

2009

**THE EFFECTS OF SEA LEVEL RISE ON
TIDAL WETLANDS IN THE
LYNNHAVEN RIVER WATERSHED**



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Executive Summary

This study classified tidal wetlands for the Lynnhaven Watershed using remote sensing techniques and high resolution imagery from 2007. This updated delineation of wetlands, was used in conjunction with a simplistic geospatial elevation model to quantify the potential loss of wetlands under various sea level rise scenarios. The study revealed that using conservative estimates of sea level rise, nearly all wetlands would be lost by the year 2100. Projecting sea level rise into the future can be considered speculative, nevertheless such predictions are necessary to begin managing for and planning for climate change impacts. Evidence from this study suggests that upland infrastructure along portions of the watershed will also be at risk to sea level rise. This study documents where and how much potential loss of both wetlands and upland land area could be experienced given current and projected rates of sea level rise.

Introduction

Climate change has many implications. In the low lying lands that comprise Hampton Roads impacts associated with sea level rise, increased storm frequency, and tidal flooding present the greatest risks. The gradual increase in sea level along a low lying coast line typical of most of Virginia will slowly drown the upland land mass and decrease available space for intertidal marshes, terrestrial forests, and human habitation. Competition for space will occur.

Sea level rise in the Hampton Roads area has already been documented by analyzing long-term tide gauge records at various locations in the region. Median estimates for the lower portion of the Chesapeake Bay approach 4.1 mm/year (Boon, 2006). Even at this rate (0.67 ft in 50 years), we can no longer casually dismiss the impacts in our own lifetimes and certainly not in the coming generations. Future predictions suggest this rate will accelerate and may exceed twice this value.

Humans have been working tirelessly for decades to “hold back the sea”; utilizing a combination of landscape and engineering techniques to stabilize uplands and preserve their living space. Other ecosystems such as inter tidal marshes find themselves in a losing battle against these anthropogenic forces which work against a wetlands natural ability to migrate and keep pace with sea level rise.

We suspect that in developed watersheds where migration capacity of wetlands is reduced there is a greater risk of permanent wetland loss. Studies however suggest some of these developed watersheds still support healthy fish and benthic communities in part because intertidal wetlands exist as nursery and foraging grounds. The Lynnhaven River watershed is one of those systems (Bilkovic et.al, 2007).

The Lynnhaven River Watershed

The Lynnhaven River Watershed encompasses 64 square miles of urban development coupled with hundreds of acres of essential fish habitat including tidal marshes and submerged aquatic vegetation (Figure 1). One of the last remaining robust stands of maritime forest habitat resides in conservation land within the watershed. Lynnhaven comprises the largest estuary in the City of Virginia Beach and supports heavy recreational fishing, crabbing, and kayaking.

Development in the Lynnhaven River watershed consists primarily of single family residential housing. There are a few multi-family dwellings and service businesses such as restaurants and marinas directly on the river front. The shoreline has been extensively hardened along most of the development. Initial estimates based on surveys along 107 of the 139 miles of shoreline indicate 24% (26.12 miles) of the shoreline has been stabilized with bulkhead, riprap, or some other fastland protection (Berman et.al, 2007). This estimate rises to 29% if you exclude the marsh islands in the watershed. Neither estimate includes breakwaters or groin fields.

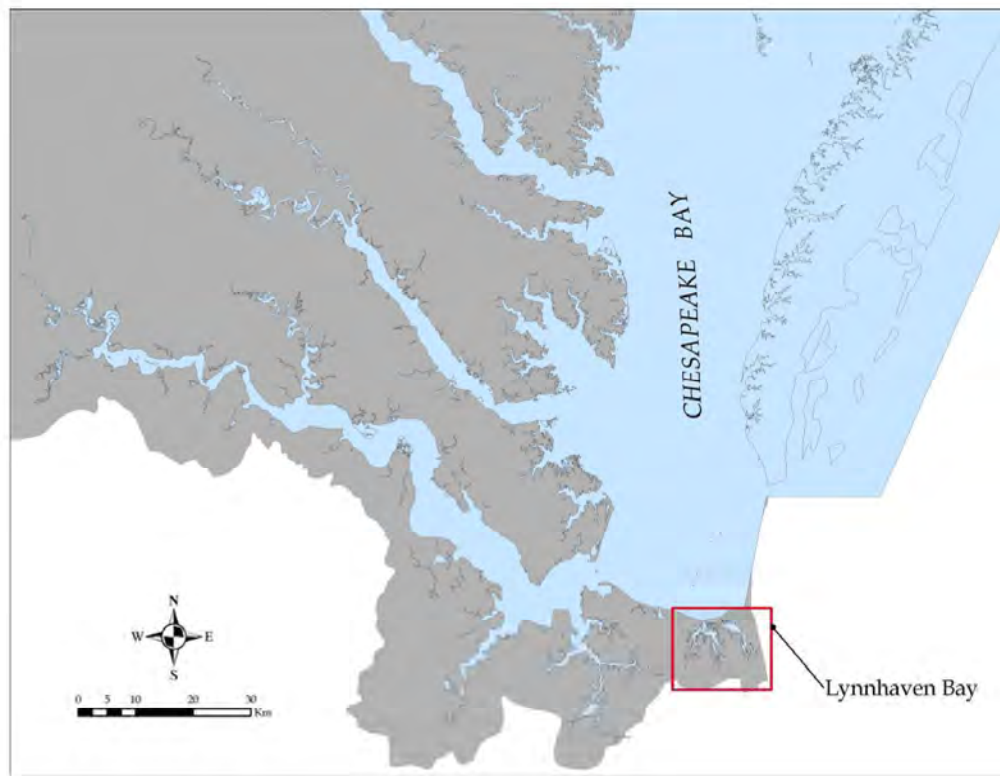


Figure 1. Location of the Lynnhaven River Watershed

Despite the development, there remain several extensive marsh complexes throughout the watershed. Marsh islands and fringe marshes dominate. Wetlands were last surveyed by the Virginia Institute of Marine Science (VIMS) in the 1970s using base maps dating back as far as the 1960s and crude mapping techniques by today's standards. More than 1100 acres of tidal wetlands were reported then (Barnard et.al, 1979). Since that time, development, storms, and climate change have potentially reduced and reshaped the tidal wetlands in the system. There is great interest in restoring these environs to enhance habitat and water quality improvement services throughout the system.

Project Objective

This project had two main goals. The first was to apply a remote sensing technique for mapping tidal wetlands from high resolution imagery and delineate current distribution of tidal wetlands for the Lynnhaven River watershed. This information will be important for supporting any future wetlands restoration efforts targeted for the watershed. It is also essential for the second major element of this project, which depends on a reliable wetlands base map in order to project future wetland losses associated with sea level rise.

The second project object was to estimate loss of tidal wetland habitat resulting from sea level rise over the next 25 and 50 years, respectively. Using current estimates of sea level

rise, a three dimensional spatial model was generated to project future shoreline position and determine the extent to which tidal marshes will be lost due to inundation. The modeling effort was conducted using geographic information system (GIS) technology and geospatial data from a variety of sources. The wetland delineation conducted in the first phase of the project serves as the baseline wetland condition. Although the spatial model applied was simplistic, it considered development and shoreline hardening as potential barriers to the sustainability of the wetland migration process.

Methods

This section describes the process for generating an updated tidal wetlands delineation and map and the process for modeling sea level rise and the subsequent loss of wetlands due to inundation.

Tidal Wetlands Delineation

From the high resolution natural color image library available through the Virginia Base Mapping Program (VBMP), a mosaic of image tiles from 2007 covering all branches of the Lynnhaven River and Broad Bay was compiled digitally and re-projected to a Universal Transverse Mercator (UTM) projection in meters.

A selection of training samples representing a large and diverse group of wetlands within the system were digitized from the high resolution (1 foot) mosaic using ERDAS Imagine Easytrace. These selected sites would be used as training samples to guide the automation of the remote sensing delineation of the wetlands.

To speed processing the high resolution mosaic was re-sampled 4X; which still maintained a suitable resolution for delineating tidal marshes, but saves hours of processing time for each iteration.

Two working image products were generated from the re-sampled image. The first was a texture image that was generated using variance in pixel values as well as a 5x5 restriction on pixel size. The second image was an IHS Image (Intensity, Hue, Saturation) which was converted from the original RGB (Red, Green, Blue) spectral image. Working with an IHS image has advantages and can assist with image processing for imagery that are not truly multi-spectral (e.g. natural color). Both products would become the image platform for the delineation of tidal wetlands.

The actual detection of tidal marshes was achieved using Feature Analyst software for Arc Info. Working with the three image products (re-sampled original, IHS image, and the texture image) the training samples were run through multiple iterations which varied input parameters such as spectral bands; pixel aggregation; and various masks, until the best desired result was achieved. Clutter removal refined the best available parameters by removing non-wetland polygons. Once optimal parameters were selected, iterations were performed on the entire image.

The delineation of tidal wetlands represents conditions mapped from 2007 imagery (Figure 2) . This GIS coverage was reviewed visually and against ancillary data including recent oblique aerial photography for accuracy and QA/QC.

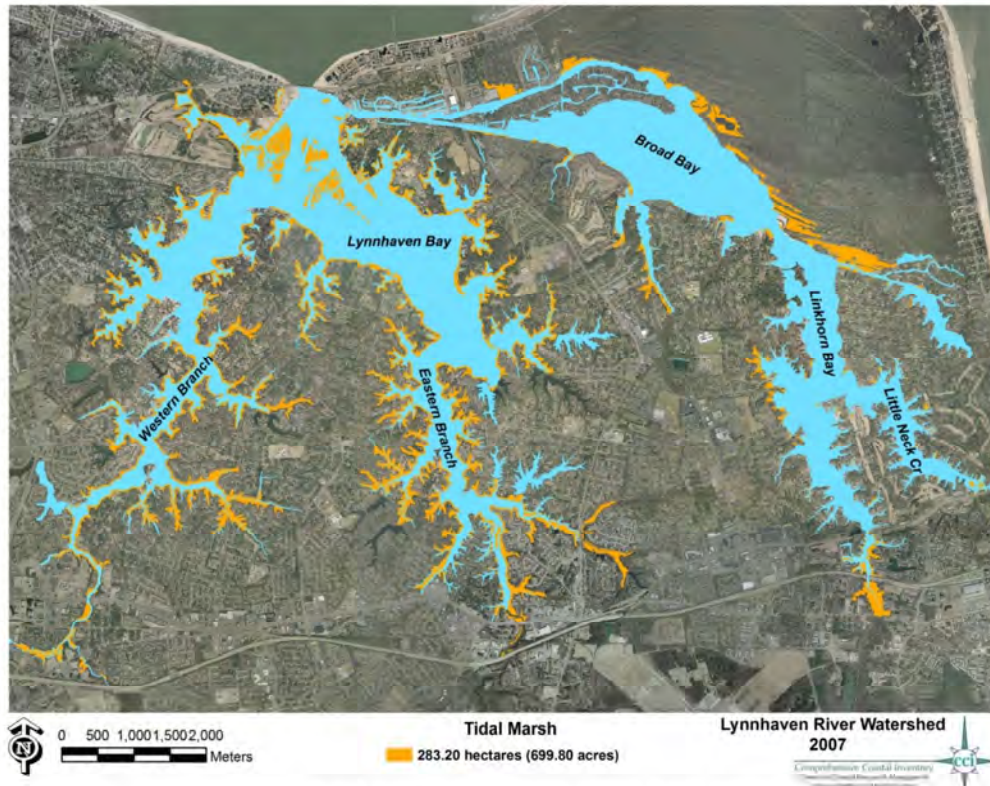


Figure 2. Delineation of tidal marshes from 2007 high resolution imagery.

Sea Level Rise Scenarios

For this study mean sea level (MSL) was established as the referenced baseline relative to the North American Vertical Datum of 1988 (NAVD88). High resolution (6 inches) topographic elevations collected using LIDAR (light detection and ranging) were acquired from the City of Virginia Beach. Using the boundary of the Lynnhaven Watershed, LIDAR points for the study area were selected from the larger Virginia Beach dataset.

A triangular integrated network or TIN was constructed in the 3D Spatial Analyst module of Arc Scene to generate a three dimensional topographic surface from the LIDAR data points using the height attribute “z”. This surface was used to examine inundation under rising sea level conditions.

Several different sea level rise scenarios were used (Table 1). The original study objective used a highly conservative sea level rise of 4.1 mm/year, and proposed to map conditions 25 and 50 years out from the baseline year. The year 2007 is considered the

baseline year for this study, so the project initially mapped MSL in the year 2032 and 2057 with a maximum sea level rise of 102.50 mm (0.34 ft) and 205 mm (0.67 ft), respectively.

Since many studies now ongoing in the region were using the year 2100 to forecast climate change impacts, we also elected to extend the analysis to 2100. We recognized that our originally proposed 4.1mm/year rise was not appropriate for projections as far out as 2100. With the anticipation that rates of sea level rise will be greater in the future we elected to use two different scenarios for the 2100 projection; 7.35 mm/year and a worst case scenario of 17.20 mm/year. These rates are consistent with other studies being done in the region (Bilkovic et.al, in progress), and suggested in the literature (Pyke et al, 2008; Rahmstorf, 2007).

Table 1. Projected rise in sea level (mm) above MSL from base year 2007

Sea Level Rise Scenarios (mm/yr)	Year 2032 (mm)	Year 2057 (mm)	Year 2100 (mm)
4.1	103	205	n/a
7.35	n/a	n/a	683
17.20	n/a	n/a	1600

Using sea level rise projections reported in Table 1, the forecasted MSL position associated with each scenario was generated using the Surface Analyst module of ESRI's 3D Analyst. A new MSL contour position was computed for each iteration.

Calculating Wetland Loss

Historic maps and aerial photography suggest marshes have sustained themselves despite evidence of rising sea level. Reed (1995) maintains that vertical accretion must be occurring at a rate equal to, or faster than sea level rise for this to occur. However, studies report that once sea level rise exceeds 3.0 mm/year marshes will be unable to vertically accrete fast enough to keep pace. Since future predictions exceed 3.0mm/year we expect to see marsh complexes erode or drown in place. This theory provides the rationale for the simple spatial model applied in this study.

While marsh accretion is possible in areas, this study also does not attempt to predict marsh accretion in new areas. This would require an analysis of data pertaining to erosion and sediment deposition rates in the Lynnhaven River in order to evaluate the potential for new marsh surfaces to form. This level of forecasting was beyond the scope of the project.

Since MSL is the baseline datum in this study, any wetland currently below this contour would need to be eliminated from the analysis. A preliminary analysis was conducted to compare the wetlands data with respect to the topographic surface generated. The analysis revealed 11.08 hectares of wetlands presently sit below the current MSL shoreline. In order to assess the impact that sea level rise would have on these wetlands we would need data to support contour generation below current MSL. Since this was not available, we could not assess change in these areas. Therefore, from the total of 283 hectares of tidal wetlands delineated from the 2007 baseline imagery, sea level rise impacts could only be assessed for 272.26 hectares. Those wetlands eliminated from the analysis were generally found along the headwaters. The largest concentration of these wetlands is found in the headwaters of the Western Branch (Figure 3).

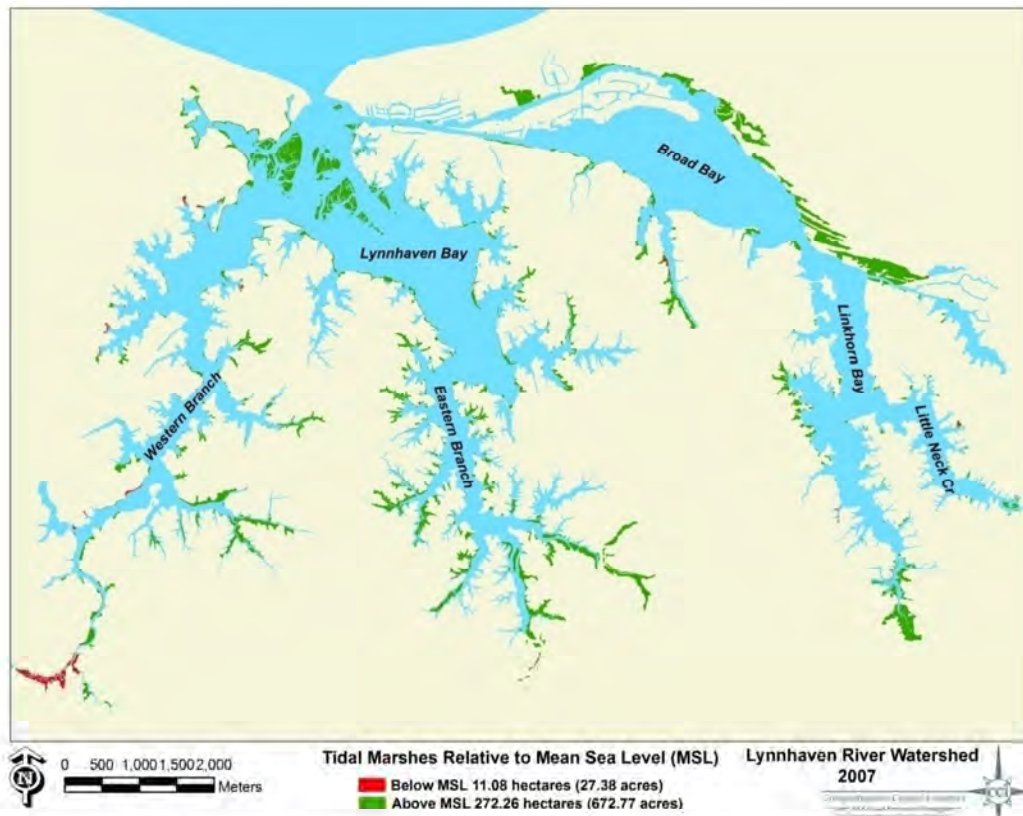


Figure 3. Location of wetlands residing below MSL is shown in red. Wetlands illustrated in green are wetlands used in the analysis.

The remaining 272 hectares of wetlands which currently exist at or above MSL are analyzed for change based on the sea level rise rates reported in Table 1. Future MSL contours, generated using ESRI's 3D Analyst techniques discussed above, are juxtaposed to the 2007 baseline wetland delineation. The new area of wetlands above the projected MSL contour is computed and the loss is calculated as the difference between the new area and the original baseline delineation (see equation below). The steps are repeated for each sea level rise scenario proposed.

e.g. wetlands (2007) – wetlands (2032) = wetlands change

Maps were developed for illustrative purposes to spatially display where the wetlands at greatest risk were located in the watershed. These are found in Appendix A-F.

Assessing the Probability for Marsh Transgression

There is a lot said about the opportunity for marshes to migrate landward. This transgression means a conversion of upland habitat to marsh environments; most likely a gradual intrusion of salt tolerant species replacing a dying community of terrestrial habitat unable to handle the periodic increase of salt water inundation. In many regards, land use practices control this landscape transition, and development combined with anthropogenic alterations contributes to the availability of “space” for the migration process to occur. This study assesses the potential for habitat migration by delineating areas adjacent and inland of tidal marshes where land use provides the opportunity for transgression across the landscape.

Using data collected as part of the Lynnhaven Bay Shoreline Inventory (Berman et al, 2007), riparian land use and presence of shoreline structures could be geographically associated with the location of tidal wetlands delineated as part of this study. The shoreline inventory uses field observations, GPS and GIS to classify conditions along the shoreline. This study included any developed riparian land use class or erosion control structures that attach to the fastland as a feature that could inhibit wetland transgression. Groins and jetties were not included. Shorelines did not have to be artificially stabilized. They could be artificially stabilized, developed, or both to be highlighted.

Calculations were made to delineate and compute the relative miles of shoreline where these conditions persisted in conjunction with the presence of existing marsh. Marsh islands were ignored in this analysis since they are more likely erode or drown in place.

Assessing the Probability of Impacted Upland Areas

Using a projected MSL position in the year 2100, the study also examined the loss of upland due to inundation. This analysis was not originally proposed, but was of great interest to local planners with the City of Virginia Beach, and with the non-government organization (NGO) Lynnhaven River NOW, a local watershed association. The analysis computed upland that was inundated daily at some point in the tidal cycle following a 1600mm rise in sea level. By masking out wetlands and water, the uplands inundated by the projected rise in sea level could be easily mapped. Losses associated with this include residential areas, road networks, public parks, community resources and public utilities. Appendix E and F show the upland losses.

Results and Discussion

Results

The delineation of tidal wetlands in the Lynnhaven watershed is illustrated in Figure 2. Individual maps are located in Appendix A. A total of 283 hectares were delineated. The analysis was run on 272.26 hectares; those wetlands above the baseline MSL elevation in 2007. The projected loss of wetlands under the forecasted sea level rise scenarios are reported in Table 2. The results indicate that even under the most conservative estimates for sea level rise, we stand to lose nearly 30% of all the wetlands in the watershed over the next 50 years. The modeling results using the accelerated sea level rise projections indicate by the year 2100, 95% and 100% of all wetlands will be gone under sea level rise rates of 7.35mm/year and 17.20mm/year, respectively. Maps illustrating the distribution of these losses are found in Appendices B-F.

Table 2. Summary of wetland losses modeled using various sea level rise projections.

Rate of Sea Level Rise (mm/yr)	Wetlands Lost/Remaining 2032 (hectares)	Wetlands Lost/Remaining 2057 (hectares)	Wetlands Lost/Remaining 2100 (hectares)	Map Appendix
4.1	34.17/238.22	81.12/191.27	n/a	B and C
7.35	n/a	n/a	258.56/13.83	E
17.20	n/a	n/a	272.26/0	F

These estimates do not account for vertical accretion that may occur or horizontal transgression. As discussed above, the opportunity for horizontal transgression depends on several factors. Ideally a low sloping naturally maintained landscape like the one illustrated in Figure 4 is optimal for promoting sustainability.



Figure 4. An example of a natural coastal profile to allow for tidal marsh transgression across the upland (courtesy of University of Maryland Center for Environmental Science)

Development, however, impacts the potential for this transition to occur. Since the Lynnhaven River is a highly developed watershed, the probability is quite high that transgression will not occur and losses will approach those reported in Table 2. We spatially compared the location of tidal fringe or embayed wetlands with the location of erosion control structures and development.

The watershed has 429 km of shoreline. Tidal wetlands grow along 205 km of the shoreline. Development is coincident with wetlands along 174 km of the shoreline. This suggests that the majority of the wetlands (85%) are at high risk. They are aligned with shoreline where development and land use practices typical of developed areas elevates their risk of survival under rising sea level conditions. Figure 5 indicates where these areas are located.

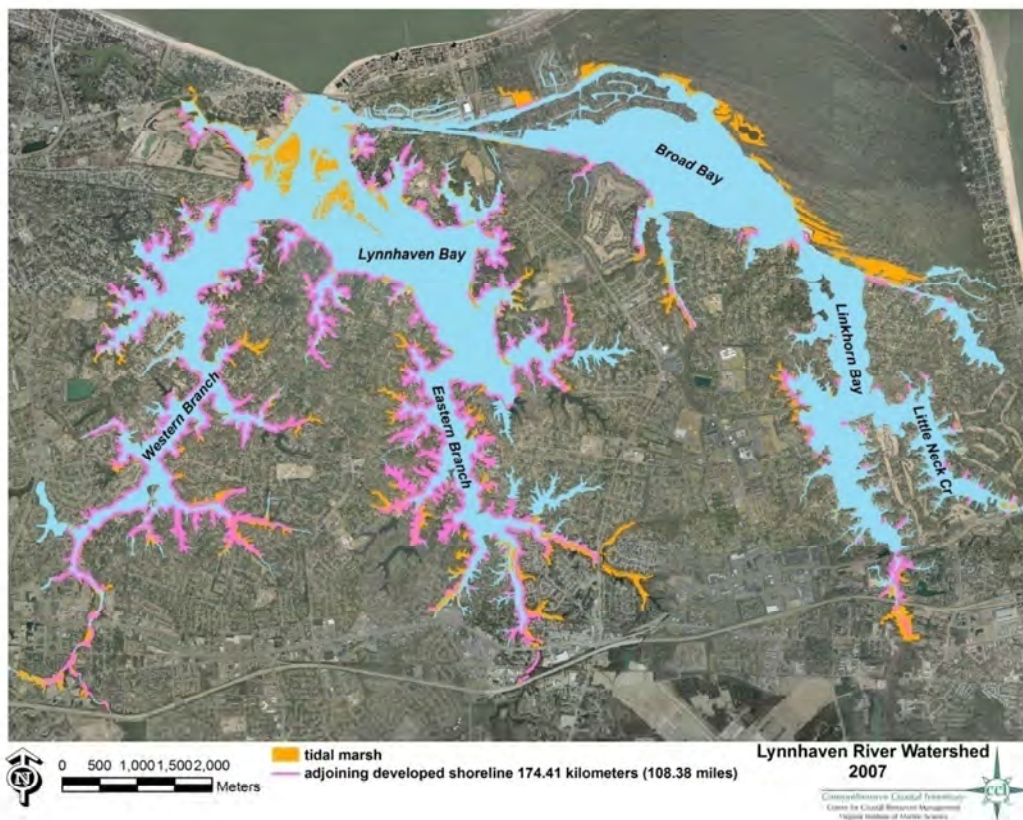


Figure 5. Development adjacent to tidal wetlands is highlighted in pink and accounts for 174 km of the shoreline. Note, development occurs elsewhere along the shoreline, however only areas coincident with wetlands are illustrated.

A large portion of the wetlands not in this high risk group are found in Broad Bay and flank the maritime forest habitat found in First Landing State Park. Since this is

undeveloped protected land, there is the potential for a natural vegetative transition to take place. Wetlands, therefore, could very likely migrate inland with sea level rise. However, this could mean a loss of maritime forest habitat in the future.

A closer examination of upland impacts was also assessed. Naturally, risk to community infrastructure is of great interest to government planners and private property owners. Using the same scenarios discussed above we looked at the projected MSL shoreline position with respect to upland in the years 2032, 2057, and 2100. We calculated upland land loss for each of these scenarios as the amount of upland below the forecasted MSL position. Table 3 summarizes the results. Maps detailing where these upland losses could occur are found in Appendix E and F for projections out to the year 2100.

Table 3. Amount of upland land loss due to sea level rise.

Rate of Sea Level Rise (mm/yr)	Uplands Submerged 2032 (hectares/acres)	Uplands Submerged 2057 (hectares/acres)	Uplands Submerged 2100 (hectares/acres)
4.1	17.67/84.43	36.74 / 90.80	n/a
7.35	n/a	n/a	259.89 / 642.20
17.20	n/a	n/a	1109.81 / 2742.39

Small losses occur over the next 50 years. However residential property loss is evident by the year 2100 using the more conservative sea level rise forecast (7.35mm/year). These losses occur primarily along the canal running parallel to the eastern side of the entrance to the Lynnhaven River. These losses are much more significant when we consider an accelerated rise of 17.20 mm/year projection which results in a 1600mm rise in sea level. Overall, the majority of the loss occurs within the state park, however substantial residential and commercial development is at risk (Figure 6).

Figure 7 is a close up of the region within the watershed where the greatest threat to development is projected if a 1600mm sea level rise holds true. The areas highlighted in red represent those that could be inundated daily during high tide. Roadways will be impassable and unless elevated, structures will have to be abandoned. Wetlands adjacent to the development will most likely be converted to subaqueous habitat. Further to the east along Broad Bay, however, upland vegetation along the marsh-upland interface could convert to wetlands.

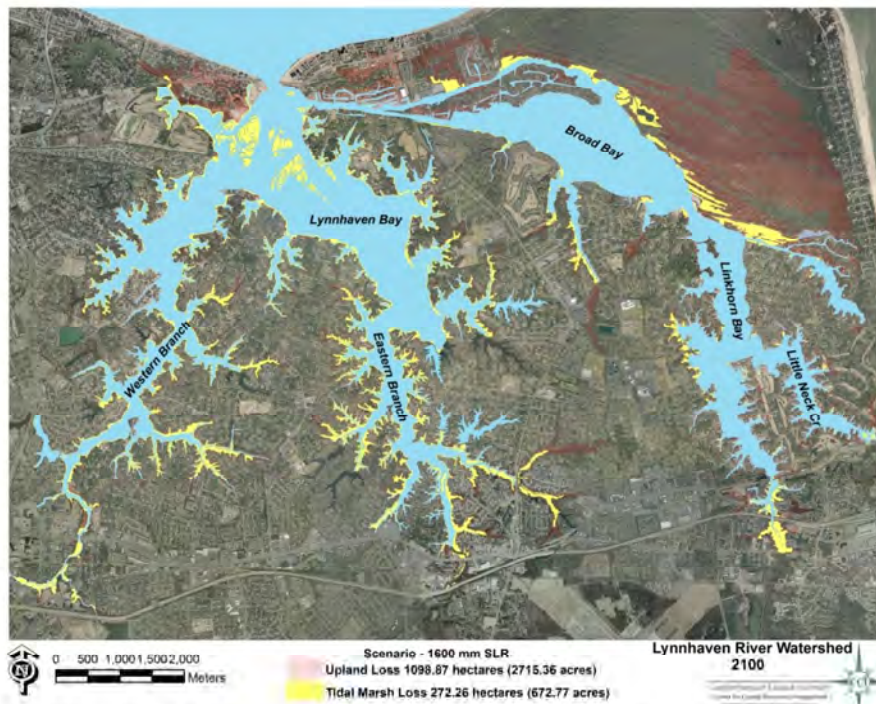


Figure 6. Delineation of projected upland and marsh loss associated with a 17.20mm/yr rise in sea level.

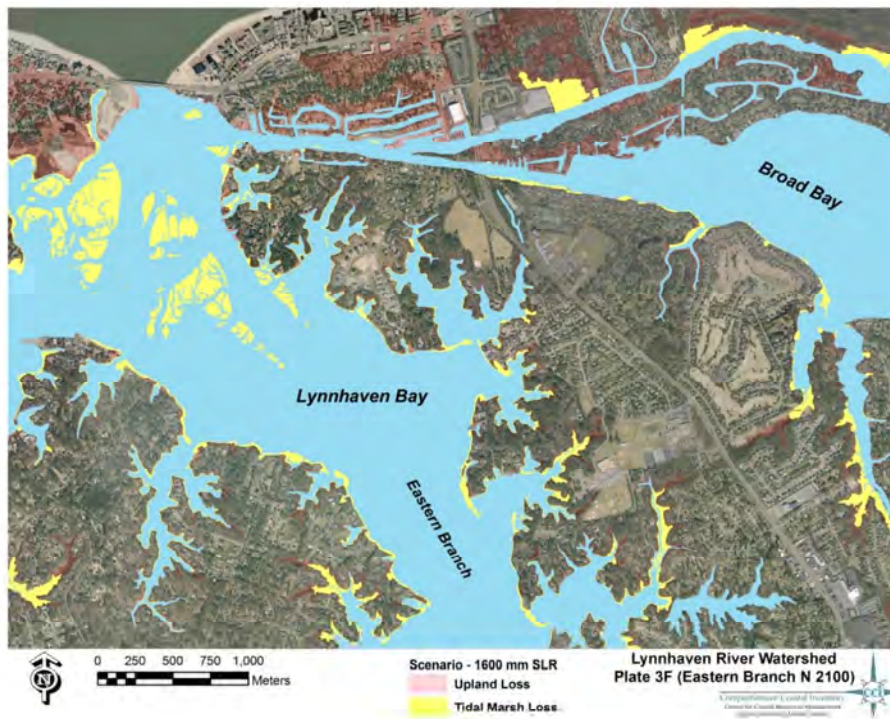


Figure 7. Detailed view of highly impacted development shown in red

Discussion

The Lynnhaven River Watershed will face some important management decisions in the coming years. There is clearly a risk to both intertidal wetlands and upland communities resulting from sea level rise. Even under the most conservative scenarios there will be loss to existing wetlands. In the coming century virtually all tidal wetlands could be lost.

The capacity for intertidal marshes to sustain themselves is greatly enhanced if landscape conditions allow for the natural progradation of the coastal landscape inland. This effectively means transitioning from upland conditions to intertidal conditions with increasing salt water intrusion.

Managing the coastal landscape with this in mind is critical. Local governments and NGOs should advocate for soft structural stabilization that minimizes impact to the natural coastal profile illustrated in Figure 4. The living shoreline approach will minimize physical barriers to migration commonly associated with structures such as riprap and bulkheads. The benefits of a living shoreline include erosion protection. A spatial model to delineate locations where these treatments are appropriate has been developed by the Center for Coastal Resources Management. The output of this model would lend itself to a Shoreline Management Plan which provides guidance for managing coastal issues such as erosion control and sea level rise.

While the Lynnhaven River Watershed is already heavily developed city officials can make choices on how to utilize or manage the last remaining undeveloped space on the upland. The study results can be used to identify areas like these that are adjacent to tidal wetlands. Setting these areas aside through conservation easements or land acquisition will provide the necessary corridors to allow for wetland migration into the future. It is understood that this could likely result in loss of essential tax revenue. Ultimately the city must make a choice with respect to a future watershed with or without wetlands.

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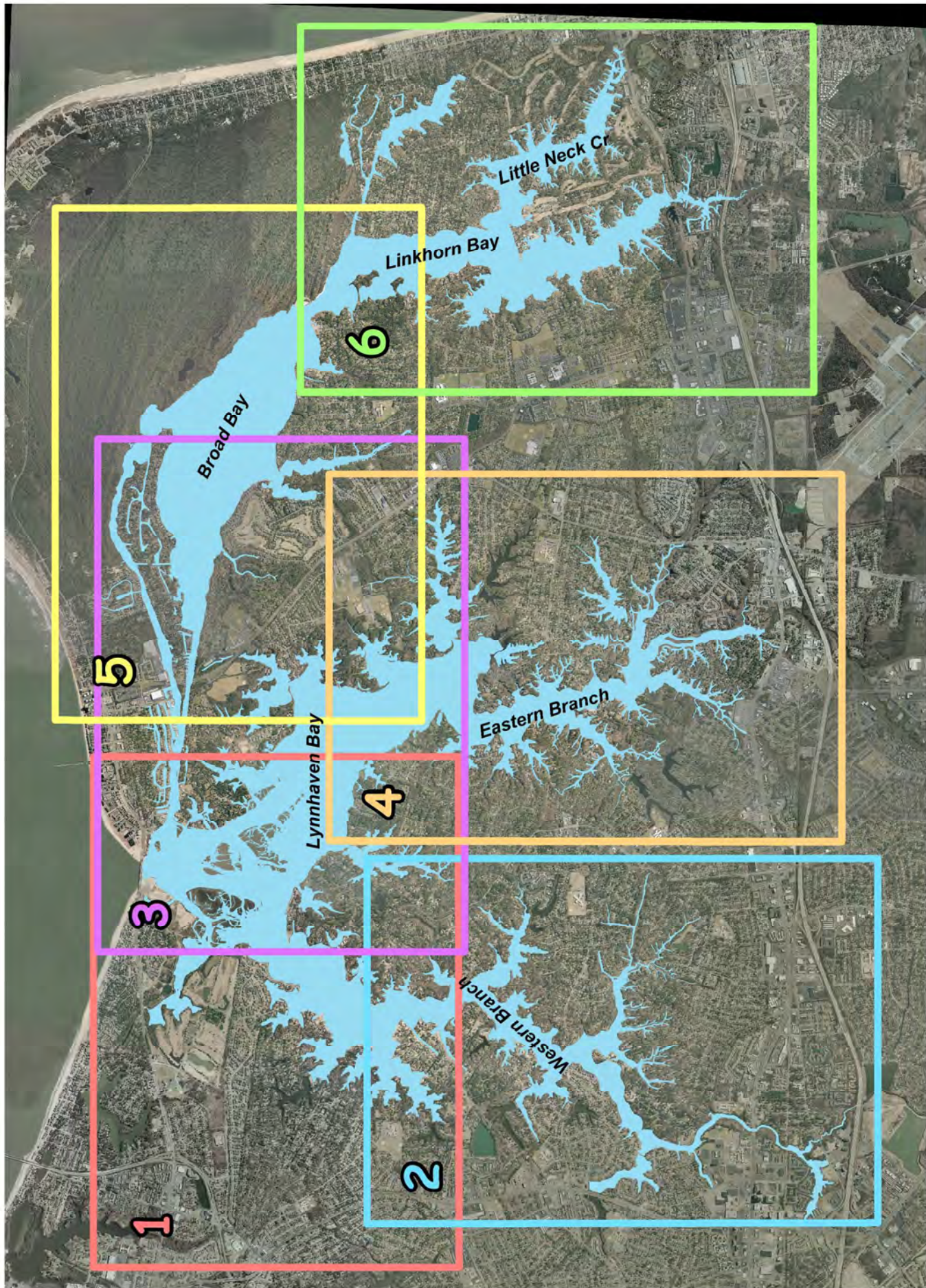
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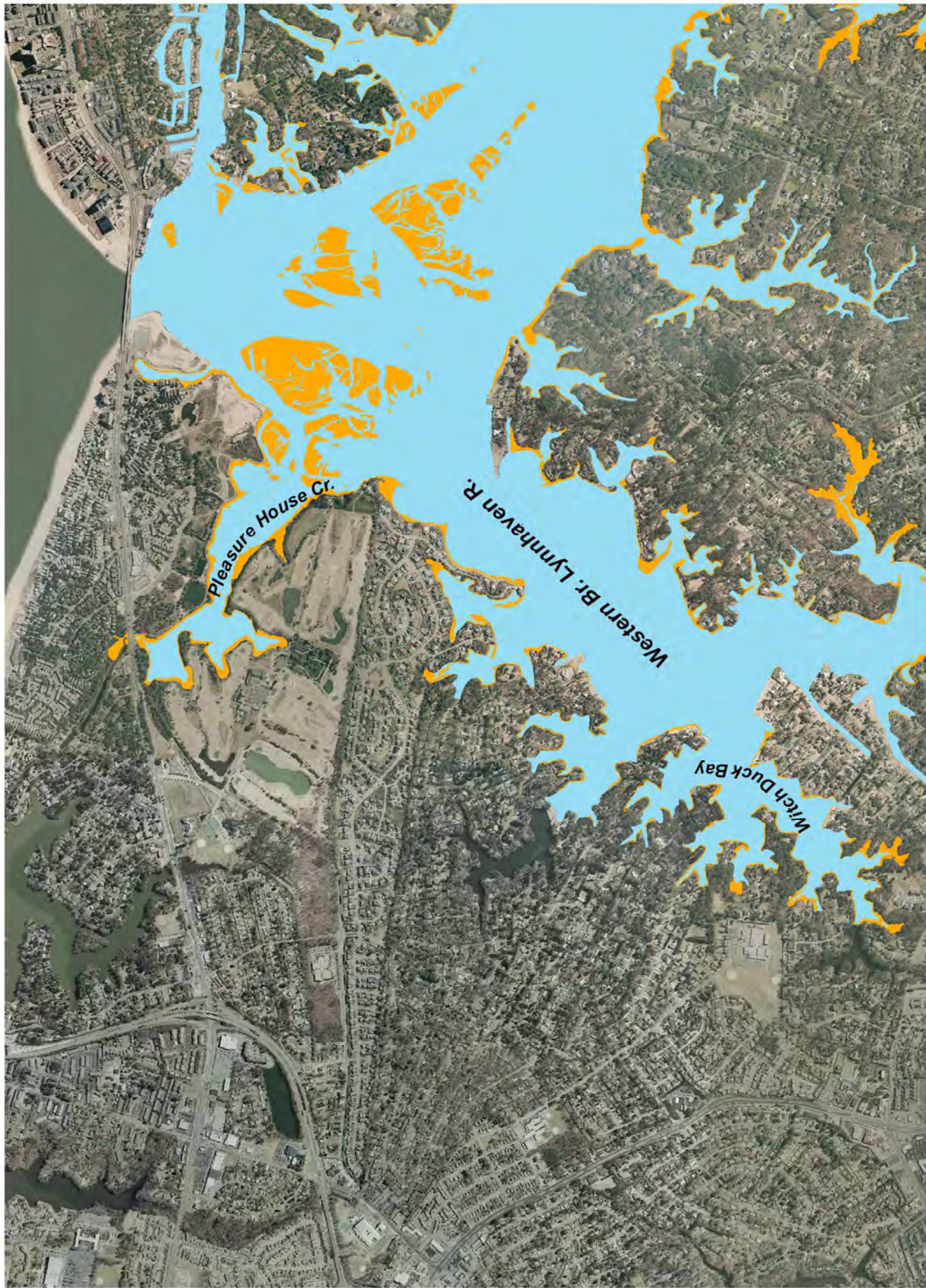
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MAP APPENDIX A – Tidal Marsh Delineation (Maps 1-6)

Baseline Model Condition:	year = 2007
Total Wetlands:	272 hectares

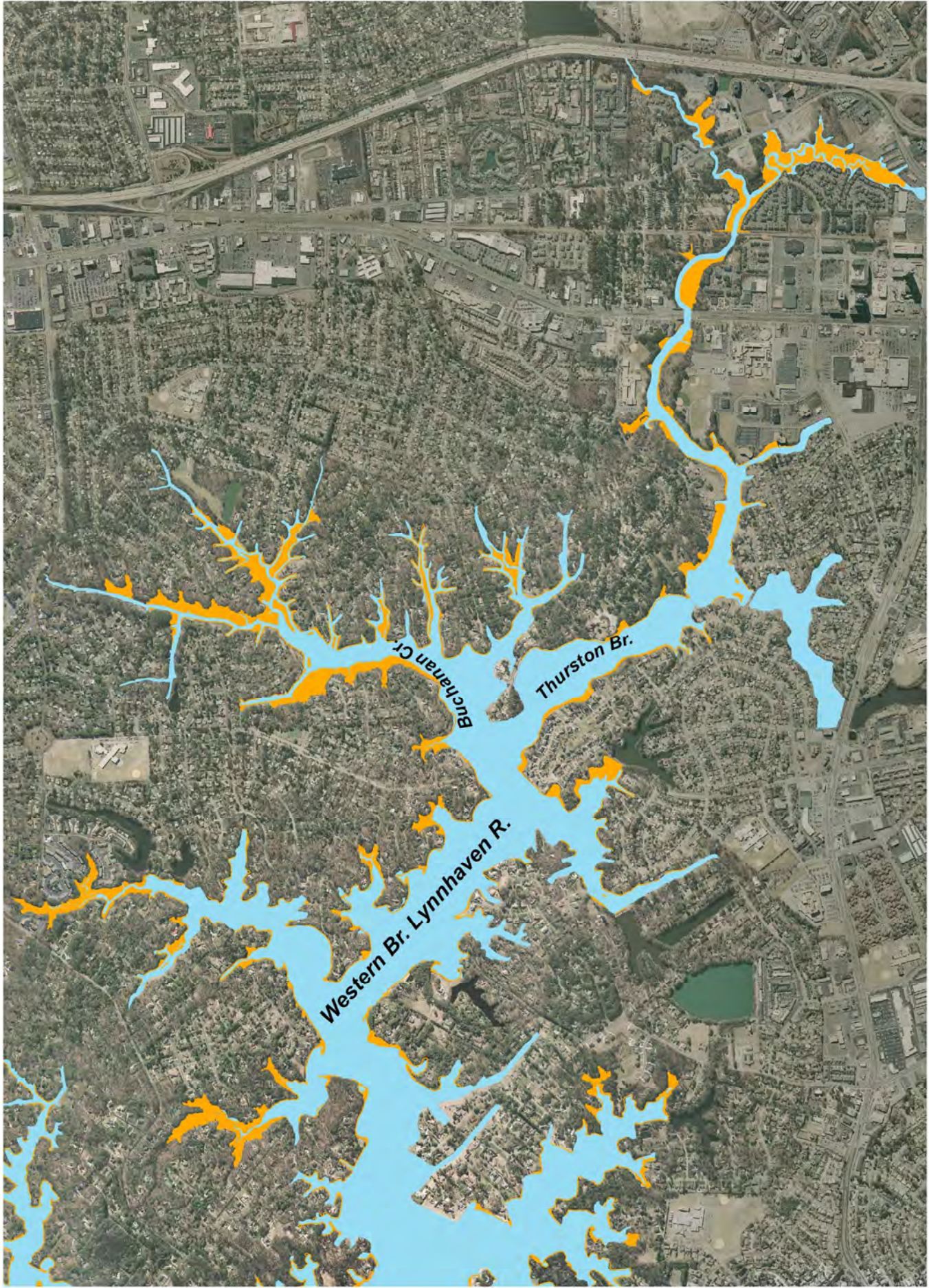




Tidal Marsh



Lynnhaven River Watershed
Plate 1A (Western Branch N 2007)



Tidal Marsh



**Lynnhaven River Watershed
Plate 2A (Western Branch S 2007)**



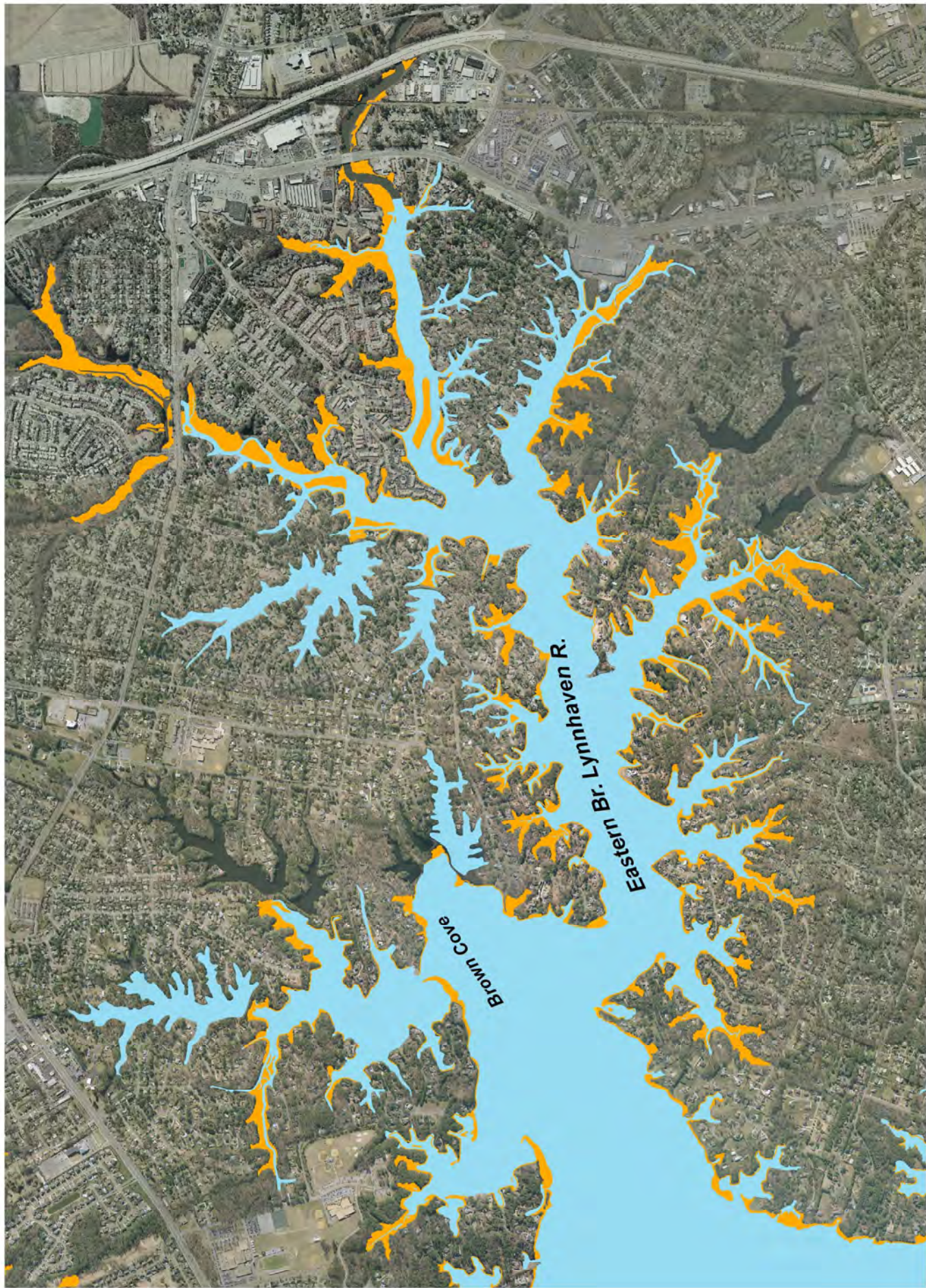
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Tidal Marsh



**Lynnhaven River Watershed
Plate 3A (Eastern Branch N 2007)**



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Meters

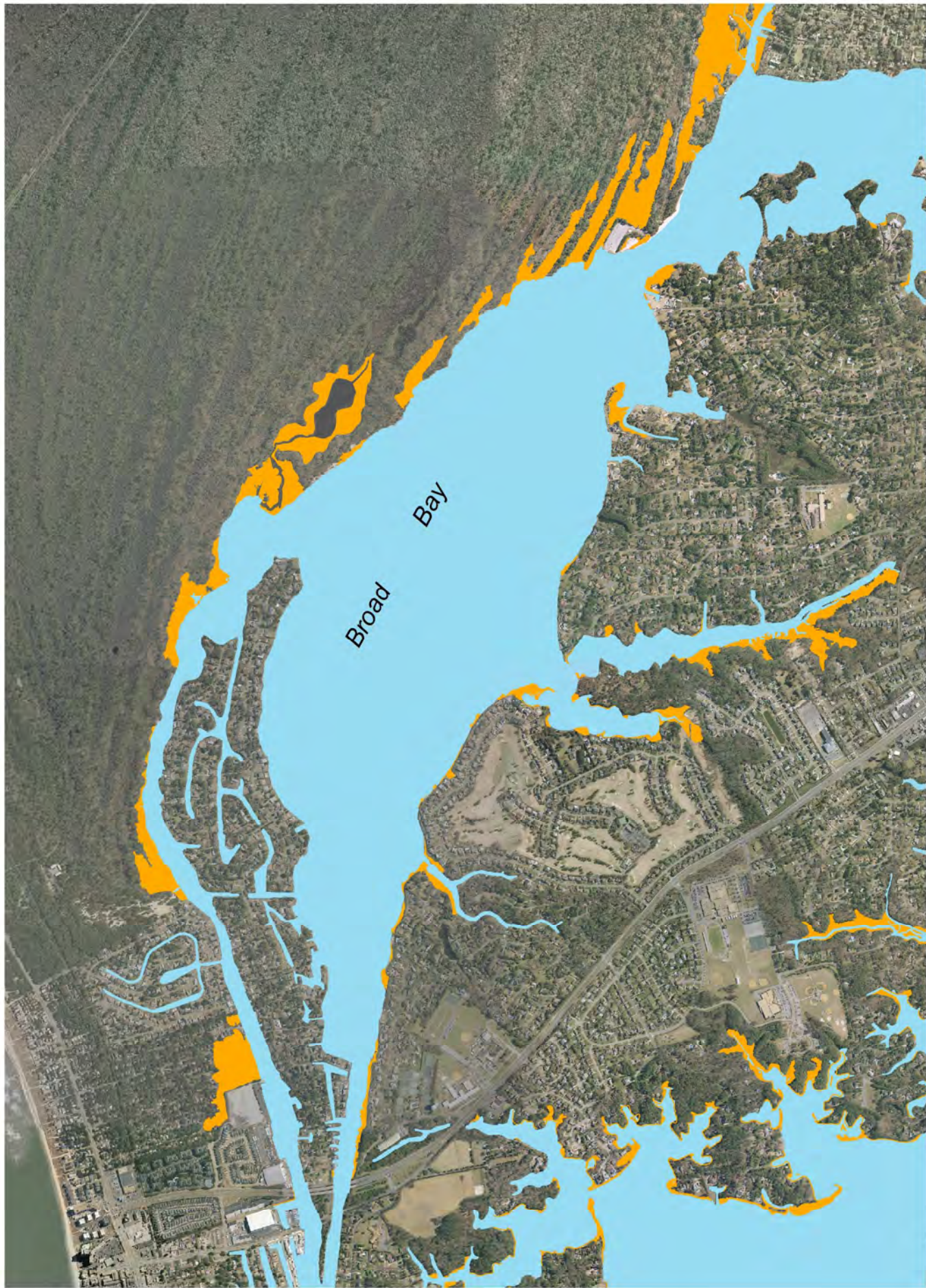
Tidal Marsh



Lynnhaven River Watershed Plate 4A (Eastern Branch S 2007)



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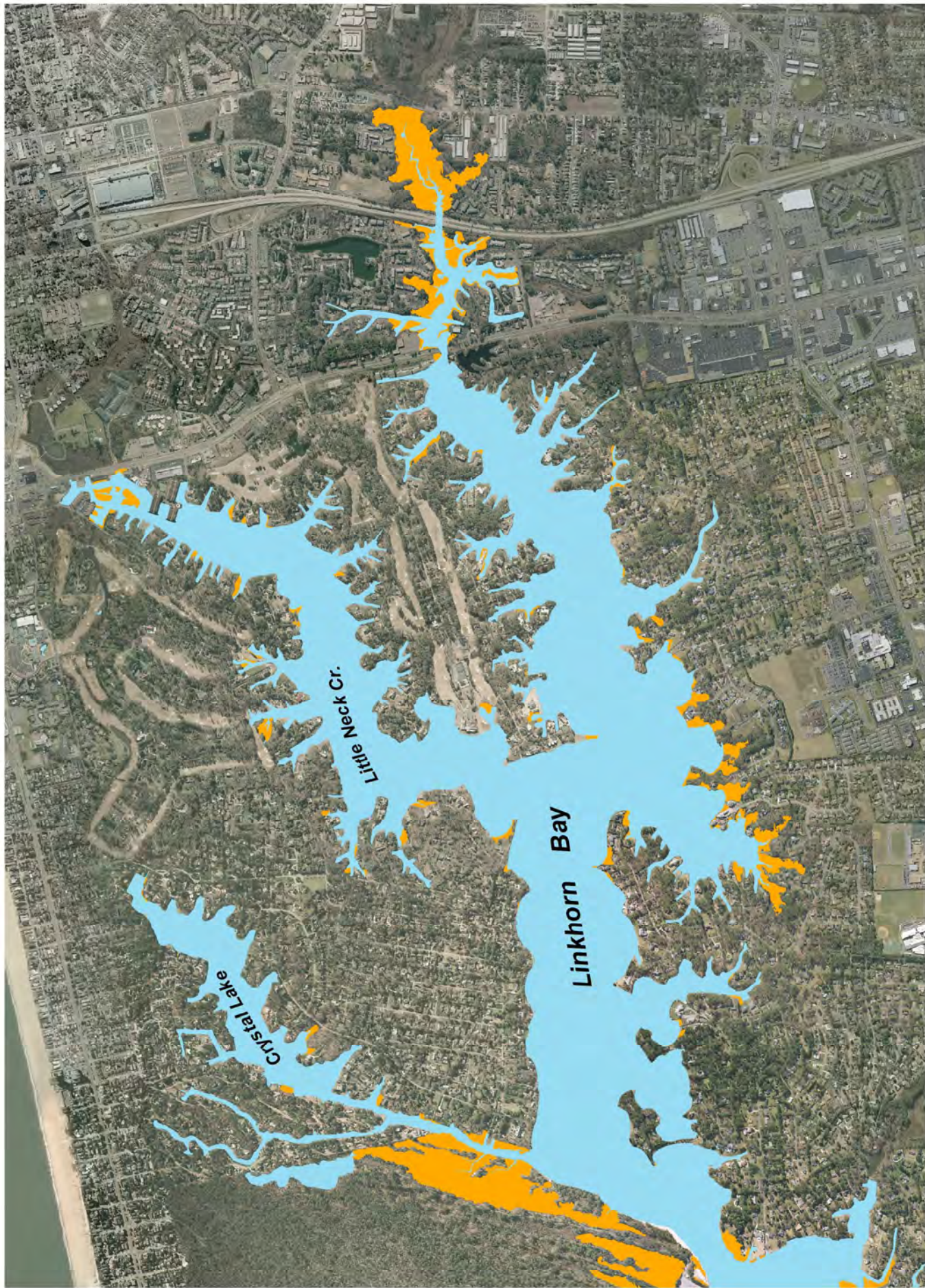
Tidal Marsh



Lynnhaven River Watershed Plate 5A (Broad Bay 2007)

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Tidal Marsh

0 250 500 750 1,000 Meters

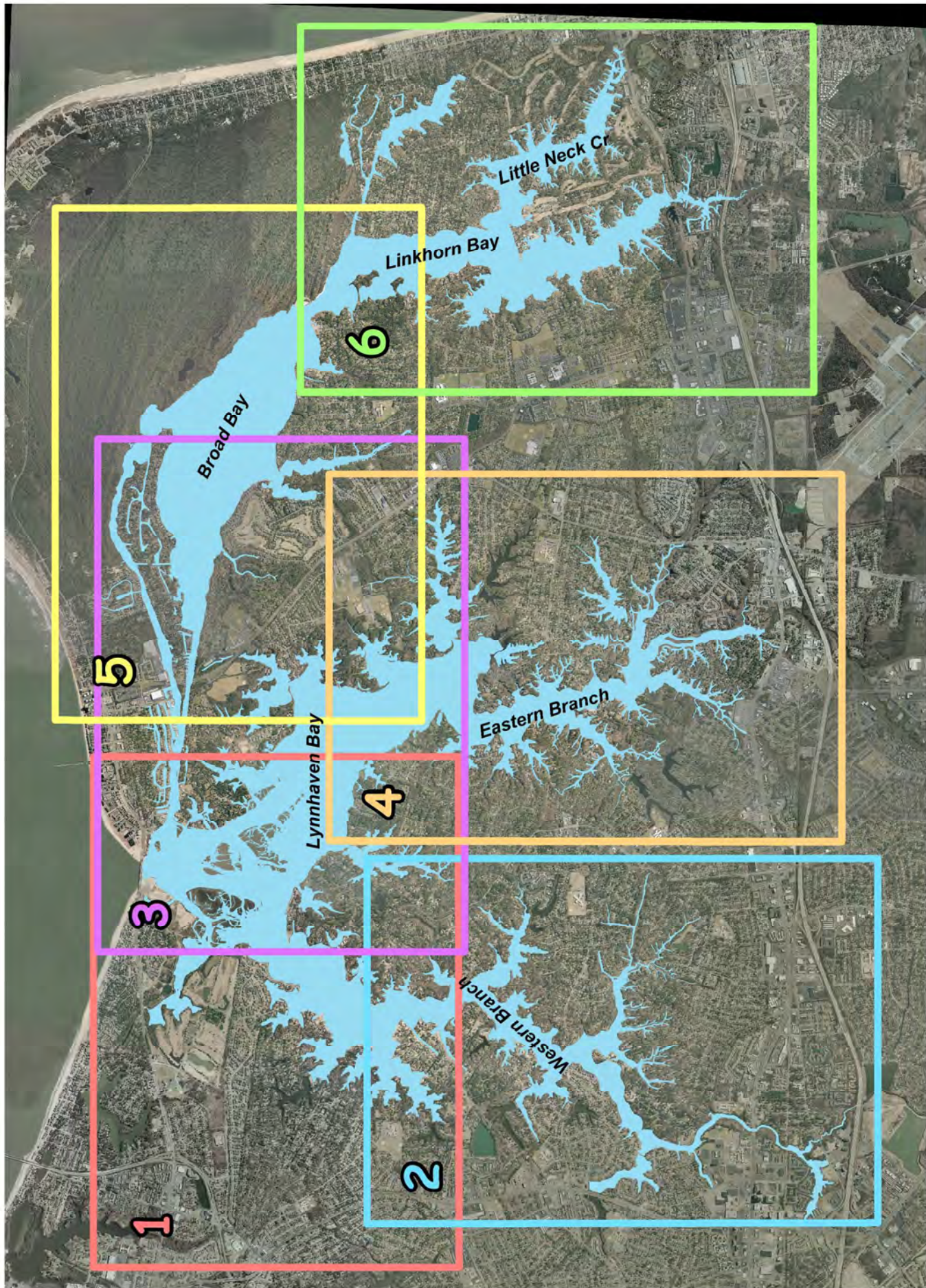


Lynnhaven River Watershed Plate 6A (Linkhorn Bay 2007)

MAP APPENDIX B – Tidal Marsh Delineation and Losses (Maps 1-6)

Model Conditions

Sea level rise scenario:	year = 2032
Rate of sea level rise:	4.1 mm/year
Elevation increase in MSL:	103 mm
Marsh loss:	34.17 hectares
Marsh remaining:	238.22 hectares

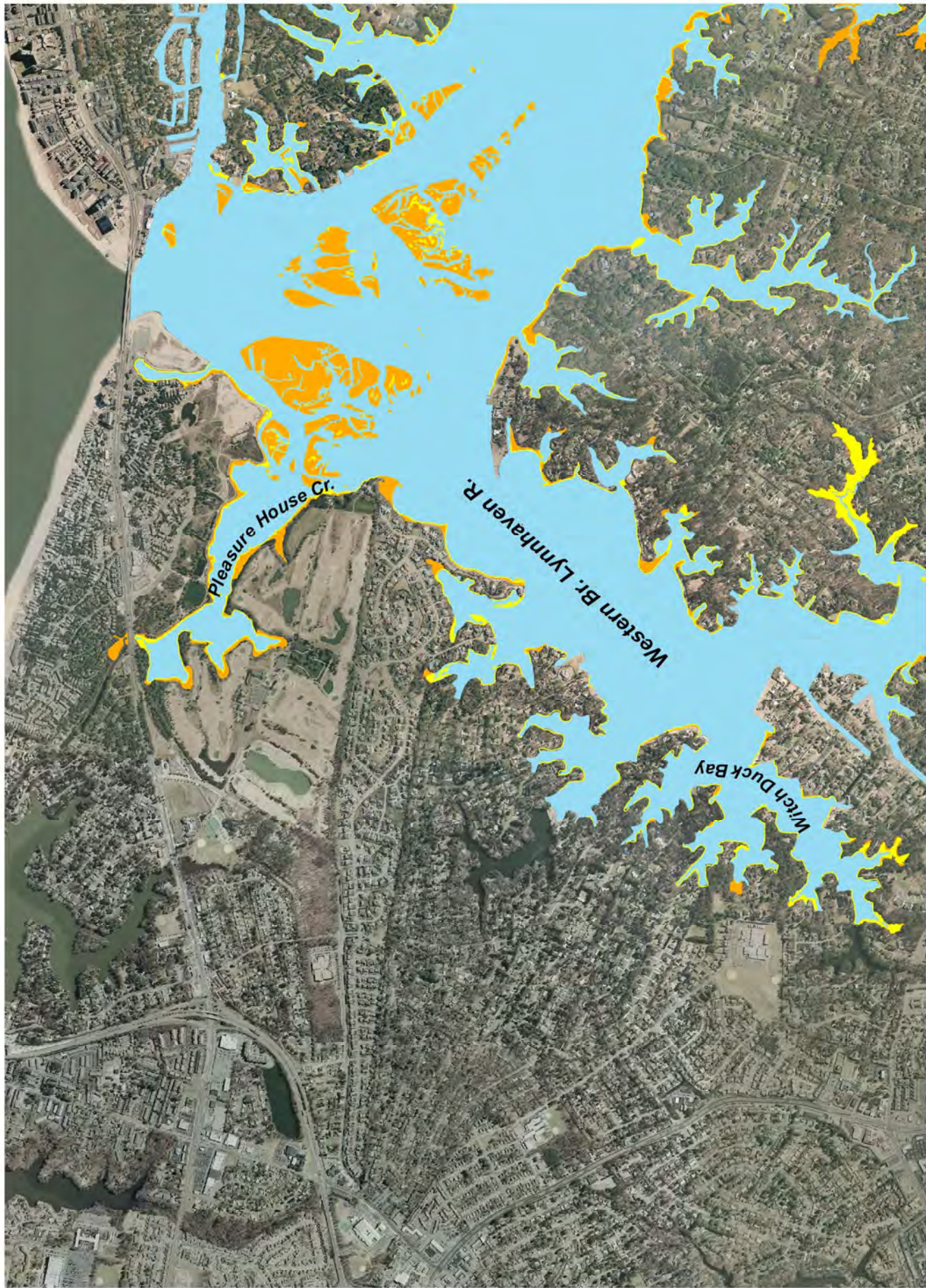


Lynnhaven River Watershed
1:24,000 Plate Index



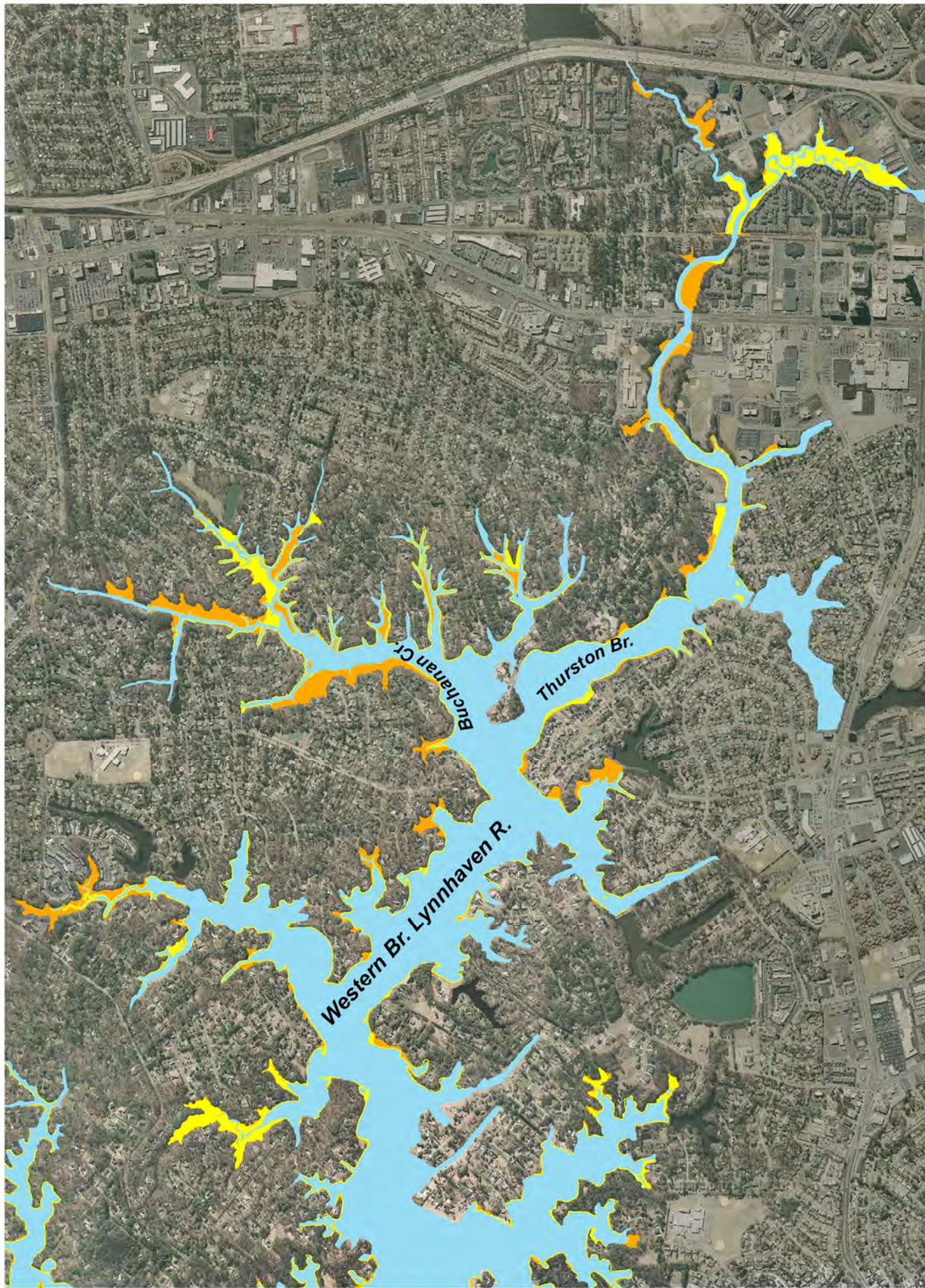
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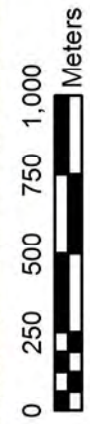
Tidal Marsh
 Remaining
 25 yr loss

**Lynnhaven River Watershed
Plate 1B (Western Branch N 2032)**

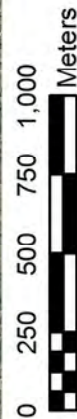
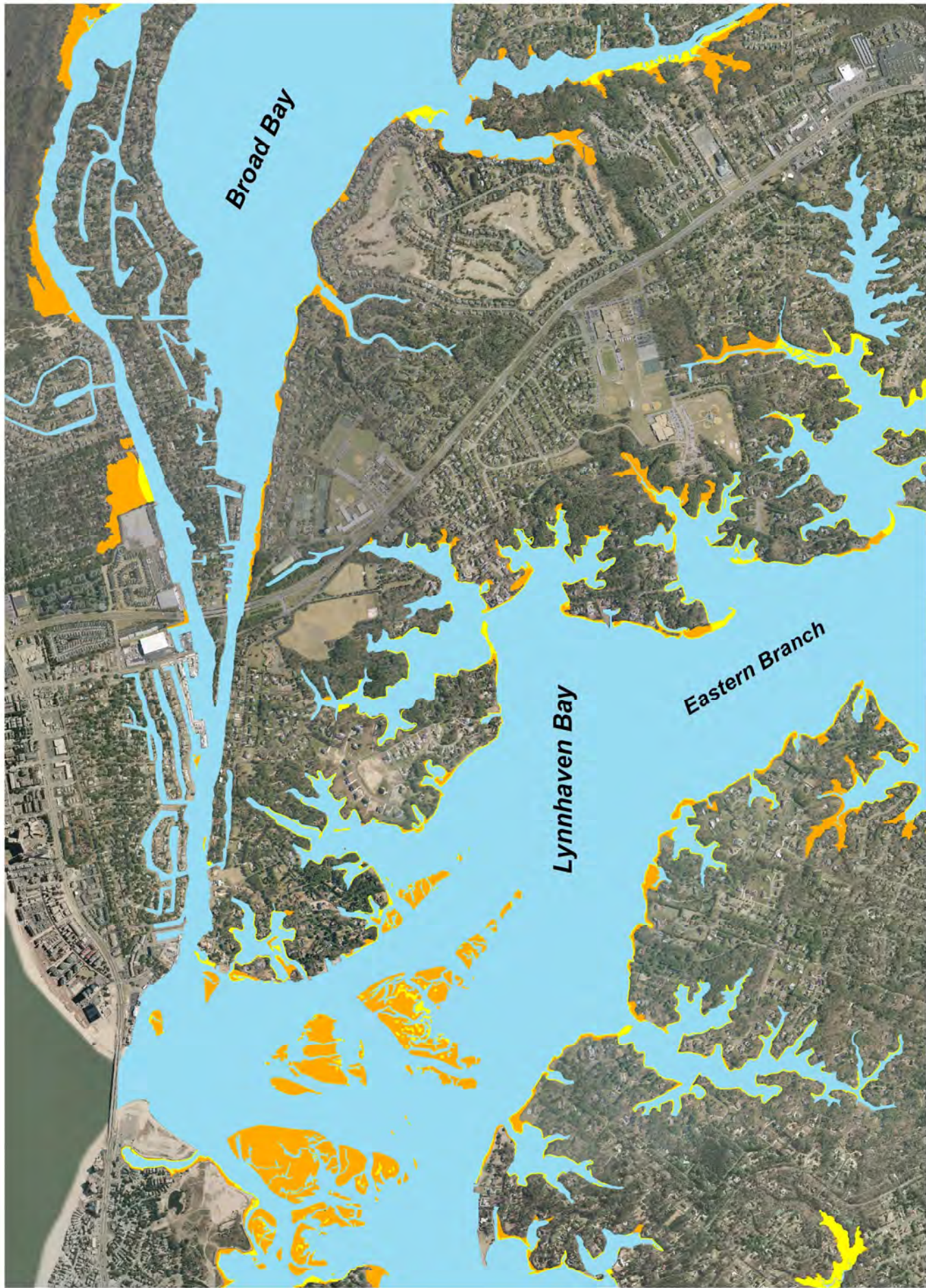


Tidal Marsh

Orange	Remaining
Yellow	25 yr loss

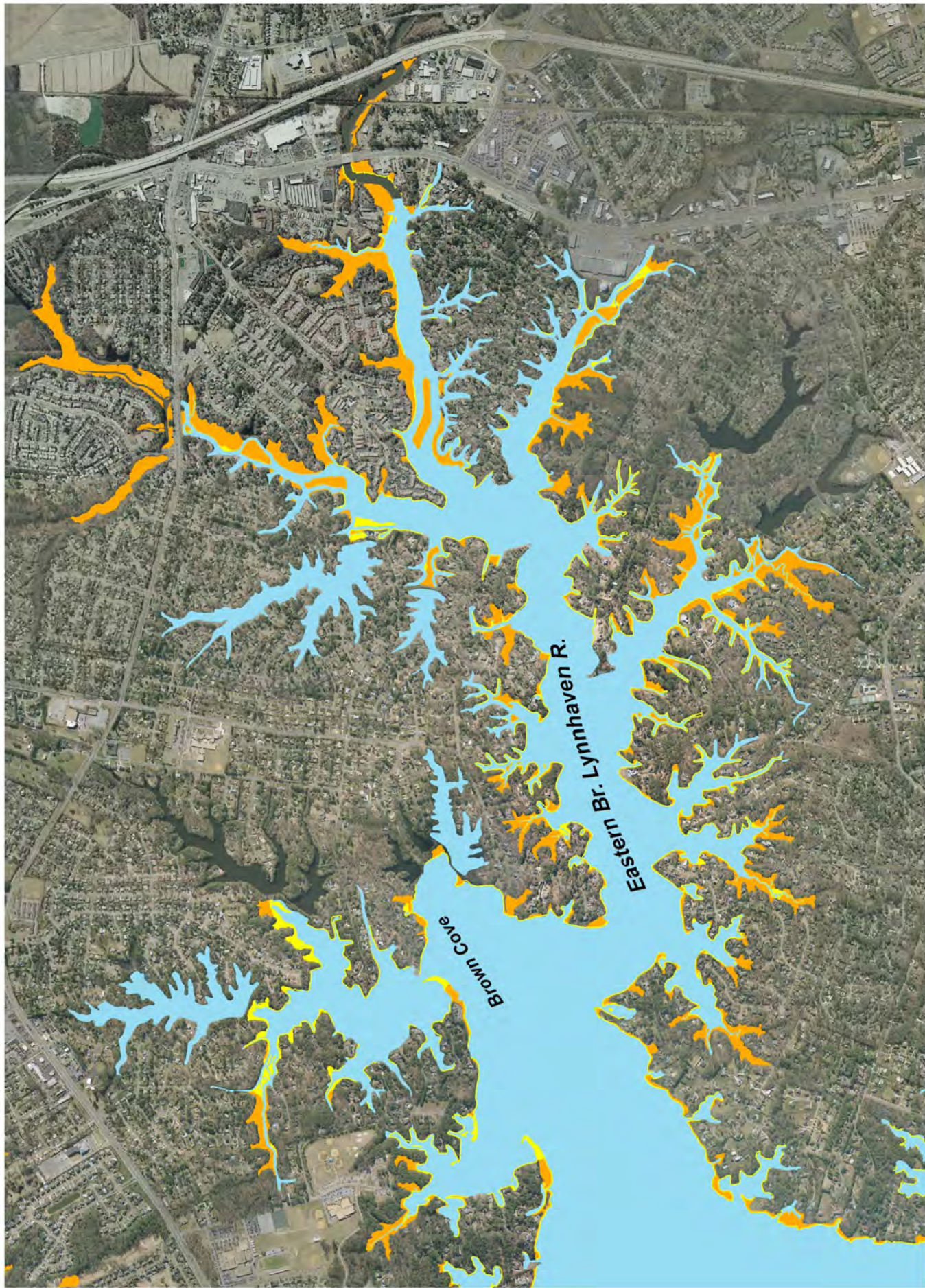


**Lynnhaven River Watershed
Plate 2B (Western Branch S 2032)**



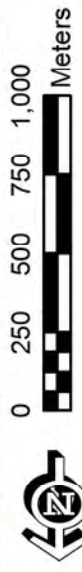
Tidal Marsh
Remaining
25 yr loss

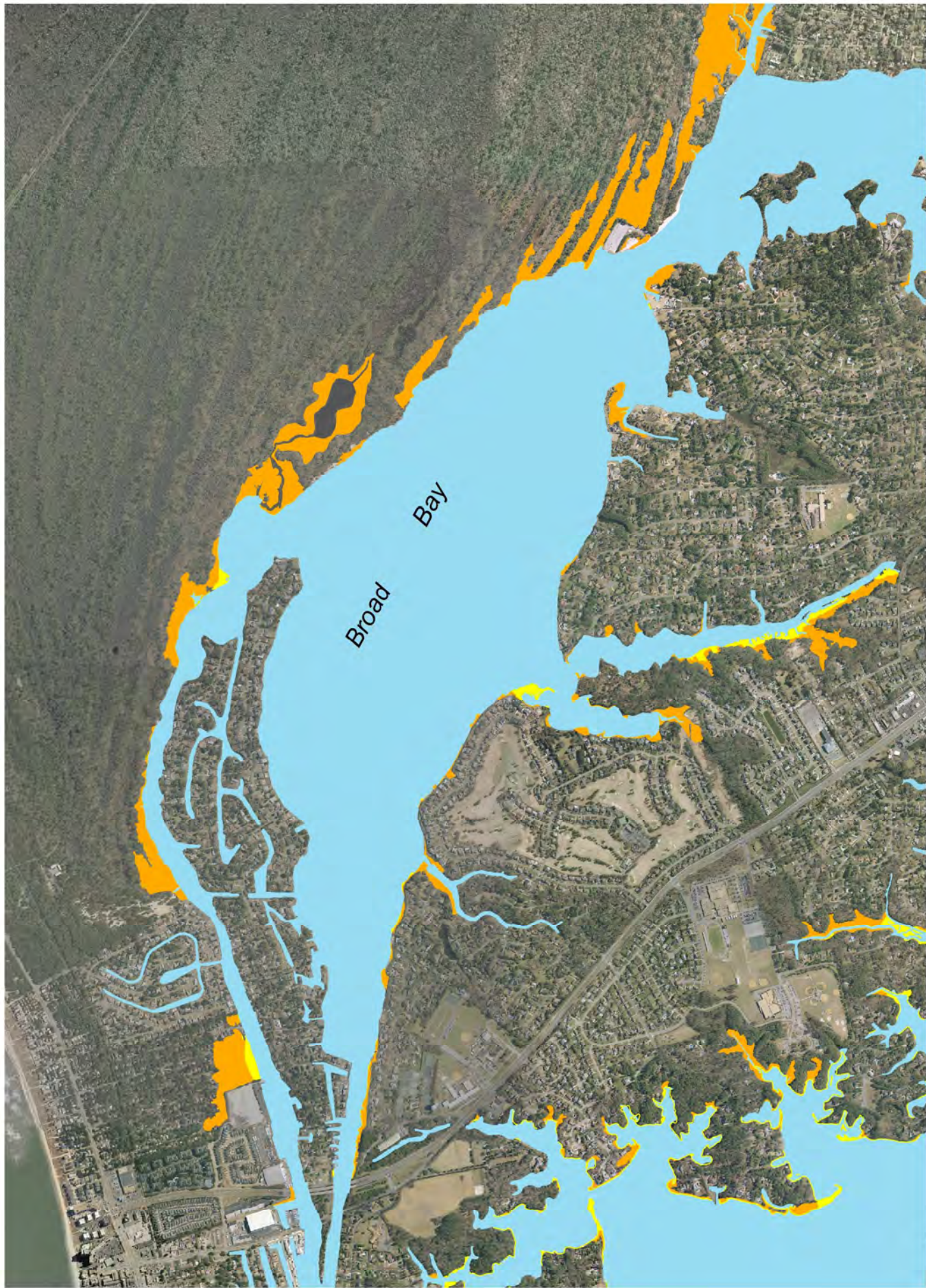
Lynnhaven River Watershed
Plate 3B (Eastern Branch N 2032)



**Lynnhaven River Watershed
Plate 4B (Eastern Branch S 2032)**

Tidal Marsh
Remaining
25 yr loss





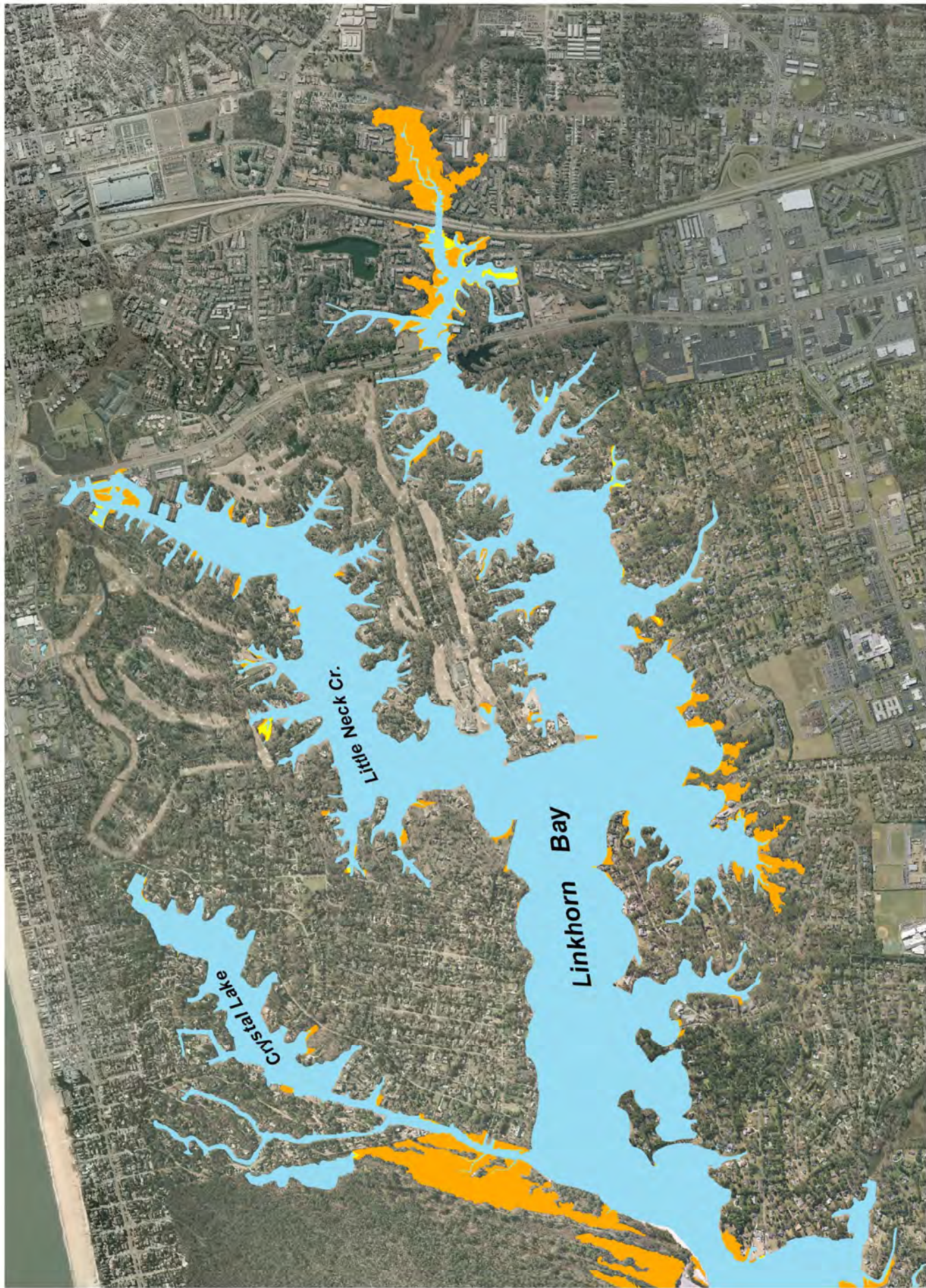
0 250 500 750 1,000
Meters

Tidal Marsh
 Remaining
 25 yr loss

Lynnhaven River Watershed Plate 5B (Broad Bay 2032)



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



Tidal Marsh

- Remaining
- 25 yr loss



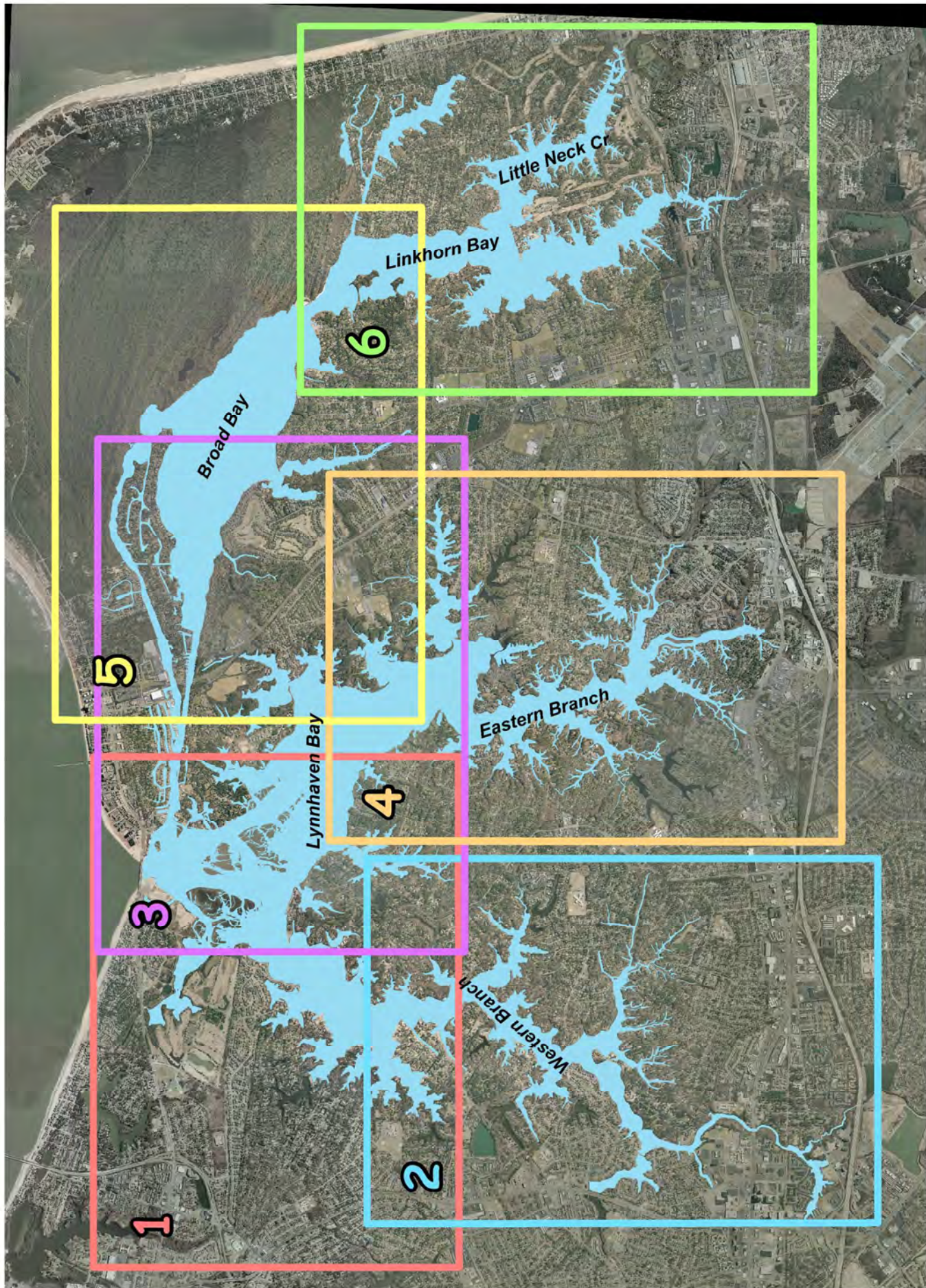
Lynnhaven River Watershed Plate 6B (Linkhorn Bay 2032)



MAP APPENDIX C – Tidal Marsh Delineation and Losses (Maps 1-6)

Model Conditions

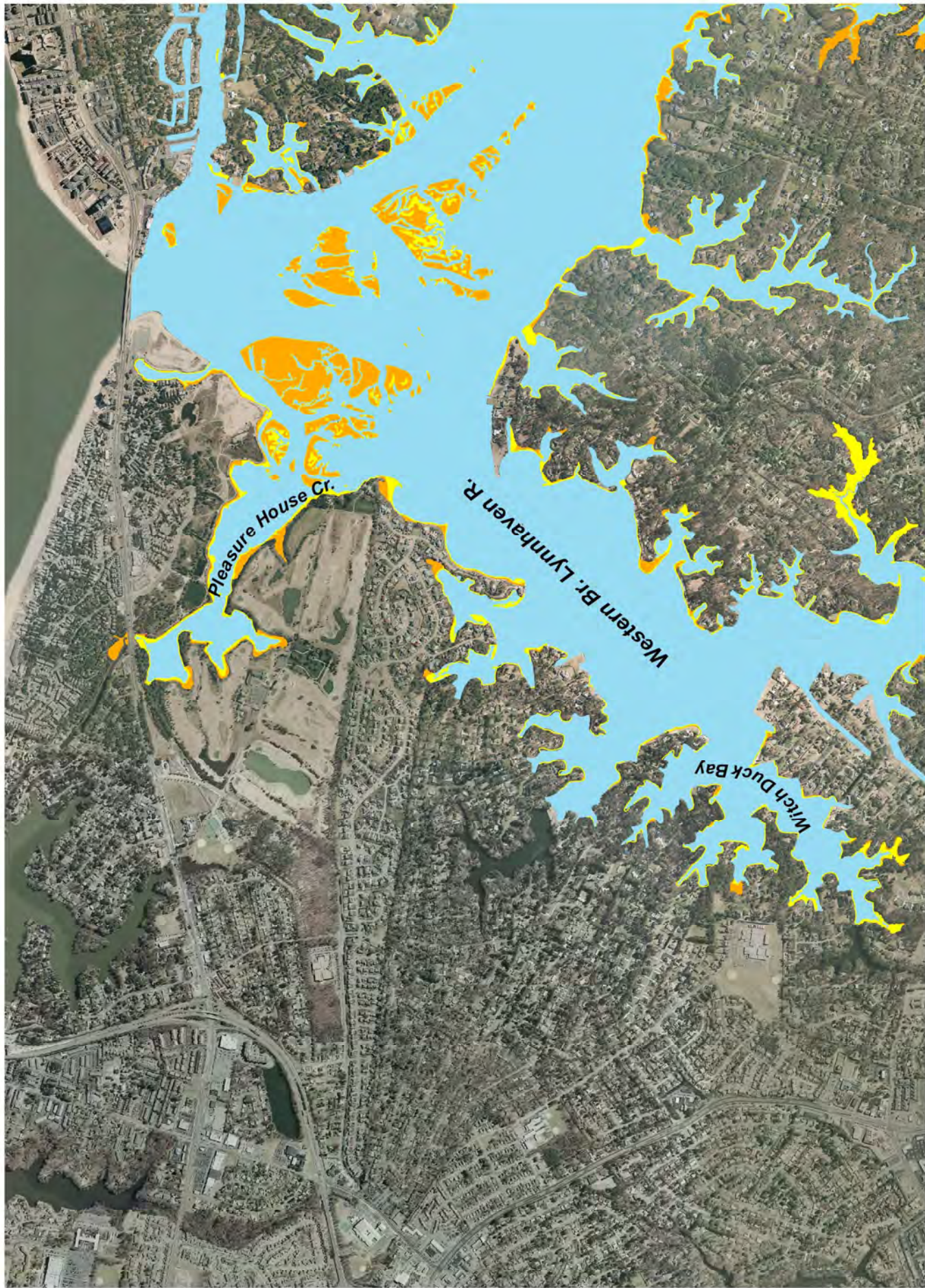
Sea level rise scenario:	year = 2057
Rate of sea level rise:	4.1 mm/year
Elevation increase in MSL:	205 mm
Marsh loss:	81.12 hectares
Marsh remaining:	191.27 hectares



Lynnhaven River Watershed 1:24,000 Plate Index

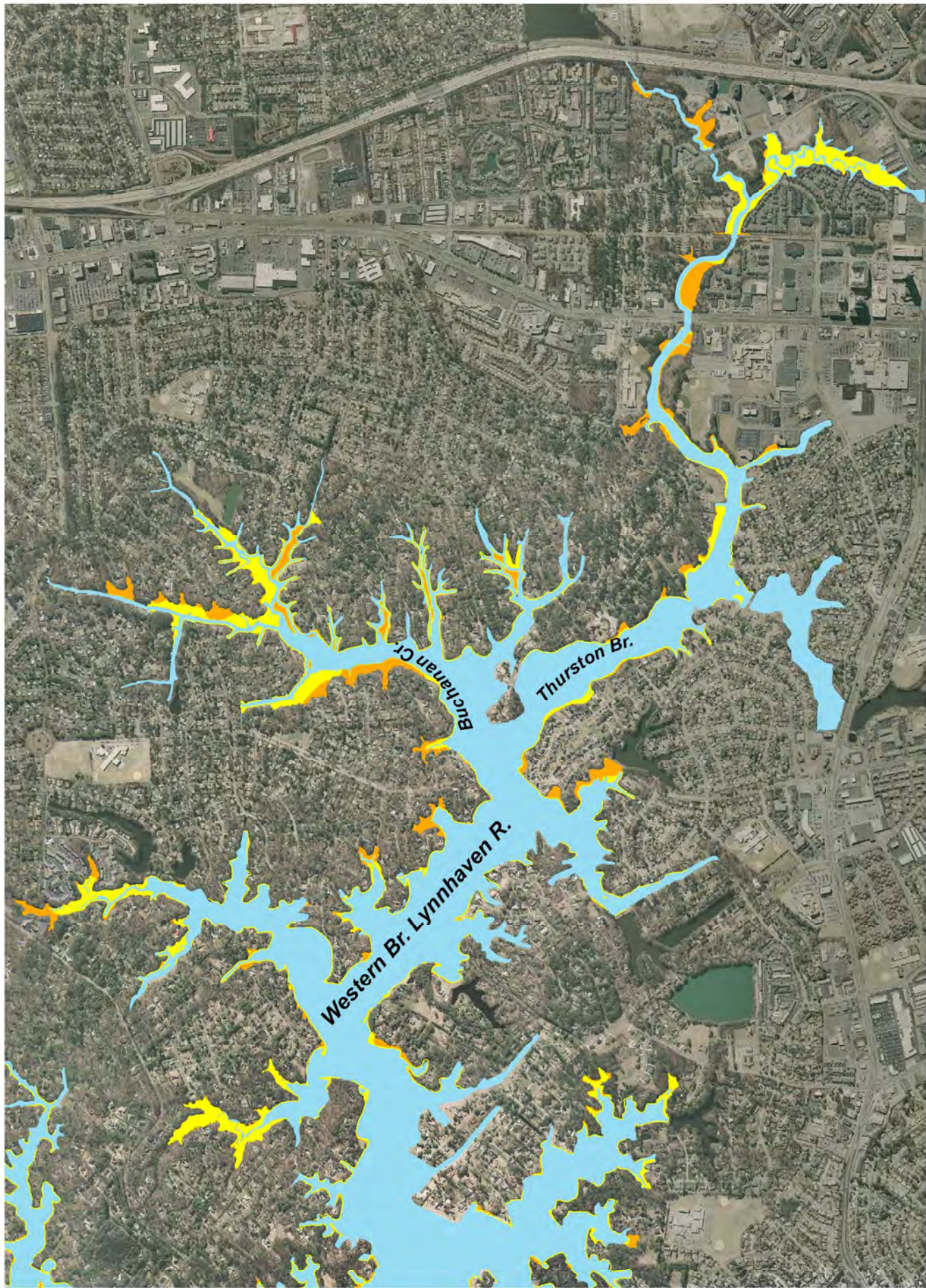


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Tidal Marsh
 Remaining
 50 yr loss

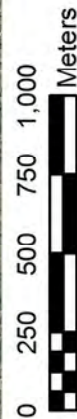
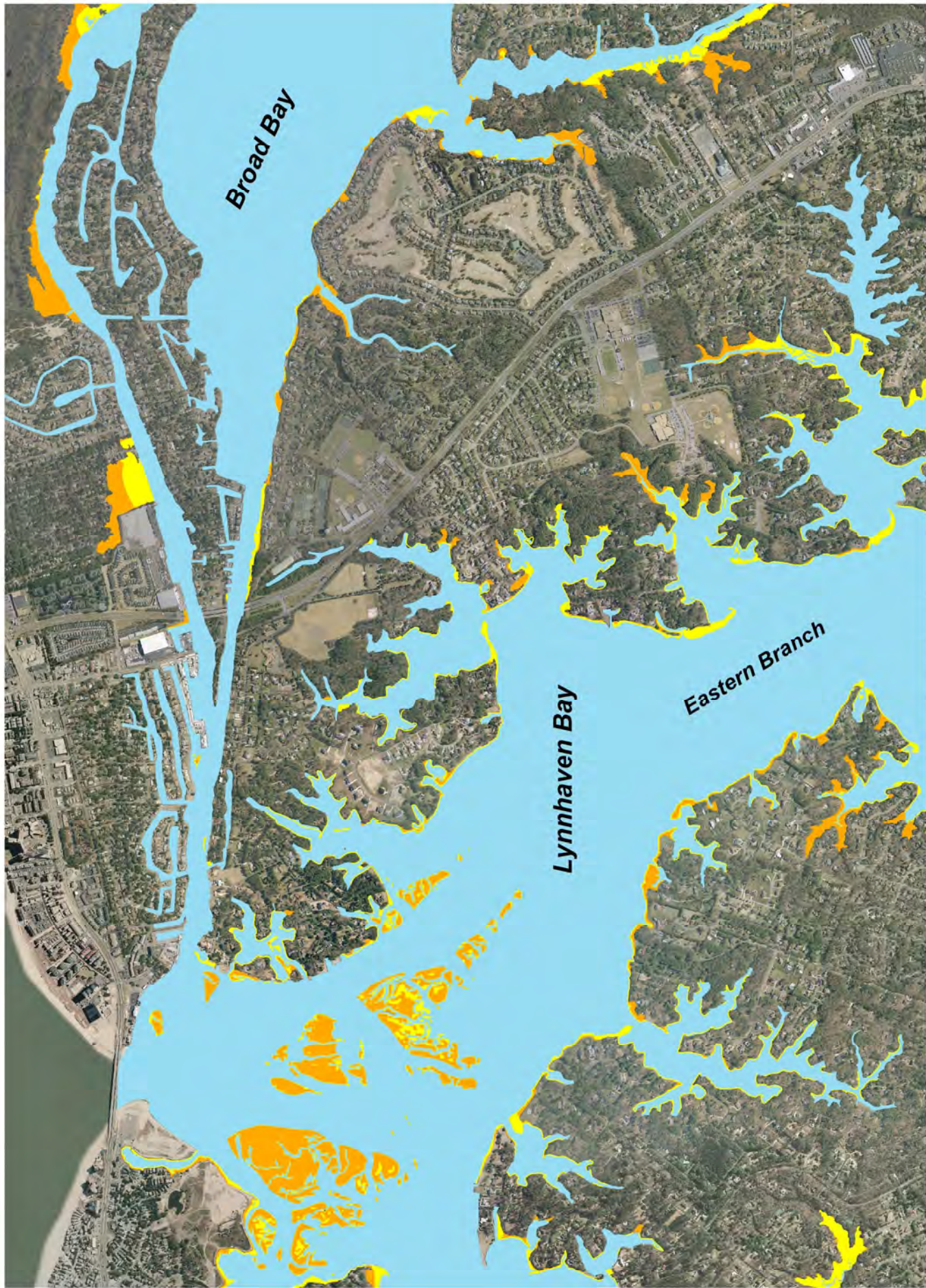
**Lynnhaven River Watershed
Plate 1C (Western Branch N 2057)**



Tidal Marsh

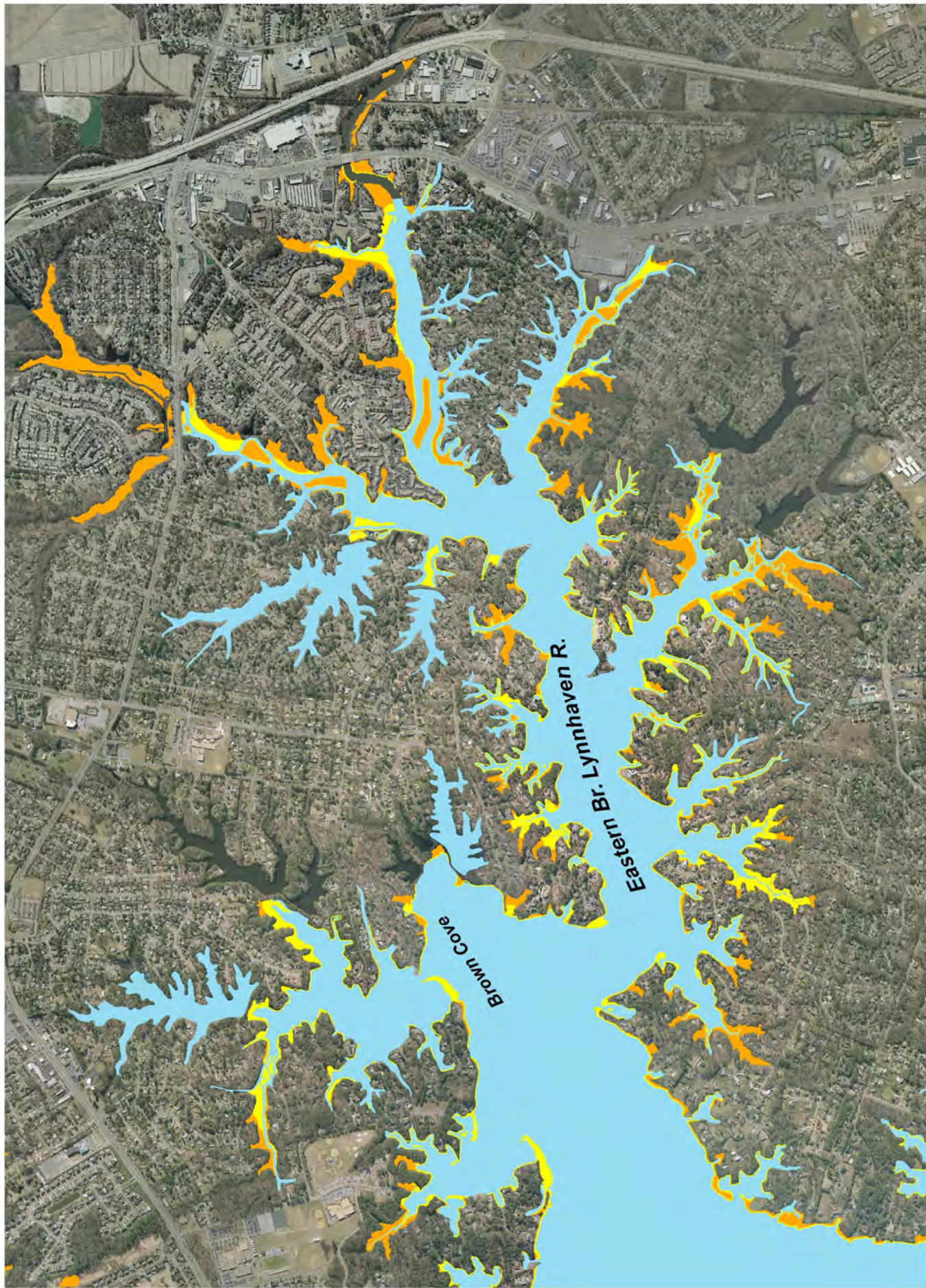
- Remaining
- 50 yr loss





Tidal Marsh
 Remaining
 50 yr loss

**Lynnhaven River Watershed
Plate 3C (Eastern Branch N 2057)**



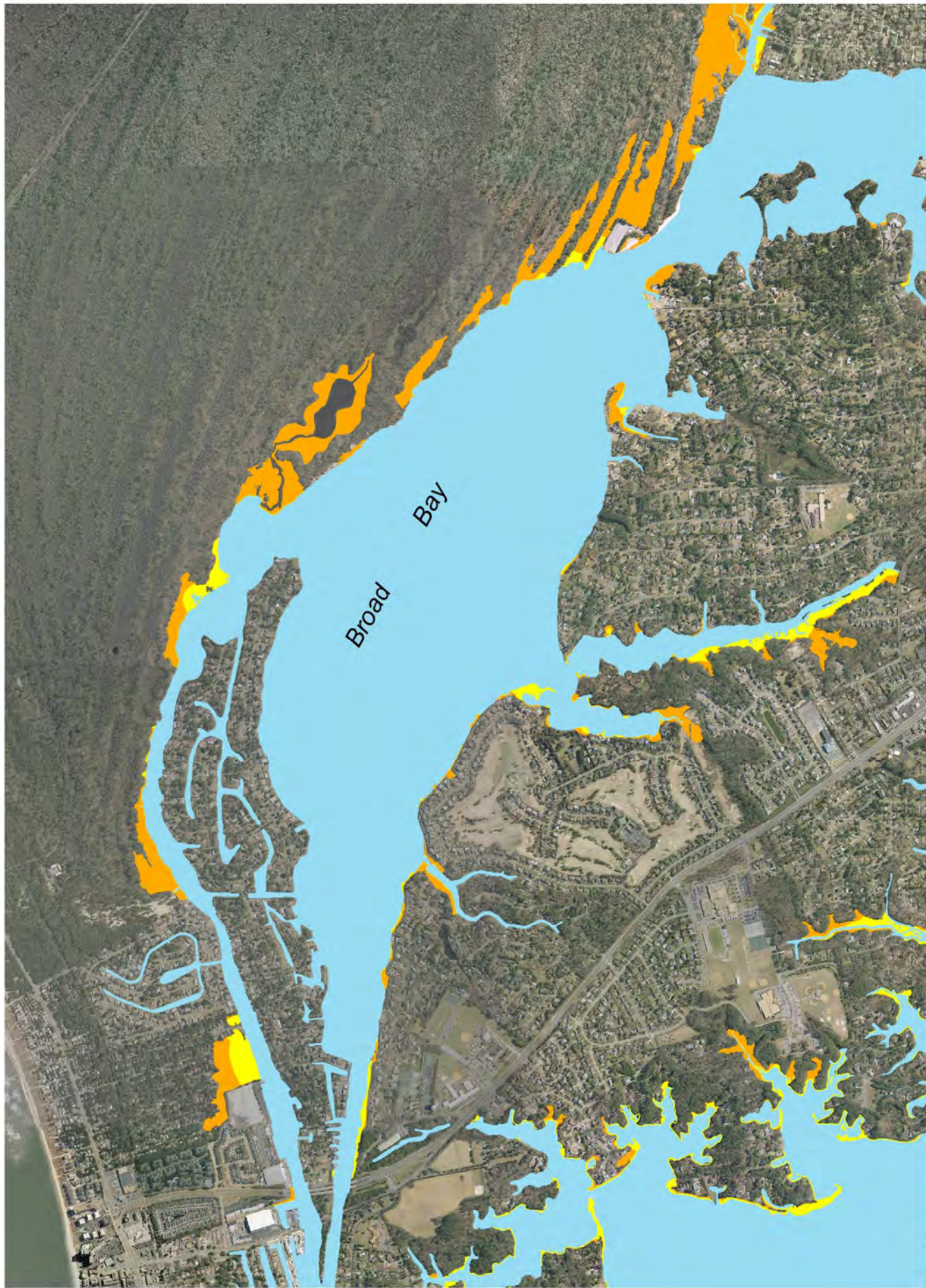
Tidal Marsh

- Remaining
- 50 yr loss

0 250 500 750 1,000 Meters



Lynnhaven River Watershed Plate 4C (Eastern Branch S 2057)



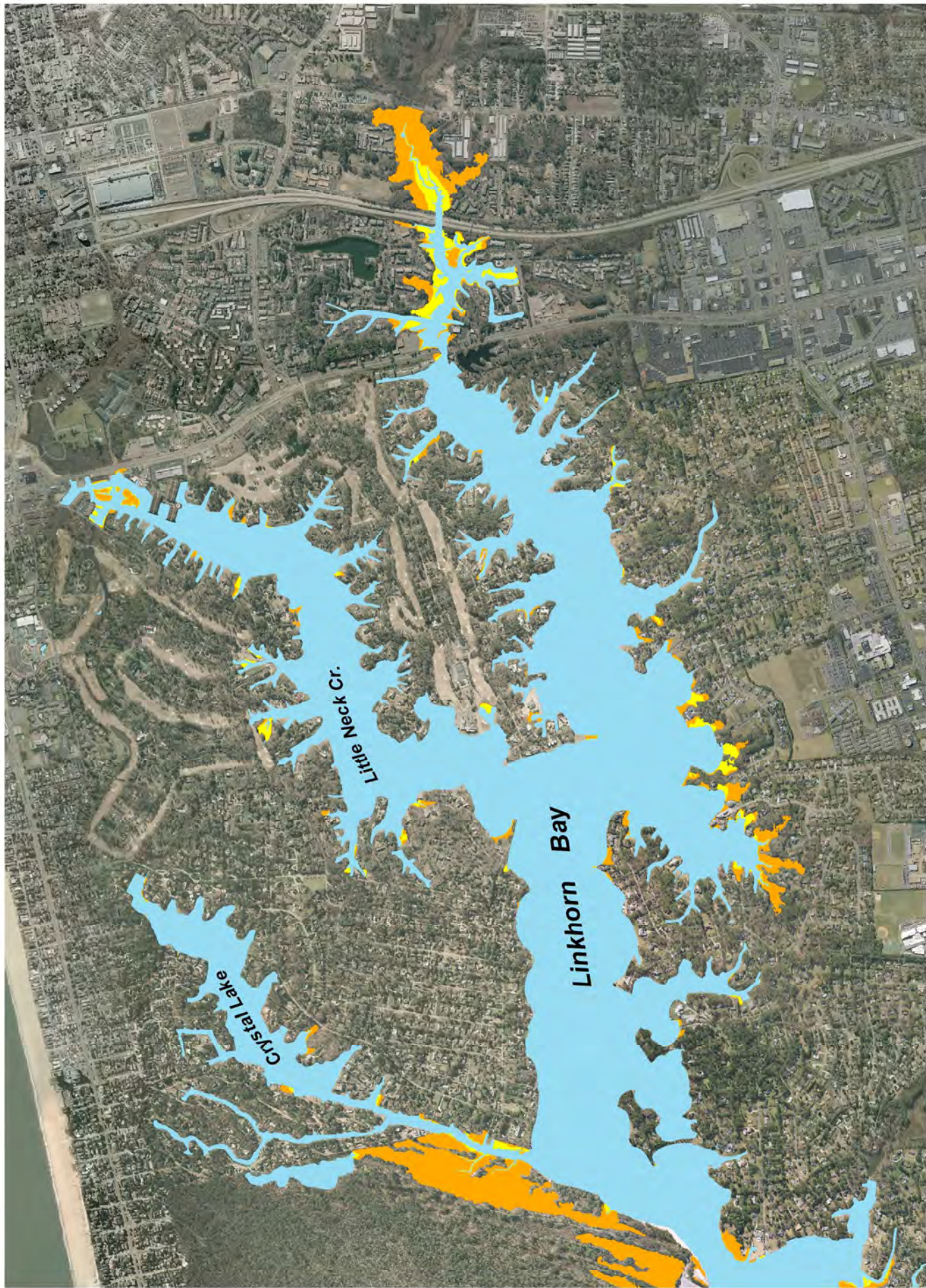
0 250 500 750 1,000
Meters

Tidal Marsh
 Remaining
 50 yr loss

Lynnhaven River Watershed Plate 5C (Broad Bay 2057)



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Tidal Marsh

- Remaining
- 50 yr loss



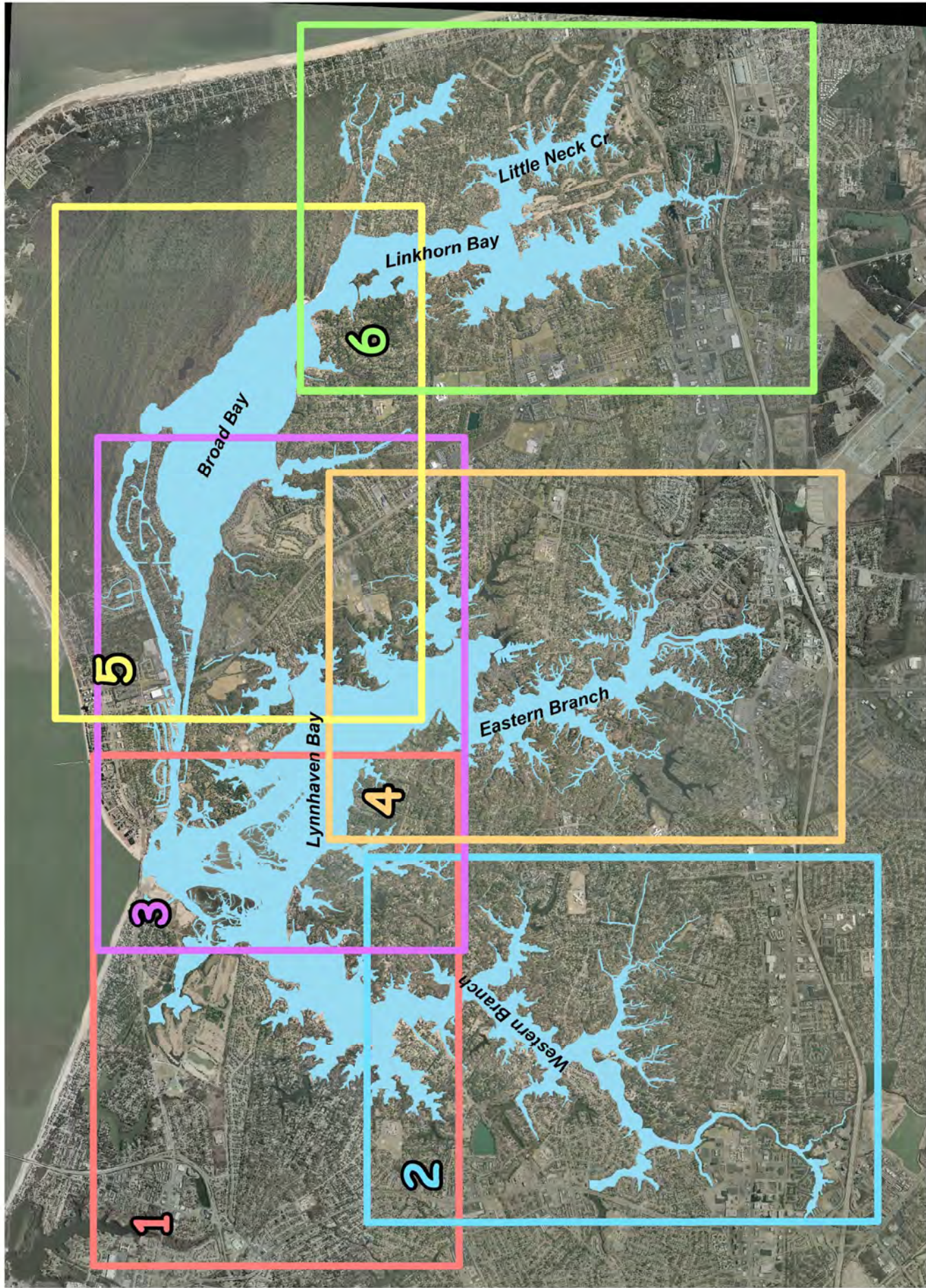
Lynnhaven River Watershed Plate 6C (Linkhorn Bay 2057)

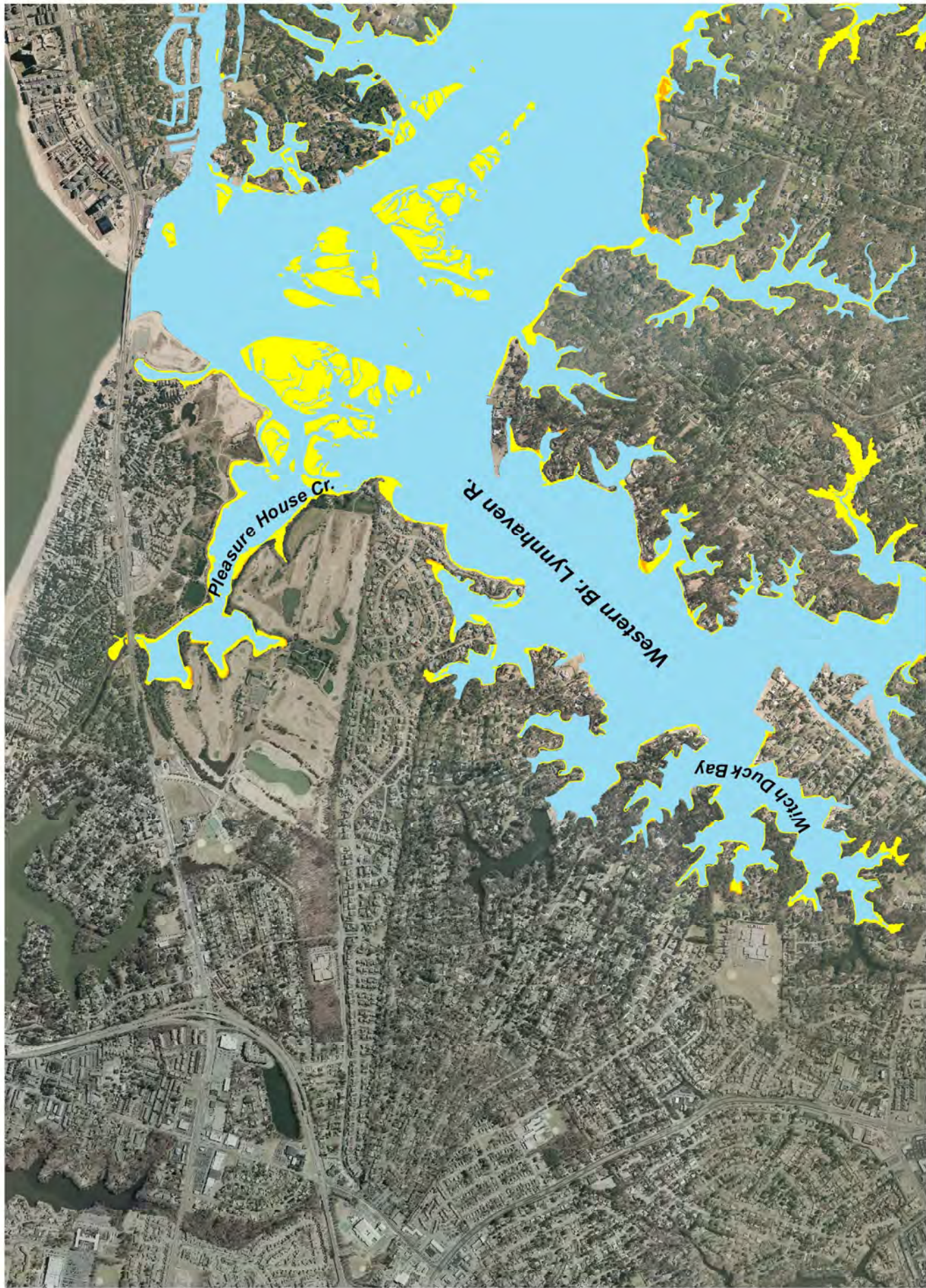


MAP APPENDIX D – Tidal Marsh Delineation and Losses (Maps 1-6)

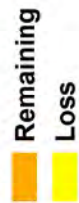
Model Conditions

Sea level rise scenario:	year = 2100
Rate of sea level rise:	7.35 mm/year
Elevation increase in MSL:	683 mm
Marsh loss:	258.56 hectares
Marsh remaining:	13.83 hectares

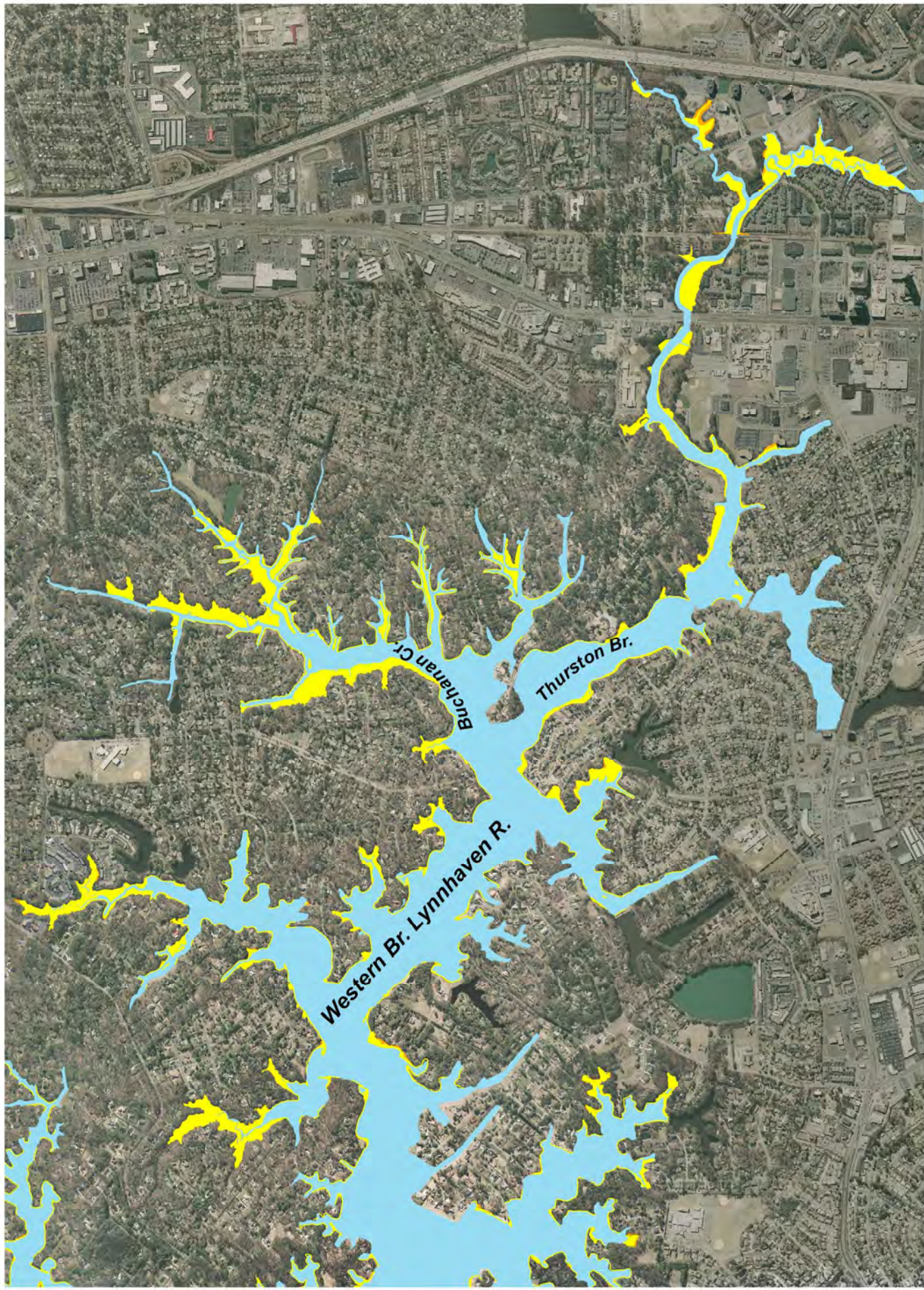




Tidal Marsh (Scenario - 683 mm SLR)



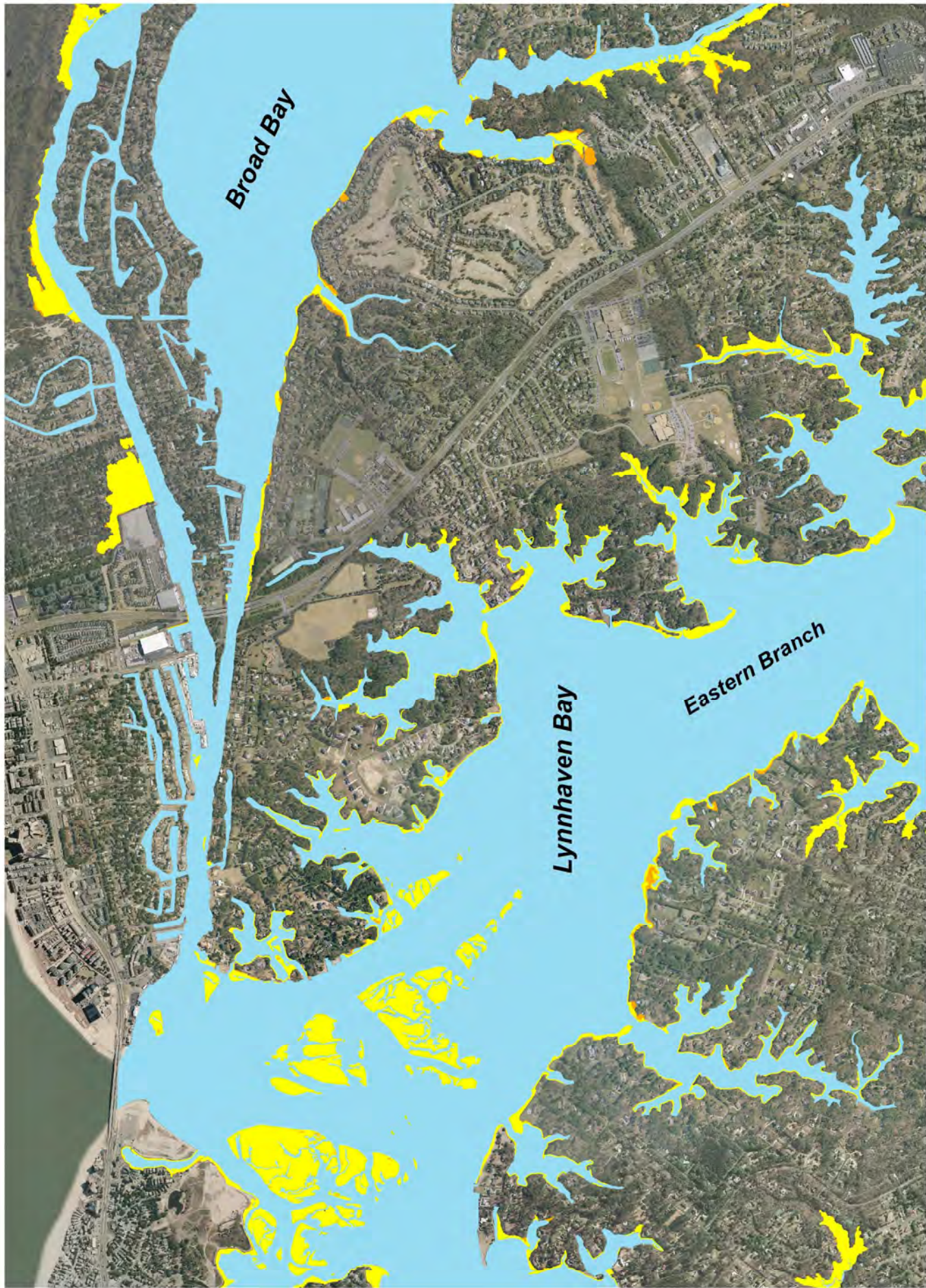
Lynnhaven River Watershed Plate 1D (Western Branch N 2100)



Tidal Marsh (Scenario - 683 mm SLR)



Lynnhaven River Watershed Plate 2D (Western Branch S 2100)



0 250 500 750 1,000 Meters

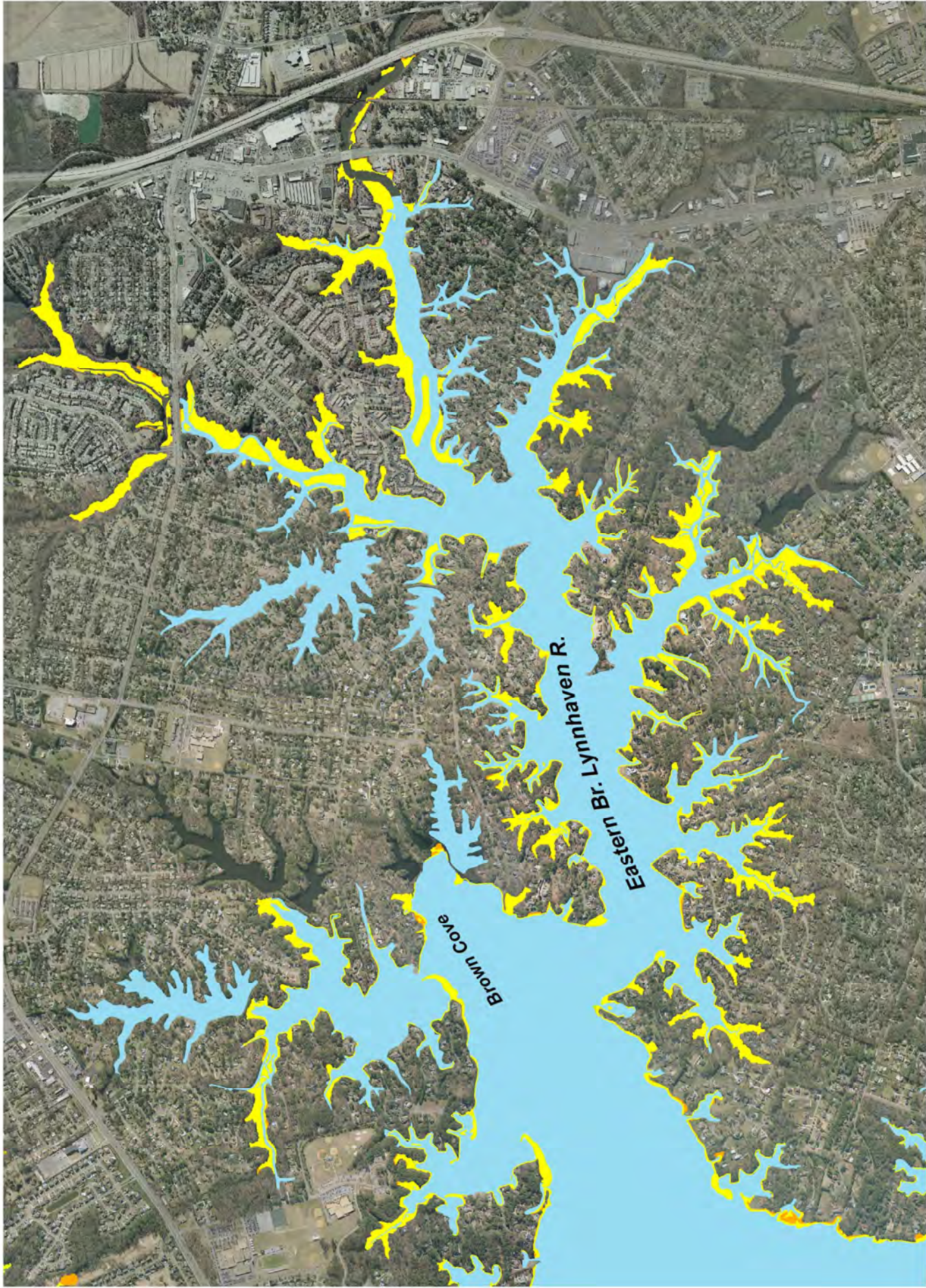
Tidal Marsh (Scenario - 683 mm SLR)

Remaining
Loss

Lynnhaven River Watershed
Plate 3D (Eastern Branch N 2100)



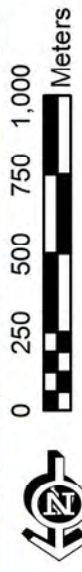
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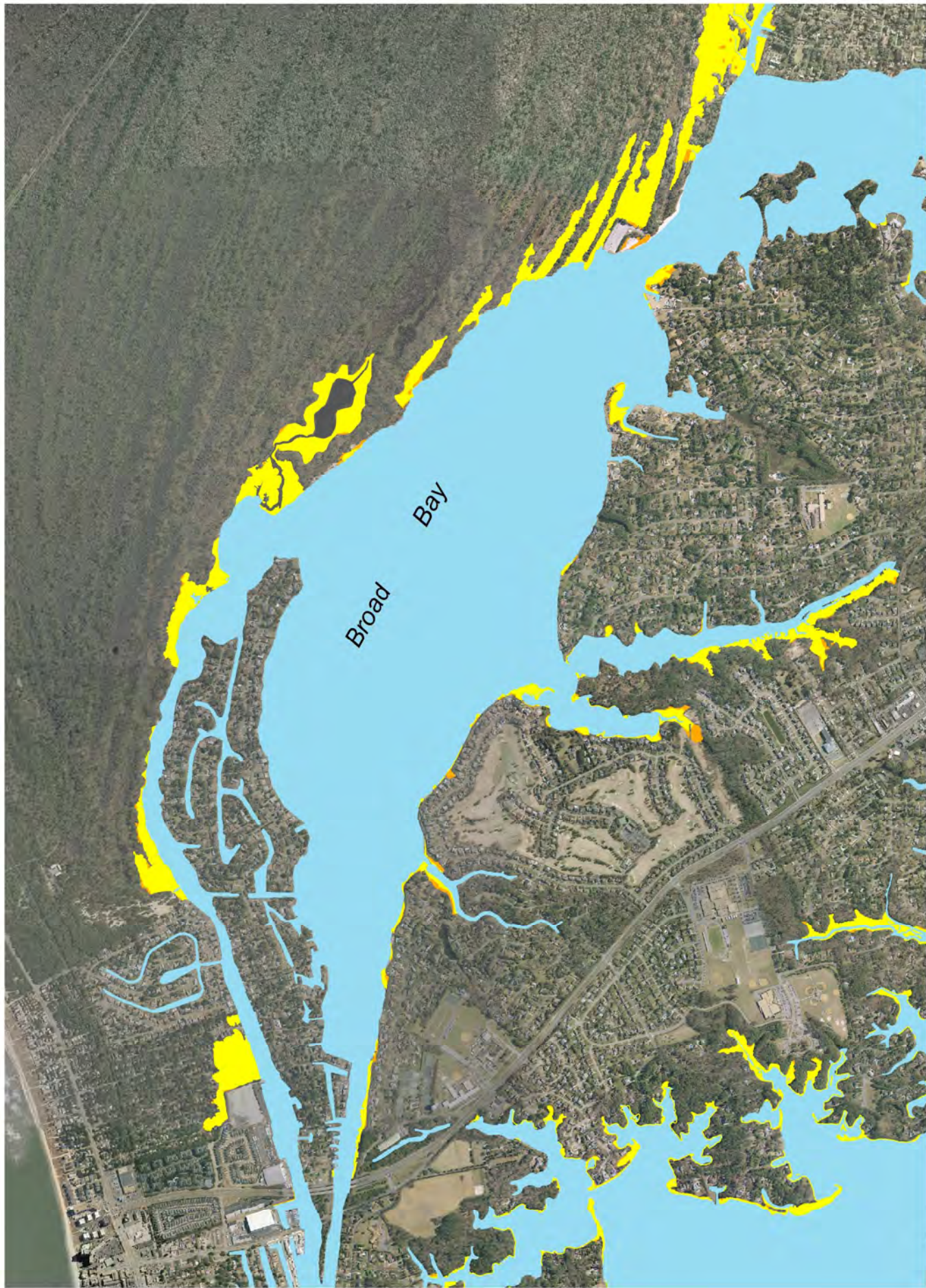


**Lynnhaven River Watershed
Plate 4D (Eastern Branch S 2100)**

Tidal Marsh (Scenario - 683 mm SLR)

- Remaining
- Loss





0 250 500 750 1,000 Meters

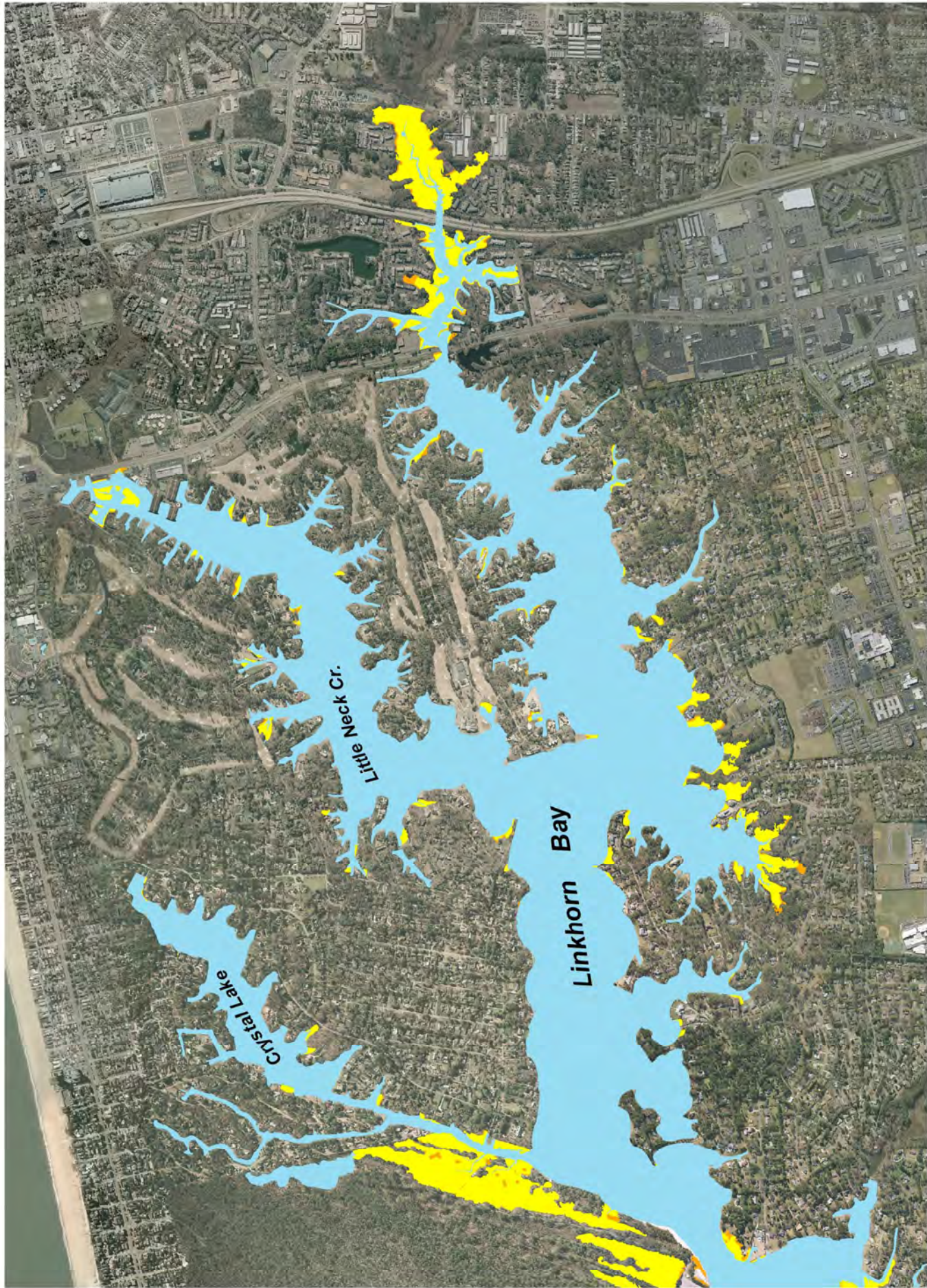
Tidal Marsh (Scenario - 683 mm SLR)

Remaining
Loss

Lynnhaven River Watershed
Plate 5D (Broad Bay 2100)



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Tidal Marsh (Scenario - 683 mm SLR)

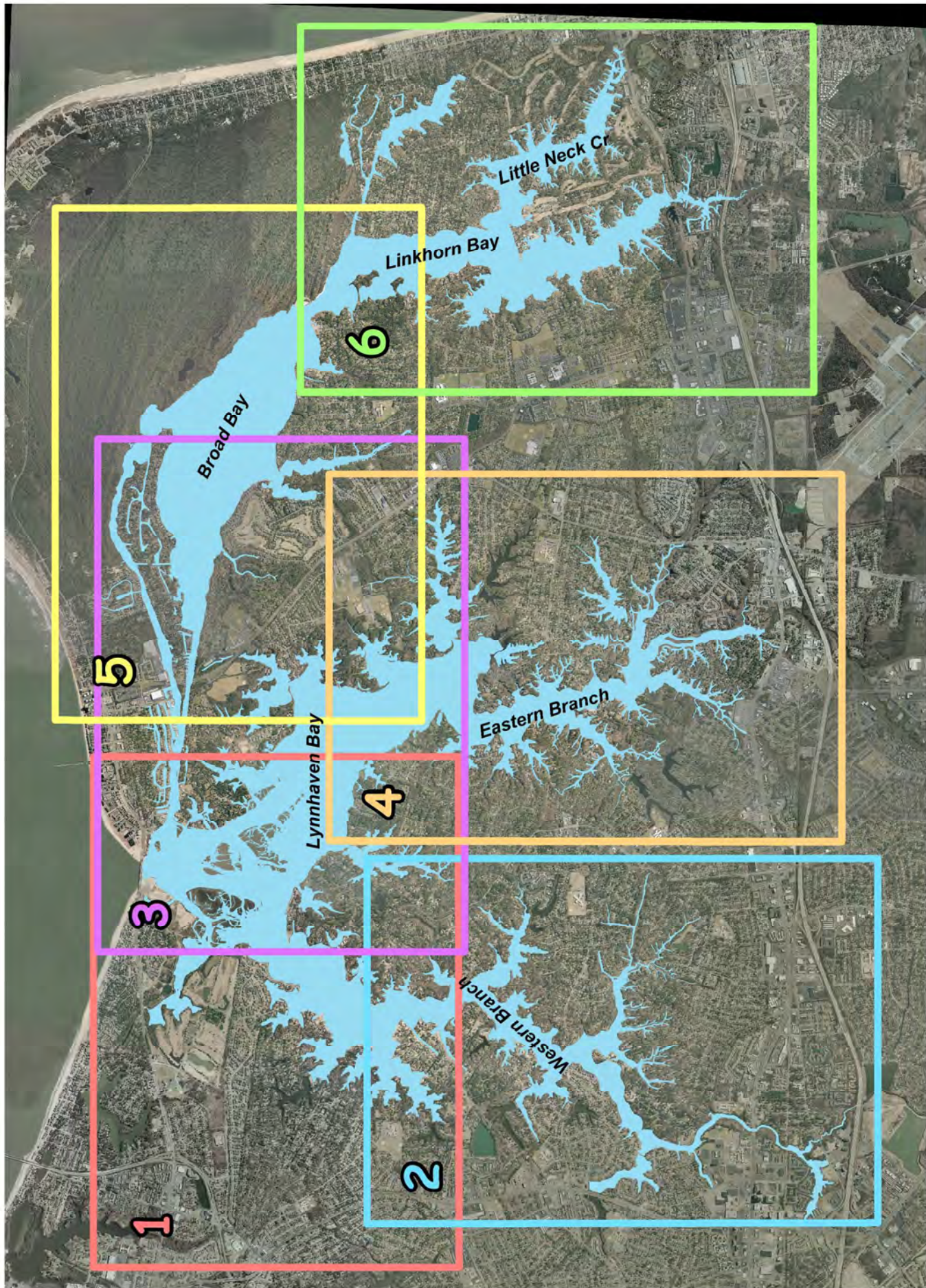
- Remaining
- Loss



MAP APPENDIX E – Tidal Marsh and Upland Losses (Maps 1-6)

Model Conditions

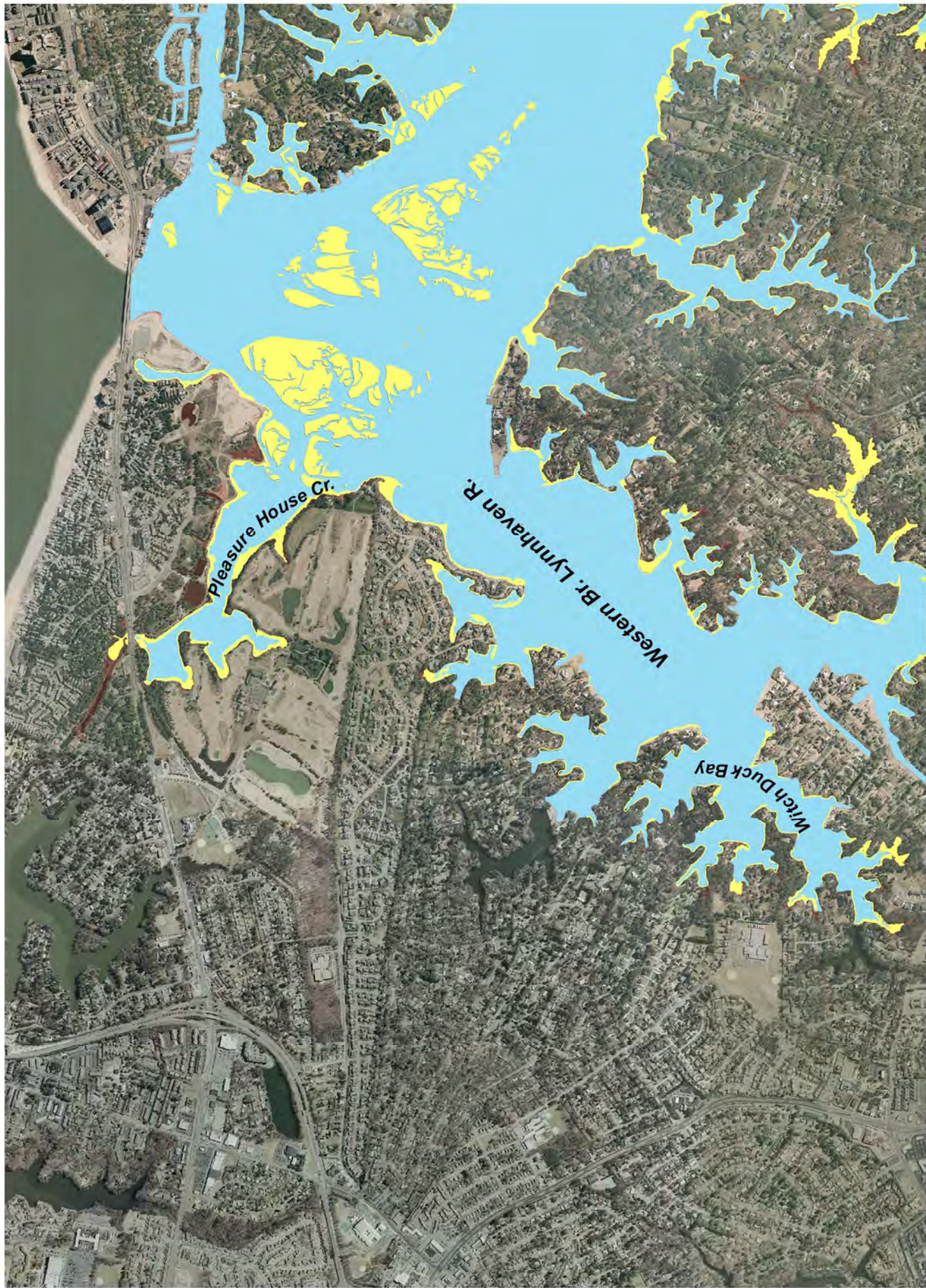
Sea level rise scenario:	year = 2100
Rate of sea level rise:	7.35 mm/year
Elevation increase in MSL:	683 mm
Marsh loss:	258.56 hectares
Marsh remaining:	13.83 hectares
Uplands submerged:	259.89 hectares



Lynnhaven River Watershed 1:24,000 Plate Index



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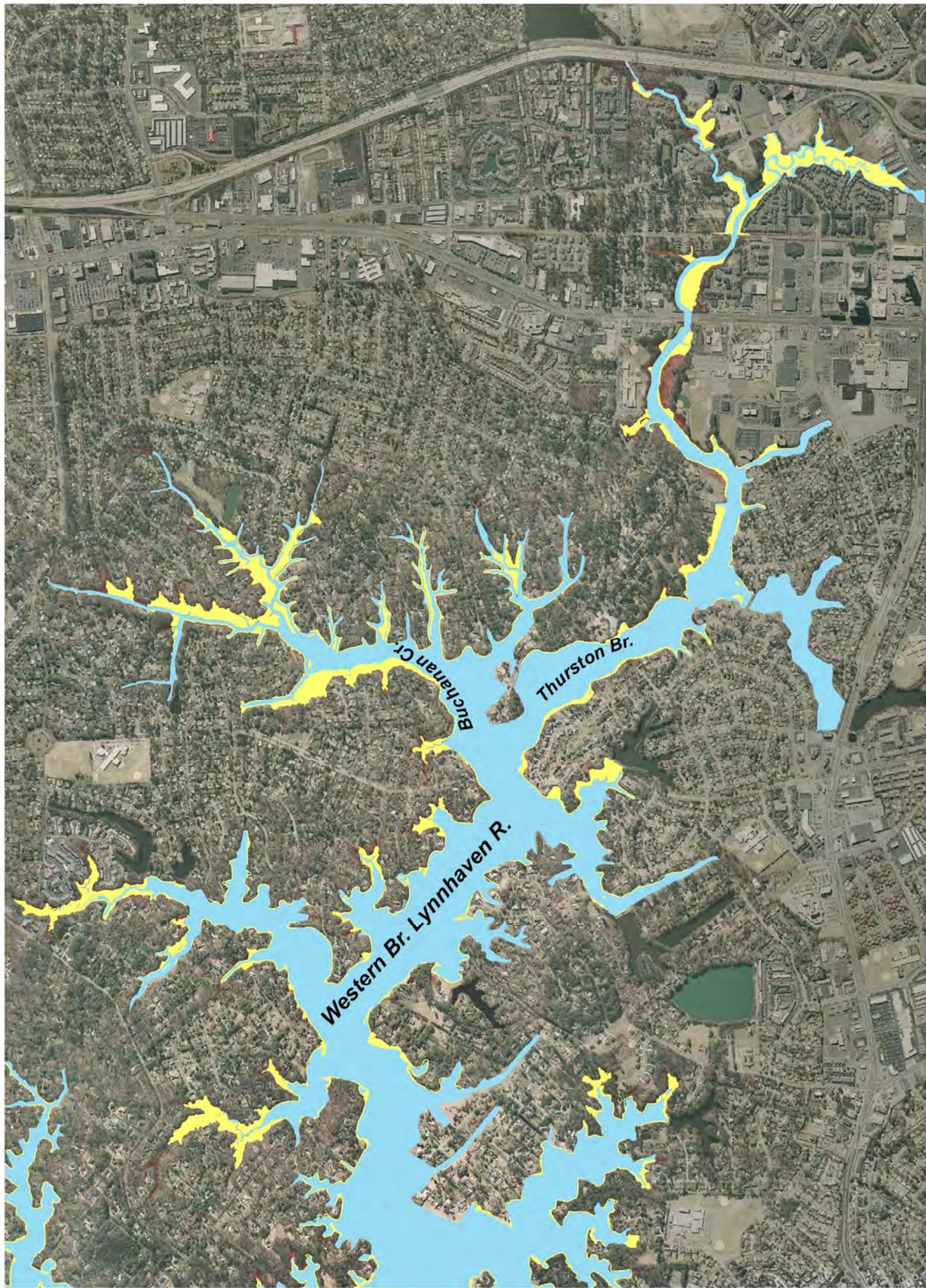
Scenario - 683 mm SLR

Pink	Upland Loss
Yellow	Tidal Marsh Loss

Lynnhaven River Watershed Plate 1E (Western Branch N 2100)



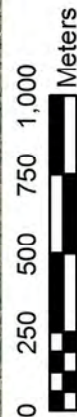
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Scenario - 683 mm SLR

Upland Loss	Tidal Marsh Loss

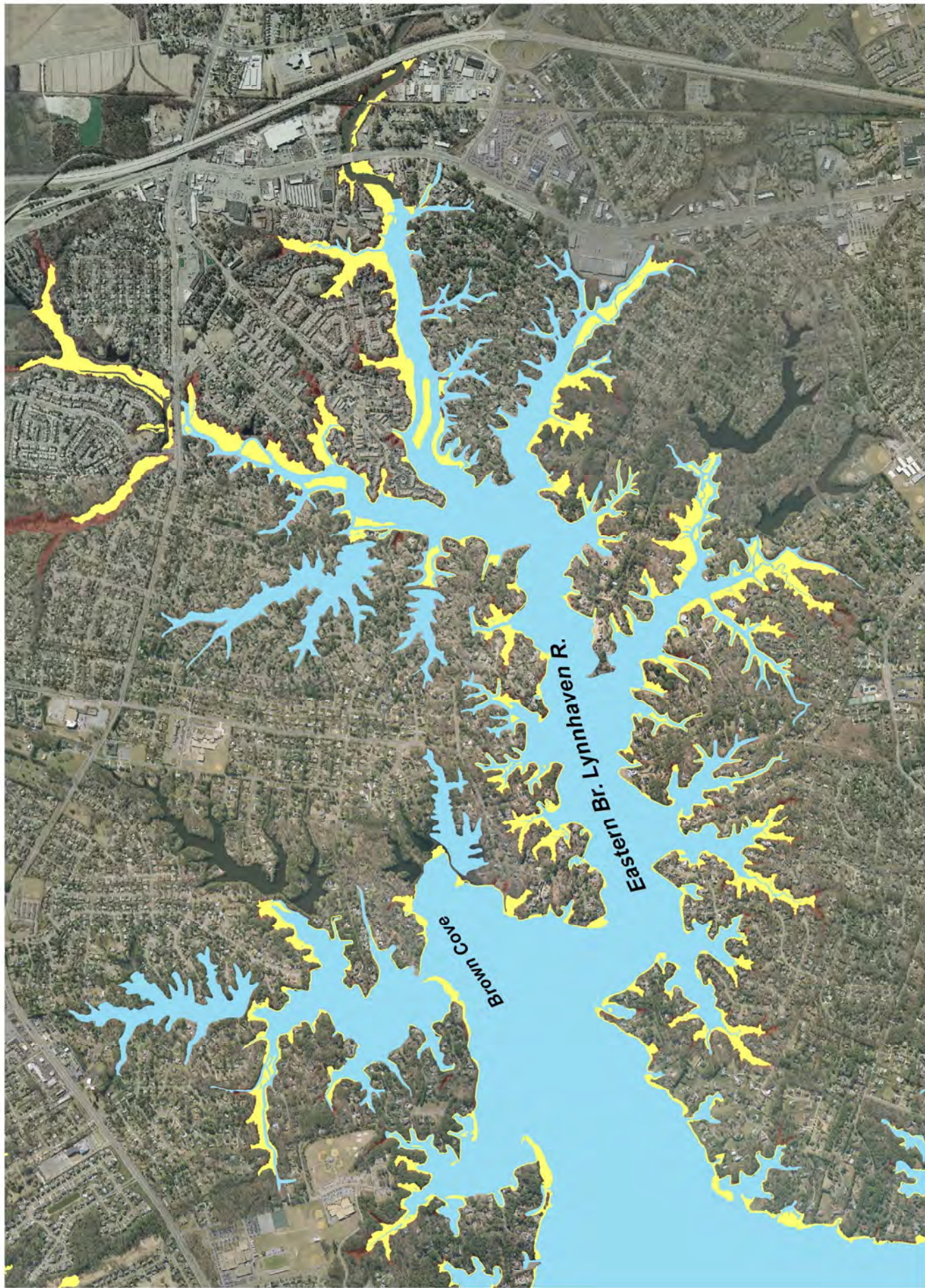




Scenario - 683 mm SLR

	Upland Loss
	Tidal Marsh Loss

Lynnhaven River Watershed Plate 3E (Eastern Branch N 2100)



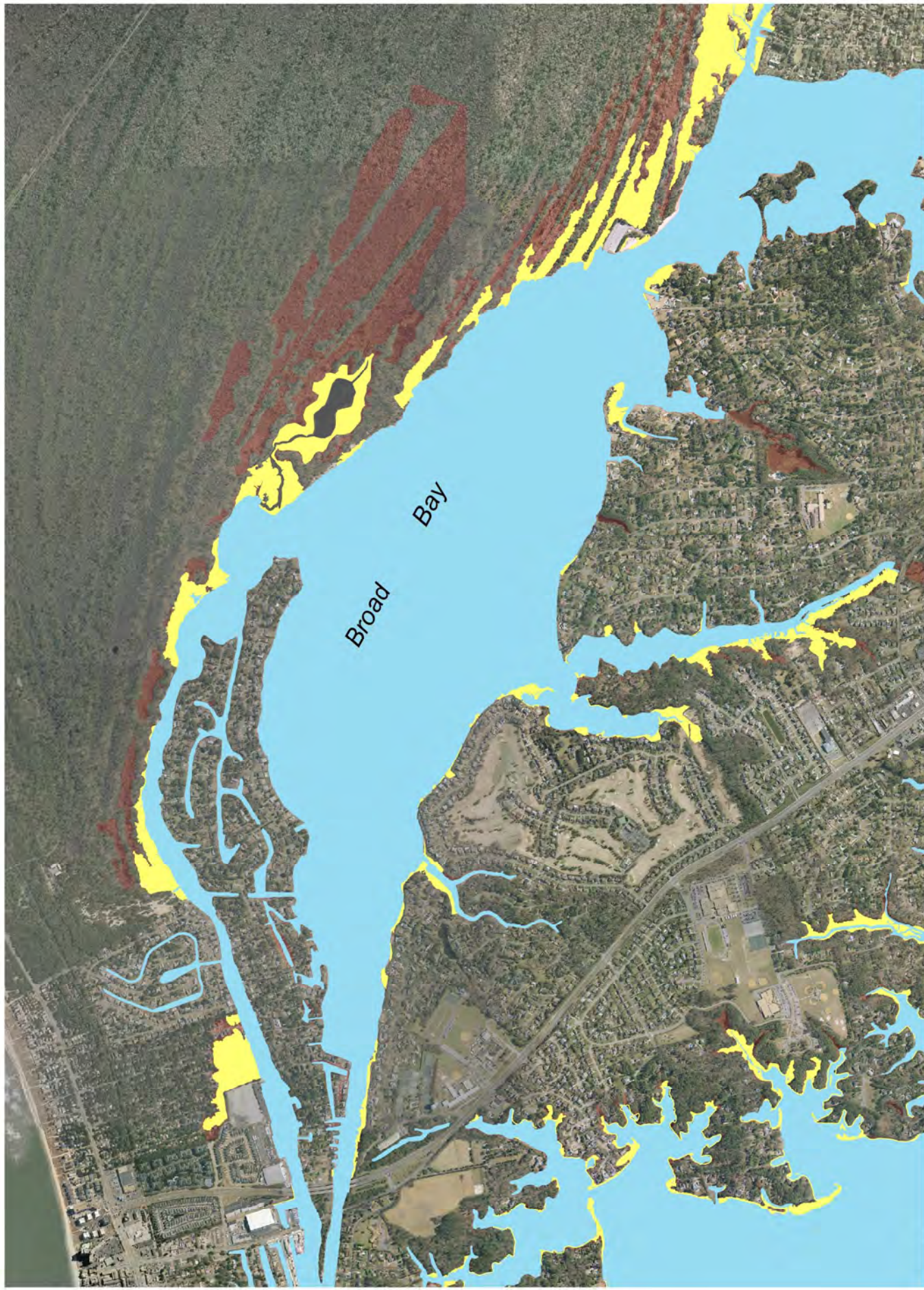
Scenario - 683 mm SLR

Upland Loss

Tidal Marsh Loss

Lynnhaven River Watershed Plate 4E (Eastern Branch S 2100)





0 250 500 750 1,000
Meters

Scenario - 683 mm SLR

Upland Loss



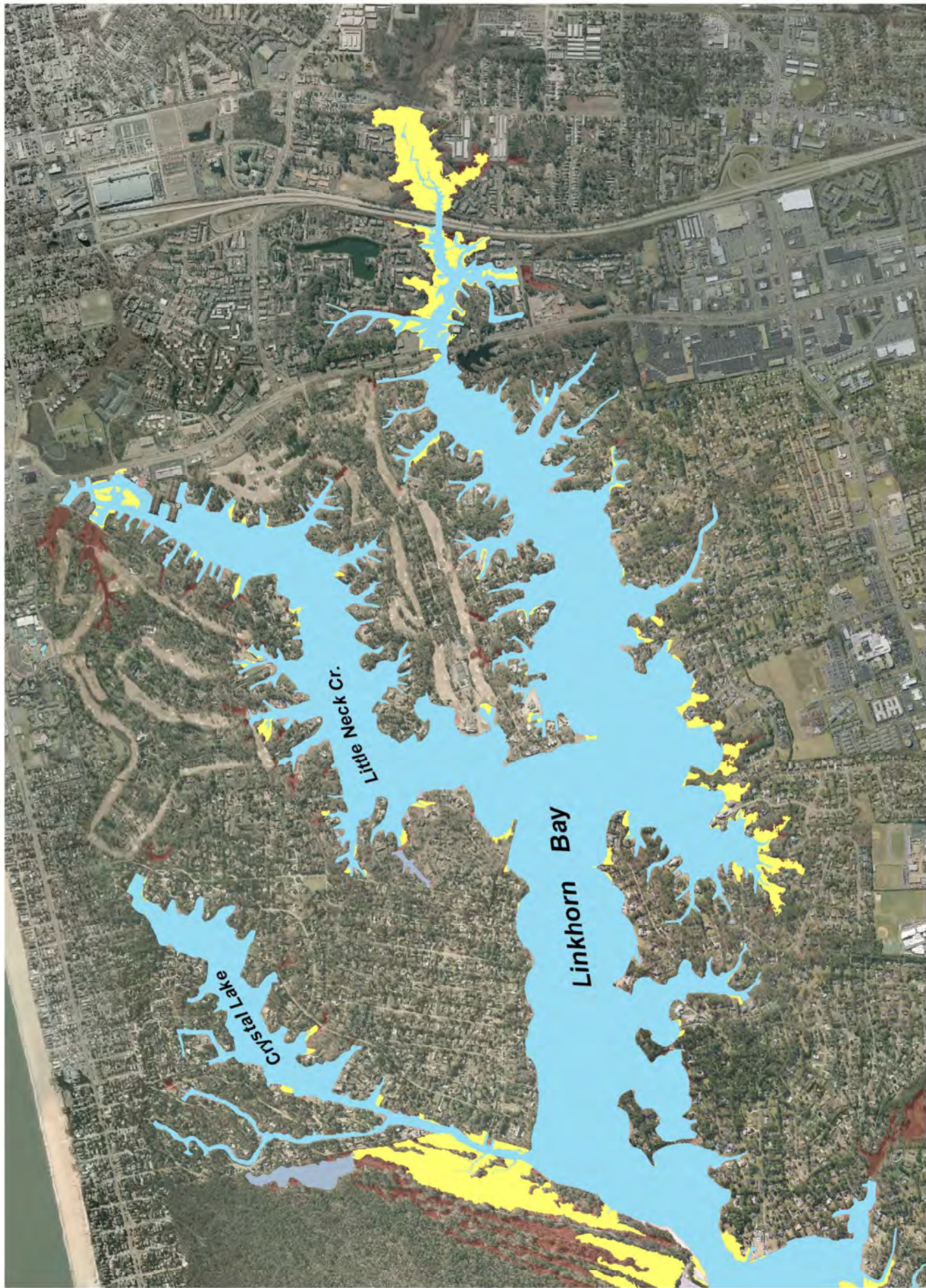
Tidal Marsh Loss



Lynnhaven River Watershed Plate 5E (Broad Bay 2100)



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Lynnhaven River Watershed Plate 6E (Linkhorn Bay 2100)

Scenario - 683 mm SLR

Upland Loss

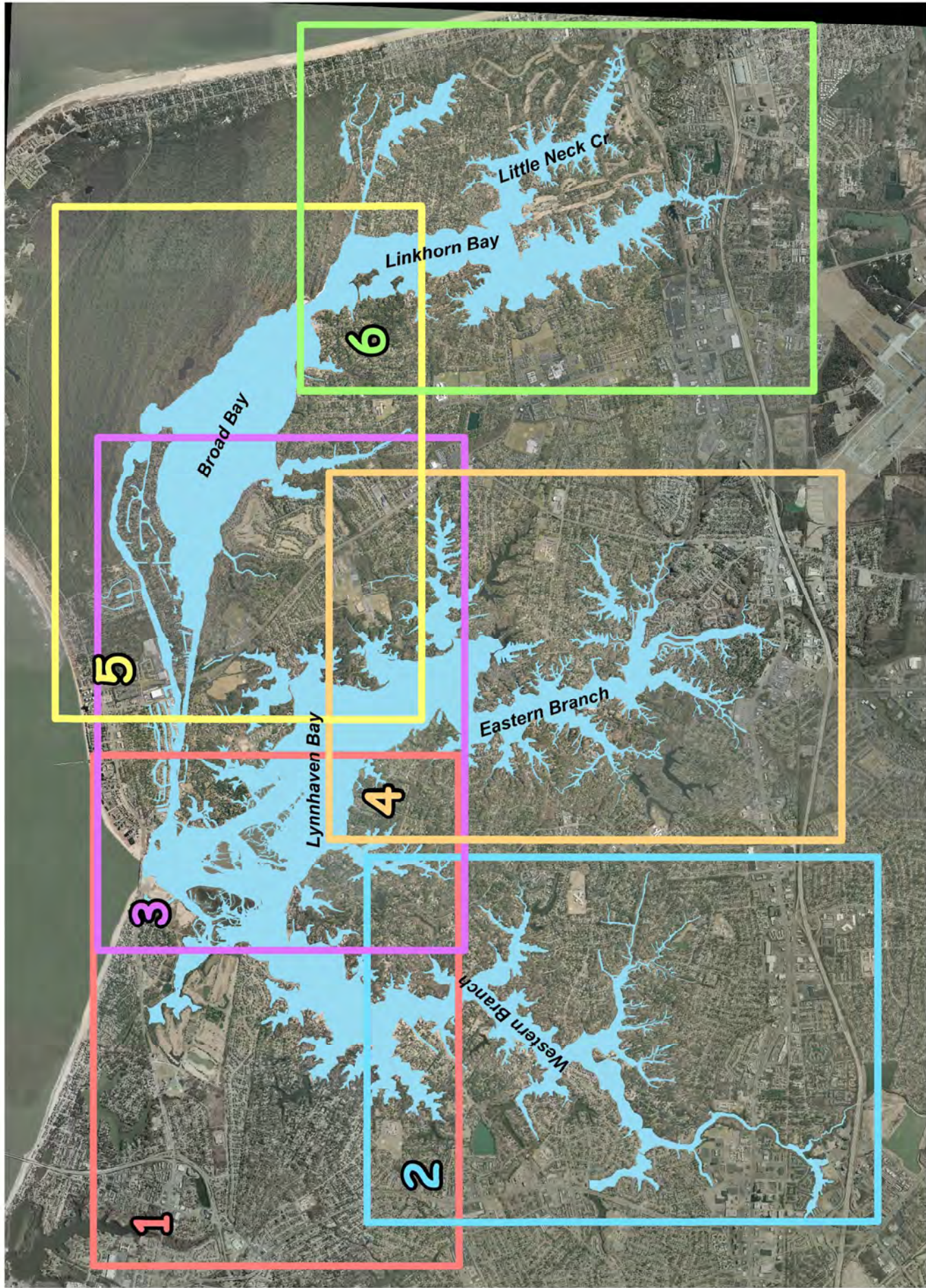
Tidal Marsh Loss

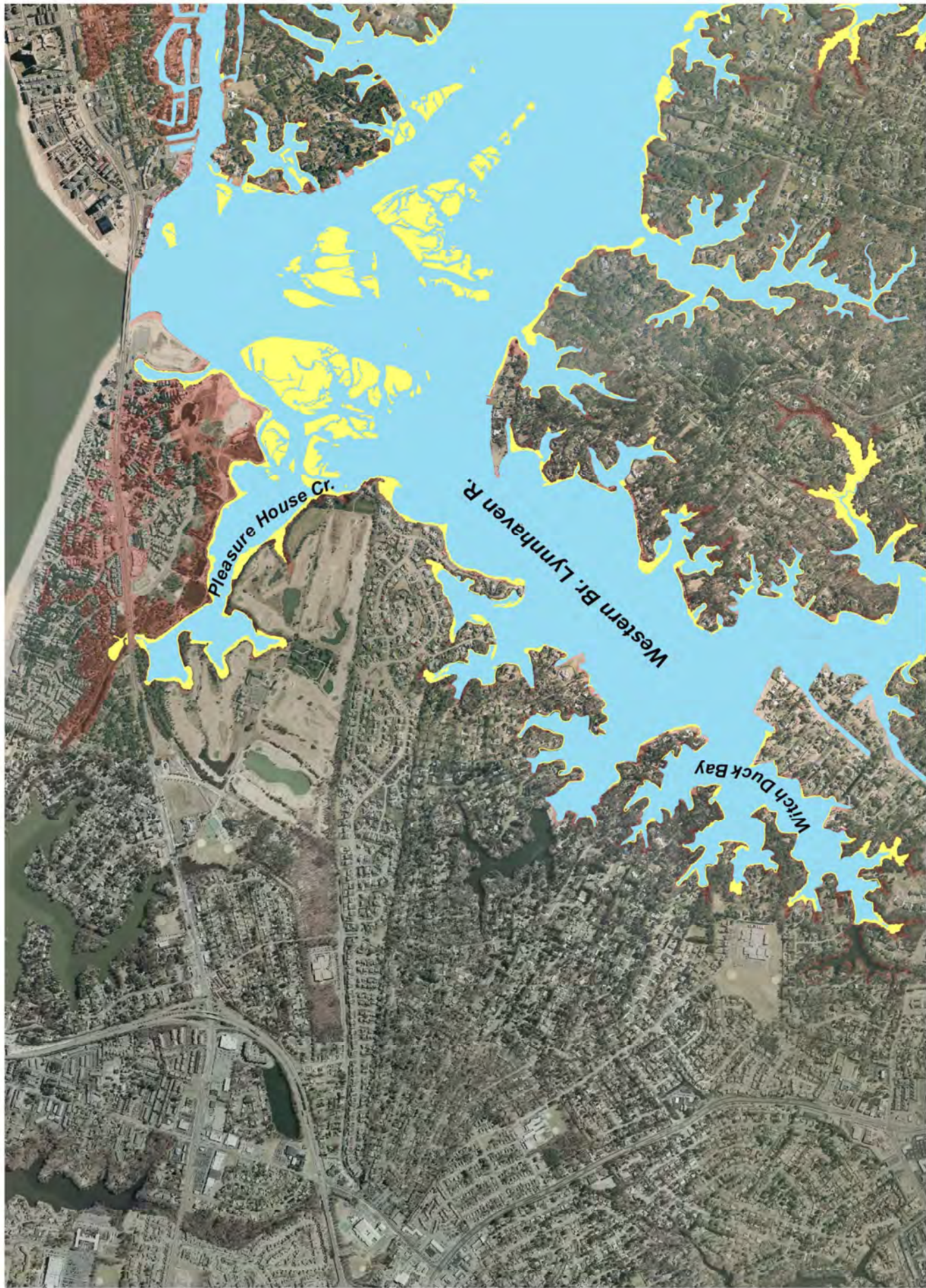


MAP APPENDIX F – Tidal Marsh and Upland Losses (Maps 1-6)

Model Conditions

Sea level rise scenario:	year = 2100
Rate of sea level rise:	17.20 mm/year
Elevation increase in MSL:	1600 mm
Marsh loss:	272.26 hectares
Marsh remaining:	0 hectares
Uplands submerged:	1109.81 hectares



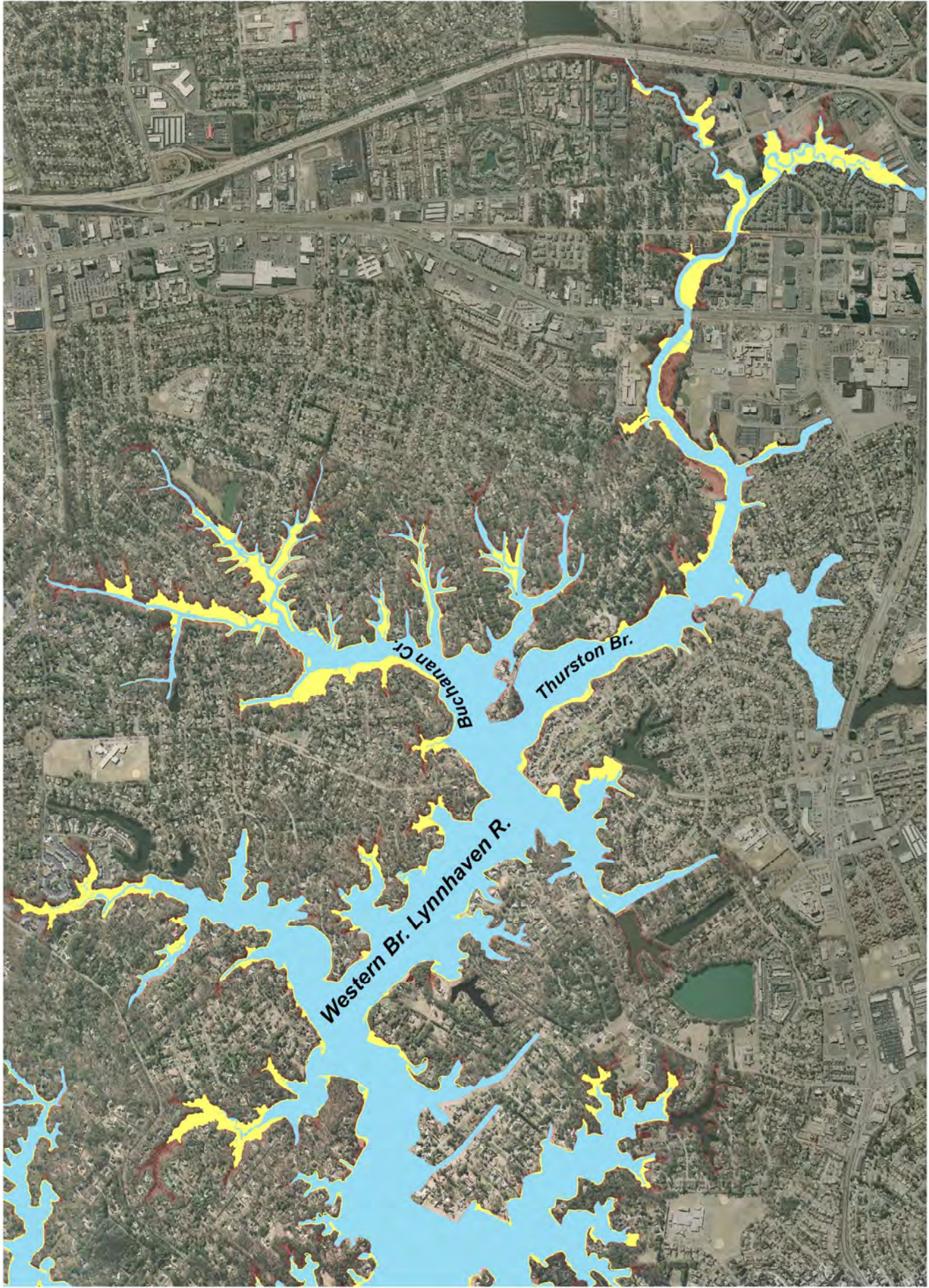


Lynnhaven River Watershed
Plate 1F (Western Branch N 2100)

Scenario - 1600 mm SLR

	Upland Loss
	Tidal Marsh Loss



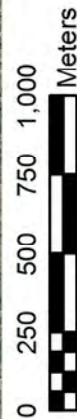


Scenario - 1600 mm SLR

Yellow	Upland Loss
Red	Tidal Marsh Loss

Lynnhaven River Watershed Plate 2F (Western Branch S 2100)



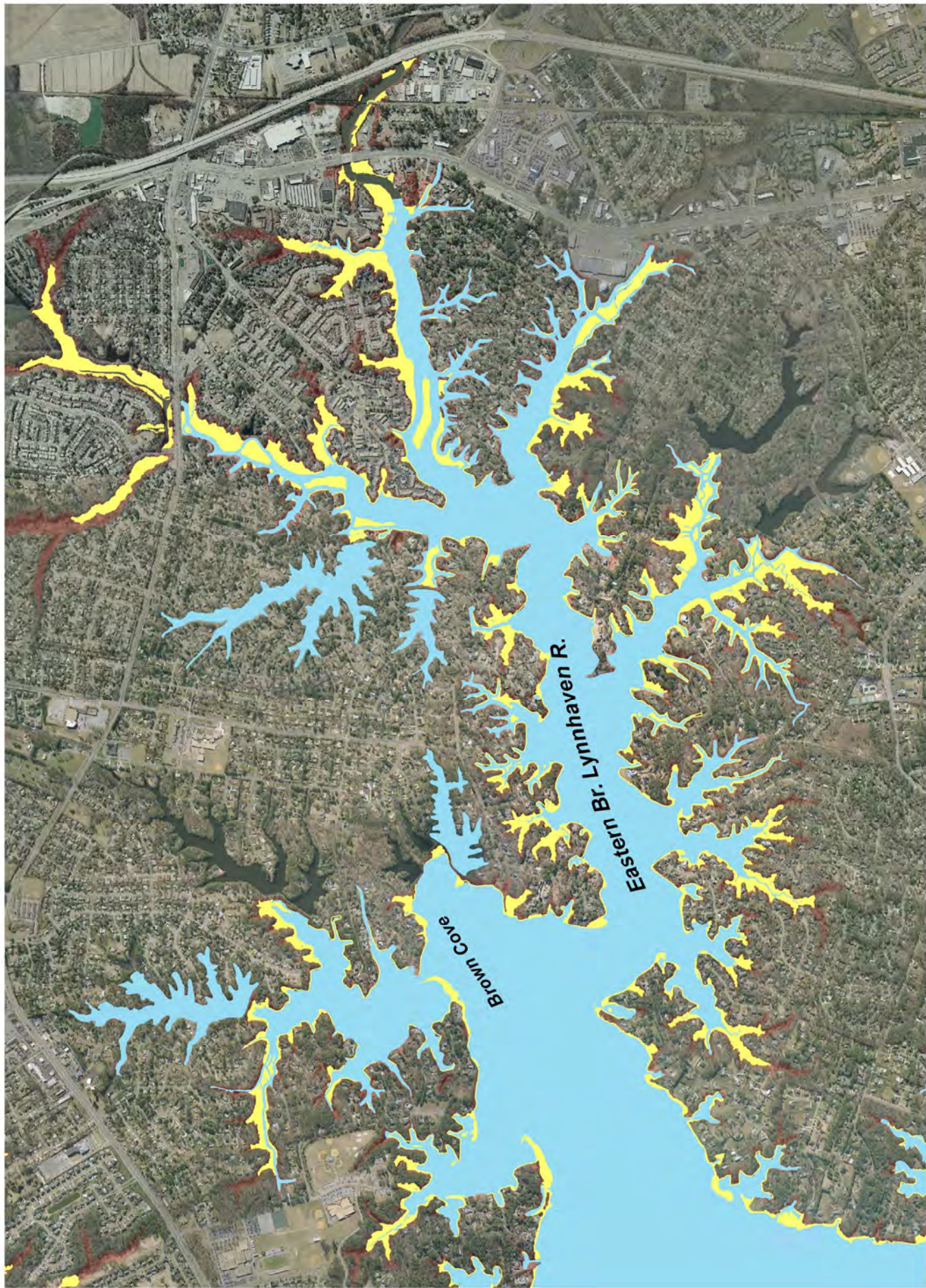


Scenario - 1600 mm SLR

Upland Loss

Tidal Marsh Loss

Lynnhaven River Watershed Plate 3F (Eastern Branch N 2100)

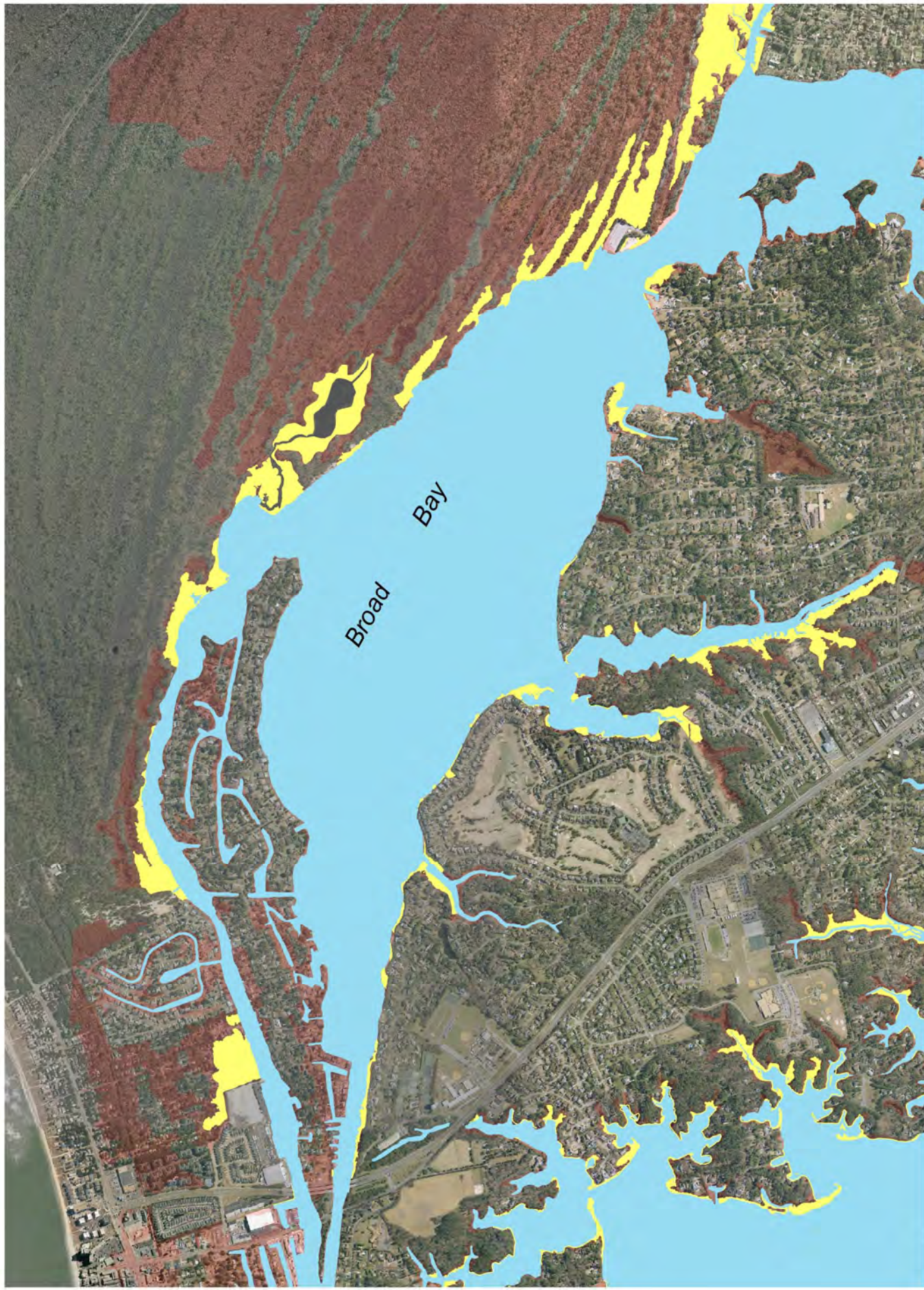


Scenario - 1600 mm SLR
Upland Loss
Tidal Marsh Loss

Lynnhaven River Watershed Plate 4F (Eastern Branch S 2100)



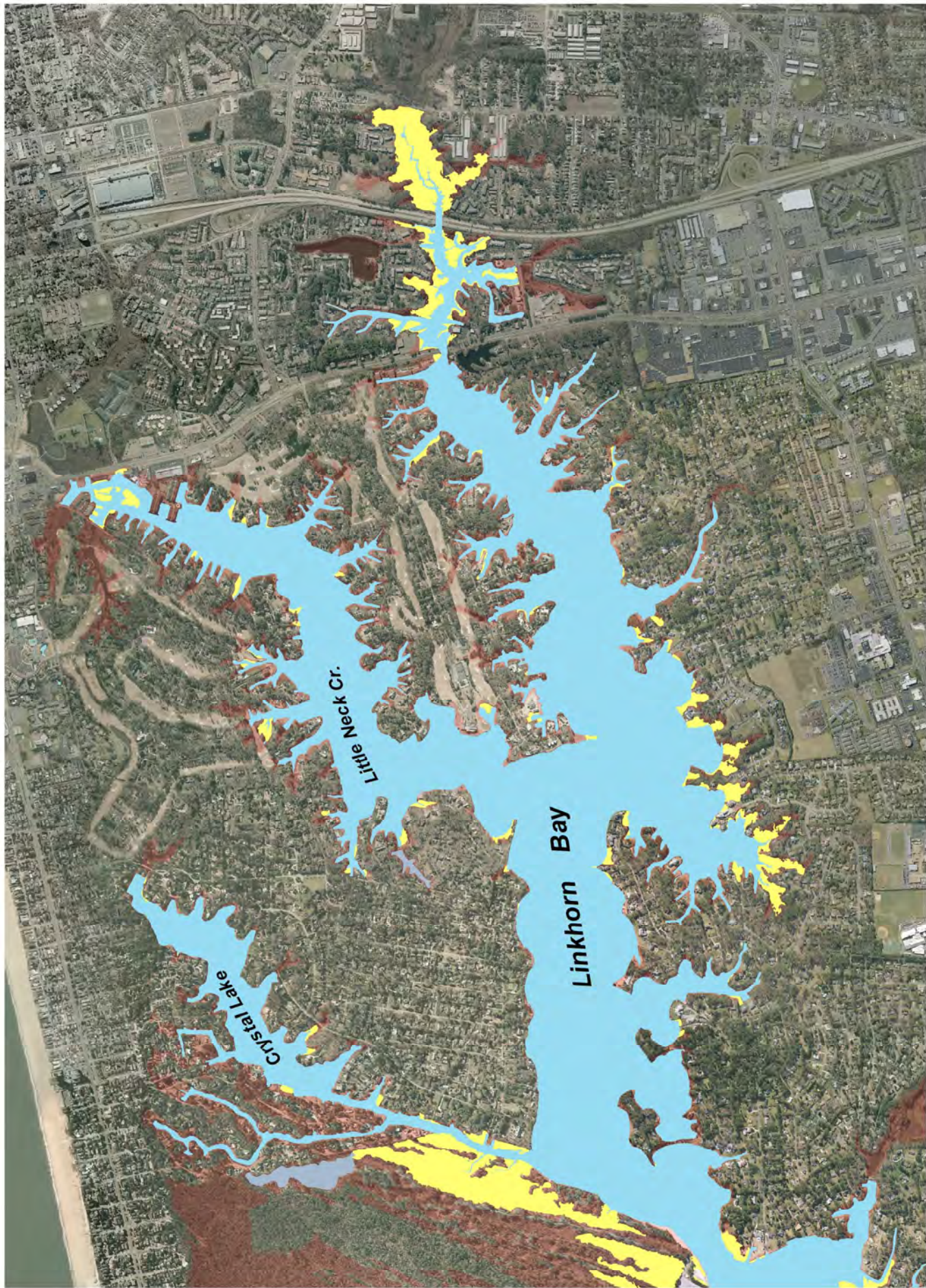
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Scenario - 1600 mm SLR

	Upland Loss
	Tidal Marsh Loss

Lynnhaven River Watershed Plate 5F (Broad Bay 2100)

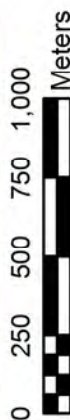


Lynnhaven River Watershed Plate 6F (Linkhorn Bay 2100)

Scenario - 1600 mm SLR

Upland Loss

Tidal Marsh Loss



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