

**MAPPING COASTAL AND SUBAQUEOUS SOILS:
NINIGRET POND PILOT STUDY**

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INTRODUCTION TO SUBAQUEOUS SOILS

The study of subaqueous soils is relatively new to the field of Pedology, or soil science. The concept that sediments in shallow water environments undergo soil forming processes, are capable of supporting rooted plants, and meet the definition of soil according to the criteria defined in Soil Taxonomy has been moving soil scientists into a new frontier of soil survey – mapping subaqueous soils.

Estuarine subaqueous soils are permanently flooded soils that occur immediately below the intertidal zone to shallow water depths (generally <5 m) in protected coves, bays, inlets, and in back-barrier coastal lagoons. This new designation is the result of work in Maryland in which estuarine substrates in shallow water were shown to undergo soil forming (pedogenic) processes. Processes operating in subaqueous soils include additions of biogenic CaCO₃ and marine humus from benthic biota, bioturbation from shellfish and worms, and chemical transformation of sulfur and iron in anoxic environments; all of which differentiate surficial sediments into soil horizons (Demas, et al., 1996; Demas and Rabenhorst, 1999).

The correlations between shallow water estuarine sediment and the classic tenets of soil formation support the inclusion of these substrates within the realm of soil science. One of the principle components of the definition of terrestrial soils is the ability to support rooted plants in a natural environment. Dense beds of submerged aquatic vegetation (SAV, or seagrass) are often found in subtidal estuaries. Unlike macro-algal species, which anchor themselves to a substrate, SAV species are rooted vascular aquatic plants in which roots serve both structural and nutrient uptake purposes. A highly diverse benthic faunal community also depends on subaqueous soils for nutrients, structure, and habitat. The actions of these marine animals are similar to those inhabiting terrestrial soils. Marine animals mix grain sizes, diffuse oxygen to the subsurface layers, decompose organic matter, and concomitantly supply organic carbon from decaying organisms, fecal pellets, and excretion of mucus.

Numerous studies have emphasized the importance of landscape components for predicting and explaining soil distributions. Submerged landscapes are fundamentally the same as terrestrial systems and have a discernable topography from which subaqueous landforms and landscape units may be identified (Bradley and Stolt, 2003).

SIGNIFICANCE OF SUBAQUEOUS SOILS

The following are some advantages of a subaqueous soil approach to shallow water classification:

- Sediment characteristics presented to a greater depth (2 m), rather than a bottom-type classification.

- Provides a comprehensive classification scheme (Soil Taxonomy, Soil Survey Manual) for shallow water sediments that is in place and nationally recognized.
- Standards are in place for describing and analyzing these soils, enabling scientists to follow established procedures and share data nationwide.
- Provide a major or missing data set for submersed aquatic vegetation (SAV) restoration, estuarine protection, planning and management.

Considerable research has focused on many components of estuarine and coastal ecosystems including hydrology, vegetation and floral and faunal interactions. However, the substrate, which supports a wide variety of benthic invertebrates and supports dense areas of SAV, has been largely ignored. Geologic studies have focused on this realm of the ecosystem, but the information provided by these studies is not detailed enough to be of ecological significance and most of these studies focused on a single parameter (e.g. grain size). An advantage of using the soil science approach to study shallow water sediments is that soils are studied as a collection of horizons that are linked with depth across the landscape. These horizons are studied and characterized by examining a combination of properties and characteristics, instead of a single component or parameter.

USES OF SUBAQUEOUS SOIL MAPPING

A major use of traditional soils surveys is to provide interpretation for various land uses and environmental planning. Interpretations for subaqueous soils are currently being developed for a variety of uses. Eelgrass replanting, shellfish production, and potential dredge hazards from acid sulfate soil formation are just a few interpretations that can be made based on a subaqueous soil survey. As more areas are surveyed and more data collected, a wide array of soil interpretations are expected (Table 1).

Table 1: Uses of subaqueous soil survey data.

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|---|--|
| • SAV Restoration | • Habitat Protection for Horseshoe Crab and Diamondback Terrapin |
| • Crab Habitat | • Effects of Dredging on Benthic Ecology |
| • Clam Stocking | • Off Site Disposal of Dredge Spoil |
| • Management for Sustainable Production Clam, Oyster, and Scallop | • Acid-Sulfate Weathering Hazards |
| • Nutrient Reduction | • Dune Maintenance/Replenishment |
| • Pathogens Pfesteria Cyst Residence Sites | • Resource inventory |
| • Benthic Preservation Site Identification | • Baseline conditions |
| • Wading Shore Birds, Migratory Waterfowl, Nurseries and Spawning Areas | • Dredging considerations |
| | • Resource remediation |
| | • Aquaculture |

NINIGRET POND PILOT PROJECT

LOCATION INFORMATION

Ninigret Pond, a coastal lagoon on the south shore of Rhode Island, was chosen as a pilot study for this research because of the large amount of background research conducted on this pond. This section describes the geology, land use history, climate, vegetation, wildlife, hydrology, and formation of subaqueous and coastal soils of Ninigret Pond and the surrounding area.

GEOLOGY

Ninigret Pond is the largest of the coastal lagoons that line the south coast of Rhode Island (Figure 1). The southern Rhode Island coastal region is dominated by thick glacial deposits that overlie an irregular bedrock surface formed by seaward-sloping granitic bedrock valleys (Masterson et al., 2007). The Charlestown Moraine is a WSW-ENE trending, linear ridge extending across much of southern Rhode Island that forms the surface-water drainage divide between northerly flowing streams that flow into the Pawcatuck River and southerly flowing streams that empty into the coastal ponds. The moraine consists of a complex mixture of ablation till and intermixed sand and gravel. Deposits south of the Charlestown Moraine were laid down by meltwater streams flowing from the ice margin forming large glaciofluvial outwash plains (Masterson et al., 2007).

The majority of the Rhode Island coastal lagoons were formed following the last glacial period as glaciofluvial plains, glaciofluvial channels, and ice-block basins were inundated by rising sea-level. Ninigret Pond is separated from coastal lagoons to the east and west by glacial headlands comprised of glacial till and glaciofluvial material, and is separated from the open ocean by a barrier spit comprised of Holocene sand deposited by longshore transport. Prior to permanent stabilization, the Ninigret barrier spit often closed the pond off from the ocean, but was naturally breached due to storms allowing intermittent flushing and tidal influence on the pond. In 1952, the Charlestown Breachway was built and remains today as the sole inlet to Ninigret Pond from the ocean. Due to the constricted flow of water through the breachway, the tidal fluctuation within Ninigret Pond ranges from 7 to 16 cm (Boothroyd et al., 1985).

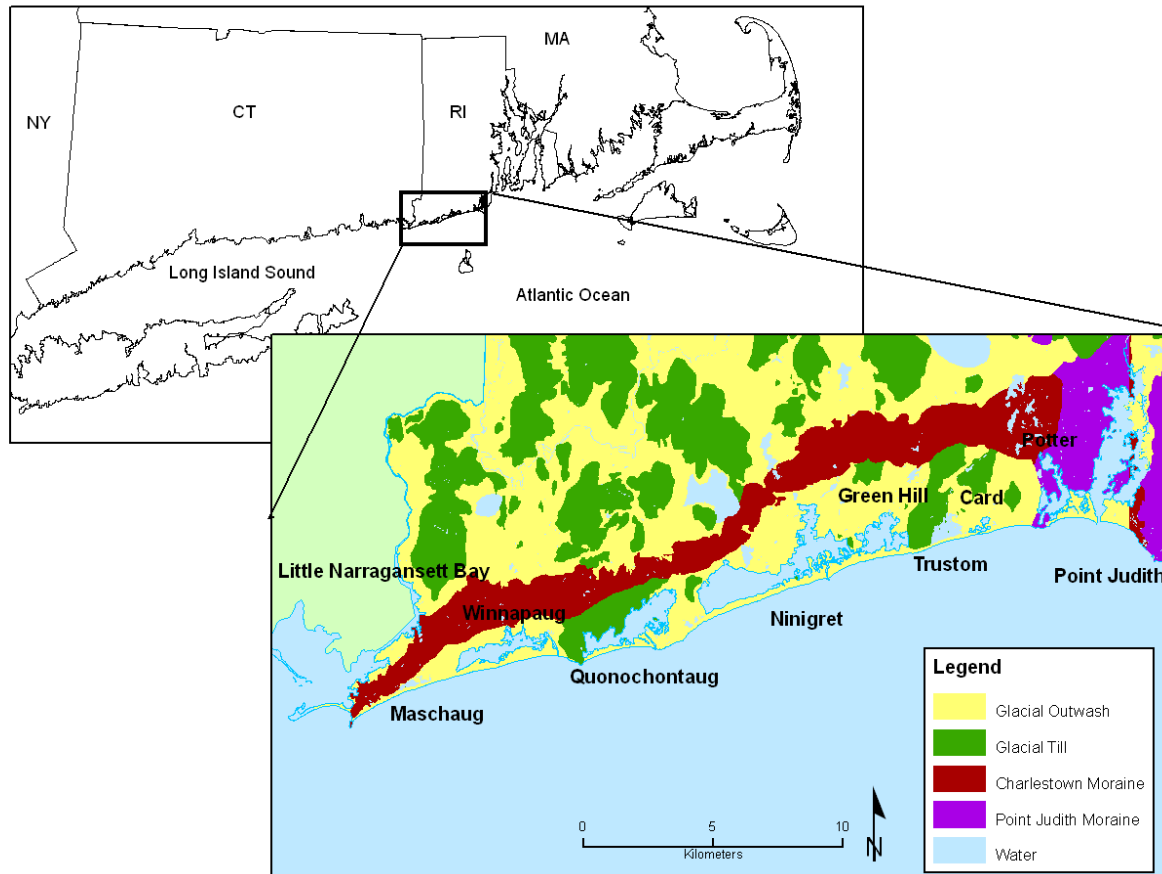


Figure 1: Glacial geology of coastal ponds of Rhode Island.

PROPOSED SOIL SERIES FOR SUBAQUEOUS SOILS

Eight new soil series have been proposed in Connecticut and Rhode Island to describe these subaqueous soils.

Pishagqua

The Pishagqua series consists of very deep, subaqueous soils that are permanently submerged in low energy depositional basins, estuaries and coastal lagoons. The Pishagqua soils formed in silty estuarine deposits. Soils consist of greater than 100 cm of moderately to highly fluid silt loam or fine sandy loam. Soils contain sulfidic materials within 50 cm of the soil surface. Slopes range from 0 to 3 percent.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, nonacid, mesic Typic Sulfaquents

PROPOSED TAXONOMIC CLASS: Fine-silty, mixed, superactive, nonacid, mesic Fluvic Sulfiwassents

TYPICAL PEDON: Pishagqua silt loam on a south facing 1 percent (concave) slope in an Eelgrass meadow of a Lagoon Bottom Channel under 2 meters of permanent estuarine water (Colors are for moist soil, dry colors ranged from 5Y 5/1 to 6/1.). Common, fine and medium distinct 5Y 5/4 concentrations were observed upon drying.

A1--0 to 15 centimeters; black (5Y 2.5/2) interior, silt loam; massive; loose, nonsticky, nonplastic; very fluid; low toughness; extremely low penetration resistance; low excavation difficulty; 1 percent flat angular weakly cemented shell fragments; hydrogen sulfide odor, clear boundary.

C2--15 to 110 centimeters; black (5Y 2.5/1) interior, silt loam; massive; loose, nonsticky, nonplastic; very fluid; extremely low penetration resistance; low excavation difficulty; 1 percent fine and medium platy shell fragments; hydrogen sulfide odor, gradual boundary.

C3--110 to 160 centimeters; black (5Y 2.5/1) interior, silt loam; massive; loose, nonsticky, nonplastic; moderately fluid; extremely low penetration resistance; low excavation difficulty; 1 percent flat subangular shell fragments; hydrogen sulfide odor, gradual boundary..

C4--160 to 191 centimeters; black (5Y 2.5/1) interior, silt loam; massive; loose, nonsticky, nonplastic; moderately fluid; extremely low penetration resistance; low excavation difficulty; 1 percent flat subangular very weakly cemented shell fragments; hydrogen sulfide odor.

TYPE LOCATION: Washington County, Rhode Island; Town of Charlestown, Fort Neck Cove of Ninigret Pond, 1,400 feet north of Potato Point and 1,100 feet west of

Tautog Cove, Carolina USGS Quadrangle; lat. 41 degrees 22 minutes 33.77 seconds N. and long. 71 degrees 38 minutes 48.47 seconds W. NAD 83.

RANGE IN CHARACTERISTICS:

The soils are permanently submerged. All horizons have an initial pH of moderately acid or slightly acid and a pH of 4.0 or less after 8 weeks incubation. Sulfidic materials occur within 50 centimeters of the soil surface, as a layer 1 centimeter or greater thick with a pH value of 4.0 or less within 8 weeks of incubation. Electrical conductivity is greater than 16 mmhos/cm and salinity ranges from 20 to 40 ms throughout the profile. The thickness of silty estuarine material is greater than 100 cm. Some areas are underlain at a depth greater than 100 cm by buried organic deposits, sandy estuarine material, loess, and/or glacial fluvial sand and gravel. Shell fragments range from 0 to 15 percent throughout. Shell fragment types observed include soft shell clam, quahog, oyster, periwinkle, and razor clam.

RANGE OF INDIVIDUAL HORIZONS:

A horizons if present range from a moist color of 2.5Y to 5Y hue, value 2.5 to 3, and chroma 2 or less. Dry colors range from 2.5Y to 5Y value 5 to 7 and chroma 2 or less. Textures range from silt loam to silty clay loam with mucky analogs on some pedons. Consistence has a moderately to very fluid manner of failure class, very friable to loose moist rupture resistance (soft dry), and is non to slightly stick and plastic. Sulphurous odor and sulfidic materials are present.

C and Cg horizons range from a moist color of 5Y to N hue, value 2.5 to 4, and chroma 2 or less. Dry colors range from 2.5Y to 5Y value 5 to 7 and chroma 2 or less. Textures of the C horizons include very fine sandy loam, silt loam, and silty clay loam with mucky analogs on some pedons. Thin strata of sandy material are found in some pedons. Consistence has a moderately to very fluid manner of failure class, very friable to loose moist rupture resistance (soft dry), and is non to slightly stick and plastic. Sulphurous odor and sulfidic materials are present.

Discontinuities: Some pedons are underlain at a depth greater than 100 cm by one or more of the following discontinuities: Sapric and hemic deposits (Oab, Oeb) from fresh and/or salt-water wetlands, silt-loam textured loess, sandy marine sand, and/or glacial deposits of Pleistocene age.

COMPETING SERIES: None

GEOGRAPHIC SETTING:

The Pishagqua soils are permanently submerged with salt or brackish water in low energy basins and channels of coastal lagoons. The soils formed in silty estuarine sediments in 1.5 to 5 meters under water. Most areas have a slope less than 3 percent and are on

slightly concave to level landforms. The mean annual air temperature is 10 degrees C, and mean annual precipitation is 132 cm

GEOGRAPHICALLY ASSOCIATED SOILS:

These are the Wamphassuc (T), and Quanaduck (T) soils. Wamphassuc soils are coarse-loamy soils in drowned stream valleys and terraces in bays. Quanaduck soils are underlain by coarse textured material.

USE AND VEGETATION:

Areas of this soil are used for recreational boating, fishing, and swimming. Benthic fauna such as tubeworms, clams, juvenile blue crabs, scallops and juvenile finfish are common.

Dominant Vegetation: Native vegetation includes rooted and floating algae, eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). Vegetative cover ranges from 0 to 100 percent.

DISTRIBUTION AND EXTENT: Permanently submerged low energy basins in coastal estuaries and coastal lagoons from New Jersey to Maine, U.S.A.; MLRA 144A and 149B. This series is of small extent but acreage may become large once full scale survey of subaqueous soils begins.

MLRA OFFICE RESPONSIBLE: Amherst, Massachusetts.

SERIES PROPOSED: Washington County, Rhode Island, 2006.

REMARKS: Series name was taken from Algonquian word for mud and/or dirt.

Pishagqua soils were formerly included with miscellaneous areas of water. They are distinguished by being permanently covered by estuarine waters that support submersed aquatic vegetation in areas where water quality (clarity, salinity, etc.) permits SAV growth. They are also mapped in areas that no longer support sub aquatic vegetation and are classified as “silty mud sediments” by other disciplines. The soils were originally called “Lagoon Bottom” prior to becoming a soil series.

Diagnostic horizons and other diagnostic soil characteristics recognized in this pedon are:

Peraquic feature--the zone from 0 to 60 inches is permanently saturated

Sulfidic feature--The zone from 0 cm to 100 cm contains sulfidic materials in all horizons (verified by moist incubation)

ADDITIONAL DATA:

This pedon was sampled as S04-RI009-001 by the University of Rhode Island. Numerous other pedons have been samples and there are over 20 pedon descriptions available for this series.

Nagunt

The Nagunt series consists of subaqueous soils that are formed in deep sandy materials deposited in a subaqueous environment as a result of a washover event. These soils consist of greater than 100 cm of sand, and may contain buried surface horizons. Slopes range from 0 to 3 percent.

TAXONOMIC CLASS: Mixed, subactive, nonacid, mesic Typic Psammaquents

PROPOSED TAXONOMIC CLASS: Mixed, subactive, nonacid, mesic Sulfic Psammowassents

TYPICAL PEDON: Nagunt sand on a 1 percent (linear) slope in a back barrier flat (Colors are for moist soil dry colors ranged from 5Y 5/1 to 6/1.). No redox features were described in moist core but upon drying common, fine and medium distinct 5Y 5/4 concentrations were observed.

C1--0 to 14 centimeters; light olive brown (2.5Y 5/3) interior, sand; 99 percent sand; 0 percent silt; 1 percent clay; single grain; loose, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; abrupt boundary.

Cg1--14 to 33 centimeters; gray (2.5Y 6/1) interior, sand; 99 percent sand; 1 percent silt; 0 percent clay; single grain; loose, nonsticky, nonplastic; nonfluid; 2 percent flat shell fragments; Common plant fragments matted in middle of core.; clear boundary.

Cg2--33 to 41 centimeters; 50 percent gray (5Y 5/1) interior and 50 percent dark gray (5Y 4/1) interior, fine sand; 95 percent sand; 4 percent silt; 0 percent clay; single grain; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; abrupt boundary.

Ab1--41 to 54 centimeters; dark gray (2.5Y 4/1) interior, fine sand; 91 percent sand; 8 percent silt; 1 percent clay; single grain; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; Few medium plant fragments throughout.; clear boundary.

Cg3--54 to 69 centimeters; gray (5Y 6/1) interior, sand; 99 percent sand; 1 percent silt; 0 percent clay; single grain; loose, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; clear boundary.

2Ab1--69 to 74 centimeters; sand; 87 percent sand; 10 percent silt; 3 percent clay; massive; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; abrupt boundary.

2Cg1--74 to 106 centimeters; gray (5Y 6/1) interior, sand; 99 percent sand; 0 percent silt; 1 percent clay; single grain; loose, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; Soft shell clam = 6cm in diameter.; clear boundary.

2Cg2--106 to 123 centimeters; dark gray (5Y 4/1) interior, sand; 98 percent sand; 1 percent silt; 0 percent clay; single grain; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; Few very fine plant fragments.; clear boundary.

2Cg3--123 to 143 centimeters; gray (5Y 5/1) interior, fine sand; 0 percent sand; 2 percent silt; 98 percent clay; single grain; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments; Scallop shell 1 cm diameter.; clear boundary.

2Cg4--143 to 150 centimeters; gray (5Y 5/1) interior, fine sand; 98 percent sand; 2 percent silt; 0 percent clay; single grain; very friable, nonsticky, nonplastic; nonfluid; 1 percent flat shell fragments.

TYPE LOCATION: Washington County, Rhode Island; Town of Charlestown, Ninigret Pond West Basin, 950 feet north of East Beach Barrier; lat. 41 degrees 20 minutes 59.39 seconds N and long. 71 degrees 40 minutes 44.08 seconds W NAD 83.

RANGE IN CHARACTERISTICS:

The soils are permanently submerged or intermittently exposed. All horizons have an initial pH of moderately acid or slightly acid. Sulfidic materials occur within 50 centimeters of the soil surface, as a layer 1 centimeter or greater thick with a pH value of 4.0 or less within 8 weeks of incubation. Electrical conductivity is greater than 16 mmhos/cm and salinity ranges from 20 to 40 ms throughout the profile. Soils consist of sands deposited from overwash or tidal events and may contain multiple buried surface horizons. Lighter colored oxidized surface layers 1-10 cm thick are often present. Shell fragments range from 0 to 15 percent throughout. Shell fragment types observed include soft shell clam, quahog, oyster, periwinkle, and razor clam.

RANGE OF INDIVIDUAL HORIZONS:

A horizons if present range from a moist color of 5Y hue, value 2.5 to 4, and chroma 3 or less. Textures are dominantly sand, with loamy sand present in some pedons. Consistence has a nonfluid manner of failure class, very friable to loose moist rupture resistance (soft dry), and is nonsticky and nonplastic. Sulphurous odor and sulfidic materials are present in buried A horizons.

C and Cg horizons range from a moist color of 5Y, value 2.5 to 6, and chroma of 1. Textures of the C horizons are range from coarse sand to loamy fine sand. Consistence has a non fluid manner of failure class, very friable to loose moist rupture resistance (soft dry), and is nonsticky and nonplastic.

COMPETING SERIES: None

GEOGRAPHIC SETTING:

The Nagunt soils are permanently submerged with salt or brackish water in high energy back barrier sand flats and storm surge platforms in lagoons. The soils formed in sandy estuarine sediments laid down by wind and storm washover events in 0.5 to 1 meters of water. Most areas have a slope less than 3 percent and are on slightly convex to level landforms. The mean annual air temperature is 10 degrees C, and mean annual precipitation is 132 cm

GEOGRAPHICALLY ASSOCIATED SOILS:

These are the Napatree (T), and Rhodesfolly (T) soils. Napatree soils found along mainland shorlines and are underlain by glacial till materials. Rhodesfolly soils are found on similar landscapes and contain no sulfidic materials.

USE AND VEGETATION:

Areas of this soil are used for recreational boating, fishing, shell-fishing, and swimming. Benthic fauna such as tubeworms, clams, juvenile blue crabs, scallops and juvenile finfish are common.

Dominant Vegetation: Native vegetation includes rooted and floating algae, eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). Vegetative cover is low and ranges from 0 to 30 percent.

DISTRIBUTION AND EXTENT: Permanently submerged low energy basins in coastal estuaries and coastal lagoons from New Jersey to Maine, U.S.A.; MLRA 144A and 149B. This series is of small extent but acreage may become large once full scale survey of subaqueous soils begins.

MLRA OFFICE RESPONSIBLE: Amherst, Massachusetts.

SERIES PROPOSED: Washington County, Rhode Island, 2006.

REMARKS: Series name was taken from Algonquian word for sand.

Diagnostic horizons and other diagnostic soil characteristics recognized in this pedon are:

Peraquic feature--the zone from 0 to 60 inches is permanently saturated
Sulfidic feature--The zone from 0 cm to 100 cm contains sulfidic materials in some horizons (verified by moist incubation)

Anguilla

The Anguilla series consists of subaqueous soils that formed in sandy marine deposits over outwash. Anguilla soils are adjacent to the mainland in areas that form a cove or embayment within the larger basin. These soils contain 30 to 50 cm of very fluid mucky sand, sand, sandy loam, loam, or silt loam of marine origin over outwash. Slope ranges from 0 to 5 percent.

TAXONOMIC CLASS: Sandy, mixed, mesic Haplic Sulfaquents

PROPOSED TAXONOMIC CLASS: Sandy, mixed, mesic Haplic Sulfiwassents

Napatree

The Napatree series consists of subaqueous soils that formed in sandy marine deposits overlying glacial till materials. Napatree soils are found in bouldery, glacial deposits adjacent to uplands. These soils contain 30 to 50 cm of non-fluid coarse sand, sand, loamy coarse sand, or sandy loam of marine origin over glacial till. Slope ranges from 0 to 2 percent.

TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Aeric Endoaquents

PROPOSED TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Aeric Haplowassents

Fort Neck

The Fort Neck series consists of subaqueous soils that formed in loamy marine deposits underlain by sandy or sandy-skeletal materials. These soils contain 15 to 30 cm of moderately to very fluid silt loam or fine sandy loam of marine origin over outwash (?). Slope ranges from 0 to 2 percent.

TAXONOMIC CLASS: Coarse-loamy over sandy or sandy-skeletal, aniso, mixed, superactive, nonacid, mesic Sulfic Fluvaquents

PROPOSED TAXONOMIC CLASS: Coarse-loamy over sandy or sandy-skeletal, aniso, mixed, superactive, nonacid, mesic Sulfic Fluviwassents

Wamphassuc

The Wamphassuc series consists of subaqueous soils that are formed in loamy marine sediments overlying thin layers of buried organic salt marsh deposits and thick loamy glacial deposits. These soils contain 50 to 100 cm (?) of moderately to highly fluid silt loam or fine sandy loam of marine origin over loamy sand glacial deposits. Soils contain sulfidic materials within 50 cm of the surface. Slope ranges from 0 to 2 percent.

TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Haplic Sulfaquents

PROPOSED TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Haplic Sulfiwassents

Billington

The Billington series consists of subaqueous soils that are formed in loamy marine deposit underlain by buried organic soil material 20 cm or more thick, with an upper boundary within 100 cm of the soil surface. Slope ranges from 0 to 2 percent.

TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Typic Sulfaquents

PROPOSED TAXONOMIC CLASS: Coarse-loamy, mixed, active, nonacid, mesic Fluvic Sulfiwassents

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