A HYDROGEOMORPHIC MAP OF ASSATEAGUE ISLAND NATIONAL SEASHORE, MARYLAND AND VIRGINIA

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A Hydrogeomorphic Map of Assateague Island National Seashore, Maryland and Virginia

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Abstract

The landforms and hydrology of Assateague Island National Seashore are interpreted and categorized in a hydrogeomorphic map of the barrier island. This report accompanies a digital map in GIS format, defines the primary map units and subunits, and explains the approach for classifying sections of the island. The base for the map is a color infrared photomosaic of the National Seashore that covers two-thirds of Assateague Island. A lidar digital elevation model of the island with 10-cm vertical resolution was used as a supplement to the photomosaic for interpretation of landforms. The interpretation of island hydrology relies on a previous study of ponds on the island and geophysical surveys of representative sites to delineate the vertical character and horizontal continuity of the surficial aquifer and fresh ground-water lens. Geophysical methods included gamma and electromagnetic induction logging of existing deep wells, ground-penetrating radar, and electrical resistivity.

The surface of Assateague Island has been sculpted mostly by the cycle of inlet formation and closure, and vigorous overwash flow during major storms. The associated inlet and storm processes have created an island surface with alternating low sections and higher-elevation uplands that are protected by sand ridges. The water table, which is the top of the surficial (unconfined) aquifer, generally follows the topography of the island surface, and its elevation above sea level in part controls the depth of the fresh ground-water lens beneath the island. Consequently, geomorphology related to storm processes is linked to the distribution of fresh ground water on the island, which in turn is a primary control on the plant communities. Vegetation, both cover and assemblage, is an excellent temporal integrator of hydrologic conditions, and changes in vegetation commonly coincide with geomorphic boundaries on the island.

The spatial distribution and dynamics of fresh and brackish ground water beneath the island are strongly affected by the frequency and magnitude of the input of saltwater onto the island surface and into the surficial aquifer by storm overwash from the ocean side and high-water flooding from the bay side of the island. Both the ocean and bay sides of the island have highly dynamic brackish zones in the aquifer produced by surface inundation of saltwater and deeper density-driven ground-water flow.

Six primary map units are defined for the island based on consistent geomorphic and hydrologic character: Island Core (IC), Over Wash (OW), Tidal Marsh (TM), [former] Inlet (IN), Wash Around (WA), and Ponds (PD). Each primary map unit is divided into map subunits based on relative elevation and degree of protection from saltwater inundation. Numerical suffixes are used to indicate relative elevation within a map unit, grading from low (1) to higher (4 or 5); for example, subunit TM2 represents the high marsh. Character suffixes of subunit identifiers are abbreviations that indicate specific landforms such as swales (*sw*) or overwash channels (*ch*). Certain map subunits may be equivalent in hydrologic and vegetative character to a subunit of another primary map unit. For example, the high marsh TM2 may appear in several different geomorphic settings including the bay side of the island core, and low areas of washarounds and former inlets. In these cases, compound identifiers are assigned, such as IC1/TM2. Subunits and characteristics of the primary map units, and equivalencies among subunits are summarized in tables.

This hydrogeomorphic map has substantial explanatory and predictive value for evaluating the spatial character of many components of the barrier-island ecosystem, including the distribution of plant species and communities, fresh-water resources for large vertebrates, and living and breeding habitat for numerous invertebrates and smaller vertebrates.

INTRODUCTION: DEVELOPING THE MAP

The ground-water hydrology of Assateague Island, a barrier island along the Atlantic coast of Maryland and Virginia (Fig. 1), is controlled largely by the geomorphology, or the landforms, of the island. In turn, the distribution of fresh and brackish ground water in the unconfined, surficial aquifer, and the geometry of the fresh ground-water lens under the island strongly influence the distribution of plant communities and habitat for a diversity of invertebrate and vertebrate wildlife. This report accompanies a hydrogeomorphic map of Assateague Island National Seashore (ASIS) that subdivides and categorizes the island surface in terms of its geomorphology as related to characteristics of the ground-water hydrology. The map itself is in a GIS format with digital polygons representing all of the map units and subunits discussed in this report overlain on a georeferenced color infrared photomosaic of the National Seashore (Fig. 2). The map covers the entire Maryland section of the island, including the National Seashore and the Maryland State Park, and extends about 1 km into the Virginia section of the island.

The conceptual framework of this map is based in part on recent studies of the ponds (Hall, 2005) and the larger-scale geomorphology of the island (Morton et al., 2007), combined with geophysical surveys and observations on the island specifically in support of interpretations for this map. As part of the pond survey, we characterized the surficial aquifer near the seven pond sites, which are documented in detail by Hall (2005), using a variety of geophysical methods: ground penetrating radar, electrical resistivity, and borehole geophysical tools. These geophysical surveys showed contrasting conditions in the surficial aquifer at the various sites, which tended to group in predictable patterns related to geomorphology and position on the island. A preliminary geomorphic map developed while conducting the pond survey helped relate the characteristics of the ponds to the broader setting of Assateague Island. That preliminary map guided additional field study to identify the end-member geomorphic and hydrologic settings, and to characterize the environmental gradients between those end members.

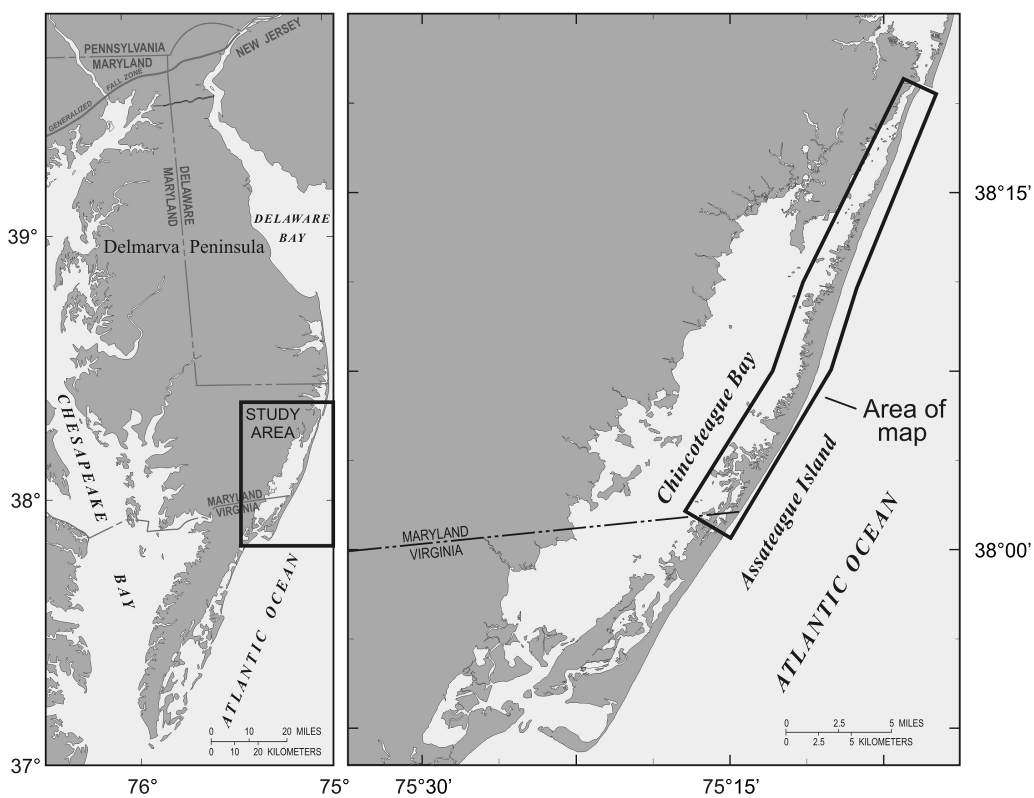


Figure 1. Regional and local setting of Assateague Island, showing the area covered by the hydrogeomorphic map as represented by the individual sections of the photomosaic in Figure 2.

All sites for the pond study and geophysical surveys are identified on the island sections presented in Figure 2 and summarized in Table 1. A separate report will document and interpret the extensive geophysical data collected on the island in support of the hydrogeomorphic map.

Table 1. Study sites on Assateague Island.

Location	Type of data	Geophysical data	Map units	Comments
KM10	geophysics, wells	GPR, resistivity	IC, OW, TM	S edge of extensive overwash area
KM11	pond		IC	
KM13	geophysics	GPR, resistivity	IC, IN	behind man-made dune
KM15	pond		IC	
KM18	pond, geophysics	GPR, resistivity	IC, OW, WA, TM	Tingles Island access
KM22	geophysics, wells	GPR, resistivity	IC, IN, WA, TM	Pine Tree Is. access; incl. brine study
KM23	ponds, geophysics	GPR, resistivity	IC, OW, IN	ponds in swales between storm ridges
KM24	pond, geophysics	GPR	IC, OW, IN	N edge of Fox Hills Level
KM26	geophysics	resistivity	IN (INsp)	Fox Hills Level salt pan
KM27-29	geophysics, well	GPR, resistivity	IC, OW, TM	Green Run Is.; well at Valentine cottage
KM30	ponds, geophysics	GPR, resistivity	IC, OW, IN	Jackson cottage access
KM33	ponds, geophysics	GPR	IC, IN	historic Green Run Inlet

[Location identifiers refer to the standard NPS kilometer designations for Assateague Island.]

Characterizing the Surficial Aquifer with Geophysical Surveys

Sets of geophysical transects were completed at each of ten study sites on the island (Fig. 2, Table 1). As mentioned above, many of these sites were part of the pond study, but the remaining sites were chosen to characterize sections that are representative of larger areas of the island. The geophysical sites cover all of the primary geomorphic and hydrologic settings of the island. In general, transects measured conditions in the center or "core" of each primary map unit, and crossed the transitions or gradients within and between the map units. For example, in the section of the island encompassing kilometers 27 to 29, immediately north of Green Run and informally referred to as "Green Run Island," four geophysical transects were completed that covered the width of the island from the edge of the overwash area to the bay-side salt marsh; four additional transects on the ocean side and bay side covered shore-parallel geomorphic transitions. These transects together comprise over 2.5 kilometers of continuous measurements at this locality. Most, but not all, of the geophysical transects were along the access roads because the vegetation was too dense elsewhere. Because most of the roads are simply cut into the island surface or filled with island sediments, there is a negligible effect on the quality of the geophysical data; for those few road sections with thicker fill (greater than ~0.5 m) or remnants of asphalt paving, the geophysical surveys were taken along the edge of the road.

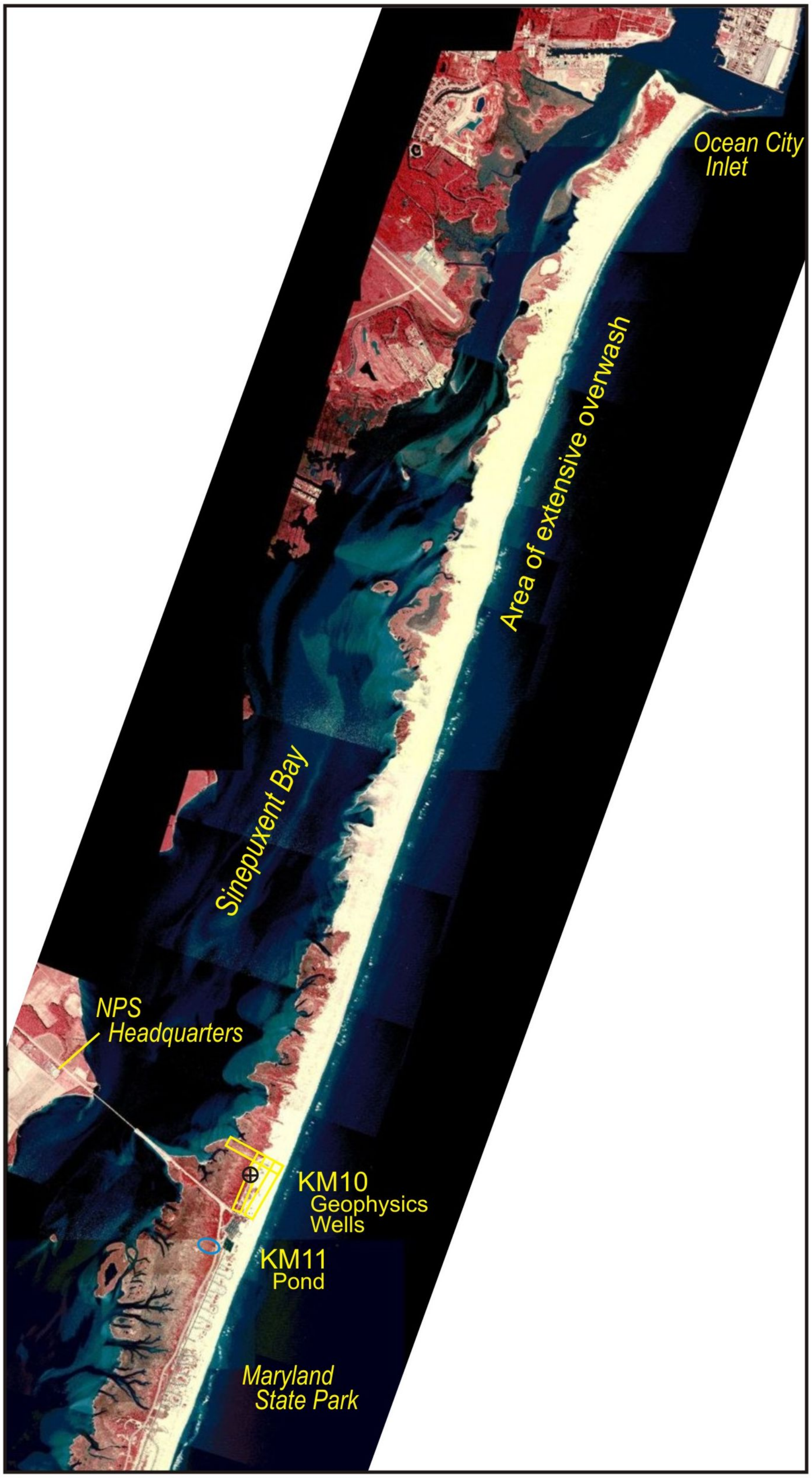


Figure 2. Color infrared photomosaic of Assateague Island National Seashore used as the base for the hydrogeomorphic map. The map extends from the Ocean City Inlet at the north end of the island to approximately 1 km south of the Maryland-Virginia border. Also shown are locations of pond sites (ovals), deep wells (crosses), and geophysical survey sites (rectangles) that are labeled by NPS kilometer designations. (All references to kilometer location on the island are based on the standard kilometer posts used by the NPS, starting with kilometer 0 [zero] at the Ocean City Inlet at the north end of the island and increasing to the south.) All aerial photographic images in this report are oriented with north toward the top of the page. Photomosaic provided by the ASIS GIS group. (A) Northern section of the map area.

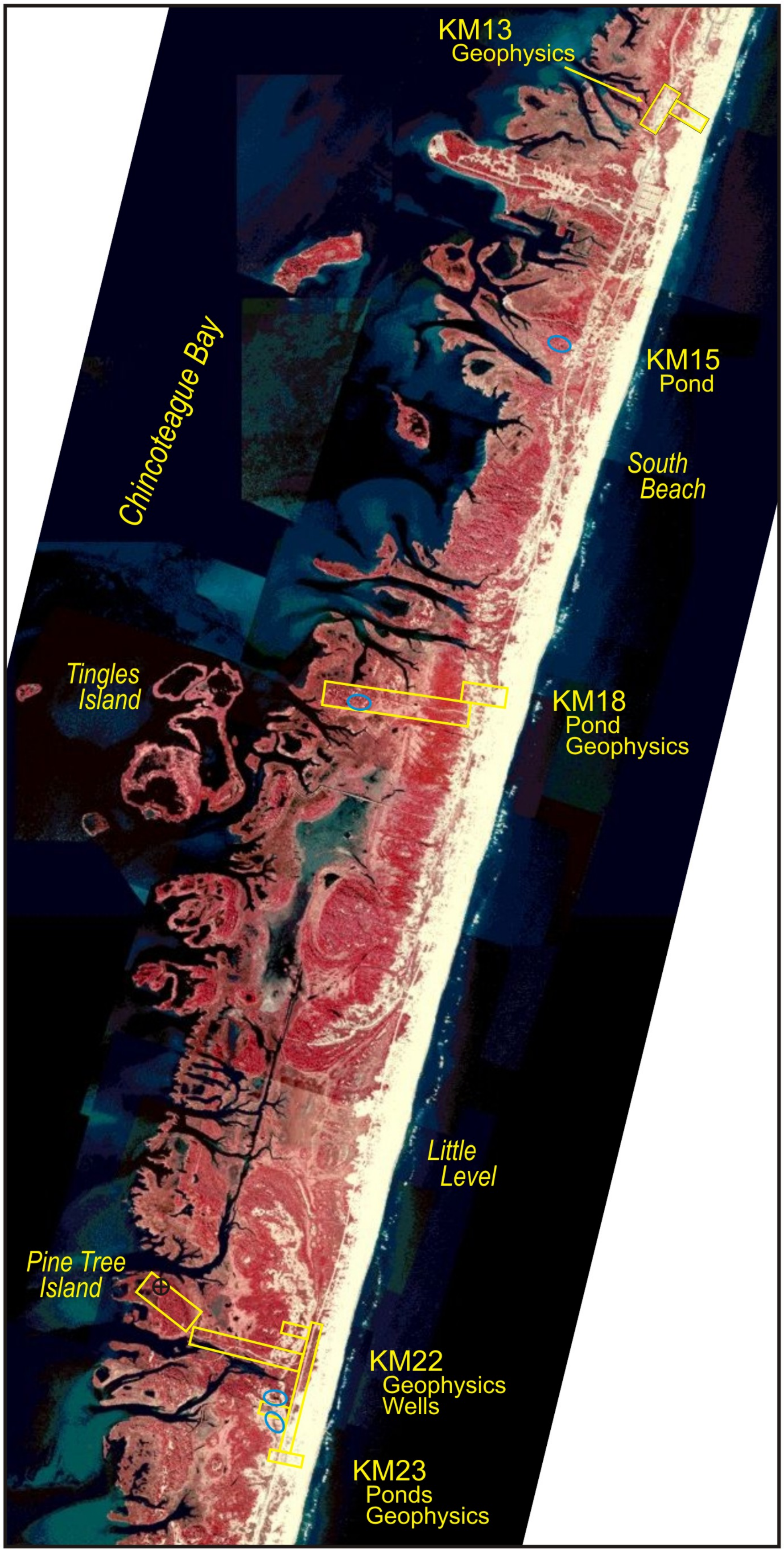


Figure 2. (B) Central section of the map area, showing locations of study sites for ponds, wells, and geophysical surveys.

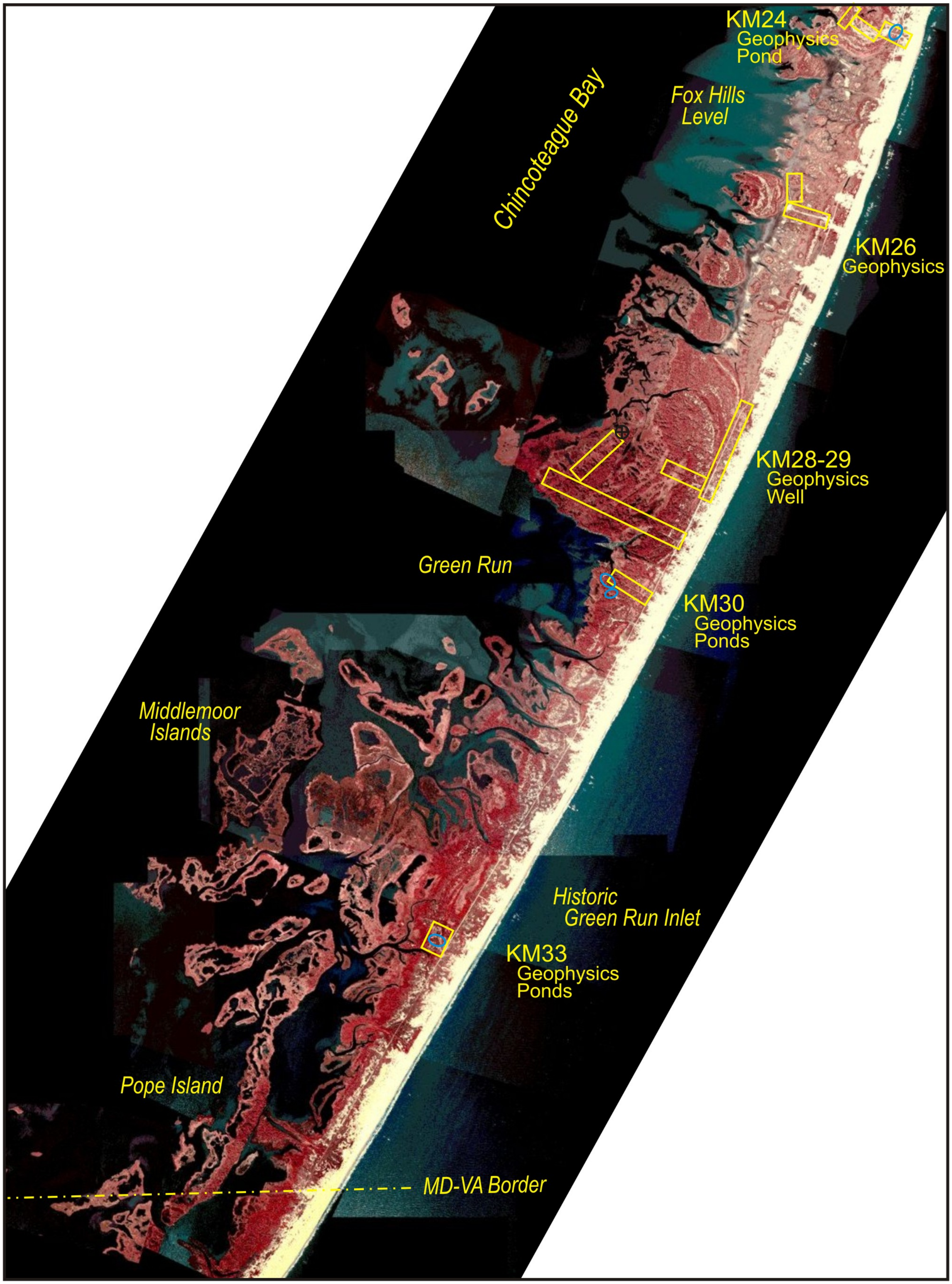


Figure 2. (C) Southern section of the map area, showing locations of study sites for ponds, wells, and geophysical surveys.

Several key sites – KM10, KM22, and KM28-29 (using the standard NPS kilometer designations) (Fig. 2) – provided critical "golden spikes" where geophysical logs down existing deep wells produced detailed vertical profiles of sediment type from gamma logs and ground-water conductivity (i.e., salinity) from electromagnetic (EM) induction logs. The vertical structure of the surficial aquifer from the well logs was mapped laterally away from the single point of the well by transects of ground-penetrating radar (GPR) and electrical resistivity. These two techniques produce two-dimensional profiles that, combined, allow the interpretation of the depth of fresh ground water in the surficial aquifer. Transects at several sites were re-occupied during successive field excursions to obtain time series showing some of the dynamics of the ground-water system.

Site KM10, along Shell Road just north of the main entrance road coming off the Verrazano Bridge (Fig. 3), is one of the key sites, and provides an example of how the ground-water hydrology is inferred from the geophysics. The gamma log from a US Geological Survey well at the site (Fig. 4) shows sand of the overwash sheet down to 4 m, underlain by back-barrier silt to about 7.5 m. The EM log shows an increase in ground-water salinity starting at about 5 m depth and continuing to 12 or 12.5 m, where it reverts to fresh ground water. The GPR profile KM10-04 (Fig. 5) across the center of the island, near the well, also shows the base of the of the overwash sands as a strong, mostly flat-lying reflection at about 4 m. Above this boundary, the GPR reflections are bright and clear, but below, they are weak, indistinct, or absent because of attenuation of the radar waves by brackish pore water. The base of the GPR reflections gives a quantitative measure of the depth from the land surface to the base of the fresh ground-water lens. One section of the profile with weak reflections below 4 m, that occurs between 40 and 140 m along the transect, is likely to have fresh (or nearly fresh) ground water penetrating down into the back-barrier silt deposits, similar to that seen in the EM well log between 4 and 6 m depth (Fig. 4). In contrast, the eastern end of GPR profile KM10-01 (Fig. 5) shows a progressively shallower fresh lens toward the ocean as the result of the injection into the surficial aquifer of seawater from overwash that percolates down through the sand and recharges the water table.

Figure 3. Location of focus site KM10, showing individual geophysical transects. The locations of scenes presented in all figures are shown in the photomosaic panels in Appendix A.

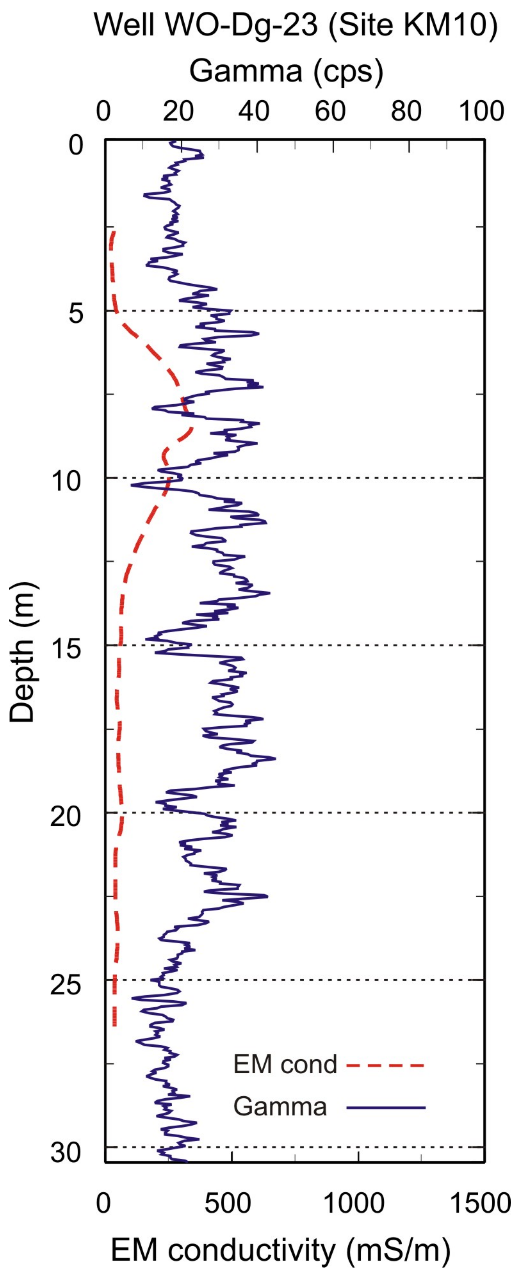


Figure 4. Gamma and electromagnetic induction logs for USGS well WO-Dg-23 at the KM10 site. The gamma log shows the relative proportion of fine-grained sediments (higher values) to sand (lower values). The EM induction log primarily shows the conductivity of the pore fluids (ground water) in the sediments surrounding the well casing; lower values indicate fresh and higher values indicate brackish to saline ground water.

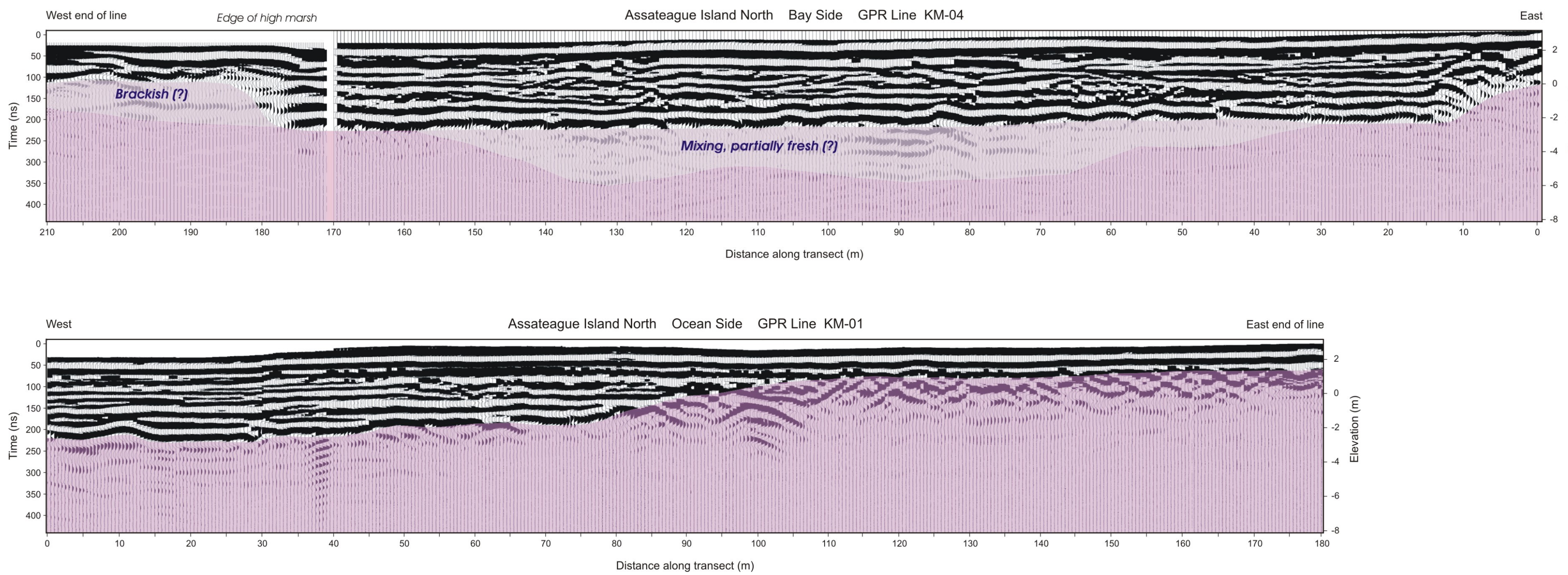


Figure 5. Ground-penetrating radar profiles KM10-04 and -01 running west to east across the island at site KM10. The attenuation of radar reflections, indicated by the light magenta shading, marks the base of the fresh ground-water lens, which correlates closely with the depth indicated by the EM conductivity log from the well at this site. The deepest, most stable part of the fresh lens is near the center of the island. An abrupt transition to brackish ground water in the shallow aquifer coincides with the edge of the high marsh on the bay side. The fresh lens toward the ocean end of the transect becomes progressively shallower because of brackish ground water resulting from frequent overwash of seawater.

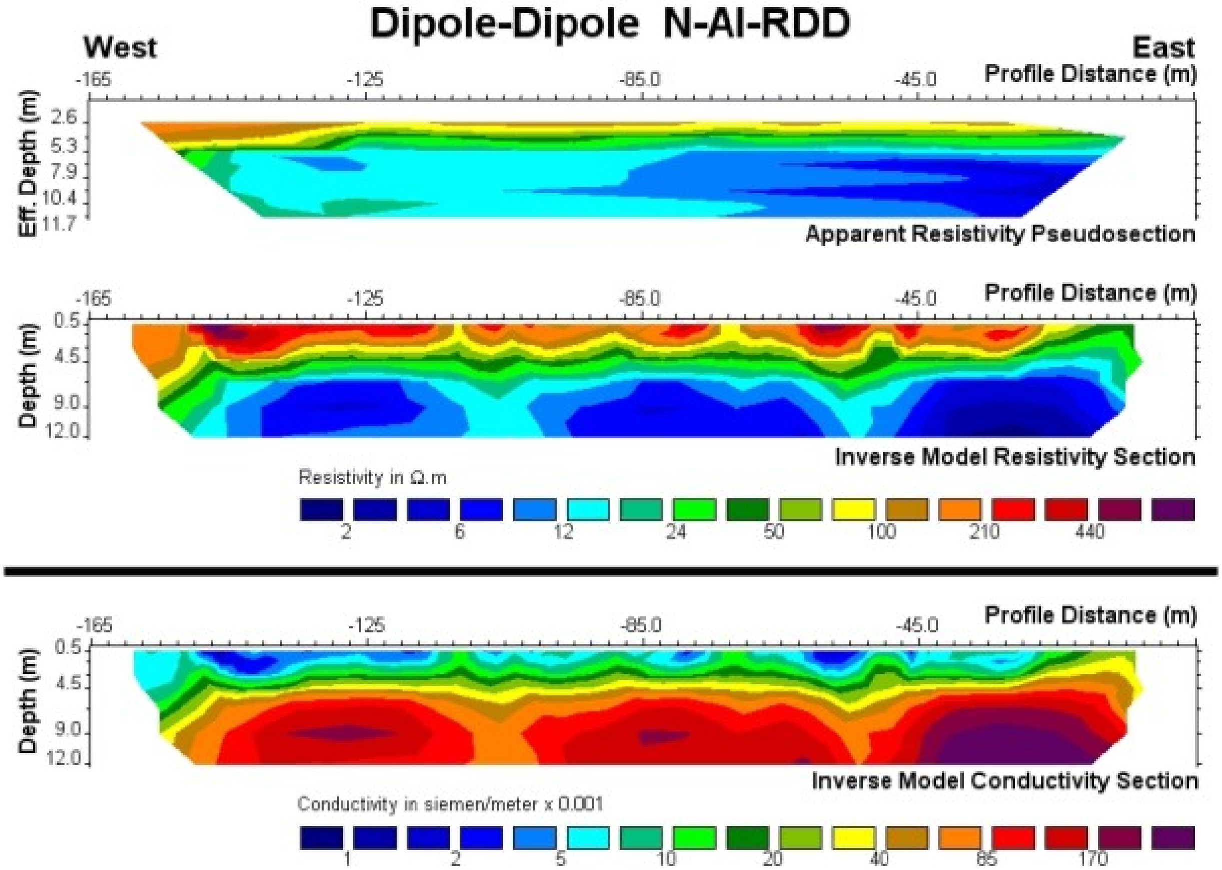


Figure 6. A dipole-dipole resistivity profile along transect KM10-04. In the bottom panel (Inverse Model Conductivity Section), the cool colors (blue and green) indicate fresh ground water, and the warm colors (orange and red) represent brackish to saline ground water. The vertical (depth) scale for this measurement has less resolution than either the EM conductivity log or the GPR profile, but the method gives excellent complementary information about the structure of the aquifer. The transition at 4.5 m depth to brackish ground water correlates well with both the GPR and well-log data. (Figure provided by G.L. Wikel.)

Electrical resistivity provides an independent, and complementary, measure of the structure of fresh and saline ground water in the surficial aquifer beneath the island. The two-dimensional resistivity profile presented in Figure 6 is from a dipole-dipole survey, which shows the continuity of the subsurface structure, but is very time-consuming to collect. This resistivity profile supports the interpretation of both the well logs and GPR profiles by showing a relatively thin layer of highly resistive materials (the equivalent of low electrical conductivity) in the upper 4 m, with a fairly abrupt transition between 4.5 and 5 m to much lower resistance materials (more highly conductive) below. This layering is interpreted as fresh ground water in sand near the surface overlying brackish to saline ground water in silt below 4.5 m.

A second type of resistivity measurement, a Schlumberger (pronounced “schlum-bear-zhay”) vertical electrical sounding (VES) was used more extensively on the island because it can be collected more rapidly – about 1 hour per sounding compared with 8-10 hours for a dipole-dipole transect – and it has greater vertical resolution. The limitations of the VES are that it represents a single vertical point rather than a two-dimensional section, and the plotted VES data are not intuitively obvious without extensive explanation. However, as with the geophysical surveys in general, sites for the VES were chosen carefully to represent end-member environments on the island, and were always done in concert with another geophysical method.

A subset of all the Schlumberger soundings, representing a wide range of hydrologic settings on and near Assateague Island, is presented in Figure 7a. The settings include the NPS Headquarters on Sinepuxent Neck, which is a late Pleistocene barrier island with stratigraphy similar to that under modern Assateague Island but with fresh ground water to depth, several sites near the center of Assateague Island with a fresh ground-water lens overlying brackish ground water, several sites with either recent or persistent seawater overwash, and one example of a subsurface hypersaline brine (beneath Pine Tree Island).

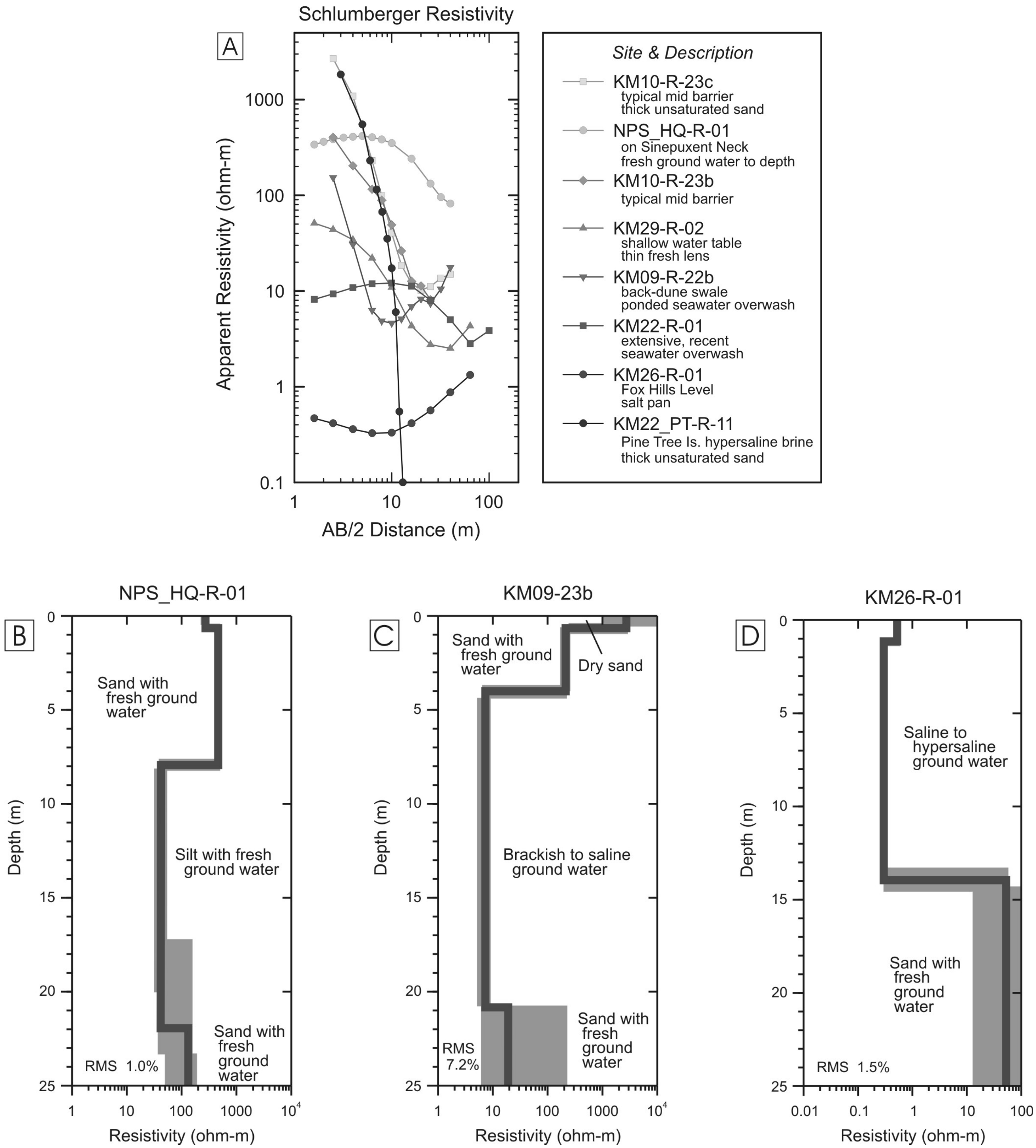


Figure 7. Representative examples of Schlumberger resistivity soundings, showing a range of distributions of ground-water salinity in the surficial and shallow confined aquifers beneath Assateague Island and Sinepuxent Neck. (A) Log-log plot of resistivity versus depth (as AB/2 distance) for eight resistivity soundings that represent conditions from completely fresh to completely saline ground water. (B) Inversion model for resistivity sounding at the NPS Headquarters on Sinepuxent Neck, with fresh ground water in a sandy upper unit and a silty lower unit. (C) Inversion model for a typical mid barrier island setting, represented by KM10, showing dry sand at the top, wet sand with fresh ground water, and a transition to brackish or saline ground water at 4 m depth; a lower transition back to fresh (or fresher) ground water in a confined aquifer occurs near 21 m depth. (D) Inversion model for a salt pan on Fox Hills Level, with saline to hypersaline ground water in the upper 14 m of the aquifer.

The data from a single sounding are plotted on log-log axes (Fig. 7a), with apparent resistivity versus a proxy for depth (AB/2 distance). In a simplified sense, the shape of each individual curve is a response to the amount of electricity that is transmitted between two electrodes through subsurface layers with different electrical properties. Some of the common layers encountered beneath Assateague Island in order from very high resistivity (very low conductivity) to low resistivity (high conductivity): dry sand, sand saturated with fresh water, silt with fresh water, and either sand or silt with saline ground water. An extreme case is the hypersaline brine beneath Pine Tree Island, which has twice the salinity of seawater and is nearly completely conductive (it acts almost like a copper wire).

To contrast two very different hydrologic settings, the resistivity curve for NPS_HQ-R-01 has high values, above 100 ohm-m, for almost the entire depth, whereas the curve for KM26-R-01, from the salt pan in Fox Hills Level, has extremely low resistivity values, generally below 1 ohm-m (Fig. 7a). The first-order effect is that the NPS_HQ site is underlain by sand saturated with fresh ground water, whereas the KM26 site has saline to slightly hypersaline ground water in the upper several meters. The downward curvature for NPS_HQ-R-01 most likely indicates fresh ground water in a layer of silt below the sand, and the upward curvature for KM26-R-01 implies fresh or nearly fresh ground water in a layer of sand deeper beneath the island.

The interpretations from the apparent resistivity curves are supported by inversion modeling of the data from each VES. Three examples are shown that represent the fresh ground water setting of Sinepuxent Neck (Fig. 7b), a typical vertical profile for the middle of Assateague Island (Fig. 7c), and the salt pan of the KM26 site (Fig. 7d). In the inversion procedure, the observed apparent resistivities with depth are back-calculated from a model that successively adds layers with different thickness and bulk resistance. Results of the models with the lowest root mean squared (RMS) error are presented graphically with a preferred solution (the dark lines in panels 7b, c, and d) and a range of possible solutions (the shaded gray areas in the same panels) where conditions change rapidly. In Figure 7, each solution is annotated with the most likely combination of sediment and ground water that would produce the layering in the inversion model.

The main point is that the individual VES curves (Fig. 7a) and the layered inversion model results (Fig. 7b, c, d) show the vertical structure of the fresh ground-water lens and underlying brackish ground water beneath sections of the island. The individual dipole-dipole transects and Schlumberger soundings were located specifically to represent end-member settings, which would become the primary map units, and the gradients within and between the primary map units, which would become the subunits and boundaries between primary units. With this approach, the characterization of aquifer conditions within representative sections of the island can be extrapolated with confidence to the entire map area.

Creating the Map Units

Because of the consistent, predictable hydrologic conditions at the end-member settings, these geomorphic environments became the six primary map units for the hydrogeomorphic map, which are: IC, Island Core; OW, Over Wash; TM, Tidal Marsh; IN, (former) Inlet; WA, Wash Around; and PD, Pond. While these primary units were not derived explicitly from the geomorphic categories of Morton et al. (2007), the two classification schemes are very similar and reflect the strong control of storm processes on forming the land surface of the island. The primary hydrogeomorphic units are further subdivided to express smaller-scale features of the island that influence the distribution of the plant communities. The map subunits reflect variations in elevation, specific features derived from the formation processes, such as overwash channels and fans, and the susceptibility of the areas to overwash or flooding by seawater.

The map was created by drawing interpretations, that is, the polygons constituting the map units and subunits, directly on printed panels from a color infrared (IR) photomosaic flown in October 1993, and provided by the GIS group at ASIS. The photomosaic is georeferenced and covers about two-thirds of the island, from the Ocean City inlet to about 1 km south of the Maryland-Virginia border (Fig. 1). Even though more recent, higher-resolution photomosaics of the island in natural color are available, this photomosaic was chosen in large part because the color IR allows distinction of subtle variations in vegetation, either cover or type, that are difficult to extract from the natural-color images. Lidar DEMs with a 10-cm contour interval (Fig. 8) were created for sections of the island from the EAARL lidar survey collected by NASA in 2002 and processed for bare-earth topography (Harris et al., 2003). Although the lidar DEMs were useful for defining dunes in the overwash area and storm ridges on the ocean side of the island core, the link between geomorphology and the hydrologic effects that control the distribution of vegetation is better expressed on the color IR image than on the lidar DEMs. For example, low-relief ridge and swale sets could be identified on the color IR but not on the lidar images. Vegetation is an effective temporal integrator of hydrologic conditions.

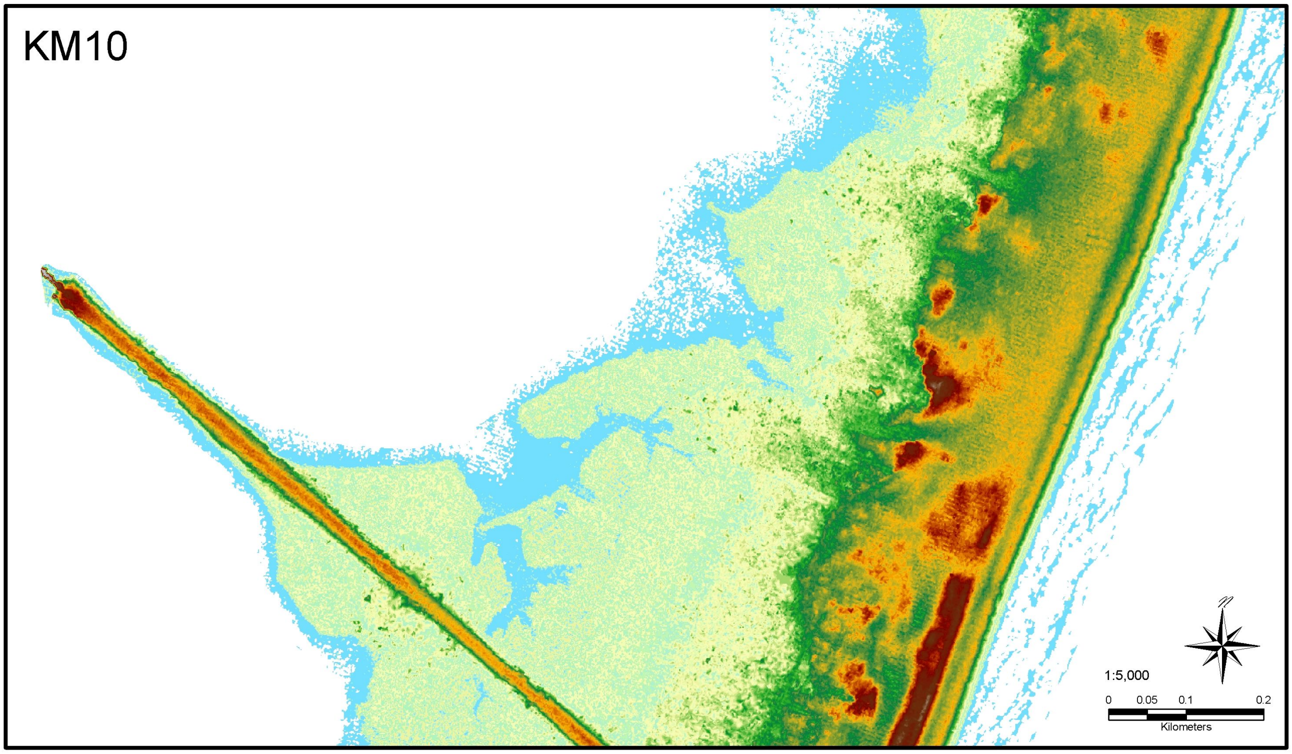


Figure 8. Example of a high-resolution DEM created from the 2002 EAARL lidar bare-earth topographic data for geophysical survey site KM10. Color contour interval is 10 cm.

As with all maps, this hydrogeomorphic map of Assateague Island is a *representation* of the actual land surface of the island. The map expresses a conceptual model, one which has been developed from numerous measurements and observations on the island, and from an evaluation of the storm processes that have shaped the island surface. The primary map units represent the end-member environments identified and quantified during the field surveys. The map subunits are a semiquantitative means of defining variations and gradients of hydrologic conditions within the primary map units. If needed by the NPS for specific projects, this classification could be applied to localized areas with more detail and greater spatial resolution. The map has considerable predictive value in explaining the distribution of plant communities, invertebrates, and vertebrates on the island, and should be tested against other independent spatial datasets.

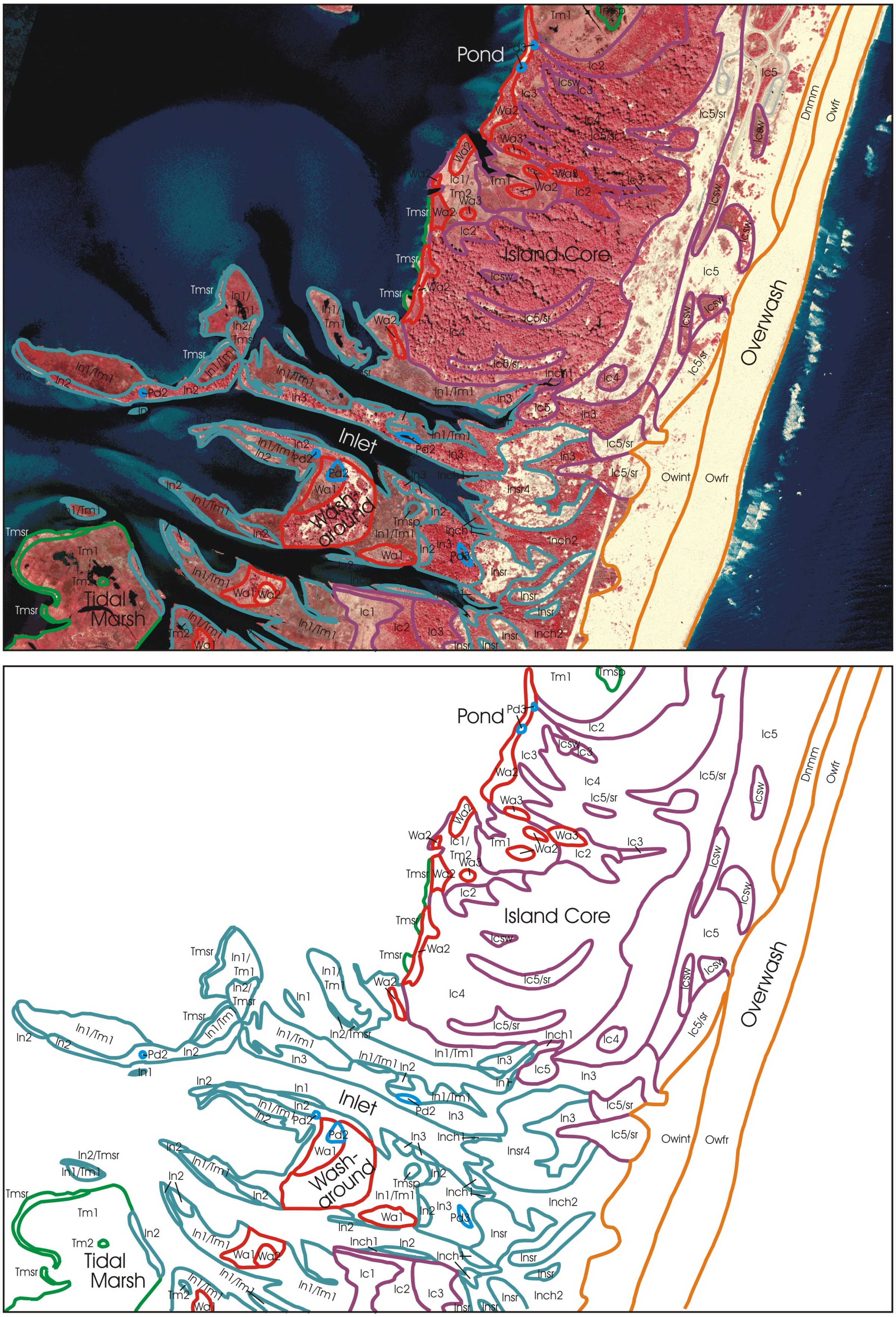


Figure 9. Section of Assateague Island showing all the primary map units. Near kilometer 16.

PRIMARY MAP UNITS

The following brief summaries describe the key features of each primary map unit and explain the dominant processes and the typical hydrologic conditions. Figure 9 shows a representative section of Assateague Island that includes all of the primary map units. Each primary map unit is further subdivided into map subunits that express variations within the primary unit. The map subunits are described and explained in the next section of the report.

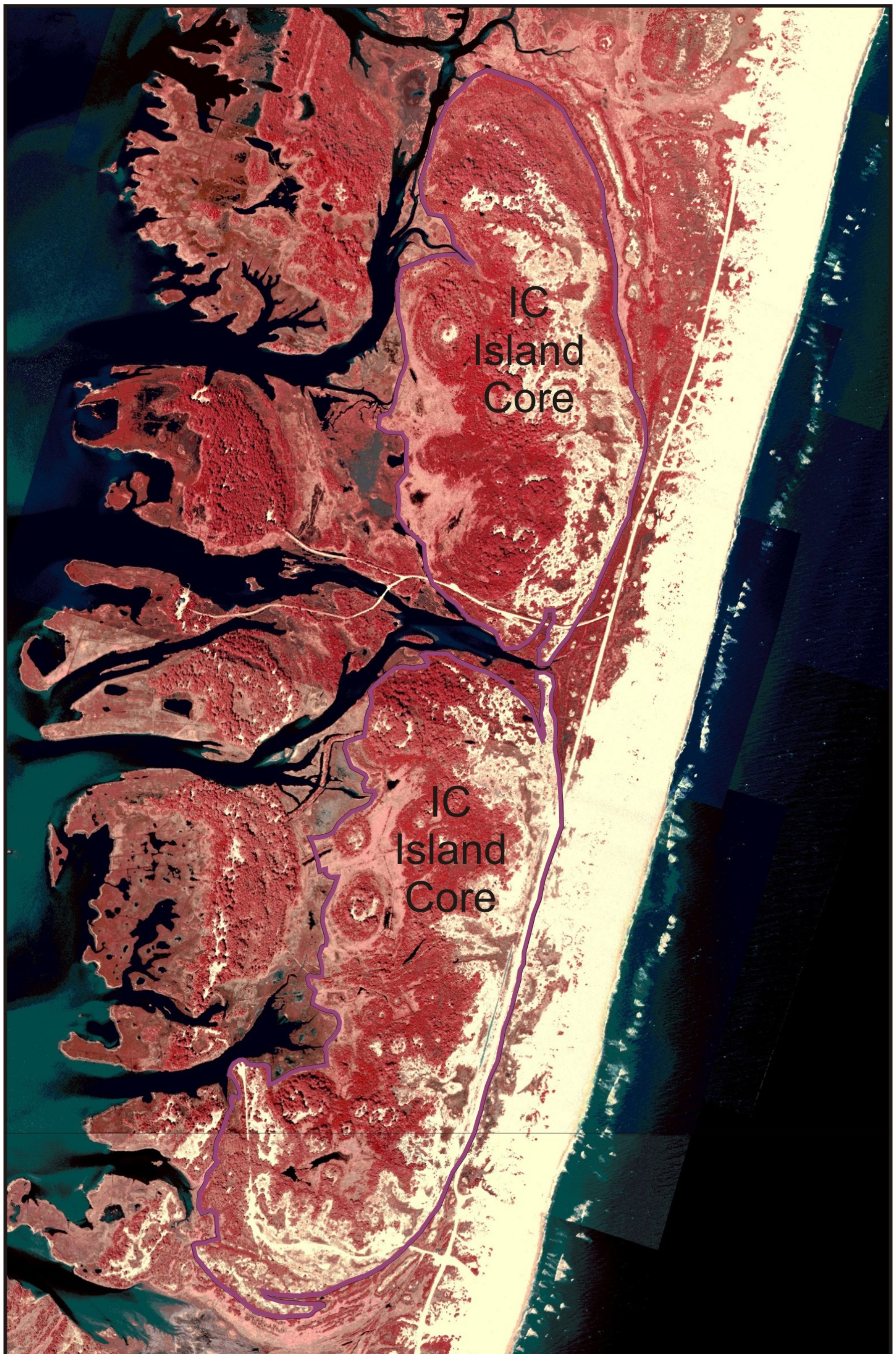


Figure 10. Representative section of the Island Core map unit, outlined with purple, between Little Level and Fox Hills Level, kilometers 19 to 24.

Island Core IC

The Island Core (IC) is the central part of the barrier island that has generally higher elevation and is typically covered by maritime forest (Fig. 10). The two most common geomorphic settings for the IC map unit are sets of recurved spits adjacent to a former inlet (Fig. 11), or an older section of the island protected on the ocean side by large storm ridges (Fig. 12). The island core lies landward/bayward of the primary dune system, and the storm ridges that protect the island core often are identified as the "secondary dunes," although the formation processes of these two landforms differ substantially. Some storm ridges exceed 4 m elevation and have thick unsaturated sands, which commonly appear as a sparsely vegetated sand ridge. Behind the storm ridges, the island core has a low slope toward the back-barrier tidal marsh and lagoon. Here the island core typically grades into the high marsh, with subtle changes of elevation on the order of 10 cm demarcated by changes in vegetation cover or assemblage. The central part of the island core has the most stable, deepest fresh ground-water lens, observed as deep as 7-8 m measured down from the land surface, and the most consistently fresh ground water. Ponds in the central island core are well protected from salt-water intrusion, permanently fresh, and particularly valuable wildlife habitat.

Figure 11. Section of the island core created as a set of recurved spits adjacent to a former inlet. Below South Beach, near kilometer 16.

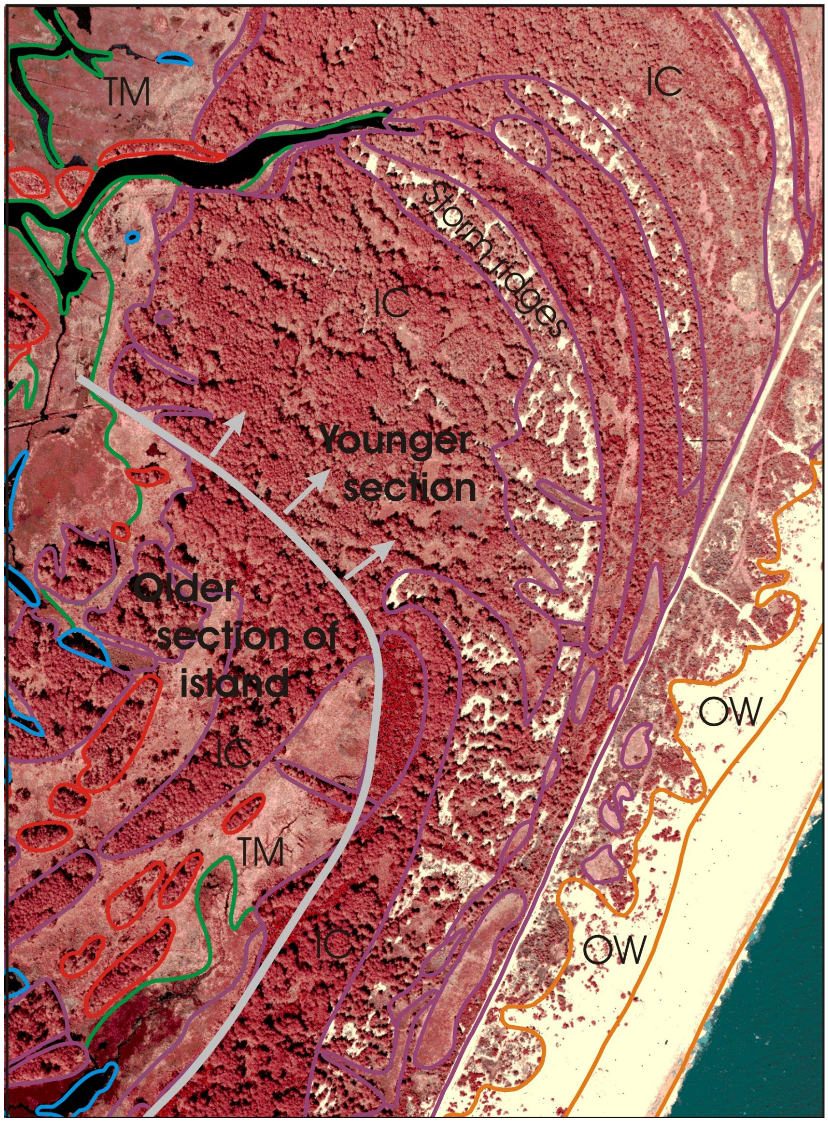


Figure 12. Section of the island core created as storm ridges wrapped around an older part of the island. Green Run Island, near kilometer 28.

Overwash OW

Overwash zones on the ocean side of the island are segregated into either frequent (OWfr) or intermittent (OWint) subunits depending upon the relative frequency of inundation with seawater. Overwash zones may cover nearly the entire width of low-lying sections the island (Fig. 13), such as in northern Assateague, or may be localized as overwash fan complexes (Fig. 14). The OWfr subunit comprises the berm and back-beach environments that receive seawater overwash during spring high tides and minor storms. The OWint subunit is delineated by near absence of vegetation and broad sheets of recently mobilized sand transported landward from the beach and berm. The OWint subunit receives seawater overwash during stronger minor storms and moderate storms, commonly once to several times a year. Overwashing seawater typically flows through low areas among the dunes, often creating channels, and will pond in swales, where the saltwater infiltrates the surficial aquifer. Ground water in the OW zone is brackish nearly year-round, and highly dynamic with the episodic input of full-salinity seawater. Vegetation in the Overwash zone is limited to those species specifically adapted to tolerate frequent inundation by seawater, persistent brackish ground water, and desiccation associated with the relatively thick unsaturated sandy soil zone.

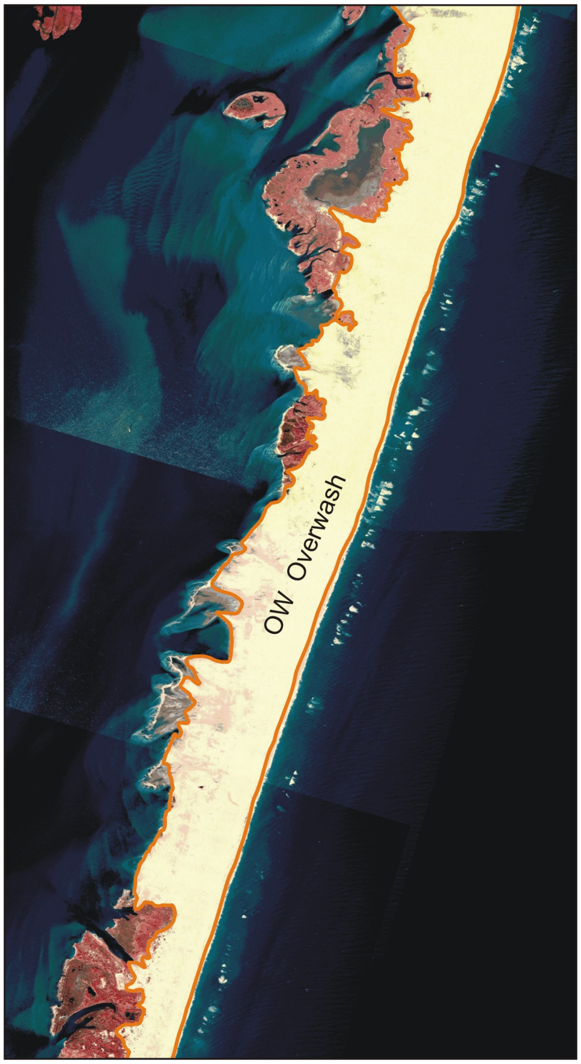


Figure 13. Area of extensive overwash, outlined with orange, that covers the entire width of the island, north Assateague, kilometers 5 to 9.

Figure 14. Overwash deposits on the seaward side of Fox Hills Level, distinguishing between frequent (OWfr) and intermittent (OWint) overwash. Near kilometer 26.

Tidal Marsh TM

One of the most extensive features on the bay side of the barrier island, tidal marshes form on the intertidal zone of the back-barrier overwash flat (Fig. 15) and on sandy islands created by the flood-tidal delta of an inlet (Fig. 16). Subtle variations in elevation are accentuated by the zonation of the salt-adapted, salt-tolerant, and salt-resistant vegetation. In most settings, the entire TM unit varies by only a few tens of centimeters with an extremely low slope. Ponds in the intertidal low marsh almost universally have saline or brackish water, which may be received either by flow through natural tidal creeks or man-made ditches, or by ponding during spring high tides and high-water events. Most ponds in the high marsh are similarly brackish but may be flushed by fresh or reduced-salinity ground water during periods with a high water table. In specific settings, salt pans in the high marsh produce hypersaline brine that sinks into the surficial aquifer. Elsewhere in former inlets, broad salt-pan areas with elevations slightly below mean high water are mostly unvegetated except for cyanobacterial mats and *Salicornia*. Ground water beneath the tidal marsh is typically brackish to fully saline, although fresher ground water recharged from the island interior may flow shallowly beneath the marsh in discrete sand beds overlain by low-permeability salt marsh peat and mud.

Figure 15. Typical Tidal Marsh setting on the back-barrier flat and adjacent low islands, outlined with green. South of main entrance road from the Verrazano Bridge, near kilometer 11.

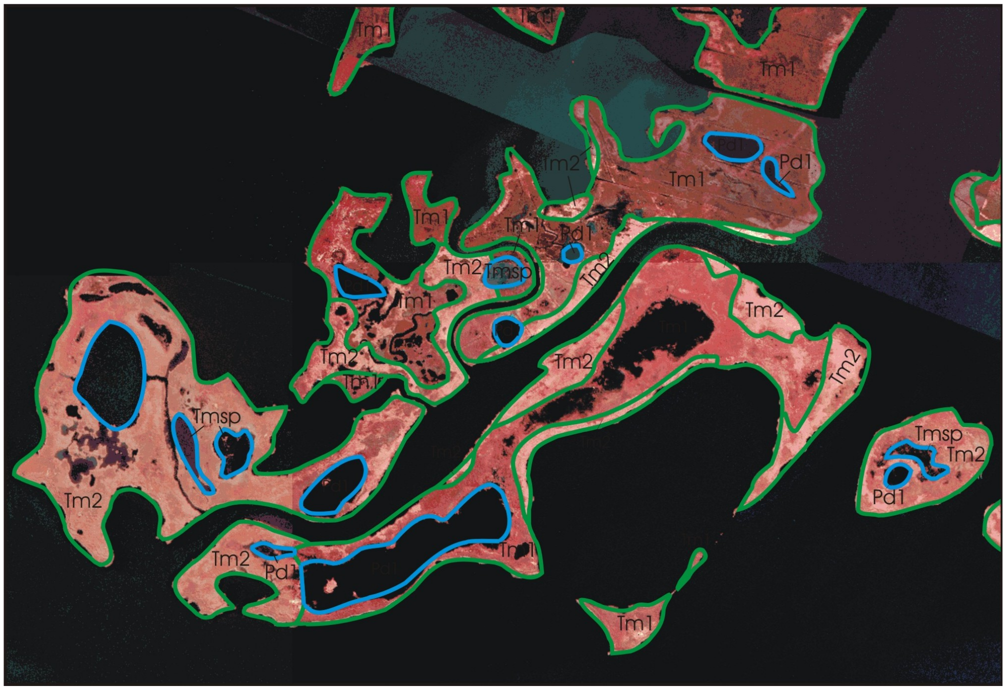


Figure 16. Tidal marsh occupying the sand bodies of the previous flood-tidal delta bayward of the historic Green Run Inlet. Middlemoor Islands, near kilometer 33. The broader view of this area is shown in Figure 2c.

[Former] Inlet IN

Assateague Island is cut extensively by former inlets, some of which were only shallow and short-lived, others were wider, deeper, and lasted longer (possibly a few hundred years). After most inlets close, they leave a low-elevation section of the island (Fig. 17), usually bounded laterally by relatively higher sand ridges or spit complexes (the Island Core map unit). At many sites, the tidal channels of the former inlet are prominent features cutting across the island and extending as deep channels into the back-barrier lagoon (Fig. 9). Associated with these cross-cutting channels are longitudinal sand ridges and lateral terraces that were created by vigorous tidal flow while the inlet was open. On the seaward side of the former inlet throat, the trace of the tributary "catchment" area of the inlet mouth is usually evident, although modified by subsequent sand transport, inlet-closure ridges, and dunes. Former inlets typically have predominantly saline to brackish ground water because these are preferential pathways for both storm overwash and subsequent ground-water flow due to the coarse, permeable channel fill. Consequently, most ponds within the IN map unit are brackish with varying degrees of flushing with fresh ground water. Vegetation in the lower-elevation sections of the IN map unit generally is equivalent to that of the low marsh and high marsh; salt-tolerant shrubs typically occupy the higher-elevation areas.

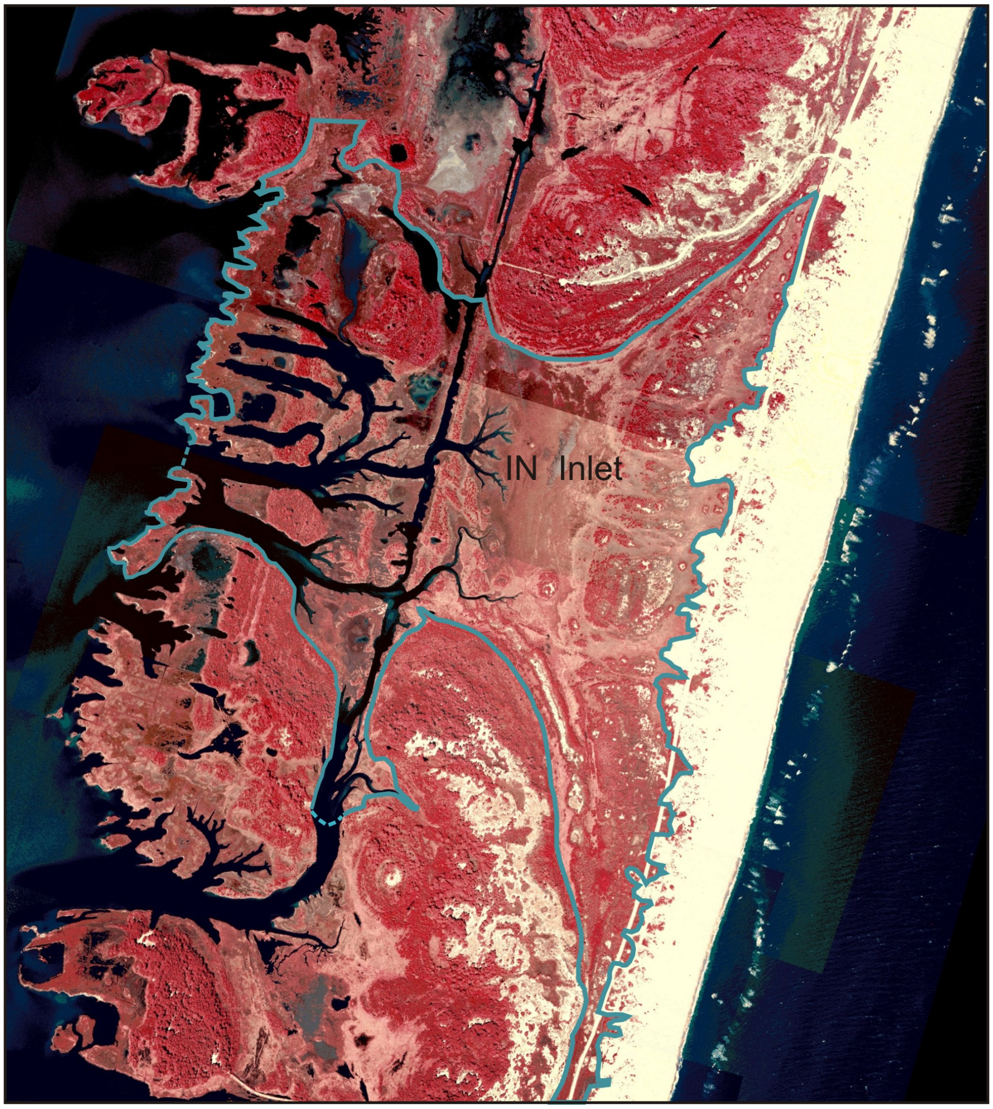


Figure 17. The low-lying section of the island at Little Level, site of a former inlet, outlined with sea green. Near kilometer 20.

Washaround WA

Washarounds are slightly higher-elevation features in the otherwise low-lying former inlets or areas of extensive overwash (Fig. 18). They were older sections of the island that have been dissected and sculpted by high-velocity flow of ocean water across the island during major storms. Washarounds characteristically have a hydrodynamically rounded or ovate form with a series of storm ridges on the seaward side of the feature, which protects the interior of the washaround. Washarounds vary in width and bayward length from a few tens of meters to several hundred meters. Many characteristics of the washarounds are analogous to the Island Core, but scaled down considerably. Vegetation is distinctly zoned, and the center of the feature may have a permanent, moderately deep (3-4 m) fresh ground-water lens. The center of the larger washarounds is covered by maritime forest with obligate freshwater plants. The plant community is steeply zoned along the seaward edges of the washaround as the elevation drops off the storm ridges. In contrast, the bayward side of a washaround is typically occupied by low-marsh grasses and high-marsh shrubs and grasses in a low-slope pocket protected by the wrapping storm ridges. Swales and ponds in the center of a washaround are mostly fresh, although they are susceptible to flooding during strong moderate and major storms.

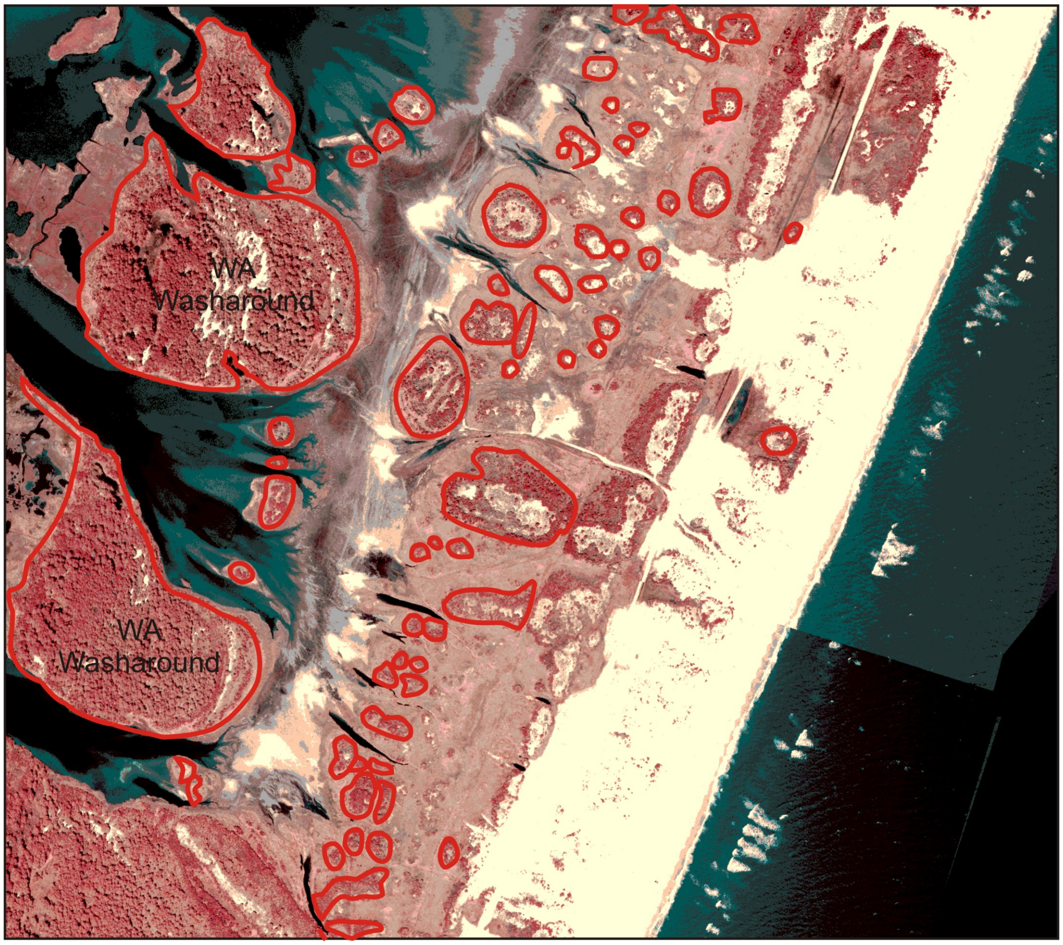


Figure 18. Large washarounds on the bay side and smaller washarounds in the center of Fox Hills Level, outlined with red. Near kilometer 27.

Ponds PD

Essentially all natural ponds on Assateague Island, and there are literally hundreds present on the island, were formed by channelized overwash flow during storms that cut below the depth of the water table (Fig. 19a). Because there are no streams on the island, other than tidal creeks in the marshes, all ponds on the island are fed by ground-water seepage, into the pond from the up-gradient end and out of the pond from the down-gradient end (Fig. 19b). Ponds are the only source of fresh water on the island for animal habitat and drinking. The character of the ponds varies dramatically depending upon the position on the island and the thickness and dynamics of the fresh ground-water lens (Fig. 20).

For the map, ponds are categorized by the relative frequency and extent of input of saltwater (Table 2), either by storm overwash from the ocean or high-water flooding from the bay. The assignment of ponds to one of the four categories is based on (1) the seasonal characteristics of pond water (specifically conductivity) as measured in eleven ponds weekly for one year by Hall (2005); (2) a broader qualitative survey of ponds observed while conducting field work that focused mostly on the vegetation in and around the ponds – for example, ponds rimmed by *Spartina alterniflora* are always brackish, those with *Typha* are predominantly fresh; (3) observations of saltwater flow into ponds associated with overwash produced by two moderate storms during the period of study; and (4) position of the pond relative to the primary map units (Fig. 20) – for example, PD4 is found almost exclusively near the center of either the Island Core or the larger Washarounds, whereas PD1 generally is found in Tidal Marsh or Inlet settings.

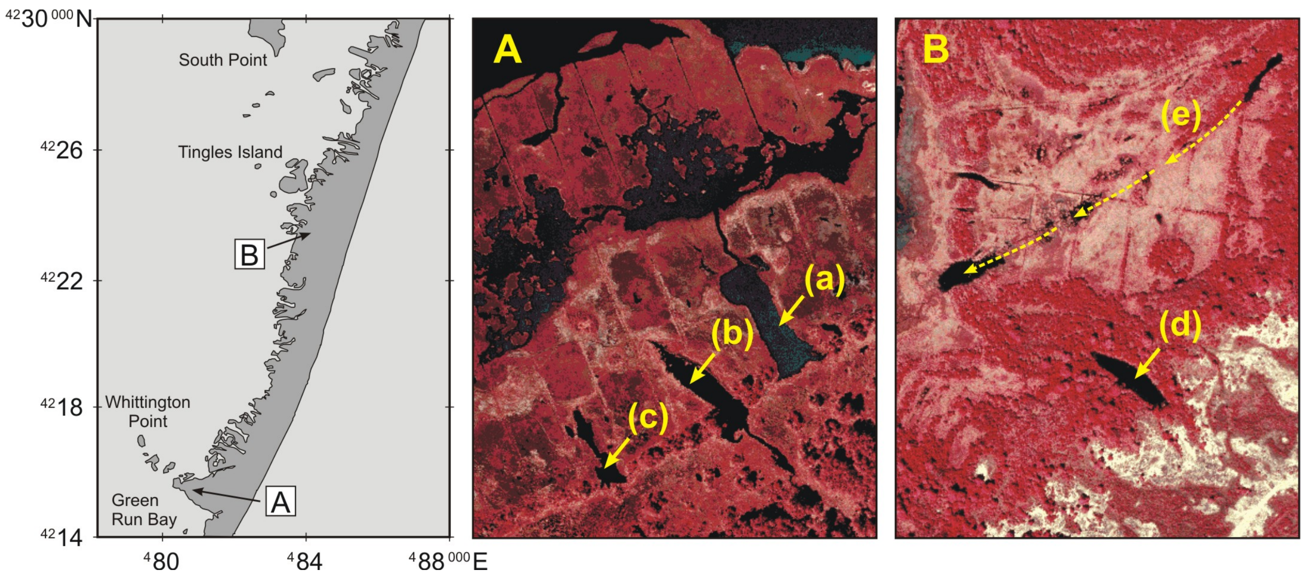


Figure 19. Examples of ponds on Assateague Island. (A) Three ponds (a, b, c) cutting across the high marsh on the bay side of Green Run Island. All three clearly were cut by channelized overwash flow. Pond (a) is connected to the brackish water of Chincoteague Bay by a narrow tidal creek. (B) Similar ponds associated with older washarounds, and also created by vigorous storm overwash flow. Pond (d) has no stream connections through the marsh. The series of ponds labeled (e) illustrate the down-gradient connection by ground-water flow among ponds in a swale.

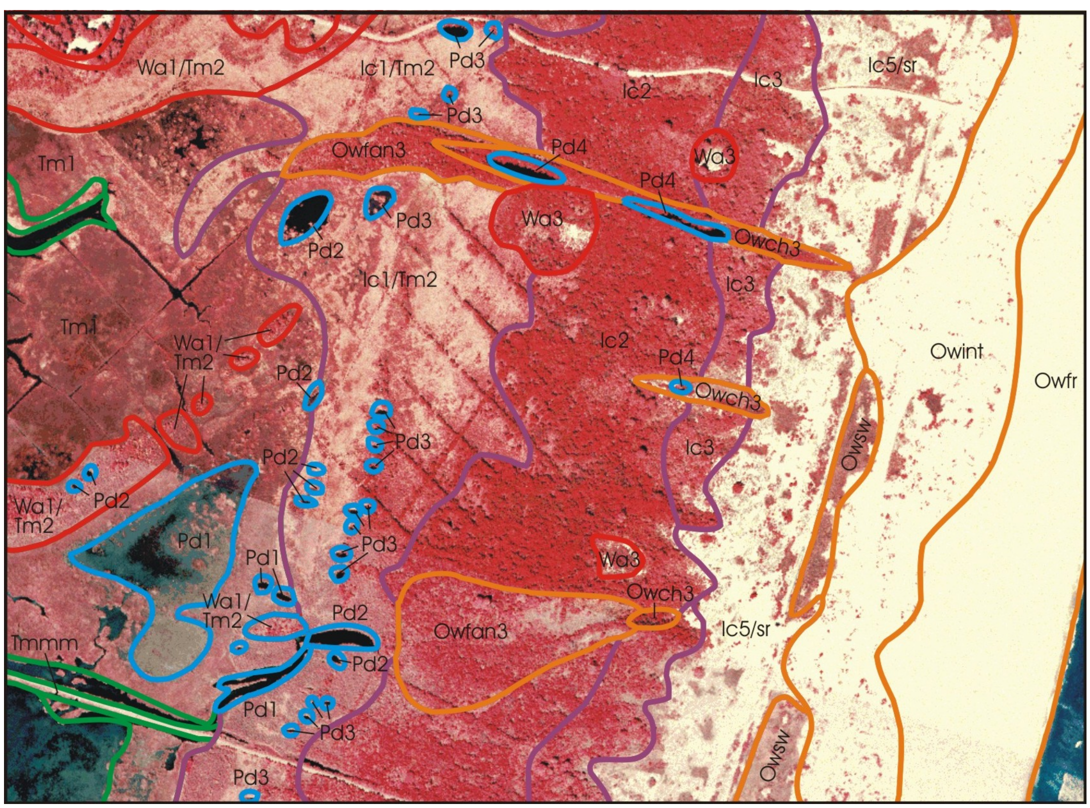


Figure 20. A diversity of ponds representing the entire range from completely fresh (PD4) to completely brackish or saline (PD1). Because all ponds on Assateague Island receive water from ground water, the salinity characteristics of the pond reflect the relative degree of protection from seawater overwash or flooding as related to geomorphology and position on the island.

Table 2. General classification scheme for ponds based on characteristic salinity.

PD1	always brackish to saline
PD2	usually brackish, may freshen from ground-water input during wet periods
PD3	usually fresh, infrequent input of brackish to saline water either from direct overland flow or from input of brackish ground water from up gradient
PD4	protected ponds that remain fresh, these are particularly important for wildlife

DEFINING THE MAP SUBUNITS

Within each primary map unit, the designations are refined further using numerical (1-4, or 1-5) and/or character suffixes. In general, the numerical suffixes grade from lower elevation (1) to higher elevation (4 or 5) within a primary map unit. However, the numerical suffixes do not indicate elevation alone, but also the degree of protection from seawater overwash or flooding by high water. Low but broad sections provide greater protection to the island interior than narrow sections of the same absolute elevation. Similarly, a relatively low-elevation area mostly surrounded by ridges, particularly on the ocean side, is better protected than an exposed area of equivalent elevation. As an example, many areas of the OWint (Overwash intermittent) subunit are actually higher elevation than the well-protected IC3 (Island Core 3) areas of the island interior.

Character suffixes are abbreviations for specific landforms, for example, *ch* for channel, *sp* for salt pan, and *sw* for swale. All suffixes used in the map are identified in Table 3. Numerical and character suffixes within cells relate elevation (the number) and specific landforms (the abbreviation), for example, a moderately high sand ridge associated with an old inlet may be categorized as IN3sr. Equivalencies are made between map subunits by reading across rows in the table. In some cases, especially for gradational changes on the island, a particular section will be classified as two different but essentially equivalent map units, for example, the classification of IC1/TM2 is applied where the bayward side of the island core (IC1) grades into the high marsh (TM2).

Two equivalent map subunits share the same or similar characteristics for elevation, hydrology, and degree of protection from overwash or flooding. Consequently, equivalent subunits generally have the same vegetation cover and assemblage. The distinction between equivalent subunits arises from the geomorphic setting and the processes of formation. To extend the example used above, the high marsh subunit TM2 appears in several different geomorphic settings: on the bayward side of the island core (IC1) or larger washarounds (WA1), intermediate elevations in former inlets (IN2), and higher ridges on marsh islands (TM2) such as those of former flood-tidal deltas. As correlated across the row in Table 3, the compound identifiers for the map subunits to categorize these examples are IC1/TM2, WA1/TM2, IN2/TM2, and simply TM2 (for the marsh island), respectively.

For the classification of ponds, the equivalencies in Table 3 indicate the map units that most commonly enclose a pond with a given numerical suffix. For cases where a pond straddles the boundary between two units, the pond will receive ground water from the higher-elevation, up-gradient area, which controls the salinity characteristics of the pond.

Table 3. Map units, suffix modifiers, and equivalencies.

Island Core	**Washaround**	**Former Inlet**	**Tidal Marsh**	**Pond**	**Overwash**
IC	WA	IN	TM	PD	OW
		1 / sp	1 / fl	1	
1	1	2 / ch, sw	2 / sr	1	fr / 1 ch
1	2	3 / sr		2	int / 2 ch, sw
2	2 / 3			3	3 ch, fan
3	3			3 / 4	
4	4 / sr			4	
5 / sr				n/a	DNmm

Numerical suffixes:
Within a primary map unit, such as IC, numerical suffixes range from lowest elevation (1) to highest elevation (4 or 5).

Abbreviated suffixes:

ch channel	fr frequent (overwash)
fl flat, tidal	int intermittent (overwash)
sp salt pan	fan overwash fan
sr sand ridge	
sw swale	mm man-made
wt wetland	DNmm man-made dune

Equivalent map subunits are read across rows, for example, an area of high marsh on the bay side of a washaround may be categorized as WA1/TM2. Pond subunits defined in Table 2 correlate with the geomorphic map subunits that enclose the pond, for example, PD3 most commonly occurs within IC2 or IC3.

Categories for Storms and Vegetation

Qualitative descriptions of the strength of coastal storms and the adaptation of plant species to salinity are used in the explanations of the map subunits. These factors relate the dominant processes of storm overwash and flooding to the resulting form of the island surface, the salinity dynamics of ground water in the surficial aquifer, and the distribution of individual plant species and plant communities on the island. Detailed quantification of storm processes or the salt tolerance of plants was not a focus of this mapping project, although it may be a goal of future field study to evaluate the relations implied by the map. The following tables define the categorical terms used in this report to describe storm intensity and salt tolerance of plants.

Table 4. Categories of storm intensity.

	Beaufort Scale descriptor	**Maximum wind speed**
Minor	Near Gale	33 knots / 61 km/hr
Moderate	Gale	40 knots / 74 km/hr
Major	Strong Gale	47 knots / 87 km/hr
	Storm	>48 knots / >89 km/hr
	Hurricane	>64 knots / >118 km/hr

Table 5. Categories of storm effects.

	Water height	Recurrence	Comments
Minor	0 to 0.5 m above MHW	once to several times per year	Most common Oct-Mar; floods high marsh and scrub fringe; active flow across OWfr areas.
Moderate	0.5 to 1.5 m	once every 2-5 years	Active flow into OWint areas; extensive back-barrier flooding.
Major	>1.5 m above MHW	once every 10-50 years, depending upon magnitude	Extent of overwash depends on magnitude; most low-lying areas completely washed over; seawater may flood edges of island core and washarounds.

Table 6. Categories of salt tolerance in plants.

	Representative taxa	Comments
Salt-adapted	*Spartina alterniflora*	Predominant grass of salt marsh, flourishes in constant exposure to saltwater.
Salt-tolerant	*Spartina patens* *Distichlis* *Juncus* *Baccharis* *Iva*	Predominant plants of the high marsh and scrub transition; able to withstand flooding of several days and persistent brackish ground water.
Salt-resistant	*Myrica* *Panicum* *Juniperus* *Phragmites*	Predominant plants of the scrub community between the high marsh and upland; also ocean-side swales that receive seawater overwash intermittently.
Freshwater-obligate	*Pinus taeda* *Acer* *Prunus* *Smilax* *Vaccinium* *Vitus* *Toxicodendron*	Predominant plants of the maritime forest; not able to withstand flooding by seawater; spatial distribution limited by shallow brackish ground water.

Plant species	Common name
Acer rubrum	red maple
Baccharis halimifolia	eastern baccharis
Distichlis spicata	saltgrass
Iva frutescens	Jesuit's bark
Juncus roemerianus	needlerush
Juniperus virginiana	eastern redcedar
Myrica cerifera	wax myrtle
Panicum amarum, virgatum	switchgrass, panic grass
Phragmites australis	common reed grass
Pinus taeda	loblolly pine
Prunus virginiana	common chokecherry
Smilax rotundifolia	green briar
Spartina alterniflora	salt marsh cordgrass
Spartina patens	salt meadow cordgrass
Toxicodendron radicans	poison ivy
Vaccinum angustifolium	lowbush blueberry
Vitus rotundifolia	wild grape

Island Core

Subunits IC3 and IC4

Island Core subunits IC3 and IC4 are generally the higher-elevation section of the island (Figs. 10-12, 21), but more important they are protected from overwash even during moderate storms. General characteristics for all the Island Core subunits are summarized in Table 7. In many settings, subunits IC3 and IC4 are protected on the seaward side by a single large ridge – usually an IC4 or IC5 feature – or by a series of moderately high ridges. Elevations for IC3 are generally 1 to 1.5 m above sea level, with ridges in the range of 1.5 to 2 m. Swales within IC3 may be as low as 0.5 m, but are protected from saltwater flooding by the surrounding high ground, and usually are occupied by freshwater wetlands or seasonal ponds. The vegetation within swales differs from the surrounding maritime forest by adaptation to hydric soils, that is, soils that are water saturated throughout most or all of the year. Elevations within subunit IC4 are commonly 1.5 to 2 m, and ridges, which are a prominent component of this feature, are upwards of 2 m. The IC4 areas are covered by the oldest-growth and most diverse maritime forests on the island, largely due to the depth and stability of the fresh ground-water lens. The maximum observed thickness of the fresh lens is 7-8 m, which is much shallower than predicted by theoretical considerations but limited in depth by the low permeability lagoonal silt layer that underlies much of the island. Many of the IC4 areas appear to have been relatively protected during the 1962 Ash Wednesday storm, one of the two most devastating storms of the 20th century for Assateague Island. Many of the prominent storm ridges that isolate the island core from the overwash areas were either created or enhanced during the 1962 storm.

Subunit IC5

Island Core subunit IC5 differs from IC4 primarily in the thickness of the unsaturated (i.e., dry) soil zone and the sparsity of vegetation (label [e] in Figure 21b), in particular trees and shrubs. *Hudsonia*, beach heather, may have a scattered distribution across the largely barren surface of the IC5 subunit. In most cases, the IC5 subunit is a high-elevation ridge created by one or more storms and subsequent aeolian processes. Elevations of IC5sr sand ridges commonly exceed 2.5 m and may be as high as 4.5-5 m. A second, non-natural setting for IC5 is landward of the high man-made dune (subunit DNmm) that fronts the island section from about kilometer 10 through kilometer 16, encompassing the Maryland State Park and the camping area of the National Seashore south to the cross-over road for off-road vehicles. The man-made dune is so effective at restricting overwash that the ground water in the seaward section of the island that otherwise would be categorized as subunits OWfr and OWint is fresh or only slightly brackish rather than brackish to saline.

Subunits IC1 and IC2

On the bayward side of the central island core, the island surface slopes gradually into the back-barrier tidal marsh. Subunits IC1 and IC2 span this transition, and in many cases will have a compound identifier such as IC1/TM2 (label [h] in Figure 21b). Geomorphically, this slope is the bayward section of the overwash sheet or a platform of amalgamated overwash fans that is slightly above mean high water, with elevations of 0.25 to about 1 m. Subunit IC2 is protected from saltwater intrusion except during intense moderate and major storms. In contrast, subunit IC1 may be flooded during strong minor and moderate storms. In the subsurface, the fresh ground-water lens that recharges in the central island core begins to shallow substantially, from 2-3 m thick beneath IC2 to generally less than 1.5 or 1 m under IC1. The vegetation is similarly zoned in response to the thickness of the fresh lens and the frequency of inundation by seawater. Vegetation of IC2 is a scrubby mixture of salt-resistant plants and pioneering freshwater plants. Trees generally do not attain full size. Vegetation grades across IC1 from salt-resistant (*Myrica*, *Juniperus*, *Phragmites*) to salt-tolerant (*Juncus*, *Baccharis*, *Iva*) toward the tidal marsh.

Ponds within IC1 but closer to the IC1-IC2 boundary are typically categorized as PD3, predominantly fresh with occasional brackish periods. For these ponds, substantial fresh ground-water flow from the island core will flush any intruded saltwater relatively quickly. Ponds toward the tidal marsh side of

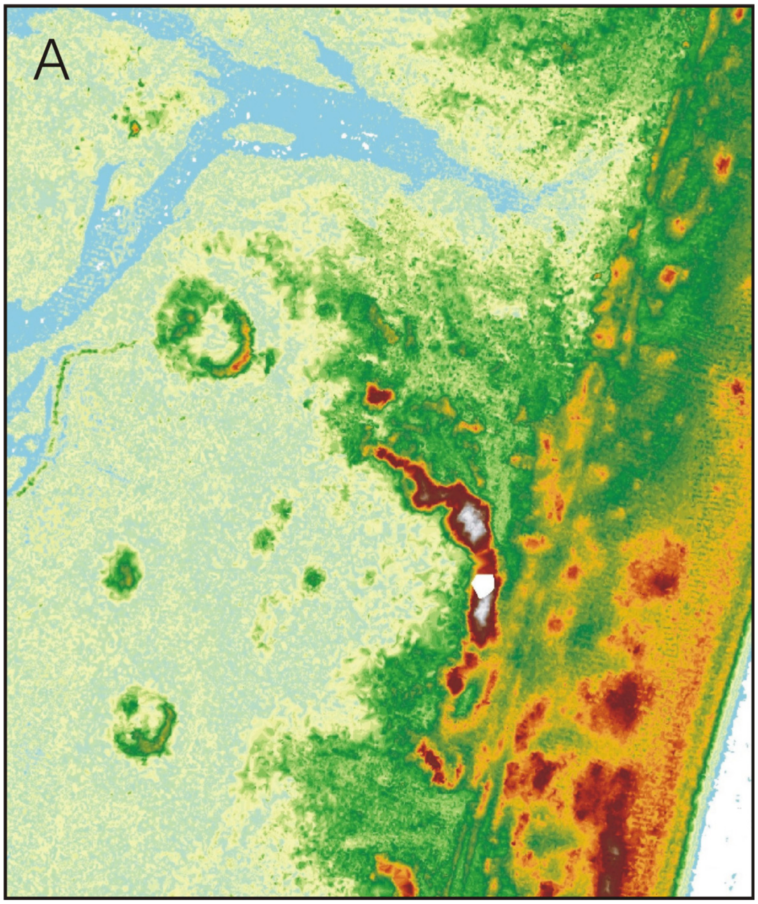


Figure 21. Subunits of the Island Core. Part of the view shown in Figure 10, near kilometer 23; access road to Pine Tree Island appears at the top of the scene. (A) Lidar DEM of the scene. (B) Color infrared aerial photograph without polygons or identifiers of map subunits; letter labels are used in the text for explanation of features. (C) Map subunits for Island Core and associated features.

IC1 are categorized as PD2 since they are more likely to be flooded with saltwater and typically are brackish except during wet periods with a high water table on the island.

In a few sections of the island, subunit IC2 appears on the seaward side of the central island core, or laterally adjacent to former inlets (primary map unit IN), as low-relief sets of ridges and swales created by storms. The ground-water hydrology of this type of IC2 area may differ from a bayward IC2 in that the up-gradient ground water is likely to be coming from the landward side of the overwash zone and would be brackish. Additionally, ridges and swales within this IC2 setting often have markedly different vegetation because each ridge may protect a narrow, shallow fresh lens isolated from the immediately adjacent brackish ground water.

Subunit ICmm

Man-made features such as causeways, dikes, or spoils piles in the back-barrier may be high enough above the tidal marsh that they have characteristics of the IC1 or IC2 subunits.

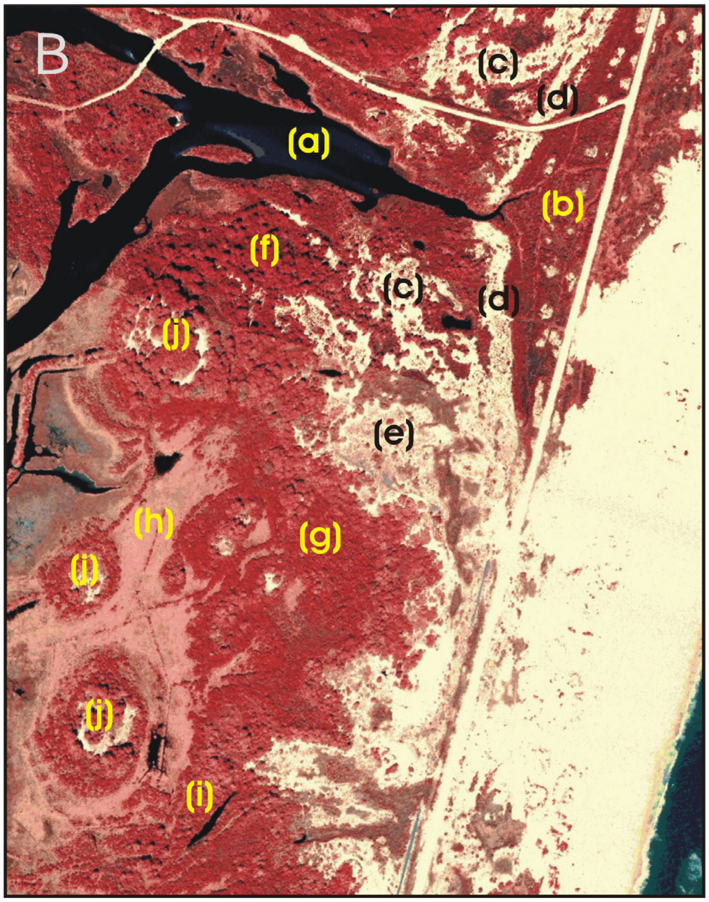


Figure 21b.

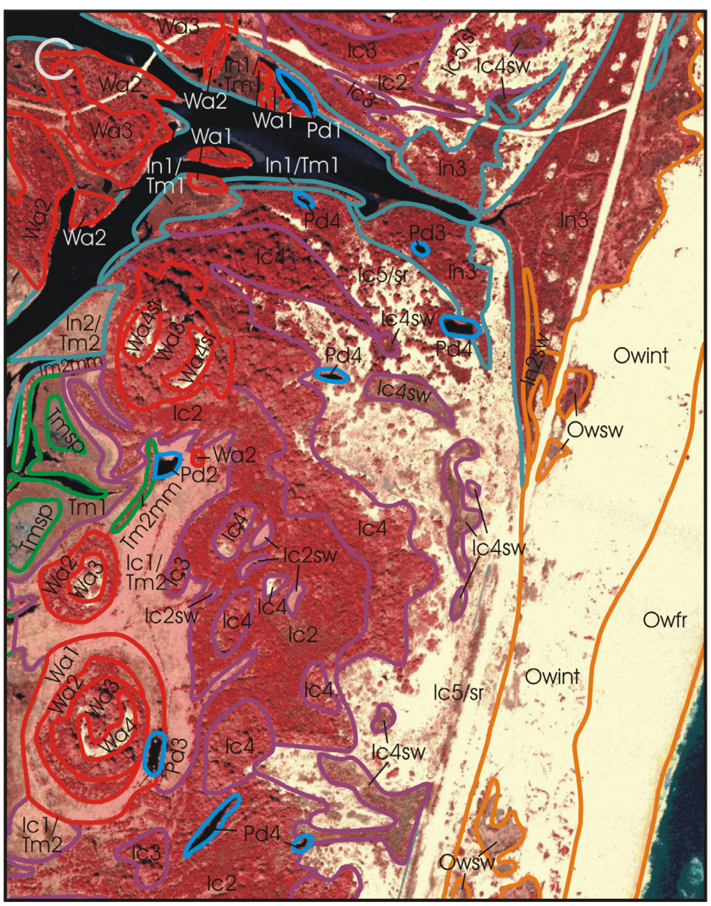


Figure 21c.

Distinguishing Island Core subunits

The scene presented in Figure 21 shows two sections of the island core that developed on either side of a small inlet that is now closed. The broader view of this area is shown in Figure 10. The single inlet channel, label (a) in Figure 21b, remains as a deep channel that connects with Chincoteague Bay but is cut off by sand ridges on the ocean side. The former inlet mouth, label (b), remains as a broad, fan-shaped low area on the seaward side of the inlet channel; the active overwash sheet is encroaching on and filling this low area. Sets of spits on either side of the inlet channel (two [c] labels) were formed by capture of longshore sand transport and diversion into the inlet when the inlet was open and active. A narrower and lower, but distinct, set of two spits (d) appear to have formed as the last stage in the closure of this inlet. The largest and highest ridge to the south of the inlet (e), as shown by the lidar DEM (Fig. 21a), formed earlier in the history of the inlet when the channel was relatively wider. The size of this large ridge may have been enhanced by aeolian transport, as suggested by what may be a wind-deflation bowl on the bay side, in the area of label (g).

The three prominent ridge sets, (c), (d) and (e), on the ocean side protect lower-lying sections of the island core to the west, areas (f) and (g), from storm surge and overwash, allowing growth of a mature maritime forest (f) and mixed forest and scrubland (g). Ponds in this protected area, such as (i), are perennially fresh and classified as PD4.

The bayward side of the island core was the former back-barrier overwash flat that is now occupied by high marsh (h), with the compound classification of IC1/TM2. Slightly higher elevation washarounds (three [j] labels), which were created before the ridge sets formed on the seaward side, are hummocks of mixed forest and scrubland in the high marsh behind the main body of the island. These three moderately large washarounds suggest a previous stage for this section of the island that was similar to the low area of Fox Hills Level today. Each washaround shows a zonation of elevation and vegetative cover, categorized as WA1 through WA3. High, presumably dry, sparsely vegetated ridges on two of the washarounds are classified WA4.

Table 7. Subunits and characteristics of the Island Core map unit.

Subunit	**Elevation**	**Relative frequency of saltwater input**	**Thickness of fresh ground-water lens**	**Vegetation**	**Geomorphic setting**
IC5	highest; 2.5-5 m	only during major storms	7-8 m (max observed) thick unsaturated zone	sparse, freshwater obligate, resistant to aridity	highest elevation ridges assoc. with recurved spits or storm ridges
IC4	1.5-2 m ridges to 3 m	only during major storms	6-8 m (max observed) mod thick unsaturated zone	maritime forest, freshwater obligate	sets of recurved spits or storm ridges
IC3	1-1.5 m ridges to 2 m	during strong moderate and major storms	3-6 m	maritime forest & scrubland, freshwater obligate	older island section, protected by ridges on ocean side
IC2	0.5-1 m	during moderate and major storms	2-3 m	scrubland with salt-resistant plants	back-barrier overwash platform or spit platform
IC1	0.25-0.5 m	during strong minor and moderate storms	1-2 m	mixed scrubland & grassland, salt tolerant.	back-barrier overwash platform or spit platform

Table 8. Subunits and characteristics of the Overwash map unit.

Subunit	**Elevation**	**Relative frequency of saltwater input**	**Thickness of fresh ground-water lens**	**Vegetation**	**Geomorphic setting**
OWfr	0-2 m, dunes higher	receives overwash several times per month; spring high tides, minor storms	always brackish to saline	none, or pioneering beach/dune assemblage	most active overwash across and behind berm
OWint	0.5-2 m, dunes higher	receives overwash several times per year; strong minor & moderate storms	alternates between shallow fresh and completely brackish	beach/dune assemblage, *Ammophila, Cakile, Solidago, Amaranthus*	overwash sheet and channels through dunes
OWsw	0.5-1 m	receives overwash several times per year; strong minor & moderate storms	alternates between shallow fresh and completely brackish	salt-tolerant grasses *Spartina patens, Juncus, Panicum*	low areas of mouths of former inlets or overwash channels

Overwash

Subunit OWfr (frequent)

In sections of the island that are not experiencing severe erosion, the beach and back-beach environments accrete vertically and prograde seaward between storms, creating the berm. The crest of the berm may be 1.5 to 2 m above mean sea level (Table 8), and the height is influenced by wave action during successive spring high tides and minor storms. The island surface slopes gently landward away from the berm crest, in part because of the progressive loss of velocity of overwashing waves and in part because of the deflation caused by removal of fine sand by aeolian (wind) processes. The landward limit of this area may be marked by the primary dunes, either natural or man-made, but in many places on Assateague Island it simply grades into the larger overwash sheet created by the stronger storms that carried beachface sands farther toward the island interior. This OWfr subunit receives overwashing seawater regularly, during periods of spring high tide with moderate wave action, and from the water-level set-up and wave action of minor storms. The ground water from this subunit drains back toward the ocean, and remains brackish to fully saline.

In low-lying sections of the island such as northern Assateague, the OWfr subunit extends considerably farther landward and may cover the entire width of the island (Fig. 13). It is likely that these sections of the island retain brackish ground water perennially, with only minor mixing and freshening from precipitation.

Subunit OWint (intermittent)

The stronger minor and moderate storms have created a broader overwash sheet than that described for the OWfr subunit. Reworking of the sand sheet by wind creates the secondary dune field, which is included in this map subunit. Where the primary dunes exist, the OWint deposits extend landward through breaches in the dunes that were cut by channelized overwash flow during storms. In these settings,

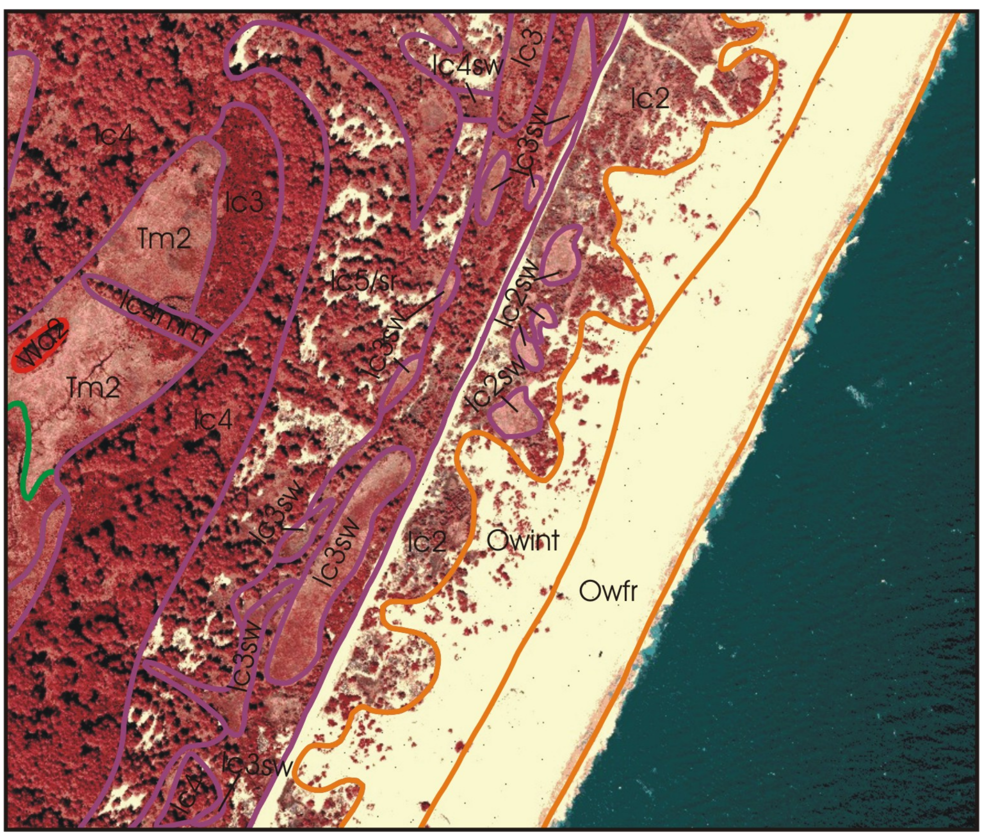
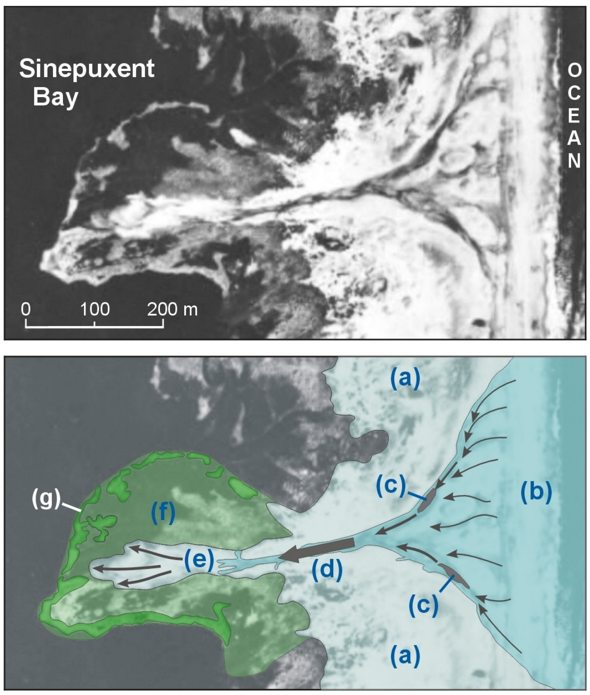


Figure 22. Ocean-side swales that receive seawater overwash intermittently. In this area, they are classified as IC3sw or IC2sw depending upon the relative frequency of inundation by seawater. These swales have a unique salt-tolerant grass community dominated by *Spartina patens*, *Distichlis*, and *Juncus*. This scene is from the southern part of Figure 12, near kilometer 29.

active overwash will follow low-lying paths through the primary dunes into the secondary dune field. As the surface flow loses momentum, seawater will pond in swales where it infiltrates into the surficial aquifer over the following days. This recharge of saltwater mixes with and pushes out any fresh ground water, then the brackish ground water flows down gradient in the subsurface. By this process, down-gradient ponds and wetlands receive brackish ground water, although with a lag time of days to weeks after the storm.



Explanation
(a) extent of overwash from most recent storm
(b) catchment area for channelized overwash
(c) deeply scoured section of overwash channel
(d) convergence of overwash flow
(e) distributary flow and deposition to form fan
(f) washover fan from previous storms
(g) reworking of washover sands by waves

Figure 23. A complete, isolated overwash system that was active during the March 1962 northeaster storm, showing the catchment area with tributary flow on the ocean side, convergence to a single deep channel, then deposition of transported sand and distributary flow on the bay side.

The swales that receive overwashing seawater several times a year tend to have a distinct salt-tolerant grass community dominated by *Spartina patens*, *Juncus*, and *Panicum*; this plant community has a unique visual appearance in the color IR images (Fig. 22). More generally, vegetation in the OWint subunit is sparse and limited to those taxa specially adapted to the harsh conditions that alternate between inundation by seawater and desiccation because of the thick unsaturated zone. These overwash areas are the habitat for American beach grass (*Ammophila breviligulata*), sea rocket (*Cakile edentula*), and the Federally-listed Threatened seabeach amaranth (*Amaranthus pumilus*), which colonize organic wrack and incipient dunes.

Subunits OWfan, OWch, and OWsw

A typical overwash system has a seaward splay of shallow tributary channels crossing the berm and back-beach flat that converge into a single channel cutting across the center of the island (Fig. 23). If there is sufficient sustained water flow during the overwash event, the system spreads out in a distributary fan on the back-barrier flat or produces a small delta prograding into the lagoon itself. The deepest incision occurs at the channel throat where overwash flow converges, and this deepened trough is commonly preserved as a pond after the storm event. In the following months or years, aeolian transport of the exposed sand of the overwash sheet often fills or smoothes over the shallower, upstream channels of the tributary catchment area. Existing overwash channel systems are likely to be reoccupied during subsequent storms until the seaward catchment area is mostly filled with sand. Consequently, many overwash fans show several depositional lobes from successive storm events.

Overwash fans that were produced relatively recently, within the past 100 years or so, often are discernible on the island surface as discrete geomorphic features (Fig. 24). With time and subsequent storms, the sand deposited in older overwash fans is reworked and smoothed out by both wind and flowing water. In most areas, the body of the barrier island is actually a platform sloping gently toward the bay created by the coalescing of many overwash fans or a broader overwash sheet.

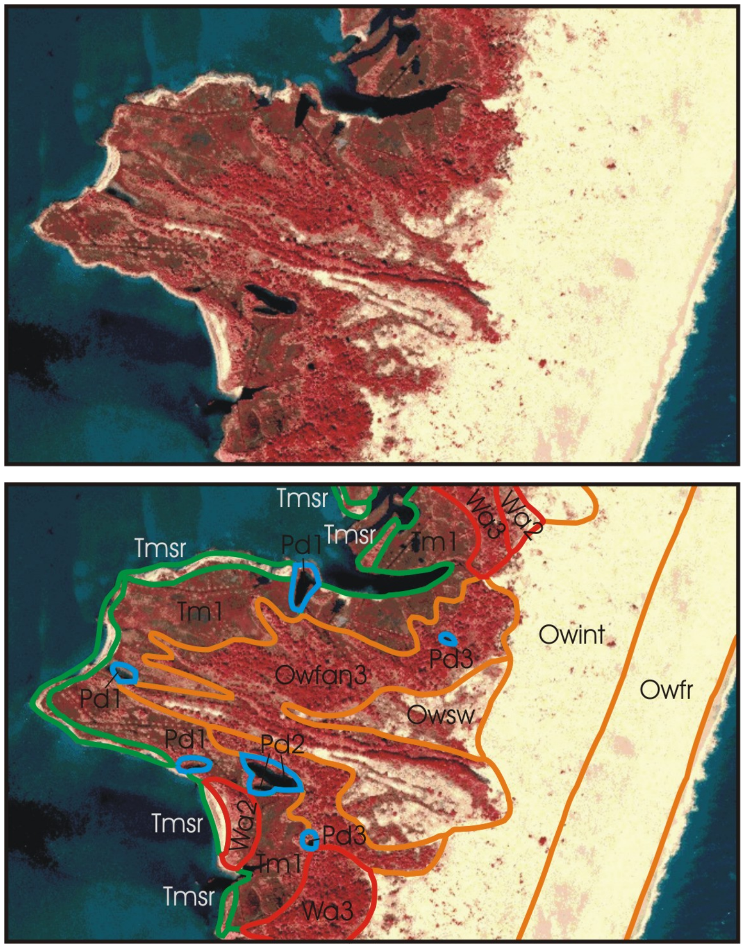


Figure 24. An overwash fan on northern Assateague Island, near kilometer 9, shown with and without interpretation of map subunits.

Overwash channels (OWch) and swales (OWsw) are both low areas that were created by overwash flow across the island surface during storms. The distinction made in assigning map subunits to these features is that OWch implies a fairly discrete, continuous channel that cuts across a significant width of the island, often crossing several map units, whereas a swale is usually an isolated low area (Fig. 25). Although the OWch features are relatively narrow, in some cases less than 10 m wide and a few meters deep, they are conduits for subsequent overwash flow and allow transport of seawater farther across the island than sheet flow across the OWint subunit. Additionally, the overwash channels connect in the subsurface to relatively coarser, more permeable sediments that permit more rapid flow of the saline or brackish ground water. As described above, the overwash swales commonly receive and allow ponding of overwashing seawater that then infiltrates the surficial aquifer by focused recharge.

Unit DN and DNmm

In delineating the OWint subunit, individual dunes were not distinguished, largely because they can not be clearly identified in the color IR image, although they do appear in the lidar DEM. The high, continuous man-made dune that fronts the Maryland State Park and the camping area of the National Seashore is delineated, and classified as DNmm (dune, man-made), because it so profoundly affects the hydrology of the island immediately behind it by restricting overwash and subsequent infiltration of seawater in the geomorphic setting that otherwise would be classified as OWint.

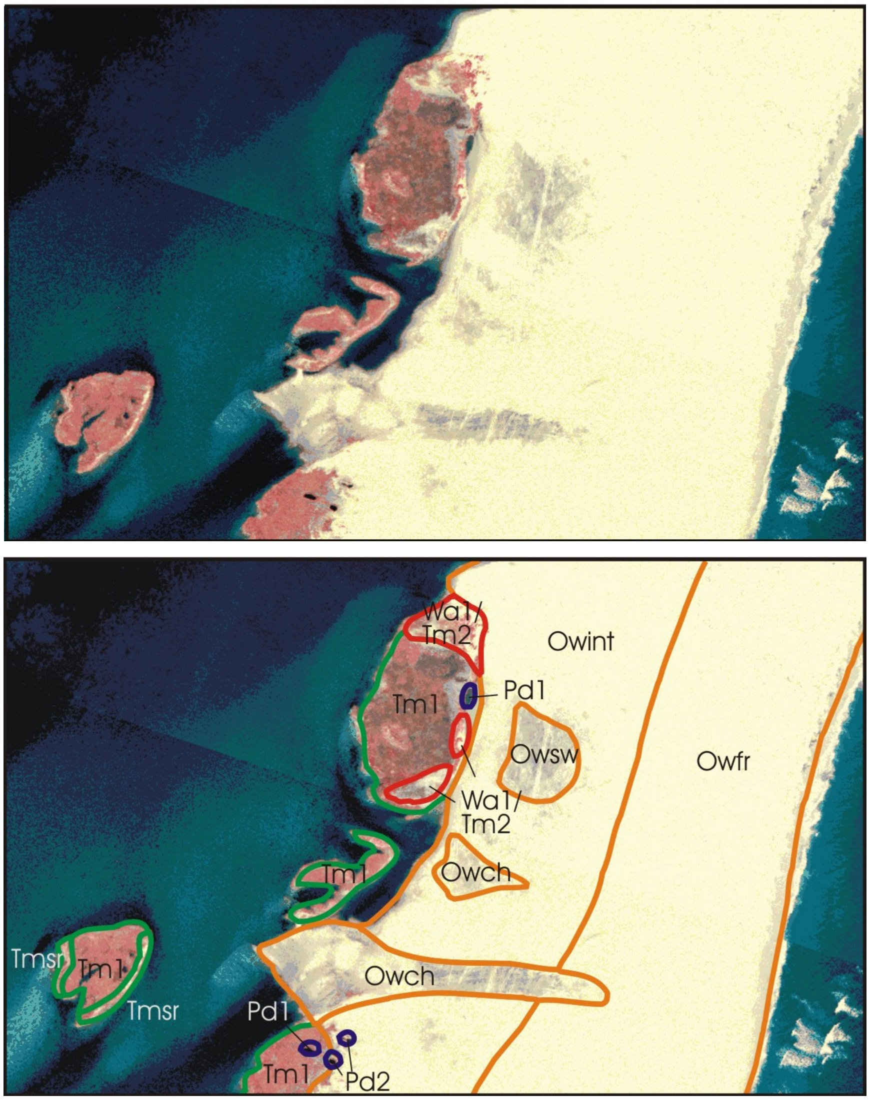


Figure 25. Overwash channels and swales on northern Assateague Island, near kilometer 5, shown with and without interpretation of map subunits.

Tidal Marsh

Subunit TM1

Much has been published about the tidal marsh setting, structure, and processes because of the importance of this environment to the barrier island and coastal bays ecosystems. For this map, subunit TM1 is essentially equivalent to the low marsh dominated by *Spartina alterniflora*. Geomorphically, the low marsh develops on the distal, bayward margins of the overwash platform where its elevation drops into the intertidal zone (Fig. 26). Mean high water generally defines the upper elevation limit of the low marsh and the transition into the high marsh (Table 9).

Alternative settings for the TM1 subunit include the extensive marsh islands that develop on the flood-tidal deltas of now-closed tidal inlets. An exceptional example of this setting is the Middlemoor Island complex on the bay side of the historical Green Run Inlet near the Maryland-Virginia state line (Figs. 2c and 16). TM1 marshes also may occupy the low areas between the island core and older, antecedent sections of the island on the bay side, which can be seen in Figures 10, 17, and 21 from the areas around Little Level and Pine Tree Island.

Because of the near-daily flooding of TM1 with saltwater, the shallow ground water beneath the marsh is predominantly brackish to saline. Locally in the marsh there may be discharge of reduced-salinity

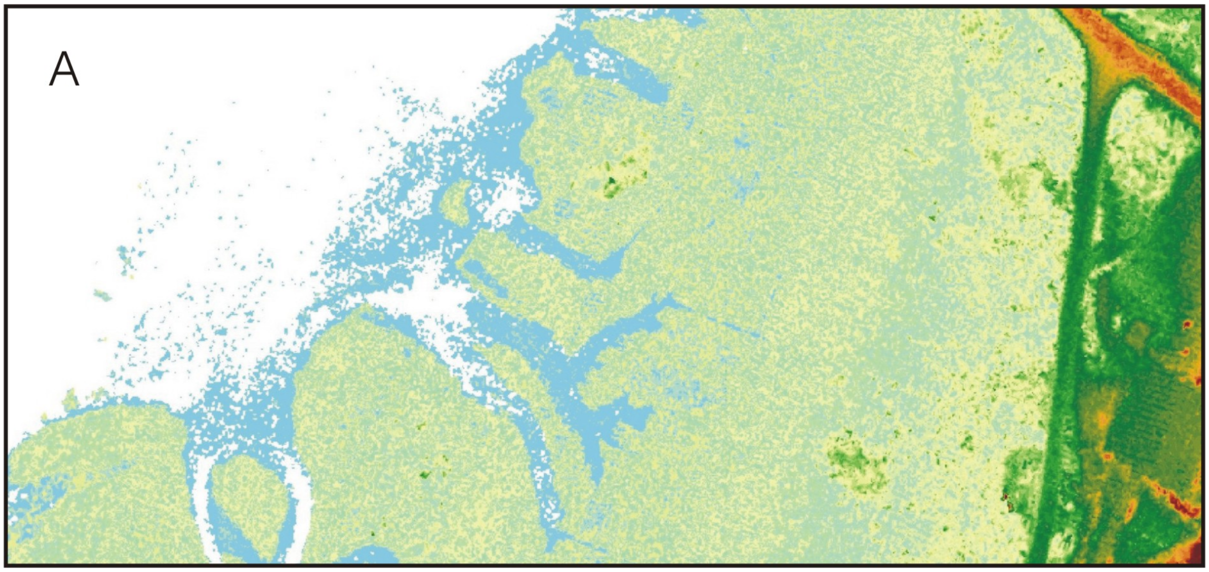


Figure 26. Subunits of the Tidal Marsh. Part of the scene shown in Figure 15, near kilometer 11. (A) Lidar DEM with 10-cm color contours.

ground water flowing from the island interior and controlled by breaches in the low-permeability mud and peat of the marsh. Hypersaline brines may be produced in isolated basins within the low marsh or near the landward edge of the marsh. During the summer, in both of these settings, seawater that floods these basins during spring high tides or high-water events is evaporated by intense solar radiation, leaving behind and concentrating the salt. Open, unvegetated areas in the grassy plain of the marsh may indicate production of brine that killed the *Spartina*; these are classified as salt pans, subunit TMsp. Salt pans and saltwater ponds in the tidal marsh (subunit PD1) almost certainly intergrade, but ponds tend to be deeper and may be connected to the bay by a tidal creek or man-made ditch. Salt pans also form on the broad intertidal flats in low-lying areas of the island such as Fox Hills Level and Little Level.

Subunit TM2

Elevation increases of even 10 cm above the low-marsh surface allow colonization by the salt-tolerant plant community. This may result in a high-marsh grassland dominated by *Spartina patens* with stands of *Distichlis* and *Juncus*, or in scrubland populated by *Baccharis* and *Iva*. In the subsurface, this transition also may coincide with the shallow availability of relatively lower-salinity and higher-oxygen ground water, which has been shown to be a control on the distribution of *Spartina patens*. Geomorphically, TM2 is most often either the low-slope distal part of the back-barrier flat, produced by overwash processes, or low sand ridges deposited by flow through former inlets or areas of extensive storm overwash. Subunit TM2 in various geomorphic settings is equivalent by vegetation and hydrology to subunits IC1, WA1, or IN2 (Table 3). Ponds within subunit TM2 are most commonly classified as PD2, filled with brackish water most of the year but occasionally flushed with reduced-salinity ground water recharged from the island core or a large washaround. Alternatively, some of the deeper ponds in subunit TM2, or those closer to the island core, will tap a flow of ground water that is more consistently fresh; these are classified as PD3.

Subunits TMsr and TMfl

The edge of the tidal marsh that is exposed to the open fetch of the coastal bay commonly has a rim of sand reworked by waves and built upon the marsh surface. These tidal marsh sand ridges (subunit TMsr) are smaller and lower than the typical ridges classified as TM2. Even so, the slight increase of elevation above the low-marsh surface is sufficient to allow colonization by *Baccharis* and *Iva*. Another subenvironment of the tidal marsh, the subtidal flat (subunit TMfl), lies slightly below mean low water, but above low low water. These flats do not have emergent vegetation, but depending upon the intensity of tidal currents and wave action, may have submerged aquatic grasses or macroalgae.

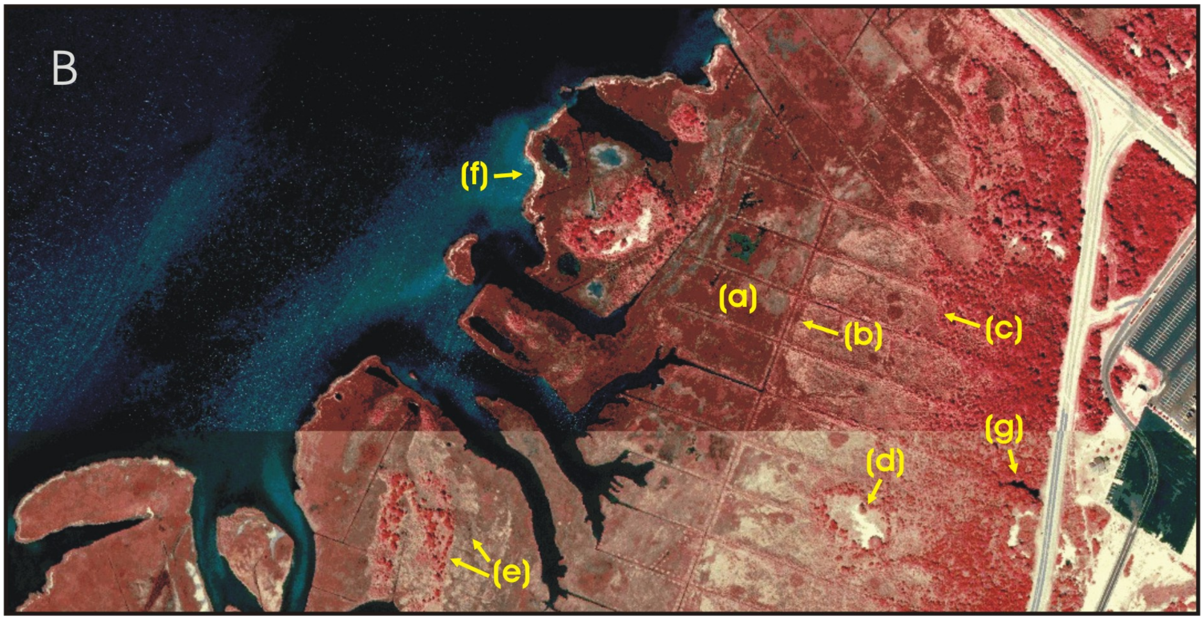


Figure 26. (B) Color infrared aerial photograph without polygons or identifiers of map subunits; letter labels are used in the text for explanation of features.

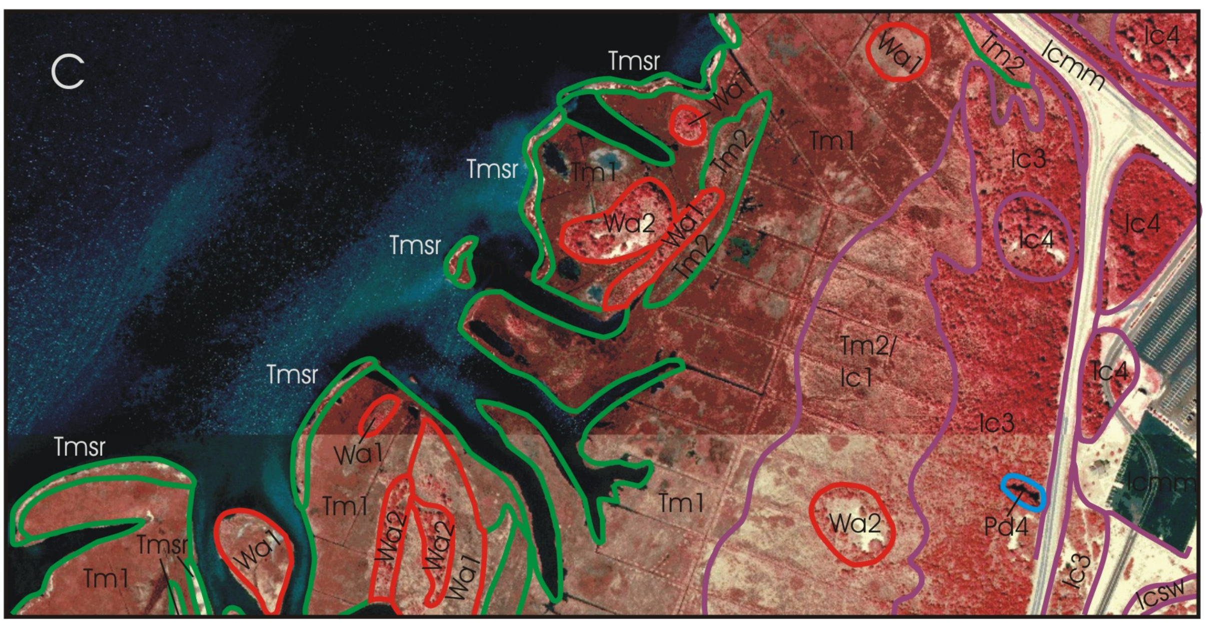


Figure 26. (C) Map subunits for Tidal Marsh and associated features.

Distinguishing Tidal Marsh subunits

The subunits of a typical tidal marsh setting are shown in Figure 26, which is zoomed in from the scene near kilometer 11 presented in Figure 15. The extensive low marsh in this back-barrier area, indicated by label (a) in Figure 26b and map subunit TM1 in Figure 26c, is cross cut by a pattern of mosquito ditches dug in the 1930s. This marsh is nearly a monoculture of salt marsh cordgrass, *Spartina alterniflora*. In the color IR images, the low marsh typically appears as a deep red, sometimes with lighter mottling that indicates areas with sand exposed at the surface. Shallow ponds and salt pans appear in the low marsh as darker areas, possibly with a light purple tint that may indicate bacterial or cyanobacterial mats on the sediment surface.

In this view, the edge of the high marsh, label (b) and subunit TM2, is fairly distinct although in many places it is more gradational. Here, the lighter tone of the combined vegetation and land surface in part indicates a sandy marsh soil with minimal accumulation of mud or mud and peat, which implies an elevation slightly above mean high water. The textural difference between the low marsh and high marsh surfaces is likely to be the addition of other salt-tolerant grasses such as *Spartina patens* and *Juncus*, and pioneering salt-tolerant shrubs. Geomorphically, this is the bayward extension of the consolidated overwash sheet from the island core, and this subunit is given the compound identifier TM2/IC1. In this area, because of the very low slope from the island core, the upland boundary of the high marsh is gradational and not clearly defined (label [c]). The scrub vegetation gets denser, some trees appear, although they do not obtain full size, and the plant assemblage moves toward salt-resistant and freshwater-obligate species.

Older washarounds (subunits WA2 and WA1) appear in the high marsh as isolated islands of slightly higher ground (label [d]) occupied by salt-resistant scrub and small trees. Other ridges that project above the marsh surface may have been reworked from earlier sections of the island or from earlier flood-tidal delta deposits also may be designated WA2 or WA1 (label [e]). These sand ridges typically are occupied by the same salt-resistant scrub assemblage. Note that with the exception of the larger washarounds, few of the subunits of the Tidal Marsh map unit can be discerned from the lidar DEM although they are reasonably distinct on the color IR image.

Label (g) marks Hall's (2005) pond KM11, which is a moderately deep overwash channel cut into the back-barrier overwash sheet. This pond sits near the transition from the uppermost part of the high marsh onto the island core. From Hall's observations over a year, this pond was consistently filled with fresh water except for an influx of saltwater during one high-water event caused by wind set-up in Chincoteague Bay. During this event, the salinity in the pond spiked rapidly, but then was flushed by fresh ground water from the island core over the following week.

Table 9. Subunits and characteristics of the Tidal Marsh map unit.

Subunit	Elevation	Relative frequency of saltwater input	Thickness of fresh ground-water lens	Vegetation	Geomorphic setting
TM2	mean high water to 0.2-0.3 m	during spring high tides and most storms	generally thin <1 m, but may be thicker with GW flow from higher ground	salt-resistant grasses and shrubs	upland edge of marsh; overwash and washaround flats
TMsr	mean high water to 0.2-0.3 m	during spring high tides and most storms	brackish ground water	salt-tolerant grasses and shrubs	wave-reworked sand rims around marsh, low inlet ridges
TM1	intertidal, generally MLW to MHW	daily inundation	brackish ground water	dominantly *Spartina alterniflora*	intertidal part of back-barrier flat and islands
TMfl	shallow subtidal, -0.2 to -0.3 m to MLW	daily inundation	brackish ground water	no emergent macrophytes, may have SAV or macroalgae	subtidal part of back-barrier flat

Table 10. Subunits and characteristics of the Inlet map unit.

Subunit	Elevation	Relative frequency of saltwater input	Thickness of fresh ground-water lens	Vegetation	Geomorphic setting
IN3	0.5-1 m, ridges higher	during moderate and major storms	2-3 m	scrubland with salt-resistant plants	spit platform or marginal terrace to inlet channel
IN2	mean high water to 0.2-0.3 m	during spring high tides and most storms	brackish ground water	salt-tolerant grasses and shrubs	marginal terrace to inlet channel & low inlet ridges
IN1	intertidal, to MHW	daily inundation	brackish ground water	dominantly *Spartina alterniflora*	edges of inlet channel
INsw	varies, but 0.5 m lower than nearby surface	susceptible to direct overwash flow and down-gradient brackish GW flow	alternates between brackish and brief periods of fresh	salt-resistant grasses and shrubs, adapted to hydric conditions	low areas between ridges of former inlet mouth

[Former] Inlet

Subunits IN1, IN2, and IN3

Locations of former inlets on Assateague Island are most commonly marked by a rounded, funnel-shaped low area on the seaward side of the island and a single deep channel or set of channels that extend from the center of the island into the back-barrier lagoon (Figs. 9, 11, and 17). The seaward low area is the former mouth of the inlet that filled with sand by longshore transport as the inlet closed. While these former inlets were open and active, the flow of the daily tides and storm surges through the inlet created streamlined longitudinal sand bars within the channel and sand ridges on the channel margins. At points where the tidal channel bifurcated or discharged into a broader, unrestricted area of the lagoon, subtidal to intertidal bars or flood-tidal ramps of sand were deposited. Even while the inlet was active, some of these features became emergent as sand was transported and deposited above mean high water by either waves or wind.

The map subunits IN1, IN2, and IN3 delineate the progressively higher-elevation remnant geomorphic features left after the inlet closed completely (Fig. 27c, Table 10). Tidal marshes generally occupy the intertidal margins of the former inlet classified as IN1 or IN1/TM1. By vegetation and hydrology, subunit IN1 is functionally equivalent to TM1.

The slightly higher-elevation sand ridges of subunit IN2 are most commonly covered with salt-resistant shrubs and grasses, and are equivalent to TM2. However, in most cases IN2 ridges are roughly perpendicular to the overall orientation of the barrier island, whereas TM2 marshes most often are roughly parallel. Subunit IN2 is also used to indicate areas of the closed inlet mouth that are above mean high water but are still susceptible to overwash from strong minor to moderate storms. These areas typically have brackish ground water and are grasslands or scrublands of salt-resistant plants, such as at Little Level (Fig. 17) and the former Sinepuxent Inlet near kilometer 17 below South Beach (Fig. 27).

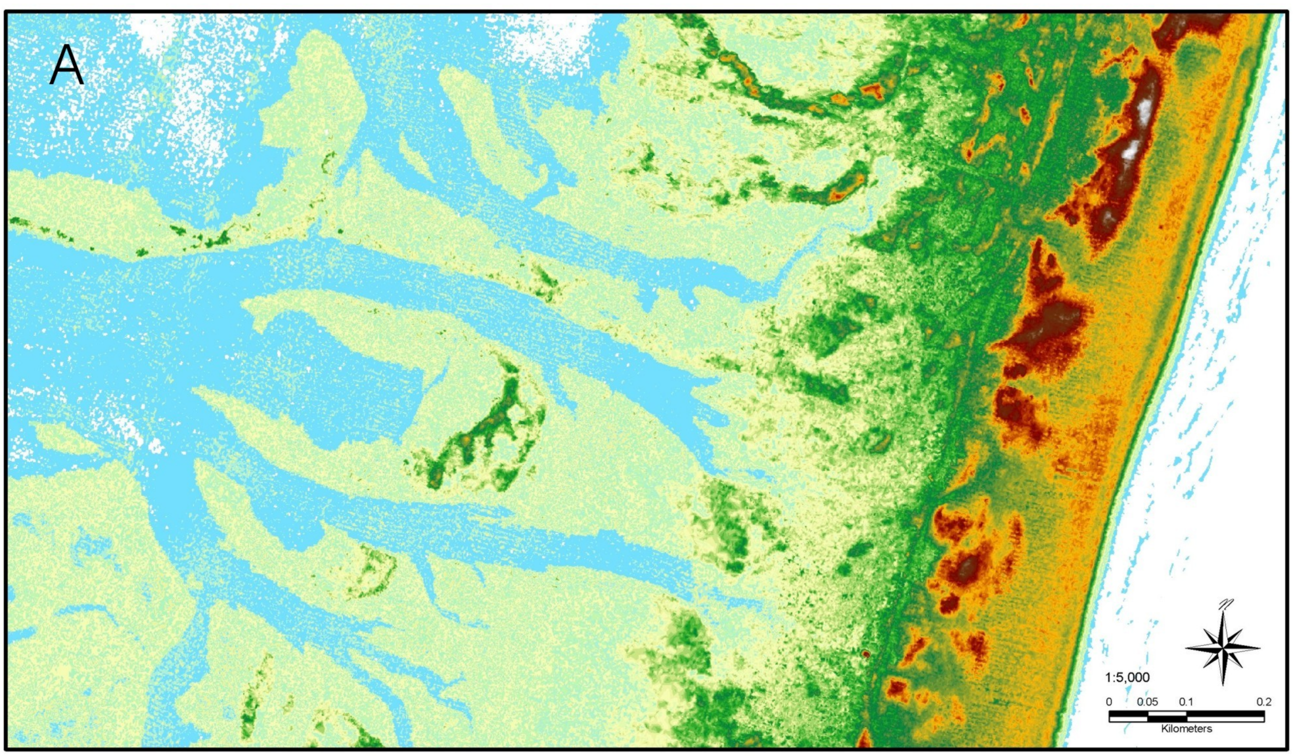


Figure 27. Subunits of the Inlet map unit. Part of the scene shown in Figure 9, near kilometer 17. (A) Lidar DEM with 10-cm color contours.

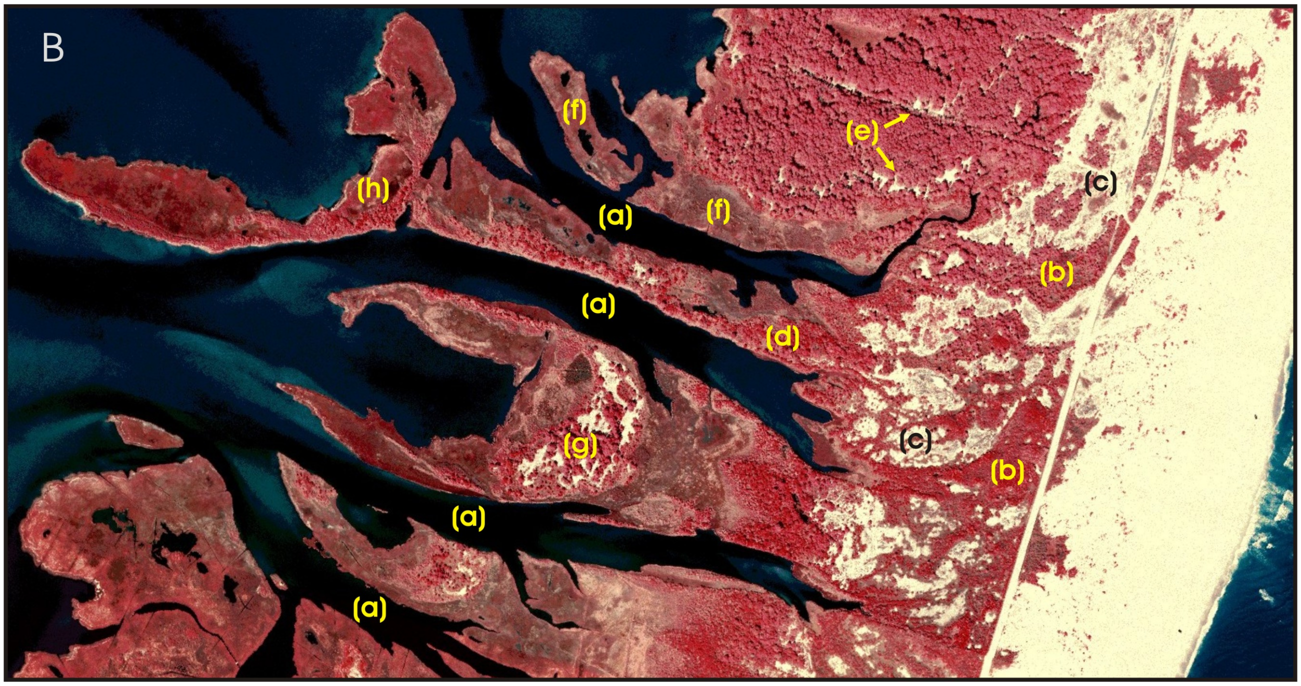


Figure 27. (B) Color infrared aerial photograph without polygons or identifiers of map subunits; letter labels are used in the text for explanation of features.

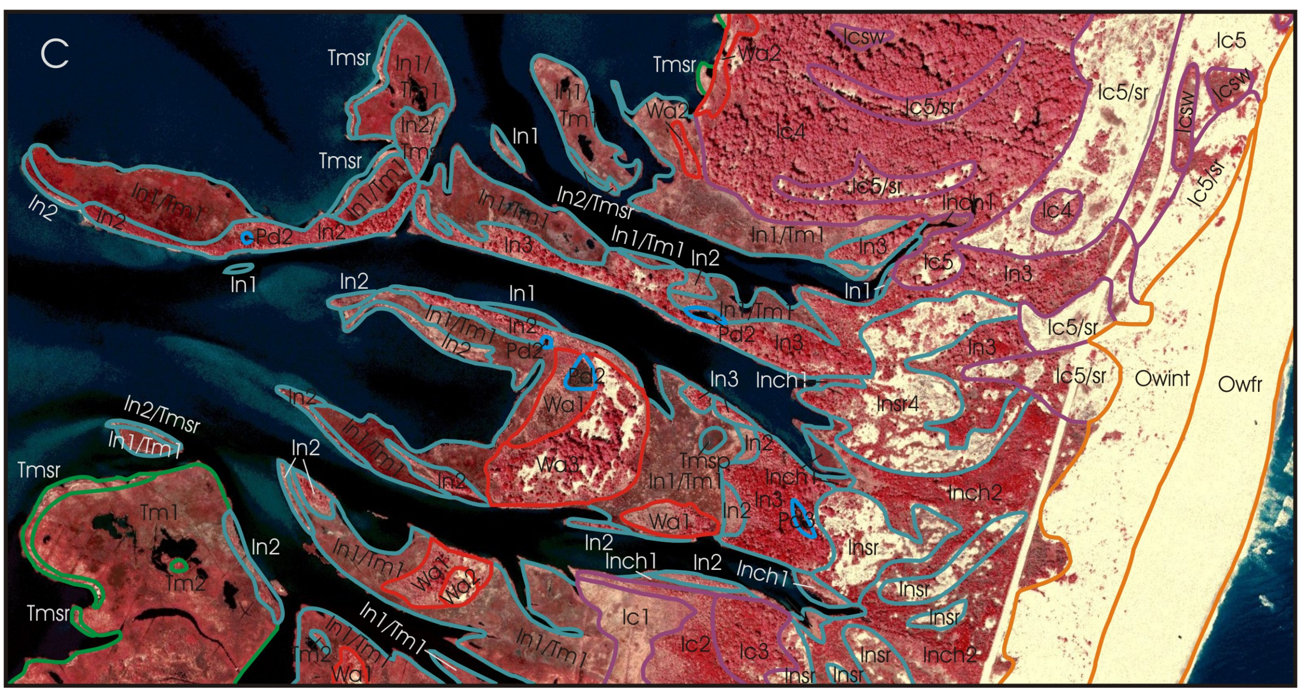


Figure 27. (C) Map subunits for Inlet and associated features.

Higher and/or more protected areas of the margins or mouth of the former inlet are classified as IN3. For most of the year these areas have fresh ground water, typically flowing from the adjacent island core, but receive input of either overwash or brackish ground water frequently enough to limit growth of the maritime forest community.

Subunits INch and INsw

Where the geomorphic features are clearly expressed, inlet channels and swales are classified as INch and INsw, respectively. These designations may be accompanied by a numerical suffix that indicates elevation and relative protection from overwash.

Distinguishing Inlet subunits

Some of the geomorphic setting of a former inlet was described for Figure 21 and the Island Core subunits. The scene presented in Figure 27 is similar, but with multiple inlet channels (four [a] labels) and a more complex set of ridges. This former inlet below South Beach, near kilometer 17, is likely to be the historical Sinepuxent Inlet that was open from the 1600s into the early 1800s. Shallow remnants of inlet-mouth channels on the ocean side (two [b] labels) are interspersed between the spit ridges that finally closed off the inlet (two [c] labels). The low areas of the former inlet mouth are generally designated subunits IN2 or IN3 depending upon relative elevation (Fig. 27c), or INch if clearly a channelized feature. Larger, higher, and sparsely vegetated spit ridges are classified as the IC5sr subunit of the Island Core, whereas lower sand ridges within the former inlet mouth may be classified as INsr.

Sand that entered the open, active inlet from the ocean was reworked into longitudinal bars and ridges within and between the tidal channels (label [d]); these are designated IN2 or IN3, again depending upon relative elevation. The former inlet is flanked by recurved spit complexes, as shown in Figure 11, which are a major component of the Island Core map unit. Typically the updrift (northern) side of the inlet has the more extensive spit complex. Individual spit ridges (label [e]) may be significantly higher than others in the set, and are categorized as IC5sr.

Intertidal spit platforms and supratidal terraces along the margins of the inlet channels were subsequently occupied by low-marsh grassland or high-marsh mixed grassland and scrubland, designated IN1/TM1 and IN2/TM2, respectively. Larger reworked sand bodies within the former inlet are generally classified as washarounds (map unit WA), as marked by label (g). Lower-elevation features (label [h]) with a hydrodynamic shape similar to a washaround are most commonly reworked from the sand deposits of the flood-tidal delta (refer also to the Middlemoor Islands shown in Figures 2c and 16).

Inlet-closure ridges

At a few locations on the island, inlet-closure ridges – a set of low, arcuate, nearly parallel ridges – create a ridge and swale barricade across the former inlet mouth (Fig. 28). Inlet-closure ridges are best expressed at kilometer 33, the site of the historical Green Run Inlet (Fig. 28b) that shallowed and closed between 1880 and 1900.

The ridges and swales preserved as the island surface at the KM33 site (Fig. 28a) show the sequence of closure for Green Run Inlet. The spit marking the southern flank of the inlet appears as a sparsely vegetated sand ridge (label [a]) that hooks around to the northwest then west. Hall's (2005) pond site KM33 is in the wooded swale south and east of label (a). The northern margin of the inlet is the fishhook-shaped higher ground identified by label (b) and shown on the historical chart (Fig. 28b).

The first stage of inlet closure at this site proceeded with sets of spits prograding from the north, indicated by labels (c) and (d). As the mouth of the inlet shallowed dramatically, lower, more continuous ridges (e), possibly produced during storm high-water events, spanned the entire width of the former inlet. The low areas between these inlet-closure ridges are now swales with perennial wetlands occupied mostly by grasses with a few shrubs. The outermost (eastern) swale receives sufficient seawater, primarily from brackish ground-water flow from the up-gradient overwash zone, to have a predominantly salt-tolerant plant community, similar to the swales shown in Figure 22.

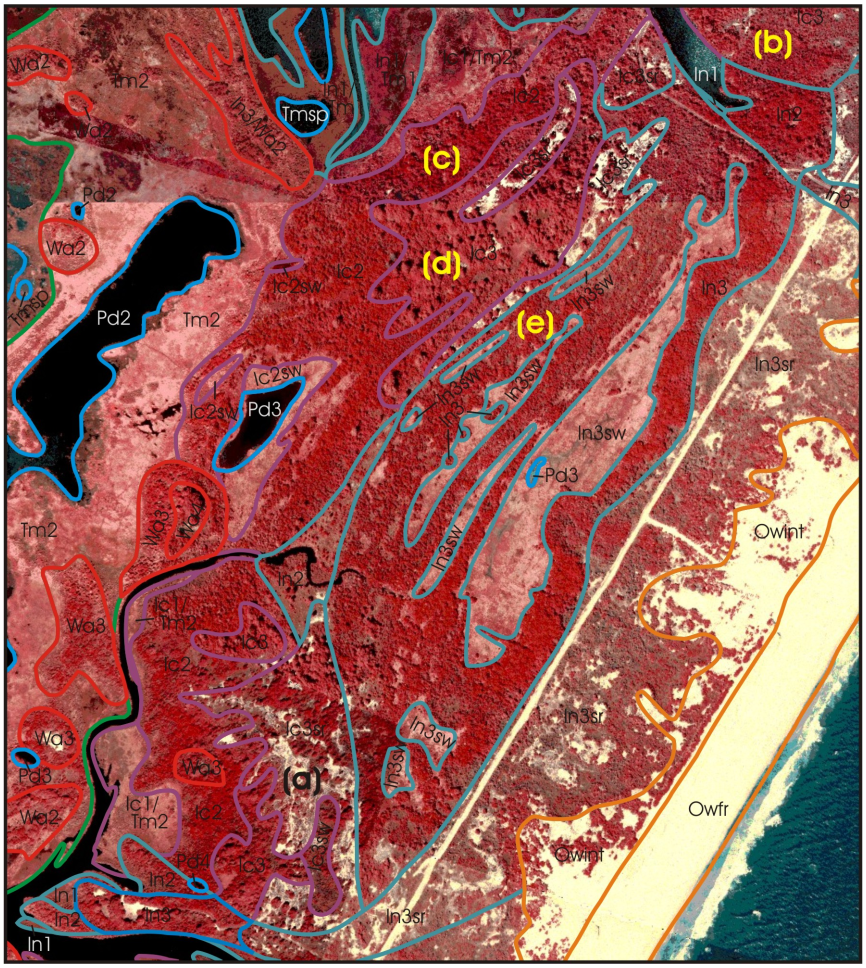


Figure 28. Inlet-closure ridges and intervening swales at the former Green Run Inlet.
(A) Modern setting, near kilometer 33.

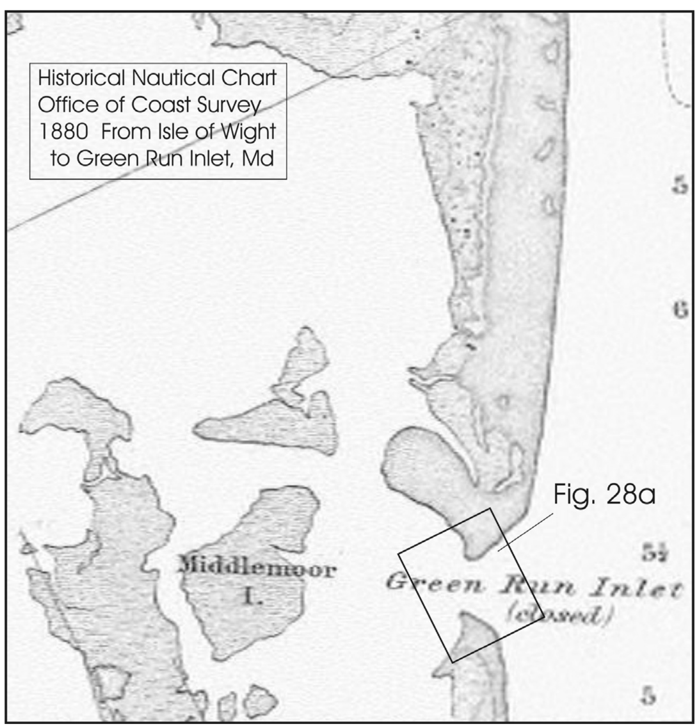


Figure 28. (B) Navigation chart from 1880 showing Green Run Inlet. (NOAA archives.)

Washaround

Subunits WA3 and WA4

Because of their process of formation by reworking of sand during successive major storms, the larger washarounds (wider than about 75 m) have a series of arcuate ridges on the seaward side (Figs. 18 and 29). The tallest of the ridge sets are commonly well above sea level, 1.5 m to as much as 3.5 m (Table 11), and protect the interior of the washaround as an island usually surrounded by brackish environments. As a result, and very similar to the island core setting, the fresh ground-water lens is deepest and most stable in the center of the washaround, with an abrupt shallowing immediately outside of the outer ridge. This effect is expressed as a coincident sharp transition, often within 5-10 m, from freshwater-obligate maritime forest to salt-tolerant scrub to high marsh. Map subunits WA3 and WA4 constitute the protected interior of the washaround.

Most of the ponds associated with washarounds lie in the swales between storm ridges on the ocean side of the feature (Fig. 29). However, in a few cases, swales in the interior of the larger washarounds are deep enough to be ponds, at least seasonally. More commonly, the swales are seasonal freshwater wetlands with a distinct plant community that may include *Osmunda* ferns. Some of these swales that become seasonally dry support trees and shrubs, whereas others that are more persistently wet are covered predominantly by grasses.

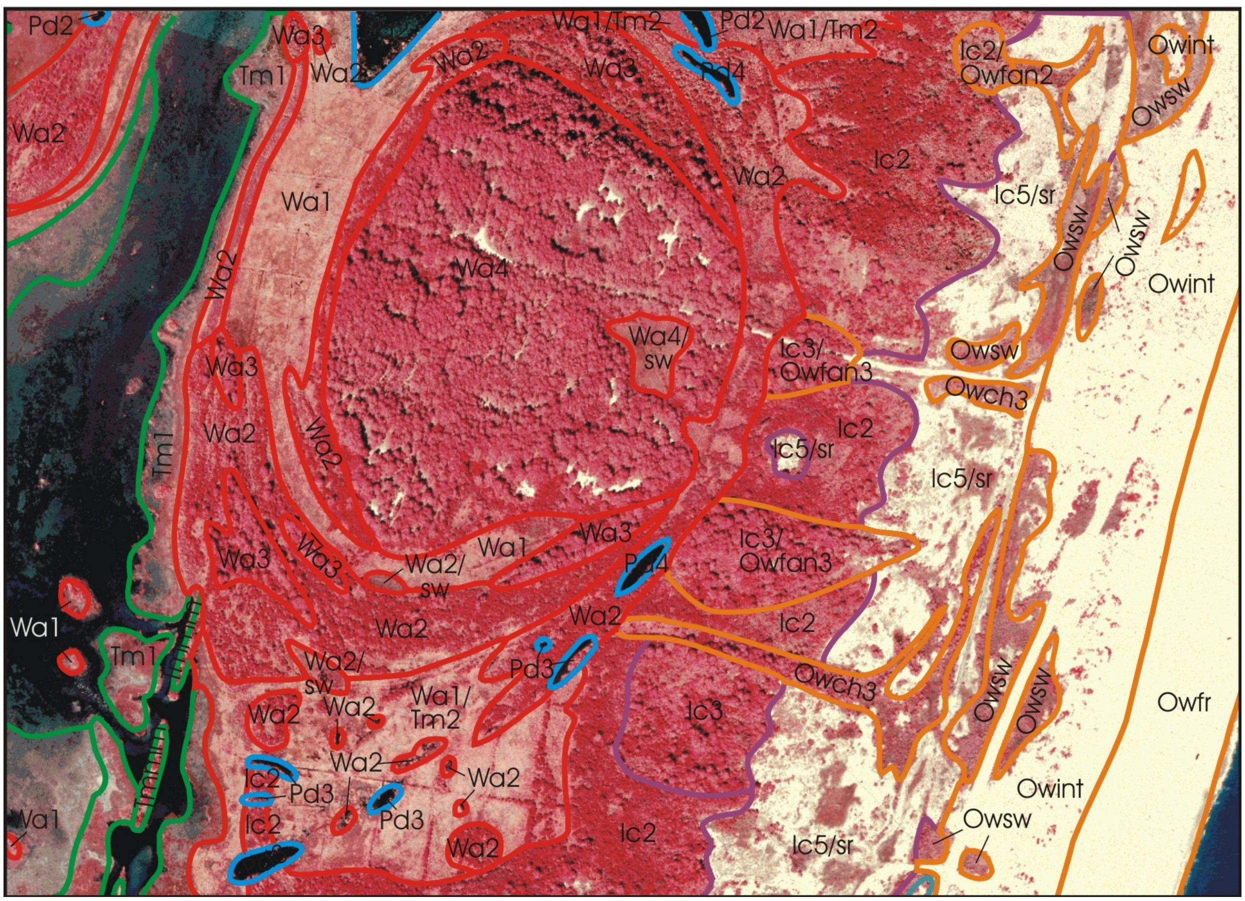


Figure 29. An older large washaround sitting behind the present island core. Near kilometer 19.

Subunits WA1 and WA2

Subunits WA1 and WA2 occur as low-lying ridges around the perimeter of the larger washarounds (the main feature in Fig. 30), and as the body of smaller washarounds (eastern side of Fig. 30). Many of the washarounds wider than about 100 m have a fringe of low ridges that grade down in elevation to the high marsh (Fig. 29). These ridge sets are categorized as WA1 and WA2, and sometimes are given a compound designation such as WA1/TM2. In these settings, the vegetation makes the transition from the salt-tolerant scrub, generally on ridges of WA2, through the salt-resistant vegetation typical of the high marsh occupying WA1, into the salt-adapted grasses of the tidal marsh itself. As with the lower-elevation subunits of the island core, the designation of washaround subunits WA1 and WA2 in part depends on the width of the feature, which affects the likelihood of complete flooding during storms.

The smaller washarounds, from less than 100 m to about 10 m wide, appear as isolated tufts or hummocks in low-lying sections of the island that are frequently overwashed. Other studies, such as those on the Virginia barrier islands, have called these features “marsh pimples.” Classification of these smaller washarounds depends largely on the width of the feature and the character of the surrounding island surface. For example, washarounds of 10-20 m width in the frequently washed over sections of Fox Hills Level and Little Level are classified as WA1, whereas slightly larger washarounds of 20-40 m may have a core of WA2 with a rim of WA1. Hydrologically, these smaller washarounds have a localized shallow lens of fresh ground water that may be only about 1 m deeper than the surrounding land surface and dissipates close the edge of the feature. However, this isolated pocket of fresh ground water may be sufficient to allow growth of salt-tolerant shrubs.

Distinguishing Washaround subunits

As mentioned previously, the larger washarounds of Assateague Island are effectively islands themselves, with many of the characteristics of the island core, just scaled down. The single large washaround presented as an example in Figure 30 lies immediately north of similar washarounds on the bay side of Fox Hills Level shown in Figure 18. All of the larger washarounds are composed of a series of sand ridges molded by high-velocity flow across the island during storm surges and overwash events. The main body of the washaround, label (a) in Figure 30b and subunit WA3 in Figure 30c, is covered by maritime forest. Individual higher ridges, three (b) labels, are sparsely vegetated because of a relatively thick unsaturated soil zone. Lower-lying ridges on the ocean side of the washaround, label (c), were created by major storms in 1952 and 1962, based on aerial photographs taken soon after these events.

Because this washaround is on the bay side of Fox Hills Level, the inlet salt pan, label (d) and subunit INsp, abuts the ocean side of the washaround. Commonly on the bay side of washarounds, the wrapping storm ridges create a sheltered low area (label [e]) that may be a shallow cove, or occupied by tidal marsh with brackish ponds. Smaller sand bodies within or along the flanks of the tidal channels may have substantial sections above sea level, such as marked by label (f), that are classified as small washarounds. Similarly, flow-sculpted, round or ovate hummocks within the broad flat of Fox Hills Level are also small washarounds (two [g] labels, but many more shown). Many of these smaller features have a central core that may be ~1 m above the surrounding island surface, and may be partly covered by salt-tolerant grasses and scrub; these are classified as WA2 with a lower fringe of WA1.

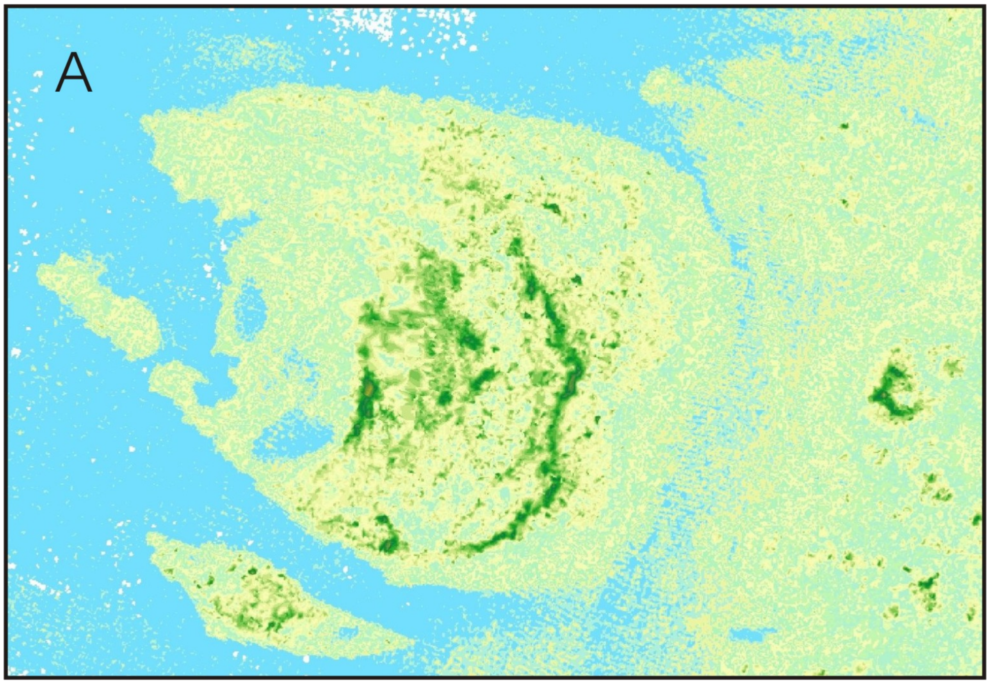


Figure 30. Subunits of the Washaround map unit. This area near kilometer 26 is immediately north of the scene shown in Figure 18. (A) Lidar DEM with 10-cm color contours.

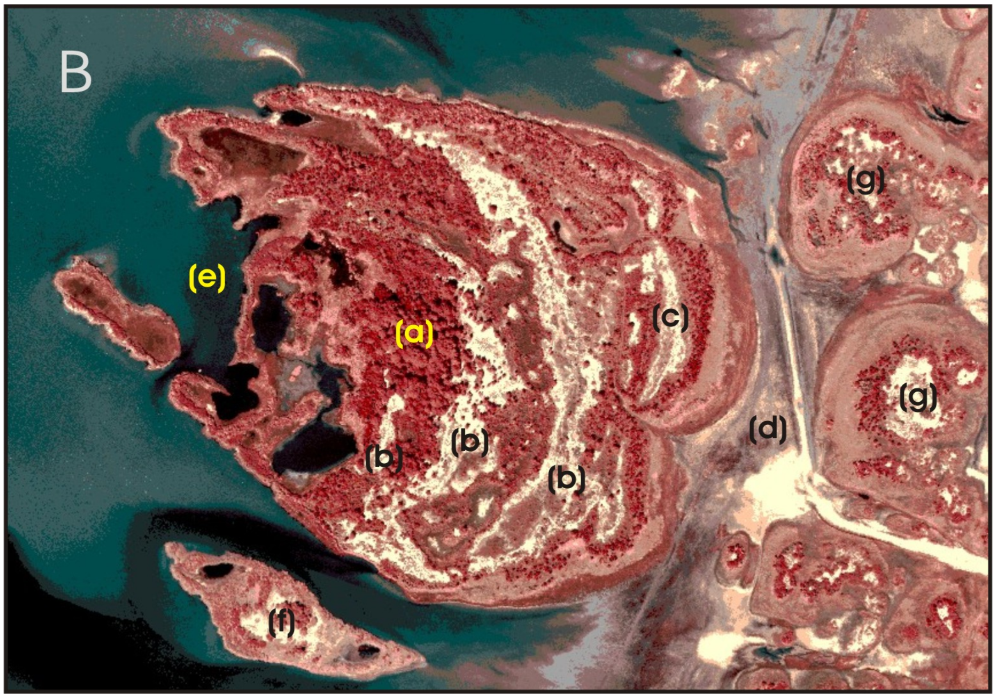


Figure 30. (B) Color infrared aerial photograph without polygons or identifiers of map subunits; letter labels are used in the text for explanation of features.

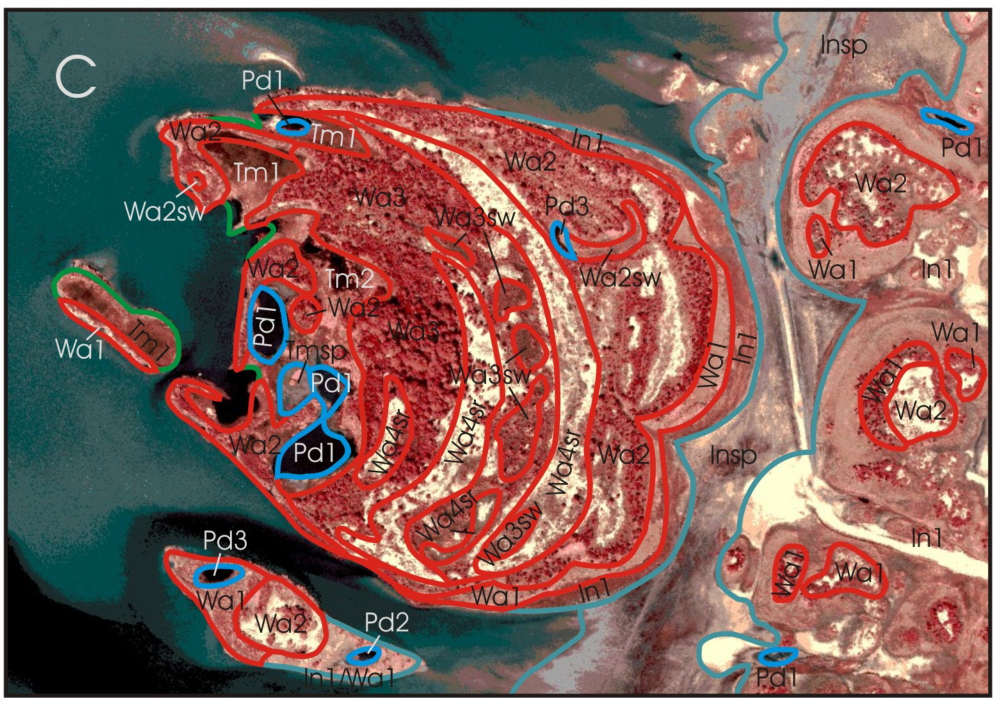


Figure 30. (C) Map subunits for Washaround and associated features.

Table 11. Subunits and characteristics of the Washaround map unit.

Subunit	Elevation	Relative frequency of saltwater input	Thickness of fresh ground-water lens	Vegetation	Geomorphic setting
WA4	1.5-2 m ridges to 3 m	only during major storms	3-5 m	maritime forest, freshwater obligate	center of washaround protected by storm ridges
WA3	1-1.5 m ridges to 2 m	during strong moderate and major storms	2-3 m	maritime forest & scrubland, freshwater obligate	near center of washaround, lower elevation than WA3, closer to marsh
WA2	0.5-1 m	during moderate and major storms	1-2 m	scrubland with salt-resistant plants	generally the margin of the washaround
WA1	0.25-0.5 m	during strong minor and moderate storms	1 m or less	mixed scrubland & grassland, salt tolerant	low margin of washaround, slightly above MHW

Ponds

Ponds on Assateague Island occur where an erosional process has cut down through the surface sediment to a base below the water table. In practically all cases, this formation process was associated with channelized flow of overwash during a storm. In a variation on this theme, existing ridges or dunes that dam the overwashing seawater during the storm may be breached at a low point. The channelized flow, with considerable velocity through the constriction, will scour a substantially deep trough; this is the formation process inferred for the ponds at Hall's (2005) site KM33 (location shown on Fig. 2c).

In other settings where the high front of the island core stands as a barrier to overwash flow across the island to the lagoon, flow is diverted laterally, usually toward an adjacent low-lying area such as a former inlet. The diverted flow follows the low swales between previous storm ridges. The geomorphic result of this process can be seen clearly at the northern edge of Fox Hills Level near kilometer 24 (Fig. 31). Similar to the effect of flow through an overwash channel, high-velocity flow along a swale between bounding ridges also creates localized deep scour troughs that become ponds. Many of the ponds associated with the larger washarounds are similarly situated in swales between ridges (Fig. 29).

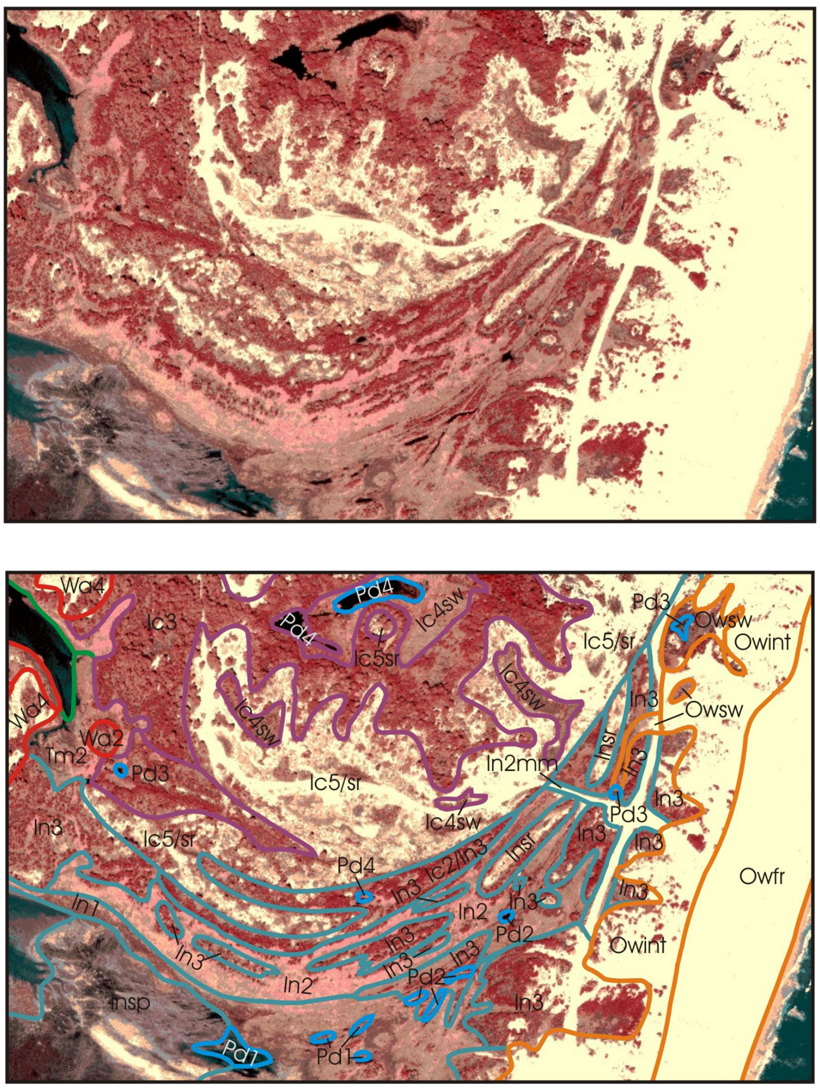


Figure 31. Ridge and swale sets created by storm overwash flow laterally around the higher section of the island core. Northern margin of Fox Hills Level, near kilometer 24.

Ponds that lie in line within either an overwash channel system or a ridge and swale system are linked by subsurface flow of ground water. The up-gradient, seaward end of either system is likely to continue to receive overwash. During moderate storms that produce overwash, surface flow of seawater may not continue through all of the aligned ponds in a swale, but may lose momentum and pond in the seaward end of the swale. Here, the saltwater infiltrates into the surficial aquifer, mixes with the existing ground water, which may be relatively fresh, then flows down gradient in the subsurface. The down-gradient ponds, even though they did not receive direct overwash, will become brackish as this slug of saline ground water moves through the system. Eventually, freshwater from precipitation fills the ponds and pushes the brackish ground water toward the bay.

From the pond study, as summarized by Sagit Hall in her 2005 thesis, ponds on Assateague Island receive salt by several processes. The one most often cited in other publications, input from salt spray from the ocean, is actually a relatively minor, although real, effect. Salt from salt spray is most important during periods of drought when evaporation removes a large volume of the pond water and concentrates the salt. As described above, the dominant input of saltwater into a subset of ponds on the ocean side of the island is from direct overwash flow. The indirect process of subsurface flow of brackish ground water is important toward the landward edge of the Overwash unit and, especially, for ponds in the Inlet unit and seaward side of the Island Core. Something of the converse process occurs with ponds on the bay side of the island. Ponds may be flooded by high water in the coastal bay, which is most commonly caused by wind set-up within the bay. Then, instead of receiving brackish ground water from up gradient, these flooded ponds may be flushed by fresh, or at least reduced-salinity, ground water flowing down gradient from recharge areas on the island core.

Subunit PD4

Ponds within the higher, protected center of the island core and the larger washarounds are the most persistently fresh and are classified as PD4. These fresh ponds are heavily utilized by the larger vertebrates of the island and commonly have paths leading to them that were created by horses and deer. The surrounding high ground not only protects the pond from direct surface overwash of saltwater, but maintains an elevated water table and thick freshwater lens with sufficient hydraulic head to protect the pond from incursion of brackish ground water.

Subunits PD3 and PD2

Ponds classified as PD3 and PD2 are similar in that both are brackish during part of the year and are flushed by either fresh or reduced-salinity ground water from up gradient, which is usually the central part of the island core or a large washaround. The distinction made between these two categories is whether they are predominantly fresh (PD3) or brackish (PD2) for most of the year. Realistically, because of the temporal dynamics, these partly fresh / partly brackish ponds represent a continuum rather than discrete categories. Further, any individual pond will become fresher or saltier through periods of above average rainfall or drought, respectively.

In geomorphic setting, PD3 ponds are most commonly situated within the mid-elevation sections of the island core, subunits IC3 and IC2, whereas PD2 ponds generally lie within the low-elevation fringe of the island core, subunit IC1, or occasionally at the edge of the high marsh (TM2). The PD2 designation is also applied to ponds on the ocean side of the island core that frequently receive overwash or brackish ground-water flow.

Subunit PD1

As mentioned in the discussion of the tidal marsh, practically all ponds in the low marsh (TM1), and most in the high marsh (TM2), are either saline or brackish and are classified as PD1. At a few sites, adjacent ponds near the boundary of the high-marsh and upland may have different designations based on connection to bay water by a natural tidal creek or man-made ditch (Fig. 19a). Isolated ponds near the upland edge of TM2 are likely to receive reduced-salinity ground-water flow from up gradient.

Pond metrics

Most of the ponds on Assateague Island that are not in the tidal marsh should be identified on the hydrogeomorphic map. However, it was not always possible to distinguish between ponds and shadows of large trees, especially on images collected in late afternoon, and some smaller ponds may have been missed. Further, the polygons on the map are coarsely drawn relatively to the size of the actual ponds, and should not be used to calculate pond area. Instead, if more detailed information about the ponds is valuable to the NPS, additional GIS work with the more recent, higher resolution natural color aerial images would be appropriate. By zooming in, pond margins could be more accurately delineated, which should yield better metrics such as the distribution of pond size and the density of ponds on different sections of the island or within map units.

SUMMARY

The basic principle underlying this hydrogeomorphic map of Assateague Island National Seashore is that the geomorphology of the island in conjunction with the active processes associated with precipitation, evapotranspiration, and inundation with seawater by storm overwash from the ocean side or high-water flooding from the bay side largely control the ground-water hydrology, which has a primary influence on the distribution of the plant communities. The vegetation responds to the frequency and magnitude of saltwater input by overwash or flooding, and the duration of inundation or brackish ground-water conditions, which are controlled by geomorphology and position on the island.

The large-scale features of the island surface have been created by several major storms over the past few centuries, and have been modified by more-frequent but lower-intensity moderate storms. Storms have breached the island at many places to create short-lived tidal inlets, the remnants of which persist as low-lying island sections that remain susceptible to overwashing seawater. Storms also created the higher-elevation sections of the island core by reworking sand into protective ridges. Storm processes that operated for only a few days have produced landforms on the island that persist for decades to centuries, and strongly affect the function of the ecosystem.

Actual observations of the structure of the surficial aquifer and fresh ground-water lens under the island deviate substantially from conventional conceptual models. Rather than having a single, deep, connected fresh ground-water lens that stretches the length of the island, the fresh lens occurs in segments and is much shallower than predicted by theoretical considerations. Higher, protected sections of the island core produce and sustain a moderately deep fresh ground-water lens, observed to be as thick as 7-8 m. Because Assateague is a transgressive barrier island, a low-permeability layer of lagoonal silt underlies most of the island, which physically limits the depth of the fresh lens. At the edges of the island core, the fresh lens shallows in response to the attenuation of hydraulic head and infiltration of saltwater into the aquifer from ocean-side overwash and bay-side flooding. The lateral extent of the fresh lens along the length of the island is similarly restricted by the low-lying areas of former inlets where the ground water is predominantly brackish. The ocean-side section of the island comprising the beach, berm, and primary and secondary dune fields has an extremely dynamic ground-water system with alternating inputs of freshwater from precipitation and saltwater from overwash, and preferential subsurface flow of brackish ground water following storm-created channels and swales.

ACKNOWLEDGEMENTS

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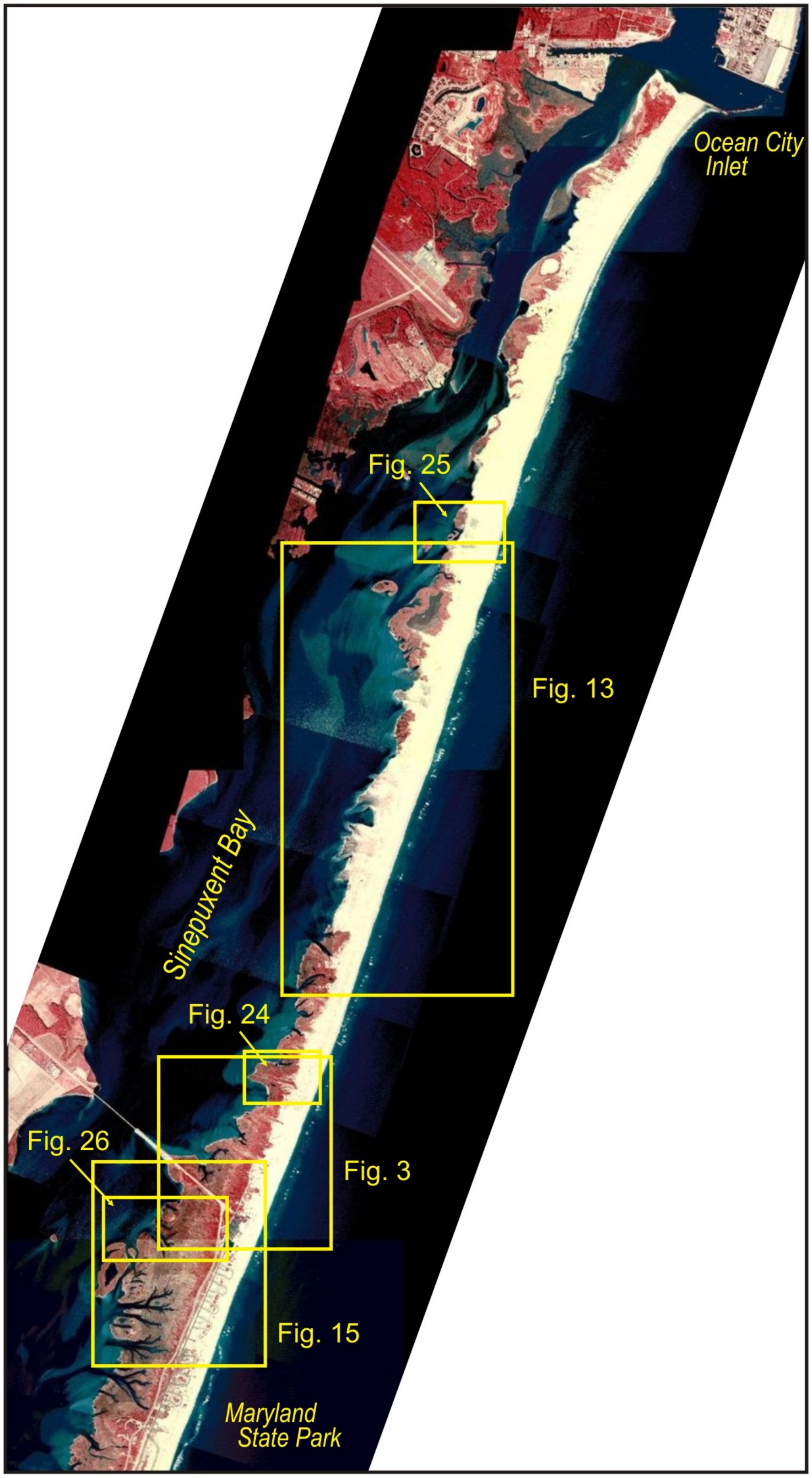
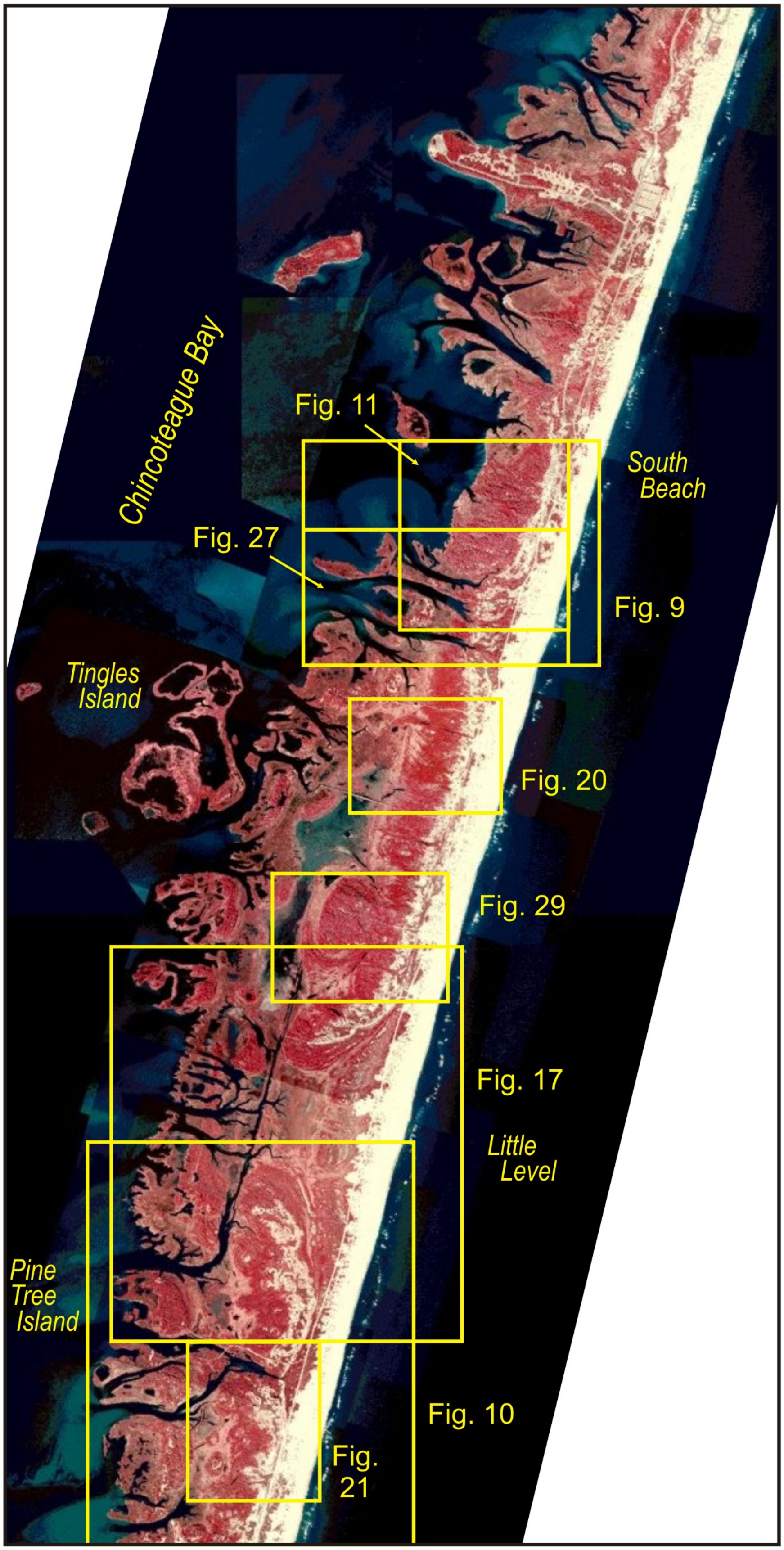
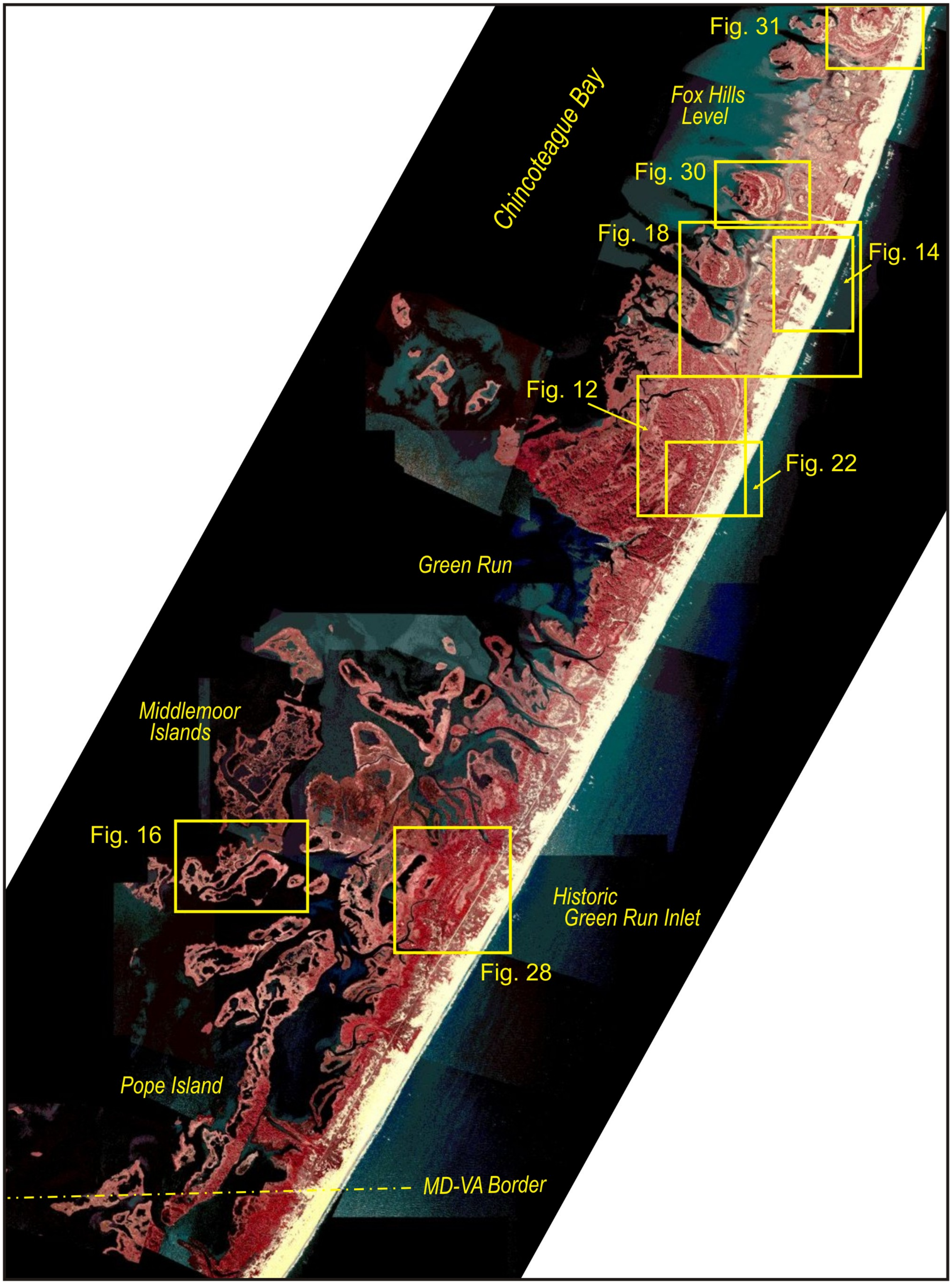
APPENDIX A. LOCATIONS OF SCENES SHOWN IN REPORT FIGURES.



Appendix A1. Northern section of Assateague Island National Seashore.



Appendix A2. Central section of Assateague Island National Seashore.



Appendix A3. Southern section of Assateague Island National Seashore.