Impacts of Sea-Level Rise on National Wildlife Refuges

Considerations for Land Protection Priorities at Blackwater, Great White Heron, Laguna Atascosa & Lower Rio Grande Valley, Lower Suwannee, Cape Romain, St. Mark, and Savannah NWRs

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Photo: National Oceanic and Atmospheric Administration

This project was made possible by the
Duke University Stanback Internship Program.

One of the well-documented impacts of climate change is a rise in sea levels, resulting from a combination of melting of land-based ice and the thermal expansion of the oceans. The 2007 assessment by the Intergovernmental Panel on Climate Change reports that sea levels have been rising in recent years at a rate of 1.7mm (0.07 inches) per year[1]. More recent studies predict that the rate will accelerate this century, leading to projections that sea-level rise could easily exceed 1 meter (39 inches) by 2100[2,3]. For the over 150 national wildlife refuges located in coastal areas, sea-level rise has the potential to reshape wetland, shift habitat types inland and upland, and even lead to complete inundation of refuge lands. This is a concern not just for the lands already within the National Wildlife Refuge System, but also those lands that have been prioritized for future acquisition. The U.S. Fish and Wildlife Service may not be maximizing the effectiveness of its conservation investments if it is making fee-title acquisitions or purchasing long-term easements on lands that are going to be underwater within a few decades. We utilized the Sea Level Affecting Marshes Model (SLAMM) to assess the threat to the lands within both the acquired and approved boundaries of eight coastal refuges, in order to help the Refuge System maximize the effectiveness of future land investments.

Background & Objectives

The National Wildlife Refuge System, managed by U.S. Fish and Wildlife Service (FWS), is composed of over 550 national wildlife refuges and 38 wetland management districts, totaling approximately 150 million acres[4] of lands and waters managed primarily for wildlife conservation. Most refuges have a Land Protection Plan (LPP) that identifies priorities for new refuge land acquisition. Furthermore, in order to make the best use of its limited land protection budget, FWS annually ranks the refuges according to criteria laid out in their Land Acquisition Priority System (LAPS). LAPS outputs numerical scores for each refuge, based on four component parts: Fisheries and Aquatic Resources, Endangered and Threatened Species, Bird Conservation, and Landscape Conservation[5]. The higher the score, the higher that refuge's priority for funding acquisitions in the upcoming fiscal year.

Though the rising sea level is starting to impact many coastal refuges, neither LAPS nor most LPPs take it into consideration. Thus, it is possible that FWS will invest in the protection of lands that will be inundated in the future. The purpose of this project is to map the impacts of sea-level rise on several national wildlife refuges, with equal emphasis on lands already acquired within a refuge boundary and lands slated to be acquired at a future date. The project also provides a reference to policymakers, to guide the updating of refuge acquisition procedures in a rapidly changing world.

Methods

We obtained the Sea Levels Affecting Marsh Model (SLAMM)[6] data for eight coastal refuges and used this geospatial data to analyze sea-level rise impacts on the future extent and configuration of wetlands and uplands. The SLAMM analysis provides a sophisticated model that tailors the impact of sea-level rise on wetlands in a particular area, by taking into account local rates of sediment accumulation and other factors affecting wetland structure and function. We examined both the lands already acquired by the refuge, and the approved boundary, which includes lands to be targeted for acquisition via purchase or easement in the future. For ease of viewing, we used analysis tools to combine various marsh types into a single "marsh/wetland" category. This allows the reader to clearly discern which areas will transition from upland to marsh, and which areas will be completely inundated. Spatial analysis was processed through ArcMap 9.3. For detailed analysis protocol, see Appendix.

Selection of National Wildlife Refuges

To maximize the relevance of our analysis to upcoming land acquisition decisions, we focused on the current highest-scoring refuges in the LAPS system. Of the top 20 LAPS ranked refuges for fiscal year 2013, eight are located in coastal areas, and had SLAMM data available for analysis (see Table 1, Figure 1). Laguna Atascosa National Wildlife Refuge (NWR) and Lower Rio Grande Valley NWR were assessed together due to their close proximity.

Table 1. Coastal refuges in LAPS 2013 Top 20

2013 Ranking	Refuge Name	Total Points
1	Great White Heron NWR	732
2	Silvio O. Conte NF&WR *(data not available)*	727
3	Savannah NWR	722
5	Laguna Atascosa NWR	710
6	Lower Suwannee NWR	683
7	St. Marks NWR	682
8	Cape Romain NWR	677
10	Lower Rio Grande Valley NWR	663
14	Yukon Delta NWR *(data not available)*	634
19	Blackwater NWR	599

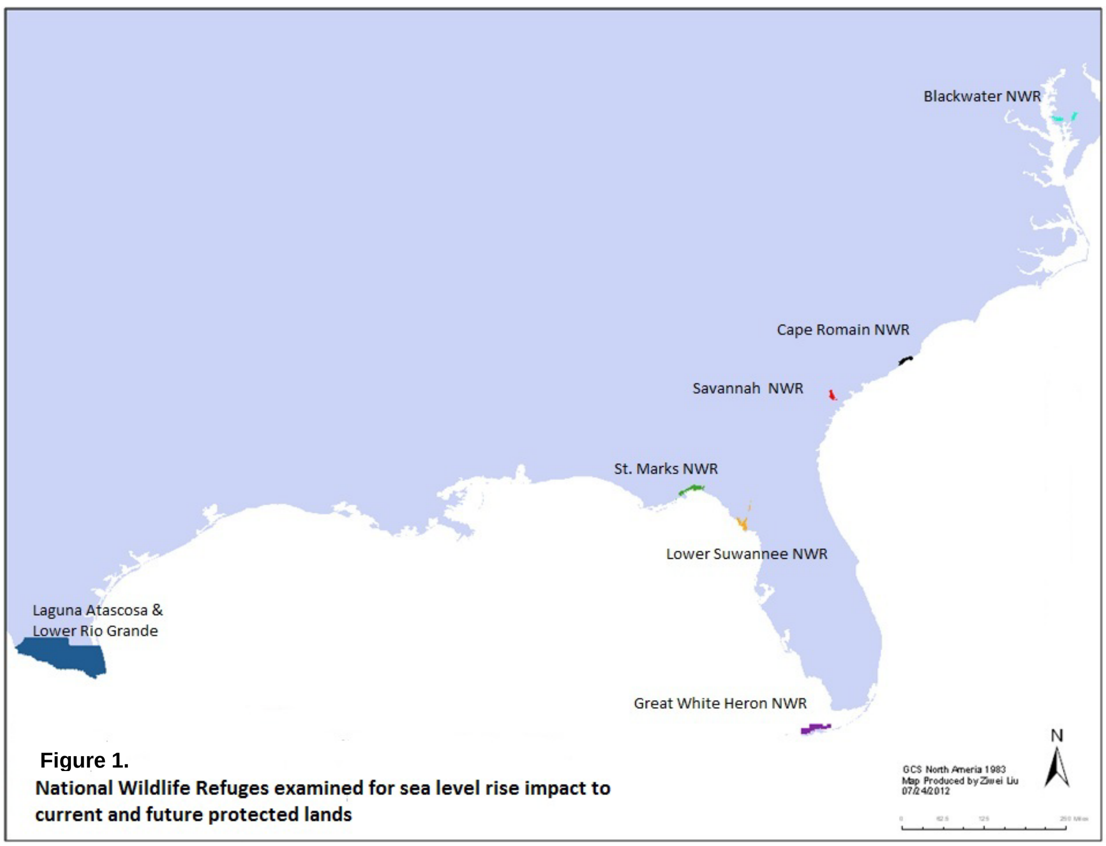

Figure 1.
National Wildlife Refuges examined for sea level rise impact to current and future protected lands

Sea-level Rise Scenarios and Output Year Applied

The 2007 assessment by the Intergovernmental Panel on Climate Change (IPCC) projected that global sea level would rise by 20 cm to 60 cm[1] (8 to 24 inches) by the year 2100. However, more recent research suggests that the rate could be considerably higher, projecting a range of 50 cm to 140 cm (20 to 55 inches), when the likely acceleration of melting of land-based ice is taken into consideration[2]. The U.S. Global Change Research Program's 2009 comprehensive assessment of climate change impacts in the U.S., using the best available scientific information at the time, projected that 90 to 120 cm (35 to 47 inches) was the most likely range of increase in the 21st century[3].

The SLAMM model allows users to choose from five different sea-level rise scenarios: 0.39 m (15 inches), 0.69 m (27 inches), 1 m (39 inches), 1.5 m (59 inches), and 2 m (78 inches). Each scenario begins at 1990 and ends at 2100, and is of global, not local, sea-level rise. For example, the 1 m sea-level rise scenario uses the assumption that global sea level will be 1 meter higher at 2100 than that in 1990. For this assessment, we chose to apply the 1 m and 1.5 m sea-level rise scenarios, because 1 m is within the range projected by the USGCRP report, and 1.5 m is close to the high-end possibility projected recent studies[7].

Similarly, the SLAMM model requires the user to choose one of five output year options: the initial year (which depends on the latest available data), 2025, 2050, 2075, and 2100. We selected for this project an output year of 2075, a time period long enough to demonstrate meaningful change and apply to long-term refuge planning, while avoiding some of the uncertainties associated with projecting out to 2100.

Figure 2, below, illustrates how the selection of the scenarios and the output year lead to the two projections of global sea-level rise used in this analysis. The maps on the following pages use an output year of 2075, at which time the 1 meter scenario projects global sea-level rise of 69.8 centimeters and the 1.5 meter scenario projects global sea-level rise of 104.7 cm. These projections, it turns out, are very similar to the "condition in 2100" projections for the A1B-max and 1 meter scenarios, respectively.

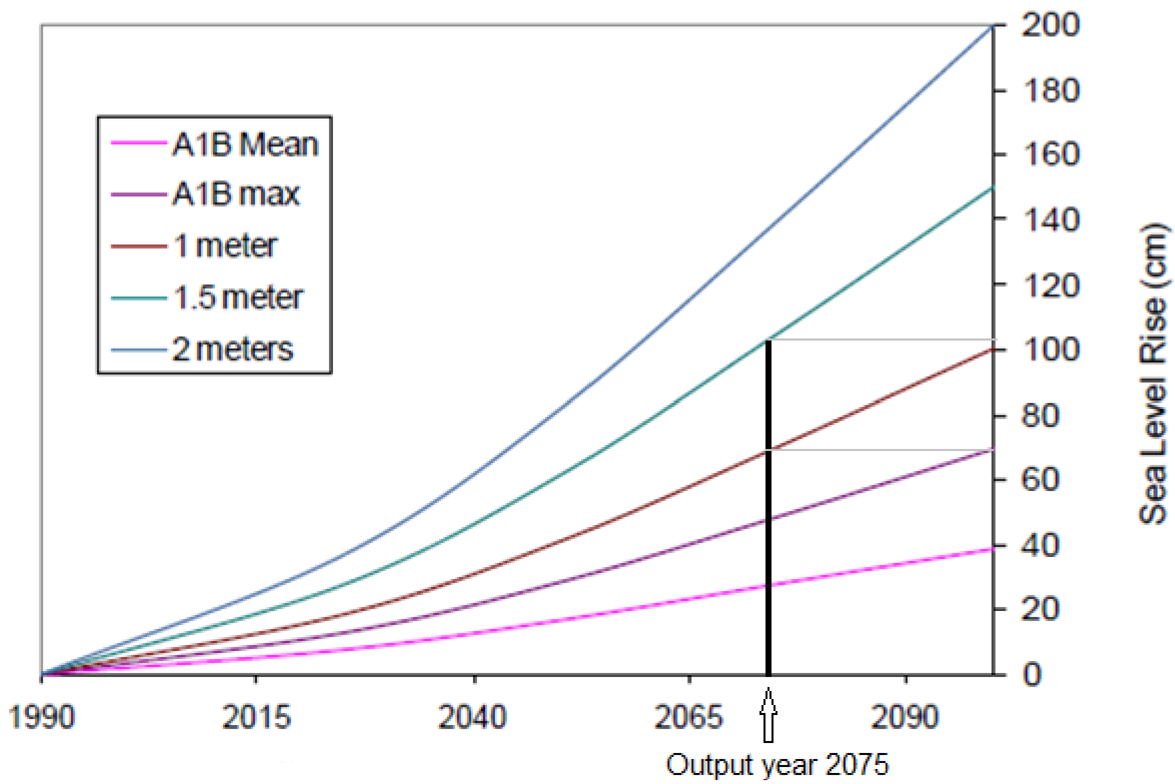

Figure 2. The various scenarios available within the SLAMM model, emphasizing the conditions in chosen output year of 2075 for the two scenarios selected. Graph based on material from SLAMM 6.0.1[5].

Results

General Findings- 1-meter Sea-level rise

The 1 meter of sea-level rise scenario, with 2075 as an output year, yields a global sea-level rise of 69.8 cm (27 inches). According to the projections of the SLAMM data, of sea-level rise varies widely among the eight refuges: four of the refuges have less than 5% of their land area vulnerable, while two face potential net loss of more than 40% of refuge lands by 2075, if sea-level rises by one meter (39 inches) over the course of the century. Results for all refuges are summarized in Table 2.

Table 2. Percent inundation by 2075 under scenario of 1 meter of sea-level rise by 2100.

Refuge	Percentage Net Loss of Upland and Wetland Within:		
	Area Already Acquired	Area Approved but not Acquired	Acquired + Approved Boundary
Blackwater	63.5%	31.8%	42%
Great White Heron	45.9%	41.5%	41.5%
Laguna Atascosa & Lower Rio Grande Valley	30%	19.3%	25.9%
Lower Suwannee	3.3%	5.9%	4.1%
Cape Romain	3.7%	2%	3.6%
St. Marks	1.4%	1.2%	1.3%
Savannah	0.2%	0.6%	0.4%

General Findings- 1.5-meter Sea-level rise

As was the case for the 1 m scenario, 1.5 meters of sea-level rise this century varies in its impact on the eight refgues in 2075, but the results of the SLAMM data project that for several of the refuges the impact is substantially greater. Great White Heron and Cape Romain, in particular, experience large increases in the area inundated. Results for all refuges are summarized in Table 3.

Table 3. Percent inundation by 2075 under 1.5 meters of sea-level rise by 2100.

Refuge	Percentage Net Loss of Upland and Wetland Within:		
	Area Already Acquired	Area Approved but not Acquired	Acquired + Approved Boundary
Blackwater	70.8%	39.8%	49.8%
Great White Heron	88.5%	73.7%	76.3%
Laguna Atascosa & Lower Rio Grande Valley	35.2%	22.4%	30.3%
Lower Suwannee	8.8%	9.8%	9.1%
Cape Romain	13.7%	4.7%	13.1%
St. Marks	4.1%	1.8%	3.2%
Savannah	0.5%	1.1%	0.7%

A more detailed discussion of the impacts to each individual refuge follows, accompanied by map results. The individual refuge results are presented in order of SLR impact in the 1 m scenario. Figures are hyperlinked within the text to allow easy navigation between text and figures. Following the case studies, we provide recommendations to FWS for incorporating SLR into land protection planning.

Blackwater National Wildlife Refuge (Maryland)

Blackwater faces severe impacts from sea-level rise under both the 1 m and 1.5 m SLR scenario (Table 4). The refuge is currently comprised mainly of wetlands and open water (Figure 3). Under the 1m sea-level rise scenario, Blackwater faces the largest losses of any of the refuges we profiled: most land from the middle to the southern part of Blackwater Refuge is projected to be inundated by 2075 (Figure 4), resulting in the loss of 64.1% of the wetlands in the area already acquired (Figure 5).

Additional upland and wetlands would be lost under the 1.5 meter scenario, with 70.3% of the wetlands replaced with open water (Figure 6). As with the 1 m scenario, most of the losses occur on the south side, and marsh does remain intact in the northern part of the area within the approved boundary (Figure 7).

In addition to the main area of the refuge, the LPP for Blackwater has targeted an area along the Nanticoke River, to the east of the current area of the refuge (Figure 8). None of this area has been acquired to date. While wetlands adjacent to the river will also be inundated by 2075 under both the 1 m (Figure 9, Figure 10) and 1.5 m SLR scenario (Figure 11, Figure 12), there will also be persistent areas of wetlands and uplands, and some new wetland creation in the corridor. Persistence within this corridor accounts for the lower levels of inundation within the "Approved, Not Yet Acquired" portions of the refuge, compared to "Acquired Refuge Lands" (Table 4).

To reduce the impact of sea-level rise on Blackwater NWR, the Refuge should focus its acquisition efforts on lands within the approved boundary that are on the north side of the acquired area, where marsh and wetlands will be more persistent. Acquisitions within the Nanticoke corridor are also likely to maintain habitat values over the coming century. However, to maximize long-term protection of marsh habitats in the vicinity, it may be necessary to extend the approved boundary of the main part of the refuge to include areas to the north where wetlands appear likely to persist.

Table 4. Summary of SLR impacts on Blackwater NWR.

Blackwater National Wildlife Refuge		Acres in 2000	1 m SLR Scenario		1.5 m SLR Scenario	
			Acres in 2075	% lost from 2000	Acres in 2075	% lost from 2000
Acquired Refuge Lands	Upland	1,857.4	791.5	57.4%	435.9	75%
	Wetlands	19,130.6	6866.9	64.1%	5,693.1	70.3%
	Total	20,988	7658.4	63.5%	6,129	70.8%
Approved, Not yet Acquired	Upland	17,205.7	11,638.6	32.4%	10,658.6	36.8%
	Wetlands	27,292.8	18,687.8	31.5%	16,143.8	41.6%
	Total	44,498.5	30,326.4	31.8%	26,802.4	39.8%
Total Approved Boundary	Upland	18,943.8	12349.3	34.8%	11,020.6	40.4%
	Wetlands	46,234.1	25425.1	45.0%	21,724.9	53.4%
	Total	65,177.9	37774.4	42.0%	32,745.4	49.8%

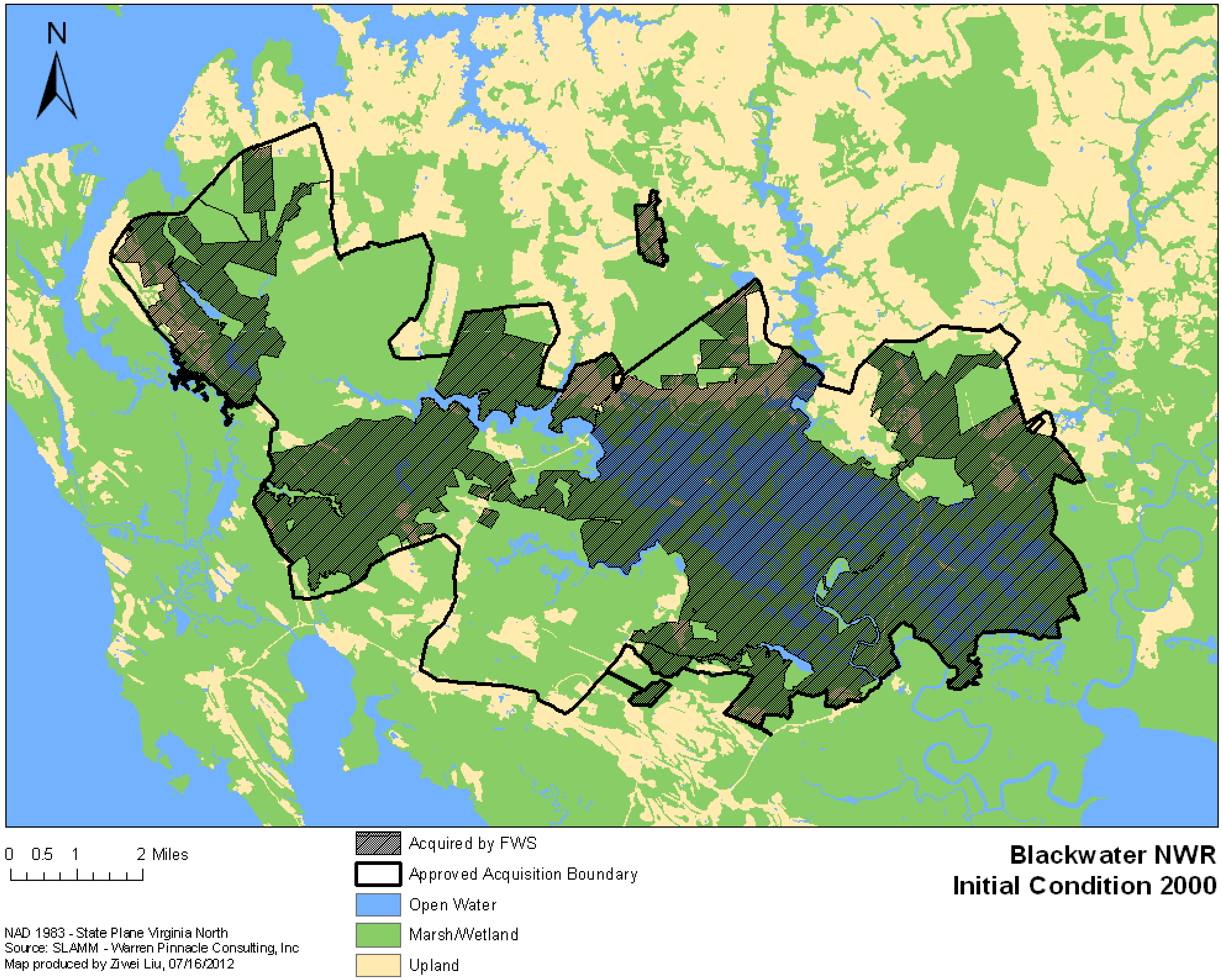

Figure 3. Blackwater NWR, main area of refuge, initial condition (2000). Back to text.

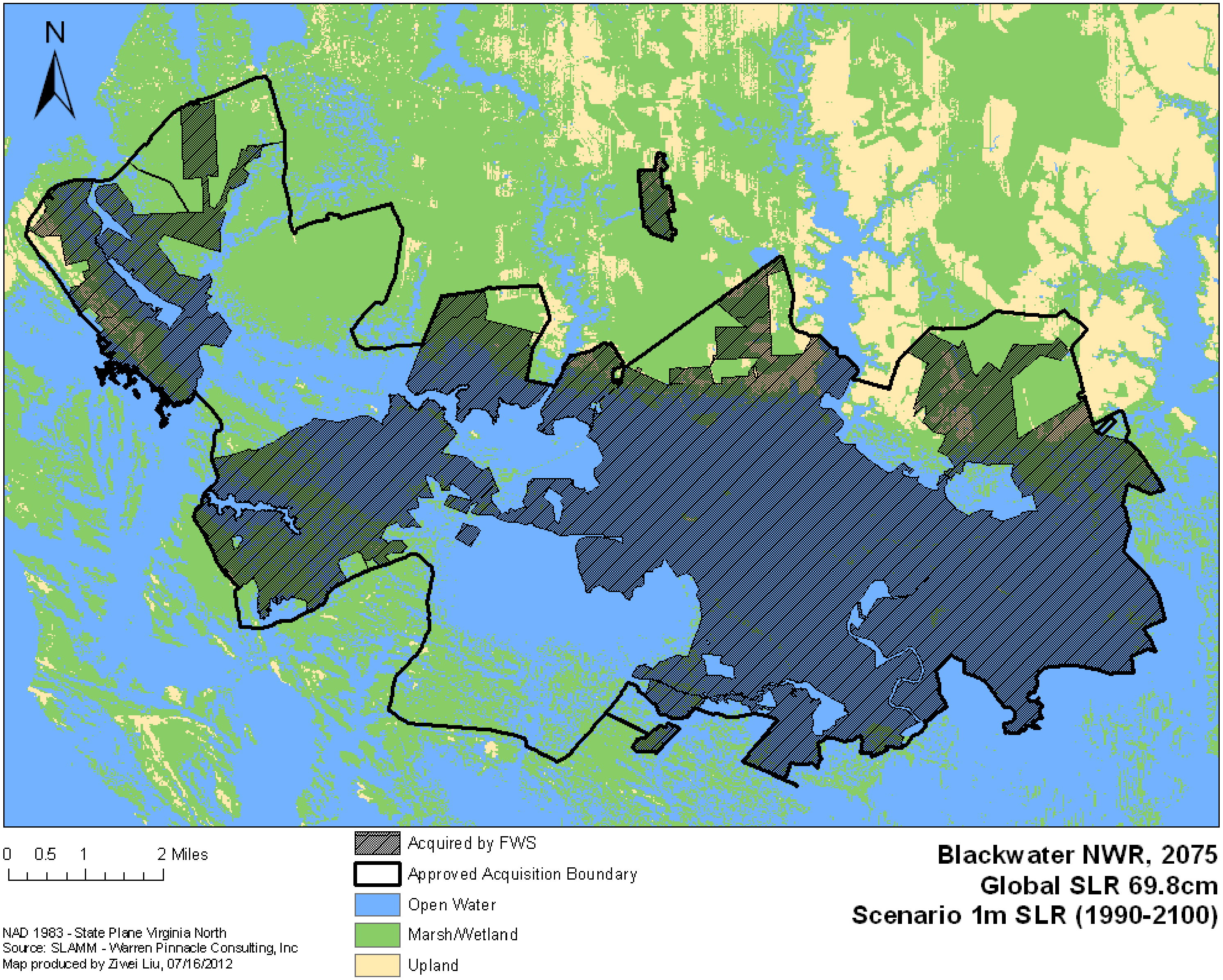

Figure 4. Blackwater NWR, main area of refuge, condition in 2075, 1 m SLR scenario. Back to text.

Much of the acquired area (shaded) of the refuge will be inundated (red), along with large parts of the southern part of the approved boundary. However, marsh habitat will remain (light green), and new marsh will be created (dark green), in the northern portion of the approved boundary as well as to the north of the current boundary.

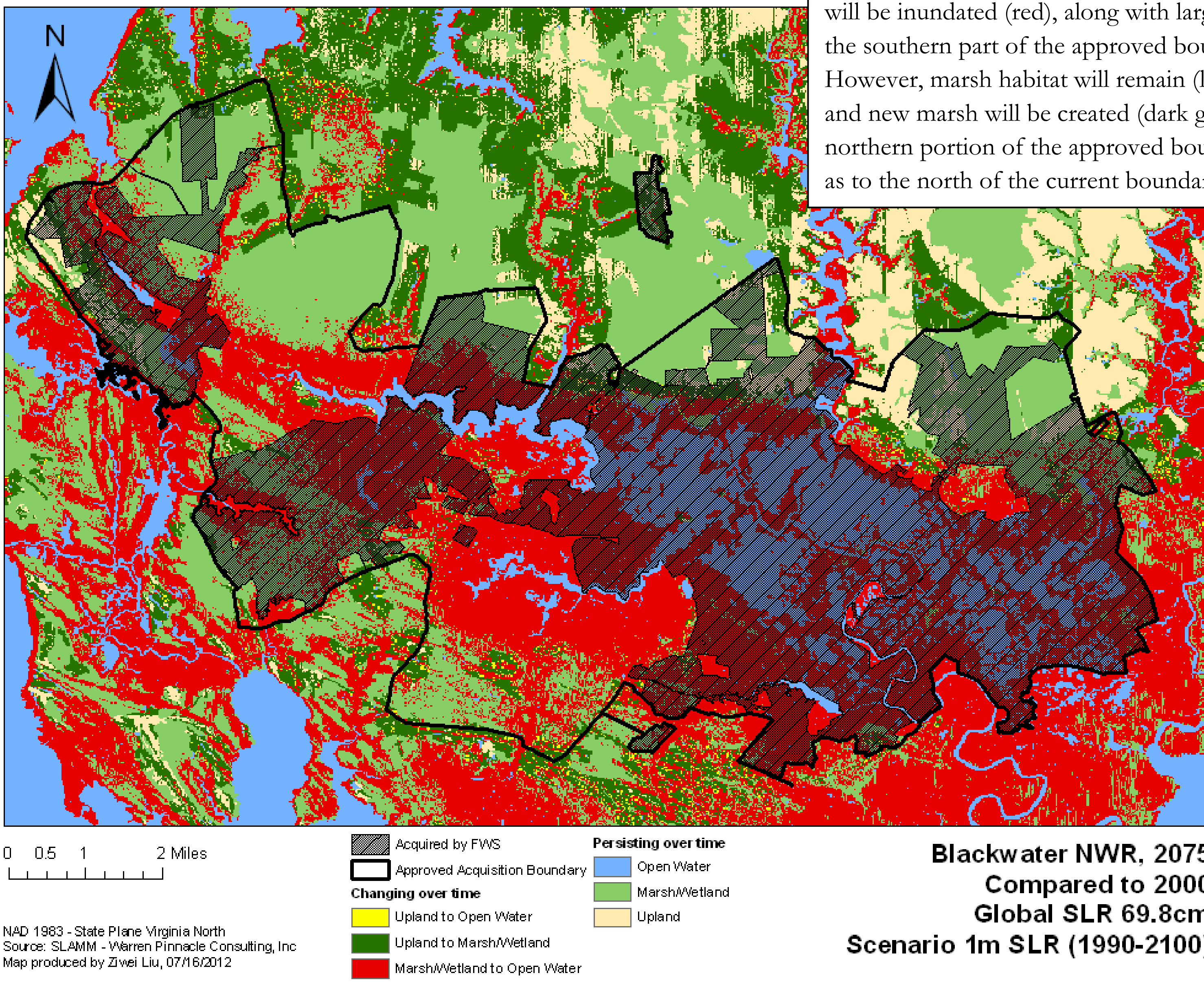

Figure 5. Blackwater NWR, main area of refuge, change from 2000 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

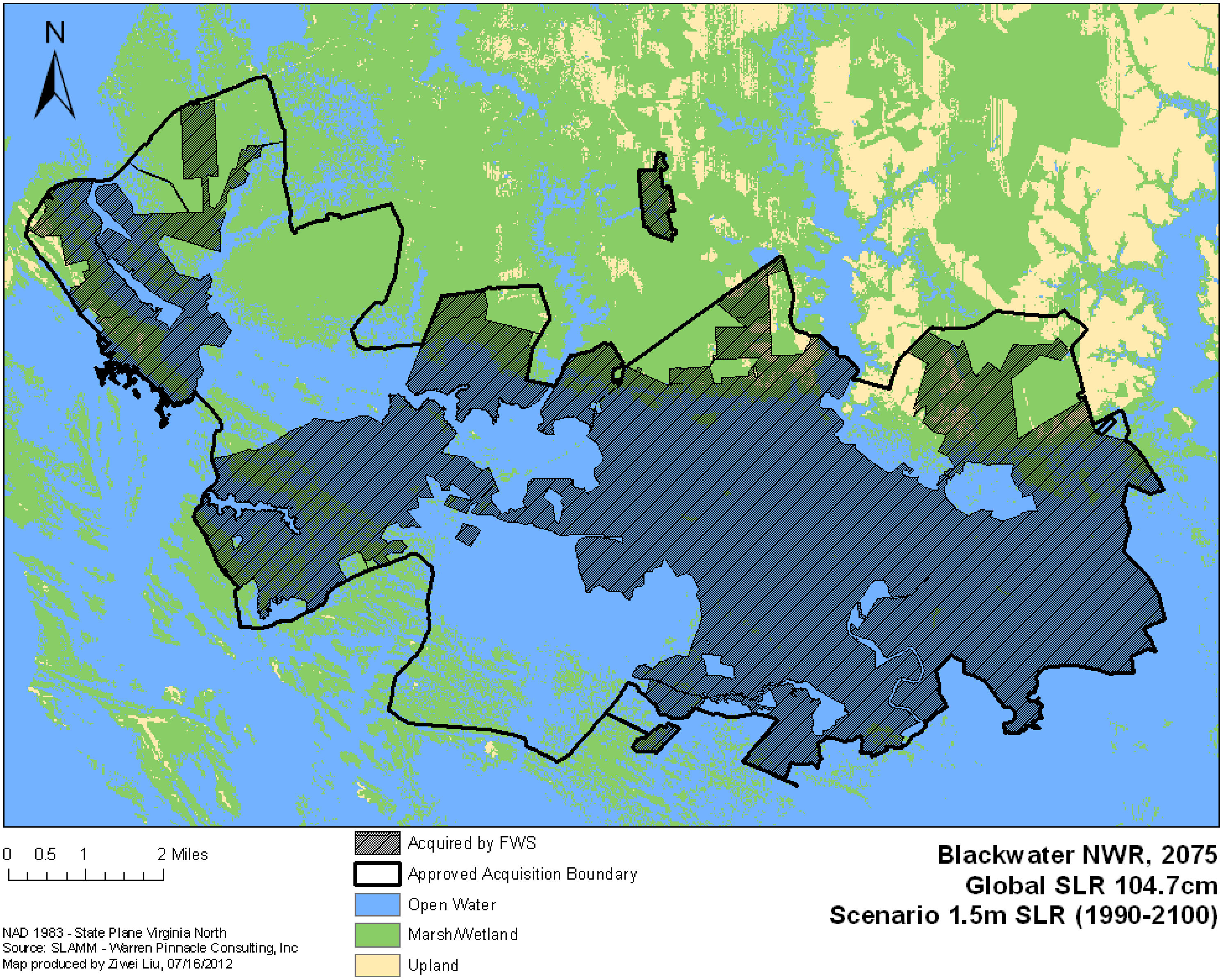

Figure 6. Blackwater NWR, main area of refuge, condition in 2075, 1.5 m SLR scenario. Back to text.

Nearly all of the acquired area of the refuge is inundated under the 1.5-m scenario. Areas with wetland habitat values will persist mainly to the north of the current refuge.

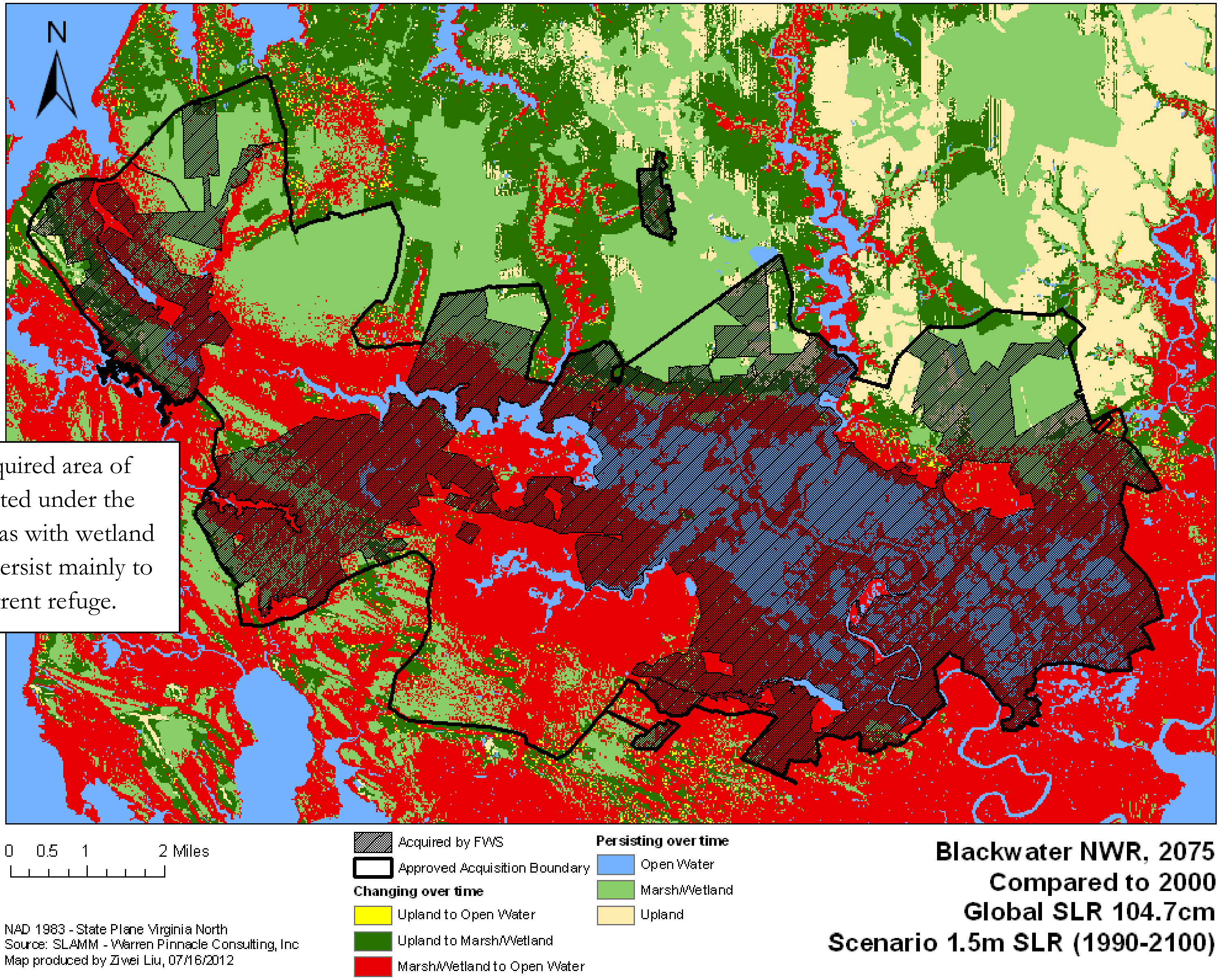

Figure 7. Blackwater NWR, main area of refuge, change from 2000 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

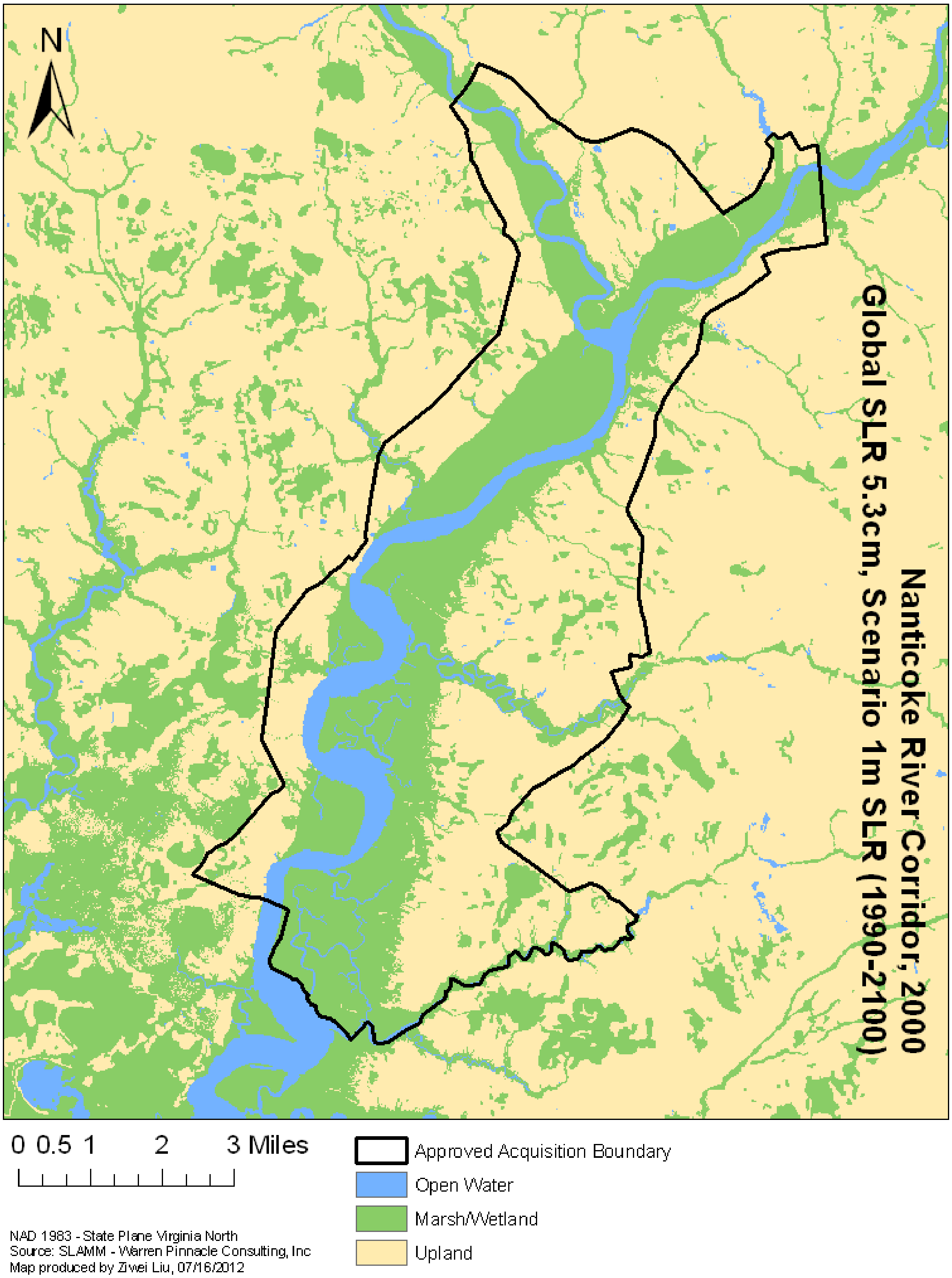

Figure 8. Blackwater NWR, Nanticoke River corridor (not yet acquired), initial condition (2000). Back to text.

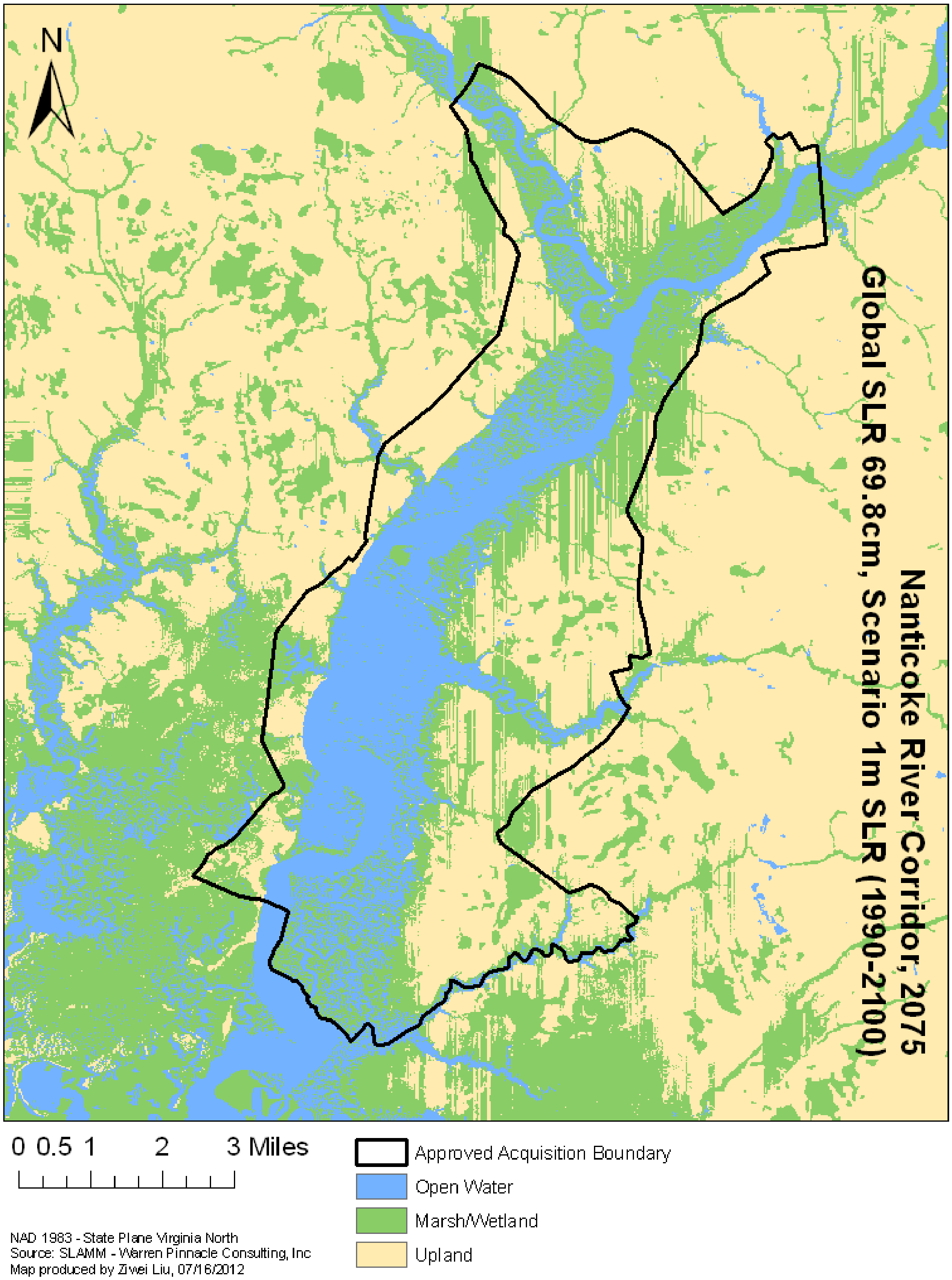

Figure 9. Blackwater NWR, Nanticoke River corridor, condition in 2075, 1 m SLR scenario. Back to text.

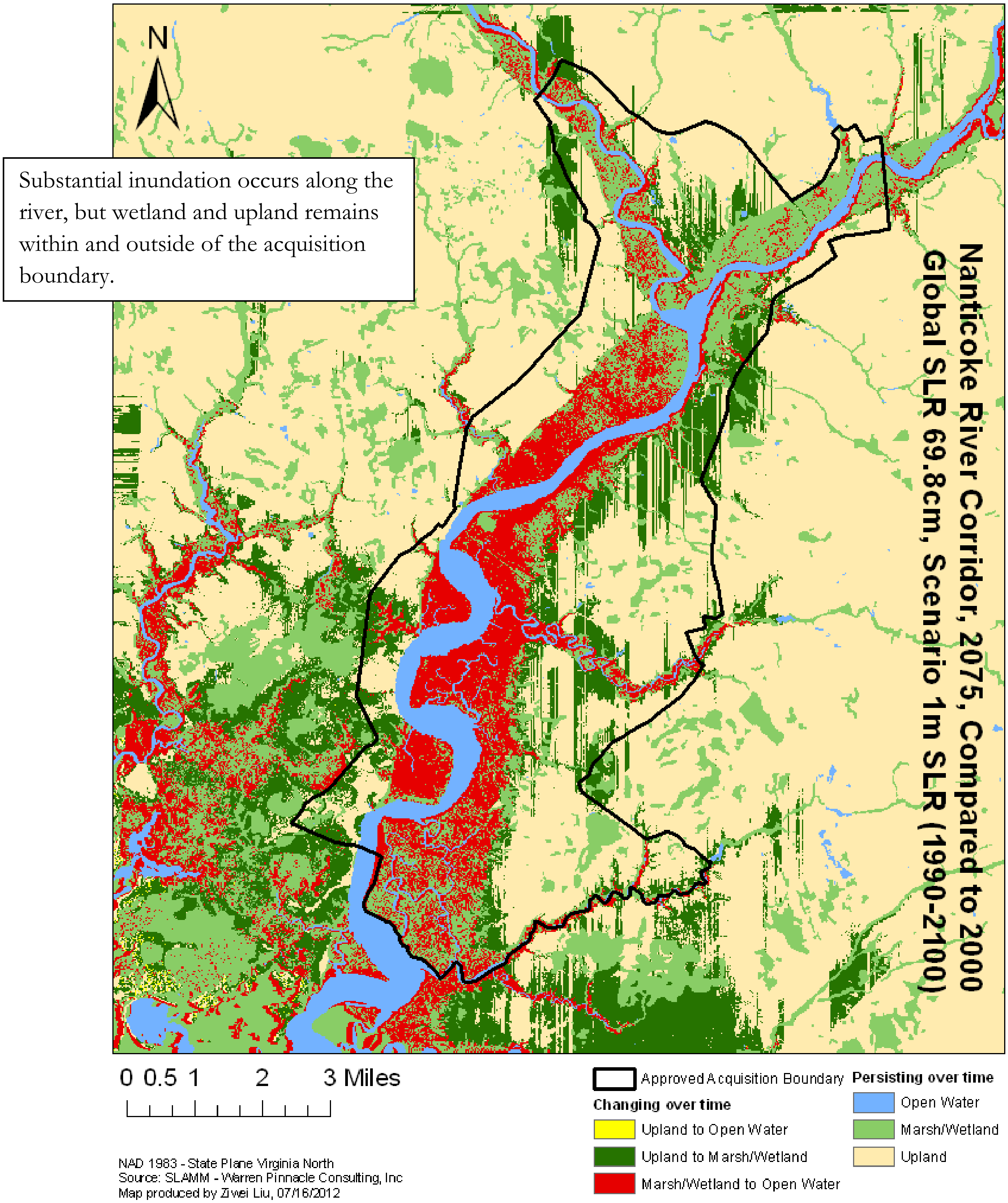

Figure 10. Blackwater NWR, Nanticoke River corridor, change from 2000 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

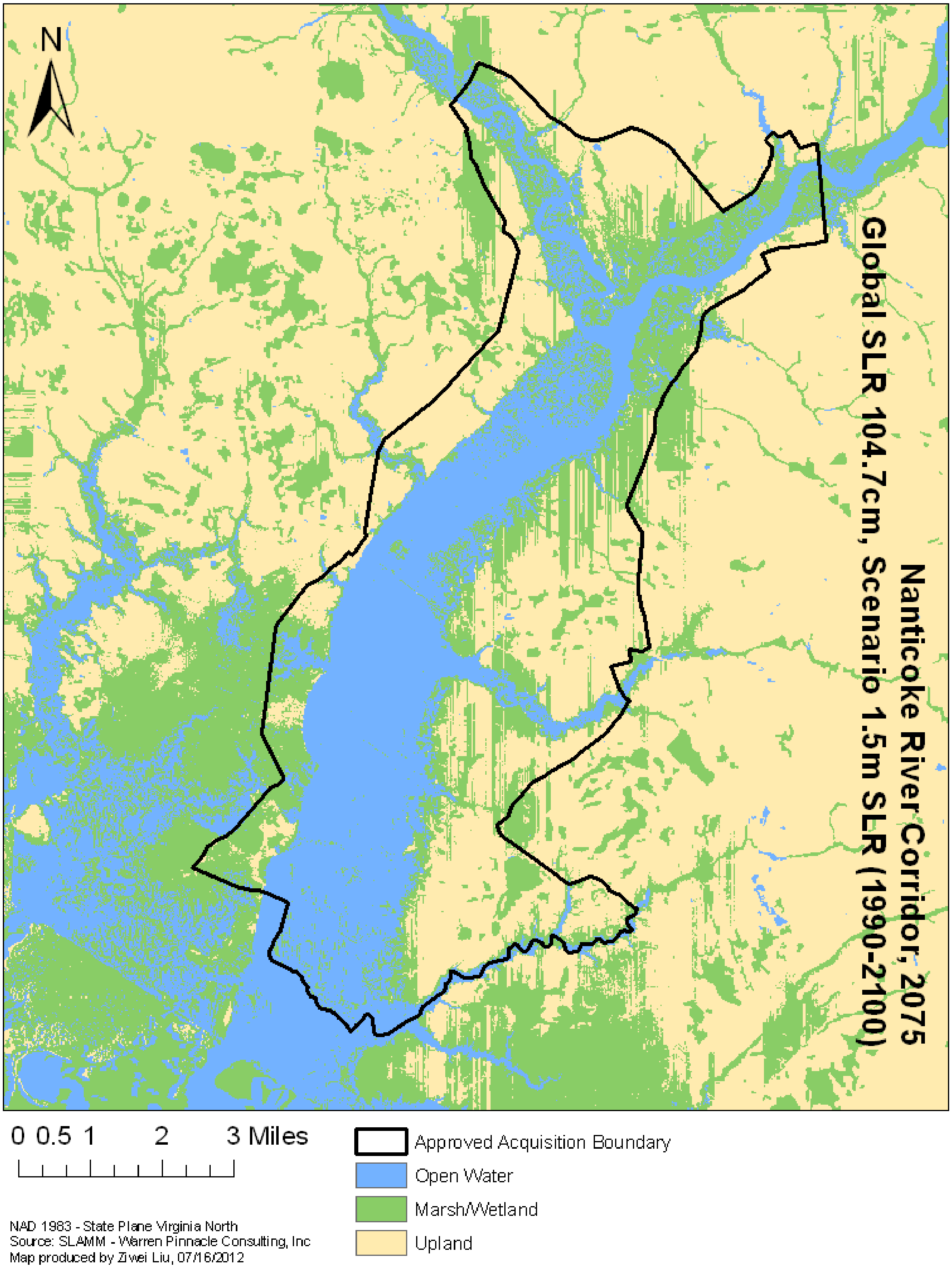

Figure 11. Blackwater NWR, Nanticoke River corridor, condition in 2075, 1.5 m SLR scenario. Back to text.

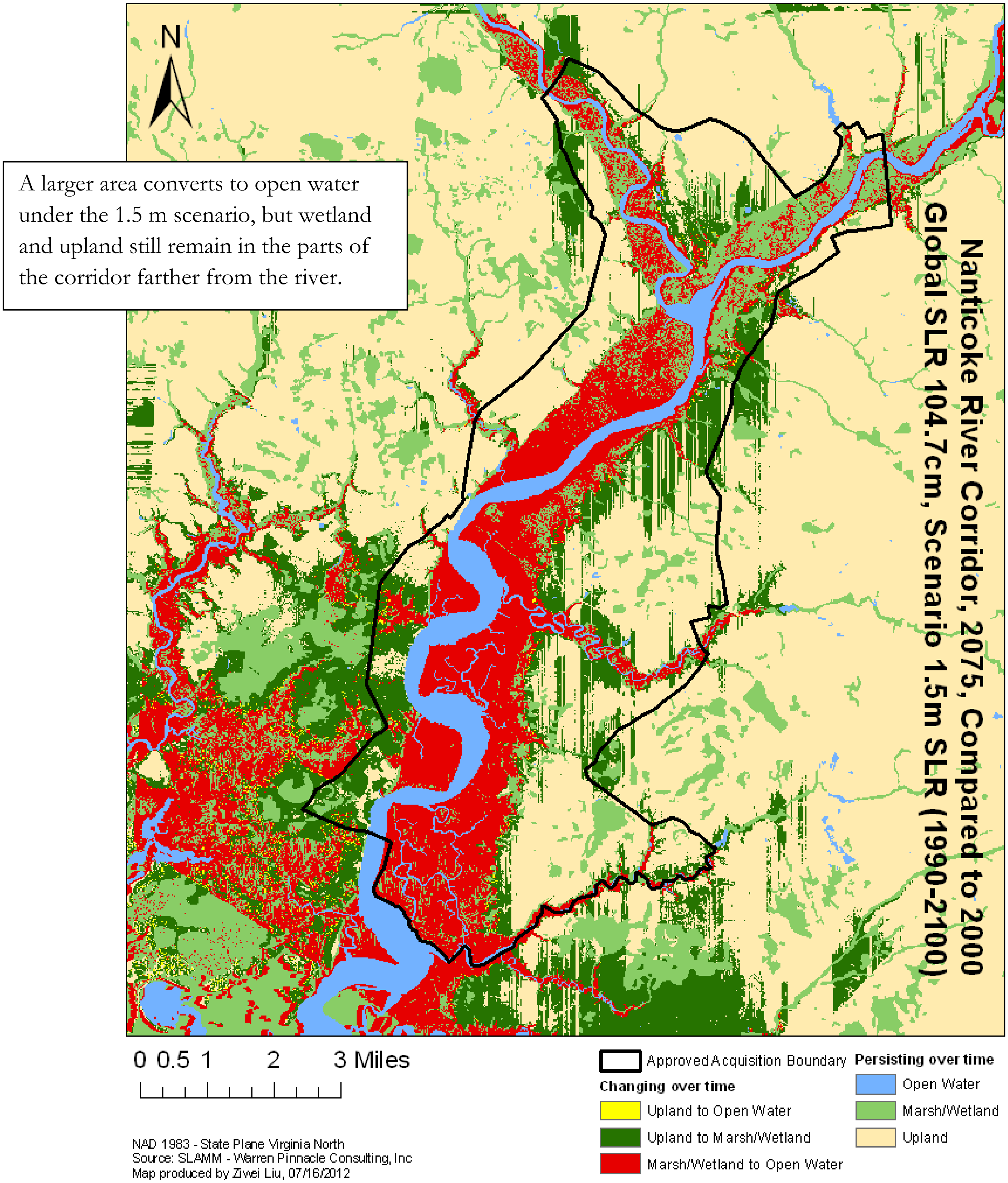

Figure 12. Blackwater NWR, Nanticoke River corridor, change from 2000 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Great White Heron NWR (Florida)

Much of the land area in the Florida Keys is less than five feet in elevation, so sea-level rise poses a substantial threat to the entire island chain. Most of the area of the refuge, both acquired and approved, is currently wetland, with very little uplands, except on some of the larger islands (Figure 13a, Figure 13b; for ease of viewing, maps of this refuge are divided into a western and eastern half). Under the 1 m SLR scenario, overall inundation of refuge lands is slightly less than at Blackwater under the same scenario (Table 5, Figure 14a, Figure 14b). Many of the islands within the acquisition boundary of Great White Heron are expected to experience wetland loss and an overall shrinkage in area by 2075 under the SLAMM projections of the 1 m SLR scenario (Figure 15a, Figure 15b); however marsh habitat will remain on some, in part due to conversion of almost all upland area into wetland acreage (see Table 5). These areas of persistent or transitioning wetlands should be prioritized for acquisition.

The sea-level rise threat to Great White Heron becomes substantially more severe under the 1.5 m SLR scenario, with projections showing much a much larger area converting to open water (Figure 16a, Figure 16b). The percentage of lands lost nearly doubles with the additional half a meter of sea-level rise, and islands that retained marsh habitat under the 1 m scenario see almost complete loss of this habitat (Figure 17a, Figure 17b). The total acreage within the area acquired to date (upland plus wetland) drops to a mere 660 acres, and the total within the approved boundary drops by 76.3% (see Table 5). Of note, Great White Heron was the top-ranked refuge for land acquisition funding for FY 2013.

Table 5. Summary of SLR impacts on Great White Heron NWR.

Great White Heron National Wildlife Refuge		Acres in 2009	**1 m SLR Scenario**		**1.5 m SLR Scenario**	
			Acres in 2075	% lost from 2009	Acres in 2075	% lost from 2009
Acquired Refuge Lands	Upland	239.7	20.8	91.2%	3.9	98.4%
	Wetlands	5,484.7	3,076	43.4%	656.5	88%
	Total	5,724.4	3,097	45.9%	660.4	88.5%
Approved, Not yet Acquired	Upland	693.5	148.2	78.6%	39.5	94.3%
	Wetlands	7832.6	4838.5	38.2%	2198.7	71.9%
	Total	8526.1	4986.7	41.4%	2238.2	73.7%
Total Approved Boundary	Upland	731.6	148.2	79.7%	39.5	94.6%
	Wetlands	9931.3	6086	38.7%	2492.6	74.9%
	Total	10662.9	623.2	41.6%	2535.1	76.3%

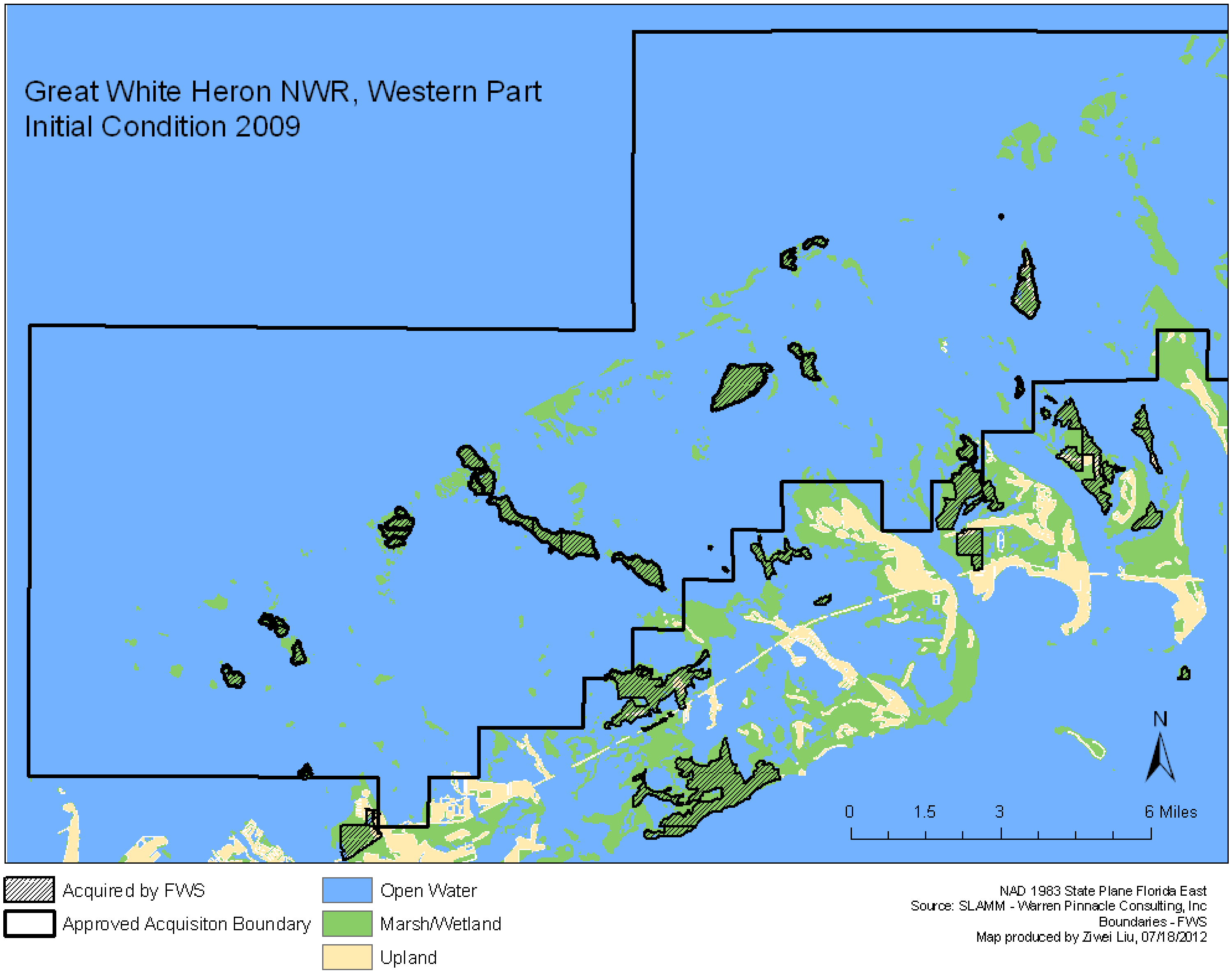

Figure 13a. Great White Heron NWR, western half, initial condition (2009). Back to text.

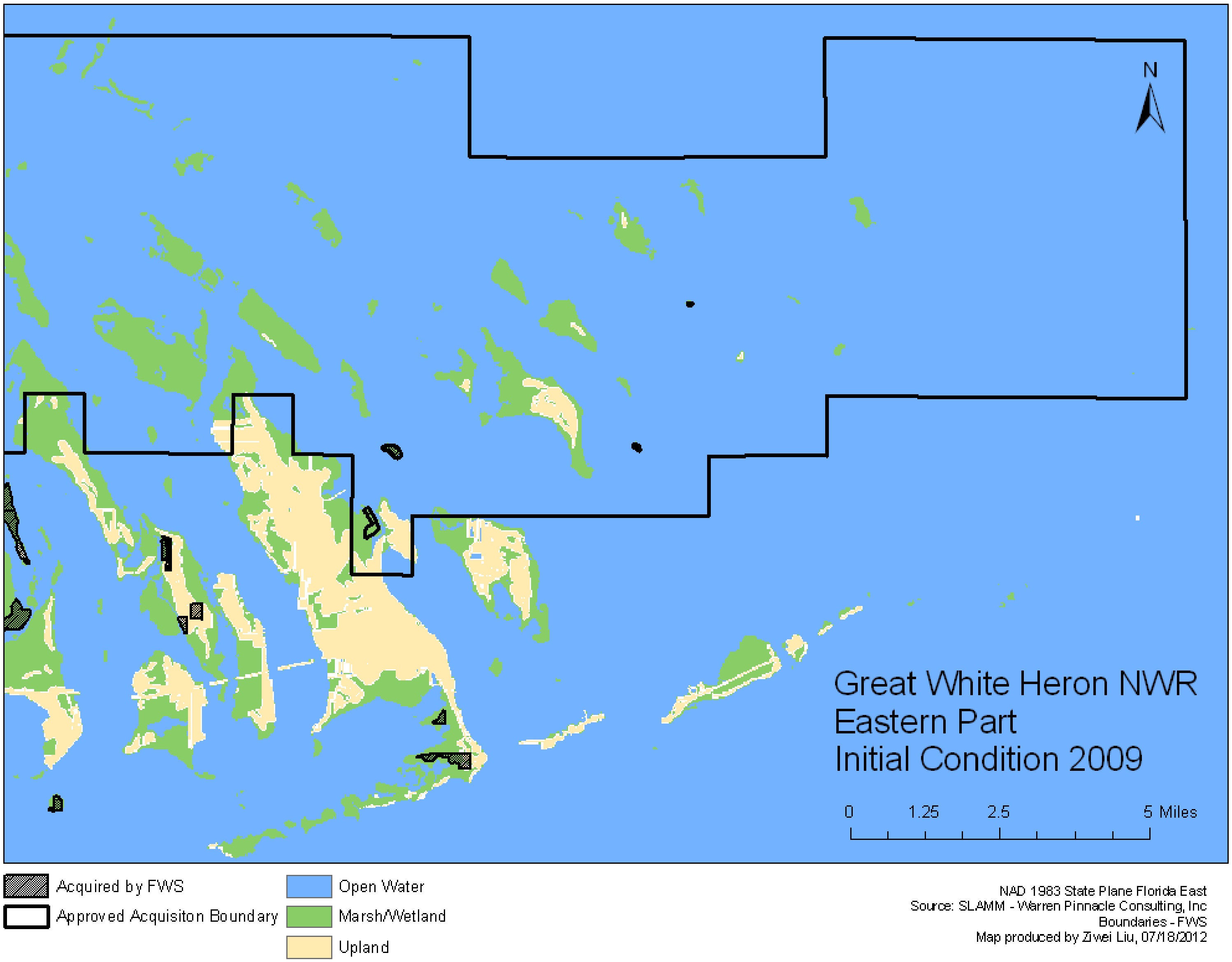

Figure 13b. Great White Heron NWR, eastern half, initial condition (2009). Back to text.

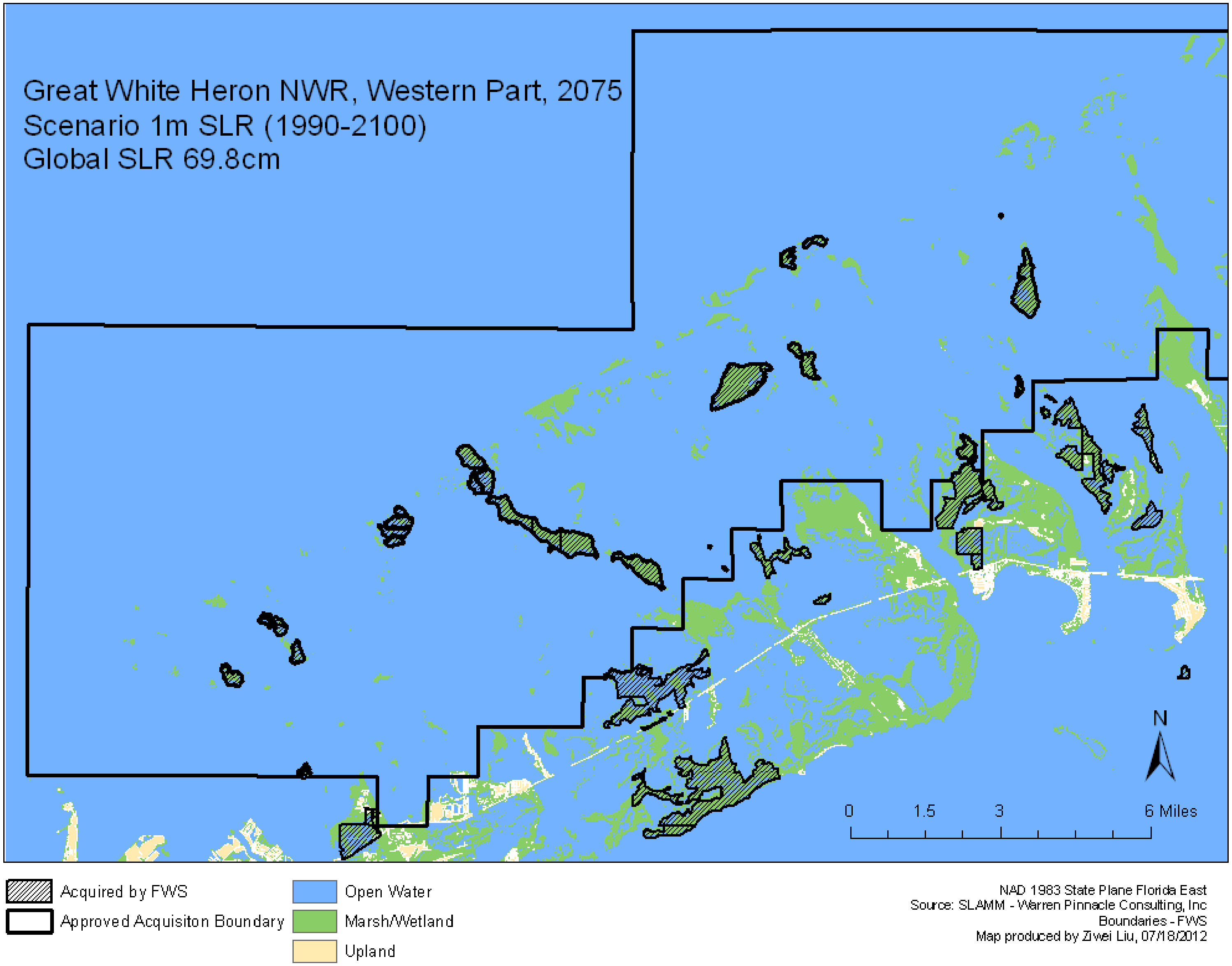

Figure 14a. Great White Heron NWR, western half, condition in 2075, 1 m SLR scenario. Back to text.

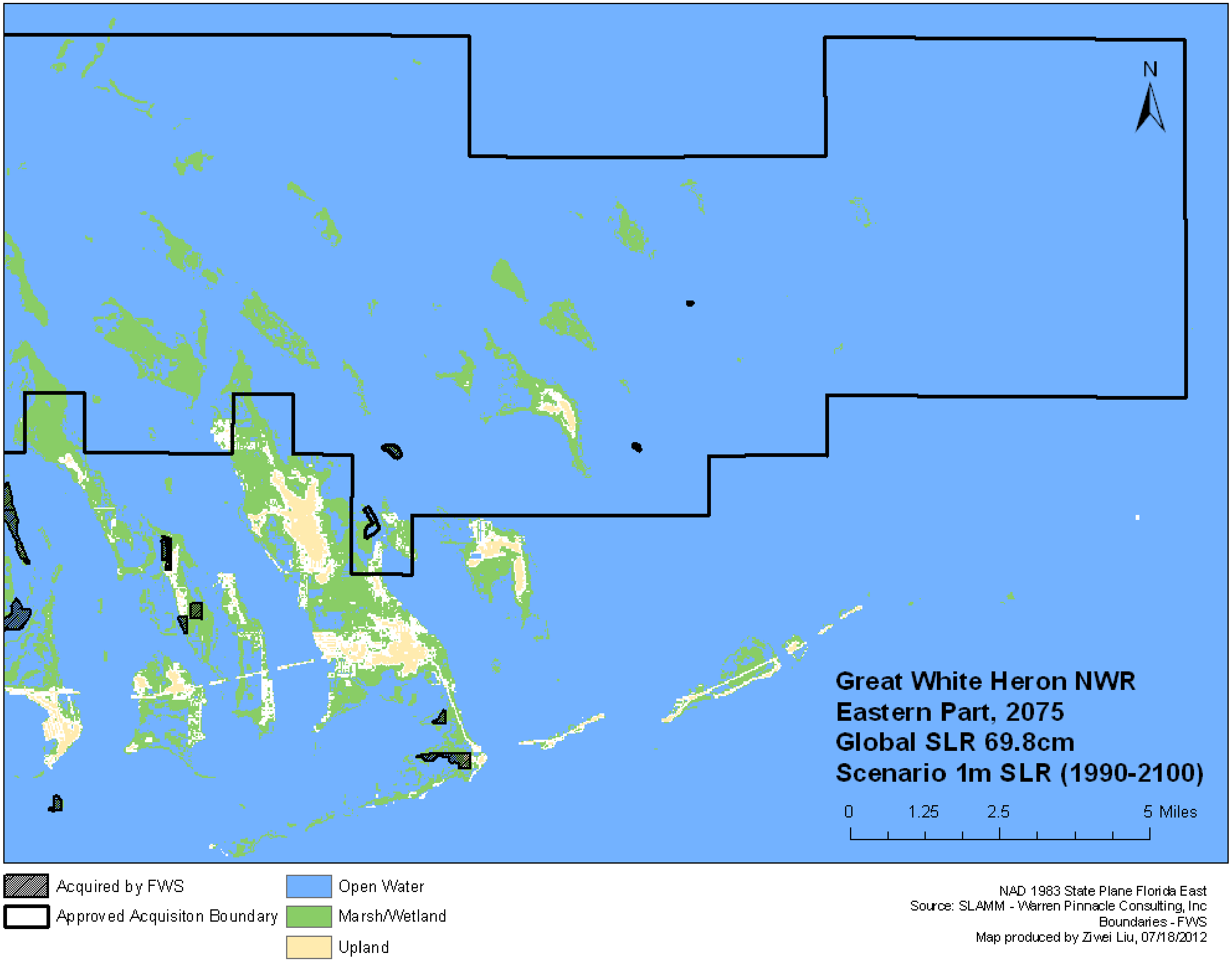

Figure 14b. Great White Heron NWR, eastern half, condition in 2075, 1 m SLR scenario. Back to text.

Many islands will suffer substantial loss of land area, while others retain marsh habitat.

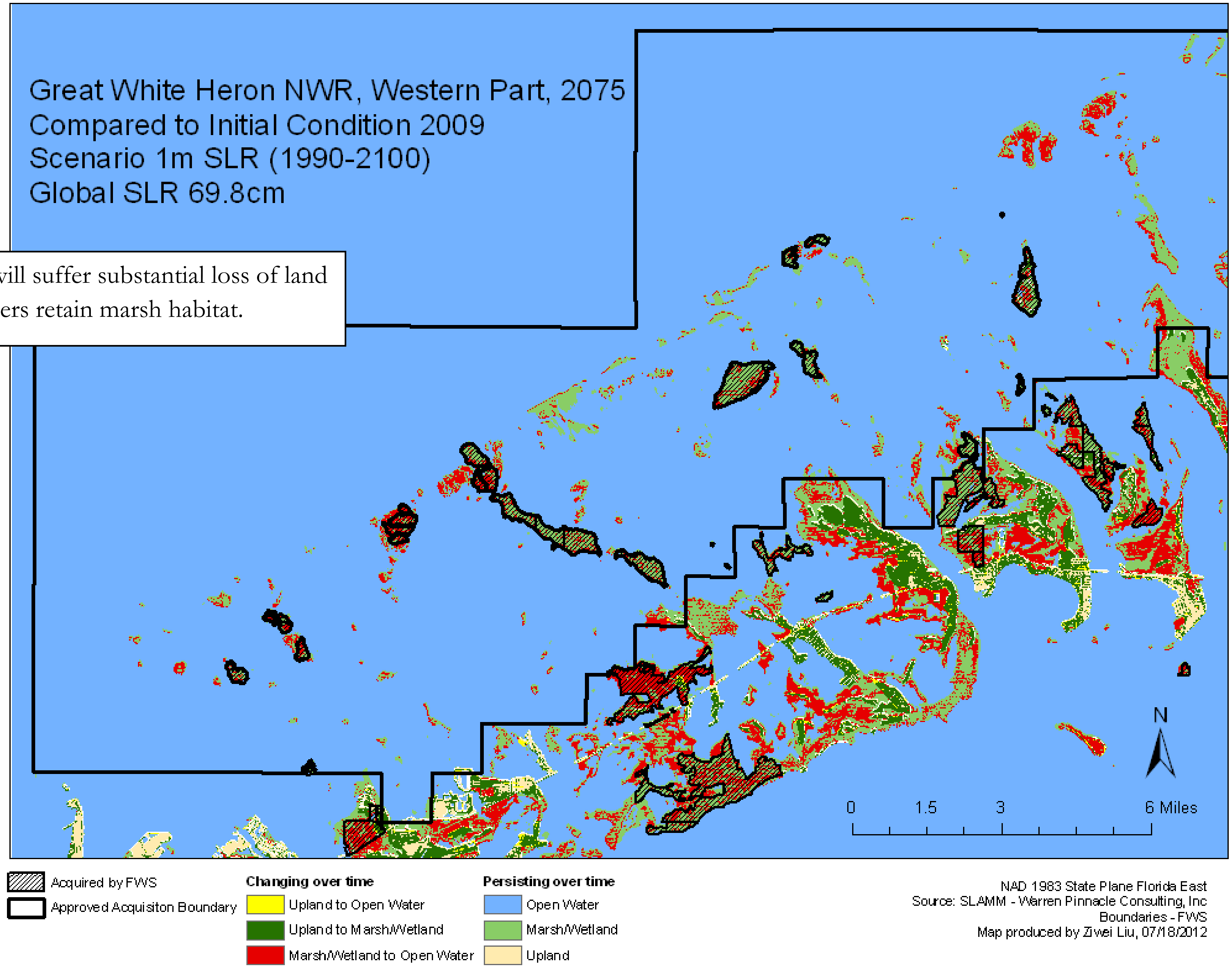

Figure 15a. Great White Heron NWR, western half, change from 2009 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

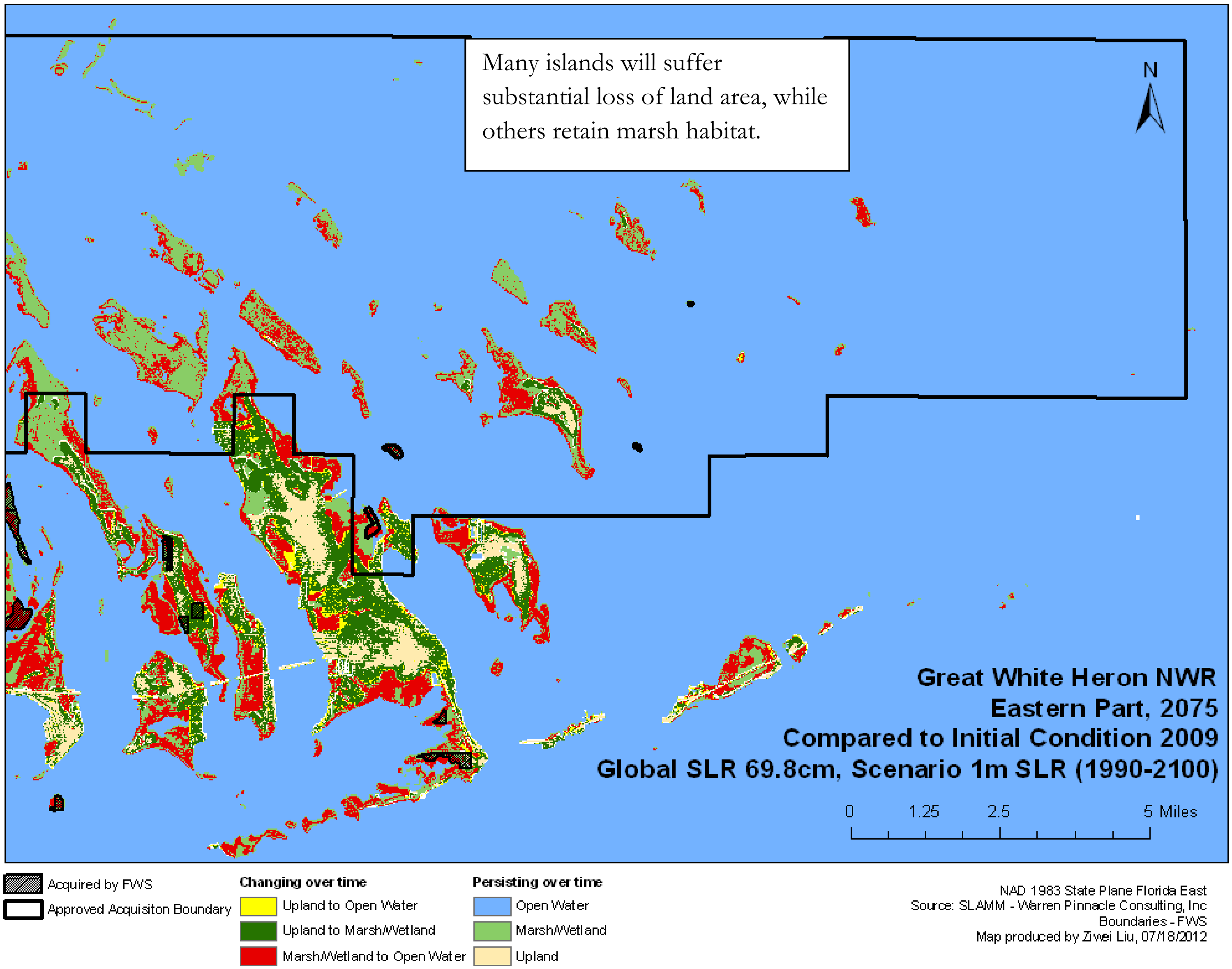

Figure 15b. Great White Heron NWR, eastern half, change from 2009 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

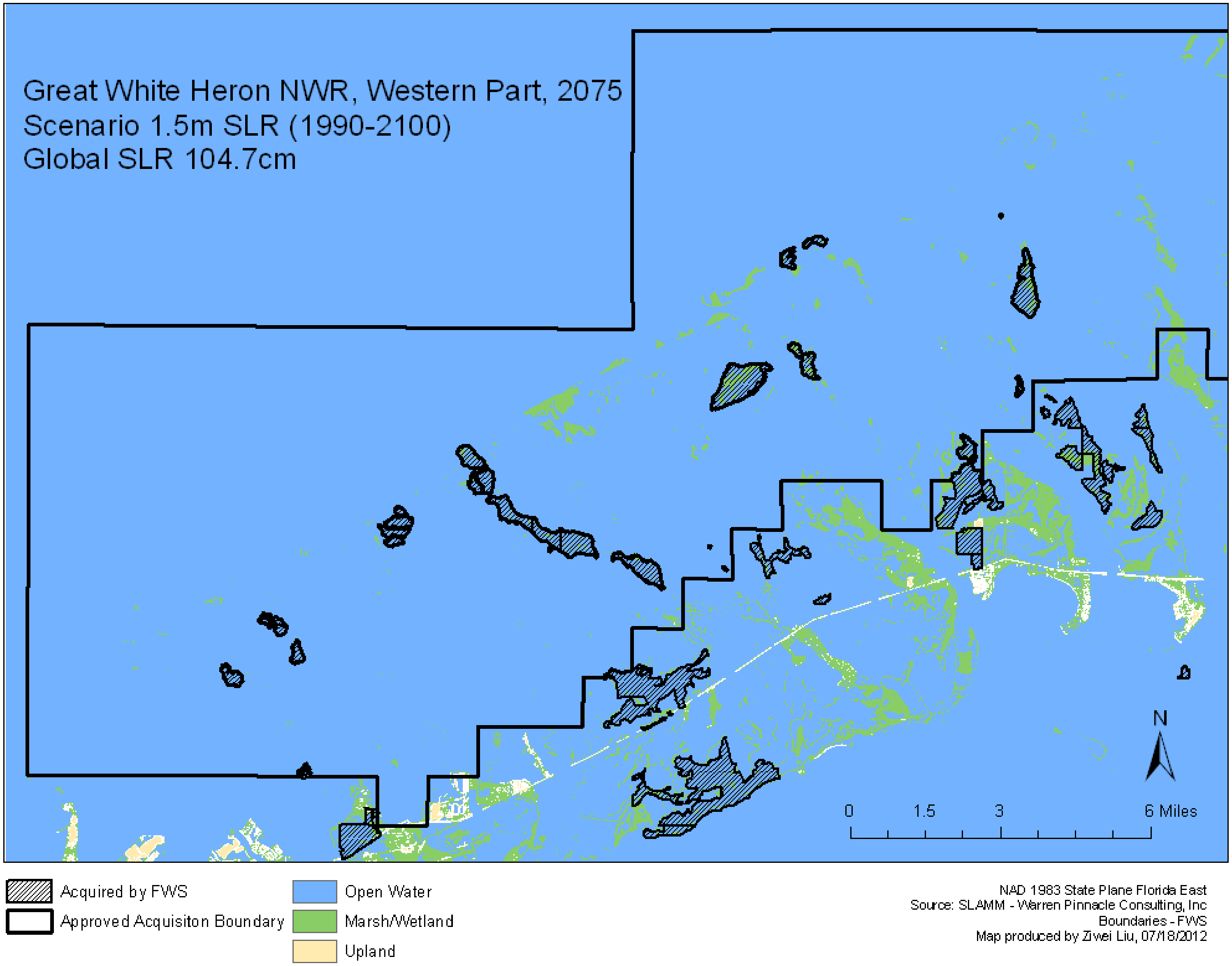

Figure 16a. Great White Heron NWR, western half, condition in 2075, 1.5 m SLR scenario. Back to text.

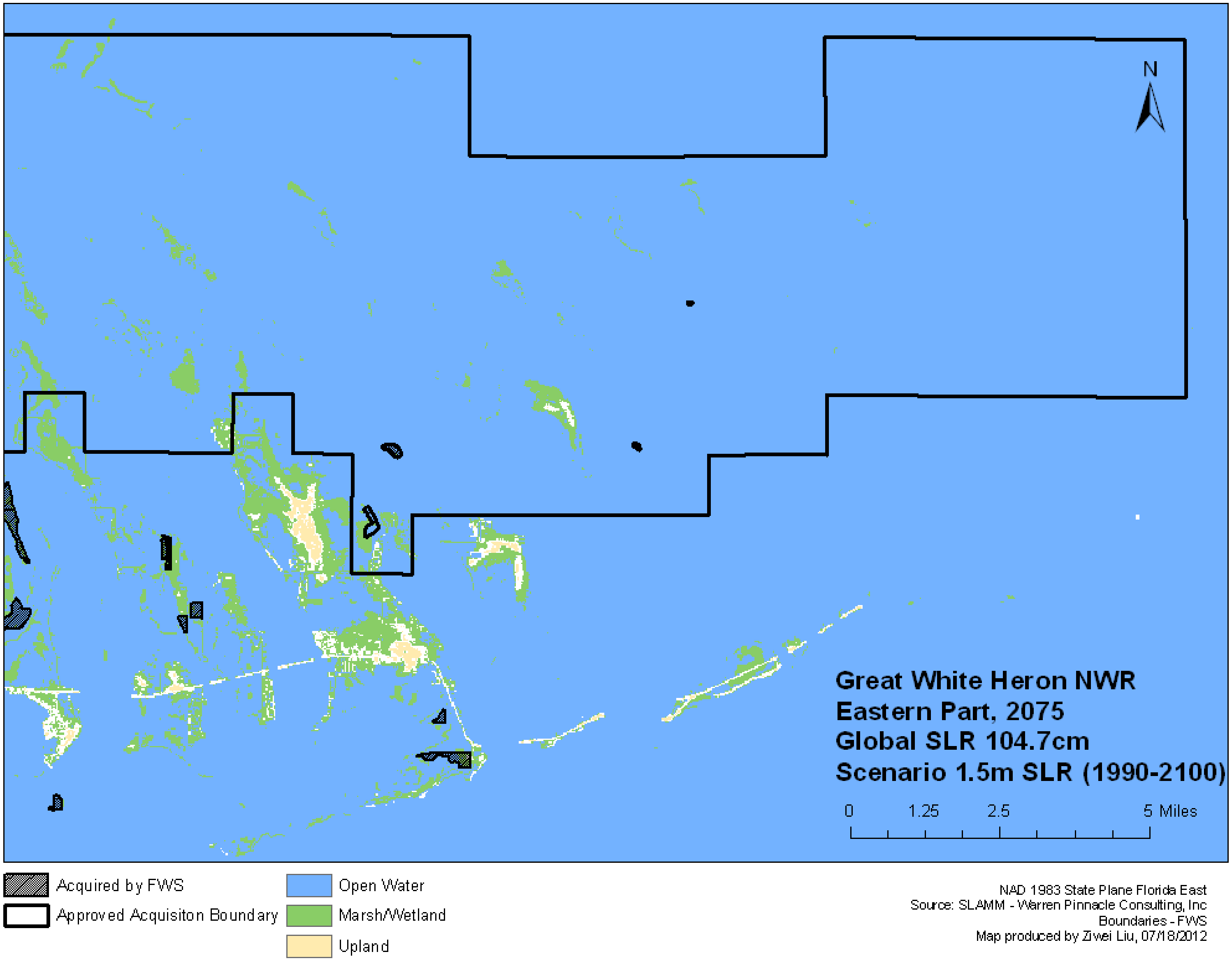

Figure 16b. Great White Heron NWR, eastern half, condition in 2075, 1.5 m SLR scenario. Back to text.

If sea-level rises to the extent projected in the 1.5 m by 2100 scenario, much of the land area within the refuge, along with much of the rest of the Keys, will be under water.

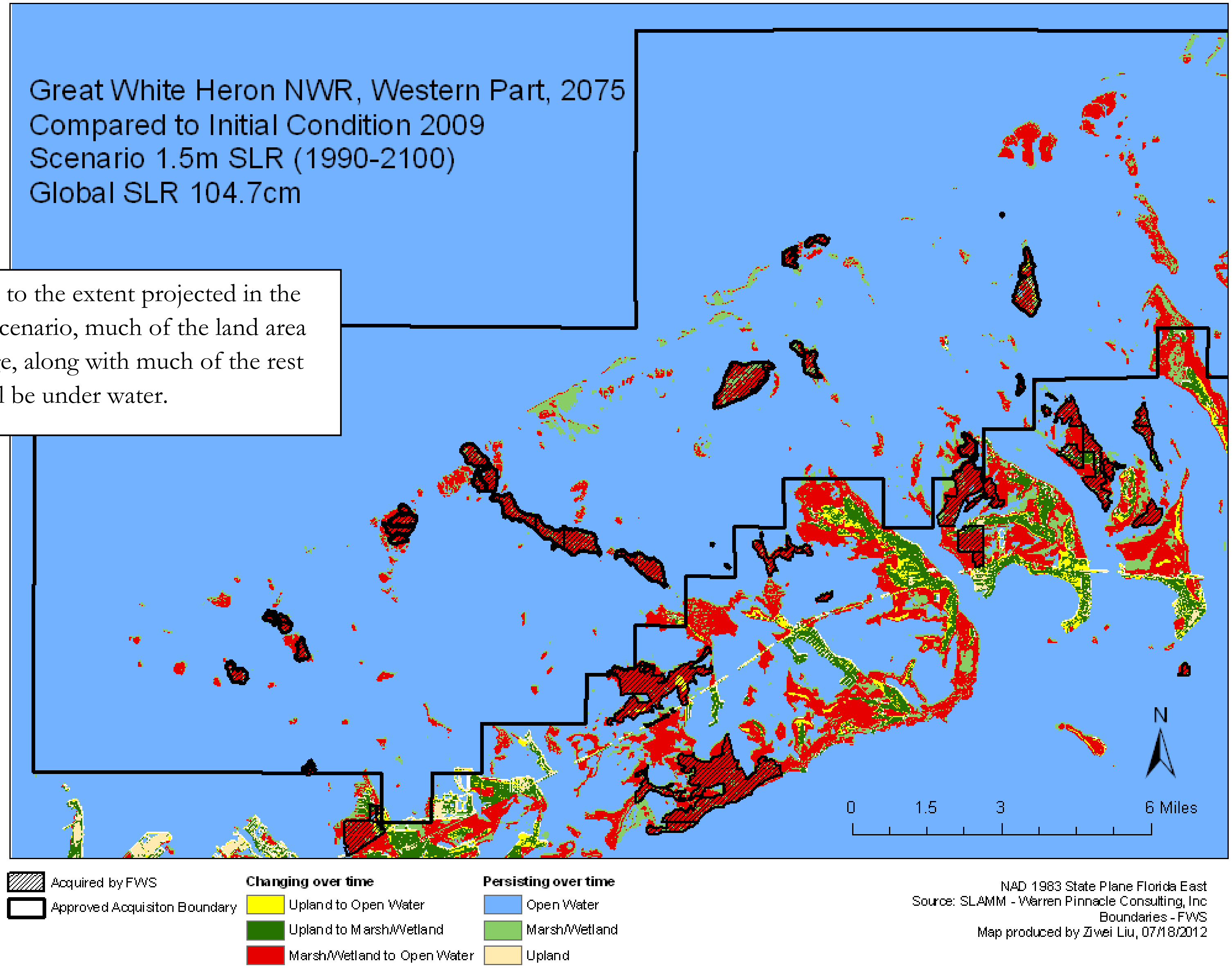

Figure 17a. Great White Heron NWR, western half, change from 2009 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

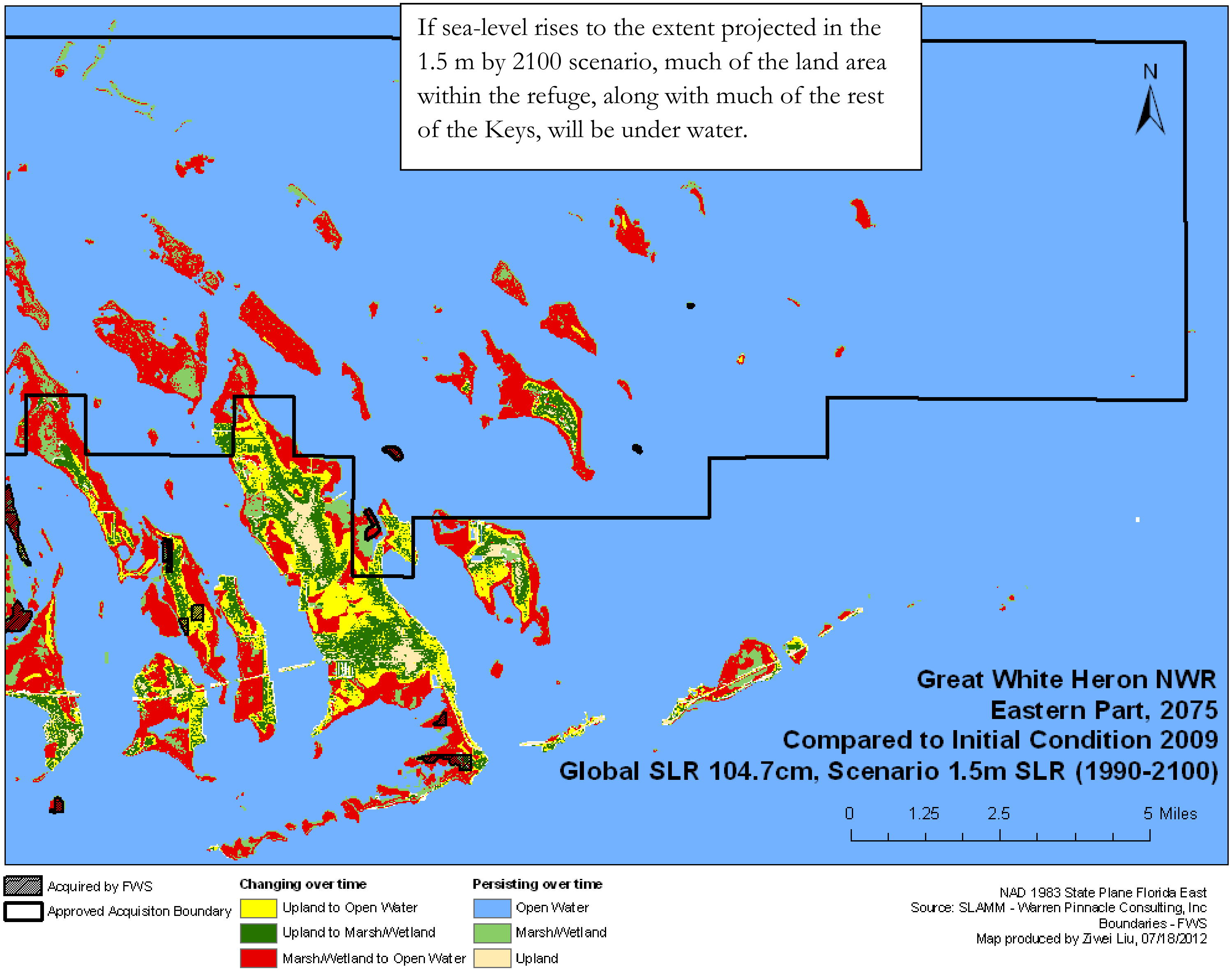

Figure 17b. Great White Heron NWR, eastern half, change from 2009 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Laguna Atascosa NWR & Lower Rio Grande Valley NWR (Texas)

These two refuges cover a patchwork of wetland and upland habitats along the southern tip of mainland Texas and nearby Padre Island (Figure 18). Overall, SLAMM projections suggest that loss of land to SLR will be less than at Blackwater or Great White Heron, but still substantial, particularly for wetlands (Table 6).

Under the 1 m SLR scenario, extensive inundation will occur in the coastal areas of the mainland and on the west side of Padre Island (Figure 19), leading to losses of over half of the wetlands within both the acquired and approved boundaries (Figure 20). These refuges will also see changes to the character of their habitats: the projections show very little marsh and wetland habitat created inland, compared to what is lost, as demonstrated by the lack of dark green parcels on Figure 20.

These losses are exacerbated somewhat under the 1.5 m scenario (Figure 21, Figure 22). Interestingly, however, the 1.5 m scenario shows creation of wetlands on former upland areas of the mainland to the north of the existing refuge boundary (Figure 22- note orientation of map). Extension of the current approved boundary northward along the mainland may be warranted, as this would provide an opportunity to protect lands with current and future wetland habitat values, as well as to extend the north-south corridor for the movement of a variety of species.

Table 6. Summary of SLR impacts to Laguna Atascosa and Lower Rio Grande Valley NWRs.

<table>
<tr><th colspan="2" rowspan="2">Laguna Atascosa & Lower Rio Grande NWRs</th><th rowspan="2">Acres in 1994</th><th colspan="2">1 m SLR Scenario</th><th colspan="2">1.5 m SLR Scenario</th></tr>
<tr><th>Acres in 2075</th><th>% lost from 1994</th><th>Acres in 2075</th><th>% lost from 1994</th></tr>
<tr><td rowspan="3">Acquired Refuge Lands</td><td>Upland</td><td>67,277.4</td><td>61,140.6</td><td>9.1%</td><td>58,635.7</td><td>12.8%</td></tr>
<tr><td>Wetlands</td><td>69,328</td><td>34,445.2</td><td>50.3%</td><td>29,857.4</td><td>56.9%</td></tr>
<tr><td>Total</td><td>136,605.4</td><td>95,585.8</td><td>30%</td><td>88,493.1</td><td>35.2%</td></tr>
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<tr><td rowspan="3">Approved, Not yet Acquired</td><td>Upland</td><td>57,228</td><td>55,509.5</td><td>3%</td><td>54,365.5</td><td>5%</td></tr>
<tr><td>Wetlands</td><td>27,464.2</td><td>12,817.3</td><td>53.3%</td><td>11,326.8</td><td>58.8%</td></tr>
<tr><td>Total</td><td>84,692.2</td><td>68,326.8</td><td>19.3%</td><td>65,692.3</td><td>22.4%</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="3">Total Approved Boundary</td><td>Upland</td><td>124,506</td><td>116,650</td><td>6.3%</td><td>113,001.3</td><td>9.2%</td></tr>
<tr><td>Wetlands</td><td>96,791.6</td><td>47,262.5</td><td>51.2%</td><td>41,202.2</td><td>57.4%</td></tr>
<tr><td>Total</td><td>221,297.5</td><td>163,912.5</td><td>25.9%</td><td>154,203.5</td><td>30.3%</td></tr>
</table>

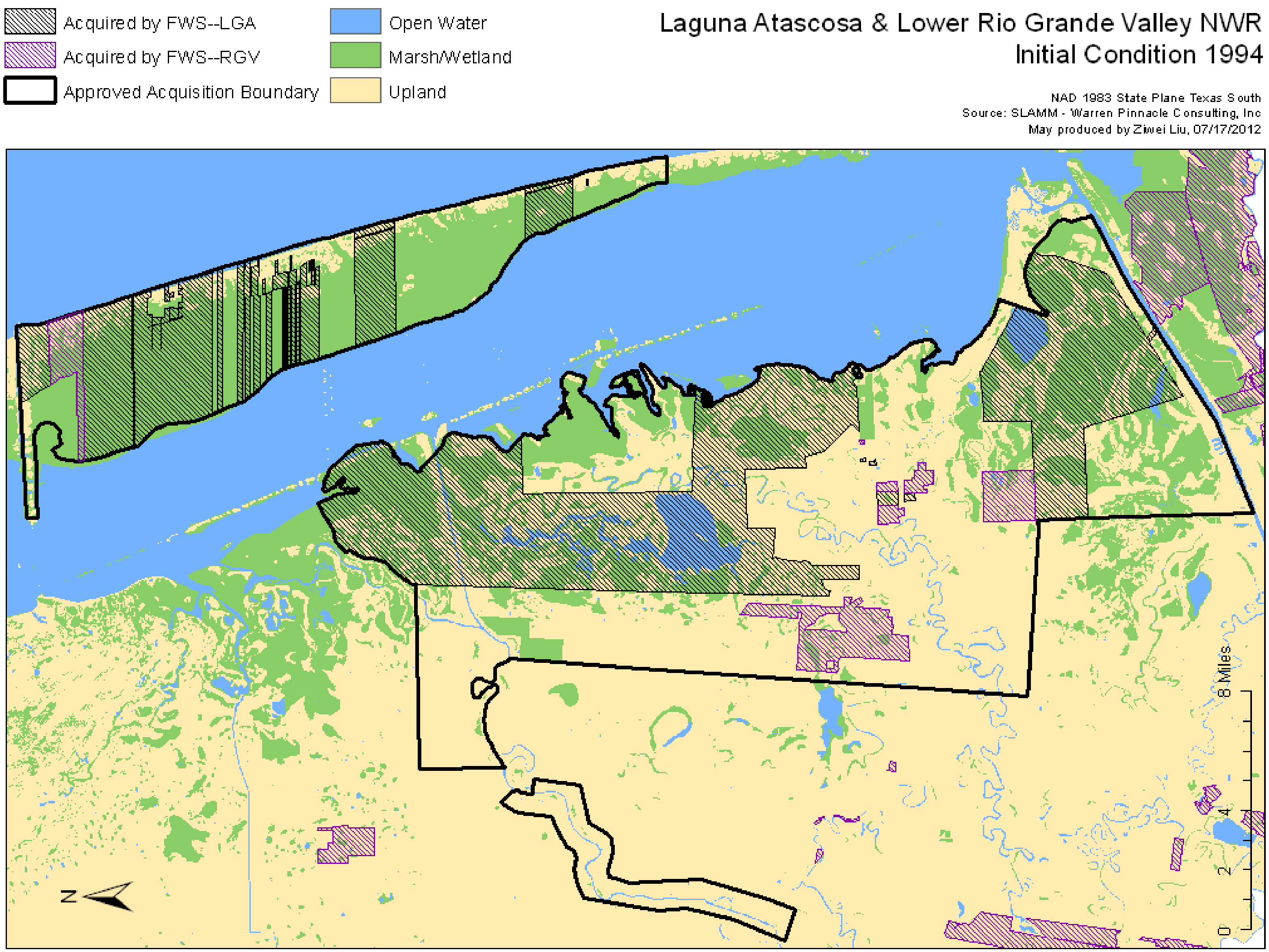


Figure 18. Laguna Atascosa NWR & Lower Rio Grande Valley NWR, initial condition (1994). Back to text.

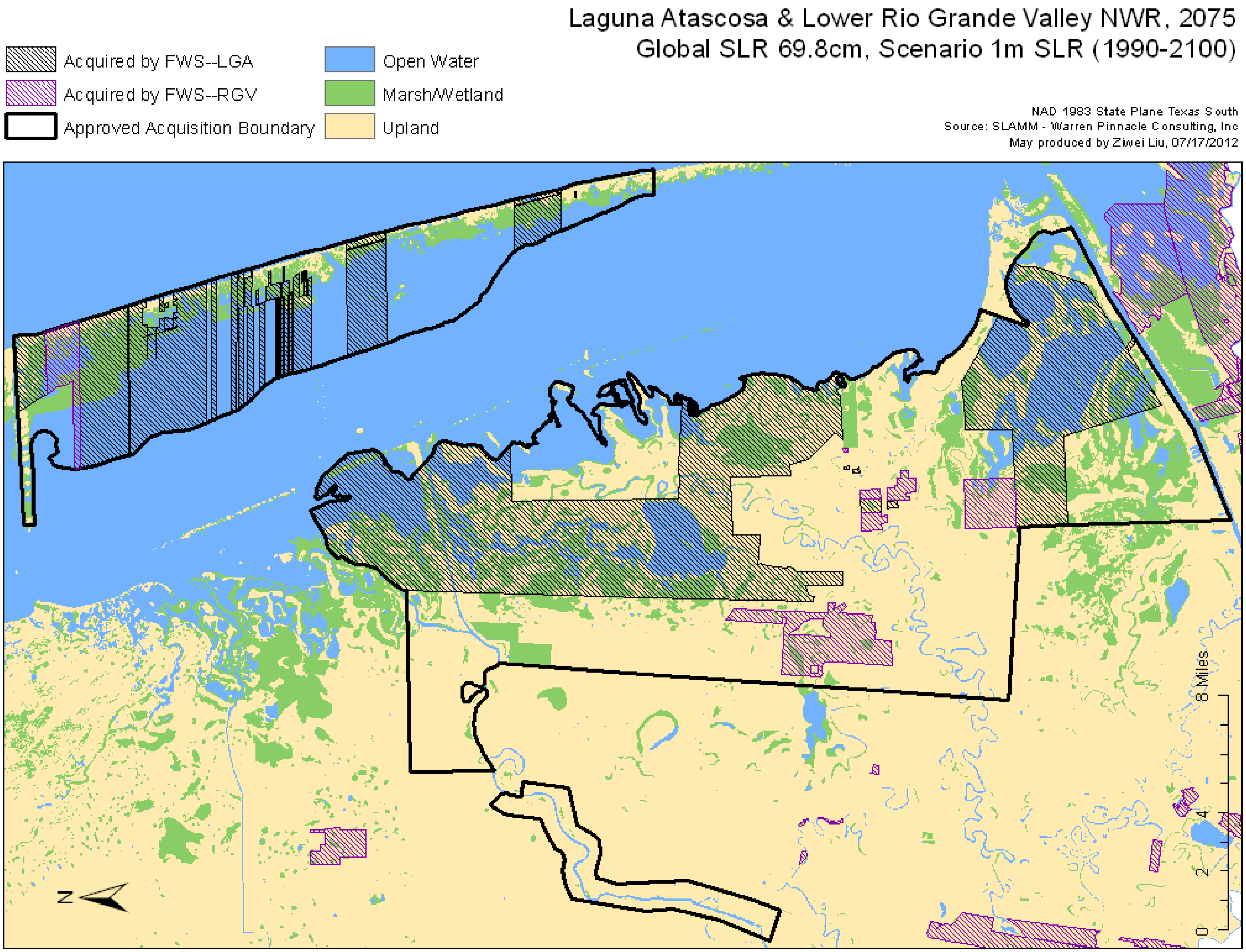


Figure 19. Laguna Atascosa NWR & Lower Rio Grande Valley NWR, condition in 2075, 1 m SLR scenario. Back to text.

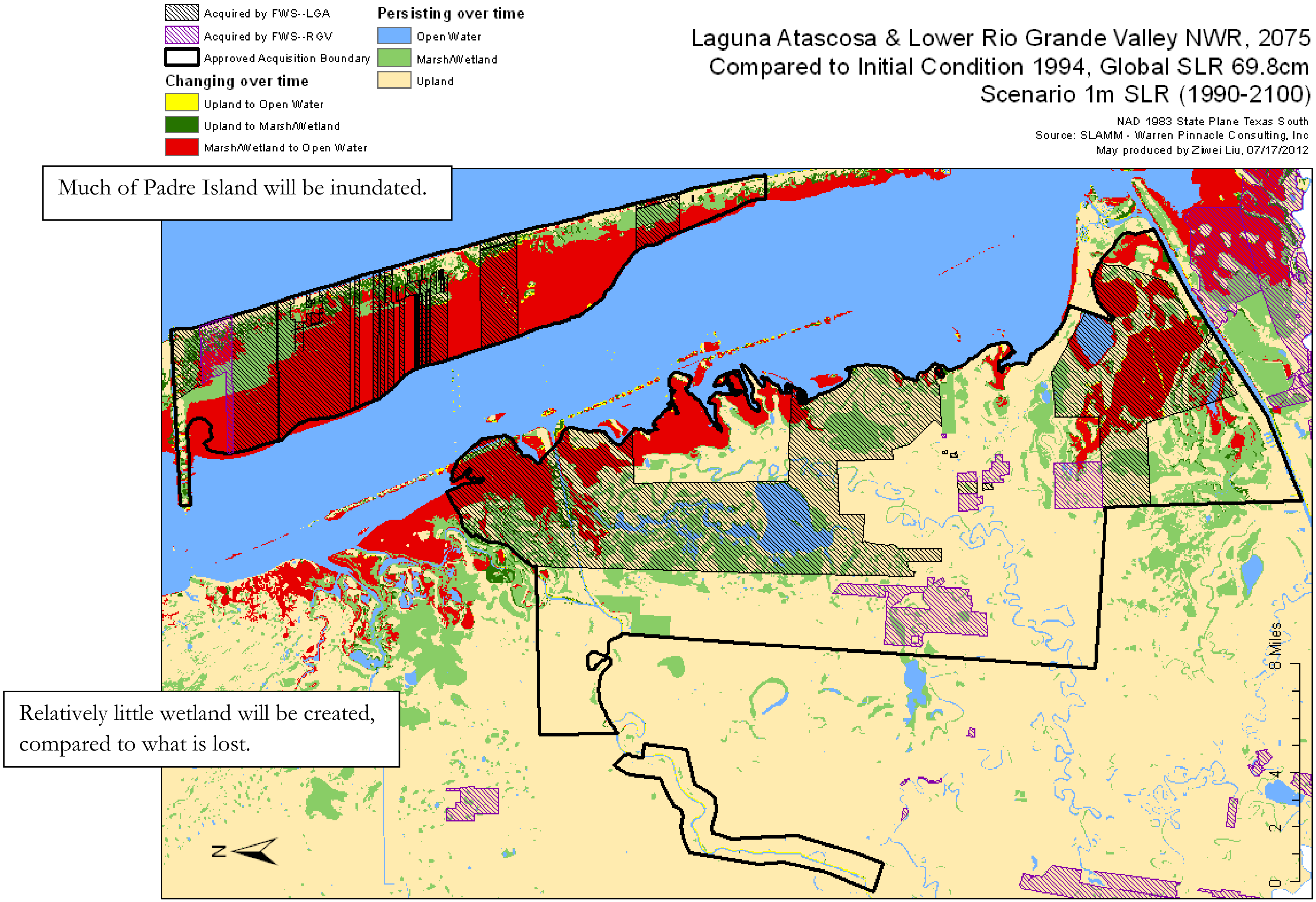


Figure 20. Laguna Atascosa NWR & Lower Rio Grande Valley NWR, change from 1994 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

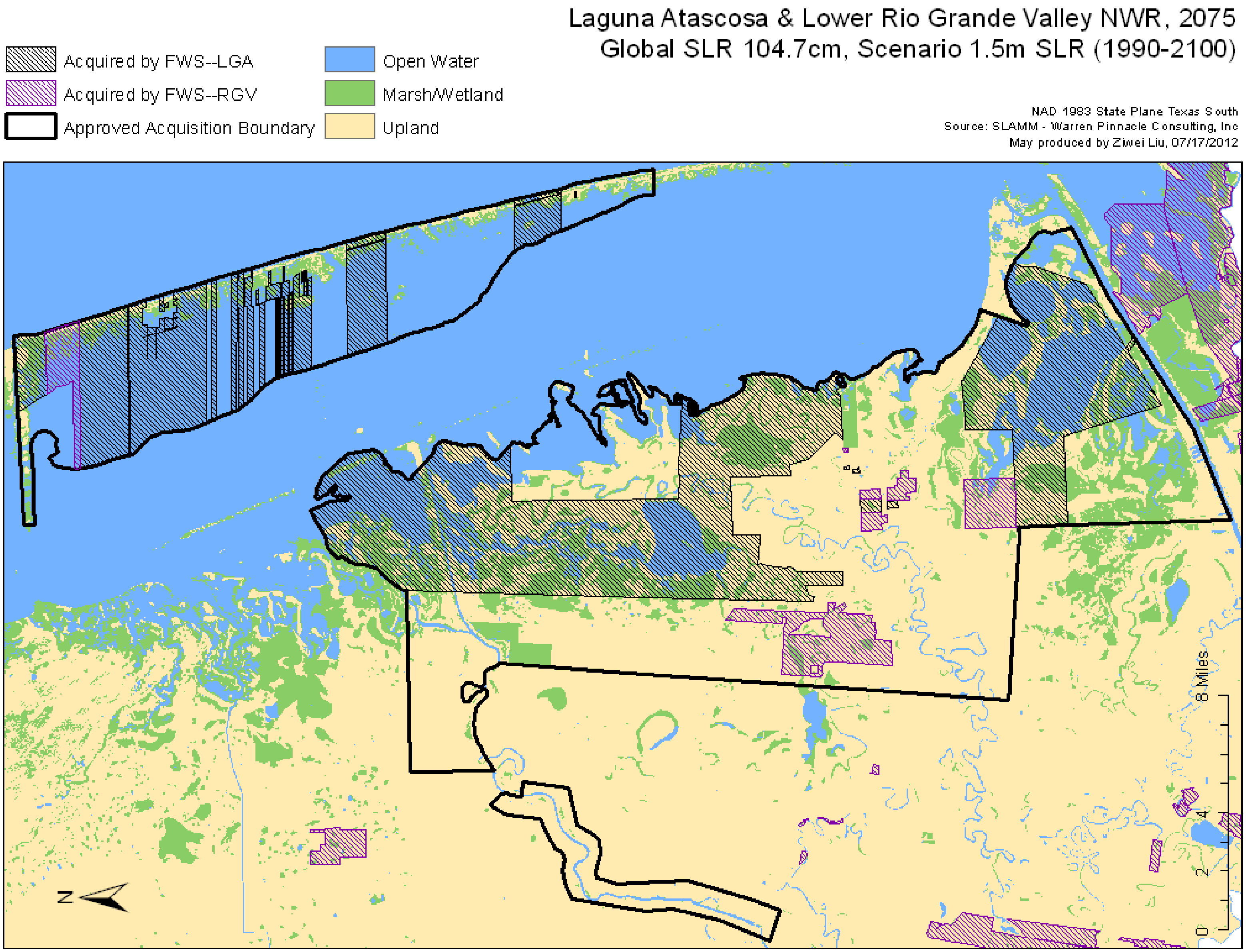
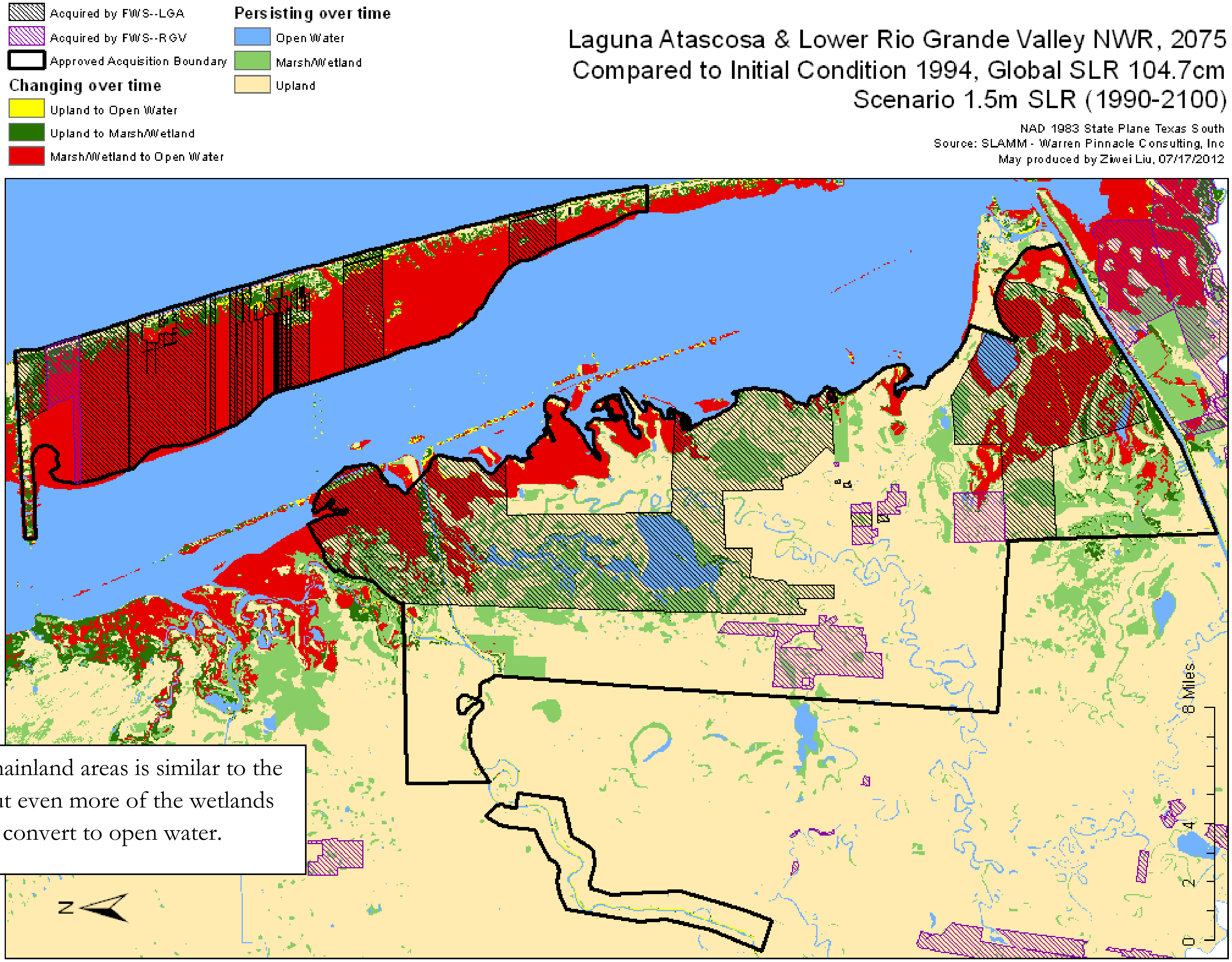


Figure 21. Laguna Atascosa NWR & Lower Rio Grande Valley NWR, condition in 2075, 1.5 m SLR scenario. Back to text.



Inundation of mainland areas is similar to the 1 m scenario, but even more of the wetlands on Padre Island convert to open water.

Figure 22. Laguna Atascosa & Lower Rio Grande NWR, change from 1994 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Lower Suwannee NWR (Florida)

Most of the area of Lower Suwannee NWR, which is located in northwestern peninsular Florida, is currently wetlands (Figure 23). SLAMM projections under the 1 m SLR scenario suggest that it faces less inundation than many coastal refuges (Figure 24). Marsh loss is distributed patchily across the refuge and concentrated in a small area along the river (Figure 25). Under the 1 m scenario, marsh lost to sea-level rise is more than made up for by conversion of uplands to wetland: nearly 40% uplands within the acquired area of the refuge transition to wetlands (Table 7); these are distributed patchily across the refuge area (Figure 25). Most of the large area for acquisition in the south part of the refuge will be persistent.

Inundation of wetlands is more widespread, but still very patchy, according to the projections under the 1.5 m scenario (Figure 26). Net loss of wetlands remains low, however, due to extensive creation of wetlands in areas that had been upland (Figure 27). The area of upland lost, mainly through transition to wetlands, reaches above 50% in this scenario.

Under both scenarios, losses are low within the area that has been approved but not yet acquired, both in the area on the south side of the main body of the refuge and in the "Northern Refuge" area further upriver (pictured at right in Figures 23-27). There is also a large area of persistent wetland to the north of the western "arm" of the refuge, outside of the current approved boundary. Thus, even though this refuge faces lower potential SLR threat than others we profiled, it may also benefit from expansion of its boundary to the north to capture the long-term habitat benefits of conserving that area.

Table 7. Summary of SLR impacts on Lower Suwannee NWR

Lower Suwannee National Wildlife Refuge		Acres in 2008	1 m SLR Scenario		1.5 m SLR Scenario	
			Acres in 2075	% lost from 2008	Acres in 2075	% lost from 2008
Acquired Refuge Lands	Upland	5,385.1	3,276.8	39.1%	2,539.5	52.8%
	Wetlands	44,634.9	45,101	+1%	43,076.5	3.5%
	Total	50,019.9	48,377.8	3.3%	45,616	8.8%
Approved, Not yet Acquired	Upland	7,226.5	6,365.8	11.9%	5,993.1	17.1%
	Wetlands	15,910.8	15,402.4	3.2%	14,868	6.5%
	Total	23,137.3	21,768.2	5.9%	20,861.1	9.8%
Total Approved Boundary	Upland	12,611.6	9,642.6	23.5%	8,532.6	32.3%
	Wetlands	60,545.6	60,503.4	0.1%	57,944.5	4.3%
	Total	73,157.2	70,146	4.1%	66,477.1	9.1%

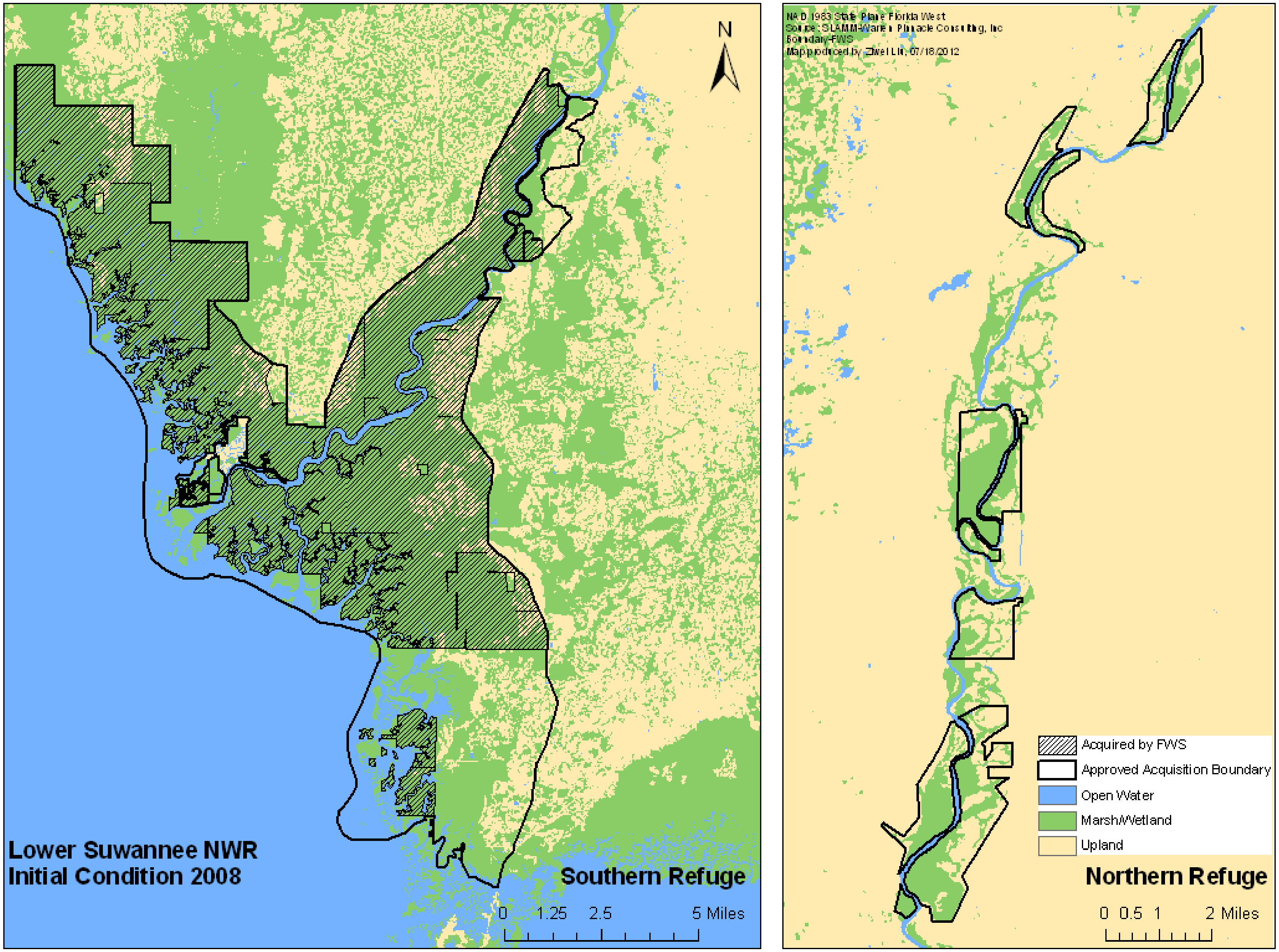


Figure 23. Lower Suwannee NWR, initial condition (2008). Back to text.

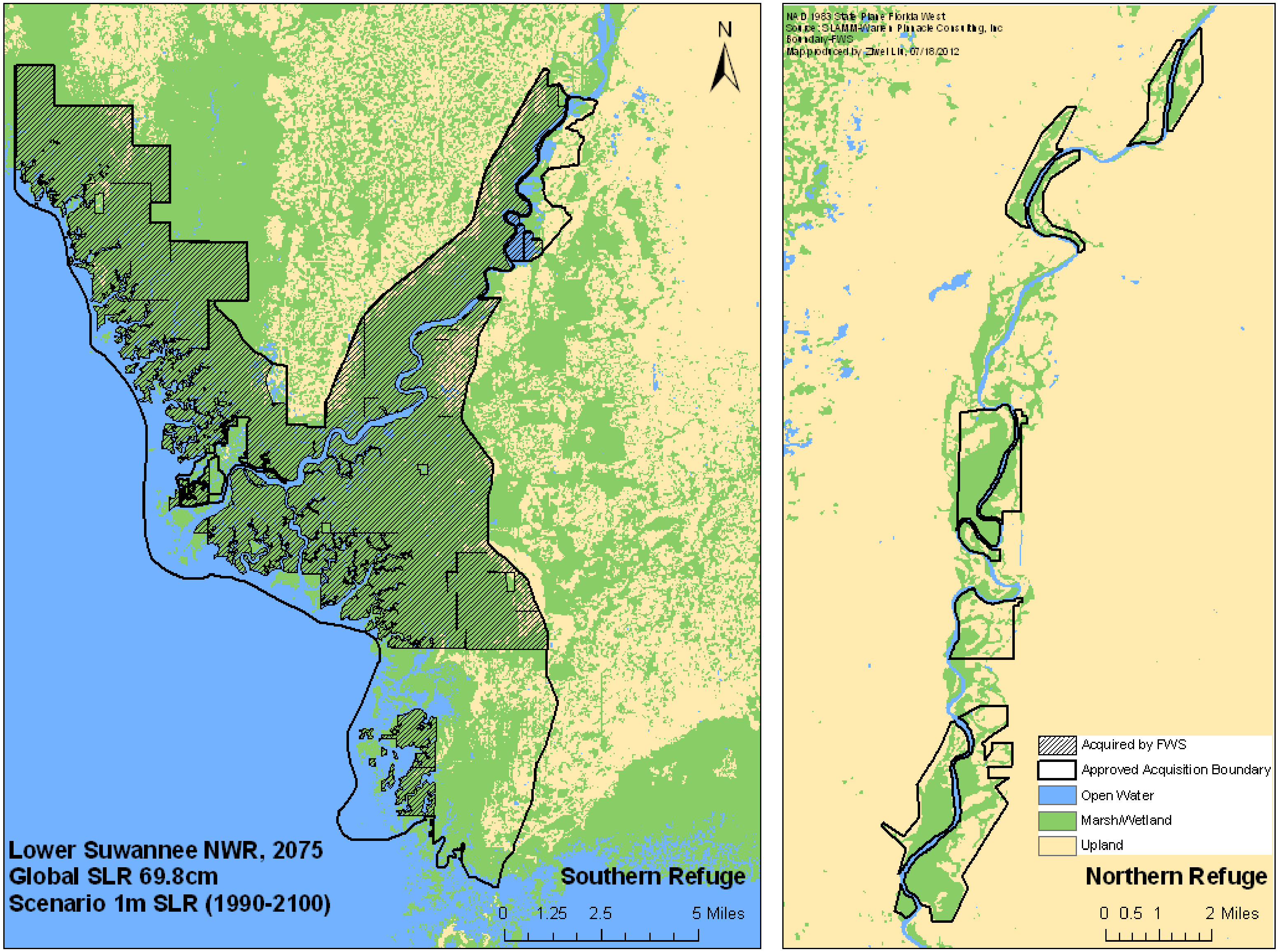


Figure 24. Lower Suwannee NWR, condition in 2075, 1 m SLR scenario. Back to text.

Extending the refuge boundary north would allow protection of large areas of persistent wetlands.

Wetlands are lost from scattered areas, but most habitat in the current refuge and not-yet-acquired area to the south will be persistent.

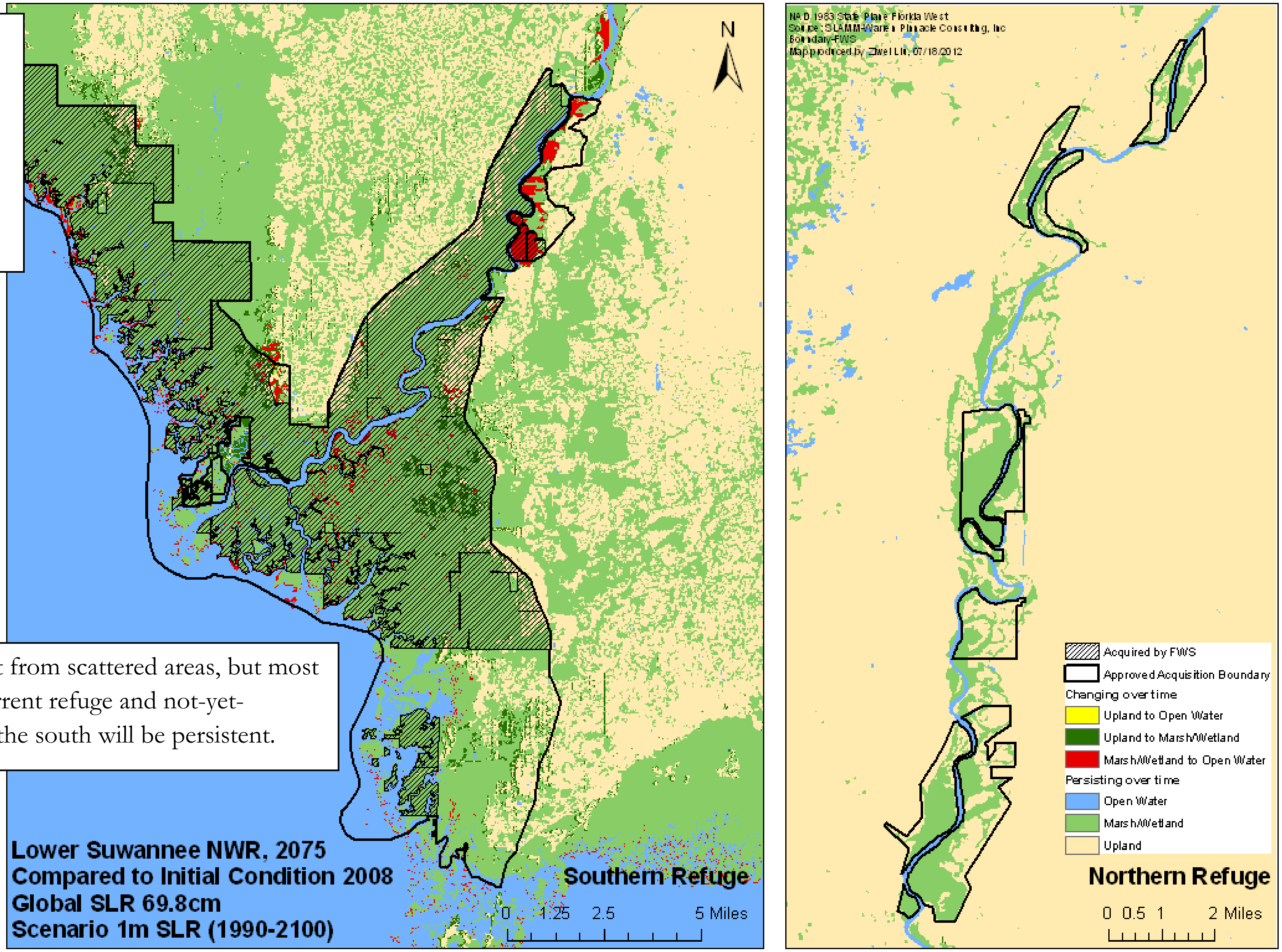


Figure 25. Lower Suwannee NWR, change from 2008 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

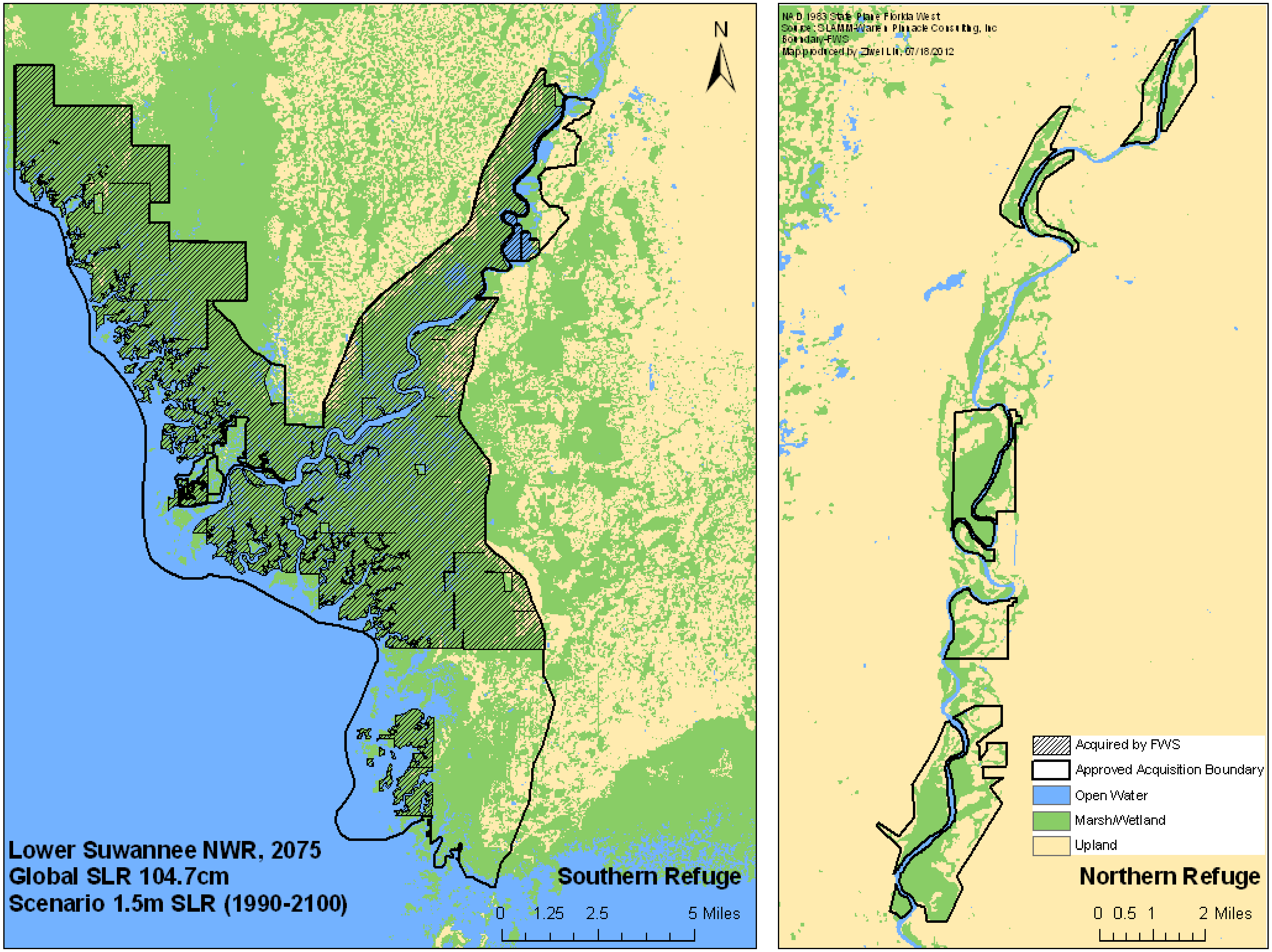
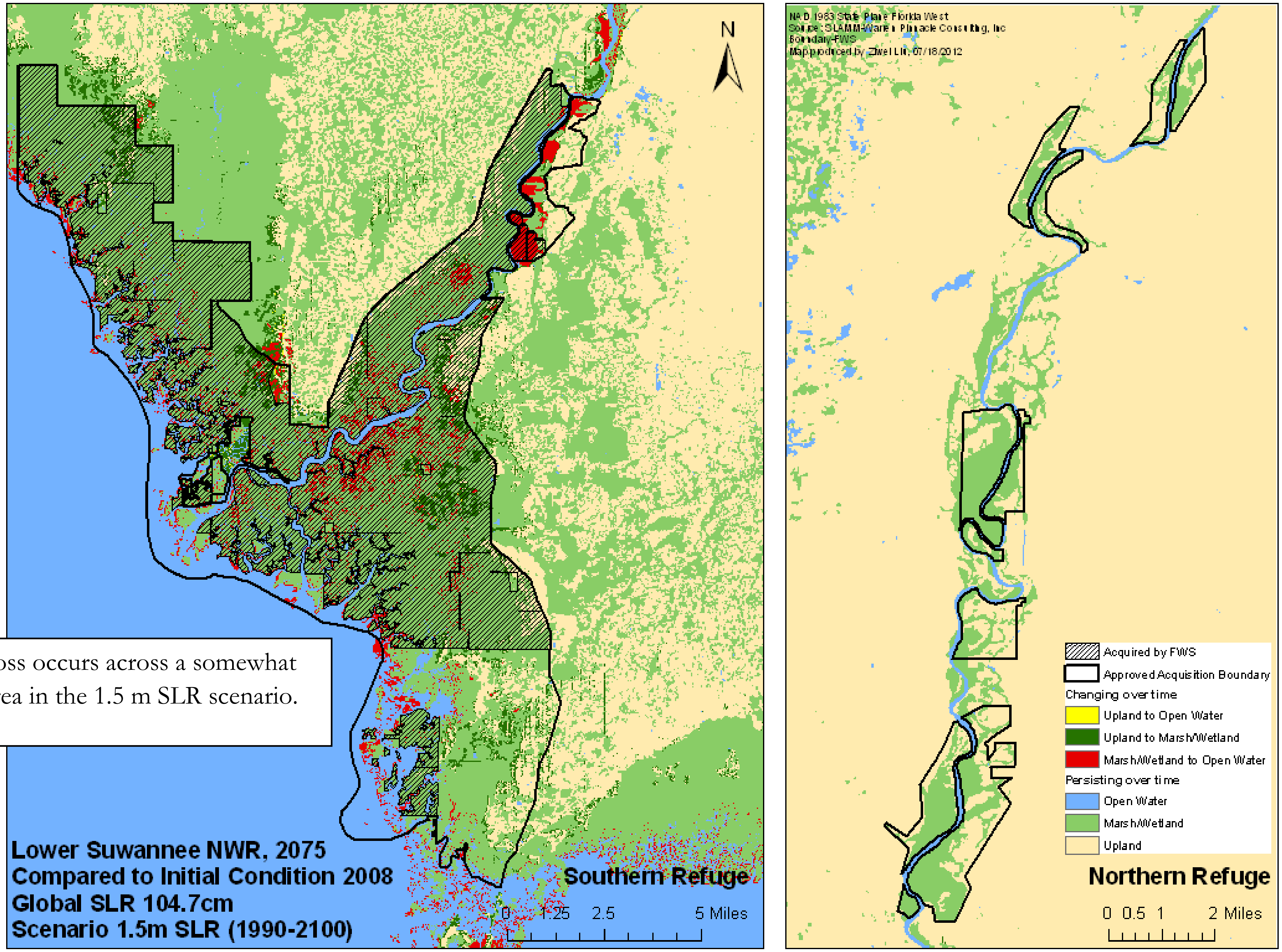


Figure 26. Lower Suwannee NWR, condition in 2075, 1.5 m SLR scenario. Back to text.



Wetland loss occurs across a somewhat broader area in the 1.5 m SLR scenario.

Figure 27. Lower Suwannee NWR, change from 2008 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Cape Romain NWR (South Carolina)

Cape Romain NWR encompasses a series of low-lying islands off the coast of South Carolina. Nearly all of the acquired area of the refuge is wetlands (Figure 28), and there is relatively little land within the approved boundary that has not already been acquired.

In general, the impact by 2075 of the 1 m SLR scenario on Cape Romain is relatively small (Figure 29, Table 8.) Wetland losses occur in thin strips along the seaward side of refuge islands, and some accretion on the inland sides results in wetland creation where there had been open water (Figure 30). Inundation is projected over a substantially larger area in the 1.5 m SLR scenario (Figure 31), with marsh loss occurring on more of the seaward side of nearly every island (Figure 32). Overall losses within the acquired refuge area jump from 3.7% to 13.7% between the two scenarios (Table 8).

As with several of the refuges in this study, large areas of wetlands that persist in both SLR scenarios are found outside of the approved boundary, in this case both up and down the coast on either side of the refuge and also farther inland. Thus the potential exists for Cape Romain to offset wetland loss by expanding the refuge boundary to include one or more of these areas.

Table 8. Summary of SLR impacts to Cape Romain NWR.

<table>
<tr><th colspan="2" rowspan="2">Cape Romain National Wildlife Refuge</th><th rowspan="2">Acres in 2009</th><th colspan="2">1 m SLR Scenario</th><th colspan="2">1.5 m SLR Scenario</th></tr>
<tr><th>Acres in 2075</th><th>% lost from 2009</th><th>Acres in 2075</th><th>% lost from 2009</th></tr>
<tr><td rowspan="3">Acquired Refuge Lands</td><td>Upland</td><td>1,013.6</td><td>876.5</td><td>3.4%</td><td>757</td><td>25.3%</td></tr>
<tr><td>Wetlands</td><td>33,601.4</td><td>31,932</td><td>13.5%</td><td>28,647.8</td><td>13.3%</td></tr>
<tr><td>Total</td><td>34,075</td><td>32,808.5</td><td>3.7%</td><td>29,404.8</td><td>13.7%</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="3">Approved, Not yet Acquired</td><td>Upland</td><td>1,364</td><td>1,348.2</td><td>1.2%</td><td>1,339.7</td><td>1.8%</td></tr>
<tr><td>Wetlands</td><td>1,102.9</td><td>1,067.8</td><td>3.2%</td><td>1,012.1</td><td>8.2%</td></tr>
<tr><td>Total</td><td>2,466.9</td><td>2,416</td><td>2%</td><td>2,351.8</td><td>4.7%</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="3">Total Approved Boundary</td><td>Upland</td><td>2,377.6</td><td>2,224.7</td><td>6.4%</td><td>2,096.7</td><td>11.8%</td></tr>
<tr><td>Wetlands</td><td>34,164.4</td><td>32,999.8</td><td>3.4%</td><td>29,660</td><td>13.2%</td></tr>
<tr><td>Total</td><td>36,542</td><td>35,224.6</td><td>3.6%</td><td>31,756.7</td><td>13.1%</td></tr>
</table>

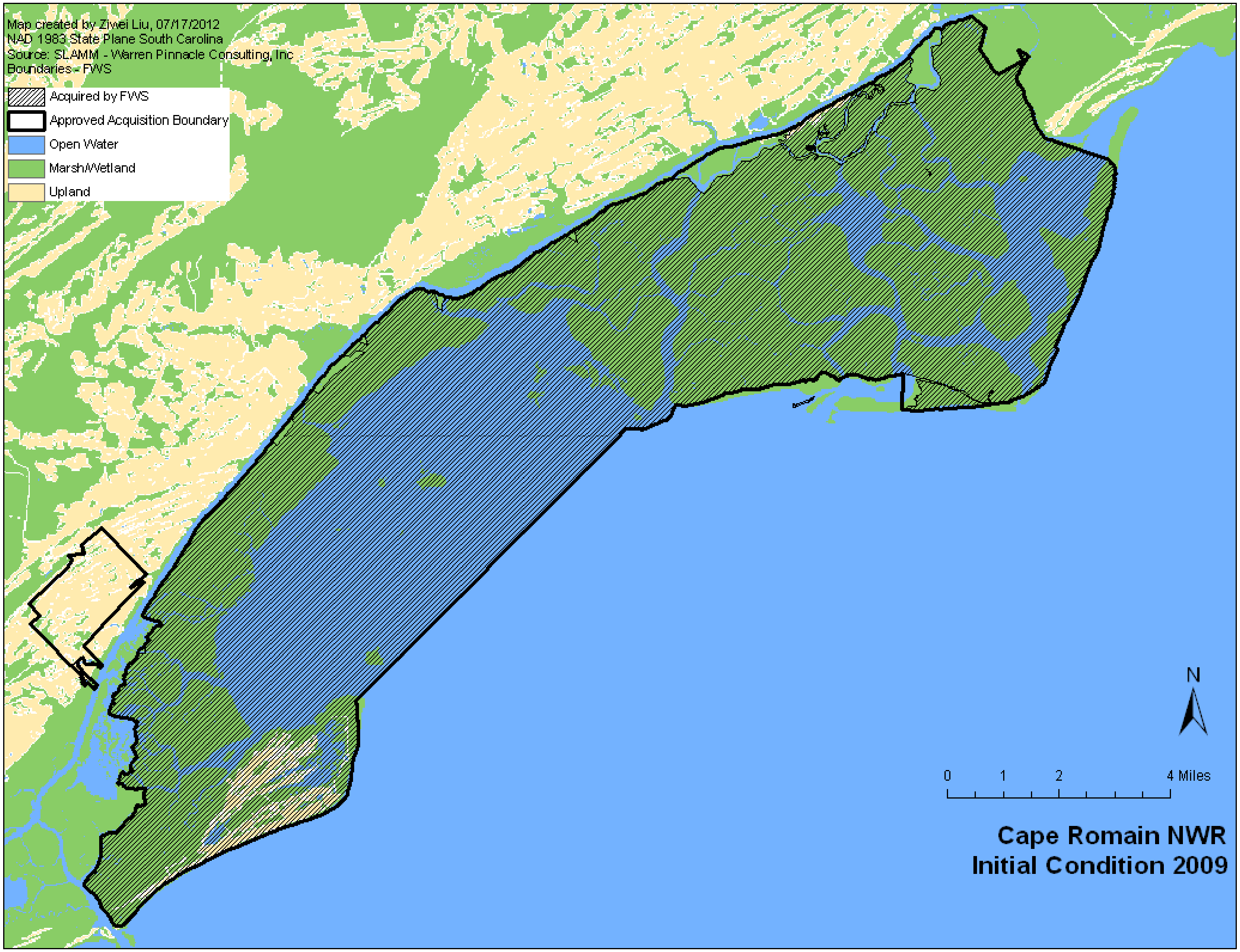


Figure 28. Cape Romain NWR, initial condition (2009). Back to text.

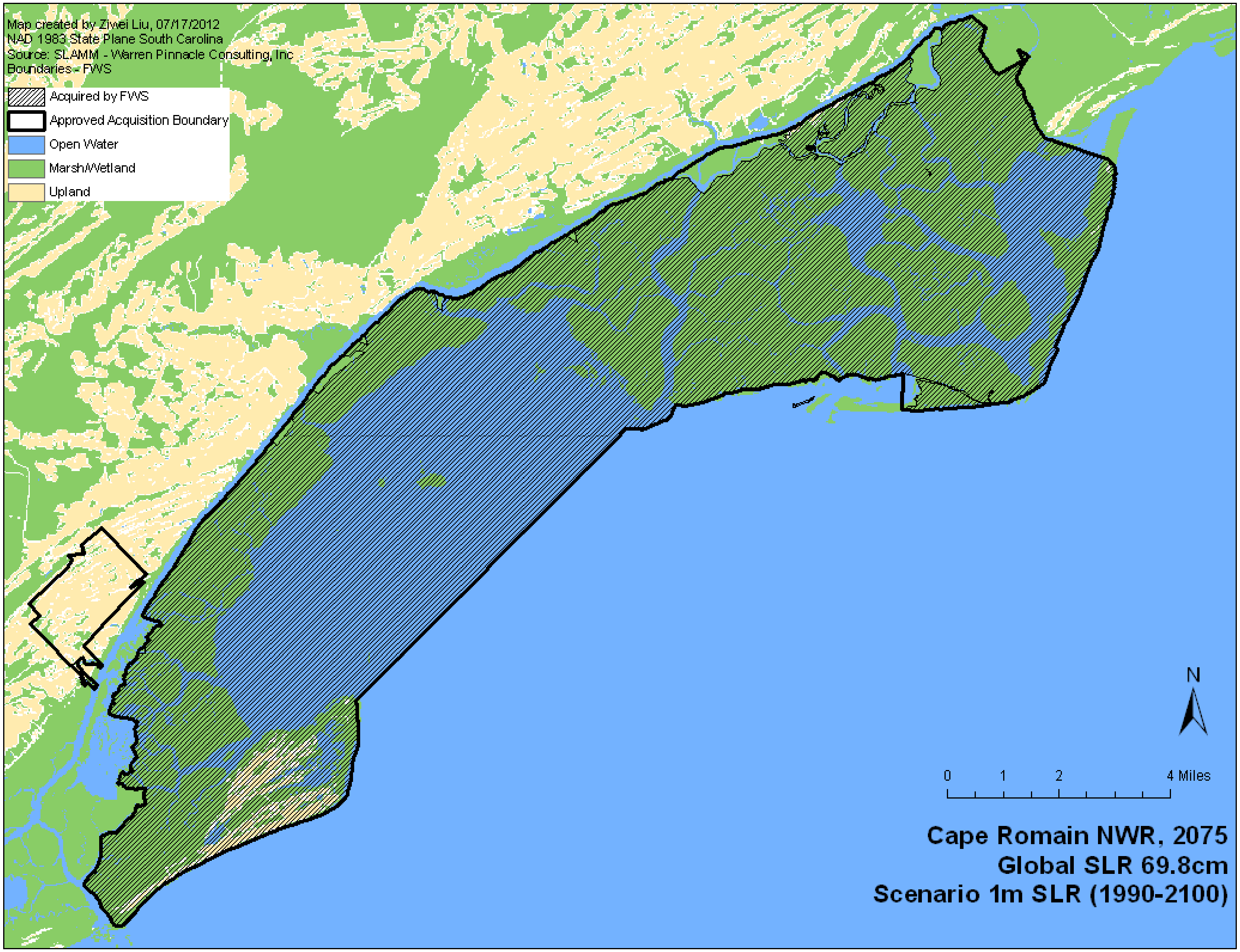


Figure 29. Cape Romain NWR, condition in 2075, 1 m SLR scenario. Back to text.

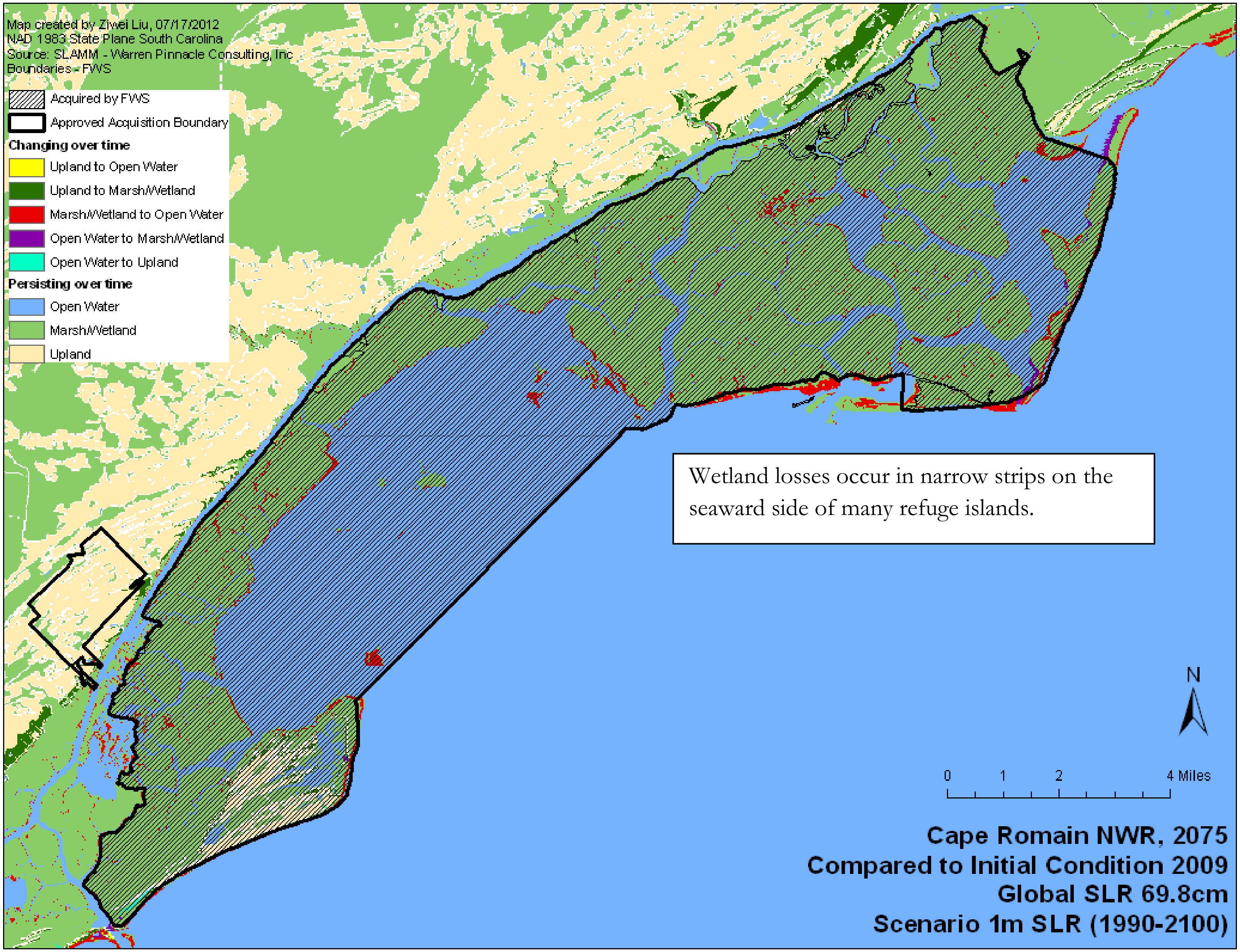


Figure 30. Cape Romain NWR, change from 2009 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

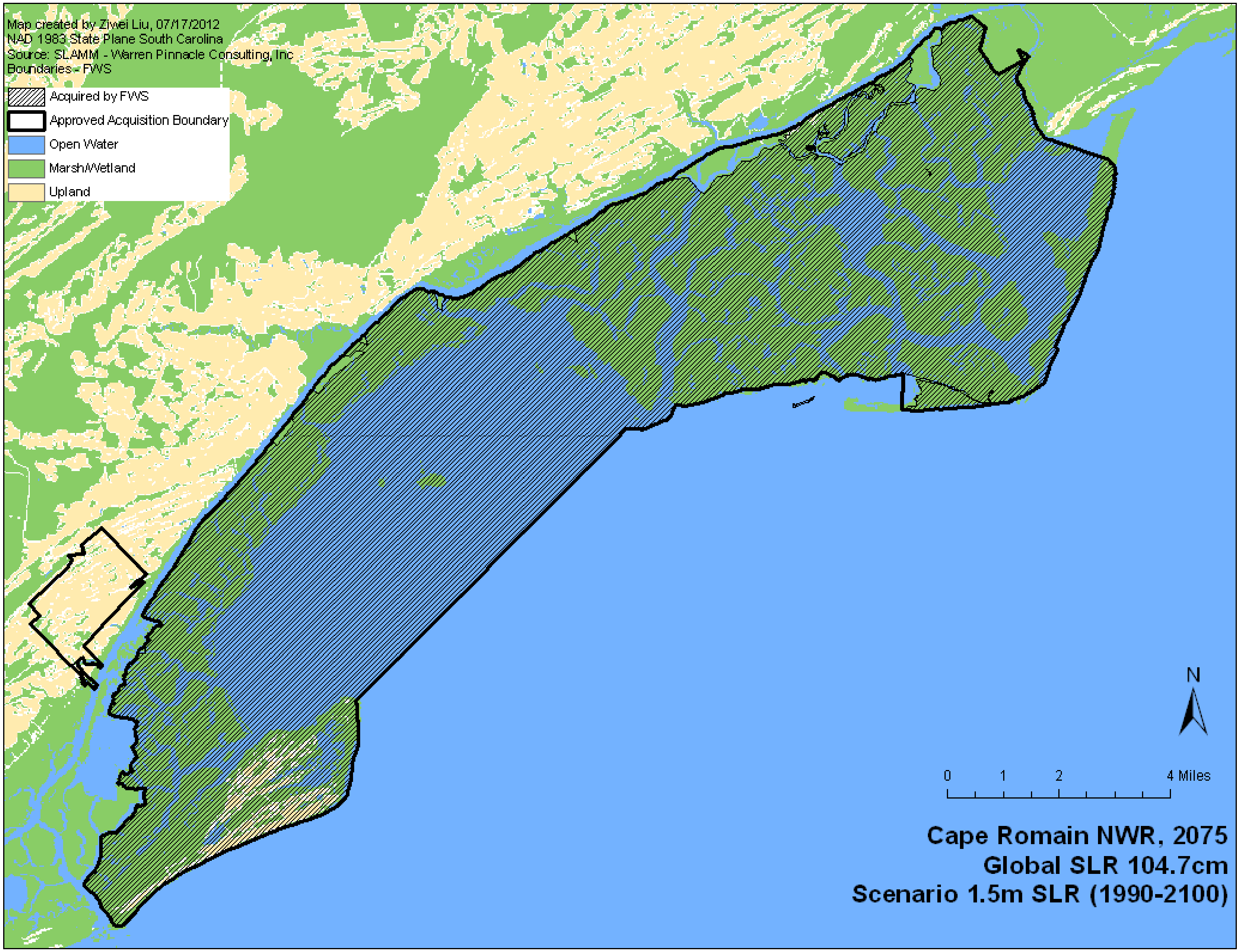


Figure 31. Cape Romain NWR, condition in 2075, 1.5 m SLR scenario. Back to text.

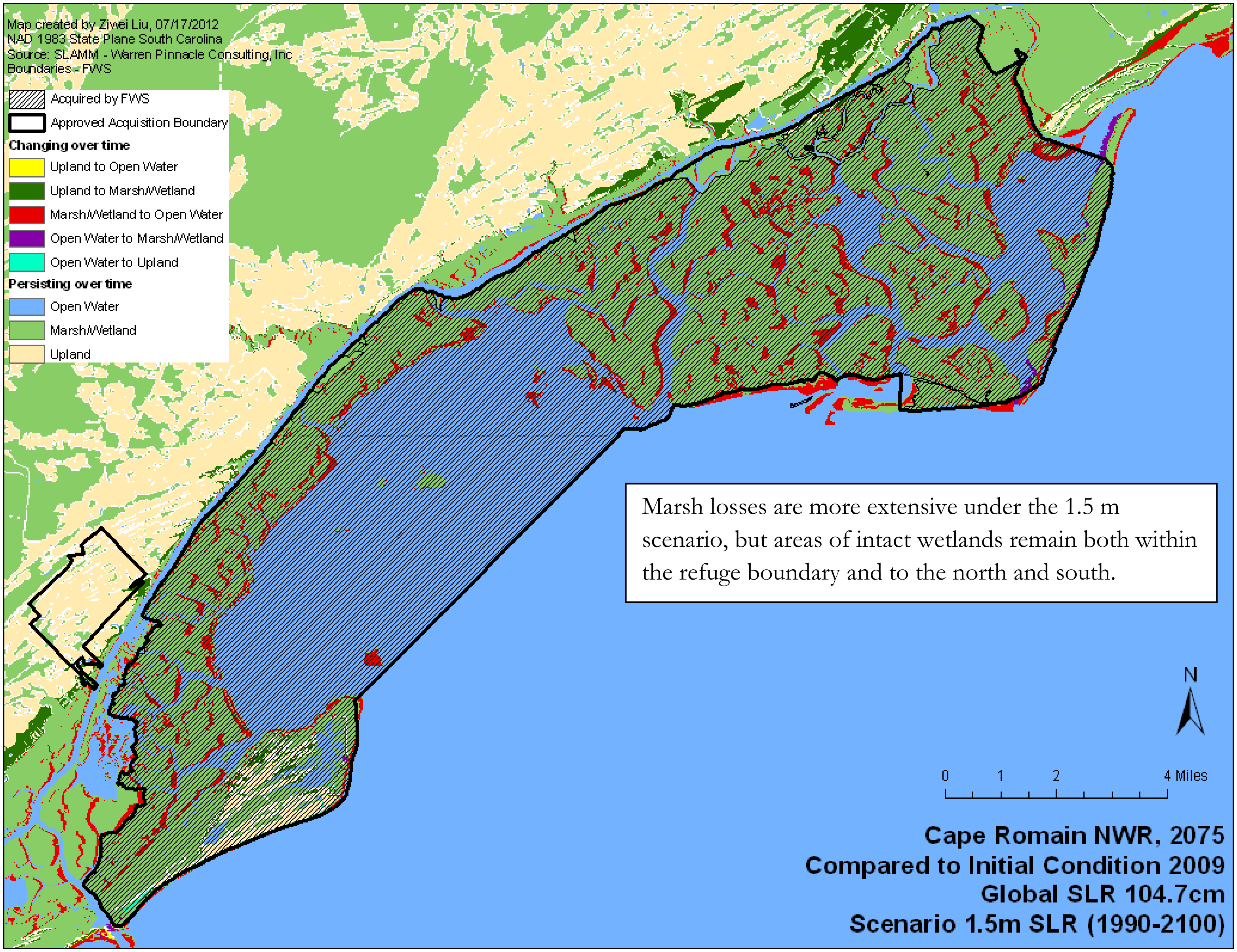


Figure 32. Cape Romain NWR, change from 2009 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

St. Marks NWR (Florida)

St. Marks NWR is located on coast of the panhandle of Florida, with stretches of lands within the approved but unacquired boundary on the inland side (Figure 33).

The impact of sea-level rise on St. Marks NWR is projected to be minimal (Figure 34, Table 9). Though SLAMM data indicates that several islands offshore will be inundated (Figure 35), those are not within the approved refuge boundary, and most areas that are within the refuge will persist. Some of the upland lost by 2075 within the acquired area is converted to marsh, leading to a net gain of wetlands under the 1 m SLR scenario. Even under the 1.5 m scenario, wetland losses are quite small (Figure 36, Figure 37), and the inland orientation of the unacquired area shields much of it from losses, so net impact to the full approved boundary area is only 3.2%.

Table 9. Summary of SLR impacts to St. Marks NWR.

St. Marks National Wildlife Refuge		Acres in 2010	1 m SLR Scenario		1.5 m SLR Scenario	
			Acres in 2075	% lost from 2010	Acres in 2075	% lost from 2010
Acquired Refuge Lands	Upland	18,026.1	16,640.4	7.7%	15,586.9	13.5%
	Wetlands	50,422.2	50,849.8	+0.85%	50,052.2	0.7%
	Total	68,448.2	67490.2	1.4%	65,639.1	4.1%
Approved, Not yet Acquired	Upland	21,052.9	20,692.9	1.71%	20,285.3	3.6%
	Wetlands	20,404.8	20,274.9	0.6%	20,439.8	+0.2%
	Total	41,457.7	40,967.8	1.2%	40,725.1	1.8%
Total Approved Boundary	Upland	39,078.9	37,333.3	4.5%	35,872.3	8.2%
	Wetlands	70,827	71,124.7	+0.4%	70,492	0.5%
	Total	109,905.9	108,458	1.3%	106,364.3	3.2%

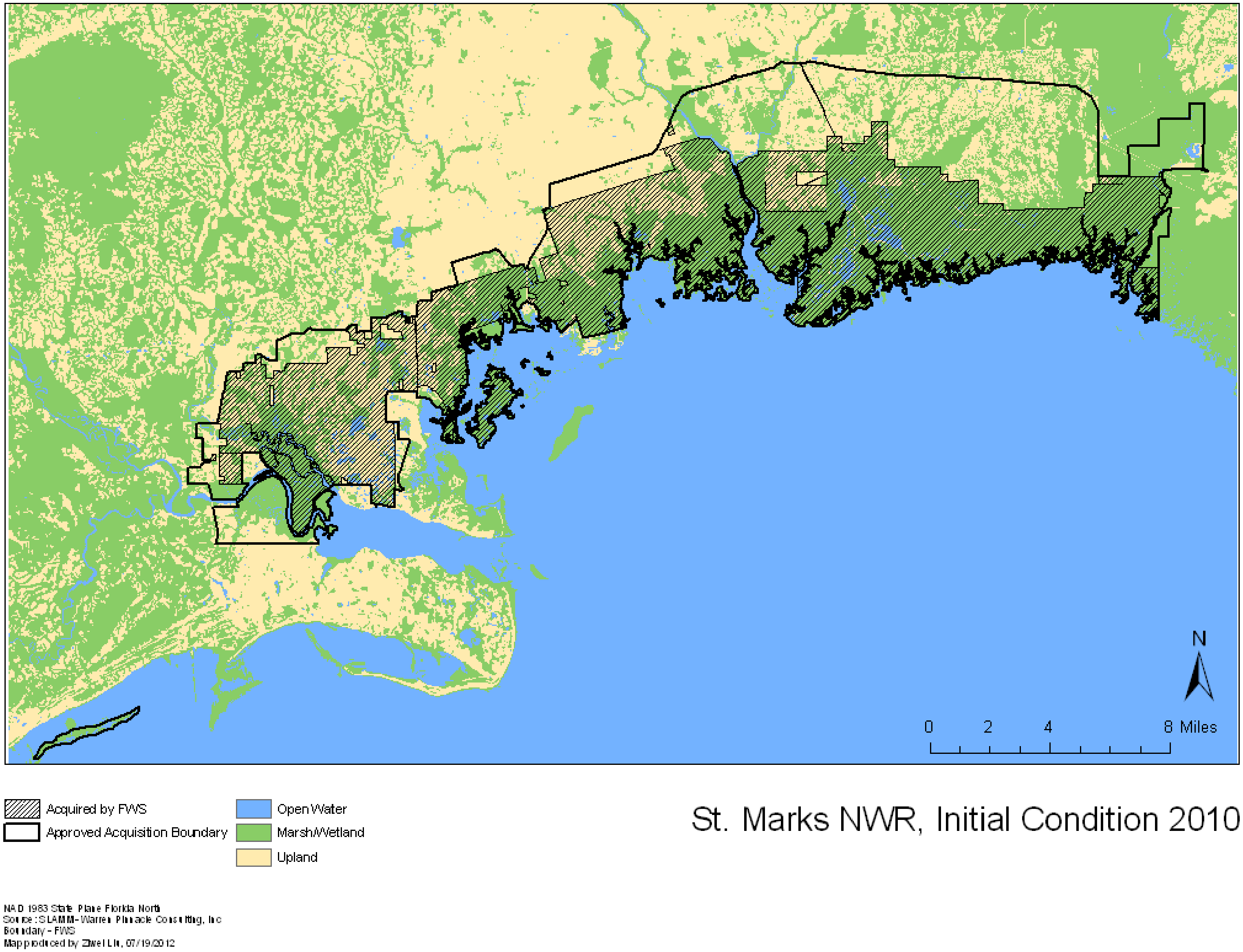


Figure 33. St. Marks NWR, initial condition (2010). [Back to text](#).

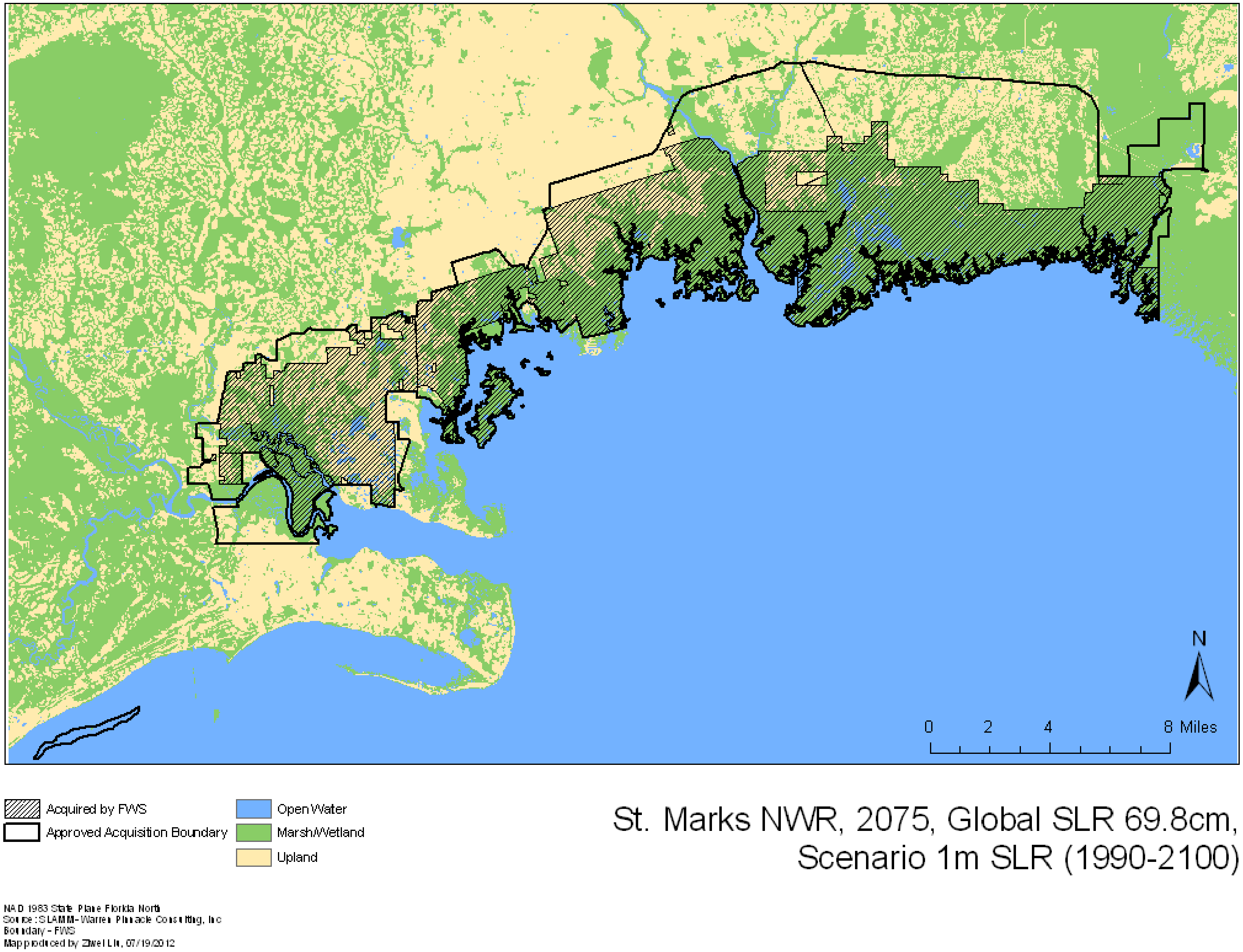


Figure 34. St. Marks NWR, condition in 2075, 1 m SLR scenario. Back to text.

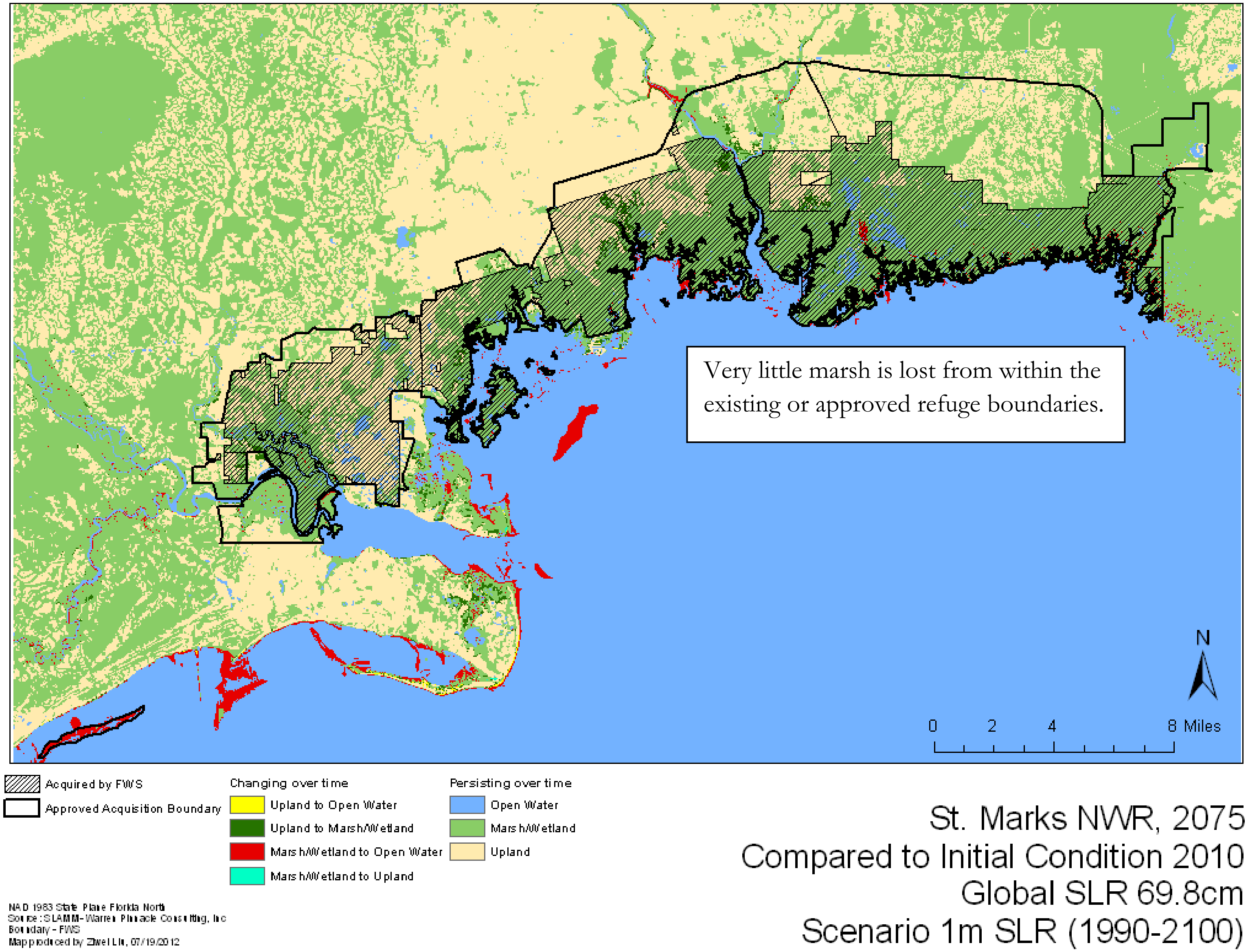


Figure 35. St. Marks NWR, change from 2010 to 2075 due to sea-level rise, 1 m SLR scenario. [Back to text](#).

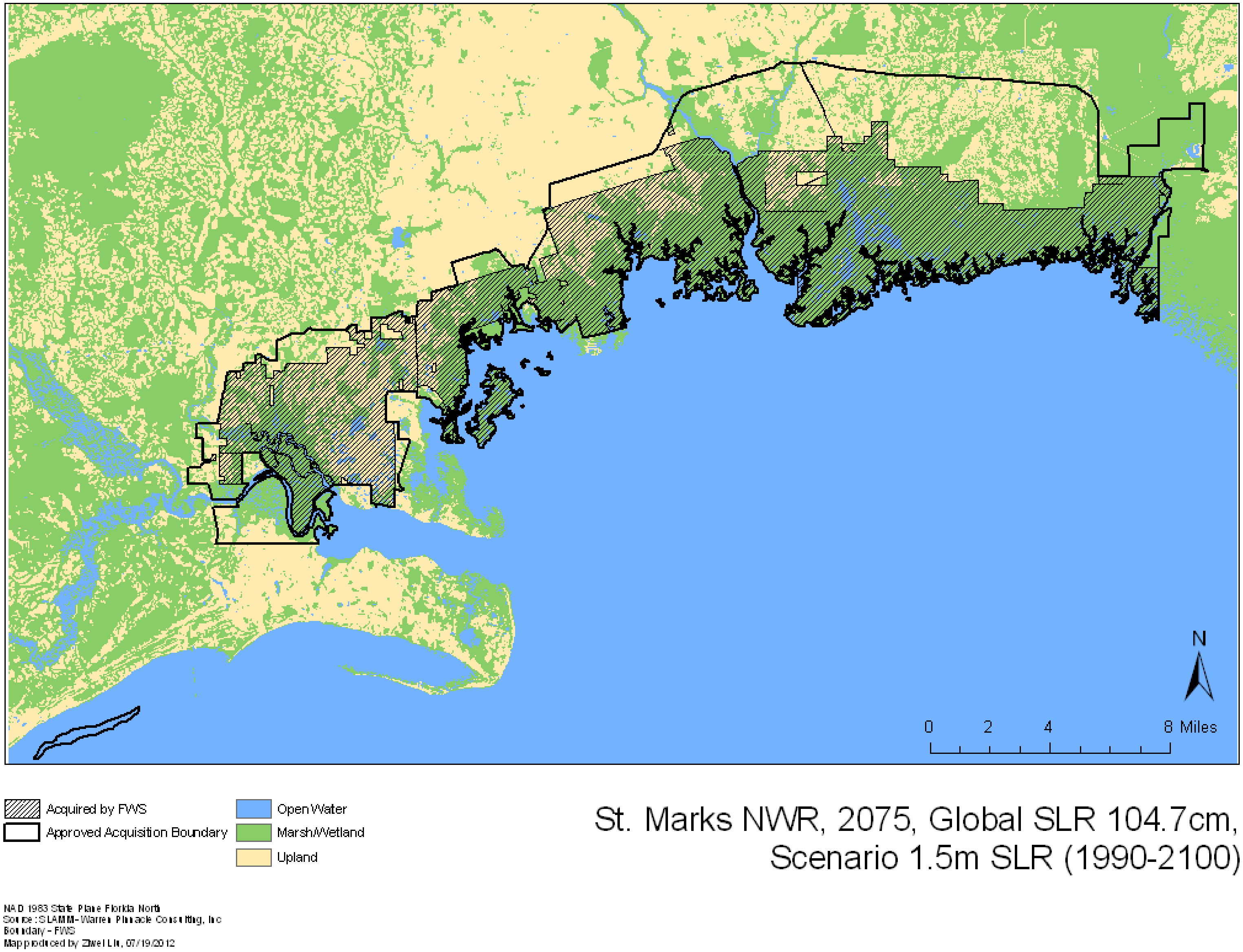


Figure 36. St. Marks NWR, condition in 2075, 1.5 m SLR scenario. Back to text.

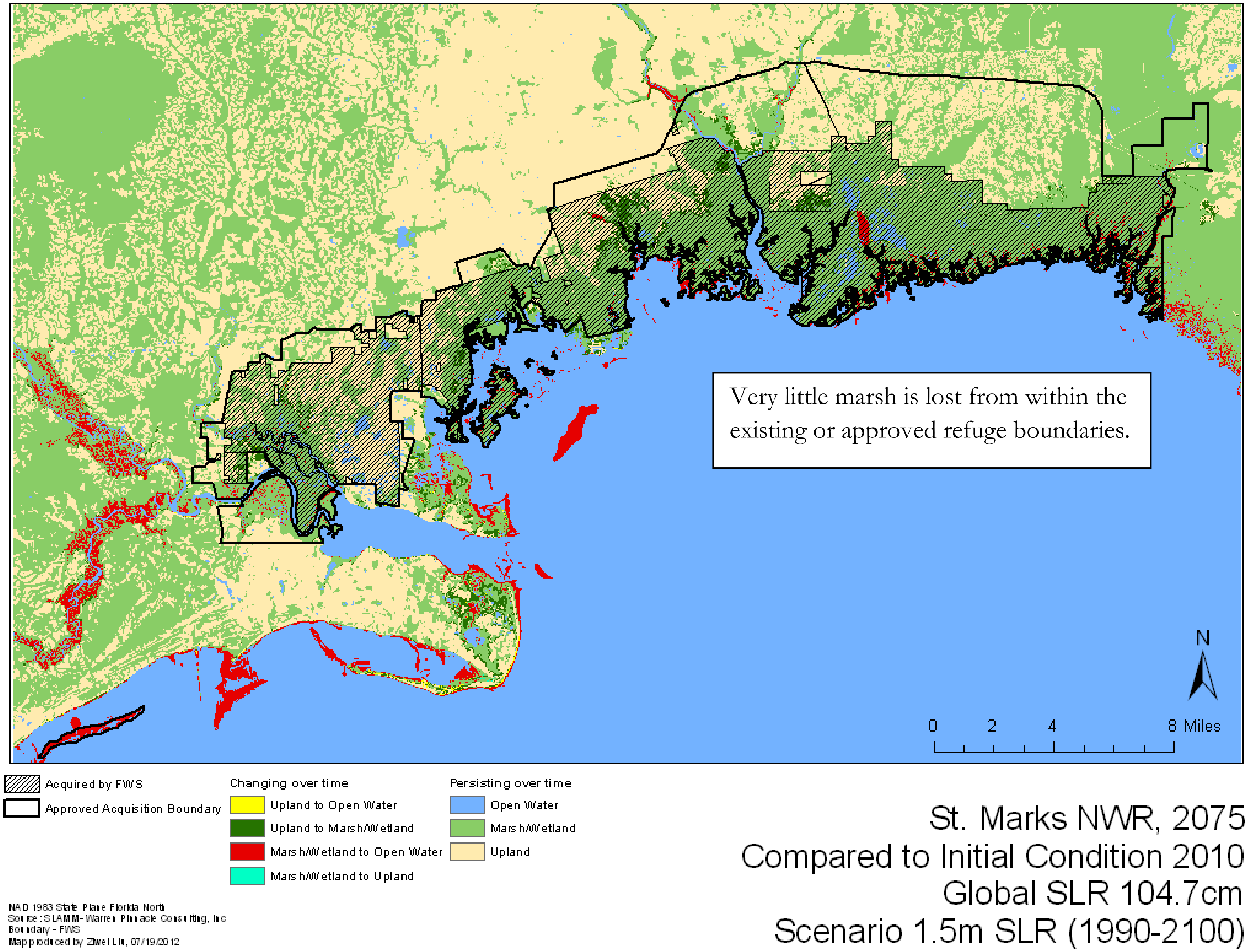


Figure 37. St. Marks NWR, change from 2010 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Savannah NWR (Georgia)

Savannah NWR is located just northwest of the city of Savannah, Georgia, along the river (Figure 38). It is farther inland than the other refuges in the study, and in an area where water flows are strictly managed with impoundments. Not surprisingly, then, SLAMM data projects that the impact of sea-level rise on Savannah NWR will be the smallest among the refuges profiled. Under both the 1 m (Figure 39) and the 1.5 m scenario (Figure 41), the refuge will experience a slight net gain of wetland acreage by 2075 (Table 10). Losses, which occur mostly in small patches along the river (Figure 40, Figure 42), are offset by the conversion of upland into wetlands. Under each scenario, an approximately 1200-acre parcel of upland within the approved acquisition boundary converts to wetland.

Table 10. Summary of SLR impacts to Savannah NWR.

Savannah River National Wildlife Refuge		Acres in 2012	**1 m SLR Scenario**		**1.5 m SLR Scenario**	
			Acres in 2075	% lost from 2012	Acres in 2075	% lost from 2012
Acquired Refuge Lands	Upland	1,211.7	713.9	41.08%	635.9	47.5%
	Wetlands	26,952.7	27,387.8	+1.6%	27,384.4	+1.6%
	Total	28,164.4	28,101.7	0.2%	28,020.3	0.5%
Approved, Not yet Acquired	Upland	4,786.1	4,338.5	9.4%	4,155.7	13.2%
	Wetlands	11,099.7	11,449.5	+3.2%	11,550	+4.1%
	Total	15,885.8	15,788	0.6%	15,705.7	1.1%
Total Approved Boundary	Upland	5,997.8	5,052.4	15.8%	4,791.6	20.1%
	Wetlands	38,052.4	38,837.4	+2.1%	38,934.4	+2.3%
	Total	44,050.2	43,889.8	0.4%	43,726	0.7%

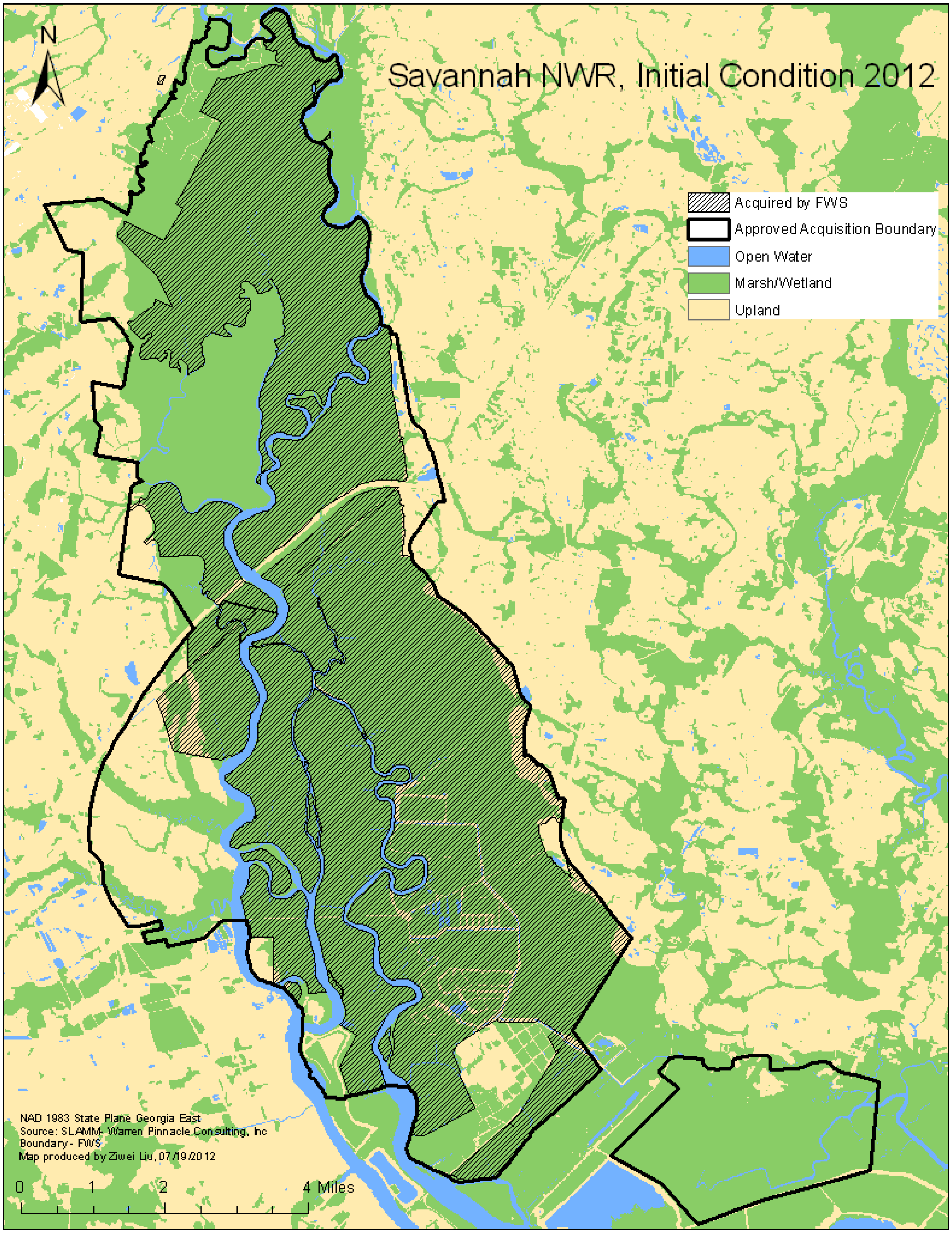


Figure 38. Savannah NWR, initial condition (2012). [Back to text](#).

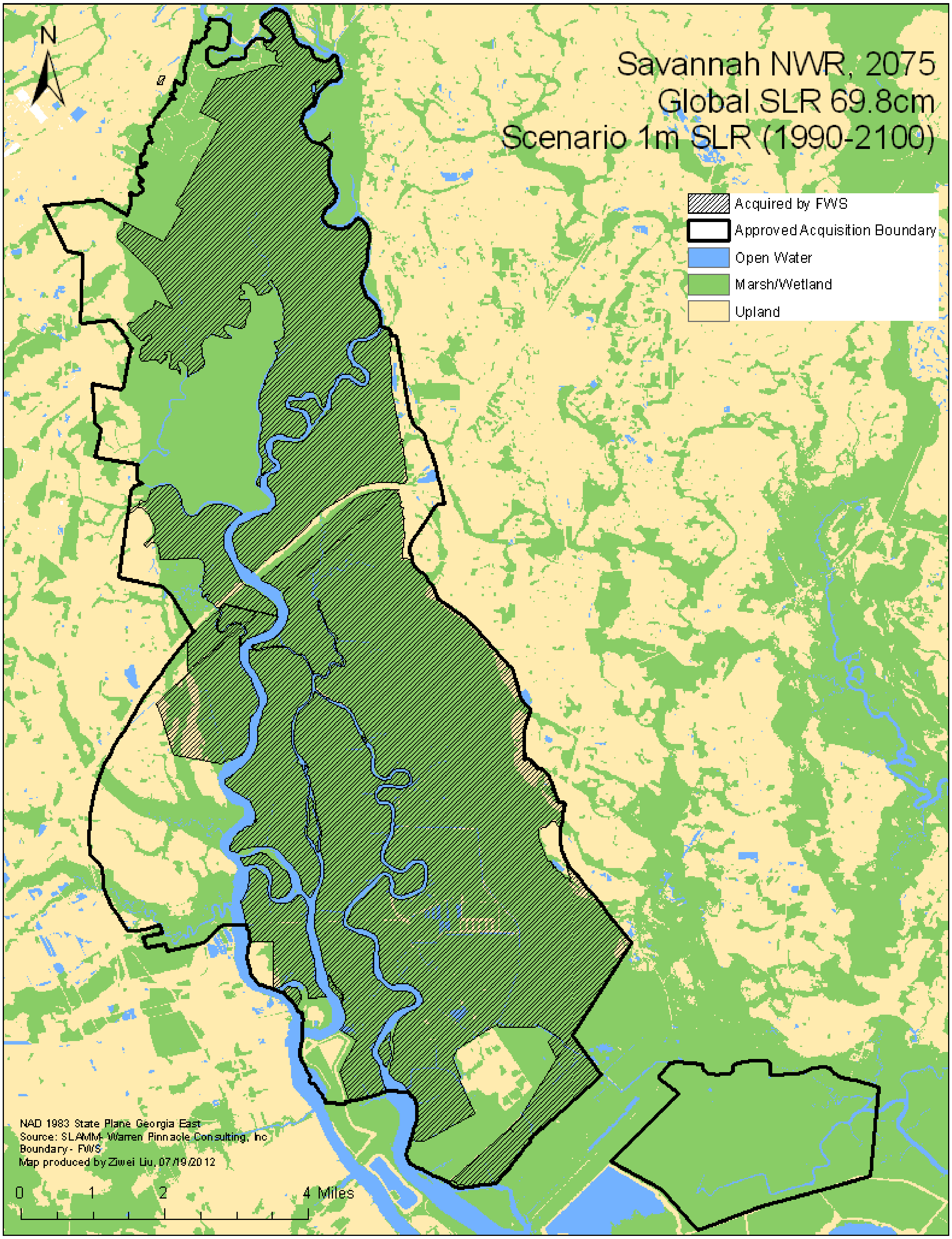
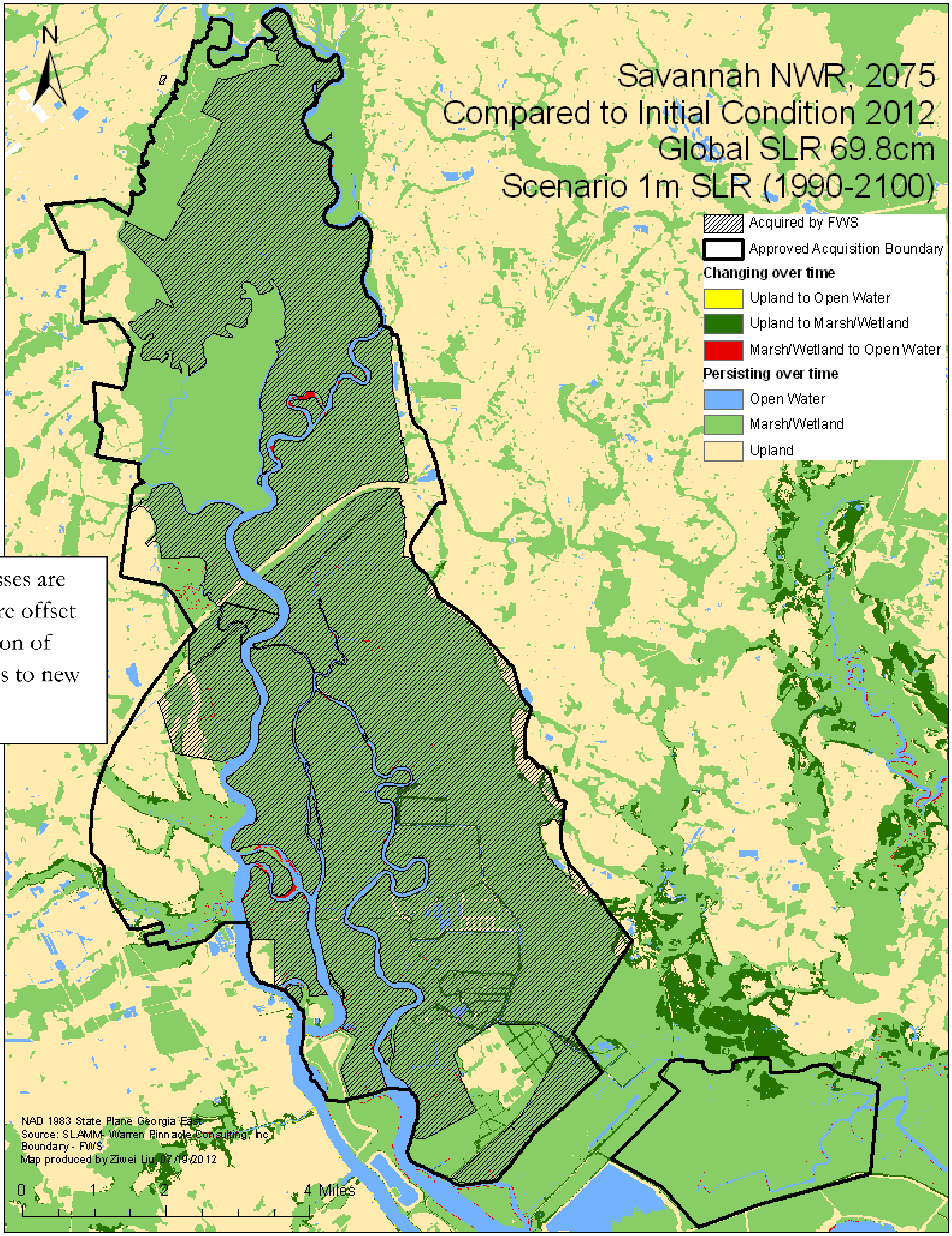


Figure 39. Savannah NWR, condition in 2075, 1 m SLR scenario. [Back to text](#).



Wetland losses are small and are offset by conversion of upland acres to new wetlands.

Figure 40. Savannah NWR, change from 2012 to 2075 due to sea-level rise, 1 m SLR scenario. Back to text.

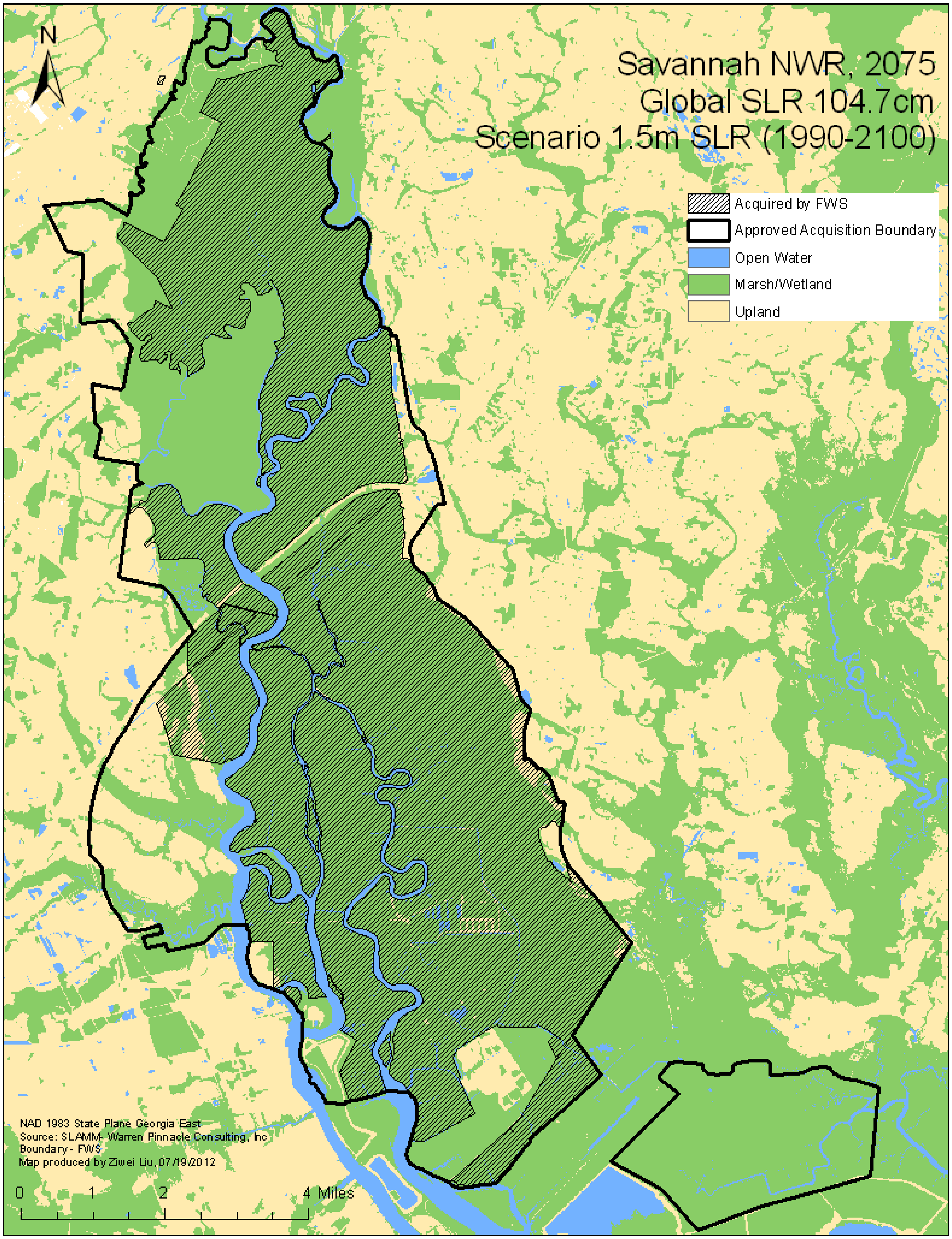
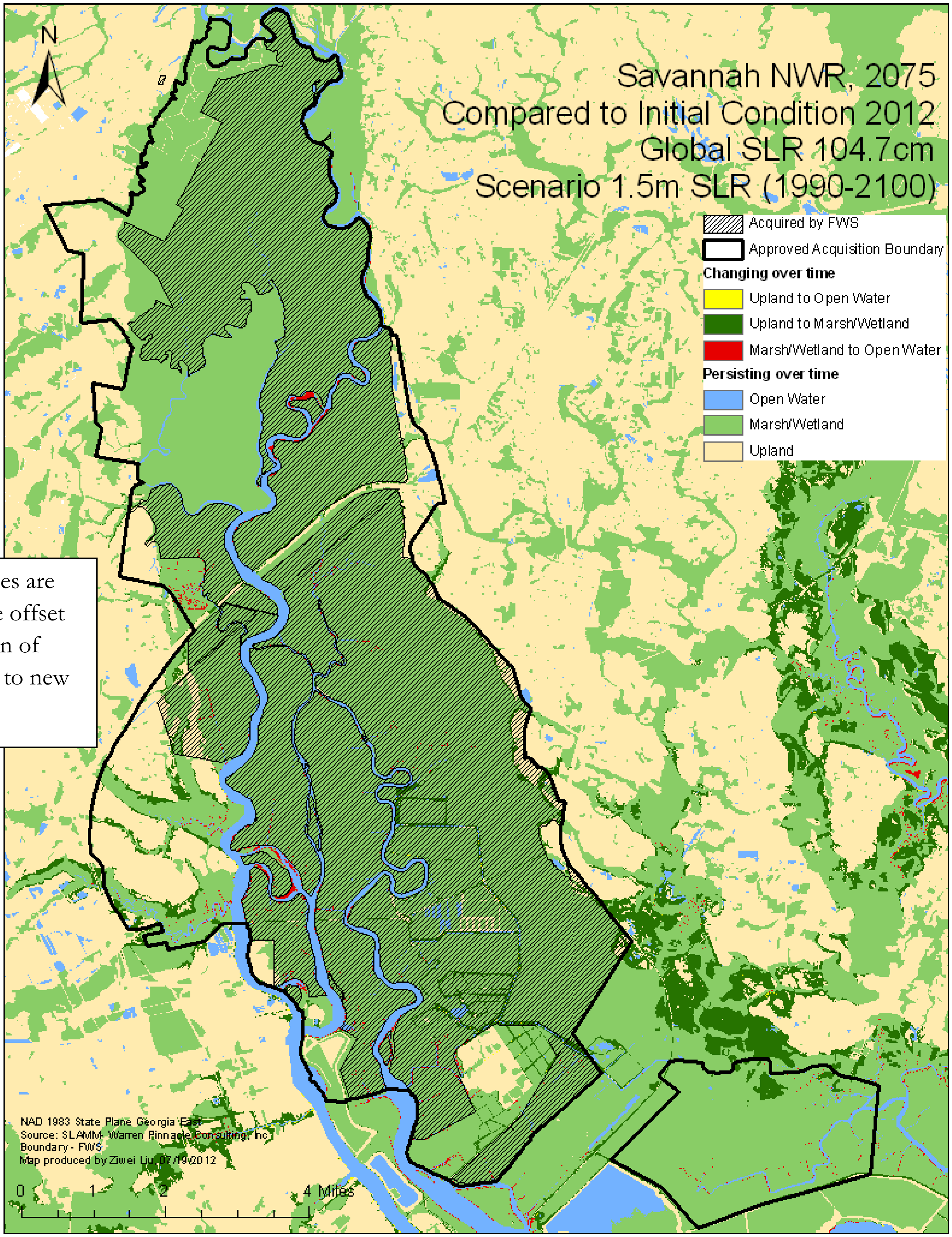


Figure 41. Savannah NWR, condition in 2075, 1.5 m SLR scenario. Back to text.



Wetland losses are small and are offset by conversion of upland acres to new wetlands.

Figure 42. Savannah NWR, change from 2012 to 2075 due to sea-level rise, 1.5 m SLR scenario. Back to text.

Conclusions and Recommendations

Sea-level rise impact will not be felt equally among coastal refuges. Lower Suwannee NWR, for instance, will have very little loss of wetlands or uplands. Some refuges, like Blackwater, will face likely inundation but have newly created areas nearby. Others, like Laguna Atascosa NWR, will face wetlands loss that may not be readily replaced. And refuges whose land area consists mainly of low-lying islands, like in the Florida Keys, may run out of land entirely, particularly if sea-level rise exceeds 1 meter.

In order to maximize the effectiveness of conservation investments in future acquisitions for coastal wildlife refuges, we offer the following recommendations:

- Individual refuges should prioritize acquisition of parcels that are less vulnerable to sea-level rise, unless there is an immediate conservation need that justifies protecting a vulnerable parcel, or when FWS determines a parcel is important to allow for marsh habitats to transition or shift inland as sea levels rise.
- When immediate protection of a vulnerable parcel is needed, FWS should consider alternatives to land purchase, such as short-term, long-term, or rolling easements.
- The FWS should amend approved refuge boundaries as appropriate to maximize long-term conservation benefits in the face of sea-level rise.
- LAPS should include maintenance of conservation value over time and long-term parcel vulnerability in its scoring system to help best allocate conservation dollars.
- Refuges should maintain GIS data of individual parcels of potential land acquisitions within the approved boundary, to facilitate analysis and management decisions.
- These recommendations should be applied not only to acquisitions using funding from the Land and Water Conservation Fund, which LAPS informs, but also other sources, chief among them the Migratory Bird Conservation Fund.

Appendix

Methodology Used to Map Sea-Level Rise Impact on National Wildlife Refuge Exemplified by St. Marks NWR

Data Source

a. SLAMM (Sea Level Affecting Marsh Model) data provided by Warren Pinnacle Consulting, Inc.
b. National Wildlife Refuge Approved Acquisition Boundary (**FwsApproved.shp**) downloaded from U.S. Fish & Wildlife Geospatial Services: http://www.fws.gov/GIS/data/CadastralDB/index.htm
c. National Wildlife Refuge Interest Boundary (**FwsInterest.shp**) downloaded from U.S. Fish & Wildlife Geospatial Services:
d. http://www.fws.gov/GIS/data/CadastralDB/index.htm

Data Preparation

e. Delete irrelevant data in FwsApproved.shp and only keep data for St. Marks National Wildlife Refuge.
f. Delete irrelevant data in FwsInterest.shp and only keep data for St. Marks National Wildlife Refuge.
g. Convert FwsApproved.shp and FwsInterest.shp into the same projection as the SLAMM data.

Analysis

h. Reclassify SLAMM data. SLAMM data are divided into 23 categories as shown in the following table[8]. To simplify the analysis and show sea-level rise impact more directly, these 23 categories are reclassified into 3 categories (Table 1): Upland, Marsh/Wetland, and Open Water.

Table 4: NWI Classes to SLAMM 6 Categories

		NWI code characters					
SLAMM Code	Name	System	Subsystem	Class	Subclass	Water Regime	Notes
1	Developed Dry Land (upland)	U					SLAMM assumes developed land will be defended against sea-level rise. Categories 1 & 2 need to be distinguished manually.
2	Undeveloped Dry land (upland)	U					
3	Nontidal Swamp	P	NA	FO, SS	1, 3 to 7, None	A,B,C,E,F,G,H,J,K None or U	Palustrine Forested and Scrub-Shrub (living or dead)
4	Cypress Swamp	P	NA	FO, SS	2	A,B,C,E,F,G,H,J,K None or U	Needle-leaved Deciduous forest and Scrub-Shrub (living or dead)
5	Inland Fresh Marsh	P	NA	EM, f **	All None	A,B,C,E,F,G,H,J,K None or U	Palustrine Emergents; Lacustrine and Riverine Nonpersistent Emergents
		L	2	EM	2 None	E, F, G, H, K None or U	
		R	2, 3	EM	2 None	E, F, G, H, K None or U	
6	Tidal Fresh Marsh	R	1	EM	2, None	Fresh Tidal N, T	Riverine and Palustrine Freshwater Tidal Emergents
		P	NA	EM	All, None	Fresh Tidal S, R, T	
7	Transitional Marsh / Scrub Shrub	E	2	SS, FO	1, 2, 4 to 7,None	Tidal M, N, P None or U	Estuarine Intertidal, Scrub-shrub and Forested (ALL except 3 subclass)
8	Regularly Flooded Marsh (Saltmarsh)	E	2	EM	1 None	Tidal N None or U	Only regularly flooded tidal marsh No intermittently flooded "P" water Regime
9	Mangrove **Tropical settings only, otherwise 7**	E	2	FO, SS	3	Tidal M, N, P None or U	Estuarine Intertidal Forested and Scrub-shrub, Broad-leaved Evergreen
10	Estuarine Beach old code BB and FL = US	E	2	US	1,2 Important codes	Tidal N, P	Estuarine Intertidal Unconsolidated Shores
		E	**2**	**US**	**None**	**Tidal N, P**	**Only when shores (need images or base map)**
11	Tidal Flat old code BB and FL =US	E	2	US	3,4 None	Tidal M, N None or U	Estuarine Intertidal Unconsolidated Shore (mud or organic) and Aquatic Bed; Marine Intertidal Aquatic Bed
		E	2	AB	All Except 1	Tidal M, N None or U	
		E	**2**	**AB**	**1**	**P**	**Specifically, for wind driven tides on the south coast of TX**
		M	2	AB	1, 3 None	Tidal M, N None or U	
12	Ocean Beach old code BB and FL = US	M	2	US	1,2 Important	Tidal N, P	Marine Intertidal Unconsolidated Shore, cobble-gravel, sand
		M	2	US	None	Tidal P	
13	Ocean Flat old code BB and FL = US	M	2	US	3,4 None	Tidal M, N None or U	Marine Intertidal Unconsolidated Shore, mud or organic, (low energy coastline)

Source, Bill Wilen, National Wetlands Inventory.

Also see the Excel database of NWI Codes to SLAMM Categories installed with the SLAMM 6 Installer in the directory with the SLAMM 6 Executable.

Table 4 (cont.): NWI Classes to SLAMM 6 Categories

		NWI code characters					
SLAMM Code	Name	System	Subsystem	Class	Subclass	Water Regime	Notes
14	Rocky Intertidal	M	2	RS	All None	Tidal M, N, P None or U	Marine and Estuarine Intertidal Rocky Shore and Reef
		E	2	RS	All None	Tidal M ,N, P None or U	
		E	2	RF	2, 3 None	Tidal M, N, P None or U	
		E	2	AB	1	Tidal M, N None or U	
15	Inland Open Water old code OW = UB	R	2	UB, AB	All, None	All, None	Riverine, Lacustrine, and Palustrine Unconsolidated Bottom, and Aquatic Beds
		R	3	UB, AB, RB	All, None	All, None	
		L	1, 2	UB, AB, RB	All, None	All, None	
		P	NA	UB, AB, RB	All, None	All, None	
		R	5	UB	All	Only U	
16	Riverine Tidal Open Water old code OW = UB	R	1	All **Except EM**	All None **Except 2**	Fresh Tidal S, R, T, V	Riverine Tidal Open water **R1EM2 falls under SLAMM Category 6**
17	Estuarine Open Water (no h* for diked / impounded) old code OW=UB	E	1	All	All None	Tidal L, M, N, P	Estuarine subtidal
18	Tidal Creek	E	2	SB	All, None	Tidal M, N, P Fresh Tidal R, S	Estuarine Intertidal Streambed
19	Open Ocean old code OW = UB	M	1	All	All	Tidal L, M, N, P	Marine Subtidal and Marine Intertidal Aquatic Bed and Reef
		M	2	RF	1,3, None	Tidal M, N, P None or U	
20	Irregularly Flooded Marsh	E	2	EM	1, 5 None	P	Irregularly Flooded Estuarine Intertidal Emergent marsh
		E	**2**	**US**	**2, 3, 4 None**	**P**	**Only when these salt pans are associated with E2EMN or P**
21	Not Used						
22	Inland Shore old code BB and FL = US	L	2	US, RS	All	All Nontidal	Shoreline not pre-processed using Tidal Range Elevations
		P	NA	US	All, None	All Nontidal None or U	
		R	2, 3	US, RS	All, None	All Nontidal None or U	
		R	4	SB	All, None	All Nontidal None or U	
23	Tidal Swamp	P	NA	SS, FO	All, None	Fresh Tidal R, S, T	Tidally influenced swamp

* **h=Diked/Impounded** - When it is desirable to model the protective effects of dikes, an additional raster layer must be specified.

** Farmed wetlands are coded Pf
All: valid components
None: no Subclass or Water regime listed
U: Unknown water regime
NA: Not applicable

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Water Regimes	
Nontidal	A, B, C, E, F,G, J, K
Saltwater Tidal	L, M, N, P
Fresh Tidal	R, S,T, V

Note: Illegal codes must be categorize by intent.
Old codes BB, FL = US
Old Code OW = UB

Source, Bill Wilen, National Wetlands Inventory

For more information on the NWI coding system see Appendix A of Dahl, Dick, Swords, and Wilen 2009.

Table 1

Category	New Code	SLAMM Code
Upland	5	1, 2
Marsh/Wetland	1	3-14, 20-23
Open Water	0	15-19

i. Calculate land type change between different years under the same scenario.
j. Produce Map.
k. Calculate land type change within FWS approved acquisition boundary and acquired boundary The outcome is a raster which shows land type change only within FWS approved acquisition boundary. Export the attribute table into Excel. The values in VALUE column show how land type changes (Table 2). The values in COUNT column show the cell numbers. Since for St. Marks NWR, 1 cell in SLAMM is 10m*10m, the area of 1 cell is 100 m^2 or 0.0247 acres. Calculations for other values can be done similarly.

Table 2

VALUE	2010 Land Type	2075, 1m Scenario Land Type	Land Type Change
-5	Upland	Open Water	Upland Loss
-4	Upland	Marsh/Wetland	Marsh/Wetland Migration
-1	Marsh/Wetland	Open Water	Marsh/Wetland Loss
0	Upland	Upland	Persistent
	Marsh/Wetland	Marsh/Wetland	
	Open Water	Open Water	
1	Open Water	Marsh/Wetland	New Marsh/Wetland
4	Marsh/Wetland	Upland	Upland Migration
5	Open Water	Upland	New Upland

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[4] U.S. Fish & Wildlife Service, National Wildlife System, http://www.fws.gov/refuges/, last updated August 13, 2012.
[5] Fiscal Year 2013 Land Acquisition Priority System ("LAPS") list, United States Department of the Interior, Fish and Wildlife Service, May 26, 2011.
[6] SLAMM 6.0.1 Technical Document Draft, Warren Pinnacle Consulting, Inc. May 2010
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