The Applicability of Geographic Information Systems (GIS) and Remote Sensing in Identifying Polybrominated Diphenyl Ethers (PBDEs) sources using NOAA National Status & Trends Mussel Watch Program Data

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Abstract –

With an ongoing assessment of more than two decades, the Mussel Watch Program is one of the longest running contaminant monitoring programs in the coastal ocean with more than 20 years of data. Mussel Watch uses bivalves (Mussels, Oysters, and Zebra Mussels) as a means to assess water quality. The purpose of the program is geared towards assessing contaminants nationally

Utilizing formats such as Geographic Information Systems (GIS) and Remote Sensing data assessment, an attempt will be made within this project to identify possible releasers of effluent waste into the major coastal watershed regions pertaining to ongoing research conducted within monitored mussel watch sites. The categorization of possible contaminating locations will be made available through the development of a large dataset. This dataset will utilize those derived from agencies such as the United States Environmental Protection Agency (U.S. EPA) and other state government databases such as the National Oceanic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS).

Utilizing platforms such as ESRI® ArcMap™ software, spatially referenced locations, via point data, vector data, line data, and polygons depicting points and sites of interest will be created using latitude and longitude information. Points and areas of interest (AOI) will be verified using Remote Sensing imagery. As such, Polybrominated Diphenyl Ethers (PBDEs) within observable mussel watch sites will be assessed by NOAA's Center for Coastal Monitoring and Assessment (CCMA). Using this data, researchers will be able to identify possible sources of contributors to the present contaminant.

I. Introduction

With a long standing tradition of more than two decades of continuous monitoring, Mussel Watch Program encompasses one of the longest running National Oceanic and Atmospheric Administration (NOAA) projects. For over twenty-three year's scientists have monitored bivalve organism, assessing their physiology for measurable levels of contaminants. Using bivalves such as mussels as a medium, scientists utilize these creatures base on their characteristics and ability to retain contaminants when filtering ocean waters. Thus, their fleshy tissues and limited ability to metabolize introduced contaminants make them the ideal specimen to study.

As such, the Mussel Watch Program primarily bases its studies on the assessment of specified mollusks (Mussels, Oysters, and Zebra Mussels) as a part of the national coastal monitoring program.

To date, approximately 372 sites have been sampled by the Mussel Watch program (Fig.1.). Of these seven targeted species of mollusk are identified within these sites for active collection. Collection sites are located within 28 states that are exposed to major coastal zones, including the Great Lakes, and American territories, Guam and Puerto Rico (Kimbrough, et al. 2008). It should be noted that within assessed bivalve populations, approximately 150 contaminates are monitored. These contaminants comprised of trace metals, industrial compounds, and pesticides (Kimbrough, et al. 2009).

In 1972 the United States Environmental Protection Agency (U.S. EPA) began regulation of the Congress proposed Clean Water Act (CWA) which strongly urges national compliance in the awareness of the nations waters (Leavitt et al. 2006). Along with the CWA, U.S. EPA also authorized the implementation of the National Pollution Discharge Elimination System (NPDES). Under implementation of the CWA, the U.S. EPA through the NPDES program is required to monitor all facilities that release waters, both treated and sewage, to obtain permits issued by U.S. EPA. Permits are controlled and enforced by state delegates as well as the U.S EPA.

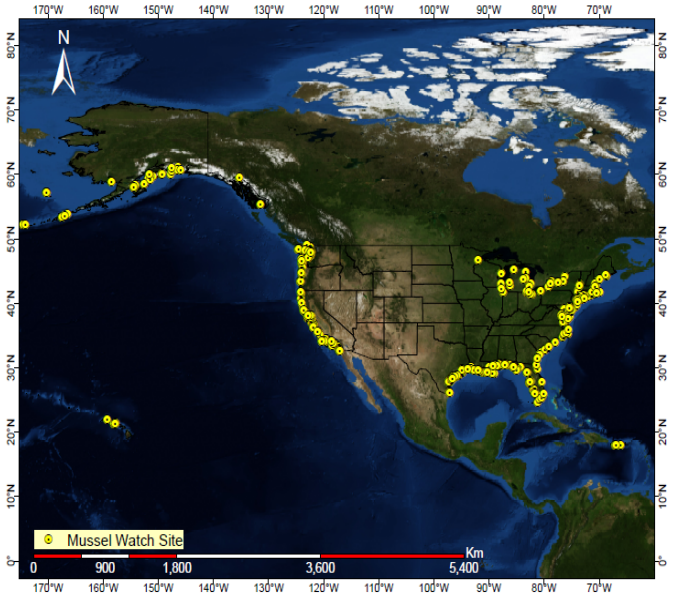

Fig.1. Mussel watch sites are situated on observed coastal regions. A percentage of sites are situated within NOAA manages areas.

Polybrominated Diphenyl Ethers or PBDEs are organic compounds that are commonly used as flame retardants (Kimbrough, et al. 2009). Found in various materials, PBDEs are distributed through out the nation's coast. Carcinogenic, and deadly when exposed in high quantities to lab rats, many countries currently have an active ban on PBDEs. Presently, several North American states are also taking actions to ban PBDEs. These include steps such as actively banning manufacturing and phasing out usage. As such, these steps are seen as a means of curbing future release of PBDEs to the environment.

Effluent sources from wastewater dischargers and Combined Sewer Overflows (CSOs) have been shown to be active releasers of PBDEs, and as such, the aforementioned facilities are assumed to be major contributors to the presence of PBDEs within the monitored NOAA mussel watch sites. Employing a series of analytical techniques and geographic referencing software, wastewater dischargers and contributors are identified. Most noticeably targeted sites included wastewater treatment facilities regulated under government NPDES permits issued by the U.S. EPA. Other major identified locations include power plants regulated under NPDES permits, unidentified remaining NPDES permitted facilities, hazardous waste sites, brownsfields, superfund sites, and combined sewer overflows (CSOs).

II. Polybrominated Diphenyl Ethers (PBDEs)

Used in an array of different products, PBDEs occur within the environment on an extremely large scale. PBDEs can be found in electronics, building materials, textiles, plastics, and polyurethane foams. It is interesting to know that PBDEs are very common and is actually found in a wide assortment of personal day to day items. These items include cell phones, computer screens, desks, children's pajamas, carpets and upholsteries, meats, seafood, and breast milk (Kay, et al. 2005).

Scientific studies have determined that PBDEs cause significant physiological disruptions within mammals. Information derived from the U.S. EPA's Integrated Risk Information System, has shown where PBDEs may possibly possess liver toxicity, neural developmental toxicity, and thyroid toxicity (U.S. EPA 2008). In experiments conducted on rodents it was observed that physical functions dealing with intelligence, brain development, and motor skills were all significant in decline (Kuriyama, et al. 2005).

In the 1970s some of the first information regarding PBDEs in humans was gathered from studies of breast milk of Swedish mothers. Between 1972 and 1997, the levels of the PBDEs in breast milk of mothers from Sweden increased rapidly. It doubled every five years, until recently. The decline is hypothesized to be linked to the phasing out of the contaminant (Washington State Department of Health., 2006).

Studies were also conducted with women within the U.S. in order to determine whether U.S. women have higher, equal, or lower milk PBDE levels as compared to other women in other countries. Within those women studied it was shown where there were markedly higher levels of PBDE in their breast milk as compared to their European counterparts (Schecter, et al. 2003).

Stored in adipose tissue, PBDEs have the ability to remain the body for long periods of time and can be found in the lipid portion of the blood (Thomas et al. 2006). The experimental effects that PBDEs have on humans, when linked to tested rodents infected with high concentrations of the chemical, are near undetectable. This is due to a comparatively low level of the chemical found in humans.

It is also important to note that in an organic state the contaminate PBDEs commonly merge with the environment through atmospheric transport (Kimbrough, et al. 2009). Concerning water emulsion, PBDEs are introduced by either *point* or *non-point* sources. Water pollution is often shown to be influenced by both point and non-point source discharges. Point source discharge refers to sources of effluent released via pipe; this includes injections made by wastewater treatment facilities, industrial plants, and municipal locations. Non-point source pollution is often a result of events occurring in nature; snow pack melting, water runoff, ground leaching, and rain are all coinciding events (Leavitt et al. 2006).

III. Methodology

In the attempt to identify possible contributors of the PBDEs contaminant, with NOAA's National Status & Trends Mussel Watch Program, a suite of software, including ESRI® ArcMap 9.3™ was utilized in assessing and compiling the acquired data. ArcGIS 9.3 was used as the primary platform in manipulating the dataset used in this project. Remote Sensing imagery acquired from ESRI™ database served as the primary base map within this project. Microsoft Office Excel was used to read, combined, sort and refine collected attribute data. Data was manipulated for desired results using the available Microsoft suite. Importantly the above remote sensing imagery was used to verify Points of Interest (POI).

Data collected from the United States Geological Survey (USGS), a national shapefile utilizing polygons depicting

respective watershed region that encompasses NOAA mussel watch sites was created. The file was edited to show coastal watersheds reflective of Mussel Watch Program and observed coastal regions.

A national dataset which comprised information regarding active NPDES permits was collected from the U.S. EPA. This data set yielded information for 49 states, Washington D.C., and United States territory of Puerto Rico. NPDES information for Alaska was gathered on an individual basis. It should be noted that Alaska was the only state unidentified in the U.S. EPA dataset.

Wastewater treatment facilities were closely examined as contaminant release sites due to their potential to release untreated wastewater. Other major contributors of contaminated water source that was included within this study, included facilities and sites such as, brownsfields, superfund sites, power plants, hazardous waste sites, unidentified NPDES permitted facilities, and CSOs. The above facilities and sites were also identified from information provided by U.S. EPA. The data gathered was analyzed and checked for irregularities, corrected, and projected using World Geodetic System (WGS 1984), unless previously provided with a projection.

Further geographic features incorporated into the GIS package include mussel watch sites, mussels watch sites positive for PBDE contamination, impaired waters, total maximum daily loads (TMDL), census tracts, and military installations. These features are identified within the GIS package using vectors, lines, points/centroids, and polygons. Features not regarding mussel watch sites are made available as additional reference, and reasons that concern linkage to possible chemical contamination. All information regarding Mussel Watch was analyzed and clipped to the watershed layer due to its encompassing of the entire study area.

IV. Results

A. PBDE Affected Sites:

With a mass heavier than that of water, PBDEs and other suspended materials that retreat from released effluent settle at benthic zones of oceans and lakes. Bottom feeders, mollusk situated within these zones have ideal access to those materials and unknowingly make these particles part of their diet. Current flows and weather also promote movement of sediments along large water bodies and ocean floors.

PBDEs were found at, 263 of the 372 active mussel watch sites (Appendix A). Elevated counts of positive PBDEs contamination are centered around highly industrialized areas and locations where watersheds experience high levels of stress from exceeds of U.S EPA regulated Total Maximum Daily Loads (TMLD). Areas generally fell within the eastern and southern parts of the United States.

Locations where PBDEs were not present are highest in numbers in the states of Alaska and California. Of the 41 sites located in Alaska only 9 tested positive for PBDEs contamination. In California 36 of 67 sites tested positive for PBDEs. Currently California is among one of the several states that implements an active ban on PBDEs (San Manteo County Environmental Health, 2005).

Mussel watch sites not testing positive for PBDEs outside of California and Alaska often showed no pattern. Many of them identify themselves as anomalies repeatedly being surrounded by PBDEs contaminated sites and impaired water sources.

B. Watersheds:

634 watershed regions are identified as sources of impaired waters (Fig.2.). They visually represent monitored coastal regions and serve as the study area for Mussel Watch. A number of mussel watch sites fell into multiple of watersheds. A contiguous dataset was developed utilizing the conterminous United States and U.S. territories Guam and Puerto Rico. This dataset was acquired from USGS at a Hydrological Unit Code (HUC) coverage scale of 1:250000.

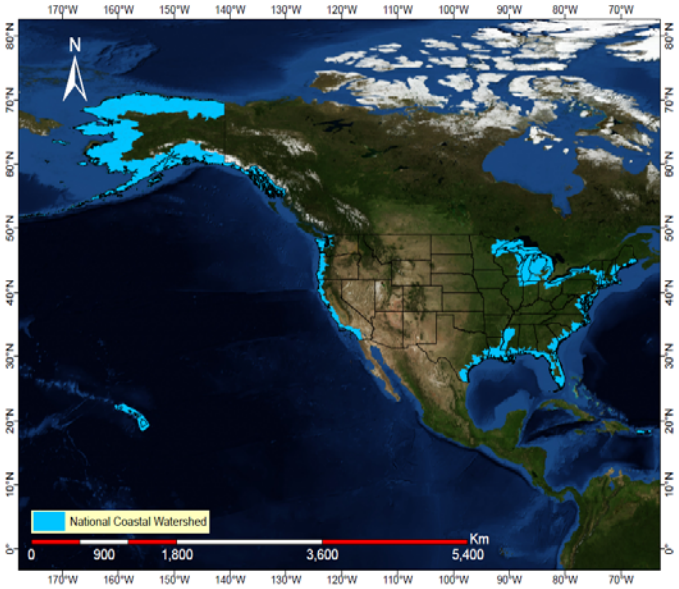

Fig.2. The National Watershed shapefile identifies 634 individual watersheds. Due to lack of information within the NOAA's spatial database watershed, information was collected from United States Geological Survey (USGS).

1) Total Maximum Daily Loads & Impaired Water Assessment

Total Maximum Daily Loads (TMDL) are required standards set by U.S. EPA that permit various states allowable levels of pollutant that can be discharged to a receiving water body without violating permitted standards (Davis, et, al., 1992). As such, TMLD are permits that are provided to effluent dischargers such as wastewater facilities, and manufacturing facilities. (Appendix B) Data used to assess TMLD is usually done or performed within the NPDES program. This data is used to estimate the level of effluent release or mass loadings with the aim of determining compliance regulation with imposed federal guidelines and limits (Davis, et, al., 1992).

On the other hand, impaired waters are usually described as

water bodies or water sources that are too polluted or degraded to meet U.S EPA standards or state and municipal requirements. These standards are imposed under section 303(d) of the CWA. Under the CWA it is required by states, municipalities, and primary wastewater dischargers are monitored and that all concerning water bodies be identified and reported to the U.S EPA NPDES program (Appendix C).

C. Primary Contributors:

The initial scope of this project was aimed at identifying water treatment locations. These facilities alone however, do not give an expansive enough insight into the various sources of effluent waste. By identifying Wastewater Treatment Facilities, CSOs, power plants, remaining NPDES permitted facilities, brownsfields, superfund sites, and hazardous waste locations, an extensive look at effluent contributors is viewed(Fig.3.).

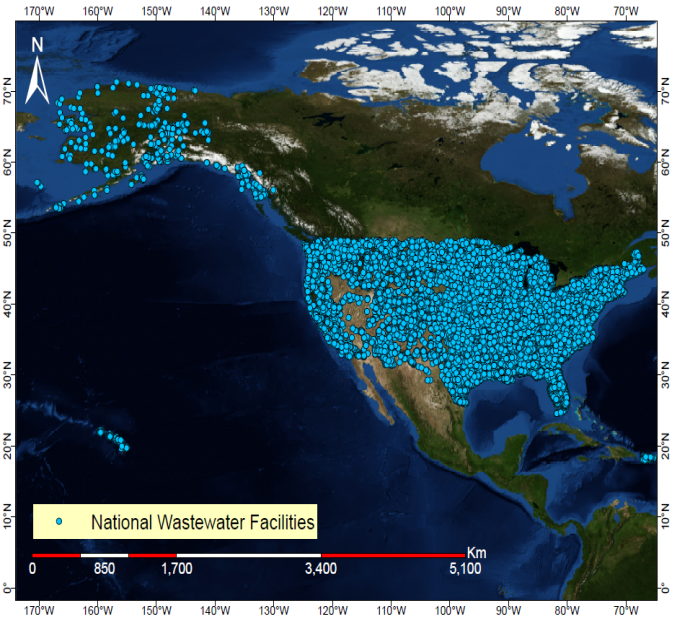

Fig.3. National Wastewater points/centroids representing National Pollution Discharge Elimination System (NPDES) permitted facilities currently monitored by the U.S EPA, as legislated under the Clean Water Act.

1) Wastewater Facilities:

The initial database obtained from the U.S. EPA provided information on all available NPDES permits nationwide. It was expansive in detail and gave variances on a multitude of levels. Information for over 170,000 different facilities permitted to release wastewater was provided Attribute data as it relates to wastewater facilities was shown to be broad and expansive in content (Fig. 4.)..

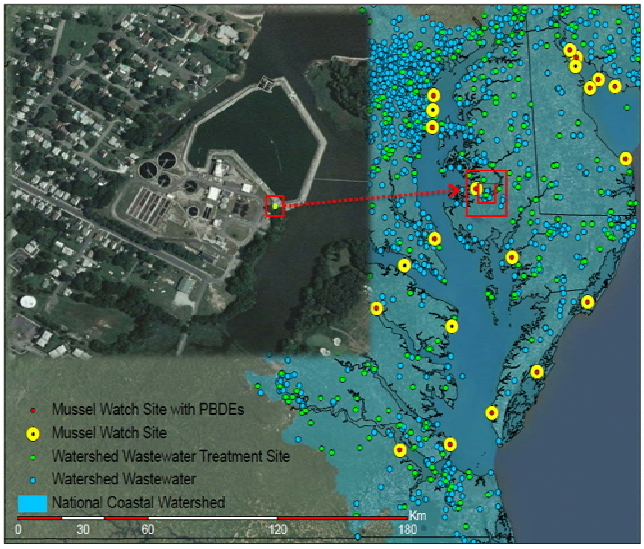

Fig.3. National Wastewater points/centroids representing National Pollution Discharge Elimination System (NPDES) permitted facilities currently monitored by the U.S EPA, as legislated under the Clean Water Act.

Accounting for the vague range of identified locations, received information was sorted and refined for desired facilities. Wastewater treatment facilities and power plants were individually identified. The remaining locations were kept and displayed in an individual shapefile. On many instances these locations were closer in proximity to mussel watch sites than other identified locaons.

2) Wastewater Treatment Facilities:

Wastewater treatment facilities were visually identified by descriptions embedded within column categories titled (common name) and (local name) (Fig. 5.). Facilities such as, Sewage Treatment Plants (STP), Sewage Treatment Facilities (STF), Water Treatment Facilities (WTF), Water Treatment Plants (WTP), Wastewater Treatment Facilities (WWTF), Wastewater Treatment Plants (WWTP), Private Owned Treatment Works (POTW), Water Pollution Control Plants (WPCP), Municipal Separate Sewer Storm Systems (MS4), Sanitary Districts (SD), Sanitary Sewer Overflows (SSO), and Public Works were identified based on their known potential of releasing the above contaminant PBDEs.

As a result, these facilities were flagged and denoted based on their category (major or minor facilities), but more importantly, their proximity and location to the NOAA Mussel Watch sites (Appendix D). The national dataset collected for identifiable wastewater treatment facilities was then clipped to the watershed regions for national mussel watch sites (Appendix E).

	A	B	C
1	EPA_PERMIT_ID	COMMON_NAME	LEGAL_NAME
2	AL0024619	ALABAMA POWER COMPANY JH FARLEY NUCLEAR PLANT	SOUTHERN NUCLEAR OPERATNG CO
3	AL0024635	BELLEFONTE	TVA BELLEFONTE NUCLEAR PLANT
4	AL0023094	WRIGHT SMITH JR WASTEWATER TREATMENT FACILITY	MOBILE WRIGHT SMITH WWTP
5	AL0024619	ALABAMA POWER COMPANY JH FARLEY NUCLEAR PLANT	SOUTHERN NUCLEAR OPERATNG CO
6	AL0024635	BELLEFONTE	TVA BELLEFONTE NUCLEAR PLANT
7	AL0024678	CEDAR BLUFF WWTP	CEDAR BLUFF UB TOWN OF WWTP
8	AL0024724	EAST ALABAMA SEWER FIRE PD	EAST AL WATER LOWER VALLEY WTP
9	AL0024783	J AND M CYLINDER GASES INCORPORATED	J AND M CYLINDER GASES INC

Fig.5. Microsoft Excel was use used to sort, edit, and refine data.

3) Power Plants:

An emerging point of interest, a database was developed from the NPDES data set regarding information on power plants. Criteria established for indentifying power plants within NPDES dataset was built on the following terminology: coal, electric, fossil fuel, natural gas, dam, hydroelectric, oil, petroleum, nuclear, refinery and power plant. (Appendix F). Locations were verified using provided remote sensing imagery (Fig.5.).

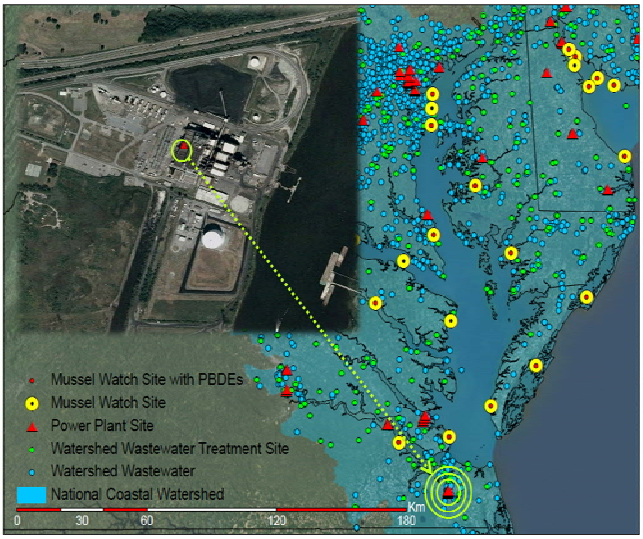

Fig.5. Raster data and Remote Sensing Imagery was gathered and used to verify random selected locations for accuracy and accurate projection.

Information gathered from agencies such as the Department of Energy (DOE) was used to verify all coal based power plants, which have been noted to be effluent release locations. As such, they are potential sources of wastewater contaminants.

4) Non-NPDES Facilities:

Identifying sources of all effluent discharge is important in locating possible releasers of the PBDEs contaminant. With close to 75 percent of mussel watch sites testing positive for PBDEs it is imperative to find origins. Brownfields, superfund sites, combined sewer overflows (CSOs) and hazardous waste sites were viewed as other potentially contaminating locations. These sites of interest were identified through centroids/point representation and displayed on individual layers (Appendix G, H). It should be noted that CSOs are only found within the Northeastern United States, Oregon, Washington and Southern California (Fig. 6.).

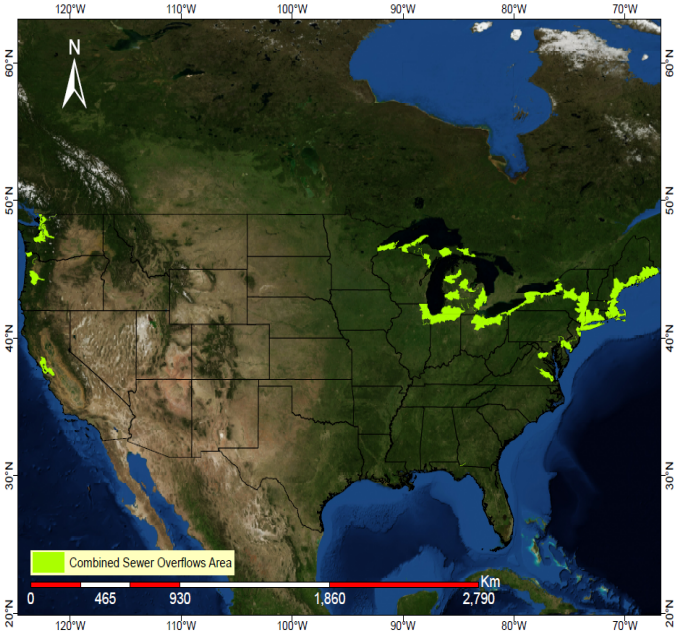

Fig.6. Map depicting identifiable regions within the continental U.S. where Combined Sewer Overflows (CSOs) systems are monitored by municipal, state, and federal entities.

Also hazardous waste sites were classified and displayed on four levels. Categories represented include: hazardous waste sites, hazardous waste handlers, hazardous waste generators, and toxic release (Appendix I, J, K).

D. Other Identifiable Contributors:

Military installations were also classified within this study as other possible sources of contaminated effluent release. They are identified for reasons concerning ongoing need to treat their effluent discharge, and there use and jurisdiction over large bodies of water located in the observed watershed regions along coastal zone.

E. Limited/No Data Areas:

Alaska was the only *state* that failed to provide NPDES data to the U.S EPA. For this reason information regarding the Alaskan region was sought out on an individual basis. Through direct contact with Alaska's Department of Environmental Conservation (DEC) water quality information was acquired from the NPDES branch. As such, it should be noted that information for Alaska is sparse, and to date not complete. Of the given data, geographical coordinates for 411 locations are either skewed, missing, or null.

Data collected for island territories was only found in entirely for Puerto Rico. The only geographical information displayed for Guam included designated watershed regions, and mussel watch locations (Fig. 7.). Guam does however

have and active environmental protection agency and adheres to the U.S. EPA NPDES permit. However, some of these facilities that are still working to meet NPDES standards and limited spatial information on these NPDES permitted facilities as it relates to meeting water quality standards are still an issue.

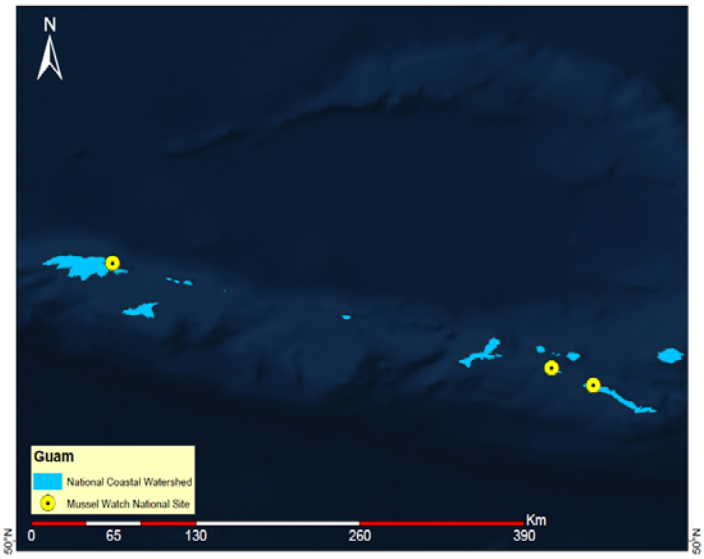

Fig.7. Information for the territory of Guam was limited to the national coastal watershed obtained from USGS, and NOAA mussel watch sites.

V. Conclusion

It is hypothesized that the location of wastewater facilities and other contributing locations factor into the presence of the PBDEs contaminants. The proximity between mussel watch sites, and locations referenced as releasers of effluent and potentially polluted substances however, do not alone allow researchers to draw final conclusions that lead to the direct source of chemical contamination. Though it may give insight into the origin, only upon further investigative studies, chemical analysis, water quality testing, and research may a location be identified as being positive or negative for a specific chemical. This then will allow conclusive identification of contaminated effluent releasers and make possible isolating facilities and locations that emit such waste.

VI. Future Applications

Further development of GIS imagery is needed in the continuance of identifying possible contaminators of mussel watch sites. In the collaboration of NOAA with other federal agencies, and individual state governments, major industries, agricultural sources, population density, metropolitan areas, and non point sources should be viewed exhaustively. Newly acquired data is to be constructive in pursuing contaminant releasers within coastal water regions, which allow watersheds to be viewed on individual basis. This less expansive scaled version of the Mussel Watch Program is to become a conducive method in identify all possible affecting chemical contaminates by allowing more in-depth visual representation of affected coastal regions and the watersheds that are positioned within them.

On a national level, watershed mapping contiguous of HUC watershed should be developed that is representative of the individual states and territories. Current flow and tidal changes is to in addition be adopted within a visual element in order to view routes and travel patterns that effluent takes when released from origin sources as well as contaminated sediment that rest in benthic zones.

Future publication of finding is furthermore proposed in aiding with studies pertaining to the Mussel Watch Project.

On a note of continuance, it is to be viewed within thought that collected information is not only applicable to the Polybrominated Diphenyl Ethers contaminant. Relevancies concerning other chemical contaminants introduced via water emulsion can gather great background from the produced application.

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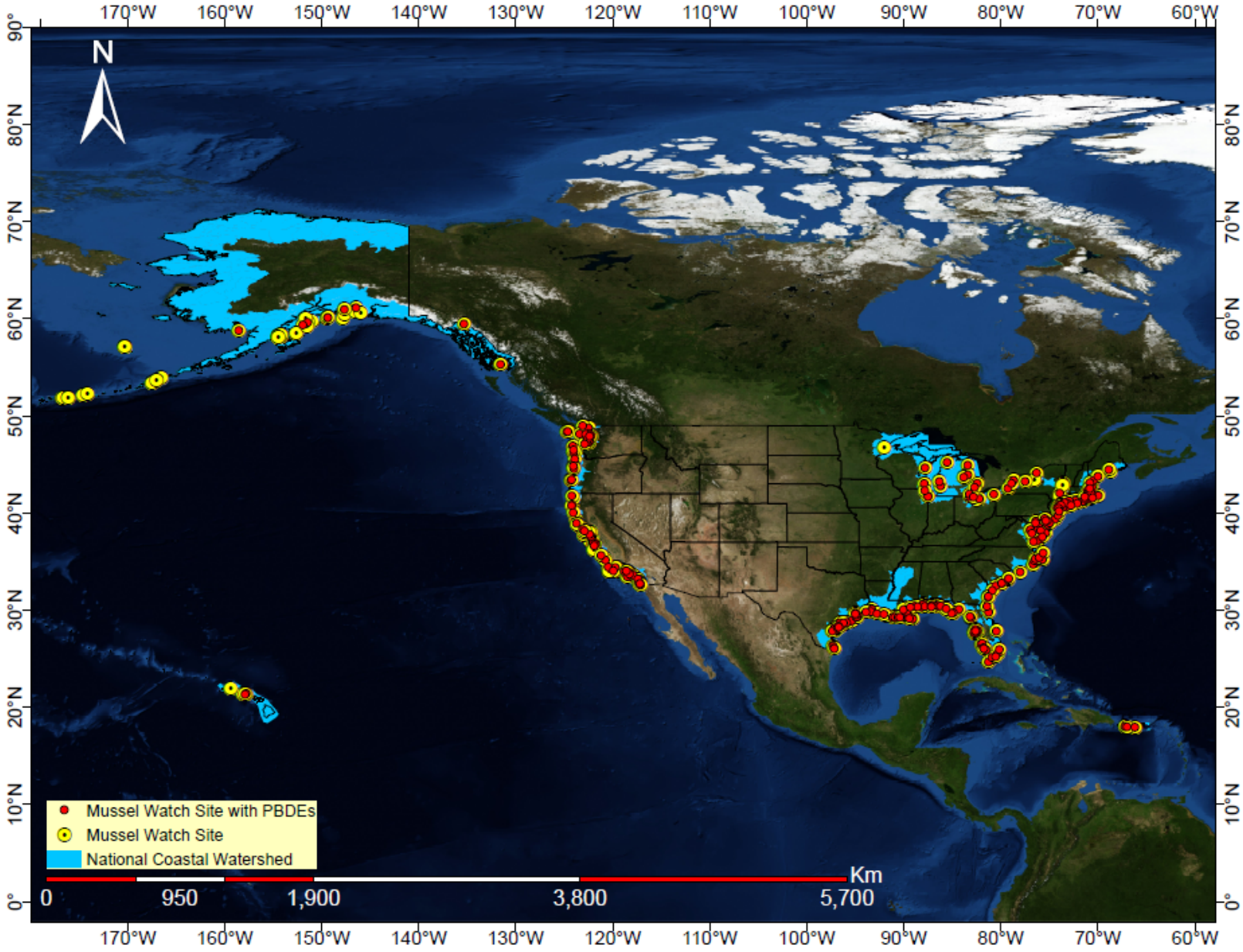
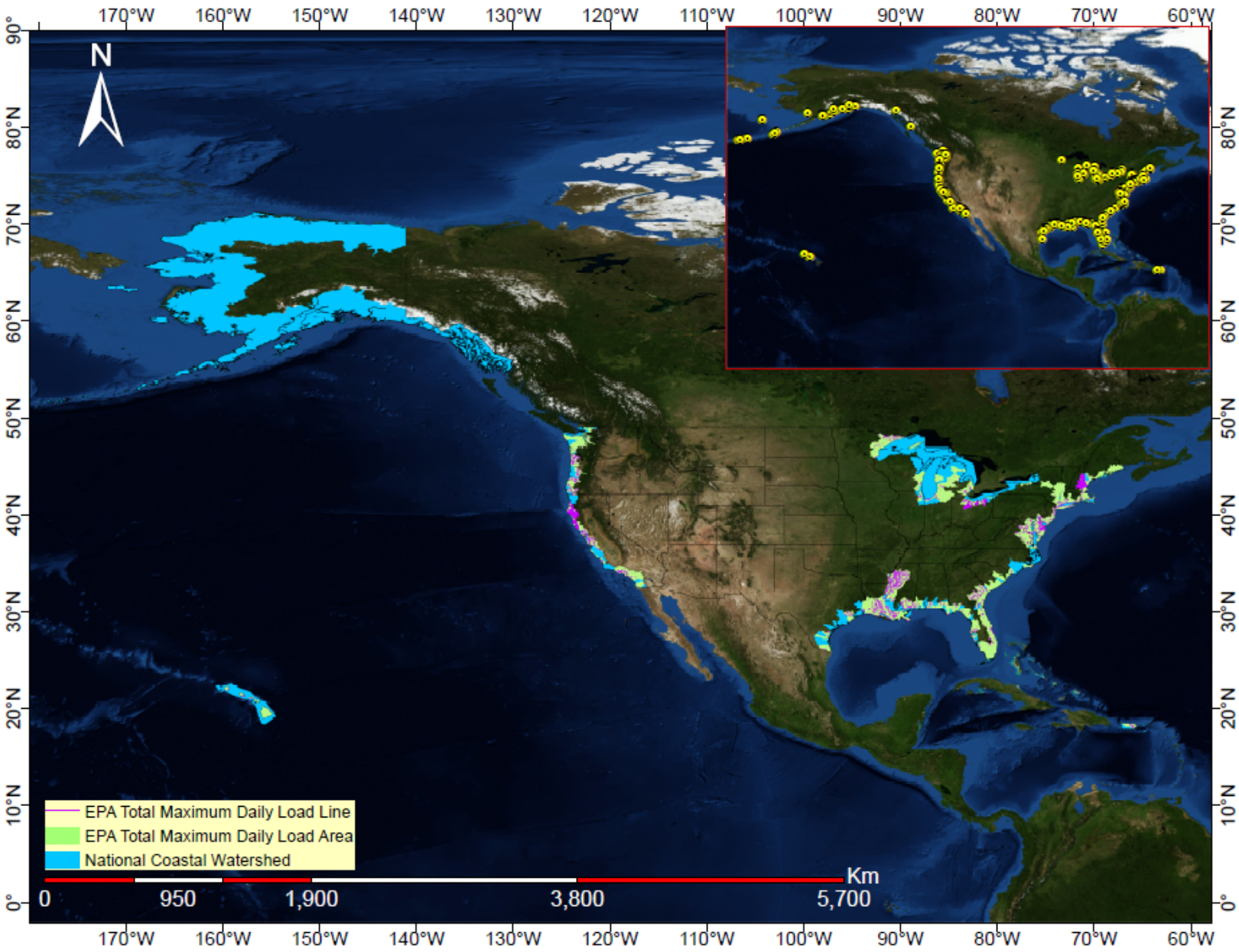
Appendix:



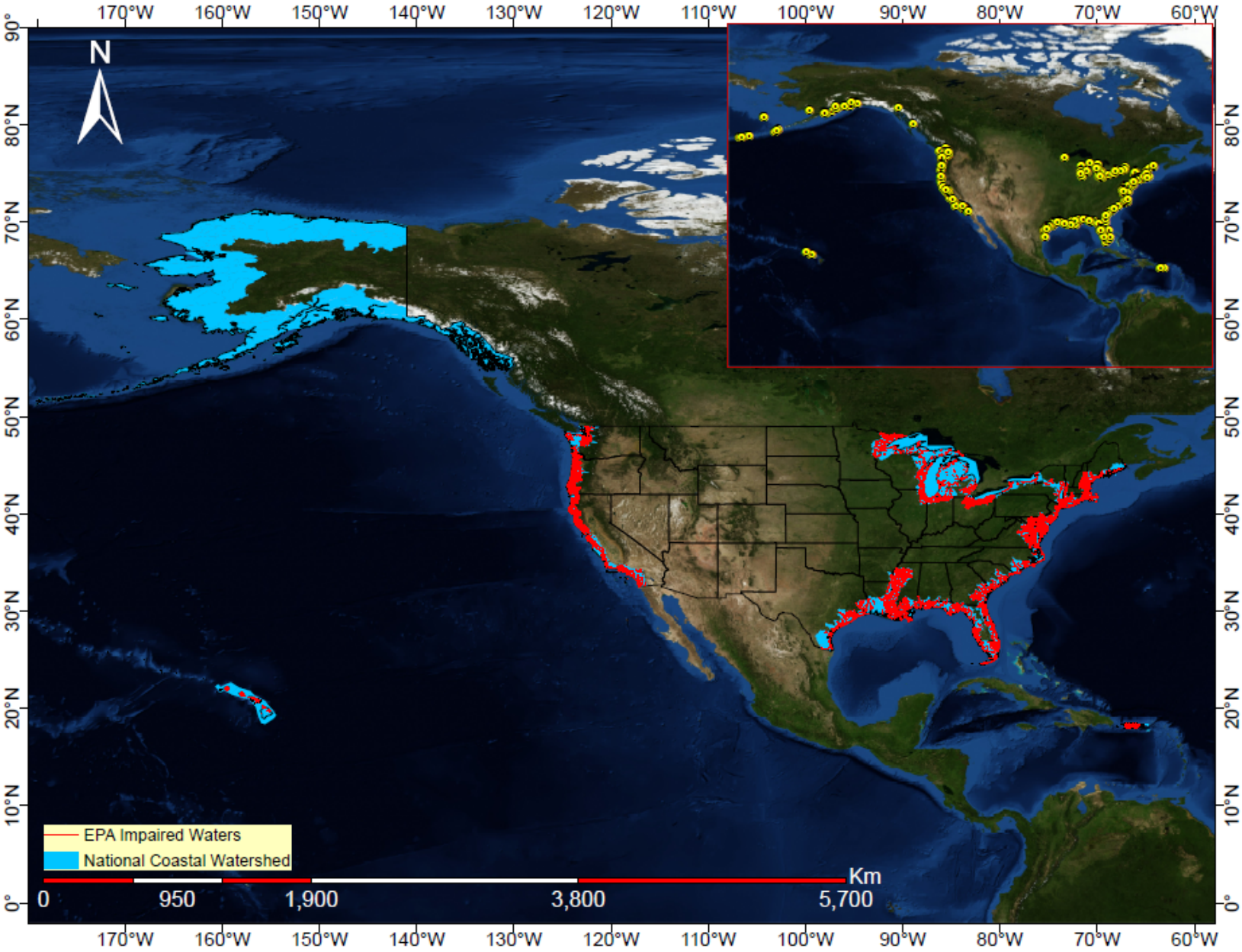
Appendix A:

Map depicting Mussel Watch Site along with sites that actively test positive for PBDEs contaminants.



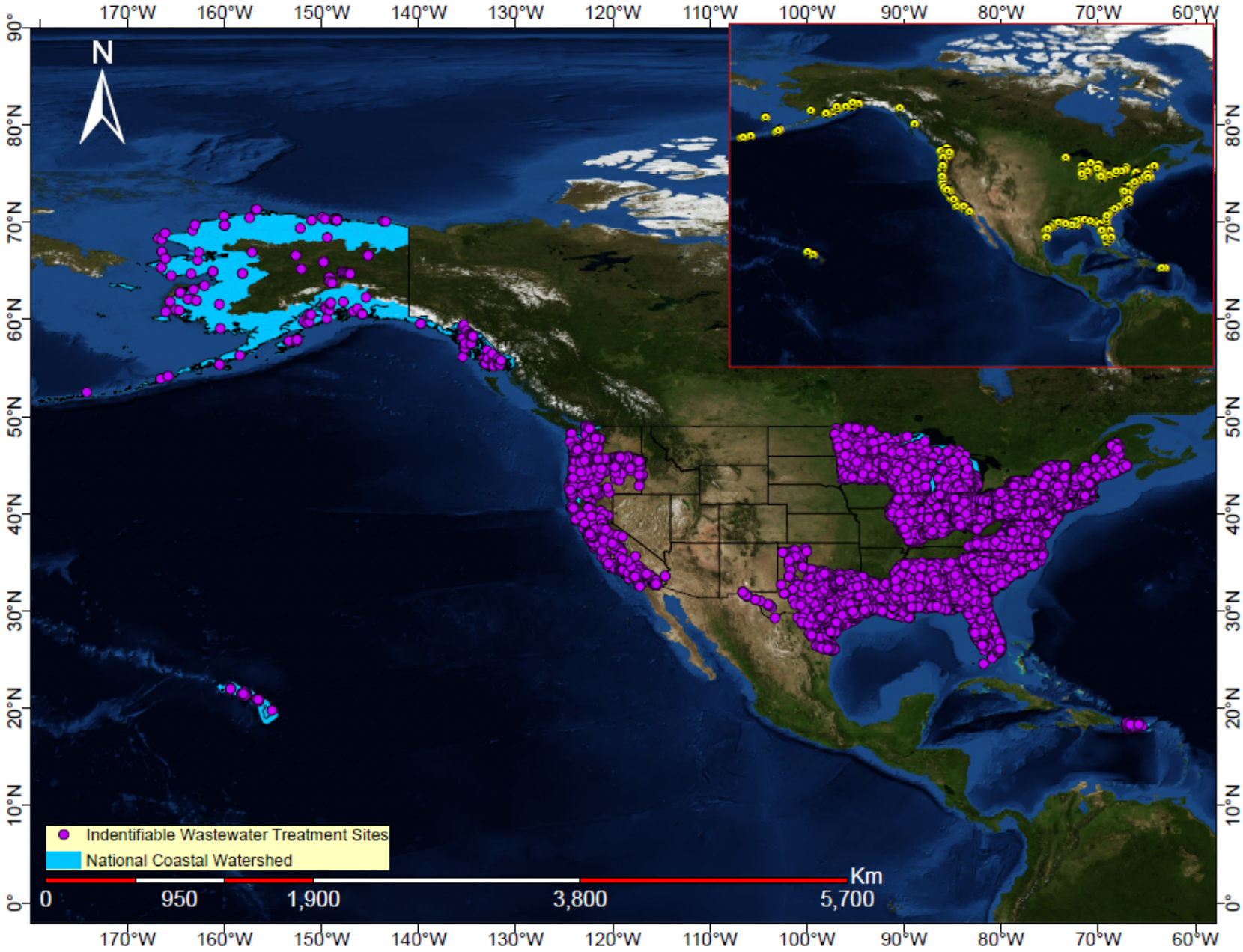
Appendix B:

U.S.EPA Total Maximum Daily Load (TMDL) areas and lines represent established maximum amount of an impairing substance that a receiving water body can digest while still meeting water quality standards.



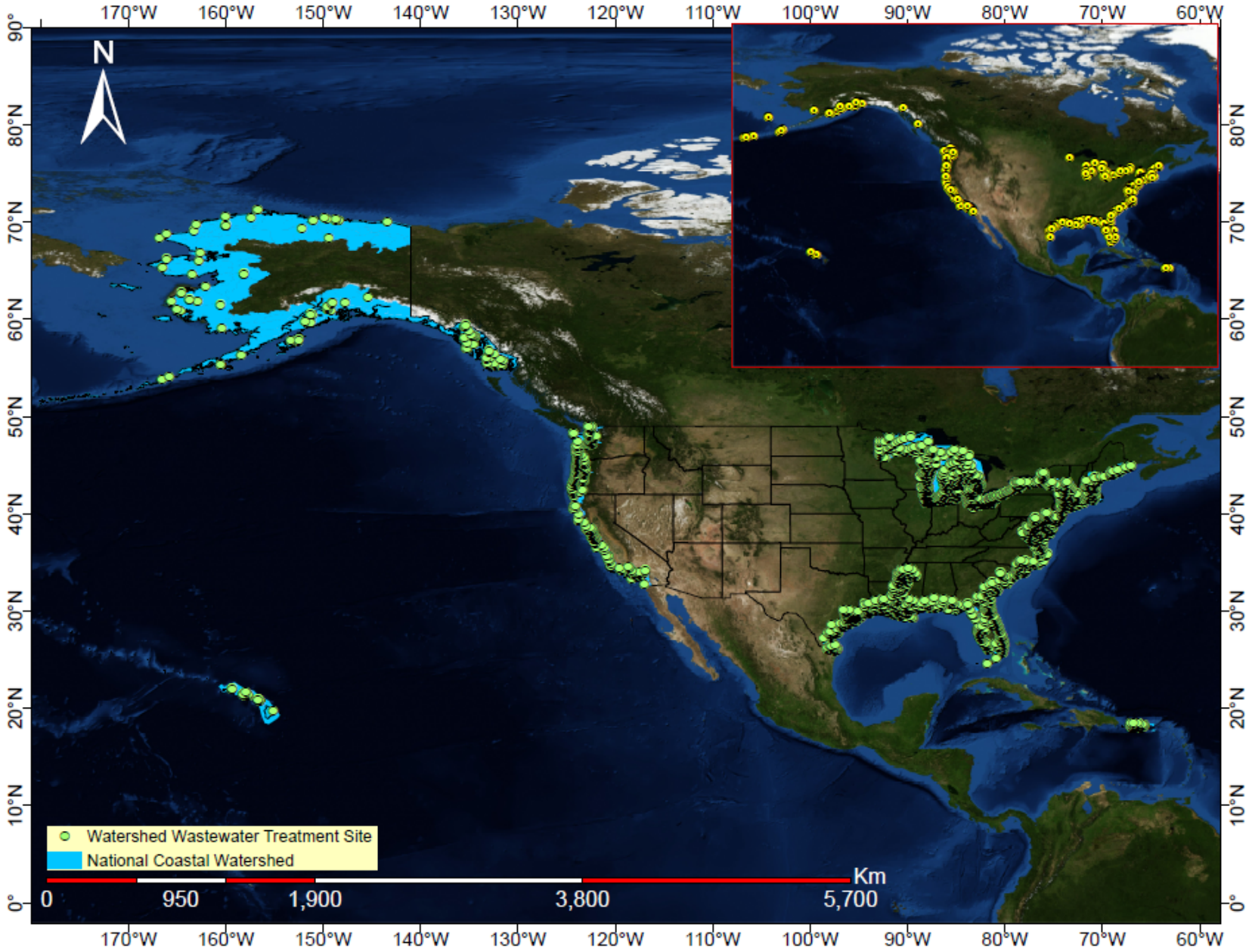
Appendix C:

Map depicting identifiable U.S. EPA classified impaired waters located within and outside of the conterminous United States.



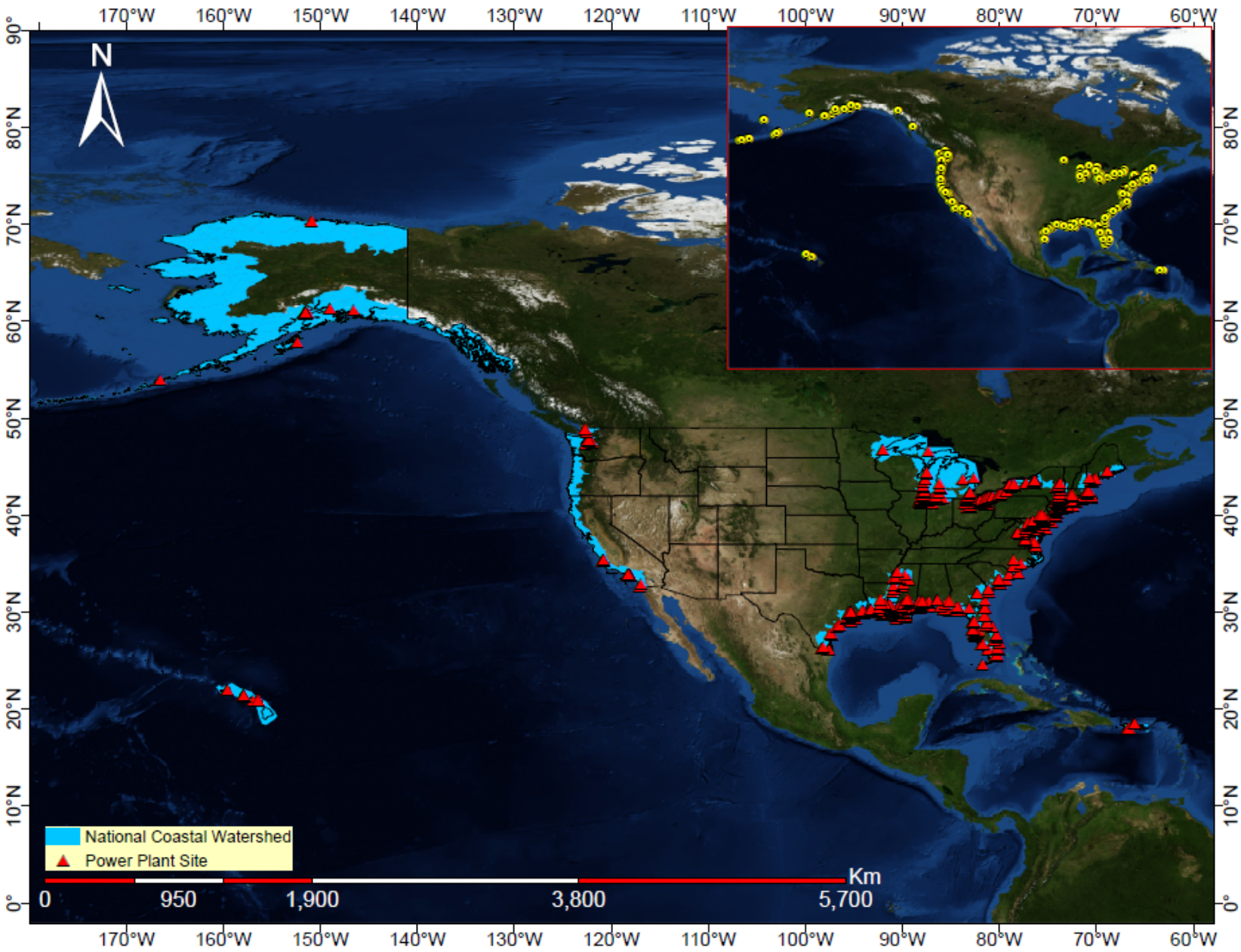
Appendix D:

Map identifies Wastewater Treatment Sites that encompass Mussel Watch observations. Locations include: Alaska, Alabama, California, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, North Carolina, New Hampshire, New Jersey, New York, Pennsylvania, Ohio, Oregon, Rhode Island, South Carolina, Texas, Virginia, Washington, Wisconsin and U.S Territories Guam and Puerto Rico.



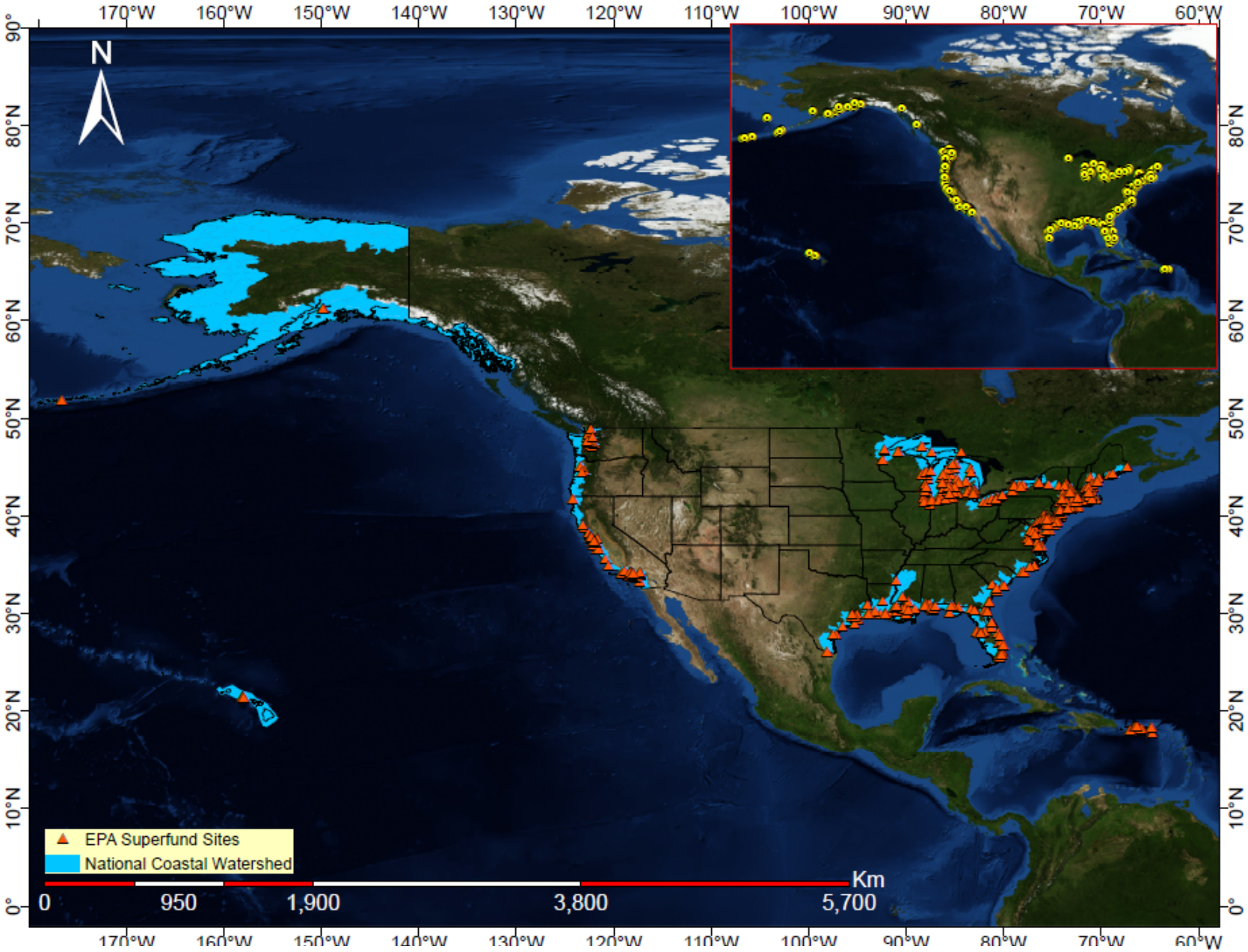
Appendix E:

Wastewater treatment facilities that fall within the observed watershed.



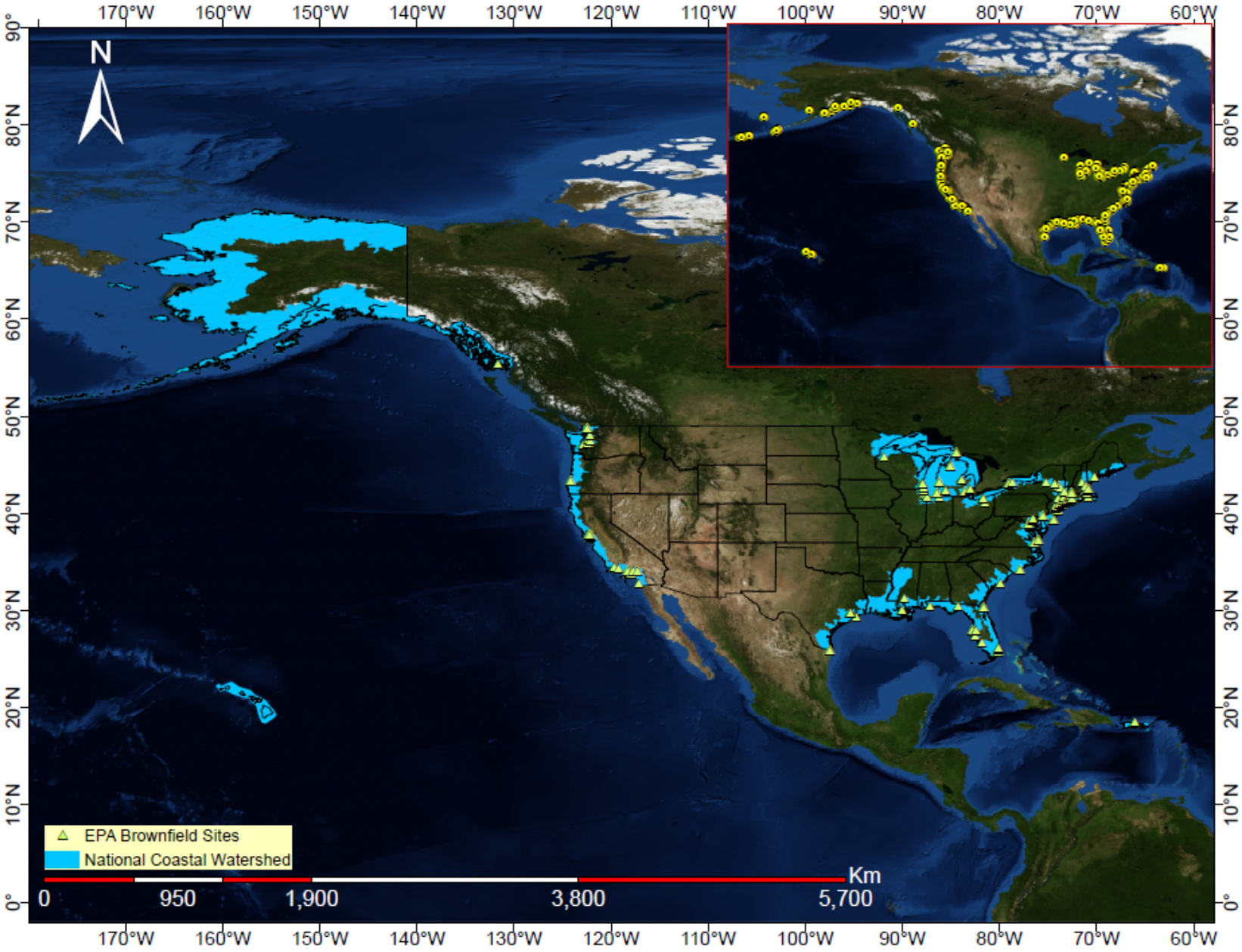
Appendix F:

Power plants identified within U.S. EPA NPDES permitted facilities.



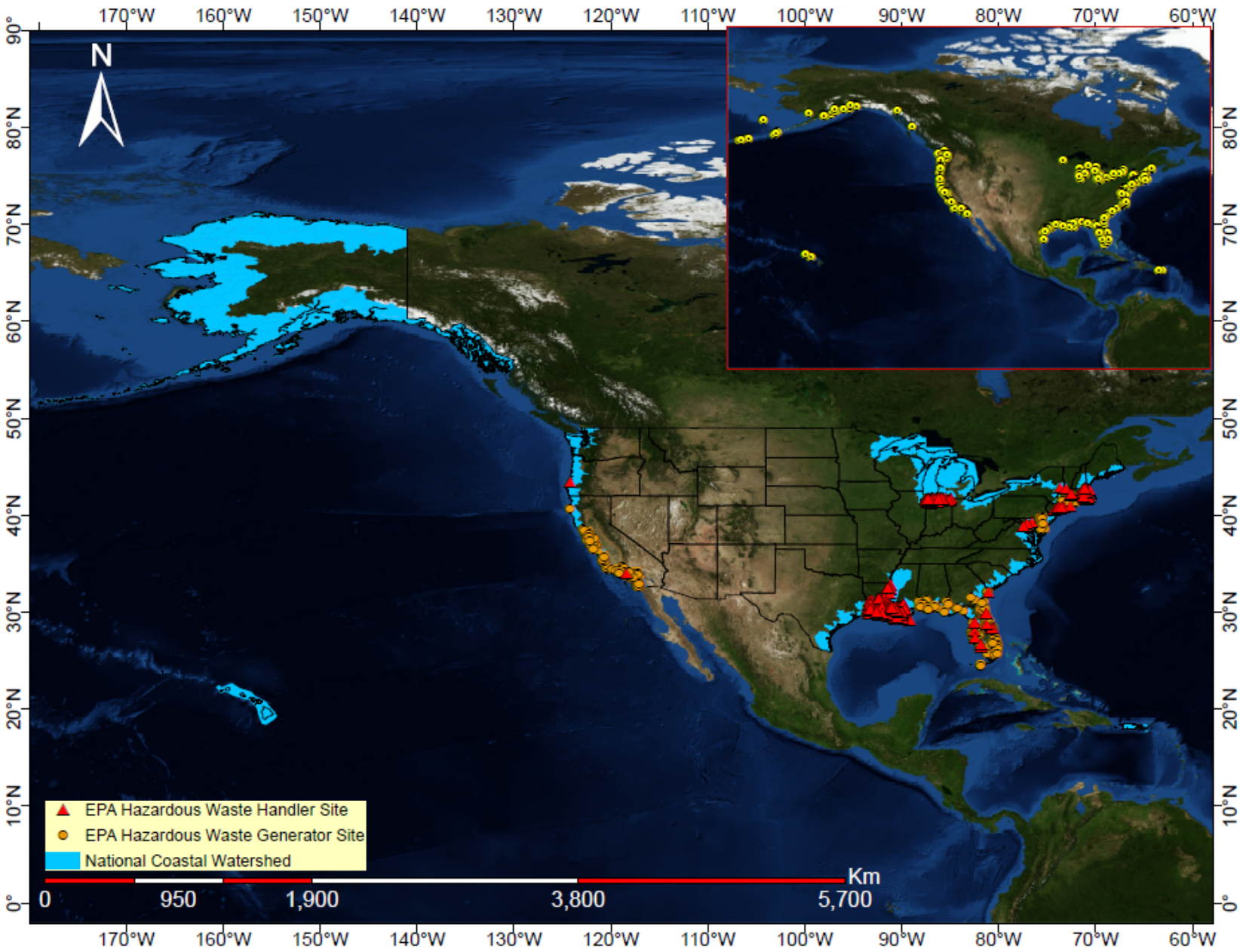
Appendix G:

U.S. EPA Superfund Sites within mussel watch watershed region.



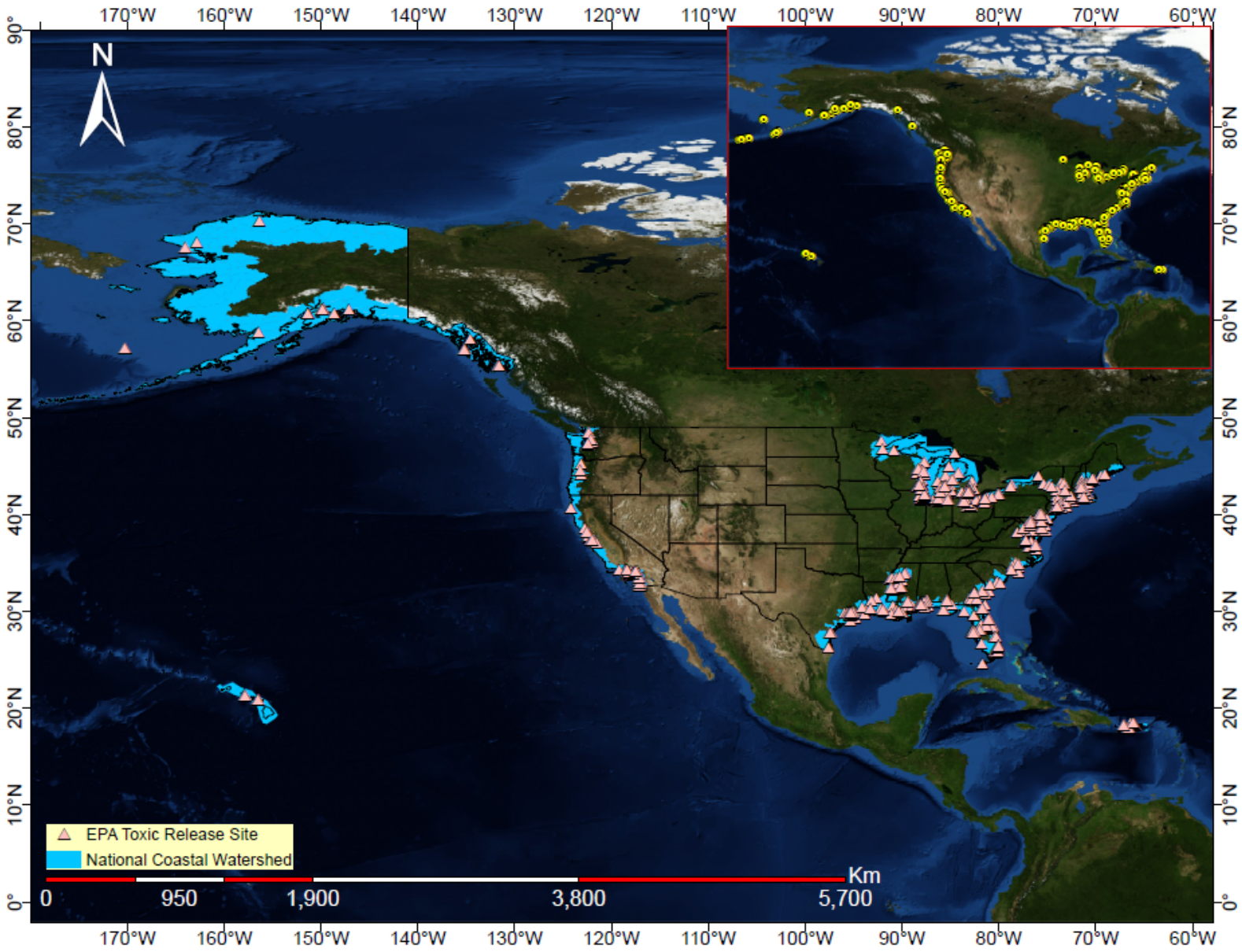
Appendix H:

Map depicting U.S. EPA brownfield sites within mussel watch watershed regions.



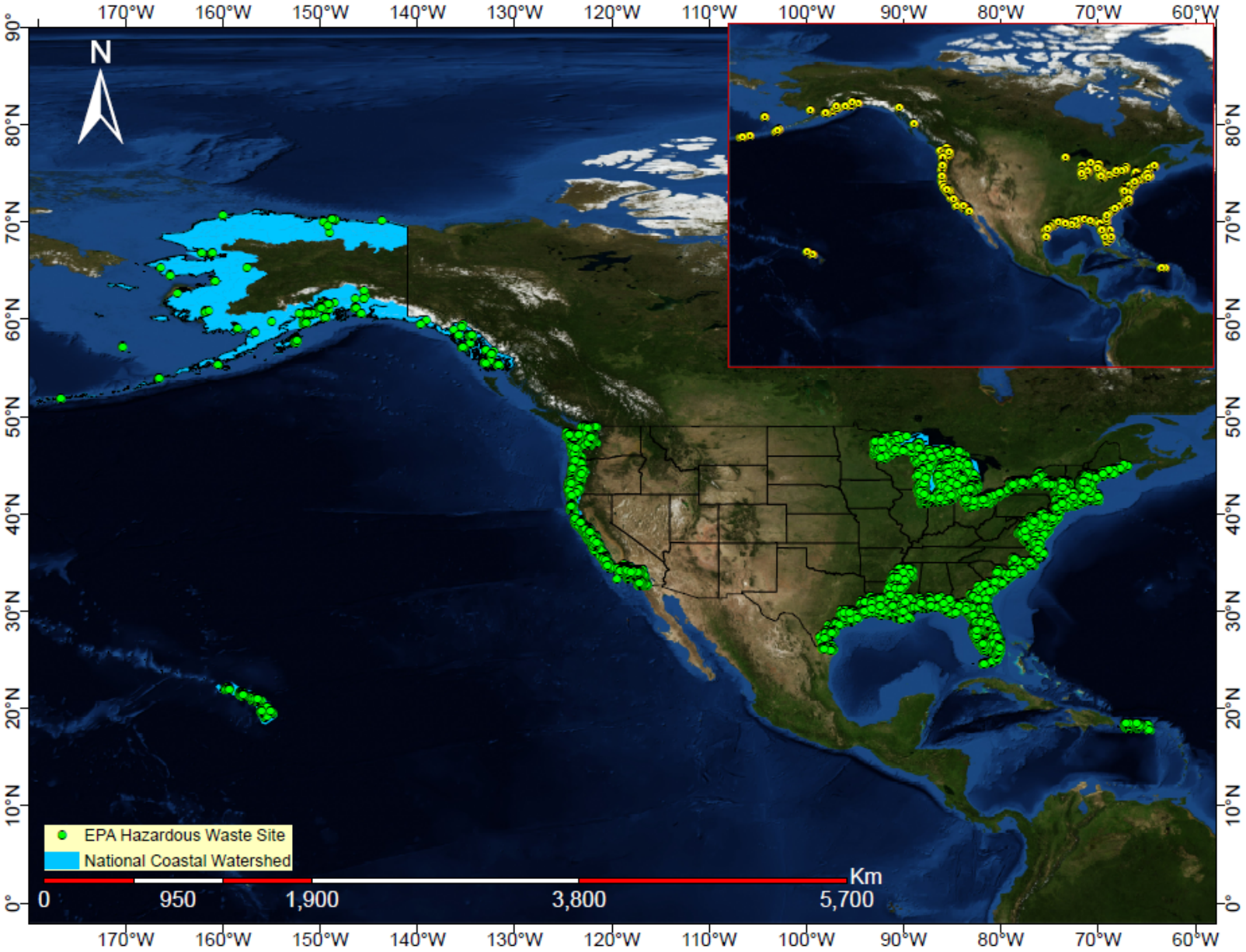
Appendix I:

U.S. EPA hazardous waste handlers and generators within mussel watch watershed regions.



Appendix J:

Map depicting U.S. EPA toxic release sites within mussel watch watershed regions.



Appendix J:

Map depicting U.S. EPA hazardous waste sites within mussel watch watershed regions. U.S EPA categorizes hazardous waste as waste that is potentially harmful to human health and/or the environment.