William & Mary
CHARTERED 1693

W&M ScholarWorks

Reports

10-2008

The Living Shoreline Suitability Model Worcester County, Maryland

Marcia Berman
Virginia Institute of Marine Science

Tamia Rudnicky
Virginia Institute of Marine Science

Follow this and additional works at: https://scholarworks.wm.edu/reports

Part of the Environmental Monitoring Commons

Recommended Citation

This project was funded by the Maryland Coastal Zone Management Program, Department of Natural Resources pursuant to NOAA award number NA05NOS4191142. Financial assistance for this project was funded by the Coastal Zone Management Act of 1972, as amended, and administered by the Office of Coastal Resource Management, National Oceanic and Atmospheric Administration. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

This Report is brought to you for free and open access by W&M ScholarWorks. It has been accepted for inclusion in Reports by an authorized administrator of W&M ScholarWorks. For more information, please contact scholarworks@wm.edu.

Living Shoreline Suitability Model
Worcester County, Maryland

Soft stabilization

Hybrid design option

Final Report Submitted to

Coastal Zone Management Program
Maryland Department of Natural Resources
Annapolis, Maryland

Submitted By

Center for Coastal Resources Management
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, Virginia

funded through grant number NA05NOS4191142/ 14-08-1182 CZM 142

The Living Shoreline Suitability Model
Worcester County, Maryland

Final report submitted to

Coastal Zone Management Program
Maryland Department of Natural Resources

Submitted by

Center for Coastal Resources Management
Virginia Institute of Marine Science
College of William and Mary

Contributing Authors
Marcia Berman (PI)
Tamia Rudnicky

This project was funded by the Maryland Coastal Zone Management Program, Department of Natural Resources pursuant to NOAA award number NA05NOS4191142. Financial assistance for this project was funded by the Coastal Zone Management Act of 1972, as amended, and administered by the Office of Coastal Resource Management, National Oceanic and Atmospheric Administration. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

October, 2008

Executive Summary

This project expands the tool box of resources available to local governments to assist with shoreline management issues. Using Worcester County as a prototype in Maryland, a geospatial model has been applied to delineate preferred alternatives to erosion control in a varied estuarine landscape. The Living Shoreline Suitability Model (LSSM) was developed by the Center for Coastal Resources Management at the Virginia Institute of Marine Science to encourage and expand the use of living shoreline treatments to counter shoreline erosion.

The model considers the use of soft stabilization as well as hybrid or mixed treatments that do net sever the connection between the upland and the aquatic ecosystem. These options can provide equal or greater benefits to the coastal landscape when constructed in the proper setting. The model uses data from various sources, including the MD Shoreline Inventory, to map where conditions are conducive to various alternatives. The model output also identifies areas where more traditional treatment options would be best.

The model classifies the shoreline into three major categories: suitable for soft stabilization, suitable for hybrid options, and not suitable for living shoreline. The model expands the hybrid options class to identify general treatment types which may be considered given conditions at the time of mapping. These types include such treatments as marsh toe revetments, marsh plantings in combination with marsh sill, and modifications to the riparian upland. The model was validated against random field inspections and permit reviews as part of another study. Those results are presented here and indicate strong agreement (75%) between the modeled output and the field review when considering a site suitable (inclusive of hybrid options) and unsuitable. The model had less agreement (58%) between the output and the field assessment when considering explicit treatment types. We attribute the discrepancy largely to the limitations associated with data availability and professional bias. Despite this, the model has enormous potential as a management tool and represents the only decision making tool currently devoted to the subject of living shorelines in the Chesapeake Bay region, and one of the few nationwide.

Deliverables for the project include a final report with maps delineating model output in Worcester County, digital shape files, and metadata. The products can be easily integrated into the expanding toolbox of the web based Maryland Shorelines Online project.

Introduction

Tidal shoreline protection continues to challenge states and local governments as property owners execute their right to defend private property from erosion. The science and management community is committed to adopting strategies that provide a best management alternative to erosion protection with minimum losses to riparian and intertidal habitat.

In Maryland over 1,000 miles of shoreline is already hardened. This represents nearly one quarter of the shoreline surveyed by the Center for Coastal Resources Management at the Virginia Institute of Marine Science in an effort to survey and catalog conditions along navigable tidal shoreline in the state (CCRM 2004).

Shoreline hardening has been the industry standard for controlling shoreline erosion problems. We know that construction of erosion control structures results in the permanent loss of living resources along impacted shorelines. Despite this, there has been little effort to initiate alternative erosion control practices on a widespread basis. If this trend continues, intertidal marshes will become fewer and fewer, and the aesthetic and ecological character of rivers and streams will be forever changed.

There is a movement advocating for preservation of the natural landscape through the use of soft stabilization in the Chesapeake Bay. "Living Shorelines" advocates the use of "non-structural" or "soft structural" control for shoreline stabilization. Soft control is endorsed by coastal scientists and environmental engineers as a viable alternative to traditional methods. Under appropriate environmental conditions, vegetating shorelines with marsh grasses could offer comparable levels of protection against shoreline erosion as seen with bulkheads and revetments. The reduced cost, long-life, and the absence of required permits make this a preferred treatment in many cases.

Private property owners, however, do not embrace this technique with the same level of confidence they have for hard structures. There are several reasons for this. Reduced revenue to contractors makes this type of construction not as lucrative. Contractors, therefore, advocate for traditional methods even when the level of erosion and environmental setting is conducive to soft stabilization. Monitoring success of these techniques versus traditional methods has been poor. Only a few test cases at this time have been monitored for long-term effectiveness of soft protection. To build public confidence, monitoring and awareness must improve.

What do we know currently? Field reviews suggest the presence of structures like bulkheads and revetments impedes the natural proliferation of fringe marshes. Co-occurrence is infrequent (CCRM, 2007). Field data also indicate naturally vegetated shoreline tend to be more stable than shorelines without vegetation; offering evidence that marshes do provide effective erosion control against wave power. Statistical testing will quantify the strength in these relationships and build stronger arguments for soft stabilization over bulkheads and riprap.

Scientists also recognize that environmental setting plays a major role in the success of non-structural control methods. In many instances a pure living shoreline alternative is not appropriate. Instead, a mix of non-structural and structural control is necessary. This approach is still preferred to a purely hardened shoreline since it maintains connectivity between the upland and the shallow intertidal zone. Therefore, the adopted definition of a living shoreline allows for this mix.

What is a Living Shoreline?

The definition of a living shoreline can vary among managers. Therefore it is important to define what constitutes a living shoreline under this body of research. The Center for Coastal Resources Management (2006) defines a living shoreline in the following manner, "A living shoreline utilizes a management practice that addresses erosion by providing for long-term protection, restoration or enhancement of vegetated shoreline habitats. This is accomplished through the strategic placement of plants, stone, sand fill and/or other structural and organic materials. Living shorelines do not utilize structures that sever natural connections between riparian, intertidal and subaqueous areas." This definition builds-upon the philosophy of Burke (2005).

Under this definition a living shoreline treatment includes not only non-structural alternatives, but also accepts non-structural alternatives used in combination with more traditional approaches which are placed in a manner that do not sever the physical connection between the above. These combined approaches are generally required because the physical environment is not conducive to a purely soft approach. We refer were to these types of projects on the ground as *hybrid construction.*

Project Outline

The objective of this project was to apply the Living Shoreline Suitability Model (LSSM) developed by VIMS' Center for Coastal Resources Management to the county of Worcester, Maryland. LSSM is a spatially explicit model that uses coastal conditions and characteristics to determine where the living shoreline alternative is an appropriate method for erosion control. The model results are delivered in a map interface accessible through the web and a dedicated website. Shape files and metadata can also be downloaded so users can integrate the data into their own programs. The output is developed for easy integration into atlas based tools such as Maryland Shorelines Online (http://shorelines.dnr.state.md.us/).

Living Shoreline Suitability Model

Conditions that favor living shoreline treatments can be modeled in a well mapped landscape. This project applied an existing spatial model that maps criteria important for determining suitability of a site for living shoreline treatments. The model was developed to use spatial information and run in a GIS environment. Studies by CCRM, 2007 and Duhring et al; (2005) were used to determine the criteria for mapping living shoreline treatments. Available datasets were queried for the attributes that reflect the requirements specified in the criteria.

In this section the model development will be reviewed. The model was validated using a combination of desk-top project reviews and field visits in the state of Virginia.

Model Caveats

The LSSM was designed around available GIS data. As the parameters are updated or revised, the model can be re-run to reflect current conditions. Currently, the Worcester County LSSM has been run using best available GIS data. As new parameters become available in GIS formats, the model may be revised to reflect these additions in the future. Other important caveats also apply.

First, the model does not currently consider a "Do Nothing" alternative as a possible outcome. It assumes that erosion is present or is perceived to be present by the property owner, and some action will take place. Second, the model does not currently recommend preferred traditional methods for erosion control in areas where the living shoreline alternative is not possible. We hope to expand the model in this capacity in the near future.

Model Development

The living shoreline suitability model uses GIS and available spatial data to map areas where the use of living shorelines would be a preferred alternative to combat shoreline erosion. The model was developed to support integrated guidance at the management level and facilitate implementation of an integrated management program. Specifically, the model output is intended as a tool to advise a regulatory or management action in response to a request for some erosion abatement technique. Therefore, the assumption is the agency(s) must make a recommendation regarding an erosion abatement strategy for a site.

From a different stakeholder viewpoint, the model output also informs property owners and marine contractors of the recommended alternatives for shoreline stabilization in a given area. This offers the opportunity for property owners, in particular, to get in front of the process and understand their options as well as the preferred strategy before the application process begins. Potentially, from this perspective, the model output can be viewed to have time and cost saving benefits to private land owners.

Regardless of the stakeholder, the living shoreline model output was developed to recommend the best course of action with the understanding that 1) some action will occur, and 2) soft stabilization is always preferred over hard structural control. The model illustrates its output in map form. The analytical rules that formulate the criteria used in the mapping are discussed below.

Data Inputs

The model uses data from various sources. Each attribute is listed in Table 1 with its origin. The Chesapeake Bay Shoreline Inventory under development by the Center for Coastal Resources Management (http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/index.html) provides a significant amount of data that describes conditions along tidal shoreline in Virginia, and Maryland. The model was developed knowing these data were available, and substantial changes to the model would be necessary to run the model in a location where an inventory of these shoreline conditions are not available. For Worcester County, the model has been run only along the shoreline where MD Shoreline Inventory data exists.

Table 1. GIS data used in Living Shoreline Suitability model

DATA	SOURCE
Fetch	CCRM exposure model*
Bathymetry	Chesapeake Bay Program 1m contour MD Geological Survey (MD DNR)
Marsh presence	CCRM Chesapeake Bay shoreline inventory* MD DNR Wetlands Inventory**
Beach presence	CCRM Chesapeake Bay shoreline inventory*
Bank Condition	CCRM Chesapeake Bay shoreline inventory*
Tree Canopy	Regional Earth Science Application Center

* CCRM: Center for Coastal Resources Management, VA Institute of Marine Science
** MDDNR: Maryland Department of Natural Resources

Each attribute listed in Table 1 has been has been adapted into the LSSM. A very brief description of each attribute is presented below. More information can be found through the metadata. Table 2 summarized how the attribute is adapted in the model.

Fetch: Fetch (the distance over water the wind blows or a wave travels before it encounters land) is based on a geospatial model developed by CCRM that calculates the longest transect cast from a point of land in one of sixteen different wind rose directions. Fetch is computed at 100 meter intervals along the shoreline. The longest transect length determines the fetch regardless of the dominant wind direction. The classification for fetch has been scaled to represent distances more typical of an estuarine environment as opposed to an open ocean coast. The classes used in the original Exposure Model and applied here are: low (0-1.0 mile), moderate (>1.0-5.0 miles), or high (> 5.0 miles).

Bathymetry: Data from the Chesapeake Bay Program has been queried to extract the 1 meter bathymetric contour. This being the shallowest contour represented throughout the study area in the database, it is being used here as a means to assess the width of the shallow water intertidal platform. In order to recommend planting marsh grasses, the nearshore must be relatively shallow. Bathymetry is combined with the distance from the shoreline to characterize the nearshore environment. If the 1 meter contour is greater than 10 meters from the shoreline we classify the nearshore environment as "shallow" and therefore suitable for marsh plantings. If the 1 meter contour is less than 10 meters from the shoreline we classify the nearshore as "deep" and not suitable for plantings unless modifications are made. All areas contiguous to the man-made canal systems found dispersed along the Worcester County shoreline are considered "deep".

Presence of Marshes: The presence of marsh vegetation along a shoreline suggests environmental conditions are favorable for growth. Presence, therefore, is used as an indicator of favorable conditions and suggests new growth through plantings may be viable. The model recognizes that some modifications to the landscape may be required in order to meet all minimum landscape parameters for marsh plantings. To assess marsh presence, this study used a combination of marsh vegetation delineated in the MD Wetlands inventory as well as the MD Shoreline Inventory. Both delineate the presence of marshes along shore. The MD Wetlands inventory maps wetlands as polygons which enables us to estimate marsh width. The criteria for the model establish a minimum marsh width of 4.6 meters (15 feet) for existing marshes to be indicators of future potential growth areas.

Presence of Beaches: The presence of beaches is used an indicator of a shallow water natural environment that represents a non-vegetated living shoreline condition. Data from the MD Shoreline Inventory was used to delineate areas where beaches exist.

Shore Stability: The MD Shoreline Inventory delineates the condition of the bank observed in the field. Bank condition is classified as high erosion (unstable), low erosion (stable), and undercutting (erosion at the bank toe).

Tree Canopy: The presence of tree canopy is an indicator of sufficient light necessary for vegetation to grow. Land use and land cover classified from 2002 Landsat TM data through the Regional Earth Science Application Center (RESAC) was used in combination with the riparian land use designations in the MD Shoreline Inventory to extract forested riparian areas likely to have canopy shading along the shoreline.

Table 2. Model variables

ATTRIBUTE	VALUES
Fetch	low (0-1.0 mile)
	moderate (1.0-5.0 miles)
	high (> 5.0 miles)
Bathymetry	1m contour > 10m from shoreline
Marsh presence	present/absent
Beach presence	present/absent
Bank Condition	high: observed erosion
	low: no observed erosion
	undercut: bank toe erosion
Tree Canopy	present/absent

Based on our knowledge of landscape characteristics that promote successful living shoreline treatments we defined the various combinations of these attributes necessary for a site to be suitable for the alternative treatment. We then generated GIS based algorithms to search the databases for these combinations and mapped suitable areas.

Model Classification

To be efficient, a simple classification scheme was developed for the model. Three main classes exist: suitable for soft stabilization, suitable for hybrid option, and unsuitable for living shoreline design. The descriptions below expand on the definition and criteria used for each class.

Suitable for soft stabilization: Soft stabilization includes the use of fiber logs, planting new marsh grass or restoring and enhancing sites. Table 3 summarizes the on site conditions necessary for soft stabilization to be recommended.

Table 3. Conditions suitable for soft stabilization

Fetch	low (0-1 mile)
Bank condition	high: observed erosion,
	low: no observed erosion
Bathymetry	shallow (1 m contour > 10 m from shoreline)
Beach presence	yes or no
Marsh presence	yes (>15 feet deep) or no
Tree Canopy	no

The model builder within the ArcGIS® software was used to query the databases and model various combinations of the different variables. The analysis returned n=6 different variable combinations. Shoreline segments with the combination found in Table 3 are classified as “suitable for soft stabilization”.

The data model for this classification is illustrated in Figure 1. Appendix 1 is a conditions matrix which tabulates the options.

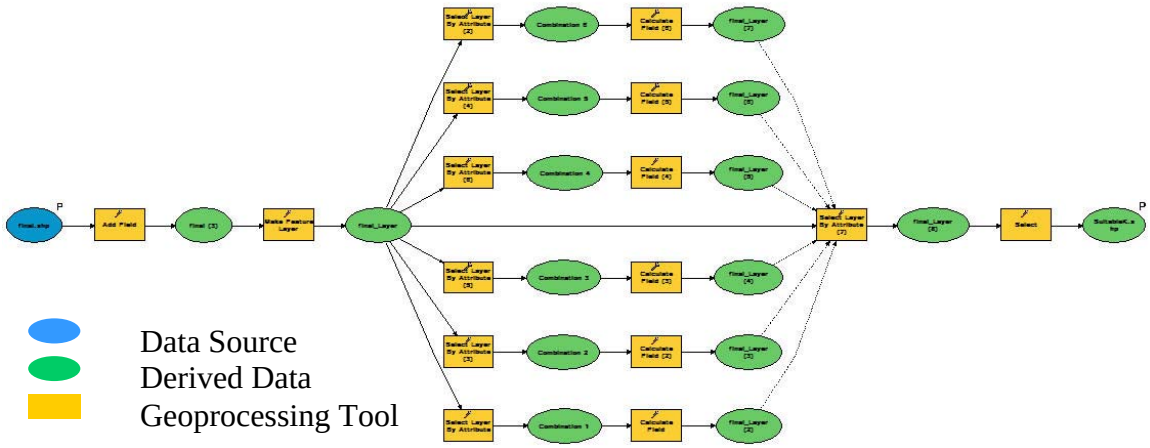


Figure 1. Geospatial data model for "Suitable for soft stabilization" Classification where n=6.

Suitable for Hybrid Options: Suitable for hybrid options characterize areas where soft stabilization techniques are used in combination with traditional structures (see Table 4). Hybrid designs include treatments such as the placement of a low rock revetment at the toe of an existing marsh to offer protection to the existing living habitat. Another example would be planting new marsh in the shallow water environment and constructing a marsh sill (also a low rock structure) to protect the new planting from erosion. Still another option would be to modify the riparian area and stabilize the bank through grading, planting upland vegetation, and trimming trees.

In any of these alternatives the definition of a living shoreline has been upheld. In other words the structures and/or actions are designed so their placement does not sever the natural connection between the upland and the aquatic habitat and therefore constitutes the working definition of a living shoreline. Since hybrid designs offer more flexibility with respect to conditions on the landscape (Table 4) the geospatial data model is much more complex. There are 39 different landscape combinations that can exist (Figure 2).

Table 4. Conditions indicative of shorelines suitable for hybrid designs

Fetch	low (0-1 ml) – moderate (1-5ml)
Bank condition	high: observed erosion
	low: no observed erosion
	undercut: bank toe erosion
Bathymetry	Shallow (1m contour>10meter from shoreline)
Beach presence	yes or no
Marsh presence	yes (>15 feet deep) or no
Tree Canopy	yes or no

Given that, we find that in any given area more than one design option may be suitable. Therefore, a second tier in the model was built to determine some options for shoreline segments that are classified as “Suitable for Hybrid Options”.

We focused on four different typical treatment options: planted marsh on existing substrate (actually a true “living shoreline”), riparian modification (inclusive of pruning, upland grading), marsh toe revetment (protection of existing marsh), and marsh sill (often in combination with the planted marsh). Data to support a baseline level of decision making was available in the existing GIS databases. Specific combinations of the attributes defined in Table 4 determine which of the four treatments mentioned above are appropriate for a shoreline segment. For more information on these treatments see (http://ccrm.vims.edu/livingshorelines/index.html). The conditions matrix can be reviewed in Appendix 2

The model output at this level is intended to provide guidance and suggestions. However, because of the complex interaction of the landscape, location of structural development on the landscape, and various regulations in place, not all options proposed will actually be possible. At this level of decision-making a site review would be recommended. Maps included in Appendix 3 illustrate the model output.

Unsuitable for a Living Shoreline Design: The model recognizes that not all coastal landscapes are suitable for the use of a living shoreline practice for erosion control. Some shorelines are too exposed and are regularly subject to high wave energy. Other shorelines can neither be modified in the riparian area or in the nearshore for one reason or another. Shorelines like these are classified as “Unsuitable” for a living shoreline design, and chronic erosion problems will most likely require a traditional erosion control method such as a revetment to stabilize a bank.

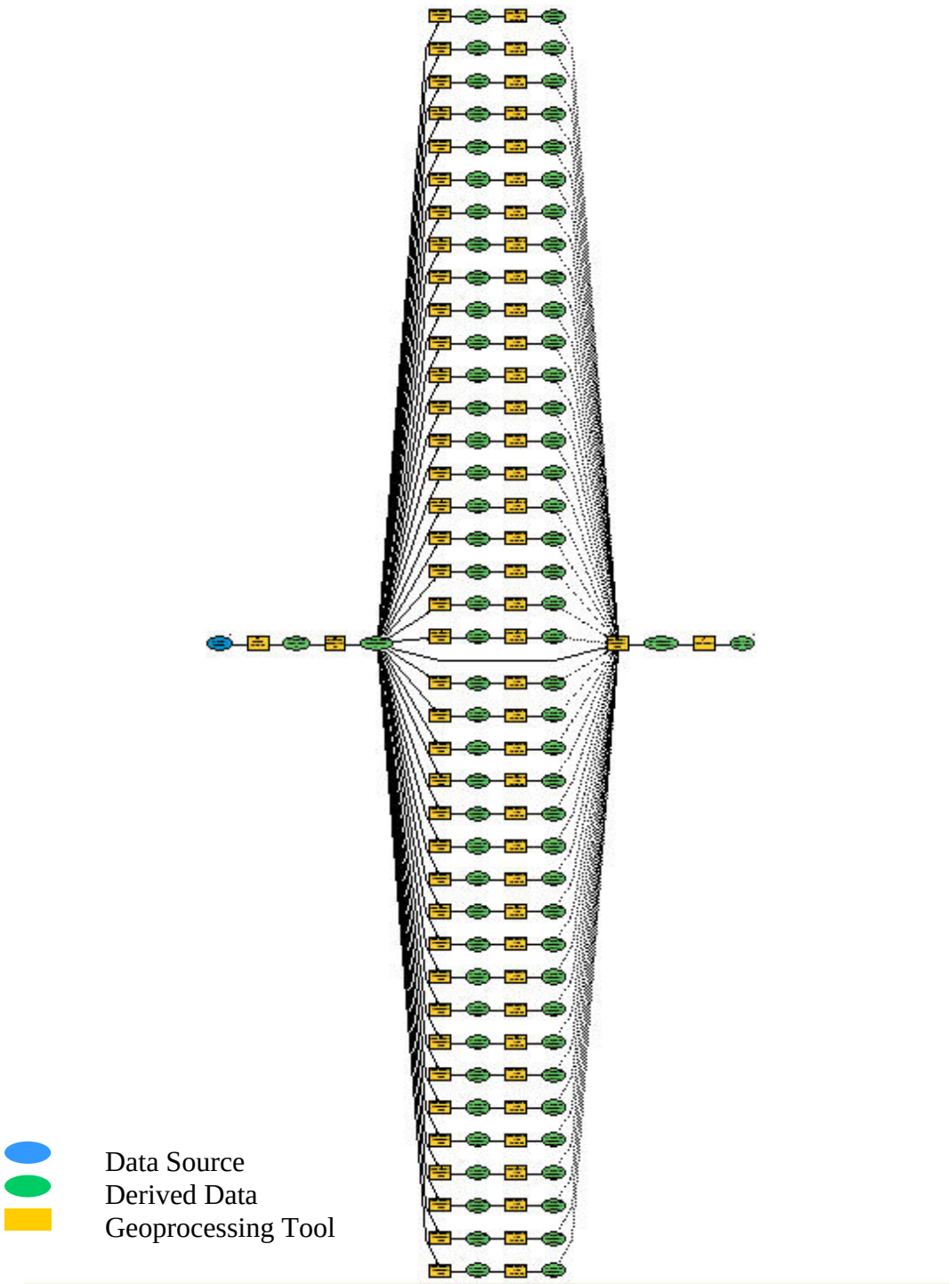


Figure 2. Geospatial data model for the class “Suitable for Hybrid Options” where n=39.

Model Validation

Model validation was performed as a component of the original model development and testing phase. The results of the validation process compared model results from the pilot area of Northumberland County, VA to field evidence gathered from site visits and permit reviews. An error matrix (or covariance matrix) was assembled in order to determine the accuracy of the model. The error matrix was developed by selecting numerous sample points (representing the different categories in the model), and determining if the field conditions at those locations agree with the conditions predicted by the GIS model. Errors in GIS can be divided into: positional errors, classification errors and error propagation. Classification errors are reported as omission, commission and overall error. In addition, as suggested by Titus et al. (1984), kappa statistic is calculated in order to express how much better (or worse) the classification is relative to chance alone.

Forty-eight sites were selected to validate the model in Northumberland County. Some of the sites (23 locations) were randomly selected because field visits were required as part of the regulatory approval process for erosion control structures and other activities. Another set of field sites (25 locations) were randomly selected from the tidal wetlands database using a random integer generator. The list of potential sites was sorted by waterway to get sites with a variety of wave climate settings. Model validation was based on shoreline observations made during site visits between 2003 and 2005 combined with current scientific understanding and recommendations.

The error matrix (Table 5) summarizes the relationship between the model output and the field data. The cells that are highlighted indicate the agreement between the model and the field evidence at each category. The commission error is analogous to a Type II error or a false positive, (i.e., the model is denoting a segment of shoreline as unsuitable, when it is, in fact, suitable). The omission error is analogous to a Type I error or a false negative, (i.e., the model is denoting a segment of shoreline as suitable, when it is, in fact, unsuitable). The development of a consistent, accurate, and easily obtainable dataset for living shoreline requires the minimization of both errors.

Table 5 – Error Matrix for the Suitability Model

		FIELD OBSRVATIONS								
		Unsuitable	Suitable (T1)	Suitable (T2)	Suitable (T3)	Suitable (T4)	Suitable (T 1or3)	Suitable (T 1or4)	TOTAL	Commission Error
MODEL PREDICTION	Unsuitable	**14**	1	0	3	5	0	0	**23**	0.39
	Suitable	0	**3**	0	0	2	0	0	**5**	0.40
	Suitable (T2)	0	0	**1**	0	0	0	0	**1**	0.00
	Suitable (T3)	1	0	0	**2**	2	0	1	**6**	0.67
	Suitable (T4)	0	0	1	1	**8**	0	0	**10**	0.20
	Suitable (T 1or3)	1	0	0	0	0	**0**	0	**1**	1.00
	Suitable (T 1or4)	1	0	1	0	0	0	**0**	**2**	1.00
	TOTAL	**17**	**4**	**3**	**6**	**17**	**0**	**1**	**48**	
	Omission Error	0.18	0.25	0.67	0.67	0.53	0.00	1.00		**0.42**

Where:

Suitable (T1): Planted marsh on existing substrate or minor fill (fiber logs may be included)

Suitable (T2): Treatment 2 - Riparian modifications = selective tree removal, pruning; bank grading; vegetation restoration

Suitable (T3): Treatment 3 - Marsh toe revetment = stone structure placed at eroding edge of existing marsh

Suitable (T4): Treatment 4- Marsh Sill = stone structure with backfill & planted marsh or beach

The agreements between the model and the field data in the categories for suitable with treatment option 2 and 3 are the ones that show more significant impact on the overall error. The model predicts only 2 sites correctly as suitable with treatment 3. This resulted in a commission error of 67%. In addition, there are discrepancies with the model output and the field evidence for the sites, where the model recommends treatment 1 or 3 or treatment 1 or 4, in each case this resulted in an error of commission of 100%. Further examination of the model indicates that four known suitable with treatment 3 sites were classified as unsuitable and suitable with treatment 4. This resulted in an error of omission of approximately 67%. Moreover, the same error of omission was generated in the sites with treatment 2. Considering these results, the overall error of the model was 42% (making the model 58% accurate).

In order to calculate the kappa statistic, a comparison between suitable and unsuitable conditions was performed (Table 6).

Table 6 – Suitable vs. Unsuitable Conditions

		FIELD	
		Suitable	Unsuitable
MODEL	Suitable	22	9
	Unsuitable	3	14

The model did well identifying sites that were unsuitable for living shoreline (Table 6). The proportion of agreement between the model output and the field evidence was 75 %. The kappa index was 0.493, indicating that the model prediction is reasonable over a simple random classification (i.e. suitable vs. unsuitable). The model looses strength when it is required to determine the type of treatment in the restricted category. Possible explanations are given below.

Model Limitations

- *The model does not capture site specific anthropogenic conditions*
  A common discrepancy between the onsite field assessment and the model output was due to conditions that the observer can see in the field but the model does not consider. While the morphologic and biologic conditions may be in agreement the field assessment may recommend a site unsuitable for a specific type of treatment because of site specific conditions the model cannot capture. Examples of these include parcel characteristics such as telephone poles or buildings built to close to the shore which would prohibit the necessary grading of the bank in order to construct the treatment. These conditions pertain mainly to scenarios which are

entirely site specific and cannot be predicted. They represent anthropogenic decisions brought about by individual property owners or communities working in concert with private utility companies (i.e. house location, telephone pole placement, regularly mowed marsh). As a result a comprehensive inventory of most of these conditions is not available and therefore cannot be incorporated into the model.

- *Accuracy of some of the data layer used in the model*

Currency in the data inventory as well as accuracy of the actual data contributes to the accuracy of the model output. If a landscape has been altered since the inventory was developed or incorrectly classified, the model output may no longer be consistent with the intended recommendation. For instance, a parcel classified as a residential land use may include a well developed forest fringe which would place restrictions on the type of treatment design appropriate for the site. If the forest cover was not recorded, the type of treatment recommended by the model output would not be consistent with the model theory or the recommendation from the field assessment.

Validation Limitations

- *Bias in the professional judgment*

  The recommended treatments suggested, based on the field evidences, come from best professional judgments which may vary among professionals. Some site-specific conditions may affect best professional judgment about living shoreline treatment suitability. For example:
  a. Proximity of upland improvements to bank edge and need for traditional structure and/or amount of room necessary to grade the bank as needed.
  b. Existing bulkhead with no intertidal area (mean low water on bulkhead face) and expectancy for reflected wave action that would compromise planted marsh.
  c. Narrow creek channel with numerous piers and significant boat wakes.

- *The model considers some environmental characteristics that are not readily or correctly observed in the field*.

  a. For example, the reviewer cannot determine the depth of the nearshore environment. As a result, this attribute is not taken into account in the field validation or incorrectly assessed. The result would be a different recommendation than the model suggests.

  b. The reviewer incorrectly determines the fetch distance.

- *GPS resolution in Validation technique*

  GPS points (representing the field sites) close to a property boundary or close to the boundary between two different shoreline treatments may result in a mismatch between the field recommendations and the site match within the model output. Here the reviewer was actually in agreement with the model output, but the position of the site review as recorded on the GPS placed the site review on an adjacent site with a different model outcome.

Summary of Validation Results

Taking into account the results from the accuracy assessment and the validation limitations, we can conclude that the model did well identifying sites that are generally either unsuitable or suitable for living shoreline (75% accurate). The accuracy of the model output for determining specific treatments along sites that are suitable for hybrid options is reduced (58%). Some model refinement is possible; however, it is unlikely the data necessary to improve the model significantly will be available without a modified data collection protocol. Therefore, we accept the model as is with the understanding that the output does not replace the need to review sites in the field for final regulatory review or recommendation.

Conclusion

The Living Shoreline Suitability Model successfully delineates shoreline reaches for which a living shoreline alternative should be recommended as a shoreline protection strategy. The model has been refined to recommend types of treatment alternatives, but users must recognize that site specific conditions may unknowingly exist on location that would negate the models recommendation. These would include location of primary building structures on a site to the shoreline. Therefore, site inspections should occur prior to issuing permits or making final determinations.

The validation of the model is good, with some limitations as described. Nevertheless, the broad scale need and uses for such a tool out way the limitations. The simple output makes the product accessible and understandable to a wide audience including private property owners. Therefore, the model is viewed as an important management tool and should be applied regionally in the Bay area, and later incorporated into shoreline management plans, situation reports, and guidance documents.

References

Burke, David, 2005, Living Shoreline Stewardship Initiative, Burke Environmental Associates, LLC, Annapolis, MD, pp.7

Center for Coastal Resources Management (CCRM), 2004. Maryland Shoreline Inventory, final products submitted to Coastal Zone Management Program, Maryland Department of Natural Resources, http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/index.html.

Titus, K., J.A. Mosher, and B.K. Williams. 1984. Chance-corrected classification for use in discriminate analysis: ecological applications. American Midland Naturalist, 111, 1-7.

Appendix1.

Living Shoreline Treatment Matrix
Suitable for Soft Stabilization

Suitable

fetch	low	x	x	x	x	x	x
	moderate						
	high						
bank erosi	low	x	x	x			
	high				x	x	x
	undercut						
bathymetry	shallow	x	x	x	x	x	x
	deep						
beach	present	x		x	x		x
	absent		x			x	
marsh	present > 15 ft		x	x		x	x
	present						
	absent	x			x		
forest	present						
	absent	x	x	x	x	x	x

Appendix2.

Living Shoreline Treatment Matrix
Suitable for Hybrid Options

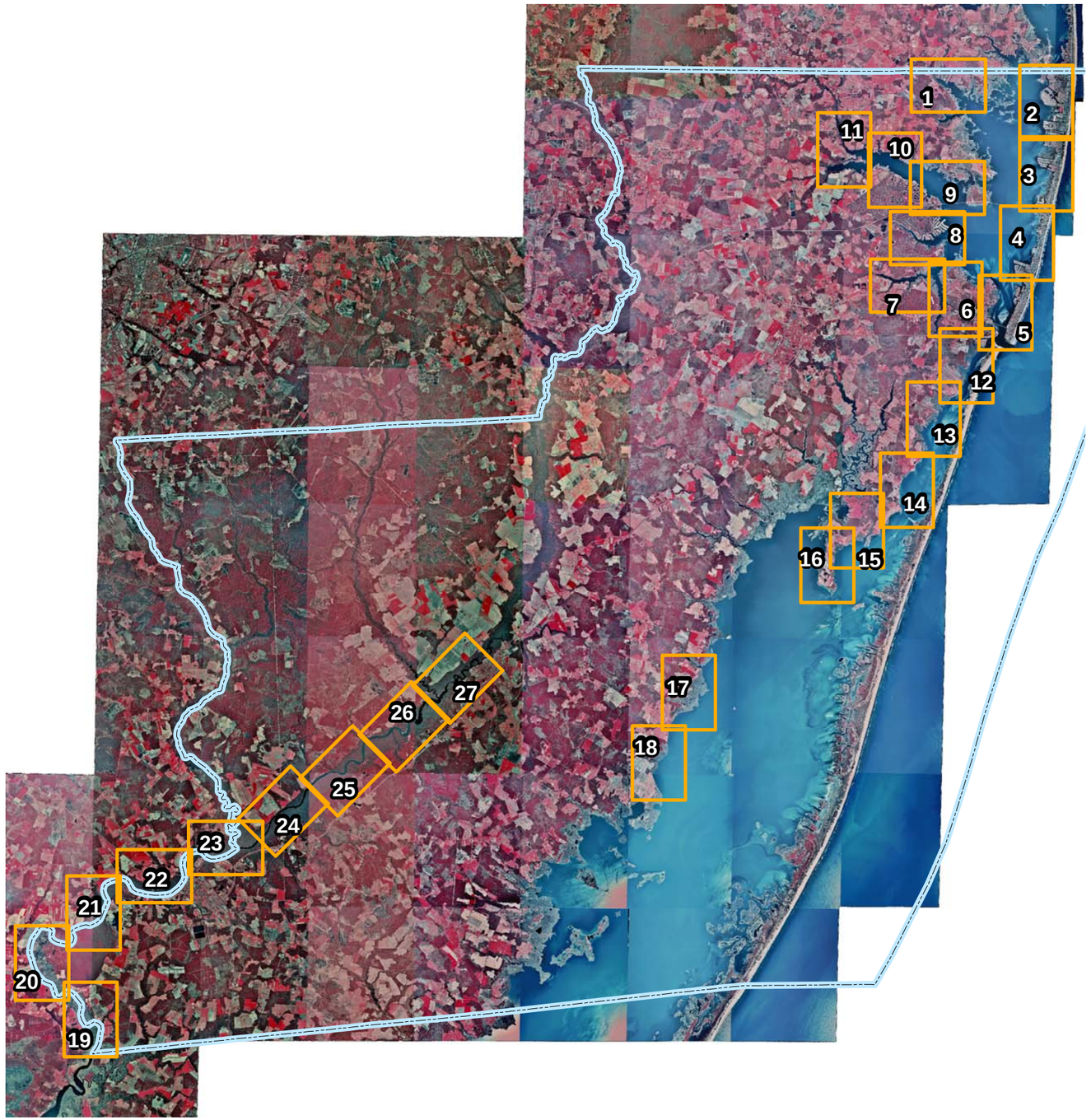
Suitable with design restrictions

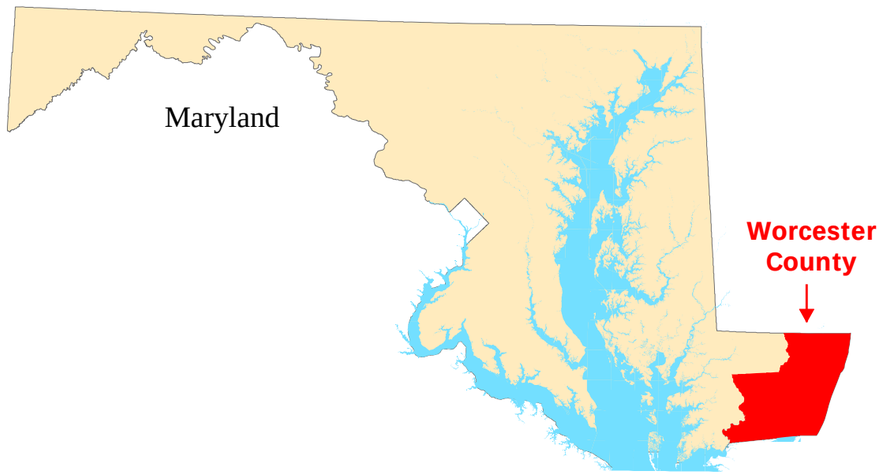
| | | |

Appendix3.

Worcester County Living Shoreline Map Atlas

Worcester County, Maryland
Index Map





Scale

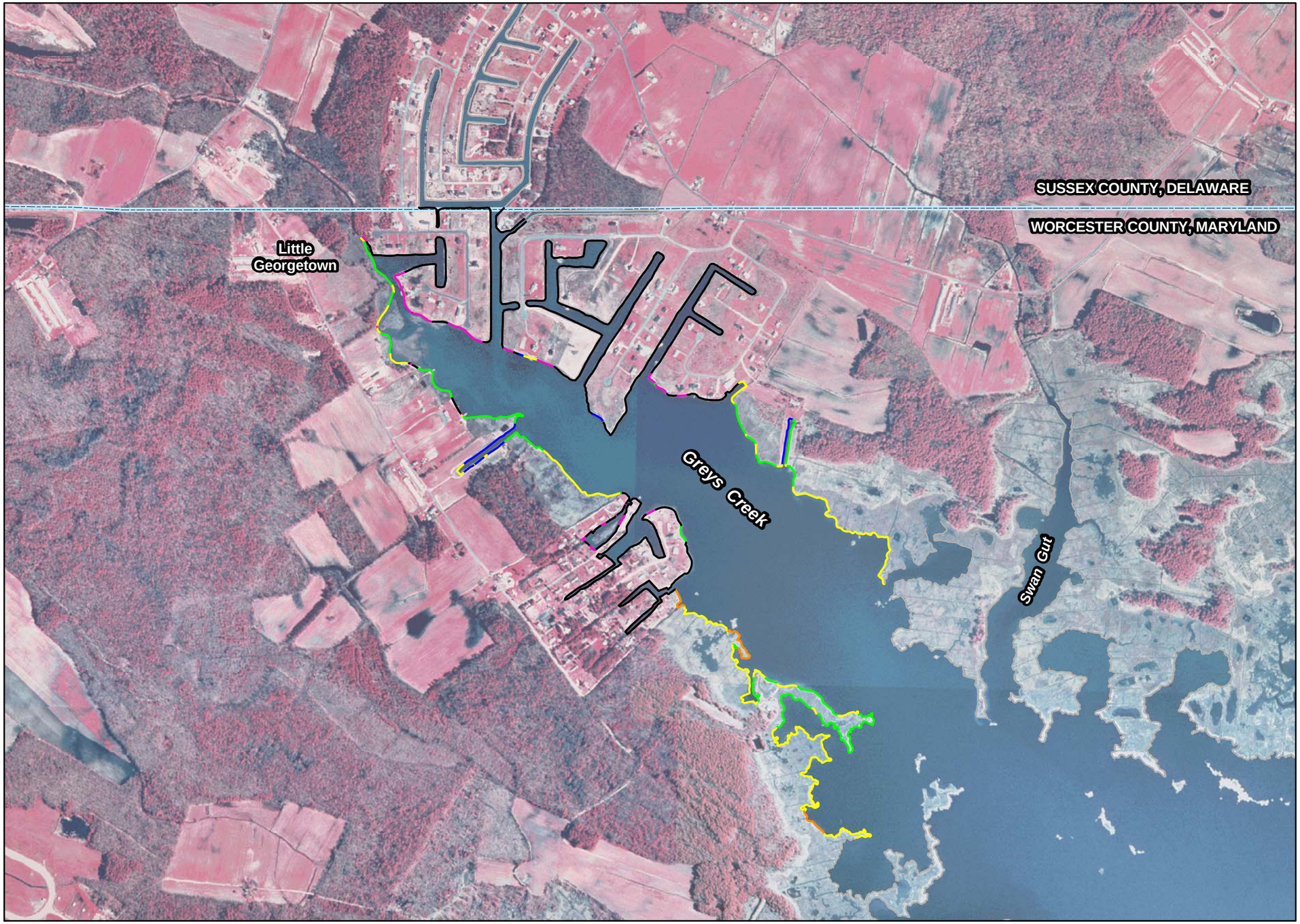
0 5 Miles

1:252,684

N
W E
S

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 1



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N
W E
S

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 2

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 3

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

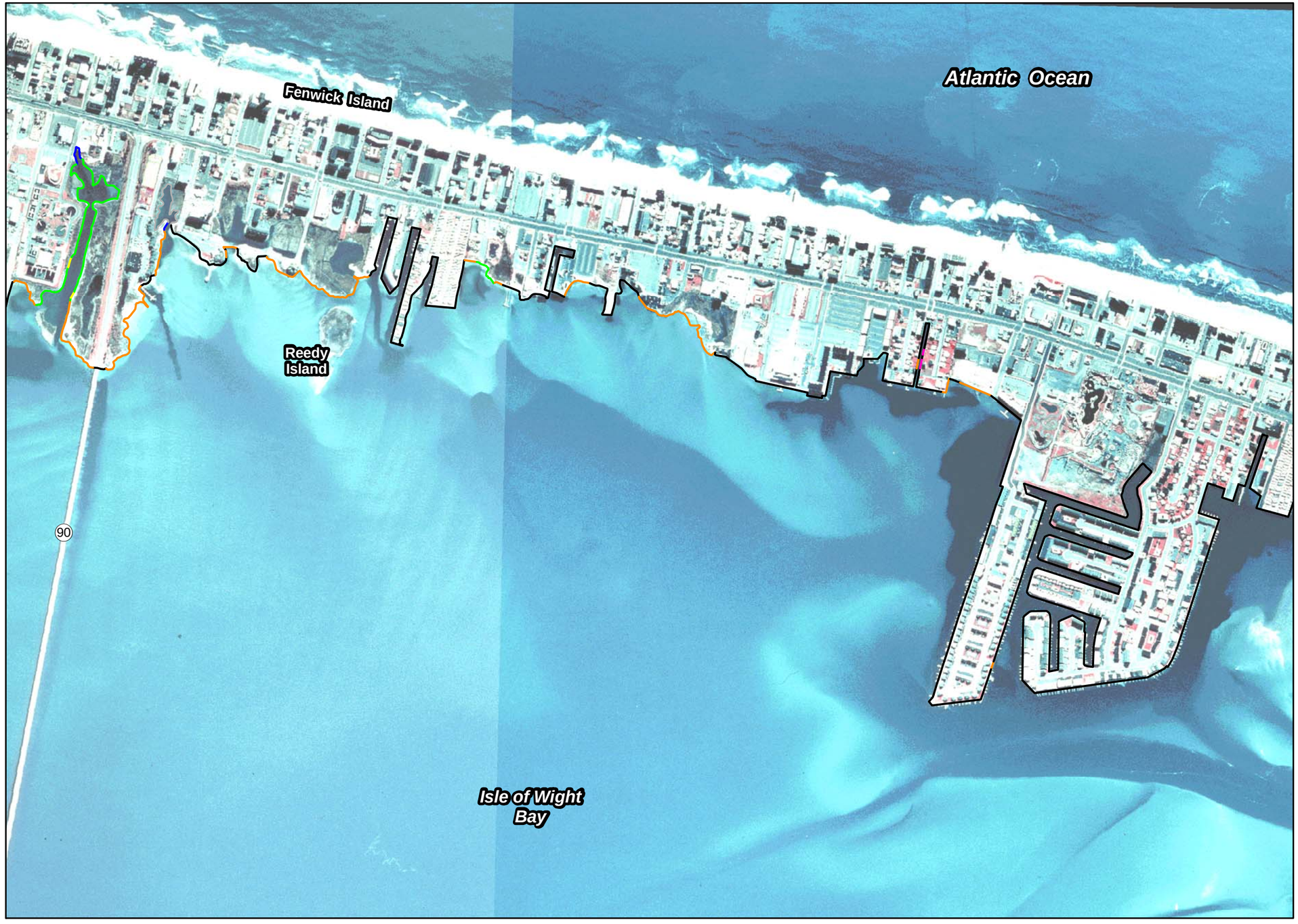
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 4



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N E S W

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 5

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

★ Note: Major dredging occurred after photography.

N E S W

Scale

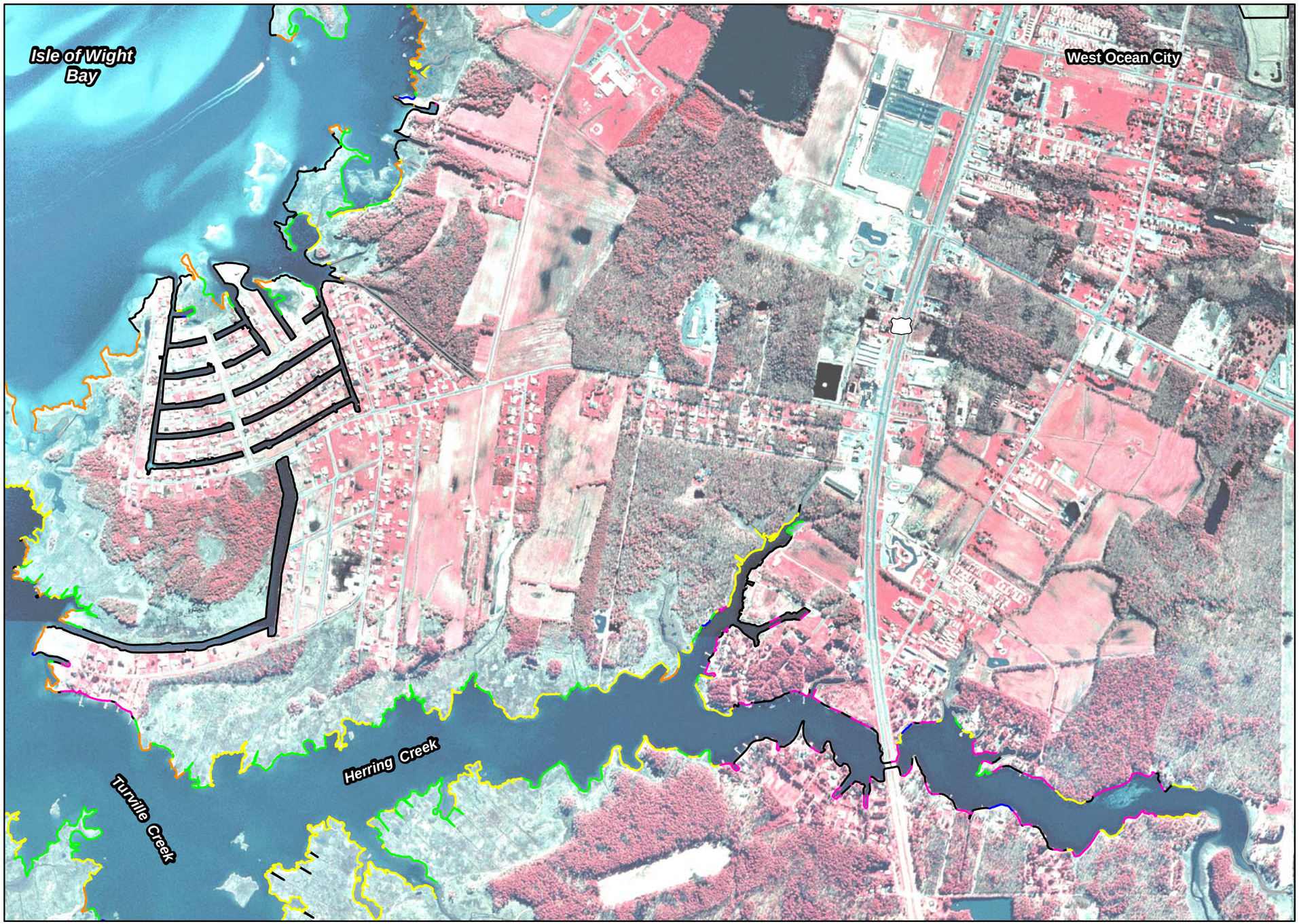
400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

cci

Living Shoreline Design Options
Worcester County, Maryland
Plate 6



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

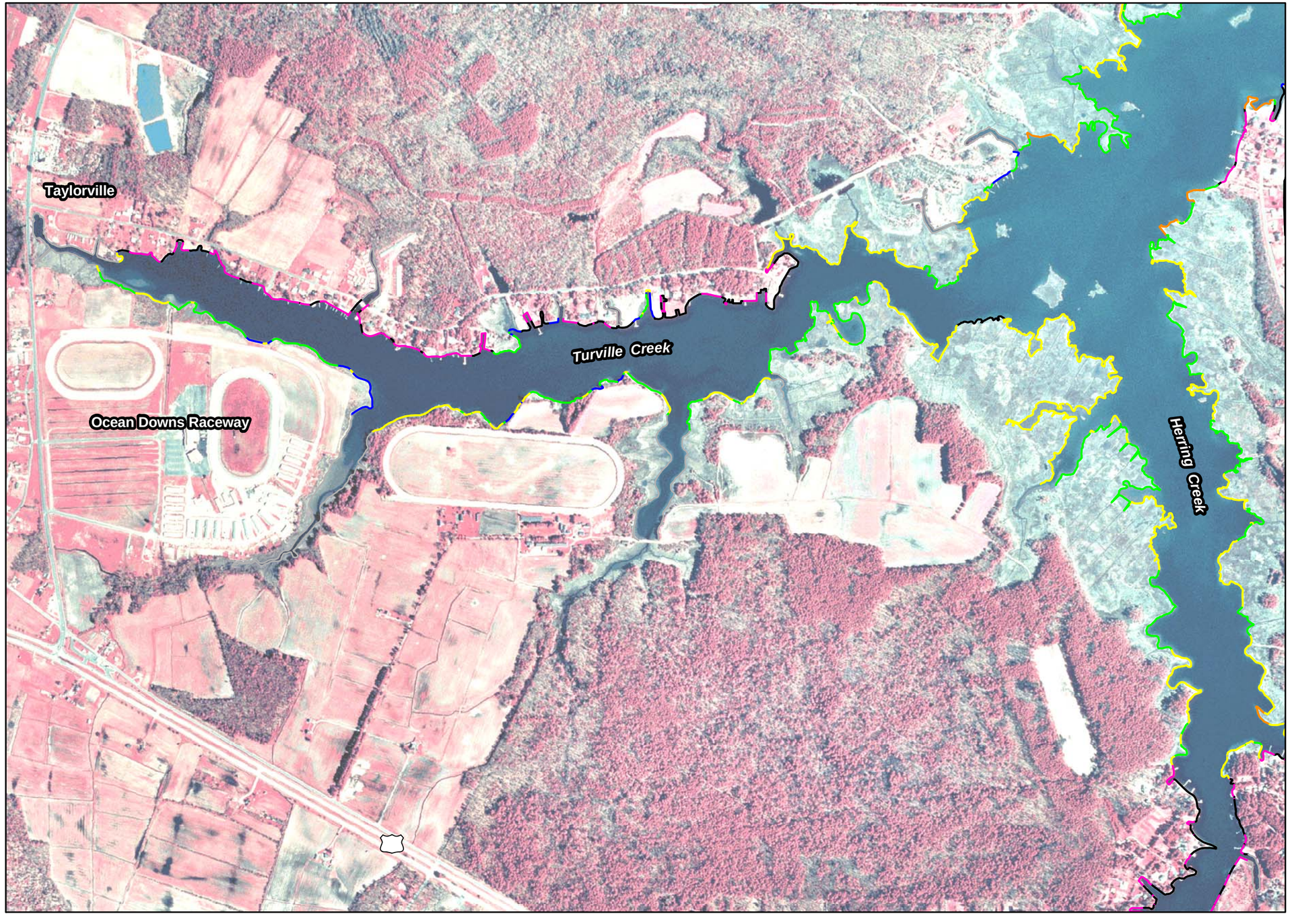
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 7



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N
W E
S

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 8

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N
W E
S

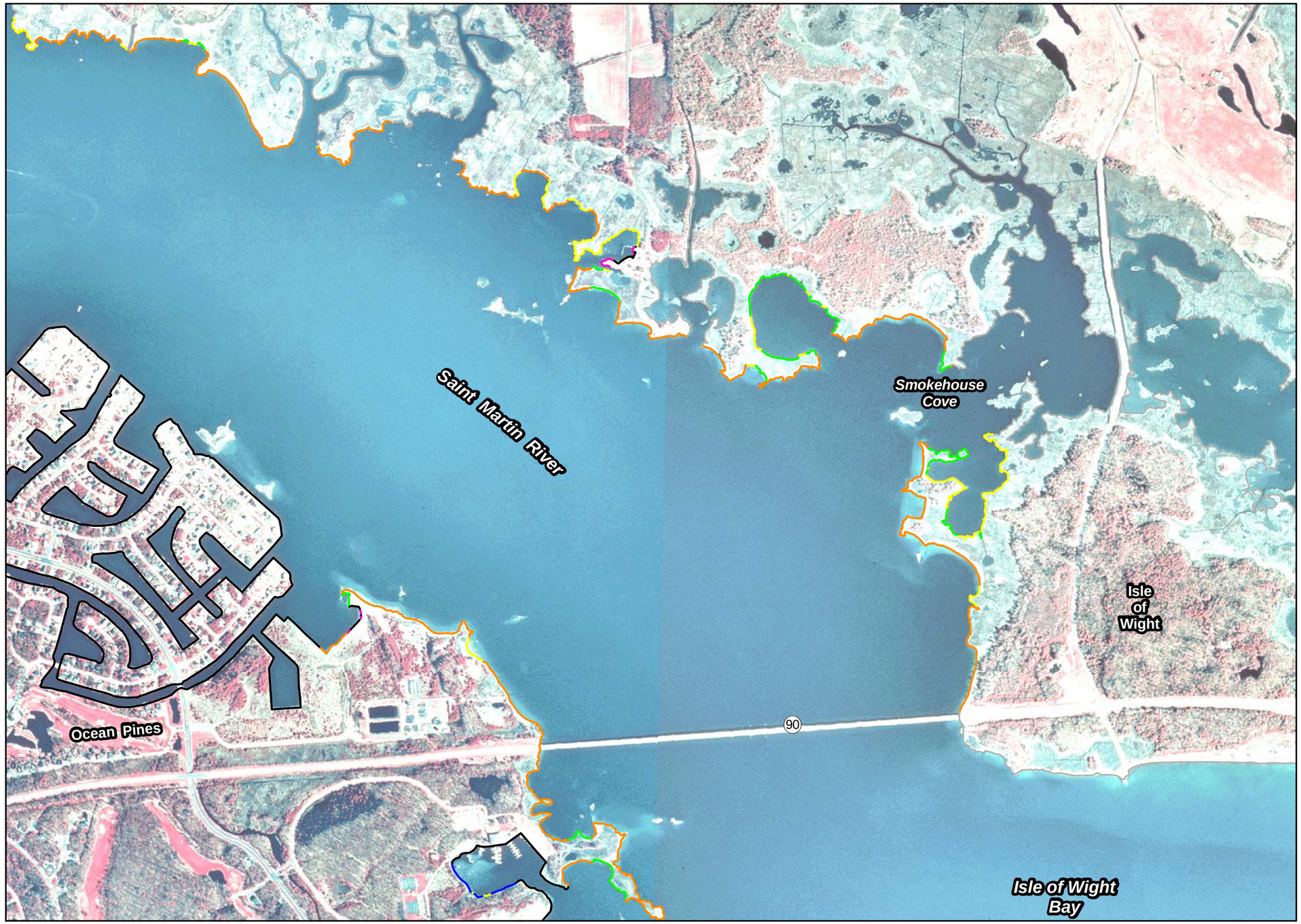
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 9



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N
W E
S

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 10

Ocean Pines

Hasty Point

Saint Martins Neck Road

Saint Martin River

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

W S N E

Scale

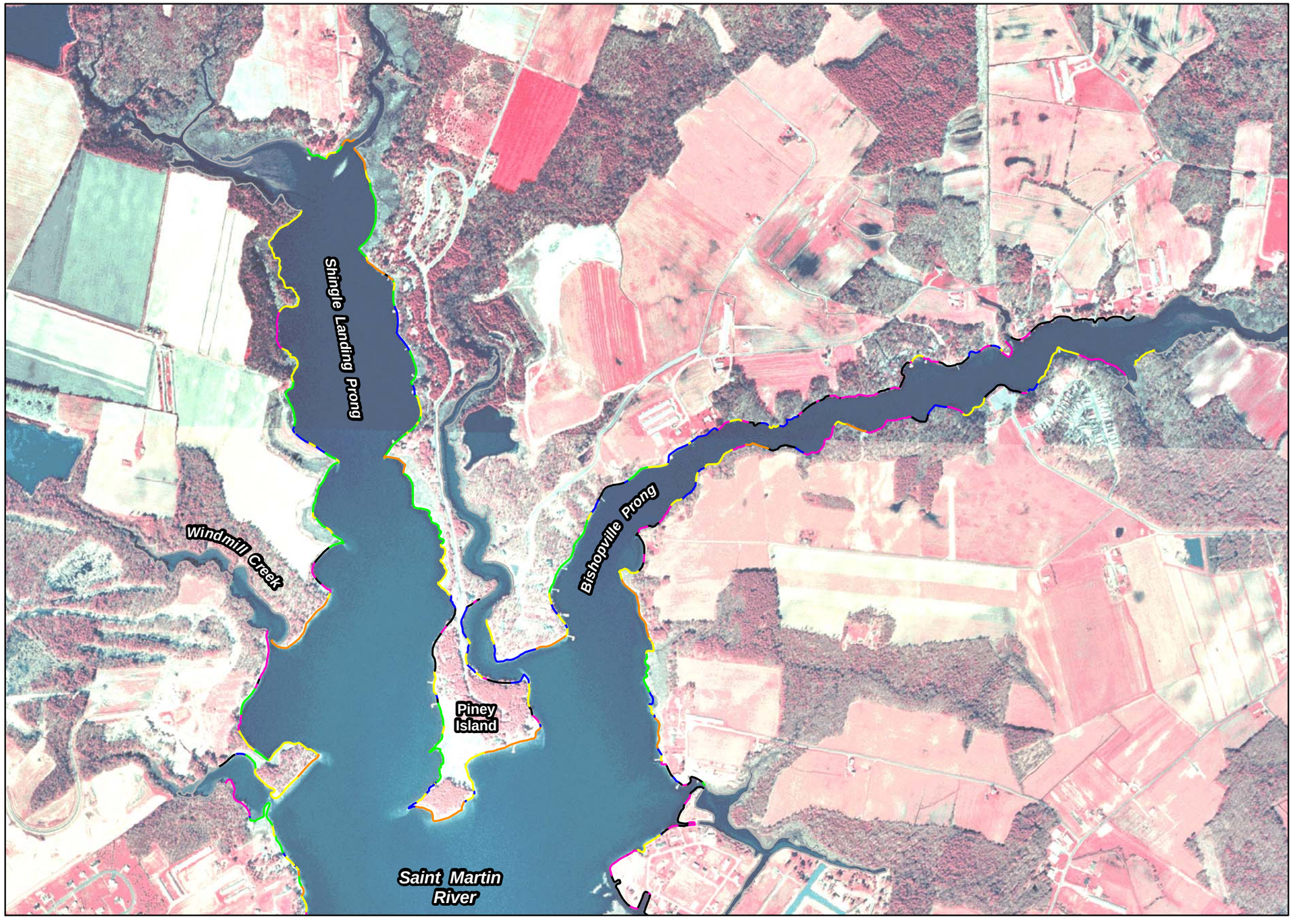
400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

cci

Living Shoreline Design Options
Worcester County, Maryland
Plate 11



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

W
S
N
E

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 12

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

★ Note: Major dredging occurred after photography.

N E S W

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 13

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization

Suitable for Hybrid Options

- marsh planting or marsh toe revetment
- marsh planting or sill
- marsh toe revetment
- riparian modifications
- sill

- No Data

N E S W

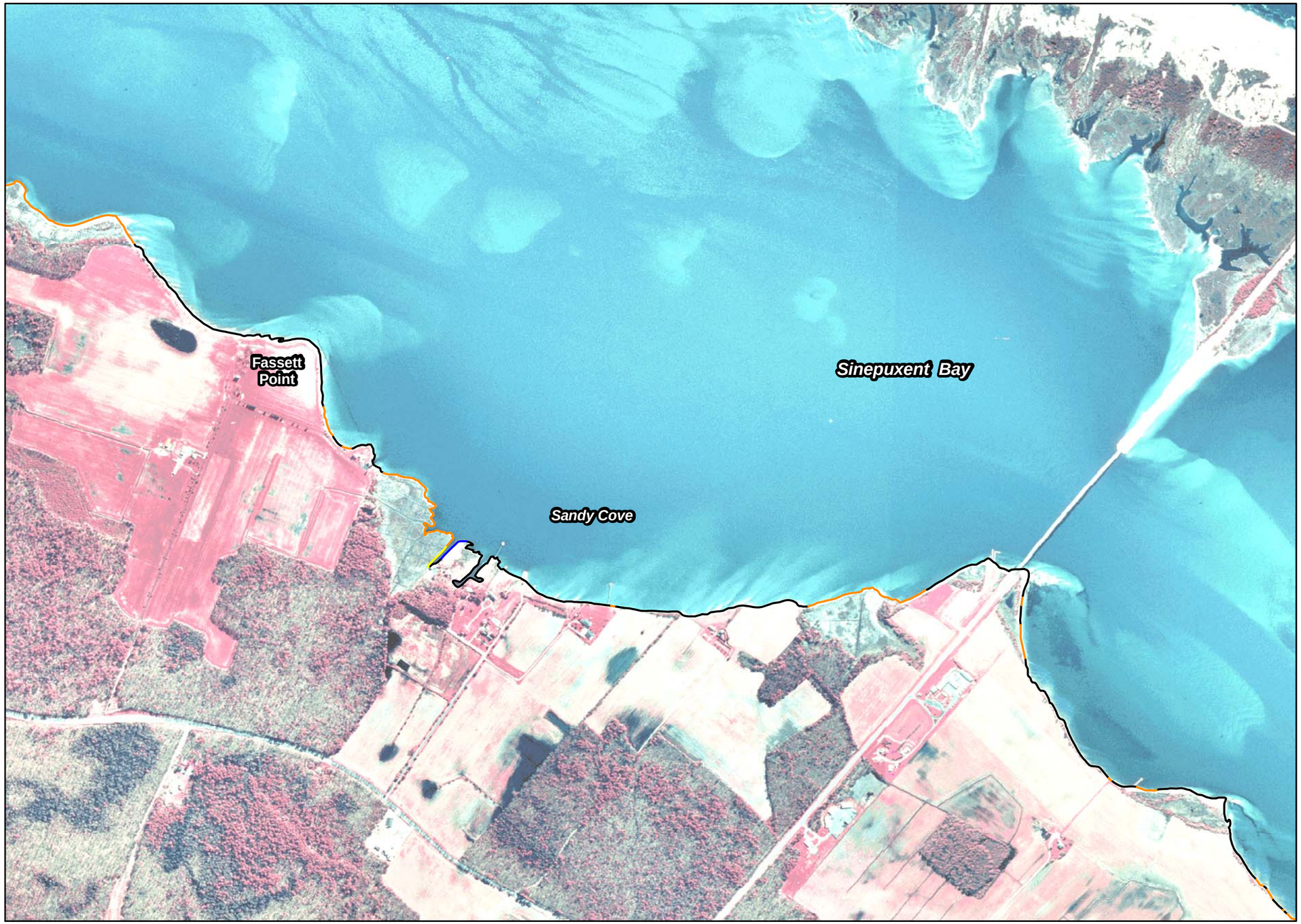
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 14



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

Scale

400 0 1,600 Feet

1:12,005

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 15

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N E S W

Scale

400 0 1,600 Feet

1:12,004

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 16

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

Scale

400 0 1,600 Feet

1:12,010

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 17

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

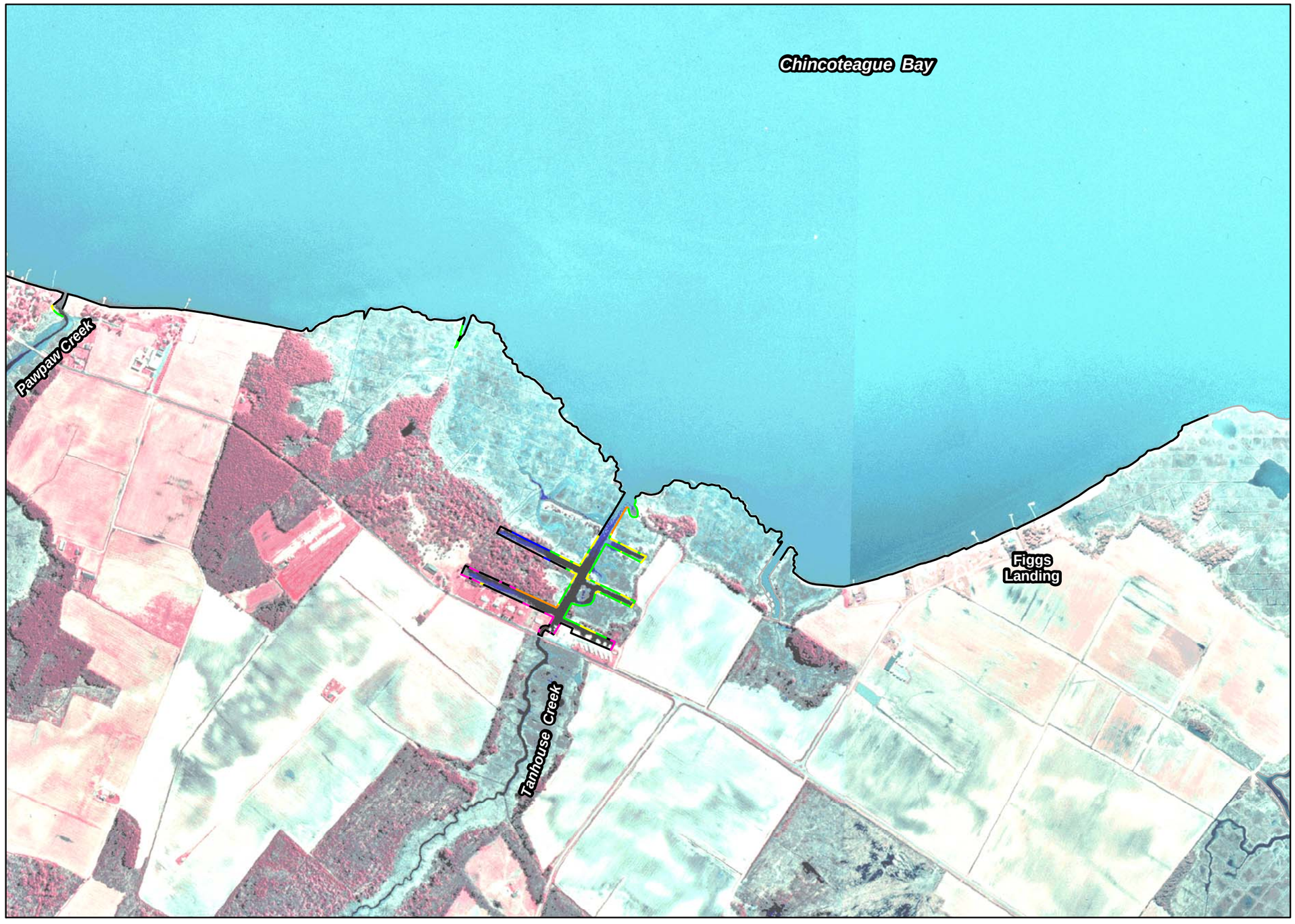
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 18



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N E S W

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 19

Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

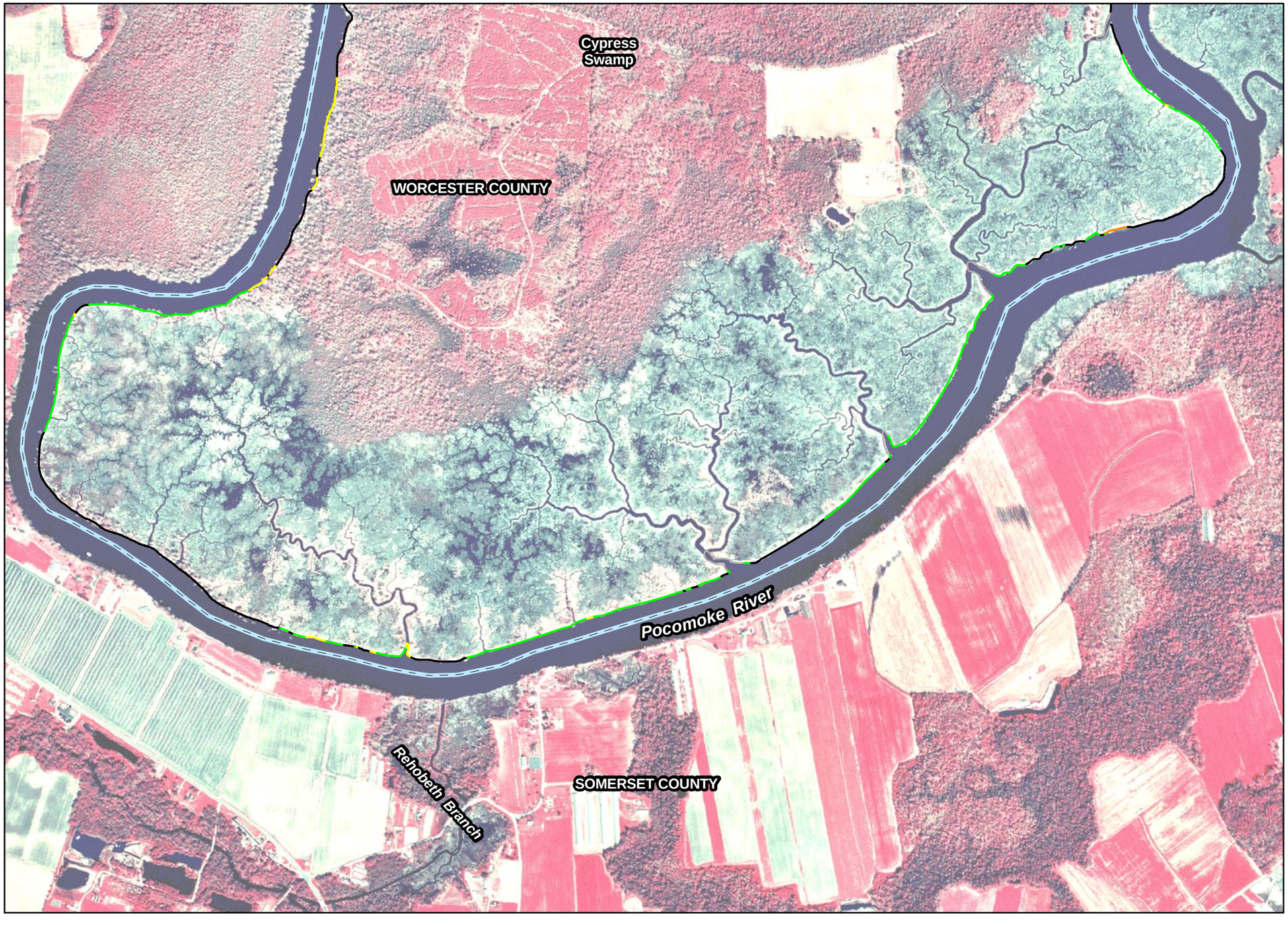
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 20



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization

Suitable for Hybrid Options

- marsh planting or marsh toe revetment
- marsh planting or sill
- marsh toe revetment
- riparian modifications
- sill

- No Data

N E S W

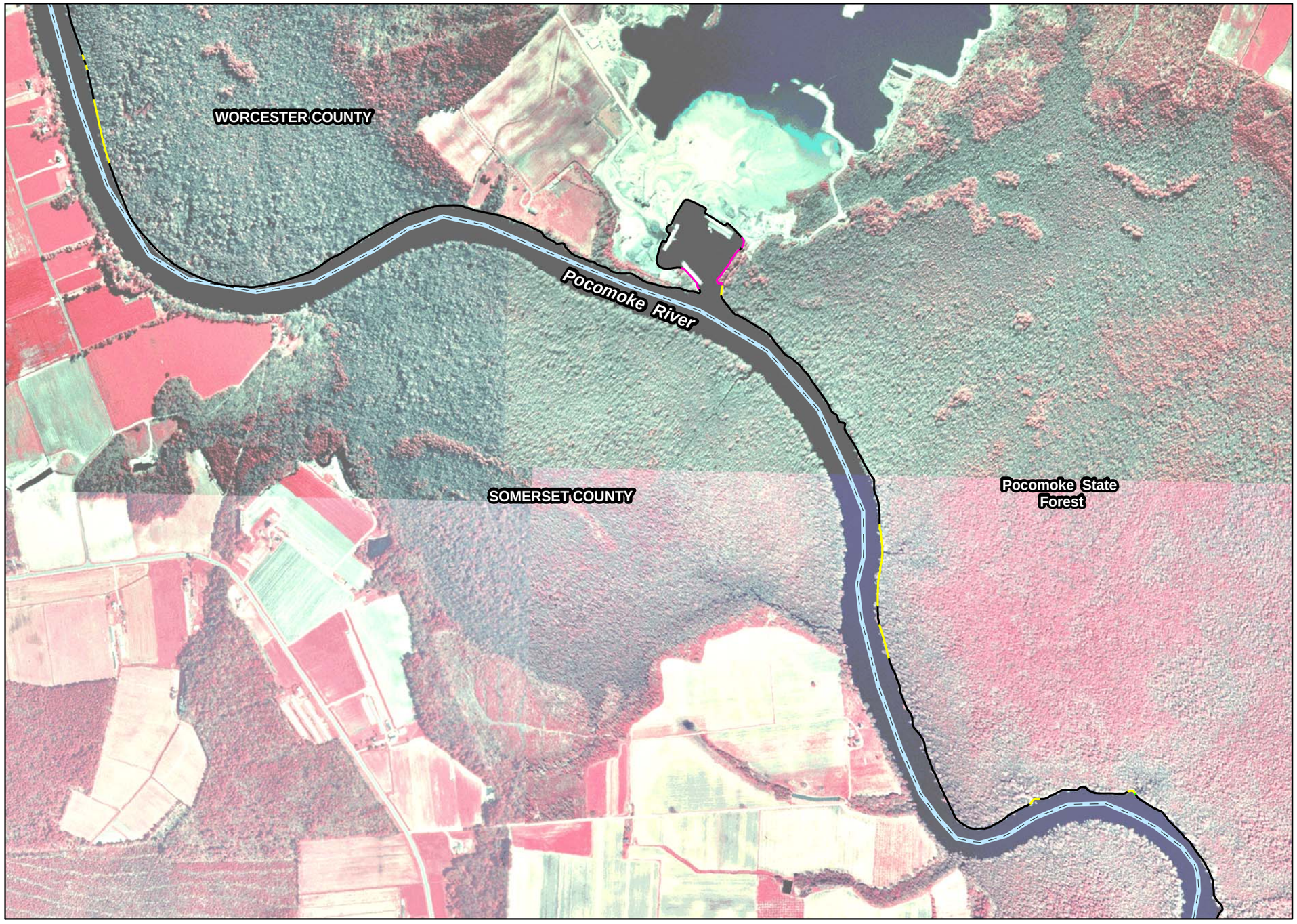
Scale

400 0 1,600 Feet

1:12,025

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 21



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N E S W

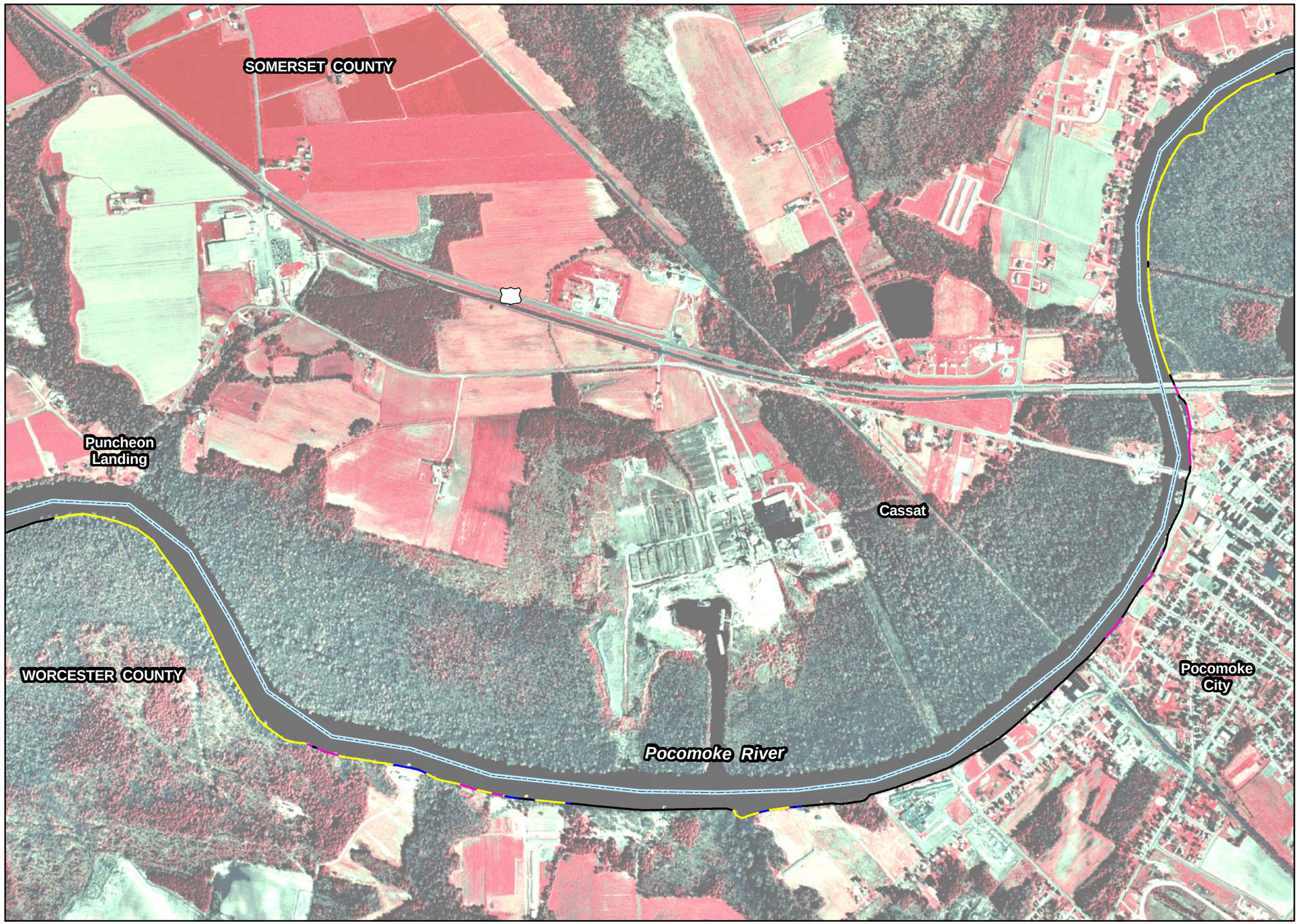
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 22



Legend

- Unsuitable for Living Shoreline
- Suitable for Soft Stabilization
- Suitable for Hybrid Options
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- No Data

N
W E
S

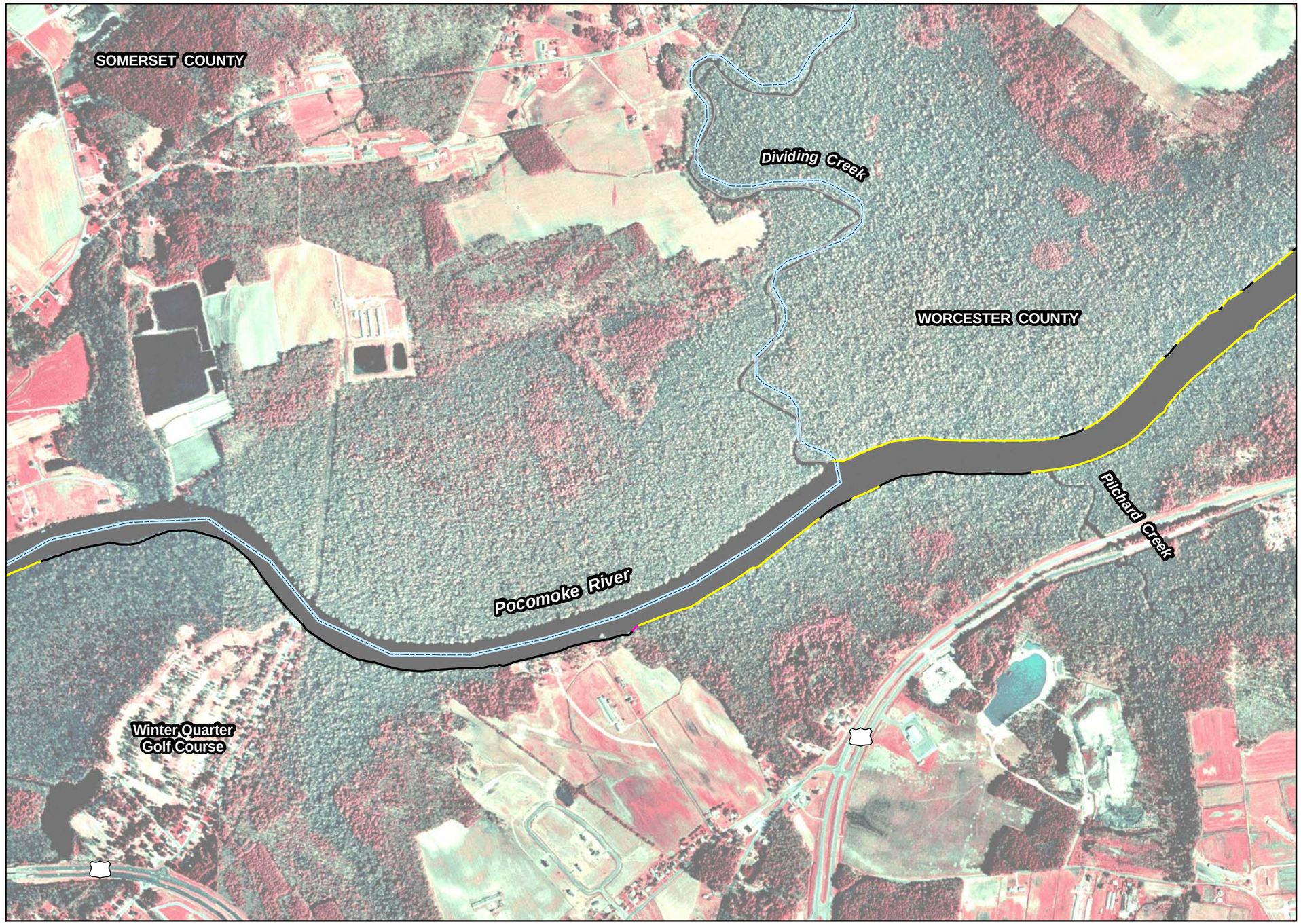
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 23



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N
W E
S

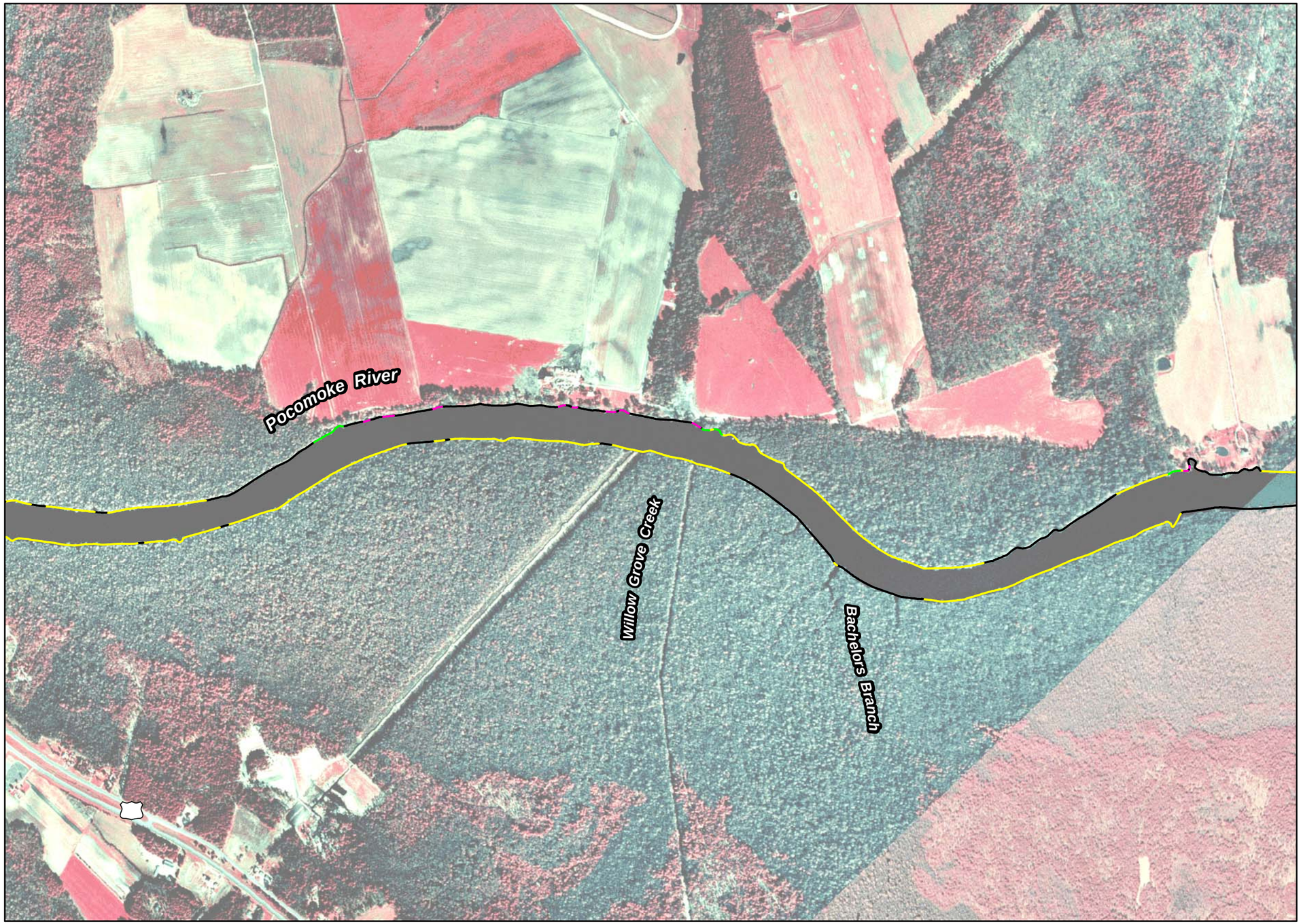
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 24



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

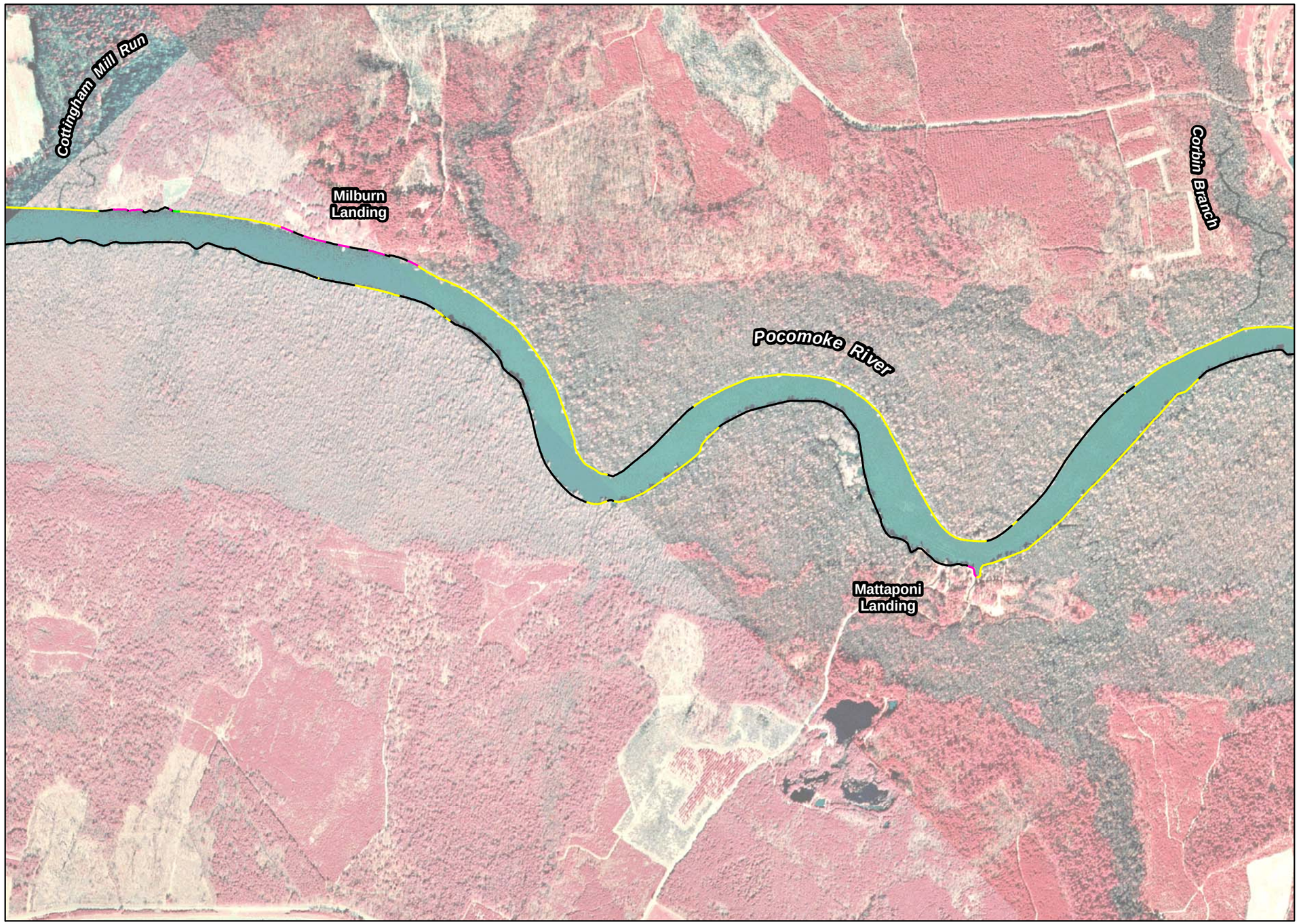
N W E S

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science



Living Shoreline Design Options
Worcester County, Maryland
Plate 25

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 26

Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

N W E S

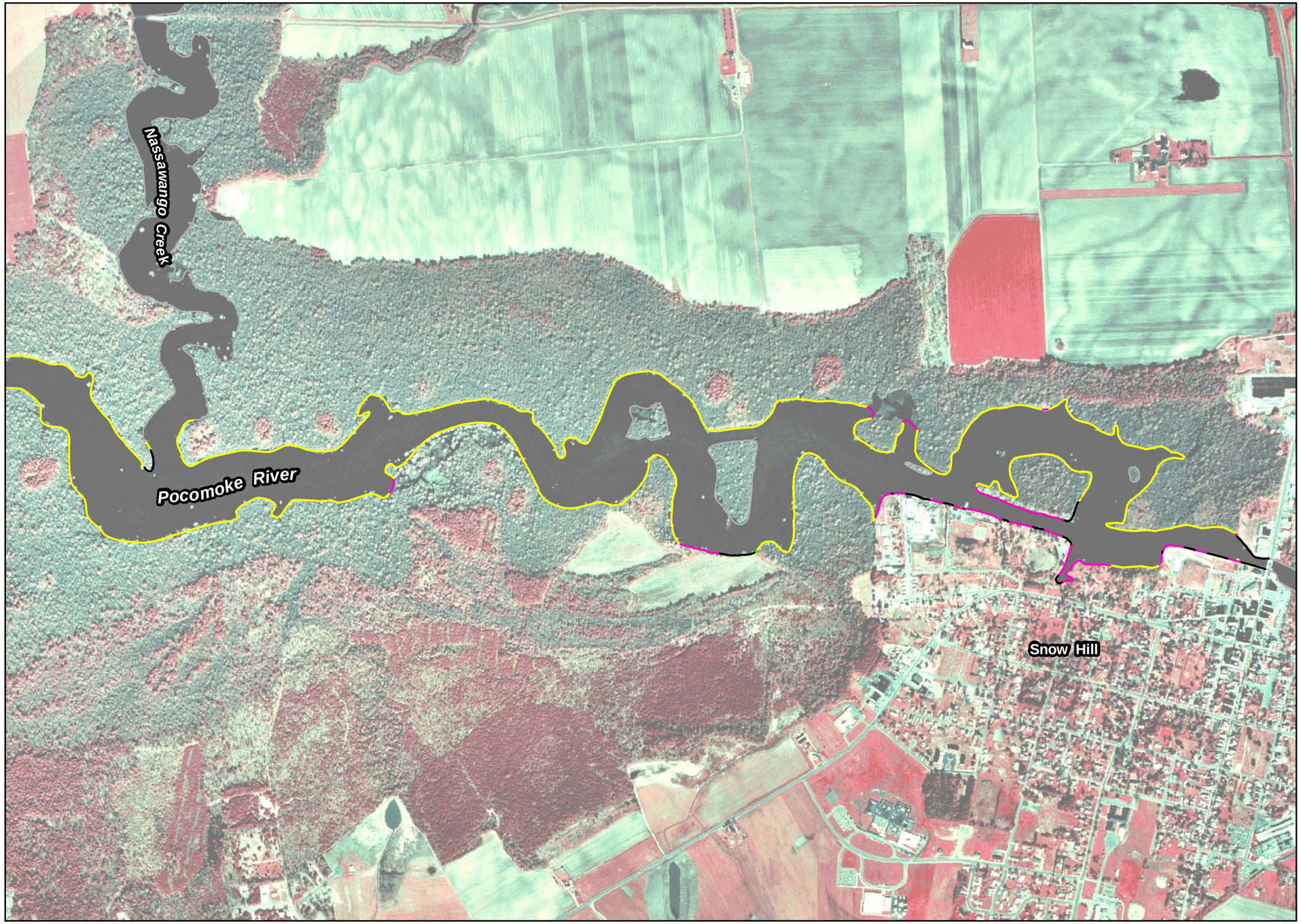
Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science

Living Shoreline Design Options
Worcester County, Maryland
Plate 27



Legend

- **Unsuitable for Living Shoreline**
- **Suitable for Soft Stabilization**
- **Suitable for Hybrid Options**
  - marsh planting or marsh toe revetment
  - marsh planting or sill
  - marsh toe revetment
  - riparian modifications
  - sill
- **No Data**

Scale

400 0 1,600 Feet

1:12,000

Comprehensive Coastal Inventory
Center for Coastal Resources Management
Virginia Institute of Marine Science