6-2007

The Stability of Living Shorelines - An Evaluation

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Recommended Citation

Center for Coastal Resources Management, Virginia Institute of Marine Science., Berman, M., Berquist, H., Herman, J., & Nunez, K. (2007) The Stability of Living Shorelines - An Evaluation. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5DT58

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Final Report Submitted to

National Oceanic and Atmospheric Administration
Chesapeake Bay Program Office
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 numberNA04NMF4570358

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This project was funded by the NOAA Chesapeake Bay Program Office under grant number: NA04NMF4570358

June, 2007

Executive Summary

This project set out to strengthen arguments that living shorelines were a viable and preferred method of erosion control along much of the Chesapeake Bay shoreline. Using statistical tests and data that describe shoreline and environmental condition along tidal shoreline, the study found that indeed marshes are frequently associated with stable shoreline and therefore recommending living shoreline treatments to manage erosion problems was a reasonable strategy that warranted strong consideration. Additional tests revealed a lower occurrence of marshes when traditional erosion control structures like bulkheads and revetments were present. This confirms these structures can permanently impact the growth of tidal marshes. Consideration of alternative treatments particularly in low energy settings is recommended. Additional statistical relationships revealed that marshes were not prolific in high energy environments, suggesting the living shoreline strategy was environmentally restricted and any model would need to account for this.

Under a separate task, erosion rates were computed along shoreline where living shoreline treatments were in place. While the results could not confirm that the living shoreline treatment performed better at reducing shoreline erosion rates, there was enough evidence from the 35 sites that were analyzed to confirm that erosion could be reduced using soft stabilization techniques.

Based on criteria evaluated in the aforementioned analyses, a protocol was developed to model the locations where living shoreline treatments should be considered for erosion control. Using existing GIS based databases a spatially explicit model was generated. The model was tested in the county of Northumberland, Virginia located on Virginia's Northern Neck. The model delineated areas as suitable, unsuitable, and suitable with design restrictions. The model was validated against random field inspections and permit reviews. The results indicate strong agreement (75%) between the modeled output and the field review when considering a site suitable (inclusive of design restrictions) and unsuitable. The model had less agreement (58%) between the output and the field assessment when considering explicit treatment types for suitable areas. 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 this region, and one of the few nationwide. The Center for Coastal Resources Management recommends the model be run throughout the Bay where data exists, and will seek avenues for funding to begin this venture.

This report as well as outreach material collected as part of this project and others within the Center for Coastal Resources Management have been posted to a new Living Shoreline Website at http://ccrm.vims.edu/livingshorelines/index.html

Acknowledgements

The authors wish to thank the following individuals for their assistance. From the VIMS Wetlands Advisory Program we wish to thank Karen Duhring and Molly Roggero for their contributions to the model development and validation. David Evans and Donna Marie Bilkovic provided advice on the statistical design and selection under Task 1. Karen Reay designed and populated the website and was assisted by Karen Duhring in gathering outreach materials. Additional thanks to Dave Weiss, Sharon Killeen and Tamia Rudnicky for GIS and administrative support to the 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 Virginia, the averaged annual miles of shoreline erosion control structures permitted surpassed 18 miles/year (Durhing, 2005). In 2003, permitted bulkhead construction impacted 2,092 m^2 of vegetated tidal wetlands in Virginia. More than 6,300 m^2 were impacted due to riprap construction in 2003 (source: VIMS Tidal Wetlands Database).

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. 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 projects are generally required because the physical environment is not conducive to a purely soft approach.

Project Outline

The objectives of this project were to evaluate the concept of maintaining the living shoreline through soft structure control as an alternative to traditional shoreline hardening. Three principal project components were targeted. The first focused on building arguments for living shorelines through scientific analysis of shoreline data. The second evaluated the success of living shoreline treatments at select sites in Virginia. Finally, the project defined a suite of metrics to classify shorelines suitable for soft shoreline control. A spatially based suitability model was developed and tested for a pilot area in Virginia.

Task 1. Trends in Shoreline Conditions

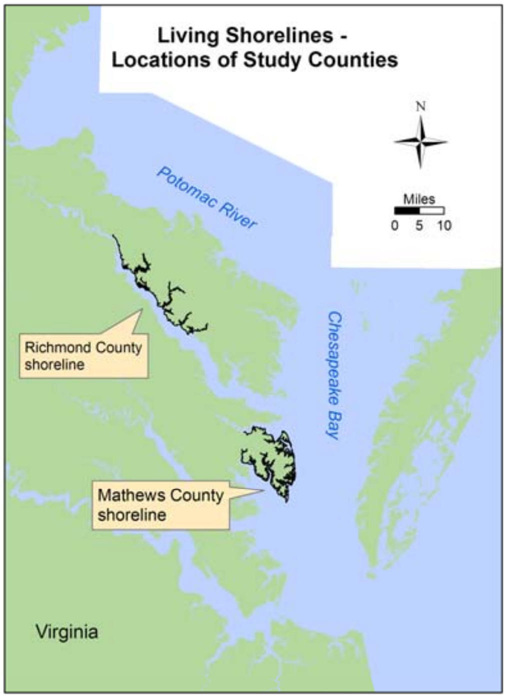
Introduction

Through data collected as part of the Chesapeake Bay Shoreline Inventory initiative at the Center for Coastal Resources Management, trends in shoreline attributes can be quantified using a combination of spatial and traditional statistics. The Shoreline Inventory consists of field data collected continuously along the shoreline of numerous counties in Virginia and Maryland (http://www.ccrm.vims.edu/shoreline_situation_rpts.html). Among attributes collected are qualitative assessments pertaining to land use, shoreline and bank stability, presence of marshes, beaches, and shoreline structures. This task hoped to use these data to validate accepted theory that marshes can provide significant shoreline protection. The analysis lends important insight and strengthens arguments that restoring and maintaining a living shoreline provides shoreline protection benefits.

Two Virginia counties, Mathews and Richmond, were chosen for this study (Fig. 1). The data values in the inventory are categorical and qualitative. Data used for this study include the following variables (and the values):

- land use (natural, agriculture, developed)
- bank erosion (low, high)
- marsh or structure (marsh, structure, marsh and structure, none)
- bank height (categories in feet—0-5, 5-10, 10-30, >30)
- exposure (low fetch < 2000m; high fetch > 2000m)

Figure 1 – Location of county shorelines used in this study.



ArcGIS® v9.1 was used to process and display the data layers and Minitab v.14 was used for the statistical tests. Since most original data are recorded continuously alongshore the datasets are very large. For the statistical analysis, the datasets were subsetted every 20 meters along the shore. Mathews County had 21,302 points and Richmond County had 20,452 points for each attribute analyzed.

Methods

Since the data are categorical, only certain statistical tests apply. Several statistical tests were tried including cluster analysis, multidimensional scaling (MDS), and chi square. Cluster analysis did not really provide any new information and the results from MDS were inconclusive at best. The chi-square test of independence indicates whether there is a relationship (i.e. dependence) between two variables and was deemed the most useful and appropriate analysis for these datasets. Eight pairs of variables were tested to look for relationships between shoreline stability (e.g. bank erosion) and shoreline treatment (e.g. marshes or structures). The pairs of variables include:

1. land use vs. bank erosion
2. land use vs. fetch
3. land use vs. marsh or structure
4. marsh vs. structure
5. fetch vs. bank erosion
6. marsh or structure vs. bank erosion
7. marsh or structure vs. fetch
8. bank erosion vs. bank height

A table is constructed with all possible combinations of the values for a pair of variables. Counts, or frequencies, of observations (O) are used to calculate estimates of expected counts (E). Observed counts are compared to expected counts and the chi-square statistic is calculated using the equation:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

If the chi-square statistic is significant at the chosen p value (e.g. $p<0.05$), the null hypothesis is rejected. The null hypothesis assumes there is no difference between the observed and expected counts of the variables, i.e. the two variables are independent. In the table, larger standardized residuals indicate which combinations of variables contribute most to the chi-square statistic. The standardized residual is the difference between the observed and the expected count in each cell divided by the square root of the expected counts. The standardized residual is like a Z score, so values >2 may be considered to have a noticeable impact on the chi-square value (Evans, pers. comm.). Positive values of the standardized residual mean that the observed count is greater than the expected count. Negative values of the standardized residual mean that the observed count is less than the expected count.

Initial chi-square tests were run using all of the points for a county. Very large chi-square values resulted from having so many data points, so all test results were significant at the $p<0.001$ level. This indicated that a subset of the data would give more reasonable results. Because there is probably a high degree of autocorrelation between points, the subsets were chosen by picking samples from regularly spaced intervals. Test results for several pairs of variables were compared using 1%, 5% and 10% subsets of the full dataset and running three trials for each subset. For example, for 1% of the data, the first subset used every 100th point chosen starting with the first point, the second subset used every 100th point starting with the 33rd point, and the third subset used every 100th point starting with the 66th point. To determine which size subset to use, the chi-square values for each test were compared for significance at the p=0.05 level as well as for patterns in the standardized residuals. The chi-square values at the p=0.05 level range from 5.99 to 7.82 because the degrees of freedom for most of the tables were 2 or 3 (Table 1).

- The chi-square values for tests using 1% of the data ranged between 0.5 and 7.5 meaning some chi-square values were significant and others were not. Many of the tests had cells with expected counts less than 5 indicating that there was an insufficient number of data points used.
- The chi-square values for tests using 10% of the data ranged from 5 to 29 and all chi-square values were significant at the p=0.05 level. The low chi-square values hovered around the p=0.05 level but the high values were very unusual. All of the results were significant, which may indicate that the sample size was too large.
- The chi-square values for tests using 5% of the data ranged from 2.3 to 10.4, with one anomalously high value of 22.5. All but one of the chi-square values was significant at the p=0.5 level and it appears that a subset using 5% of the data may be a reasonable size.

Table 1. Chi-square values for different levels of p and degrees of freedom.

df	P = 0.05	P = 0.01	P = 0.001
1	3.84	6.64	10.83
2	5.99	9.21	13.82
3	7.82	11.35	16.27

The chi-square test only shows if there is a relationship, but not the nature of the association. One measure of the association between two variables is Cramer’s V^2. Cramer's V^2 equals the square root of chi-square divided by sample size, n, times m, which is the smaller of (rows - 1) or (columns - 1). A value of zero indicates that there is no association; a value of one indicates that there is a perfect association.

Results and Interpretations

Using subsets with 5% of the data for each county, the 3 trials for each test were compared and used to summarize results. A table representative of the 3 trials is included in this report. Unless stated, the tables represent the 5% subsets. In a few cases, the 1% or 10% subsets also were examined for comparison.

In each cell of the chi-square table there are 3 values:

Observed count
Expected count
Standardized residual

Standardized residuals ≥ 2 are highlighted in blue; standardized residuals ≤ -2 are highlighted in yellow.

1. Land use vs. Bank Erosion

Tables of statistical results show:

Mathews		Bank erosion		
		low	high	All
Land use	natural	477	59	536
		490.2	45.8	536
		-0.5962	1.9506	*
	agriculture	56	4	60
		54.87	5.13	60
		0.1521	-0.4976	*
	developed	441	28	469
		428.93	40.07	469
		0.583	-1.9073	*
	All	974	91	1065
		974	91	1065
		*	*	*

Pearson Chi-Square = 8.41, DF = 2, P-Value = 0.015
Cramer's V-square 0.008

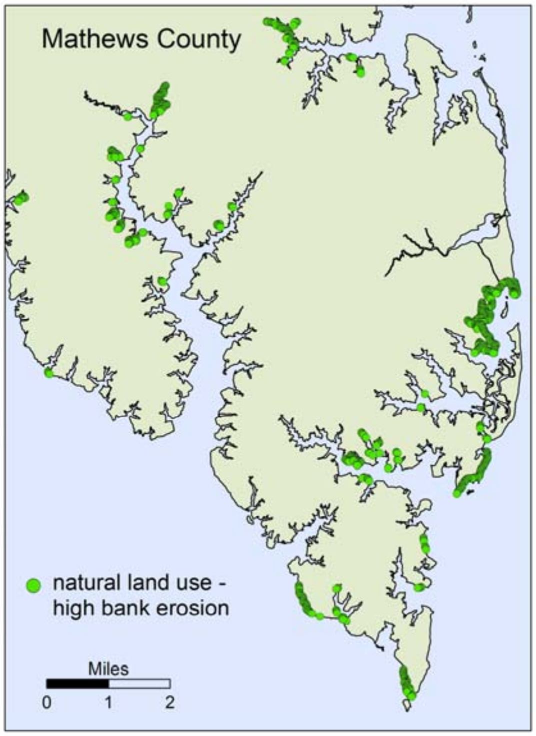
Richmond		Bank erosion		
		low	high	All
Land use	natural	836	11	847
		831.16	15.84	847
		0.1679	-1.216	*
	agriculture	95	5	100
		98.13	1.87	100
		-0.316	2.2888	*
	developed	66	3	69
		67.71	1.29	69
		-0.2078	1.5051	*
	All	997	19	1016
		997	19	1016
		*	*	*

Pearson Chi-Square = 9.15, DF = 2, P-Value = 0.010
Cramer's V-square 0.009

Interpretation of results:

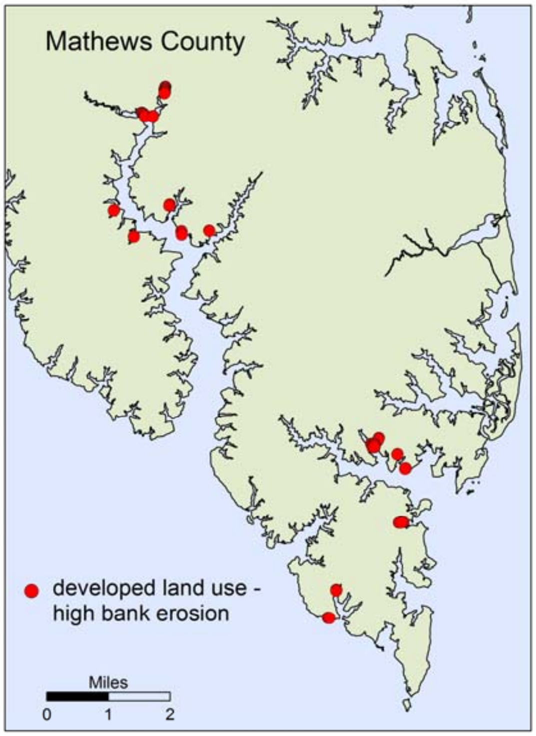
Chi-square tests are significant at a p value <0.05 for both counties, but Cramer's V^2 is very small. In Mathews County, there are more occurrences of natural land uses and high erosion than expected. The distribution is split between sheltered areas and open reaches (Fig. 2).

Figure 2 – Examples of locations of natural land uses and high bank erosion in Mathews County. Note that figure shows all the data, not subsets.



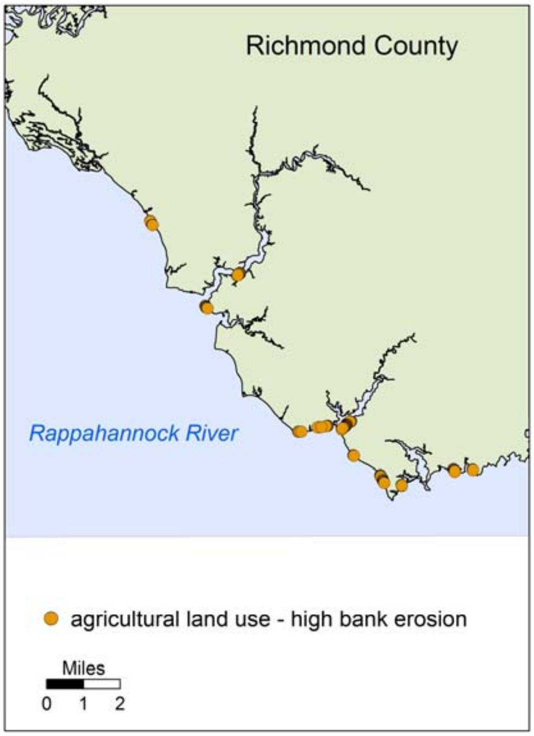
Developed land uses and high bank erosion occur less than expected. Most of these locations are in sheltered areas, which may indicate that boat wakes are a cause of the bank erosion (Fig. 3).

Figure 3 – Examples of locations of developed land uses and high bank erosion in Mathews County. Note that figure shows all the data, not subsets.



In Richmond County, there are more occurrences of agricultural land uses and high bank erosion than expected (Fig. 4). Most of these are in areas with high fetch, and agricultural lands tend to have fewer structures built (see section 3).

Figure 4 – Examples of locations of agricultural land uses and high bank erosion in Richmond County. Note that figure shows all the data, not subsets.



2. Land use vs. Fetch

Tables of statistical results show:

Mathews		Fetch		
		low	high	All
Land use	natural	414	107	521
		427.7	93.3	521
		-0.6601	1.4128	*
	agriculture	57	6	63
		51.7	11.3	63
		0.7354	-1.5739	*
	developed	404	78	482
		395.6	86.4	482
		0.4204	-0.8998	*
	All	875	191	1066
		875	191	1066
		*	*	*

Pearson Chi-Square = 6.44, DF = 2, P-Value = 0.040
Cramer's V-square 0.006

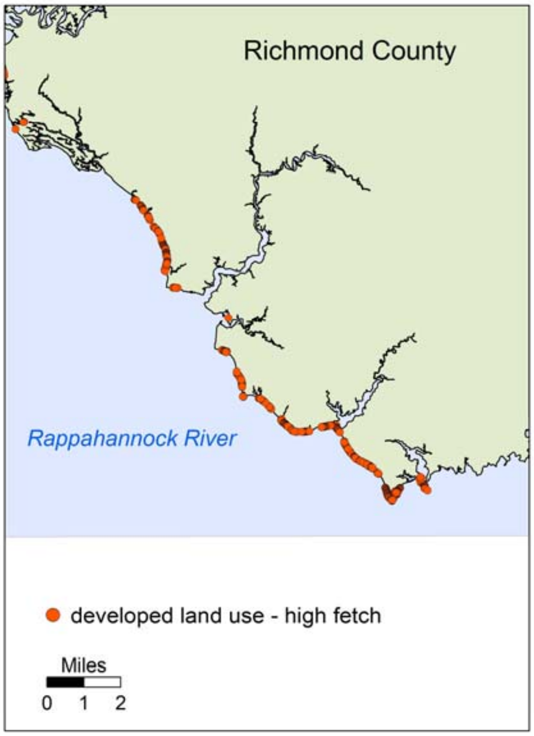
Richmond		Fetch		
		low	high	All
Land use	natural	683	160	843
		668.1	174.9	843
		0.5752	-1.1244	*
	agriculture	85	21	106
		84	22	106
		0.1078	-0.2108	*
	developed	42	31	73
		57.9	15.1	73
		-2.0847	4.0749	*
	All	810	212	1022
		810	212	1022
		*	*	*

Pearson Chi-Square = 22.60, DF = 2, P-Value = 0.000
Cramer's V-square 0.02

Interpretation of results:

Chi-square values are significant for both counties at the $p<0.05$ level; Cramer's V^2 are small. In Mathews County there are no standardized residuals that overly contribute to the chi-square value. In Richmond County, developed land uses and high fetch occur more than expected (Fig. 5). This may be due to locations of residences along the main stem of the Rappahannock River where fetch is higher, in order to take advantage of the scenic views, as well as the premium placed on waterfront property. In addition, there are fewer occurrences of developed land uses and low fetch than expected. These results suggest that fetch is not a deterrent to waterfront development despite the greater risk of exposure to high wave energy and accelerated shoreline erosion.

Figure 5 – Examples of locations of developed land uses and high fetch in Richmond County. Note that figure shows all the data, not subsets.



3. *Land use vs. Marsh or Structure*

Tables of statistical results show:

Mathews		Marsh or Structure				
		structure	marsh and structure	marsh	none	All
Land use	natural	6	9	452	55	522
		37.74	16.17	383.78	84.3	522
		-5.167	-1.784	3.482	-3.192	*
	agriculture	3	0	43	9	55
		3.98	1.7	40.44	8.88	55
		-0.49	-1.305	0.403	0.039	*
	developed	68	24	288	108	488
		35.28	15.12	358.78	78.81	488
		5.508	2.283	-3.737	3.288	*
	All	77	33	783	172	1065
		77	33	783	172	1065
		*	*	*	*	*

Pearson Chi-Square = 114.62, DF = 6, P-Value = 0.000
Cramer's V-square 0.05

Richmond		Marsh or Structure			
		structure	marsh	none	All
Land use	natural	2	757	79	838
		27.14	708.06	102.8	838
		-4.826	1.839	-2.347	*
	agriculture	3	80	30	113
		3.66	95.48	13.86	113
		-0.345	-1.584	4.335	*
	developed	28	24	16	68
		2.2	57.46	8.34	68
		17.384	-4.414	2.652	*
	All	33	861	125	1019
		33	861	125	1019
		*	*	*	*

Pearson Chi-Square = 382.32, DF = 4, P-Value = 0.000
Cramer's V-square 0.19

Interpretation of results:

The chi-square values for both counties are very large and is significant at $p<0.005$. This may suggest that land use and the presence of structures are highly related.

In Mathews County there are more occurrences of natural land uses and marshes than expected, and fewer structures or nothing (neither marsh nor structure) than expected. There are fewer occurrences of developed land uses and marshes than expected, and more structures or nothing than expected. These results are consistent with current practices to armor residential shorelines and often impact marshes, while leaving marshes along natural reaches.

In Richmond County, there were so few occurrences of marsh and structures together that the category had to be removed in order to get a valid chi-square value. The pattern of standardized residuals is very similar to Mathews County, except for agricultural land uses and no marsh or structures occur more than expected.

The results indicate property owners are more likely to defend private property under development than undeveloped or agricultural lands within private ownership. The results also indicate that marshes do not persist as frequently as expected along developed shorelines. This specific test does not generate a cause and effect relationship, however, best professional judgment suggests that land use practices along developed shorelines may result in an overall decline in the resource. Long-term preservation of marshes may be at risk, therefore, along developing shorelines unless sound management practices sensitive to the preservation on marsh communities are enforced. The next sequence of tests lends support to this hypothesis.

4. Marsh vs. Structure

Tables of statistical results show:

Mathews		Structure			
		none	bulkhead	rip rap	All
Marsh	marsh	783	9	24	816
		731.72	24.52	59.76	816
		1.896	-3.134	-4.626	*
	none	172	23	54	249
		223.28	7.48	18.24	249
		-3.432	5.673	8.375	*
	All	955	32	78	1065
		955	32	78	1065
		*	*	*	*

Pearson Chi-Square = 148.92, DF = 2, P-Value = 0.000
Cramer's V-square 0.14

Richmond		Structure			
		none	bulkhead	rip rap	All
Marsh	marsh	866	0	3	869
		839.21	17.87	11.92	869
		0.925	-4.228	-2.583	*
	none	120	21	11	152
		146.79	3.13	2.08	152
		-2.211	10.109	6.176	*
	All	986	21	14	1021
		986	21	14	1021
		*	*	*	*

Pearson Chi-Square = 170.61, DF = 2, P-Value = 0.000
Cramer's V-square 0.17

Interpretation of results:

Both counties have chi-square values that are significant at the $p<0.005$ level with relatively high Cramer's V^2 (i.e. higher than most of the other pairs of variables). The standardized residuals for both counties have the same pattern. There are fewer occurrences of marshes and bulkheads or riprap than expected. There are more occurrences of no marshes and bulkheads or riprap than expected. 72-75% of these structures occur where land use is residential. These results suggest two things. First that bulkhead and riprap construction may have an influence on the ability of marsh grasses to persist. Second, along developed shorelines, more structures are being built than necessary. The living shoreline alternative might suffice.

5. Fetch vs. Bank Erosion

Tables of statistical results show:

Mathews - 10% subset		Bank erosion		
		low	high	All
Fetch	low	1603	141	1744
		1589.3	154.7	1744
		0.3431	-1.0997	*
	high	339	48	387
		352.7	34.3	387
		-0.7283	2.3345	*
	All	1942	189	2131
		1942	189	2131
		*	*	*

Pearson Chi-Square = 7.307, DF = 1, P-Value = 0.007
Cramer's V-square 0.003

Richmond - 10% subset		Bank erosion			
		low	high	undercut	All
Fetch	low	1574	35	12	1621
		1570.3	41.2	9.5	1621
		0.0941	-0.9686	0.8067	*
	high	407	17	0	424
		410.7	10.8	2.5	424
		-0.1841	1.8939	-1.5773	*
	All	1981	52	12	2045
		1981	52	12	2045
		*	*	*	*

Pearson Chi-Square = 7.707, DF = 2, P-Value = 0.02
Cramer's V-square 0.004

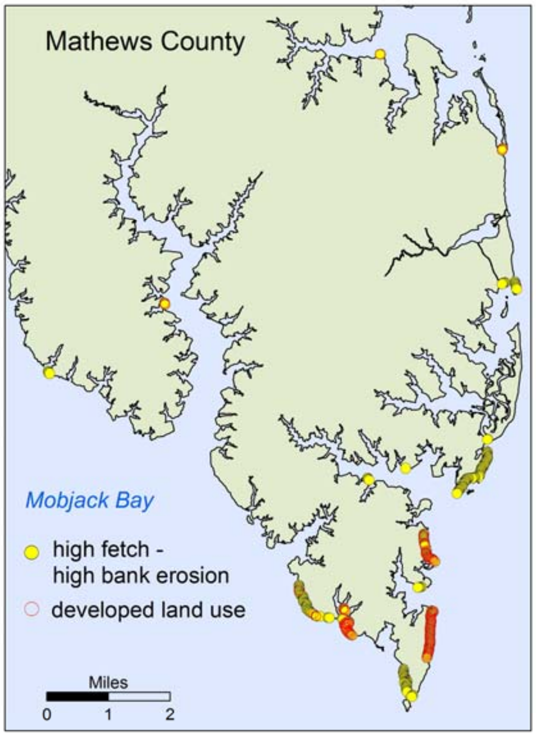
Interpretation of results:

For 5% subsets, most of the trials have chi-square values that are not significant at the $p<0.05$ level. For 10% subsets, most of the trials have chi-square values that are significant at the $p<0.05$ level, but Cramer's V^2 statistics are essentially 0.

Bank erosion is, in part, a function of fetch, but the chi-square tests show little relationship. It is possible that there is a large enough anthropogenic imprint on the shoreline to mask the expected statistical relationships of some physical processes. Alternatively, the classification of fetch used in this study may not be sensitive or discriminating enough to detect variations.

In Mathews County, the standardized residual that contributes more to the chi-square value indicates there are more occurrences of high fetch and high erosion than expected. 38% of the high fetch and high erosion locations occur on developed land uses. In part this may be due to their locations on the west side of Chesapeake Bay (Fig. 6), which receives the full force of northeast storms.

Figure 6 – Examples of locations of high fetch and bank erosion and developed land uses in Mathews County. Note that figure shows all the data, not subsets.



6. Marsh or Structure vs. Bank Erosion

Tables of statistical results show:

Mathews		Bank erosion		
		low	high	All
Marsh or Structure	structure	68	3	71
		64.93	6.07	71
		0.3806	-1.2451	*
	marsh and structure	25	0	25
		22.86	2.14	25
		0.4467	-1.4616	*
	marsh	735	65	800
		731.64	68.36	800
		0.1241	-0.406	*
	none	146	23	169
		154.56	14.44	169
		-0.6885	2.2525	*
	All	974	91	1065
		974	91	1065
		*	*	*

Pearson Chi-Square = 9.76, DF = 3, P-Value = 0.021
Cramer's V-square 0.009

Richmond		Bank Erosion		
		low	high	All
Marsh or Structure	marsh	857	5	862
		840.9	21.1	862
		0.554	-3.501	*
	none	101	19	120
		117.1	2.9	120
		-1.485	9.382	*
	All	958	24	982
		958	24	982
		*	*	*

Pearson Chi-Square = 102.79, DF = 1, P-Value = 0.000
Cramer's V-square 0.10

Interpretation of results:

The chi-square values are significant at the p<0.05 level for both counties, although in Richmond County, there were so few occurrences of structures, and marsh and structures, that the categories had to be removed in order to get a valid chi-square value.

In both counties, there are more occurrences of no marshes or structures and high erosion then expected. In Richmond County, marshes and high bank erosion occur less than expected. All of these results support the concept that marshes protect shorelines by buffering wave impacts, and therefore marsh construction (i.e. the living shoreline alternative) should be upheld as a an effective erosion control method.

7. Marsh or Structure vs. Fetch

Tables of statistical results show:

Mathews		Fetch		
		low	high	All
Marsh or Structure	structure	36	35	71
		57.9	13.1	71
		-2.882	6.068	*
	marsh and structure	17	8	25
		20.4	4.6	25
		-0.753	1.585	*
	marsh	688	112	800
		652.8	147.2	800
		1.379	-2.903	*
	none	128	41	169
		137.9	31.1	169
		-0.843	1.775	*
	All	869	196	1065
		869	196	1065
		*	*	*

Pearson Chi-Square = 62.39, DF = 3, P-Value = 0.000
Cramer's V-square 0.06

Richmond - 10% subset		Fetch		
		low	high	All
Marsh or Structure	structure	7	66	73
		57.9	15.1	73
		-6.687	13.074	*
	marsh and structure	4	4	8
		6.3	1.7	8
		-0.93	1.818	*
	marsh	1463	256	1719
		1362.6	356.4	1719
		2.72	-5.319	*
	none	147	98	245
		194.2	50.8	245
		-3.387	6.623	*
	All	1621	424	2045
		1621	424	2045
		*	*	*

Pearson Chi-Square = 310.84, DF = 3, P-Value = 0.000
Cramer's V-square 0.15

Interpretation of results:

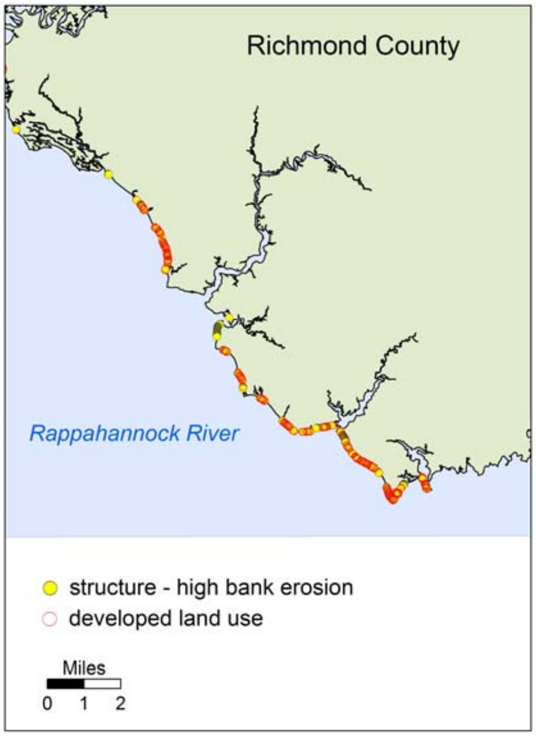
In Richmond County, the 5% subsets have expected cell counts of less than one so the chi-square values are not valid; therefore the 10% subsets were used.

In both counties, there are more occurrences of high fetch and structures than expected. 82% of these occur on developed land uses (e.g. Fig. 7). As discussed in section 2, this is probably related to development on main stem reaches. Despite the risks of ownership in these settings, property owners will build erosion control structures in order to protect their investment.

There are fewer occurrences of low fetch and structures than expected. High fetch and marshes occur less than expected and suggests that while marshes may buffer the shoreline from wave impact, marshes cannot grow in areas that are too energetic. Therefore as will become evident later in the model development, high energy environments are not suitable for living shoreline treatments. Living shoreline treatments should be restricted to low-moderate fetch environments.

In addition to the results described above, in Richmond County there are more occurrences of high fetch and no marshes or structures, and fewer low fetch and no marshes or structures than expected. In addition, low fetch and marsh occur more than expected. This is consistent with results in Mathews.

Figure 7 – Examples of locations of high fetch and structures and developed land uses in Richmond County. Note that figure shows all the data, not subsets.



8. *Bank Erosion vs. Bank Height*

Tables of statistical results show:

Richmond		Bank height		
		0-5 ft.	5-10 ft.	All
Erosion	low	897	63	960
		892.41	67.59	960
		0.1537	-0.5585	*
	high	14	6	20
		18.59	1.41	20
		-1.0649	3.8695	*
	All	911	69	980
		911	69	980
		*	*	*

Pearson Chi-Square = 16.443, DF = 1, P-Value = 0.000
Cramer's V-square 0.02

For Mathews County, none of the trials with the 5% or 10% subsets produced chi-square values that were significant at the $p<0.05$ level. For Richmond County the 5% and 10% subsets did not produce valid chi-square values because there were too few samples with bank heights between 10-30ft and >30ft. Removing these 2 categories produced chi-square values that are significant at the $p<0.005$ level.

Interpretation of results:

In Richmond County, high erosion and high (5-10ft) bank heights occur more than expected. However, the Cramer's V^2 statistic is very small, so the association is very weak.

Discussion

In summary, most of the chi-square statistics are significant at the $p<0.05$ level, indicating that the null hypothesis is rejected and the variables are dependent. However, most of the Cramer's V^2 statistics are small (<0.19), so the associations are weak. The strongest associations occur between:

- land use and marsh/structure in Richmond County
- marsh and structure in both counties
- marsh/structure and fetch in Richmond County (10% subset)

The weak association between some of the variables as seen in the Cramer's V^2 statistic may in part be due to the fact that most of these attributes are interconnected in nature and in space. Land use typically drives decisions along the shoreline, but decisions provide both costs and benefits to the environments. For example, erosion control structures are typically found along high energy shorelines. They will reduce erosion but they also impact marshes. At the same time the absence of marshes would not be untypical in high energy environments regardless of the presence of erosion control structures.

The scientific and management interpretations of the results are consistent with current theory on issues such as the occurrence of marshes and structures, the impact of fetch on marshes, and the construction of structures by residential landowners. The analyses performed do generate some important evidence to be communicated to coastal managers. Land use plays a pivotal role in controlling the characteristic of our coastal environments. Traditional management of developed shorelines has promulgated significant and irreplaceable losses in tidal wetlands. Evidence suggests decisions regarding shoreline protection have contributed greatly to these wetland losses and that our shorelines may be “over hardened”.

We can further look to the study results to understand that erosion control structures may, in part, be responsible for wetlands losses. While traditional methods of erosion control may be warranted in some settings, the results suggest that marshes also provide erosion control, and given the correct mix of landscape features, marsh creation should be upheld as a preferred method for stabilizing shorelines.

Task 2. Shoreline Change Analysis

Introduction

Reliable estimates for shoreline erosion are difficult to obtain. Shoreline position measurements for various eras can be used to derive estimates of the rate of shoreline change in terms of recession and accretion. These rates contribute to our understanding of the magnitude of the shoreline erosion problem in any given area, and assist in developing erosion control strategies.

This analysis computes shoreline change to evaluate the success of living shoreline treatments currently in place at selected sites in Virginia. The analysis assesses whether a measurable difference in shoreline erosion can be detected at sites with living shoreline treatments versus those without. From selected treatment sites, shoreline change is evaluated along a reach extending 1 km updrift and downdrift of the site. The Digital Shoreline Analysis System (DSAS) (Thieler, 2003) was used to compute shoreline change.

This study acknowledges that due to temporal and spatial resolutions and accuracies of data, DSAS may not be able to detect measurable differences in shoreline change along the analyzed shoreline reach. Therefore, each site was visited prior to the analysis and a review was conducted to determine if the treatment appeared to be successful post construction.

Methods

The DSAS v.2.0 was developed by the USGS in cooperation with Perot Systems Government Services. The application extension is designed to efficiently lead a user through the major steps of shoreline change analysis in a clearly organized and attractive user interface. This extension to ArcView contains three main components to assist a user to define a baseline, generate orthogonal transects at a user defined separation along the coast and to calculate rates of change. Details of the analysis are presented below.

DSAS can accept any number of shoreline files or multiple eras of shoreline within a single file. Then from a baseline file, created automatically, manually or as in this study, a combination, transects are cast across the various eras of shoreline. As the transect crosses each era represented in the shoreline, an intersection point is recorded. The transects are recorded as a shape file and associated attribute table (data base file).

The End Point Ratio (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and the latest measurements. The EPR is relatively easy to compute and requires only a minimum of two shoreline eras as was used in this study. While more than two shorelines can be used, the EPR only uses the earliest and the latest periods. Therefore intermittent shoreline behavior across multiple eras is not accounted for.

In this study, methods described by Hennessee et.al, (2003) in the Maryland Geological Survey report *Determining Shoreline Erosion Rates for the Coastal Regions of Maryland (Part 2)* were followed to the extent possible. For simplicity, shorelines of just two eras were used. Since this study was trying to evaluate change occurring around relatively recent activities, there was no reason to seek historic shoreline basemaps. The earliest shoreline used was digitized from 1:12,000 digital orthophotography from 1994. The more recent shoreline was extracted from a digital terrain model (DTM) generated as part of the 2002 Virginia Base Mapping Program (VBMP).

These shoreline files were in ArcView shape file format. A baseline was made by first creating a 50 meter buffer of the shoreline. The polygon formed was split at the ends and the offshore half was deleted. Thus leaving a baseline 50 meters inshore from the shoreline. The baseline was further edited according to protocols developed by the Maryland Geological Survey. These are, in summary:

- At upstream ends of tributaries delete the baseline if the shorelines do not converge.
- Delete the baseline if it parallels only one shoreline.
- Examine the headward extent of tributaries. If one shoreline extends considerably further upstream than the other, truncate the baseline at the shorter shoreline.

150 meter long transects were cast shore-normal from the baseline at 20 meter intervals along-shore using the 2-legged method. This method casts the transect from a supplemental baseline that intersects the existing baseline at a user specified interval.

Thirty-five (35) study sites were analyzed. These sites all had documented living shoreline treatments placed along their shoreline prior to the most recent shoreline era used (2002). Geographically, the sites span six (6) different localities (Table 2), and site selection attempted to vary the types of physical settings for each location.

Table 2. Counties

County	#sites
Essex County	1
Gloucester County	2
Lancaster County	7
Mathews County	10
Middlesex County	5
Northumberland Co.	10

Shoreline change was calculated from the EPR at 20 meter intervals for approximately 1 km upriver and downriver of each treatment area. Treatment locations were verified using GPS in the field. A classification system comparable with that developed by the Maryland Geological Survey was applied (Table 3). The final interpretation and assessment was inclusive of any shoreline defense structures that could influence shoreline change at the treatment area or anywhere along the 2 km study reach. Structure data was gathered from the Chesapeake Bay Shoreline Inventory database.

The Mean, Min, Max, Range and Standard Deviation of the EPRs were calculated using ArcGIS® Summary Statistics at each site for both the entire shoreline and for the treatment area.

Maps were created for each study site analyzed using

Table 3. Shoreline Classification

Shoreline Change (m/yr)	Erosion Classification
> 0.003	Accretion
+/ – 0.003	No change
-0.003 to –0.600	Slight
-0.600 to –1.200	Low
-1.200 to –2.400	Moderate
< -2.400	High

Virginia Base Mapping Program (VBMP) imagery overlaid with the classified shoreline (Appendix 1). The location of the treatment area and any erosion control structures coincident with the classified shoreline are depicted. Line graphs depicting the relative change in shoreline position along the reach were plotted for each site (Appendix 2). These graphs illustrate erosion/accretion (Y axis) at measured 20 meter intervals from the treatment area (X axis). The treatment area is highlighted.

Results

The shoreline change analysis was able to compute a difference in erosion rates at and near the location of shoreline segments where living shoreline treatments were constructed. Of thirty five sites assessed, 18 sites had a reduced erosion rate when compared to the upriver and downriver shoreline reaches. This suggests that the treatment was affective in abating erosion on site.

Among the remaining 17 sites that did not exhibit a measurable difference in erosion rate when compared with upriver and downriver reaches, Duhring (2005) found 15 of these to be effective living shoreline structures. The presence of shoreline structures in the adjacent reaches may have impacted the DSAS results and returned lower erosion rates in these segments than in the treatment areas.

Duhring (2005) visited all 35 sites and found 7 did not meet the minimum conditions for a living shoreline. One other site was discounted. Their study also found 20 of the original 35 sites to be very effective for erosion control. The DSAS analysis showed that 14 of these treatment areas had reduced erosion rates from their up and down river segments. Eight of these sites had measurable accretion at the treatment location. Six sites still had measurable erosion, but erosion was less than the up or down river areas. This conclusion assumes that the upriver and downriver sites had comparable erosion rates prior to the installation of the living shoreline treatment and the decline in erosion was in fact due to the treatment. Field investigations indicate a majority of the up and down river segments were already defended at most sites.

Based on the EPR computed for each treatment area, “slight” erosion still persisted at half the sites. Since erosion rates were not computed prior to the construction of the treatment, there is no way to know whether erosion was greater prior to construction of the living shoreline structures.

Discussion

The results of this analysis support the living shoreline alternative as an effective mechanism for deterring shoreline erosion. However, whether the treatments result in better shoreline protection when compared with adjacent shoreline conditions can not be concluded from the study results. Since most of these treatments had not been in place for more than a few years, it is conceivable that their long-term capacity to reduce shoreline erosion and promote accretion has yet to be realized. Monitoring studies at specific sites would be required to better understand this.

DSAS is an accepted and practical analytical tool for computing shoreline change. However, in sheltered areas where shoreline change is significantly lower and more difficult to measure, the DSAS analysis may actually yield lower than normal results. It is in these areas where the living shoreline alternative is most effective and generally recommended as a management approach.

The following section will focus on the environs and conditions most applicable for living shoreline treatments. The model was developed as part of this project and piloted in one locality in Virginia.

Task 3. Living Shoreline Suitability Model

Introduction

Conditions that favor living shoreline treatments can be modeled in a well mapped landscape. Task 3 of this project develops a 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. We draw upon studies like the ones above and the work of Duhring et al; (2005) for determining criteria for living shoreline treatments.

In this section the model development will be reviewed and demonstrated in a Tidewater locality in Virginia. The model validation will be presented. Guidance will be offered with respect to future applications and management needs.

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 therefore assumes that there is an existing or perceived erosion problem on site. The model, therefore, does not consider the "do nothing" alternative. Rather, the model was developed in part to support the need for a regulatory or management action in response to a request for some erosion abatement technique. Therefore, the agency(s) must make a recommendation regarding an erosion abatement strategy for a site. 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 and delineates the classification criteria discussed below.

Data Inputs

The model will use data from various sources. Each attribute is listed in Table 4 with its origin. The Chesapeake Bay Shoreline Inventory under developement by the Center for Coastal Resources Management (http://www.ccrm.vims.edu/shoreline_situation_rpts.html) provides a significant amount of data that describes conditions along tidal shoreline in Virginia and Maryland. Without these data, it would be difficult to run the model, as developed, without making substantial changes.

Table 4. GIS data used in living shoreline suitability model

DATA	SOURCE
Fetch	CCRM exposure model*
Bathymetry	Chesapeake Bay Program 1m contour
Marsh presence	CCRM Chesapeake Bay shoreline inventory* USFWS National 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

Each attribute listed in Table 4 can vary on the landscape according to some classification system. For example, fetch is classified as low (0-1.0 mile), moderate (1.0-2.0 mile), or high (> 2.0 mile) depending on the distance across the water from vectors extending out from the land. Marshes, beaches, and tree canopy may be present or absent. Bank erosion is can be high, low, or undercut at the bank toe. Finally the model looks for a shallow water nearshore with the 1 meter bathymetric contour within 10 meters of the shoreline. These parameters are summarized in Table 5.

Table 5. Model variables

ATTRIBUTE	MODEL APPLICATION
Fetch	low (0-1.0 mile) moderate (1.0-2.0 mile) high (> 2.0 mile) low
Bathymetry	1m contour > 10m from shoreline
Marsh presence	present/absent
Beach presence	present/absent
Bank Condition	observed erosion 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. The suitability classification scheme initially divides the shoreline into three classes: suitable, suitable with design restrictions, and unsuitable.

Suitable: Suitable areas constitute conditions which are suitable for purely soft stabilization only (marsh plantings, fiber logs, etc.). Table 6 outlines the variables and conditions that must persist on site.

Table 6. Conditions suitable for soft stabilization

Fetch	low (0-1 mile)
Bank condition	low or high
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

When you run these conditions through the spatial model developed using the model builder capabilities within the ArcGIS® software, the model returns n=6 possible data combinations. The data model is illustrated in Figure 8. Appendix 3 is a conditions matrix which tabulates the options.

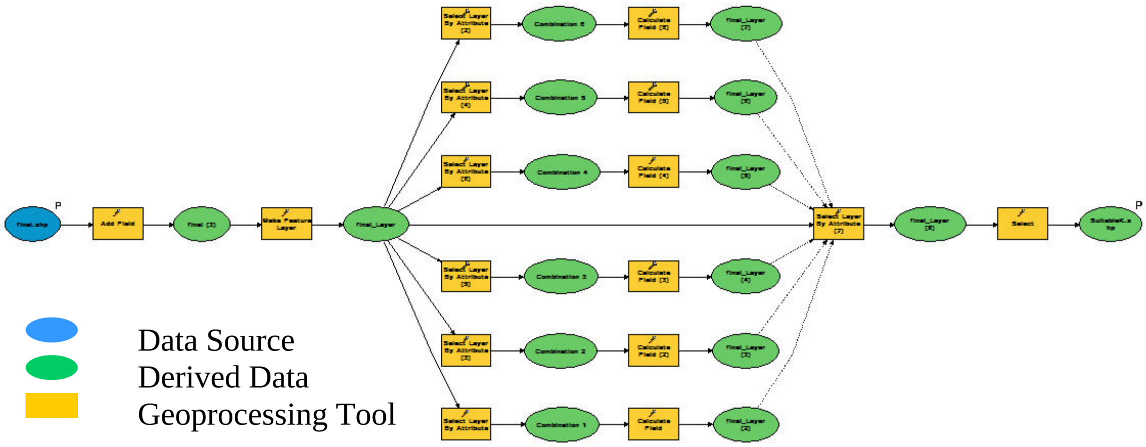


Figure 8. Geospatial data model for “Suitable” Classification where n=6.

Suitable with Design Restrictions: Suitable with design restrictions characterize areas where soft stabilization techniques are used in combination with traditional structures (see Table 7). These are often known as hybrid designs. By definition, however, the structures are designed so their placement does not sever the natural connection between the upland and the aquatic habitat and therefore maintains our working definition of a living shoreline (from Chapter 1). Finally, the model recognizes not all coastal landscapes are suitable for the use of a living shoreline practice for erosion control. These areas are classified as “unsuitable” and a traditional erosion control method should be allowed if erosion on the site is demonstrated.

Table 7. Conditions indicative of shorelines which require a hybrid design

Fetch	low (0-1 ml) – moderate (1-5ml)
Bank condition	low, high, or undercut
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

The output of the geospatial model run to delineate the various combinations of these attributes classified as "Suitable with Design Restrictions" is more complex. There are 39 different landscape combinations that can exist (Figure 9). More importantly the variability in the landscape also means more variability in the design possibilities. Recognizing this, a second tier in the model was built to determine best options for shoreline segments that fell within the "Suitable with Design Restrictions" category.

We focused on four different typical treatment options: planted marsh on existing substrate (actually a true "living shoreline"), riparian modification (includes pruning, upland grading), marsh toe revetment (protection of existing marsh), and marsh sill (often in combination with the planted marsh). These were options for which criteria could be developed and mapped using existing GIS data from this project. Specific combinations of the attributes defined in Table 7 determine which of the four treatments mentioned above are appropriate for a shoreline segment. A visual inspection of the site would be required to determine how construction should proceed. For more information on these treatments see (http://ccrm.vims.edu/livingshorelines/design_options.html). The conditions matrix can be reviewed in Appendix 3

The final model was run and tested in Northumberland County located on the Northern Neck of Virginia. This locality was selected for several reasons. There were active living shoreline projects in the county which were reviewed under Task 2. A relatively recent shoreline inventory had been completed and therefore data were available to support a model run. Finally, the locality is diverse in its geography and geomorphology and would capture a wide variety of geospatial characteristics to be mapped. The final modeled map outputs are illustrated in Appendix 4.

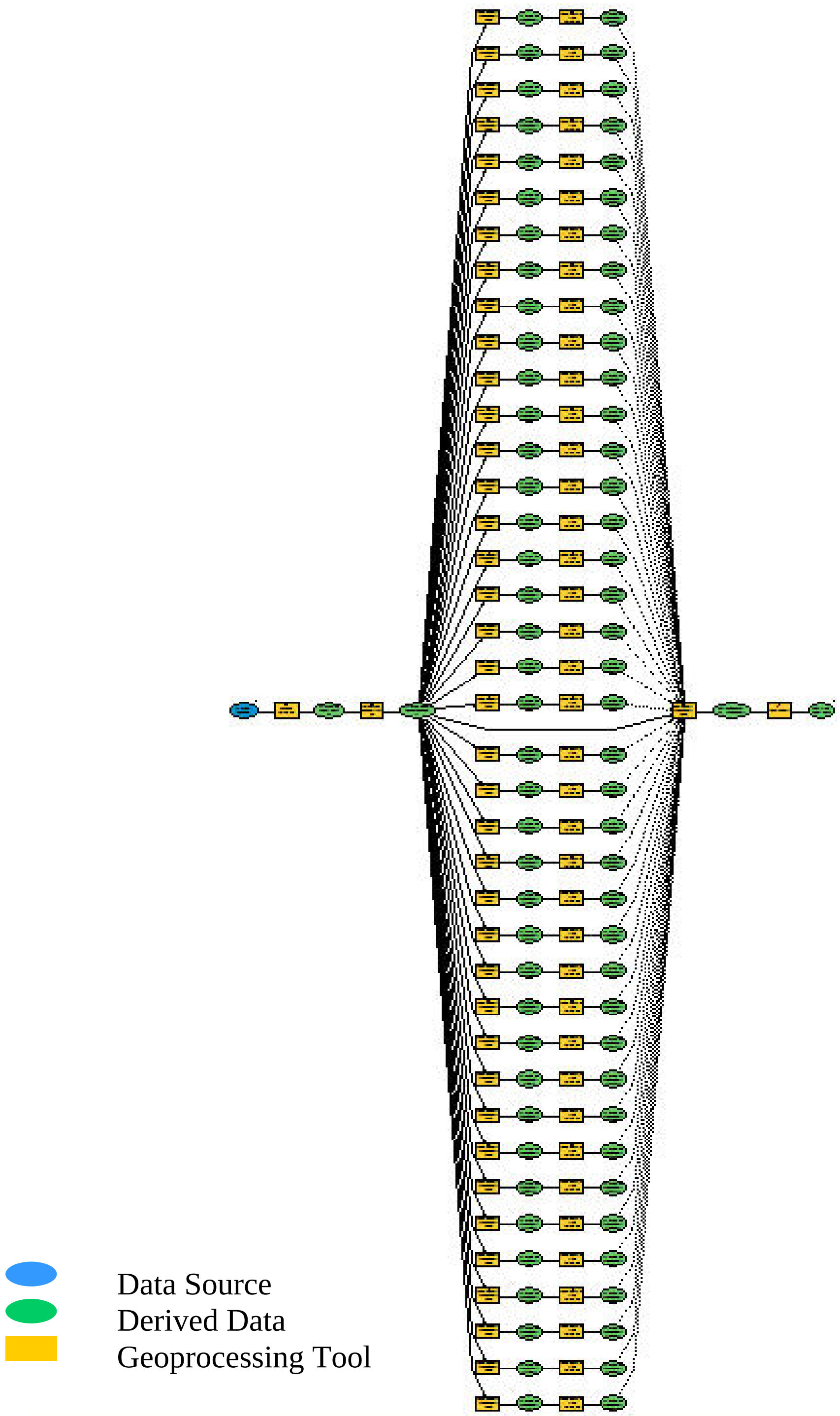


Figure 9. Geospatial data model for the class "Suitable with Design Restrictions" where n=39.

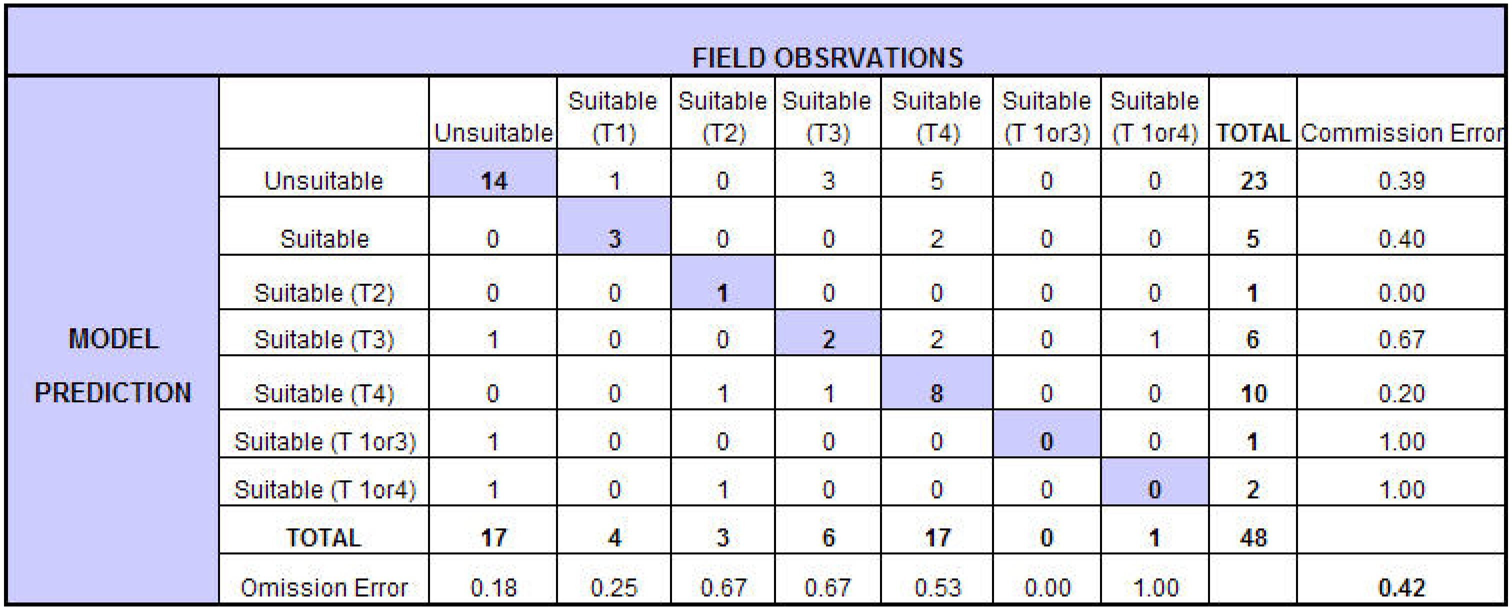
Model Validation

Model validation was intended as a direct comparison of model results with field evidence. 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 were 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 8) 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 8 – 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 9).

Table 9 – Suitable vs. Unsuitable Conditions

		FIELD	
MODEL		Suitable	Unsuitable
	Suitable	22	9
	Unsuitable	3	14

The model did well identifying sites that were unsuitable for living shoreline (Table 9). 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 with design restrictions is reduced (58%). Some model refinement is possible, however, it is unlikely the data necessary to improve the model significantly will be available. 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. 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.

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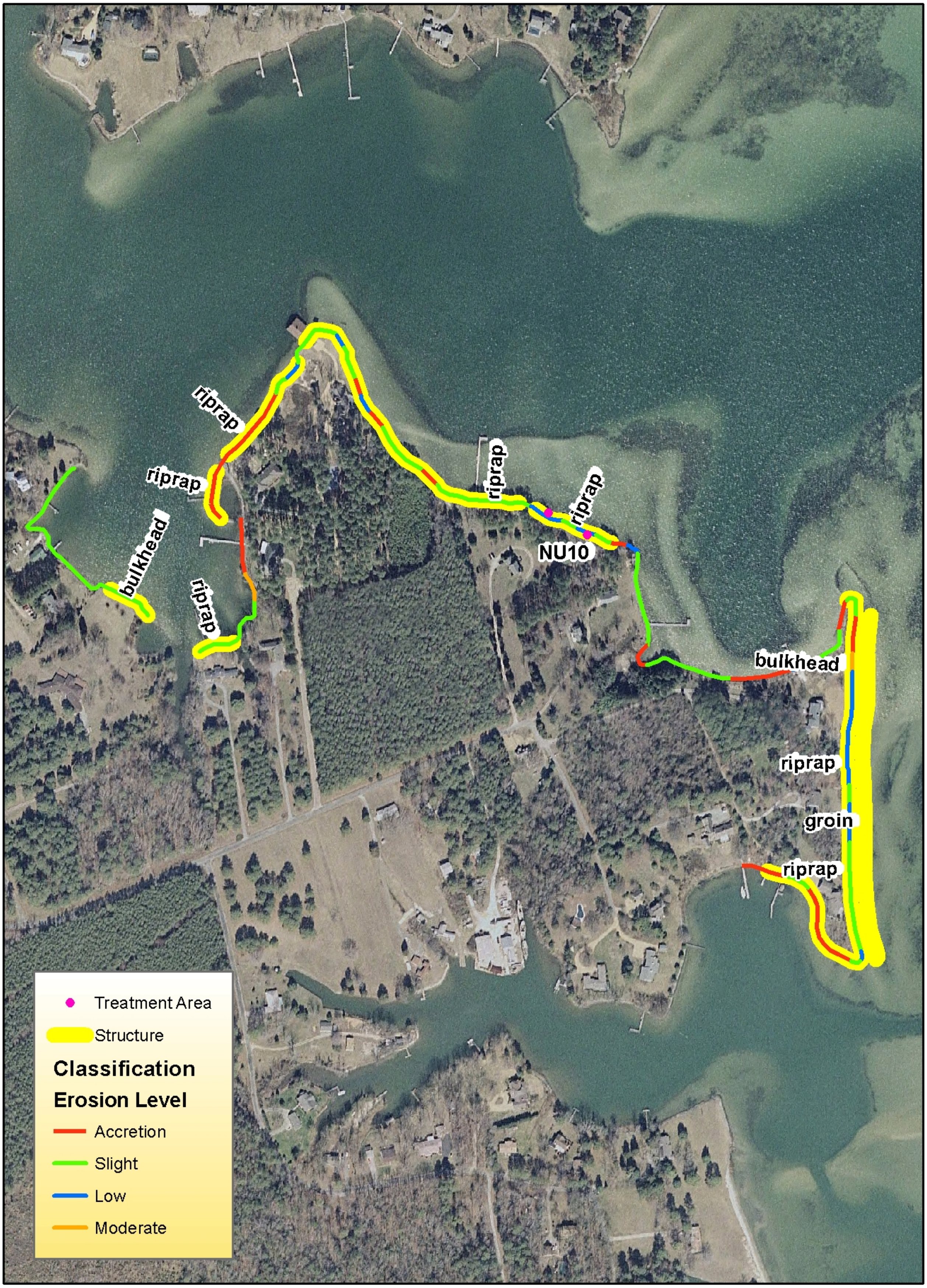
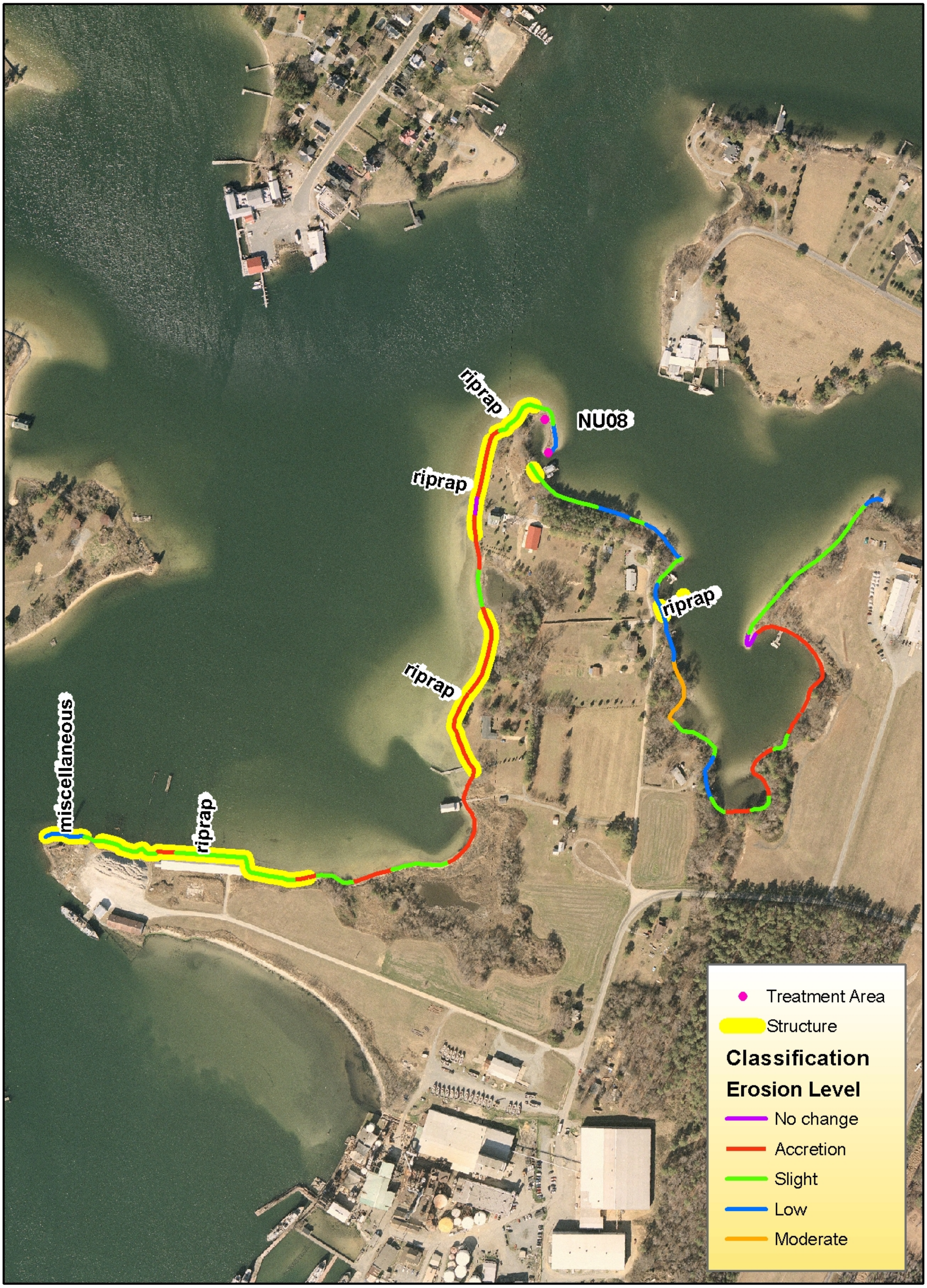
Appendix 1.

Treatment Sites

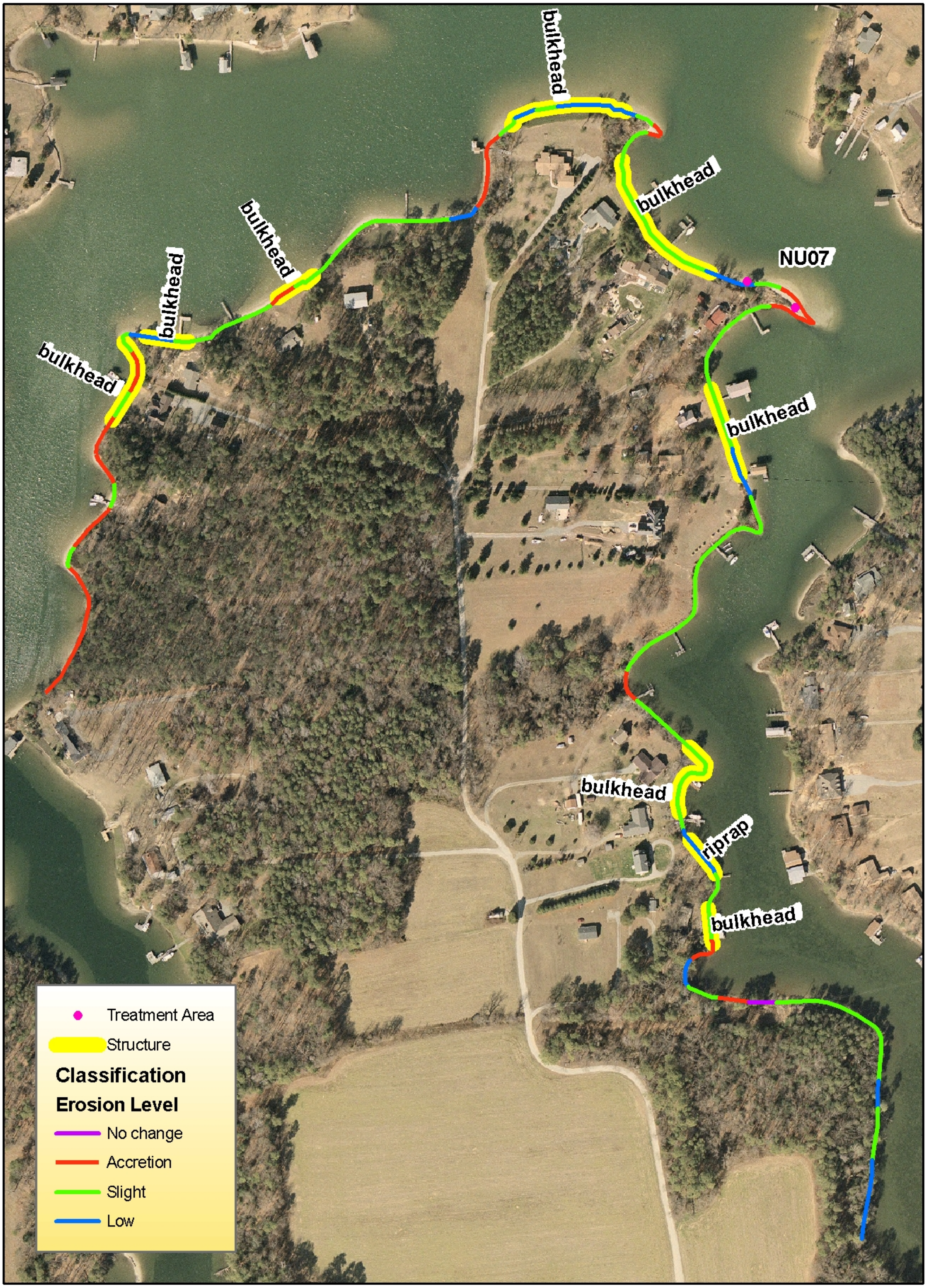
Living Shoreline Assessment - Site NU10



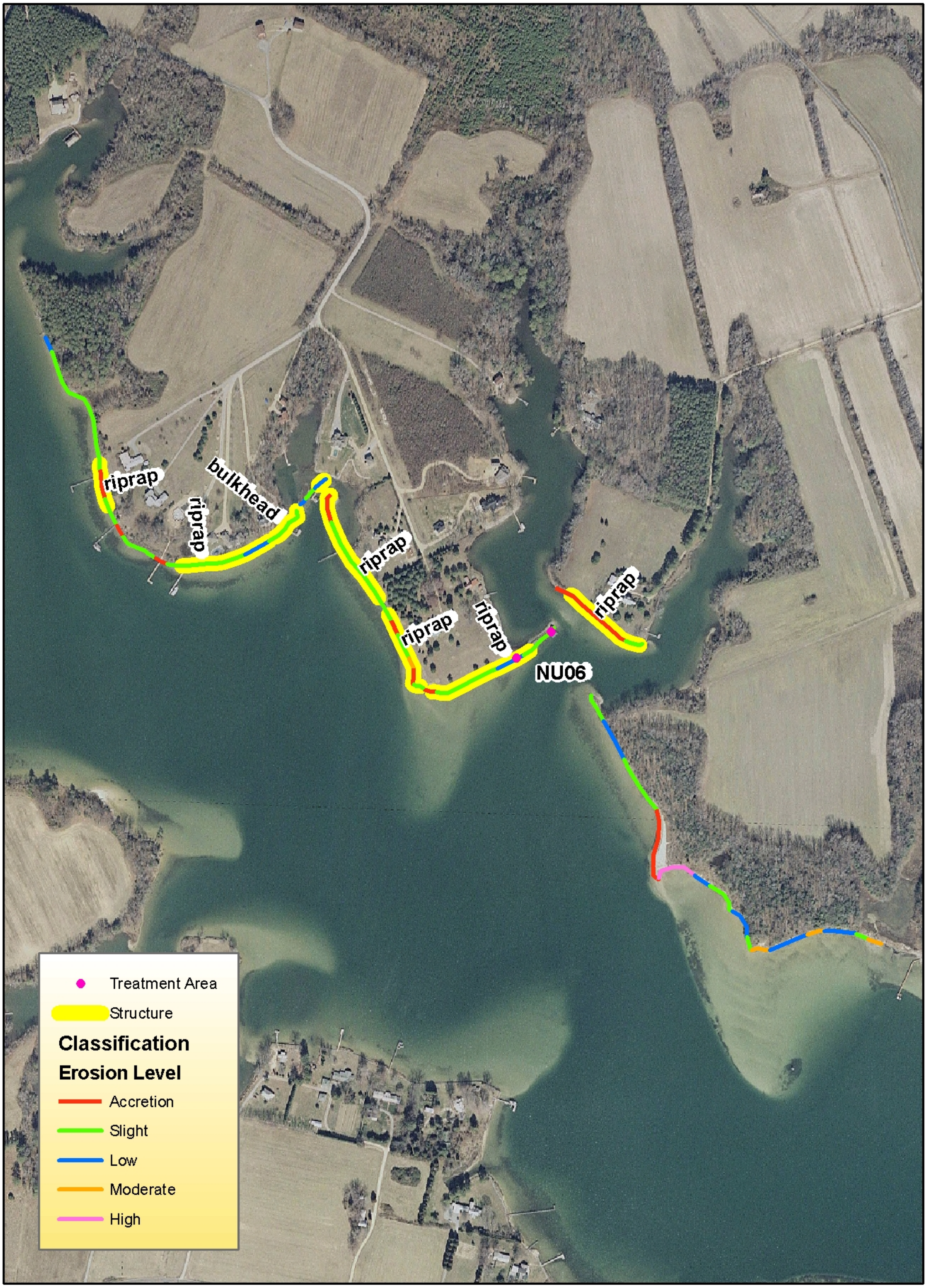
Living Shoreline Assessment - Site NU08



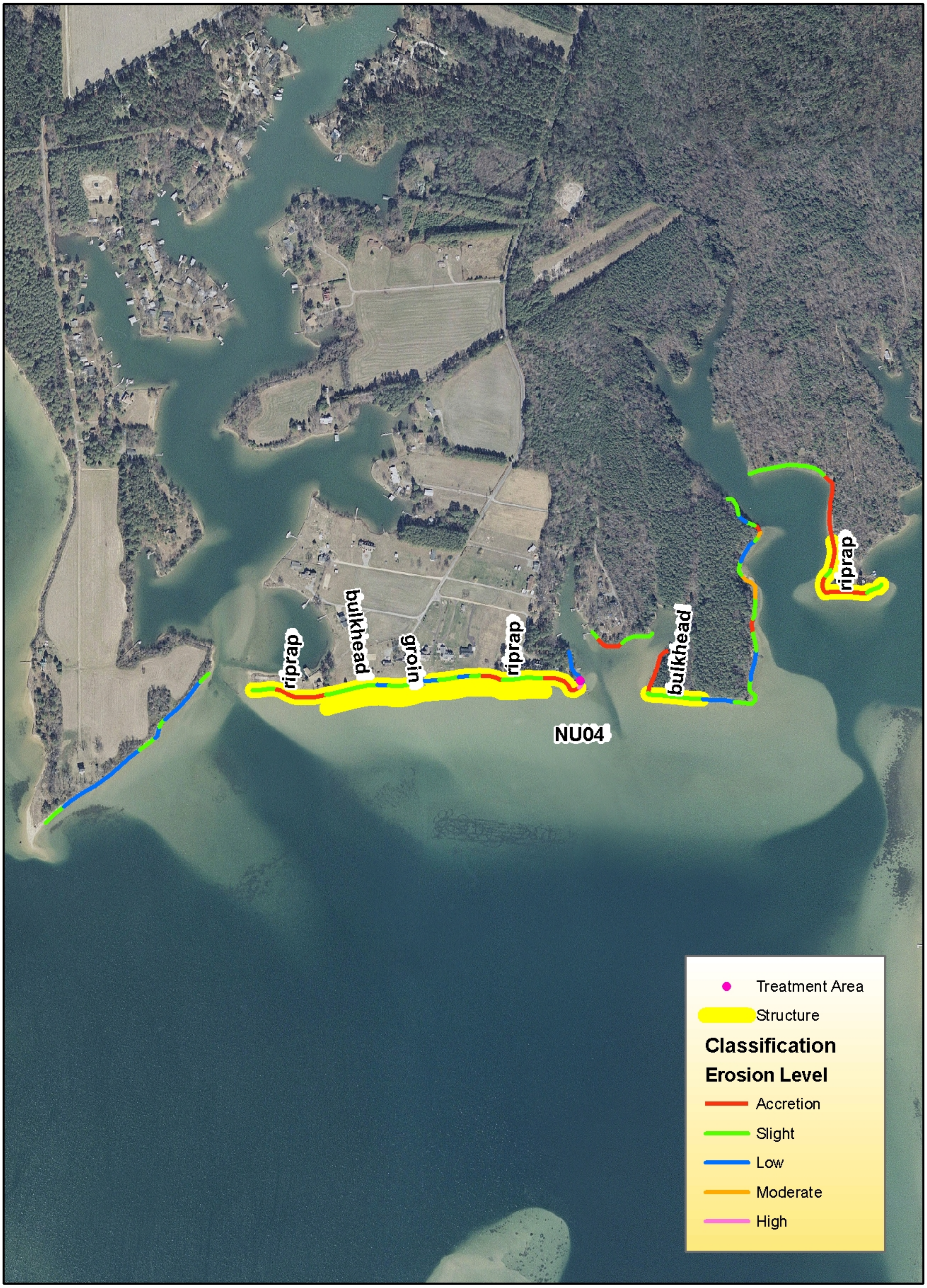
Living Shoreline Assessment - Site NU07



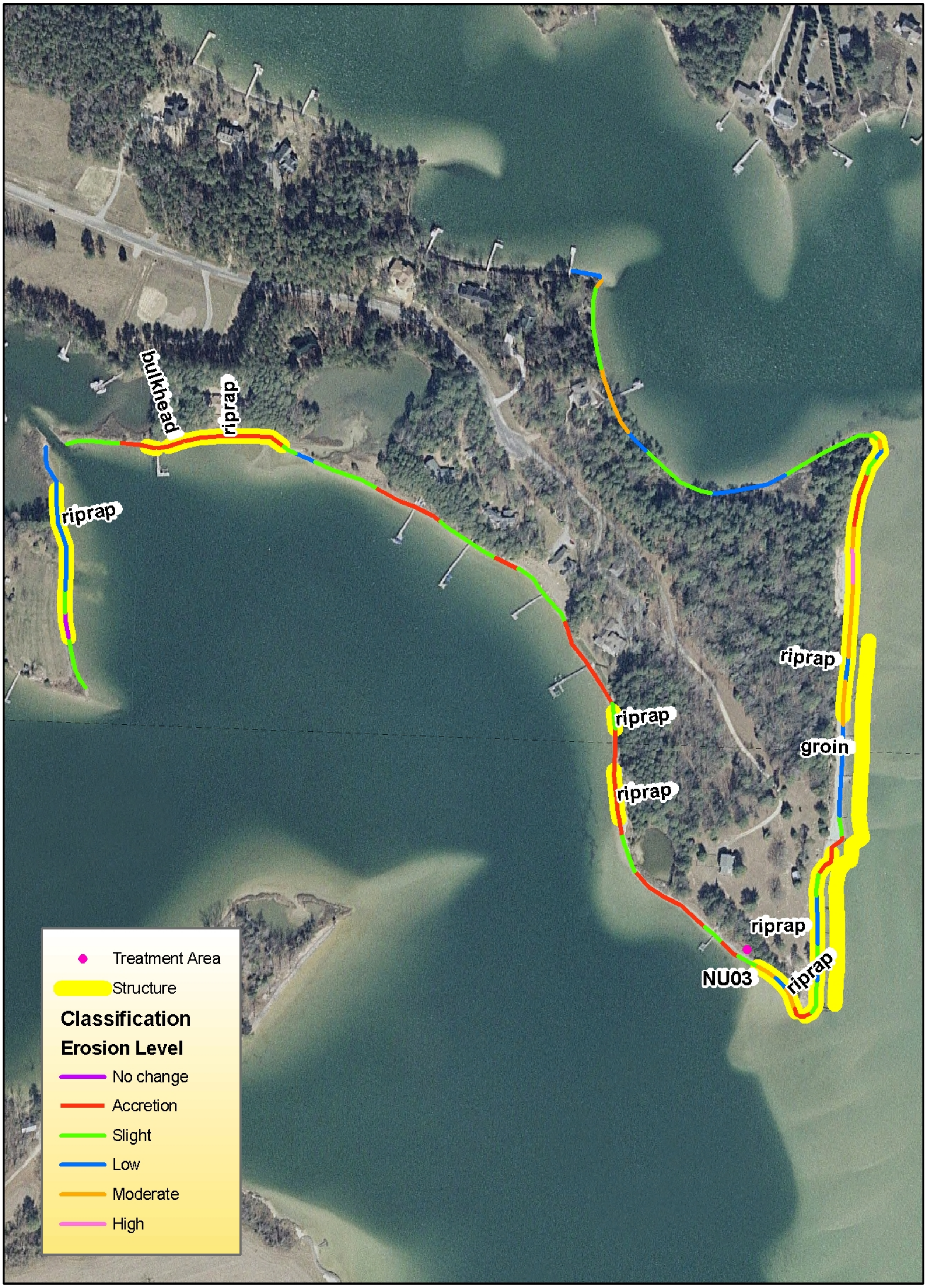
Living Shoreline Assessment - Site NU06



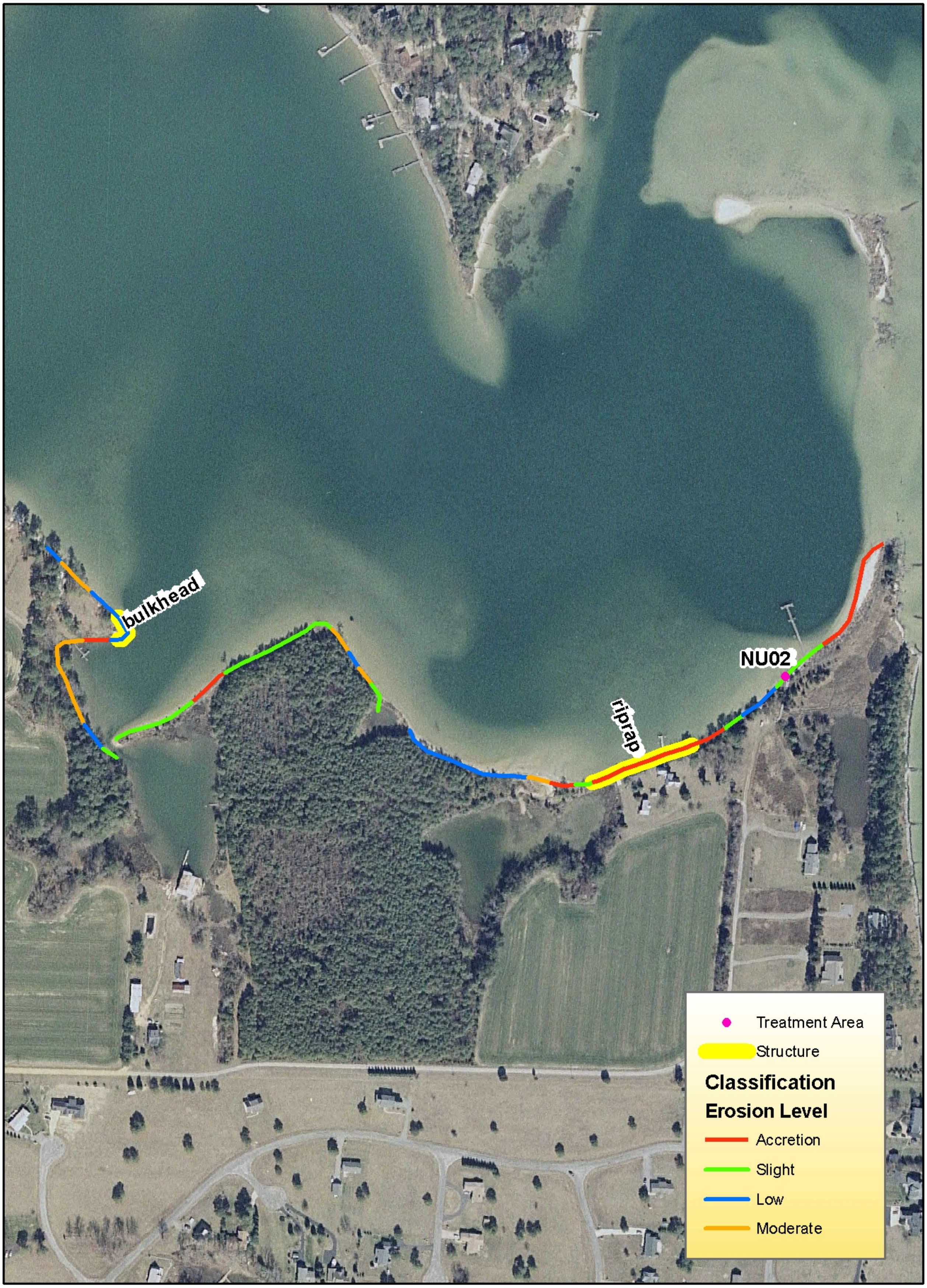
Living Shoreline Assessment - Site NU04



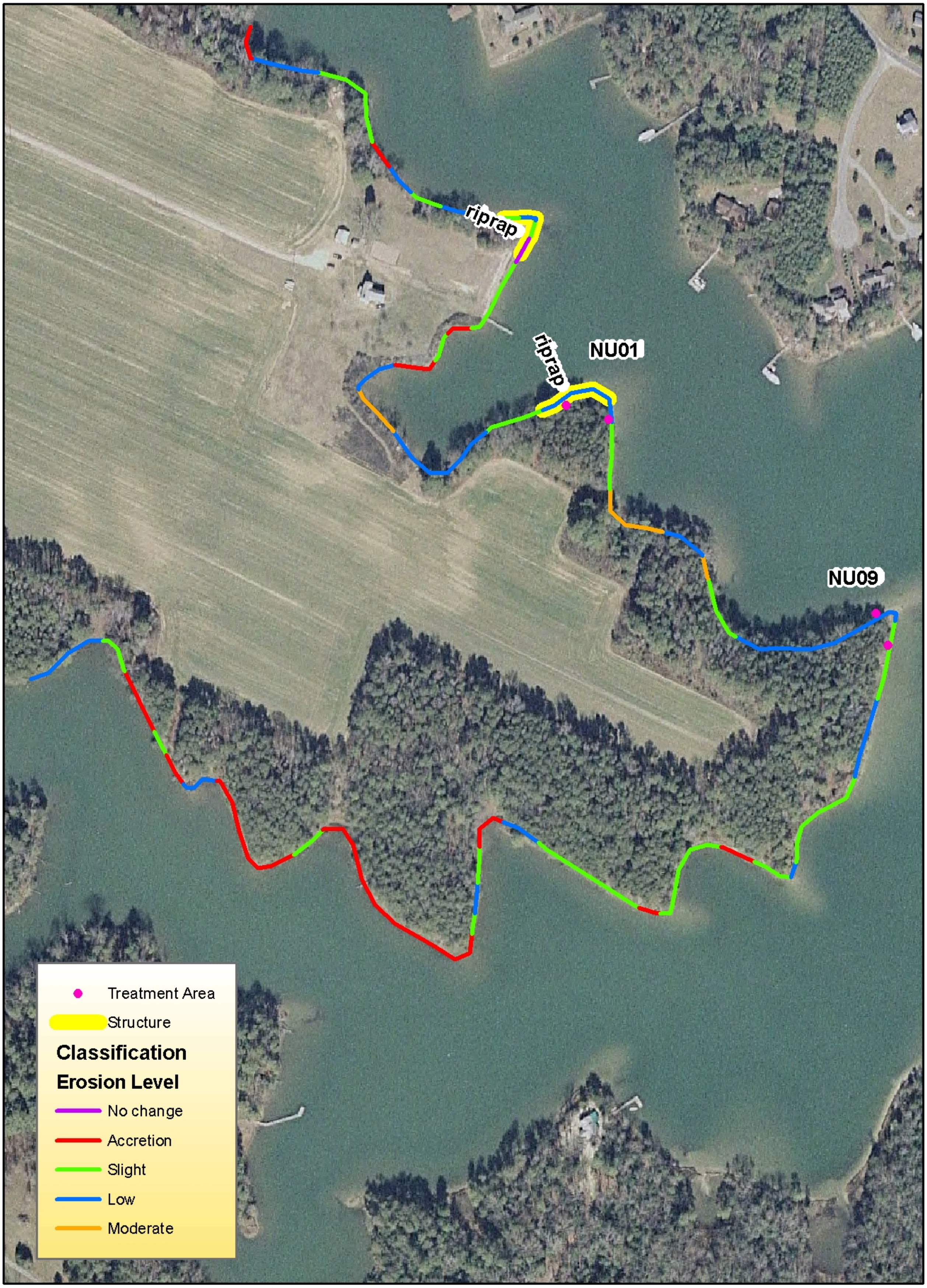
Living Shoreline Assessment - Site NU03



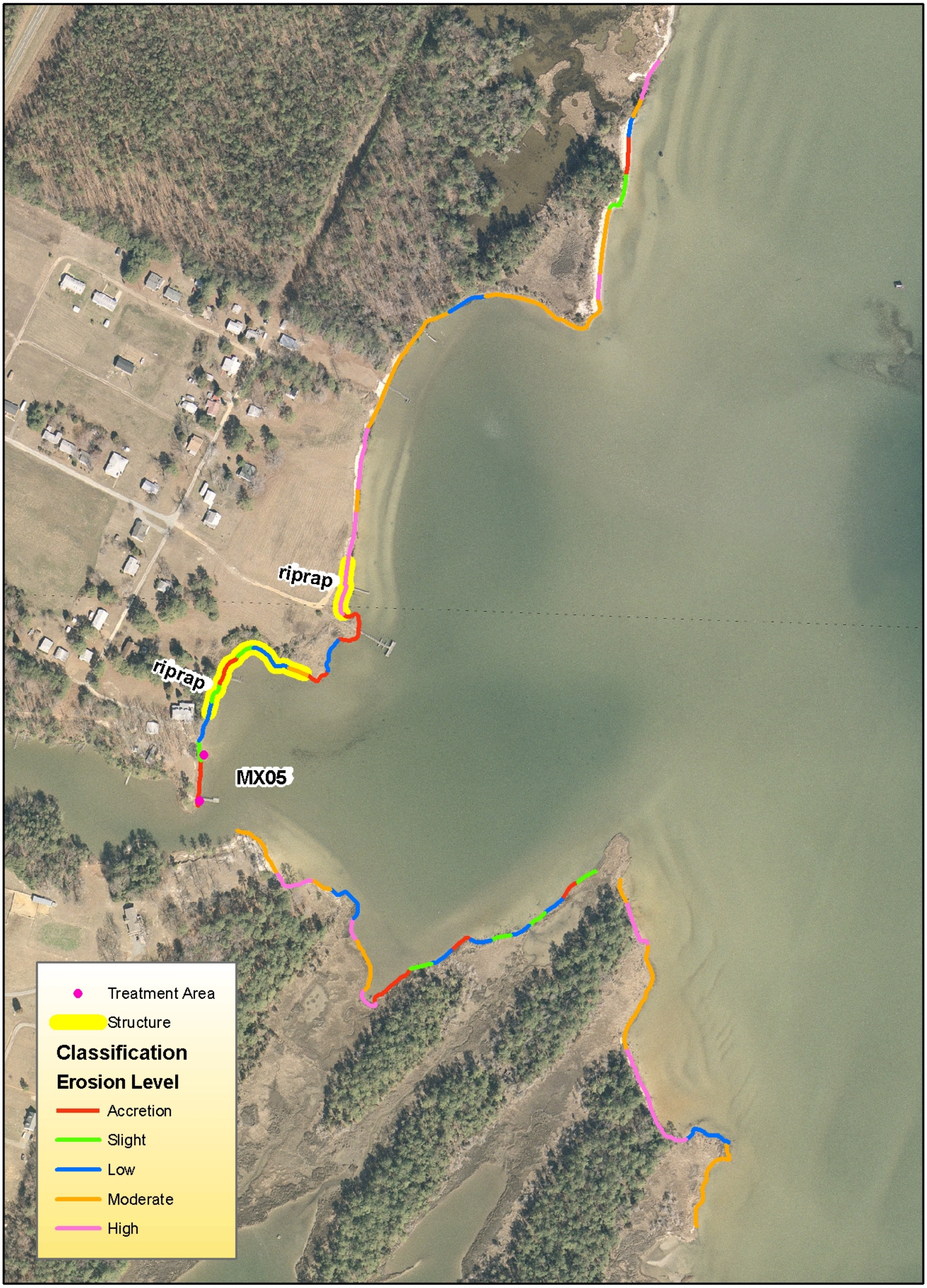
Living Shoreline Assessment - Site - NU02



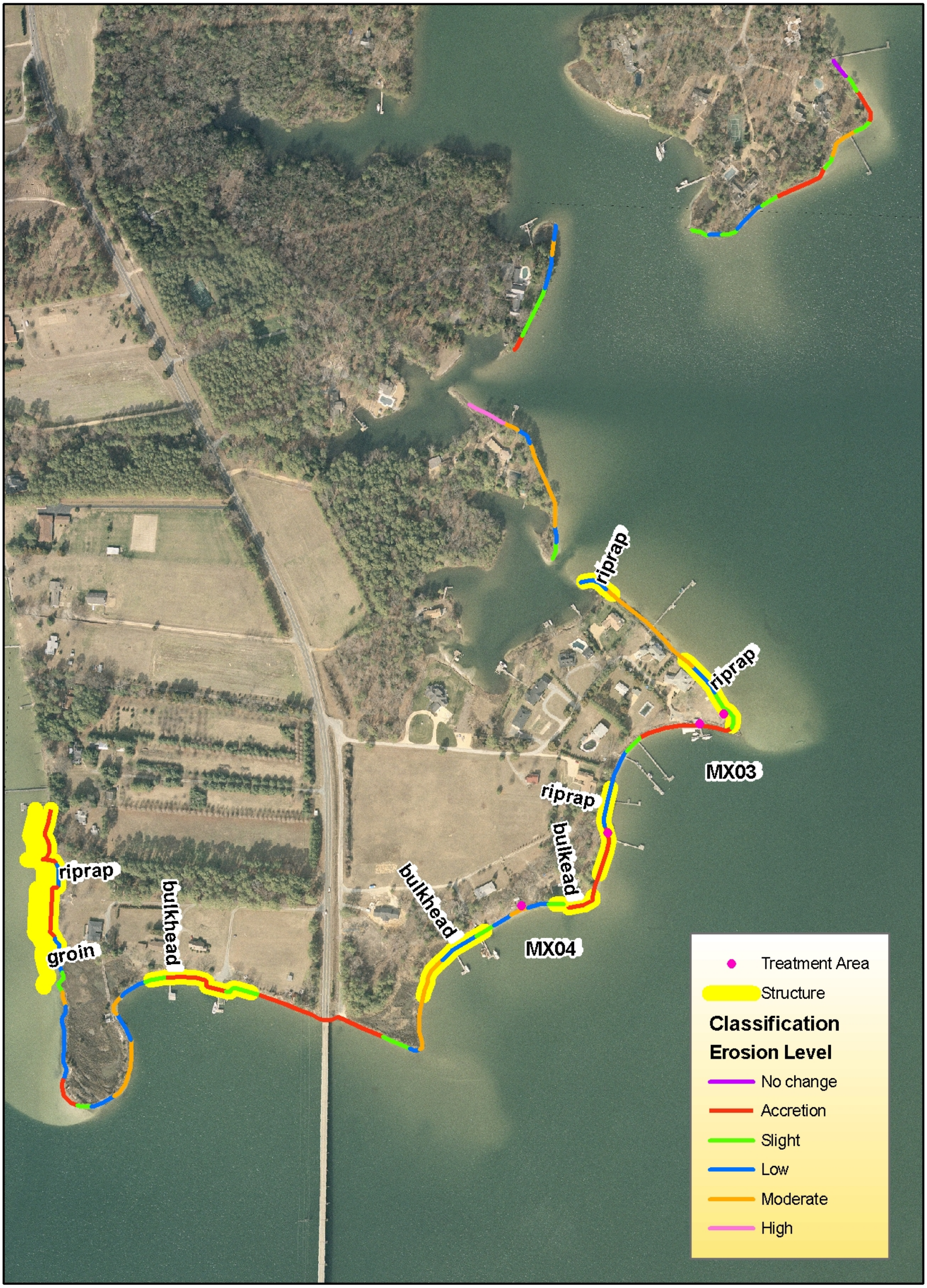
Living Shoreline Assessment - Site NU01 and NU09



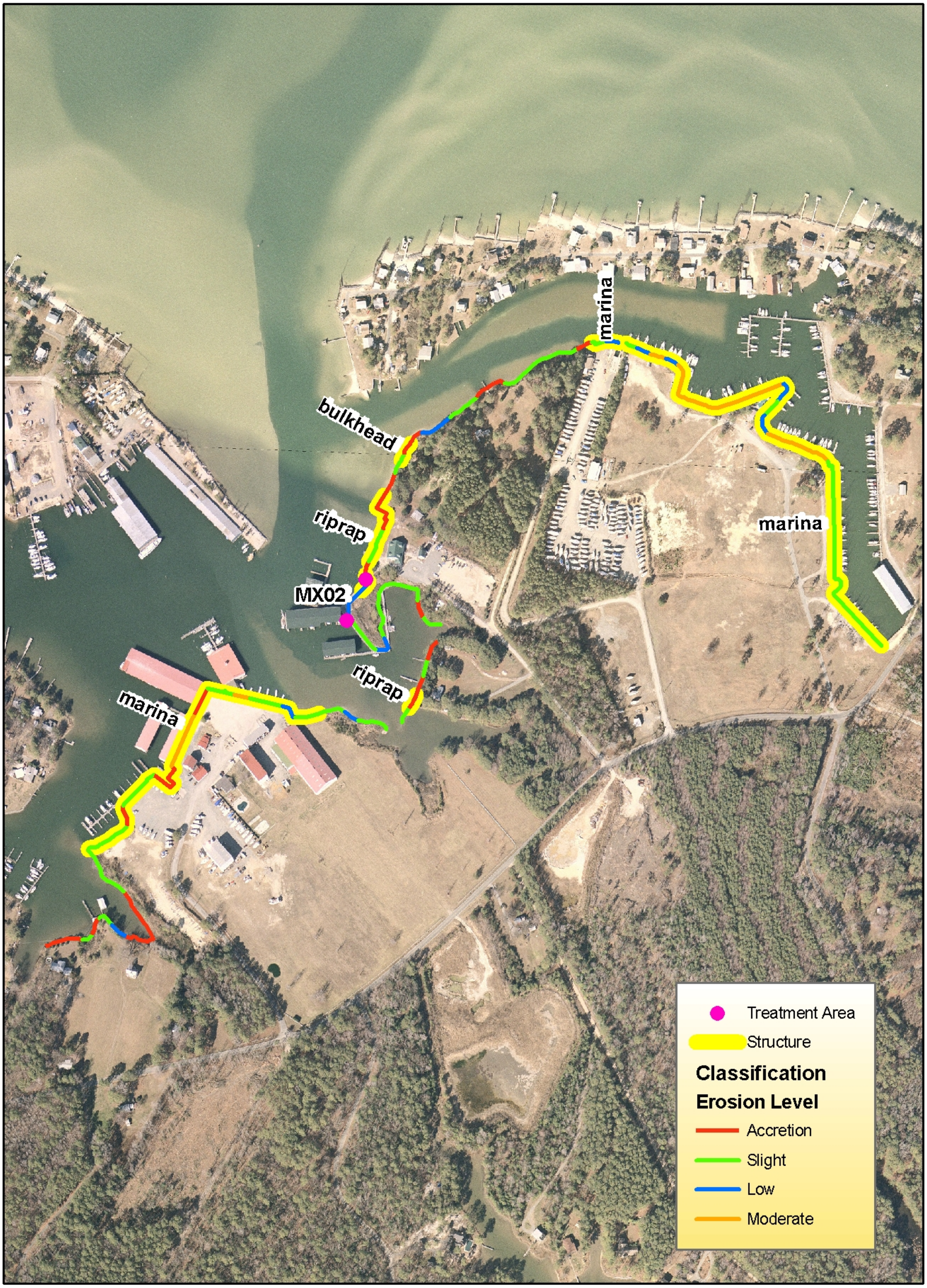
Living Shoreline Assessment - Site MX05



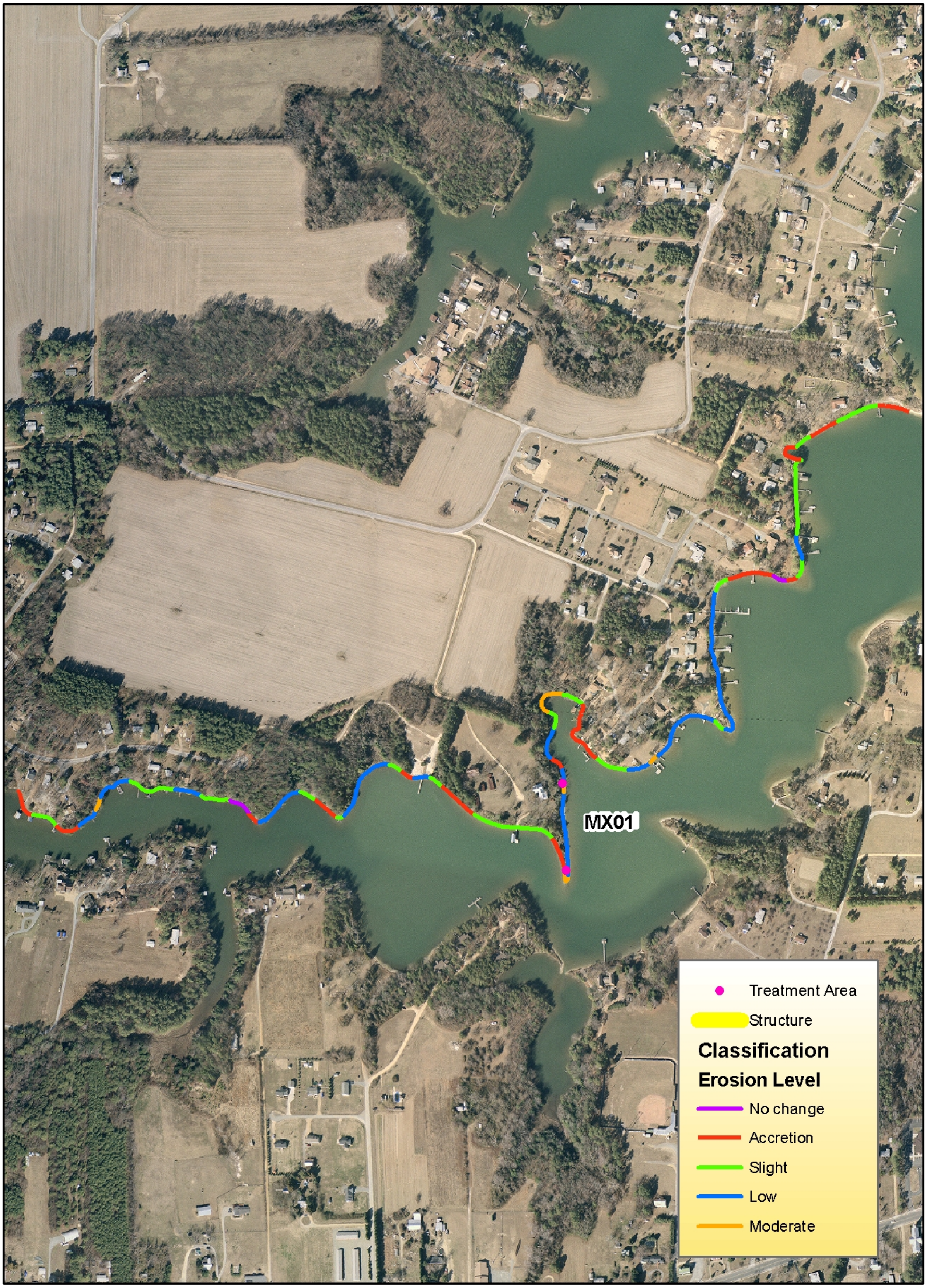
Living Shoreline Assessment - Site MX03 and MX04



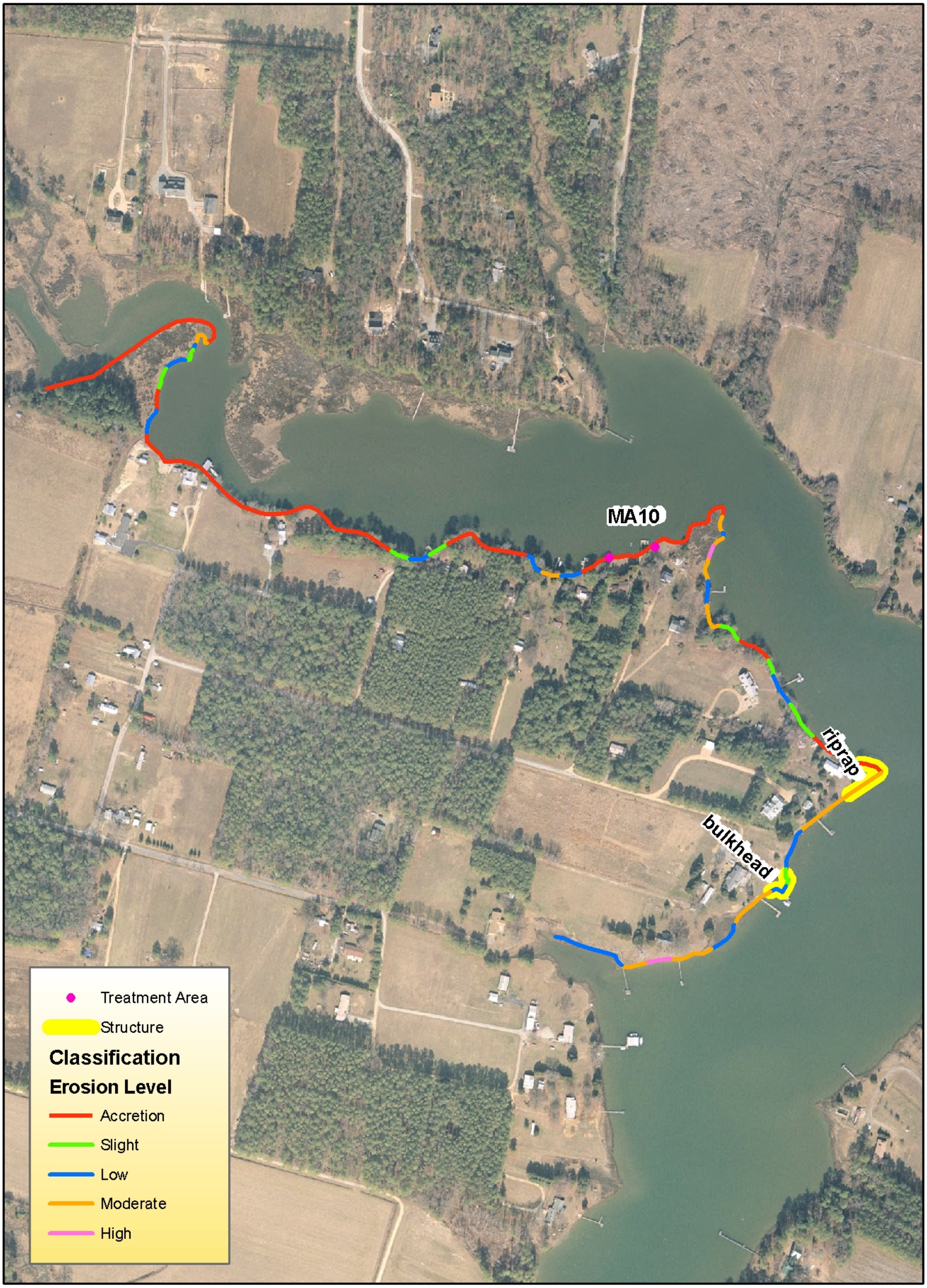
Living Shoreline assessment - Site MX02



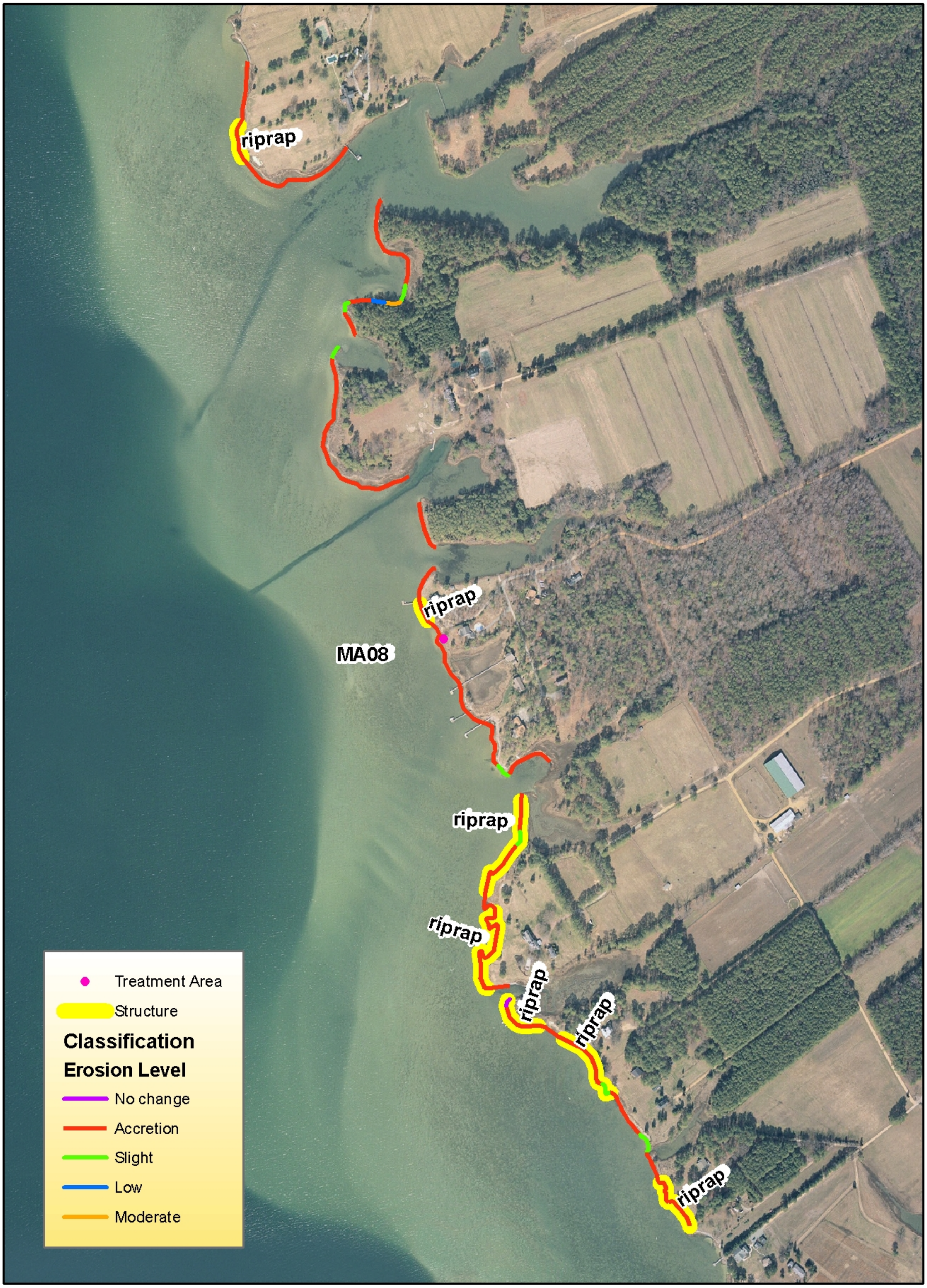
Living Shoreline Assessment - Site MX01



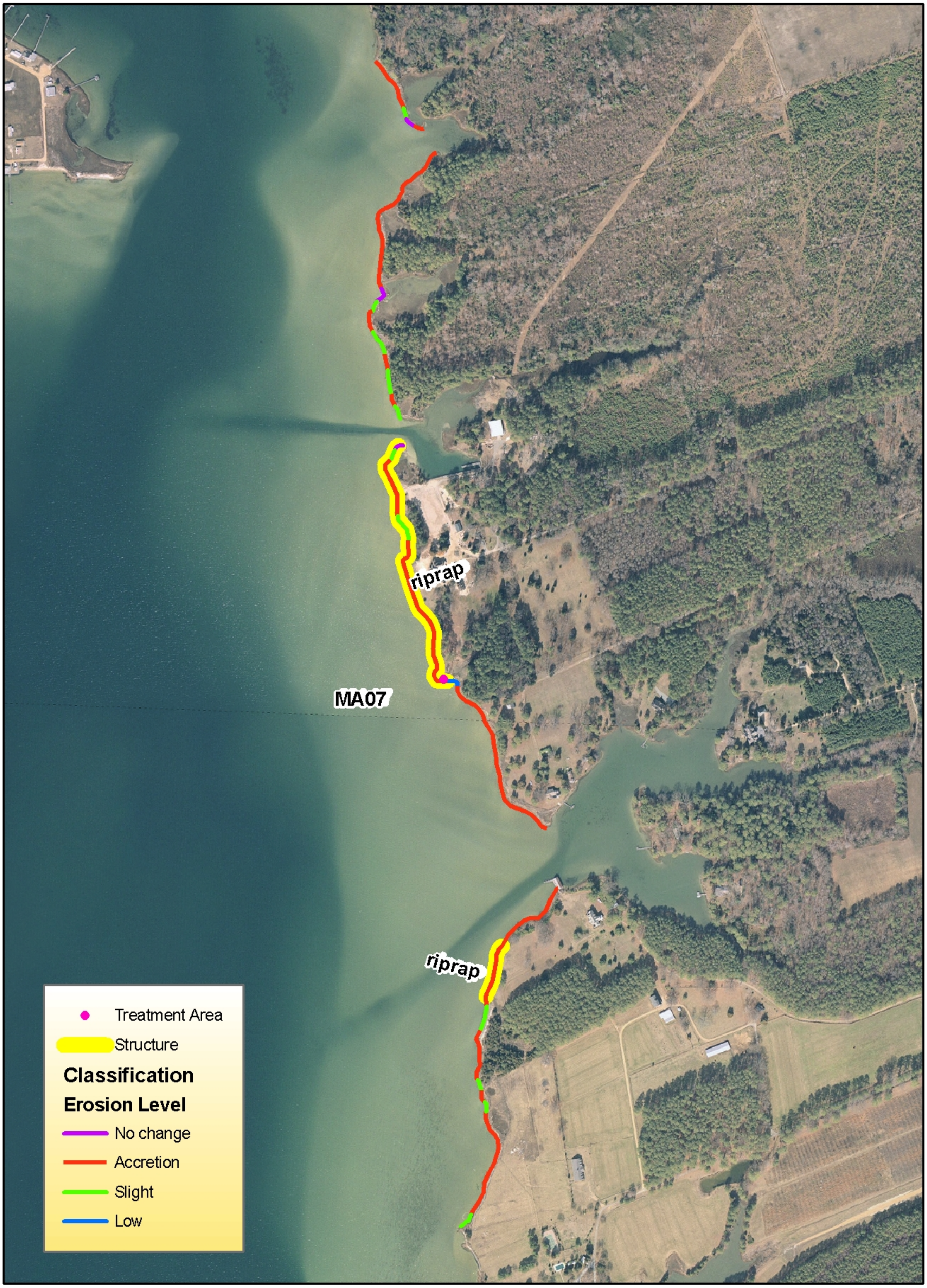
Living Shoreline Assessment - Site MA10



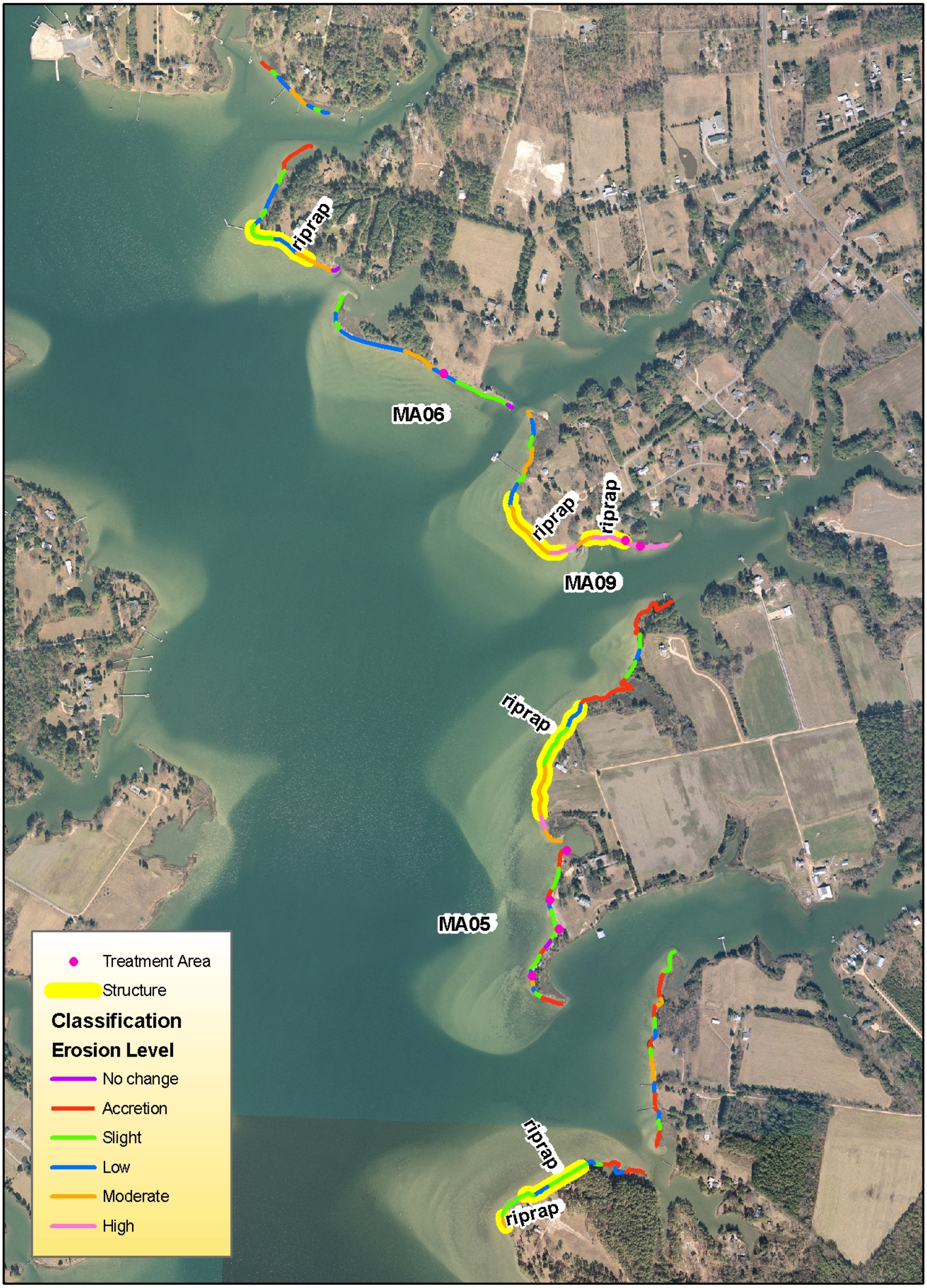
Living Shoreline Assessment - Site MA08



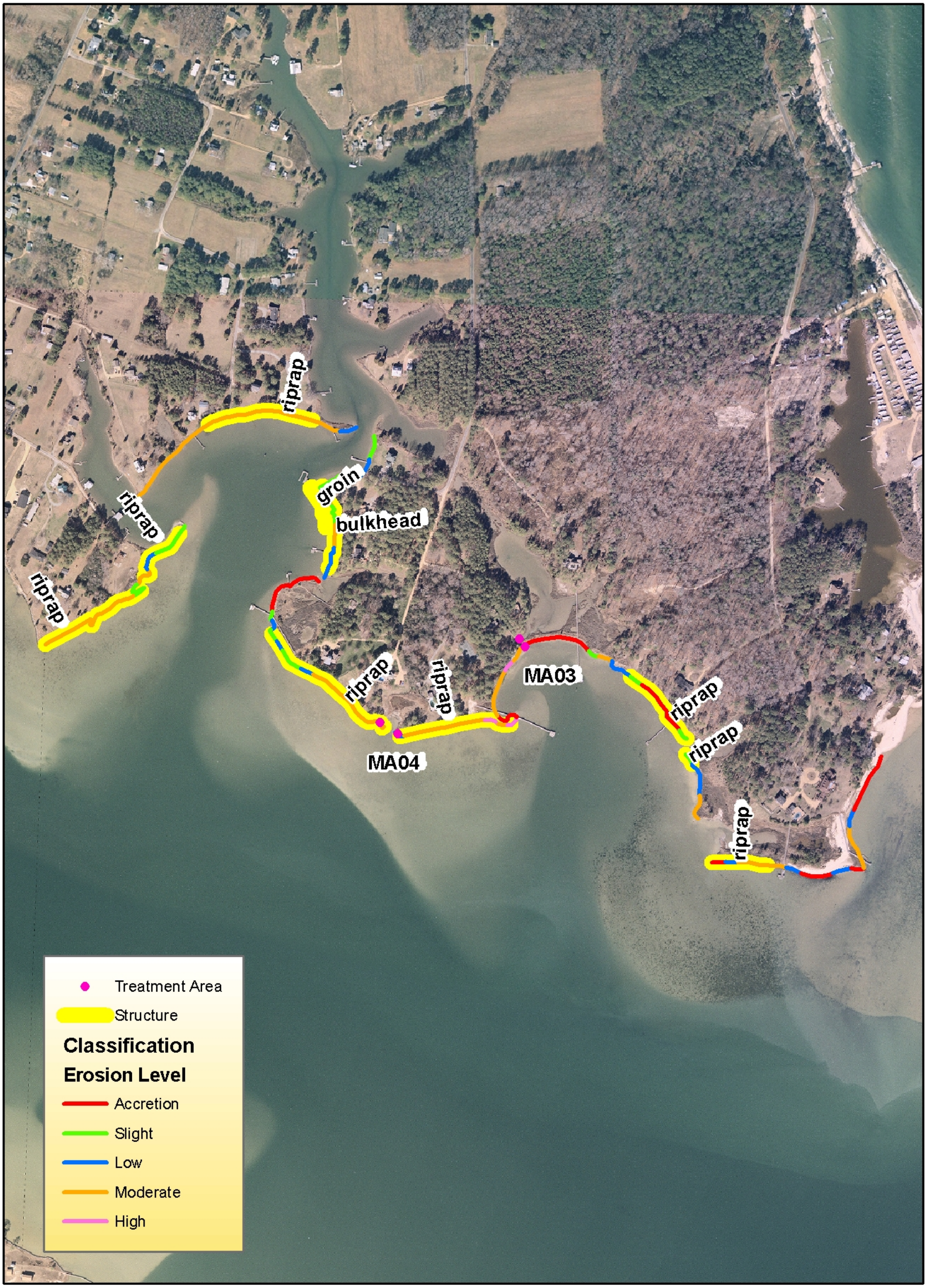
Living Shoreline Assessment - Site MA07



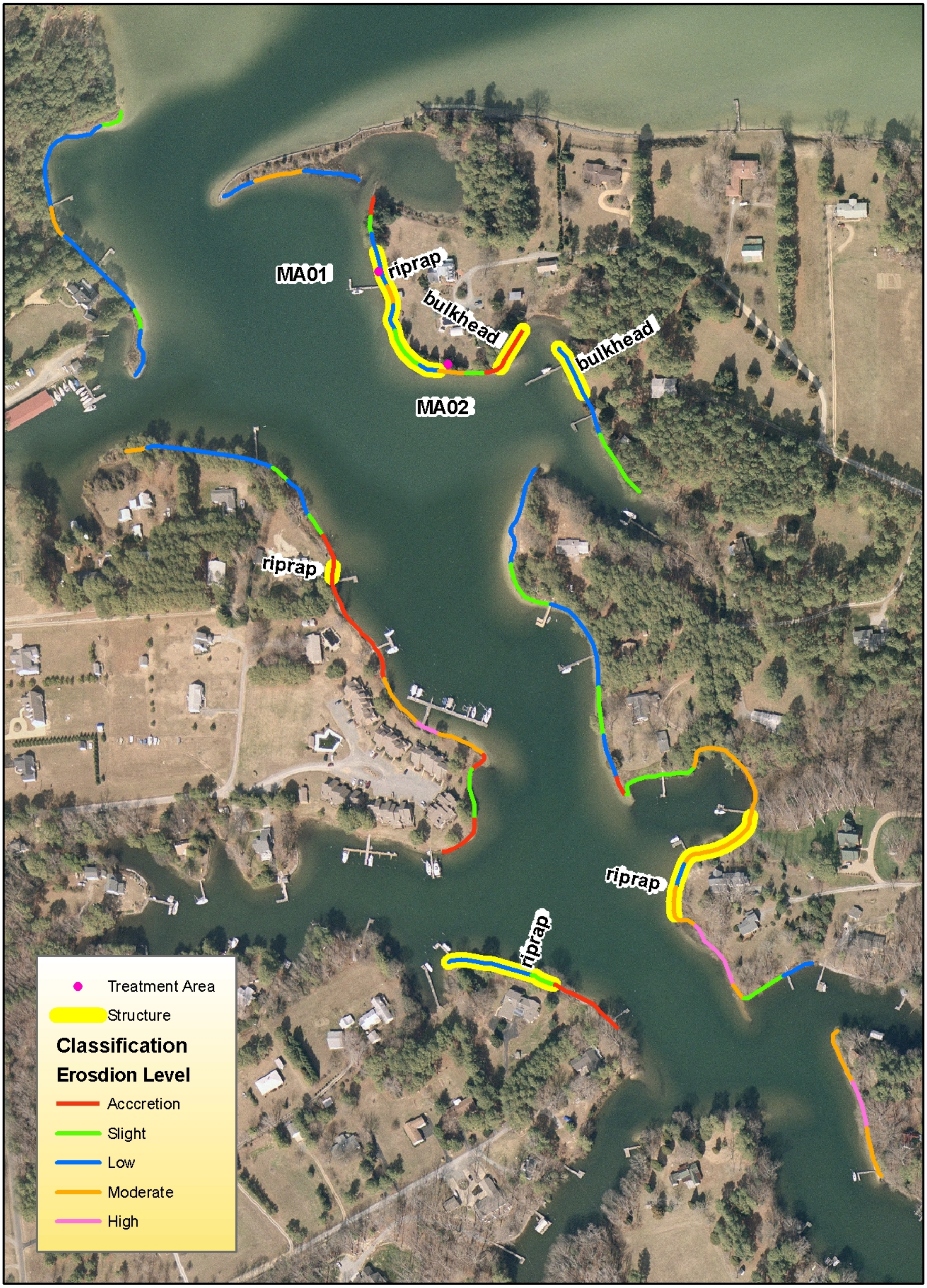
Living Shoreline Assessment - Site MA05, MA06 and MA09



Living Shoreline Assessment - Site MA03 and MA04

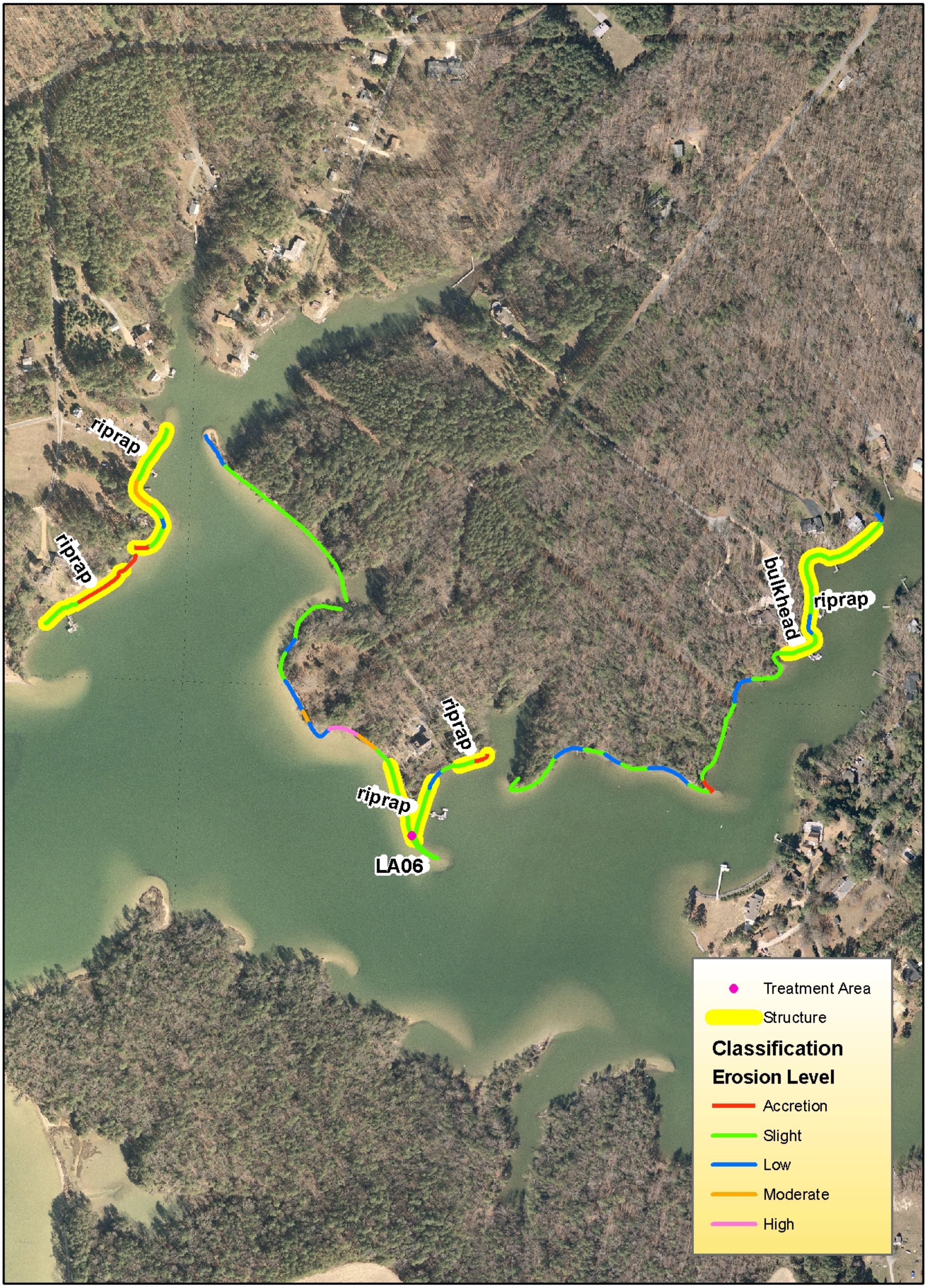


Living Shoreline Assessment - Site MA01 and MA02

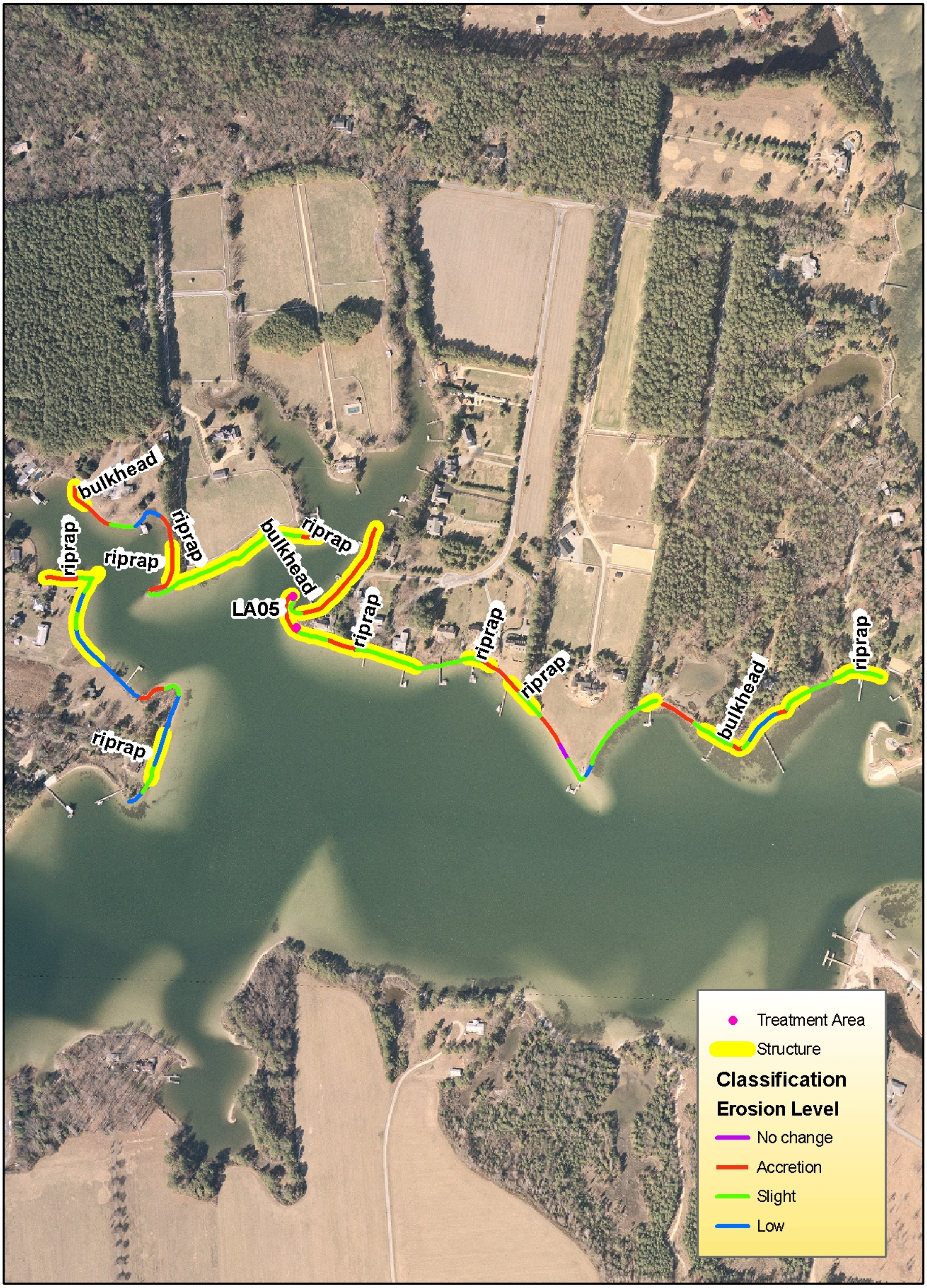


Living Shoreline Assessment - Site LA07

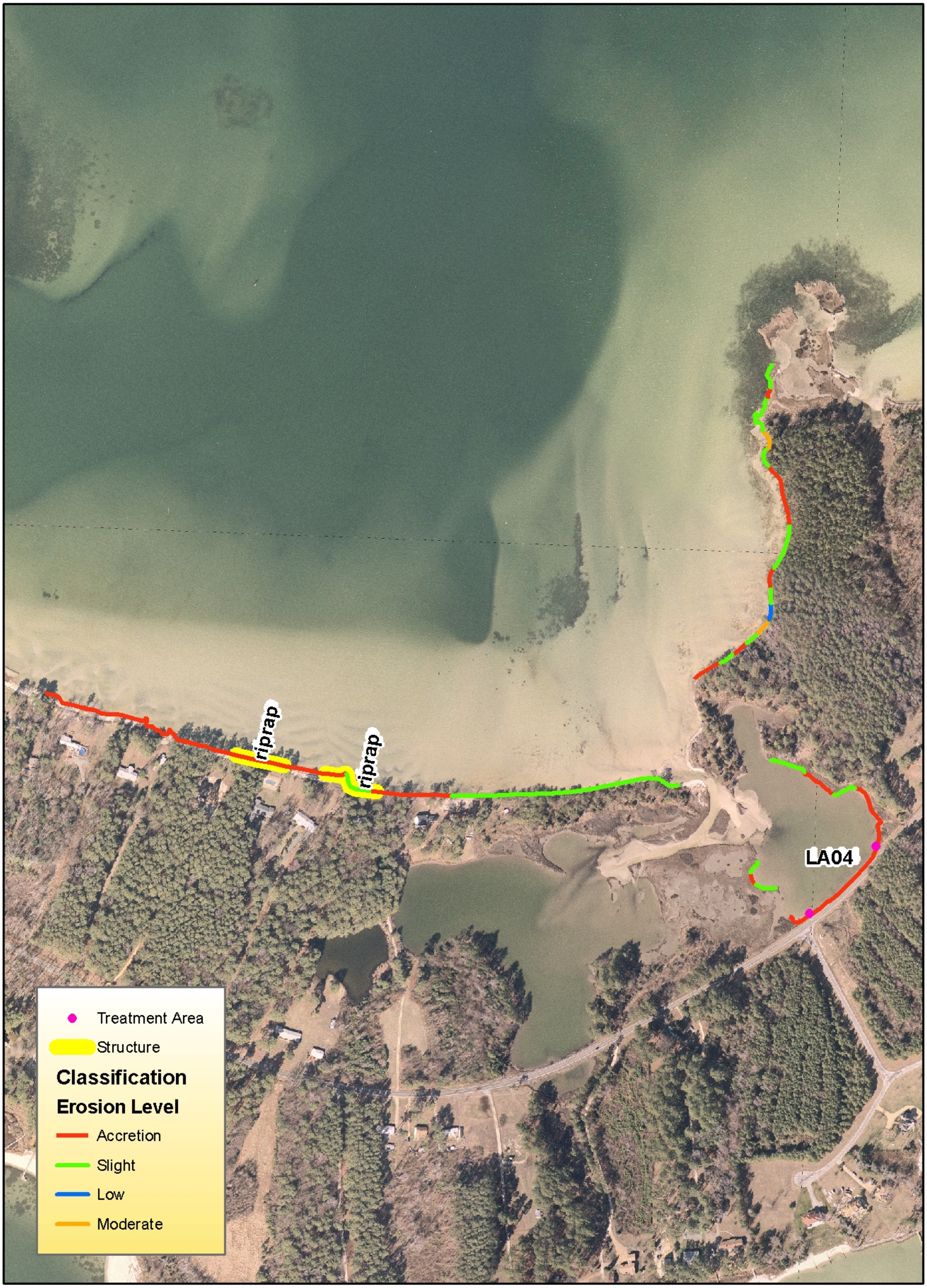
Living Shoreline Assessment - Site LA06



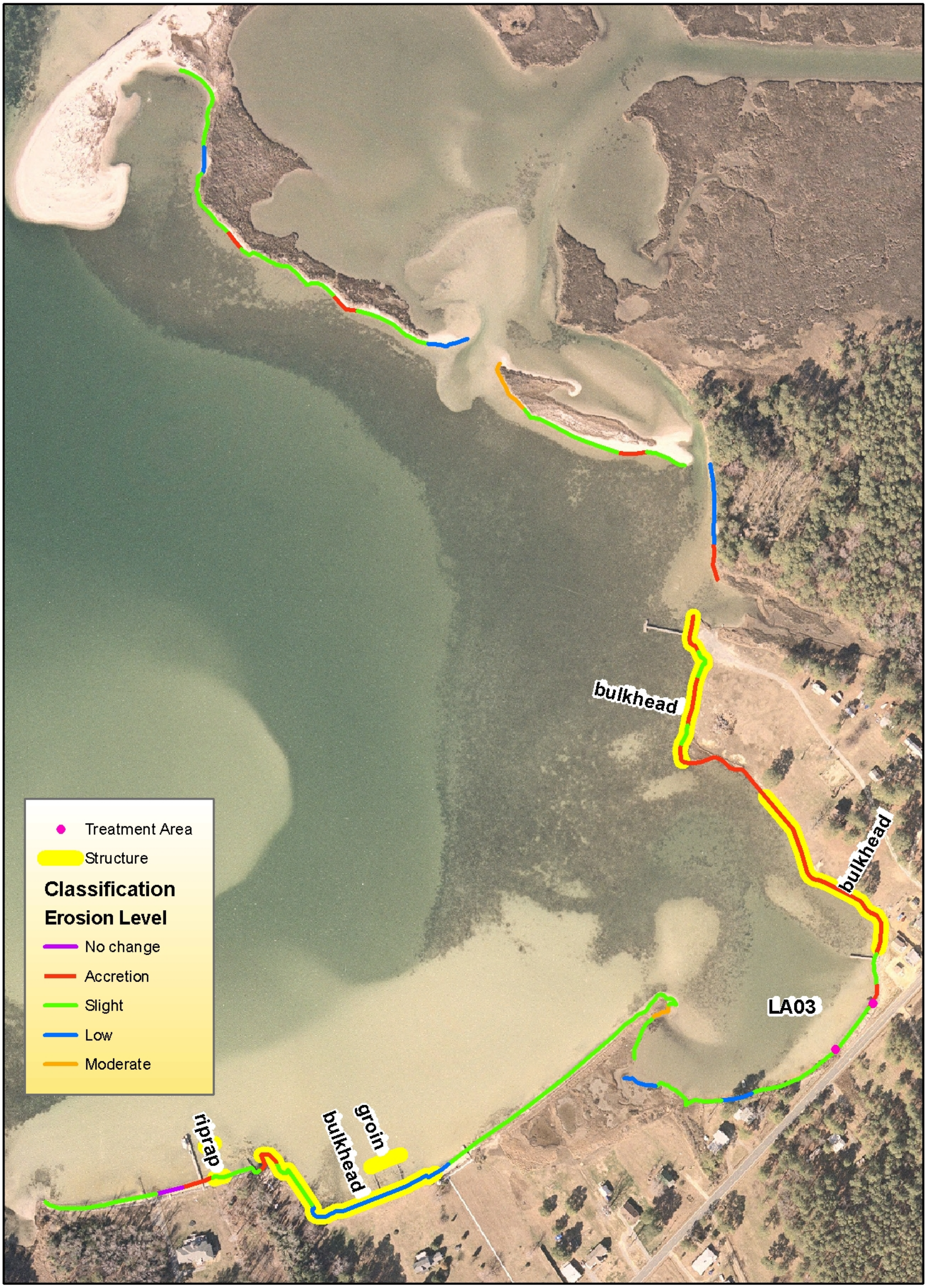
Living Shoreline Assesssment - Site LA05



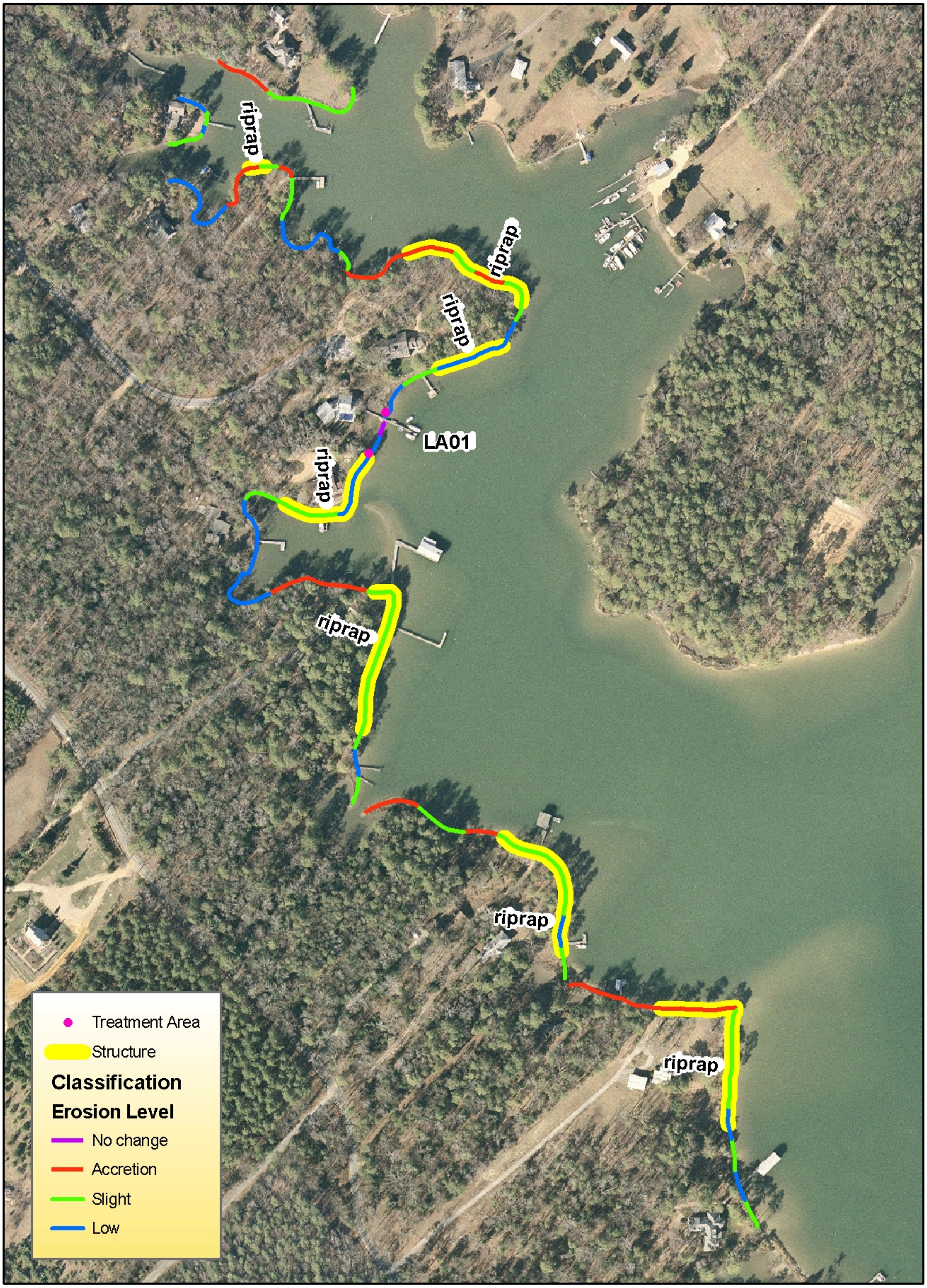
Living Shoreline Assessment - Site LA04



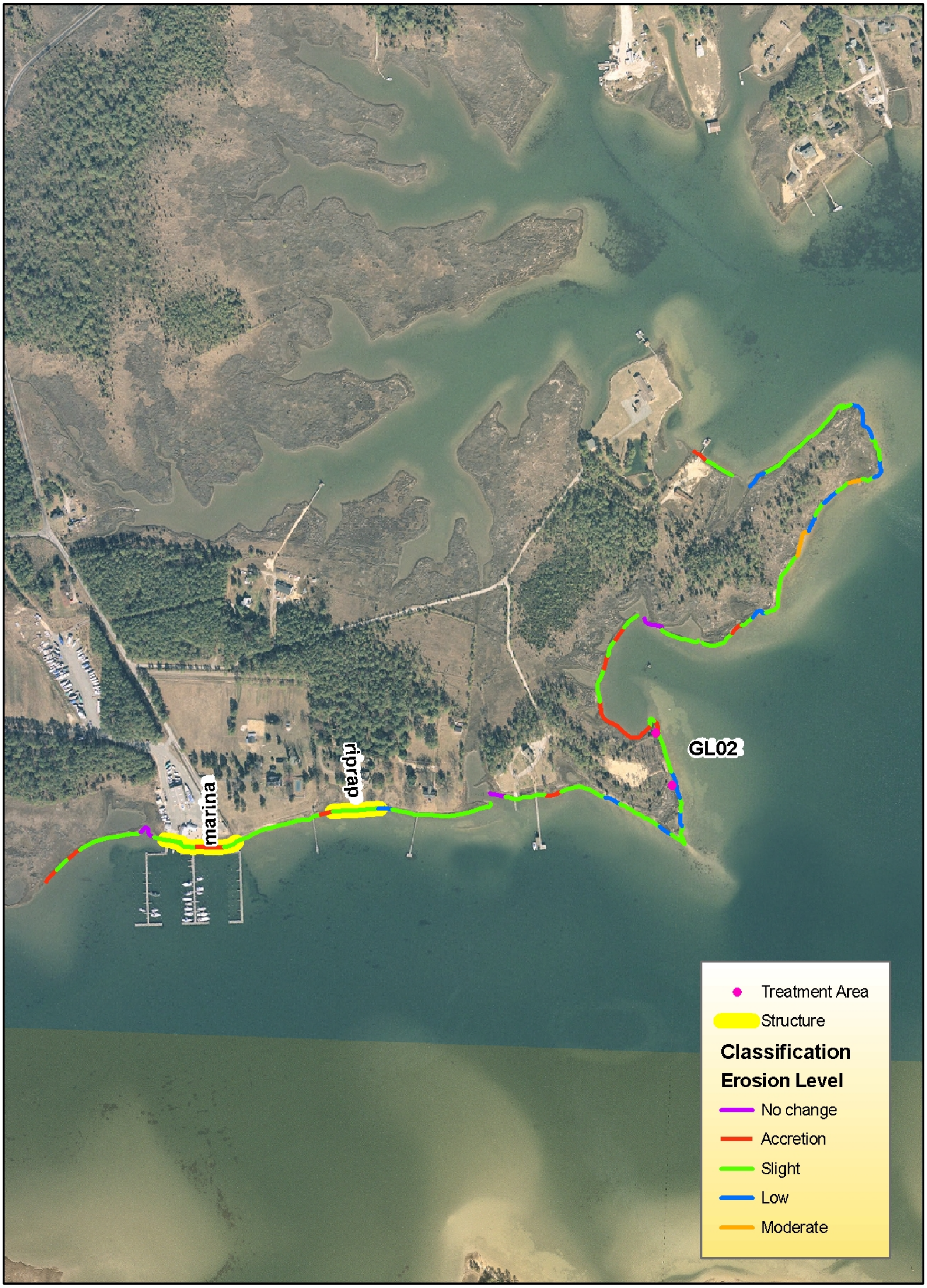
Living Shoreline Assessment - Site LA03



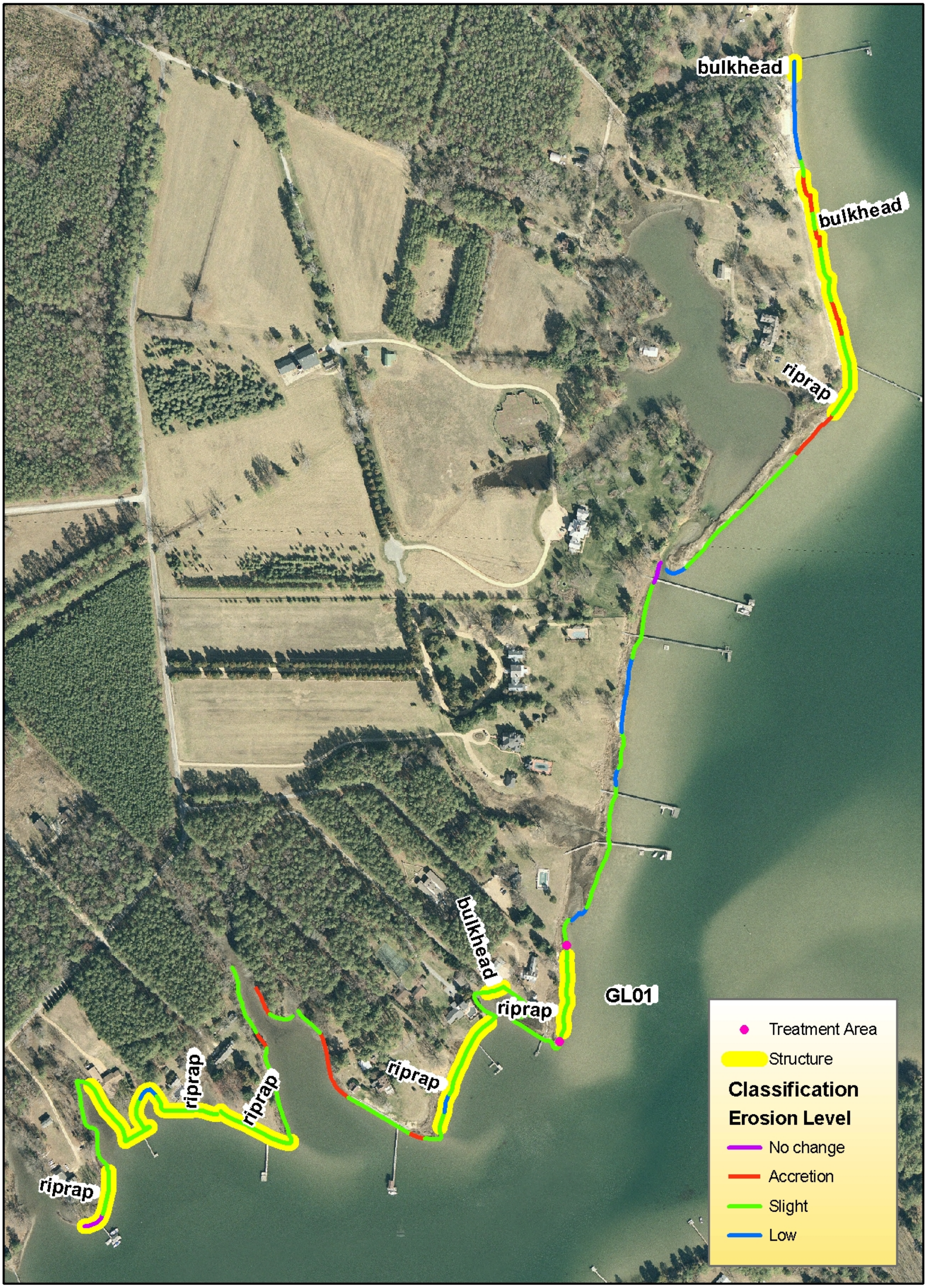
Living Shoreline Assessment - Site LA01



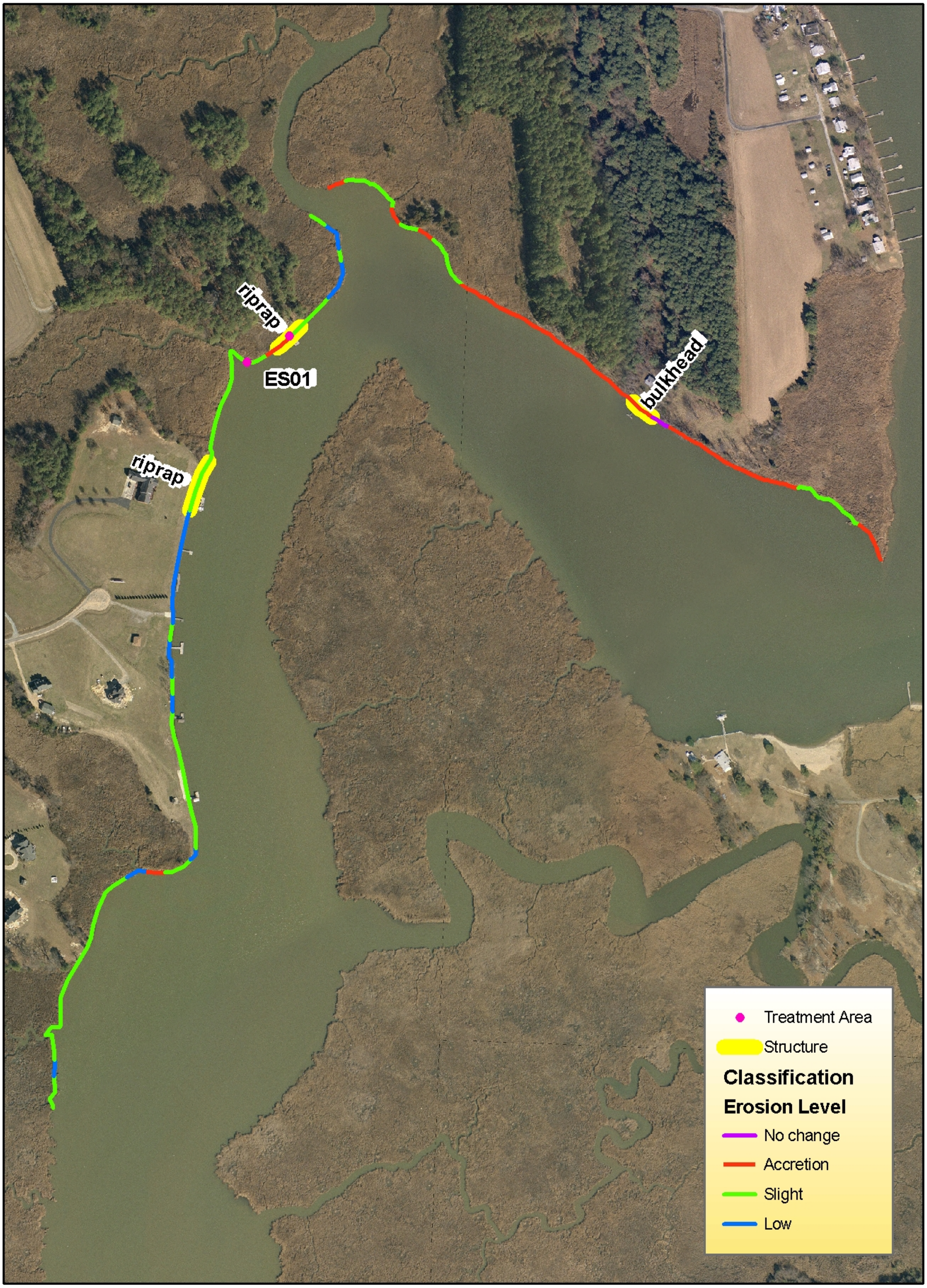
Living Shoreline Assessment - Site GL02



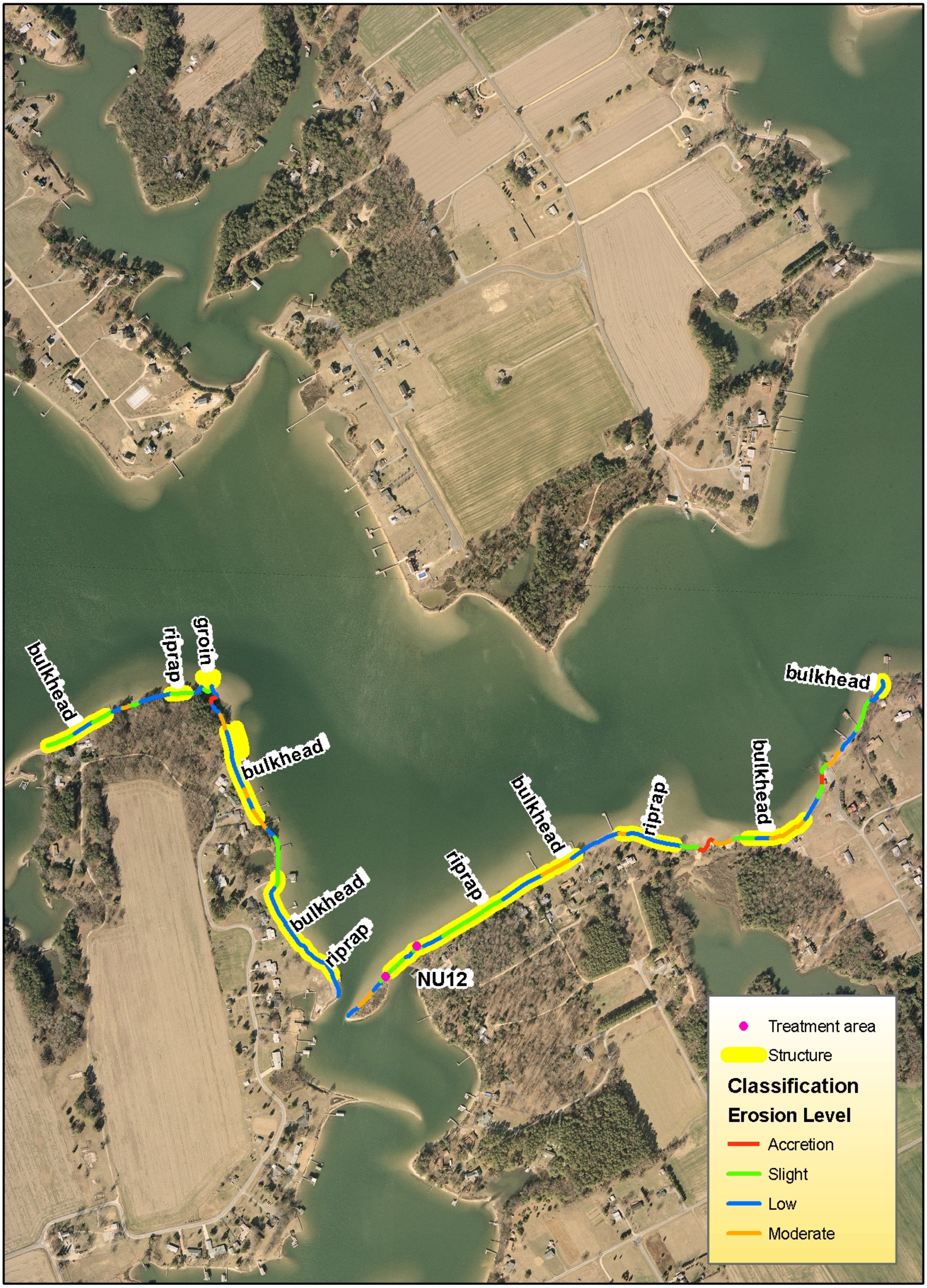
Living Shoreline Assessment - Site GL01



Living Shoreline Assessment - Site ES01

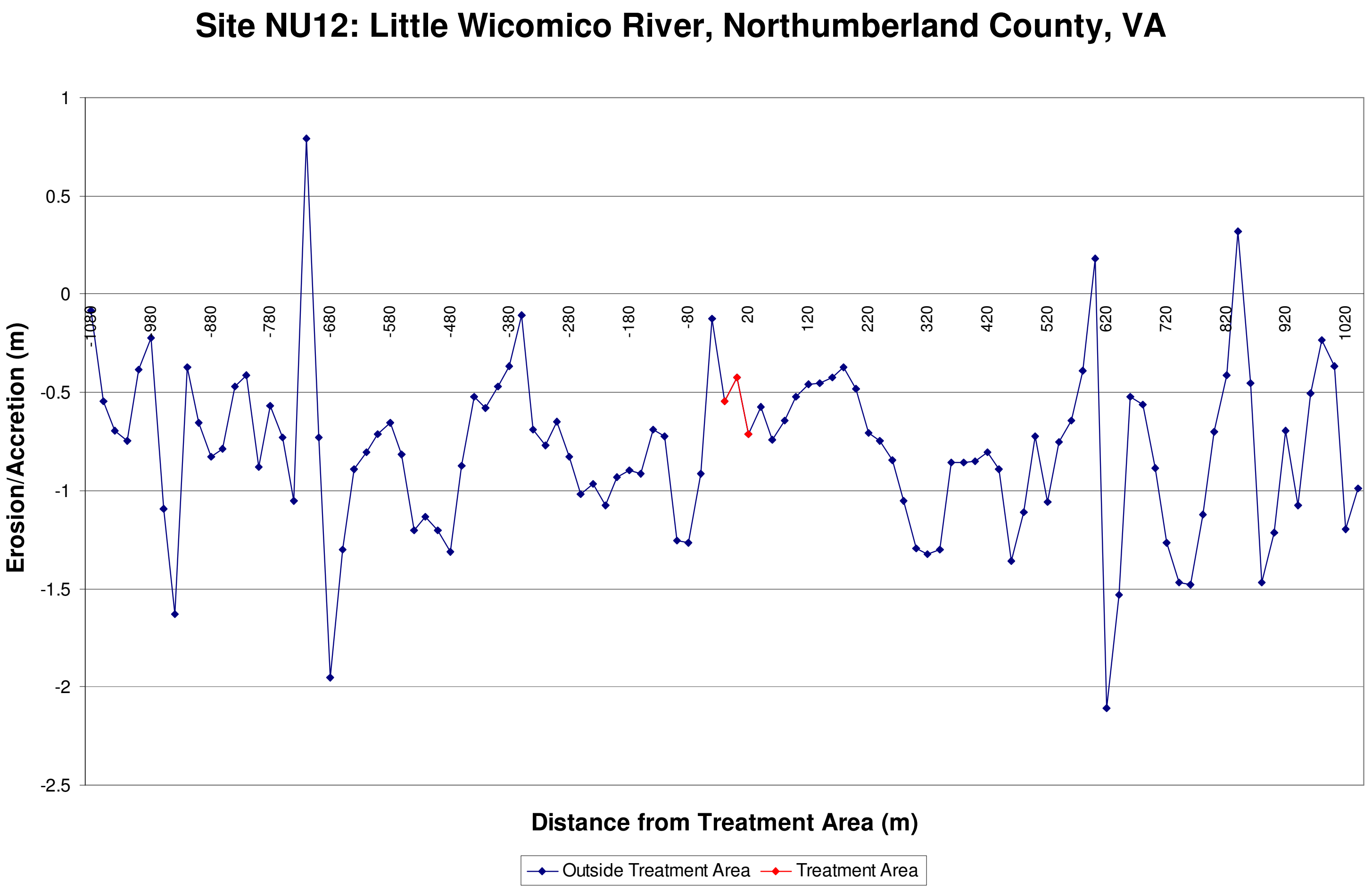


Living Shoreline Assessment - Site NU12



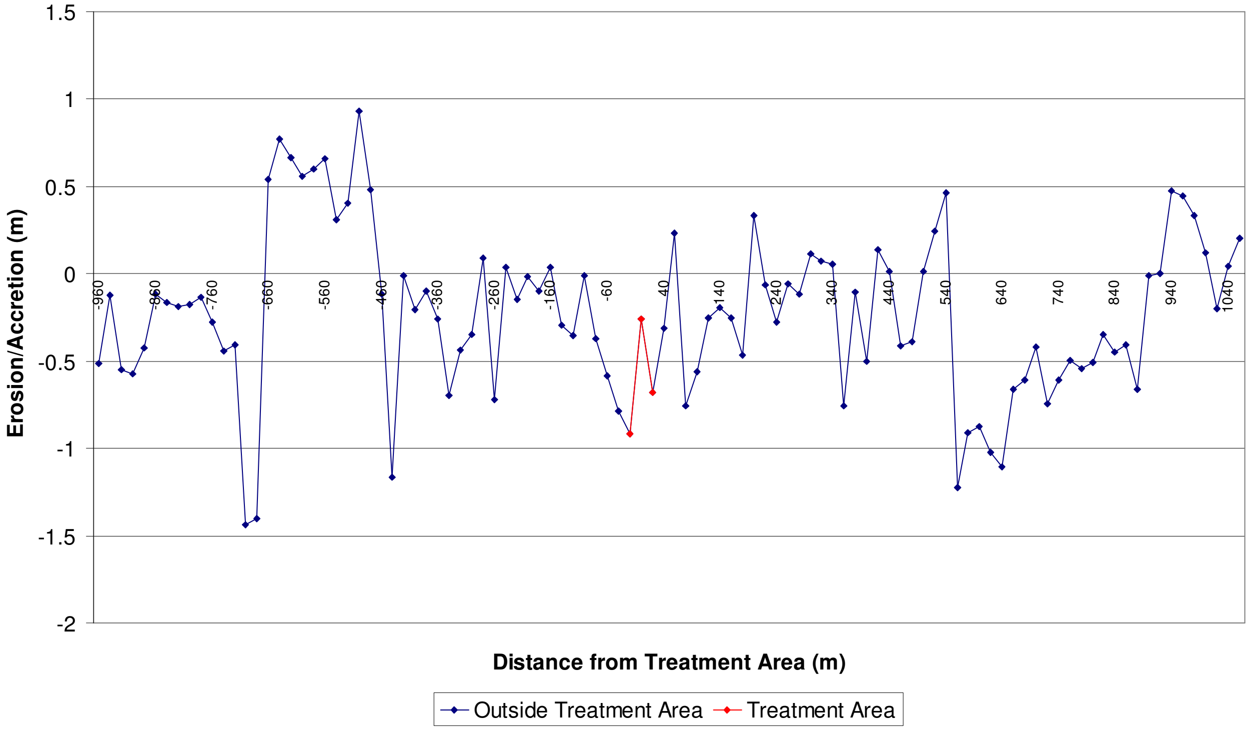
Appendix 2.

Shoreline change rates at treatment areas

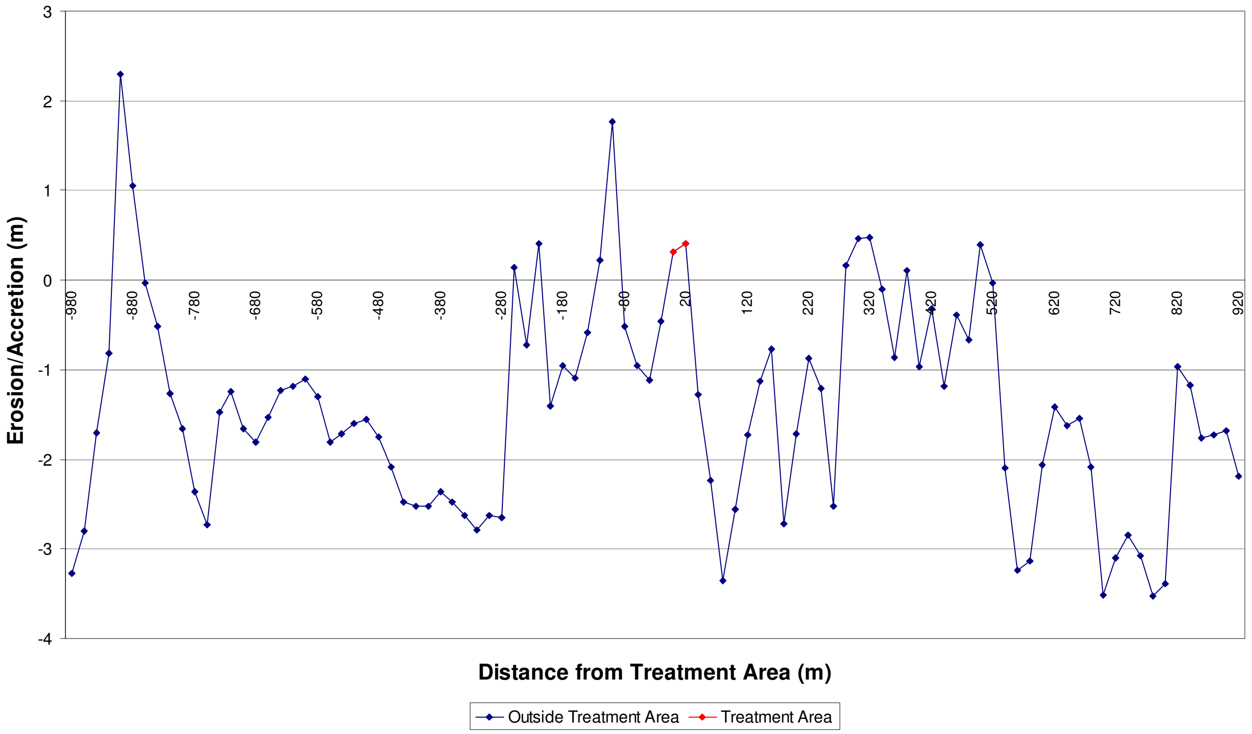


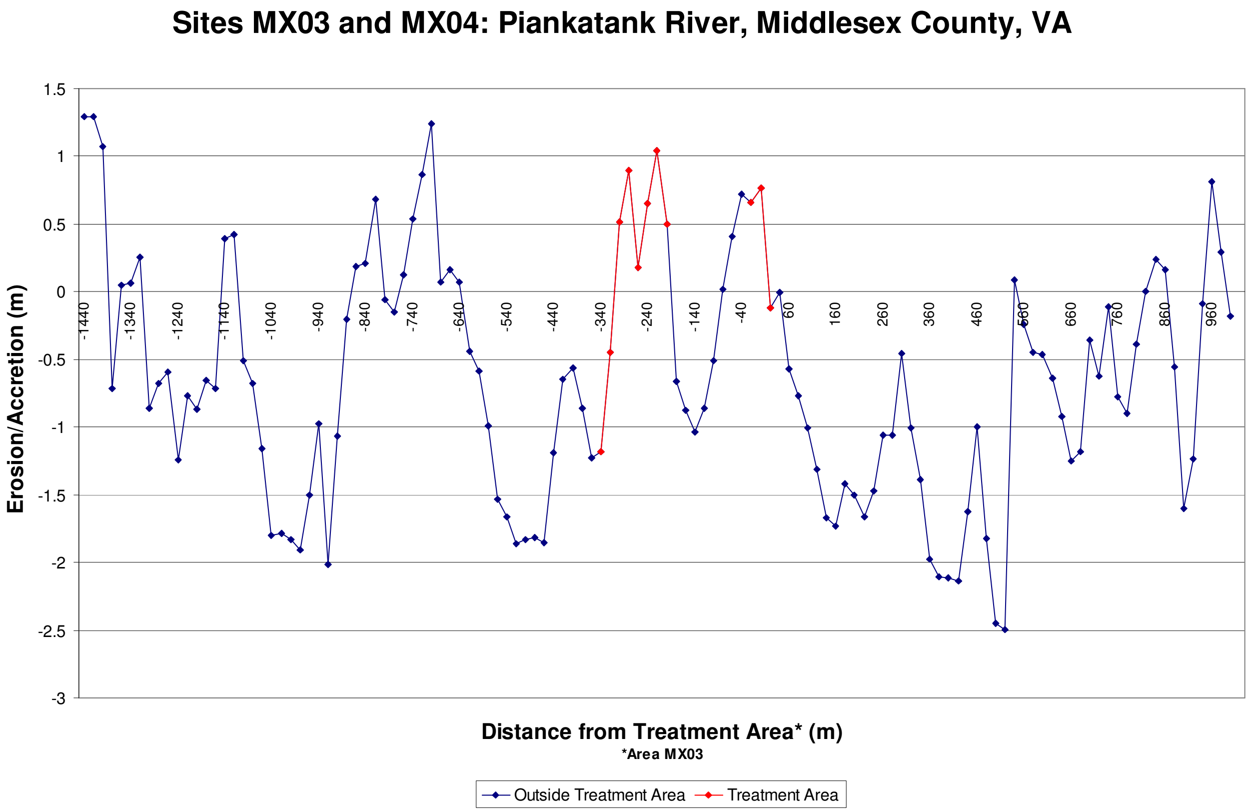
Site NU12: Little Wicomico River, Northumberland County, VA

Site NU10: Prentice Creek, Lancaster County, VA

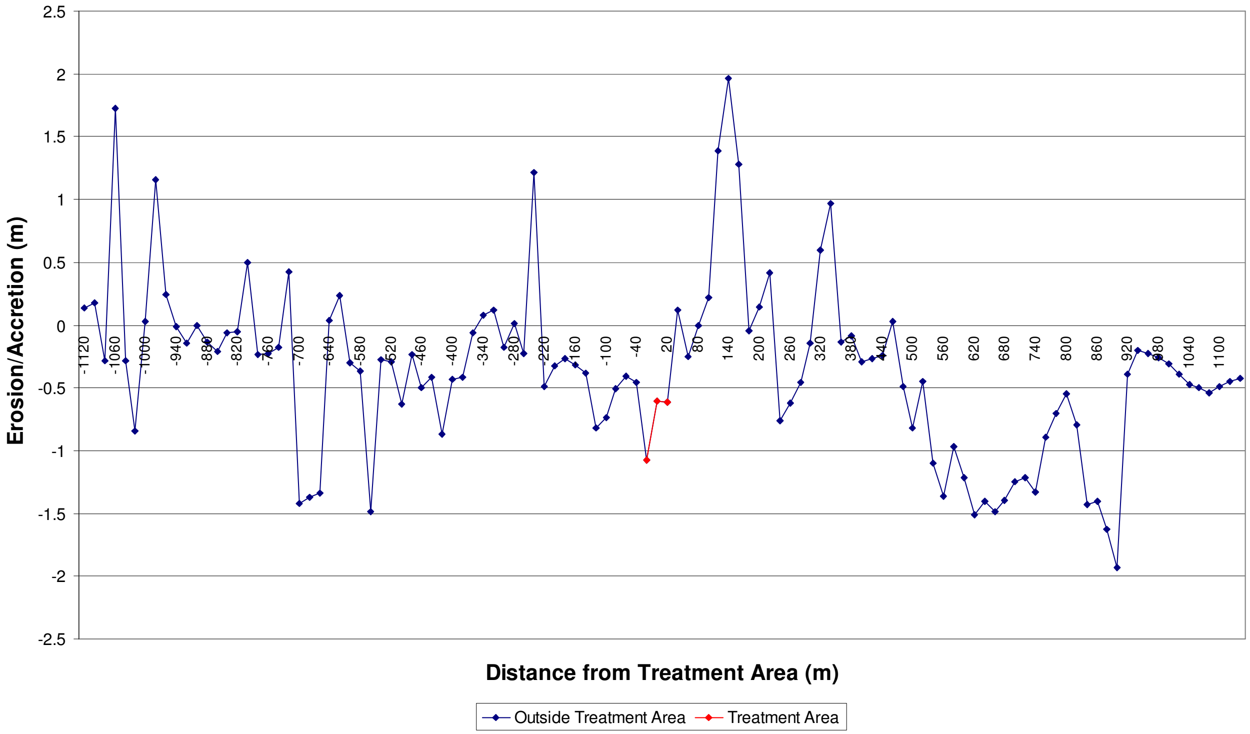


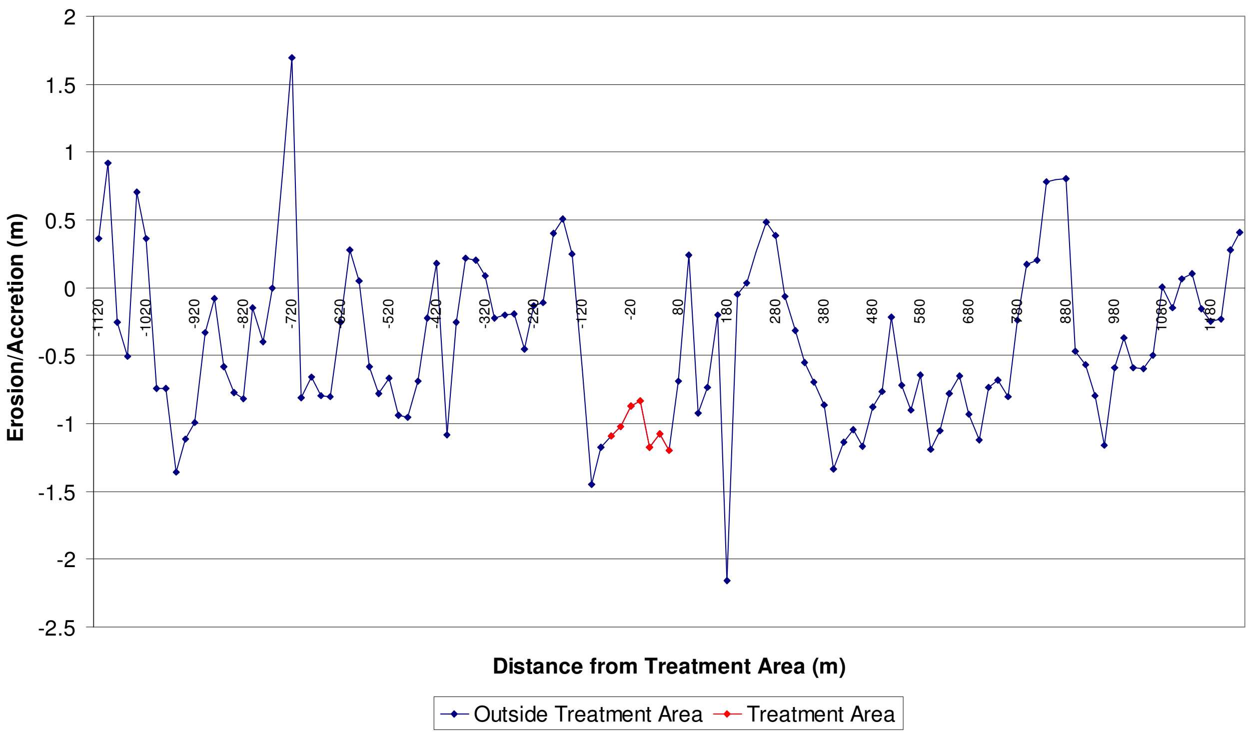
Site MX05: Rappahannock River, Middlesex County, VA



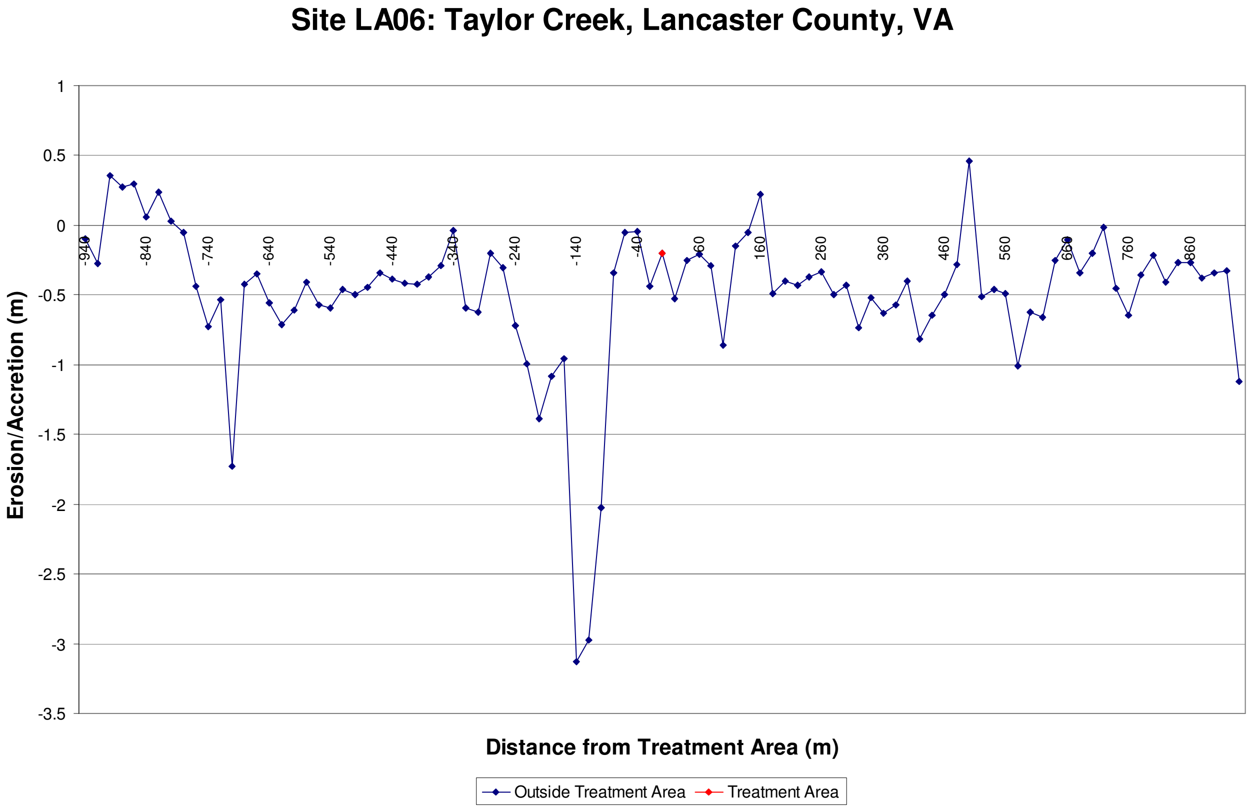

Sites MX03 and MX04: Piankatank River, Middlesex County, VA
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
Erosion/Accretion (m)
-1440
-1340
-1240
-1140
-1040
-940
-840
-740
-640
-540
-440
-340
-240
-140
-40
60
160
260
360
460
560
660
760
860
960
Distance from Treatment Area* (m)
*Area MX03
Outside Treatment Area
Treatment Area

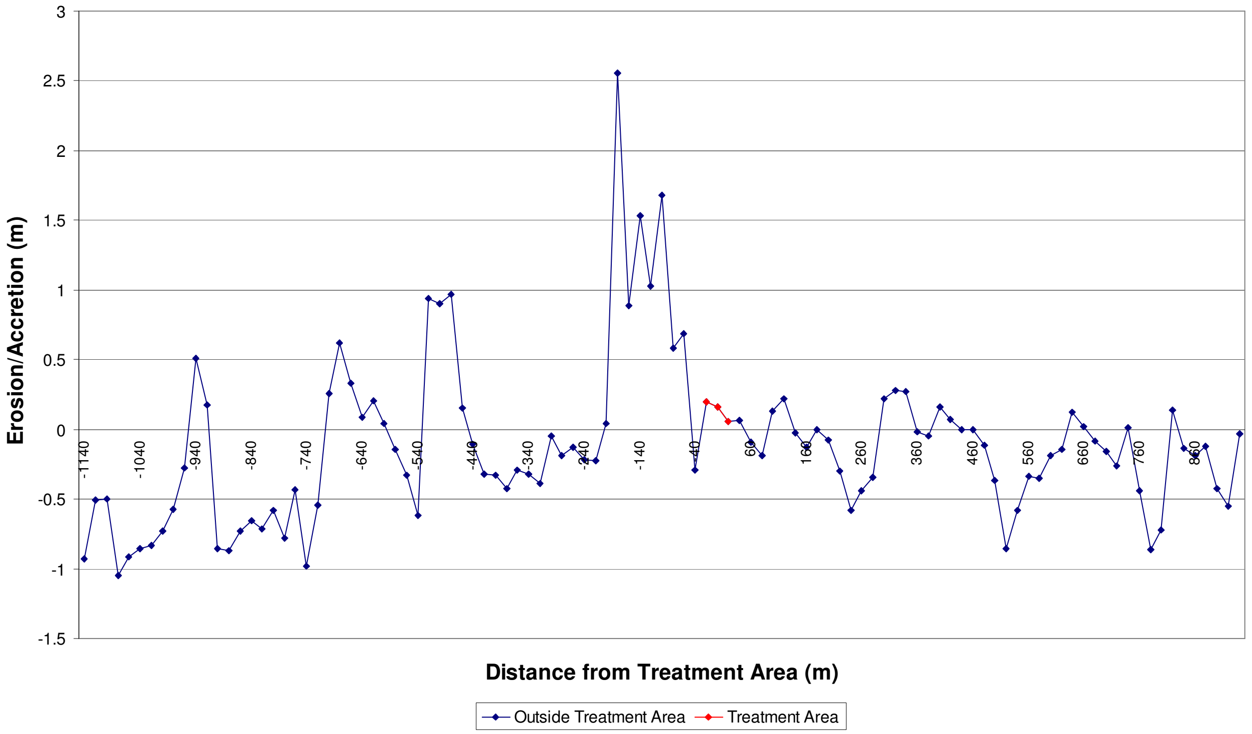
Site MX02: Broad Creek, Middlesex County, VA



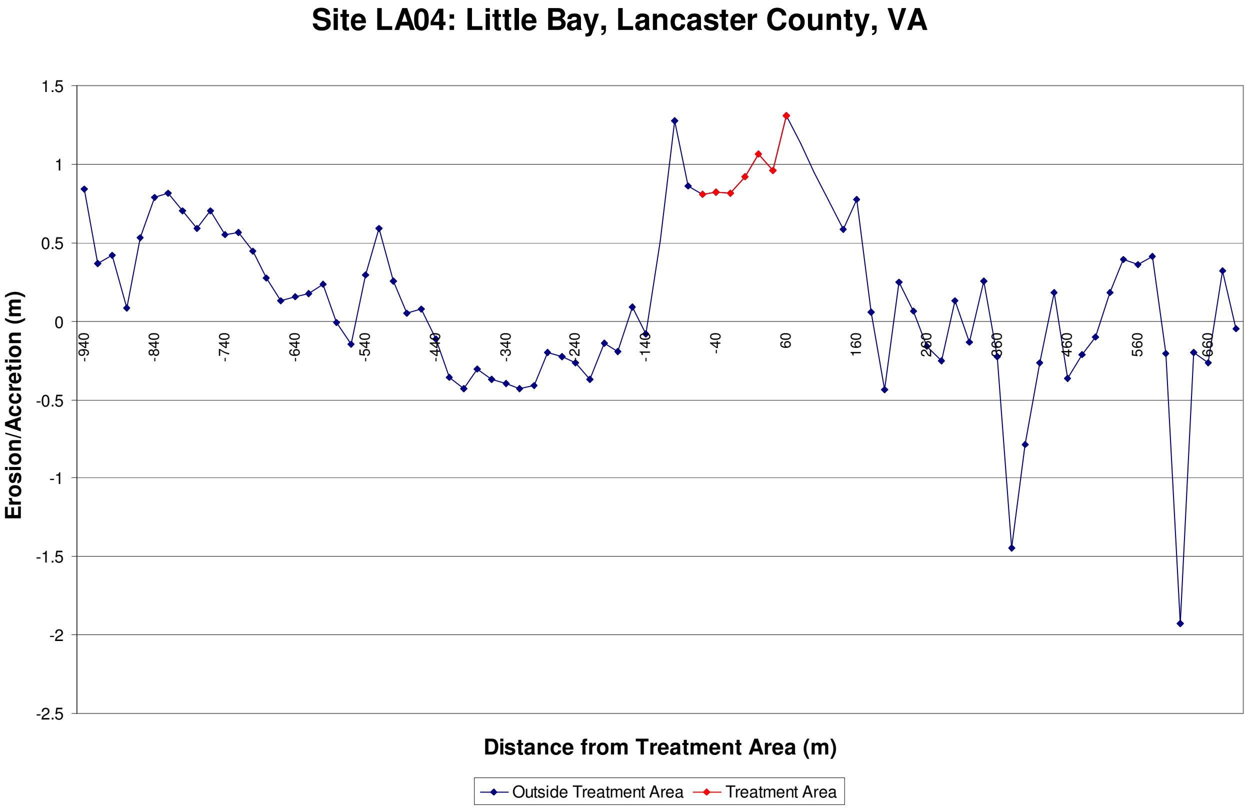


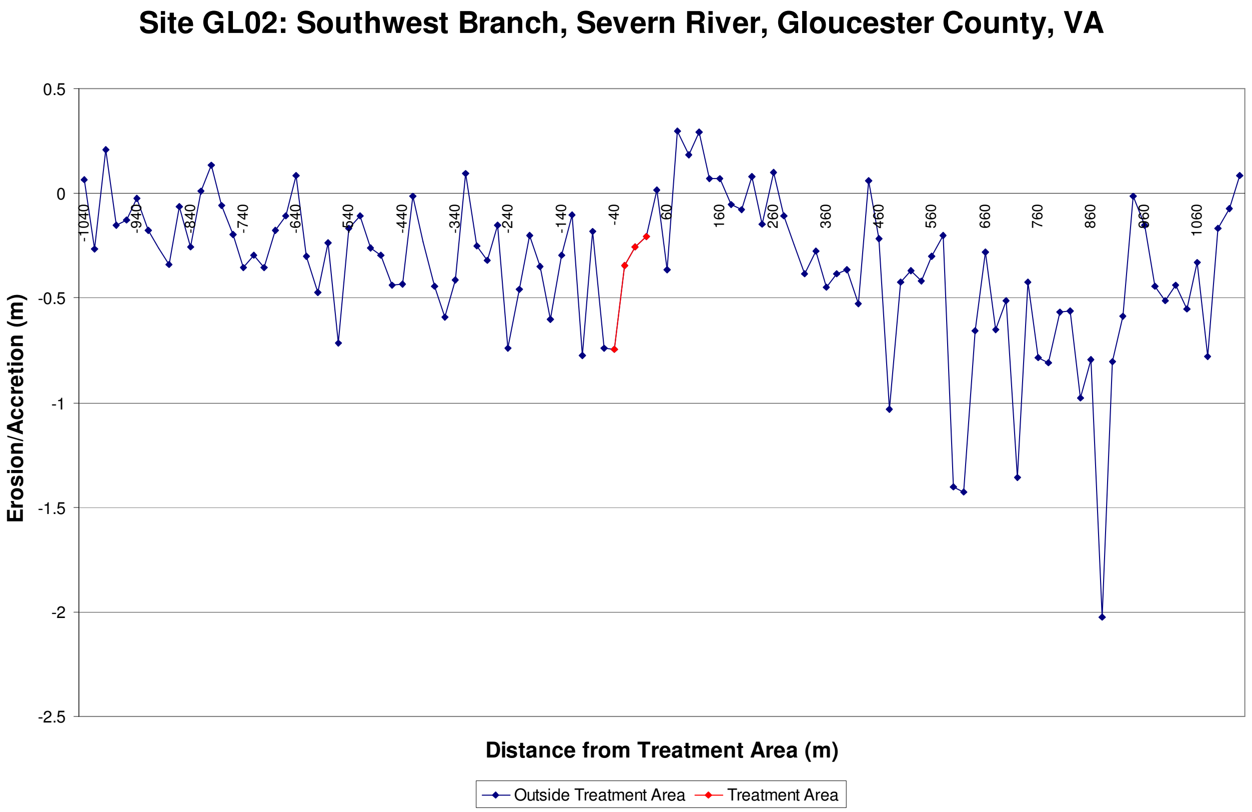
Site MX01: Sturgeon Creek, Middlesex County, VA

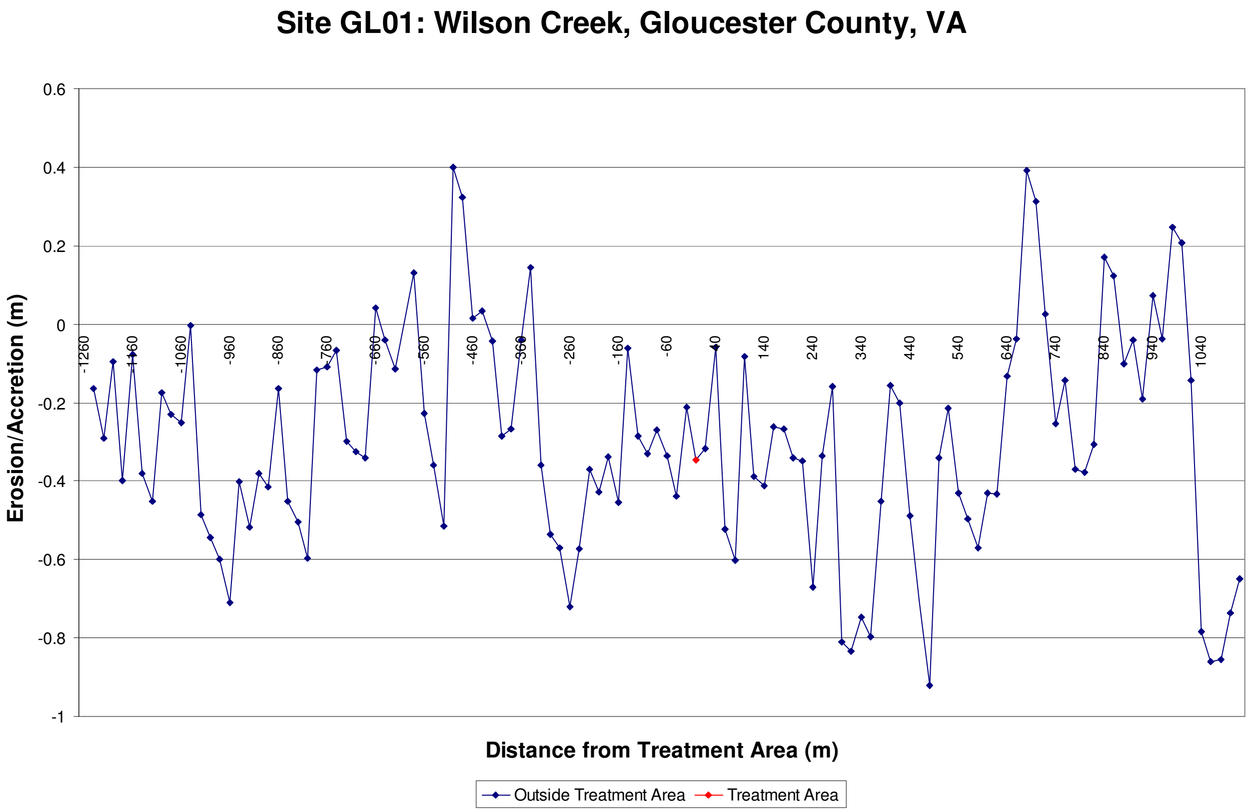

Site LA06: Taylor Creek, Lancaster County, VA
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
Erosion/Accretion (m)
-940
-840
-740
-640
-540
-440
-340
-240
-140
-40
60
160
260
360
460
560
660
760
860
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area



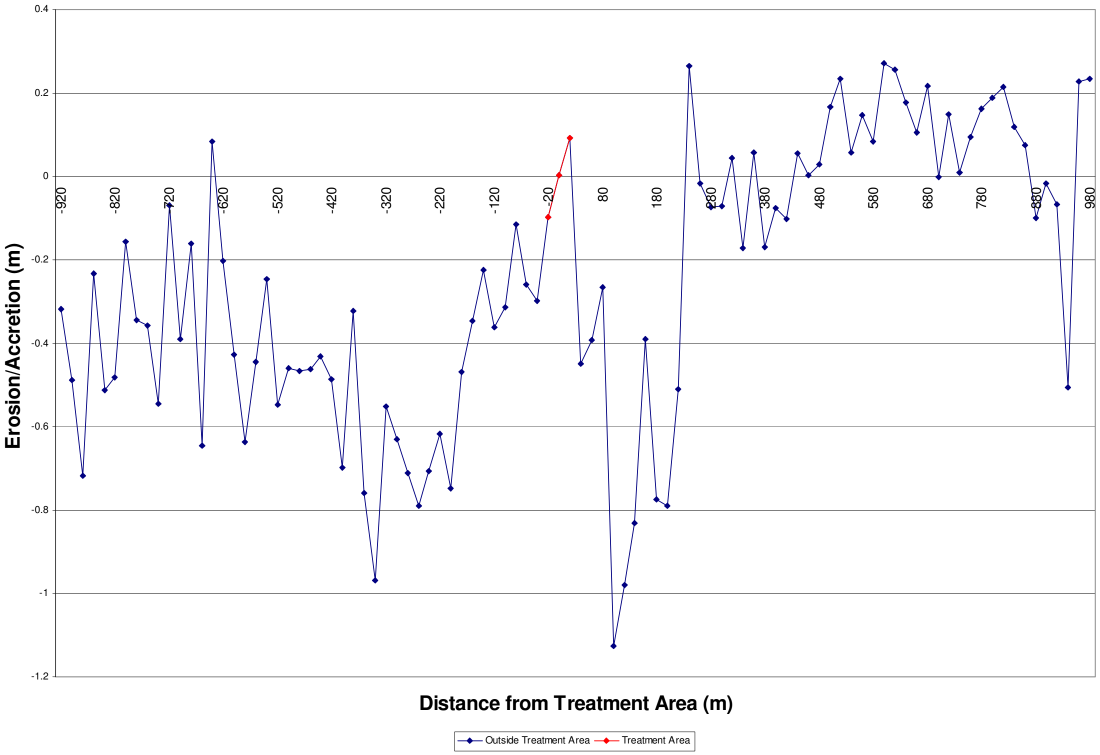
Site LA05: Antipoison Creek, Lancaster County, Virginia

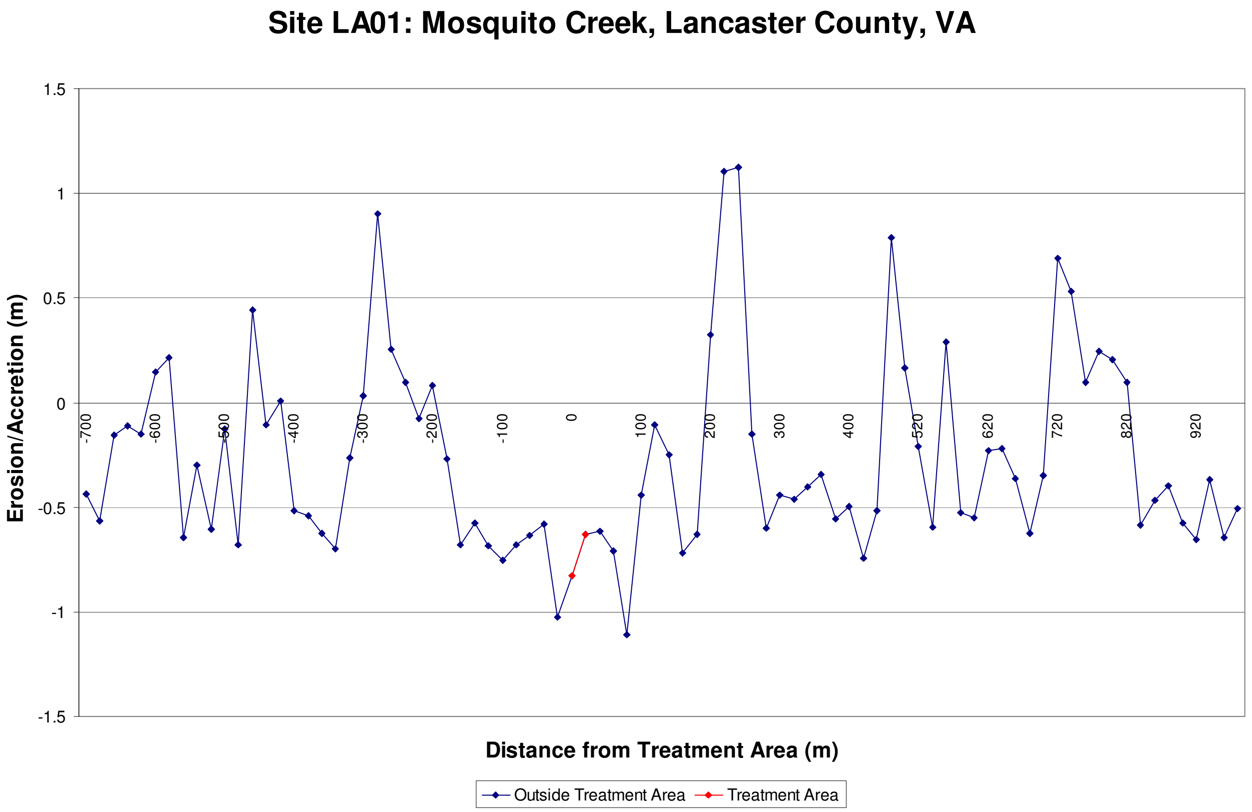

Site LA04: Little Bay, Lancaster County, VA
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Erosion/Accretion (m)
-940
-840
-740
-640
-540
-440
-340
-240
-140
-40
60
160
260
360
460
560
660
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area


Site GL02: Southwest Branch, Severn River, Gloucester County, VA
Erosion/Accretion (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-1040
-940
-840
-740
-640
-540
-440
-340
-240
-140
-40
60
160
260
360
460
560
660
760
860
960
1060
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area

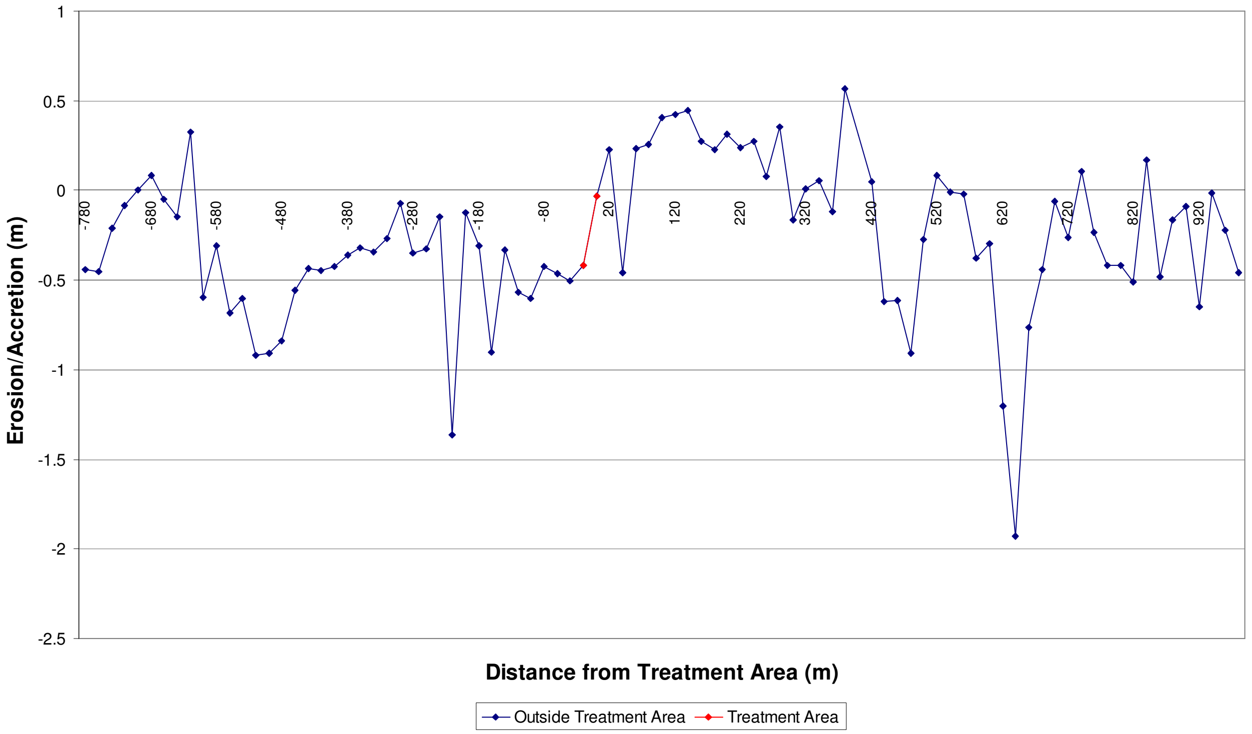

Site GL01: Wilson Creek, Gloucester County, VA
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Erosion/Accretion (m)
-1260
-1160
-1060
-960
-860
-760
-660
-560
-460
-360
-260
-160
-60
40
140
240
340
440
540
640
740
840
940
1040
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area

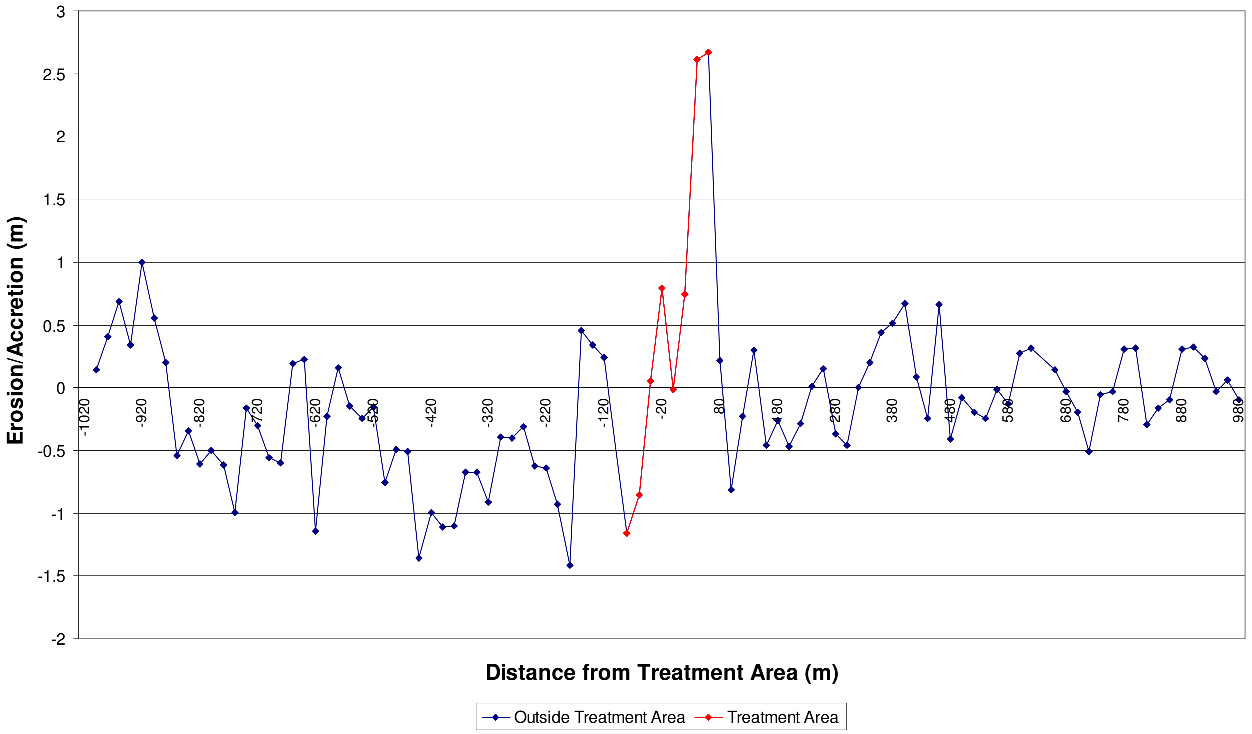
Site ESO1: Piscataway Creek, Essex County, VA




Site LA01: Mosquito Creek, Lancaster County, VA
Erosion/Accretion (m)
1.5
1
0.5
0
-0.5
-1
-1.5
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
520
620
720
820
920
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area

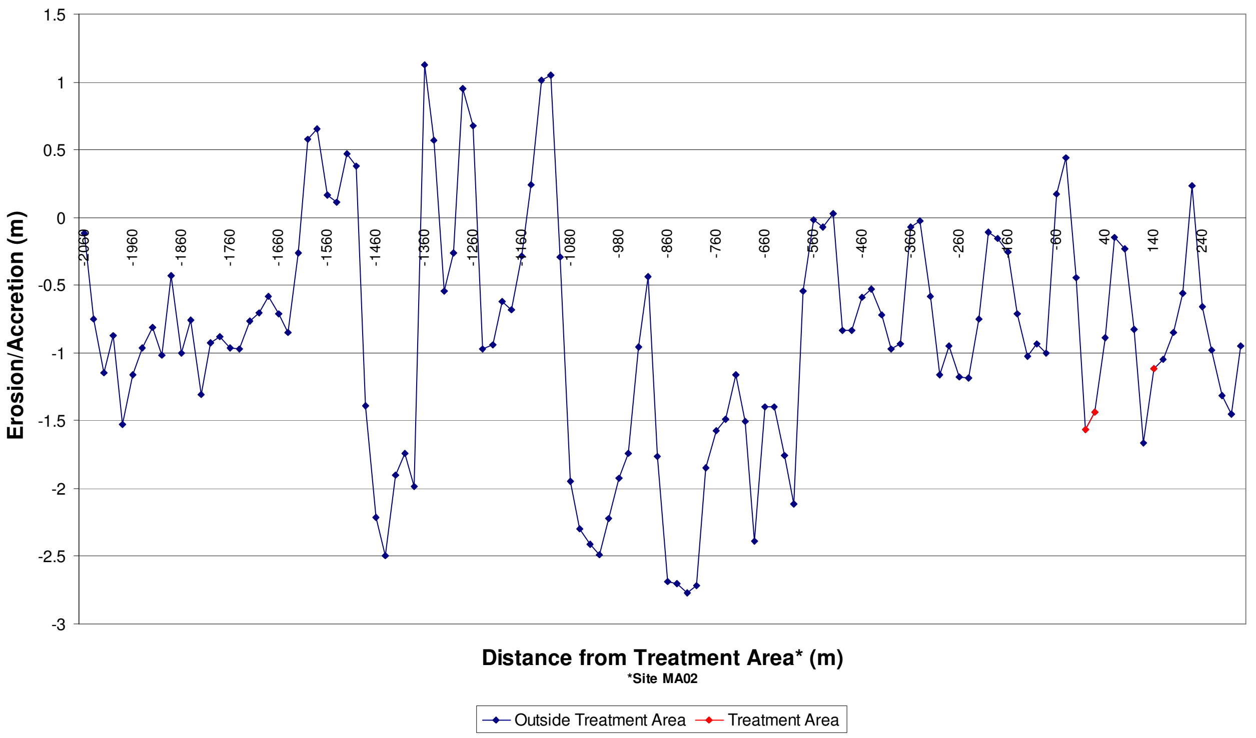
Site LA03: Horsepen Cove, Lancaster County, VA

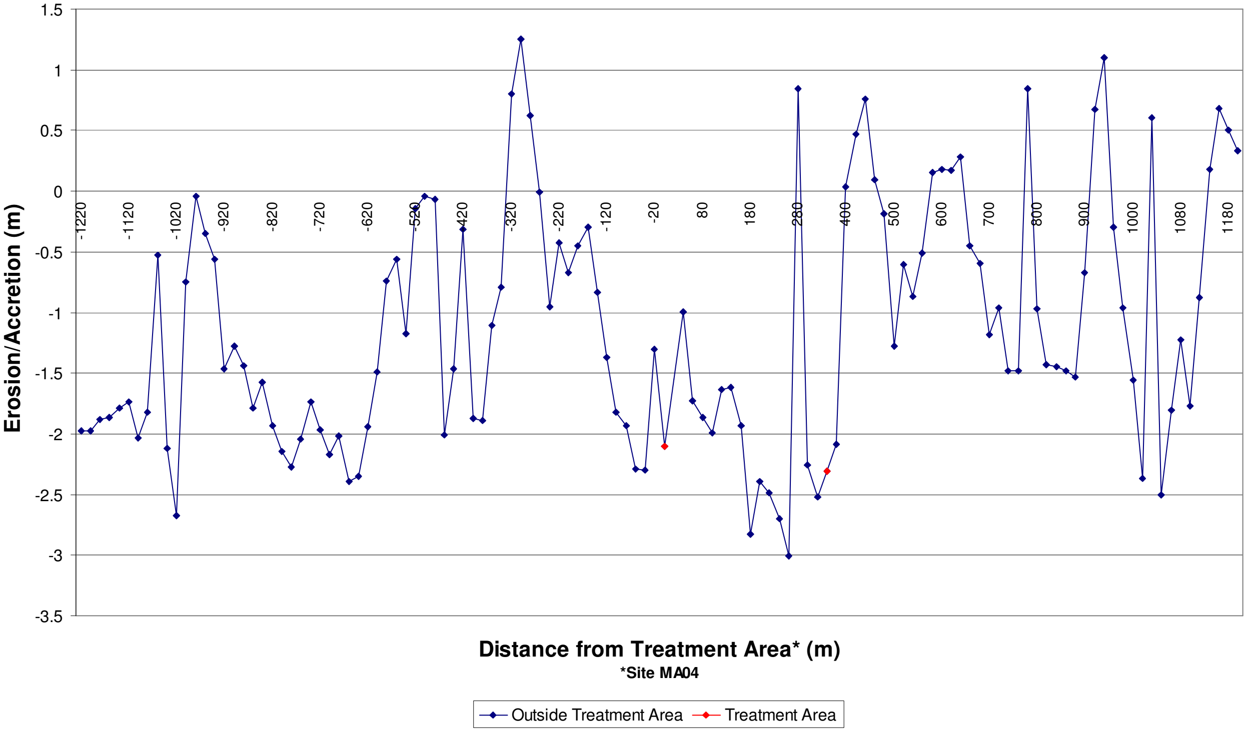




Site LA07: Windmill Point Creek, Lancaster County, VA

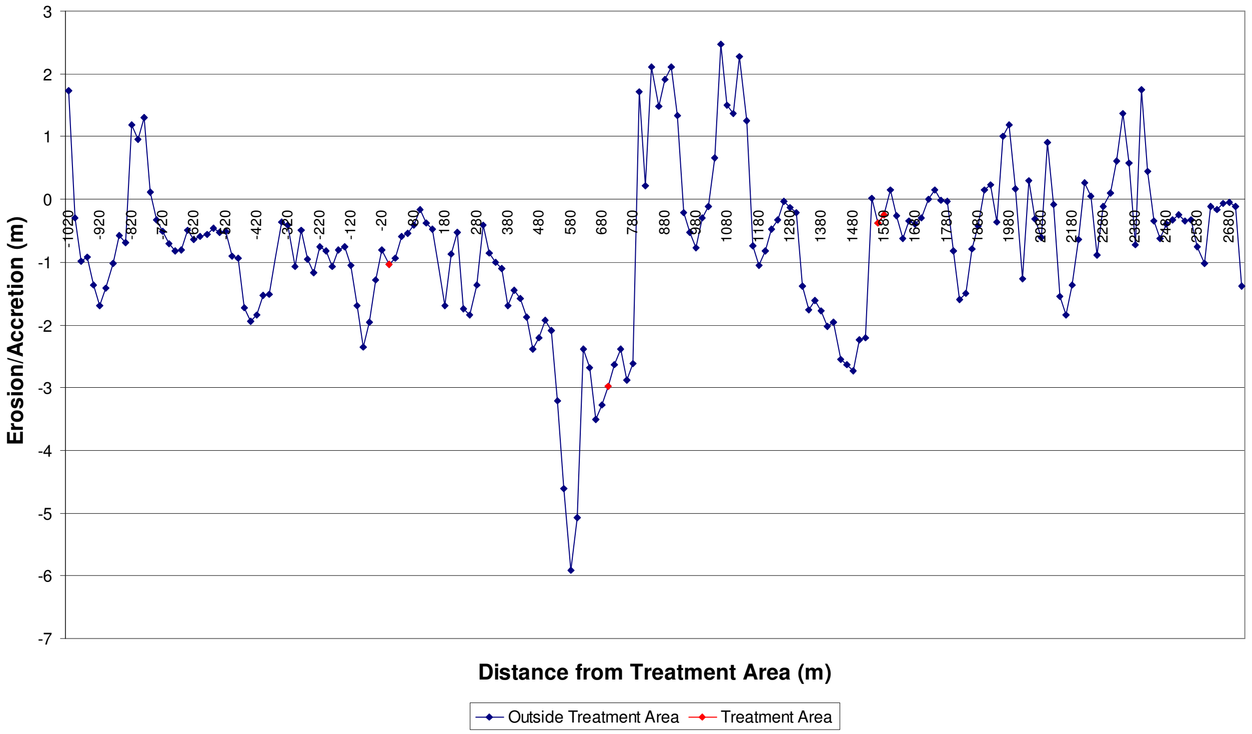
Sites MA01 & MA02: Cobbs Creek, Mathews County, VA



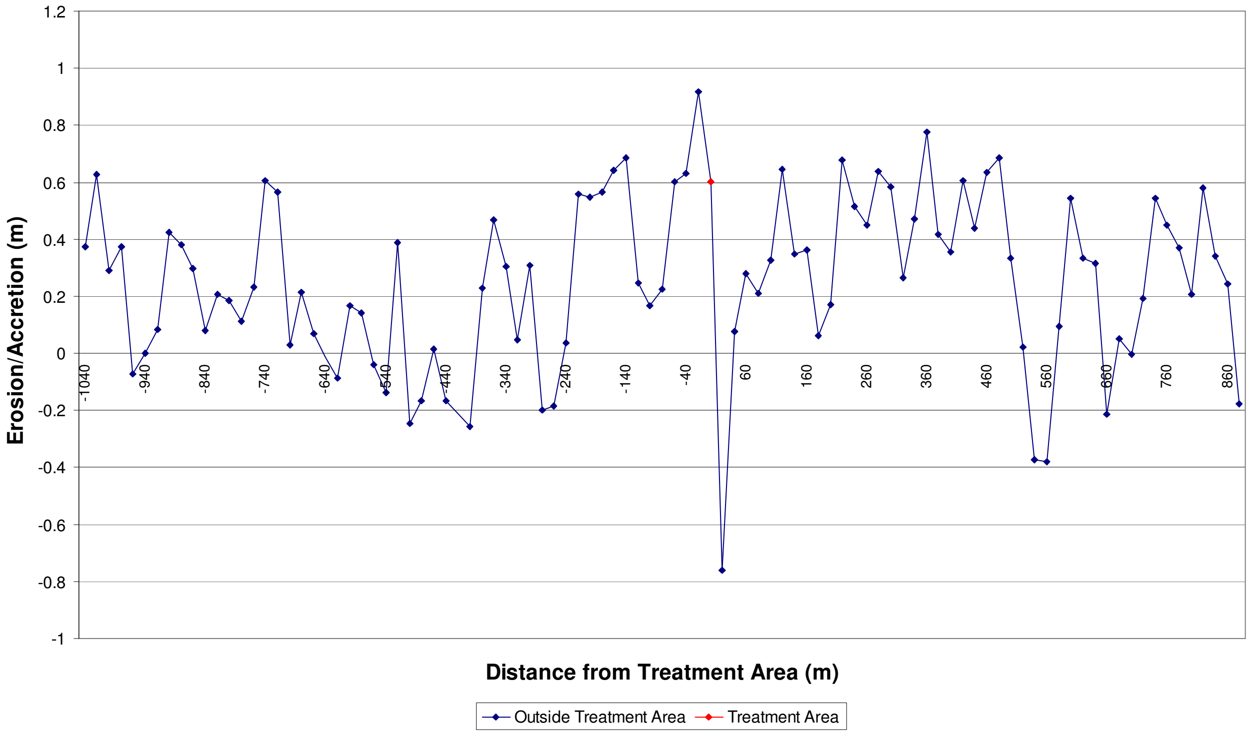


Sites MA03 & MA04: Milford Haven, Mathews County, VA

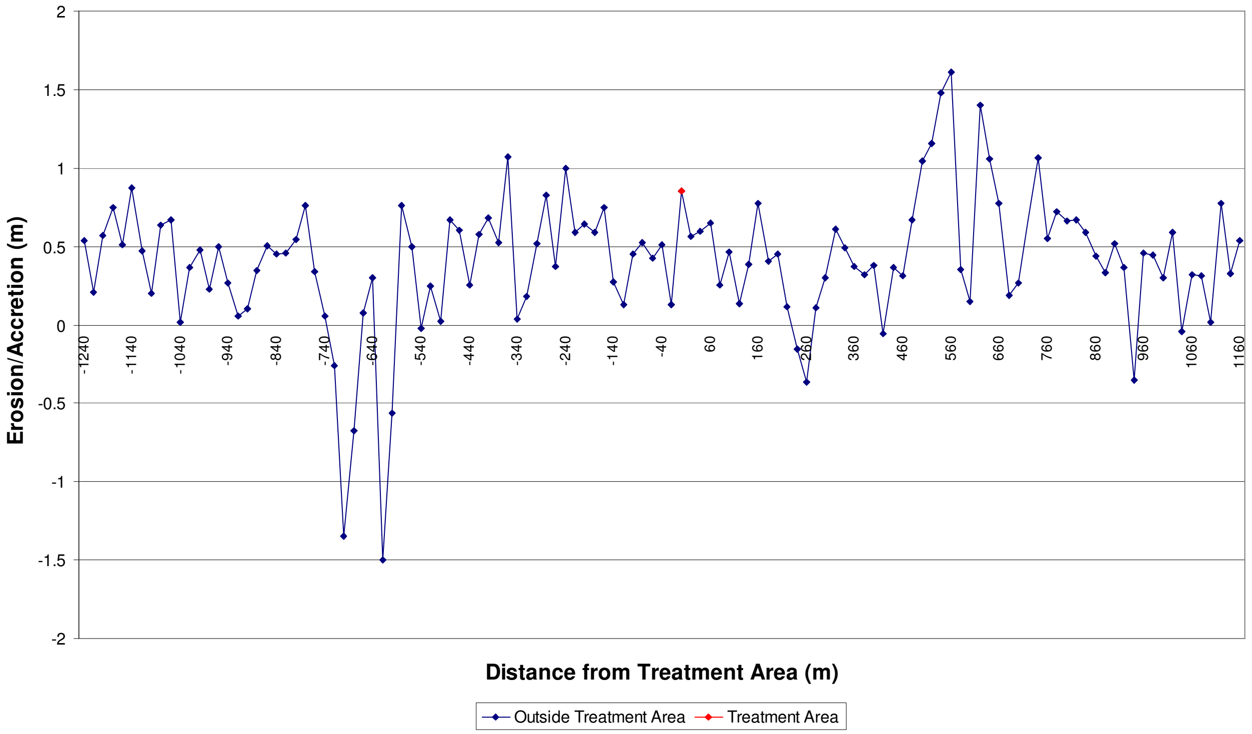
Sites MA05, MA06 & MA09: East River, Mathews County, VA

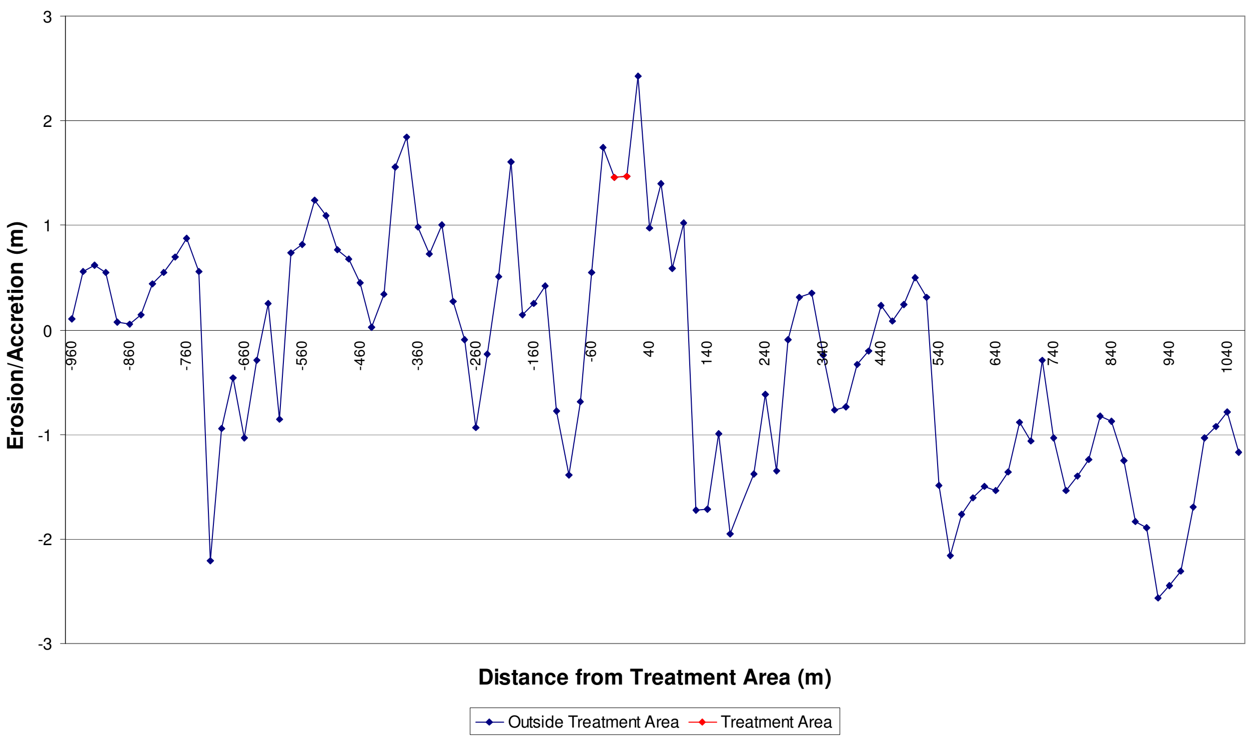


Site MA07: North River, Mathews County, VA

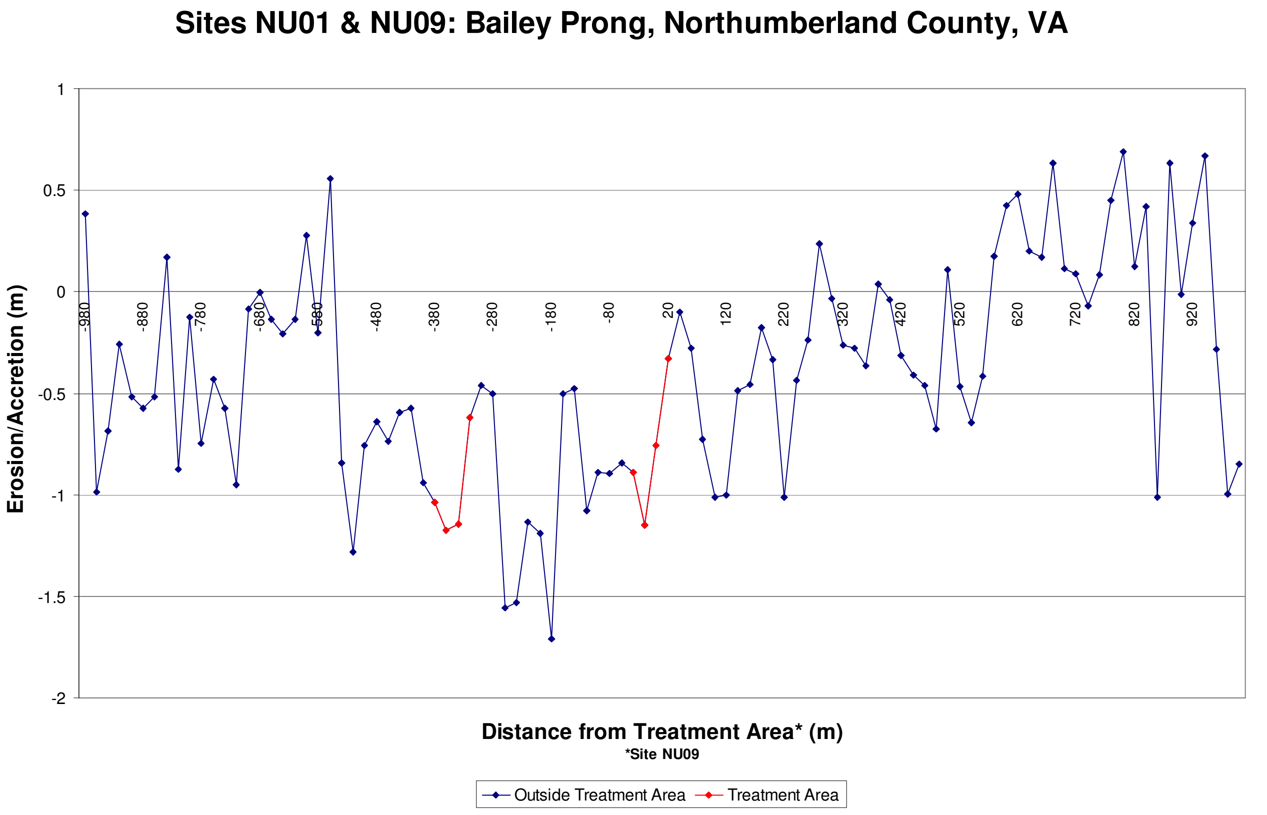


Site MA08: North River, Mathews County, VA

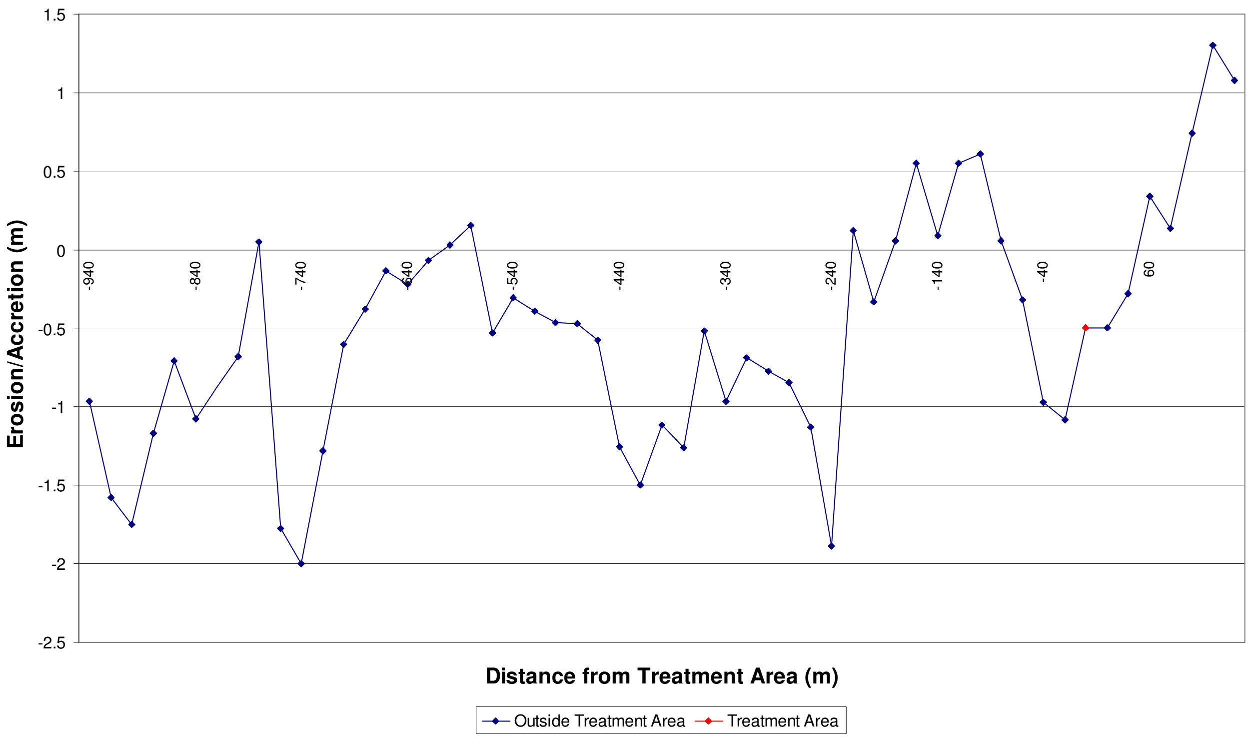




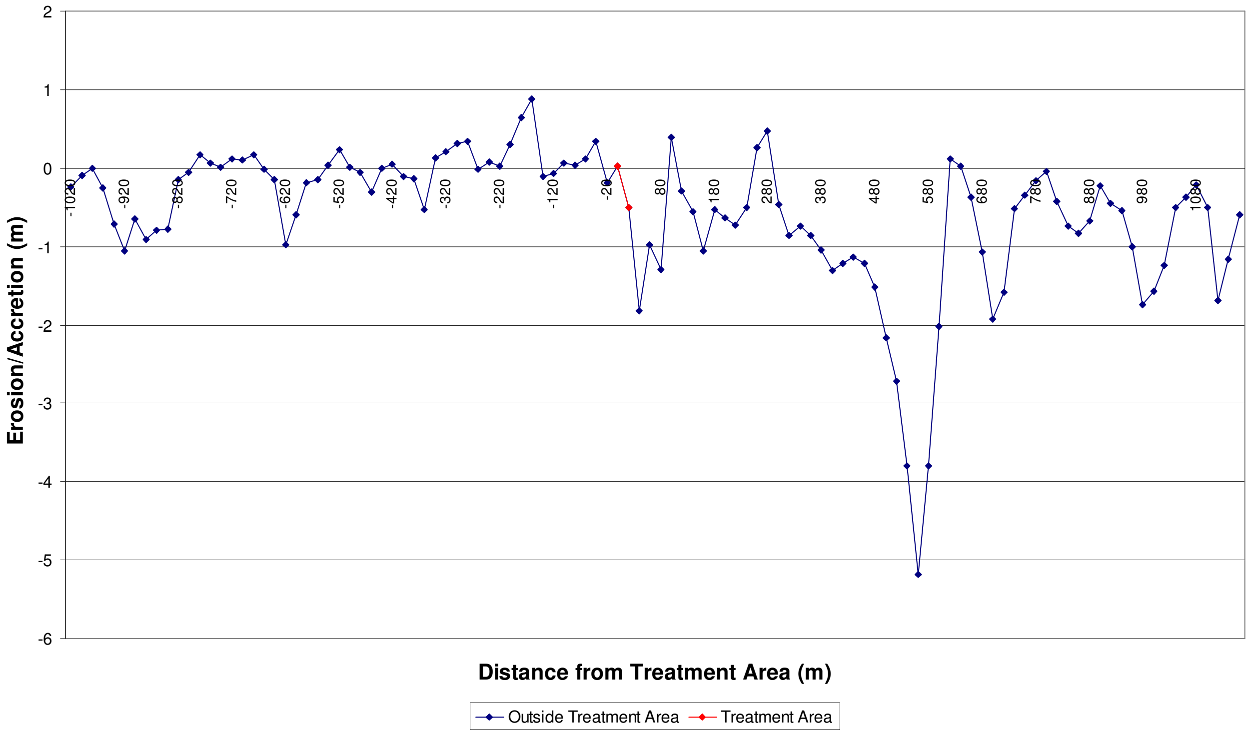
Site MA10: East River, Mathews County, VA

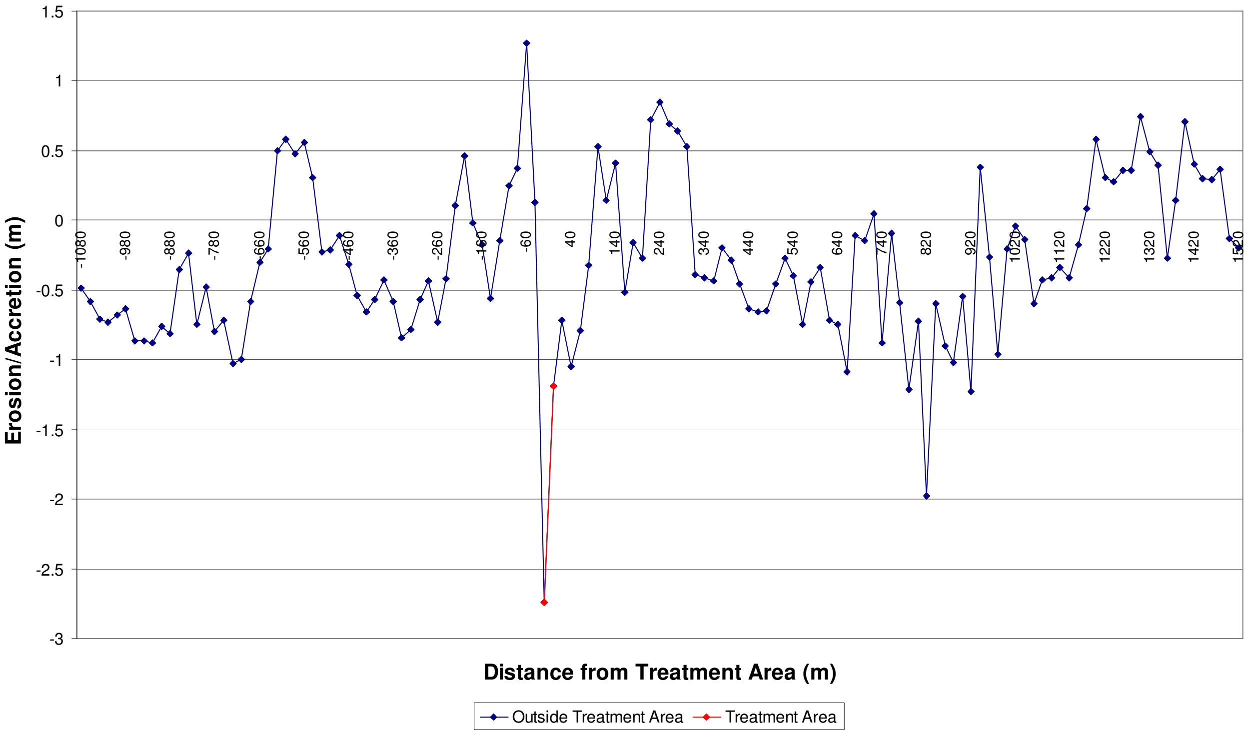

Sites NU01 & NU09: Bailey Prong, Northumberland County, VA
Erosion/Accretion (m)
1
0.5
0
-0.5
-1
-1.5
-2
-980
-880
-780
-680
-580
-480
-380
-280
-180
-80
20
120
220
320
420
520
620
720
820
920
Distance from Treatment Area* (m)
*Site NU09
Outside Treatment Area
Treatment Area

Site NU02: Bailey Prong, Northumberland County, VA



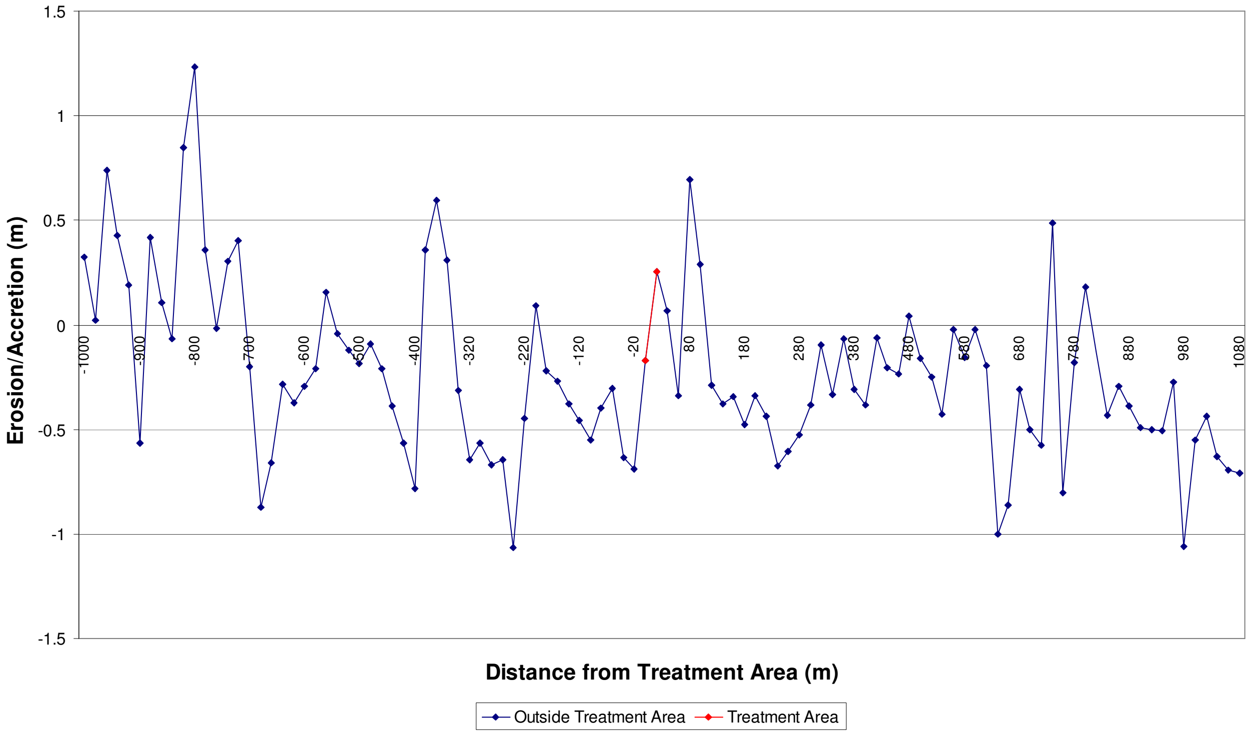
Site NU03: Mill Creek, Northumberland County, VA



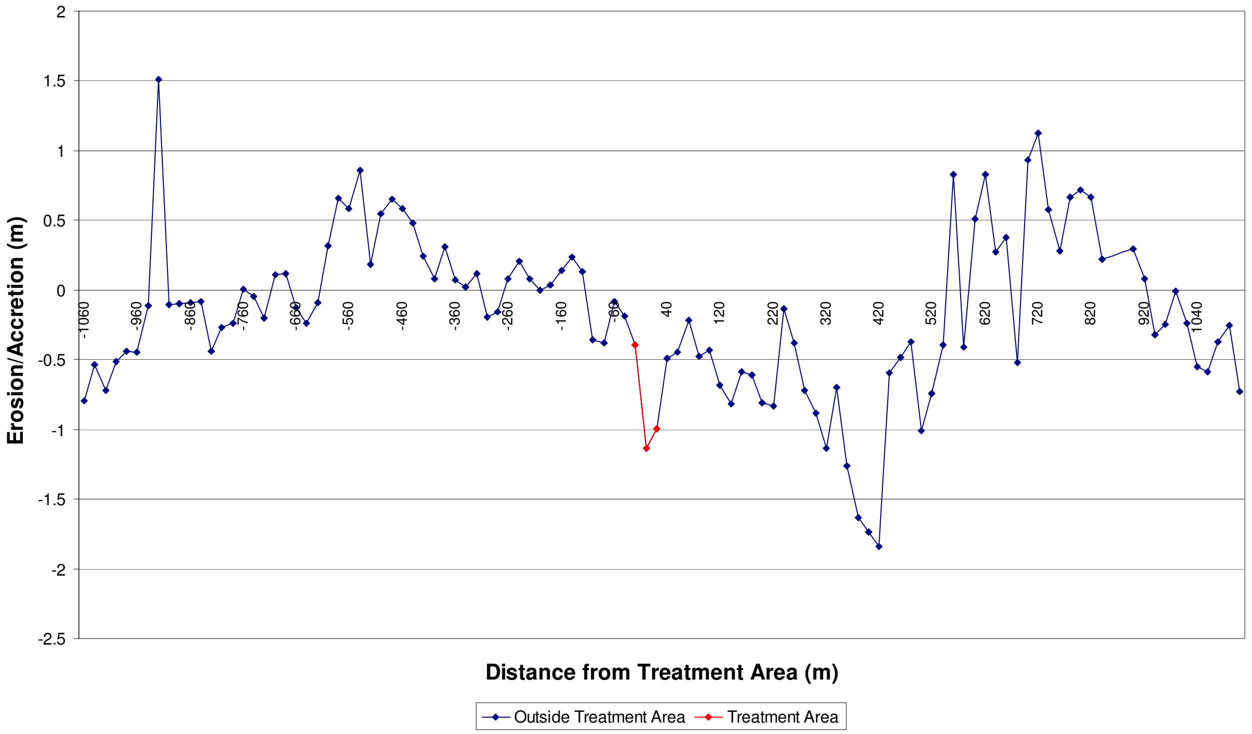


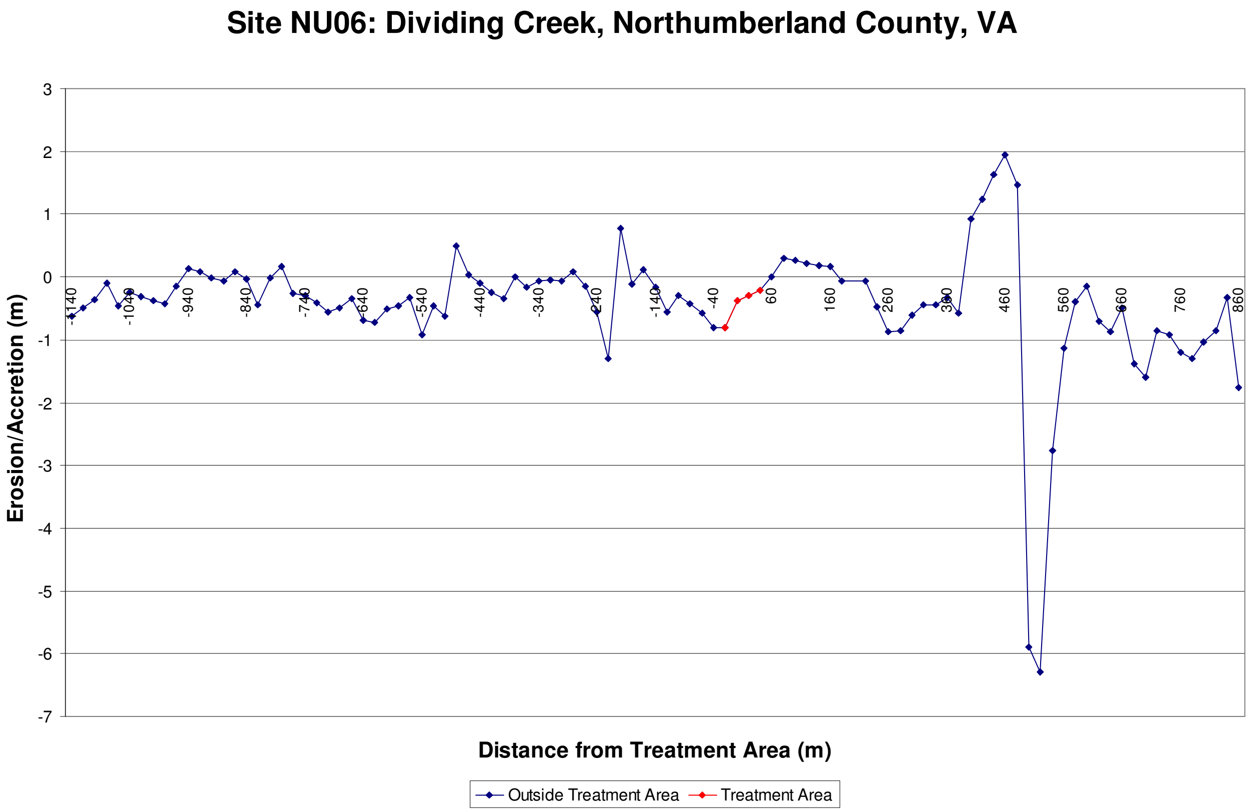
Site NU04: Great Wicomico River, Northumberland County, VA

Site NU07: Bridge Creek, Northumberland County, VA



Site NU08: Cockrell Creek, Northumberland County, VA



Site NU06: Dividing Creek, Northumberland County, VA
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Erosion/Accretion (m)
-1140
-1040
-940
-840
-740
-640
-540
-440
-340
-240
-140
-40
60
160
260
360
460
560
660
760
860
Distance from Treatment Area (m)
Outside Treatment Area
Treatment Area

Appendix 3

Conditional Matrices

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

Suitable with design restrictions

fetch	low	x	x				x	x				x	x				x	x	x	x					x	x	x	x					x	x	x	x				
	moderate			x	x	x			x	x	x			x	x	x					x	x	x	x					x	x	x	x					x	x	x	x
	high																																							
bank erosion	low	x	x	x	x	x											x	x	x	x	x	x	x	x																
	high						x	x	x	x	x														x	x	x	x	x	x	x	x								
	undercut											x	x	x	x	x																	x	x	x	x	x	x	x	x
bathymetry	shallow	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	deep																																							
beach	present		x	x		x		x	x		x		x	x		x		x	x			x	x			x	x			x	x			x	x			x	x	
	absent	x			x		x			x		x			x		x			x	x			x	x			x	x			x	x			x	x			x
marsh	present > 15 ft																																							
	present	x	x		x	x	x	x		x	x	x	x		x	x	x	x			x	x			x	x			x	x			x	x			x	x		
	absent			x					x					x					x	x			x	x			x	x			x	x			x	x			x	x
forest	present																x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	absent	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																								
		3	**3**	**4**	**4**	**4**	**2***	**2***	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**1 or 3****	**1 or 3****	**1 or 4*****	**1 or 4*****	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**

***2 Riparian modifications should be considered in all cases; '2' indicates riparian modifications only with no intertidal or subaqueous encroachment**

**** 1 or 3 Site may be suitable for planted marsh on existing substrate (enhance width of existing marsh) if erosion & forest condition allows or forest condition can be made suitable with riparian modifications; if not, then marsh toe revetment advised to substitute for wider marsh**

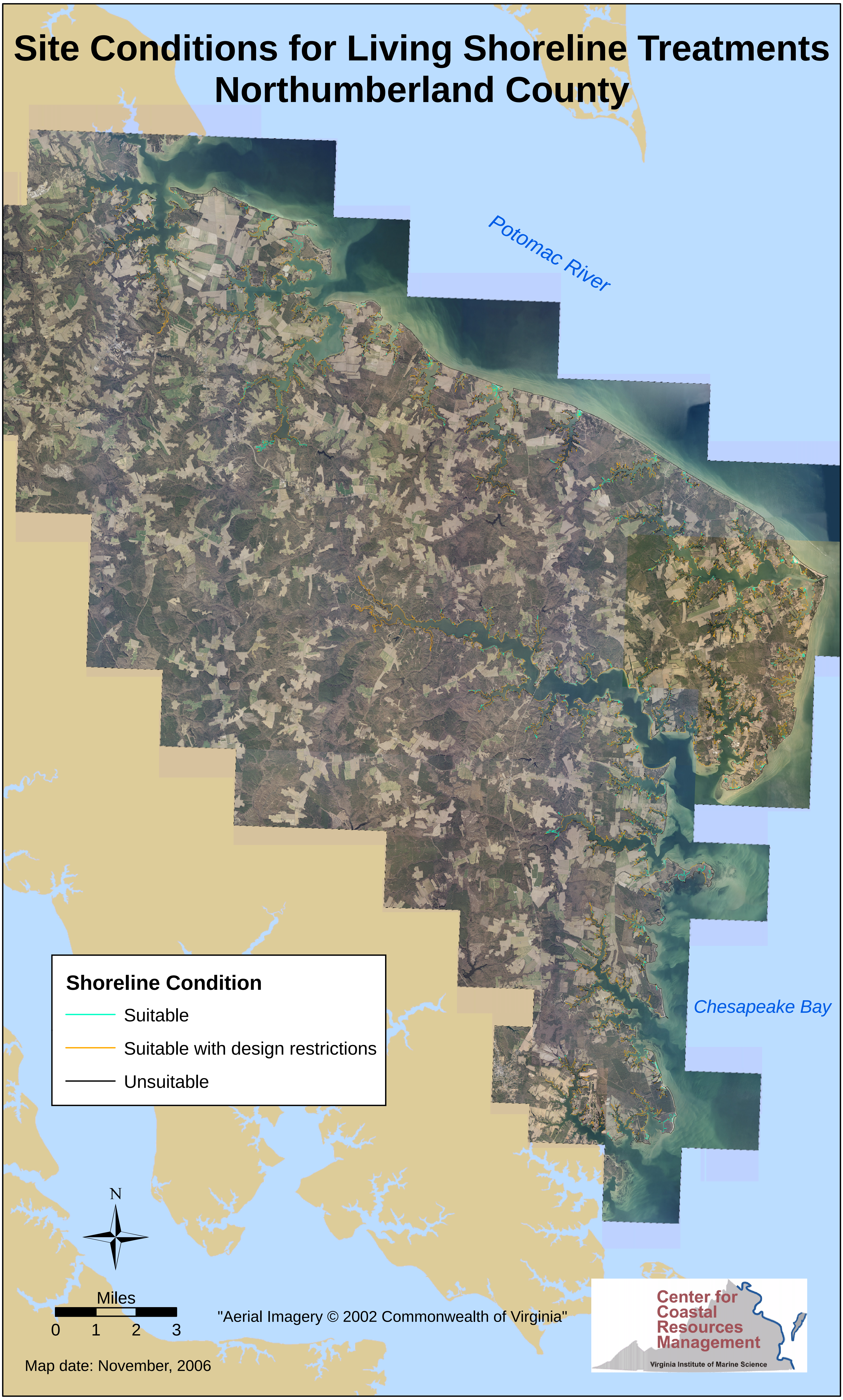
***** 1 or 4 Site may be suitable for planted marsh on existing substrate (create new marsh) if erosion & forest condition allows or forest condition can be made suitable with riparian modifications; if not, then sill advised to create marsh**

1	Planted marsh on existing substrate or minor fill (fiber logs may be included)
2	Riparian modifications = selective tree removal, pruning; bank grading; vegetation restoration
3	Marsh toe revetment = stone structure placed at eroding edge of existing marsh
4	Sill = stone structure with backfill & planted marsh or beach

Appendix 4

Living Shoreline Suitability Model Output

Site Conditions for Living Shoreline Treatments
Northumberland County



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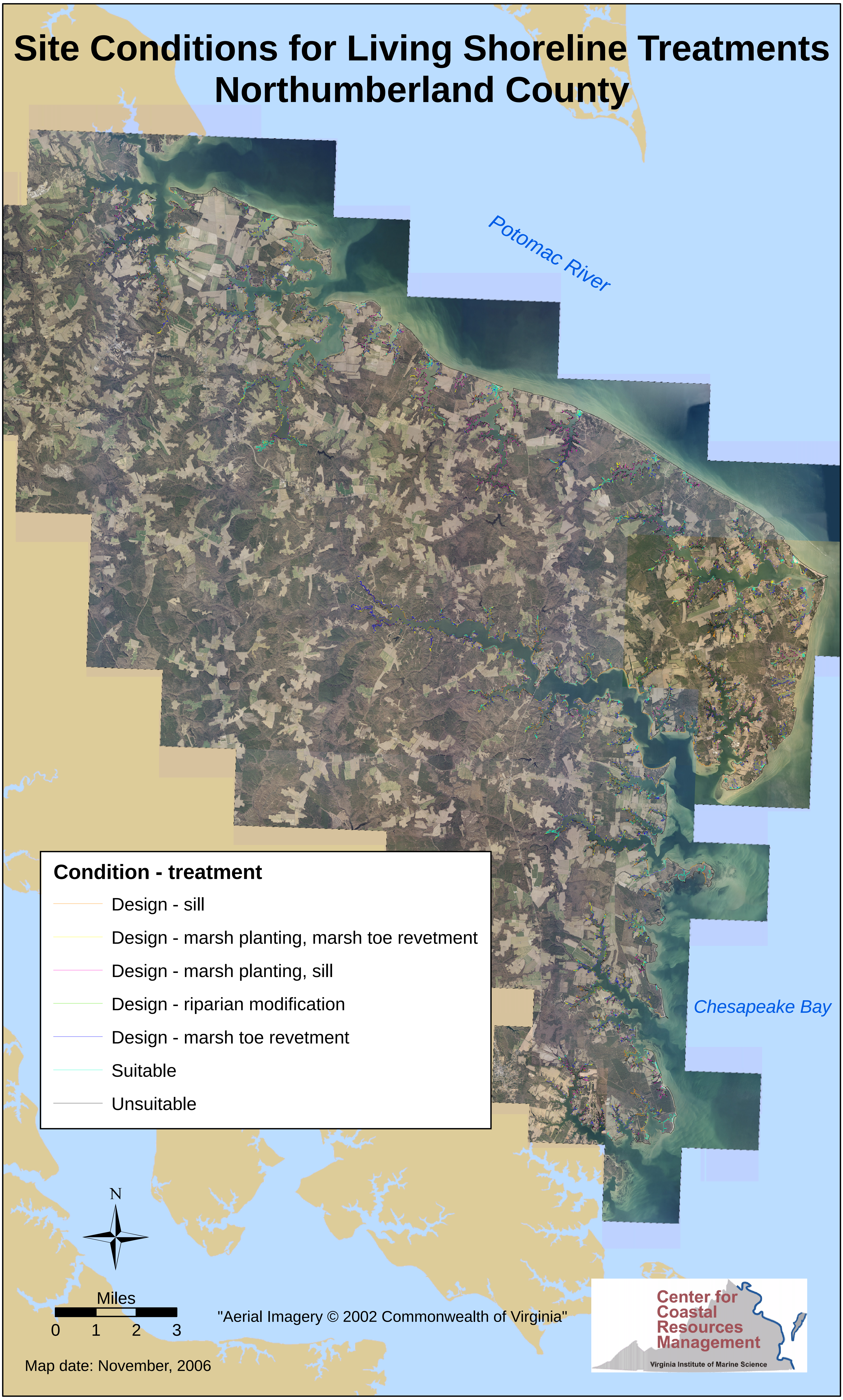
Map date: November, 2006

Center for Coastal Resources Management
Virginia Institute of Marine Science

Site Conditions for Living Shoreline Treatments
Northumberland County



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