Tidal Wetland Prioritization for the Tillamook Bay Estuary

Tillamook River, view upstream to Tillamook River Rd., near low tide on 2/15/12. Photo by Michael Ewald.

October 2012

Prepared for:

Tillamook Estuaries Partnership, Garibaldi, Oregon

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This project was a joint endeavor of Green Point Consulting and the Estuary Technical Group of the Institute for Applied Ecology. The mission of the Estuary Technical Group is to restore estuarine habitats, improve estuarine restoration results, and advance the understanding of estuarine ecosystems through cost-effective application of the best available science. The mission of the Institute for Applied Ecology is to conserve native ecosystems through restoration, research and education.

Please direct questions about this report to Laura Brophy (contact information provided on the cover page).

Acknowledgments: We are grateful for the expertise and local knowledge contributed by the members of our advisory team: Scott Bailey, Lisa Phipps and Rachel Hagerty of the Tillamook Estuaries Partnership, Chris Knutsen (Oregon Department of Fish and Wildlife), Mitch Cummings (U.S. Department of Agriculture Natural Resources Conservation Service), Mark Trenholm (Wild Salmon Center), Bruce Taylor (Pacific Coast Joint Venture), Denise Lofman (Tillamook Bay Watershed Council), and Kristen Maze (Tillamook County).

Recommended citation: Ewald, M.J., and L.S. Brophy. 2012. Tidal Wetland Prioritization for the Tillamook Bay Estuary. Prepared for the Tillamook Estuaries Partnership, Garibaldi, Oregon. Green Point Consulting, Corvallis, Oregon.

Author contributions: Both authors contributed equally to this work. Brophy developed the project plan, communicated with stakeholders, and wrote introductory, background and interpretive sections of the report. Ewald developed spatial analysis methods, conducted numeric and spatial analysis, created the database of site characteristics, and wrote methods and results sections of the report. Both authors collaborated on development and refinement of methods, and discussed the results and implications of the work at all stages.

Funding for this project was provided by the Wild Salmon Center, Ducks Unlimited, Pacific Coast Joint Venture, the U.S. Fish and Wildlife Service Coastal Program, and the Tillamook Estuaries Partnership.

Abbreviations

CSC	Coastal Services Center
DEM	Digital Elevation Model
DLCD	Oregon Department of Land Conservation and Development
DSL	Oregon Department of State Lands
EPB	Estuary Plan Book
GeoTIFF	Georeferenced Tagged Image File Format (e.g., computerized aerial photographs)
GIS	Geographic Information Systems (computerized mapping)
GPS	Global Positioning System
HGM	Hydrogeomorphic (as in, the HGM method for wetland functional assessment)
HMT	Highest measured tide (also called "highest observed water level")
LiDAR	Light Detection And Ranging (a remote sensing technology)
LMZ	Landward migration zone (for tidal wetlands)
LWI	Local Wetland Inventory
MHHW	Mean Higher High Water (the average height of the higher of the two daily high tides observed over a specific time interval)
NAIP	National Agricultural Imagery Program
NAVD88	North American Vertical Datum of 1988 (an elevation reference system)
NCLC	North Coast Land Conservancy
NGVD29	National Geodetic Vertical Datum of 1929 (an elevation reference system)
NOAA	National Oceanographic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
NWI	National Wetland Inventory
ODA	Oregon Department of Agriculture
ODFW	Oregon Department of Fish and Wildlife
ORBIC	Oregon Biodiversity Information Center
ORWAP	Oregon Rapid Wetland Assessment Protocol
OWEB	Oregon Watershed Enhancement Board
PDF	Portable Document Format
TCCA	Tillamook County Creamery Association
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Study overview

> *Important note: The term "tidal wetlands" is used throughout this study to refer to areas identified as current or likely former tidal wetlands. This project did not identify regulatory boundaries or delineate wetlands; likely former tidal wetlands were mapped using existing data sources, including the National Wetland Inventory, other wetland mapping, NOAA tidal datums, and a LiDAR digital elevation model. Mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.*

This study identified and characterized 6035A of current and likely former tidal wetlands in the Tillamook Bay estuary (in the emergent, shrub, and forested classes), divided the wetlands into 92 "sites" suitable for action planning purposes, and used ecological criteria to prioritize the sites for conservation and restoration activities. The project is intended for use in strategic planning of voluntary conservation and restoration efforts; products are not intended for regulatory use.

Mapping and site characterization drew upon many data sources including a digital elevation model (DEM) derived from Light Detection and Ranging (LiDAR) data; National Wetland Inventory (NWI) and other wetland maps; recent inventories of dikes and tide gates; historic vegetation data; other Geographic Information System (GIS) and tabular data sources; expert local knowledge; and recent aerial orthophotographs. Alterations were characterized for each of the 92 sites.

The total area of current and former tidal wetlands identified (6035A) is greater than most past estuarine wetland mapping efforts such as the National Wetland Inventory and Estuary Plan Book. About half of this area, 2964A, was tidal swamp (forested or shrub tidal wetland) prior to European settlement; 1829A was historically tidal marsh, and about 1240A was historically open water, which has converted to tidal marsh through accretion of sediments since the 1800s. The higher elevation zones identified in this study may be inundated only occasionally. However, including these higher areas in tidal wetland conservation and restoration planning will assist current resource management and adaptive planning for sea level rise.

Of the 92 sites, 16 were ranked in the highest priority group for restoration and conservation actions. The largest high-priority sites were along the eastern bay fringe; other high-priority sites were identified along Hathaway, Squeedunk, Hall and Hoquarten Sloughs; and in the upper tidal reaches of the Tillamook River. Twenty-one sites were ranked medium-high; the largest of these were located in the Trask and Tillamook sub-basins. The remaining 55 sites, about half the total area, were ranked medium to low and were distributed across the entire study area. A low priority ranking in this study does not indicate that a wetland is unimportant; all tidal wetlands provide critical ecosystem services and wetland functions, and all wetlands are protected by applicable federal and state laws.

Introduction

Project goals and approach

Throughout the Pacific Northwest and the United States, there is increasing recognition of estuarine contributions to watershed and marine processes. This recognition has generated new interest in tidal wetland conservation and restoration. In Oregon, overall losses of tidal wetlands since the 1850's are estimated at about 70% (Thomas 1983, Boule and Bierly 1987, Good 2000, Christy 2004), so there is a clear need for restoration. Conservation of remaining tidal wetlands is equally important. Because each estuary offers a wide variety of restoration and conservation opportunities, strategic planning is needed to reach conservation and restoration goals. Prioritization of tidal wetlands for protection and restoration was established as a goal in the Tillamook Bay National Estuary Program's Comprehensive Conservation and Management Plan (TBNEP 1998).

This prioritization is designed to provide strategic focus for tidal wetland conservation and restoration actions undertaken in partnership with willing landowners. The study highlights locations in the Tillamook Bay estuary where tidal wetland restoration or conservation action may offer the biggest ecological "bang for the buck" – that is, the highest potential to protect or increase estuary functions. The information provided by this study provides a basis for working with interested landowners to develop site-specific action plans.

This study's products are meant for active use. The GIS datasets, spreadsheets and maps can be used to organize information about tidal wetlands and estuary conservation activities. The estuary is a dynamic place, so we recommend regular updating of site-specific data, as well as verification of the details in this report before site-specific action planning. Sufficient data are provided for fine-tuning site selection and action planning; these data (and additional new data) can also be used to re-rank sites using alternative methods if desired.

This prioritization uses ecological factors to rank sites for both conservation and restoration actions. Criteria for prioritization included size of site, tidal channel condition, connectivity to other wetlands, salmonid diversity, historic vegetation type, and diversity of current vegetation types. Information on these characteristics was obtained from publicly available data, field reconnaissance (generally offsite observation), aerial photograph interpretation, and local expert knowledge. Number of landowners, ownership type, and land use zoning are can also be important in restoration planning; they are briefly addressed in this report.

This study has no regulatory intent or significance; it is intended only to foster conservation and restoration by interested and willing landowners. This project does not provide regulatory delineation of wetlands; site boundaries were taken from existing NWI mapping and a LiDAR-derived digital elevation model. *Mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.*

This prioritization is not intended to be an assessment of wetland functions. Assessment of tidal wetland functions is a separate endeavor (Adamus 2006, Adamus *et al.* 2009a) and was not within the scope of this analysis. However, the prioritization criteria used in this study – the same criteria used in the Oregon estuary assessment method (Brophy 2007) – were selected because they strongly influence tidal wetland functions.

This prioritization is intended to provide a broad perspective and help guide decisions; it should not be used to eliminate any site from consideration for restoration or conservation. In other words, all tidal wetlands are important (and all are protected under state and federal regulations). Prioritization is simply a way to focus action planning on sites where the return for that effort may be the greatest.

This study strives for transparent methods, simplicity, flexibility, and accessibility. The data sources, data manipulations, scoring methods, and results are thoroughly documented and all analyses are repeatable. A limited number of criteria were used, to make results understandable. All of the data that were used to calculate priority rankings are shown in this report and can be accessed, checked for accuracy, and updated as needed.

Throughout this study, we actively sought input from local experts and resource specialists to improve our results. This information has been included in the site characterization and prioritization, the site attribute table, and this written report.

This study's map of tidal wetlands of the Tillamook Bay estuary differs from past maps, and probably will differ from future maps. Each map is the product of project goals, available data, and specific mapping methods. Since differences between maps can create confusion, we have tried to make our methods clear and consistent. See **Methods** below for important details.

Study area and tidal wetland classes included

This study included all current and former tidal wetlands in the Tillamook Bay Estuary up to the head of tide for the Tillamook, Trask, Wilson, Kilchis and Miami Rivers, their tributaries and all tidal sloughs such as Hoquarton, Dougherty, and Hall Sloughs (Map 1). Mapped head of tide, as published by the Oregon Department of State Lands (OR DSL 2007), was not assumed to be correct; current and likely former tidal wetlands were included even if they occurred upstream of mapped head of tide. This was necessary because the DSL mapping sometimes shows head of tide at tide gates or other barriers; and because our field experience has shown that mapped head of tide is sometimes inaccurate (e.g., Brophy 2012).

Emergent tidal wetlands ("tidal marsh"), shrub tidal wetlands, and forested tidal wetlands were included in this study. Shrub and forested tidal wetlands are also referred to as "tidal swamps." Consistent with the statewide estuary assessment method (Brophy 2007), tidal wetlands found lower in the tide range (eelgrass beds, algae beds, and mud flats) were not included in this study, because they require very different resource management approaches. Also consistent with the statewide method, former tidal wetlands that have been completely filled for industrial, residential, commercial lands or infrastructure ("developed lands") were excluded from the study.

Definition of tidal wetlands

Several definitions of tidal wetlands have been used through the years, but for this assessment, we used the following definition: *A tidal wetland is a wetland that is periodically inundated by tidal waters, generally daily at high tide or monthly during spring tides, but at least annually*. This definition was used in the hydrogeomorphic assessment method (HGM method) for Oregon's tidal wetlands (Adamus 2006) and in the Estuary Assessment module of the Oregon Watershed Assessment Manual (Brophy 2007). Emergent, scrub-shrub and forested wetland classes are defined in Cowardin *et al*. (1979), and we followed those definitions in this study.

Tidal waters are any waters that rise and fall with the tides, regardless of salinity (Definition of Waters of the United States, 2012). Salinity in tidal waters ranges from full ocean salinity to completely fresh in the "freshwater tidal" zone, where river flows are "held up" by the tides.

The frequency of tidal inundation in tidal wetlands varies by wetland type and landscape setting. Low marsh is typically inundated by the tides on a daily basis, but high marsh is inundated only on higher-high tides during spring tide cycles (new or full moon). Tidal swamps may be inundated during most spring tide cycles, or may undergo tidal inundation only in winter, when high river flows add to the high tide elevation (Diefenderfer 2007, Brophy 2009, Huang *et al.* 2011). This last category is particularly extensive in the Tillamook Bay Estuary, where high river flows, high tides and storm surge combine to create widespread winter flooding (Phillip Williams and Associates 2004, USACE 2005).

Summary of results

Tidal wetland area: Working from existing NWI maps, and enhancing those maps using the LiDAR DEM (Map 2), other geospatial data, field observation, local expert knowledge, and aerial photograph interpretation, we identified 6035A (2442.3 ha) of likely current and historic tidal wetlands in the Tillamook Bay estuary (Maps 3-5). This estimate is 2.4 times greater than the NWI-mapped area of tidal wetlands in these classes (USFWS 2010), and 1.4 times the Estuary Plan Book's mapping in these classes (Cortright *et al.* 1987). The upslope boundary of our mapping was Highest Measured Tide ("HMT," which is 11.5ft relative to the North American Vertical Datum (NAVD88) at the Garibaldi tide station (Mojfeld *et al*. 2008). Tidal inundation in some of the mapped areas may be infrequent, and it is possible that some of these areas do not inundate tidally. However, based on available data, these areas are likely to experience inundation due to tidal forces, particularly during high river flows in winter. Moreover, they are likely to inundate more frequently in the future due to sea level rise.

Tidal swamp and tidal marsh – past and present: Using historic vegetation maps obtained from the Oregon Biodiversity Information Center, we identified the historic vegetation types for these current and historic tidal wetlands (Map 14). Of the 6035A identified, about half the area (2964A) was historically "tidal swamp" (forested or shrub tidal wetland, as opposed to grassy "tidal marsh"). Tidal swamp was once widespread in Oregon, but is now very rare. In the Tillamook, 91% of the historic tidal swamp has been lost or converted to nontidal wetland or tidal marsh; only about 285A of intact tidal swamp remains. Historic tidal marsh totaled 1829A, of which only 15% remains; however, 1240A of new tidal marsh has formed on the bay fringe due to sediment deposition (accretion).

Alterations: Within the mapped tidal wetlands, we defined 92 sites (Map 3) and characterized conditions within these sites, focusing on site-specific alterations. Flow restrictions were considered site-specific alterations, even if the restriction was offsite. We classified sites into three groups based on in-channel flow restrictions (tide gates and culverts). The results (Map 13) show that 45 sites totaling 3984A (66% of total area) have tide gates or other flow restrictions that block tidal exchange. An additional 584A (16 sites) have restrictive culverts or other flow restrictions that reduce tidal exchange – a "muted tidal" condition. Thirty-one sites totaling 1467A have no in-channel flow restrictions and are fully connected to the tides. The fully-tidal sites generally have other types of alterations; only 5 sites totaling 119A have no mapped alterations. It is important to remember that all sites are affected by landscape-scale changes (see **Estuary-wide alterations and offsite effects** below).

Prioritization: We prioritized the 92 tidal wetland sites for restoration and conservation actions. To help in interpretation of the site rankings, we defined five priority ranking groups using the "Jenks natural breaks" grouping method (Map 6). The high priority group contains 16 sites totaling 1315A (22% of total area). The medium-high priority group contains 21 sites (1809A; 30% of total area). Fifty-five other sites rank medium or lower, but it is important to recognize that all of the sites provide vital ecosystem services and wetland functions. Six ecological prioritization criteria contributed to site rankings: tidal channel condition (including connection to tidal flows), size of site, wetland connectivity, salmonid diversity, historic wetland type, and diversity of vegetation classes (Maps 7-12).

Land ownership: Land ownership strongly affects the feasibility, planning, and logistics of restoration and conservation actions. We determined the approximate number of landowners and land ownership type for each site and mapped the results (Maps 16-17) to help with site-specific action planning. Twenty sites totaling 611A have a single landowner; 16 sites (1094A) have two landowners, and the rest have three or more landowners. Land ownership type reflects the agricultural nature of the Tillamook estuary; land ownership is classified as farm operations, at least in part, for two-thirds of the sites (62 sites, 84% of total area).

Sea level rise adaptation planning: To assist climate change adaptation, we used the LiDAR DEM to map the "landward migration zone" (LMZ) for tidal wetlands in the Tillamook Bay estuary (Map 15). This is the area located just above current tidal range that may inundate with higher sea levels. We summarized the area within 1m, 2m and 3m of the highest measured tide

(HMT) at the Garibaldi tide station, the nearest active long-term tide station operated by the National Oceanic and Atmospheric Administration (NOAA). HMT at this station is 11.5ft NAVD88 (Mofjeld *et al.* 2004). The Tillamook Bay area has a broad floodplain, which would appear to offer better landward migration opportunities compared to many other Oregon estuaries. However, the total landward migration area identified is only 5563A – less than the current tidal wetland area. This suggests that sea level rise will lead to substantial tidal wetland loss, an effect that will be heightened by the barriers to landward migration such as the economically important Highway 101 corridor.

Conclusion: Mapping of tidal wetlands is a complex and challenging task; results depend on project goals, methods, and available data. This study identified a larger tidal wetland area than past maps of the estuary, due to the methods used; future efforts will no doubt differ from this study's maps as available information improves and conditions change. Despite the challenges, this study provides useful, updated tools for managing tidal wetland resources in the Tillamook Bay estuary, particularly in light of potential climate change impacts.

Products

The following products are provided with this report:

1. Written report (paper and PDF formats). Contains background, methods, results, and the following appendices:

> **Appendix 1. Maps.** Maps of study area, sites, elevation (LiDAR DEM), prioritization scoring, tidal connection status, historic vegetation type, landward migration zones, and ownership status.
>
> **Appendix 2. Additional tables.** Tables of site ranking scores; key to site attributes; table of site attributes; tax parcel property classification table; tables of site zoning status.
>
> **Appendix 3. GIS flow chart for site definition**
>
> **Appendix 4. Introduction to the high-resolution hierarchical basins dataset**
>
> **Appendix 5. Data management and software**
>
> **Appendix 6. Restoration principles.** Principles of tidal wetland restoration for Oregon.
>
> **Appendix 7. Restoration approaches.** General guidelines for restoration actions in Oregon's estuaries.

2. GIS dataset of study sites (Till_tidalw_FINAL_31oct2012.shp and associated files). Attributes match those in the site attribute table in **Appendix 2**. Projection is Oregon Lambert NAD83 (intl ft); metadata are included. The GIS data are provided in ESRI Shapefile® format.

3. Excel spreadsheet of site information (Till_tidalw_FINAL_31oct2012.xlsx). The Excel file contains a duplicate of the shapefile attribute table and the site attribute tables in **Appendix 2**, as well as analysis tables.

4. High-resolution hierarchical nested basins and flowpaths. These GIS datasets (provided in ESRI Shapefile® format) break up the area below HMT into analysis units based similar to watersheds. Zipfile filename: basins_shp_w_metadata.zip.

All of these products are necessary for accurate understanding of results. If any of the above products are missing, please contact Laura Brophy at Green Point Consulting, (541) 752-7671 or e-mail Laura@GreenPointConsulting.com for replacements.

Background information

Classification of the Tillamook Bay estuary

Geologically, the Tillamook Bay estuary is classified as a large drowned river mouth estuary (Bottom *et al*. 1979). Drowned river mouth estuaries were formed when coastal river valleys flooded as sea levels rose after the last ice age (Emmett *et al*. 2000). In terms of land use, the Tillamook Bay estuary is classified by the Oregon Department of Land Conservation and Development (DLCD) as a Shallow-draft Development Estuary. Other estuaries in this category include Nehalem Bay, Depoe Bay, Siuslaw River, Umpqua River, Coquille River, Rogue River, and the Chetco River. DLCD states that Shallow-draft Development Estuaries have "maintained jetties and a main channel maintained by dredging at 22 feet or less" (State of Oregon 2012).

General locations of tidal wetlands in the Tillamook Bay estuary

Although the Tillamook Bay estuary's classification (drowned river mouth estuary) is typical for the Oregon coast, it has characteristics that are unique among Oregon's estuaries. Five rivers pass through the estuary and exit to the ocean through a single outlet at the mouth of Tillamook Bay: the Miami, Kilchis, Wilson, Trask and Tillamook. The lower floodplains of these rivers, once tidal but now largely diked, provide high quality pasture and support a large dairy industry (TBNEP 1998).

Oregon's tidal wetlands include mud flats, aquatic bed habitats (eelgrass and algae beds, exposed only briefly during lower low tides), emergent marsh (low and high marsh), scrub-shrub wetlands, and forested wetlands. (Tidal scrub-shrub and forested wetlands are collectively known as "tidal swamps.") The Tillamook Bay estuary contains all of these tidal wetland habitat types. As in other estuaries, the low marsh is located near the ocean on the fringes of the bay. High marsh is located slightly upslope from low marsh. Tidal swamps are located further from the bay where ocean salinities are diluted by fresh river flows, allowing woody species to survive. Consistent with statewide methods (Brophy 2007), this study does not address mud flats or aquatic bed habitats, which require different management methods from tidal marsh and swamp.

Tidal wetlands are found throughout the full range of salinities, from the marine salinity zone up to the freshwater tidal zone, where river flows are "backed up" by the tides. Recent studies have shown that even tidal swamps, traditionally thought to occur only in freshwater tidal zones, thrive in brackish salinities throughout Oregon's outer coast (Brophy 2009, Brophy *et al*. 2011). Wetlands in the low-salinity and freshwater portions of Oregon's outer coast estuaries – particularly tidal swamps -- have been little studied and poorly mapped. In the maps of the 1970s and 1980s that formed the basis for Oregon's estuarine land use planning process (Akins and Jefferson 1973), many upper estuary brackish and freshwater tidal wetlands were not mapped. The Oregon Estuary Plan Book (EPB) mapping for the Tillamook Bay estuary (Cortright *et al*. 1987) stops well short of head of tide on most rivers; for example, the EPB does not map forested and diked tidal wetlands in the middle and upper tidal reaches of the Tillamook River. The National Wetland Inventory (USFWS 2012) shows wetlands in many of these areas, but does not classify them as tidal wetlands, nor does the NWI recognize the hydrologically modified status of many diked and tide gated wetlands (that is, diking modifiers are not present for these wetlands). One of our goals for this study was to improve the mapping of tidal wetlands in the upper portions of the Tillamook Bay estuary.

Tidal wetland functions and values

Tidal wetlands serve many vital functions in the watershed. Many of these functions are evaluated in the hydrogeomorphic functional assessment method for tidal wetlands of the Oregon coast (Adamus 2006). These functions include water quality protection (sediment detention and stabilization, nutrient and contaminant stabilization and processing), ecological support (food chain support, native vegetation support), and wildlife habitat (for fish, birds, invertebrates, and mammals) (Adamus 2006).

The value of tidal wetland functions may be enhanced by the location of these wetlands in the landscape—low in the watershed, in an economically important nursery zone for anadromous and marine organisms, and immediately below concentrations of the agricultural and developed land uses that can generate warmed, polluted surface waters.

In Oregon, interest in salmon has brought attention to the salmon habitat functions of tidal wetlands. Tidal wetlands are important to salmon population size, diversity and viability in Oregon and the Pacific Northwest (Simenstad 1983, Solazzi *et al*. 1991, Miller and Sadro 2003, Bottom *et al*. 2004). The health of Pacific Northwest salmon populations depends on a continuum of diverse habitats across freshwater, estuarine and marine zones. Tidal wetlands are considered a crucial link in this chain, providing rearing habitat characterized by a highly productive food web, deep meandering channels for shelter from predators and high velocity river flows, cool water temperatures, and a brackish-freshwater interface for physiological adaptation to marine salinities. These tidal wetland features contribute to accelerated juvenile salmon growth during estuarine rearing, in turn supporting increased ocean survival.

The Tillamook Bay watershed supports spawning runs of six salmonid stocks: fall chinook, spring chinook, chum, coho, winter steelhead, and summer steelhead (ODFW 2012). The estuary also supports runs of sea-run cutthroat trout, but their distribution is not mapped by ODFW. As juveniles of these species move through the estuary on their way to the ocean, they all use the estuary, though length of residence time varies by species and life history strategy (e.g. Bottom *et al.* 2004, 2008).

The full value of tidal wetland functions is not generally recognized in our economic system. Several authors have estimated the value of various tidal wetland functions; the values below are all from Costanza *et al.* (1997). Overall, the ecosystem services valuation of tidal marsh is estimated at a minimum of $4043 per acre per year ($4043/A/yr), placing it fourth among the highest-valued ecosystems on earth. (The top three are open-water estuarine habitats, freshwater swamps and floodplains, and seagrass and algae beds.) Of all ecosystems on earth, tidal marshes and swamps rate by far the highest in waste treatment (recovery and removal of excess, mobile nutrients); the minimum estimated value for this function is $2710/A/yr. Tidal and freshwater marshes and swamps together form the world's most important environmental "capacitors;" that is, these ecosystems absorb and moderate drastic environmental fluctuations like flooding, storm damage, and drought (valued at more than $1837/A/yr). Tidal marshes are the second-highest ranking ecosystems in the world for food production ($186/A/yr), habitat and refuge for rare organisms ($68/A/yr), and recreation ($266/A/yr). It is important to recognize that these values may be nonlinear and do not represent the cost of replacing the services provided (Barbier *et al.* 2008, Valiela and Fox 2008). All wetlands are important, beyond the ecosystem service values identified above.

Human uses

People have always used Oregon's estuaries intensively. Native Americans occupied villages on the lowlands near the sea, where easy-to-access waters provided abundant fish and shellfish (Byram 2002, Hall 2009). After European settlement, many estuary lands were filled for towns and industrial sites, diked and converted to agriculture, dredged for navigation, or otherwise altered (Boulé and Bierly 1987). Grassy tidal marshes were diked for pasture. In the tidal swamp zone, trees were harvested and tidal channels were blocked so that the lands could be converted to pasture or home sites (Brophy 2007).

Since European settlement about 150 years ago, human activities have led to a 70 to 90% loss of Oregon's tidal wetlands (Boulé and Bierly 1987, Good 2000, Christy 2004). However, the rate of change has slowed in recent years. Estuary zoning and wetland protection regulations have helped reduce human impacts to tidal wetlands (Good 1997). Today, many groups are restoring tidal wetlands to regain their original functions. A broader goal is to reconnect these wetlands to other natural areas, re-establishing the landscape array of ecosystems that once spread from ocean to ridgetop.

Estuary alterations

Alterations to estuaries can affect an entire estuary, individual sites (e.g. dikes and ditches), or multiple sites (river mouth tide gates, tributary stream tide gates, and roadways or developments that block flow to large areas). This assessment focuses on alterations affecting individual sites or several adjacent sites ("site-specific alterations"), for two main reasons: 1) these types of alterations are more easily removed to accomplish restoration; and 2) they can be used to distinguish among sites, allowing us to establish priorities for conservation and restoration activities. However, estuary-wide alterations and offsite effects of site-specific alterations are discussed briefly below.

Estuary-wide alterations and offsite effects

Estuary-wide alterations affect all tidal wetlands in an estuary, even wetlands with no site-specific alterations. Examples of estuary-wide alterations include jetties that affect tidal exchange and river flow patterns; upstream dams that strongly influence freshwater outflows (such as those on the Columbia River); and widespread land use practices that alter sediment movement and peak flows (like past splash-damming, extensive clear-cutting in upper watersheds, and impervious surfaces affecting upstream hydrology). More subtle estuary-wide changes can result from introduced species like European beachgrass, which stabilizes sand spits at the estuary mouth, resulting in altered flows and sediment deposition patterns. It is difficult to quantify the effect of these landscape-scale changes on individual tidal wetland sites.

This study documented site-specific alterations like dikes and tide gates, but site-specific alterations also affect surrounding sites and landscapes. For example, Hood (2004) documented offsite effects of dikes in the Skagit River estuary. In the Tillamook, effects of dikes on system-wide sediment transport and flooding patterns have been explored in several studies (e.g. Phillip Williams and Associates 2004, USACE 2005). It is important to remember that restoration benefits the specific site being restored, but also helps re-establish natural ecosystem function in surrounding areas.

Site-specific alterations and their effects on tidal wetland functions

The main types of site-specific tidal wetland alterations on the Oregon coast are dikes, tide gates, ditches, restrictive culverts, fill placement (including dredged material disposal), road and railroad crossings and embankments, dams, channel armor, excavation, tillage, grazing, driftwood removal, and logging and brush clearing in tidal swamps. Invasive species are another type of alteration (though generally not a deliberate one); the scale of impacts from invasive species can range from site-specific to coast-wide.

Of these alterations, the types most prevalent in the Tillamook Bay estuary are dikes, tide gates, restrictive culverts, and ditching. The vast majority of these alterations are associated with agricultural land use, primarily dairy cattle pasture. Diking, tide gates and restrictive culverts are designed to protect sites from tidal flooding. By definition, tidal inundation creates the unique functions of tidal wetlands -- so these alterations reduce, alter or eliminate all tidal wetland functions. Examples of visible wetland changes due to altered tidal flow can include a decrease in tidal channel complexity (particularly when sites are also ditched); a shift in the composition and distribution of vegetation communities (particularly when pastures are improved through seeding of non-native grasses); changes in soil biology and chemistry; and altered patterns of sediment deposition and erosion.

In many cases, sites where tidal flows have been reduced or eliminated undergo soil subsidence. This is a gradual lowering of the soil surface elevation caused by soil compaction, decomposition (oxidation) of organic plant material in the soil, and loss of buoyancy when tidal influence is removed (Frenkel and Morlan 1991). Many of Oregon's diked tidelands have undergone 2 to 4 feet of subsidence. In the Tillamook Bay estuary, subsidence appears to be widespread, particularly in areas that were formerly tidal swamp. We have observed particularly strong subsidence at former tidal swamp sites (Brophy and Lemmer 2012, Brophy 2009); the effect may be greatest for these former swamps because their soils originally had very high levels of organic matter (Brophy *et al.* 2011, MacClellan 2011).

Former tidal wetlands that are no longer tidally influenced because of human alteration may still be wetlands, and may still perform many wetland functions. Because of soil subsidence and impeded drainage, these areas often become nontidal freshwater wetlands. However, many of the original tidal wetland functions (such as salmonid habitat and osmotic transition zones) may be greatly reduced or completely lost.

Even where tidal flows are still present, human alterations can strongly affect tidal wetland functions. For example, ***Ditches*** change tidal flow patterns and channel morphology, affecting nearly all tidal wetland functions. For example, ditches are usually shallower and broader than natural tidal wetland channels, creating warmer water conditions that reduce habitat value for juvenile salmon. Ditches speed water flow off a site, reducing duration of inundation and diminishing wetland area. ***Road and railroad crossings*** can greatly affect water flow patterns by blocking channels and redirecting or impeding both subsurface flows and "sheet flow" (non-channelized surface flow). ***Tillage*** and ***grazing*** compact soils, contribute to erosion of channel banks, and reduce vegetation diversity and wildlife habitat. ***Channel armor*** and ***riprap*** reduce vegetation diversity and channel shading, eliminate "edge" foraging for aquatic organisms including salmon, and can cause erosion in adjacent areas. ***Excavation, fill*** and ***dredged material disposal*** change site elevations, water flow patterns, and soil biology, altering the many wetland functions that depend on these basic physical characteristics of tidal wetlands. ***Logging*** and ***driftwood removal*** directly reduce wildlife habitat, alter productivity and food webs, and reduce channel shading. ***Invasive species*** can strongly alter the character of a tidal wetland. For example, New Zealand mudsnails can rapidly dominate the benthic fauna in a brackish or freshwater tidal wetland, reducing prey availability for salmon (Bersine *et al*. 2008).

Earthquakes and tsunamis

Earthquakes and tsunamis create major changes to estuarine landscapes – but these are changes caused by natural rather than human forces. Cascadia subduction zone earthquakes have occurred repeatedly in the Pacific Northwest, and a major earthquake of this type would have serious consequences for the Tillamook Bay estuary. Along with damage from the quake itself, the associated tsunami would likely inundate parts of the cities of Tillamook, Garibaldi and Bay City, major portions of Highway 101, and thousands of acres of lowlands in the estuary (http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Tsunamis-Evacuation). In addition, major landscape changes would likely result from land surface subsidence accompanying a subduction zone earthquake, as well as from erosion of land surfaces due to tsunami currents. We did not attempt to incorporate such cataclysmic events into this study's prioritization. However, the possibility of a major quake adds incentive for protection and restoration of tidal wetlands for several reasons. First, awareness of the importance of tidal wetlands will help minimize future filling and development in these wetlands, thus reducing exposure of infrastructure to tsunami risk. Second, protection and restoration of tidal wetlands in the upper reaches of the estuary can help provide "insurance" against wetland loss due to coastal subsidence (or more gradual sea level rise), since tidal wetlands in the upper estuary may occur at slightly higher elevations (Brophy and others, 2011).

Restoration: Removing alterations and restoring natural processes

Tidal wetland restoration generally focuses on removal of human alterations. Dikes can be breached or removed; tide gates replaced with fish-friendly models or self-regulating gates that remain open except during extreme high tides. Road crossings with restrictive culverts can be replaced with bridges or culverts can be resized to allow free exchange of tidal flow. Ditches can be filled, and meandering channel remnants reconnected.

Removal of human alterations is the most practical restoration approach, often the most economical, and generally the approach with the highest chances of success (Mitsch 2000, Simenstad and Bottom 2004) because it re-establishes the natural processes that form and maintain tidal wetlands. These natural processes (tidal flows, sediment deposition, organic matter accumulation, and so on) are necessary for the return of tidal wetland functions over time (see **Appendix 6, Restoration Principles**). Successful re-establishment of natural forces minimizes the need for further human intervention after restoration, maximizing long-term restoration effectiveness.

Restoration of tidal flow is the most important component of tidal wetland restoration design. Other restoration techniques may be needed, such as meander restoration, reconnection of freshwater flows, removal of invasive species, and planting of woody species (in areas suitable for tidal swamp). Potential restoration actions corresponding to specific alterations are discussed in **Restoration recommendations** below. Other details are provided in **Appendix 7**, **Restoration approaches.**

Past studies

Many past studies have recommended tidal wetland restoration as a central tool for enhancing the health and resilience of the Tillamook Bay estuary. For example, the USACE Feasibility Study (2005) and Project Exodus Final Report (2010) recommended tidal wetland restoration and flow management to reduce flood impacts and provide habitat benefits. The first recommendation in the Tillamook Bay Integrated River Management Strategy (IRMS) (Philip Williams and Associates 2002) was to "prioritize tidal marshes and tidally influenced floodplains for flood management efforts, because of the potential for relatively quick gains in salmon production with the restoration of natural processes from the daily ebb and flood of the tides." In other words, the IRMS recommended tidal wetland restoration because it would improve fish production and offer flood management benefits. The Tillamook Bay Comprehensive Conservation and Management Plan (CCMP) (TBNEP 1998) lists 10 critical habitat actions related to tidal wetland mapping, characterization, restoration, and reconnection. The actions most directly related to this prioritization are HAB-18 ("characterize estuarine and tidal habitats"), HAB-19 ("prioritize tidal sites for protection and restoration"), HAB-20 ("protect new salt marsh"), HAB-21 ("restore tidal wetlands"), HAB-25 ("update estuary plan"), and HAB-26 ("reconnect sloughs and rivers to improve water flow"). Simenstad *et al*. (1999) ranked 15 potential dike-breach restoration projects in the estuary, focusing on the juvenile salmonid production; these 15 sites were clustered along the lower Wilson, Trask and Tillamook. The current study is the first comprehensive assessment of all tidal wetlands in the Tillamook Bay estuary; it was designed to advance the goals and actions prioritized in these past studies.

Methods

This study prioritized tidal wetland sites for conservation and restoration, using existing data, aerial photograph interpretation, field reconnaissance, and local knowledge.

Information sources

We mapped and characterized tidal wetlands in the Tillamook Bay estuary using publicly accessible data, local knowledge, and new information from aerial photo interpretation and field reconnaissance. Geographic information systems (GIS) software was used to organize, analyze and display data for this study. GIS data came from a variety of publicly available sources; sources are listed in Table 1.

This assessment followed the methods outlined in the Estuary Assessment module of the Oregon Watershed Assessment Manual (Brophy 2007). The method uses existing GIS wetland maps as a base layer ("starting point") for the assessment. The recommended base layer is either the National Wetland Inventory (NWI), or GIS data created by Scranton (2004). Scranton (2004) maps tidal wetlands, but categorizes 83% of the mapped area in the Tillamook as "restoration consideration areas" ("RCAs"), stating that these areas require ground-truthing. After reviewing the two base map options and applying our knowledge of tidal wetland ecology on the Oregon coast and in the Tillamook Bay estuary, we determined that the NWI provided the most suitable base map for this study.

As described in Brophy (2007), the National Wetland Inventory's classification of wetlands can be inaccurate, particularly in the middle and upper estuary zones. In the Tillamook, it was immediately clear that the NWI would not be useful for identifying former tidal wetlands, because many large areas of diked wetlands were classified as palustrine wetlands in the NWI, with no diking modifier to indicate their altered hydrology. In addition, many areas within tidal range – likely historic tidal wetlands – were not mapped as wetlands in the NWI. Our other estuary assessments (Brophy 1999, 2005a, 2010, 2012; Brophy and So 2005a, b, c) have shown that this situation is typical for Oregon estuaries. Therefore, to determine which of the NWI wetlands might be subject to tidal influence, and to identify former tidal wetlands that not mapped in the NWI, other data sources were needed. The best source proved to be elevation data (the LiDAR DEM). To define sites suitable for action planning, we used the LiDAR DEM to create hydraulic basin units, and then merged and/or split the NWI mapping and hydraulic basin units following the methods described in **Site definition** below.

Four sets of aerial orthophotographs were analyzed to define and characterize sites: 1939 historical aerial photography flown by the US Army Corps of Engineers and archived by the University of Oregon Map and Aerial Photography Library; 1955 historical aerial photography flown by the Oregon Department of Forestry and archived by the University of Oregon Map and Aerial Photography Library; 1999 Digital Orthophoto Quadrangles (DOQs) flown by the USGS; 2005 color infrared images from USEPA/Oregon DLCD; and 2005 and 2009 true color orthophotos (1/2m GeoTIFFs) from the National Agricultural Imagery Program (NAIP) (Table 1).

Our advisory team provided a wealth of important information for this study. We consulted with the advisory team during two meetings at the Tillamook Estuaries Partnership (TEP) in Garibaldi, one field trip (February 2012), and numerous emails and phone calls. Scott Bailey of the Tillamook Estuaries Partnership (TEP), Chris Knutsen of the Oregon Department of Fish and Wildlife (ODFW), and Mitch Cummings of the Natural Resources Conservation Service (NRCS) provided key information on site characteristics and overall estuary conditions. Chris Knutsen provided crucial input on salmonid use and hydrologic connections throughout the estuary.

We conducted field reconnaissance during February and April 2012 to gain information on site conditions and hydrologic connections to confirm GIS observations. Our field observations were generally made from publicly accessible vantage points; a few sites were visited with landowner permission.

Table 1. Information sources and descriptions

Information source	Provider	Data type	Scale	Metadata available?	Complete?*
1939 black and white orthoimagery http://libweb.uoregon.edu/map/orephoto/imagery.html	USACE	Printed Photo	1:10,500	Yes	Yes
1955 black and white orthoimagery http://libweb.uoregon.edu/map/orephoto/imagery.html	Oregon Dept. of Forestry	Printed Photo	1:12,000	Yes	Yes
1995 black and white orthoimagery http://oregonexplorer.info/imagery/AccesstheImagery/StreamImagery	USGS 1995	Raster	1m pixel	Yes	Yes
2005 color infrared aerial orthoimagery http://www.coastalatlas.net/downloads/rasters/cir2005_til_mosaic.zip	USEPA/DLCD 2005	Raster	1:20,000	Yes	Yes
2005 true color aerial orthoimagery http://oregonexplorer.info/imagery/AccesstheImagery/StreamImagery	NAIP 2005	Raster	1/2m pixel	Yes	Yes
2009 true color aerial orthoimagery http://oregonexplorer.info/imagery/AccesstheImagery/StreamImagery	NAIP 2009	Raster	1/2m pixel	Yes	Yes
LiDAR "bare earth" Digital Elevation Model http://www.oregongeology.org/sub/lidardataviewer/index.htm	OWEB	Raster	See LiDAR metadata	Yes	Yes
Head of tide for the mainstem river and tributaries http://navigator.state.or.us/sdl/data/shapefile/tide.zip	DSL	Shapefile	n/a	Yes	Yes
Estuarine Levees Inventory (Mattison 2011) http://spatialdata.oregonexplorer.info/GPT9/catalog/search/resource/details.page?uuid=%7BB794DBD7-4775-4BCC-932A-EA7B35334E8F%7D	DLCD	Shapefile	Unknown	Yes	Yes
Tillamook County Creamery Association culverts and tide gates	TEP	Shapefile	Unknown	No	Yes
Tide gates (Mattison 2011) http://spatialdata.oregonexplorer.info/GPT9/catalog/search/resource/details.page?uuid=%7BB794DBD7-4775-4BCC-932A-EA7B35334E8F%7D	DLCD	Shapefile	Unknown	Yes	Yes
National High-Resolution Hydrography Dataset http://nhd.usgs.gov/data.html	USGS	Geodatabase	1:24,000 or greater	Yes	Yes
National Wetlands Inventory http://www.fws.gov/wetlands/Data/Mapper.html	USFWS	Shapefile	1:24,000	Yes	Yes
Tidal wetlands of Oregon's Coastal Watersheds (Scranton 2004) ("HGM layer") http://www.coastalatlas.net/downloads/shapes/tidal_marsh.zip	Scranton 2004	Shapefile/ geodatabase	Unknown	Yes	Yes
SSURGO soil survey http://www.or.nrcs.usda.gov/pnw_soil/or_data.html	NRCS	Coverage and Tabular	1:24,000	Yes	Yes
Historic vegetation (Hawes *et al*. 2008) http://www.pdx.edu/sites/www.pdx.edu.pnwlamp/files/glo_coast_2008_03.zip	ORBIC	Shapefile	1:24,000	Yes	Yes

Information source	Provider	Data type	Scale	Metadata available?	Complete?*
Oregon Estuary Plan Book http://www.coastalatlas.net/downloads/shapes/tillamook_habs.zip, http://www.coastalatlas.net/downloads/shapes/tillamook_sighabs.zip	Oregon Coastal Atlas	Shapefile	1:5000 unless noted	Yes	Yes
Salmon distribution and habitat use types http://rainbow.dfw.state.or.us/nrimp/information/fishdistdata.htm	ODFW	Coverage	Generally 1:100,000	Yes	Yes
Tillamook County tax parcels (land ownership)	Tillamook County	Shapefile	unknown	No	Yes
USEPA 2005 Intertidal Seagrass Classification	USEPA ORD NHEERL	Raster / Shapefile	Unknown	Partial	Yes

* “Complete” indicates the spatial extent of the data included the entire study area; it does not indicate the accuracy of the data.

Extent of tidal influence

The Oregon Estuary Assessment method (Brophy 2007) uses a combination of existing GIS data, aerial photograph interpretation, soils mapping, historic vegetation mapping, field reconnaissance, local knowledge, and other data to identify the current and historic extent of tidal influence. However, since development of the Oregon Estuary Assessment Method, LiDAR data have become available for the entire Oregon coast, providing a more consistent, reliable and powerful way to identify the likely extent of historic tidal wetlands. We made heavy use of the LiDAR data in this study, as described below.

LiDAR data

High-resolution elevation data obtained with LiDAR technology became available for the Oregon coast in 2010 (Watershed Sciences Inc. 2009). The LiDAR "bare earth model" (also called a "digital elevation model" or DEM) is a depiction of the ground surface developed through processing of the LiDAR data (NOAA CSC 2011). The availability of the LiDAR DEM allowed us to estimate land areas that might be subject to tidal inundation – either currently or historically (prior to human alteration of the estuary).

Upper elevation boundary

As described in **Definition of tidal wetlands** above, tidal wetlands are inundated by tidal waters at least once annually (Adamus 2006). However, locating areas in the landscape that inundate at this frequency (or may have done so historically) would require a complete hydrologic model of the entire estuary (incorporating the effects of river flows). Such a model is not available for the entire Tillamook estuary, nor was it within our scope of work for this project. Therefore, we selected an upper elevation boundary or "cutoff" for mapping tidal wetlands, and used the LiDAR DEM to locate land surfaces below that elevation boundary (see **Site definition** below). The upper elevation boundary we used was 11.5ft NAVD88; this elevation was selected because it is the highest measured tide at the nearest active NOAA tide station, Station 9437540 at Garibaldi (see below).

NOAA tidal datums and highest measured tide

An understanding of elevation datums is critical to tidal wetland assessment; information on elevation datums is provided in the Oregon Estuary Assessment method (Brophy 2007). Tidal elevation datums are necessary to understand tidal wetland ecology; by contrast, geodetic elevation datums are used in most mapping and engineering applications. For example, the LiDAR DEM uses the NAVD88 elevation datum. The relationships between tidal and geodetic datums can be obtained from NOAA's Tides and Currents website (NOAA CO-OPS 2012) and by using the NOAA VDatum utility (http://vdatum.noaa.gov/). Although NOAA does not publish the relationship between tidal datums and the NAVD88 datum online for the Garibaldi station, these relationships are available in a NOAA technical memorandum (Mofjeld *et al*. 2004). We obtained the geodetic elevation of Highest Measured Tide for the Garibaldi station (11.5ft NAVD88) from this source (Mofjeld *et al.* 2004).

Highest measured tide ("HMT"—also referred to as "highest observed tide," "highest observed water level," or "maximum observation") makes a reasonable upper boundary for mapping tidal wetlands, for several reasons. First, it is the only published tidal datum above Mean Higher High Water (MHHW), and Oregon's high marsh and tidal swamp wetlands definitely extend well above MHHW. For example, Brophy (2009) found that elevations of high marsh and tidal swamps in the Siuslaw River estuary ranged from around 0.4 to 1.5ft above local MHHW; and Brophy *et al*. (2011) found that elevations of high marsh and tidal swamp in the Coos, Siletz and Nehalem estuaries ranged from 0.3 to 0.5ft above local MHHW. Second, HMT is a jurisdictional boundary, used in defining the upper limit for the State of Oregon's removal-fill jurisdiction within estuaries (Oregon Administrative Rules (OAR 141-085-0515(2) and OAR 141-085-0510(97)). Third, strategic planning for adaptation to climate change (particularly sea level rise) increases the importance of including areas near the upper limit of tidal influence, rather than omitting these areas. Even if these areas currently are seldom inundated by the tides at current sea levels, they are likely to be inundated more often in the future if sea level rise projections (NRC 2012) are accurate. Finally, in Oregon's estuaries, the added water heights due to "backup" of river flows can raise high tide water levels well beyond what would be predicted by tides alone (Brophy 2009, Huang *et al.* 2011). Because of this added "fluvial component" of the tidal inundation regime, tidal wetland studies need to include areas above typical higher high tides. The expected additional water height due to combined tidal and fluvial forces can be determined for specific locations using a modeling approach (Brophy 2009, Huang *et al.* 2011), but such modeling was beyond the scope of this project.

Site definition

To provide strategic guidance for tidal wetland restoration and conservation, this study defined analysis units called "sites." In general, a site is a contiguous wetland area with strong internal hydrologic connectivity and a consistent level of alteration. The goal of site definition was to create analysis units that are appropriate for action planning, while recognizing the ecological importance of large contiguous blocks of wetland. Land ownership in itself was generally not used to define sites, but since different landowners often use the land differently, site boundaries sometimes followed ownership boundaries.

Defining the extent and shape of sites within the Tillamook Bay estuary is challenging because much of the estuary consists of large, contiguous, flat land surfaces (primarily pastures). Mapped wetland areas provided by the National Wetland Inventory (NWI), Hydrogeomorphic (HGM) Assessment Guidebook, and the Estuary Plan Book (EPB) were inadequate for delineating study sites on their own because they lacked either the resolution, accuracy, or extent required to cover the entire study area. We therefore delineated sites by combining combined the geometry of NWI with a hydraulic basins layer we developed from LiDAR data.

The hydraulic basins we created are similar to watersheds (also called "catchments"). Each polygon (i.e., basin) represents a contiguous geomorphic unit based on the LiDAR-derived elevation and an idealized computer simulation of how water would flow over that surface. As part of this study, we developed several different nested basin layers to help understand variation in elevation within the estuary. However, the site definition process used only the most detailed of these layers ("level 7").

Steps used in site definition are outlined in Appendix 3 and details are provided in Appendix 4. Briefly, the level 7 basins and NWI were combined to provide numerous complex, spatially explicit geometry fragments. Fragments were manually selected and grouped into regions of similar level of alteration, environmental history, and along natural geomorphic breaks. Developed areas (farm structures or residences) below Highest Measured Tide (HMT) were excluded from our study. These exclusions have little impact on the overall study, because only small areas were excluded and the exclusions affected only 5 of the 92 sites. After site polygon fragments were aggregated to form larger sites, their geometry was clipped to the extent of HMT on the land surface and dissolved to form final site geometry. The resulting layer is free from internal boundaries and represents only wetlands areas below HMT, the upper boundary of our study.

The minimum size for a site defined in this study was 0.5A; isolated wetlands smaller than 0.5A were excluded from the study. However, site polygons smaller than 0.5A that were close to other wetlands were retained and merged with the adjacent areas as appropriate.

As stated in <u>Project goals and approach</u> above, this study did not provide regulatory "delineation" of wetlands. Existing data (NWI mapping, the LiDAR DEM and derivative products, and NOAA tidal datums) were used to define sites. The mapping resulting from this study does not have any regulatory significance and may not meet federal mapping standards (FGDC 2009); mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.

Site numbering

Sites are numbered from north to south and from the river mouth upstream to the head of tide (Map 3). Site 1 is adjacent to the northern jetty; Sites 2-5 are on the Miami River; Sites 6-22 are on Tillamook Bay; Sites 23-34 are on the Kilchis River; Sites 35-43 are on the Wilson River; Sites 44-59 are on the Lower Tillamook and Trask River; and Sites 60-92 are on the upper Tillamook River.

Alterations

Our analysis of alterations focused on alterations affecting hydrology, since hydrology is a controlling factor for all tidal wetland functions. We identified the following types of hydrologic alterations: dikes, roads acting as dikes (overlaps with "dikes"), breached dikes and removed dikes, tide gates, restrictive culverts, and ditches. We characterized hydrologic alterations using aerial photo interpretation, inventories of dikes and tide gates developed by Mattison (2011a, 2011b), the Tillamook County Creamery Association's culvert layer, and analysis of the LiDAR DEM (Table 1). Mattison (2011a) provided the data on breached and removed dikes. We analyzed aerial photos from 2005 through 2011 (Table 1) as well as historic aerials from 1939; the 1939 aerials were especially useful for understanding site and landscape changes. For sites where questions remained after these analyses, we consulted our advisory team and conducted field reconnaissance to determine site alterations. Field reconnaissance generally consisted of viewing sites from an offsite vantage point, but a few sites were visited with landowner permission.

Using recent aerial photos (e.g. NAIP 2009) and LiDAR, we also evaluated grazing, peripheral development, dredged material disposal, and road/railroad crossings, but these alterations were more difficult to identify in a consistent manner, and they were not used in the prioritization. Onsite evaluation of alterations is recommended as part of site-specific action planning.

Restoration sites vs. conservation sites

This study, like the statewide method (Brophy 2007), used a single set of criteria to prioritize all sites, whether they are obviously in need of restoration ("restoration sites") or are primarily in need of protection ("conservation sites"). However, our experience has shown that restoration practitioners often want help in locating restoration sites. The most obvious restoration sites in the estuary are those with major hydrologic alterations (tidal flows blocked by tide gates, restrictive culverts and dikes). To help practitioners locate these sites, we classified the 92 sites as "non-tidal," "muted tidal," and "fully tidal" by examining the presence and location of in-channel flow restrictions (tide gates and restrictive culverts). The "non-tidal" and "muted tidal" sites are potential candidates for restoration. The "fully tidal" sites are candidates for conservation of existing wetland values. This analysis of tidal exchange was also used in the tidal channel condition scoring (tidal exchange subfactor), as part of the prioritization (see **Tidal channel condition** below).

When site-specific details are considered, it is clear that the 92 sites present a continuous spectrum of degree of alteration. For example, many sites are altered and offer restoration opportunities, but also currently provide substantial wetland functions. This is particularly true for the "muted tidal" sites. Many "fully tidal" sites offer some restoration opportunities, such as improved culverts on the upslope side, removal of introduced non-indigenous species, creation of native vegetation buffers, and woody plantings for tidal swamp restoration (where elevations and salinities are suitable). The appropriate actions usually derive from the alterations present. For more guidance, see **Restoration recommendations** below, and **Appendix 6** (**Restoration approaches**).

Prioritization criteria

The following ecological criteria were used to prioritize sites:

1. Size of site
2. Tidal channel condition
3. Wetland connectivity
4. Salmonid diversity
5. Historic wetland type
6. Diversity of vegetation classes

Each site was scored for each of these criteria, and the criterion scores were summed for a total site score (Map 6). The resulting total score represents a site's likelihood of contributing to tidal wetland functions in its current or restored state. After scoring, the sites were grouped into five priority categories (high, medium-high, medium, medium-low, and low). These rankings are intended to provide a broad perspective and help guide decisions. **The rankings should not be used to eliminate any site from consideration for restoration or conservation actions. In other words, all tidal wetlands are important**; prioritization is simply a way to focus action planning on sites where the return for that effort may be the greatest.

Non-ecological criteria, such as number of landowners, landowner type, and availability of landward "migration zones" for upslope migration of tidal wetlands under sea level rise scenarios, also affect restoration decision-making. These factors are addressed in the sections **Land ownership** and **Landward Migration Zones** below.

Table 2 shows a summary of the criteria used to prioritize sites, the data sources, and the scoring levels for each criterion.

Table 2. Summary of prioritization criteria

Factor	Data source	Description	Levels
Size of site	Map of sites	Size in acres. Threshold size for including a site is 0.5A.	Rescale full range of values for study area to scores of 1 (smallest) to 5 (largest).
Tidal channel condition	Aerial photograph interpretation, LiDAR	Visual interpretation of aerial photographs and LiDAR for evidence of tidal flow restrictions, ditching, and dikes.	Assign a score of 1 to 5 (1= poor channel condition/tidal exchange; 5=good condition, full tidal exchange). See scoring matrix below.
Wetland connectivity	National Wetland Inventory, USEPA Seagrass	Total area of aquatic beds and other wetlands (emergent, scrub-shrub, and forested wetlands) outside site and within a 1.0 mile buffer around site perimeter, excluding the site itself.	Rescale the full range of values for study area to scores of 1 (smallest area) to 5 (largest area).
Salmonid diversity	ODFW salmonid distribution data (streamnet.org)	Number of salmon stocks rearing, migrating, or spawning in river or tributaries upstream of a site (including fall / spring chinook, chum, coho and winter / summer steelhead).	Rescale the number of stocks to scores of 1 to 5 (score of 1 = 0 stocks; score of 5 = 6 stocks).
Historic wetland type	Oregon Biodiversity Information Center historic vegetation mapping	Proportion of site that was historically swamp (either forested or shrub swamp)	Rescale the full range of values for study area to scores of 1 (smallest proportion) to 5 (largest proportion).
Diversity of current vegetation types	National Wetland Inventory/Aerial photograph interpretation	Number of Cowardin vegetation classes (emergent, scrub-shrub, forested wetlands) mapped by NWI on a site.	Rescale the number of Cowardin classes to scores of 1 to 5 (score of 1 = 0 classes; score of 5 = 3 classes).
TOTAL SCORE			Sum of all 6 criteria scores, double-weighting the channel condition score. Maximum possible score = 35; minimum possible score = 7.

Size of site

Site size is recognized as an important factor in wetland prioritization methods (Lebovitz 1992, Schreffler and Thom 1993, White *et al*. 1998, Costa *et al*. 2002). The size of a wetland is closely related to the level of functions it provides. All other factors being equal, bigger is simply better when it comes to providing ecosystem services. The science of biogeography (McArthur and

Wilson 1967) has established that larger sites are more self-sustaining, have higher diversity of plant and animal species, and have greater ability to buffer against outside pressures and disturbances such as pollution and invasive species. Larger sites can also present an efficiency of scale, reducing the per-acre cost of restoration.

Site size was calculated within our data management environment using the GDAL software library (versions 1.8 and 1.9, http://gdal.org). (For more information about the software we used, see Appendix 5.) The threshold for including a site in this study was 0.5A. Sites smaller than this threshold were not included in our study. Site size was rescaled to obtain a size score ranging from one (smallest site in study area) to five (largest site in study area).

Tidal channel condition

Channel morphology and tidal connectivity are important indicators of tidal wetland function and overall hydrologic condition. Site alterations such as ditching, diking, tide gates, restrictive culverts, and roads impede or prevent tidal flow and alter tidal channel structure, resulting in lower channel complexity and shorter total channel length. Highly altered channels and blocked tidal flow reduce tidal wetland functions, and make restoration more difficult and more expensive.

Tidal channel condition was evaluated using aerial photographs, field reconnaissance, and local knowledge. Each site was scored using the scoring matrix shown in Table 3. Four subfactors contributing to tidal channel condition were evaluated: tidal exchange, tide gate location, ditching, and remnant channels. Each of these subfactors was assigned a score ranging from 1 (highly altered condition) to 5 (low alteration). The four subfactor scores were averaged to obtain a tidal channel condition score ranging from 1 (highly altered/low tidal connectivity) to 5 (relatively unaltered/intact tidal connectivity).

Table 3. Tidal channel condition scoring matrix

Subfactor	Highly- altered condition		Medium alteration		Least-altered condition	
	Description	**Score**	**Description**	**Score**	**Description**	**Score**
Tidal exchange	None	1	Restricted	3	Full	5
Tide gate location	Offsite	1	Onsite	3	No tide gate	5
Ditching	Heavy	1	Some	3	None	5
Remnant channels	None	1	Some	3	Many*	5

*or, channels are in natural condition (unditched)

A site was considered to have no tidal exchange (“Tidal exchange” subscore = 1) if tidal flows to the site were blocked by one of the tide gates mapped in Mattison (2011) or the Tillamook County Creamery Association culvert layer, or if our advisory group or field investigation confirmed presence of a tide gate. Mattison’s layer contains 43 tide gates in the Tillamook basin; the Creamery layer contains 61 tide gated culverts (identified by a value of 1 for the attribute "TIDEGATED"). We recognize that some tide gates allow limited tidal exchange (e.g. "fish friendly" tide gates), but available data and project scope did not allow us to determine the type or functionality of each tide gate.

If a culvert restricted tidal flow to a site, we assigned a "tidal exchange" subscore of 3 (restricted tidal exchange or "muted tidal" status). For this analysis, we used culverts mapped in the Tillamook County Creamery Association culvert layer (see Table 1); we also used aerial photo interpretation and field reconnaissance to locate unmapped restrictions. It is not possible to distinguish tide gates from restrictive culverts in aerial photographs, so for sites where aerial photos were our sole source of information, we assigned the intermediate "muted tidal" classification. Sites with no culvert or tide gate were assigned a score of 5 ("fully tidal").

The "tide gate location" subfactor scores the location of the tidal restriction (tide gate or other tidal restriction) in three categories (offsite, onsite, or none). Tide gates in the Tillamook Bay estuary often control flow to large areas; sites that have tidal flows blocked by a tide gate on another site are considered to have an "offsite" tide gate.

The "ditching" and "remnant channels" scores were determined by visual analysis of the LiDAR DEM in the GIS, at an on-screen display scale of 1:5000.

Wetland connectivity

In landscape ecology terms, connectivity (spatial connection of habitats to one another) is the opposite of fragmentation (isolation of habitats). Wetlands with good connectivity – those located near other wetlands and connected via stream or narrow wetland corridors – can perform many of their functions better, compared to isolated wetlands (Adamus and Field 2001, Amezaga *et al.* 2002, Adamus 2006). If a particular wetland is disturbed, the creatures that depend on it for shelter and livelihood may need to move to another nearby wetland. Mobile species such as anadromous fish, shorebirds, waterfowl, and native landbirds and mammals often feed and rest in several wetlands, so a single isolated wetland does not serve their needs. Interconnected salt marsh, brackish marsh and freshwater wetlands offer juvenile salmon the opportunity to adjust to ocean salinities before migrating to the sea.

Wetland connectivity also buffers environmental change. Each type of tidal wetland occupies a specific elevation range relative to sea level – but sea level itself is slowly changing. Land uplift and subsidence due to tectonic activity are fairly rapid in places; for example, Cape Blanco is estimated to be rising at a rate of about a foot every 100 years (Komar 1998). At the same time, the world's sea level is also rising (OCCRI 2010), though the rate of sea level rise relative to the land surface varies along the length of the Oregon coast. However, periodic earthquakes can change this relationship radically; the earthquake of 1700 caused a subsidence of about 3 feet in the land surface across much of the Oregon coast (Leonard *et al*. 2004). Adding to these geologic scale changes, human activities may also have caused major changes in the location of head of tide in some estuaries. For example, head of tide in the Coquille estuary appears to have shifted about 4 miles downstream since the 1850's (Benner 1992).

Wetland connectivity was evaluated using the Oregon Estuary Assessment method (Brophy 2007), with minor methods adjustments reflecting the specific data available for the Tillamook. For each site, we analyzed the total area of seagrass beds mapped by the United States Environmental Protection Agency (USEPA) plus NWI-mapped emergent (EM), shrub (SS) and forested (FO) wetlands within a one-mile buffer around the perimeter of each site, excluding the site itself. Both tidal and nontidal wetlands were included in the area.

We tested other buffer sizes, including a half-mile buffer, and determined that the one-mile buffer was most appropriate for this study. One-mile buffers adequately captured available wetland area near a site while also capturing regional differences within sections of the estuary.

This wetland connectivity analysis represents two minor departures from the standard Estuary Assessment method (Brophy 2007). First, the Estuary Assessment method includes NWI-mapped aquatic bed habitats (eelgrass and algae beds) in the analysis. However, there are limited aquatic bed habitats mapped in the NWI for the Tillamook Bay estuary. Another source of mapped aquatic bed habitats is the Estuary Plan Book (EPB), which maps about 2025A (819ha) of aquatic beds in the estuary. However, the EPB mapping is now outdated and the layer registers poorly with other data layers. We were fortunate to have a recent, high-resolution source of mapped aquatic bed habitats, a 2005 aerial photo classification of seagrass in Tillamook Bay produced by the USEPA Office of Research and Development National Health and Environmental Effects Research Laboratory (USEPA 2005). The USEPA seagrass layer was used as the source of mapped aquatic bed within our analysis instead of NWI or EPB because it is more recent and higher resolution, and therefore likely to be more accurate. The increased resolution of the USEPA seagrass layer is due to the methods used. USEPA used remote sensing techniques to classify seagrass from high-resolution color-infrared aerial photography flown over the estuary in 2005 using the Soil Adjusted Vegetation Index and ERDAS ERMapper software developed by Intergraph (USEPA 2005 metadata).

The second departure from the Oregon Estuary Assessment method was the use of raster-based analysis methods to calculate wetland area within the 1-mile buffers. We elected to use this method because the wetland connectivity datasets (particularly the USEPA seagrass layer) were large and complex, and therefore computationally intensive. ArcGIS and other GIS tools failed to perform the analysis using vector data, requiring the use of raster based methods. We converted the NWI and USEPA seagrass datasets into raster form and merged the two into a single dataset. Wetland area within the 1-mile buffer was calculated using the Maptools and Raster libraries available within the R software environment (Hijmans and van Etten 2012, Lewin-Koh *et al*. 2012). Contact the authors for further details on the wetland connectivity analysis.

Salmonid diversity

As described in **Tidal wetland functions and values** above, estuarine wetlands provide important rearing and foraging habitat for juvenile salmonids prior to their ocean entry (Simenstad 1983, Solazzi *et al*. 1991, Miller and Sadro 2003, Bottom *et al*. 2004). The Oregon Department of Fish and Wildlife (ODFW) StreamNet fish distribution mapping (Table 1) shows that the Tillamook Bay estuary supports six salmonid stocks: fall chinook, spring chinook, chum, coho, winter steelhead, and summer steelhead (ODFW 2012), and the estuary also supports runs of sea-run cutthroat trout (Ellis 1998). All of these anadromous fish must migrate through the estuary, so all of the tidal wetland sites in the estuary could potentially provide salmonid habitat functions. However, some sites are located along the migration corridors for all of the species, whereas other sites are located on tributaries that support spawning populations of fewer salmonid species. Sites located along migration corridors for a larger number of salmon species were given priority in this study.

Ideally, a prioritization like this one would rank sites by using precise and high-resolution data on abundance and distribution of juvenile salmonids in tidal channels and streams. However, no such comprehensive, consistent, and appropriate-scale data were available for this study. Therefore, sites were scored by using the available salmon distribution mapping, without regard to the population condition or size. This was considered acceptable, since the remainder of the prioritization criteria also address factors that strongly affect salmon habitat functions (site size, channel condition, wetland connectivity, historic wetland type, and vegetation diversity).

Following the Oregon Estuary Assessment method (Brophy 2007), this study scored salmonid diversity by counting the number of salmonid stocks using the river or stream directly adjacent to each site. This number was determined by visual analysis of the mixed-scale (1:24,000 to 1:100,000) StreamNet salmonid distribution mapping described above (ODFW 2012). The StreamNet mapping does not include sea-run cutthroat distribution, so this scoring process does not include that species. The number of stocks was then rescaled to derive the salmon habitat connectivity score ranging from 1(0 stocks) to 5 (all 6 stocks).

This score is not intended to evaluate actual use levels; comprehensive surveys of salmonid use of tidal wetlands in the Tillamook Bay are not available. In fact, comprehensive surveys of juvenile salmonid foraging and distribution in tidal wetlands are not yet available for any of Oregon’s estuaries, though numerous studies have documented salmonid behavior in Oregon estuaries (e.g. Miller and Sadro 2003, Bottom *et al*. 2004).

Historic wetland type

A major goal of estuarine restoration is to re-establish the full suite of habitat types that were historically present. Simenstad and Bottom (2004) state that “Restoration plans should be designed to restore ecosystem complexity, diversity, and riparian-flood plain connectivity based on the historic estuarine landscape structure.” Of all tidal wetland types in Oregon, tidal swamps have been the most heavily affected by development and agricultural conversion. Estimates of tidal swamp losses since the 1850’s within Oregon’s estuaries and sub-estuaries range from 90 to 95% (Thomas 1983, Brophy 2005a, 2012), compared to about 70% for tidal marshes (Graves *et al*. 1995, Christy 2004, Brophy 2005a).

Tidal forested and scrub-shrub wetlands (tidal swamps) have unique characteristics supporting salmonid habitat functions. In addition to providing the usual benefits of brackish-to-freshwater tidal wetlands—an osmotic transition zone, a rich foraging environment, and deep, cool channels with overhanging banks for shelter from predators—tidal forests also have trees and shrubs that provide additional shade, physical shelter and large woody debris. Woody vegetation, leaf fall, and root masses provide habitat structure and detrital contributions to the food web. Because of these characteristics, and because of their disproportionate losses to development, former tidal swamps were prioritized within this study.

Most of the tidal swamp historically found in Oregon was spruce swamp, with Sitka spruce (*Picea sitchensis*) as the dominant tree species (Jefferson 1975, Thomas 1983). Sitka spruce swamp and shore pine swamp were also found in the Tillamook Bay estuary (Christy *et al.* 2001, Hawes *et al.* 2002). Regardless of the tree or shrub species present, nearly all of these swamp areas were cleared early in the 20th century. Therefore, we used historic vegetation mapping (Christy *et al.* 2001, Hawes *et al.* 2002) to locate areas of former swamp within the tidal wetland zone. All historic vegetation classes that were dominated by woody species were considered to have been tidal swamps if they fell within tidal range. The historic vegetation layer was intersected with the sites layer to determine the proportion of each site that was historically swamp. This proportion was then rescaled to derive the historic vegetation score ranging from 1 (0% swamp) to 5 (100% swamp).

Diversity of current vegetation types

Many wetland functional assessment methods use diversity and interspersion of vegetation cover classes as an indicator of functional level; in Oregon, examples include Roth *et al*. (1996), Adamus and Field (2001), Adamus (2006), and Adamus *et al*. (2009 a, 2009b). Diversity of cover classes provides a variety of habitat types, resulting in more ecological niches and presumably higher animal species diversity. Cowardin cover classes (Cowardin *et al*. 1979) were used to define vegetation diversity for this project. The three Cowardin classes included in this study are emergent (dominated by grass, sedges, or other herbaceous vegetation), scrub-shrub (dominated by shrubs), and forested (dominated by trees). To obtain a vegetation diversity score, we intersected each site with the NWI, obtaining the Cowardin class for each resulting polygon. We determined then counted the number of Cowardin classes within the borders of each site. The total number of cover classes on a site was rescaled to obtain each site’s score, ranging from 1 (0 Cowardin class) to 5 (3 Cowardin classes).

Scoring method

Each prioritization factor (criterion) was scored for each individual site on a scale of 1 to 5. On the scoring scale, 1 represents relatively poor condition and 5 corresponds to the best condition based on this study's prioritization factors (i.e., large size, good channel condition, high wetland connectivity, high number of salmon species, high percent historic swamp, high vegetation type diversity). For the total score, all six scores were added to get a total score (TOT_SCO in the site attribute table), with the tidal channel condition score double-weighted because tidal hydrology is a very important controlling factor that affects all tidal wetland functions and restorability. The formula for the total score is:

TOT_SCO = [SIZE_SCO] +(2* [TCC_SCO])+ [WLCN_SCO] + [NTYP_SCO] + [SWMP_SCO] + [CWDN_SCO]

Abbreviations in the formula above are explained in **Appendix 2**, Table 3.

After scoring, the sites were placed in the "ranking groups" shown in Map 6, Table 5, and the tables in **Appendix 2**. The groups were calculated using the "Jenks natural breaks" method, which uses natural groupings to divide the data into the desired number of categories (in this case, five). These groups provide an easy way of visualizing scores on a map. Differences of one group (e.g., medium *versus* medium-low or medium-high *versus* high) should not be considered significant, because sites on either side of the dividing line may have very similar scores. Scores for each ranking criterion and the total score can be found in both the ranking tables (**Appendix 2**, Tables 1 and 2) and the site attribute table (**Appendix 2**, Table 4).

It is important to note that the priority groups and the underlying scores should be used as a **general guide** for action planning, not a final arbiter of the absolute priority or ecological value of each site. To fine-tune action planning decisions, we recommend reviewing the details contained in the site attribute table, as well as the supplemental data contained in the next sections of this report (**Landward migration zone mapping**, **Land ownership**, and **Land use planning and zoning**).

Landward migration zone mapping

Climate change adaptation planning requires awareness of areas that may become tidal wetlands under sea level rise scenarios. These areas – the "landward migration zone" for tidal wetlands – are good candidates for conservation or restoration activities right now. Protecting these areas from development may offer multiple advantages: reduction of potential earthquake and tsunami damage, and maintenance of adequate tidal wetland resources if lower-lying wetlands become submerged due to sea level rise.

Although mapping of the landward migration zone ("LMZ") is not part of the Estuary Assessment Method (Brophy 2007), we included this analysis to provide an additional planning tool for estuarine resource management. To map the LMZ, ESRI ArcGIS Spatial Analyst software was used to classify and map three elevation zones, using the LiDAR DEM. The elevation zones were 1m, 2m and 3m above this project's upper boundary for tidal wetlands (HMT is equal to 11.5ft NAVD88), representing sea level rise (SLR) scenarios of 1m, 2m, and 3m respectively:

- ***11.5-14.78 ft NAVD 88 (1m sea level rise)***
- ***14.78-18.06 ft NAVD88 (2m sea level rise)***
- ***18.06-21.33 ft NAVD88 (3m sea level rise)***

We selected the first two elevation ranges because they bracket the current SLR projections for the Pacific Northwest of 0.3 to 4.7ft by 2100 (NRC 2012). Current global projections are higher (1.9 to 7.05ft in Vermeer and Rahmstorf 2009, Grinsted *et al.* 2009, and Jevrejeva *et al*. 2010, as cited in the Oregon Climate Assessment Report, OCCRI 2010), so we included a third elevation zone extending to 3m above HMT.

Reclassification of the LiDAR data is a simplified approach to modeling sea-level rise because it assumes that the only variable that changes within the landscape is sea-level. This is referred to a "bathtub" model (NOAA/CSC 2009); it ignores subsidence or uplift of the Earth's surface, hydrogeomorphic responses to changing sea levels such as accretion and deposition, or other factors that may be evaluated in more sophisticated modeling approaches. Despite the limitations of the "bathtub" approach, our simple LMZ analysis provides a broad landscape-planning tool that can be used to identify areas that may be more impacted by sea-level rise than other areas. These maps should not be used to evaluate public safety concerns or other important management decisions for which a more rigorous modeling effort may be required.

Land ownership

The number of landowners at a site can affect restoration logistics, because the more landowners are involved, the more difficult it can be to coordinate restoration activities. The type of ownership of a site also affects decision-making. Private *versus* public ownership may influence the potential for loss of a wetland since it influences the likelihood of development. Ownership type may also influence the cost of restoration and the appropriate avenues and strategies for restoration.

Other site ranking protocols (Lebovitz 1992, Dean *et al*. 2000) have included ownership type as a ranking criterion. However, the method used for this study (like the statewide method, Brophy 2007) focuses on ecological factors -- and land ownership, in itself, is not an ecological factor. Of course, land ownership is closely related to land use and intensity of alteration, but those factors are reflected in the other scoring criteria such as tidal channel condition, vegetation diversity, and wetland connectivity.

We used a GIS layer of tax parcels for Tillamook County to determine the approximate number of landowners and the type of ownership for each site. To perform this analysis, each site was intersected with the tax parcels GIS layer and the results stored within our database. The GIS data was visually inspected for each site, and ownership was aggregated by similar landowner names. This step was needed because the raw landowner names often differ slightly (e.g. "Doe, John" *versus* "Doe John T") even if they represent the same owner, so automated tools to count landowners were unreliable. All landowners for a given site were counted regardless of how much of the site they owned. For a complete picture of landownership of a site, especially during restoration project planning, landownership determinations must be made on the ground using property boundary surveys.

We defined nine land ownership categories using the property class code present in the parcels database and a code lookup table available on the Assessor's website (http://www.co.tillamook.or.us/gov/A&T/Assessment/sales/pca.htm). A description of each category is provided in Table 4 below. Appendix 2, Table 7 provides cross-walk between these categories and the assessor's property class codes, major classifications, and minor classifications.

Table 4. Land ownership categories

Category	Description
Residential	Parcels identified by the assessor as a residential use, including both improved and vacant lots.
Commercial	Property parcels identified by the Assessor as a commercial use. This includes both improved and vacant lots.
Farm	Property parcels classified as an agricultural use by the Assessor.
Forest	Properties classified as forestland by the Assessor
School	Vacant and improved properties owned by a school
City	Vacant and improved properties owned by a city
County	Vacant and improved properties owned by the county
State	Vacant and improved properties owned by the state
Other	Properties that do not fall into one of the categories above.

Because land ownership can change rapidly, we recommend verifying ownership in the earliest stages of planning site-specific actions. In addition, appropriate authorities should be contacted before planning conservation or restoration actions that could affect roads and railroads, even though ownership for road and railroad rights-of-way was not generally shown in the assessor's GIS data.

Land-use planning and zoning

Land-use planning affects estuary lands in many ways. All cities and counties in Oregon have local comprehensive plans and associated land use regulations. The comprehensive planning documents produced by the Cities of Seaside and Gearhart are highly relevant to this study.

These plans contain resource inventories, analyses and priorities that are used in the development of local land use policies.

We did not conduct detailed assessment of local land-use ordinances or overlays for this assessment, but we did analyze generalized land use zoning for the study sites. The generalized land use zoning information was downloaded from the Oregon Spatial Data Library (http://navigator.state.or.us/sdl/data/shapefile/k100/zoning.zip). Sites were intersected with the zoning layer and the proportion of each zoning category on each site was calculated using the GDAL software library within our data management framework.

This zoning analysis addresses only a small part of the land-use planning context within the estuary. Thus, one of the first steps that should be taken in site-specific action planning is to consult directly with local (City and County) planning staff. See the Oregon Watershed Assessment Manual's Estuary module (Brophy 2007) for further details.

Results and discussion

Site prioritization is shown in Map 6 (**Appendix 1**); scores for each prioritization criterion are provided in Maps 7-12 and in tables in **Appendix 2**. A detailed site attribute table is also provided in **Appendix 2**. Detailed results are described below, and narrative descriptions of some sites are provided.

Prioritized sites

Ranking tables (**Appendix 2**, Tables 1 and 2) show the total prioritization scores and individual prioritization criterion scores for all sites, sorted by rank and by site. To provide a visual summary of results, we divided the study sites into five priority groups: High, medium-high, medium, medium-low, and low (Map 6). The ranking groups were calculated using the "Jenks natural breaks" classification method in ArcMap applied to the total prioritization score. The Jenks method uses natural groupings to divide the data into the desired number of categories (in this case, five). As described in **Methods** above, these ranking groups can be used as general guides for planning conservation and restoration actions in the estuary, but **it is important to recognize that a separation of one ranking group does not have much significance**, since sites on either side of the dividing line may have similar scores.

Of the 92 sites totaling 6035A, 16 sites were ranked "high" and these constituted 1315A—approximately 22% of the total area (Table 5). The largest high-priority sites were along the eastern bay fringe; other high-priority sites were identified along Hathaway, Squeedunk, Hall and Hoquarten Sloughs; and in the upper tidal reaches of the Tillamook River. Twenty-one sites (1809A, about 30% of the wetland area) were ranked "medium-high;" the largest of these were located in the Trask and Tillamook sub-basins. Most of the remaining sites (55 sites, totaling 2911A) were in the medium and medium-low groups. Only 10 sites (430A) were ranked "low;"

these lower-ranked sites should not be considered substantially different from the “medium-low” sites due to the factors listed above.

Table 5. Number of sites and area (acres) in each priority group

Priority group	Number of sites	Acres
High	16	1314.5
Medium-high	21	1809.3
Medium	28	1513.4
Medium-low	17	967.5
Low	10	430.1
Grand Total	92	6034.6

Many of the prioritized sites were located in sub-basins and other geographic areas prioritized in previous studies of the Tillamook Bay estuary and watershed. For example, the USACE Feasibility Study (USACE 2005) and Project Exodus (NHC and HBH Consulting Engineers 2010) recommended wetland acquisition, restoration and flow management covering several high and medium-high priority sites (Sites 38, 39, 40, 44, 52, and 53, plus parts of several other sites). The large, high-priority tidal marsh sites on the eastern bay fringe were ranked high for juvenile salmonid production potential by Simenstad *et al*. (1999). The high and medium-high priority sites along the Tillamook River were within sub-basins prioritized for coho intrinsic potential and landowner outreach in the Tillamook Bay Computational Ecological Restoration Prioritization (CERP) tool. Most of the prioritized wetlands were within the lowland floodplain area identified in the Integrated River Management System (Philip Williams and Associates 2002); levee and dike modifications (such as wetland restoration *via* dike breaching or dike setbacks) were recommended in this area.

This prioritization is a first step in strategic planning for conservation and restoration in the Tillamook Bay estuary. In general, the next step in action planning involves outreach to find those landowners interested in restoring or conserving the identified sites. Once willing and interested landowners are located, a variety of site-specific activities can begin, including preliminary onsite assessment, verification of alterations and potential restoration or enhancement actions, monitoring of current conditions, determination of land ownership boundaries, regulatory contacts to determine required permits, archaeological investigations, and many other steps to maximize the chances of effective results.

Lower-priority sites are important, too

Although this study prioritizes sites to assist in conservation and restoration planning, **no tidal wetland is unimportant**. Conservation of all existing tidal wetlands is recommended, because the majority of tidal wetlands in the estuary have been converted to other uses, and those being restored may take decades or more to recover their original functions (Frenkel and Morlan 1991). Similarly, restoration of all tidal wetlands is important. A “low” priority ranking in this project does not mean that the low-ranked wetland is ecologically unimportant, nor does it imply that the site should be given reduced protection in a regulatory context. As discussed above, this study has no regulatory significance or intent. It is intended only to provide a strategic approach to conservation and restoration of tidal wetlands in the estuary.

Total tidal wetland area

We identified 6035A (2442.3 ha) of current and likely historic tidal wetlands (emergent, shrub and forested classes) in the Tillamook Bay estuary (Maps 3-5). This estimate is 2.4 times greater than the NWI-mapped area of tidal wetlands in these classes (USFWS 2010), and 1.4 times the Estuary Plan Book's mapping in these classes (Cortright *et al.* 1987). Our estimate of 6035A is only 57% of the tidal wetland area mapped by Scranton (2004) during development of the Hydrogeomorphic (HGM) Assessment Guidebook for Tidal Wetlands of the Oregon Coast (Adamus 2006). However, 83% of Scranton's mapped wetland area was classified as "Restoration Consideration Area," a category that included lands of uncertain former tidal status as well as diked lands.

These differences in tidal wetland area result from differing methods and goals in each study. In our study, newly available LiDAR DEM enabled identification of land surfaces within tidal range (that is, below Highest Measured Tide (HMT), which is 11.5ft NAVD88 at the Garibaldi NOAA station (Mofjeld *et al*. 2004). We considered these areas below HMT to be likely current or former tidal wetlands. Based on information from our advisory group and our research into the influence of coastal Oregon river flows on tidal water levels (Brophy *et al.* 2011, Huang *et al*. 2011), we believe this procedure provides a reasonable estimate of current and former tidal wetland extent. However, precise definition of the area influenced by tidal fluctuation is challenging in broad, complex floodplains like the Tillamook Bay estuary. More accurate determination of areas subject to tidal inundation would require whole-estuary hydrodynamic modeling, which was beyond the scope of this study.

Many of the tidal wetlands we mapped are farther from the estuary's tidal water bodies than previous tidal wetland mapping in the NWI and the Estuary Plan Book. This is especially true along the major tidal sloughs and the Tillamook River. Tidal inundation in some of these areas may be infrequent, and it is possible that some of these areas do not inundate tidally. However, based on available data, these areas are likely to experience at least occasional inundation due to tidal forces, particularly during high winter flows. Further, based on Pacific Northwest sea level rise projections of 0.3 to 4.7 feet by 2100 (NRC 2012), these areas are likely to experience more tidal inundation over the next 100 years. We mapped these areas to help guide strategic planning for tidal wetland conservation under sea level rise scenarios, as recommended in Oregon's Climate Change Adaptation Framework (OR DLCD 2010).

Alterations to tidal wetlands

Our analysis of alterations focused on hydrologic alterations, and the core of the analysis was classification of each study site by its tidal connection status (see **Tidal channel condition** above). About 66% of the total historic tidal wetland area (45 sites, 3984A) is currently disconnected from the tides (Table 6, Map 13). Ten percent of the total area (16 sites, 584A) is currently "muted tidal," meaning that in-channel flow restrictions limit tidal exchange. In most cases, sites in this category contain restrictive culverts that allow some exchange under a road crossing or railroad. The remaining 24% of the total current and historic tidal wetland area (31 sites, 1467A) is classified as fully tidal, with open tidal exchange.

It is important to note that the current locations of tidal wetlands are not the same as the historic locations. Most of the fully-tidal acreage (1240A) consists of former mud flats and open water that have filled in with sediment and are now tidal marsh (see **Tidal swamp and tidal marsh – past and present** below).

We characterized many other alterations besides in-channel tidal flow restrictions: dikes, roads acting as dikes, breached dikes, removed dikes, ditches, grazing, peripheral development, dredged material disposal, and road/railroad crossings. Descriptions of these alterations and data sources used to identify them are provided in Table 3, Appendix 2. Presence or absence of each alteration is shown for each site in the site attribute table (Table 4, Appendix 2) and the site shapefile, and can be used to evaluate potential restoration actions for each site. For example, the 16 fully-tidal sites lack tide gates and restrictive culverts that block or reduce tidal exchange, but 11 of these sites have other types of alterations such as ditching, dredged material disposal, diking and/or culverts that do not appear to block tidal exchange, or which affect only a small part of the site. Only five sites (7, 11, 23, 33 and 48) are free of the alterations we evaluated, and even these sites are not completely pristine. For example, sites 7, 11 and 23 have roadways or railroads on their upslope edge, which affects freshwater hydrology. Finally, most sites probably have other alterations that could not be evaluated using this study's methods.

Table 6. Number of sites and area (acres) in each tidal connection status group

Tidal connection status	Number of sites	Area (A)	Percent of area
Fully tidal	31	1467.1	24%
Muted tidal	16	584.0	10%
Tides excluded	45	3983.4	66%
Grand total	*92*	*6034.6*	*100%*

Site-specific alterations also affect surrounding sites and landscapes, and all sites are affected by landscape-scale changes (see **Estuary-wide alterations and offsite effects** above). We did not attempt to analyze or quantify interactions between site-specific and landscape-scale alterations, but awareness of these interactions provides added impetus for restoration.

Restoration doesn't only benefit the specific site being restored – it also helps re-establish natural ecosystem processes in surrounding areas.

Tidal swamp and tidal marsh – past and present

Of the 6035A of current and historic tidal wetlands identified in this study, about half the area (2964A) was historically tidal swamp (tidal wetland dominated by woody vegetation, that is, trees or shrubs) (Map 14). Of this historic tidal swamp, 91% has been lost or converted to other wetland types (Table 7, Table 8). Seven tidal swamp sites remain (forested and fully tidal): Sites 7, 33, 40, 53, 55, 72 and 91 (Map 13). The total acreage of these seven sites is 285A – only 9% of the original tidal swamp area in the Tillamook.

Disproportionate losses of tidal swamp have been documented in other Oregon estuaries. Brophy (2005a) found that 70% of historic tidal wetlands in the Siuslaw River estuary were swamps, but 97% of these tidal swamps had been lost since the 1850s. By comparison, 30% of historic tidal wetlands in the Siuslaw were marshes; 40% of these tidal marshes had been lost. About 95% of tidal swamp was lost from Youngs Bay in the Columbia River estuary by the 1980s (Thomas 1983).

Tidal marsh has fared better than tidal swamp in the Tillamook, primarily due to accumulation of sediment in the bay (accretion) that has created new areas of marsh. Although 81% of the historic tidal marsh (1475A) has been completely disconnected from the tides and only 15% (279A) remains fully tidal, 1240A of new marsh has formed since the 1800s (Table 7, Table 8). These new marsh areas are on the east side of the bay in areas that were formerly mud flat or open water. Tillamook Bay is known for its extensive sediment accumulation in historic and recent times (Komar 1997, McManus *et al*. 1998, Pearson 2002), and rapid sediment buildup leading to new marsh formation has been documented in other Oregon estuaries such as the Nehalem (Johannessen 1964).

Table 7. Tidal wetland area (acres) by historic vegetation type and tidal connection status

	Area (acres)			
	Historic vegetation type			
Tidal connection status	**Marsh**	**Swamp**	**Water**	***Grand Total***
Fully tidal	279.4	265.1	922.5	*1467.0*
Muted tidal	75.0	352.5	156.5	*584.0*
Tides excluded	1474.9	2346.1	162.2	*3983.1*
Grand Total	*1829.3*	*2963.7*	*1241.1*	*6034.1*

Table 8. Tidal wetland area (%) by historic vegetation type and tidal connection status

	Area (percent of historic total for type)			
	Historic vegetation type			
Tidal connection status	**Marsh**	**Swamp**	**Water**	**Grand Total**
Fully tidal	15.3%	8.9%	74.3%	24.3%
Muted tidal	4.1%	11.9%	12.6%	9.7%
Tides excluded	80.6%	79.2%	13.1%	66.0%
Grand Total	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Landward migration zones

The Tillamook Bay area has a broad floodplain, which appears to offer better landward migration opportunities for tidal wetlands compared to many other Oregon estuaries. However, areas available for landward migration (Landward Migration Zones, or "LMZs") are still quite limited (Map 15, Table 9). The total area of all mapped LMZs was 5563A. The most prominent LMZs are along the Wilson River and Trask River, including Hall Slough, Dougherty Slough, and Hoquarten Slough, and in lowlands east of Highway 101 in the Trask sub-basin. Sites that could potentially benefit from this LMZ include 42, 43, 45, 51, 54, 55, 56 and 59. However, for sites west of Highway 101 (42, 43, 45, and 51), landward migration is limited by the Highway 101 commercial corridor.

Table 9. Sea level rise landward migration zone summary

Sea-level Rise Scenario	Landward Migration Zone area (Acres)	Cumulative LMZ (Acres)
+ 1 meter	1883	1883
+ 2 meters	1975	3858
+ 3 meters	1704	5563
Grand Total	*5563*	*5563*

The southern part of the study area, along the Tillamook River and between the Tillamook and Trask, contains a high proportion of historic tidal wetlands in the estuary. However, this area lacks the broader floodplain associated with the major slough systems north of the City of Tillamook, and consequently has less available landward migration area.

The vertical elevation range contained within the mapped LMZs is 3m. By comparing the land surface within that elevation range to the land surface within current tidal range, we can gain some understanding of the system's resilience to sea level rise. Based on visual inspection of the LiDAR DEM, the lowest salt marsh currently occurs at about 4-5ft NAVD88 on the east side of the bay. Since our upper boundary is 11.5ft NAVD88, the current elevation range for emergent, shrub and forested tidal wetlands is about 7ft (about 2m). Our study shows that the land area within this 2m elevation range is 6035A. By comparison, the cumulative area available within the 2m LMZ is only 3858A – 65% of current tidal wetland area – and the area added when the LMZ is expanded to 3m is only 1704A. These figures suggests that landward migration opportunities will be considerably less than current tidal wetland area; in other words, it is likely that sea level rise will lead to considerable loss of tidal wetlands. This is particularly true given the major barriers to landward migration in the estuary (particularly the economically important Highway 101 corridor).

Protection of the LMZs from development would maximize the chances of retaining adequate tidal wetland area within the estuary, and would improve resilience to climate change. Development in these areas may be limited by other considerations, since they are also highly flood-prone; almost all of the LMZs are within the FEMA 100-year floodplain (The Wetlands Conservancy 2012).

The results of this LMZ analysis are intended to provide a landscape-level planning tool; they are not intended for site-specific planning or hazard assessment.

Land ownership

The number of landowners was summarized for each site using five categories: One owner, 2-3 owners, 4-6 owners, 7-9 owners, and 10 or more owners (Table 10, Map 16).

Table 10. Summary of number of landowners per site

Number of owners	**Number of sites**	**Total area (acres)**
One owner	20	610.8
2 - 3	25	1093.6
4 - 6	32	2581.5
7 - 9	10	1027.9
10 or more	5	720.9
Grand total	*92*	*6034.7*

Land ownership in the Tillamook Bay estuary is mostly private and consists mainly of relatively large parcels, often in active agricultural use. Since sites were defined on the basis of hydrologic connectivity and land alterations, not ownership (see **Site definition** above), most sites have more than one owner (Table 10). However, 20 sites have only a single owner, and six of these are high or medium-high priority sites (Sites 7, 9, 14, 15, 72, and 75).

All other factors being equal, the logistics of restoration or land protection are usually simpler for a site with a single owner. For sites with more than one owner, several landowners may reach an agreement on restoration or conservation of their parcels; if not, it may be possible to begin action on sub-areas of the site without affecting other areas. The feasibility of such partial restoration should be considered during the earliest stages of action planning for a site.

Land ownership classification in the Tillamook Bay estuary is primarily agricultural; 62 sites and 84% of total area were primarily in farm ownership classes (Table 11). The ownership categories in Table 11 were determined from the Tillamook County Assessors' property class coding (**Appendix 2**, Table 7).

Table 11. Summary of land ownership type (for each site as a whole)

Land ownership type	Number of sites	Total area (acres)	Percent of total area
Primarily public ownership	15	713.9	12.0%
Primarily "Residential"	8	139.7	2.4%
Primarily "Other"	7	75.6	1.3%
"Farm" only	8	680.1	11.4%
Primarily "Farm" and public ownership	3	1050.0	17.7%
Primarily mixed "Farm" and "Residential"	21	1715.3	28.9%
Primarily mixed "Farm" and "Other"	30	1570.0	26.4%
Grand Total [1]	*92*	*5944.6*	100.0%

1) The grand total area for this ownership analysis is slightly less than the total site area, due to incomplete coverage and spatial registration errors in the GIS data for ownership.

Land use planning

Zoning

Zoning analysis, like the ownership analysis above, shows that tidal wetlands of the Tillamook Bay estuary exist in an agricultural context. 72 sites covering 4389A (about 73% of the total area) are primarily zoned for agricultural land uses (Table 12). The predominantly agricultural zoning illustrates the challenges and opportunities for conservation and restoration in the Tillamook Bay estuary. The agricultural economy is active and vital, and productive pastures on diked former tidal wetlands are a highly valued resource. On the other hand, agricultural lands often retain some wetland functions and values, and retain the potential for restoration in the future. By contrast, developed urban, commercial or industrial lands offer little or no wetland function and very limited potential for future restoration.

Table 12. Summary of generalized zoning classes (for the study area as a whole)

Zoning Category	Number of sites	Acres
Agriculture	72	4388.8
Water	28	1014.2
Urban	17	244.0
Forestry	25	143.2
Rural Residential	20	91.6
Park and Recreation	4	90.2
Coastal	3	31.1
Rural Commercial	3	24.9
Public Facility	2	5.2
Rural Service Center	1	0.8
Rural Industrial	1	0.4

1) The sum of "Number of sites" does not equal the total number of sites because each site can contain multiple zoning classes.

Restoration recommendations

Planning a tidal wetland restoration project is a technically demanding task. Some principles and general recommendations are provided in **Appendices 6 and 7 (Restoration Principles** and **Restoration Approaches)**. Additional guidance is found in the Oregon Watershed Assessment Manual's estuary module (Brophy 2007) and in other resources listed there.

This study does not provide site-specific restoration design recommendations, because additional data from field monitoring are needed to develop restoration plans. However, Table 13 below shows some potential restoration actions for each alteration type.

For all sites, the top priority for site action is protection of existing wetlands. After that is accomplished, further action may be taken to restore resources as described in Table 13.

Tidal wetland restoration options generally focus on restoring tidal flow, because tidal exchange is a controlling factor for all tidal wetland functions (Thom *et al*. 2004). For grazed sites, an important restoration option to consider is simply removal of grazing or setback of grazing from the wettest areas (including channels). For every site, native plantings (particularly of woody species) should be considered in portions of the site where the elevation and salinity are appropriate for growth of shrubs or trees; expert advice is often useful in deciding where woody plantings are likely to succeed. All sites would also benefit from protection or establishment of a native vegetated buffer around the margins of the site. Many sites in the study area already have such a buffer, but some do not.

The alteration types we documented, and some potential restoration actions for each alteration type, are listed in Table 13 below. Specific decisions among these options (and others) will require careful consideration of site characteristics and restoration goals. Some of the listed restoration actions may be inappropriate for particular sites; only careful onsite assessment can determine the appropriate actions. **Appendix 6 (Restoration Principles)** and **Appendix 7 (Restoration approaches)** provide general guidance for restoration actions.

Table 13. Alteration types and applicable restoration options

Alteration type	Potential restoration alternatives
Tide gates or restrictive culverts	Remove tide gate; replace tide gate/restrictive culvert with bridge; install self-regulating tide gate for controlled tidal exchange; install fish-friendly tide gate
Dikes	Dike removal; dike breach; setback dike
Ditches	Channel meander reconnection; ditch filling; meander restoration
Grazing	Pasture management; riparian fencing and plantings; off-channel watering; removal of livestock
Dredged material disposal	Remove spoils to historic wetland grade, based on nearby reference areas
Road/railroad crossings	Upgrade culvert; install bridge; raise road on viaduct to allow non-channelized flow underneath; realign road/railroad and remove fill
None	No restoration action needed, but protect existing wetland; establish buffers; plant trees/shrubs where appropriate in former swamp areas or on natural levees; apply other active wetland management techniques where needed

Beyond the site-specific actions listed above, it is important to consider conservation and restoration of nontidal wetlands and other habitats near the tidal sites in this study. The most effective conservation and restoration projects are those which protect or restore habitat linkages and connections (see **Appendix 6**, **Restoration Principles**). The slightly-brackish to freshwater tidal zone of the estuary may offer particularly high habitat values (Simenstad and Bottom 2004), so linking sites in this zone to adjacent nontidal wetlands may offer great benefits.

Cultural resources

Before European settlement, Oregon's estuaries were widely used by Native American peoples for dwellings, gathering places, and a source of livelihood (Byram 2002, Hall 2009). Therefore, every estuary restoration project should be conducted with awareness that there may be cultural resources within or near the project area. State and federal laws prohibit destruction or disturbance of known archaeological sites. In the case of inadvertent discovery of cultural resources, state and federal laws require that the project be halted and the appropriate Tribe be contacted immediately. To understand the historic and cultural context of each site, and to avoid possible impacts to cultural resources in the Tillamook Bay estuary, we recommend consultation with the Clatsop-Nehalem tribes (503-895-5643, info@clatsop-nehalem.com), Confederated Tribes of Siletz Indians (541) 444-2532, info@ctsi.nsn.us), and other tribes with interests in the area during the early phases of site-specific project planning.

Invasive species

Three invasive plant species are of special concern in the Tillamook Bay estuary: Cordgrass (*Spartina* spp.), purple loosestrife (*Lythrum salicaria*), and reed canarygrass (*Phalaris arundinacea*). These species are important for several reasons: 1) They are wetland plants which can occupy large areas of current and former tidal wetlands, to the exclusion of native species; 2) They are on the Oregon Department of Agriculture's "T" list (ODA 2011a), indicating they are considered economic threats to the state; 3) Two of the three (cordgrass and loosestrife) are tolerant of brackish water, making them particular threats in the estuary.

ODA asks individuals who observe "T" list weed species to call 1-866-INVADER to report the observations.

Cordgrass (*Spartina* spp.) has not been documented in the Tillamook Bay estuary, but is considered a serious threat to Oregon estuaries in general. Several species of cordgrass are invasive in the Pacific Northwest, and two (smooth cordgrass and saltmeadow cordgrass) have been documented in Oregon (ODA 2011b, 2011c). Monitoring for cordgrass is important to prevent its further spread and establishment in new areas. People working in estuaries throughout Oregon are advised to familiarize themselves with cordgrass species, maintain vigilance, and report any new populations to the Oregon Department of Agriculture at 1-866-INVADER.

Purple loosestrife (*Lythrum salicaria*) is an invasive, non-native wetland plant that is considered a serious threat to freshwater and brackish wetlands throughout the Pacific Northwest. It has invaded large portions of the Columbia River estuary (Ferrarese *et al.* 2010). It has been documented in the Tillamook Bay estuary; locations are shown at the Oregon Weedmapper application (http://cms.oregon.gov/ODA/PLANT/WEEDS/WEEDMAPPER/Pages/index.aspx). Landowners should be informed of the possible presence of loosestrife in the estuary, and control efforts should be undertaken as soon as possible if its presence is confirmed.

Reed canarygrass (*Phalaris arundinacea*) is very widespread in the low-brackish to freshwater tidal portion of the estuary, particularly in disturbed areas and along river banks. This species is intolerant of highly saline water but can persist in slightly brackish water, so it is also common in altered tidal wetlands where salt water has been excluded by diking, tide gates, or restrictive culverts. Its native or non-native status has been disputed; recent studies suggested the species may be native, but the invasive populations may be a non-native genotype (Antieau 1993). Regardless of its native or non-native status, it is considered undesirable because it is highly invasive, forming dense single-species stands that exclude other species. At sites where reed canarygrass is dominant, restoration plans should include methods for reed canarygrass control or suppression. Woody plantings such as willows and Sitka spruce are often the most effective control method, since the low-brackish to fresh salinities that allow reed canarygrass growth are also appropriate for woody species.

Several other invasive species are found in the Tillamook Bay estuary and should be controlled within restoration or conservation sites. The Oregon Weedmapper application (http://www.weedmapper.oregon.gov/) shows several populations of Himalayan, Japanese and giant knotweed (*Polygonum polystachyum, P. cuspidatum,* and *P. sachalinense* respectively) as well as yellow flag iris (*Iris pseudacorus*). These species are a concern not just in the estuary, but also in nontidal wetlands throughout the watershed.

Intended uses and limitations of mapping

This study is meant for use in strategic planning of voluntary restoration and conservation activities; products are not intended for regulatory use. The maps produced in this study were derived from existing mapping (the National Wetland inventory). Users of the maps produced in this study should be aware that there may be upland areas within mapped wetlands, and there may be unmapped wetlands and tidal waters of the state that are subject to state and/or federal regulation under State Removal-fill Law, Federal Clean Water Act or Federal Rivers and Harbors Act. Furthermore, because the NWI uses the Cowardin definition of a wetland, which is different from the definition of a regulatory wetland subject to state and federal regulations, not all NWI wetlands are necessarily subject to regulation.

Data limitations

In any spatial analysis, it is possible for errors in the original data to be carried forward through data processing steps, resulting in inaccuracies in the final results. However, the processing methods used in this study reduced the potential for errors, because the broad conclusions drawn (i.e., ranking groups) are not dependent on highly accurate data. In other words, the data used are adequate for the analyses conducted.

This study used aerial photograph interpretation, existing data, and field investigation (usually observation from offsite) to characterize the sites in this study. Such “remote” data are inherently less accurate than data collected onsite in the field. Therefore, landowner contacts and site visits are recommended early in the restoration or conservation planning process, to verify the data presented in this report.

Although this prioritization used criteria that are strongly related to wetland functions, the prioritization is not intended to assess specific site functions. Assessment of tidal wetland functions requires onsite fieldwork for each site assessed (Simenstad *et al.* 1991, Adamus 2006, Adamus *et al*. 2009) and is not within the scope of this study.

In this study, we attempted to include the full historic extent of tidal wetlands in the estuary. However, it may not be possible to restore the full historic range of tidal influence at every site. (See **Appendix 6**, **Restoration Principles** for details.) Factors such as urban and residential development, subsidence, agricultural activities (e.g., cultivation, ditching, draining, and channeling), remaining dikes and other obstructions (e.g., roads), and basin-wide hydrologic changes all affect the potential to restore tidal exchange on a site. Field investigation is needed at any site where restoration is planned. Field investigation should include elevation surveys, water level (tidal range) measurements, analysis of water flow barriers, plant community analysis, and other measurements as needed to determine the feasibility of restoring tidal influence and tidal wetland habitats at the site. Expert assistance is recommended for these analyses.

Our study relies on accuracy of elevations in the LiDAR DEM. The DEM's tested accuracy on open ground is 10 to 20cm (Watershed Sciences, Inc. 2009) – certainly accurate enough for this landscape-scale assessment. However, research has shown that bare-earth modeling approaches, such as the methods that were used to produce the Oregon bare-earth model, may be inaccurate in heavily vegetated emergent and forested tidal wetlands (Brophy and van de Wetering 2012; Gopfert and Heipke 2006). Other approaches to deriving ground elevations from the LiDAR point-cloud data, such as the "minimum-bin" method, may provide better results in areas where dense vegetation interferes with LiDAR signal (Kim *et al.* 2006). We recommend ground-truthing of the LiDAR DEM for site-specific action planning and restoration design.

Spatial registration errors may also affect our analysis. This source of uncertainty occurs when two or more data layers contain errors that artificially shift the position of a feature relative to another. For example, the historic vegetation dataset (Christy *et al.* 2001) is compiled from paper notes produced by the General Land Office surveyors in the late 1850s through the 1930s. The extent of a given historic vegetation class recorded as a GIS feature may not exactly represent spatial extent of the same area in the LiDAR data. The cumulative positional error of each layer relative to another is difficult to measure, and each geographical dataset may contain registration errors of varying magnitudes due to the methods used to produce that dataset. Therefore, our analysis is appropriate for environmental management at a basin scale, but site-specific project planning should not be undertaken without onsite data collection and ground-truthing of the GIS data.

Site narratives

In this section, narrative descriptions are provided for selected high priority sites and a few lower-ranked sites that have unusual features. These narratives do not repeat the information found in the site information tables (Table 4, Appendix 2); instead, the narratives address unique site characteristics that came to light during the study. This information may be important for decision-making, and should be reviewed before contacting landowners or taking other actions in the estuary. **For all of these sites, the highest priority action is conservation of**

the existing wetlands. Other potential actions are described below and in the **Restoration recommendations** section above.

Site 1

This site, located behind the North Jetty, is quite different from the majority of sites in the study. The site is mapped as open water in the historic vegetation mapping, and as shown in Komar and Terich (1976), the site is situated on sand that accumulated rapidly after construction of the jetty. Based on aerial photo interpretation, tidal influence appears to be substantial; there is a large accumulation of drift logs at the north edge of the site, and the low-growing herbaceous vegetation and lack of woody species suggests saline conditions. The lack of in-channel flow restrictions, along with these observations, resulted in classification of this site as "fully tidal" (attribute "CON_STATUS;" see Appendix 2, Table 3 for methods). This designation is somewhat misleading, since the jetty no doubt reduces tidal exchange. On the other hand, the tides is probably not an appropriate candidate for restoration, since it was not historically a tidal wetland prior to construction of the jetty. If the jetty were not present, the site would most likely be rapidly eroded and would return to its former open water condition (Komar and Terich 1976).

Site 2

This site lies on the outlet of the Miami River into Tillamook Bay. A road with a restrictive culvert bisects the site. Our advisory team explained that the road is used to service the adjacent power line, and that the culvert has "blown out" during high flows at least once. The 1939 aerial photos show that the road was constructed prior to 1939 to service a dock constructed along the Miami. In the imagery the dock appears to be in poor condition; a larger, newer dock is visible from where the bisecting road turns and high ground exists, waterward of the road. The dock probably serviced a quarry just north of the site, which is still visible today adjacent to Highway 101. Tidal marsh at this site has advanced into the bay considerably since 1939, due to the rapid sediment accretion that is typical of much of Tillamook Bay (Dicken 1961).

Site 4

Site 4 is the location of the Miami Tidal Wetland Enhancement project, a major project of the Tillamook Bay Estuaries Partnership. Restoration, accomplished during 2010-2012, included dike removal, filling of linear ditches, construction of a meandering channel system, and extensive native plantings (Vigil-Agrimis 2008). Extensive baseline monitoring was conducted at the site (Bailey 2011), providing detailed information on pre-restoration conditions and providing a solid basis for future evaluations of restoration trajectory. Much of the site was mapped as open water in the historic vegetation map (Hawes et al. 2008). Assuming the site has not been filled, the current high elevations in these former open water areas (9-10ft

NAVD88) demonstrate the very high rates of sediment deposition that can occur at sites in this geomorphic setting.

Site 7

This small, single-owner site on Bayocean Spit is one of seven remaining intact tidal swamp sites in the estuary. Historic vegetation was dense shore pine, and the site remains forested today. Elevation is high in the tide range (9-11ft); tidal inundation may be infrequent, particularly since this site does not have a fluvial component to the inundation regime (Huang *et al*. 2011, Brophy 2009). It is also likely that the actual ground surface is somewhat lower, since dense vegetation in forested tidal swamps of Oregon can prevent penetration of the LiDAR signal to the ground (Brophy and Van de Wetering 2012).

Site 10

This site consists of a fringing emergent wetland on the north side of Cape Meares Lake. The lake was formed after the Army Corps of Engineers built the combined dike and road following the 1952 Bayocean Spit breach during heavy storms. Our advisory team confirmed that the road acts as a combined dike and dam, preventing tidal exchange and impounding freshwater flow. Based on that input, we classified this site as nontidal.

Site 22

Site 22 is the largest site in our study area; it is located on the east side of Tillamook Bay. As described by Dicken (1961), much of the marsh on this site has accreted recently. Heavy loads of sediment were carried into Tillamook Bay after the Tillamook Burn (a series of extensive forest fires in the 1930s and 1940s); this sedimentation and more recent deposits have led to marsh advance ("progradation") into the bay. The marsh advance is clear by comparing the 1939 imagery and the historic vegetation layer (Hawes *et al.* 2008) with current aerial photos. Vegetation on the lowest fringe of the site (west edge) shows a clonal growth pattern typical of pioneering vegetation on newly deposited sediment, so it appears that marsh advance is ongoing. However, the majority of the site is now well-established tidal marsh, with a dense and clearly-defined tidal channel network.

This is one of the least-altered sites within our study; it has probably remained unaltered due to low elevation and frequent flooding. No mapped alterations exist on the western (downslope) edge of the site; minor ditching and sidecast can be seen in recent aerial imagery on the eastern (upslope) side of the site.

Site 23

This site is recommended as a least-disturbed monitoring site for examining physical conditions (e.g. tidal inundation regime, salinity, and soils) at the transition between tidal marsh and tidal swamp. The eastern third of the site (about 7A) consists of Sitka spruce tidal swamp, a wetland type that was once prevalent in Oregon estuaries but is now very rare (Graves *et al*. 1995, Brophy 2005a, 2007, 2009). Historic vegetation mapping (Hawes *et al*. 2008) shows the swamp area was tidal marsh in the mid-1800s. In the 1939 aerials, this area was unvegetated and was covered by a large accumulation of drift logs. The current tidal swamp appears to have developed on the former drift logs, a common phenomenon at the upslope edge of brackish tidal marsh (Dicken 1961, Jefferson 1975). The western 2/3 of the site consists of tidal marsh, most of which has accreted since the 1939.

Site 30

This site was recently acquired by The Nature Conservancy; restoration planning is underway.

Site 33

This 38A tidal swamp is one of the least disturbed sites in the Tillamook Bay estuary and has very high potential scientific value as a reference site. Mapped as Sitka spruce swamp in the 1800s historic vegetation map (Hawes *et al*. 2008), it is still dominated by mature Sitka spruce, with other species such as red alder and willow filling the gaps between the spruce. The fairly wide spacing of the spruce suggests the site may have been logged or partially logged, as is the case for most spruce swamps on the coast; however, scattered Sitka spruce are also typical of many tidal swamp areas (Dicken 1961, Jefferson 1975). The northern edge of the site is relatively high due to alluvial deposition (natural levee deposits) from the Kilchis River.

Portions of Squeedunk Slough were excavated to remove large amounts of gravel deposited during Kilchis River floods (Leo Kuntz, personal communication). This excavation may have created the cutoff channel that bypasses the western meander of Squeedunk Slough immediately south of its junction with the Kilchis River. Sidecast from that excavation may have raised the elevations of adjacent channel banks, and vegetation near the junction of Squeedunk Slough and the Kilchis River was probably disturbed. Monitoring of conditions at this site could provide urgently needed data on tidal swamp ecosystems. Monitoring should focus on the least-disturbed interior of the site, along the extensive tidal channel network that enters the site from the south (tributary to Squeedunk Slough). This would be an ideal long-term monitoring site for documenting future changes to wetlands on the Oregon coast.

Site 39

This complex site was mapped as tidal marsh in the 1800s (Hawes *et al*. 2008). It probably served as pasture in the past but grazing currently is light or nonexistent, judging from the extensive development of woody vegetation. The LiDAR DEM “bare earth” surface has a rough texture, suggesting that dense vegetation may have interfered with the LiDAR signal, as observed by Brophy and Van de Wetering at Bandon Marsh National Wildlife Refuge (2012). This site is owned by Tillamook County and was acquired as part of the Fuhrman Wetland Acquisition. Recommendations for this site in the Project Exodus Final Report (NHC and HBH

Consulting Engineers 2010) are complex, including removal of dikes and dredge spoils, channel reconnection, excavation of a new tidal channel and installation of a drainage control structure at the site's southeast boundary. We recommend well-planned baseline monitoring in support of the restoration design process, since the site's hydrology, vegetation, and history are obviously complex. Our advisory team told us that a high school group is currently monitoring the site.

Site 40

This 20A site on Hall Slough, owned by Tillamook County and acquired as part of the Fuhrman Wetland Acquisition, is one of seven remaining intact tidal swamps in the estuary. Although 16% of the site is mapped as water in the historic vegetation layer, this is most likely due to poor registration between the historic vegetation layer and other GIS data. The site appears unaltered from 1939 to the present.

We considered this site fully tidal because tidal channels are clearly visible in the LiDAR DEM, connecting the site to Hall Slough. However, a substantial dike runs along the site's SW boundary; the dike appears to control flow into Site 39, but it probably also affects tidal inundation on Site 40.

Recommendations in the Project Exodus Final Report include removal of the dike. This will enhance the condition of Site 40 if done carefully, to minimize impact to the rest of the site.

Site 41

This site lies on Hall Slough and the Wilson River. Despite the site's three tide gates, the site appears to have muted tidal exchange; the site's dikes are breached (Mattison 2011) and the LiDAR DEM suggests there are channels through the breaches . There is fairly extensive ditching on the southern half of the site. The 1939 aerial photos revealed extensive active logging – including yarding lanes and slash piles, diking, and road construction. A newly constructed dike is visible along the entirety of the site. Although the northern and southern halves of the site appear to have much different levels of alteration today, the logging and diking history is nearly identical. The site overlaps Simenstad (1999) sites 4 (northern half of our site) and 5 (southern half). The site boundary intersects four parcels, but there are only two primary landowners.

Site 48

A fringing marsh along the lower Tillamook River, this site ranks high due to its high wetland connectivity, large number of salmonid stocks using the adjacent river, and lack of onsite alterations. It was mapped as open water in the 1800s (Hawes et al. 2008), and the entire site probably formed as a result of accretion outside the dike that separates it from the adjacent diked pasture. Unless the adjacent diked pasture is restored via dike removal, allowing landward migration, this site will be vulnerable to sea level rise.

Site 50

This is an agricultural site and former tidal swamp located between Hoquarten Slough and the Wilson River. Mattison (2011) maps dikes along the Wilson River; a large tide gate (mapped by Mattison and TCCA) restricts tidal flow into the NW corner of the site. The southeast portion of the site adjacent to the City of Tillamook is tidal, based on field observation, and probably receives flow from Hoquarten Slough, where Mattison (2011) maps a breached dike. Although five landowners are mapped for the site, just one private landowner owns 94% of the site. The rest are fragments and may represent registration errors between the ownership layer and other layers.

The northern part of this site is within the "Southern Flow Corridor" recommended in the Project Exodus Final Report (NHC and HBH Consulting Engineers 2010). Proposed actions for the site include removal of the dikes along Hoquarten and Dougherty Sloughs (some of which are already breached according to Mattison [2011]), and construction of a setback levee that would block tidal flows to the southern third of the site, to protecting the adjacent developed lands to the south. These actions are appropriate and if carefully implemented, should greatly improve wetland function within the dike removal area. As always, we recommend well-planned baseline monitoring in support of the restoration design process, since the site's hydrology, vegetation, and history are obviously complex.

Site 53

This site is one of the few remaining intact tidal swamps in the estuary, and its scientific value is very high. It lies between Hoquarten and Dougherty Sloughs and has just two major landowners. We considered this site fully tidal; large sinuous tidal channels are clearly visible in the LiDAR DEM and no in-channel flow restrictions (tide gates or culverts) are mapped or visible in aerials or LiDAR. The natural levee along Dougherty Slough has been built up, but this does not affect tidal inundation *via* Hoquarten Slough, which appears to be the main tidal entry point. The LiDAR shows remnants of a dike along portions of Hoquarten Slough; Mattison (2011) mapped this as a breached dike along Hoquarten Slough and adds the notes "Dredge spoils" and "County plans to remove this levee." Removal of the dike/dredge spoils is recommended in the Project Exodus Final Report (NHC and HBH Consulting Engineers 2010); the work awaits funding. Dredge spoil removal could benefit the site if done carefully to avoid damage the rare and valuable tidal swamp habitat.

Mattison (2011) also mapped a removed dike bisecting the site from east to west, and notes that it is "labeled as levee on soil survey map." Our advisory group explained that this feature is a large ditch which was excavated as part of Project Exodus; the ditch is clearly visible in the LiDAR DEM. In 2009, the Tillamook Estuaries Partnership (TEP) conducted riparian plantings on the north perimeter of the site along Dougherty Slough.

Site 55

Like Site 53, this site is one of the few remaining intact tidal swamps in the estuary. In comparison to Site 53, this site's hydrology is probably more affected by surrounding development such as Highway 101 to the west. The western third of the site is highest (near the Highway 101 corridor), and some disturbance is evident in that area. For example, the LiDAR DEM reveals a filled linear feature, probably an old road. However, the eastern two-thirds of the site is in excellent condition, with an intact and intricate tidal channel network and vegetation dominated by mature Sitka spruce. The scientific value of this site is high, and its potential for education and scientific outreach is also high due to the presence of the Hoquarten Interpretive Trail Park (http://www.tillamookor.gov/images/Hoquarton_Slough_Story1.pdf). This Tillamook City Park is located on the south bank of Hoquarten Slough across from Site 55; it could potentially provide an access point for scientific studies or educational activities.

The actual ground surface elevation in this site may be lower than shown in the LiDAR DEM. The DEM's rough-looking "bare earth" surface may in fact show considerable interference from the site's typical dense tidal swamp vegetation, which includes dense slough sedge ground cover. Our monitoring at Bandon National Wildlife Refuge showed that dense slough sedge in forested wetlands can prevent penetration of the LiDAR signal to bare earth, causing the LiDAR to show elevations 1-2ft higher than the actual ground surface (Brophy and Van de Wetering 2012).

Site 57

This site, adjacent to the Carnahan city Park boat ramp, has two unmapped tide gates. On the north side of the boat ramp is an 18" culvert with a tide gate; the culver is half plugged with sediment, and the tide gate cannot open. A scour pool shows that high velocity flows occur through the pipe. On the south side of the boat ramp, tidal flow into the ditch is excluded by a functional top-hinged tide gate on the 24-36" culvert.

Sites 58 and 59

Our advisory group explained that these sites are connected to the Trask by a ditch that exits through tide gates and/or culverts at Tone Bridge, Tillamook Loop Bridge, and Highway 101. These tide gates and culverts are not mapped in Mattison (2011) or the TCCA culverts layer. Our advisors said that these sites have very poor drainage and that they receive flood flows from the southern side.

Site 72

This single-owner site is one of the few remaining intact tidal swamps in the estuary. However, it is not unaltered; a dredged channel forms the northern boundary of the site, and a basin has been excavated on the east portion of the site. Our advisory team informed us that the basin was excavated in an attempt to construct a recreational marina. The LiDAR elevation of this site is roughly three feet higher than the elevation of the diked agricultural area directly to the north (Site 70).

The LiDAR DEM on this site has a rough, patchy texture; in our experience, forested wetlands with this LiDAR signature often have substantial vegetation interference with the LiDAR signal (Brophy and van de Wetering 2012). Therefore, we expect that the actual ground surface on this site may be lower than shown in the DEM. Although the historic vegetation layer shows part of this site as water, that appears to be a registration error; the site was completely forested in the 1939 aerials and appears unaltered at that time. The site is still forested today, although large Sitka spruce were removed between 1939 and the present time.

Site 74

This site, located in the freshwater tidal section of the Tillamook River, includes a forested wetland and a very wet pasture that has not been grazed recently. It has two main landowners; the ownership boundary follows the edge of the forested portion. The site is currently non-tidal; tidal exchange is blocked by Burton-Fraser Road, which acts as a dike (Mattison 2011). Our advisory team reports that flooding occurs over the road during periods of high water. A concrete apron has been installed to protect the road from erosion during these flood events.

Our fieldwork revealed an unmapped 24” culvert under Burton-Fraser Road; the culvert has an intact top-hinged tide gate. During our visit in February 2012, water was impounded upstream of the gate and a turbulence pool was visible around both sides of the culvert, indicating substantial tidal forcing at the tide gate.

The LiDAR DEM shows a sharp elevation drop (about 3ft) at the fenceline that forms the boundary between Site 74 and Site 73 to the west. Field reconnaissance suggests this may be due in part to inaccuracy in the LiDAR DEM due to the dense vegetation (cattail and slough sedge) on the site. Our monitoring at Bandon National Wildlife Refuge showed that dense slough sedge in forested wetlands can prevent penetration of the LiDAR signal to bare earth, causing the LiDAR to show elevations 1-2ft higher than the actual ground surface (Brophy and van de Wetering 2012). Another possibility is that the difference is due to subsidence of Site 73, which appears to have been grazed more intensely and is aggressively ditched.

In the 1939 imagery this site was relatively undisturbed, but there were several roads cleared around the site. Log rafting was visible upstream of the site.

Site 75

This single-landowner site is a forested wetland in the freshwater tidal section of the Tillamook River, adjacent to the excavated basin on Site 72 (see Site 72 description above). It is diked but not ditched; there are no mapped tide gates and we were unable to see tidal connections from our field reconnaissance vantage point on Burton-Fraser Road. The LiDAR DEM shows a prominent tidal channel running through the center of the site; the channel appears to be in good condition (sinuous, not ditched). Based on the LiDAR, this channel may be culverted through the dike that surrounds the excavated basin on Site 72. Given the uncertain tidal connection status, we assigned the intermediate tidal connection category (muted tidal).

The LiDAR DEM shows elevations from 7-10ft NAVD88 but as for several sites above, the patchy, "rough" texture of the LiDAR DEM suggests that the higher areas may be dense vegetation rather than the actual ground surface.

The site's historic vegetation is mapped as Sitka spruce swamp and substantial swamp vegetation was still visible on the site in the 1939 aerials, although it had been partially logged. The site had not yet been diked in 1939.

Conclusion

This study:

- maps tidal wetlands using current data sources;
- provides detailed site-specific characterization;
- summarizes the site-specific data to create robust overviews of tidal wetland changes and current conditions; and
- offers a clear prioritization to guide restoration and conservation actions.

The Tillamook Bay estuary is an area of intensive agricultural land use, valued natural resources, and frequent disastrous floods. The commonalities and conflicts among its users have prompted many past studies and recommendations. A central theme among these past studies has been protection and restoration of tidal wetlands to improve the health of the estuary while reducing flood risks. We hope that the detailed characterization and prioritization of tidal wetlands in the current report will advance these goals, providing a foundation for future on-the-ground restoration and conservation actions.

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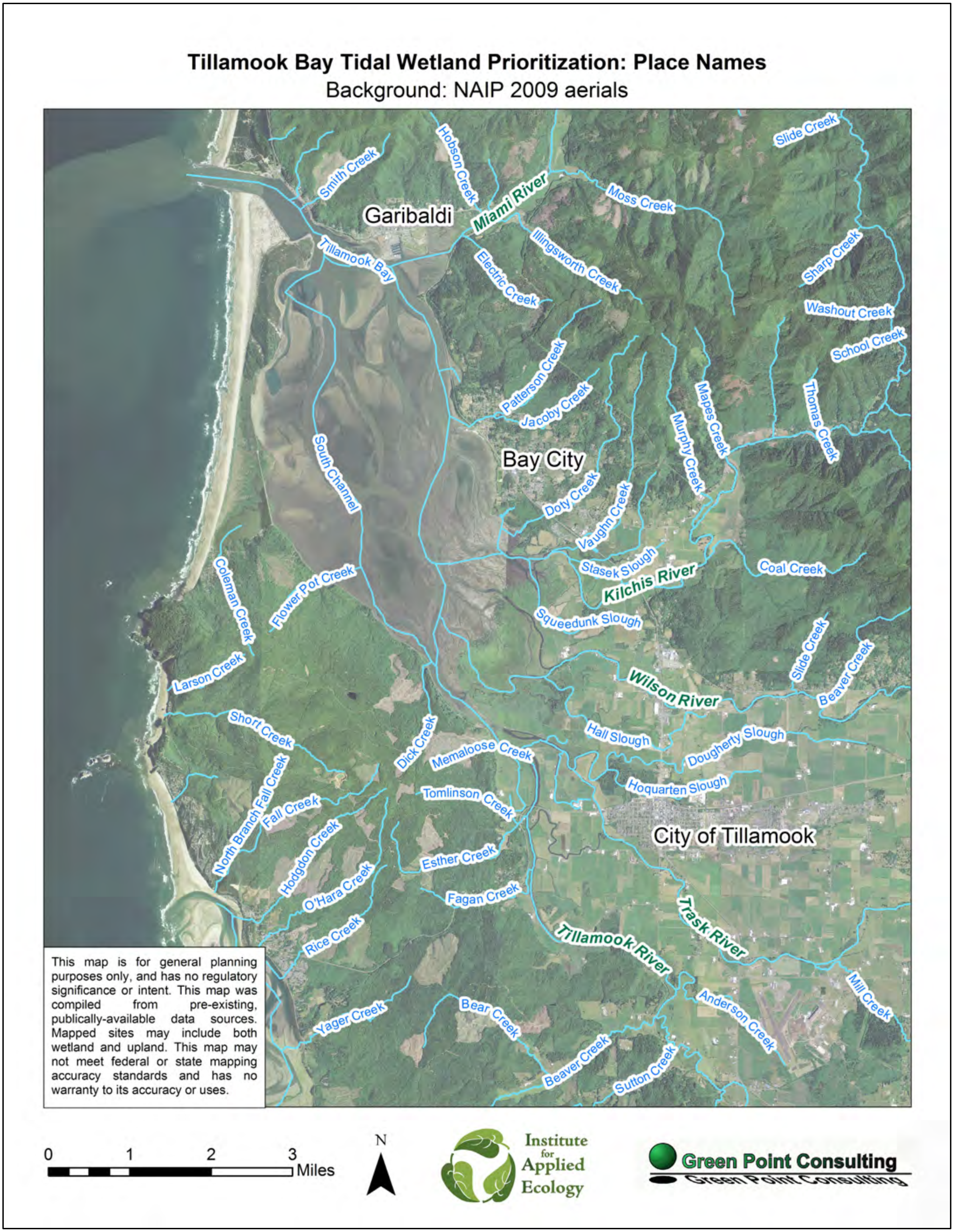
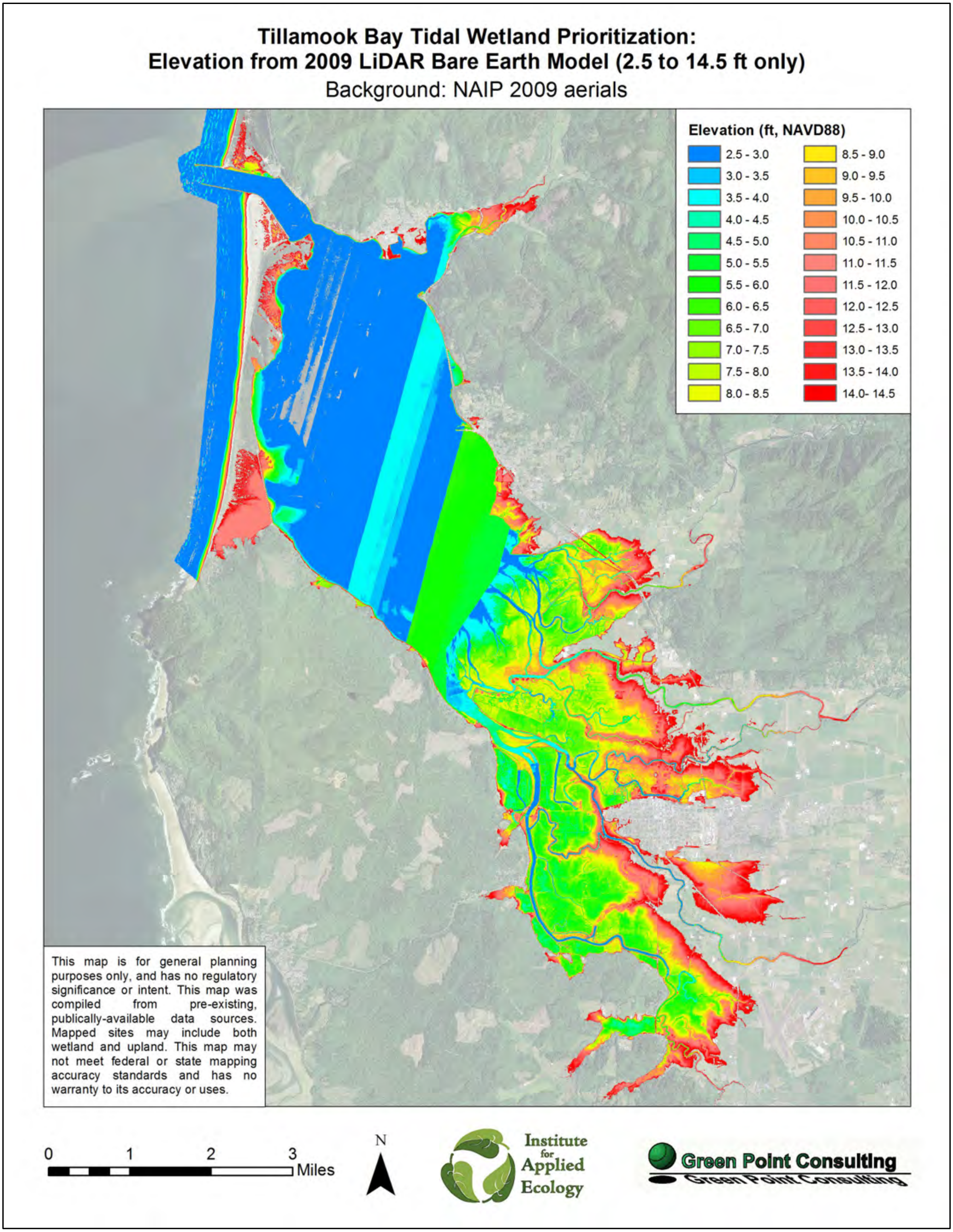
Appendix 1. Maps

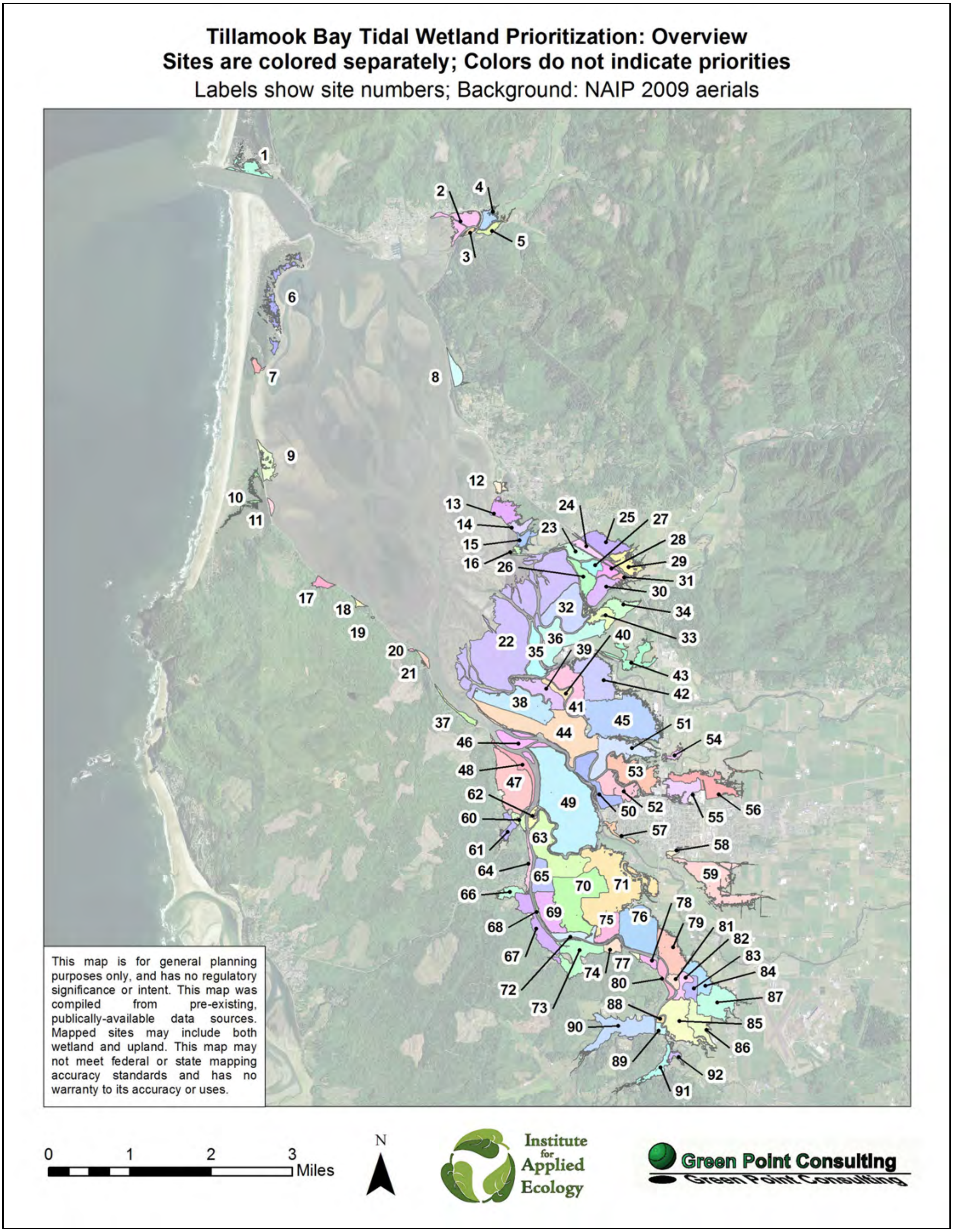
1. Place names
2. Ground surface elevation (LiDAR bare earth model)
3. Overview of study sites (colored by site number)
4. Study site boundaries overlaid on high-resolution aerial
5. Study site boundaries overlaid on LiDAR elevations
6. Total prioritization score
7. Score for size of site
8. Score for tidal channel condition
9. Score for wetland connectivity
10. Score for salmonid diversity
11. Score for historic vegetation type
12. Score for diversity of vegetation classes
13. Tidal connection status
14. Historic vegetation types
15. Landward migration zones
16. Number of landowners
17. Landowner type



Map 1. Place names



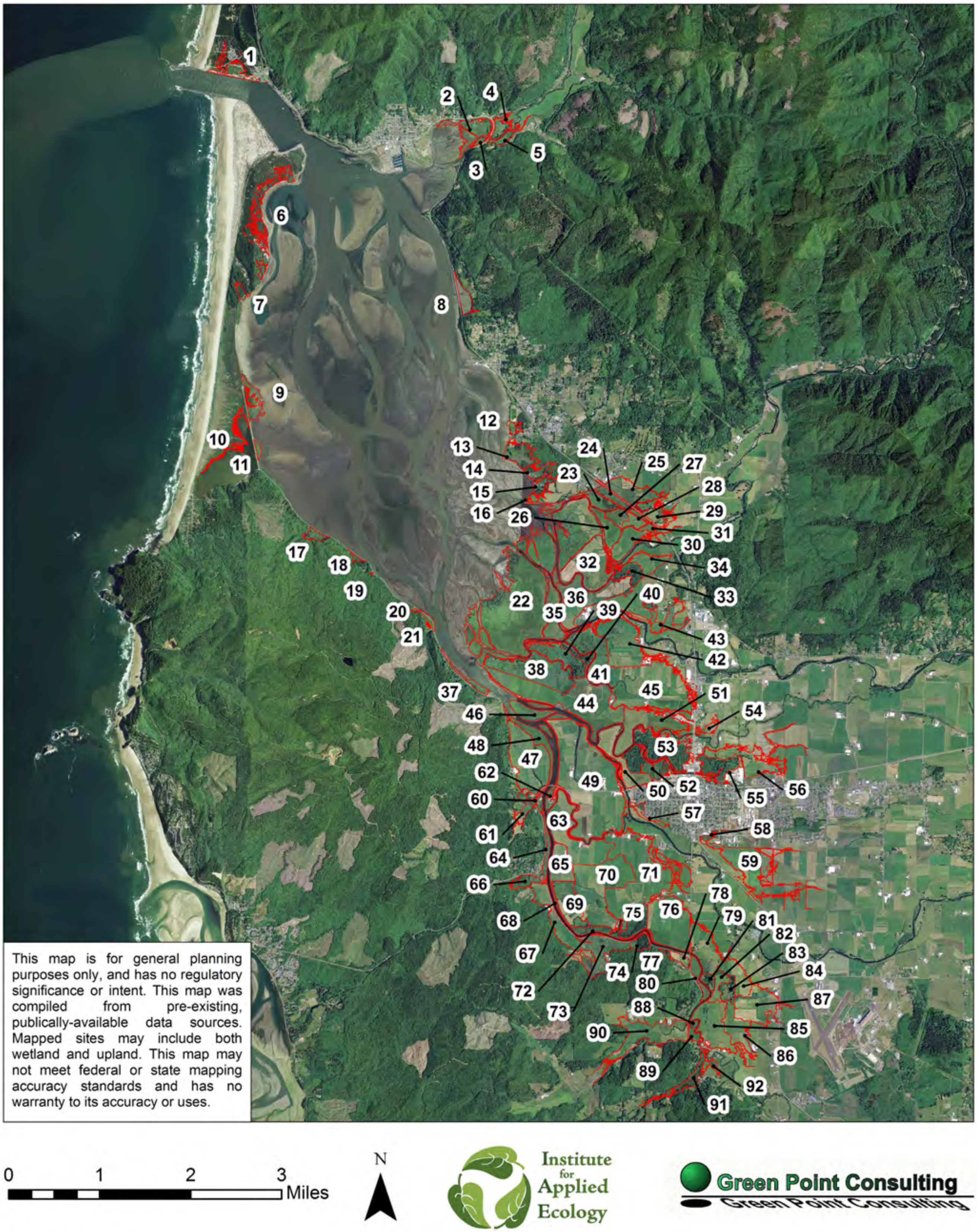
Map 2. Elevations (2.5 to 14.5ft NAVD88 only), from LiDAR DEM ("bare earth model")



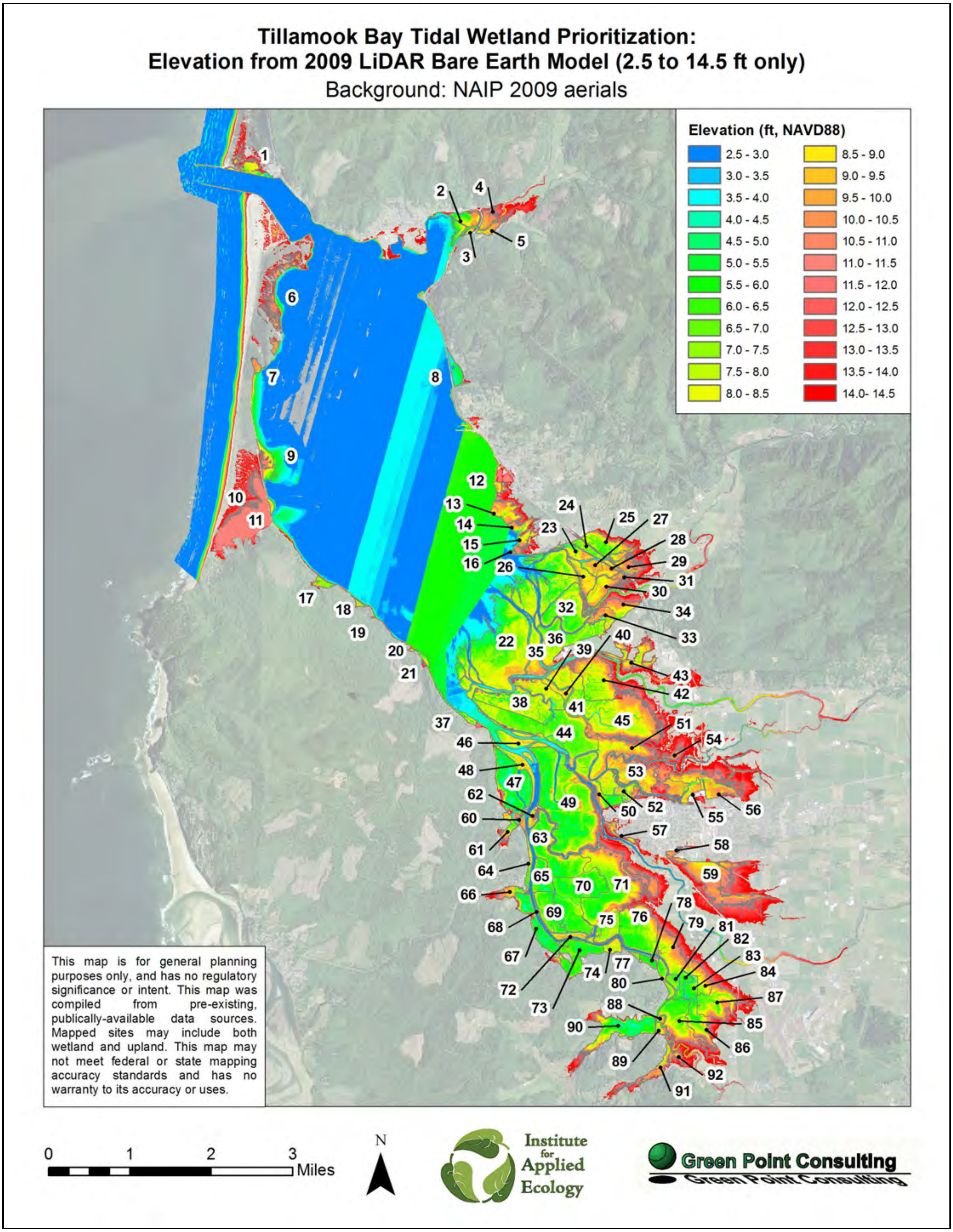
Map 3. Overview of study sites, colored by site number

Tillamook Bay Tidal Wetland Prioritization: Site boundaries

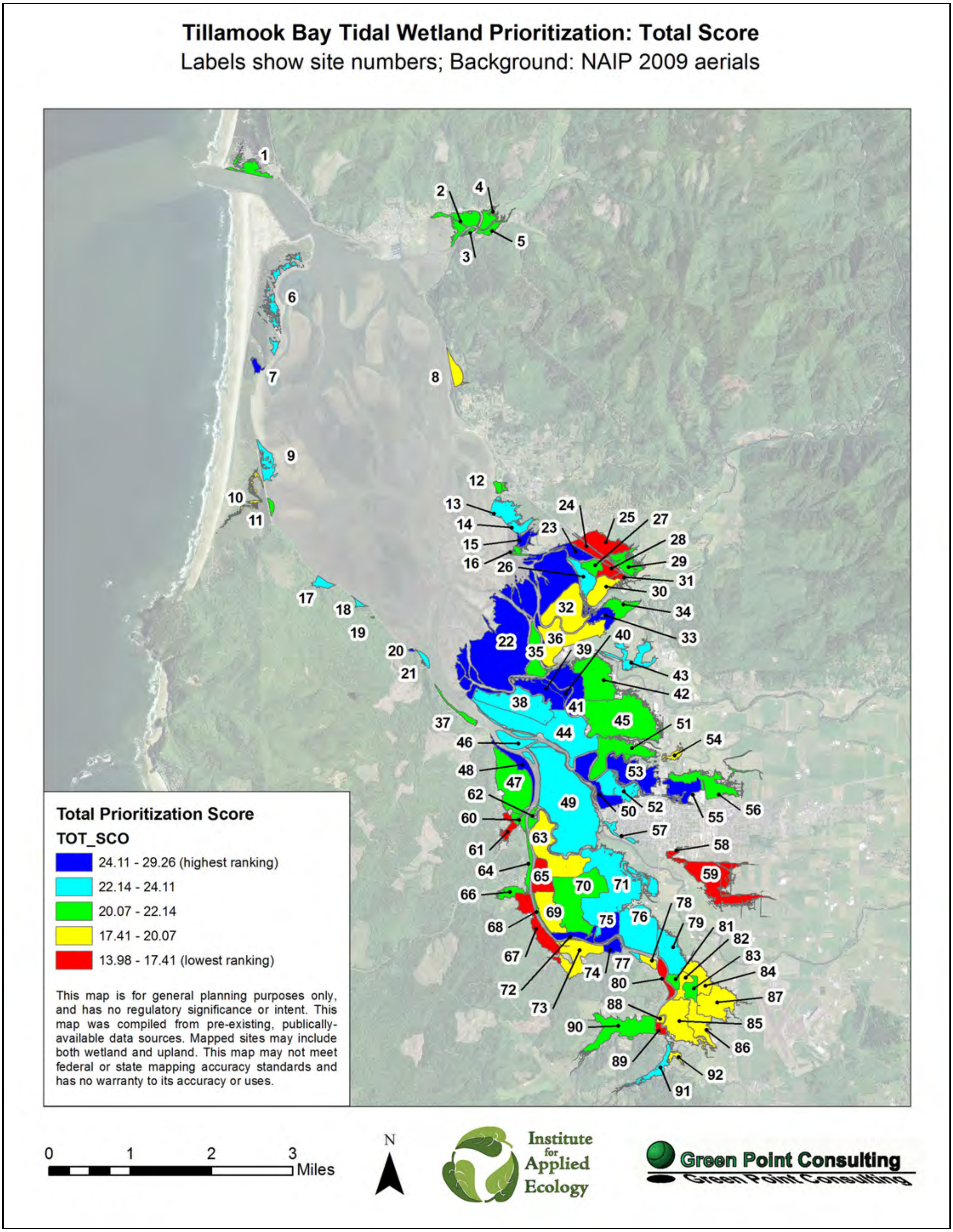
Labels show site numbers; Background: NAIP 2009 aerials



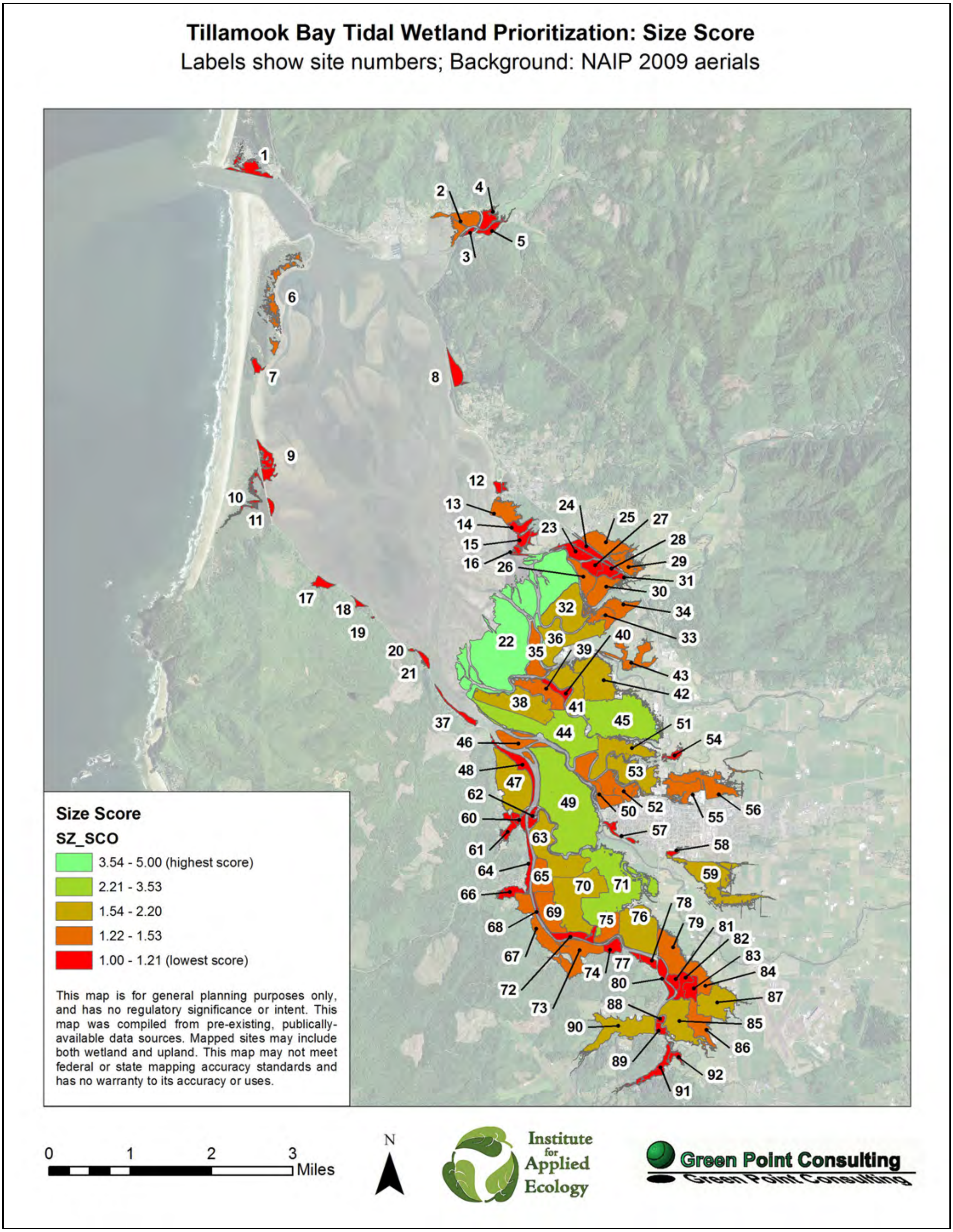
Map 4. Study site boundaries overlaid on high-resolution 2009 NAIP aerial orthophotograph



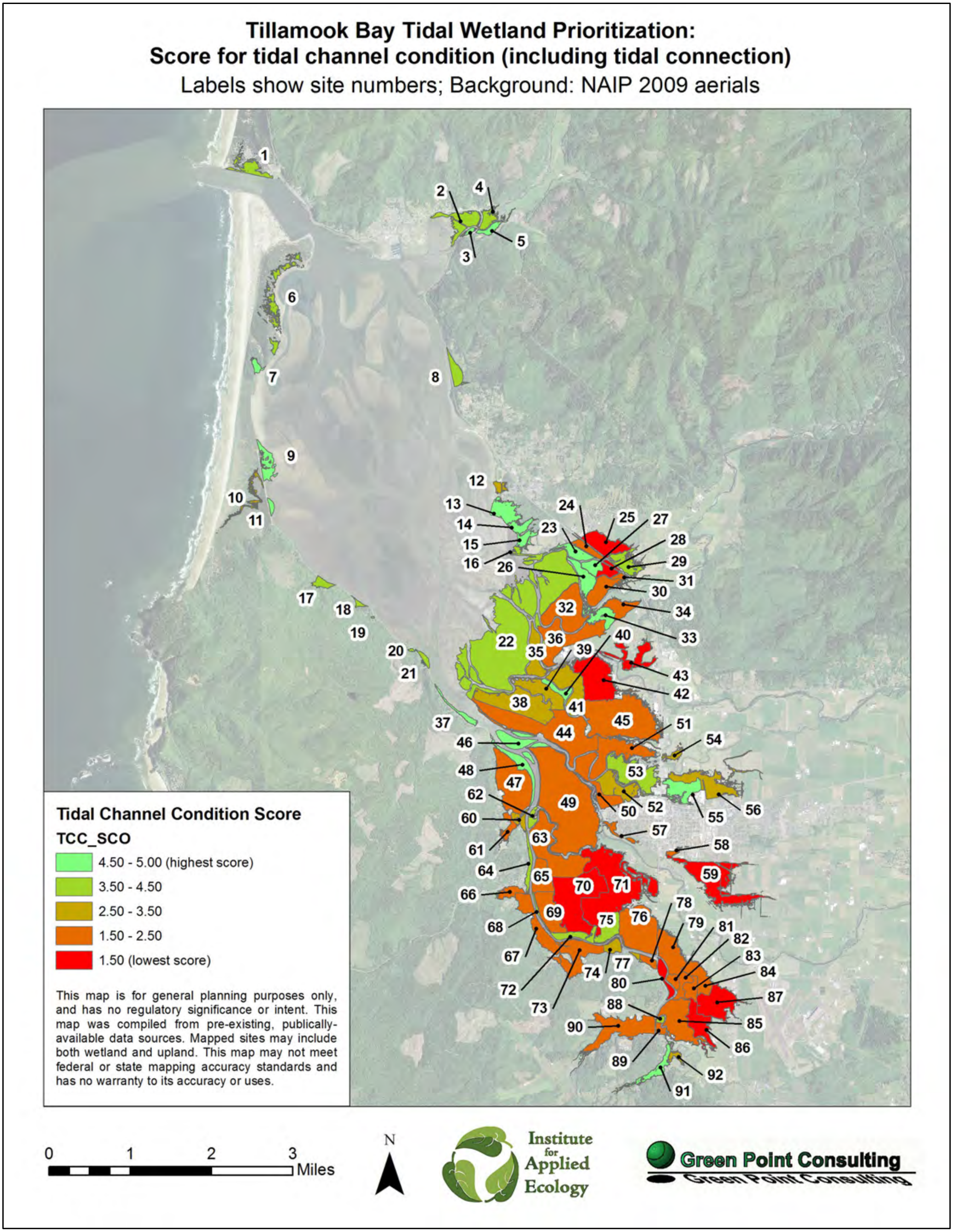
Map 5. Study site boundaries overlaid on 2009 LiDAR DEM



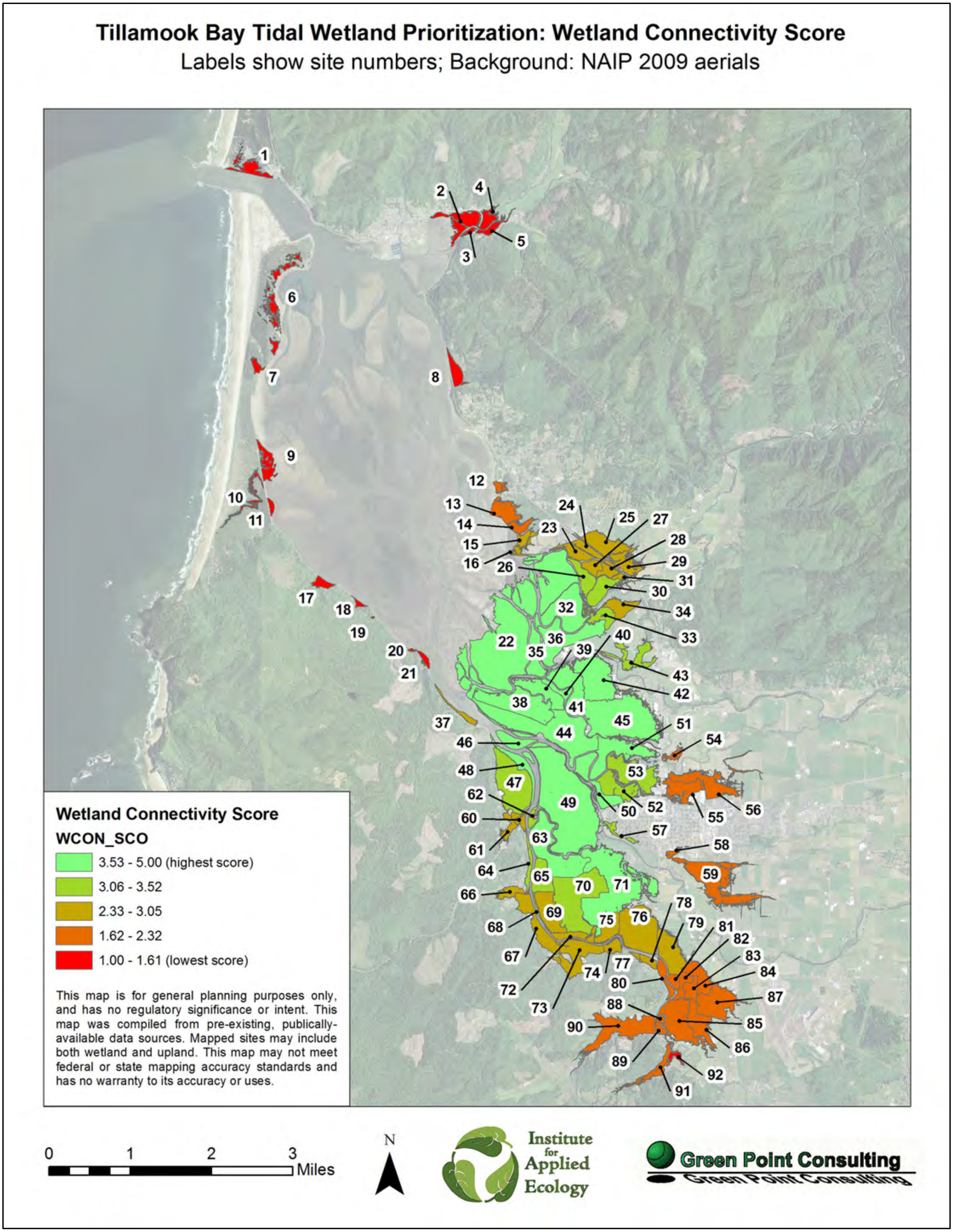
Map 6. Total prioritization score



Map 7. Score for size of site



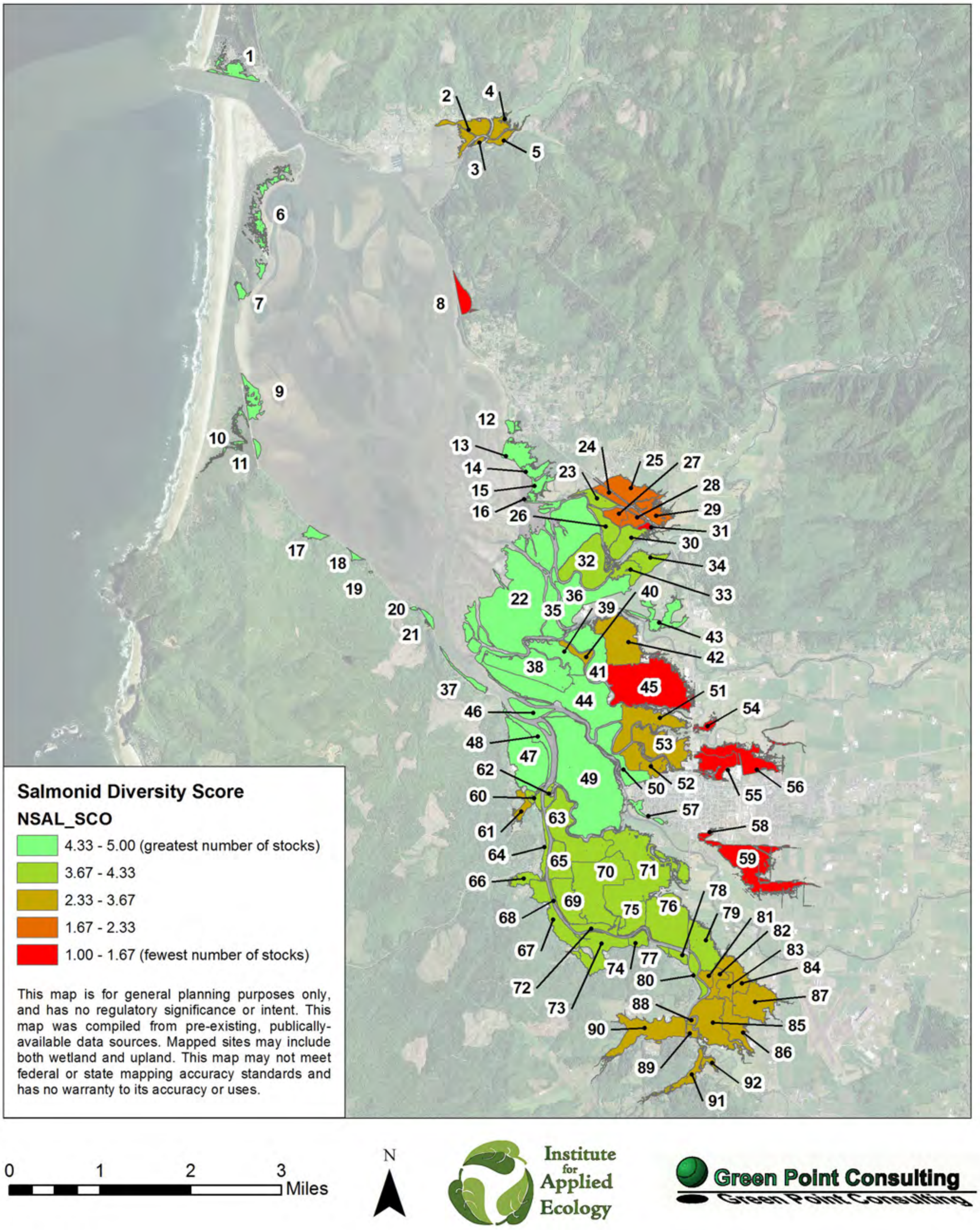
Map 8. Score for tidal channel condition



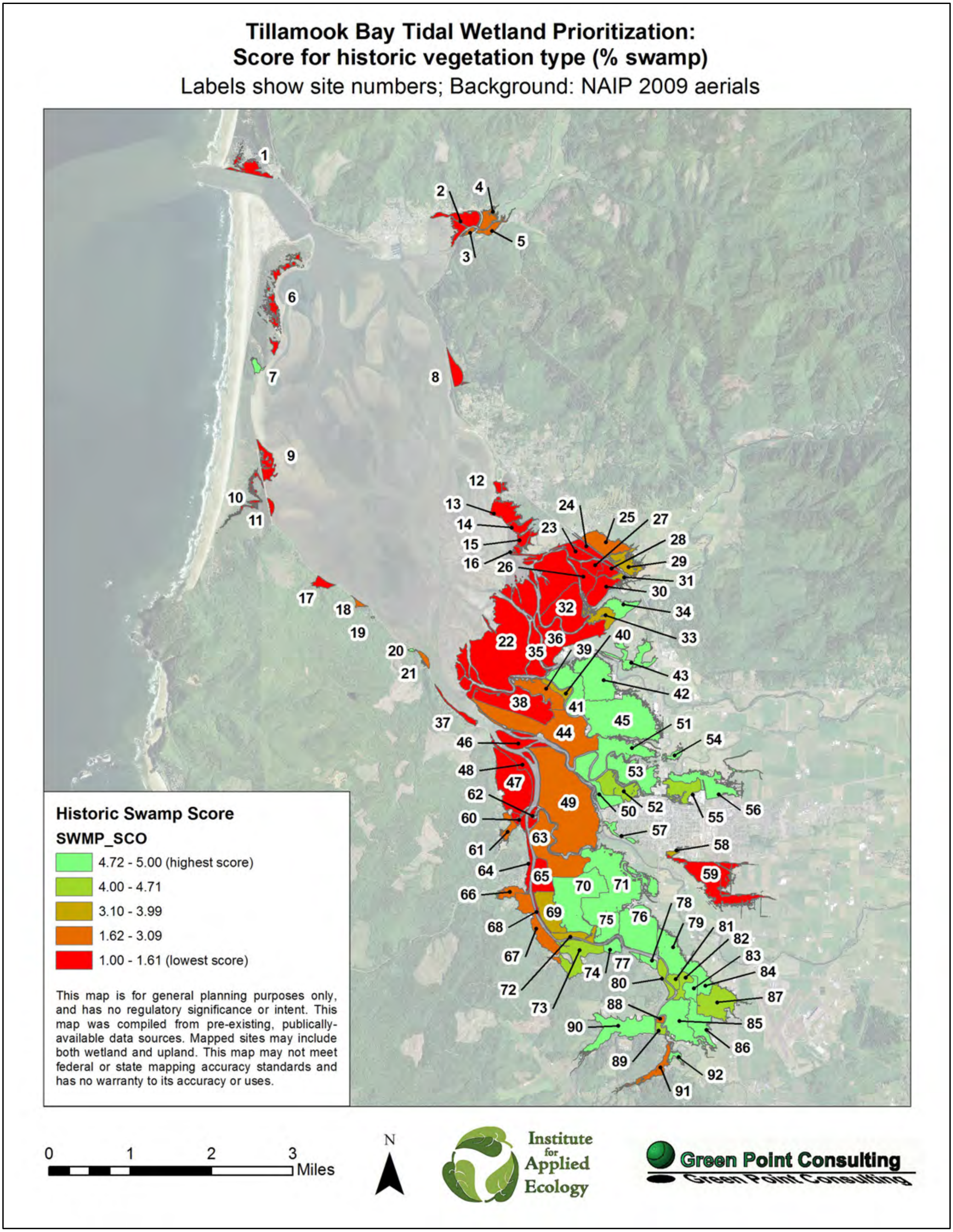
Map 9. Score for wetland connectivity

Tillamook Bay Tidal Wetland Prioritization: Salmonid Diversity Score

Labels show site numbers; Background: NAIP 2009 aerials



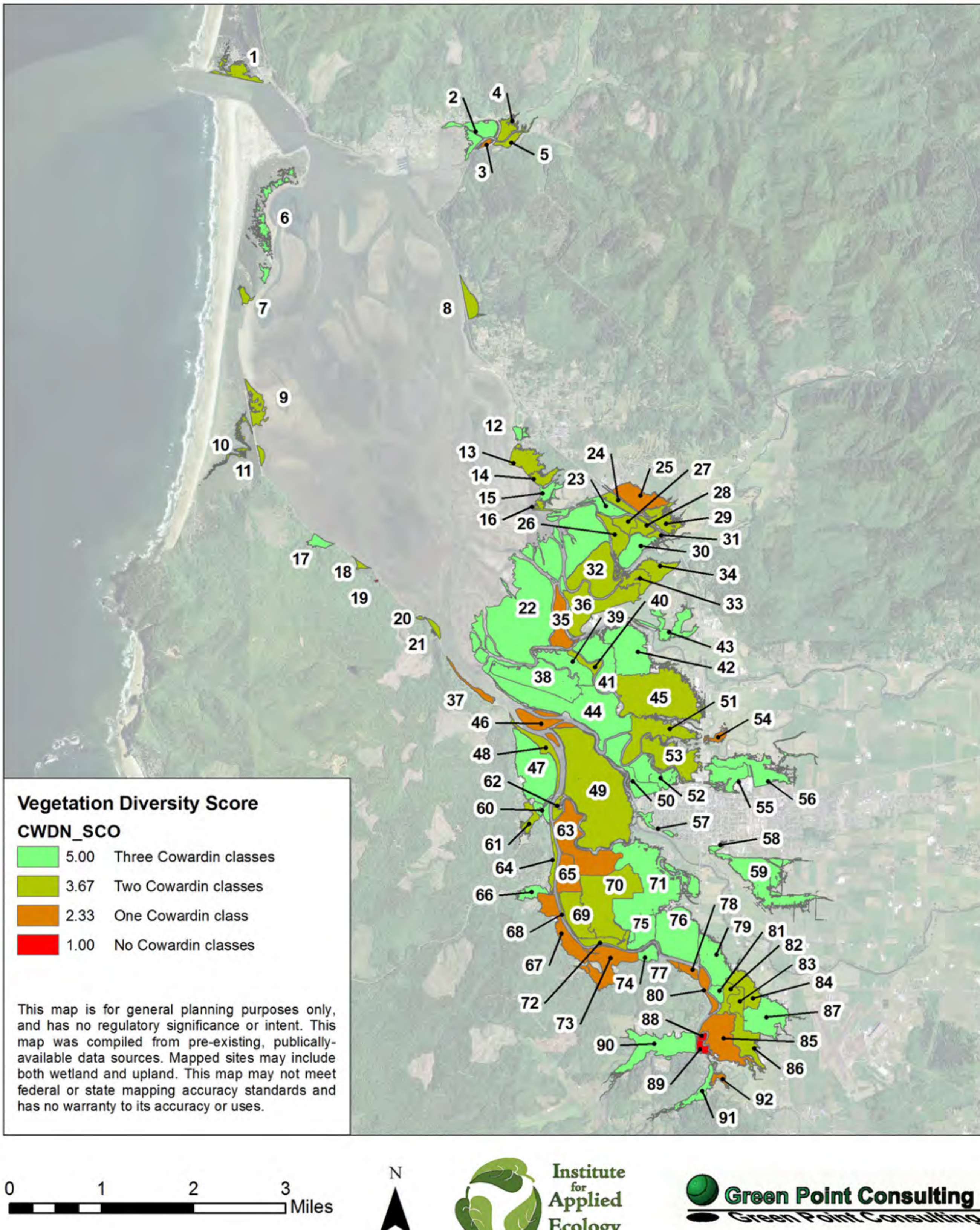
Map 10. Score for salmonid diversity



Map 11. Score for historic vegetation type (% historic swamp)

Tillamook Bay Tidal Wetland Prioritization: Vegetation Diversity Score

Labels show site numbers; Background: NAIP 2009 aerials



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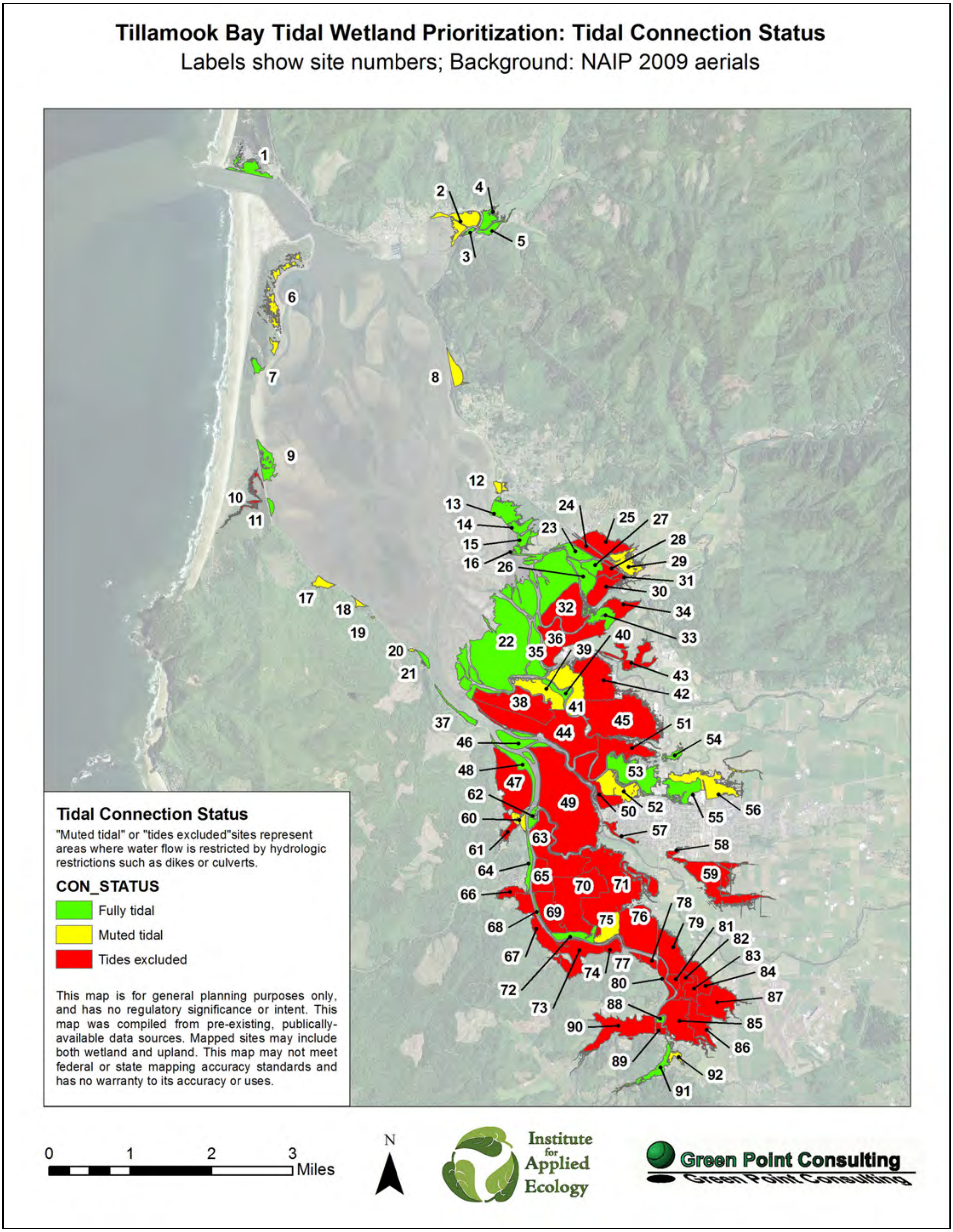
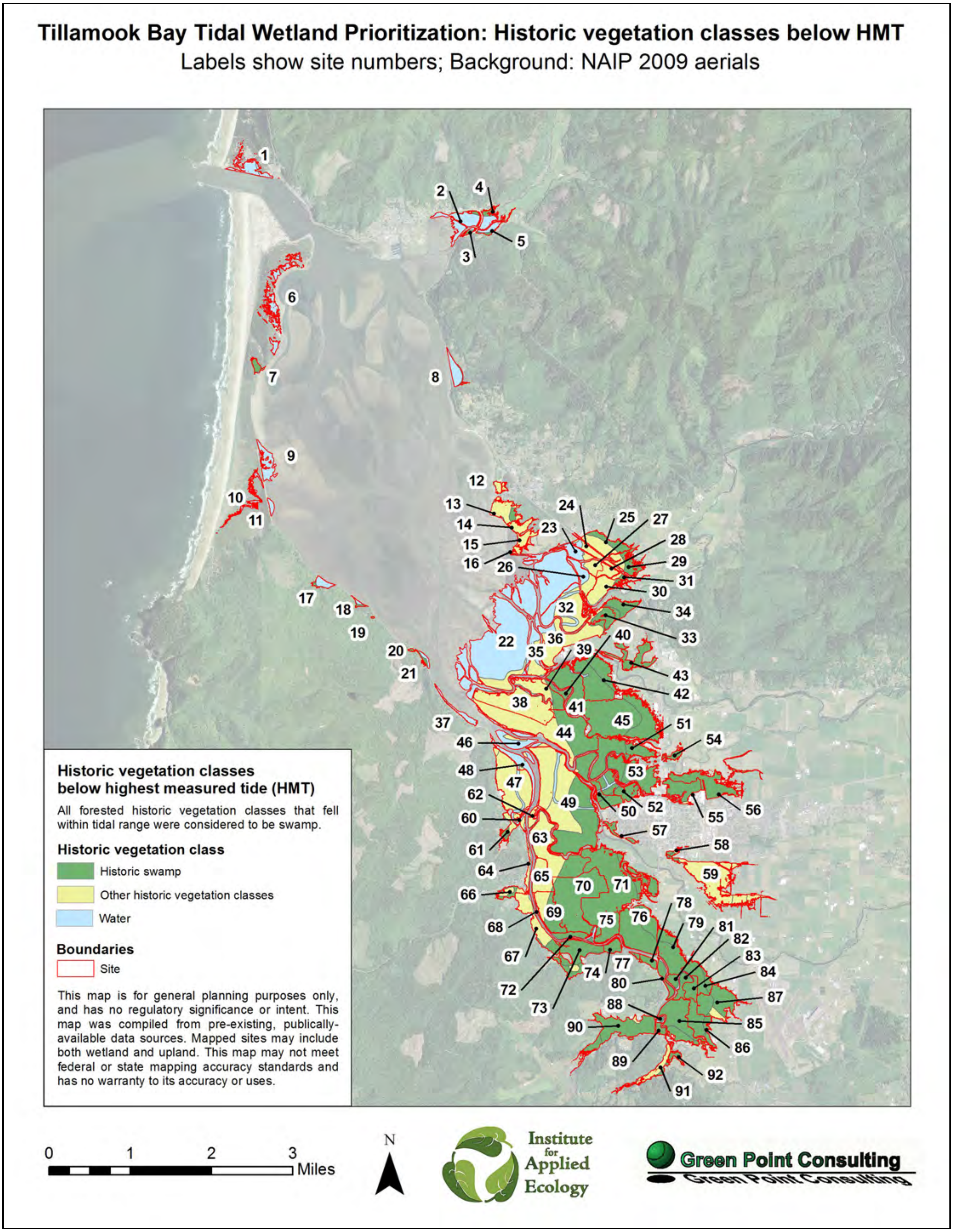
Map 12. Score for diversity of vegetation classes (number of Cowardin classes)



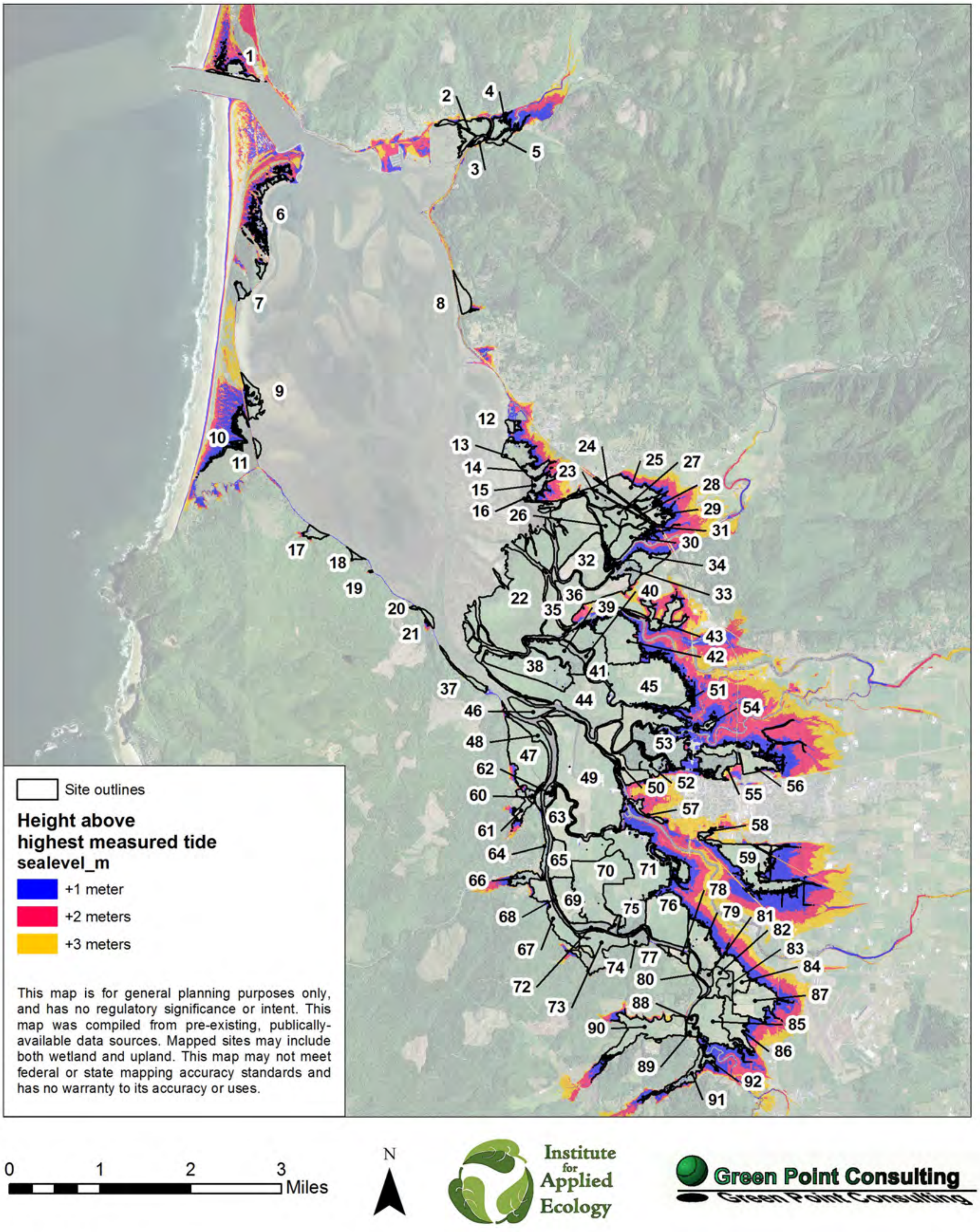
Map 13. Tidal connection status



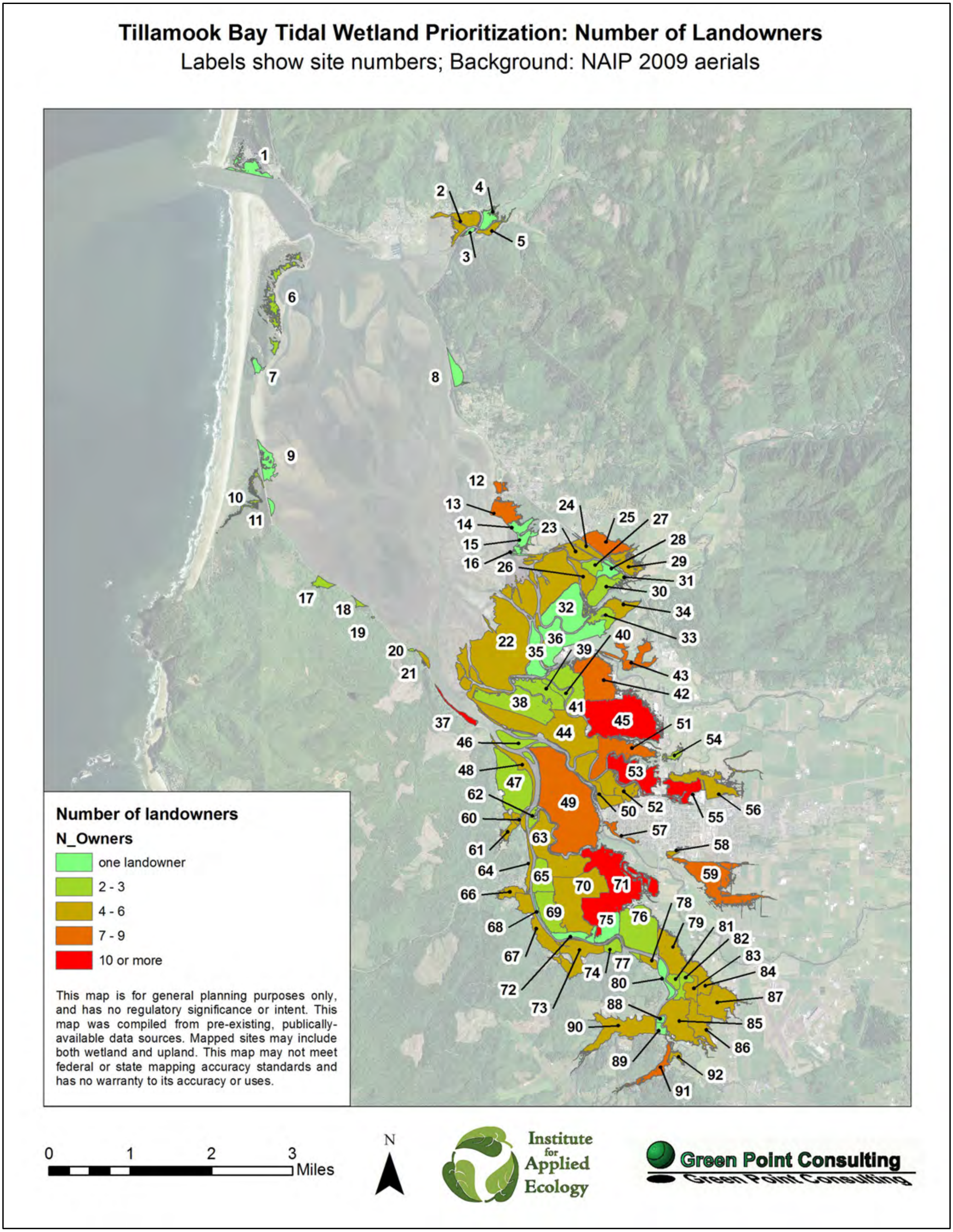
Map 14. Historic vegetation type

Tillamook Bay Tidal Wetland Prioritization: Landward migration zones for tidal wetlands

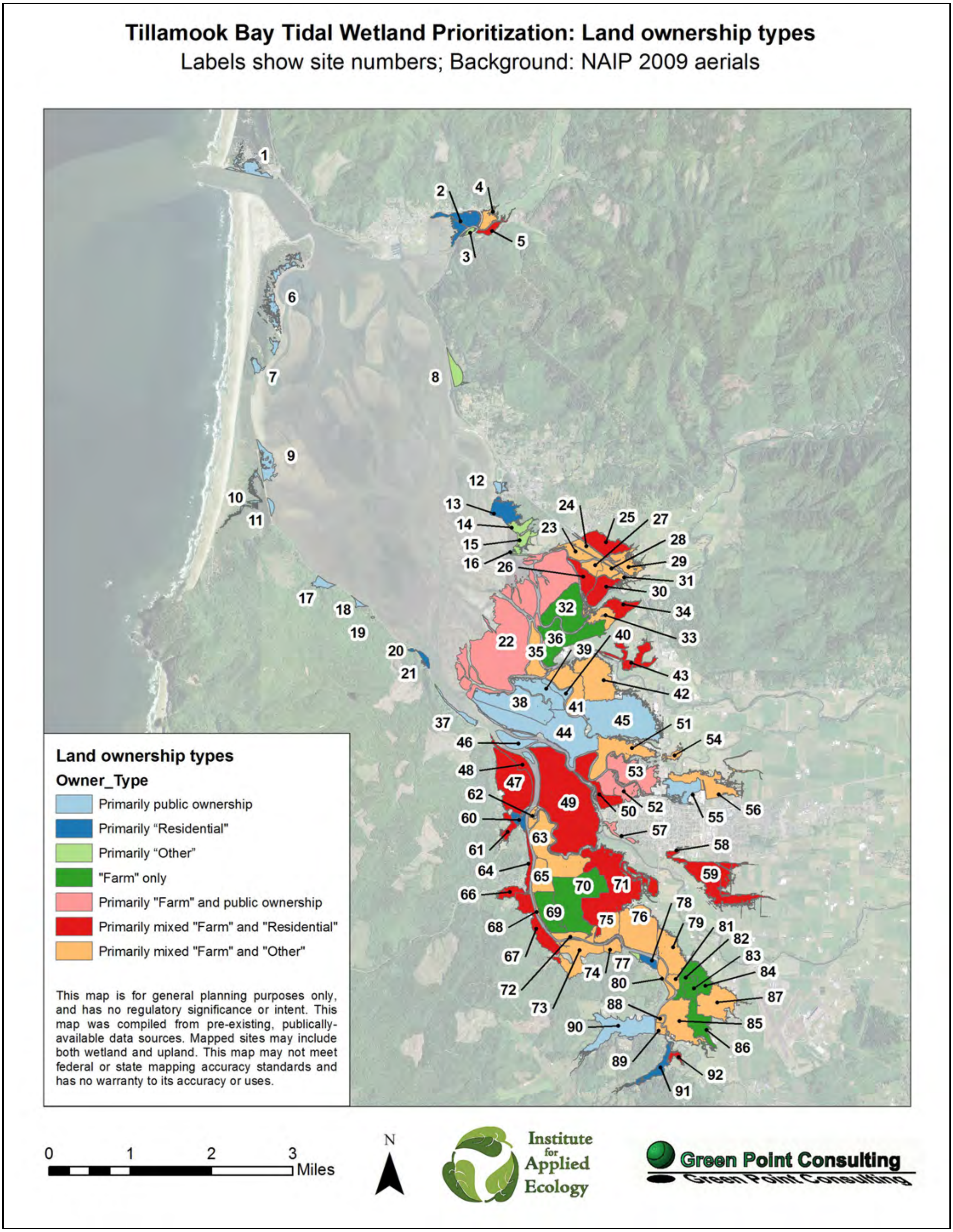
Labels show site numbers; Background: NAIP 2009 aerials



Map 15. Landward migration zones for tidal wetlands



Map 16. Number of landowners per site



Map 17. Land ownership type (per site)

Appendix 2. Additional tables

Table 1. Scores for individual prioritization criteria and total score, sorted by rank. *Note that tidal channel condition is double-weighted when calculating total score.*

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
22	5	4.5	4.26	5	1	5	29.26	High
75	1.27	4.5	2.93	4.33	4.88	5	27.41	High
41	1.58	3	4.81	5	4.81	5	27.2	High
33	1.22	5	3.43	4.33	3.77	3.67	26.42	High
40	1.11	5	4.33	3	3.99	3.67	26.1	High
7	1.05	5	1.29	5	4.84	3.67	25.85	High
53	1.61	4.5	3.22	3	4.79	3.67	25.29	High
74	1.12	3.5	2.89	4.33	4.79	5	25.13	High
72	1.17	4.5	2.96	4.33	3.93	3.67	25.06	High
20	1.01	4.5	1.27	5	5	3.67	24.95	High
39	1.39	3.5	4.31	5	2.13	5	24.83	High
48	1.21	5	3.88	5	1	3.67	24.76	High
15	1.12	5	2.6	5	1	5	24.72	High
55	1.32	5	2.03	1.67	4.67	5	24.69	High
50	1.43	2	4.37	5	4.76	5	24.56	High
23	1.17	5	3.05	4.33	1	5	24.55	High
71	2.74	1.5	4.05	4.33	4.99	5	24.11	Medium-high
49	3.53	2	5	5	2.74	3.67	23.94	Medium-high
44	2.53	2	4.62	5	2.64	5	23.79	Medium-high
26	1.23	5	3.49	4.33	1	3.67	23.72	Medium-high
46	1.32	5	4.01	5	1	2.33	23.66	Medium-high
13	1.27	5	2.05	5	1.61	3.67	23.6	Medium-high
57	1.08	2	3.43	5	4.98	5	23.49	Medium-high
52	1.38	3	3.52	3	4.52	5	23.42	Medium-high
79	1.47	2.5	2.6	4.33	4.97	5	23.37	Medium-high
14	1.11	5	2.29	5	1.13	3.67	23.2	Medium-high
76	1.87	2	3.02	4.33	4.96	5	23.18	Medium-high
38	1.85	3	4.14	5	1	5	22.99	Medium-high
91	1.19	5	1.73	3	1.96	5	22.88	Medium-high
21	1.05	4.5	1.51	5	2.63	3.67	22.86	Medium-high
6	1.27	4.5	1.38	5	1.04	5	22.69	Medium-high

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
17	1.08	4.5	1	5	1.61	5	22.69	Medium-high
43	1.3	1.5	3.4	5	4.96	5	22.66	Medium-high
18	1.02	4.5	1	5	2.94	3.67	22.63	Medium-high
9	1.19	5	1.58	5	1	3.67	22.44	Medium-high
77	1.02	3.5	2.62	4.33	5	2.33	22.3	Medium-high
34	1.22	2.5	2.97	4.33	4.95	3.67	22.14	Medium-high
11	1.03	5	1.38	5	1	3.67	22.08	Medium
37	1.08	5	2.4	5	1.23	2.33	22.04	Medium
5	1.09	5	1.16	3.67	2.42	3.67	22.01	Medium
45	2.53	2.5	4.03	1.67	5	3.67	21.9	Medium
42	1.78	1.5	4.19	3	4.92	5	21.89	Medium
90	1.67	2.5	2.09	3	4.91	5	21.67	Medium
29	1.26	4	2.63	2.33	3.73	3.67	21.62	Medium
70	2.2	1.5	3.33	4.33	4.96	3.67	21.49	Medium
68	1.03	4	3.27	4.33	1.17	3.67	21.47	Medium
60	1.09	3.5	3	4.33	1	5	21.42	Medium
64	1.1	4	3.31	4.33	1	3.67	21.41	Medium
62	1.08	4	3.27	4.33	1	3.67	21.35	Medium
2	1.31	4.5	1.16	3.67	1.18	5	21.32	Medium
16	1.04	4	2.59	5	1	3.67	21.3	Medium
3	1.02	5	1.2	3.67	3.04	2.33	21.26	Medium
56	1.53	3	2.03	1.67	5	5	21.23	Medium
27	1.13	5	2.96	2.33	1	3.67	21.09	Medium
81	1.08	2.5	1.98	3.67	4.3	5	21.03	Medium
19	1	4	1.01	5	5	1	21.01	Medium
51	1.61	2	3.82	3	4.85	3.67	20.95	Medium
1	1.18	4.5	1.05	5	1	3.67	20.9	Medium
35	1.31	3.5	4.25	5	1	2.33	20.89	Medium
4	1.12	4.5	1.14	3.67	2.17	3.67	20.77	Medium
12	1.06	3.5	1.66	5	1	5	20.72	Medium
66	1.12	2.5	2.47	4.33	2.59	5	20.51	Medium
47	1.91	2	3.51	5	1.02	5	20.44	Medium
83	1.14	2.5	1.85	3.67	4.96	3.67	20.29	Medium
69	1.44	2	3.03	4.33	3.6	3.67	20.07	Medium
36	1.74	2	4.41	5	1.22	3.67	20.04	Medium-low
92	1.05	3.5	1.61	3	4.99	2.33	19.98	Medium-low
82	1.13	2.5	1.95	3.67	4.56	3.67	19.98	Medium-low

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
73	1.53	2	2.9	4.33	4.71	2.33	19.8	Medium-low
84	1.29	2	2.03	3.67	4.93	3.67	19.59	Medium-low
87	1.56	1.5	1.71	3.67	4.56	5	19.5	Medium-low
10	1.09	3.5	1.46	5	1.04	3.67	19.26	Medium-low
78	1.07	2	2.51	4.33	5	2.33	19.24	Medium-low
30	1.3	2	3.17	4.33	1.4	5	19.2	Medium-low
54	1.06	3.5	2.05	1.67	4.97	2.33	19.08	Medium-low
63	1.89	2	4.08	4.33	2.24	2.33	18.87	Medium-low
32	1.72	2	3.86	4.33	1	3.67	18.58	Medium-low
88	1.02	4	1.75	3.67	3.09	1	18.53	Medium-low
86	1.36	1.5	1.83	3.67	4.99	3.67	18.52	Medium-low
85	1.62	2	1.9	3.67	4.98	2.33	18.5	Medium-low
8	1.15	4.5	1.42	1.67	1.4	3.67	18.31	Medium-low
80	1.13	1.5	2.32	4.33	4.3	2.33	17.41	Medium-low
61	1.11	2	2.74	3	2.85	3.67	17.37	Low
89	1.06	2.5	1.73	3.67	4.65	1	17.11	Low
58	1.02	2	2.08	1	3.78	5	16.88	Low
67	1.45	2	2.76	4.33	2	2.33	16.87	Low
31	1.04	2.5	2.49	1	3.25	3.67	16.45	Low
65	1.33	2	3.26	4.33	1.09	2.33	16.34	Low
24	1.12	2	2.91	2.33	1	3.67	15.03	Low
25	1.37	1.5	2.85	2.33	2.71	2.33	14.59	Low
59	1.91	1.5	2.32	1	1.1	5	14.33	Low
28	1.13	1.5	2.85	2.33	1	3.67	13.98	Low

Table 2. Scores for individual prioritization criteria and total score, sorted by site. *Note that tidal channel condition is double-weighted when calculating total score.*

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
1	1.18	4.5	1.05	5	1	3.67	20.9	Medium
2	1.31	4.5	1.16	3.67	1.18	5	21.32	Medium
3	1.02	5	1.2	3.67	3.04	2.33	21.26	Medium
4	1.12	4.5	1.14	3.67	2.17	3.67	20.77	Medium
5	1.09	5	1.16	3.67	2.42	3.67	22.01	Medium
6	1.27	4.5	1.38	5	1.04	5	22.69	Medium-high
7	1.05	5	1.29	5	4.84	3.67	25.85	High
8	1.15	4.5	1.42	1.67	1.4	3.67	18.31	Medium-low
9	1.19	5	1.58	5	1	3.67	22.44	Medium-high
10	1.09	3.5	1.46	5	1.04	3.67	19.26	Medium-low
11	1.03	5	1.38	5	1	3.67	22.08	Medium
12	1.06	3.5	1.66	5	1	5	20.72	Medium
13	1.27	5	2.05	5	1.61	3.67	23.6	Medium-high
14	1.11	5	2.29	5	1.13	3.67	23.2	Medium-high
15	1.12	5	2.6	5	1	5	24.72	High
16	1.04	4	2.59	5	1	3.67	21.3	Medium
17	1.08	4.5	1	5	1.61	5	22.69	Medium-high
18	1.02	4.5	1	5	2.94	3.67	22.63	Medium-high
19	1	4	1.01	5	5	1	21.01	Medium
20	1.01	4.5	1.27	5	5	3.67	24.95	High
21	1.05	4.5	1.51	5	2.63	3.67	22.86	Medium-high
22	5	4.5	4.26	5	1	5	29.26	High
23	1.17	5	3.05	4.33	1	5	24.55	High
24	1.12	2	2.91	2.33	1	3.67	15.03	Low
25	1.37	1.5	2.85	2.33	2.71	2.33	14.59	Low
26	1.23	5	3.49	4.33	1	3.67	23.72	Medium-high
27	1.13	5	2.96	2.33	1	3.67	21.09	Medium
28	1.13	1.5	2.85	2.33	1	3.67	13.98	Low
29	1.26	4	2.63	2.33	3.73	3.67	21.62	Medium
30	1.3	2	3.17	4.33	1.4	5	19.2	Medium-low
31	1.04	2.5	2.49	1	3.25	3.67	16.45	Low
32	1.72	2	3.86	4.33	1	3.67	18.58	Medium-low
33	1.22	5	3.43	4.33	3.77	3.67	26.42	High
34	1.22	2.5	2.97	4.33	4.95	3.67	22.14	Medium-high
35	1.31	3.5	4.25	5	1	2.33	20.89	Medium

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
36	1.74	2	4.41	5	1.22	3.67	20.04	Medium-low
37	1.08	5	2.4	5	1.23	2.33	22.04	Medium
38	1.85	3	4.14	5	1	5	22.99	Medium-high
39	1.39	3.5	4.31	5	2.13	5	24.83	High
40	1.11	5	4.33	3	3.99	3.67	26.1	High
41	1.58	3	4.81	5	4.81	5	27.2	High
42	1.78	1.5	4.19	3	4.92	5	21.89	Medium
43	1.3	1.5	3.4	5	4.96	5	22.66	Medium-high
44	2.53	2	4.62	5	2.64	5	23.79	Medium-high
45	2.53	2.5	4.03	1.67	5	3.67	21.9	Medium
46	1.32	5	4.01	5	1	2.33	23.66	Medium-high
47	1.91	2	3.51	5	1.02	5	20.44	Medium
48	1.21	5	3.88	5	1	3.67	24.76	High
49	3.53	2	5	5	2.74	3.67	23.94	Medium-high
50	1.43	2	4.37	5	4.76	5	24.56	High
51	1.61	2	3.82	3	4.85	3.67	20.95	Medium
52	1.38	3	3.52	3	4.52	5	23.42	Medium-high
53	1.61	4.5	3.22	3	4.79	3.67	25.29	High
54	1.06	3.5	2.05	1.67	4.97	2.33	19.08	Medium-low
55	1.32	5	2.03	1.67	4.67	5	24.69	High
56	1.53	3	2.03	1.67	5	5	21.23	Medium
57	1.08	2	3.43	5	4.98	5	23.49	Medium-high
58	1.02	2	2.08	1	3.78	5	16.88	Low
59	1.91	1.5	2.32	1	1.1	5	14.33	Low
60	1.09	3.5	3	4.33	1	5	21.42	Medium
61	1.11	2	2.74	3	2.85	3.67	17.37	Low
62	1.08	4	3.27	4.33	1	3.67	21.35	Medium
63	1.89	2	4.08	4.33	2.24	2.33	18.87	Medium-low
64	1.1	4	3.31	4.33	1	3.67	21.41	Medium
65	1.33	2	3.26	4.33	1.09	2.33	16.34	Low
66	1.12	2.5	2.47	4.33	2.59	5	20.51	Medium
67	1.45	2	2.76	4.33	2	2.33	16.87	Low
68	1.03	4	3.27	4.33	1.17	3.67	21.47	Medium
69	1.44	2	3.03	4.33	3.6	3.67	20.07	Medium
70	2.2	1.5	3.33	4.33	4.96	3.67	21.49	Medium
71	2.74	1.5	4.05	4.33	4.99	5	24.11	Medium-high
72	1.17	4.5	2.96	4.33	3.93	3.67	25.06	High
73	1.53	2	2.9	4.33	4.71	2.33	19.8	Medium-low

Site	Size score	Tidal channel condition score	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score	Ranking group
74	1.12	3.5	2.89	4.33	4.79	5	25.13	High
75	1.27	4.5	2.93	4.33	4.88	5	27.41	High
76	1.87	2	3.02	4.33	4.96	5	23.18	Medium-high
77	1.02	3.5	2.62	4.33	5	2.33	22.3	Medium-high
78	1.07	2	2.51	4.33	5	2.33	19.24	Medium-low
79	1.47	2.5	2.6	4.33	4.97	5	23.37	Medium-high
80	1.13	1.5	2.32	4.33	4.3	2.33	17.41	Medium-low
81	1.08	2.5	1.98	3.67	4.3	5	21.03	Medium
82	1.13	2.5	1.95	3.67	4.56	3.67	19.98	Medium-low
83	1.14	2.5	1.85	3.67	4.96	3.67	20.29	Medium
84	1.29	2	2.03	3.67	4.93	3.67	19.59	Medium-low
85	1.62	2	1.9	3.67	4.98	2.33	18.5	Medium-low
86	1.36	1.5	1.83	3.67	4.99	3.67	18.52	Medium-low
87	1.56	1.5	1.71	3.67	4.56	5	19.5	Medium-low
88	1.02	4	1.75	3.67	3.09	1	18.53	Medium-low
89	1.06	2.5	1.73	3.67	4.65	1	17.11	Low
90	1.67	2.5	2.09	3	4.91	5	21.67	Medium
91	1.19	5	1.73	3	1.96	5	22.88	Medium-high
92	1.05	3.5	1.61	3	4.99	2.33	19.98	Medium-low

Table 3. Key to site attributes

Fields in Table 4 (Part 1 of Site Attribute Table):

Site_ID	Final site number. Use this to refer to specific sites.
Draft_ID	Draft site identifier, used during the identification and prioritization phases of this project. Included only for reference purposes; use Site_ID to refer to sites.
HGM_CD	Hydrogeomorphic classes of wetlands within site (if any), from Scranton 2004
NWI_CD	Cowardin classes of wetlands within site, from National Wetland Inventory mapping
HVEG_CD	Historic vegetation classes of wetlands within site, from Christy *et al.* (2001). Forested lands were assumed to have been swamp (forested wetland), since all sites are within tidal range.
SIZE_SqFt	Size of site in sq. feet
SIZE_AC	Size of site in acres
SIZE_SCO	Size score (scale of 1 to 5, 5 is largest)
TID_X_SCO	Tidal exchange score (1=none, 3=restricted, 5=full)
TG_LOC_SCO	Score for location of tidal restriction (restrictive culvert, tide gate or other restriction) (1=offsite, 3=onsite, 5=no tide gate or restriction)
DITCH_SCO	Ditching score (1=heavily ditched, 3=somewhat ditched, 5=unditched)
RMCH_SCO	Remnant channel score (1=no remnant channels, 3=some, 5=many)
TCC_SUM	Tidal channel condition sum (TID_X_SCO + TG_LOC_SCO + DITCH_SCO + RMCH_SCO)
TCC_SCO	Tidal channel condition score (TCC_SUM/4)

Fields in Table 5 (Part 2 of Site Attribute Table):

WCON_SZ	Area of other wetlands within 1.0 mile buffer (Ac)
WCON_SCO	Wetland connectivity score (scale of 1 to 5)
N_STOCKS	Number of salmonid stocks using the tidal water body connected to the site
NSAL_SCO	Score for number of salmonid stocks (scale of 1 to 5)
SWMP_PCT	Percent of site that was historically swamp (forested or scrub-shrub wetland)
SWMP_SCO	Score for percent of site that was historically swamp (forested or scrub-shrub wetland) (scale of 1 to 5)
N_CWDN	Number of NWI Cowardin classes on site
CWDN_SCO	Score for number of NWI Cowardin classes on site (1 class = score of 1, 2 classes = score of 3, 3 classes = score of 5)
TOT_SCO	Sum of all 6 component scores, with tidal channel condition double-weighted: TOT_SCO = SZ_SCO + 2(TCC_SCO) + WLCN_SCO + NTYP_SCO + SWMP_SCO + CWDN_SCO
PRI_GRP	Priority group, derived from TOT_SCO using the Jenks classification method (high, medium-high, medium, medium-low, or low)
N_Owners	Number of landowners for site (grouped into 1, 2-5, and >5 landowners)
Owner_type	Landownership types present within site (city, commercial, farm, residential, county, other)
ALT_TYP	Alterations present (DIKE=dike, BRDIKE=breached dike, RD_DIKE=road acting as dike, RDKE=removed dike, CLVT=restrictive culvert or tide gate, DTCH=ditch, GRZ=grazing, DEV=peripheral development, DMD=dredged material disposal, RDRR=road/railroad crossing)

CON_STATUS	Tidal connection status, based on presence/absence of tide gates and restrictive culverts. “Fully tidal” = no tide gate or restrictive culvert; “muted tidal” = culvert without tide gate, or presence/absence of tide gate uncertain; “tides excluded” = tide gate observed in field, or tide gate mapped by Mattison or Tillamook County Creamery Association. Primary data sources: GIS data, aerial photo interpretation and site reconnaissance.
BRDIKE	Breached dike alteration? 1=Yes, 0=No. Indicates sites with breached dikes. Primary data source: Mattison (2011).
DIKE	Dike alteration? 1=Yes, 0=No. Indicates sites with dikes; includes offsite dikes affecting the site. In nearly all cases, sites with this alteration are classified as "tides excluded" or "muted tidal" in attribute "CON_STATUS." A few sites with this alteration are classified as "fully tidal;" these have internal or partial dikes that affect only a small part of the site. Primary data source: Mattison (2011).
RD_DIKE	Road acting as a dike? 1=Yes, 0=No. Identifies sites where a road is acting as a dike to exclude tides. Roads are often placed on top of built up dikes or levees. Sites with this alteration are classified as "tides excluded" or "muted tidal" in attribute "CON_STATUS." Primary data sources: GIS data, aerial photo interpretation and site reconnaissance.
DTCH	Ditching alteration? 1=Yes, 0=No. Identifies sites with ditching. Primary data sources: aerial photo interpretation and site reconnaissance.
DMD	Dredged material disposal / ditching sidecast alteration? 1=Yes, 0=No. This alteration consists of dredged material disposal or substantial sidecast berms from ditching (other than dikes). Primary data sources: GIS data, aerial photo interpretation and site reconnaissance.
GRZ	Grazing alteration? 1=Yes, 0=No. This alteration consists of current or recent grazing apparent in aerial photographs and during site reconnaissance.
DEV	Peripheral development alteration? 1=Yes, 0=No. This alteration consists of development such as houses or farm buildings at the periphery of the site. Primary data sources: aerial photo interpretation and site reconnaissance.
RDKE	Removed dike alteration? 1=Yes, 0=No. This alteration indicates sites where a dike has been deliberately removed by people (not by natural forces). Primary data sources: Mattison (2011), aerial photo interpretation.
CLVT	Culvert / tide gate alteration? 1=Yes, 0=No. Identifies sites with culverts or tide gates affecting flow. In nearly all cases, sites with this alteration are classified as "tides excluded" or "muted tidal" in attribute "CON_STATUS." A few sites with this alteration are classified as "fully tidal;" these have internal culverts that affect only a small part of the site. Primary data sources: GIS data, aerial photo interpretation and site reconnaissance.
RDRR	Road / railroad alteration? 1=Yes, 0=No. Identifies sites with roads or railroads that affect the site but do not act as dikes. Primary data sources: aerial photo interpretation and site reconnaissance.

Table 4, part 1: Site Attribute Table – size, classification, notes, tidal channel condition

Site_ID	Draft_ID	HGM_CD	NWI_CD	HVEG_CD	SIZE_SqFt	SIZE_AC	SZ_SCO	TIDE_X_SCO	TG_LOC_SCO	DITCH_SCO	RMCH_SCO	TCC_SUM	TCC_SCO
1	CL	MSH (25.3%), W (20.6%), MSL (18.4%), PF (0.1%)	E2EMP (43.1%), PEM/SSC (8%), PSSC (6.1%), PEMC (0.4%)	Water (100%)	1317951.4	30.26	1.18	5	5	3	5	18	4.50
2	A	MSL (55.5%), W (21.1%), MSH (12%), PF (8.8%), RCA (1%), F (0.9%)	E2EMN (60.8%), E2EMP (7.6%), PSSR (6.8%), PFOR (3.8%)	Water (95.6%), Swamp (4.4%)	2273262.5	52.19	1.31	3	5	5	5	18	4.50
3	B	MSL (66.3%), MSH (22.6%), PF (5%), UP (3.7%), W (2.4%)	E2EMP (63.8%)	Swamp (51%), Water (49%)	182952.3	4.20	1.02	5	5	5	5	20	5.00
4	C	RCA (84.8%), PF (11.6%), W (3.4%), F (0.2%)	PEMAd (84.2%), PFOS (6.9%), PFOR (5.7%)	Water (70.9%), Swamp (29.1%)	893139.0	20.50	1.12	5	5	5	3	18	4.50
5	D	RCA (65.1%), PF (21.4%), W (9.3%)	PEMCh (56.4%), PFOS (20.2%), PFOA (5.1%), PEMA (2.3%), PEMAd (0.4%)	Water (64.5%), Swamp (35.5%)	679913.7	15.61	1.09	5	5	5	5	20	5.00
6	E		PEMC (9.3%), PEMA (5.9%), PSSA (4.2%), PFOA (2.2%), PSSC (2.1%)	Water (99.1%), Swamp (0.9%)	1995958.6	45.82	1.27	3	5	5	5	18	4.50
7	F	MSL (17.4%), W (1.8%)	PSSA (75.7%), E2EMN (8.7%)	Swamp (96%), Water (4%)	391467.4	8.99	1.05	5	5	5	5	20	5.00
8	CA	W (82.6%), MSL (5%), F (2.9%)	E2EMN (3.7%), PFOC (2.6%)	Water (89.9%), Swamp (10.1%)	1115620.6	25.61	1.15	3	5	5	5	18	4.50
9	G	MSL (70.7%), W (8.5%), F (0.4%)	E2EMN (70.1%), PSSA (16.1%), E2EMP (11.9%), PSSR (0.1%)	Water (100%)	1420229.4	32.60	1.19	5	5	5	5	20	5.00
10	H	PF (41.5%), RCA (36.8%), W (21.1%), F (0.7%)	PSSC (46.5%), PEMC (31%), PEMF (16.3%)	Water (99.1%), Swamp (0.9%)	708848.1	16.27	1.09	1	3	5	5	14	3.50
11	I	MSL (51.3%), MSH (43.9%), F (2.9%), W (2%)	E2EMN (69.5%), E2EMP (20.1%), PSSC (10.5%)	Water (100%)	271447.3	6.23	1.03	5	5	5	5	20	5.00
12	CB	MSL (59.5%), RCA (10.8%), W (5.4%)	E2EMP (56.3%), PEMC (16%), PFOA (14.1%)	Marsh (97.8%), Water (2.2%)	422132.9	9.69	1.06	3	5	3	3	14	3.50
13	CC	PF (30.6%), MSL (30.4%), MSH (27.2%), W (8.5%), RCA (3.2%)	E2EMN (33.2%), PFOC (31.4%), E2EMP (14.3%), PEMC (7.8%), E2FOP (2.9%)	Marsh (83.4%), Swamp (15.2%), Water (1.4%)	2021776.4	46.41	1.27	5	5	5	5	20	5.00
14	CD	MSL (44.4%), PF (40.8%), MSH (9.7%), W (5.1%)	PFOC (48.9%), E2EMN (35.9%), PEMT (4%), PFO1C (0.1%)	Marsh (95.9%), Swamp (3.1%), Water (0.9%)	788030.2	18.09	1.11	5	5	5	5	20	5.00
15	CE	PF (46.4%), MSL (38%), W (6.6%), MSH (4.8%), RCA (4.1%)	PFOC (45.3%), E2EMN (42%), PEMC (4%), PEMAd (2.6%), E2EMP (2%), PSSC (0.8%), PFO1C (0.7%)	Marsh (97.5%), Water (2.4%), Swamp (0.1%)	872917.5	20.04	1.12	5	5	5	5	20	5.00
16	CF	RCA (60.6%), F (17.5%), MSL (16%), W (13.2%), PF (5%)	PEMAd (35.2%), E2EMP (27%), PEMC (26.4%), PFOC (11.4%)	Marsh (81.1%), Water (18.9%)	314055.8	7.21	1.04	5	5	5	1	16	4.00
17	AK	MSH (34.1%), MSL (29.9%), W (7.4%), RCA (1.6%)	E2EMN (74.6%), PFOS (7.8%), PEM/SSC (3.6%), PFOA (0.4%)	Water (84.6%), Swamp (15.4%)	571159.4	13.11	1.08	3	5	5	5	18	4.50
18	AL	MSL (68.3%), W (2.6%)	E2EMN (75.8%), PFOA (6.1%), PFOR (3.7%)	Water (51.5%), Swamp (48.5%)	185802.6	4.27	1.02	3	5	5	5	18	4.50
19	AM			Swamp (100%)	19368.3	0.44	1.00	3	5	5	3	16	4.00
20	AN	MSH (41.9%), W (2.6%)	E2EMP (76.5%), PFOA (15.6%)	Swamp (100%)	58875.8	1.35	1.01	3	5	5	5	18	4.50
21	CM	W (44.3%), MSL (38.3%), MSH (7.6%)	E2EMN (24.2%), E2EMP (17%), PFOR (5%)	Water (59.2%), Swamp (40.8%)	353208.3	8.11	1.05	5	5	3	5	18	4.50
22	AC	MSL (75.7%), W (13.9%), MSH (8.1%), RCA (1.9%), F (0.1%), PF (0.1%)	E2EMP (55.3%), E2EMN (35.7%), E2EM1N (2.9%), E2EM1P (2.2%), E2FOP (0.2%), PEMAdh (0.2%), PEMAd (0.1%), PFO1C (0.1%)	Water (93.2%), Marsh (6.7%)	29263589.5	671.80	5.00	5	5	3	5	18	4.50
23	BH	MSL (63.3%), PF (20.2%), W (9%), RCA (4.8%), F (2.8%)	E2EM1N (60.2%), E2SS1/FO4N (23.4%), PFO1C (6%), PEM1R (4.6%)	Water (76.5%), Marsh (23.5%)	1290171.2	29.62	1.17	5	5	5	5	20	5.00

Site_ID	Draft_ID	HGM_CD	NWI_CD	HVEG_CD	SIZE_SqFt	SIZE_AC	SZ_SCO	TIDE_X_SCO	TG_LOC_SCO	DITCH_SCO	RMCH_SCO	TCC_SUM	TCC_SCO
24	BG	RCA (83.8%), W (6.1%), F (4.3%), MSL (3.1%)	PEM1Rd (83.2%), PFO1C (2.5%)	Marsh (76.9%), Water (23.1%)	893333.6	20.51	1.12	1	3	1	3	8	2.00
25	BF	RCA (94.1%), W (5.2%), F (0.3%)	PEM1Rd (67.9%)	Marsh (57.3%), Swamp (42.6%)	2709002.9	62.19	1.37	1	1	1	3	6	1.50
26	BB	RCA (49.7%), MSH (45.8%), W (4.5%)	PEMAdh (60.1%), E2EMP (22.2%), E2EM1N (14.5%), PFOS (1.5%)	Water (54.4%), Marsh (45.6%)	1734567.7	39.82	1.23	5	5	5	5	20	5.00
27	BC	MSH (92.6%), W (4.4%), RCA (2.4%), F (0.6%)	E2EMP (50.6%), E2EM1N (41.9%), PSS1R (3.9%)	Marsh (90.3%), Water (9.7%)	933562.1	21.43	1.13	5	5	5	5	20	5.00
28	BD	RCA (94.4%), F (2.7%), W (2.4%), MSH (0.4%)	PEMAd (69.6%), PEM1R (14.2%), PSS1R (1.6%)	Marsh (100%)	944324.0	21.68	1.13	1	3	1	1	6	1.50
29	BI	RCA (89.1%), F (5.1%), W (3.1%), PF (2.7%)	PEMAd (23.8%), PSS1R (11.1%), PSSC (3.4%), PEM1Rd (0.8%)	Swamp (68.3%), Marsh (31.7%)	1885910.2	43.29	1.26	3	5	5	3	16	4.00
30	BA	RCA (97.3%), W (2.6%), F (0.1%)	PEMAdh (94.2%), PEMAd (1.5%), PFOS (1.5%), PSSC (1.4%)	Marsh (83.4%), Swamp (10.1%), Water (6.6%)	2206267.4	50.65	1.30	1	3	1	3	8	2.00
31	BE	RCA (96.5%), W (3.5%)	PEMAd (94.6%)	Swamp (56.3%), Marsh (43.7%)	315231.6	7.24	1.04	1	1	5	3	10	2.50
32	AE	MSH (92.8%), W (7.3%)	PEMCdh (94.6%), E2EMP (1.2%), PFOS (0.1%)	Marsh (65.9%), Water (34.1%)	5318490.0	122.10	1.72	1	3	1	3	8	2.00
33	BJ	PF (90.9%), MSH (4.4%), W (2.9%), RCA (1.8%)	PFOA (83.1%), PFOS (10.8%), PEMR (2%), PEMCdh (1.8%), PEMAd (0.9%), PEMAdh (0.6%)	Swamp (69.2%), Marsh (25.8%), Water (5%)	1655467.7	38.00	1.22	5	5	5	5	20	5.00
34	BK	RCA (98.8%), PF (1.2%), F (0.1%)	PEMAd (24.2%), PFOA (0.6%)	Swamp (98.7%), Marsh (1.3%)	1658193.3	38.07	1.22	1	3	3	3	10	2.50
35	AF	MSH (94.7%), W (5.3%)	E2EMP (99.2%)	Marsh (59%), Water (41%)	2303617.6	52.88	1.31	5	5	1	3	14	3.50
36	AD	RCA (94.4%), W (4.1%), PF (1.8%), F (0.1%)	PEMAdh (93.5%), PFOA (1.9%), E2EMP (1.7%), PEMCx (0.4%), PEMFx (0.2%)	Marsh (85.1%), Water (9.3%), Swamp (5.5%)	5401082.8	123.99	1.74	1	3	1	3	8	2.00
37	AO	MSL (81.3%), W (8.3%), F (2.1%)	E2EMP (76.3%)	Water (94.3%), Swamp (5.7%)	637594.2	14.64	1.08	5	5	5	5	20	5.00
38	M	RCA (79.7%), W (9.5%), PF (7.2%), F (3%), MSL (0.6%)	PEMAd (66.5%), PEMT (6.8%), PSSR (6.2%), PSSC (5.7%), PEMR (0.3%), PFOR (0.3%), PEMCx (0.2%)	Marsh (97.8%), Water (2.2%)	6209730.2	142.56	1.85	1	3	3	5	12	3.00
39	L	RCA (56.8%), PF (17.2%), MSH (11.6%), W (8.1%), F (4.4%), MSL (1.8%), RS (0.1%)	PEMAd (63.7%), PFOA (17.1%), PSSR (6.4%), PSSC (3%), PEMFx (1.1%), E2EMN (0.4%)	Marsh (63.8%), Swamp (28.2%), Water (8%)	2855398.0	65.55	1.39	3	3	3	5	14	3.50
40	K	PF (85.6%), MSH (8.2%), F (2.8%), RCA (1.9%), W (1.4%)	PFOA (92.3%), E2EMP (7.3%), PEMFx (0.2%)	Swamp (74.9%), Water (16.1%), Marsh (9%)	852716.5	19.58	1.11	5	5	5	5	20	5.00
41	J	RCA (91.2%), PF (5.4%), W (2.1%), F (0.9%), RS (0.4%)	PEMAd (85.5%), PFOA (6.6%), PFOS (3.1%), PFOR (2.1%), PSSC (0.3%)	Swamp (95.4%), Water (4.6%)	4271606.0	98.06	1.58	3	3	1	5	12	3.00
42	BQ	RCA (96.5%), W (2.9%), F (0.6%)	PEMAd (72.1%), PFOA (6.5%), PSSC (0.3%)	Swamp (98.1%), Water (1.9%)	5736553.7	131.69	1.78	1	1	1	3	6	1.50
43	BO	RCA (85.1%), PF (8.9%), W (4.8%), F (0.6%)	PEMAd (21%), PEMCd (17.2%), PEMC (10.4%), PSSC (8.4%), PFOA (4.6%), PEMCx (2.1%), PFOC (1.3%)	Swamp (98.9%), Water (1.1%)	2227264.9	51.13	1.30	1	3	1	1	6	1.50
44	N	RCA (91.9%), W (3.8%), MSH (1.7%), F (1.3%), PF (1.3%)	PEMAd (57.7%), PEMCdh (32%), PEMCx (2.1%), E2EMP (1.7%), PFOA (1.4%), PEMF (0.7%), PSSC (0.5%)	Marsh (55.9%), Swamp (40.9%), Water (3.2%)	11214954.1	257.46	2.53	1	3	1	3	8	2.00
45	BR	RCA (89.6%), F (6.6%), W (3.5%), RS (0.2%)	PEMAd (58.6%), PEMC (1.3%), PFOC (0.2%), PEMCx (0.1%)	Swamp (99.9%), Water (0.1%)	11173842.2	256.52	2.53	1	3	3	3	10	2.50
46	O	MSH (90%), W (9.6%), RCA (0.3%)	E2EMP (94.3%)	Water (79.9%), Marsh (20.1%)	2332233.5	53.54	1.32	5	5	5	5	20	5.00
47	Q	RCA (91.4%), W (5.5%), F (1.1%), PF (0.9%), MSH (0.1%)	PEMAdh (89%), PFOA (0.5%), E2EMP (0.1%)	Marsh (90.7%), Water (8.9%), Swamp (0.4%)	6649384.2	152.65	1.91	1	3	1	3	8	2.00

Site_ID	Draft_ID	HGM_CD	NWI_CD	HVEG_CD	SIZE_SqFt	SIZE_AC	SZ_SCO	TIDE_X_SCO	TG_LOC_SCO	DITCH_SCO	RMCH_SCO	TCC_SUM	TCC_SCO
48	P	MSH (88.9%), W (10.1%), RCA (0.5%)	E2EMP (83.3%), PSSR (8.4%), PEMAdh (2.3%)	Water (94.4%), Marsh (5.4%), Swamp (0.1%)	1577882.6	36.22	1.21	5	5	5	5	20	5.00
49	AB	RCA (91.4%), F (4%), W (3.7%), MSH (0.9%)	PEMAdh (59%), PEMAd (27%), PEMC (0.8%), PEMR (0.7%), PEMCx (0.3%), E2EMP (0.2%), PSSC (0.2%)	Marsh (50.6%), Swamp (43.3%), Water (6%)	18495314.8	424.59	3.53	1	3	1	3	8	2.00
50	AX	RCA (94.8%), F (2.4%), W (1.9%), PF (0.1%)	PEMAd (79.3%), PEMCx (0.4%)	Swamp (93.9%), Water (4.4%), Marsh (1.7%)	3168490.6	72.74	1.43	1	3	1	3	8	2.00
51	BN	RCA (95.4%), W (3%), F (1.5%)	PEMAd (82.9%), PSSC (0.9%)	Swamp (96.4%), Water (3.7%)	4473831.9	102.71	1.61	1	3	1	3	8	2.00
52	AY	PF (92.4%), W (6%), RCA (0.3%)	PFOA (73.2%), PSSC (17.6%), PEMFx (4.2%), PEMC (0.4%)	Swamp (87.9%), Water (12%)	2832769.2	65.03	1.38	3	3	3	3	12	3.00
53	AZ	PF (73.4%), RCA (22.4%), F (2.8%), W (1.4%)	PFOA (78.8%), PEMA (14.9%), PEMC (2.3%)	Swamp (94.8%), Water (5.2%)	4497230.2	103.24	1.61	5	5	3	5	18	4.50
54	CN	RCA (98.9%), F (0.8%), W (0.3%)	PEMA (33.3%)	Swamp (99.2%), Water (0.8%)	490975.2	11.27	1.06	5	5	3	1	14	3.50
55	BL	PF (83.8%), RCA (6.7%), W (2.8%), F (0.5%)	PFOA (86.5%), PEMAd (3.7%), PSSC (1.5%), PEMC (1%), PEMA (0.9%)	Swamp (91.9%), Marsh (4.2%), Water (4%)	2367233.0	54.34	1.32	5	5	5	5	20	5.00
56	BM	RCA (94.8%), W (2.6%), F (2%), PF (0.3%)	PEMA (14.4%), PEMAd (13.1%), PEMC (2.5%), PEMCx (0.7%)	Swamp (100%)	3859477.2	88.60	1.53	3	5	1	3	12	3.00
57	AI	RCA (90.4%)	PSSC (19.6%), PEMC (19.3%), PEMCx (8.6%), PFOCx (4.8%), PSSCx (2%)	Swamp (99.4%), Water (0.6%)	575183.0	13.20	1.08	1	3	3	1	8	2.00
58	CK	PF (69.1%), RCA (16.6%), W (13.9%), F (0.1%)	PFOC (80.2%), PEMCh (14.1%), PSSC (2.6%)	Marsh (72.3%), Swamp (27.6%)	193989.6	4.45	1.02	1	1	3	3	8	2.00
59	AA	RCA (92.5%), W (0.2%), PF (0.1%)	PEMAd (25.2%), PEMCx (3%), PEMB (0.1%)	Marsh (97.9%), Swamp (2%)	6708354.2	154.00	1.91	1	1	1	3	6	1.50
60	AG	MSH (34%), RCA (25%), F (23%), W (16.4%)	PFOA (26.3%), PEMC (15.1%), E2EMN (9.7%), PSSC (8.9%), PEMFx (2.4%)	Marsh (63.5%), Water (36.5%)	684564.5	15.72	1.09	3	5	3	3	14	3.50
61	AJ	RCA (74.9%), W (4.8%), F (1.2%)	PEMAd (30%), PEMCd (17.7%), PFOA (2.9%)	Marsh (48%), Swamp (46.3%), Water (5.7%)	849806.5	19.51	1.11	1	3	1	3	8	2.00
62	S	MSH (71.7%), F (11.5%), W (9.1%), RCA (7.7%)	E2EMP (46.2%), PSSR (13.4%), PSSC (11.7%)	Marsh (79.5%), Water (20.4%)	613563.6	14.09	1.08	5	5	3	3	16	4.00
63	T	RCA (92.7%), F (3.9%), W (3.4%)	PEMAdh (45.1%), PEMAd (40.6%), E2EMP (1.6%), PEMCx (0.9%)	Marsh (66.2%), Swamp (30.9%), Water (2.8%)	6507716.6	149.40	1.89	1	3	1	3	8	2.00
64	R	RCA (57.2%), MSH (30.1%), W (6.2%)	PEMCh (33.2%), E2EMP (25.7%), PEMAd (25.6%)	Marsh (63.3%), Water (36.7%)	767438.7	17.62	1.10	5	5	3	3	16	4.00
65	BS	RCA (96.3%), W (3.6%)	PEMAdh (88.8%), E2EMP (4.6%)	Marsh (96.1%), Swamp (2.3%), Water (1.6%)	2407170.9	55.26	1.33	1	3	1	3	8	2.00
66	BP	RCA (25.3%), W (3.4%)	PSSC (29.7%), PEMCh (27.5%), PEMAd (16.4%), PFOCh (13.7%), PEM/SSC (0.7%)	Marsh (60.3%), Swamp (39.6%)	925364.8	21.24	1.12	1	3	3	3	10	2.50
67	X	RCA (80.1%), F (4.3%), W (3%)	PEMAd (50.4%), PEMAdh (24.9%), PEMCd (1.6%), PEMCx (0.1%)	Marsh (93.7%), Water (3.2%), Swamp (3%)	3287172.7	75.46	1.45	1	3	1	3	8	2.00
68	V	RCA (98.3%), W (1.7%)	E2EMP (58.2%), PEMAdh (39.8%)	Marsh (59.6%), Water (36.1%), Swamp (4.3%)	263151.3	6.04	1.03	5	5	3	3	16	4.00
69	BT	RCA (95.2%), W (3.8%), PF (0.9%)	PEMAdh (93%), PFOAd (3.5%)	Swamp (65%), Marsh (35%)	3234342.7	74.25	1.44	1	3	1	3	8	2.00
70	BU	RCA (89.6%), PF (6.7%), W (3.8%)	PEMAd (58%), PEMAdh (25.4%), PEMA (6.9%), PFOA (5.4%), PFOCd (1.5%), PEMCx (1%), PEMF (0.2%)	Swamp (99%), Marsh (1%)	8774354.9	201.43	2.20	1	1	1	3	6	1.50

Site_ID	Draft_ID	HGM_CD	NWI_CD	HVEG_CD	SIZE_SqFt	SIZE_AC	SZ_SCO	TIDE_X_SCO	TG_LOC_SCO	DITCH_SCO	RMCH_SCO	TCC_SUM	TCC_SCO
71	U	RCA (93.8%), F (3.8%), W (2.1%), PF (0.1%)	PEMAd (77.7%), PEMC (1.2%), PSSC (0.6%), PEMCx (0.5%), PEMAdh (0.1%)	Swamp (99.6%), Marsh (0.3%)	12726229.8	292.15	2.74	1	1	1	3	6	1.50
72	AH	PF (65.7%), W (17.3%), RS (8.8%), RCA (8.2%)	PEM/SSR (55%), PEMT (9.2%), PEMR (8.6%), PEMAd (6.8%)	Swamp (73.4%), Water (26.6%)	1234857.8	28.35	1.17	5	5	3	5	18	4.50
73	Y	RCA (88.1%), W (4.2%), F (3.2%), RS (1.9%)	PEMCd (54.3%), PEMAd (37%)	Marsh (80.9%), Swamp (18%), Water (1.1%)	3864741.7	88.72	1.53	1	3	1	3	8	2.00
74	Z	RCA (24.9%), RS (6.3%), F (5.2%), W (1.1%)	PFOA (51.8%), PEMC (18%), PSSC (9%), PEMAd (0.2%)	Marsh (90.4%), Water (5.2%), Swamp (4.4%)	881900.9	20.25	1.12	1	3	5	5	14	3.50
75	W	PF (85.6%), RCA (14.2%), W (0.2%)	PSSC (53%), PFOA (42.7%), PEMC (3.6%), PEMAd (0.6%)	Swamp (97.1%), Water (2.9%)	2017198.5	46.31	1.27	3	5	5	5	18	4.50
76	BV	RCA (96.8%), W (3%), F (0.1%)	PEMAdh (94%)	Swamp (99.1%), Water (0.9%)	6398470.2	146.89	1.87	1	3	1	3	8	2.00
77	AP	RCA (8.3%), F (2.1%)		Swamp (71.3%), Marsh (28.7%)	182671.3	4.19	1.02	1	3	5	5	14	3.50
78	AQ	RCA (95%), F (1.1%)	PEMAdh (88.5%)	Swamp (100%)	555768.7	12.76	1.07	1	3	1	3	8	2.00
79	BW	RCA (96.9%), F (1.7%), W (1.3%)	PEMAd (43.7%), PSSC (6.5%), PEMA (2.2%), PEMC (2.1%), PFOA (1.5%), PEMCx (1.3%)	Swamp (99.2%), Water (0.8%)	3482569.9	79.95	1.47	1	3	1	5	10	2.50
80	AR	RCA (56.4%), RS (33.1%), PF (2.9%), W (1.3%)	PEMAdh (61.4%), PEMCdh (31.3%)	Swamp (82.6%), Water (17.4%)	949508.2	21.80	1.13	1	3	1	1	6	1.50
81	BX	RCA (91.4%), W (8.6%)	PFO/EMA (91.7%), PEMR (3.7%)	Swamp (82.6%), Water (17.4%)	613056.6	14.07	1.08	1	3	3	3	10	2.50
82	CG	RCA (85.4%), PF (9.5%), W (5.1%)	PEMA (54.5%), PEMAd (33.4%), PFOA (9.9%)	Swamp (89.1%), Water (10.9%)	992307.8	22.78	1.13	1	3	3	3	10	2.50
83	BZ	PF (80.8%), RCA (13.6%), W (5.6%)	PFOA (66.1%), PEMC (28%), PFOAd (0.6%)	Swamp (99.1%), Water (0.9%)	1070363.5	24.57	1.14	1	1	3	5	10	2.50
84	BY	RCA (97.3%), W (1.3%), PF (1%), F (0.4%)	PFOAd (1.1%), PEMCx (0.8%), PFOA (0.5%)	Swamp (98.2%), Water (1.9%)	2160464.5	49.60	1.29	1	1	3	3	8	2.00
85	CH	RCA (99.3%), F (0.7%), W (0.1%)	PEMAd (28.8%), PEMCx (0.9%)	Swamp (99.5%), Water (0.5%)	4526453.0	103.91	1.62	1	3	1	3	8	2.00
86	CI	RCA (96.5%), W (2.9%)	PEMAd (23.6%), PEMC (3.6%), PEMCx (2.6%)	Swamp (99.7%), Marsh (0.3%)	2676361.3	61.44	1.36	1	1	1	3	6	1.50
87	CJ	RCA (92.5%), PF (5.7%), W (1.5%), F (0.1%)	PEMAd (68.1%), PFOAd (6.1%), PEMCx (1.9%), PSSC (1.2%)	Swamp (89.2%), Marsh (10.9%)	4097962.8	94.08	1.56	1	1	1	3	6	1.50
88	AT	RCA (56.4%), RS (23.5%), W (20.1%)		Swamp (52.4%), Water (47.6%)	180138.9	4.14	1.02	5	5	5	1	16	4.00
89	AU	RCA (94.1%), W (4.5%)		Swamp (91.4%), Water (8.6%)	424767.4	9.75	1.06	1	3	3	3	10	2.50
90	AS	RCA (83.3%), W (4.7%), PF (2.3%), F (0.3%)	PEMAd (74.3%), PEMCx (1.6%), PSSC (1.5%), PEMC (0.3%), PFOC (0.1%)	Swamp (97.6%), Marsh (2.4%)	4947237.5	113.57	1.67	1	3	3	3	10	2.50
91	AV	PF (85.1%), RCA (3%), W (3%), F (1%)	PSSC (43.5%), PFOA (31%), PFOC (10%), PEMC (1.1%)	Marsh (74.9%), Swamp (24.1%), Water (0.9%)	1405739.7	32.27	1.19	5	5	5	5	20	5.00
92	AW	RCA (89.5%), F (7.6%)	PEMA (27.2%), PEMC (24.4%)	Swamp (99.6%), Marsh (0.4%)	391477.6	8.99	1.05	3	5	3	3	14	3.50

Table 4, part 2: Site Attribute Table – scoring, ownership, alterations

Site_ID	WCON_SZ	WCON_SCO	NSTOCKS	NSAL_SCO	SWMP_PCT	SWMP_SCO	N_CWDN	CWDN_SCO	TOT_SCO	PRI_GRP	N_Owners	Owner_Type	ALT_TYPE	CON_STATUS	BRDIKE	DIKE	RD_DIKE	DTCH	DMD	GRZ	DEV	RDKE	CLVT	RDRR
1	10.30	1.05	6	5.00	0.00	1.00	2	3.67	20.90	Medium	1	County, Other	DIKE, DTCH	Fully tidal	0	1	0	1	0	0	0	0	0	0
2	20.95	1.16	4	3.67	4.43	1.18	3	5.00	21.32	Medium	5	Residential, Other, Commercial	CLVT, RDRR, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	1	1
3	24.29	1.20	4	3.67	50.98	3.04	1	2.33	21.26	Medium	1	Other	RDRR, DIKE	Fully tidal	0	0	0	0	0	0	0	0	0	1
4	18.43	1.14	4	3.67	29.13	2.17	2	3.67	20.77	Medium	1	Farm, Other	GRZ, BRDIKE	Fully tidal	1	0	0	0	0	1	0	1	0	0
5	20.41	1.16	4	3.67	35.52	2.42	2	3.67	22.01	Medium	5	Farm, Residential, State, Other, Forest	BRDIKE, GRZ	Fully tidal	1	0	0	0	0	1	0	1	0	0
6	42.09	1.38	6	5.00	0.92	1.04	3	5.00	22.69	Medium-high	2	County, Other	RDRR, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	0	1
7	33.45	1.29	6	5.00	95.97	4.84	2	3.67	25.85	High	1	County, Other		Fully tidal	0	0	0	0	0	0	0	0	0	0
8	46.10	1.42	1	1.67	10.06	1.40	2	3.67	18.31	Medium-low	1	Other	RDRR, CLVT, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	1	1
9	61.25	1.58	6	5.00	0.00	1.00	2	3.67	22.44	Medium-high	1	County, Other	DMD	Fully tidal	0	0	0	0	1	0	0	0	0	0
10	49.77	1.46	6	5.00	0.94	1.04	2	3.67	19.26	Medium-low	2	County, Other	RDRR, RD_DIKE	Tides excluded	0	1	1	0	0	0	0	0	1	1
11	42.37	1.38	6	5.00	0.00	1.00	2	3.67	22.08	Medium	1	County, Other		Fully tidal	0	0	0	0	0	0	0	0	0	0
12	69.06	1.66	6	5.00	0.00	1.00	3	5.00	20.72	Medium	8	City, Other, Residential	DTCH, CLVT, RDRR, DEV, RD_DIKE	Muted tidal	0	0	1	1	0	0	1	0	1	1
13	107.16	2.05	6	5.00	15.25	1.61	2	3.67	23.60	Medium-high	8	Residential, Other, Forest	BRDIKE	Fully tidal	1	0	0	0	0	0	0	0	0	0
14	129.98	2.29	6	5.00	3.16	1.13	2	3.67	23.20	Medium-high	1	Other	BRDIKE	Fully tidal	1	0	0	0	0	0	0	0	0	0
15	160.39	2.60	6	5.00	0.07	1.00	3	5.00	24.72	High	1	Other	BRDIKE, RDRR	Fully tidal	1	0	0	0	0	0	0	0	0	1
16	159.05	2.59	6	5.00	0.00	1.00	2	3.67	21.30	Medium	1	Other	BRDIKE, GRZ	Fully tidal	1	0	0	0	0	1	0	0	0	0
17	5.73	1.00	6	5.00	15.37	1.61	3	5.00	22.69	Medium-high	2	County, Other, Forest	CLVT, RDRR, DMD, RD_DIKE	Muted tidal	0	0	1	0	1	0	0	0	1	1
18	5.29	1.00	6	5.00	48.46	2.94	2	3.67	22.63	Medium-high	3	County, Residential, Other, Forest	CLVT, RDRR, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	1	1
19	6.24	1.01	6	5.00	100.00	5.00	0	1.00	21.01	Medium	2	Other	CLVT, RDRR, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	1	1
20	31.34	1.27	6	5.00	100.00	5.00	2	3.67	24.95	High	2	Residential, Other, Forest	CLVT, RDRR, RD_DIKE	Muted tidal	0	0	1	0	0	0	0	0	1	1
21	54.30	1.51	6	5.00	40.76	2.63	2	3.67	22.86	Medium-high	4	Residential, Other, Forest	DTCH, RDRR, CLVT, DEV	Fully tidal	0	0	0	1	0	0	1	0	1	1
22	320.76	4.26	6	5.00	0.00	1.00	3	5.00	29.26	High	4	Farm, County, Other	BRDIKE, DMD, DTCH	Fully tidal	1	0	0	1	1	0	0	0	0	0
23	203.67	3.05	5	4.33	0.00	1.00	3	5.00	24.55	High	4	Farm, Other		Fully tidal	0	0	0	0	0	0	0	0	0	0
24	189.72	2.91	2	2.33	0.00	1.00	2	3.67	15.03	Low	4	Farm, Other	DIKE, CLVT, DTCH, GRZ	Tides excluded	0	1	0	1	0	1	0	0	1	0
25	184.40	2.85	2	2.33	42.63	2.71	1	2.33	14.59	Low	7	Farm, Residential, Other	CLVT, DTCH, DIKE, GRZ, RDRR, DMD	Tides excluded	0	1	0	1	1	1	0	0	1	1
26	246.16	3.49	5	4.33	0.00	1.00	2	3.67	23.72	Medium-high	5	Farm, Residential, Other	GRZ	Fully tidal	0	0	0	0	0	1	0	0	0	0
27	194.54	2.96	2	2.33	0.00	1.00	2	3.67	21.09	Medium	3	Farm, Other	GRZ	Fully tidal	0	0	0	0	0	1	0	0	0	0
28	184.16	2.85	2	2.33	0.00	1.00	2	3.67	13.98	Low	1	Farm, Other	CLVT, GRZ, DTCH, DIKE, RDRR, RD_DIKE	Tides excluded	0	1	1	1	0	1	0	0	1	1
29	162.68	2.63	2	2.33	68.32	3.73	2	3.67	21.62	Medium	6	Farm, Other	GRZ, DEV, RDRR, CLVT	Muted tidal	0	0	0	1	0	1	1	0	1	1

Site_ID	WCON_SZ	WCON_SCO	NSTOCKS	NSAL_SCO	SWMP_PCT	SWMP_SCO	N_CWDN	CWDN_SCO	TOT_SCO	PRI_GRP	N_Owners	Owner_Type	ALT_TYPE	CON_STATUS	BRDIKE	DIKE	RD_DIKE	DTCH	DMD	GRZ	DEV	RDKE	CLVT	RDRR
30	215.37	3.17	5	4.33	10.05	1.40	3	5.00	19.20	Medium-low	3	Farm, Residential, Other	DIKE, CLVT, DTCH, GRZ	Tides excluded	0	1	0	1	0	1	0	0	1	0
31	149.22	2.49	0	1.00	56.32	3.25	2	3.67	16.45	Low	2	Farm, Other	GRZ, CLVT, RDRR	Tides excluded	0	0	0	0	0	1	0	0	1	1
32	281.85	3.86	5	4.33	0.00	1.00	2	3.67	18.58	Medium-low	1	Farm	DIKE, CLVT, GRZ, DTCH, RDRR	Tides excluded	0	1	0	1	0	1	0	0	1	1
33	240.72	3.43	5	4.33	69.22	3.77	2	3.67	26.42	High	2	Farm, Other		Fully tidal	0	0	0	0	0	0	0	0	0	0
34	195.81	2.97	5	4.33	98.72	4.95	2	3.67	22.14	Medium-high	5	Farm, Residential	GRZ, CLVT, DIKE, DMD, DTCH	Tides excluded	0	1	0	1	1	1	0	0	1	0
35	320.03	4.25	6	5.00	0.00	1.00	1	2.33	20.89	Medium	1	Farm, Other	DTCH, GRZ, CLVT, DIKE	Fully tidal	0	1	0	1	0	1	0	0	1	0
36	335.51	4.41	6	5.00	5.54	1.22	2	3.67	20.04	Medium-low	1	Farm	CLVT, DIKE, DTCH, GRZ	Tides excluded	0	1	0	1	0	1	0	0	1	0
37	140.34	2.40	6	5.00	5.71	1.23	1	2.33	22.04	Medium	20	County, Residential, Other	DEV	Fully tidal	0	0	0	0	0	0	1	0	0	0
38	309.39	4.14	6	5.00	0.00	1.00	3	5.00	22.99	Medium-high	3	County, Farm, Other	CLVT, DIKE, DMD, DTCH, GRZ, RDRR	Tides excluded	0	1	0	1	1	1	0	0	1	1
39	325.27	4.31	6	5.00	28.22	2.13	3	5.00	24.83	High	2	County, Residential, Other	CLVT, DIKE, DMD, DTCH, GRZ	Muted tidal	0	1	0	1	1	1	0	0	1	0
40	327.02	4.33	3	3.00	74.86	3.99	2	3.67	26.10	High	2	County, Residential	DIKE	Fully tidal	0	1	0	0	0	0	0	0	0	0
41	374.03	4.81	6	5.00	95.37	4.81	3	5.00	27.20	High	3	Farm, Other	DTCH, BRDIKE, DIKE, GRZ, CLVT, DEV	Muted tidal	1	1	0	1	0	1	1	0	1	0
42	313.57	4.19	3	3.00	98.12	4.92	3	5.00	21.89	Medium	9	Farm, Other	CLVT, DIKE, GRZ, DTCH, RDRR	Tides excluded	0	1	0	1	0	1	0	0	1	1
43	237.16	3.40	6	5.00	98.94	4.96	3	5.00	22.66	Medium-high	7	Farm, Residential, Other, Commercial	CLVT, GRZ, DTCH, DMD	Tides excluded	0	0	0	1	1	1	0	0	1	0
44	355.52	4.62	6	5.00	40.93	2.64	3	5.00	23.79	Medium-high	4	County, Farm, Other	DIKE, DTCH, CLVT, GRZ, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	0
45	298.20	4.03	1	1.67	99.93	5.00	2	3.67	21.90	Medium	13	City, Commercial, Farm, Residential, County, Other	GRZ, CLVT, DIKE, DTCH, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	0
46	296.73	4.01	6	5.00	0.00	1.00	1	2.33	23.66	Medium-high	2	County, Other	RDKE	Fully tidal	0	0	0	0	0	0	0	1	0	0
47	248.26	3.51	6	5.00	0.43	1.02	3	5.00	20.44	Medium	3	Farm, Residential, Other	CLVT, DIKE, DTCH, GRZ, RDRR, RD_DIKE	Tides excluded	0	1	1	1	0	1	0	0	1	1
48	284.03	3.88	6	5.00	0.11	1.00	2	3.67	24.76	High	5	Farm, Residential, Other, County		Fully tidal	0	0	0	0	0	0	0	0	0	0
49	392.26	5.00	6	5.00	43.42	2.74	2	3.67	23.94	Medium-high	8	Farm, Residential, Other, Commercial	CLVT, DIKE, DTCH, GRZ, DEV, RDRR	Tides excluded	0	1	0	1	0	1	1	0	1	1
50	331.18	4.37	6	5.00	93.90	4.76	3	5.00	24.56	High	4	Farm, Residential, Other, Commercial	CLVT, DIKE, DTCH, GRZ, RDRR	Tides excluded	0	1	0	1	0	1	0	0	1	1
51	277.98	3.82	3	3.00	96.35	4.85	2	3.67	20.95	Medium	7	Farm, Other, Commercial	GRZ, CLVT, DIKE, DTCH, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	0
52	249.44	3.52	3	3.00	88.01	4.52	3	5.00	23.42	Medium-high	6	Farm, City, Other, Commercial, Residential	DIKE, CLVT, DTCH	Muted tidal	0	1	0	1	0	0	0	0	1	0
53	220.41	3.22	3	3.00	94.81	4.79	2	3.67	25.29	High	12	Farm, City, Other, Commercial, Residential	BRDIKE, DIKE, DTCH, GRZ	Fully tidal	1	1	0	1	0	1	0	0	0	0
54	106.53	2.05	1	1.67	99.17	4.97	1	2.33	19.08	Medium-low	3	Farm, Other, Commercial	GRZ, DTCH	Fully tidal	0	0	0	1	0	1	0	0	0	0
55	105.36	2.03	1	1.67	91.87	4.67	3	5.00	24.69	High	12	City, Commercial, Farm, Residential, County, Other	CLVT, DEV	Fully tidal	0	0	0	0	0	0	1	0	1	0
56	104.78	2.03	1	1.67	100.00	5.00	3	5.00	21.23	Medium	6	Farm, Other, Commercial	GRZ, DTCH, RDRR, CLVT, DMD	Muted tidal	0	0	0	1	1	1	0	0	1	1
57	240.40	3.43	6	5.00	99.39	4.98	3	5.00	23.49	Medium-high	7	Farm, City, Other, Residential	CLVT, GRZ, DEV, RDRR, DTCH	Tides excluded	0	0	0	1	0	1	1	0	1	1

Site_ID	WCON_SZ	WCON_SCO	NSTOCKS	NSAL_SCO	SWMP_PCT	SWMP_SCO	N_CWDN	CWDN_SCO	TOT_SCO	PRI_GRP	N_Owners	Owner_Type	ALT_TYPE	CON_STATUS	BRDIKE	DIKE	RD_DIKE	DTCH	DMD	GRZ	DEV	RDKE	CLVT	RDRR
58	109.36	2.08	0	1.00	69.39	3.78	3	5.00	16.88	Low	5	Farm, Residential, School, Other, City	CLVT, DEV, DTCH, RDRR	Tides excluded	0	0	0	1	0	0	1	0	1	1
59	132.64	2.32	0	1.00	2.44	1.10	3	5.00	14.33	Low	8	Farm, Residential, School, Other	CLVT, DTCH, GRZ, RDRR	Tides excluded	0	0	0	1	0	1	0	0	1	1
60	198.90	3.00	5	4.33	0.00	1.00	3	5.00	21.42	Medium	6	Residential, State, Other, Commercial, Forest	DIKE, DMD, DTCH, DEV, CLVT, RDRR, RD_DIKE	Muted tidal	0	1	1	1	1	0	1	0	1	1
61	173.37	2.74	3	3.00	46.28	2.85	2	3.67	17.37	Low	5	Farm, Residential, Other, Forest	DIKE, DTCH, GRZ, CLVT, RDRR, RD_DIKE	Tides excluded	0	1	1	1	0	1	0	0	1	1
62	224.80	3.27	5	4.33	0.00	1.00	2	3.67	21.35	Medium	3	Farm, Other, Commercial	DIKE, DEV, DTCH, RDRR	Fully tidal	0	1	0	1	0	0	1	0	0	1
63	303.40	4.08	5	4.33	30.95	2.24	1	2.33	18.87	Medium-low	4	Farm, Other	CLVT, DIKE, DTCH, GRZ, DEV	Tides excluded	0	1	0	1	0	1	1	1	1	0
64	229.02	3.31	5	4.33	0.00	1.00	2	3.67	21.41	Medium	5	Farm, Residential, State, Other	DTCH, BRDIKE, DMD	Fully tidal	1	0	0	1	1	0	0	0	0	0
65	224.08	3.26	5	4.33	2.28	1.09	1	2.33	16.34	Low	3	Farm, Other	CLVT, DIKE, DTCH, GRZ, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	0
66	147.02	2.47	5	4.33	39.65	2.59	3	5.00	20.51	Medium	5	Farm, Residential, Other, Forest	CLVT, DIKE, RDRR, DTCH	Tides excluded	0	1	0	1	0	0	0	0	1	1
67	175.35	2.76	5	4.33	24.96	2.00	1	2.33	16.87	Low	6	Farm, Residential, Other, Forest	CLVT, DIKE, DTCH, GRZ, RDRR, DEV, RD_DIKE	Tides excluded	0	1	1	1	0	1	1	0	1	1
68	225.20	3.27	5	4.33	4.27	1.17	2	3.67	21.47	Medium	1	Farm, Other	DTCH	Fully tidal	0	0	0	1	0	0	0	0	0	0
69	202.15	3.03	5	4.33	65.03	3.60	2	3.67	20.07	Medium	3	Farm	CLVT, DIKE, DTCH, GRZ	Tides excluded	0	1	0	1	0	1	0	0	1	0
70	230.90	3.33	5	4.33	98.99	4.96	2	3.67	21.49	Medium	5	Farm	CLVT, GRZ, DIKE, DTCH, RDRR	Tides excluded	0	1	0	1	0	1	0	0	1	1
71	300.52	4.05	5	4.33	99.66	4.99	3	5.00	24.11	Medium-high	14	Farm, Residential, Other	DTCH, GRZ, CLVT, DIKE, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	0
72	194.99	2.96	5	4.33	73.36	3.93	2	3.67	25.06	High	1	Farm, Other	DTCH, CLVT	Fully tidal	0	0	0	1	0	0	0	0	1	0
73	189.17	2.90	5	4.33	92.63	4.71	1	2.33	19.80	Medium-low	6	Farm, Other, Forest	DTCH, GRZ, CLVT, DIKE, RDRR, RDKE, DMD, DEV, RD_DIKE	Tides excluded	0	1	1	1	1	1	1	1	1	1
74	188.10	2.89	5	4.33	94.78	4.79	3	5.00	25.13	High	3	Farm, Other, Forest	CLVT, DIKE, RDRR, GRZ, RD_DIKE	Tides excluded	0	1	1	0	0	1	0	0	1	1
75	191.91	2.93	5	4.33	97.08	4.88	3	5.00	27.41	High	1	Farm, Other	CLVT, DIKE	Muted tidal	0	1	0	0	0	0	0	0	1	0
76	200.44	3.02	5	4.33	99.10	4.96	3	5.00	23.18	Medium-high	3	Farm, Other	CLVT, DIKE, DTCH, GRZ, DMD	Tides excluded	0	1	0	1	1	1	0	0	1	0
77	161.59	2.62	5	4.33	100.00	5.00	1	2.33	22.30	Medium-high	3	Other, Forest	CLVT, DIKE, RDRR, RD_DIKE	Tides excluded	0	1	1	0	0	0	0	0	1	1
78	151.71	2.51	5	4.33	100.00	5.00	1	2.33	19.24	Medium-low	4	Residential, Other	CLVT, GRZ, DTCH, DIKE, RDRR, DMD, RD_DIKE	Tides excluded	0	1	1	1	1	1	0	0	1	1
79	160.30	2.60	5	4.33	99.16	4.97	3	5.00	23.37	Medium-high	5	Farm, Other	CLVT, DIKE, DTCH, GRZ, RDRR, DMD, RD_DIKE	Tides excluded	0	1	1	1	1	1	0	0	1	1
80	132.56	2.32	5	4.33	82.59	4.30	1	2.33	17.41	Medium-low	1	Farm, Other	CLVT, DIKE, GRZ, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
81	100.42	1.98	4	3.67	82.59	4.30	3	5.00	21.03	Medium	2	Farm, Other	CLVT, DIKE, DMD, DTCH, GRZ	Tides excluded	0	1	0	1	1	1	0	0	1	0
82	97.37	1.95	4	3.67	89.11	4.56	2	3.67	19.98	Medium-low	3	Farm	CLVT, GRZ, DIKE, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
83	87.32	1.85	4	3.67	99.10	4.96	2	3.67	20.29	Medium	4	Farm	CLVT, DIKE, GRZ, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
84	104.50	2.03	4	3.67	98.14	4.93	2	3.67	19.59	Medium-low	5	Farm	CLVT, DIKE, GRZ, DTCH, RDRR	Tides excluded	0	1	0	1	0	1	0	0	1	1

Site_ID	WCON_SZ	WCON_SCO	NSTOCKS	NSAL_SCO	SWMP_PCT	SWMP_SCO	N_CWDN	CWDN_SCO	TOT_SCO	PRI_GRP	N_Owners	Owner_Type	ALT_TYPE	CON_STATUS	BRDIKE	DIKE	RD_DIKE	DTCH	DMD	GRZ	DEV	RDKE	CLVT	RDRR
85	92.54	1.90	4	3.67	99.47	4.98	1	2.33	18.50	Medium-low	4	Farm, Other	CLVT, DIKE, DTCH, GRZ, RDRR, DEV	Tides excluded	0	1	0	1	0	1	1	0	1	1
86	85.30	1.83	4	3.67	99.72	4.99	2	3.67	18.52	Medium-low	6	Farm	CLVT, DIKE, DTCH, GRZ	Tides excluded	0	1	0	1	0	1	0	0	1	0
87	74.35	1.71	4	3.67	89.12	4.56	3	5.00	19.50	Medium-low	6	Farm, Other	CLVT, DIKE, GRZ, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
88	77.60	1.75	4	3.67	52.37	3.09	0	1.00	18.53	Medium-low	1	Farm, Other	GRZ, DIKE	Fully tidal	0	1	0	0	0	1	0	0	0	0
89	75.71	1.73	4	3.67	91.35	4.65	0	1.00	17.11	Low	1	Farm, Other	CLVT, DIKE, GRZ, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
90	110.64	2.09	3	3.00	97.63	4.91	3	5.00	21.67	Medium	6	County, Other, Forest	CLVT, GRZ, DIKE, DTCH	Tides excluded	0	1	0	1	0	1	0	0	1	0
91	75.70	1.73	3	3.00	24.11	1.96	3	5.00	22.88	Medium-high	9	Residential, Other, Forest	RDRR	Fully tidal	0	0	0	0	0	0	0	0	0	1
92	64.28	1.61	3	3.00	99.63	4.99	1	2.33	19.98	Medium-low	6	Farm, Residential, Forest	GRZ, RDRR, DTCH, DEV, RD_DIKE	Muted tidal	0	1	1	1	0	1	1	0	1	1

Table 5: Zoning information (area)

	Area (acres)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
1				27.7					0.8		1.7	30.3
2		18.7					0.4			33.0		52.2
3		3.7								0.5		4.2
4	20.5											20.5
5	15.6											15.6
6				41.8	4.0							45.8
7				7.7							1.2	9.0
8		8.6	1.3					11.8		3.9		25.6
9											32.6	32.6
10				12.9							3.3	16.3
11											6.2	6.2
12										9.7		9.7
13			3.8							41.4	1.2	46.4
14			16.8							0.4	0.9	18.1
15			18.7								1.3	20.0
16			5.5								1.7	7.2
17			13.1									13.1
18			0.3					0.6			3.3	4.3
19								0.4				0.4
20			1.4									1.4
21			1.8								6.3	8.1
22	6.4		0.0					0.0			665.3	671.8
23	18.9							3.0			7.7	29.6
24	20.5							0.0				20.5
25	62.0							0.2				62.2
26	24.4										15.4	39.8
27	19.5										1.9	21.4
28	21.7											21.7
29	43.3											43.3
30	50.7											50.7
31	7.2											7.2
32	59.2										62.9	122.1
33	38.0											38.0
34	37.7		0.3									38.1
35	1.0										51.9	52.9
36	112.9										11.1	124.0
37			8.4								6.3	14.6

	Area (acres)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
38	126.3										16.3	142.6
39	54.5										11.1	65.6
40	19.6										0.0	19.6
41	97.9										0.2	98.1
42	131.7											131.7
43	49.6		1.6									51.1
44	247.4										10.0	257.4
45	239.3							1.6		15.6		256.5
46	0.4										53.2	53.5
47	133.4		2.2					0.4			16.7	152.7
48	17.6										18.6	36.2
49	408.1					10.6					6.0	424.6
50	60.0									12.7		72.7
51	98.6									4.2		102.7
52	10.4							2.0		52.7		65.0
53	39.6							33.9		29.8		103.2
54	8.6									2.7		11.3
55	33.9									20.4		54.3
56	87.9									0.7		88.6
57	0.7									12.5		13.2
58	1.0									3.4		4.5
59	153.5							0.0		0.5		154.0
60	15.7							0.0				15.7
61	14.0		0.0					5.5				19.5
62	3.7					10.4		0.0				14.1
63	145.4					4.0		0.0				149.4
64	13.8							3.8				17.6
65	55.3											55.3
66	1.3		20.0									21.2
67	68.0		7.5									75.5
68	6.0											6.0
69	74.3											74.3
70	201.4											201.4
71	292.2							0.0				292.2
72	28.4											28.4
73	71.6		17.1									88.7
74	7.0		13.3									20.2
75	46.3		0.0									46.3
76	146.5		0.4									146.9
77	1.5		2.7									4.2

	Area (acres)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
78	6.8		6.0									12.8
79	80.0											80.0
80	21.2		0.6									21.8
81	14.1											14.1
82	22.8											22.8
83	24.6											24.6
84	49.4							0.2				49.6
85	103.9											103.9
86	61.4											61.4
87	92.9				1.2							94.1
88	4.1											4.1
89	9.8											9.8
90	113.2		0.4									113.6
91	4.2							28.0				32.3
92	9.0											9.0

Table 6: Zoning information (proportion of site)

	Area (% of site)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
1				92					3		6	100
2		36					1			63		100
3		89								11		100
4	100											100
5	100											100
6				91	9							100
7				86							14	100
8		34	5					46		15		100
9											100	100
10				79							21	100
11											100	100
12										100		100
13			8							89	3	100
14			93							2	5	100
15			93								7	100
16			77								23	100
17			100									100
18			8					14			78	100
19								100				100
20			100									100
21			23								77	100
22	1										99	100
23	64							10			26	100
24	100											100
25	100											100
26	61										39	100
27	91										9	100
28	100											100
29	100											100
30	100											100
31	100											100

	Area (% of site)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
32	49										52	100
33	100											100
34	99		1									100
35	2										98	100
36	91										9	100
37			57								43	100
38	89										11	100
39	83										17	100
40	100											100
41	100											100
42	100											100
43	97		3									100
44	96										4	100
45	93							1		6		100
46	1										99	100
47	87		1								11	100
48	49										51	100
49	96					3					1	100
50	83									18		100
51	96									4		100
52	16							3		81		100
53	38							33		29		100
54	76									24		100
55	63									38		100
56	99									1		100
57	5									95		100
58	23									77		100
59	100											100
60	100											100
61	72							28				100
62	26					74						100
63	97					3						100

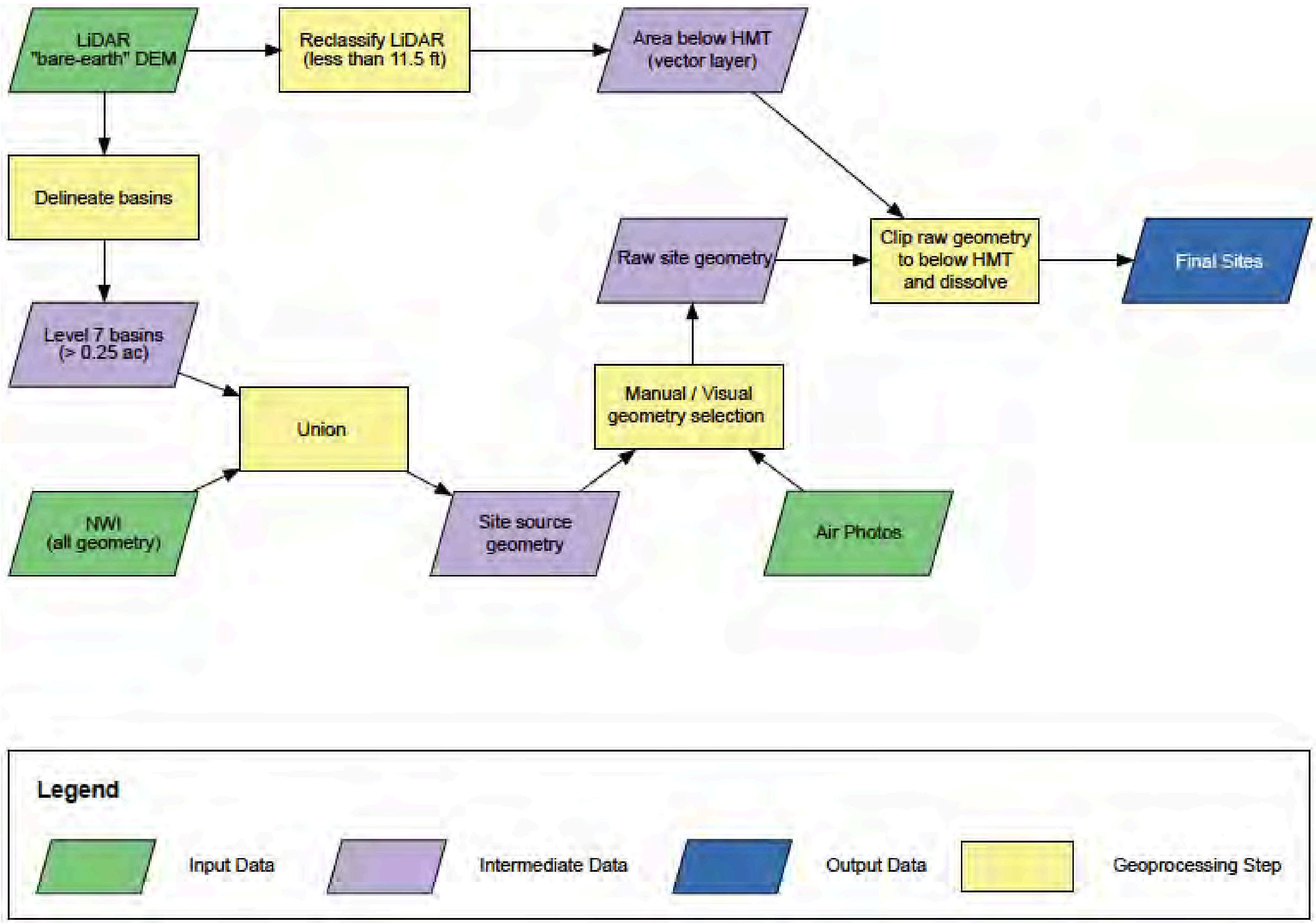
	Area (% of site)											
Site	Agriculture	Coastal	Forestry	Park and Recreation	Public Facility	Rural Commercial	Rural Industrial	Rural Residential	Rural Service Center	Urban	Water	Grand Total
64	79							22				100
65	100											100
66	6		94									100
67	90		10									100
68	100											100
69	100											100
70	100											100
71	100											100
72	100											100
73	81		19									100
74	34		66									100
75	100											100
76	100											100
77	36		64									100
78	53		47									100
79	100											100
80	97		3									100
81	100											100
82	100											100
83	100											100
84	100											100
85	100											100
86	100											100
87	99				1							100
88	100											100
89	100											100
90	100											100
91	13							87				100
92	100											100

Table 7. Tax Parcel Property Classification Table

Property Class	Assessor's Major Classification	Assessor's Minor Classification	Land Ownership Category
0	<blank>	<blank>	Other
10	Miscellaneous Property	Unbuildable Properties	Other
93	Miscellaneous Property	Public Utilities "Centrally Accessed"	Other
100	Residential	Vacant Residential Land	Residential
101	Residential	Improved Residential Land	Residential
109	Residential	Improved with a Manufactured Structure	Residential
121	Residential	A Residence in a Commercial Zone	Residential
131	Residential	A Residence in an Industrial Zone	Residential
200	Commercial	Vacant Commercial Zoned Land	Commercial
201	Commercial	Improved Commercial Zoned or Unzoned	Commercial
209	Commercial	Improved Commercial with a Manufactured Structure	Commercial
300	Industrial	Vacant Land Zoned Industrial	Other
301	Industrial	Improved Industrial	Other
303	Industrial	Industrial Property, State Appraised	Other
400	Tract	Vacant Rural Property	Other
401	Tract	Improved Rural Property	Other
409	Tract	Improved Rural Property with a Manufactured Structure	Other
500	Unzoned Farm Land Specially Assessed	Vacant H&B Use Farm, Not Receiving Farm Deferral, Zoning Not Significant	Farm
540	Unzoned Farm Land Specially Assessed	Vacant H&B Use Farm, Receiving Farm Deferral, Zoned Non-EFU	Farm
541	Unzoned Farm Land Specially Assessed	Improved H&B Use Farm, Receiving Farm Deferral, Zoned Non-EFU	Farm
549	Unzoned Farm Land Specially Assessed	MS H&B Use Farm, Receiving Farm Deferral, Zoned Non-EFU	Farm
550	Zoned F-1 Farm Land Specially Assessed	Vacant H&B Use Farm, Receiving Farm Deferral, Zoned EFU	Farm
551	Zoned F-1 Farm Land Specially Assessed	Improved H&B Use Farm, Receiving Farm Deferral, Zoned EFU	Farm
559	Zoned F-1 Farm Land Specially Assessed	MS H&B Use Farm, Receiving Farm Deferral, Zoned EFU	Farm
600	Highest & Best Use Forest Land Specially Assessed	Vacant Forest Land	Forest
640	Designated Forest Land Specially Assessed	Vacant Forest Land	Forest
641	Designated Forest Land Specially Assessed	Improved Forest Land	Forest
649	Designated Forest Land Specially Assessed	Improved Forest Land with a Manufactured Structure	Forest
660	Designated Forest Land Specially Assessed	Vacant Forestland in Small Tract Forestland Option (STF) program	Forest
661	Designated Forest Land Specially Assessed	Improved Forestland in STF program	Forest

Property Class	Assessor's Major Classification	Assessor's Minor Classification	Land Ownership Category
669	Designated Forest Land Specially Assessed	Improved Forestland in STF program with a Manufactured Structure	Forest
701	Multi-Family (5 units or more)	Improved Multi-Family (5 Units or More)	Other
707	Multi-Family (5 units or more)	Improved Manufactured Home Park	Other
807	Recreational Property	Improved Recreational Vehicle (RV) Park	Other
911	Non-Assessable	Churches Improved	Other
913	Non-Assessable	Property leased to a church	Other
920	Non-Assessable	Schools Vacant	School
921	Non-Assessable	Schools Improved	School
940	Non-Assessable	Cities Vacant Land	City
941	Non-Assessable	Cities Improved	City
950	Non-Assessable	County Vacant Land	County

Appendix 3. Site definition GIS processing flowchart



Appendix 4. Introduction to the high-resolution hierarchical basins dataset

Basin delineation in low-relief topography using LiDAR

The explosion of available high spatial resolution (<100 $meters^2$ cell size) digital elevation model datasets collected using Light Detection and Ranging (LiDAR) and other technologies has yielded rich datasets that can be applied to a wide variety of land management questions. A common task is exploring how water flows over the land using computerized flow modeling techniques and defining water catchment areas. These catchments provide a repeatable definition of related land area based on the morphology of the landscape. The USGS's Hydraulic Unit Code (HUC) system is widely used when describing the general location of scientific data, studies, project locations for environmental permitting efforts, and other tasks where location provides context to the document. The HUC system is too coarse for work within a single estuary and assumes a single flow-path with predictable dendritic channel relationships (Seaber, Kapinos and Knapp 1987). This assumption breaks down when applied to water flow in estuaries where flow patterns are likely to be very hydrologically complex.

The concept developed within this project is designed to identify water catchment boundaries (e.g. sub-watersheds) within low relief topography and the potential for internally draining areas (i.e., sinks in the data). Classical approaches to defining catchments within Geographic Information Systems (GIS) (e.g. O'Callaghan and Mark 1984) fail to yield reasonable results within low-relief topographies because they assume that internally draining areas are the result of data errors (i.e., sinks) (Ehlschlaeger 1989). Sinks are filled and water is routed over the digital topography using a simple algorithm that examines the analysis pixel and its immediate neighbors (i.e., Deterministic-8 method). If a true sink exists in the landscape, the classical catchment delineation method will fill the entire catchment until water can be routed over it from other areas in the data. Streams are defined at the lowest elevation within an analysis window. Catchments are related if the stream channels converge and merge into one channel. In dendritic environments with predictable stream gradients and coarse resolution digital data these assumptions do not pose a problem. In estuaries with high-resolution data the assumption fails because the algorithm can't segment and relate catchments based on the resulting streams layer. As expected, when we applied the classical approaches to the Tillamook study area we noticed that known internally draining areas were excluded from the catchment output because the sink-filling algorithm identified the area as a data error when in fact it wasn't. A new approach was needed.

Novel approaches to water routing within GIS systems and access to more powerful computer hardware removes many of the constraints imposed by the earlier catchment delineation methods. One of our biggest challenges was routing water flow over the landscape without changing the source data by filling sinks. GRASS GIS, a free and open source GIS platform originally developed by the Army Corps of Engineers and now managed by a worldwide network of volunteers, implemented a least-cost watershed delineation tool (Ehlschlaeger

1989; Jasiewicz and Metz 2011). Instead of delineating watershed using the resulting streams layer this method mimics the way a human geographer would manually delineate watersheds using a paper topographic map. Water from a given pixel can flow across the landscape in multiple directions at once with partial contributions of water to downstream pixel neighbors. Water will follow the path of least resistance to a known sink or the lowest point in the dataset.

The method yields a flow channel layer (i.e., streams) which is the path of least resistance to a low elevation pixel or sink. Dendritic relationships within this layer are unreliable because of the low-relief nature of the data and its high spatial resolution. The layer can be used to explore the net flow direction of a basin or how one basin is related to another but the streams layer should not be used to nest catchments to form a larger parent watershed as the HUC system suggests. Instead, the hierarchical relationship of catchments can be determined by changing the definition of a basin by controlling the minimum drainage area required for delineation. By stacking a coarse delineation (large minimum drainage area) on top of a small delineation (smaller minimum drainage area) and performing a spatial selection analysis, we can determine the relationship of the smaller catchments to their parent (larger) catchments. The step size of minimum catchment area and the number of levels is arbitrary but useful for exploring and delineating management units based on topography.

We tested our method on synthetic topography and it yielded the expected results. Further work is needed to automate the delineation, relationship, and attribute calculation steps of the process and deliver it as a tool.

Summary:

- “Standard” approaches to delineating basins fail in low-relief environments because they fill sinks and use simple routing algorithms.
- Our method works because it uses a least cost approach (Ehlschlaeger 1989; Jasiewicz and Metz 2011) to flow routing that doesn’t require filling sinks.
- We changed the definition of a watershed and re-ran the analysis yielding a rich dataset of nested basins. A stack-spatial-join was used to relate fine catchments to their parents. This approach mimics the way a human geographer would perform a basin / watershed segmentation from paper maps.
- We tested our method against synthetic topography and it performs as expected.

Works Cited:

Ehlschlaeger, C. 1989. Using the AT search algorithm to develop hydrologic models from digital elevation data. In *International Geographic Information Systems (IGIS) Symposium.*

Jasiewicz, J and M Metz. 2011. A new GRASS GIS toolkit for hortonian analysis of drainage networks. *Computers & Geosciences*doi:10.1016/j.cageo.2011.03.003.

Seaber, Paul R, F. Paul Kapinos, and George L Knapp. 1987. Hydrologic unit maps. *Water Supply Paper 2294.* U.S. Geological Survey, 1994. http://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294.pdf (accessed October 27, 2011).

Appendix 5. Data management and software

Database

Our data was stored in a web-application we designed specifically for Estuary Prioritization projects and built using the python Django framework (https://www.djangoproject.com/).

The application stores data in a fully relational database, an advantage for a large study like the Tillamook Estuary Prioritization. This means that objects can be related to other objects. For example, a site is related to many alterations. We can ask the database for all alterations related to a site, or alternatively, all sites of a given alteration.

The Django framework also allows us to develop custom python-based operations that work with the database and other data. This allowed us to write a wide range of scripts that did things like intersect NWI / HGM / landowners with our sites, compute statistics, and store the results in the database. Other scripts handle data QA/QC and output. The result is fully repeatable derivative scoring and export even if changes are made to the database. If new information is identified that changes a field within the database for one of the sites, and that field is required to compute a scaled score (e.g., Total score), the database can automatically check, recalculate, and export the scoring for all sites. The Tillamook project was highly iterative with many changes. Tracking, quality checking, and exporting the data would have been extremely challenging and time-consuming using Excel or other tabular-based data management techniques. Using a framework such as Django to store the data allowed us to reduce the potential for error and maintain data integrity, while remaining productive.

Sites are associated with:

- Final Site ID
- Draft Site ID
- Contains historic tidal swamp? (Yes / No: based on ORBIC historic vegetation geodata)
- Site Area (Square feet and Acres)
- Site Area score (rescaled)
- Historic swamp % - proportion of site area
- Historic swamp score (rescaled)
- Wetland connectivity area – Square feet and Acres
- Wetland connectivity score (rescaled)
- Number of Cowardin classes derived from NWI
- Diversity of current vegetation score: (rescaled from # Cowardin classes)
- Tidal Exchange Score (1: Highly Altered, 3: Restricted, 5: Full Exchange)
- Tide Gate Location Score (1: Offsite, 3: Onsite, 5: No tide gate)
- Ditching Score derived from identified ditching alterations and their intensity (rescaled)
- Remnant Channel Score: (1: None, 3: Some, 5: Many)
- Number of Salmonid Stocks
- Salmon Stock Score (score of 1 represents no stocks, score of 5 represents six stocks)
- Tidal Channel Condition sum: derived from other scores

- Tidal Channel Condition score: rescaled (1-5) from TCC_sum
- Combined Ecological Score / Total Score: derived from other scores
- Priority Group: derived from total score using Jenks
- Major Alteration Index: derived from alterations
- Alteration Group: derived from TCC_score
- Area between 9.0 and 11.5 ft. NAVD88 (sq. ft., acres, and proportion of site)
- Summary and general notes
- Notes associated with a specific time-sensitive data source (i.e., 1939 aerial imagery)
- Alterations - including their type, source used to identify the alteration, and site-specific intensity
- Number of landowners (visually checked and altered to reflect transcription errors present in the Assessor's data)
- Landownership - including owner name, ownership type, and area of the site occupied by the owner
- NWI Codes – including the area covered and proportion of the site
- HGM Codes – including the area covered and proportion of the site
- Historic Vegetation – including the area covered and proportion of the site
- Zoning – including the area covered by the landuse and proportion of the site

Software

The primary GIS software we used in this project for mapping and analysis was ESRI ArcGIS 9.3.1 and its associated extensions including Spatial Analyst, 3D Analyst, and Maplex. Other GIS software was used during the project to explore and verify output but was not critical to the project. These included Quantum GIS (http://www.qgis.org/), GRASS GIS (http://grass.osgeo.org/), and SAGA GIS (http://www.saga-gis.org/).

In situations where scripting was required to perform geospatial analysis (e.g., intersections with sites, complex translations or conversions), our programming language of choice was Python (version 2.7, http://www.python.org/) coupled with the Geospatial Data Abstraction Library (GDAL) (versions 1.8 and 1.9, http://www.gdal.org/) and its python bindings. To track changes to our code and database, including bug fix histories and troubleshooting notes, the version control system Git (http://git-scm.com/) was employed. Our data was stored in a web application we developed in house and described above, built using the Django framework. The statistics software R (http://www.r-project.org/) was used to calculate available wetland area as part of the wetland connectivity criterion. The libraries we used within the R environment include the classInt, raster, and maptools libraries available within the Comprehensive R Archive Network (CRAN) available at http://cran.r-project.org/.

Appendix 6. Restoration principles

Tidal wetland restoration is most likely to be successful if it follows basic principles of restoration design. The headings below are taken directly from the document, "Guiding ecological principles for restoration of salmon habitat in the Columbia River Estuary" (Simenstad and Bottom 2004). The text below each heading was written by this report's author (Laura Brophy) to address concerns specific to Oregon estuaries south of the Columbia River. These principles should be carefully incorporated into every restoration project.

Protect first – restore second

The immediate need for every current and former tidal wetland site in Oregon is protection of existing wetlands. This is particularly true for unaltered sites, but must also be considered for every altered site. Many former tidal wetlands are currently freshwater wetlands, and many are partially tidal ("muted tidal") wetlands. The balance of nontidal and tidal wetlands should be considered during each restoration project; ideally, no restoration should cause a net loss of wetland area or functions.

To conserve existing wetlands, the water sources, flow restrictions, and potential hydrologic effects of restoration actions must be carefully considered. In particular, freshwater wetlands formed by impoundment behind a tidal flow restriction (tide gate or restrictive culvert) should be carefully analyzed to determine the likely effects of removing the tide gate or upgrading the culvert. Tidal range outside the restriction must be compared to site elevations within the freshwater wetland, to ensure that restoration will in fact restore tidal wetland and not merely drain the current freshwater wetland.

Do no harm

In this assessment, restoration is defined as "return of an ecosystem to a close approximation of its condition prior to disturbance. ... Restoration is ... a holistic process not achieved through the isolated manipulation of individual elements" (National Research Council 1992). It is important to avoid manipulations that may harm existing wetland functions or prevent recovery of original functions. For example, some tidal wetland restoration projects have included construction of features (such as excavated ponds) that would not have been found in the wetland prior to human alteration. Pond excavation may provide more waterfowl habitat (a valued function), but may decrease foraging habitat and protective shelter for juvenile salmon. Excavation of ponds may also prevent recovery of the site's original hydrology, channel morphology, and associated functions such as nutrient processing and water temperature moderation.

Use natural processes to restore and maintain structure

Tidal wetlands are created by natural processes. The most distinctive and basic of these is tidal flow; examples of other natural processes include sediment and detritus deposition, freshwater input, groundwater flow, and nutrient cycling. The goal of restoration is to re-establish these natural processes where they have been altered by human disturbance. Restoration is generally more successful, more sustainable, and more cost-effective when it uses natural processes rather than engineered solutions (Mitsch 2000. Simenstad and Bottom 2004).

Restore rather than enhance or create

Enhancement is "the modification of specific structural features of an existing wetland to increase one or more functions based on management objectives, typically done by modifying site elevations or the proportion of open water" (Gwin *et al* 1999). Gwin goes on to state that "Although this term [enhancement] implies gain or improvement, a positive change in one wetland function may negatively affect other wetland functions." Enhancement should not be implemented if it results in a net loss of wetland functions or detracts from the main goal of restoration: to re-establish site conditions that existed prior to disturbance.

Wetland creation means making a wetland where one did not previously exist. By definition, wetland creation sites lack the natural processes that normally create tidal wetlands, so a much higher level of engineering is required to attempt to replicate those natural processes. Wetland creation may be unsuccessful and unsustainable, particularly in the long term, because it relies on human intervention and engineering rather than pre-existing natural forces (Mitsch 2000). Tidal wetland creation (making a new tidal wetland where tidal flow never existed previously) may even cause unexpected problems for other nearby tidal wetlands by altering the natural patterns of tidal flows. Hood (2004) documented offsite effects of diking, and similar offsite hydrologic responses might occur near areas excavated to form new tidal wetlands.

Incorporate salmon life history

Current research is rapidly expanding our knowledge of how salmon use Oregon's tidal wetlands, but our knowledge base is still very limited. To restore tidal wetlands for salmon habitat functions, a landscape approach is needed, focusing on connectivity of habitats and restoration of the full continuum of habitats needed by rearing and migrating juveniles. Some studies have suggested that the slightly brackish (oligohaline) zone of the estuary may be particularly important for osmotic transition, and may need to be strategically targeted for restoration (Simenstad and Bottom 2004). The oligohaline zone includes the tidal swamp habitat that is prioritized in this study.

Develop a comprehensive, strategic restoration plan

This study uses landscape-scale analysis and ecological principles to establish priorities for restoration – an approach that has been called "strategic planning for restoration." Strategic planning is preferable to "opportunistic restoration," which selects sites simply because they are available for restoration. Action planning subsequent to this study should continue to address ecosystem issues such as habitat interconnections, the effects of nearby (or distant) disturbance on project sites, and the relative scarcity of different habitats within the study area.

An important example of a strategic approach is combining tidal and nontidal wetland conservation and restoration actions. Sites in this study that have adjacent nontidal wetlands offer particularly valuable opportunities for protecting or restoring vital habitat connections and linkages and maximizing resilience to climate change. Planning for tidal wetland conservation and restoration should include adjacent nontidal wetlands and uplands whenever possible.

Use history as a guide, but recognize irreversible change

This study identifies all current and likely historic tidal wetlands. While most of these sites can probably be restored, some sites may be difficult to restore to their historic wetland type. Human land uses in the estuaries and their watersheds have caused long-term, estuary-wide changes. Examples include altered sediment and detritus deposition patterns; changed peak flows, water circulation patterns, and flooding regimes; and widespread fill, urbanization, and road building. These changes to the fundamental processes that historically created tidal wetlands may affect the "restorability" of some areas. In addition, subsidence (sinking of the soil surface) that occurs after diking and tidal disconnection can mean that former high marsh and tidal swamp sites restore to mud flats or low marsh rather than their original habitat types. Subsided sites may return to their original elevations through accretion of sediment, but the process may be very slow (Frenkel and Morlan 1991).

This study included all lands below highest measured tide at the nearest active NOAA tide station (Garibaldi). Some of these areas probably have infrequent tidal inundation – particularly areas distant from major tidal water bodies. However, the future may bring major changes in the form of sea level rise. Areas that are now inundated infrequently may become more frequently inundated in the near future. Therefore, it is important to consider not just historic conditions, but possible future conditions when planning conservation and restoration actions in the estuary. Onsite data collection (e.g. elevations relative to tidal and geodetic datums; tidal inundation; freshwater flows; and groundwater levels) will help inform site-scale and basin-scale climate change adaptation planning. These analyses are highly technical, so expert assistance is recommended.

Monitor performance both independently and comprehensively

Guidance from national and regional resource management agencies emphasizes that every tidal wetland restoration site should be monitored using established monitoring protocols (Simenstad *et al*. 1991, Zedler 2001, Thayer *et al.* 2005). Monitoring must begin before restoration is designed, because baseline information is very needed for critical design decisions. Monitoring should continue long after restoration to provide accountability for the restoration investment, to determine the effectiveness of the restoration actions, and to assist in adaptive management. Post-restoration monitoring is also needed to help guide future restoration efforts, because tidal wetland restoration is still very much a developing science. Development of an efficient, practical and effective monitoring program requires careful consideration of local and regional ecosystem characteristics, national and regional guidance and standards, and project goals. Expert assistance is highly recommended – as described below.

Use interdisciplinary science and peer review

Interdisciplinary technical assistance is needed for restoration design. Expertise may be needed in biology (such as botany and fish ecology), hydrology, geology, sedimentology, chemistry, statistics, engineering, and other fields. The best approach is to assemble an interdisciplinary advisory team as the first step in the site planning process – well before restoration design is begun. Such a team is invaluable in evaluating the biological soundness and technical feasibility of restoration goals, reviewing restoration alternatives, and designing the monitoring program.

Early consultation with the advisory team should establish baseline monitoring protocols, because baseline data are needed to develop a restoration design. Baseline monitoring will provide solid data on site characteristics critical to restoration design, such as site topography (elevations), tidal range, groundwater hydrology, current fish use, and plant communities (which are good indicators of long-term tidal and hydrologic conditions).

Appendix 7. Restoration approaches

This section provides some general considerations for tidal wetland conservation and restoration actions in the Pacific Northwest and Oregon in particular. For all restoration projects, we recommend consultation with appropriate technical experts during early planning phases.

Permits and regulatory coordination

Restoration activities often require extensive coordination with many different regulatory agencies. Numerous permits and approvals may be needed, so it is important to start this process early to avoid unexpected obstacles or delays. Early contact with land use planning officials at the City, Port, County, and State levels is recommended to obtain comprehensive information. The Wetlands Program of the Oregon Department of State Lands, (503) 986-5200, can provide information about the process and recommended contacts.

Archaeological sites

Before European settlement, Oregon's estuaries were widely used by Native American peoples for dwellings, gathering places, and a source of livelihood. Therefore, every estuary restoration project should consider the possibility that there may be archaeological sites within or near the project area. State and federal laws prohibit destruction or disturbance of known archaeological sites. In the case of inadvertent discovery of cultural resources, state and federal laws require that the project be halted and the appropriate Tribe be contacted immediately. To understand the historic and cultural context of each site, and to avoid possible impacts to cultural resources, every restoration project should begin with consultation with the appropriate tribal groups.

Conservation and habitat linkages

The immediate need for every site in the study area is conservation of the existing wetlands. This is particularly true for the unaltered sites. Written landowner agreements for conservation (such as conservation easements and deed restrictions) are among the many useful tools for wetland conservation. At a minimum, current stewardship should be continued; additional conservation actions such as establishment of protective buffers may also be important to maintain existing functions. Many conservation and restoration sites offer good opportunities for education. School groups and local organizations can assist in planning, implementing, and monitoring conservation and restoration activities at tidal wetland sites. Public understanding leads to public support of wetland conservation.

It is important to identify and conserve adjacent nontidal wetlands as well as upland habitats when planning conservation at tidal wetland sites. The best conservation plans protect the linkages and connections that are vital to wetland and upland habitat functions. Protecting the gradient from tidal to nontidal wetlands may also help prevent loss of tidal wetlands in the event of sea-level rise due to sudden or gradual geomorphic or large-scale hydrologic change.

Dike breaching and dike removal

Many of Oregon's tidal wetlands have been diked to block tidal flows and allow conversion to pastures. Restoration in diked tidal wetlands generally includes dike breaching or dike removal. Dikes can be breached at selected locations, preferably at locations of former natural tidal channels. Alternatively, dikes can be removed completely, enhancing sheet flow, nutrient cycling and natural sedimentation patterns.

Dike breaching and removal can be technically challenging operations, with complex trade-offs in biological functions, hydrology, erosion and deposition patterns, costs, infrastructure issues, and engineering constraints. Techniques for successful dike breaching and dike removal are still evolving in Oregon, so early consultation with experts (such as wetland scientists, hydrologists, and engineers) is recommended before designing restoration.

Ditch filling and meander restoration

If a site has extensive ditching that has eliminated flow through meandering channels, ditch filling and meander restoration should be considered. Deep, winding, natural tidal channels with overhanging banks offer a higher quantity and quality of habitat for fish and other organisms, compared to shallow, broad, straight ditches. To redirect water through meandering remnant or restored channels, ditches may be filled or blocked. Ditch filling is generally more effective than plugging, because the relentless force of tidal ebb and flow will usually erode blockages placed in ditches (Brophy 2004, Cornu 2005). This is particularly true if the ditches are deeper than the remnant tidal channels – generally the case on grazing land where remnant channels are often filled with sediment and ditches are "scoured".

Partial excavation of meandering channels, preferably following visible or surveyed remnant channels, may speed the restoration process. However, excavation is not always recommended, and this process presents complex design questions and challenges. Excessive excavation of channels may dewater adjacent areas, much as ditching can. Input from experts (such as tidal wetland scientists, hydrologists, geomorphologists, and engineers) is required for this aspect of restoration.

If tidal action is strong at a site, excavation of remnant channels maybe unnecessary. "Self-design," in which water flows are allowed to create their own meandering path through processes of erosion and deposition, may be the best approach in many cases (Mitsch 2000). Self-design avoids the dilemma of water "not going where the engineers want it to go." Self-design also encourages diffuse flow of water across the site, which contributes to natural restoration of wetlands.

Culvert and tide gate upgrades

It can be difficult for basin-wide tidal wetland studies to assess conditions at specific tide gates and restrictive culverts. These structures cannot be directly viewed on aerial photographs, and they are difficult to characterize during brief field trips because they are often underwater at mid- to high tide, and/or hidden under dense overhanging vegetation.

During initial site-specific planning, careful evaluation is needed for all water inlets and outlets to and from candidate restoration or conservation sites. Measurements and observations should include:

- culvert invert elevations (the elevation of the bottom of the culvert above the streambed);
- the action of tide gates (free or impeded);
- differences in water levels at the upstream and downstream ends of culverts (at both high and low tide);
- impounded water on the upslope side;
- flow velocities relative to surrounding water bodies;
- other evidence of restricted or impeded water flow, including beaver activity.

Where existing culverts are impounding water on the upslope side, culvert upgrades might have unintended consequences such as loss of freshwater wetlands. If a proposed culvert upgrade might drain impounded wetlands, this loss should be balanced against the ecological benefits of the upgrade.

One restoration option is installation of "fish-friendly" tide gates, which increase fish access to streams and wetlands above the gate. Such devices may be a good choice where a landowner does not want to restore tidal flow. However, providing fish access to a site does not restore the ecological functions of tidal wetlands if tidal flow is still impeded. Tide gate removal (often accompanied by a culvert upgrade, or replacement of the culvert with a bridge) is a better option for restoration of the tidal wetland ecosystem, but the guidance above applies in all cases.

Water flow issues and property protection

Tidal wetland restoration usually alters surface water flows, and careful planning is necessary to ensure this does not damage property. Many tidal wetlands can be restored with no risk to adjacent properties, because restoration sites are often at a considerably lower elevation than nearby structures. However, it is still important to assess existing conditions and proposed changes to site hydrology and flow patterns when planning restoration. Particular attention should be paid to topography, elevations of buildings and infrastructure, tidal range, water table depths, and surface and subsurface water flow. Tidal range should be monitored or modeled during both normal and extreme events of tidal action, river or stream flow, and precipitation. The potential effects of water flow changes on nearby structures and properties should be carefully considered. Expert assistance should be sought from hydrologists and engineers experienced in the tidal zone.

Buffer establishment

Buffers around wetlands can greatly improve their functions by protecting habitats from sediment and nutrient-laden runoff, invasive species, fill intrusion, and other disruptive effects of human land uses. In addition, interfaces between wetlands and uplands are heavily used by many species of wildlife.

Buffer establishment around the margins of wetland sites should preferentially use native upland plantings. Native plantings require a weed control plan. Technical help from experts in native plant restoration and weed control is recommended.

Fill removal

The most expensive type of restoration is removal of large areas of fill material. Former wetlands that have been entirely filled were excluded from this study. Most of these areas have been converted to economically valuable uses – usually residential or commercial development, so they are not potential restoration sites. Even if a filled area has been abandoned from past economic uses, restoration via fill removal is very expensive and is also less likely to succeed, because the original soils are gone and there may be few native plant communities nearby to provide seeds and propagules for revegetation.

However, some sites have small areas of fill that could be removed to improve wetland functions. Old roadways that are no longer used, former home sites abandoned due to frequent flooding, and small areas of dredged material offer such opportunities.

Grazing reductions

Many coastal agricultural lands are used for pastures, and the resulting livestock production contributes to the local economy. However, livestock grazing alters plant communities and the physical structure of tidal and formerly tidal wetlands. Livestock degrade tidal channels, lowering the quality of fish habitat and altering water characteristics. Grazing compacts soils, leading to oxidation of soil organic matter and major changes in biological soil processes. Because grazing greatly reduces many wetland functions, removal or reduction of grazing is an important component of many tidal wetland restoration projects. The lowest, wettest portions of pastures may provide poor grazing and little economic return, so they are good candidates for grazing reductions and set-asides. Expansion of grazing set-asides beyond the boundaries of wetlands is also desirable, in order to establish upland buffers that enhance the biological functions of the wetland (see **Buffer establishment** above).