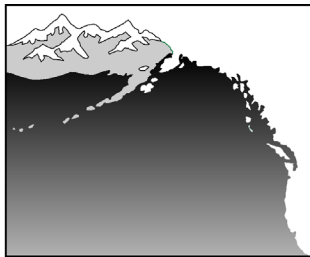


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Inventory and Mapping of City of Seattle Shorelines along Lake Washington, the Ship Canal, and Shilshole Bay

J TOFT, C SIMENSTAD, C YOUNG, L STAMATIOU

Wetland Ecosystem Team



University of Washington

**SCHOOL OF AQUATIC
& FISHERY SCIENCES**

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Jason Toft

Charles Simenstad

Carl Young

Lia Stamatiou

Wetland Ecosystem Team

School of Aquatic and Fishery Sciences

University of Washington

Prepared for Seattle Public Utilities, City of Seattle

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Key Words

shoreline modification, docks, shoreline habitats, aerial photographs, Seattle, chinook salmon, GIS, Lake Washington, Ship Canal, Shilshole Bay

Executive Summary

The main objective of this study was to inventory and map the above water shoreline habitats and docks along City of Seattle shorelines throughout Lake Washington, the Ship Canal, and Shilshole Bay. Juvenile endangered chinook salmon use the littoral zone for rearing and migration to the ocean, thus placing an emphasis on understanding the degree of shoreline modifications. Shoreline measurements included current field surveys and GIS aerial photography analyses on: (1) dock characteristics, (2) shoreline modifications, and (3) general shoreline habitats.

There were 914 recreational docks and 519 marina docks along the surveyed shoreline, with 181 overwater structures and 42 overwater platforms. These areas shaded 17.3% of the shoreline's edge. 74.71% of the shoreline was retained by rip-rap or bulkhead, while an unretained 25.29% of the shoreline was beach, naturally vegetated, or landscaped. The majority of the shoreline was partially exposed to wave energy, had a moderate or low gradient terrestrial slope, an upland cover of garden/lawn or impervious surface, and shoreline substrata of sand or mixed coarse substrates. Submerged aquatic vegetation (SAV) was present along 59.1% of the shoreline.

Future research should attempt to assess the impacts that such shoreline modifications have on the surrounding biological community. This is a challenging avenue for scientific studies, but one that is necessary in order to quantify possible affects of altered shorelines. Managing urbanized waterways and shoreline developments may be an important component for enhancing the recovery of endangered salmonid populations.

Introduction

The goal of this study was to inventory and map shoreline habitats along City of Seattle shorelines throughout Lake Washington, the perimeter of the Lake Washington Ship Canal, and Shilshole Bay. These shorelines have been significantly modified due to anthropogenic influences in the surrounding Seattle metropolitan area. A detailed habitat mapping of the shorelines is a necessary step in order to effectively manage the system,

especially since the listing of Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) as a threatened species in March 1999 by the National Marine Fisheries Service. Juvenile chinook use the littoral zone along these shorelines for rearing and migration to the ocean (Tabor and Piaskowski 2002; Simenstad et al. 2003). It is important to understand juvenile chinook habitat usage along shoreline developments, in order to ensure that vital habitat is available to enhance the recovery of endangered salmonid populations.

The aquatic systems from Lake Washington to Shilshole Bay have a history of anthropogenic alterations to their hydrology, including construction of the Lake Washington Ship Canal, the Hiram M. Chittenden Locks, and diversion of several river systems (Chrzastowski 1983). With the completion of a new link from Lake Washington to Puget Sound in 1916, the water level of Lake Washington was lowered 8.8 feet, and the routing of the Cedar River into the Lake provided a new source of water with an output through the Ship Canal (Chrzastowski 1983). The product of these alterations also created a new freshwater to saltwater rearing and migration corridor for salmonid populations.

In this report we seek to examine how the historic shorelines have been modified by docks and retaining structures along the following waterways – Shilshole Bay between Meadow Point and West Point, through the Locks into the Ship Canal including Salmon Bay, Fremont Cut, Lake Union, Portage Bay, Montlake Cut, continuing through Union Bay and ending at the City of Seattle’s boundaries for the Western edge of Lake Washington. Our new surveys build upon the techniques developed by Toft et al. (2001) and Hockett (1976) in their analyses of Lake Washington shorelines, as well as surveys along the City of Seattle’s boundaries (Parametrix and NRC 1999).

Main Objectives:

Inventory of Dock Characteristics

- Classify docks into the following types: (1) recreational docks, (2) large marine docks, (3) overwater structures, and (4) overwater platforms.
- Classify the number of docks that are high above water surface (> 2m), low above water surface (< 2m), or floating.
- Classify the number of docks that have attached buildings.

Inventory of Shoreline Modifications

- Classify the shoreline into categories of retained structures (rip-rap, vertical bulkhead, sloping bulkhead) and unretained (beach, natural vegetated, landscaped).

Inventory of General Shoreline Habitat Types

- Classify large segments of the shoreline into general categories of substrata type, shoreline wave energy exposure, shoreline geomorphology, and upland cover.

Material and Methods

Dock and shoreline mapping were conducted by boat during October 22-30, 2002. Subsequent surveying and groundtruthing by land were continued through February 2003. All classifications were based on Lake water levels during the October fieldwork, as documented by reference gages described in the results section of this report. The high-resolution digital orthophotos of the City of Seattle (image source Triathlon, Inc., August 1999) were used for data input and observations.

Dock Characteristics

Docks were counted mainly from aerial photography. Addition or removal of docks since the date of the aerial photograph was recorded in the field. We used the definitions of Hockett (1976) to separate docks into main categories of recreational and large marina docks, and further specified dock types according to the following:

1. Dock Type

- *Recreational docks*: "...associated with a single-family residence, a single-family residence projecting over the water, small marinas which accommodated a few boats and readily identifiable single piers projecting from public or neighborhood parks (Fig. 1; Hockett 1976)."
- *Large marina docks*: "...large multifamily or commercial structures which projected over the water, the large pier networks, the large marinas, the large filled areas supporting structures or combinations of the foregoing which formed complexes (Hockett 1976)." Large marina docks were also separated into three

types of main usage: recreational boats (Fig. 2), houseboats (Fig. 3), and industrial (Fig. 4).

- *Overwater Structures*: Large buildings constructed over the water (Fig. 5).
- *Overwater Platforms*: Platforms shading the water (Fig. 6).

2. Dock Height

- *Low*: Docks < 2m above water surface.
- *High*: Docks > 2m above water surface.
- *Floating*: Docks floating on the water.

3. Attached Building

- Docks with a small attached building (Fig. 7), separate from the *Overwater Structure* category above.

Shoreline Types and Modifiers

We printed 268 detailed sections of the shoreline from the digital aerial photography. The shoreline structures were delineated by marking these maps with color-coded lines while boating slowly along the shoreline. For example, a section that consisted of rip-rap was designated on the map with a brown marker. Shoreline designations were placed into the following categories, expanding on those from Toft (2001):

1. Shoreline Type:

- *Rip-Rap*: Shoreline retained with rocks (Fig. 8).
- *Vertical Bulkhead*: Separated into types of steel, wood, concrete, rock/cobble (Figs. 9-12).
- *Sloping Bulkhead*: Steel, wood, concrete, rock/cobble.
- *Beach*: (Fig. 13)
- *Natural Vegetated*: Unretained shoreline with natural vegetation (Fig. 14).
- *Landscaped*: Unretained garden/lawn landscaped shoreline.

2. Shoreline Modifiers:

- *Boat Ramp*: Boat ramp entering water.
- *Shade*: Shoreline shaded by dock, overwater structure, or platform.

General Shoreline Mapping

Larger segments of the shoreline were classified into general categories of substrata type, shoreline wave energy exposure, shoreline geomorphology, and upland cover. The WDNR (Dethier 1990) and NWI (Cowardin et al. 1979) classification schemes were used as a basis for these demarcations (Table 1). These large segments were classified whenever our field crew determined a change in the categories; scientific measurements were not utilized. A total of 162 segments were classified in this manner along the entire shoreline. Most categories were easily determined, with substrata being the most difficult as it involved observing underwater substrates from the boat. Samples of the substrate were collected when possible for verification. All categories pertained to the major habitat type at the shoreline where it could be visualized from the boat, specific checks were made at least once per segment. At least one digital photograph was taken per segment as well, to allow for visualizations at a later date. Pipe outfalls along the shoreline were recorded when noticed.

Geographic Information System (GIS) Analysis

All of the above measurements were incorporated into GIS format using ArcView version 3.2a (Projection: Washington State Plane, North Zone NAD83(91); Vertical Datum: NAVD 88). Dock characteristics were entered into a point shapefile. Shoreline measurements were entered by digitizing the shoreline into a line shapefile. From these shapefiles, total counts and linear lengths of the various categories were determined.

Results

Dock Characteristics

There were 914 recreational docks and 519 marina docks along the surveyed shoreline, with 181 overwater structures and 42 overwater platforms (Fig. 15). Of these docks, 5% had an attached building. Most of the marina docks were for recreational boats, followed by industrial usages and houseboats. The majority of the docks were low

(< 2m) above the water surface (73.1%), with 8.9% of the docks high (> 2m) above the water and 18% floating docks (Fig. 16).

Shoreline Structures

74.71% of the shoreline was retained by rip-rap or bulkhead, while an unretained 25.29% of the shoreline was beach, naturally vegetated, or landscaped (Fig. 17). Most of the bulkheads were constructed with concrete, followed by wood, steel, and rock/cobble (Fig. 18). Sometimes it was difficult to see continuous details of shoreline structures and bulkhead type underneath heavily modified areas such as marinas; in these instances groundtruthing by land and contact with property owners was used to verify measurements as much as possible. Docks, overwater structures, or overwater platforms shaded 17.3% of the shoreline's edge (Fig. 19). Boat ramps accounted for only 0.3% of the shoreline. Linear length of the entire shoreline was 50.84 miles. Lake level measurements were 20.5 feet at the Ballard Locks during our fieldwork (USACE Hydraulics and Hydrology Section). Mapping of Shilshole Bay was conducted on a high tide (+ 10.8 feet) so that water levels would be at the shoreline edge.

General Shoreline Classifications

The majority of the shoreline was partially exposed to wave energy, with the least amount of exposed areas (Fig. 20). The Ballard Locks were not classified for the following categories, as the Locks traversed a cut in the waterway. The shoreline geomorphology was almost all moderate or low gradient terrestrial slope, with few areas of emergent marsh and stream delta habitats, and some high bank areas in Shilshole Bay (Fig. 21). The upland cover directly above the shoreline was mostly garden/lawn or impervious surface, with lower values of a combined 34.2% natural shrub-scrub, forested, or herbaceous habitat (Fig. 22). Shoreline substrata was mostly sand or mixed coarse substrates (Fig. 23), with submerged aquatic vegetation (SAV) also present in many areas (Fig. 24). Eight pipe outfalls were noticed along the surveyed shoreline (Fig. 15). These were large pipes that were clearly visible at the shoreline, dependent on water clarity and lake elevation.

Discussion

The shorelines between Shilshole Bay and Lake Washington are largely modified by the surrounding Seattle metropolitan area. With 75% of the shoreline retained by bulkhead or rip-rap, an average of 32.6 docks/mile, and 17.3% of the shoreline shaded, the impact of shoreline modifications on the ecological community must be seriously investigated. Although areas of natural vegetation and unretained shorelines do exist, they are in the minority and include mostly parks and marshes. Protection of these natural areas will be important to preserve them from future developments as the City of Seattle grows in population.

In comparing past and future surveys of shorelines in Lake Washington and the Ship Canal, it should be noted that the Lake level can affect the observed shoreline structures at the water edge. Water levels can vary as much as 2 feet throughout the year due to adjustment at the Locks (Chrzastowski 1983). For example, sometimes sections of shoreline that we classified as ‘beach’ would have a bulkhead or landscaped vegetation setback from the water’s edge, and therefore at a higher water level could be classified as a different shoreline type. Water levels were 20.5 feet at the Locks gage during our fieldwork, 21.20 – 21.29 at the Kenmore gage during the surveys of Lake Washington by Toft et al. (2001), and 21.98 – 22.22 feet at the Kenmore gage during the surveys of Parametrix and NRC (1999). Thus, characteristics of the “shoreline” can be a dynamic feature due to fluctuations in the height at which the water interfaces with the shore.

With current habitats of the shorelines now identified and mapped in the Lake Washington, Ship Canal, and Shilshole Bay areas, it is important to incorporate these findings with other related projects. Potential factors that could affect chinook populations have been identified (Kahler et al. 2000; Parametrix et al. 2000). Emerging scientific studies have started to test the relation of shoreline developments to various biological factors such as habitat usages of fish and invertebrates (Koehler 2002, Tabor and Piaskowski 2002; Simenstad et al. 2003, Toft et al. 2003).

Future studies should further seek to link attributes of shoreline habitats with their affects on the biological community. This is a challenging step, as it is clear that there are a diversity of modifiers to the shoreline, including different types and heights of

recreational and marina docks, construction types of bulkheads, and degrees of shoreline shading. The only way we can truly assess how shoreline modifications may influence the surrounding biological community is by attempting to quantify such interactions by utilizing scientific studies.

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Figure 1. Recreational docks along the shoreline.



Figure 2. Large marina docks with recreational boats.



Figure 3. Large marina docks with houseboats.



Figure 4. Large marina docks used primarily for industry.



Figure 5. Overwater structure shading the shoreline.



Figure 6. Overwater platform shading the shoreline.



Figure 7. Dock with attached building.



Figure 8. Shoreline retained with rip-rap.



Figure 9. Shoreline retained with a steel bulkhead.



Figure 10. Shoreline retained with a wood bulkhead.



Figure 11. Shoreline retained with a concrete bulkhead.



Figure 12. Shoreline retained with a rock bulkhead.



Figure 13. Unretained shoreline with a beach.



Figure 14. Unretained shoreline with natural vegetation.

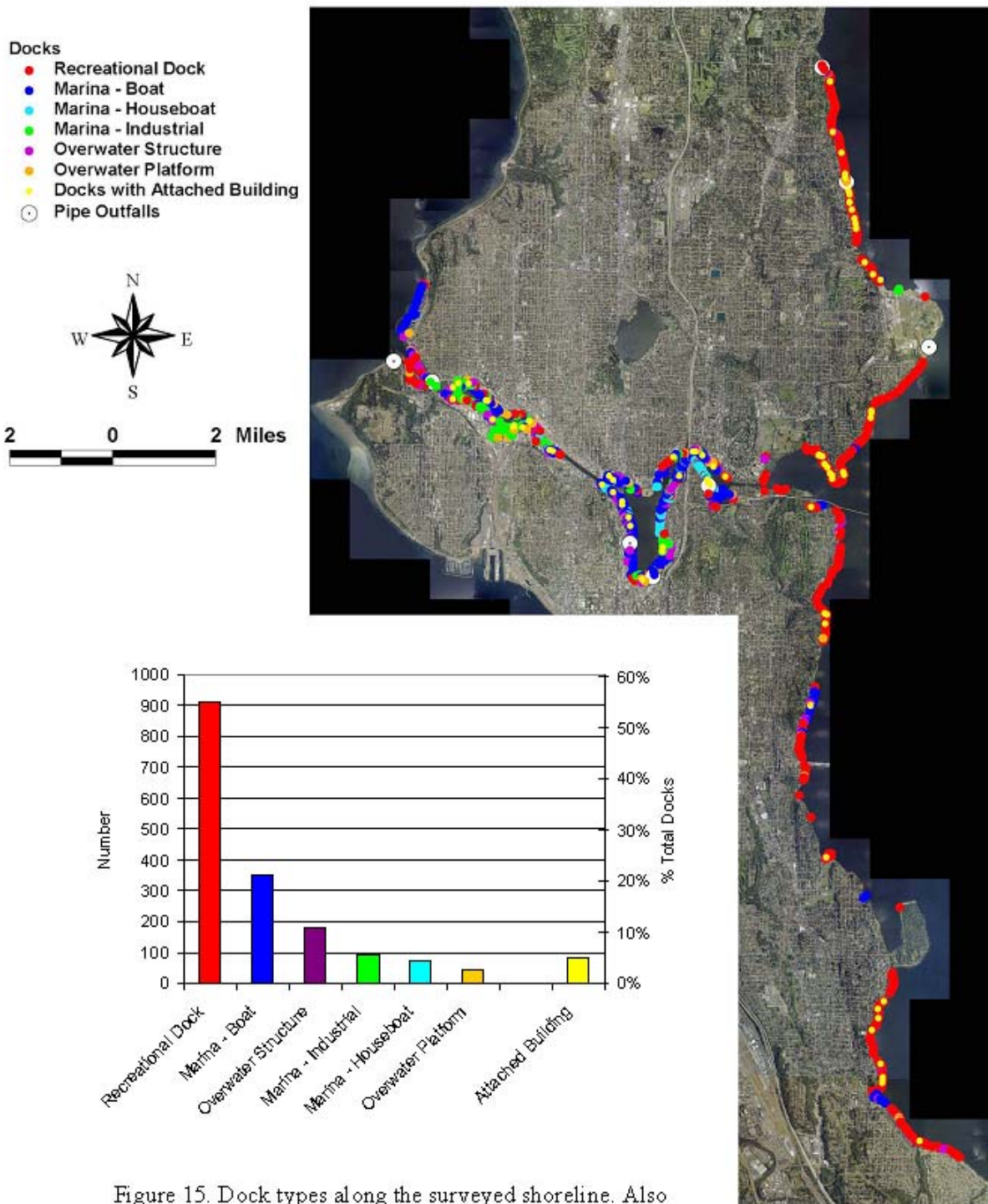


Figure 15. Dock types along the surveyed shoreline. Also included are major pipe outfalls, that are large and clearly noticeable at the shoreline.

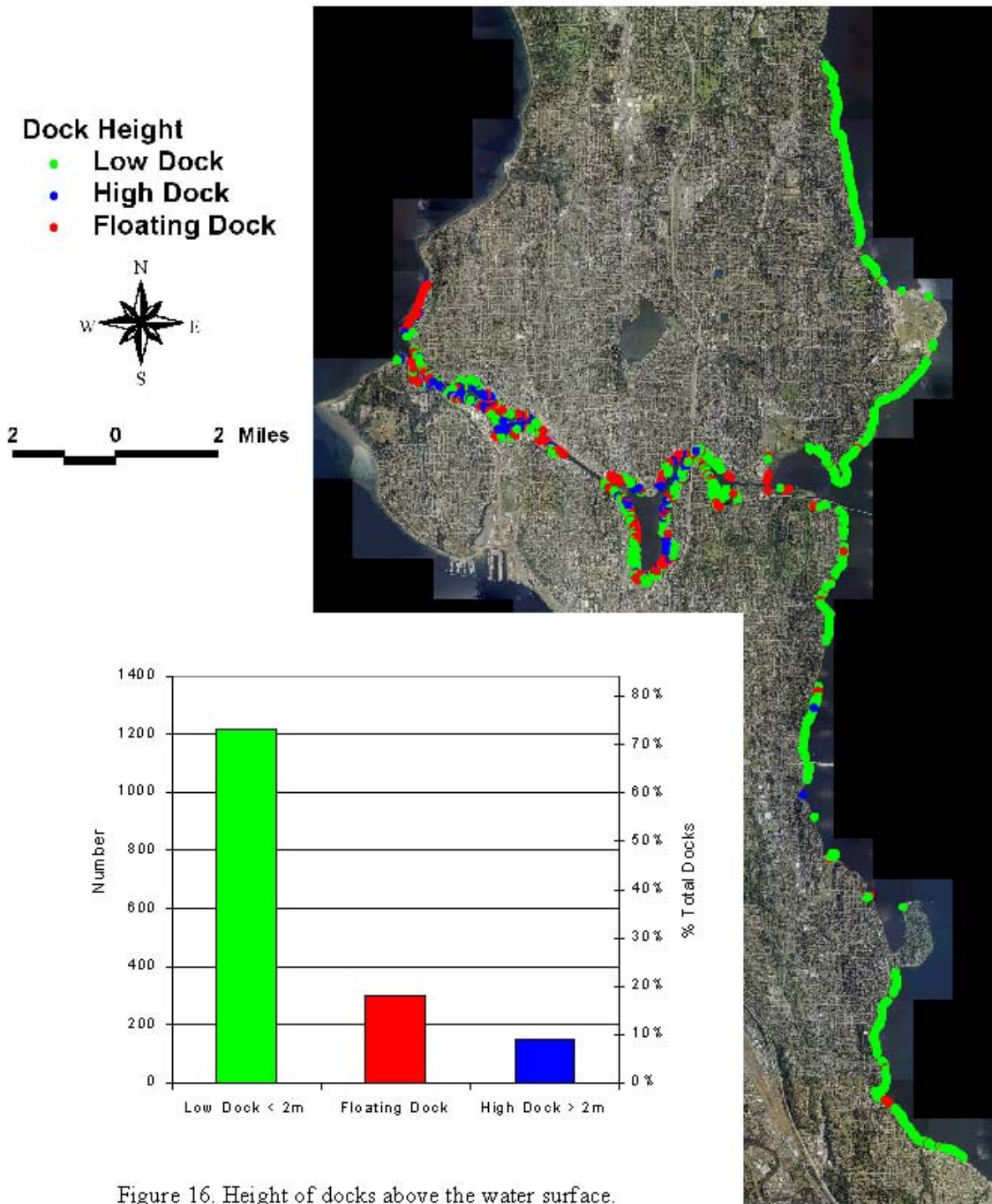


Figure 16. Height of docks above the water surface.

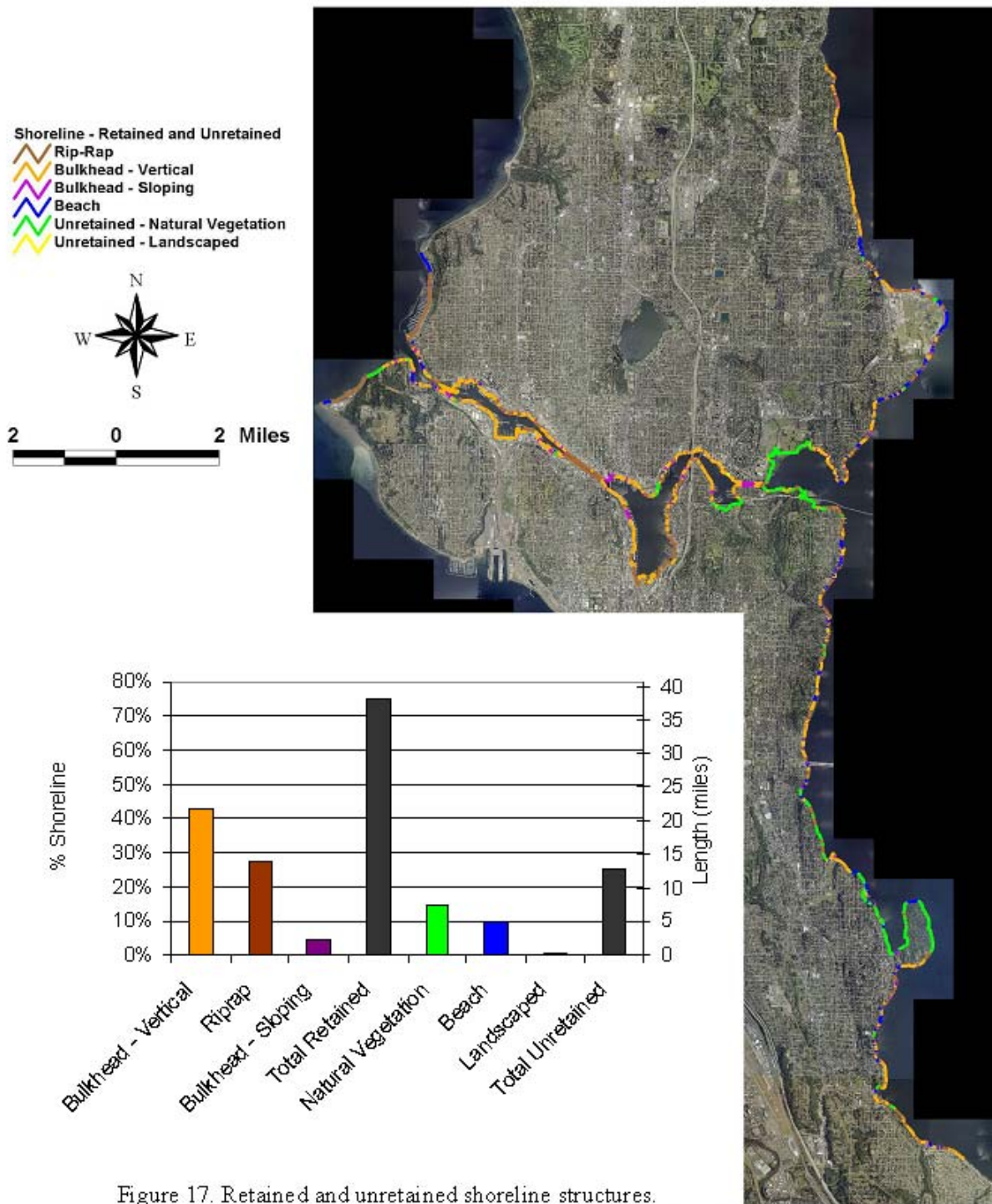


Figure 17. Retained and unretained shoreline structures.

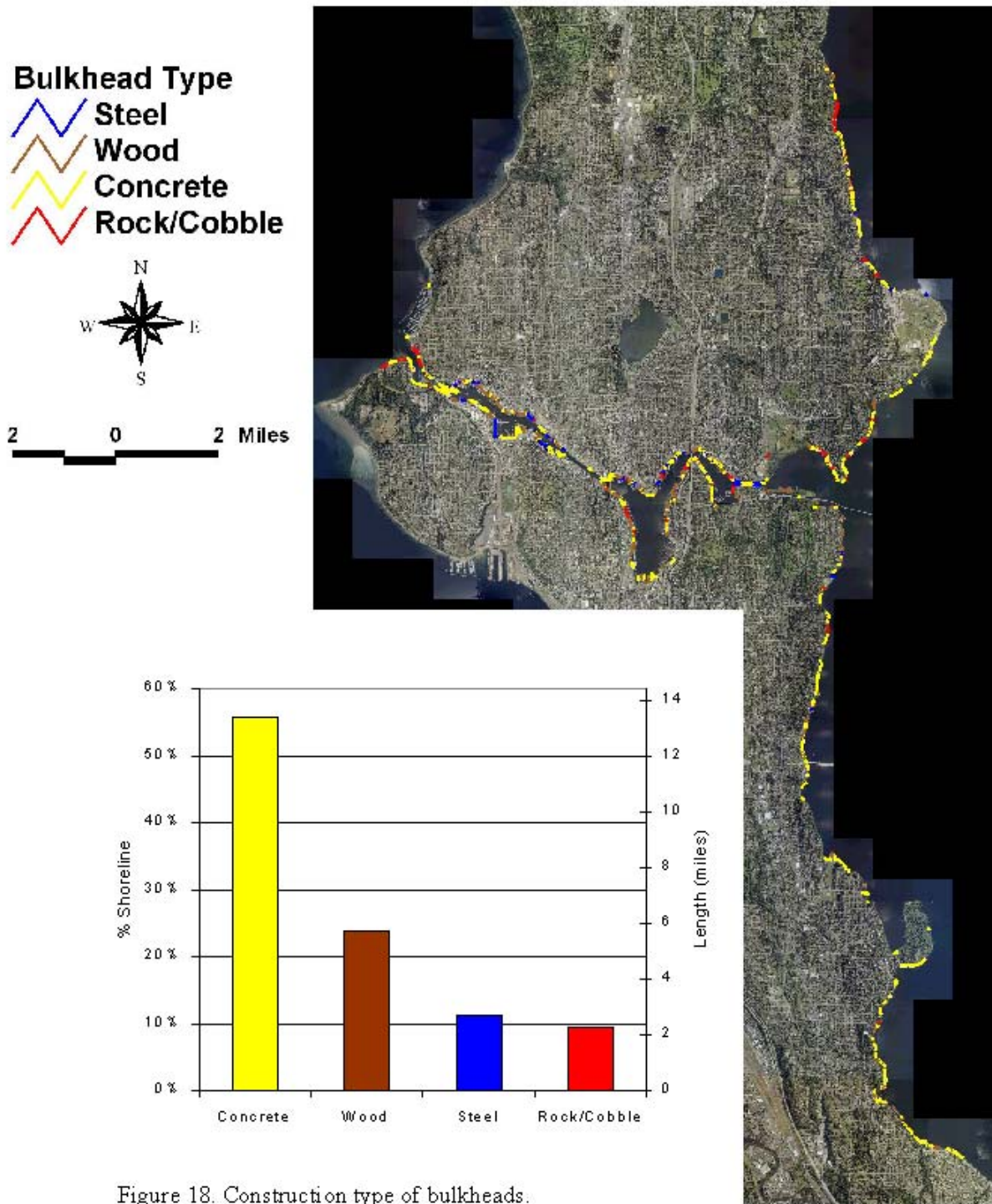


Figure 18. Construction type of bulkheads.

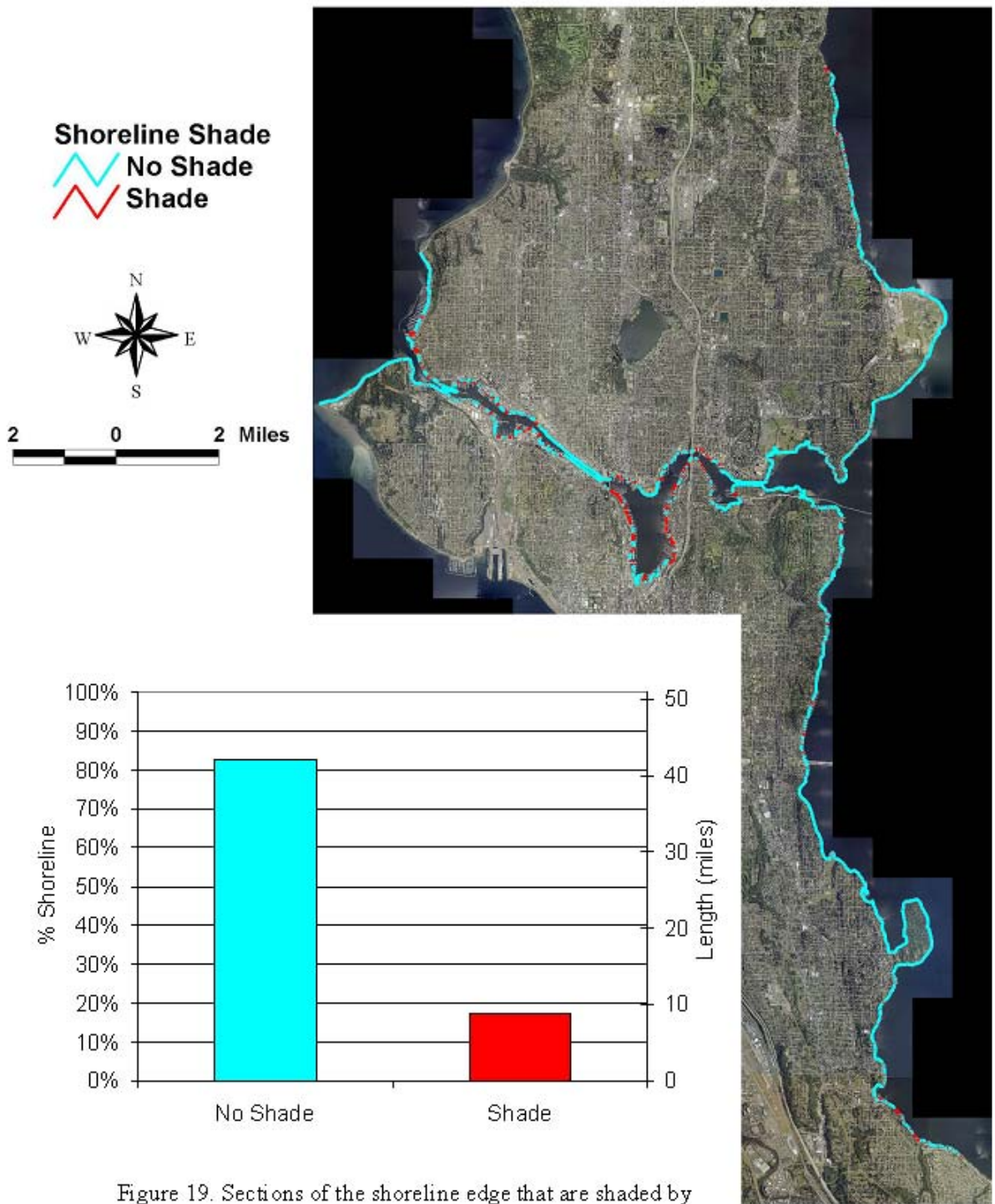


Figure 19. Sections of the shoreline edge that are shaded by docks, overwater structures, or overwater platforms.

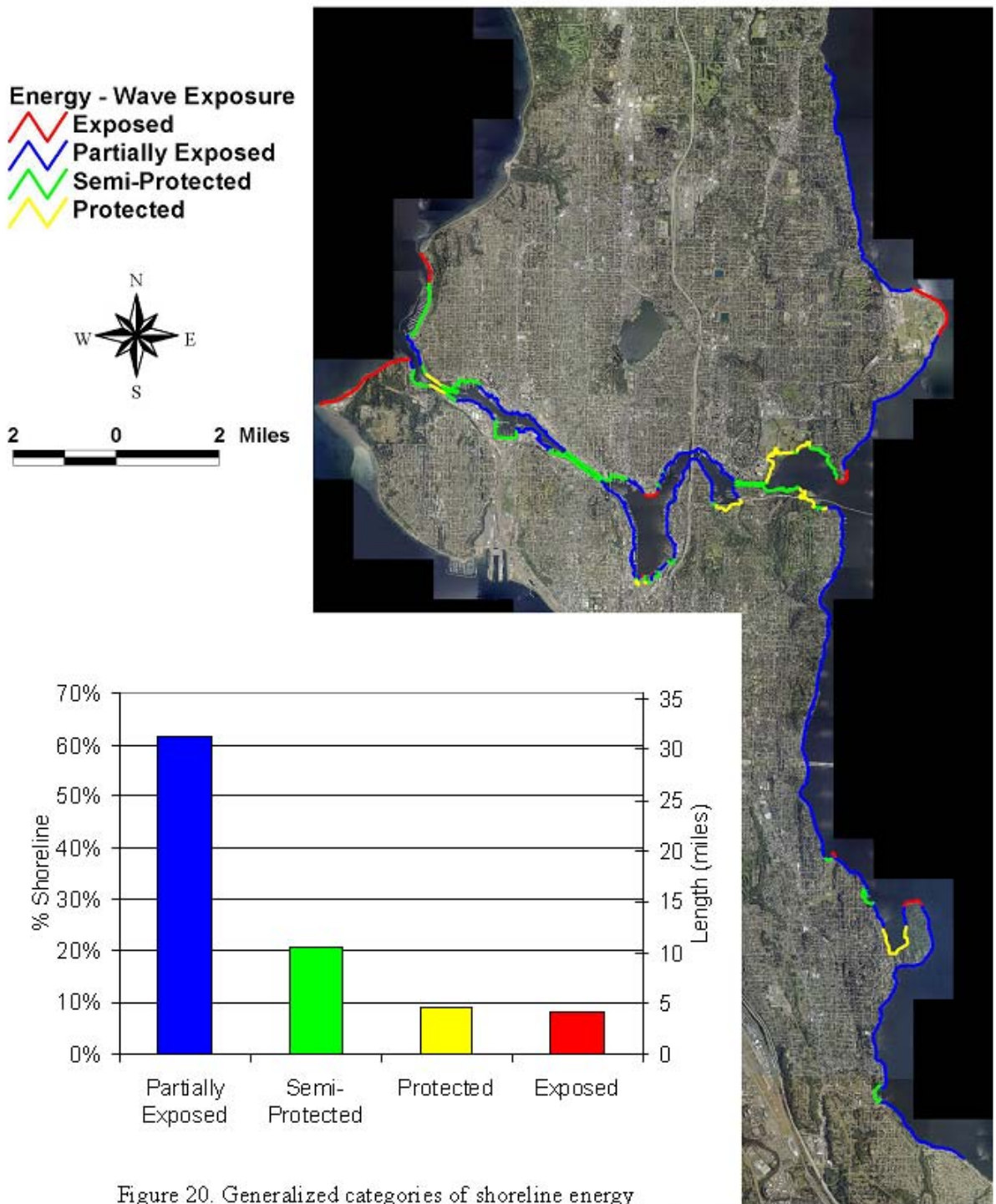


Figure 20. Generalized categories of shoreline energy (wave exposure).

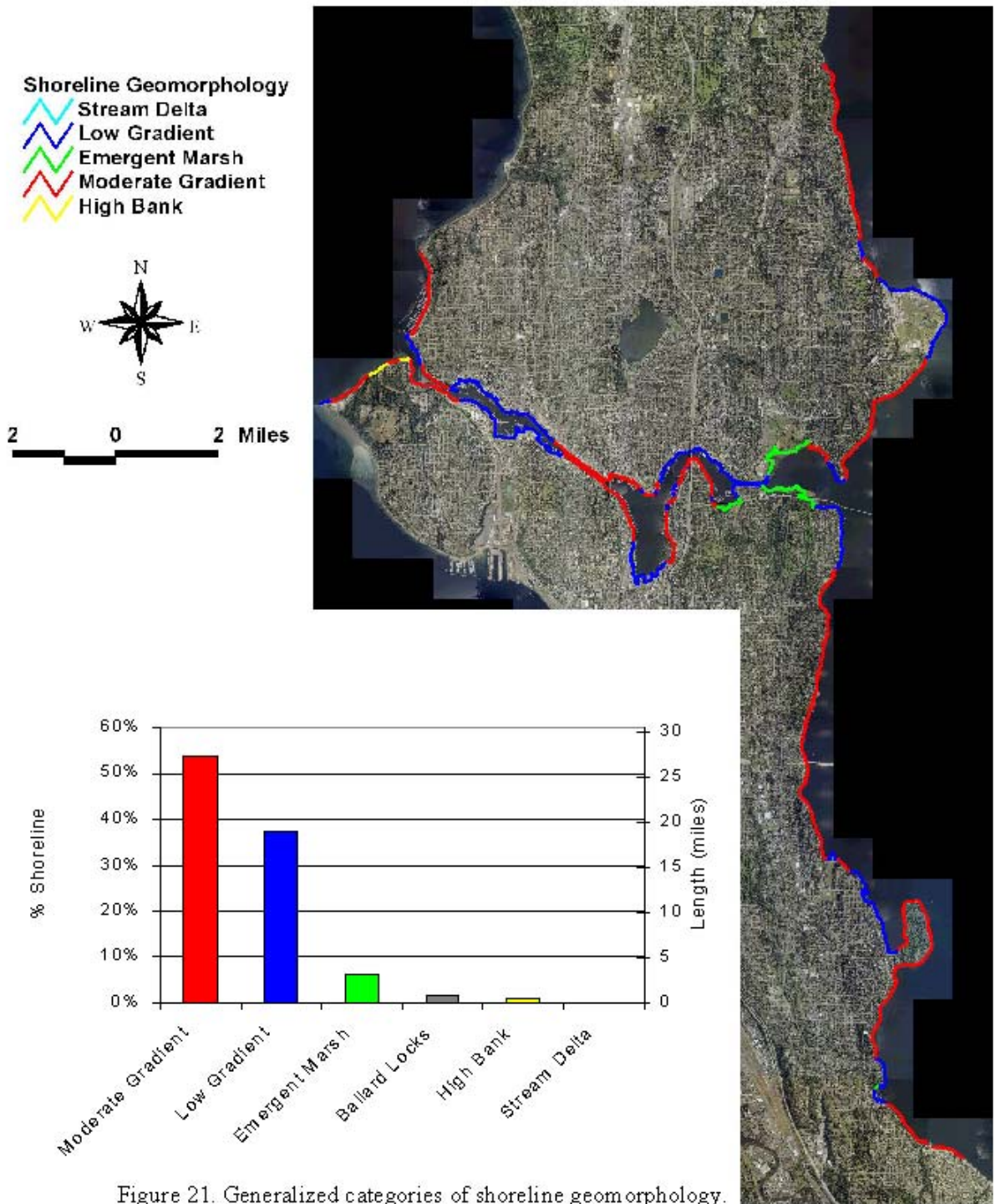


Figure 21. Generalized categories of shoreline geomorphology.

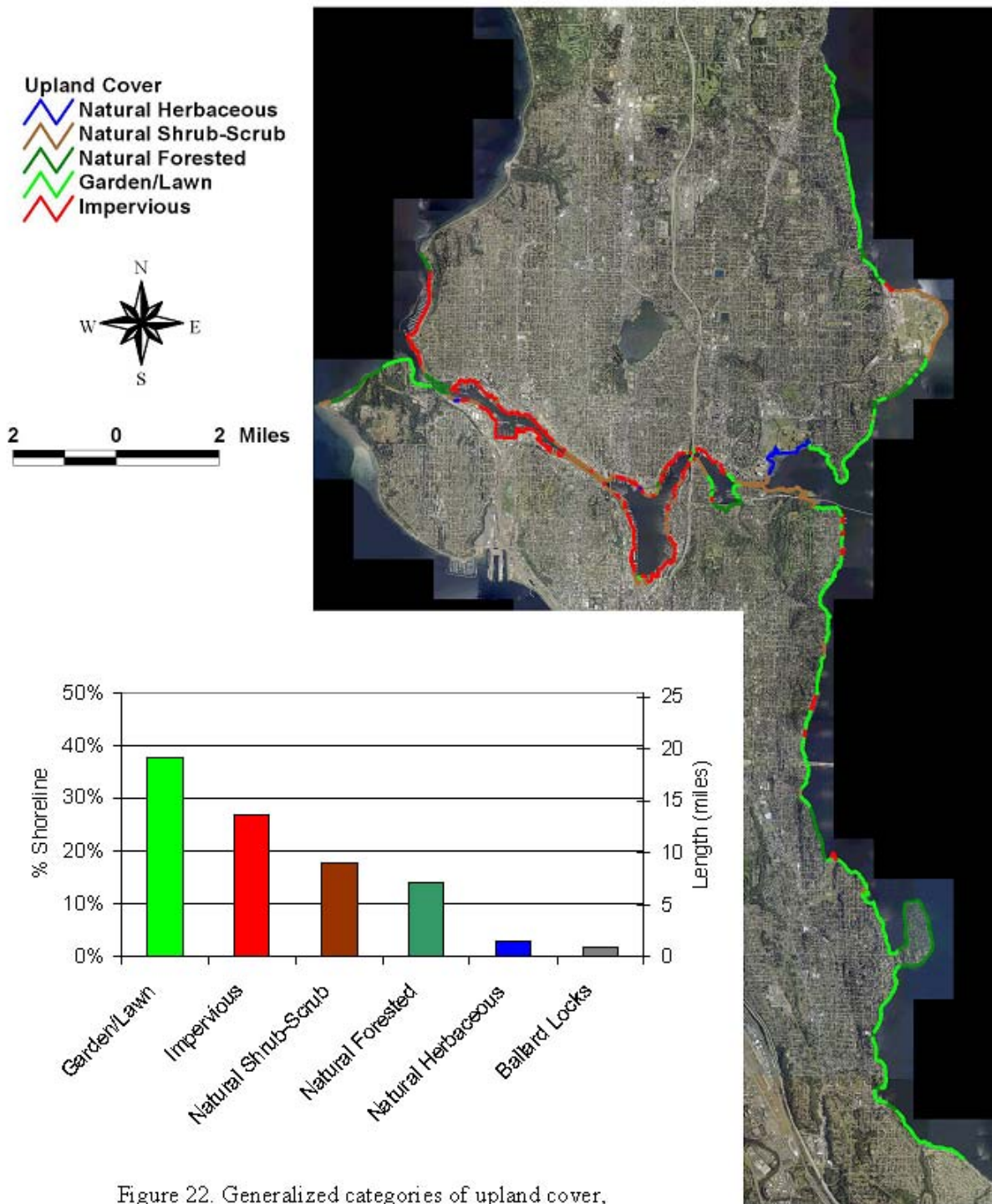


Figure 22. Generalized categories of upland cover, from the shoreline to approximately 50 feet upland.

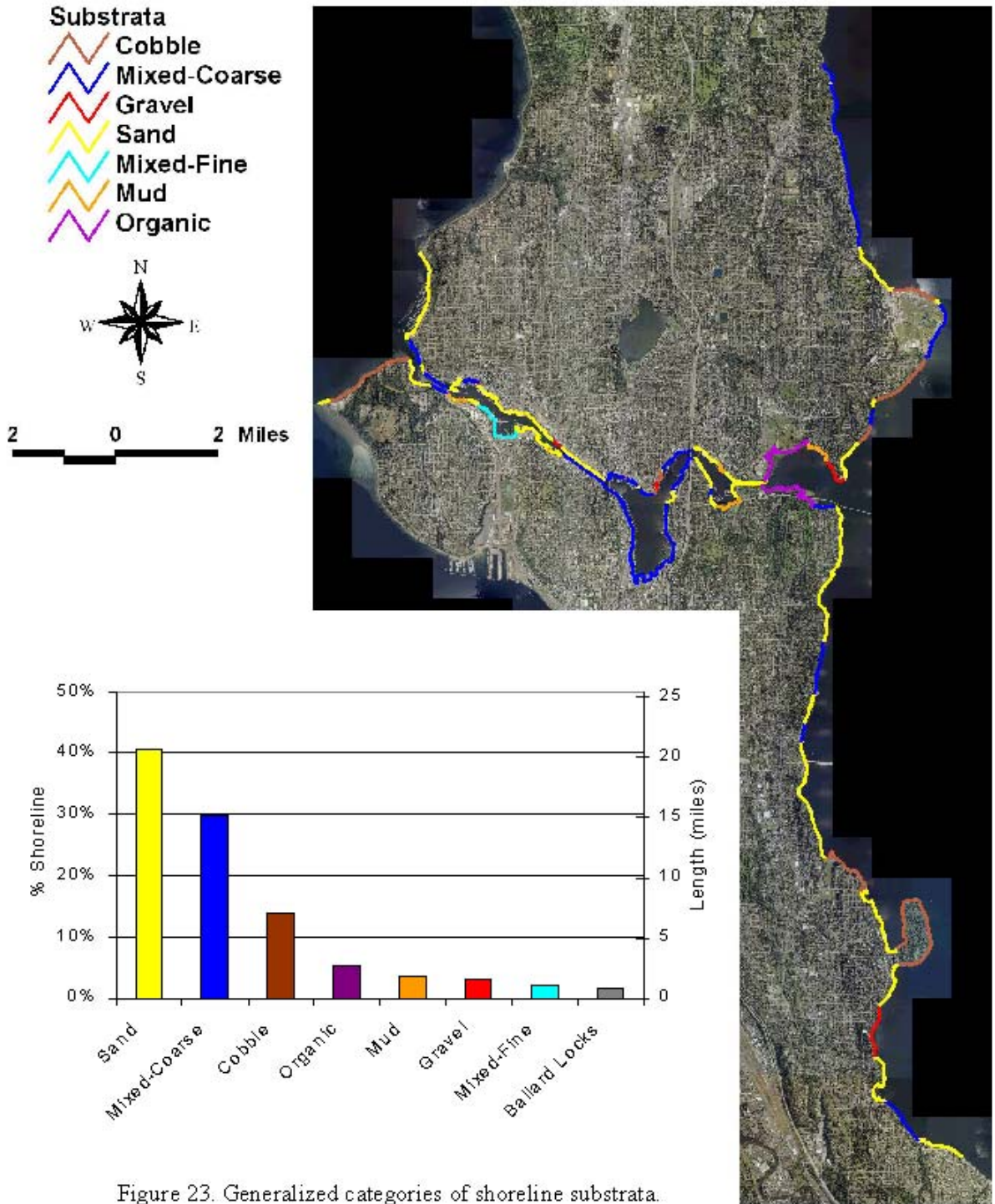


Figure 23. Generalized categories of shoreline substrata.

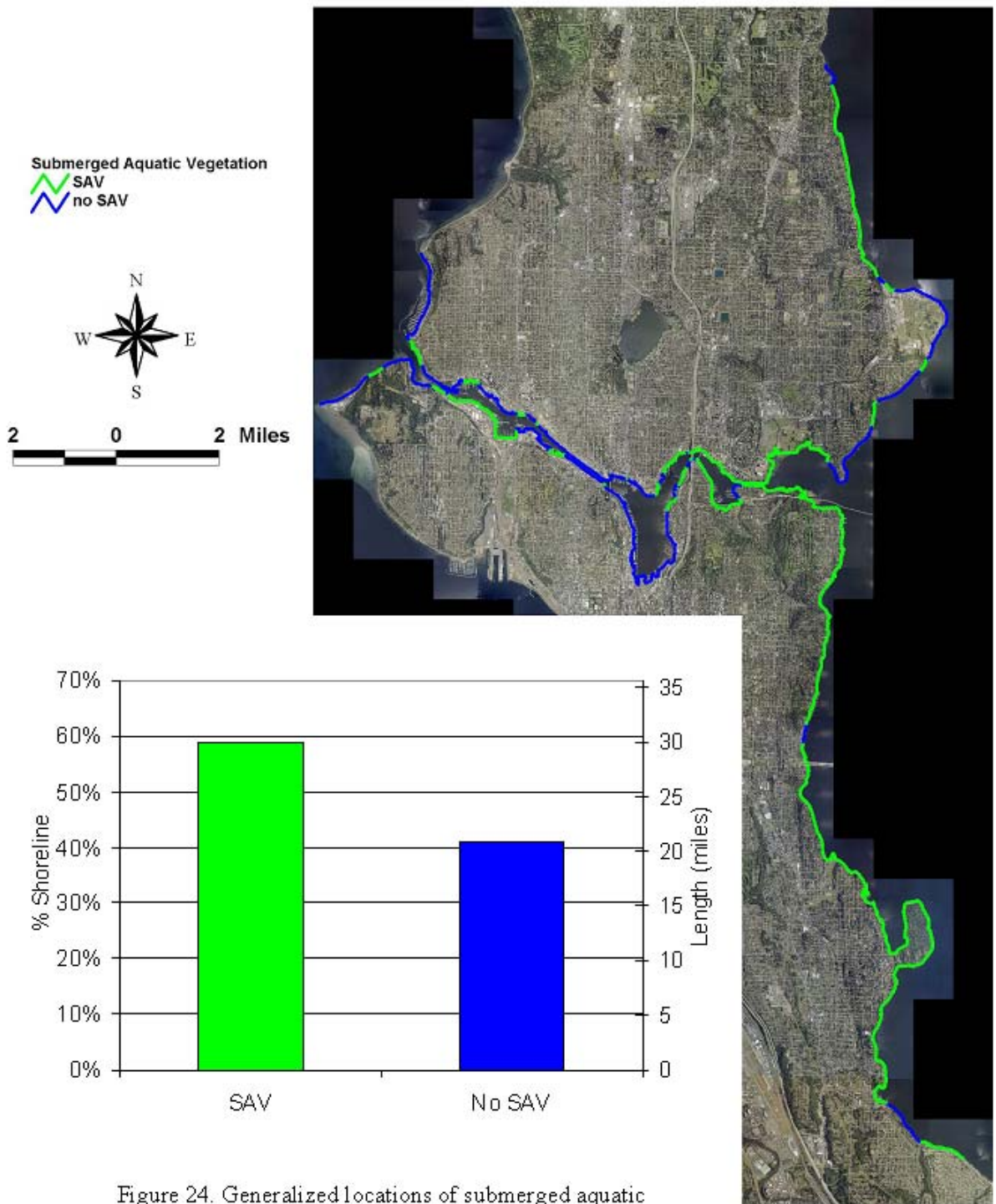


Figure 24. Generalized locations of submerged aquatic vegetation.

Table 1: Shoreline Classification Scheme

Modified from two well-accepted hierarchical wetland classification systems, the basic lacustrine classification of Cowardin et al. (1979) and Dethier's (1990) conceptual modifications. Following are the categories that were utilized:

System: *Lacustrine; Marine*

Subsystem: *Limnetic; Littoral*

Class: *Substrata* (Natural)

Unconsolidated – Classifications pertain to major substrate type at the shoreline.

- Cobble: rocks < 256 mm (10") but > 64 mm (2.5") diameter – unstable.
- Mixed-coarse: substrata consisting of cobbles, gravel, shell, and sand.
- Gravel: small rocks or pebbles, 4-64 mm diam.
- Sand: 0.06-4 mm.
- Mixed-fine (sand-mud): mixture of sand and mud, with little gravel, likely to change seasonally.
- Mud: fine substrata < 0.06 mm, usually mixed with organics.
- Organic: substrata composed primarily of organic matter such as wood chips, leaf litter, other detritus.
- Submerged Aquatic Vegetation (SAV): presence of along shoreline.

Subclass: *Energy* – wave exposure

- Exposed: highly exposed to waves and wind fetch.
- Partially-exposed: shoreline substantially exposed to waves.
- Semi-protected: shoreline moderately protected from waves.
- Protected: shoreline mostly restricted from waves.

Modifiers: *Shoreline Geomorphology*

- Stream delta: Stream entering along shoreline.
- Low-gradient: Terrestrial shoreline with a low gradual slope.
- Moderate gradient: Terrestrial shoreline with a moderately inclined slope.
- Emergent marsh: Marsh along shoreline.

Upland Cover

- Natural herbaceous
- Natural shrub-scrub
- Natural forested
- Garden/lawn
- Impervious

Appendices

A. Raw Data

Shoreline Structures	Sum Length (miles)	Percentages
Bulkhead - Vertical	21.77	42.82%
Rip-rap	13.91	27.36%
Bulkhead - Sloping	2.31	4.53%
<i>Total Retained</i>	<i>37.98</i>	<i>74.71%</i>
Natural Vegetation	7.63	15.01%
Beach	5.06	9.95%
Landscaped	0.17	0.33%
<i>Total Unretained</i>	<i>12.86</i>	<i>25.29%</i>

Bulkhead Type	Sum Length (miles)	Percentages
Concrete	13.40	55.67%
Wood	5.70	23.70%
Steel	2.68	11.15%
Rock/Cobble	2.28	9.48%

Shade	Sum Length (miles)	Percentages
No Shade	42.05	82.7%
Shade	8.79	17.3%

Boatramp	Sum Length (miles)	Percentages
No Ramp	50.69	99.7%
Boatramp	0.15	0.3%

Substrata	Sum Length (miles)	Percentages
Sand	20.64	40.6%
Mixed-Coarse	15.16	29.8%
Cobble	7.10	14.0%
Organic	2.69	5.3%
Mud	1.80	3.5%
Gravel	1.59	3.1%
Mixed-Fine	1.02	2.0%
Ballard Locks	0.84	1.6%

Submerged Aquatic Vegetation	Sum Length (miles)	Percentages
SAV	30.02	59.1%
No SAV	20.81	40.9%

Energy – wave exposure	Sum Length (miles)	Percentages
Partially Exposed	31.43	61.8%
Semi-Protected	10.59	20.8%
Protected	4.65	9.2%
Exposed	4.17	8.2%

Geomorphology	Sum Length (miles)	Percentages
Moderate Gradient	27.32	53.7%
Low Gradient	18.99	37.4%
Emergent Marsh	3.16	6.2%
Ballard Locks	0.84	1.6%
High Bank	0.49	1.0%
Stream Delta	0.04	0.1%

Upland Cover	Sum Length (miles)	Percentages
Garden/Lawn	19.06	37.5%
Impervious	13.56	26.7%
Natural Shrub-Scrub	8.90	17.5%
Natural Forested	7.00	13.8%
Natural Herbaceous	1.48	2.9%
Ballard Locks	0.84	1.6%

Dock Type	Number	Percentages
Recreational Dock	914	55.2%
Marina - Boat	353	21.3%
Overwater Structure	181	10.9%
Marina - Industrial	93	5.6%
Marina - Houseboat	73	4.4%
Overwater Platform	42	2.5%

Dock Height	Number	Percentages
Low Dock < 2m	1216	73.1%
Floating Dock	300	18.0%
High Dock > 2m	148	8.9%

Attached Building	Number	Percentages
No Building	1581	95.0%
Attached Building	83	5.0%

B. Metadata of GIS layers

Projection: Washington State Plane, North Zone NAD83(91); Vertical Datum: NAVD 88

Orthophotos: Digital orthophotos provided by the City of Seattle (image source Triathlon, Inc.; August 1999; 1-foot resolution; Cortho_s.sid and Cortho_n.sid).

All other shapefiles prepared by:

Jason Toft
 Wetland Ecosystem Team
 School of Aquatic and Fishery Sciences
 Box 355020
 University of Washington
 Seattle, WA 98195-5020
 (206) 221-5460
tofty@u.washington.edu

Shapefile codes: **Citydock.shp (point)**

Column		
Dock_type	Type	Color Code
1	Recreational Dock	Red
2	Marina - Boat	Navy Blue
3	Marina - Houseboat	Light Blue
4	Marina - Industrial	Green
5	Overwater Structure	Purple
6	Overwater Platform	Orange
7	Pipe Outfalls	White

Height	Type	Color Code
0	Low Dock < 2m	Green
1	High Dock > 2m	Navy Blue
2	Floating Dock	Red

Building	Type	Color Code
0	No Building	
1	Attached Building	Yellow

Shoreseg.shp (line)

Column		
Shore_type	Name	Color Code
1	Rip-rap	Brown
2	Bulkhead - Vertical	Orange
3	Bulkhead - Sloping	Purple
4	Beach	Navy Blue
5	Natural Vegetation	Green
6	Landscaped	Yellow

Modifier	Name	Color Code
1	Steel	Navy Blue
2	Wood	Brown
3	Concrete	Yellow
4	Rock/Cobble	Red

Shade	Type	Color Code
0	No Shade	Light Blue
1	Shade	Red

Boatramp	Type	Color Code
0	No Ramp	
1	Boatramp	Light Yellow

Substrata	Type	Color Code
0	Ballard Locks	
4	Cobble	Brown
5	Mixed-Coarse	Navy Blue
6	Gravel	Red
7	Sand	Yellow
8	Mixed-Fine	Light Blue
9	Mud	Orange
10	Organic	Purple

Sav	Type	Color Code
0	No SAV	Blue
1	SAV	Green

Energy	Type	Color Code
1	Exposed	Red
2	Partially Exposed	Navy Blue
3	Semi-Protected	Green
4	Protected	Yellow

Geomorph	Type	Color Code
0	Ballard Locks	
1	Stream Delta	Light Blue
2	Low Gradient	Navy Blue
3	Emergent Marsh	Green
4	Moderate Gradient	Red
5	High Bank	Yellow

Upland_cov	Type	Color Code
0	Ballard Locks	
2	Natural Herbaceous	Navy Blue
3	Natural Shrub-Scrub	Brown
4	Natural Forested	Dark Green
5	Garden/Lawn	Green
6	Impervious	Red