

SHELLFISH AQUACULTURE SUITABILITY WITHIN BAYLOR GROUNDS OF THE LOWER RAPPAHANNOCK RIVER

FINAL REPORT TO

VIRGINIA COASTAL ZONE MANAGEMENT PROGRAM
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY
RICHMOND, VIRGINIA

SUBMITTED BY

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This mapping project was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant # NA07NOS4190178 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended.

The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.

November, 2008



ABSTRACT

Should the Commonwealth of Virginia ever consider a regulated expansion of the aquaculture industry to public Baylor ground, timely information regarding the productivity of these grounds and the ability to support aquaculture would be highly desirable information. In this scenario, public bottom will be opened to private shellfish growers in the Commonwealth under what will likely be a tightly monitored regulation. The demise in productivity of natural oyster beds within Baylor Grounds is well known. However, there is no comprehensive resource that addresses whether Baylor Grounds would be suitable for aquaculture.

This study uses Geographic Information Systems (GIS) to model suitable shellfish growing areas within the public Baylor Grounds. The model considers basic physical and biological conditions necessary for aquaculture success, potential ecological use conflicts, and the impacts that current land use has on suitable growing areas. The study uses data available from federal, state, and local government sources to derive salinity, bathymetry, submerged aquatic vegetation (SAV) distribution, water quality, oyster rock, and land use. A classification is scaled to reflect current conditions. The project focuses on Baylor Ground within the Lower Rappahannock River only. Results do not reflect conditions elsewhere in the Bay.

The model results indicate that water depth in a large percent of the Baylor Ground in this particular area is too deep for most aquaculture operations. Salinity values in the river are generally too low for clam aquaculture. Oyster aquaculture appears to be the only viable shellfish growing opportunity on Baylor Grounds in the Lower Rappahannock River. The locations of preferred sites are depicted on maps.

Introduction

Aquaculture is a multi-million dollar industry in Virginia. Presently, Virginia leads the nation in the production of clams grown in cultured environments and distributed in the seafood market. Most aquaculture in Virginia is located on the Eastern Shore; however, commercial operations are expanding on the western shore as well.

The Commonwealth has considered a regulated expansion of the aquaculture industry to Baylor Ground as a potential future model for use of this public resource. In this scenario, public bottom will be opened to private shellfish growers in the Commonwealth under what will likely be a tightly monitored regulation. The question arises regarding the ability of Baylor Grounds to support aquaculture. The demise in productivity of natural oyster beds within Baylor Grounds is well known. However, there is no comprehensive resource that addresses whether Baylor Grounds remain suitable for aquaculture.

As a first attempt to address this question, the Coastal Policy Team's adhoc Aquaculture workgroup chose to apply the VIMS Aquaculture Suitability Model (ASM) to determine if basic conditions necessary to support aquaculture were present. This model was generated by the Center for Coastal Resources Management at VIMS and originally applied to all shellfish growing areas in VA. It was later revised to include current and future land use and zoning conditions for the Eastern Shore and the county of Gloucester (CCRM, 2007).

The workgroup proposed a pilot project focused on the Lower Rappahannock River. An Oyster Management Plan has been developed for this area and the state has issued new regulation regarding the oyster fishery here. This report documents procedures and outcomes of the ASM run for the Lower Rappahannock River.

Background

Aquaculture is an environmentally sensitive industry which requires some relatively specific conditions for success. This is particularly true of oyster aquaculture. Providing data are available, conditions necessary for the success of shellfish growing can be mapped using spatial analysis through a Geographic Information System (GIS).

Previous efforts to map suitability for aquaculture focused primarily on physical elements: salinity, water depth, and water quality. The presence of SAV was also considered since current state policy affords preferential status to SAV over aquaculture. Existing land use also has the potential to impact water quality and industry experts have indicated that shellfish growing activities would be impacted by development. This element was added to the original suitability model in a second modeling phase directed at the Eastern Shore of Virginia. In the current model, the degree to which land use and zoning can impact the aquaculture industry is ultimately based on best professional judgment from scientists and industry professionals. To support this, there are countless observations and studies that link development to a host of adverse conditions all of which contribute to reduced water quality. The list of impacts include: point source discharge from sewage treatment facilities, non-point source discharge from surface

runoff due to impervious surfaces, fecal coliform loads due to failing septic systems, and the overall reduction in nutrient uptake due to clear cutting of riparian forest buffers.

Project Objective

A modified version of the second modeling phase was applied to the Lower Rappahannock from the Essex-Middlesex County border down to the mouth where the river discharges into the Chesapeake Bay. This version would not consider county zoning which was not readily available in required formats. The objective was to determine where within the current Baylor Ground boundaries conditions favor the growing of either clams or native oysters.

Model Development and Criteria

Spatial models are highly dependent upon available GIS data, and utilize a series of rules or process steps for each attribute (i.e. data parameter) brought into the model. These rules or process steps reflect a set of conditions or criteria necessary for the desired outcome. In this case, the model seeks to identify areas suitable for aquaculture on existing Baylor Ground in the lower Rappahannock River. Experts in the field of aquaculture, and molluscan ecology have defined the parameters and the limits for each parameter being applied. These conditions are reported in Table 1. The parameters are described below. Maps illustrating the distribution of these attributes within the study area can be found in Appendix 1.

INPUT PARAMETERS

The most recent digitized **Baylor Ground** coverage available through the VIMS data archive was used. These data were verified by Virginia Marine Resources Commission (VMRC) as being suitable for this project.

Salinity data from the Chesapeake Bay Program's online database was queried. From the monitoring database, 14-year averaged annual salinity values from 1986-2000 were used for the oyster model. Since clams are limited by low salinities as juveniles, waters with salinities less than 20 ppt can be lethal. Seed clams planted in the fall are therefore highly sensitive to salinity values during late fall and spring. For this reason we use the spring averaged salinities (1997-2007) for the clam aquaculture model.

The model also requires **bathymetry** which comes from NOAA's National Geophysical Data Center. The dataset is known to be limited in the shallow water environments, but represents the best available and most comprehensive data. This model uses a bathymetric cutoff of 5 meters. Thus, depths greater than 5 meters are considered too deep for aquaculture. This was based on combined input from the scientific community and aquaculturists.

The Virginia Department of Health's, Bureau of Shellfish Sanitation collects water quality monitoring data in all potential shellfish growing areas. These data result in closures – both permanent and seasonal, if conditions do not meet criteria established for the agency. In general closures or **shellfish condemnation areas** remain in affect until the next sampling. For the study region, the most recent condemnation zones were

applied. While basically restricted to fecal coliform measurements, shellfish closures are considered an indicator of water quality.

Submerged aquatic vegetation (SAV) is one of the primary ecological use conflicts addressed in this study. Aquaculture and SAV require similar shallow water habitats to thrive. The potential for there to be a conflict for use does exist. The Virginia Marine Resources Commission prohibits aquaculture among SAV beds. We used 2005 data from the VIMS SAV Mapping Program to determine where these conflicts were present in the study area.

Land use is known to contribute to water quality degradation in a variety of ways and therefore reduces environmental quality to support aquaculture. Aesthetically, aquaculture operations present a different appeal for waterfront property owners, as well. We used land use primarily as another indicator of potential water quality impacts in the model, although no water quality problems may have been noted. Data were derived from the National Land Cover Dataset in 2001 (NLCD, 2001).

Finally a second ecological conflict was added to this model. Since the model was targeting only public oyster ground that have over the last several years been the prime target areas for the oyster restoration effort, we used data generated from a different spatial model to denote locations within Baylor Grounds where suitable areas for oyster reef restoration existed. This was largely based on the presence of **oyster rock or shell bottom** surveyed within the Baylor bottom by the VMRC. These areas were to be reserved for future restoration and therefore considered unavailable for aquaculture.

PROCESS STEPS

This section describes several of the process steps necessary to integrate data into the model. These steps are directed toward GIS modelers and provide specific details on how attributes function spatially and analytically in the model. This is particularly complex for upland features such as land use that influence conditions occurring in the water. You will note that a considerable amount of attention is given to land use data. You will also read that buffering is used as an analytical device to define spatially explicit zones.

The process steps below also introduce the shoreline coverage which was not mentioned above. This baseline boundary coverage is intrinsic to any aquatic analysis. We applied a 1:24,000 shoreline coverage generated from topographic maps for this study. As described below, a “water” polygon was extracted from the NLCD.

Processing for the aquaculture models took place using ArcInfo Workstation version 9.2. Three arc macro language (aml) programs (newmodels07_rap.aml, nearprocess_rap.aml, and point_anal_rap.aml) were written to complete the analysis. An analytical buffer equal to 150 meters inland from the shoreline was developed for processing land use. The dominant land use within the buffer was determined for indiscriminant segments along the water whose length was coincident with the extent of the land use pattern.

A simplified land use classification was developed which clustered similar classes together. The original NLCD classification was condensed as follows: pasture/hay and cultivated crops became ‘agriculture’; developed open, developed low, developed medium, and developed high became ‘developed’; evergreen forest, deciduous forest, and mixed forest were grouped as ‘forest’; and the remaining land use categories were not changed.

TABLE 1. SHELLFISH AQUACULTURE SUITABILITY MODEL CRITERIA

| AQUACULTURE | | SUITABILITY INDEX | | | | |
|---------------|----------------------------|-------------------|----------|---------------------------------|----------------------------------|------------|
| TYPE | ATTRIBUTE | Optimal | Suitable | Existing Water Quality Concerns | Potential Water Quality Concerns | Unsuitable |
| CLAM | | | | | | |
| | SAV | absent | absent | absent | absent | present |
| | Avg. Spring Salinity (ppt) | ≥ 20 | ≥ 15 | ≥ 15 | ≥ 15 | < 15 |
| | Shellfish Closure | o | o | c, sc | o | prohibited |
| | Bathymetry (m) | ≤ 5 | ≤ 5 | ≤ 5 | ≤ 5 | >5 |
| | Dom. Land Use | n | n, d-fb | n, d-fb, d | d | n/a |
| | Baylor Grounds | yes | yes | yes | yes | n/a |
| | Oyster Rock | absent | absent | absent | absent | present |
| OYSTER | | | | | | |
| | SAV | absent | absent | absent | absent | present |
| | Avg. Salinity (ppt) | ≥ 7 | ≥ 7 | ≥ 7 | ≥ 7 | < 7 |
| | Shellfish Closure | o | o | c, sc | o | prohibited |
| | Bathymetry (m) | ≤ 5 | ≤ 5 | ≤ 5 | ≤ 5 | >5 |
| | Dom. Land Use | n | n, d-fb | n, d-fb, d | d | n/a |
| | Baylor Grounds | yes | yes | yes | yes | n/a |
| | Oyster Rock | absent | absent | absent | absent | present |

Shellfish Closure: "o" = opened, "c" = condemned, "sc" = seasonally condemned

Dominant Land Use: "n" = natural, "d-fb" = developed or agriculture with forest buffers, "d" = developed or agriculture

The model regards agriculture and existing developed lands with the same potential impacts to aquaculture. For analytical purposes, these land use designations are clustered in the model under “developed” lands. The model also considers the benefit of riparian forest buffers and therefore a new class was generated (“developed-fb”) to include forest buffers along the margins of water and developed or agriculture lands. The buffer must be a minimum of 30 meters wide. “Natural” lands include forest lands, wetlands, scrub-shrub, and barren areas. Remaining land classes are water.

A new water coverage was created for the analysis by combining the tidal waters from the Virginia shoreline (SHL) coverage with the water class from NLCD01. This coverage was converted to a grid (10m pixel size) and then converted to a point coverage. Points not associated with water were deleted.

The new water polygon coverage was buffered 2m, 30m, and 150m. The inland arc of the 2m buffer became the new shoreline and was analyzed for dominant land use adjacent to the water. Forest or woody wetlands classified along the 2m buffer line were coded as a forest buffer. Forest buffers are recognized as mitigating water quality impacts from upland land uses that typically have high nutrient discharges (e.g. agriculture and developed). The model “credits” these land uses if forest buffers are maintained. Arcs coded as water or having an empty land use value were deleted. The 150m buffer was combined with the land use and the new water coverages. The 150m buffer provides the inland boundary limit and land use beyond this buffer is not considered in the model.

An aml (nearprocess_rap.aml) was prepared where the “near” command was used to associate the land use points within the 150m buffer to the new shoreline arcs described above. “NEAR” computes the distance from each point to the nearest arc, point, or node in another coverage. The distance and the internal number of the closest feature are saved as new items in the input coverage’s feature attribute table (ESRI Help). The attributes of the shoreline arcs were joined to the land use points based on the near cover’s internal number.

Nearprocess_rap.aml calls point_anal_rap.aml to analyze the points tied to each arc segment and determine the primary land use for that arc segment. Land use values were lumped into two groups: natural (includes forest, wetlands, shrub-shrub, and barren) and developed (includes agriculture, grassland, and developed). “Developed” should more appropriately be viewed not as a group of land use categories associate with development, but rather a group of land use classes that all represent similar degrees of impact to aquaculture. Primary land use for each shoreline arc was determined by using frequencies and percentages. An arc segment with a predominant land use of ‘natural’ was coded dominant_lu = ‘natural’; a predominant land use of developed with a forest buffer was coded dominant_lu = ‘developed-fb’ (with forest buffer); and a predominant land use of developed but no forest buffer was coded dominant_lu = ‘developed’.

Since the aquaculture model is to address conditions in the water and not on the shoreline, the next step transfers the dominant_lu attributes from the shoreline arcs to the water points. The “near” command followed by a “joinitem” command was used. The water points were then converted to a grid, then back to a polygon coverage.

To prevent the occurrence of sliver polygons in these final steps of the aquaculture model (a result of combining an angular polygon coverage with a smooth polygon coverage), the water, land use and water zoning coverages were unioned with the new water coverage. The labels from sliver polygons were selected and saved in a point coverage. “Near” and “joinitem” commands were used to find the nearest zoning and dominant land use with which to label each sliver polygon.

The final clipped and processed datasets were combined (salinity, land use, bathymetry, condemned areas, SAV, Baylor Grounds, and oyster rock) to produce coverages for hard clam aquaculture and oyster aquaculture. The model criteria listed in Table 1 were applied to the final coverages to determine aquaculture suitability.

Model Output and Results

The criteria used in the model development were integrated into a suitability classification that designates the potential for a Baylor ground to support aquaculture based on the combination of conditions present at the site. The discussion above describes the analytical process used to reach these conclusions using spatial analysis within a GIS framework. The valuation or “ranking” was reached using best professional judgment based on science, current policy, and industry specifications. In the end, the classification is simplified into 5 classes which 1) will permit easy dissemination by the varied stakeholder groups, and 2) reflects a wide and varied expert opinion base for qualifying conditions under which clam or oyster aquaculture “success” is achieved. The classification is described in Table 2. Table 1 provides reference to the specific GIS rules applied.

It is important to note that within the study region, the majority of the river and its tributaries include Baylor Ground. This is not typical of all major tributaries and creeks. A total of 39,118 acres of Baylor Ground were computed. It is also important to note that a significant area of those Baylor Grounds, 26,222 acres, exceeds the water depth limits established for this study. These areas are not specifically classified as unsuitable. They were removed from the analysis as a boundary limit for the study. This is true for both the clam and aquaculture models. By subtraction, there are 12,894.80 acres of available Baylor Ground bottom remaining.

Differences between the oyster aquaculture and the clam aquaculture model are extreme. The differences are driven entirely by the selected salinity distributions. Under the selected salinity regimes for clam aquaculture using the spring averages there are virtually no areas suitable for clam aquaculture on Baylor Grounds in the lower Rappahannock River (Appendix 2). The model output for oyster aquaculture is quite different.

Areas suitable for oyster aquaculture are best visualized through a series of maps shown in Appendix 3. From the 12,894.80 acres of Baylor Ground with depths less than 5 meters, more than 7,600 acres meet optimal growing conditions. Another 3,339 acres currently meet water quality standards, but have been flagged due to existing land use. This means that under current conditions the area should support aquaculture but land use may contribute to water quality degradation in the future. Table 3 provides a summary of the model output.

Table 2. Description of the Suitability Index

Suitability Index

Optimal

These areas represent regions where optimal growing conditions are present and ecological conflicts are generally absent. Current upland is unmanaged, natural lands such as scrub-shrub or forest cover. Bathymetry and salinity regimes are appropriate, and there are no designated shellfish closures at the present time suggesting existing water quality is good.

Suitable

These areas represent locations where optimal growing conditions exist (shellfish waters are “opened”) and ecological use conflicts are absent. Salinity and bathymetric criteria established for the model are met. The major distinction between areas designated as Suitable versus Optimal is current land use. Land use data reports these areas have some level of development or existing agricultural practices that threaten water quality. However, these lands also maintain healthy natural forest buffers that can mitigate water quality impacts from these land uses providing they are preserved.

Existing Water Quality Concerns

These areas have been found by the Virginia Department of Health’s Division Shellfish Sanitation to have water quality parameters that do not meet minimum standards for the consumption of shellfish. The areas are designated as either condemned or seasonally condemned. The designation does not prohibit the growing of shellfish in these waters, however, growers are required to mitigate for potential water quality impacts by moving animals to cleaner waters before going to market.

Potential Water Quality Concerns

Areas with this designation currently meet all physical and water quality parameters necessary, and have no ecological conflicts. However, land use in this area is conducive to degraded water quality and future water quality issues could arise. These areas may currently support aquaculture or maintain a level of water quality and other factors consistent with good shellfish growing. Unlike developed and farmed lands with riparian forest buffers, these lands have no buffers present.

Future Water Quality Concerns

Since this study did not consider local government zoning, future water quality concerns were not modeled in this study.

Unsuitable

Any area that does not meet the salinity requirements is classified as unsuitable. Areas where the Health Department classifies waters as “prohibited” for the taking of shellfish are also unsuitable. These areas are designated by the division as such because they do not meet minimum salinity requirements as opposed to a water quality standard. Other areas that dominate this category are Baylor grounds that present a conflict with regards to one of two specific ecological resources. They include the presence of submerged aquatic vegetation (SAV) or the presence of oyster rock or hard shell bottom which would potentially be available as a reef restoration site. The former is mapped through a long-term annual monitoring program. The later was mapped as a component of a spatial model to map sites suitable for oyster restoration.

Table 3. Summary of acres of Oyster and Hard Clam Aquaculture Suitability within Baylor Grounds in the Lower Rappahannock River.

Oyster Suitability:

| Baylor | oyster index | acres |
|--------------|--------------------------------|-----------------|
| yes | | 0.34 |
| yes | deep water | 26221.67 |
| yes | optimal | 7645.56 |
| yes | suitable | 135.10 |
| yes | existing H2O quality concerns | 106.99 |
| yes | potential H2O quality concerns | 3339.59 |
| yes | unsuitable | 1668.38 |
| Total | | 39117.63 |

Hard Clam Suitability:

| Baylor | hard clam index | acres |
|--------------|--------------------------------|-----------------|
| yes | | 0.34 |
| yes | deep water | 26221.67 |
| yes | suitable | 0.01 |
| yes | potential H2O quality concerns | 0.81 |
| yes | unsuitable | 12894.80 |
| Total | | 39117.63 |

MODEL VALIDATION

Spatial models of this nature are difficult to validate. Due to the physical complexity of the environments within which aquaculture occurs, there is great uncertainty in predicting water quality responses to land use and land use changes. We can, however, test some elements of the models sensitivity through a simple review of current aquaculture. This was done as a component of an earlier study (CCRM, 2007). In a collaborative effort with the Virginia Marine Resources Commission (VMRC) data pertaining to private leases known to have active aquaculture operations were compared with the model output. We used data from the Eastern Shore of Virginia to map leases where clam and oyster aquaculture has been reported.

The results of the model validation indicated the active leases appeared to be located in areas currently classified as Optimal or Suitable. This indicates the model is sensitive enough to predict areas that support aquaculture.

SUMMARY

This analysis sought to determine if bottom habitat within the existing Baylor Grounds could support aquaculture if the Commonwealth chose to initiate policy that would open

the public resource to a regulated commercial activity. An existing spatial model with some modifications was applied. The results indicated that water depths exceeded the maximum threshold for aquaculture on more than half of the Baylor Ground. Salinity values averaging <15ppt eliminated clam aquaculture as a viable industry for the remaining bottom. The clam aquaculture suitability model output can be reviewed in maps found in Appendix 2.

Opportunities for oyster aquaculture within Baylor Grounds located in water less than 5 meters deep are found in various locations. These locations are mapped and illustrated in Appendix 3. They will be useful tools if a change in policy and/or new regulation is to be forthcoming.

Acknowledgements

The Center for Coastal Resources Management would like to thank the following individuals for their assistance on the project. Mr. Tom Walker and Mr. John West provided invaluable feedback on the original model development. Dr. Jim Wesson and Ben Stagg of the Virginia Marine Resources Commission provided important data to assist with the model validation. Drs. Jim Wesson, Mark Luckenbach, and Roger Mann all contributed to the development of the model criteria.

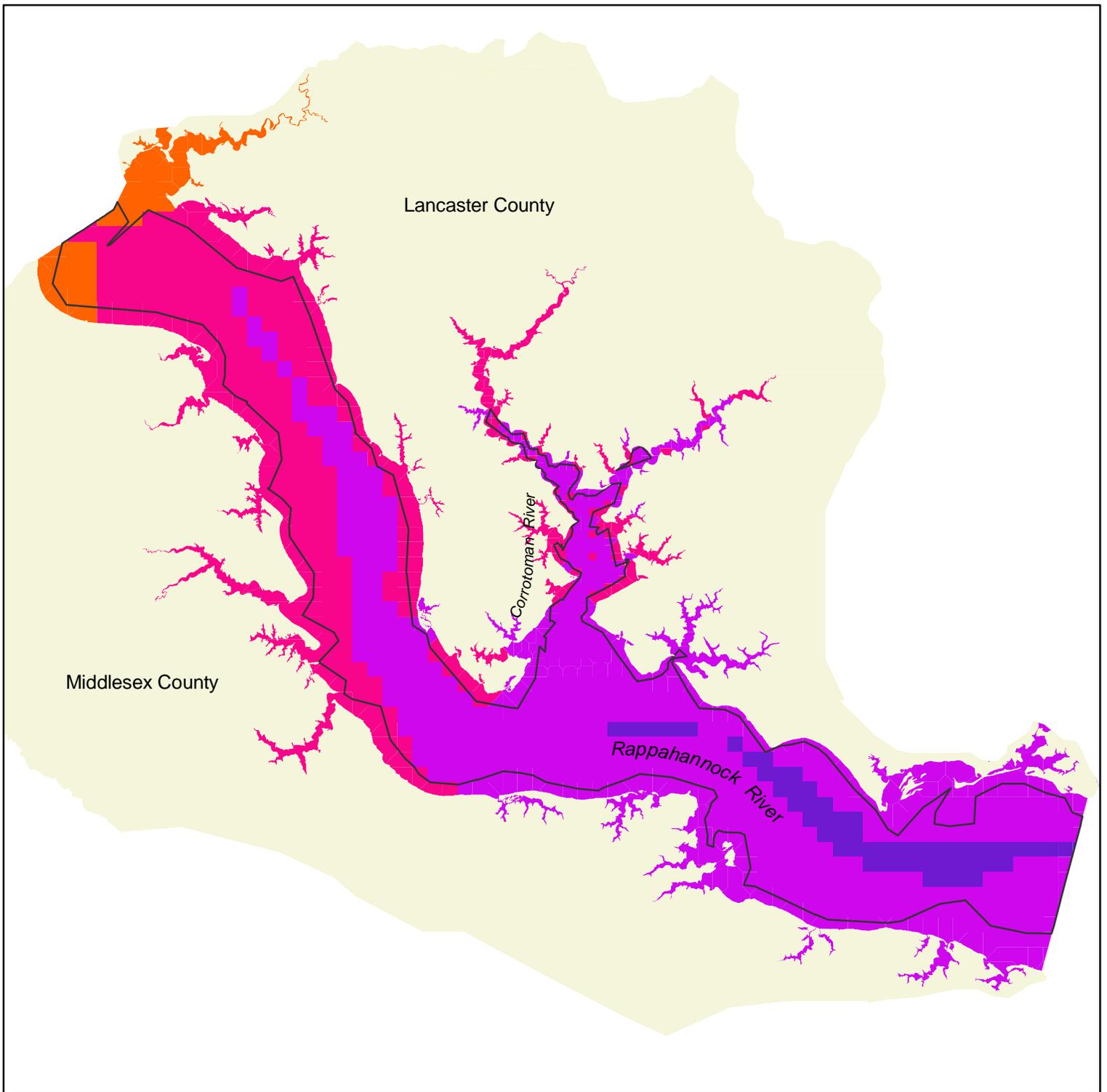
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REFERENCES

Center for Coastal Resources Management (CCRM), 2007. Shellfish Aquaculture Vulnerability Model, Final report submitted to the Virginia Coastal Zone Management Program, Virginia Department of Environment Quality, pp. 68.

APPENDIX 1.
SHELLFISH AQUACULTURE SUITABILITY MODEL
BASELINE DATA



Legend

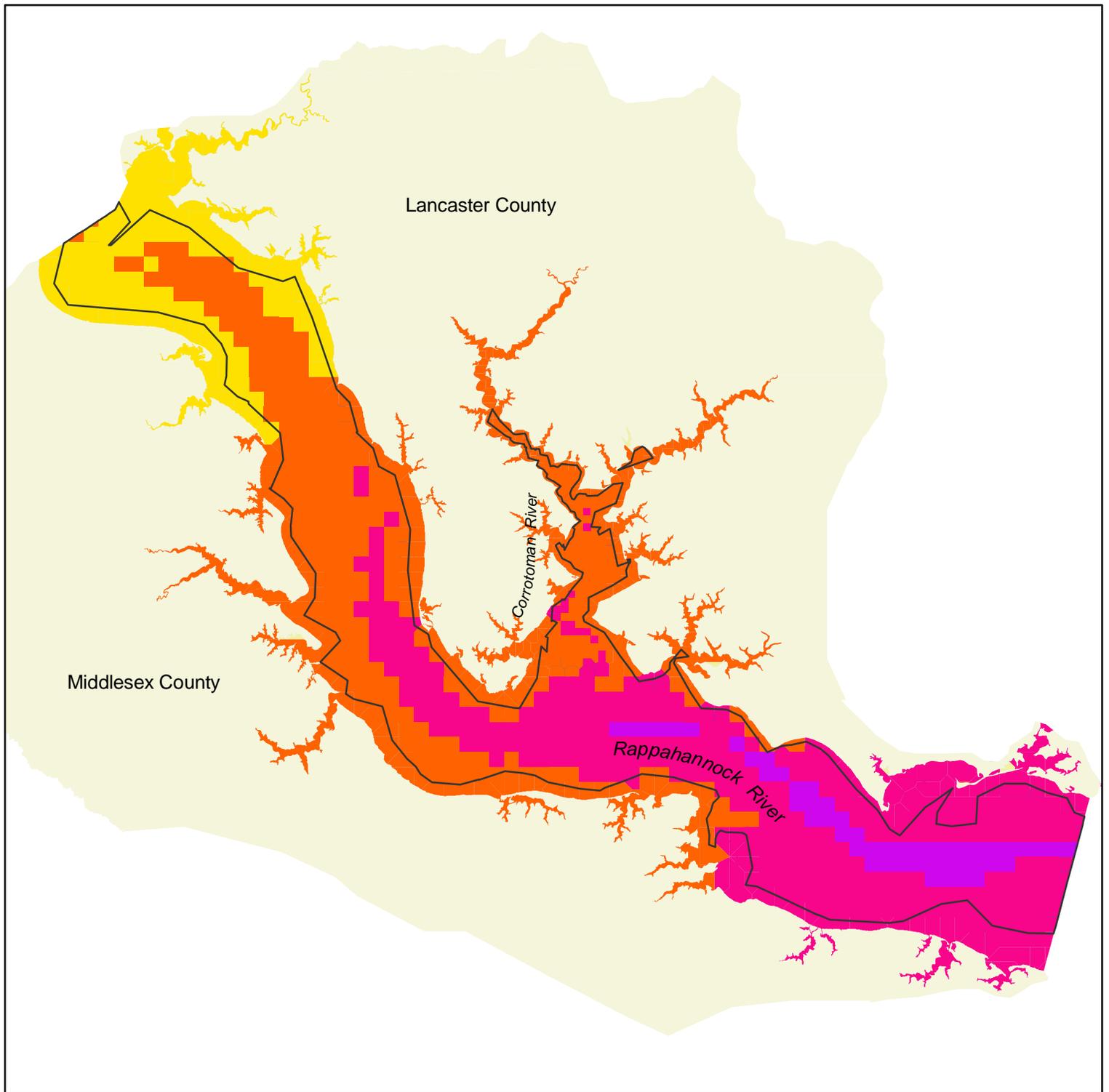
- land
- Baylor grounds

average salinity (ppt)

- < 7.000000
- 7.000001 - 9.000000
- 9.000001 - 11.000000
- 11.000001 - 13.000000
- 13.000001 - 15.000000
- 15.000001 - 17.000000
- 17.000001 - 19.000000
- 19.000001 - 21.000000

Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Average Salinity



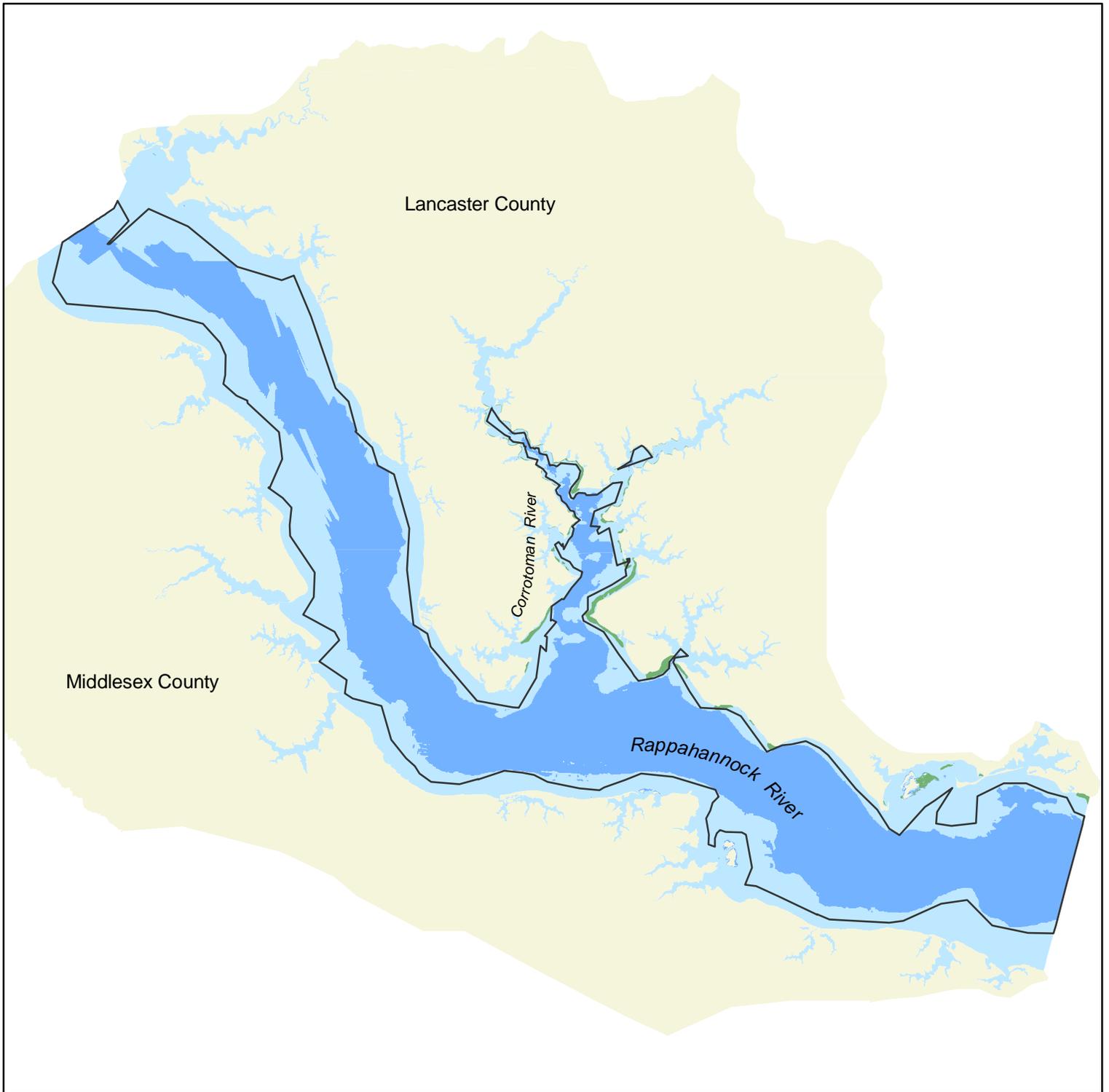


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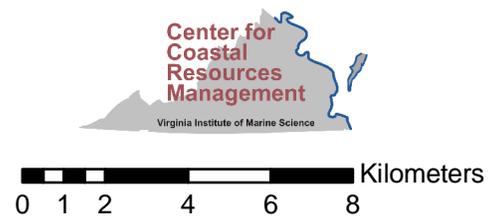
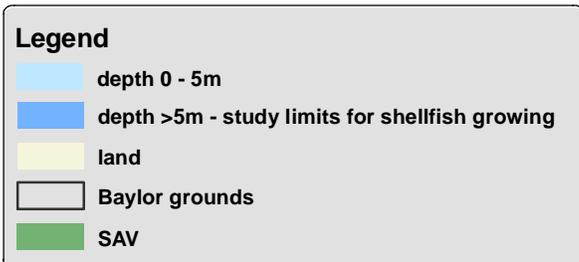
- land
- Baylor grounds
- average spring salinity (ppt)**
- < 7.000000
- 7.000001 - 9.000000
- 9.000001 - 11.000000
- 11.000001 - 13.000000
- 13.000001 - 15.000000
- 15.000001 - 17.000000
- 17.000001 - 19.000000
- 19.000001 - 21.000000

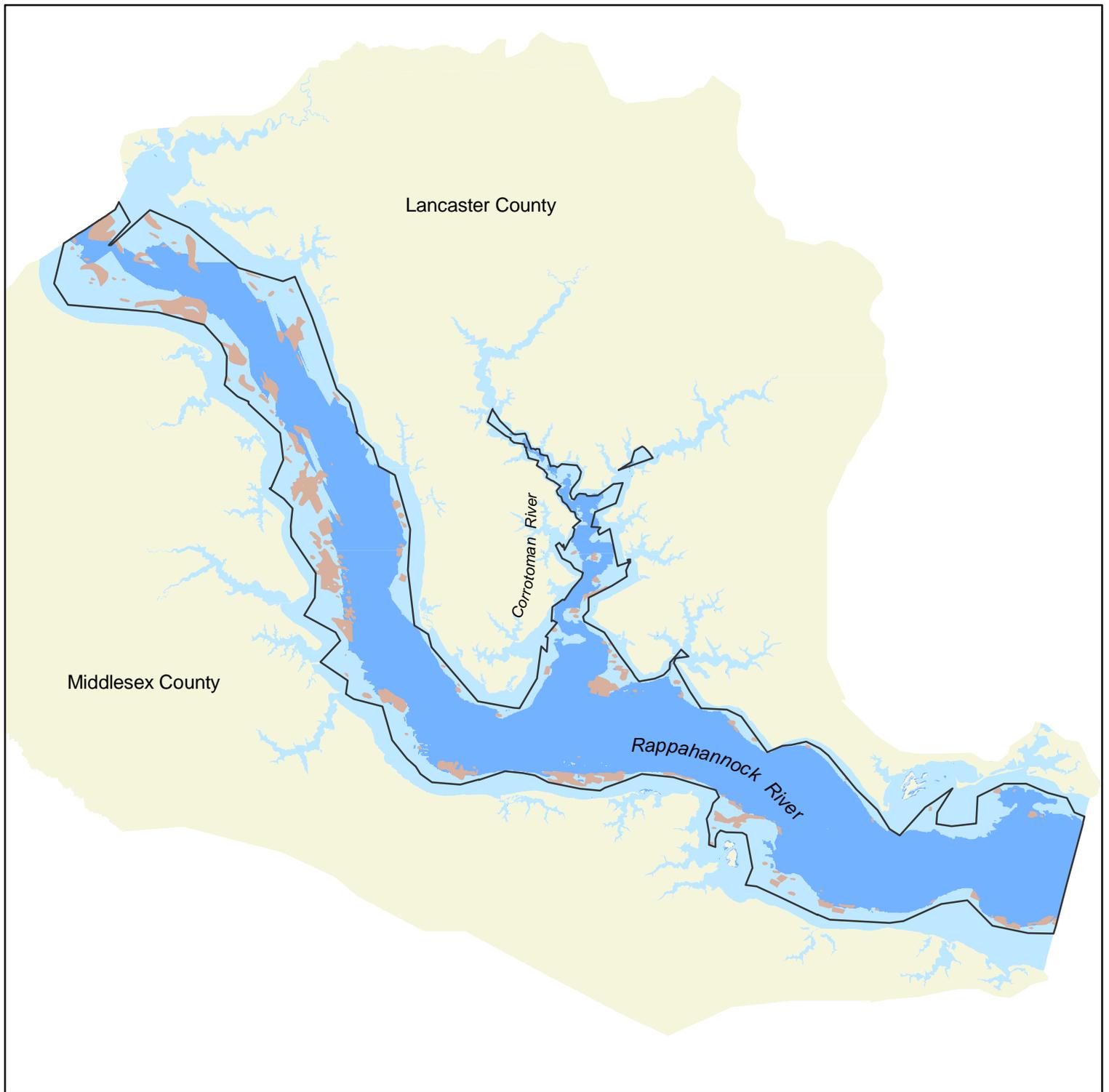
Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Average Spring Salinity



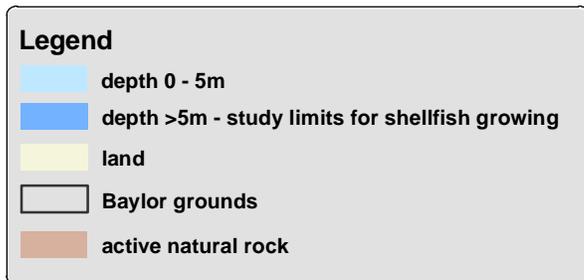


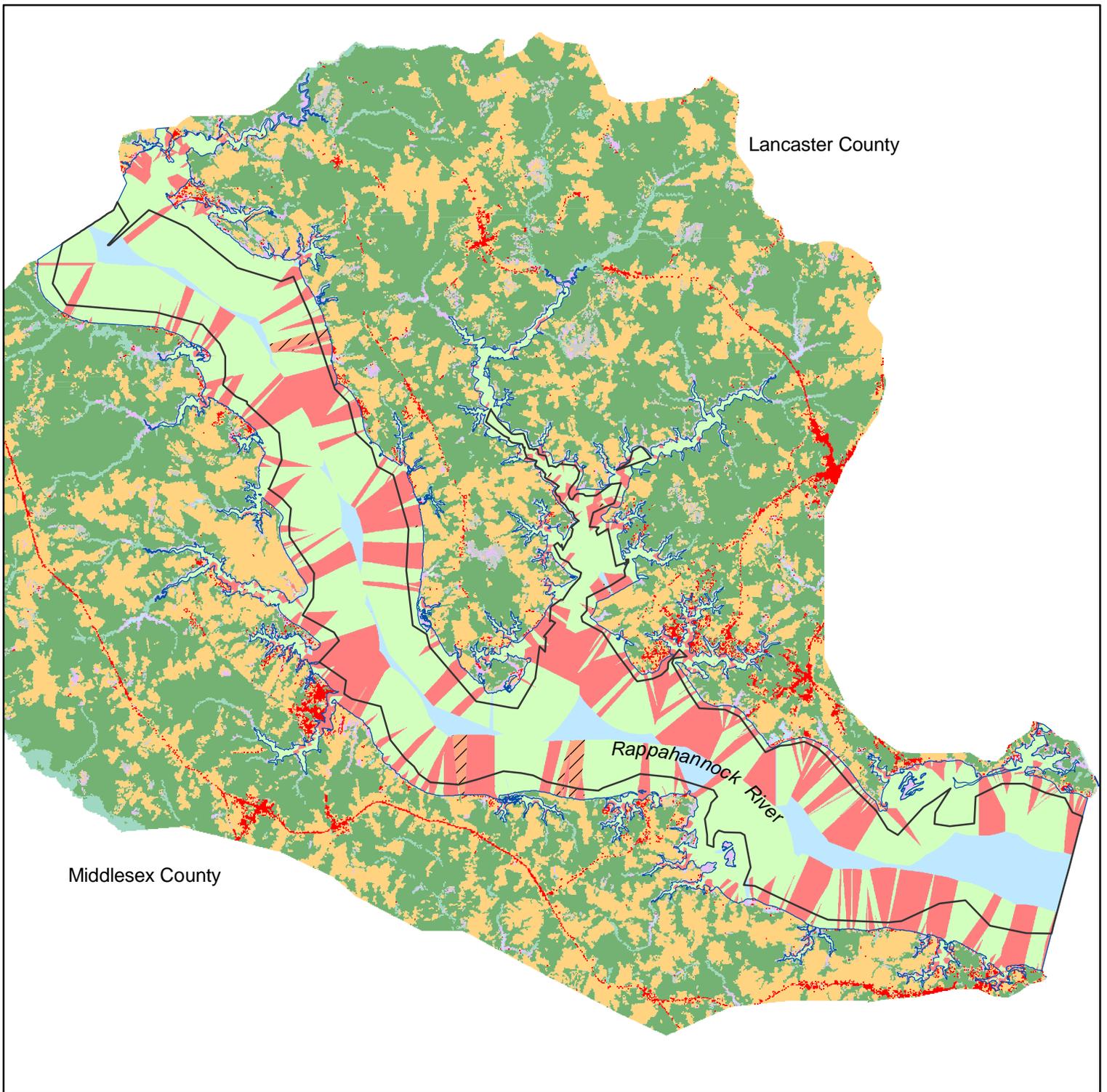
Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - SAV





Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Oyster Natural Rock





Legend

□ Baylor grounds

land use

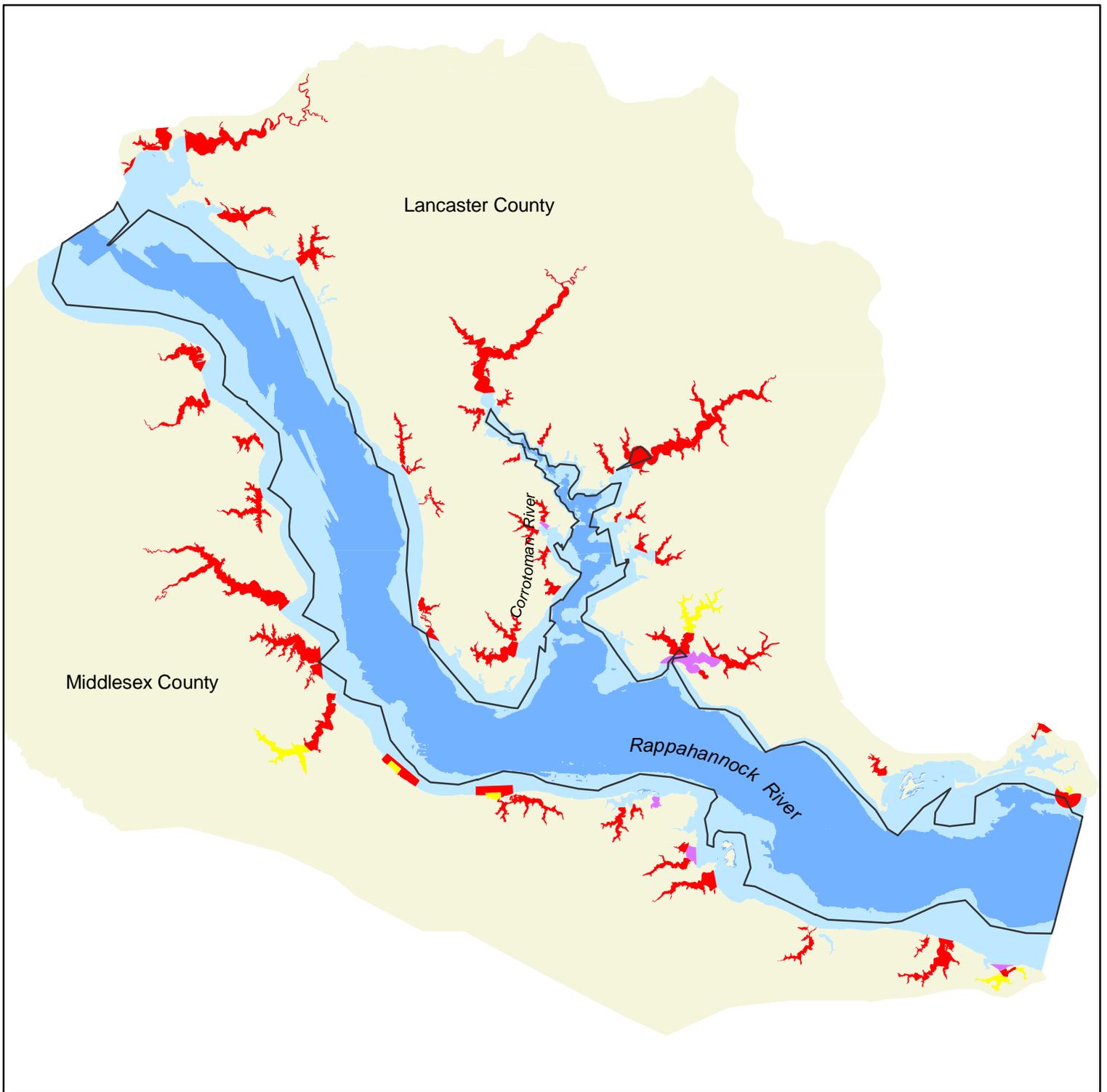
- agriculture
- barren land
- developed
- emergent wetlands
- forest
- water
- woody wetlands

dominant land use projected into water

- developed
- developed with forest buffer
- natural

Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Land use





Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds

Oyster condemnation areas:

- condemned
- open
- prohibited
- seasonally condemned

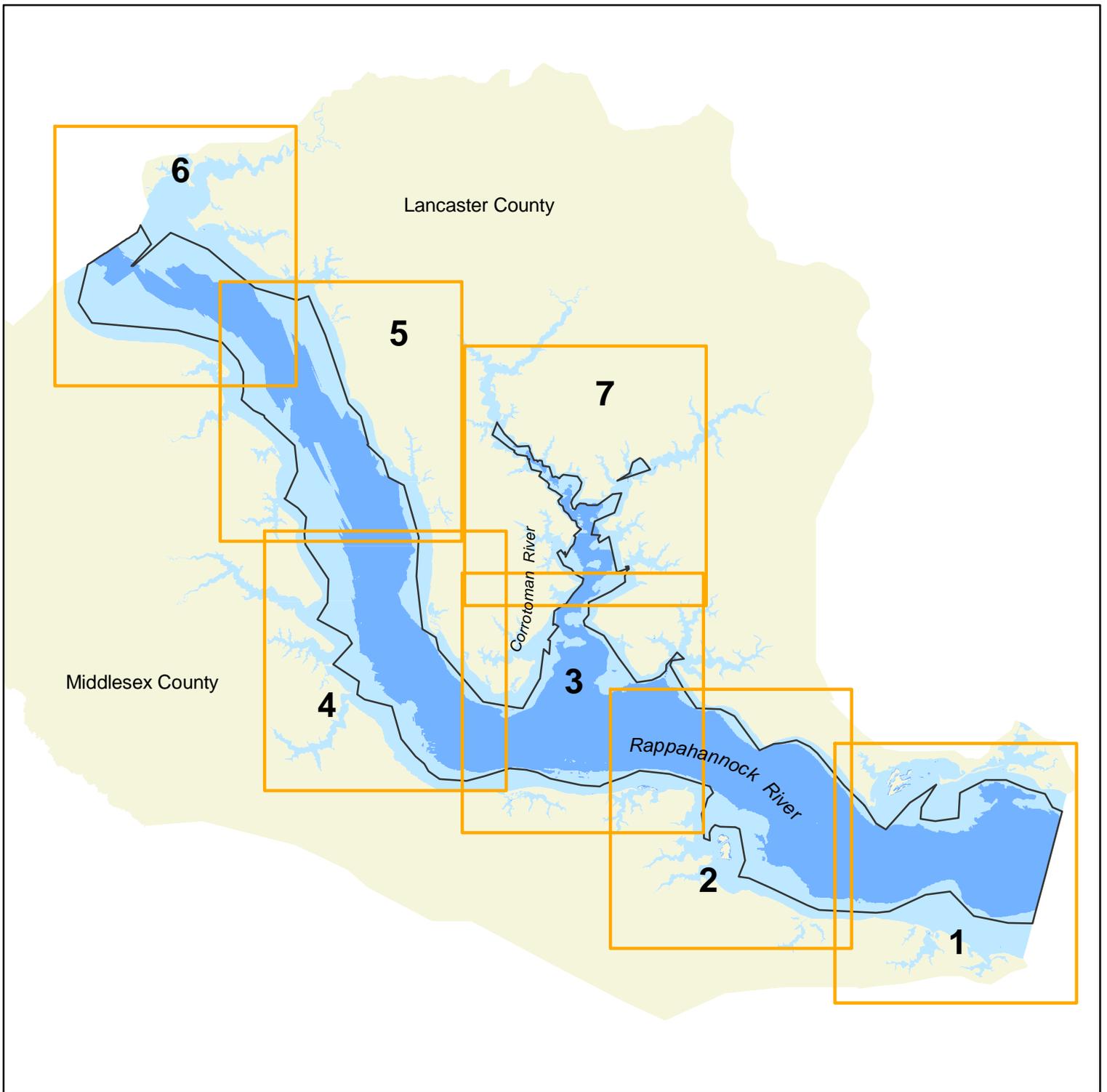
Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Condemnation Areas



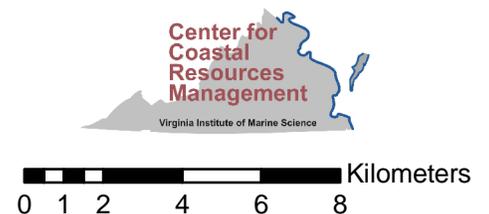
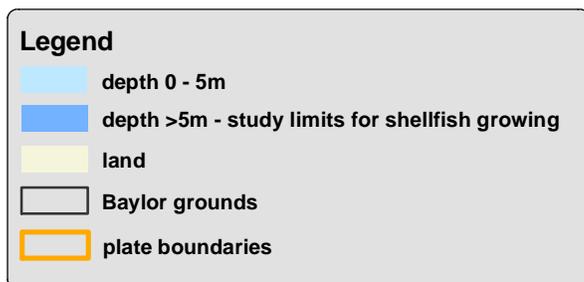
APPENDIX 2.

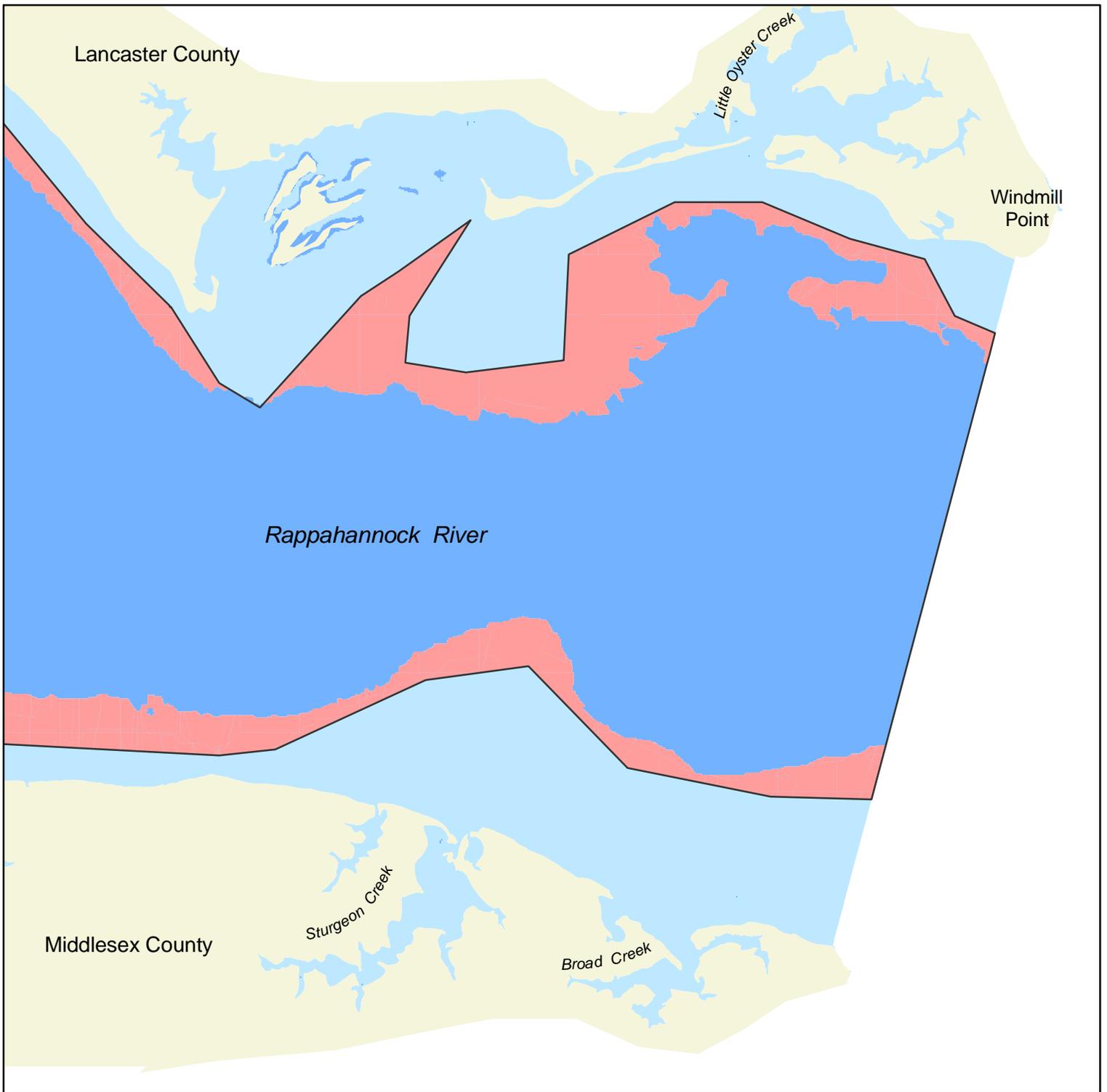
SHELLFISH AQUACULTURE SUITABILITY MAPS

Potential Hard Clam Aquaculture in the Lower Rappahannock River



Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Index

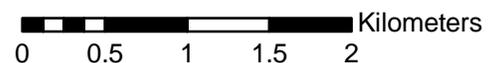


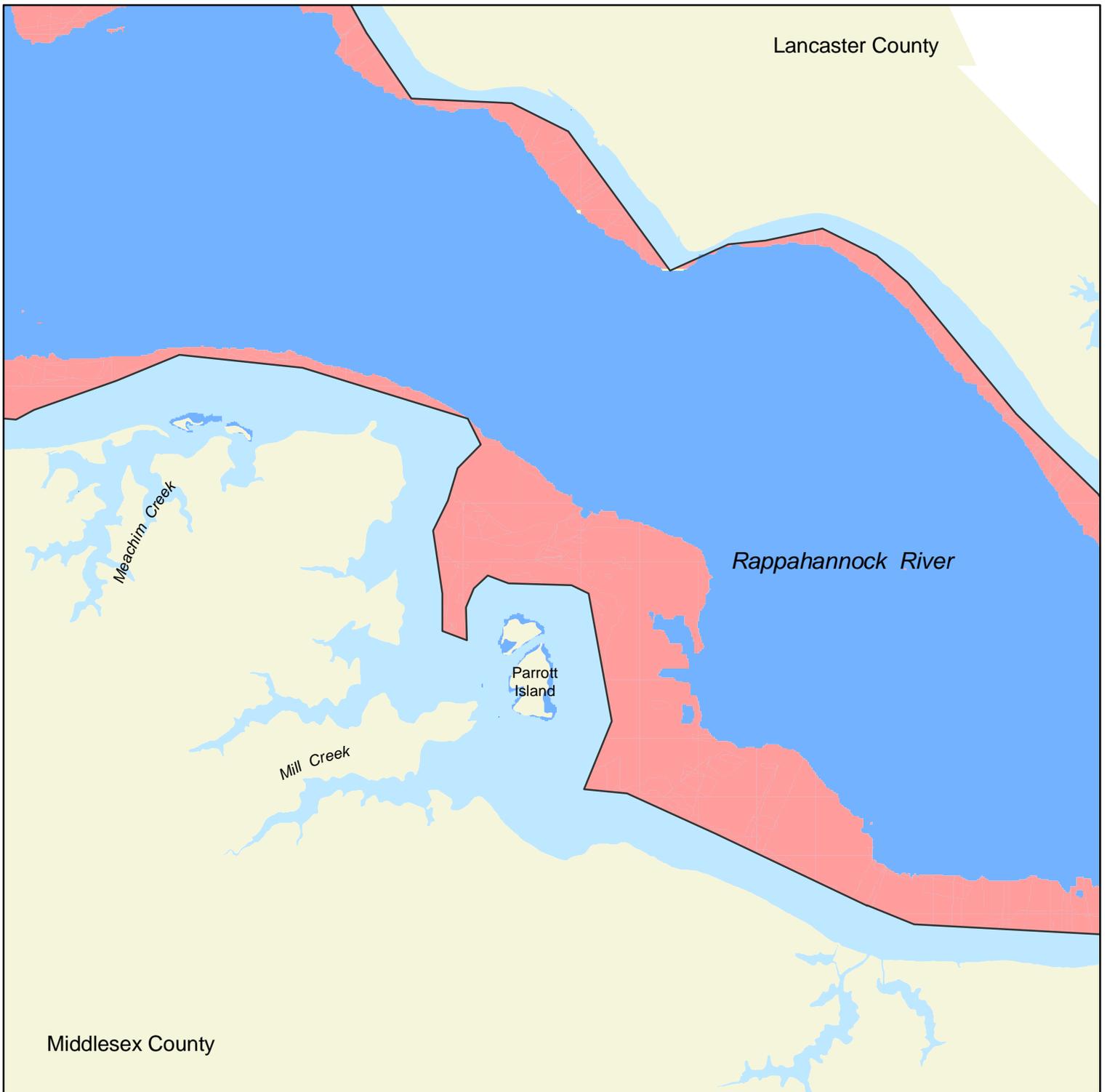


Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 1

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable





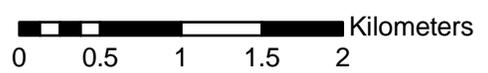
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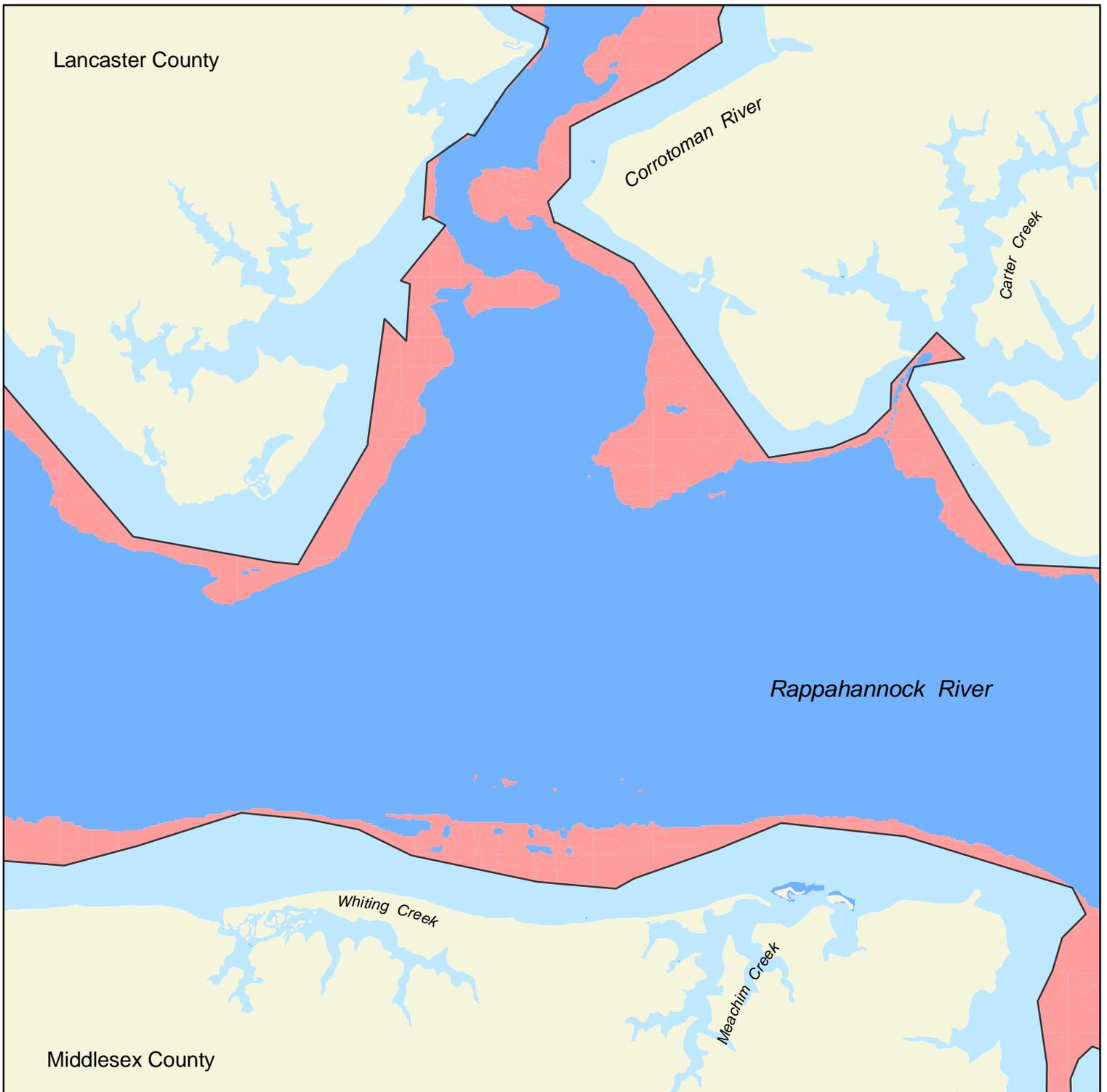
- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds

Suitability Index

- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 2



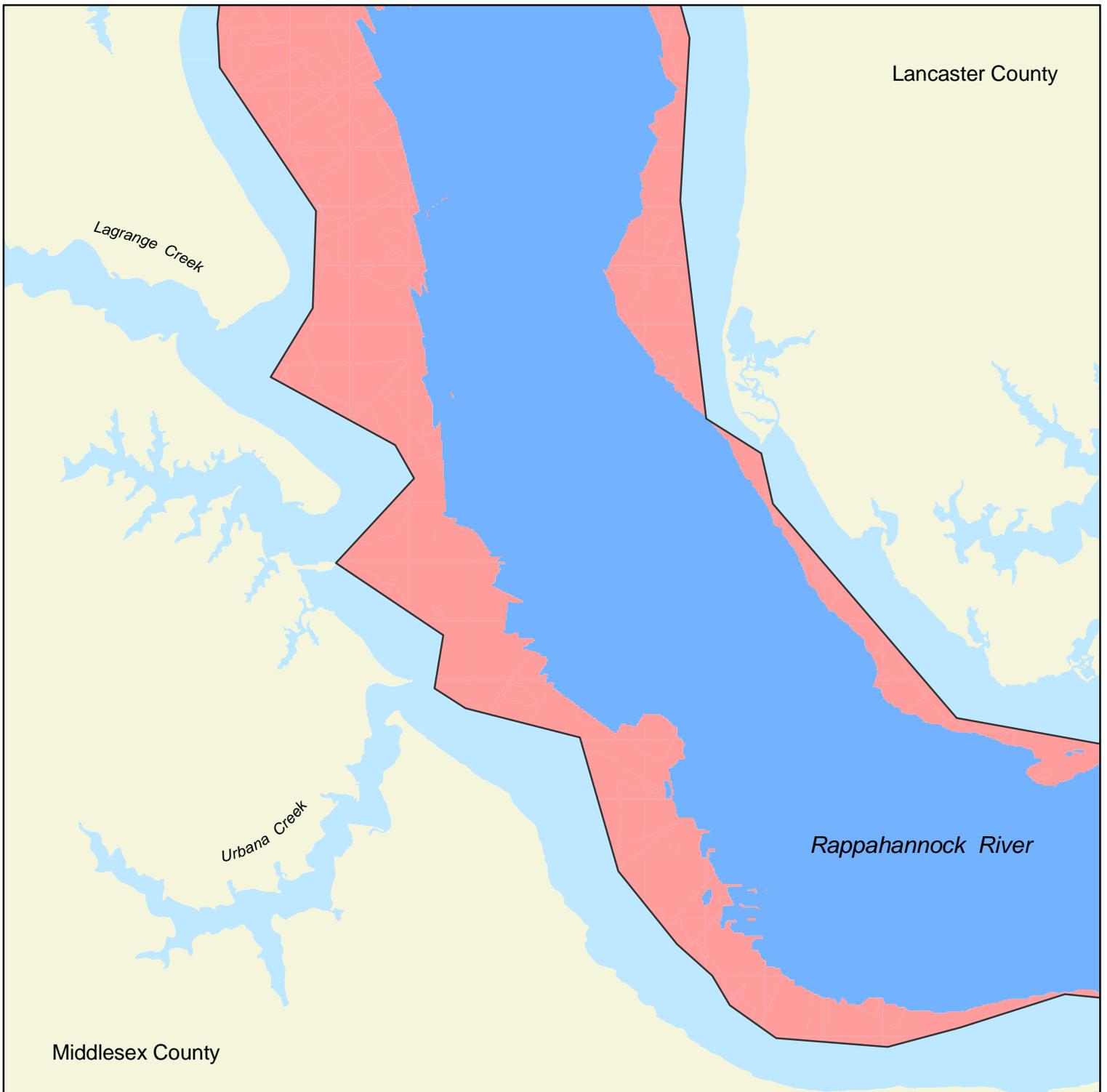


Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 3

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



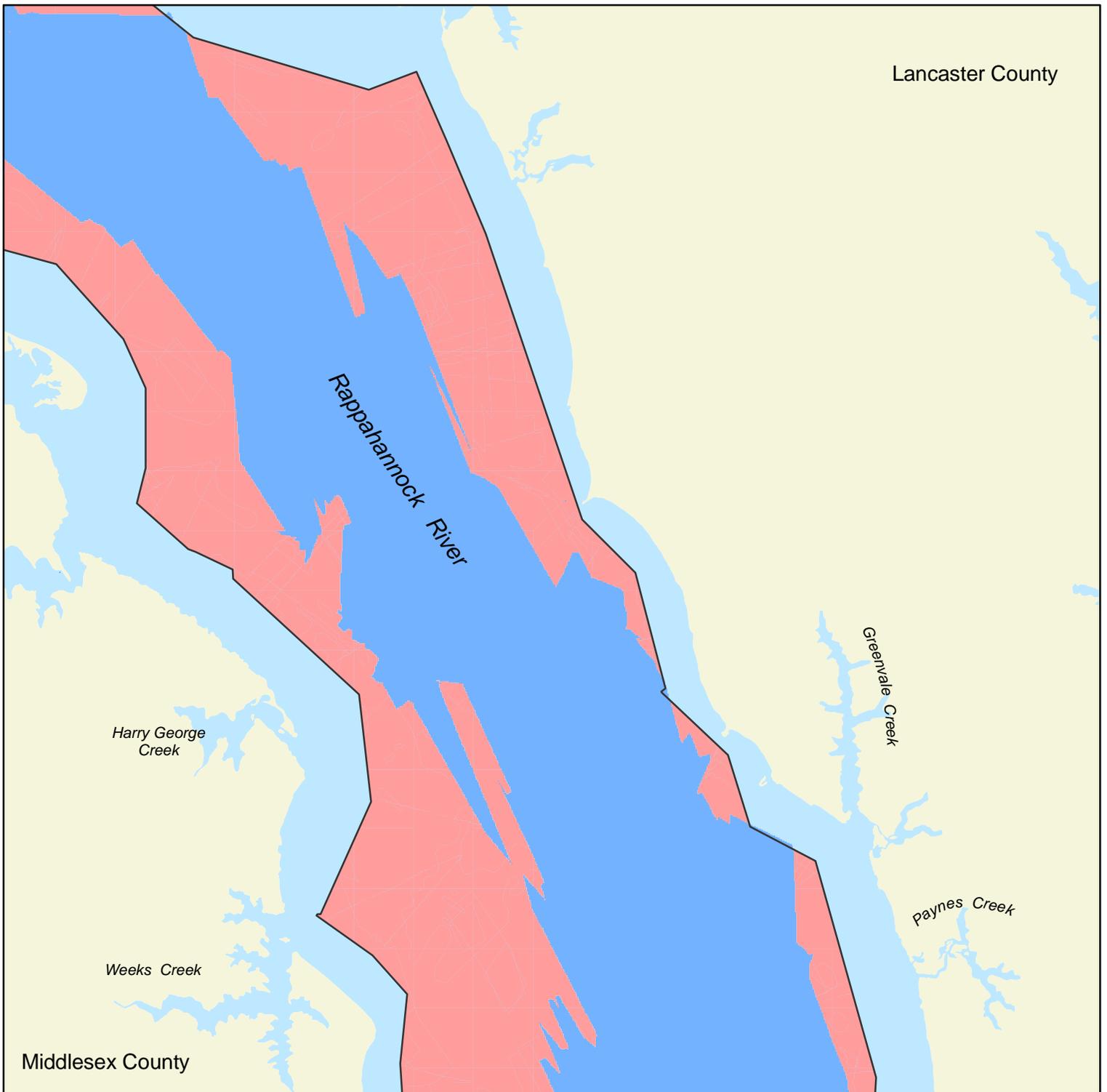


Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 4

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



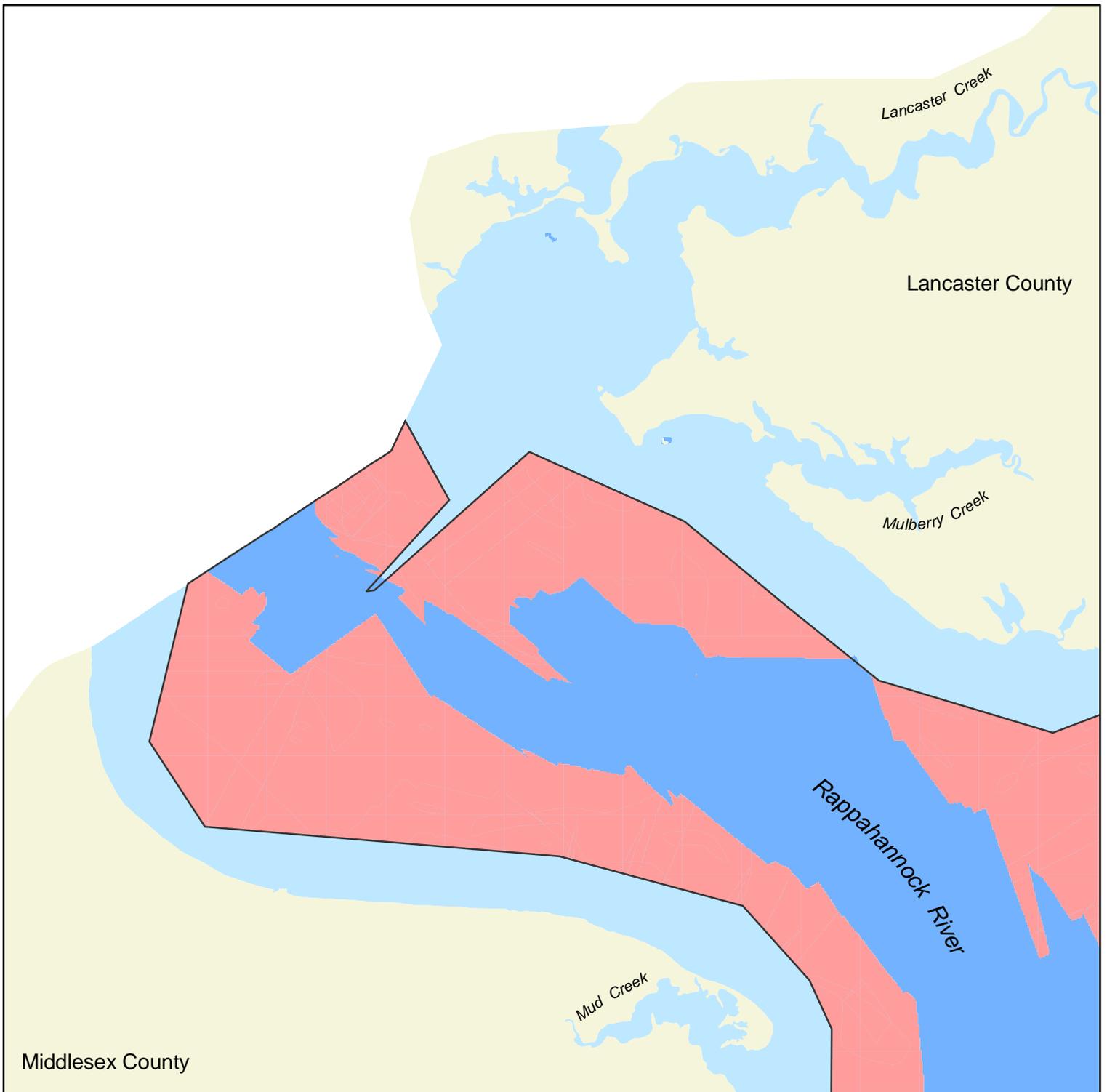


Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 5

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



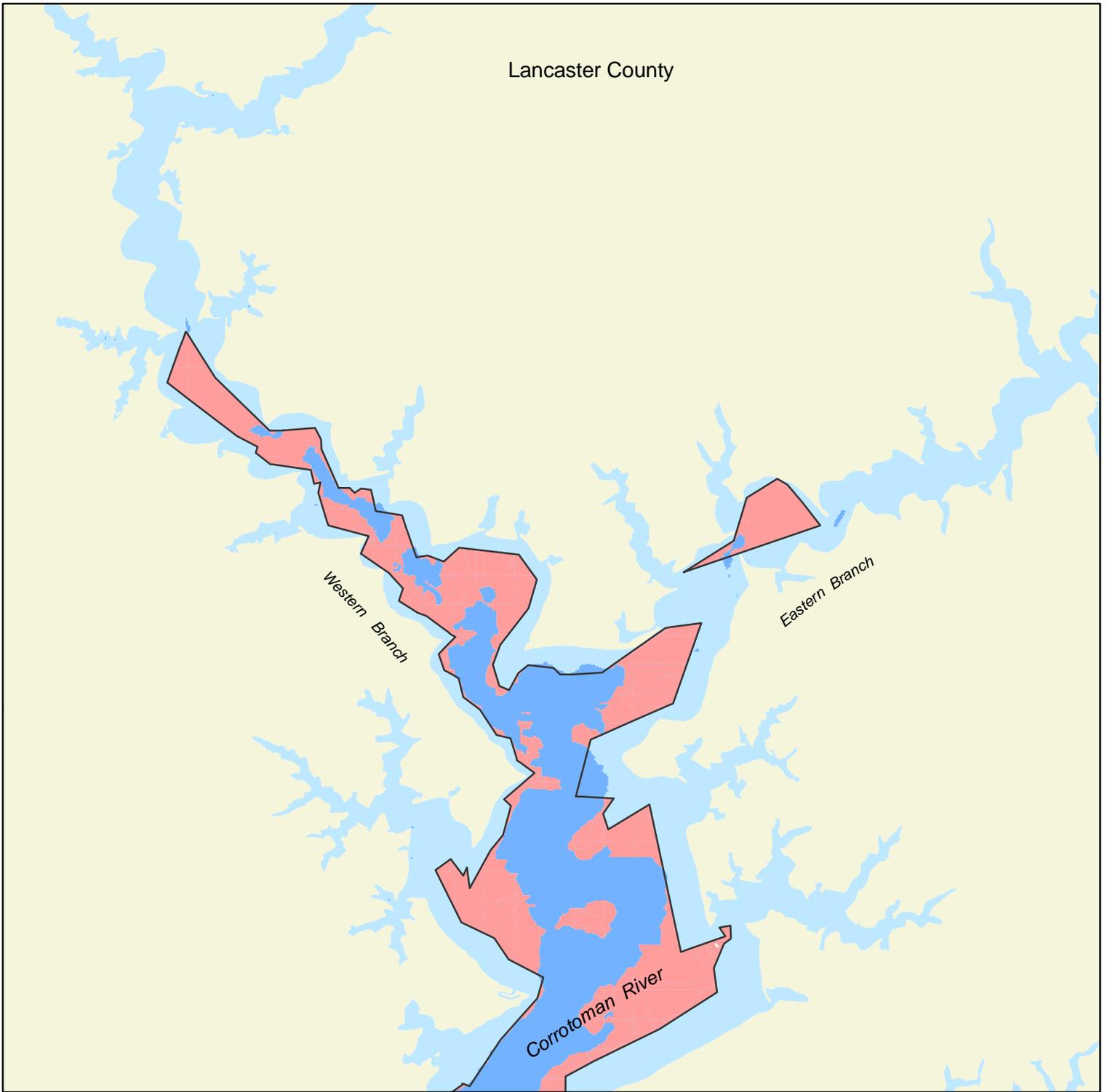


Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 6

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

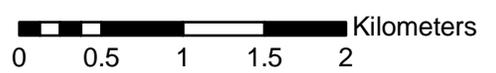




Lower Rappahannock River Hard Clam Aquaculture Suitability Areas within Baylor Grounds Plate 7

Legend

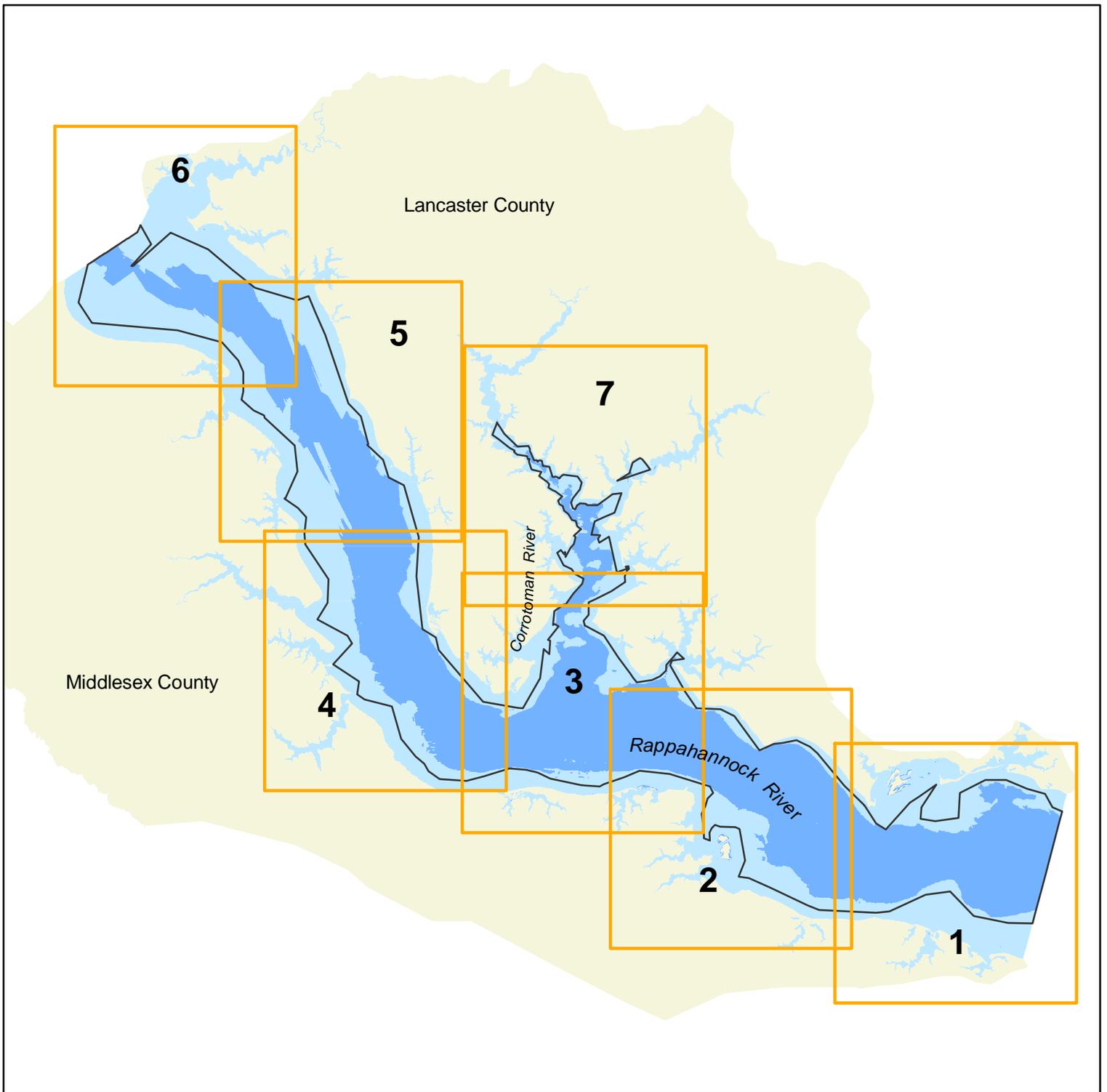
- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



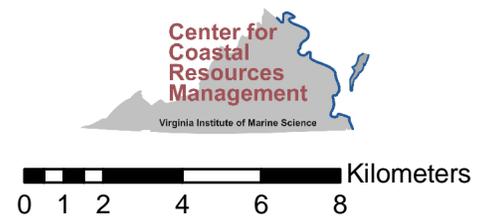
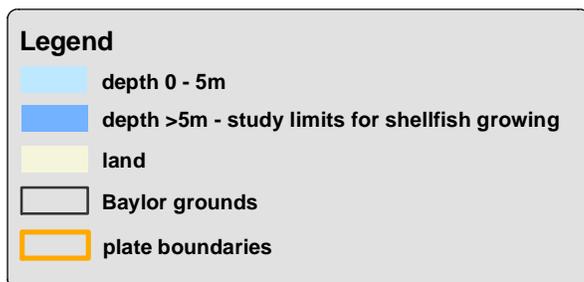
APPENDIX 3.

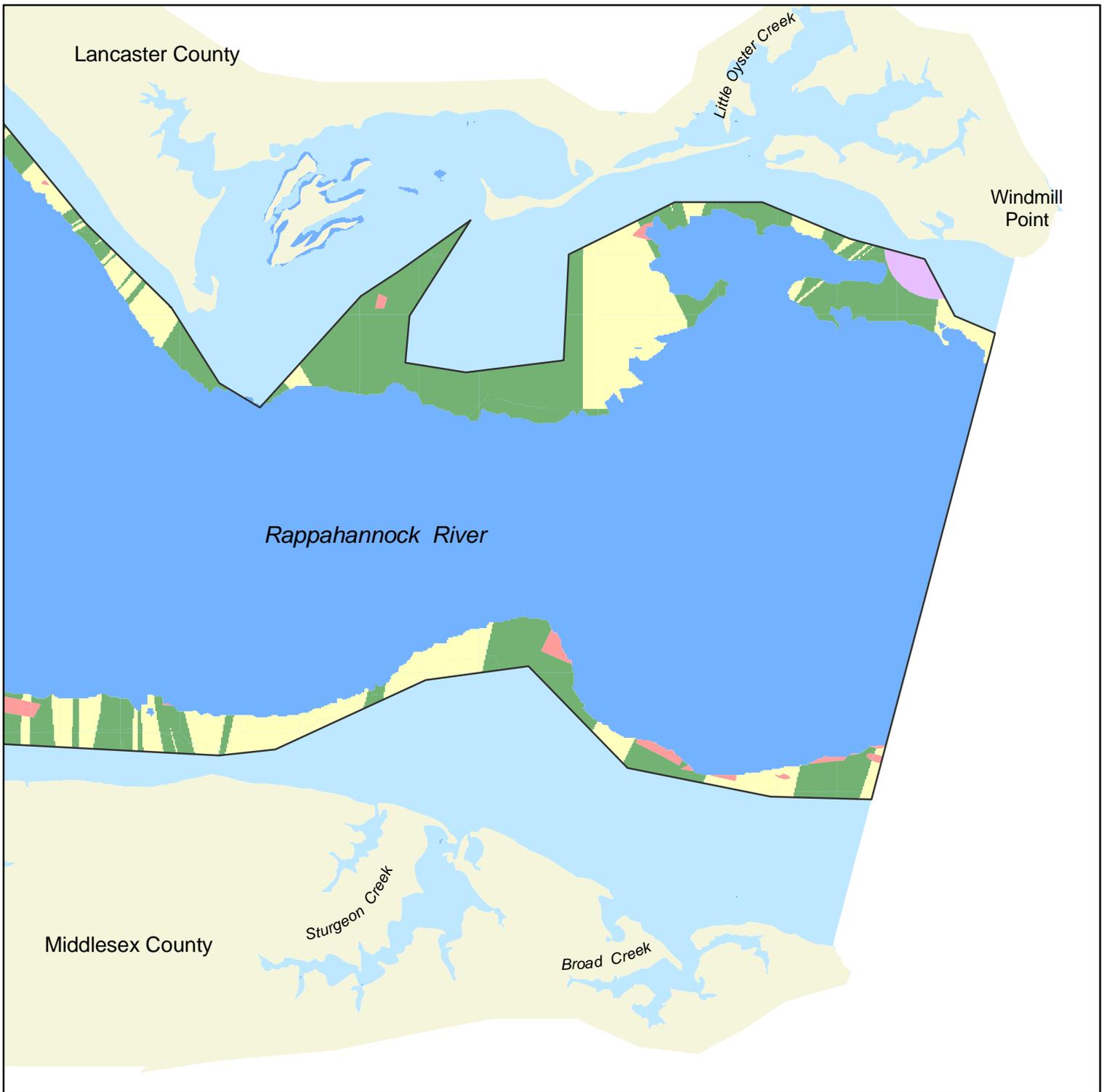
SHELLFISH AQUACULTURE SUITABILITY MAPS

Potential Oyster Aquaculture in the Lower Rappahannock River



Lower Rappahannock River Aquaculture Suitability within Baylor Grounds - Index





Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 1

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



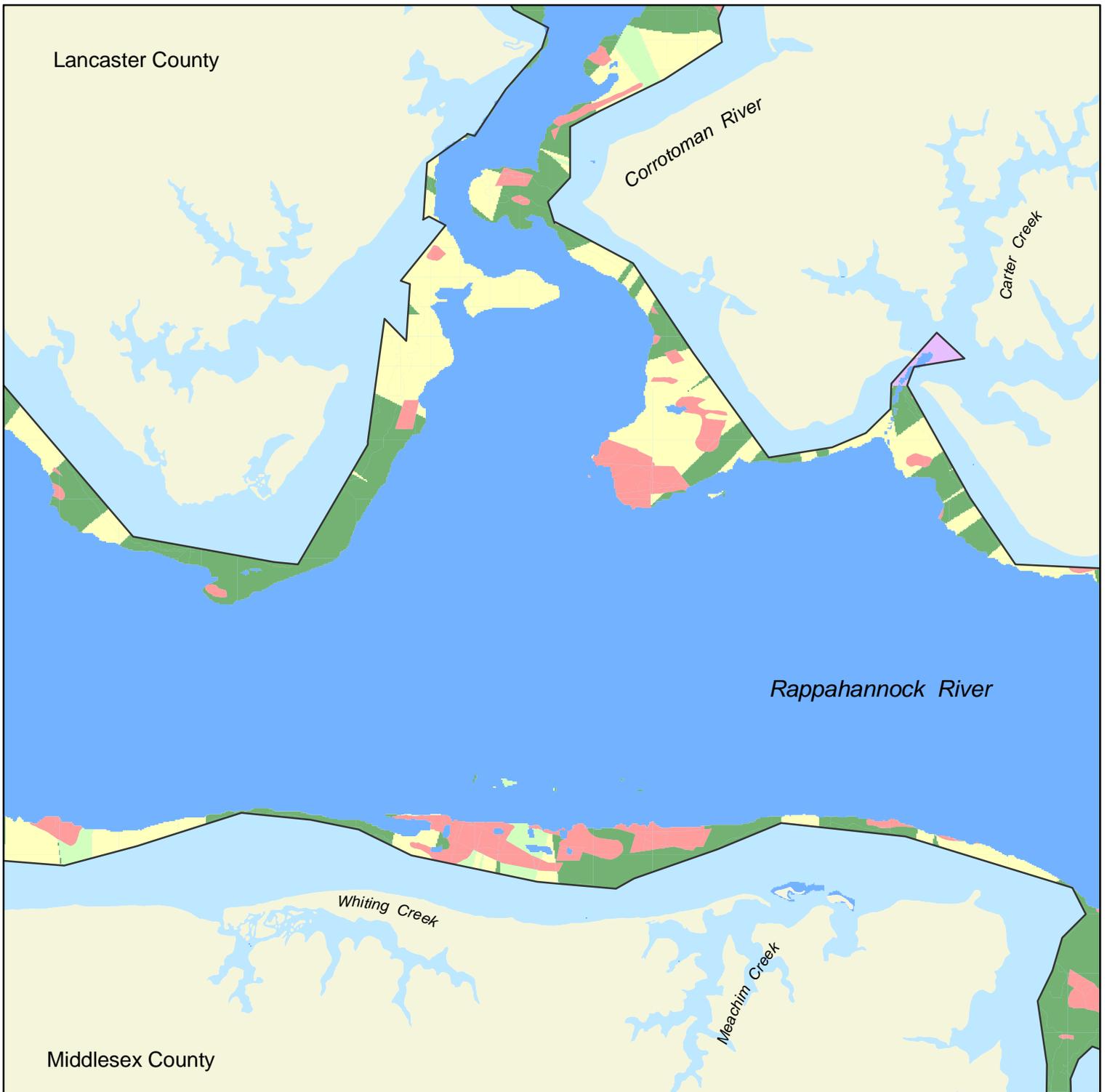


Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 2



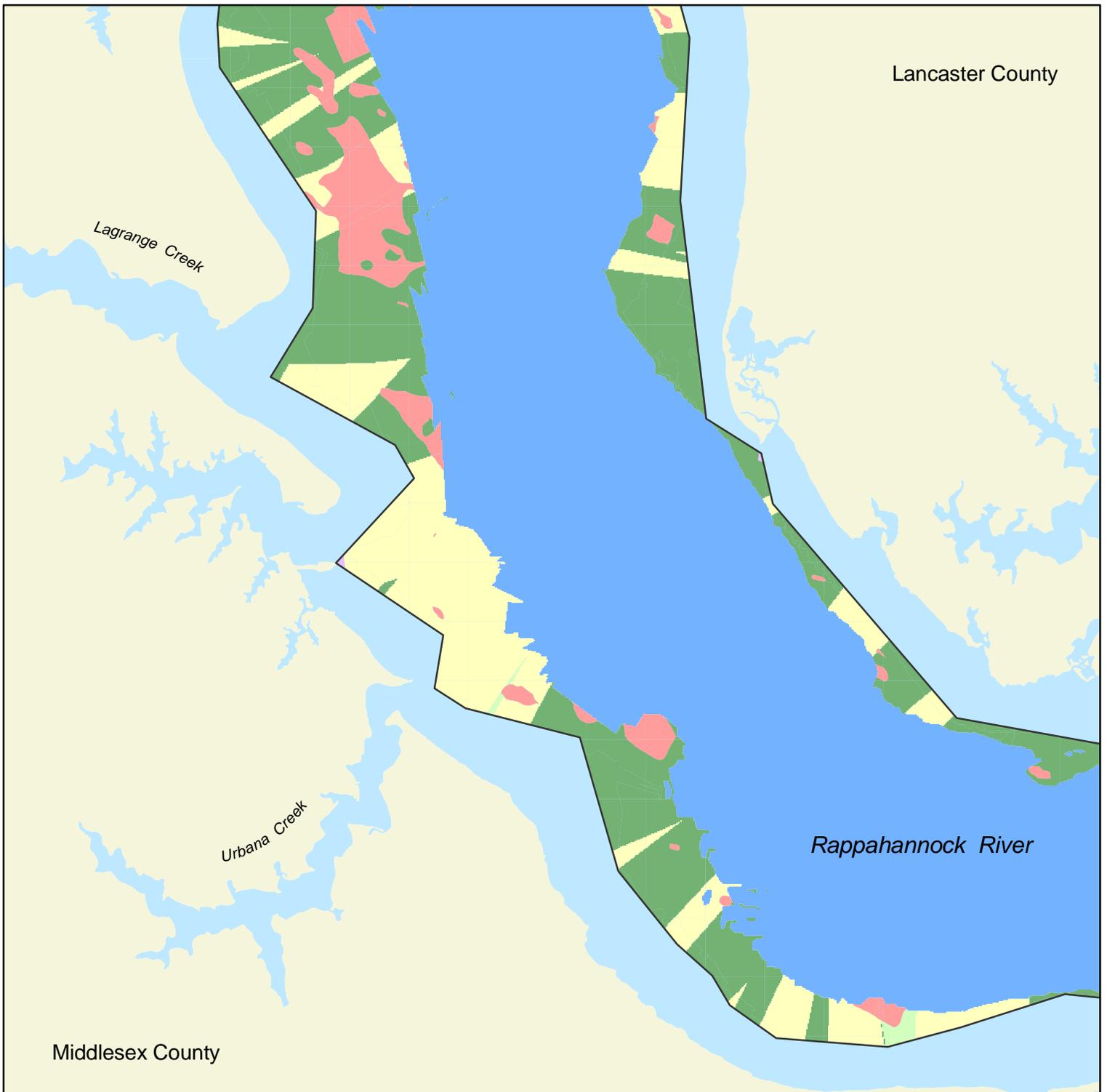


Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 3

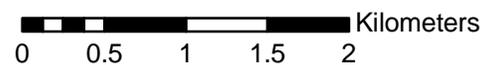


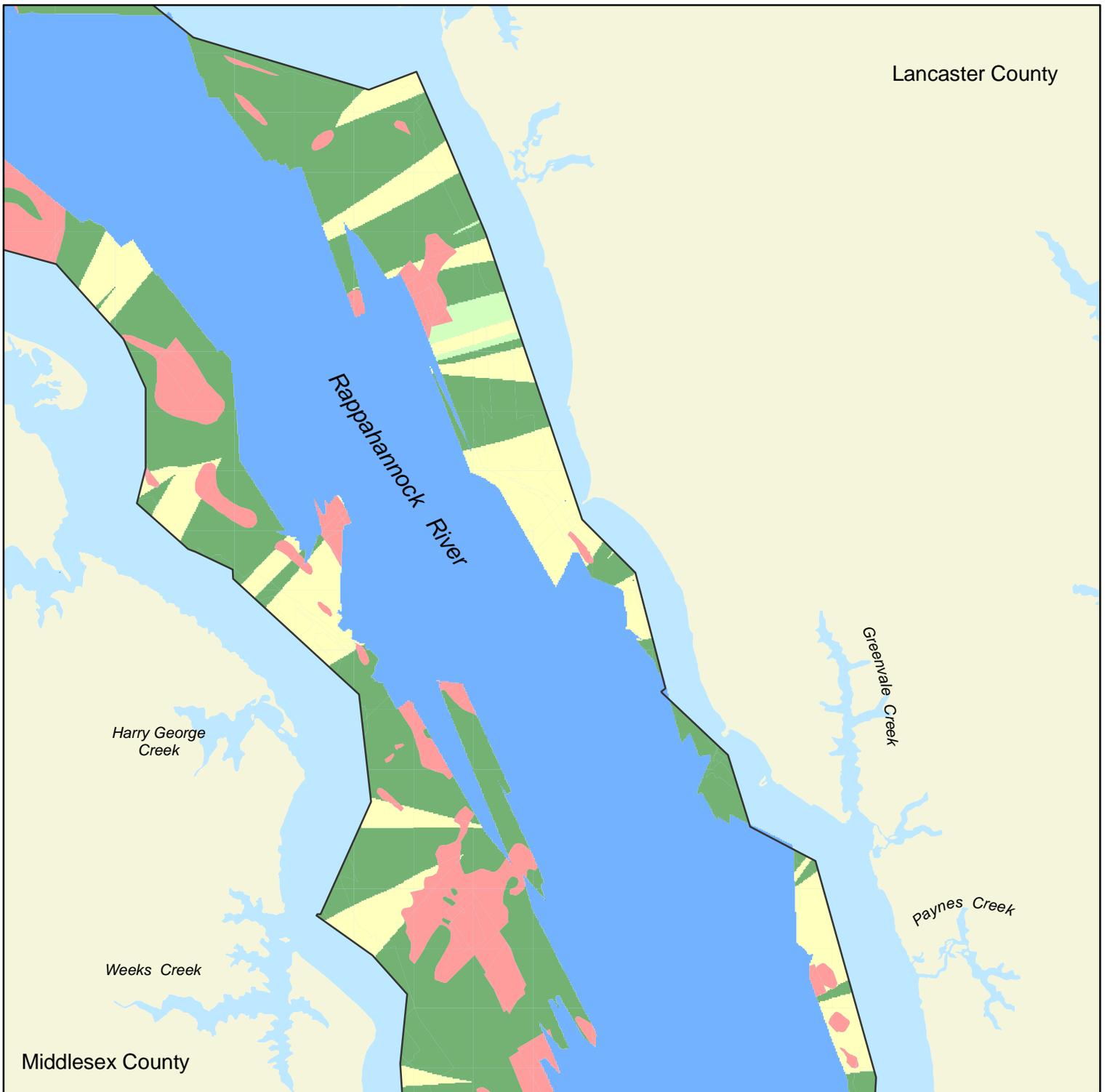


Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 4

Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable



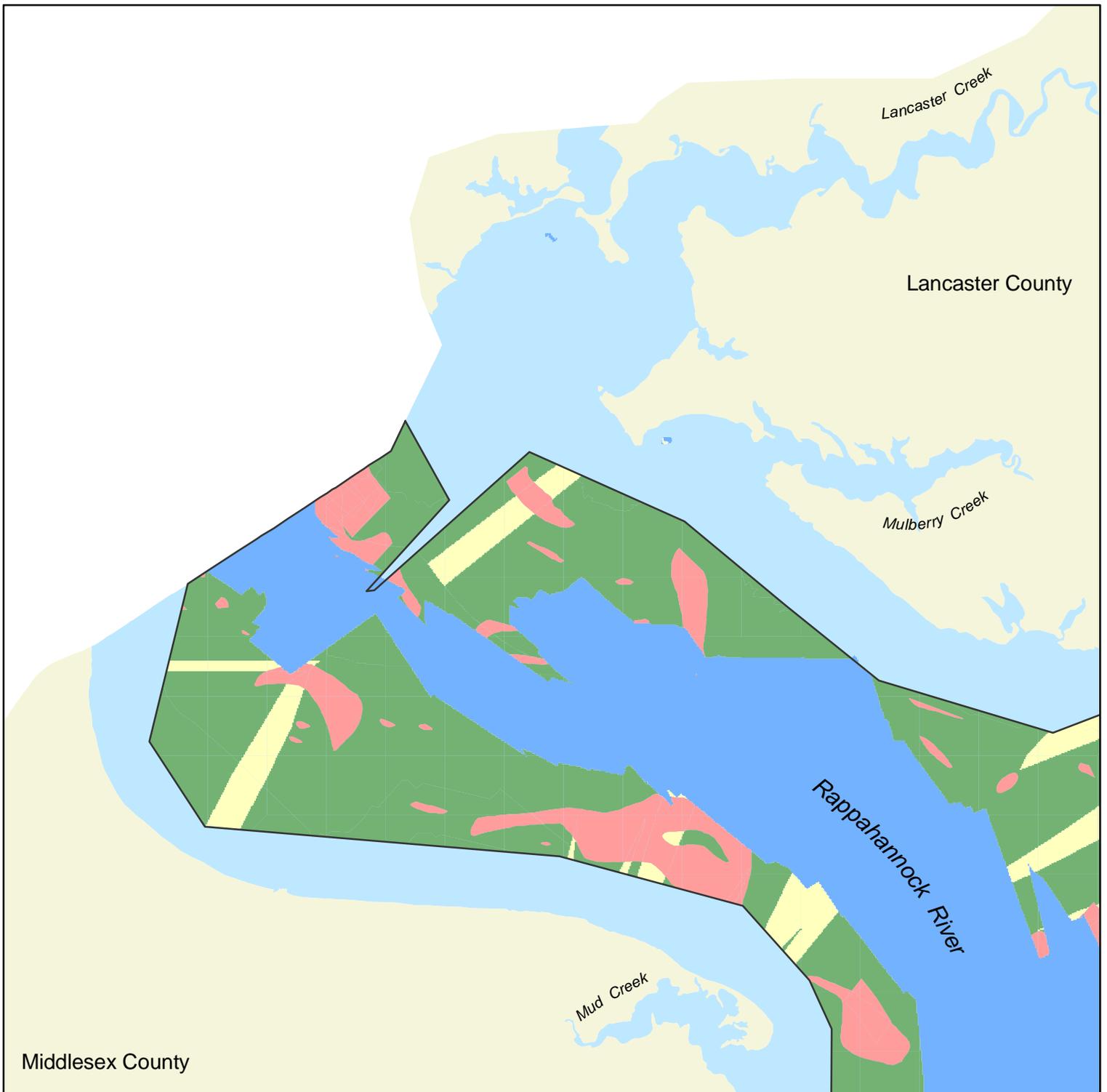


Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 5



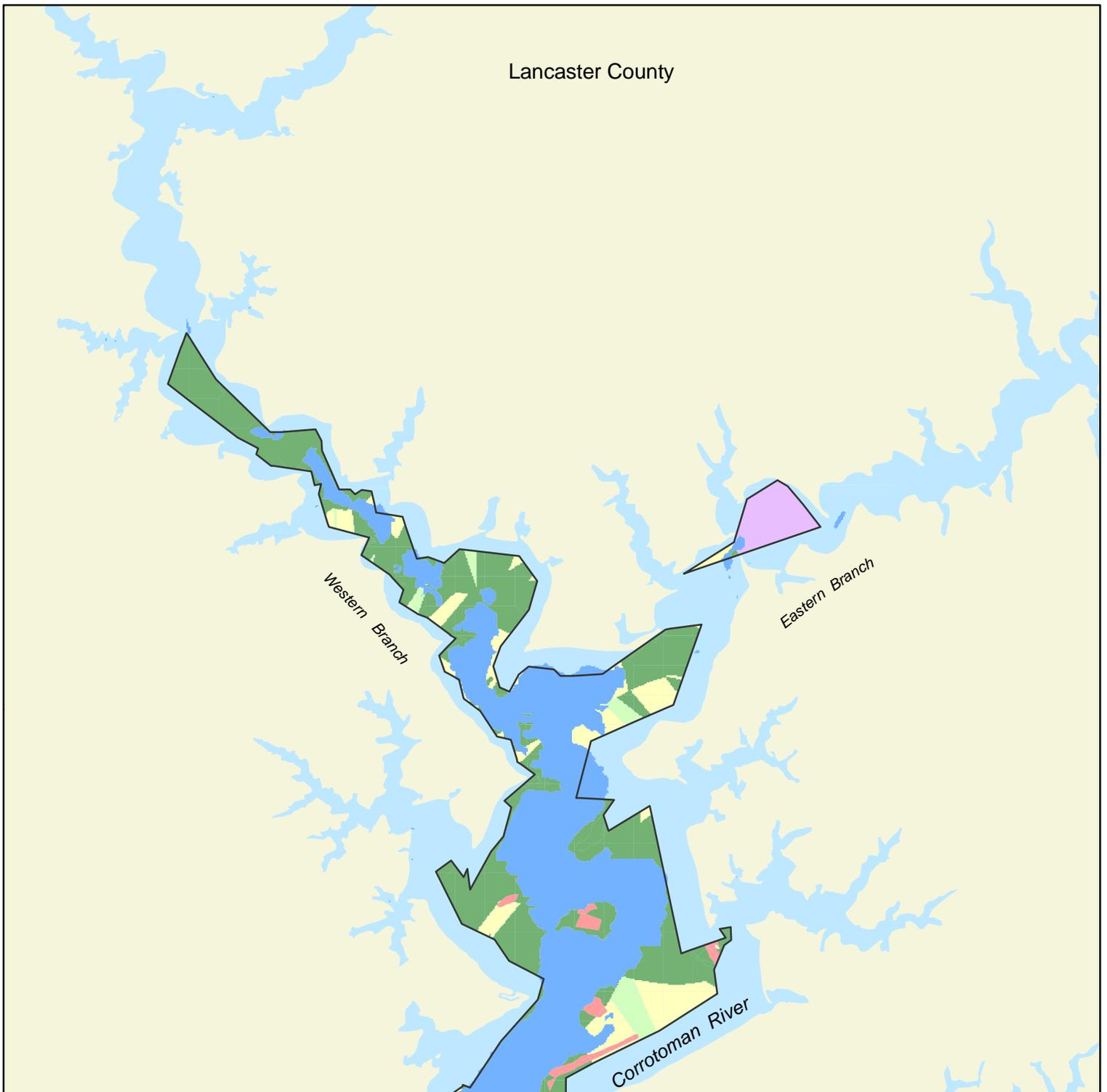


Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds
- Suitability Index**
- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 6





Legend

- depth 0 - 5m
- depth >5m - study limits for shellfish growing
- land
- Baylor grounds

Suitability Index

- optimal
- suitable
- existing H2O quality concerns
- potential H2O quality concerns
- future H2O quality concerns (not assessed in this study)
- unsuitable

Lower Rappahannock River Oyster Aquaculture Suitability Areas within Baylor Grounds Plate 7

