFR 131.10(k).

Presently, the Pennsylvania Department of Environmental Protection (PADEP) and the Delaware River Basin Commission (DRBC) both have designated the Study Area as below the Clean Water Act swimmable goal. DRBC has designated this area "secondary contact," and in its 2020 Triennial Review PADEP has excluded primary contact from this reach.

(1) Naturally occurring pollutant concentrations prevent the attainment of the use; or

(2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or

(3) Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or

(4) Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or

(5) Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or

(6) Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.

Figure 1.2 UAA Factors 1-6 Defined in 40 CFR 131.10(g) (CFR)

11.1. Delaware Estuary Use Attainability (DEL USA) Project

In 1986, the DRBC launched the Delaware Estuary Use Attainability Project (DEL USA Project) with support from numerous federal and state agencies and the Academy of Natural Sciences (DRBC, 1989). The objective was to assess what constraints, if any, prevent the attainment of fishable and swimmable uses in the 85-mile tidal section of the Delaware River. At the time only the upper portion of DRBC Zone 2 and the lower portion of Zone 5 were designated for primary contact recreation use. The remaining portion of DRBC Zone 2, all of Zones 3 and 4, and the upper portion of Zone 5 were designated for secondary contact recreation use only.

The DEL USA Project focused on the attainability of swimmable water quality when recommending whether certain reaches of the tidal Delaware River should be designated for primary contact recreation use. While the final report mentioned safety conditions inherent to an urban-industrial shoreline and river, these did not factor into determining attainability of primary contact recreation use. The final report stated that issues of public safety were outside the purview of the project, noting that swimming activities are particularly hazardous from a safety viewpoint, and litter and debris control programs are warranted to protect recreational activities (Figure 1.3).

The DEL USA Project did not examine all UAA Factors 1-6, specifically detailed considerations of Factor 3 (human-caused conditions) or Factor 6 (widespread economic and social impact). At the time of the DEL USA project, water quality conditions documented within the Study Area (DRBC Zones 3 and upper Zone 4) were used to establish the designated use as below Clean Water Act swimmable goals.

> **ARE THERE OTHER ISSUES CONCERNING PRIMARY CONTACT RECREATION?**
>
> Issues of public safety are outside the purview of the DEL USA Project. In lieu of attaining primary-contact recreation uses in Zone 3 and the upper portion of Zone 4, it is recommended that the appropriate public health agencies initiate actions to discourage such uses in the river. Swimming activities, readily observable, are particularly hazardous from a safety as well as a health viewpoint. In a similar vein, litter and debris control programs are warranted to protect recreational boaters.

Figure 1.3 1989 DEL USA Project Final Report Comments on Public Safety (DRBC, page 13)

11.2. Recreational Use Attainability Analyses Considering Safety

The Commonwealth of Pennsylvania Environmental Quality Board (PAEQB) and other state agencies have precedent for considering safety within the use attainability context. The PAEQB is responsible for issuing the Triennial Review of Water Quality Standards and swimmable use requirements under Section 101 (a)(2) of the Clean Water Act. The PAEQB has acknowledged safety as a factor in primary contact use decisions in the 2020 Triennial Review, addressing safety in the Study Area by excluding primary contact recreation due to "... continuing impacts from combined sewer overflows, and hazards associated with commercial shipping and navigation." The Commonwealth of Pennsylvania set precedent for including safety in UAAs in 1985. A 1985 Pennsylvania Department of Environmental Resources (PADER) UAA on Erie Harbor and Presque Isle Bay found that "boating and shipping traffic . . . is considered to be an irretrievable man-induced condition which has an adverse impact on water contact recreation in and around the harbor," (Pennsylvania Department of Environmental Resources, 1985). The language of the PADER is consistent with UAA Factor 3 regarding "human-caused conditions."

UAAs have long been conducted in U.S. waterways to determine whether safety conditions prevent the attainment of primary contact recreation use. Following are several examples of use attainability analyses that considered safety.

11.2.1. Port of Metropolitan St. Louis, Missouri

The Metropolitan St. Louis Sewer District (MSD) conducted a recreational use attainability analysis in 2007 for the Mississippi River in the vicinity of St. Louis (MEC Water Resources, Inc., 2007). Commercial vessel traffic, river hydraulics and morphology, river access and adjacent land use were evaluated in the UAA segment. The MSD concluded that human-caused conditions under UAA Factor 3 prevent the attainment of primary contact recreation use in the Mississippi River UAA segment, citing restricted shoreline access due to the industrialization/ commercialization of the shoreline, dangerous hydraulic conditions created by regulating works and dangerous conditions created by barge traffic. The MSD identified no reasonable or practical means by which to remedy these human-caused conditions, noting the Port of Metropolitan St. Louis ships and receives over 32 million tons of freight a year worth over $5 billion. The MSD concluded the same hydrologic modifications discussed under UAA Factor 3 are applicable to UAA Factor 4 *(*dams, diversions or other types of hydrologic modifications*)*, citing the fact that regulating works designed to direct river current and maintain channel depths prevent the attainment of primary contact recreation use. The MSD further explained it is neither feasible to restore the Mississippi River to its original condition nor to operate these modifications in a way that would result in the attainment of the primary contact recreation use. The UAA was submitted to the Missouri Department of Natural Resources for consideration.

11.2.2. Port of Mobile, Alabama

The Alabama Department of Environmental Management (ADEM) conducted a recreational use attainability analysis in 2001 for the Mobile River adjacent to Mobile, Alabama (Alabama Department of Environmental Management, 2001). The ADEM evaluated commercial shipping and adjacent land use in the UAA segment. The ADEM concluded human-caused conditions under UAA Factor 3 prevent the attainment of primary contact recreation use in the Mobile River UAA segment, citing consistent barge/vessel traffic associated with the intensive industrial activity. The ADEM used this UAA to justify prohibiting primary contact recreation use within this stretch of the Mobile River.

11.2.3. Port of Erie, Pennsylvania

The PADER conducted a recreational use attainability analysis in 1985 for the Presque Isle Bay and Outer Erie Harbor (Pennsylvania Department of Environmental Resources, 1985). The PADER concluded that commercial and recreational boat traffic poses a serious safety hazard and is considered to be a permanent, irretrievable condition that warrants restriction of primary contact recreation use along the waterfront adjacent to the City of Erie and in the harbor basin. Though the Port of Erie UAA did not evaluate separately all UAA Factors 1-6 applicable to that water body, it assessed commercial and recreational boat traffic for safety considerations and declared an irretrievable man-induced condition that would clearly align with the definition of UAA Factor 3 for human-caused conditions. The PADEP continues to cite this UAA in its justification for excluding primary contact recreation from the designated uses in the harbor basin of the Presque Isle Bay and the entrance channel of the Outer Erie Harbor (Pennsylvania Bulletin, 2020).

11.2.4. Summary of Recreational Use Attainability Analyses Considering Safety

The use attainability analyses conducted in these three U.S. ports are examples of government and non-government entities concluding that attaining primary contact recreation use is not feasible because of safety considerations. Table 1.1 summarizes the UAA factors identified in the use attainability analyses conducted in the Ports of Metropolitan St. Louis, Mobile and Erie.

Table 11.1 Safety Hazards Identified in Example Recreational UAAs

Entity	UAA Year	UAA Factor 3 Reasoning	UAA Factor 4 Reasoning
Metropolitan St. Louis Sewer District	2007	• Restricted shoreline access due to the industrialization/ commercialization of the shoreline • Dangerous hydraulic conditions created by regulating works • Dangerous conditions created by barge traffic	• The same hydrologic modifications discussed under Factor 3 are applicable to Factor 4
Alabama Department of Environmental Management	2001	• Consistent barge/vessel traffic associated with the intensive industrial activity	
Pennsylvania Department of Environmental Resources	1985	• Commercial and recreational boat traffic	

11.3. Delaware River Safety Study

Attaining primary contact recreation in the Study Area is not feasible due to human-caused conditions and hydrologic modifications, Factors 3 and 4. Human-caused conditions relevant to Factor 3 include commercial shipping and navigation activities, maritime traffic density, active infrastructure, legacy infrastructure, and restricted shoreline access due to urban, commercial and industrial development. Hydrologic modifications relevant to Factor 4 include the federal navigation channel, channel dredging, active infrastructure and legacy infrastructure. Removing these hazards is not feasible; they are permanent conditions of the Study Area.

The shoreline has been developed over hundreds of years and includes a mix of abandoned and active infrastructure associated with major metropolitan areas, manufacturing facilities, refineries and shipping terminals. The established maritime industry in the Study Area is a major source of food, energy, and raw materials for the eastern United States and into the heartland. The federal navigation channel that runs through the Study Area has been deepened over the years to accommodate ever-growing cargo ships and is currently maintained at 45 feet. The Study Area is so *narrow*, including the majority of the Philadelphia shoreline, that the recommended 200-yard safety buffer from the navigation channel extends onto the shoreline. Without the ability to maintain a safe distance from the federal navigation channel, swimmers and paddlers are especially vulnerable to maritime hazards. Restricting or limiting maritime traffic in the Study Area to mitigate the many safety risks maritime hazards pose to primary contact recreation activities is neither feasible nor practical. Dense maritime traffic and developed hazardous shorelines are irretrievable conditions of the Study Area.

Table 11.2 Safety Study Conclusions in a Use Attainability Context

Study Name	Year	UAA Factor 3 Reasoning Human-Caused Conditions	UAA Factor 4 Reasoning Hydrologic Modifications
Delaware River Recreation Safety Study	2022	• Commercial shipping and navigation activities • Maritime traffic density • Active infrastructure • Legacy infrastructure • Restricted shoreline access due to urban, commercial and industrial development	• Federal navigation channel deepening and dredging • Active infrastructure • Legacy infrastructure

While consideration of physical conditions, Factor 5, may only preclude attainment of aquatic life protections, the uniqueness of the Study Area makes ignoring the hydraulic hazards to safe primary contact recreation difficult. Deep water, tidal fluctuations in water depth and current direction, high current velocity and wind-generated waves are hazards to swimming, wading, and paddlesports as detailed in Section 9. At the very least, the hydraulic hazards in the Study Area exacerbate the safety concerns created by human-caused conditions and hydrologic modifications, Factors 3 and 4.

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Appendix A Additional Maps

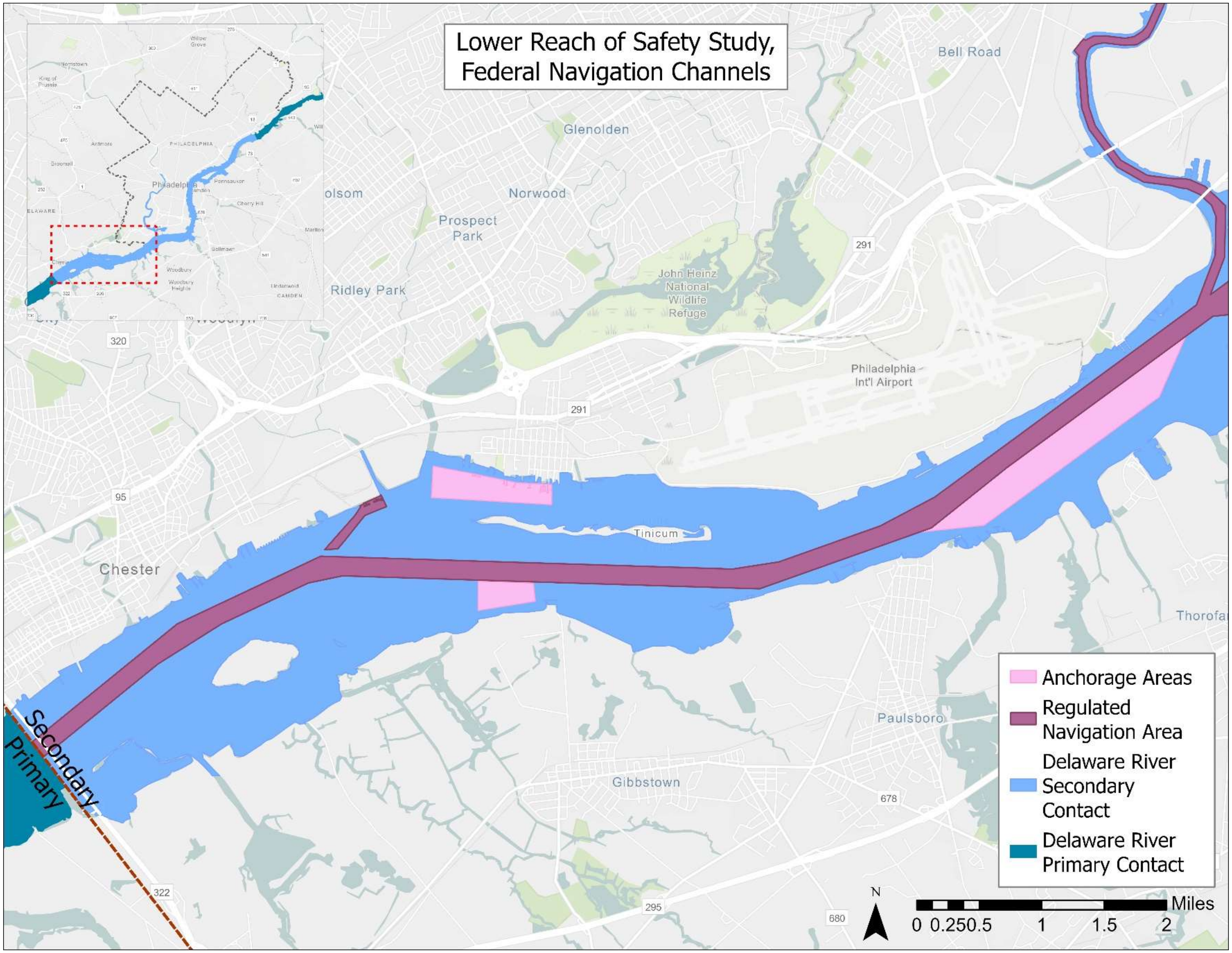

Figure A.1 Lower Reach Extent of Federal Navigational Channels in the Study Area

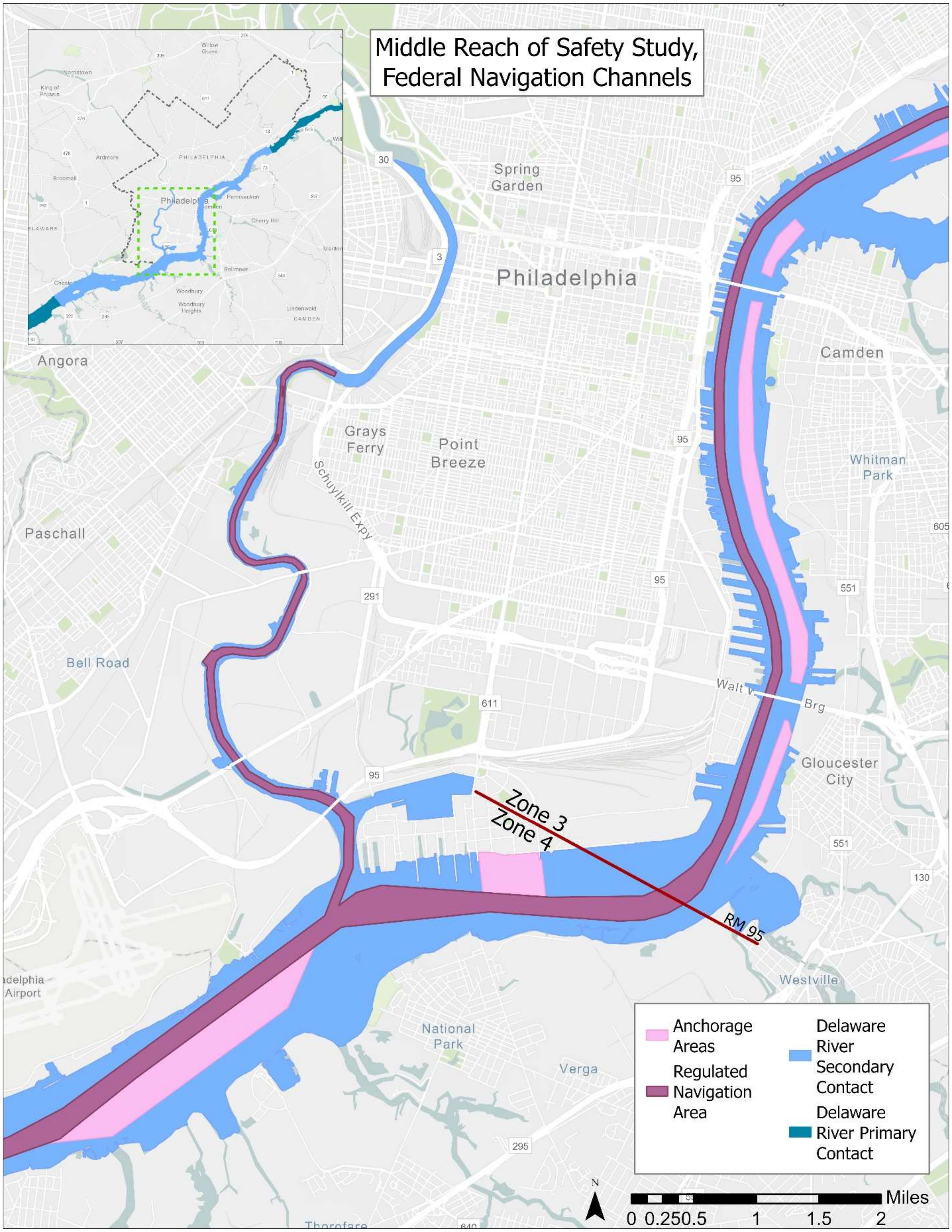

Figure A.2 Middle Reach Extent of Federal Navigational Channels in the Study Area

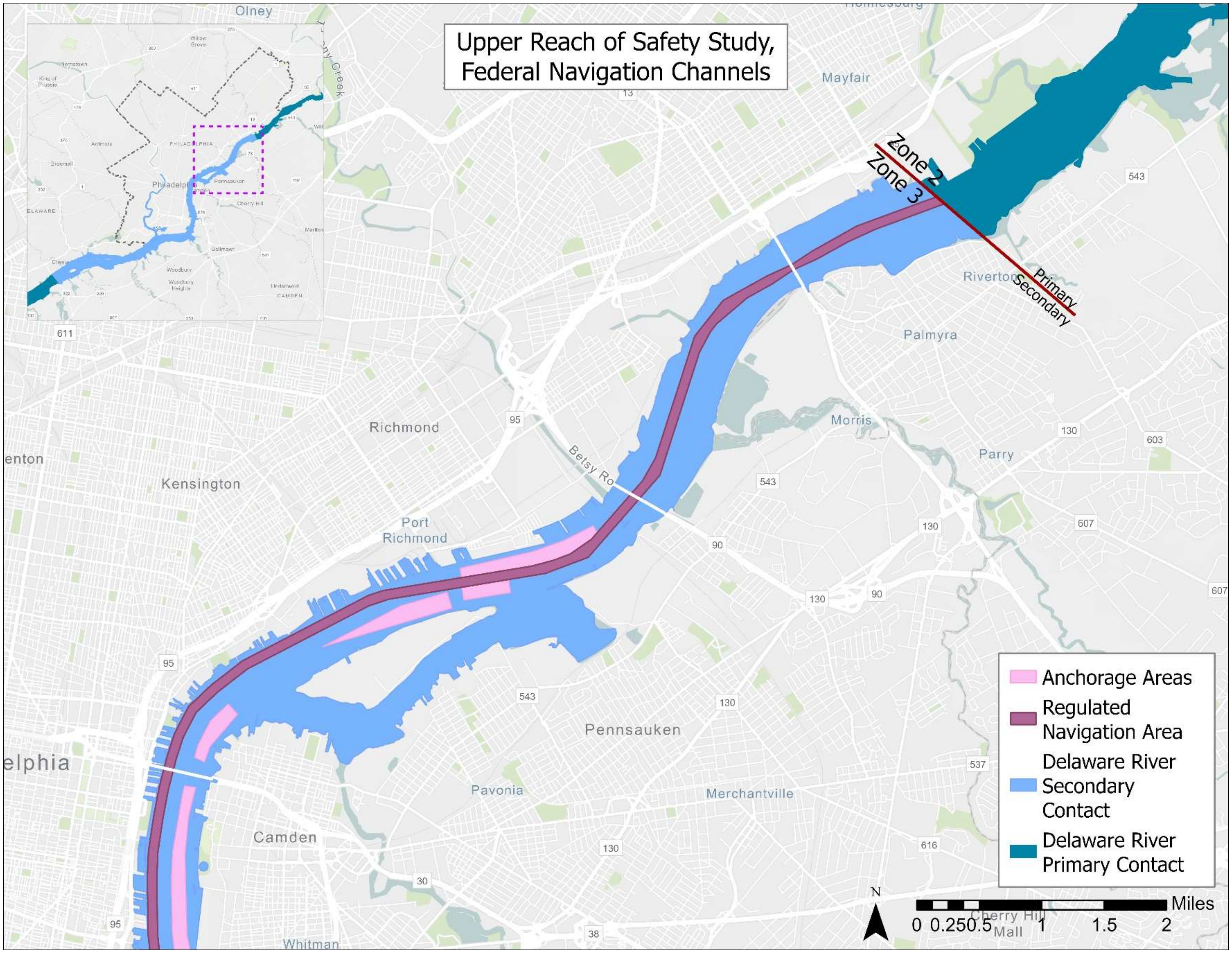

Figure A.3 Upper Reach Extent of Federal Navigational Channels in the Study Area

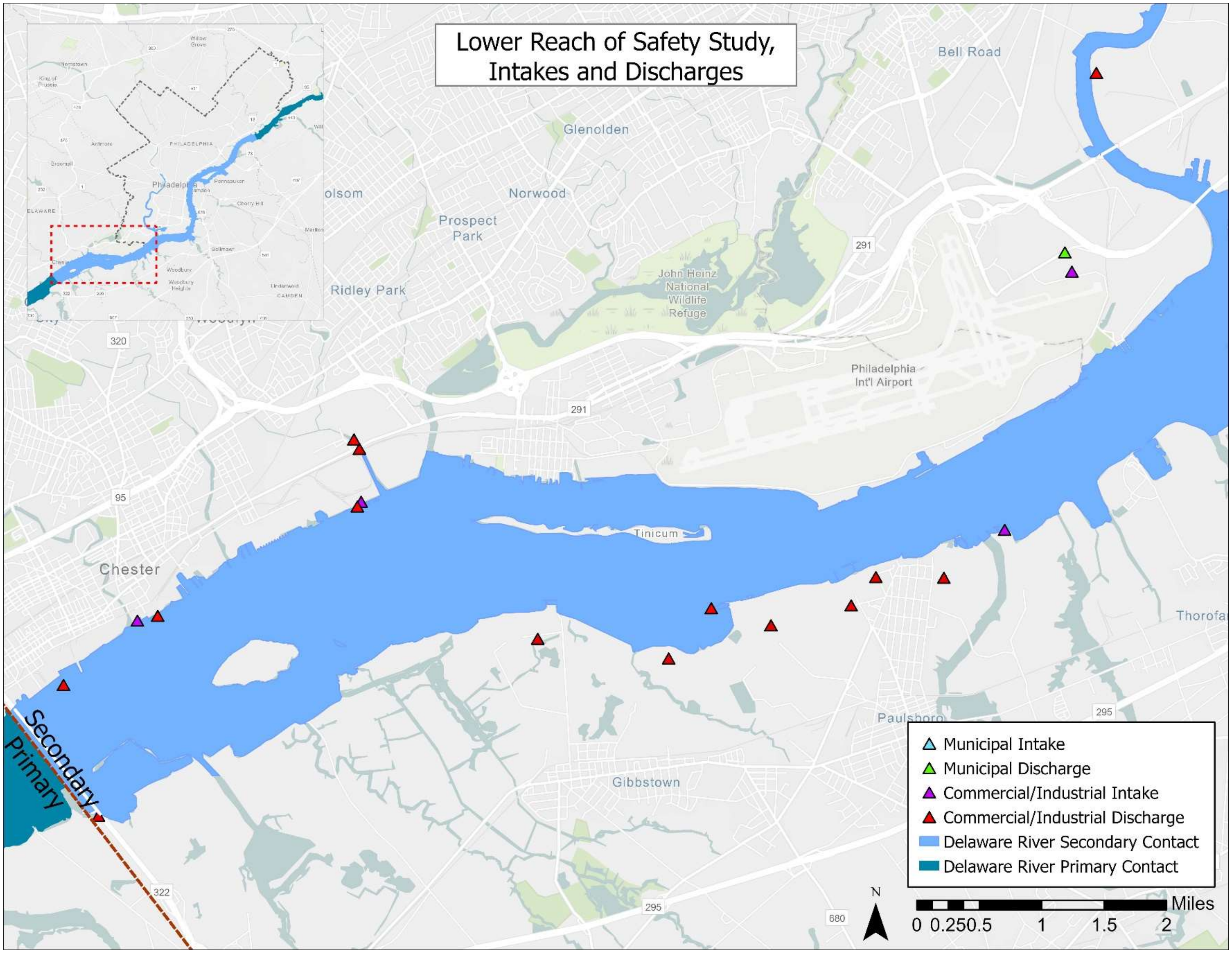

Figure A.4 Lower Reach Extent of Intake and Discharge Structures in the Study Area

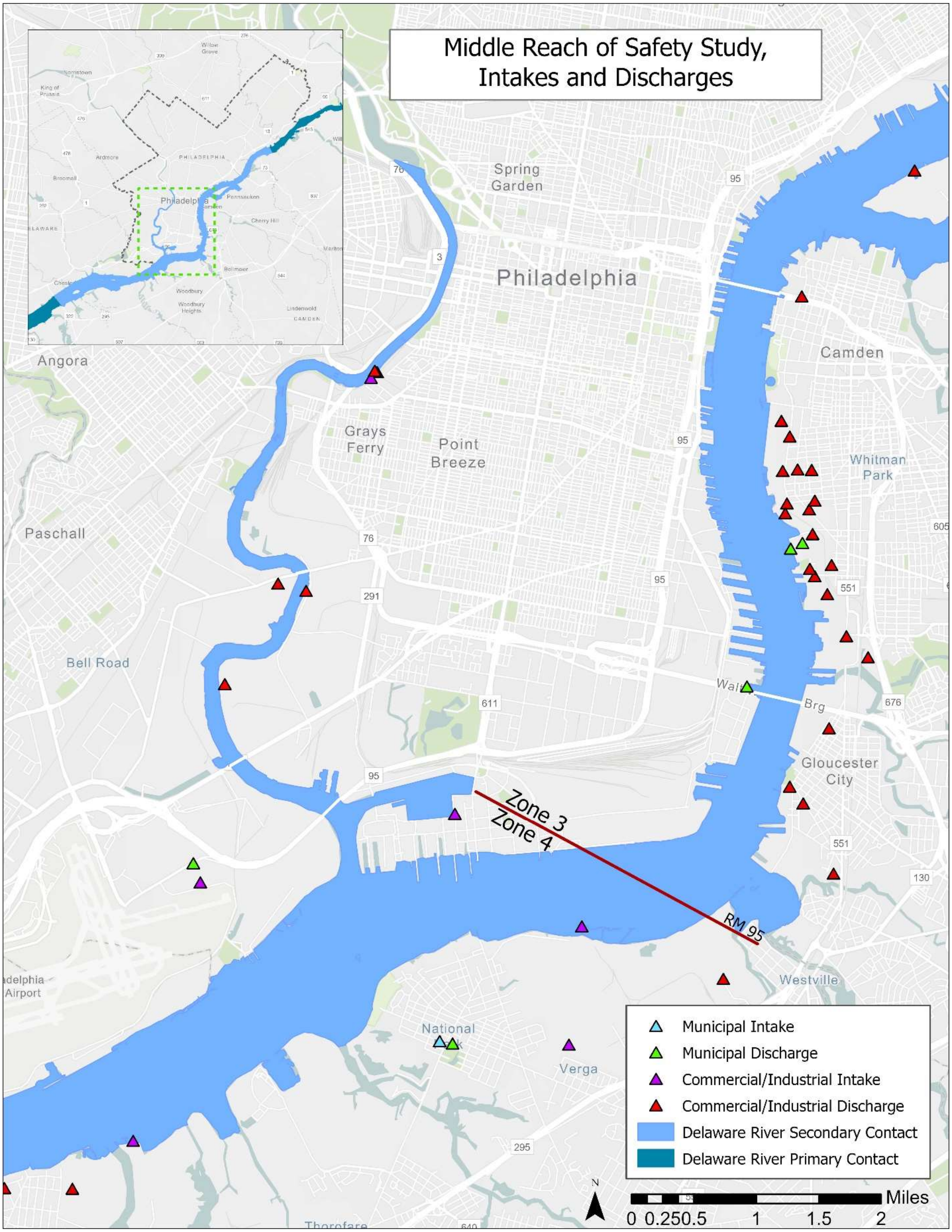

Figure A.5 Middle Reach Extent of Intake and Discharge Structures in the Study Area

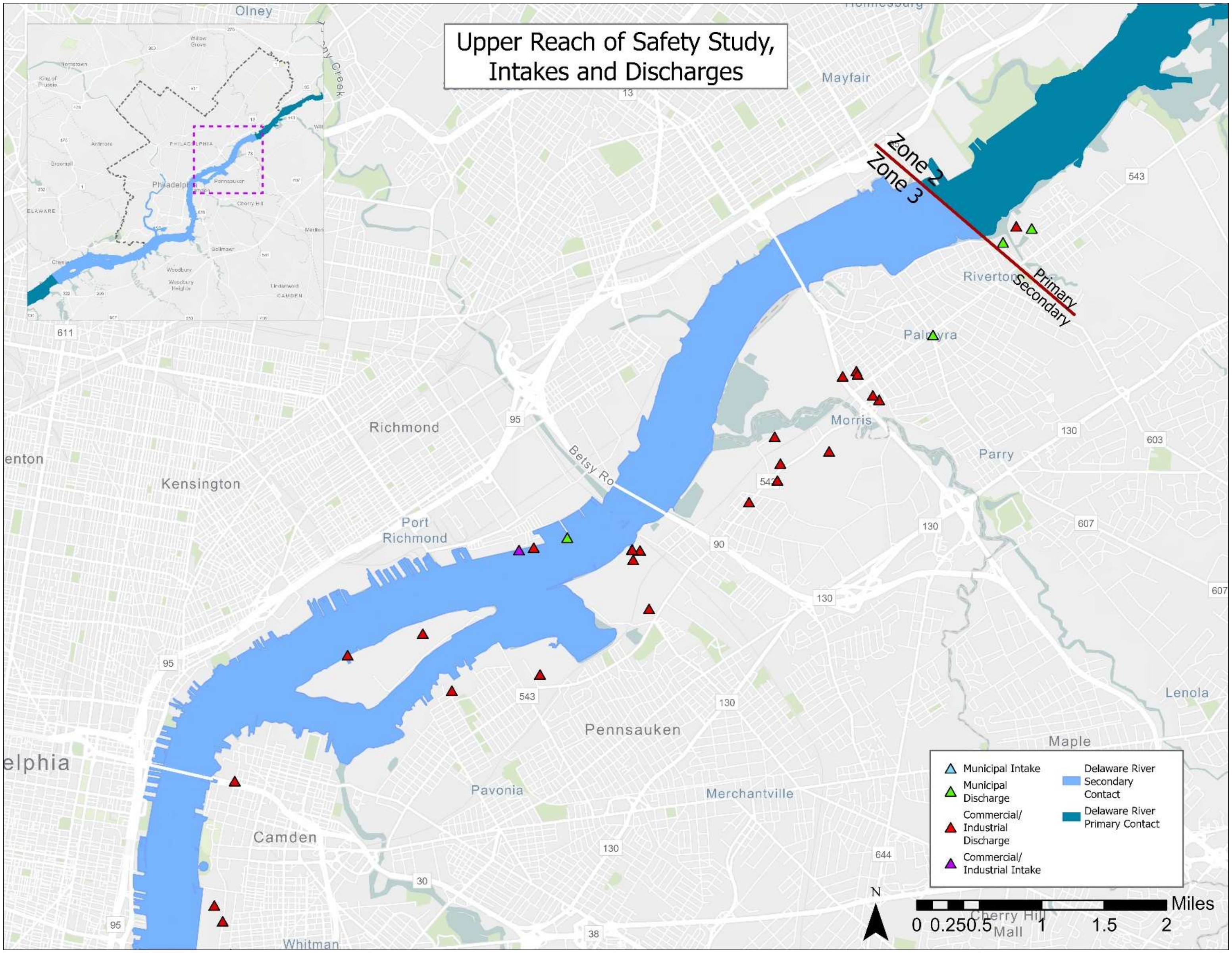

Figure A.6 Upper Reach Extent of Intake and Discharge Structures in the Study Area

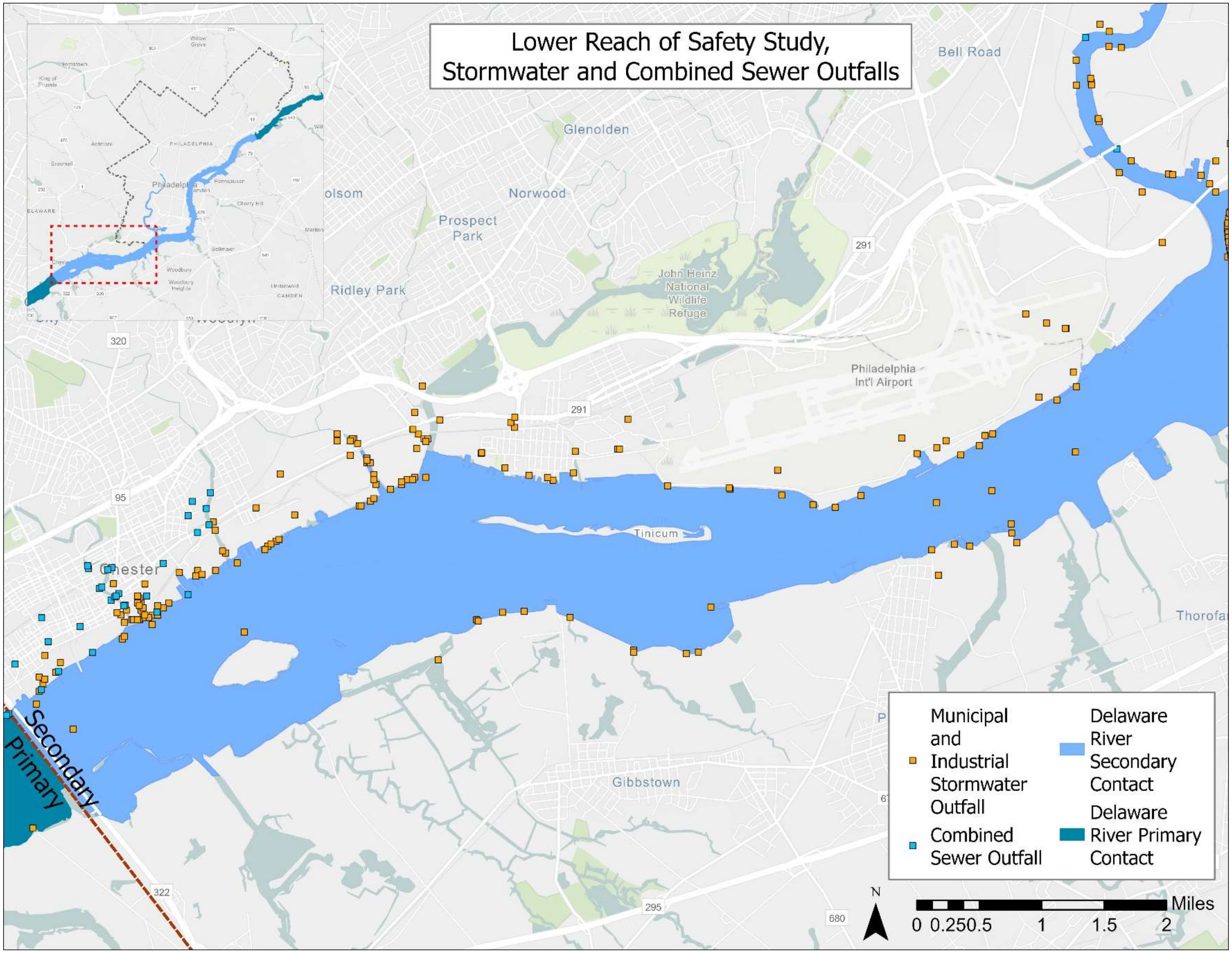

Figure A.7 Lower Reach Extent of Stormwater and Combined Sewer Outfalls in the Study Area

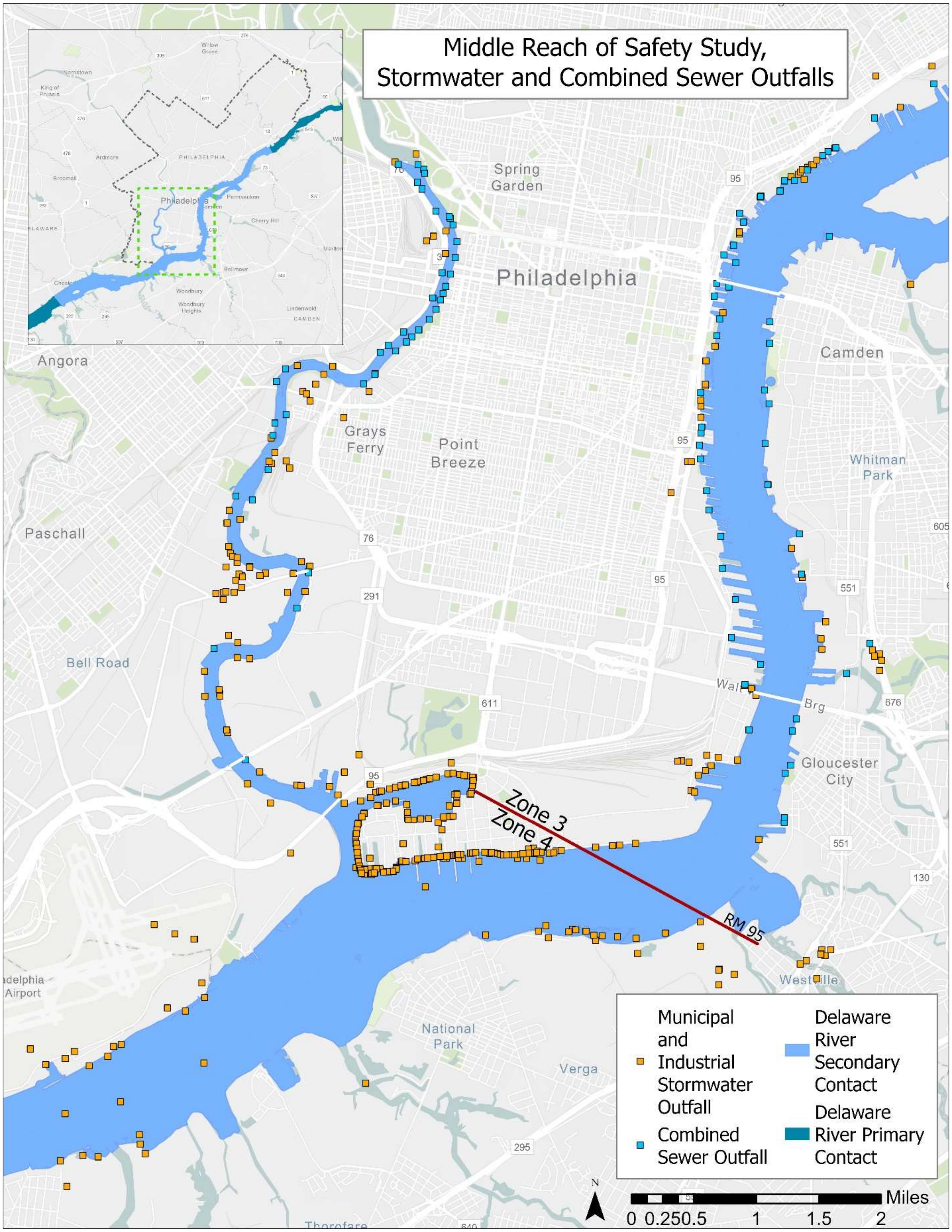

Figure A.8 Middle Reach Extent of Stormwater and Combined Sewer Outfalls in the Study Area

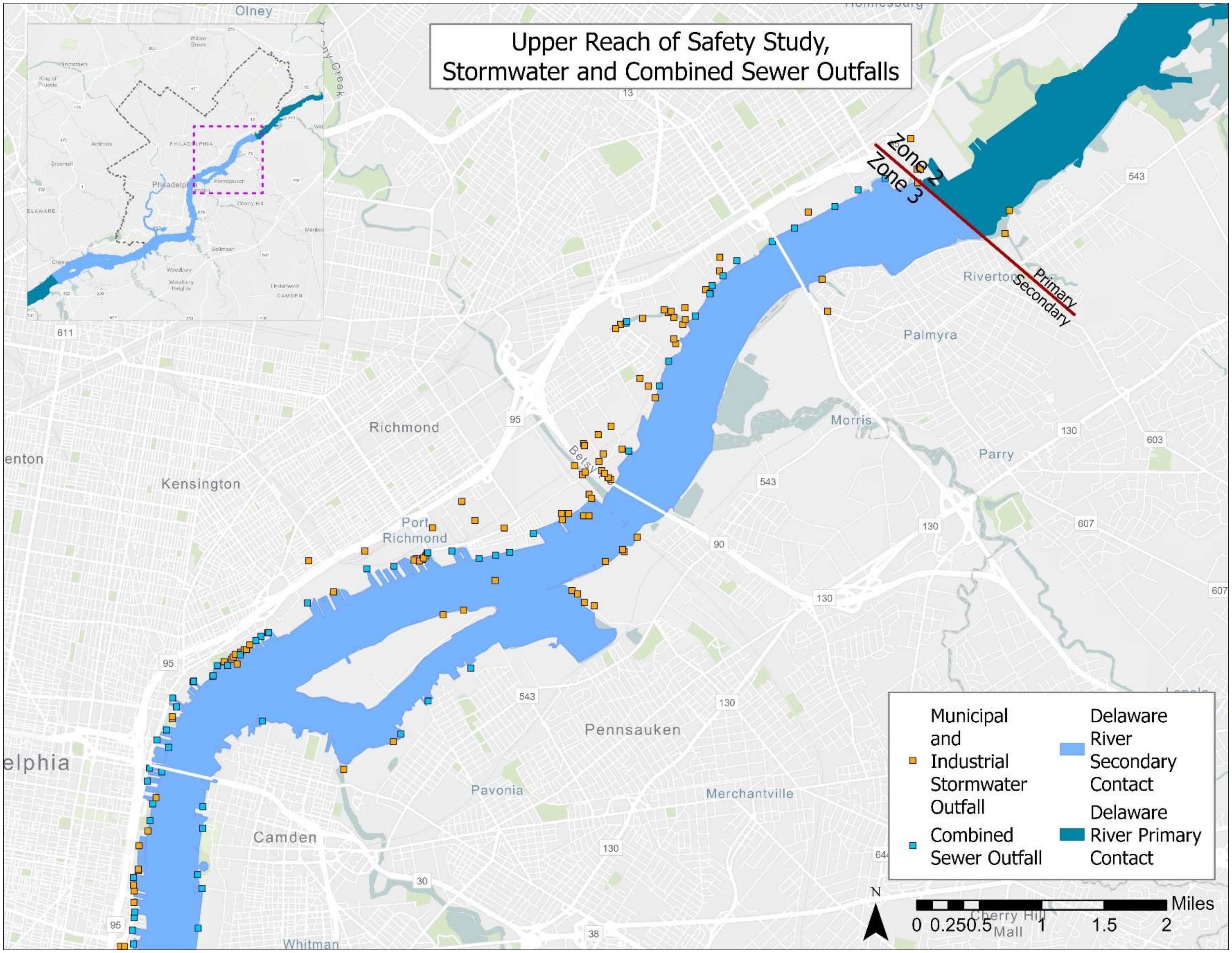

Figure A.9 Upper Reach Extent of Stormwater and Combined Sewer Outfalls in the Study Area

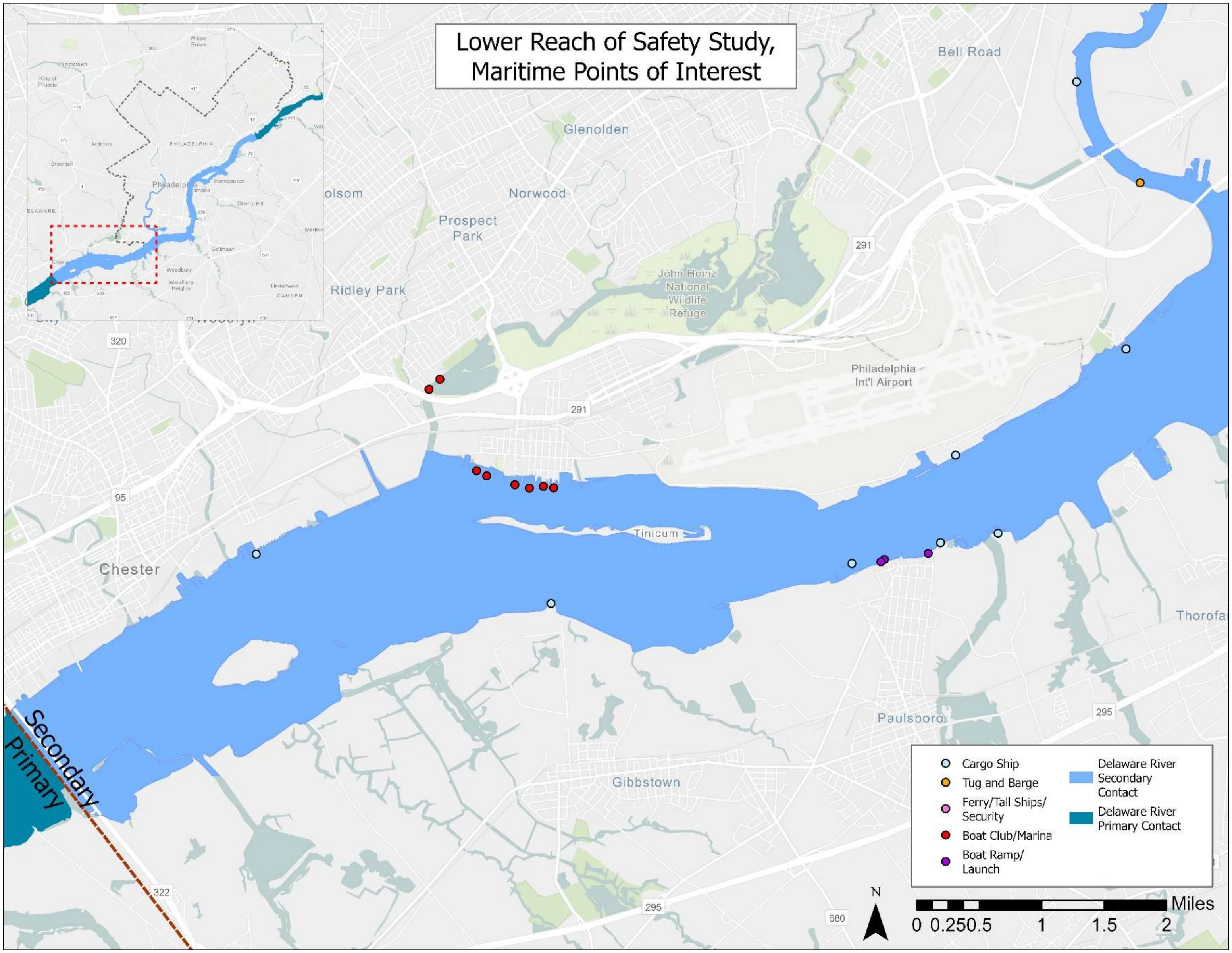

Figure A.10 Lower Reach Extent of Maritime Points of Interest in the Study Area

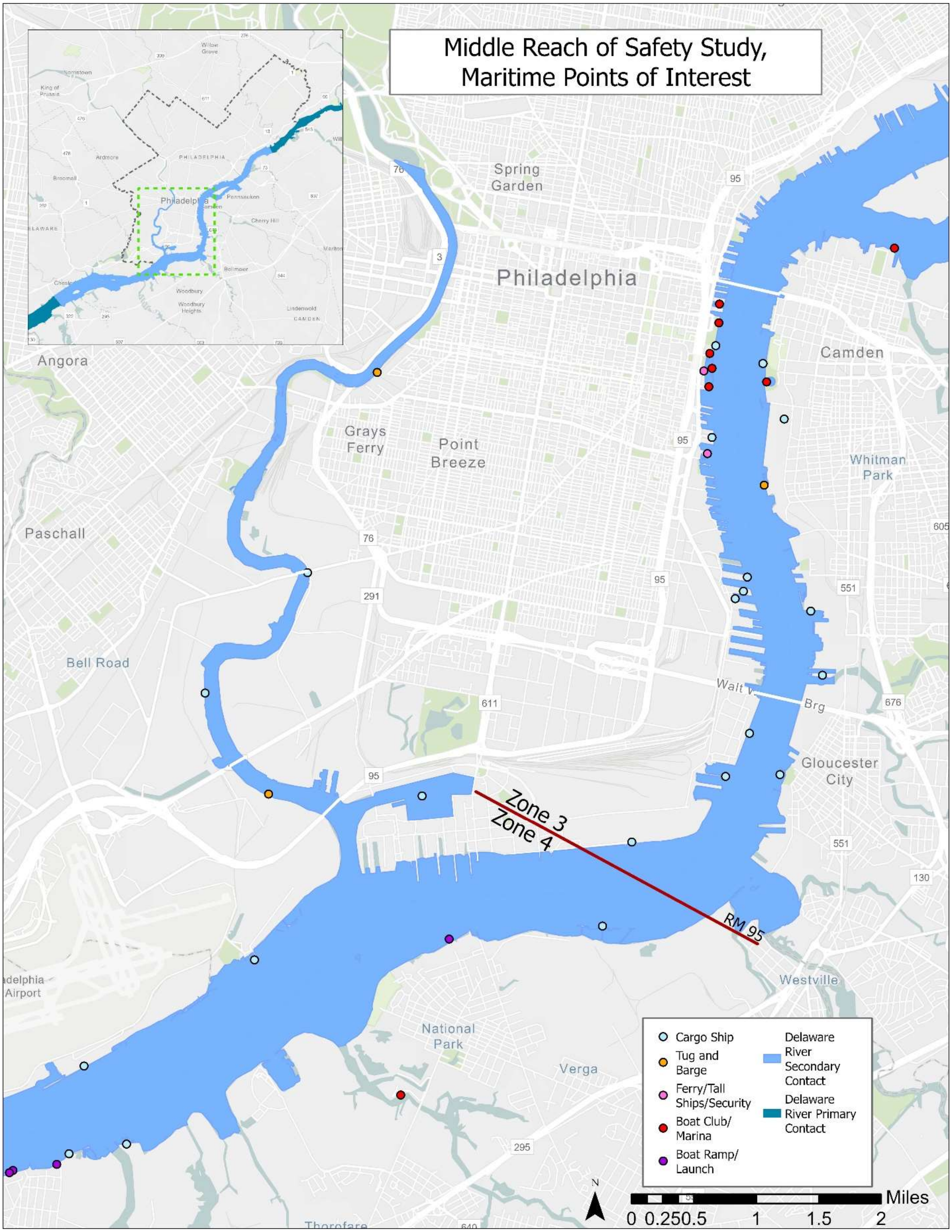

Figure A.11 Middle Reach Extent of Maritime Points of Interest in the Study Area

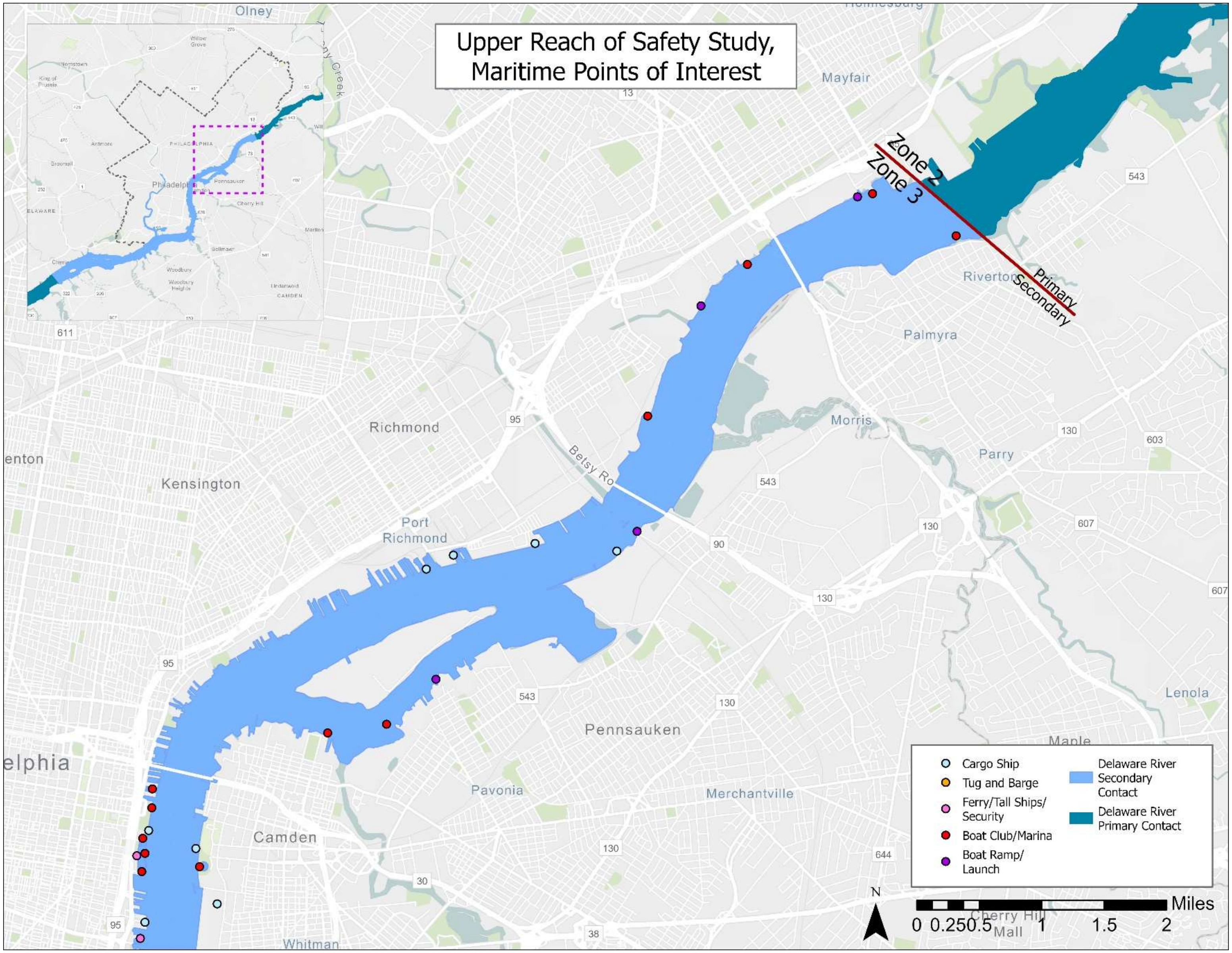

Figure A.12 Upper Reach Extent of Maritime Points of Interest in the Study Area

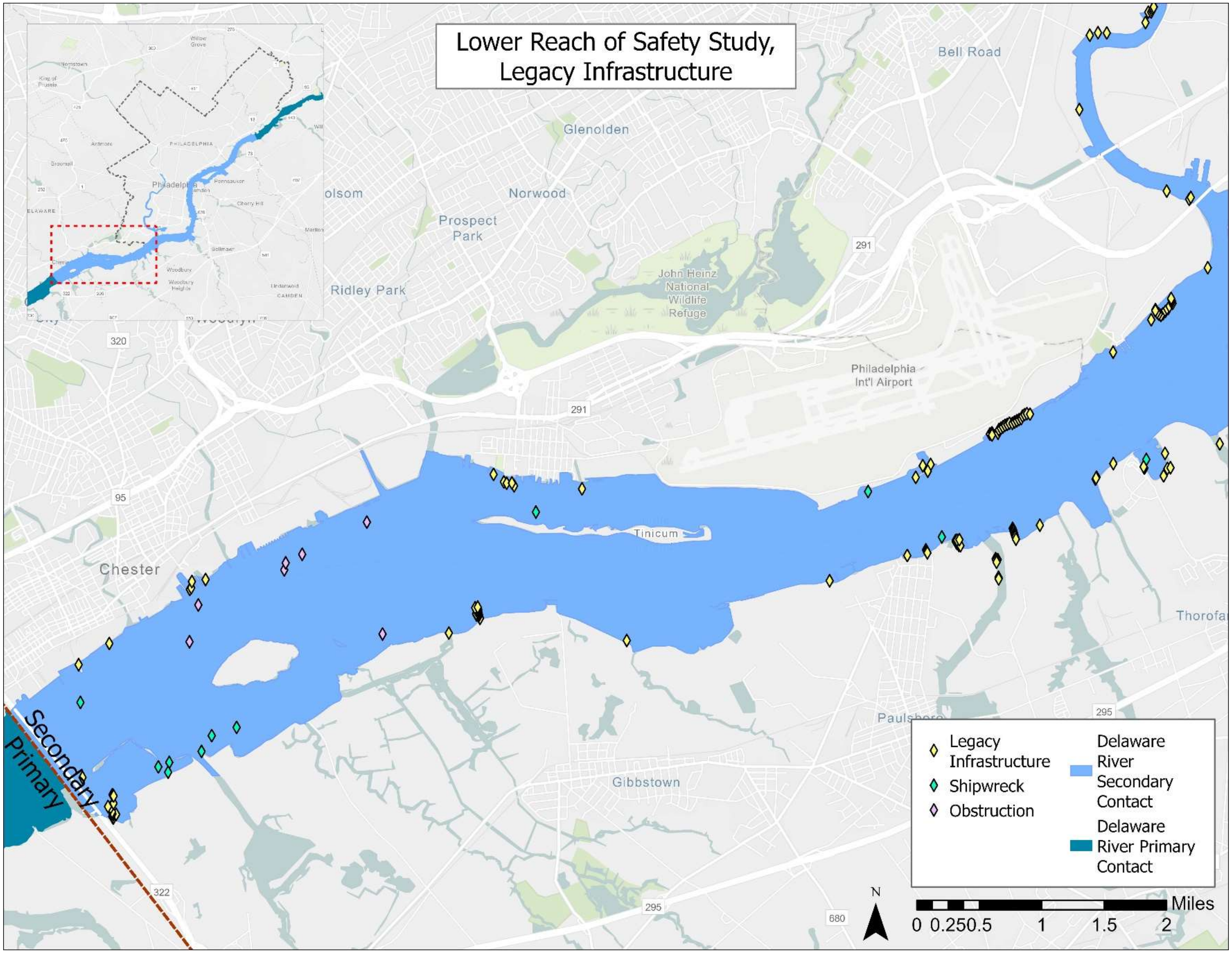

Figure A.13 Lower Reach Extent of Legacy Infrastructure, Shipwrecks and Obstructions in the Study Area

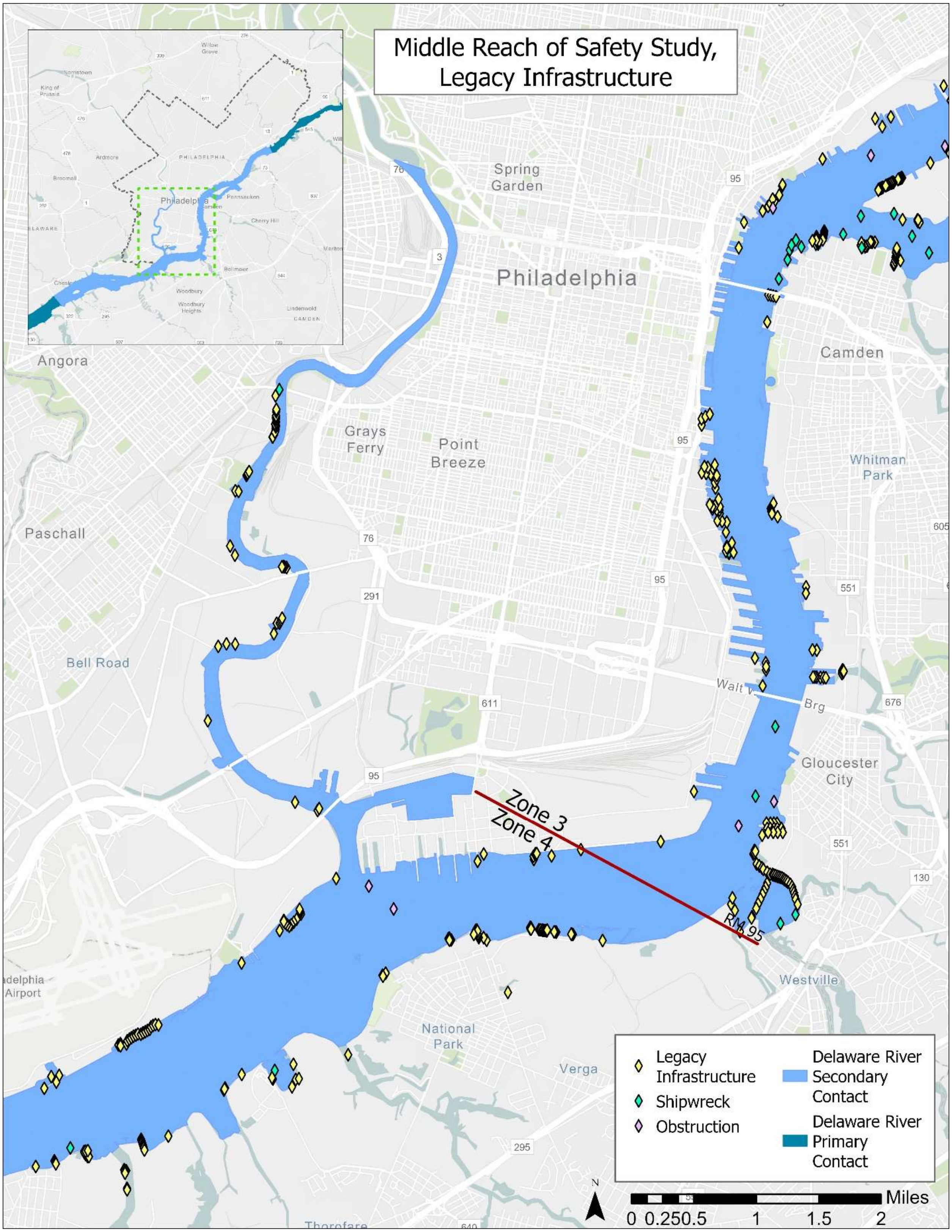

Figure A.14 Middle Reach Extent of Legacy Infrastructure, Shipwrecks and Obstructions in the Study Area

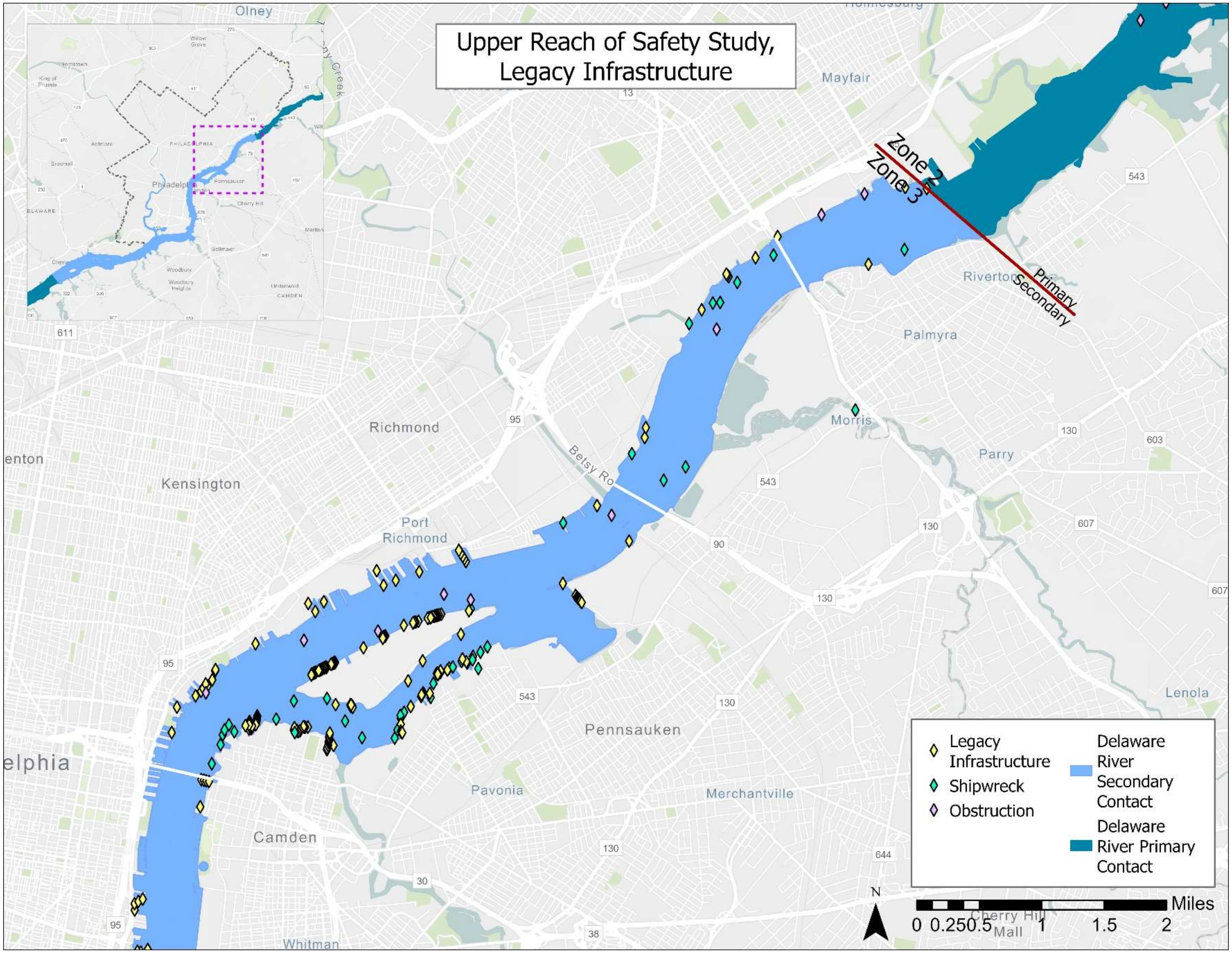

Figure A.15 Upper Reach Extent of Legacy Infrastructure, Shipwrecks and Obstructions in the Study Area

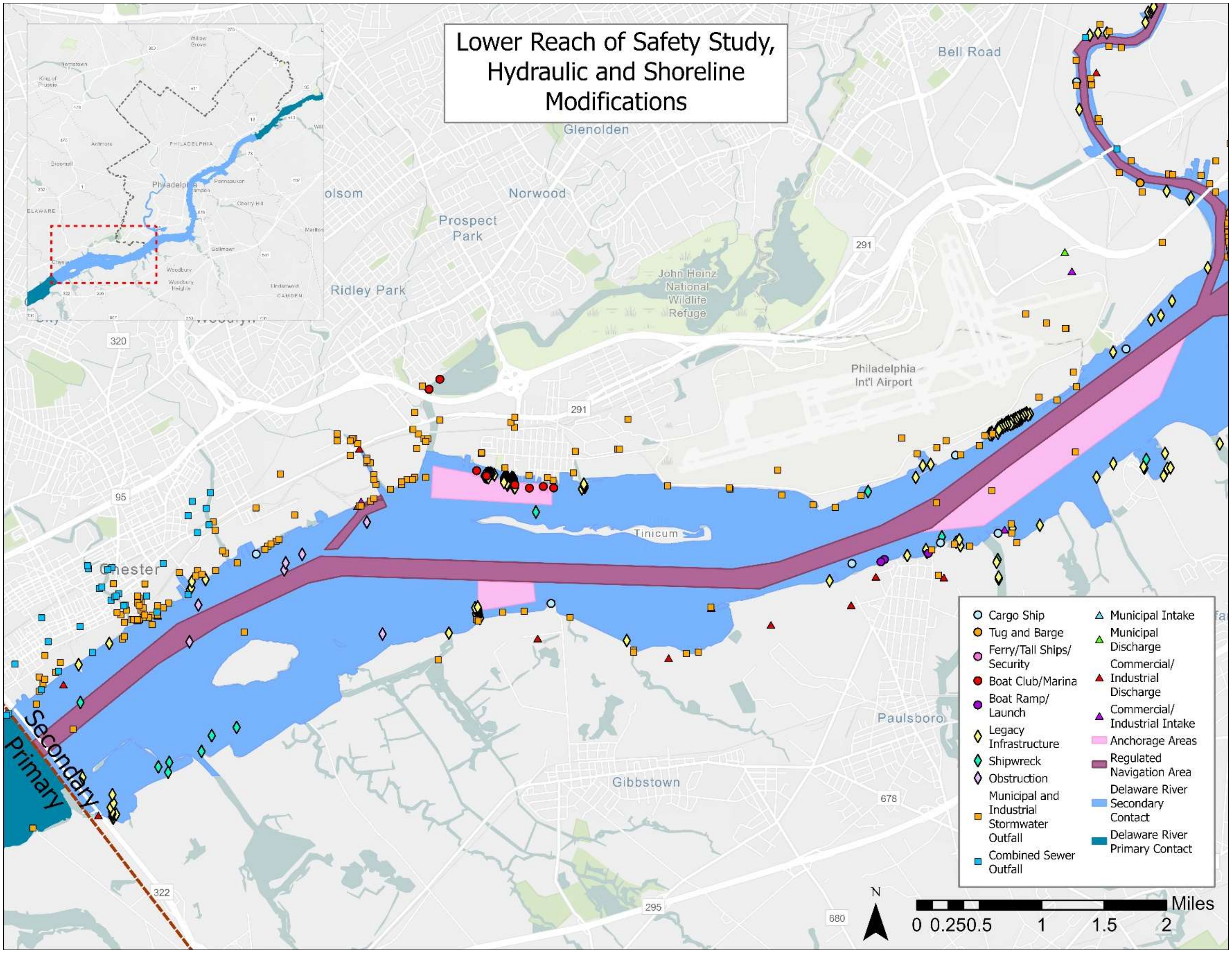

Figure A.16 Lower Reach Extent of the Total Hydraulic and Shoreline Modifications in the Study Area

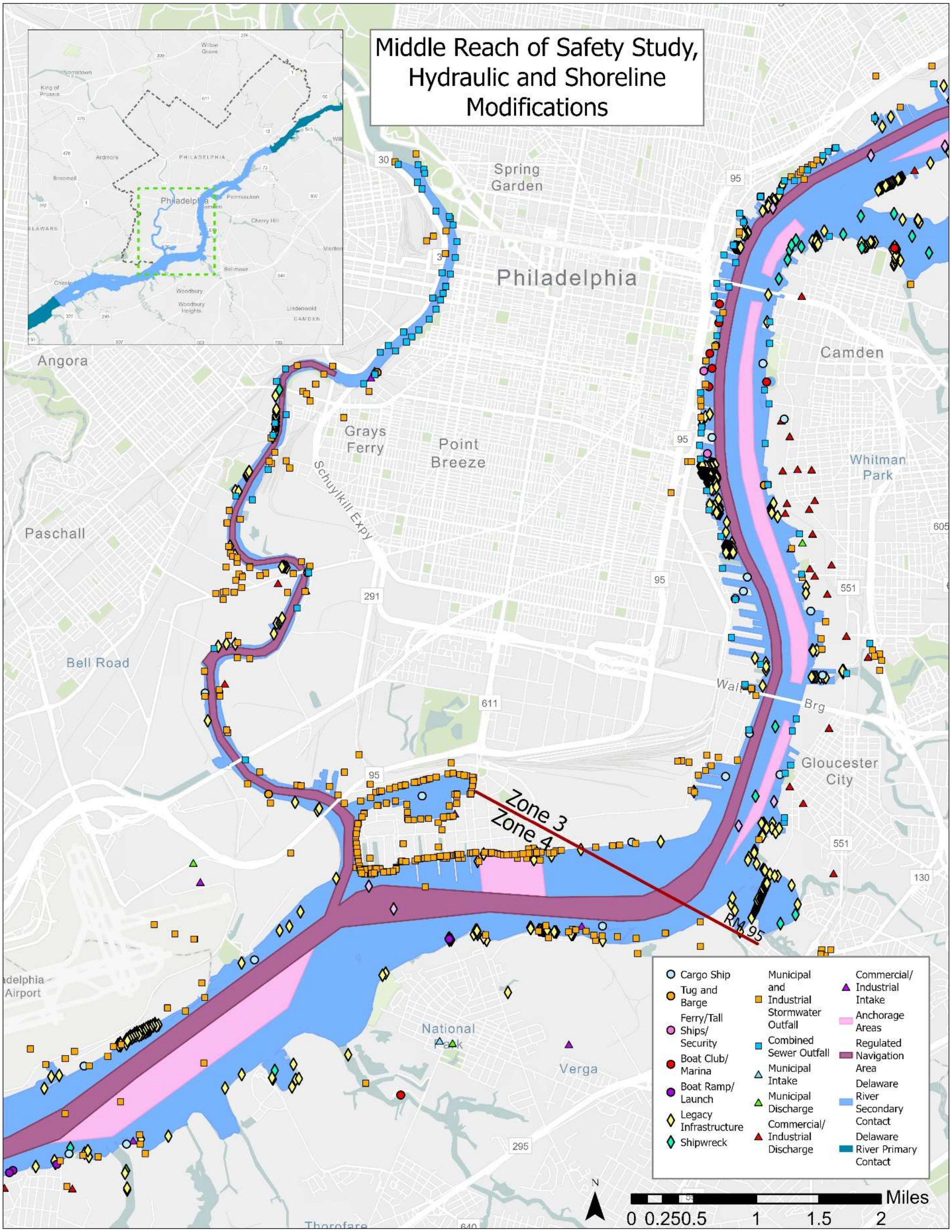

Figure A.17 Middle Reach Extent of the Total Hydraulic and Shoreline Modifications in the Study Area

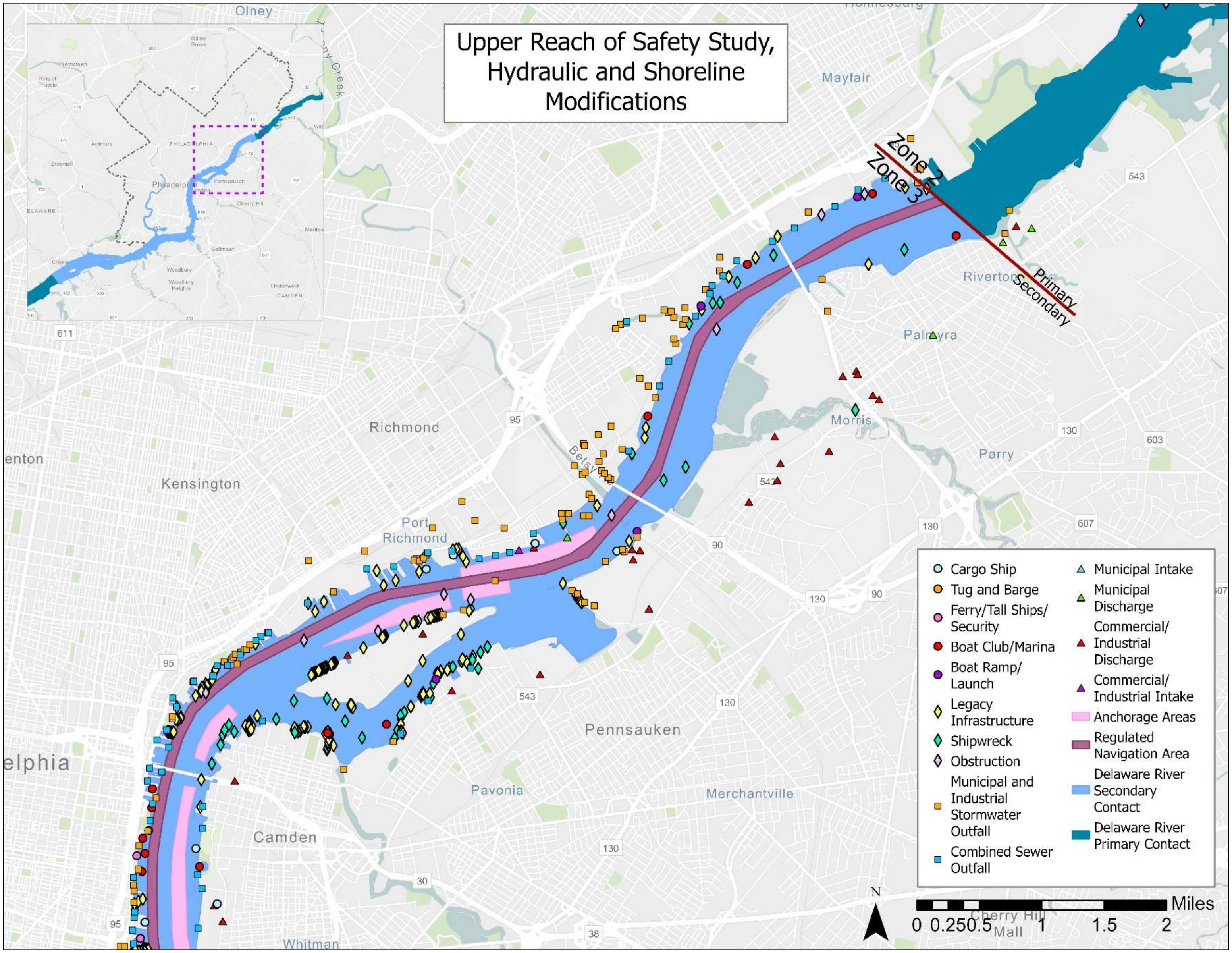

Figure A.18 Upper Reach Extent of the Total Hydraulic and Shoreline Modifications in the Study Area

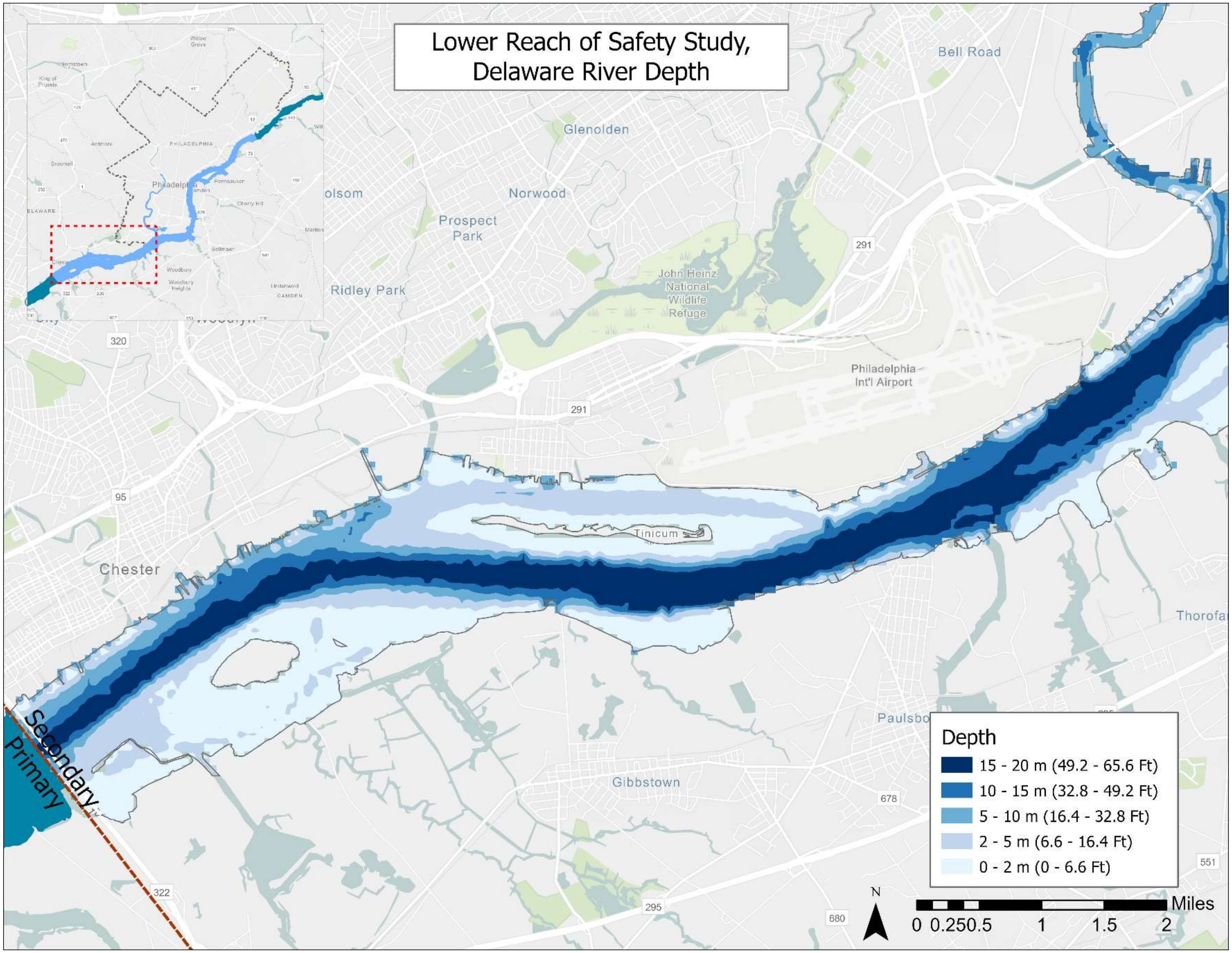

Figure A.19 Water Depth - Lower Reach Extent of the Study Area

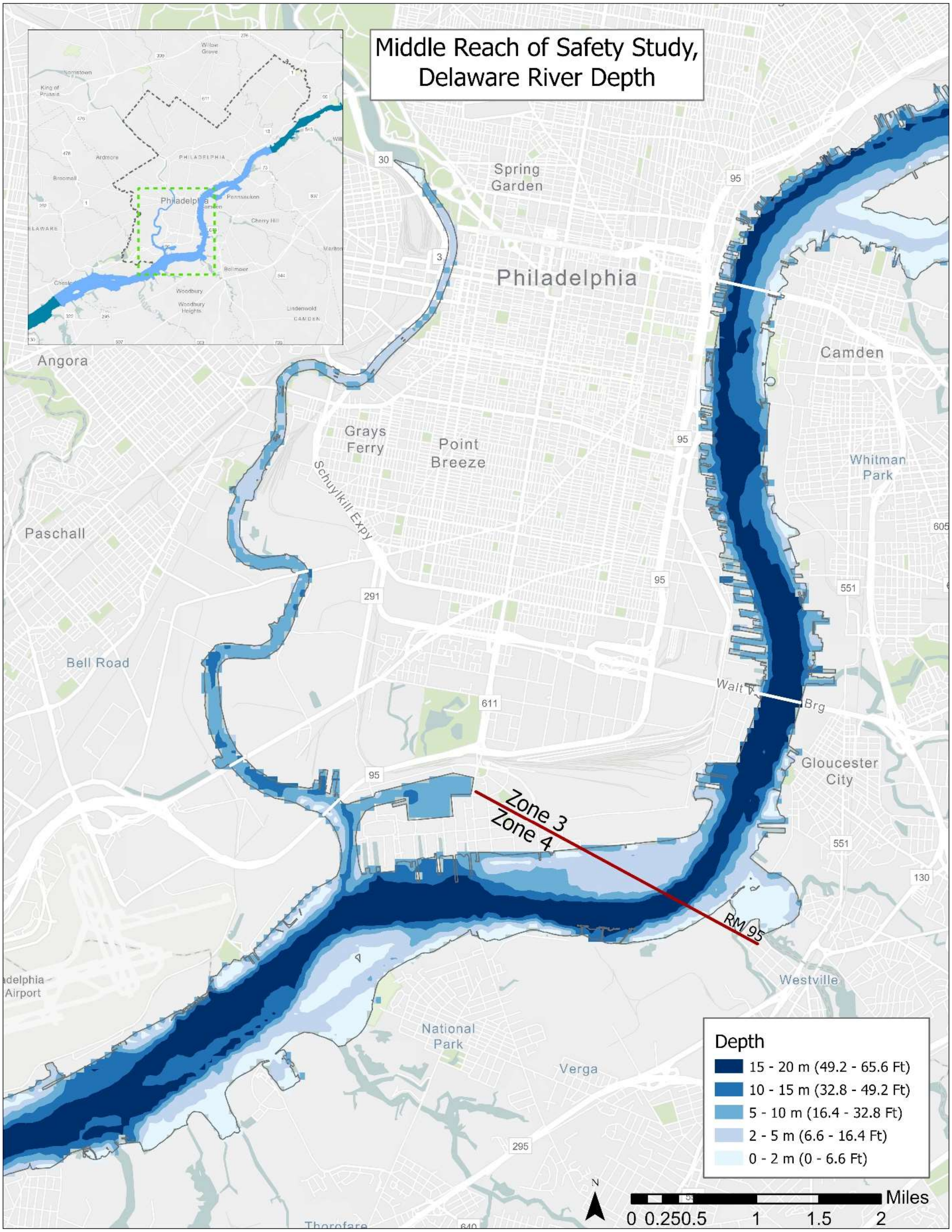

Figure A.20 Water Depth - Middle Reach Extent of the Study Area

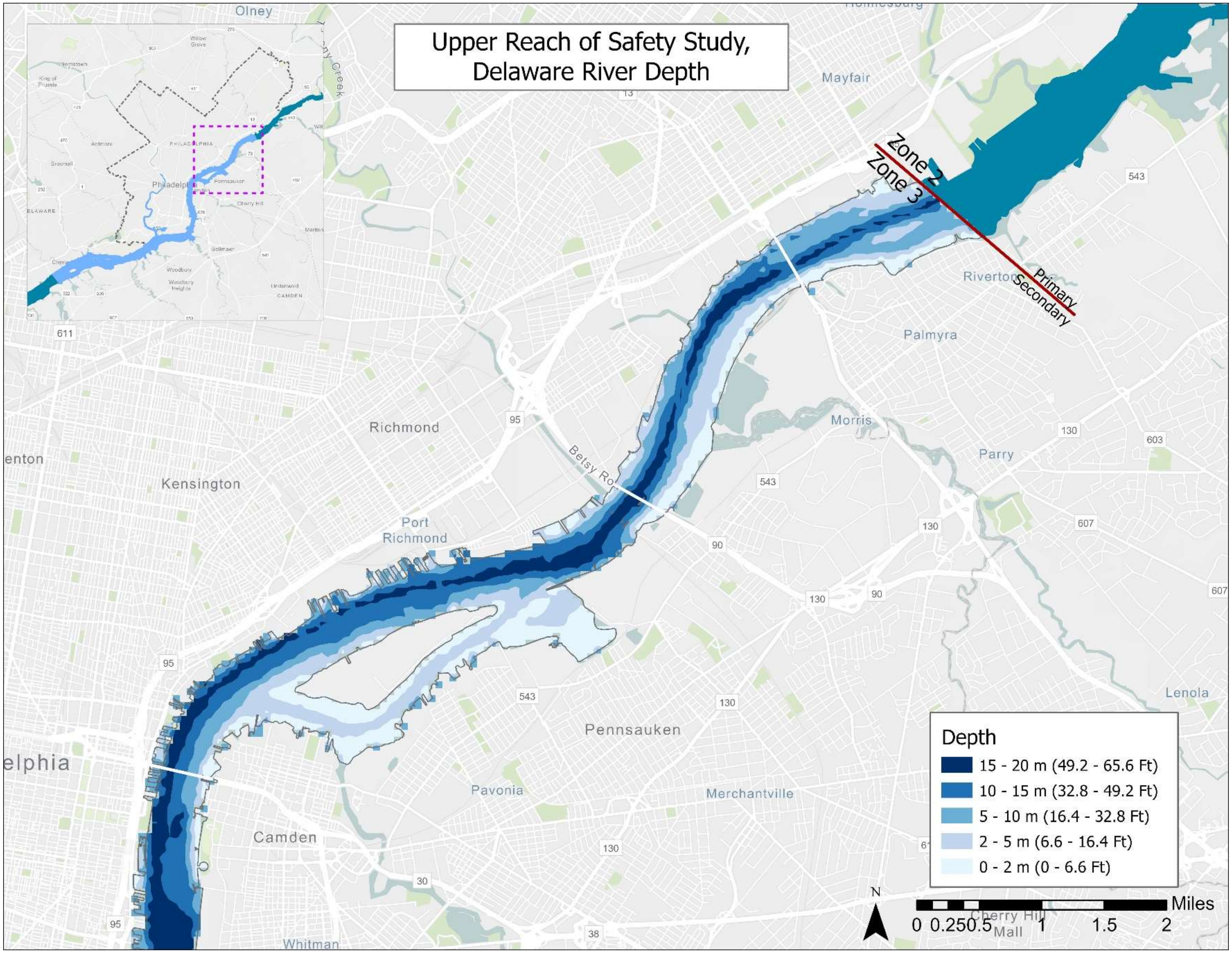

Figure A.21 Water Depth - Upper Reach Extent of the Study Area

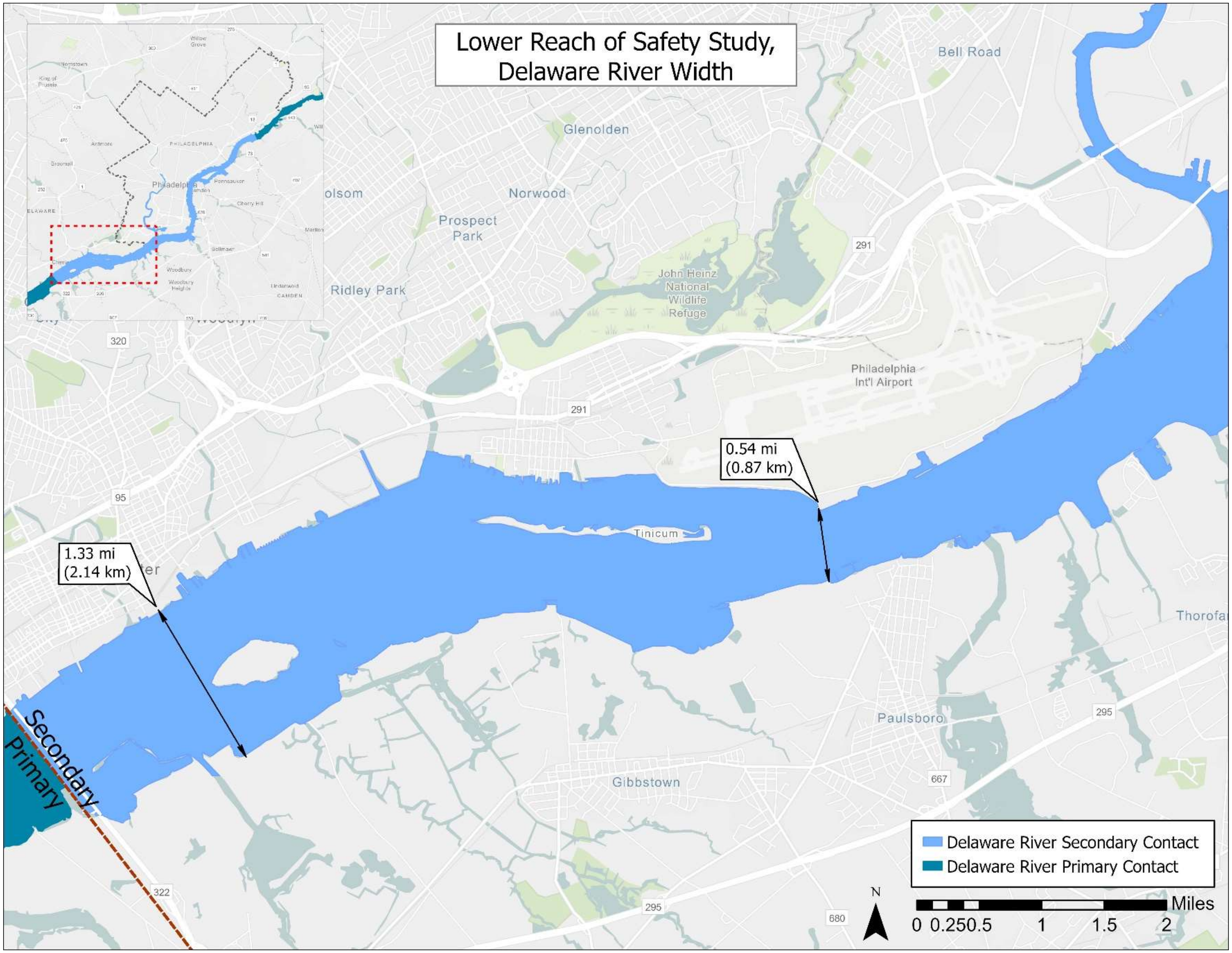

Figure A.22 Distance from Shore – Lower Reach Extent of Study Area

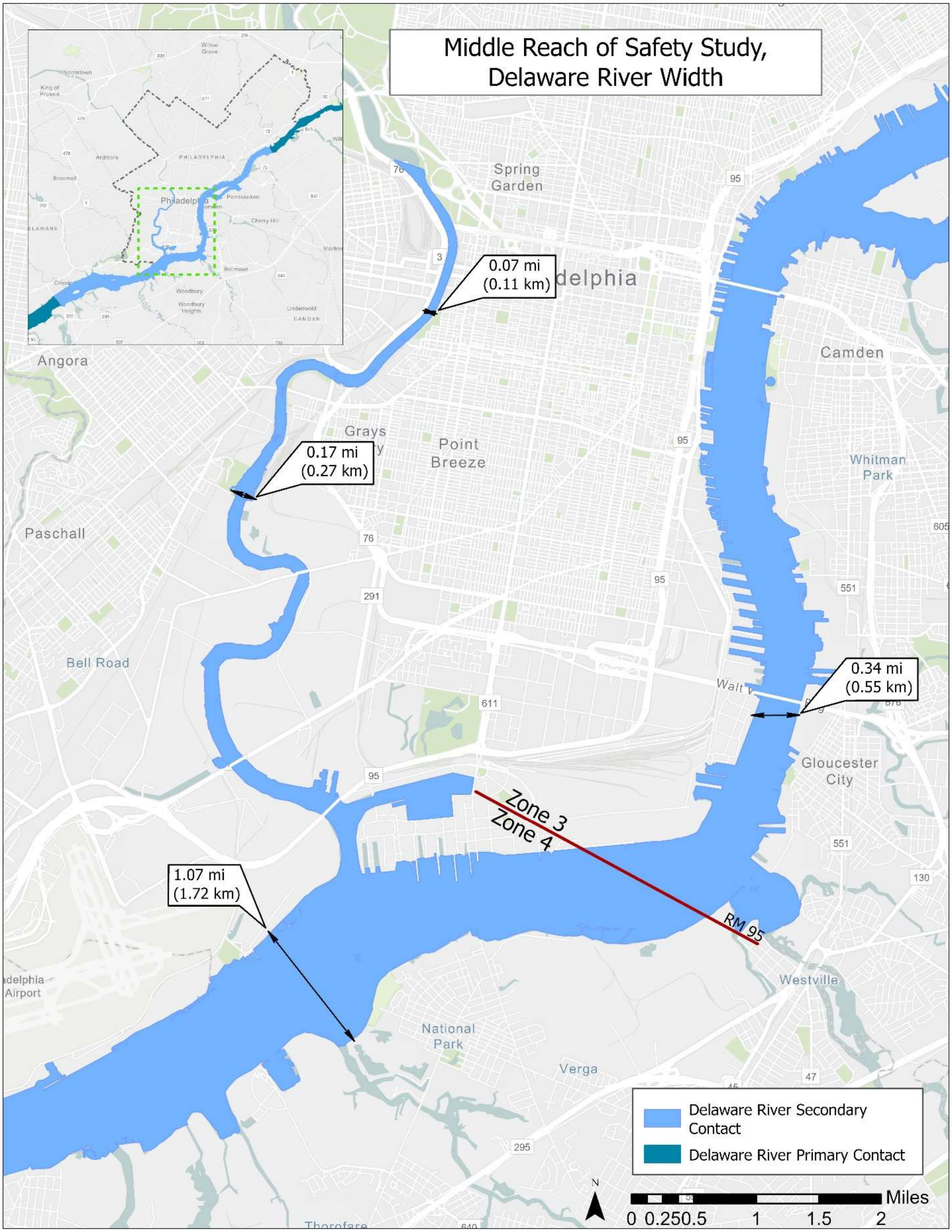

Figure A.23 Distance from Shore – Middle Reach Extent of the Study Area

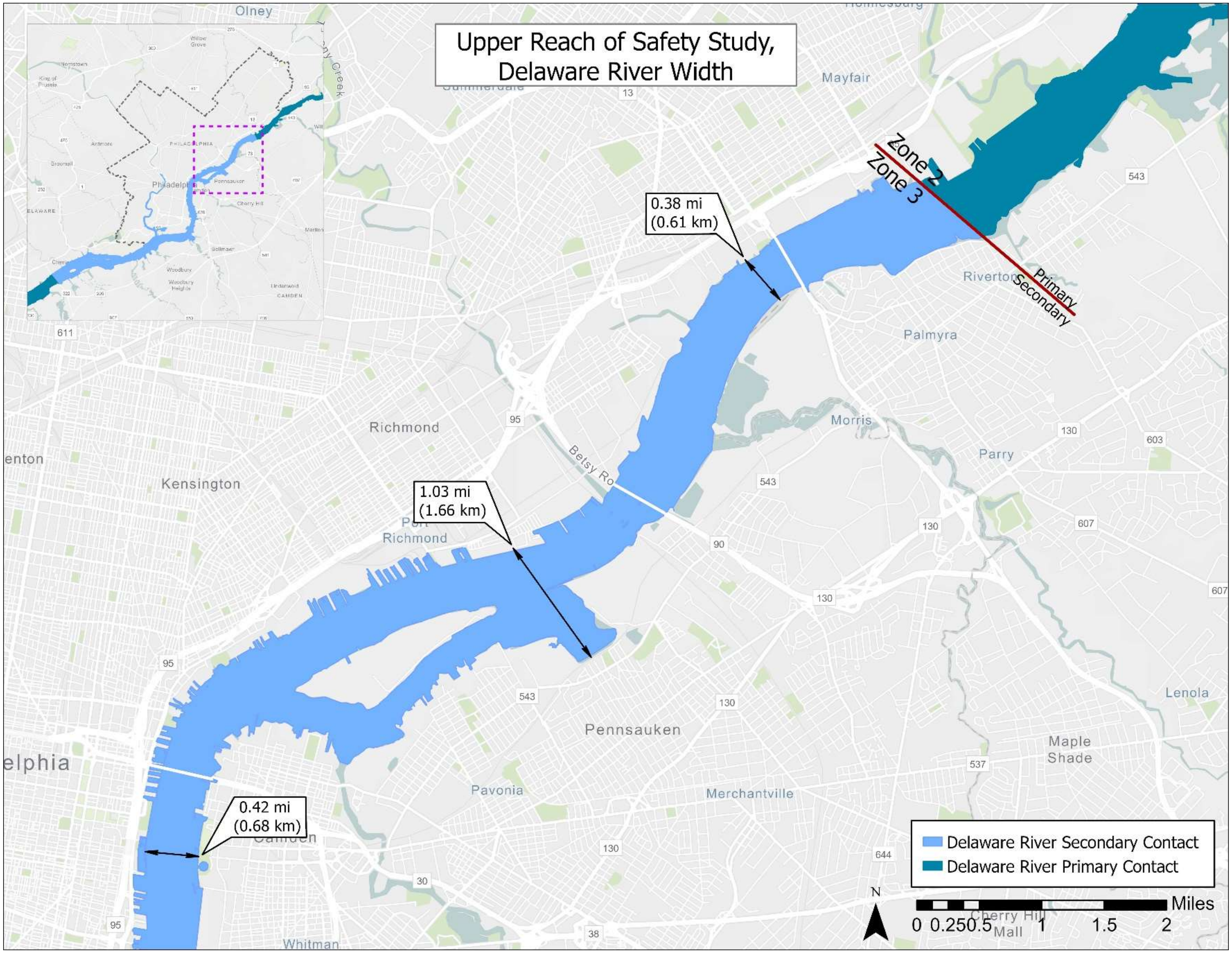

Figure A.24 Distance from Shore – Upper Reach Extent of Study Area

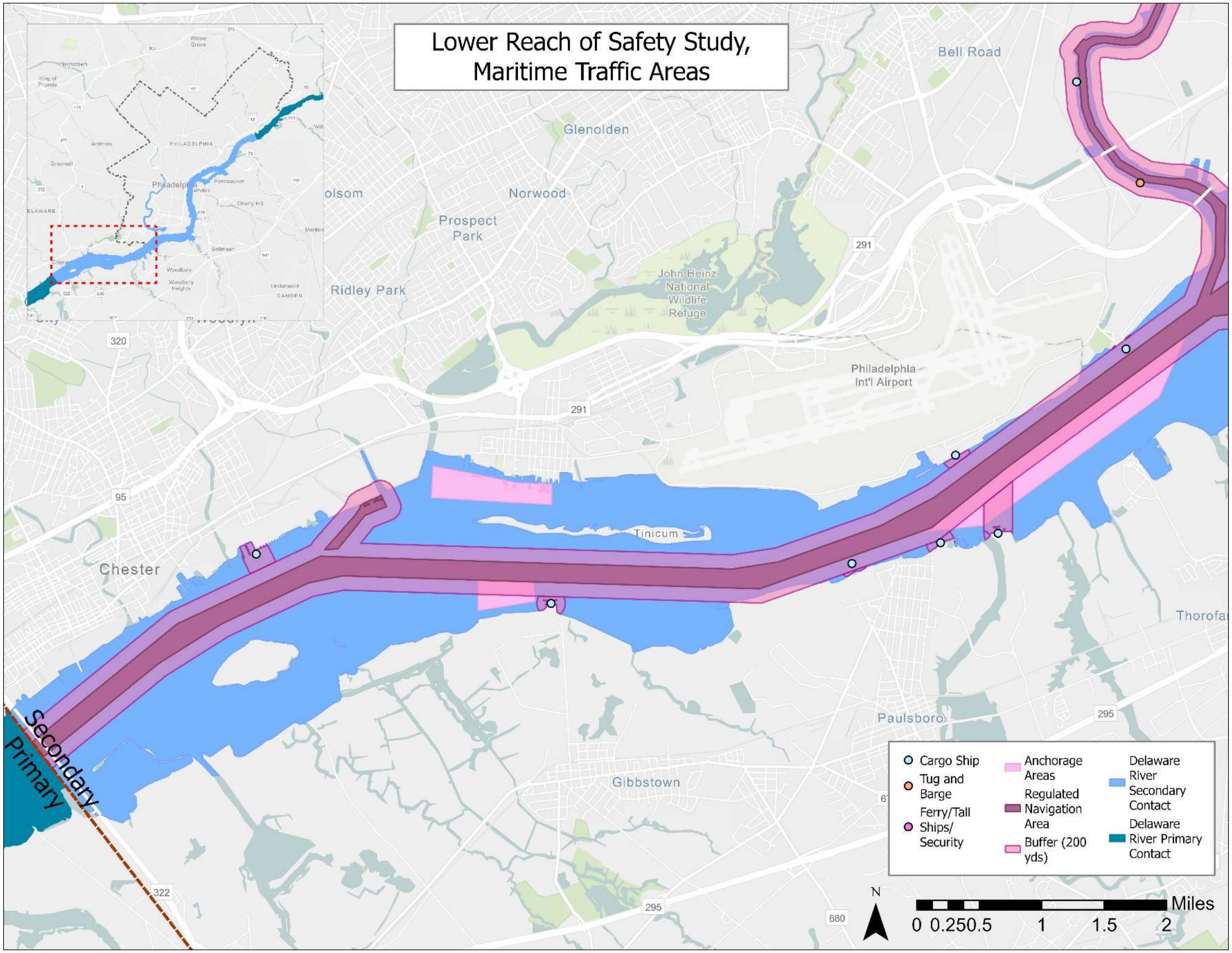

Figure A.25 Lower Reach Extent of Maritime Traffic Areas

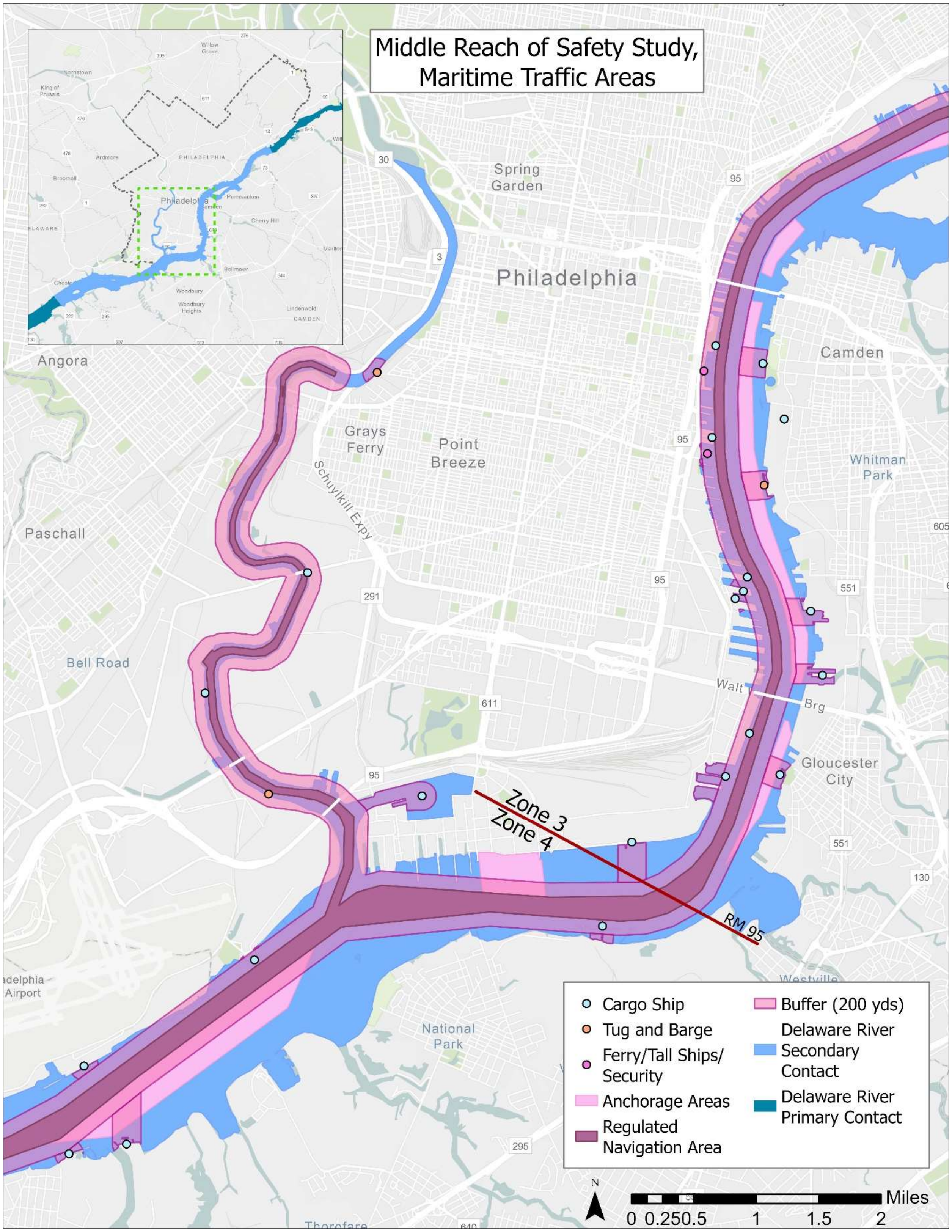

Figure A.26 Middle Reach Extent of Maritime Traffic Areas

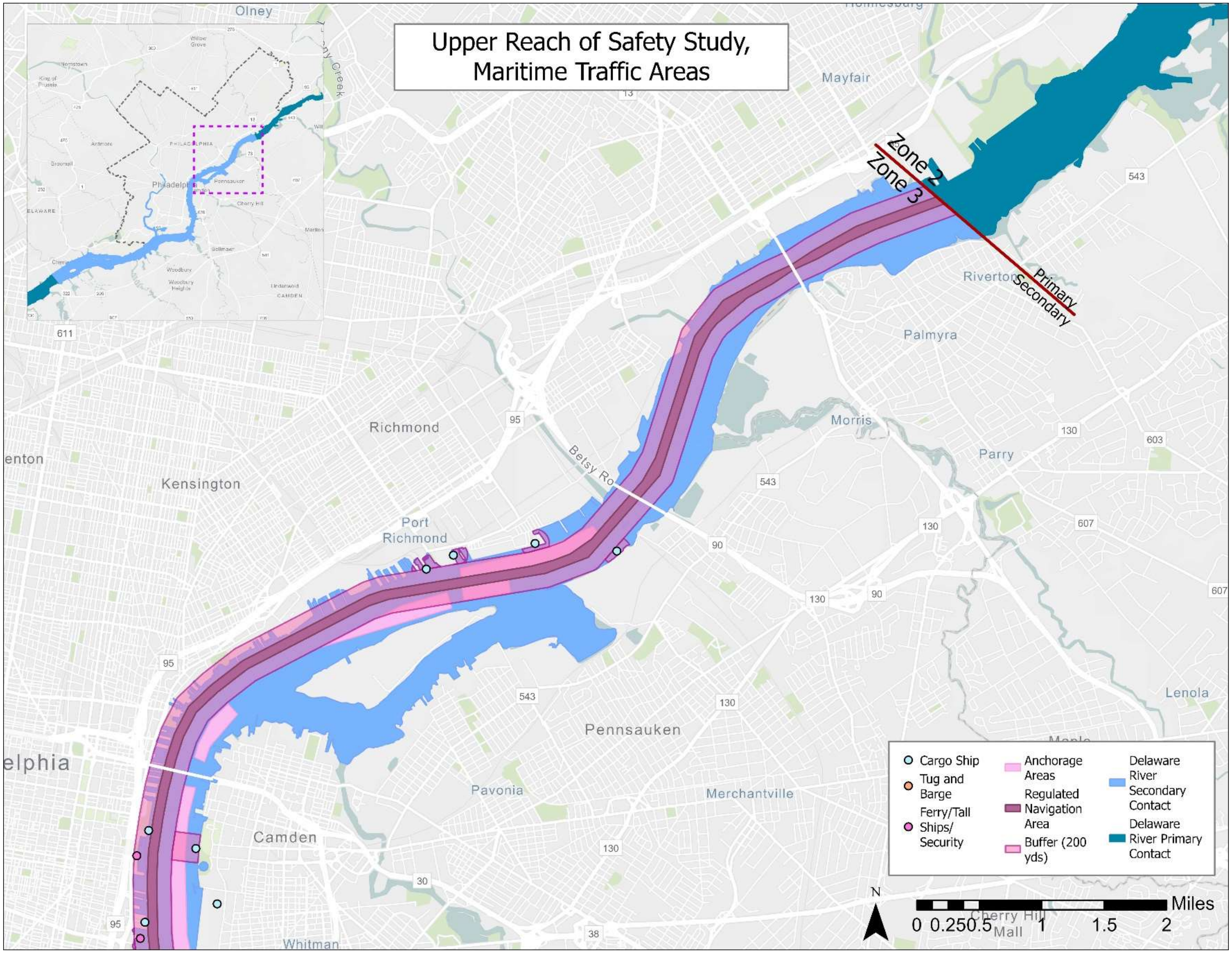

Figure A.27 Upper Reach Extent of Maritime Traffic Areas

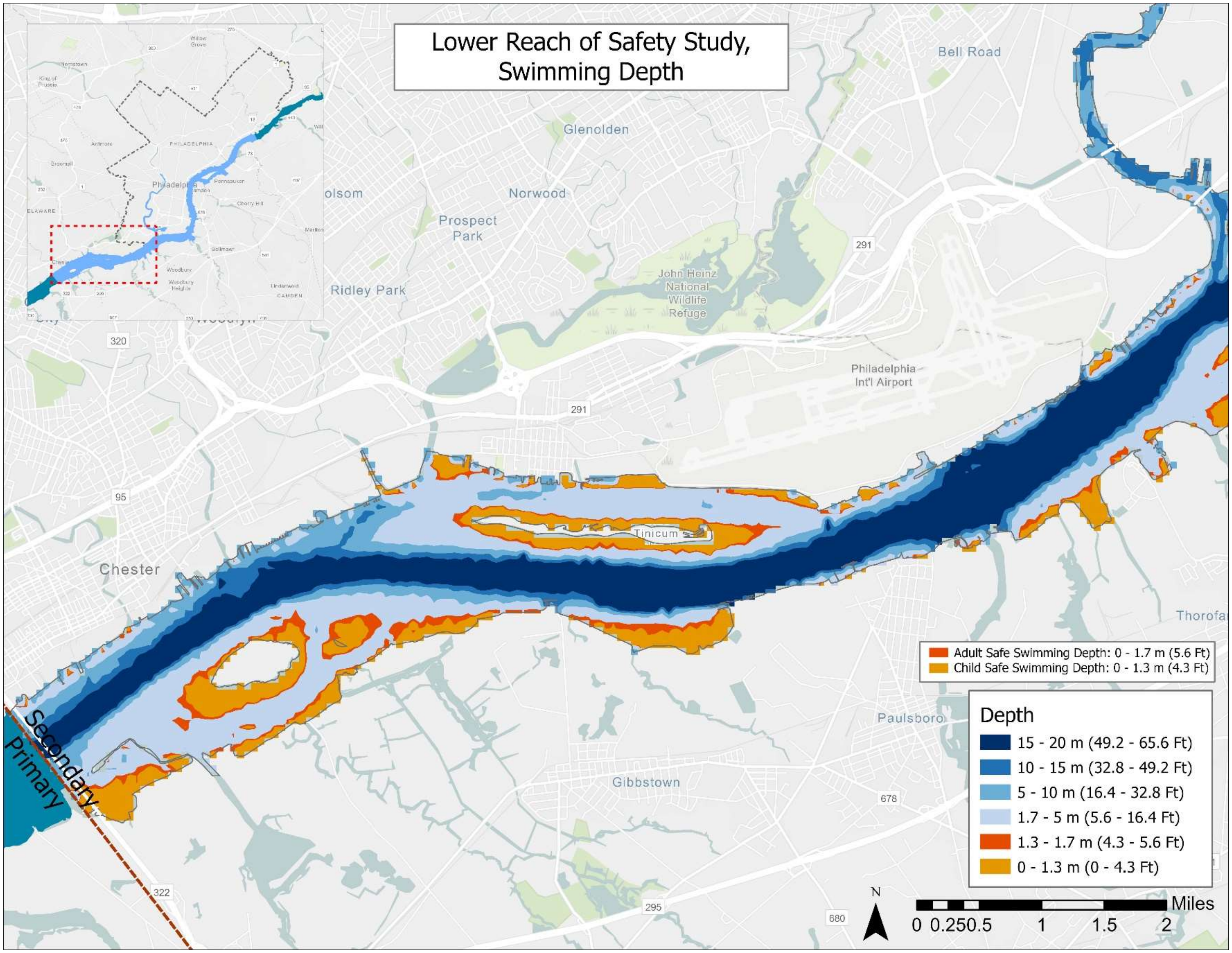

Figure A.28 Lower Reach Extent of Swimming Safety Criteria and Approximate Mean Tidal Depth

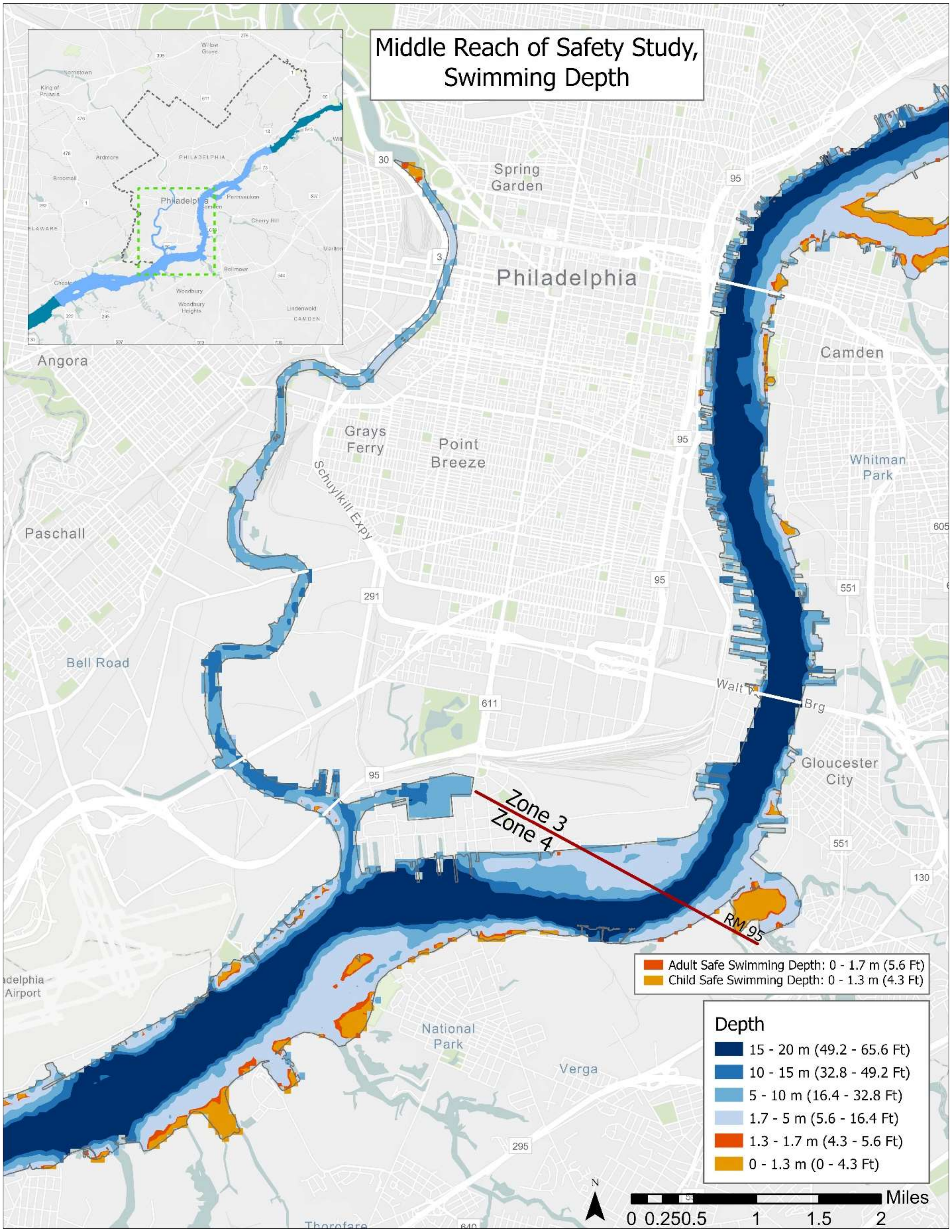

Figure A.29 Middle Reach Extent of Swimming Safety Criteria and Approximate Mean Tidal Depth

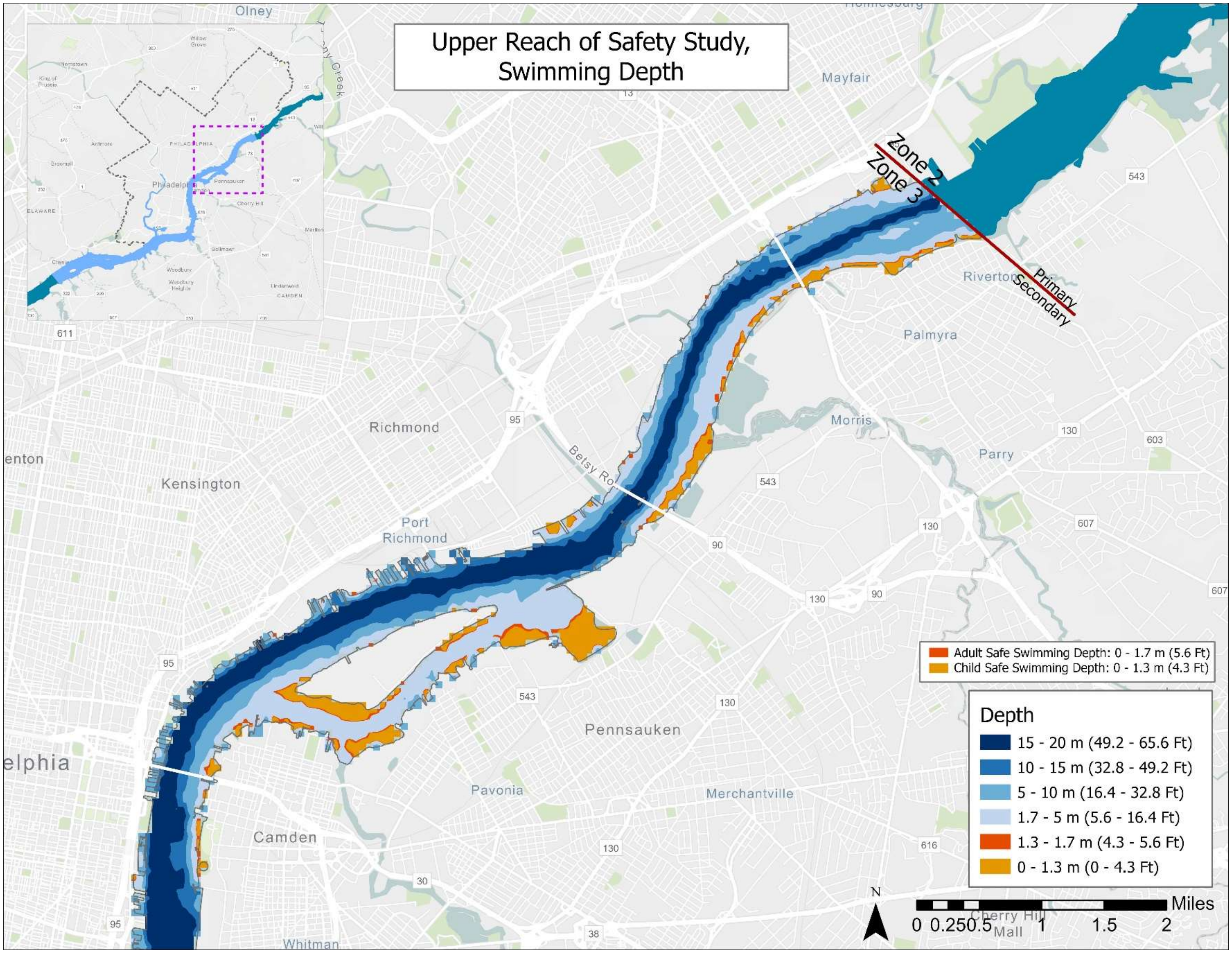

Figure A.30 Upper Reach Extent of Swimming Safety Criteria and Approximate Mean Tidal Depth

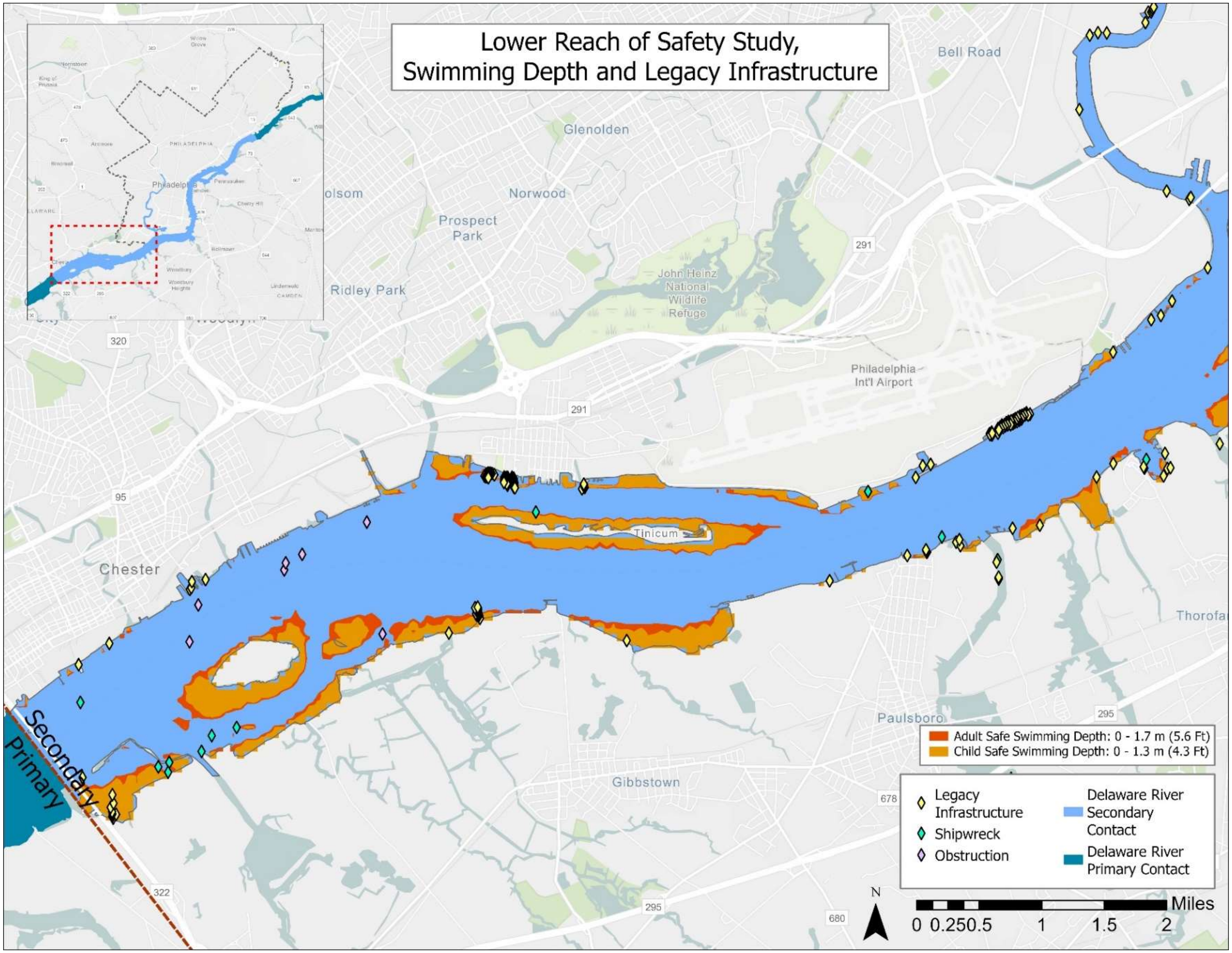

Figure A.31 Lower Reach Extent of Legacy Infrastructure and Safe Swimming Depth

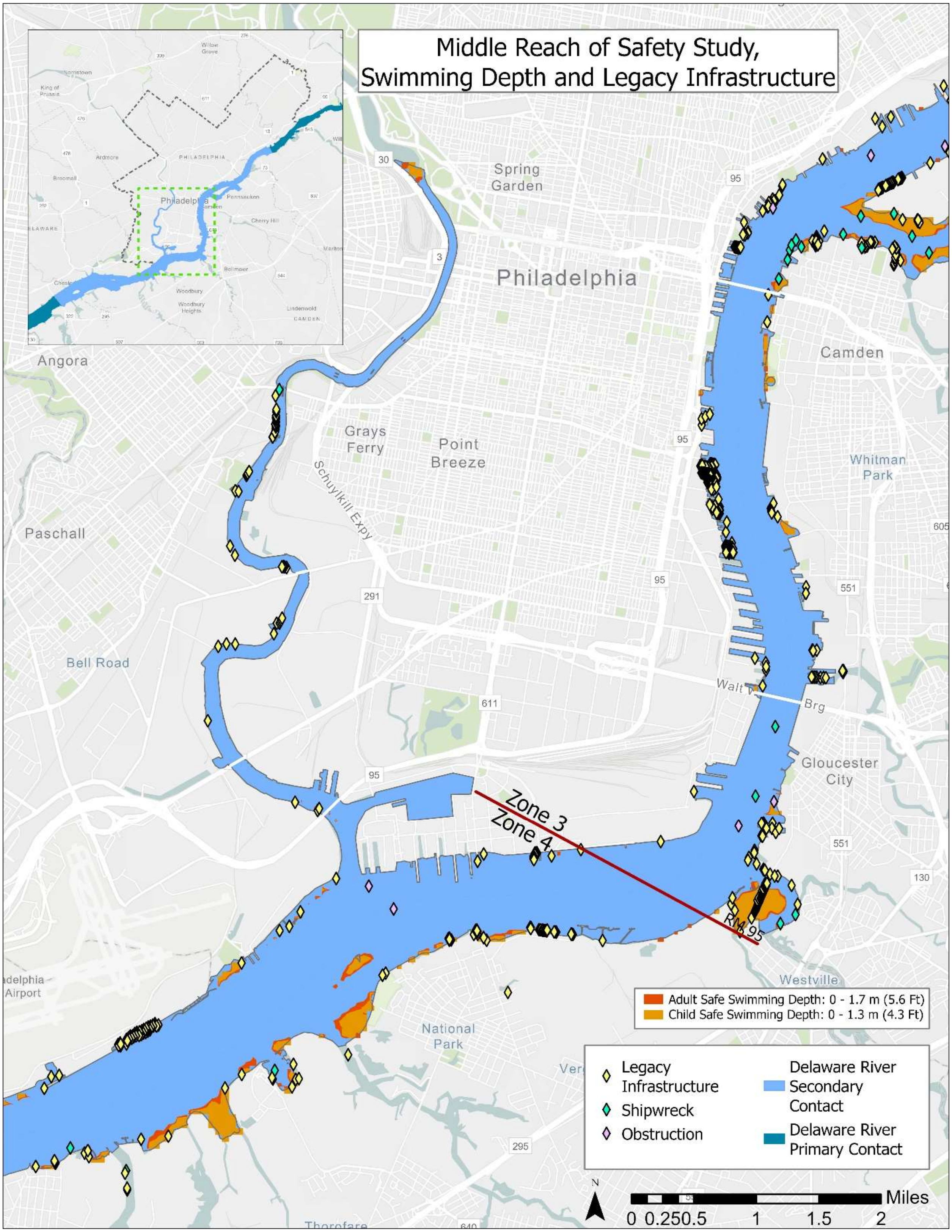

Figure A.32 Middle Reach Extent of Legacy Infrastructure and Safe Swimming Depth

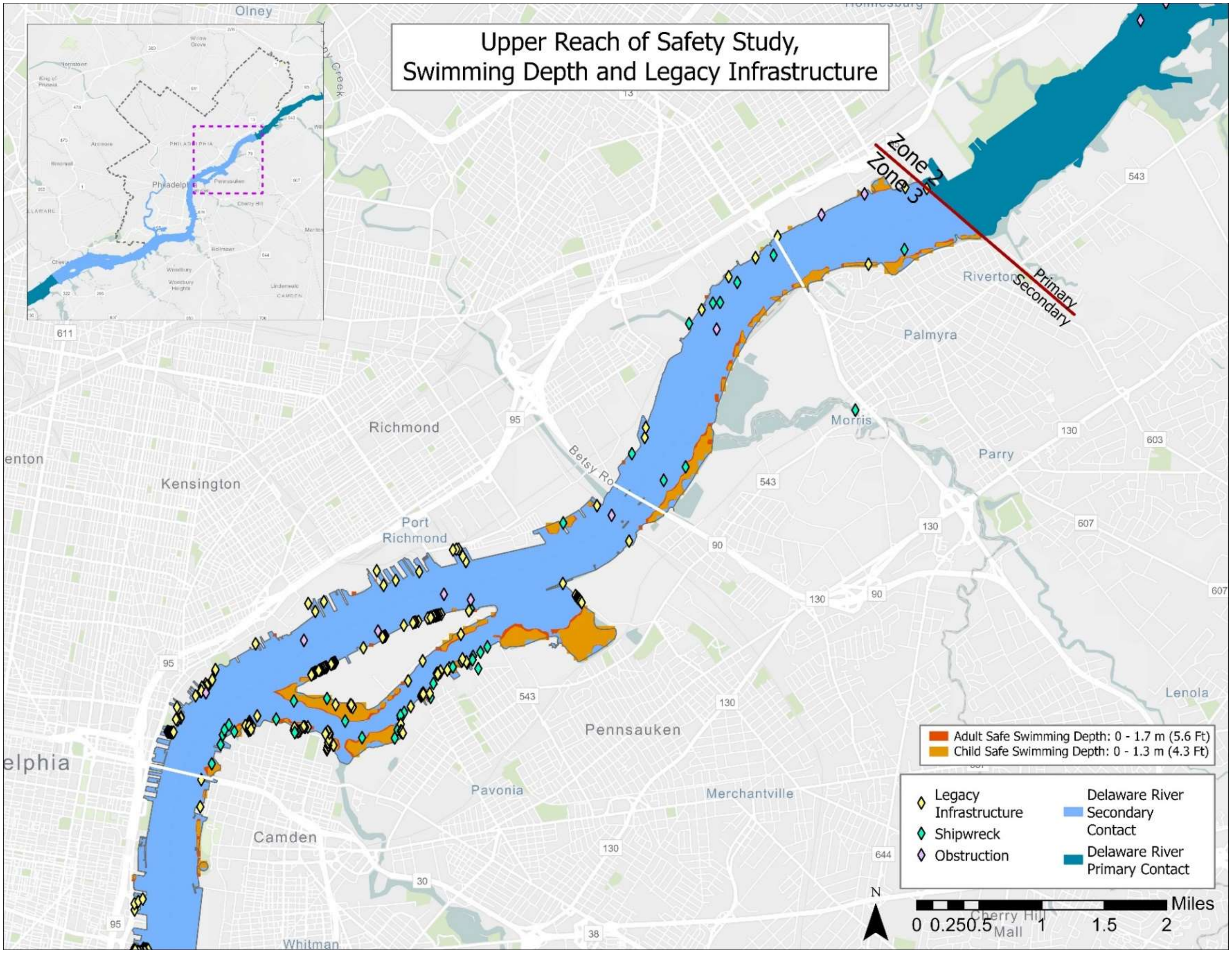

Figure A.33 Upper Reach Extent of Legacy Infrastructure and Safe Swimming Depth

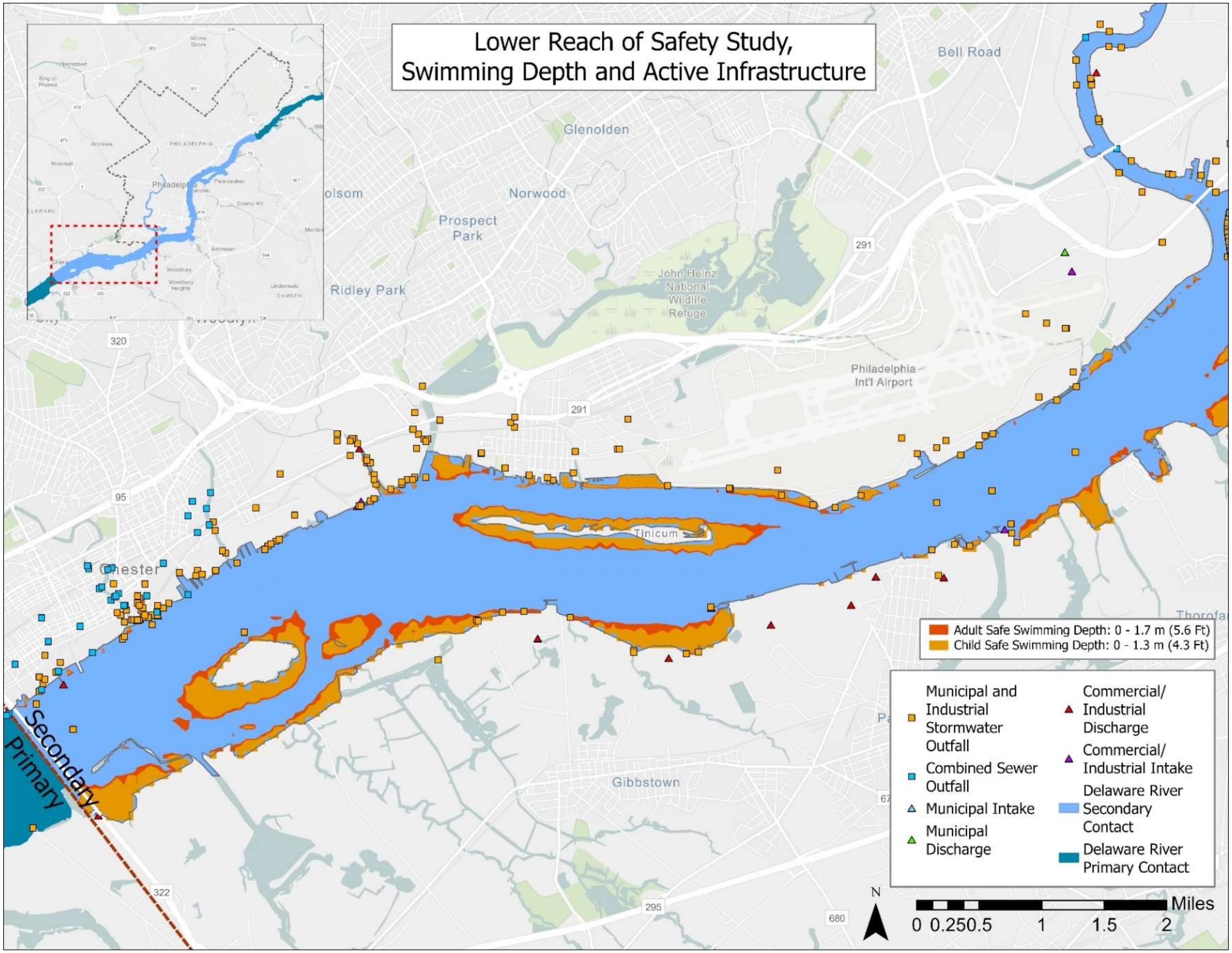

Figure A.34 Lower Reach Extent of Active Infrastructure and Safe Swimming Depth

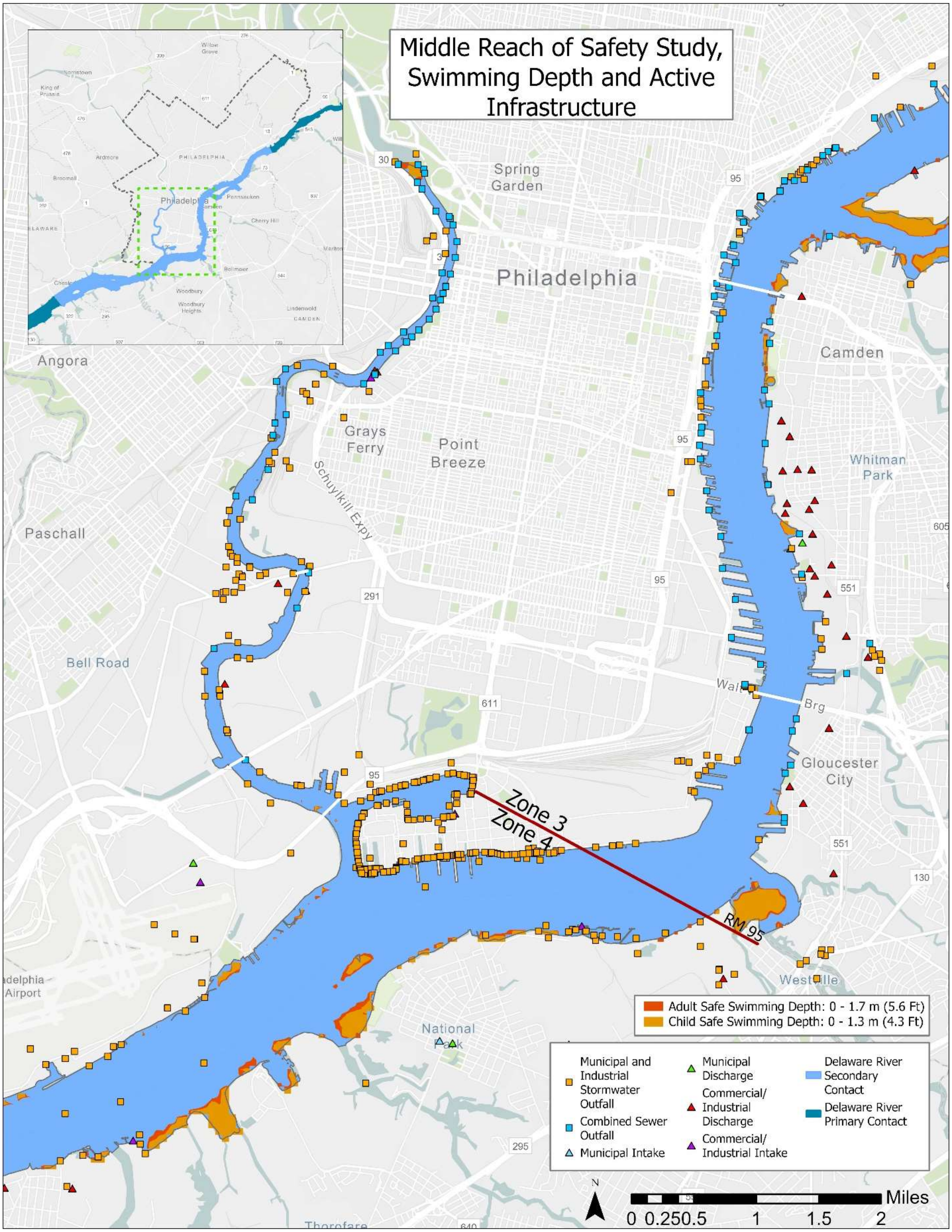

Figure A.35 Middle Reach Extent of Active Infrastructure and Safe Swimming Depth

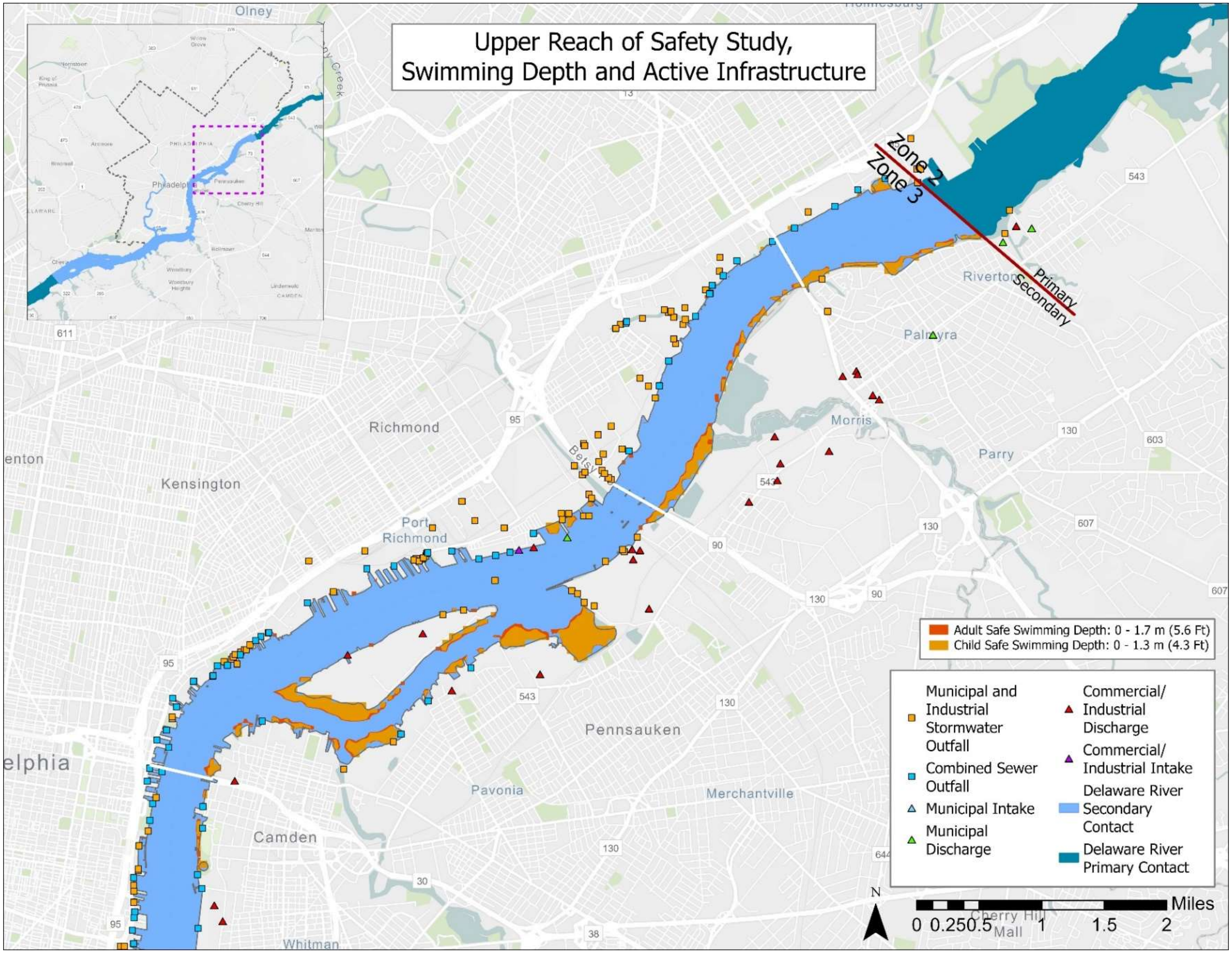

Figure A.36 Upper Reach Extent of Active Infrastructure and Safe Swimming Depth

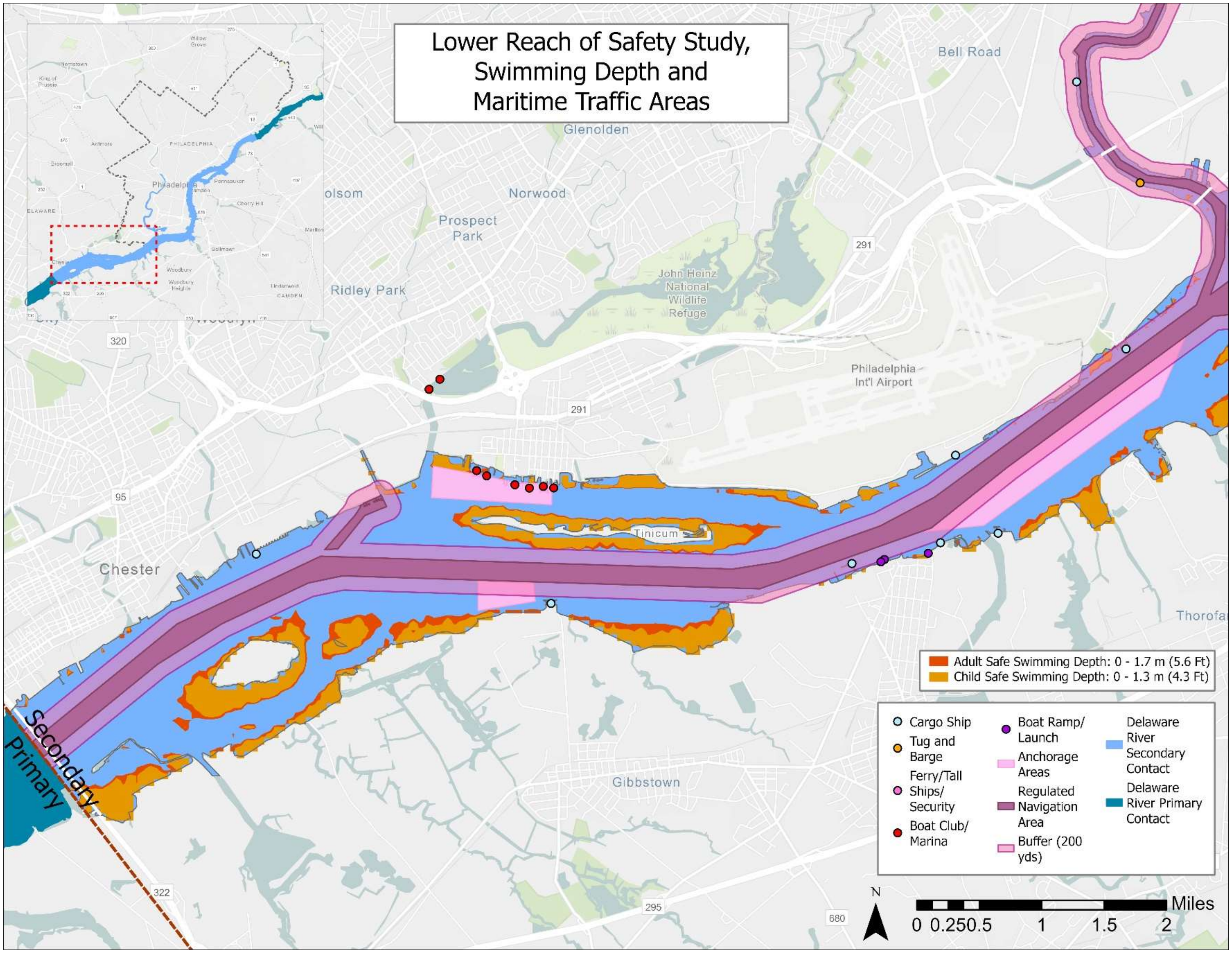

Figure A.37 Lower Reach Extent of Maritime Traffic Areas and Safe Swimming Depth

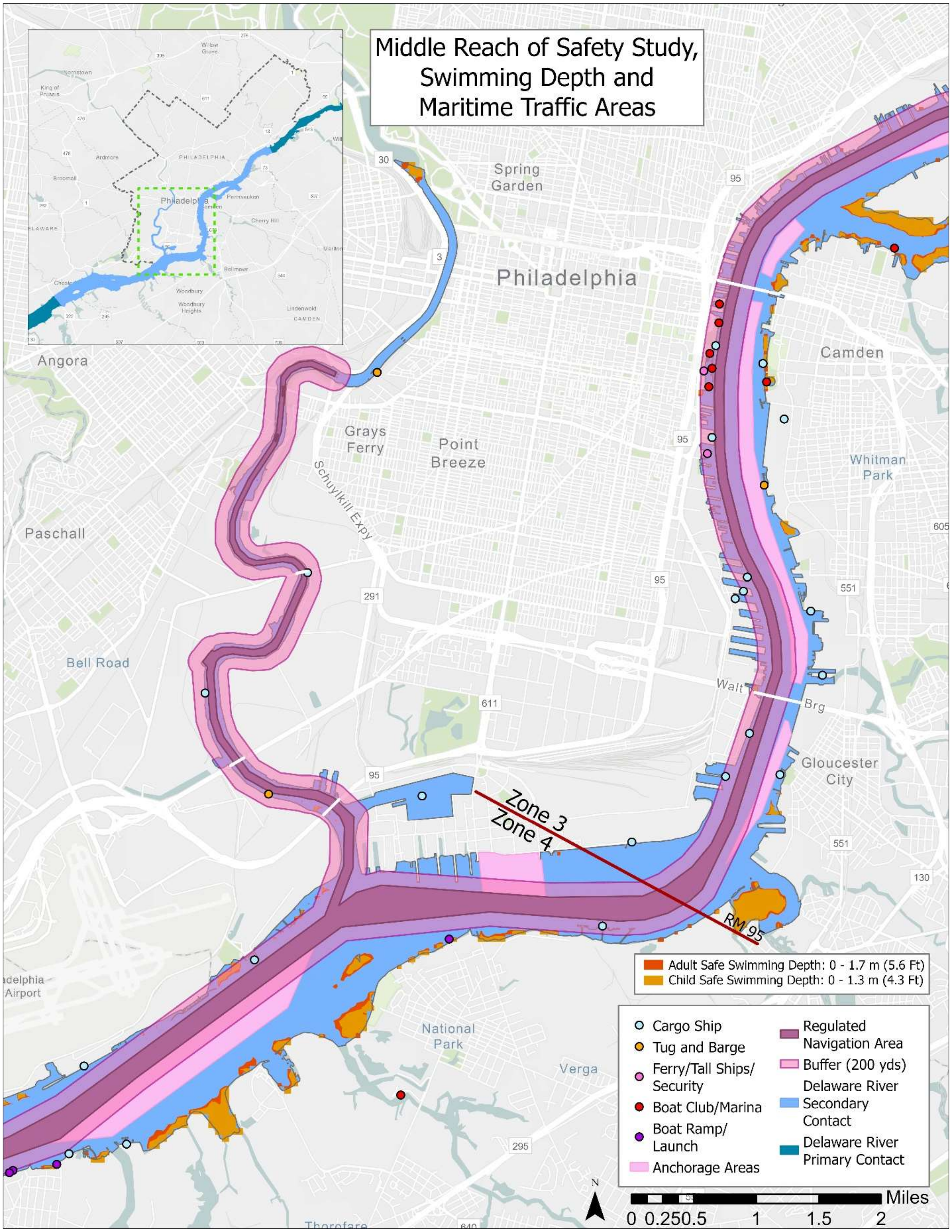

Figure A.38 Middle Reach Extent of Maritime Traffic Areas and Safe Swimming Depth

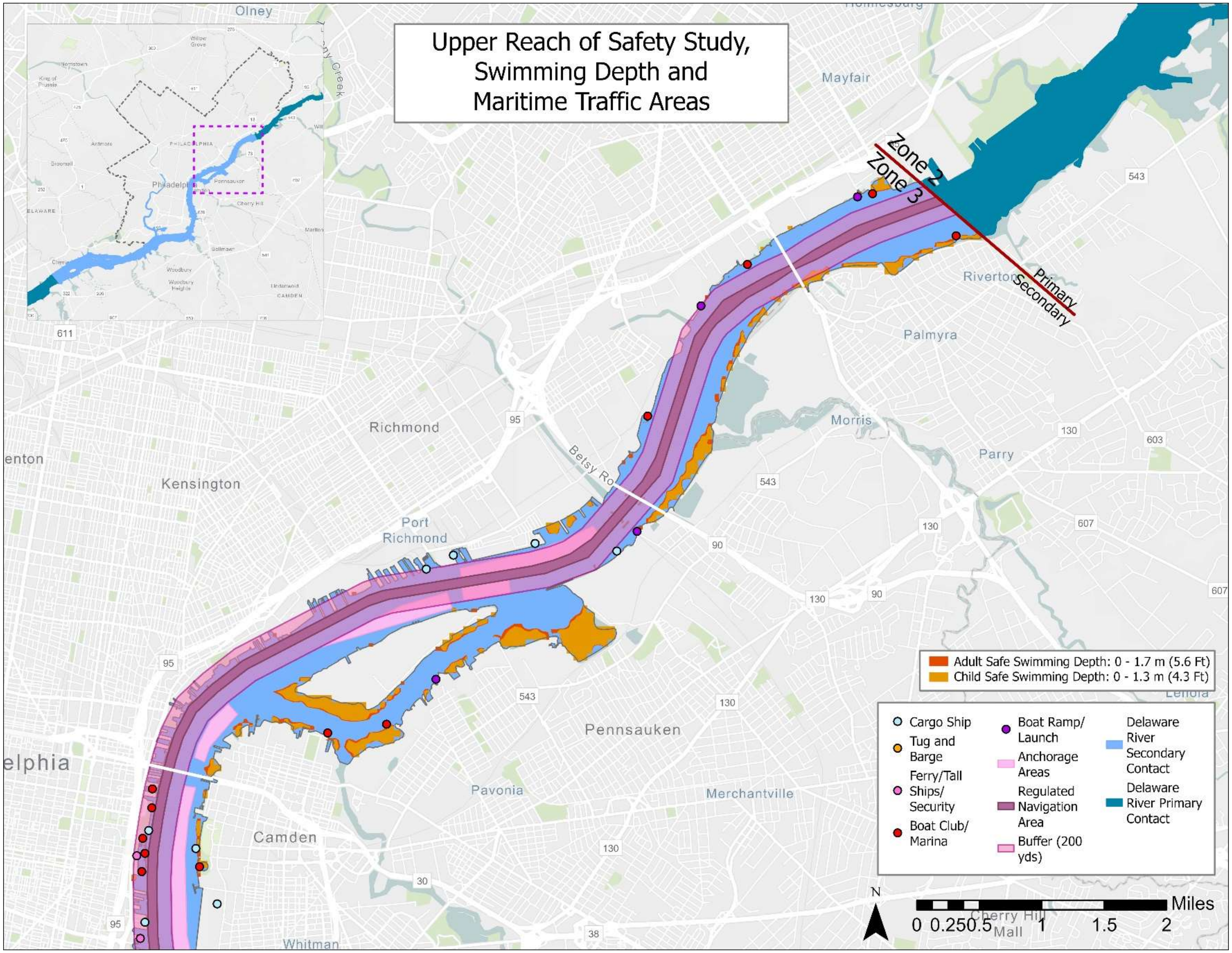

Figure A.39 Upper Reach Extent of Maritime Traffic Areas and Safe Swimming Depth

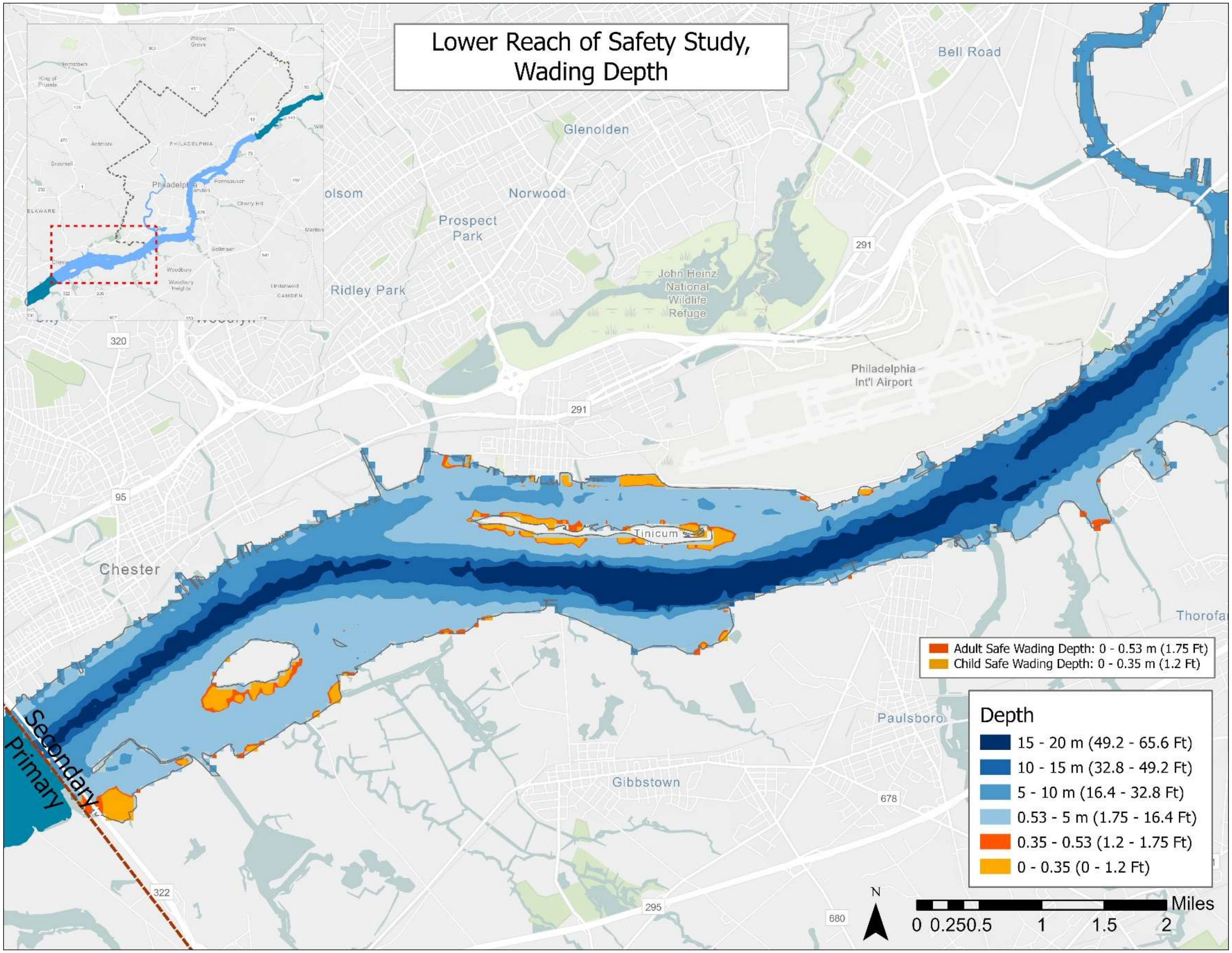

Figure A.40 Lower Reach Extent of Mean Tidal Depth and Safe Wading Depth

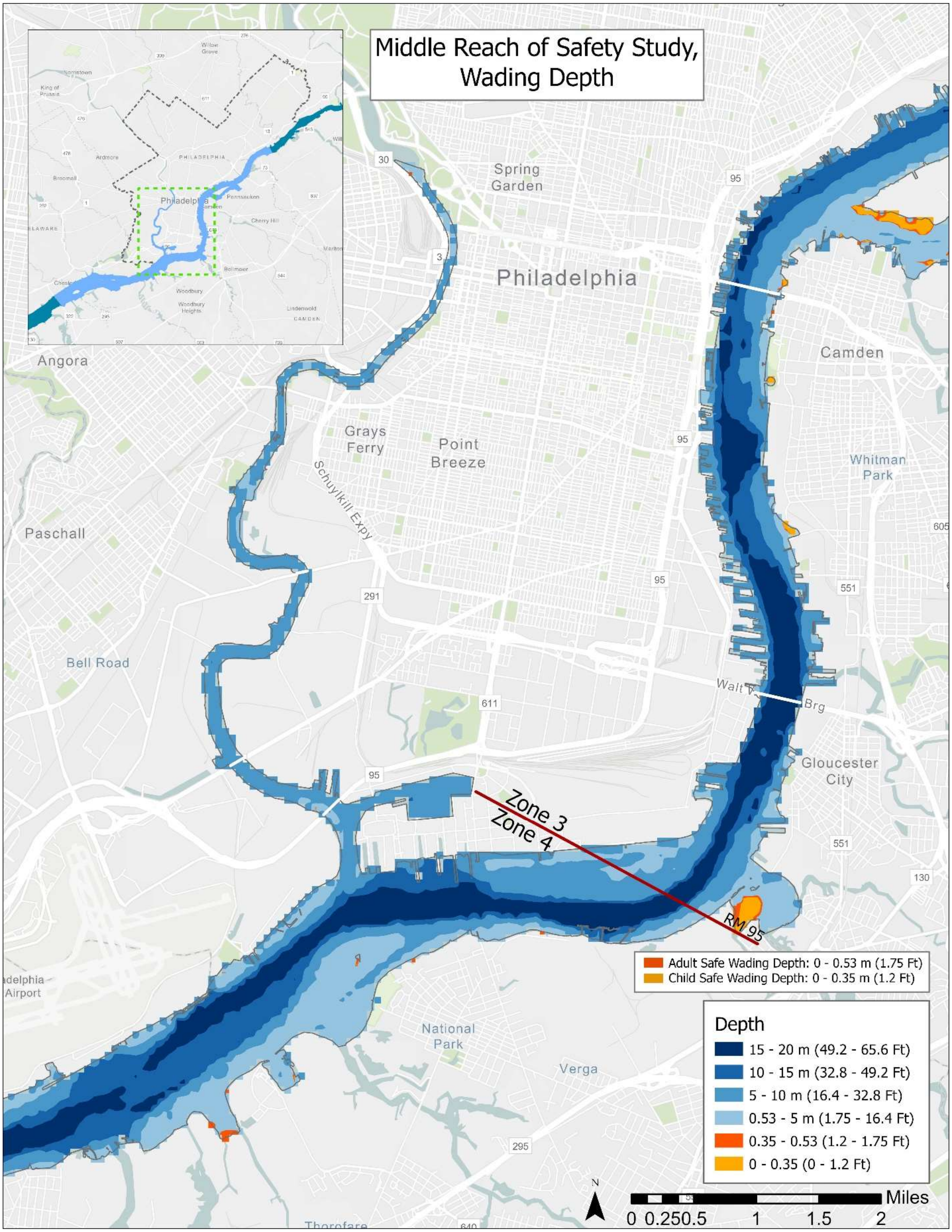

Figure A.41 Middle Reach Extent of Mean Tidal Depth and Safe Wading Depth

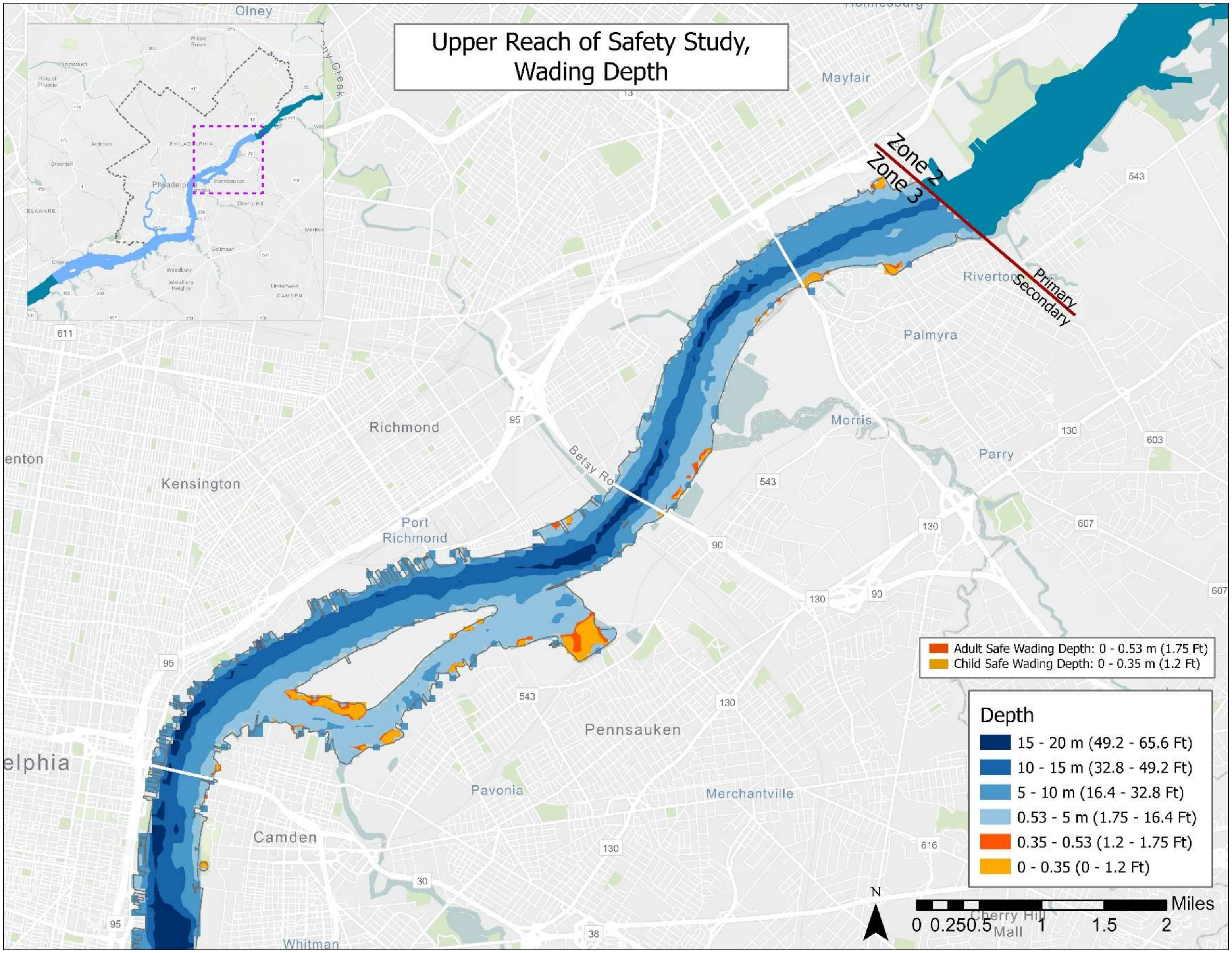

Figure A.42 Upper Reach Extent of Mean Tidal Depth and Safe Wading Depth

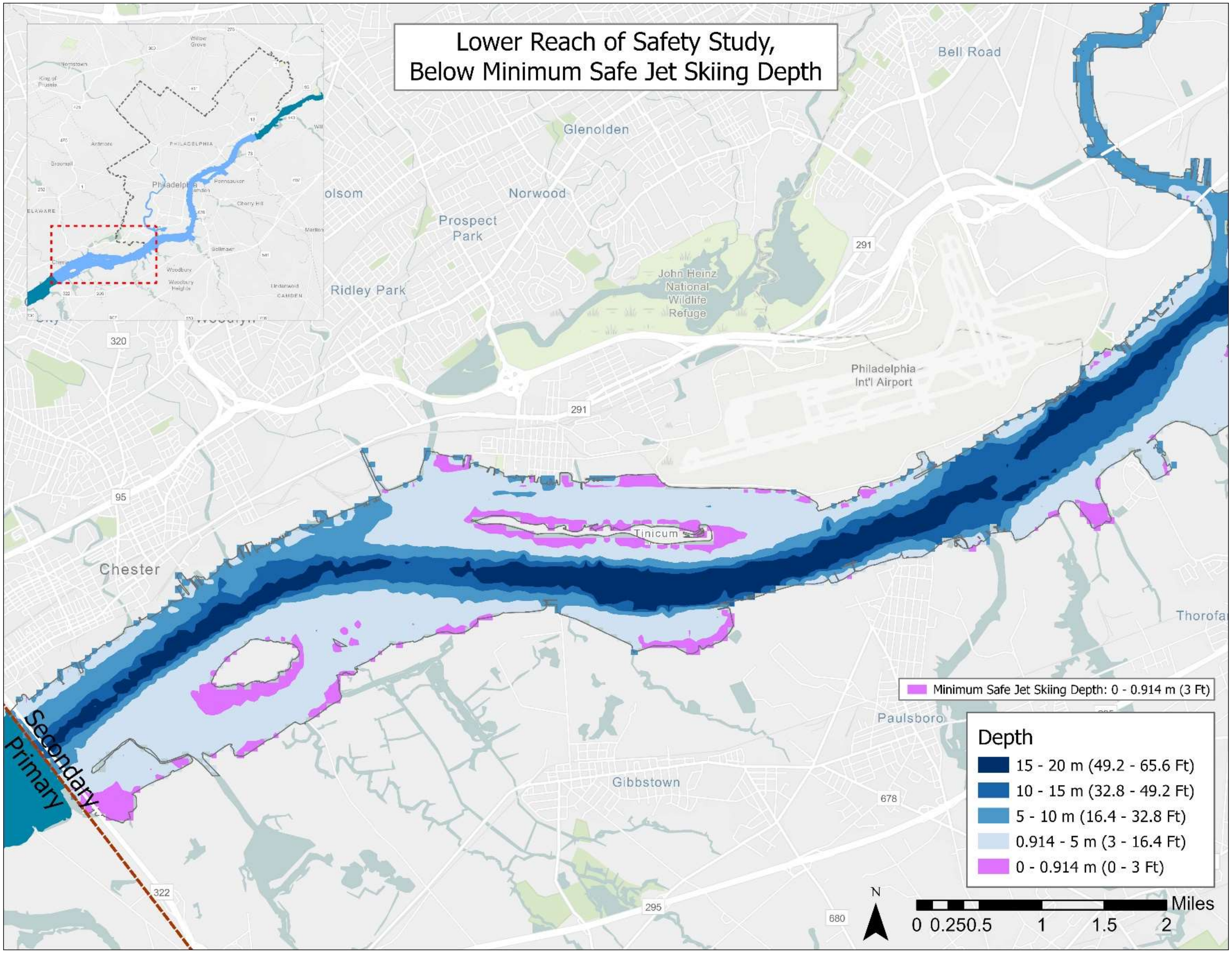

Figure A.43 Lower Reach Extent of Mean Tidal Depth and Safe Jet Skiing Depth

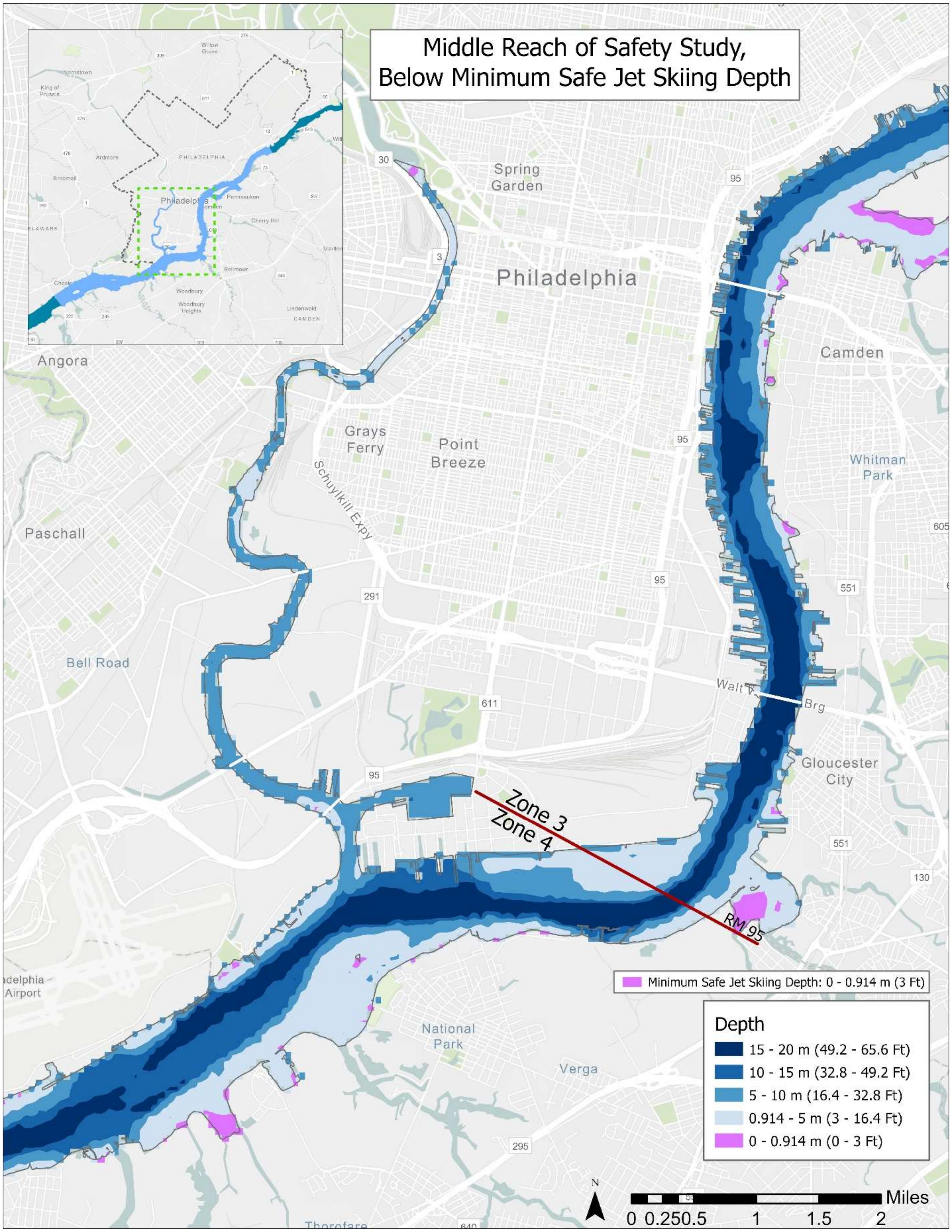

Figure A.44 Middle Reach Extent of Mean Tidal Depth and Safe Jet Skiing Depth

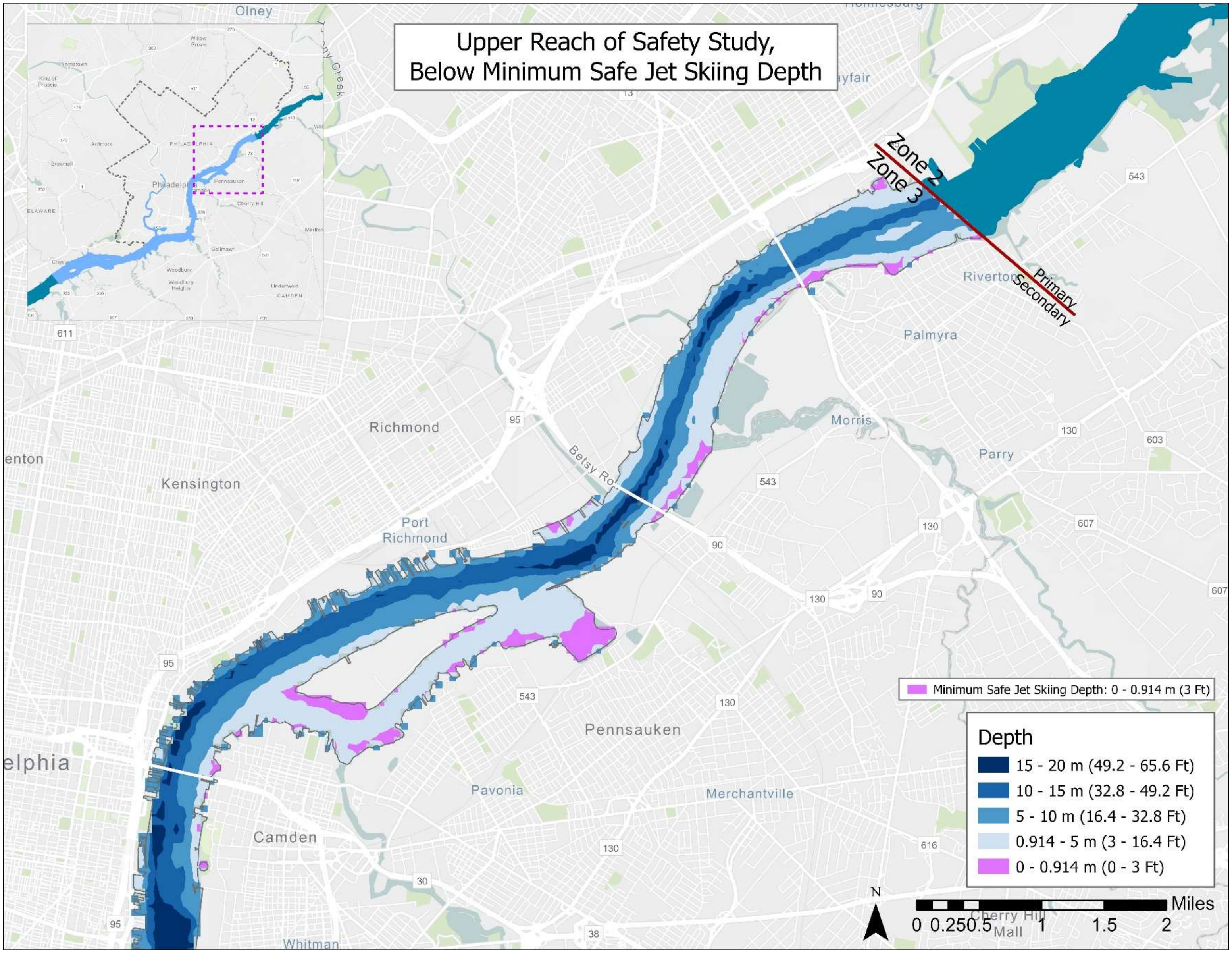

Figure A.45 Upper Reach Extent of Mean Tidal Depth and Safe Jet Skiing Depth

Appendix B Map Data Sources

Appendix B details the data sources used in all maps in the main report and Appendix A. Data sources are so numerous, especially in the more complex maps, that Appendix B is provided instead of listing map data sources within each map. Appendix B is organized by map layer, in alphabetical order. Each data source used in each layer is described as well as any modifications made. In many instances, new map layers are created from multiple data sources which are cited, and the consolidated layer is attributed to Sage Services.

Basemap

The reference map on which all other data layers are overlain. This map is made of multiple layers.

CIM_Technology (2019). *CIM Light Gray Canvas.* Retrieved from: https://www.arcgis.com/home/item.html?id=fecb5021dab64ee69e3c4f795a601754

Erwinn_NewGIN (2021). *Slight Color Grey Canvas Base.* Retrieved from: https://basemaps.arcgis.com/arcgis/rest/services/World_Basemap_v2/VectorTileServer

Sage Services, LLC (2021). *Delaware River Primary Contact*. Custom dataset created on ArcGIS Pro.

Sage Services, LLC (2021). *Delaware River Secondary Contact*. Custom dataset created on ArcGIS Pro.

Anchorage Areas

Office for Coastal Management (2022). *Anchorage Areas.* Retrieved from: https://www.fisheries.noaa.gov/inport/item/48849.

Bathymetry

PWD provided bathymetry point cloud that combines sounding datasets from NOAA National Geophysical Data Center Digital Elevation Model Discovery Portal (2013), PWD (2011-2013), and Army Corps of Engineers (2011-2016). Bathymetry data from PWD modified using the ArcGIS Pro geoprocessing spatial analysis tool "Spline with Barriers", resulting in a new layer of the Study Area.

City of Philadelphia (2016). *Bathymetry.* Retrieved from PWD.

Sage Services, LLC (2022). *Bathymetry*. Custom dataset created on ArcGIS Pro.

Bridges

Polyline graphics layer was created using the latitude and longitude derived from visual inspection of Pennsylvania Spatial Data Access (PASDA) satellite imagery from 2015 and 2020.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Bridges*. Custom dataset created on ArcGIS Pro.

Boat Club/Marina

Custom dataset created on ArcGIS Pro. Maritime facility data was provided by the Maritime Exchange Commission. A point layer was created by locating these facilities through visual inspection of Google Earth and PASDA satellite imagery.

Google (n.d.). [*Google Maps Delaware River, Philadelphia, PA*]. Retrieved 2021.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Maritime Points of Interest*. Custom dataset created on ArcGIS Pro.

Boat Ramp/Launch

Custom dataset created on ArcGIS Pro. Maritime facility data was provided by the Maritime Exchange Commission. A point layer was created by locating these facilities through visual inspection of Google Earth and PASDA satellite imagery.

Google (n.d.). [*Google Maps Delaware River, Philadelphia, PA*]. Retrieved 2021.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Maritime Points of Interest*. Custom dataset created on ArcGIS Pro.

Cargo Ship

Custom dataset created on ArcGIS Pro. Maritime facility data was provided by the Maritime Exchange Commission. A point layer was created by locating these facilities through visual inspection of Google Earth and PASDA satellite imagery.

Google (n.d.). [*Google Maps Delaware River, Philadelphia, PA*]. Retrieved 2021.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Maritime Points of Interest*. Custom dataset created on ArcGIS Pro.

Combined Sewer Outfall

Several datasets are utilized in conjunction.

NJDEP Bureau of GIS (2016). *Combined Sewer Overflow (CSO) for NJ.* Retrieved from: https://gisdata-njdep.opendata.arcgis.com/datasets/25bace29e8114519b2d08d04c75873f3_0/explore?location=40.408472%2C-74.554350%2C9.00

City of Philadelphia (2021). *Stormwater_Outfalls.* Retrieved from: https://services2.arcgis.com/POWz8dBwmjnei8fu/arcgis/rest/services/Stormwater_Outfalls/FeatureServer

DELCORA (2021). *DELCORA_CSO_Regulator*. Dataset provided by DELCORA.

DELCORA (2021). *DELCORA_Outfall*. Dataset provided by DELCORA.

Commercial/Industrial Discharge

DRBC (2022). *All Docket*. Retrieved from: https://services1.arcgis.com/HERT3Lrqxe0YUfxz/arcgis/rest/services/All_Docket/FeatureServer

Commercial/Industrial Intake

DRBC (2022). *All Docket*. Retrieved from: https://services1.arcgis.com/HERT3Lrqxe0YUfxz/arcgis/rest/services/All_Docket/FeatureServer

Ferry/Tall Ships/Military

Custom dataset created on ArcGIS Pro. Maritime facility data was provided in a table by the Maritime Exchange Commission. A point layer was created by locating these facilities through visual inspection of Google Earth and PASDA satellite imagery.

Google (n.d.). [*Google Maps Delaware River, Philadelphia, PA*]. Retrieved 2021.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Maritime Points of Interest*. Custom dataset created on ArcGIS Pro.

Legacy Infrastructure

Custom dataset created on ArcGIS Pro. Legacy infrastructure points were derived using visual inspection of Pennsylvania Spatial Data Access satellite imagery from 2015 and 2020. Large, intact legacy infrastructure such as decaying docks or railroad beds was identified as one singular point. For example, one visibly intact decaying dock is identified as one point, which represents the entire object. Smaller, individual legacy infrastructure such as dock piling or debris, is identified as multiple points.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Legacy Infrastructure*. Custom dataset created on ArcGIS Pro.

Maritime Points of Interest Buffer

Custom dataset created on ArcGIS Pro. Data was created using the "Buffer" geoprocessing analysis tool.

Sage Services, LLC (2022). *Maritime Points of Interest Buffer (200 yards).* Custom dataset created on ArcGIS Pro.

Municipal and Industrial Stormwater Outfall

Several datasets are utilized in conjunction.

City of Philadelphia (2021). *Stormwater_Outfalls.* Retrieved from: https://services2.arcgis.com/POWz8dBwmjnei8fu/arcgis/rest/services/Stormwater_Outfalls/FeatureServer

NJDEP Bureau of GIS (2017). *Outfalls in New Jersey, NJDEP MS4 Inventory and Mapping*. Retrieved from: https://gisdata-njdep.opendata.arcgis.com/datasets/outfalls-in-new-jersey-njdep-ms4-inventory-and-mapping/explore?location=40.238821%2C-74.930050%2C9.87

NJDEP Bureau of GIS (2022). *NJPDES Surface Water Discharges in New Jersey, (1:12,000)*. Retrieved from: https://gisdata-njdep.opendata.arcgis.com/datasets/njdep::njpdes-surface-water-discharges-in-new-jersey-112000/explore?location=39.927958%2C-75.106389%2C11.98

Pennsylvania Department of Environmental Protection (2022). *Water Pollution Control Facilities*. Retrieved from: https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=288

Municipal Discharge

DRBC (2022). *All Docket*. Retrieved from: https://services1.arcgis.com/HERT3Lrqxe0YUfxz/arcgis/rest/services/All_Docket/FeatureServer

Municipal Intake

DRBC (2022). *All Docket*. Retrieved from: https://services1.arcgis.com/HERT3Lrqxe0YUfxz/arcgis/rest/services/All_Docket/FeatureServer

Navigation Channel Buffer

Custom dataset created on ArcGIS Pro. Data was created using the “Buffer” geoprocessing analysis tool.

Sage Services, LLC (2022). *Navigation Channel Buffer (200 yards).* Custom dataset created on ArcGIS Pro.

NOAA db0301

Custom dataset created on ArcGIS Pro. The dataset “dxdy_fineGrid_R21” was used to locate db0301. A point layer was created once db0301 was located.

City of Philadelphia (2020). *Philadelphia Aerial Photography 2020*. Retrieved from: https://metadata.phila.gov/#home/datasetdetails/569684f4c99154d56b426105/

Obstruction

Office of Coast Survey (2022). *Office of Coast Survey's Automated Wreck and Obstruction Information System.* Retrieved from: https://www.fisheries.noaa.gov/inport/item/39961.

PWD Buoys

For “PWD Buoy B” and “PWD Buoy C”.

City of Philadelphia (2020). *PWD_Buoys*. Retrieved from: https://services2.arcgis.com/POWz8dBwmjnei8fu/arcgis/rest/services/PWD_Buoys/FeatureServer

Regulated Navigation Area

Office for Coastal Management (2022). *Regulated Navigation Areas.* Retrieved from: https://www.fisheries.noaa.gov/inport/item/54194.

Shipwrecks

Office of Coast Survey (2022). *Office of Coast Survey's Automated Wreck and Obstruction Information System.* Retrieved from: https://www.fisheries.noaa.gov/inport/item/39961.

Tug and Barge

Custom dataset created on ArcGIS Pro. Maritime facility data was provided by the Maritime Exchange Commission. A point layer was created by locating these facilities through visual inspection of Google Earth and PASDA satellite imagery.

Google (n.d.). [*Google Maps Delaware River, Philadelphia, PA*]. Retrieved 2021.

PASDA (2015). *Delaware Valley Regional Planning Commission, 2015*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/DVRPC2015/MapServer

PASDA (2020). *Philadelphia Imagery, 2020*. Retrieved from: https://imagery.pasda.psu.edu/arcgis/rest/services/pasda/PhiladelphiaImagery2020/MapServer

Sage Services, LLC (2022). *Maritime Points of Interest*. Custom dataset created on ArcGIS Pro.

Wave Calculation Reaches

Custom dataset created on ArcGIS Pro using .KMZ layer created by CDM Smith. The .KMZ layer was converted into polylines using the ArcGIS "KML to Layer" geoprocessing tool.

Sage Services, LLC (2022). *Wave Calculation Reaches Polylines*. Custom dataset created on ArcGIS Pro.