LOUISIANA COASTAL PROTECTION AND RESTORATION
FINAL TECHNICAL REPORT

COASTAL RESTORATION PLAN AND STRUCTURAL ENVIRONMENTAL IMPACTS

APPENDIX

June 2009

U. S. Army Corps of Engineers
New Orleans District
Mississippi Valley Division

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PURPOSE

The Louisiana Coastal Protection and Restoration (LACPR) Technical Report has been developed by the United States Army Corps of Engineers (USACE) in response to Public Laws 109-103 and 109-148. Under these laws, Congress and the President directed the Secretary of the Army, acting through the Chief of Engineers, to:

- Conduct a comprehensive hurricane protection analysis and design in close coordination with the State of Louisiana and its appropriate agencies;
- Develop and present a full range of flood control, coastal restoration, and hurricane protection measures exclusive of normal policy considerations for South Louisiana;
- Consider providing protection for a storm surge equivalent to a Category 5 hurricane; and
- Submit preliminary and final technical reports.

The purpose of this appendix is to support *(Coastal Restoration evaluation)* for LACPR, which is discussed in the main Technical Report.

BACKGROUND

A determination was made by the LACPR team, with concurrence and guidance from the Corps Vertical Team, that adequate technical development of any alternative plan to a degree that would support specific recommendations for action was not feasible. Therefore at this stage of development no attempt is being made to indicate formulation or selection of a "preferred" alternative. Since a "preferred alternative" is not being proposed by this technical report, an environmental analysis is not being conducted as required by the National Environmental Policy Act and the Council on Environmental Quality regulations. However, the development of a basic understanding of the coastal landscape contribution to comprehensive and systemic risk reduction could be and was developed from the available hydrodynamic analyses. Based on this understanding alternative coastal plans were tested for their ability to perform effectively in maintaining long-term risk reduction capacity. Based on this assessment effective alternative plans have been applied to represent the general restoration need and approach could be presented as part of this report.

Sustaining the integrity of the estuarine environments in coastal Louisiana is critical to the ecological, social and economic welfare of the region. Model analyses of storm surge levels and wave magnitudes demonstrate the value of coastal features to lowering storm risks; allowing existing coastal features to degrade results in an increase in surge levels and wave heights. Thus, the planning goal was to achieve **"maximum sustainability"** to the greatest degree possible

The LACPR project area stretches across Louisiana's coast from the Pearl River on the Mississippi state line to the Sabine River on the Texas state line. The project area is comprised of two wetland-dominated ecosystems, the Deltaic Plain of the Mississippi River and the closely linked Chenier Plain, both of which are influenced by the Mississippi River.

Figure 1 - LACPR General Project Area

Louisiana's coastal wetlands, which extend as much as 81 miles (130 km) inland and along the coast for about 435 miles (700 km), represent roughly 40 percent of the coastal wetlands of the continental United States. These wetlands are both regionally and nationally significant because they (a) provide protection from storm surge and wave erosion for a population of 2 million people and an infrastructure investment of more than $100 billion, (b) support a commercial marine fishery valued in excess of $250 million and recreational hunting and fishing expenditures of about $1 billion annually, (c) provide habitat for 4.4 million migratory waterfowl, and (d) are the site of a significant portion of U.S. oil and gas production.

Prior to human intervention, the state's coastal marshes were thought to be maintaining themselves through natural processes in spite of periodic hurricanes. Losses in some areas would be offset by gains in other areas. Riverine inputs to coastal marshes were especially critical for this assumed self-sustainability.

Subsidence, sea-level rise, decreased sediment and nutrient delivery, erosion, impacts from human activities and other factors have contributed to rates of coastal wetland loss in south Louisiana exceeding 25 mi^2/yr (65 km^2/yr) - about 80 percent of the total national losses (Boesch 1994). Barras et al. 2003, projected loss rates in 2003 at 10.3 mi^2/yr or 513 mi^2/yr between 2000 – 2050 when including restoration projects. Without restoration projects, the wetland loss rate is increased to approximately 13.48 mi^2/yr. Barras 2006, matched wetland loss trends with LCA trend data (all wetland loss) and determined a loss rate of approximately 500 mi^2 (10.63%) over a 50 year period. The total land loss rate (including non-wetland areas) is approximately 8.44%. Factoring in the impacts of the 2005 hurricanes on coastal Louisiana increases the wetland loss rates to 14.6 mi^2/yr to year 2050 (Barras 2007, PersCom). Not all the wetlands are receding; in fact some wetlands are stable, and others are growing. But the projected net loss over the next 50 years, with current restoration efforts taken into account, is estimated to be approximately 500 mi^2 (1295 km^2) (Barras et al. 2003). According to land loss estimates, Hurricanes Katrina and Rita transformed 217 mi^2 (562 km^2) of marsh to open water in coastal Louisiana (USGS 2006). Approximately 12.3% (730 mi^2) of the total land area within the project area was lost in 2004 (Barras 2007, PersCom).

Several efforts have been initiated to reduce the rate of wetland loss. In 1990, Congress passed the Coastal Wetlands Protection and Preservation Act (CWPPRA) to provide federal funding (approximately $50 million per year) for coastal restoration. This program has constructed a number of small to medium sized projects of varying types. The LCA plan (the Near-Term Plan (NTP)) developed by the U.S. Army Corps of Engineers (USACE), New Orleans District (MVN) and the Louisiana Department of Natural Resources (LADNR) was authorized in the Water Resources Development Act of 2007 by Congressional Presidential veto override. The NTP includes 15 specific coastal restoration projects and three programs (i.e., science and technology needs research).

As a result of the devastation caused by hurricanes Katrina and Rita in 2005, Congress directed the MVN, in partnership with the State of Louisiana, to initiate the LACPR project. A determination was made by the LACPR team, with concurrence and guidance from the Corps Vertical Team, that adequate technical development of any alternative plan to a degree that would support specific recommendations for action was not feasible. Therefore at this stage of development no attempt is being made to indicate formulation or selection of a "preferred" alternative. Since a "preferred alternative" is not being proposed by this technical report, an environmental analysis is not being conducted as required by the National Environmental Policy Act and the Council on Environmental Quality regulations. However, the development of a basic understanding of the coastal landscape contribution to comprehensive and systemic risk reduction could be and was developed from the available hydrodynamic analyses. Based on this understanding alternative coastal plans were tested for their ability to perform effectively in maintaining long-term risk reduction capacity. Based on this assessment effective alternative plans have been applied to represent the general restoration need and approach could be presented as part of this report.

The plan is to include restoration of the coastal landscape, and the USACE formed a Habitat Evaluation Team (HET) with representatives from 11 federal and state environmental- resource agencies to assist in plan formulation and to identify appropriate metrics for assessing the environmental benefits and impacts of proposed plans.

HABITAT EVALUATION TEAM

The HET is one of several teams formed to assist in the plan formulation and evaluation process for the LACPR. Membership on the HET included the following:

- Ronny Paille – United States Fish and Wildlife Service
- Craig Fischenich – United States Army Corps of Engineers, Engineer Research and Design Center, Environmental Laboratory
- Pat Williams – National Marine Fisheries Service
- John Ettinger – Environmental Protection Agency, Region VI
- Cindy Steyer – Natural Resource Conservation Service
- Troy Mallach – Natural Resource Conservation Service
- Heather Finley – Louisiana Department of Wildlife and Fisheries
- Manuel Ruiz – Louisiana Department of Wildlife and Fisheries
- Michael Massimi - Barataria-Terrebonne National Estuary Program
- Bren Haase – Louisiana Department of Natural Resources, Coastal Restoration Division
- Greg Steyer – United States Geological Survey
- Sean Mickal – United States Army Corps of Engineers, New Orleans District
- Sandra Stiles – United States Army Corps of Engineers, New Orleans District

Tasks and Goals

The HET was assigned several responsibilities in support of the LACPR, including 1) the formulation of coastal restoration alternatives to be combined with structural and non-structural measures to generate plans for the LACPR, 2) identification of environmental metrics for use in evaluating the LACPR plans, and 3) quantification of the environmental impacts and benefits of those plans. The HET determined that the goal of their combined efforts could be summarized as ***"Achieve ecosystem sustainability in coastal Louisiana to the greatest degree possible".*** This would be accomplished through:

- Examination of coastal restoration strategies that contribute to sustainable hurricane protection;
- Inclusion of individual measures of varying sizes to restore and maintain landscape features and essential wetland maintenance processes;
- Identification and programmatic assessment of combinations of individual measures which provide ecosystem-level synergistic benefits;
- Programmatic assessment of the potential of alternative plans to achieve or exceed no-net loss of coastal wetlands;
- Examination of the potential for trade-offs associated with various restoration alternatives (e.g. near-term protection vs. long-term sustainability and fisheries changes vs. deltaic processes).

Guiding Principles

An overarching principle established by the HET is that sustaining the integrity of the estuarine environments in coastal Louisiana, including the various landscape features that make up those environments, is critical to the ecological health and, by extension, the social and economic welfare of the region. Model analyses of storm surge levels and wave magnitudes demonstrate the value of coastal features to lowering storm risks. While the models show benefits from additional marsh, island and landbridge habitat, the effects of allowing existing features to degrade are even more pronounced. Thus, sustaining the integrity of the estuarine environments in coastal Louisiana is a key component of a comprehensive storm risk reduction strategy for the region.

The HET identified several additional principles related to ecosystem quality and maintenance that served to guide plan formulation and assessment decisions. Included were (in no order of particular importance):

- Relatively intact estuarine ecosystems are a key attribute in coastal Louisiana, and alternatives should seek to enhance the resilience and self-sustainability of the estuarine environments, including protection of existing high-quality estuaries. Consequently, development of plans that would only reduce wetland losses were precluded from consideration.
- Because the driving processes and conditions are different, the Deltaic Province (Planning Units 1, 2, 3a, & 3b) and Chenier Plain (Planning Units 3b, & 4) should be viewed separately and different criteria may apply in plan formulation and evaluation. While several scales of assessment are important, the basin scale is the most relevant for analyses in the LACPR.
- Within the Deltaic Province, restoration of key processes and dynamics is critical to the long-term health of the ecosystem. However, it is important to recognize that these processes vary spatially and temporally, so some areas may experience losses while others are gaining. (See *Screening Criteria and Prioritization* in the PLAN FORMULATION section of this appendix for more information on ranking of critical marsh features)
- Because of drastically reduced Mississippi River sediment loads, riverine diversions must be carefully sited to maximize sediment retention within the coastal ecosystem and avoid sediment loss to the Gulf. Therefore, alternatives must seek to maximize the combined benefits of diversions that seek to restore natural processes with mechanical marsh creation measures. Additional sources of sediments should be sought wherever feasible; recognizing that such measures should not contribute to ecosystem degradation in the source area.
- Measures should be combined synergistically to maximize possible cumulative benefits. As such, the position of features within the landscape has a direct influence on the potential benefits.
- Wetland losses in coastal Louisiana occur from a number of factors. Many of those factors are beyond our control. However, causes of accelerated degradation, such as disrupted hydrologic functions; salinity intrusion, direct removal of wetland habitat; etc., should be directly addressed wherever possible.
- Our capacity to assess and quantify benefits and impacts from various measure combinations is limited at present due to the state-of-the-science, scheduling constraints in the LACPR process and uncertainty associated with future development, relative sea level rise (RSLR) and other factors. Flexibility is required in project design and

implementation to permit adaptive management as conditions change and more is learned.

- To address the above constraints, a concerted monitoring and adaptive management program should be a central component of the LACPR. Additional scientific investigation, model development, and programmatic re-evaluations will be required.

Approach

A number of studies and reports on Louisiana’s coastal ecosystem and water resources development in the study area have been prepared by the USACE, other Federal, state, and local agencies, research institutes, and individuals. These previous studies established an extensive database for the LCA Study, which in turn served as a significant starting point for the State’s Master Planning Process and the LACPR. Historical trends and existing conditions were identified to provide insight into future conditions, help isolate the problems, and identify the most critical areas for restoration.

Building upon this foundation, the HET held frequent meetings throughout the study period to discuss and reach consensus on critical issues. Subgroups of the HET developed analytical tools, conducted evaluations, assembled alternatives and otherwise executed the various work efforts associated with the assigned tasks. Working groups submitted findings to the full HET for approval.

The HET interacted with program managers for the LACPR and leaders from the working groups of other technical areas to coordinate activities and ensure integration of the plan components. Two formal workshops were held to elicit input from recognized regional experts in a broad range of disciplines, and numerous formal and informal interactions were held with regional, state, and Federal resource agency personnel; researchers from the academic community with expertise in the pertinent subject areas; and representatives of NGOs regarded as stakeholders in the LACPR.

Other Restoration Programs

- The **Louisiana Coastal Area (LCA) Ecosystem Restoration Plan** was established to reverse the degradation trend of the Louisiana coastal ecosystem. The LCA Plan emphasizes the use of restoration strategies towards achieving and sustaining a coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana. The LCA Plan identified the most critical ecological needs and a near-term program of cost-effective projects to address them. A Science and Technology (S&T) Program has been executed as a partnership between the State of Louisiana, the US Army Corps of Engineers, the US Geological Survey, and other Federal agencies for the purpose of improving LCA program performance through application of the best available science, technology and engineering. The S&T Program supports the LCA Ecosystem Restoration Plan by:
    1. Providing the necessary science and technology to effectively address coastal ecosystem restoration needs

2. Providing analytical tools and recommendations to the Program Management Team for appropriate studies to reduce uncertainties
3. Integrating the roles and resources of the scientific community and other coastal protection agencies and partners at the state, local, and Federal level
4. Providing for internal and external technical review and a systematic approach for coordination with other ongoing and planned related research activities

- In 1990, passage of the **Coastal Wetlands Planning, Protection and Restoration Act** (CWPPRA; PL-101-646, Title 111), locally referred to as the Breaux Act, provided authorization and funding for a multi-agency task force to begin actions to curtail wetland losses. In 1998, after extensive studies and construction of a number of coastal restoration projects accomplished under CWPPRA, the State of Louisiana and the Federal agencies charged with restoring and protecting the remainder of Louisiana's valuable coastal wetlands adopted a new coastal restoration plan in 1998. The underlying principles of the new plan, "Coast 2050: Toward a Sustainable Coastal Louisiana," are to restore and mimic the natural processes that built and maintained coastal Louisiana. This plan necessitates basin-scale action to restore more natural hydrology and sediment introduction processes; it subdivides Louisiana's coastal zone into four regions with a total of nine hydrologic basins. The plan proposes ecosystem restoration strategies that would result in efforts larger in scale than any that have been implemented in the past.

  The Coast 2050 Plan report served as the basis for a Federal 905(b) Reconnaissance Report for undertaking feasibility studies in 2000 to seek Water Resources Development Act approval of a comprehensive plan and authorization of major projects beyond what was being pursued under CWPPRA. In 2000, it was envisioned that a series of feasibility reports would be prepared over a 10-year period. The first feasibility efforts focused on the Barataria Bay basin and involved marsh creation and barrier shoreline restoration. Early in fiscal year 2002, however, it was recognized that a more in-depth, comprehensive study was needed.

- The State of Louisiana also is a **Coastal Impact Assistance Program (CIAP)** was established by Section 384 of the Energy Policy Act of 2005 (Act) to assist producing states and their coastal political subdivisions in mitigating the impacts from Outer Continental Shelf (OCS) oil and gas production. The CIAP legislation appropriated $250 million per year for Fiscal Years 2007 through 2010 to be distributed among eligible producing States and their coastal political subdivisions. The State of Louisiana has worked cooperatively with the 19 coastal parishes to assemble a group of restoration, conservation and infrastructure projects that will produce significant results. The Plan components include the following major categories: Enhanced Management of Mississippi River Water and Sediment; Protection and Restoration of Critical Land Bridges; Barrier Shoreline Restoration and Protections; Interior Shoreline Protection; Marsh Creation with Dredged Material; Coastal Forest Conservation Initiatives; Infrastructure Projects to Mitigate Onshore OCS Impacts;

CONCEPTUAL ECOLOGICAL MODEL

Thom (2000) proposed that conceptual ecological models (CEM) are a key component of an adaptive management program associated with coastal ecosystem restoration projects and recommended them for planning projects, evaluating the effectiveness of the restoration, providing guidance on adjustments to improve projects success, and refining the understanding of the ecosystem being restored. CEMs are non-quantitative planning tools that can be used to identify major stressors on an ecosystem, the effects of those stressors, and the best way to measure those effects (Ogden et al. 2005:795-809). The objective of a CEM is to contribute to the determination of what needs to be restored, why, and perhaps where the restoration might be most effective. The CEM is used to identify the connection (cause-and-effect relationships) between the restoration actions (e.g., physical manipulations) and the physical and biological reactions to such actions, based on the best available information on qualitative and conceptual relationships (Barnes and Mazzotti 2005; Ogden et al. 2005:955-979)

Considerable scientific research into the form, function and change of the Louisiana coastline preceded the LACPR, and served as a basis for the formulation of the conceptual model for the LACPR. The HET formulated a CEM for coastal Louisiana on the basis of discussions during a series of meetings. The model is based upon widely-held views of the structure and function of the coastal ecosystem, and is supported by numerous technical publications, field studies, and the experience of the HET members. The following sections describe the model, including the scale, key processes and features, external drivers and stressors. The relationship between proposed restoration actions and ecosystem response is discussed in detail in later sections.

Geographic Scale

Louisiana's coastal wetland ecosystem is an interface between the Gulf of Mexico and the Mississippi River ecosystems. The Mississippi River drains 41% of the continental U.S. and brings nutrient- and sediment-rich runoff from 31 states and two Canadian provinces through Louisiana's coastal zone and into the Gulf of Mexico. While the Mississippi River, and its distributary the Atchafalaya River, is perhaps the most significant factor influencing the character of Louisiana's coast, other smaller rivers and streams supply nutrients and minerals to the coastal wetlands. Those upland and/or riverine inputs are reworked and distributed by marine processes of the Gulf of Mexico. Together with local climatological processes, they create the ever shifting landscape that is coastal Louisiana.

The central and eastern Louisiana coast consists of a deltaic system with fronting barrier islands built by the Mississippi River. Louisiana's western coast, or Chenier Plain, is a geologically distinct region formed through the deposition of littoral Mississippi River sediment along the shallow Gulf shoreline. Because the natural processes that occur in each planning unit differ, restoration plans for those respective areas will also differ. In order to have more manageable units for development of measures and alternative plans, as well as to present a more appropriate scale for analysis, the deltaic province is further divided into its four distinct hydrologic basins. As a consequence of these divisions, the planning area has been divided into five planning units, as follows:

- **Planning Unit #1:** Pontchartrain Basin (area east of the Mississippi River and South Pass)
- **Planning Unit #2:** Barataria Basin (from the Mississippi River and South Pass, west to Bayou Lafourche)
- **Planning Unit #3a:** Eastern Terrebonne Basin (from Bayou Lafourche west to Bayou de West)
- **Planning Unit #3b:** Atchafalaya Influence Area (from Bayou de West to Freshwater Bayou Canal)
- **Planning Unit #4:** Chenier Plain (from Freshwater Bayou Canal to the Sabine River)

Key Processes

An estuary and its immediate catchment form a complex system of ecological, physical, chemical and social processes, which interact in a highly involved and, at times, dynamic fashion. The distribution and abundance of wetland habitats in the Deltaic Plain has been, and continues to be, in constant flux — a function of the differing salinity gradients that occur during the land building and degradation phases of the deltaic processes as well as the myriad other key processes that influence wetland and estuarine conditions. The following sections summarize the key processes involved in this ecosystem.

Deltaic Processes

The 186 mile wide (300 km) Mississippi River delta plain and its associated wetlands and barrier shorelines are the product of the continuous accumulation of sediments deposited by the river and its distributaries during the past 7,000 years. Regular shifts in the river's course have resulted in four ancestral and two active delta lobes, which accumulated as overlapping, stacked sequences of unconsolidated sands and muds. As each delta lobe was abandoned by the river, its main source of sediment, the deltas experienced erosion and degradation due to compaction of loose sediment, rise in relative sea level, and catastrophic storms. Marine coastal processes eroded and reworked the seaward margins of the deltas forming sandy headlands and barrier beaches. As erosion and degradation continued, segmented low-relief barrier islands formed and eventually were separated from the mainland by shallow bays and lagoons.

The result of the building and subsequent abandonment of these delta lobes by the river was the construction of a modern deltaic Coastal Plain. Each delta cycle lasts about 1,000 years, and the most recent delta (the Mississippi birdfoot) is approaching the end of that time scale. The natural progression of this process is for a new distributary, the Atchafalaya River, to draw increasing portions of the Mississippi River's water and sediment discharge forming a new Atchafalaya delta. These processes are discussed in detail in the LCA (2004) report.

Marine Processes

Water fluxes in the coastal marshes are driven by the water-level differences across the estuary. These change over the long term, seasonally, and daily. Long-term rises in sea level have been documented by many investigators, and recently average about .04 to .08 inches (1 to 2 millimeters) per year, but are projected to increase due to climate change (Titus and Richman 2001). Superimposed on this long-term trend is a mean water level that varies seasonally by .79 to .98 inches (200 to 250 millmeters), with peaks in the spring and late summer. Part of this seasonal variation is related to the dominant variable wind regime over the Gulf of Mexico; east and southeast winds in spring and fall move water toward the shore whereas westerly winds strengthen the Mexican Current and draw a return flow of water from the estuaries during winter and summer (Baumann 1980). Superimposed on the seasonal water level change is a diurnal tide, which averages about 11.81 inches (300 millimeters) at the coast. Because of the broad, shallow expanse of the coastal estuaries, the tides decrease inland.

These marine processes serve to redistribute sediments and nutrients, as well as regulate salinity levels and fluxes in the estuaries. Large, episodic storms can significantly alter the landscape developed as a consequence of the more normal marine processes. Tropical storm events can directly and indirectly contribute to coastal land loss through a variety of ways: erosion from increased wave energies, removal and/or scouring of vegetation from storm surges, and saltwater intrusion into interior wetlands carried by storm surges. These destructive processes can result in the loss and degradation of large areas of coastal habitats in a relatively short period of time (days and weeks versus years).

Fluvial Processes

The largest source of fresh water and sediment to the Louisiana coast is the Mississippi River and its major distributary, the Atchafalaya River. Other, smaller rivers contribute additional water and sediments from local watersheds. Flow is strongly seasonal, peaking in late spring, fed by melting snow and spring rains in the Upper Mississippi watershed. Flows on the Mississippi River are independent of local rainfall because of the size of the watershed, but fresh water and sediment from local rivers and streams along the coast is supplied mainly during periods of heavy local rainfall.

The inactive delta of the Mississippi River (the part that has been abandoned by the river) is isolated from direct riverine input by natural and artificial levees. The Mississippi and Atchafalaya rivers discharge into the Gulf of Mexico through the active Balize and Atchafalaya delta lobes. Most of their waters are carried westward along the coast, freshening the Gulf waters that move in and out of the Barataria, Terrebonne, and Vermilion estuaries. Thus, although these three estuaries have almost no direct freshwater inflow except from local runoff, the rain surplus and the moderated salinities offshore keep estuarine salinities much lower than that of seawater.

Chemical Processes

Elements and compounds can enter tidal wetlands by tidal exchange, precipitation, upland runoff, and groundwater flow. Once in the wetlands, they may be deposited on water bottoms, adsorbed to particles, or taken up and fixed in the tissues of rapidly growing vascular plants. These substances may be incorporated or otherwise transformed by microbial assemblages associated with the complex of surfaces provided by the sediment, live plants, litter, and detritus.

This conceptual model considers primarily exchanges and transformation of elements and compounds mediated by surface water flows from both tidal and upland sources. The potential for groundwater input is not specifically addressed, since nutrient exchange in marshes characterized by tidal ranges of less than 3.3 feet (1 meter) occurs primarily within marsh surface waters (Childers et al. 1993). Because tidal amplitude along the north-central Gulf of Mexico region is low (~ 1.64 feet (0.5 meters)), and larger tidal ranges are associated only with infrequent meteorological events, it is assumed that subsurface water exchanges can be ignored for regional applications.

Odum (1974) proposed that nutrient inputs via tidal waters were important in maintaining the characteristic high productivity of *S. alterniflora* in creekside salt marshes. This occurs as a result of direct infiltration of nutrient-laden surface waters, horizontal recharge driven by rise and fall of the tide and vertical recharge from below the root zone. Salt marsh vegetation is primarily nitrogen limited, with ammonium nitrogen being the form most readily available in interstitial waters for uptake by plant roots. Phosphorus is abundant in saline waters and marsh soils, and is generally not considered a limiting nutrient in salt or brackish marsh systems. Numerous studies have attributed variation in *S. alterniflora* growth form to gradients in chemical and physical characteristics of tidal marshes, including nutrient availability (Valiela and Teal 1974, Broome et al. 1975; DeLaune and Pezeshki 1988). This is particularly true for developing or restored salt marshes. Other workers suggest that, in mature marshes, edaphic factors affecting nutrient uptake are the primary determinants of *Spartina* growth form. Variables known to stress plants (high soil salinity and sulfide concentrations, waterlogging, low dissolved oxygen) reduce the uptake efficiency of nitrogen at the root-pore water interface, especially when multiple stressors are present.

Biogeochemical processes within the wetland are also affected by offsite inputs from the surrounding drainage area. Eutrophication caused by anthropogenic nutrient enrichment of coastal ecosystems has been a major concern for resource managers for the last few decades. The effects of nutrient enrichment include stimulation of primary production by algae and phytoplankton and depletion of oxygen, which can lead to hypoxia (a deficiency of oxygen while not being devoid of oxygen) (Deegan 2002). Nutrient enrichment can also cause shifts in plant species distribution and zonation in mixed species tidal wetlands, resulting in increased dominance of *S. alterniflora* at the expense of other tidal marsh species (Pennings et al. 2002).

Recent research has shown that anthropogenic eutrophication may cause shifts in benthic invertebrate and fish community food webs that are manifested long before actual loss of the habitat occurs (Deegan 2002). Furthermore, the cumulative effects of nutrient enrichment on a landscape scale may cause increased or decreased rates of subsidence, although these predictions have not yet been tested (Deegan 2002). Highly developed or industrial watersheds may also serve as sources of metals, hydrocarbons, and other toxins that is deposited in wetland sediments, posing risks for benthic organisms that inhabit them. As predators consume these organisms, food web dynamics may be altered through accumulation of toxins in the tissues of higher trophic level organisms. The accumulation of toxins in animal tissues may reduce growth and fecundity (or productivity), and may render them unsuitable for consumption as food.

Biological Processes

Coastal fringe marshes provide habitat for a variety of vertebrate wildlife including fish, birds, mammals, and reptiles. Teal (1986) stated that one of the most important functions of salt marshes is to provide habitat for migrant and resident bird populations. Some wildlife species inhabiting tidal marshes are important game animals (e.g., mallard (*Anas platyrhynchos*) and American wigeon (*A. americana*)), whereas the muskrat (*Ondatra zibethicus*) and raccoon (*Procyon lotor*) are valuable furbearers. The American alligator (*Alligator mississippiensis*) is harvested for both its skin and meat. Many of the birds that commonly use coastal fringe wetlands, especially larger species such as ospreys, herons, egrets, and Roseate Spoonbills (*Ajaia ajaia*) provide recreational opportunities for birdwatchers, nature enthusiasts, and wildlife photographers.

The majority of wildlife species that utilize the subclass have neither commercial nor recreational value, but simply are ecologically important members of the ecosystem. For example, the rice rat (*Oryzomys palustris*) and other small mammals play a key role in marsh trophic cycles, providing food for several species of avian and mammalian predators. Many of the vertebrates that use the marsh ecosystem are highly mobile and serve as a transfer mechanism for nutrients and energy to adjacent terrestrial or aquatic ecosystems. Some of the larger vertebrates, including the muskrat and nutria (*Myocastor coypus*), consume copious amounts of forage and at high densities may have significant impacts on marsh vegetation structure.

Tidal marshes provide forage habitat, spawning sites, and a predation refuge, and serve as a nursery for resident and nonresident fishes and macrocrustaceans. These organisms use tidal marshes or adjacent subtidal shallows either year round or during a portion of their life history as nurseries. A number of ecologically and economically important nekton species are dependent on the availability of suitable tidal marsh habitat. Estuarine-dependent species such as the penaeid shrimp (*Farfantepenaeus* spp., *Litopenaeus* spp.), the blue crab (*Callinectes sapidus*), the sciaenids (*Cynoscion* spp., *Sciaenops ocellatus*, *Leiostomus xanthurus*, *Micropogonias undulatus*, and *Bairdiella chrysoura*, etc.), and others use tidal marshes and shallow, subtidal bottoms as nurseries. The ubiquitous killifishes (*Fundulus* spp.), grass shrimp (*Palaemonetes* spp.), and gobies (*Gobiosoma* spp., *Gobionellus* spp., *Microgobius* spp., etc.) are characteristic residents of Atlantic and Gulf coast intertidal wetlands. These organisms are consumed by nektonic and avian predators and are considered to represent an important link in marsh-estuarine trophic dynamics.

Most evidence suggests that resident organisms (e.g., killifishes, grass shrimps) utilize the entire marsh surface across the range from low to high elevations, but that the dense vegetation characteristic of high marsh habitats may offer greater protection from natant predators than low marshes. However, resident nekton are also widely distributed throughout the lower intertidal marsh early and late in the tidal cycle in Louisiana and Mississippi (Rozas and Reed 1993, Fulling et al. 1999, Hendon et al. 2000), and may use these areas as staging areas prior to marsh flooding. Resident nekton can make extensive use of high marsh when spring tide conditions facilitate access to the upper intertidal zone. Several resident killifish species, including *Fundulus grandis, F. similis, F. pulverus*, and *Adinia xenica,* rely on availability of high intertidal marsh, coincident with spring tidal events, for use as spawning sites (Greeley and

MacGregor 1983, Greeley 1984, Greeley et al. 1986, Greeley et al. 1988). Killifishes also use tidal marshes for foraging sites; as Rozas and LaSalle (1990) noted, the Gulf killifish (*F. grandis*) consumed more prey when they had access to the marsh surface than when they were confined to subtidal areas by low tides.

Key Landscape Features

Barrier Islands

Barrier islands fronting the Mississippi River delta plain act as a buffer to reduce the effects of ocean waves and currents on associated estuaries and wetlands. Louisiana's barrier islands are eroding, however, at a rate of up to 20 meters per year; so fast that, according to recent USGS estimates, several will disappear by the end of the century. As the barrier islands disintegrate, the vast system of sheltered wetlands along Louisiana's delta plains are exposed to the full force and effects of open marine processes such as wave action, salinity intrusion, storm surge, tidal currents, and sediment transport that combine to accelerate wetlands deterioration.

Coastal Ridges and Cheniers

Natural levees of major and minor distributaries that diverge from larger distributaries as they trend toward the coast, and cheniers (elevated inland ridges) that run parallel to the coast, are key landscape features in Coastal Louisiana. Deposits of mostly linear dredged material that crisscross the coast may be included in this category if they mimic natural levees. These features do not encompass a large area compared with the coastal marshes, but in coastal basins they play an important ecological role through their function as barriers between the ocean and the estuary and as water regime barriers within an estuary and because they present the only elevated, sometimes forested land within a plain of wetland and water. They provide periodic or continuous habitat for nearly all mammals and birds in the coastal zone.

Wetlands

The vegetation mosaic in a given locale is primarily a function of climate, soil type, and suitable water conditions, including depth of water table, length and frequency of inundation, flow, and water quality. These plant communities, in turn, provide food and/or habitat for wildlife. Thus, changes in distribution, abundance, and species composition of plant communities have a direct effect upon type and quality of associated animal communities (Sharitz and Gibbons 1989). Habitat loss directly impacts availability of resources required by organisms that use these areas. However, distribution of these habitats across the landscape is even more important because few organisms use only one habitat type, particularly in a seasonally fluctuating landscape.

Since the source of salinity in coastal Louisiana is the Gulf of Mexico, salinity levels exist along a gradient, which declines as the saltwater moves inland. A distinct zonation of plant communities, or vegetative habitat types, differing in salinity tolerance exists along that gradient, with the species diversity of those zones increasing from salt to fresh environments. The dominant vegetative habitats with increasing distance from the coast are salt, brackish, intermediate, and freshwater organic marshes, swamp and bottomland hardwood communities.

Chabreck et al. (1968), Chabreck (1970, 1972), and later, Chabreck and Linscombe (1978, 1988) and Chabreck et al. (2001), subdivided and mapped Louisiana coastal wetlands into four marsh zones on the basis of Penfound and Hathaway's (1938) and O'Neil's (1949) descriptions of the major vegetation types within salinity zones. This classification of marsh vegetation is widely recognized and often used in broadly describing coastal wetlands. Transition between adjacent zones is typically found to be an intergrading of communities rather than appearing as an abrupt change from one community to another (Penfound & Hathaway, 1938; Craig et al, 1987). The four marsh vegetation types are fresh, intermediate, brackish, and saline, and occur in zones that generally parallel the coast (figure 1). Coast wide, the range of salinity within each of these vegetation zones can vary drastically; however, as shown in the Coast 2050 Report (LADNR, 1998), the typical ranges of salinity that occur most frequently are much more narrow (table 1**).**

Table 1
Salinity ranges for the four coastal wetland types as reported by Chabreck (1972)

Marsh Type	Range (ppt)	Mean (ppt)	Typical Range (ppt)
Fresh	0.1 - 6.7	<3.0	0 – 3
Intermediate	0.4 - 9.9	3.3	2 – 5
Brackish	0.4 - 28.1	8.0	4 – 15
Saline	0.6 - 51.9	16.0	12+

(From Chabreck 1972 and Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998)

In a coastwide survey, Chabreck (1972) recorded a total of 118 species of vascular plants in all marsh types. The species found in the greatest abundance overall was marshhay cordgrass (*Spartina patens*), making up about one-fourth of the vegetation in the coastal marshes.

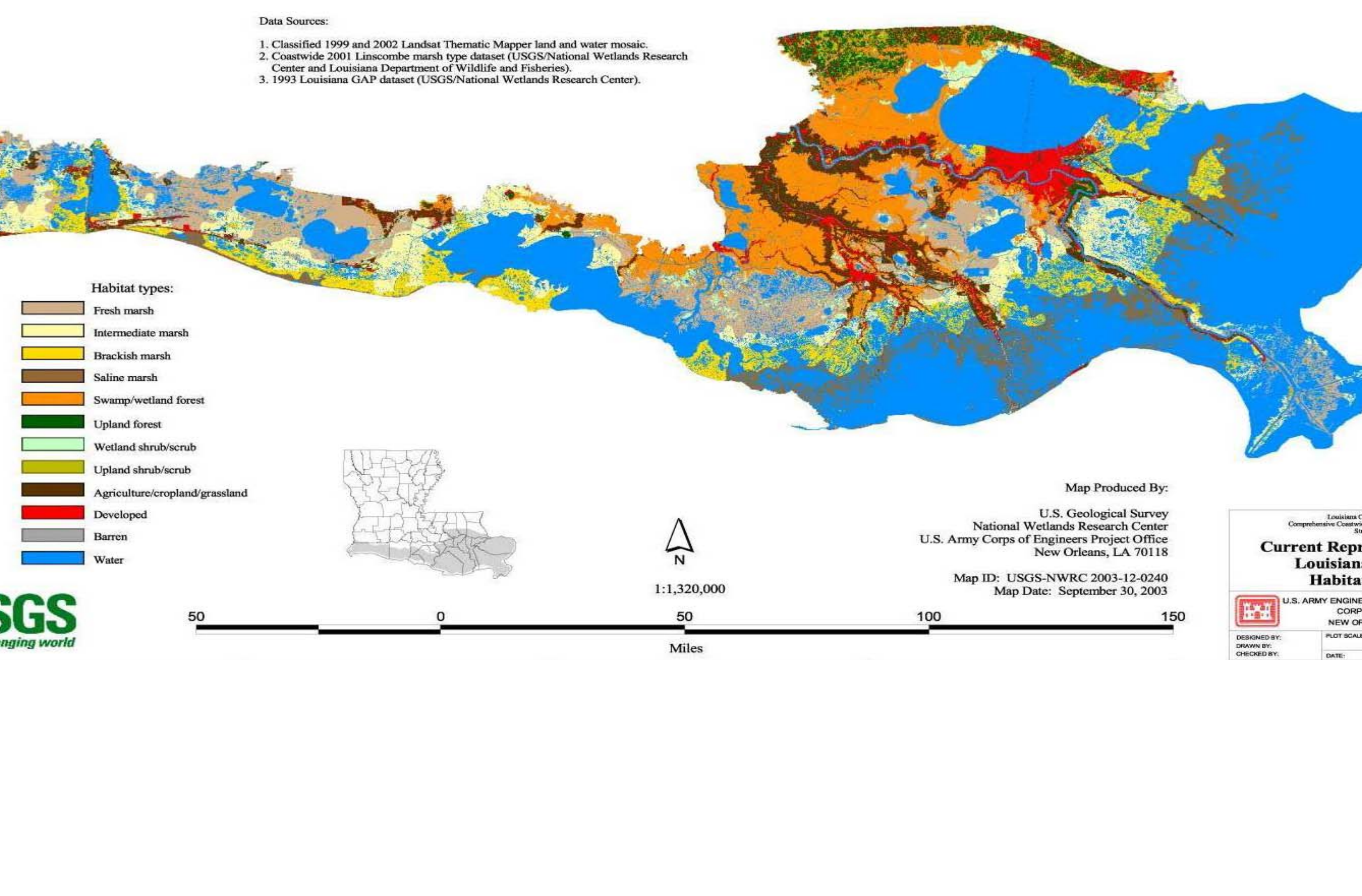
Saline marsh.
Nearest the coast and subjected to regular tidal inundation is salt marsh. Smooth cordgrass *(Spartina alterniflora)* the dominant plant in this marsh type, and often forms near-monotypic stands. Average salinity is approximately 16 parts per thousand (ppt). Relative to other marsh types, salt marsh typically supports fewer terrestrial vertebrates although some species like Seaside Sparrows and Clapper Rails are common.

Saline marshes are typically located adjacent to open water bodies such as bays and estuaries. Their salinity levels are the highest, usually falling in the mesohaline (5.0 - 18 ppt) [1] or polyhaline (18 - 30 ppt) [2] range. Herbaceous vegetation of the saline marsh is typically dominated by smooth cordgrass intermixed with saltgrass (*Distichlis spicata*), marshhay cordgrass, black needlerush (*Juncus roemerianus*), and saltwort (*Batis maritima*). Chabreck (1972) identified 12 species of emergent vegetation typically associated with this marsh type. Within the described marsh zones, many ponds and lakes support submerged and/or floating-leafed aquatic vegetation (SAV). Aquatic vegetation is rare in saline waters along the Louisiana coast (Chabreck, 1972; Chabreck et al., 2001). However, widgeon grass (*Ruppia maritima*) may occur in open water areas of saline marshes bordering on the brackish marsh zone and in saline areas where tidal flow has been decreased by structures or other changes in hydrology. In addition, submerged seagrass beds have occurred in waters behind some barrier islands,

[2] Classification of Wetlands and Deepwater Habitats of the United States FWS/OBS-79/31, DECEMBER 1979, Reprinted 1992

especially the Chandeleur Island chain. Seagrass species occurring in this area included shoal grass (*Halodule beaudettei*), turtle grass (*Thalassia testudina*), and manatee grass (*Cymodocea filiformis*) (Craig, 1987). These communities however have been severely impacted with the barrier island degradation.

Current Representation of Louisiana Coastal Habitat Types



Brackish marsh.

Inland from salt marsh, and subjected to reduced tidal influence, is brackish marsh. This marsh type is dominated by marsh-hay cordgrass, which grows in a relatively open condition, interspersed with numerous small ponds and water channels. Brackish marshes are extremely important as nurseries for fish and shellfish. Other characteristic species include muskrat and shorebirds. This marsh type is very susceptible to saltwater intrusion damage and conversion to open water.

Brackish marshes generally occur in association with freshwater input from coastal rivers and bayous. Salinity levels are usually within the mesohaline or oligohaline (0.5 – 5.0 ppt)[1] range and average salinity is in the range of 8 ppt. In the brackish marsh, marshhay cordgrass is the dominant herbaceous species. Saltgrass, three-cornered grass (*Schoenoplectus americanus*, formerly *Scirpus olneyi*), smooth cordgrass, black needlerush, and leafy three-square (*Schoenoplectus maritimus* formerly *Scirpus maritimus*) are often co-dominant or common in this zone. It should be noted that some of the species are the same as for saline marsh, but the order of dominance is changed. Chabreck (1972) identified forty species of plants in brackish marsh. Aquatic plants that commonly occur in brackish marsh waters include widgeon grass, Eurasian watermilfoil (*Myriophyllum spicatum*), water celery (*Vallisneria americana*), and horned pondweed (*Zannichellia palustris*) (Craig, 1987).

Intermediate marsh.

Intermediate marsh occurs in an oligohaline salinity range with year-round average salinities of 3-4 parts per thousand (ppt); but may be fresh for much of the year with higher salinity conditions occurring during the late summer and early fall. Intermediate marshes are characterized by near total ground cover of emergent wetland plants with scattered small open water ponds. Chabreck's (1972) identification of 54 species of plants in intermediate marsh indicates that plant species richness is relatively high. The intermediate marsh can be difficult to identify, as it sometimes may appear less as a distinct zone than a transitional mix between brackish and fresh zones. Marshhay cordgrass or bulltongue (*Sagittaria lancifolia*) is usually the dominant or co-dominant species. These are commonly accompanied by three-cornered grass, roseau or common reed (*Phragmites australis*), seashore paspalum (*Paspalum vaginatum*), coastal waterhyssop (*Bacopa monnieri*), bullwhip (*Schoenoplectus californicus* formerly *Scirpus californicus*), Walter's millet (*Echinochloa walteri*), sawgrass (*Cladium jamaicense*), deer pea (*Vigna luteola*), rush (*Eleocharis sp.*), dwarf spikerush (*Eleocharis parvula*), and fragrant flatsedge (*Cyperus odoratus*). Aquatic plant species found in intermediate marsh waters include widgeongrass, Eurasian watermilfoil, water celery, and southern naiad (*Najas guadalupensis*). Intermediate marshes are considered extremely important for many wildlife species, such as alligators and wading birds, and serve as important nursery areas for larval marine organisms. Although still a common natural community type in Louisiana, intermediate marsh appears to be declining in aerial extent, which has been attributed to a shift toward brackish marsh due to increased salinity levels.

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[1] Classification of Wetlands and Deepwater Habitats of the United States FWS/OBS-79/31, DECEMBER 1979, Reprinted 1992

<u>Fresh water marsh.</u>
Freshwater marshes are quite heterogeneous, with local species composition governed by frequency and duration of flooding, micro-topography, substrate, current flow and salinity. This marsh type is typically dominated by maidencane, bulltongue, spikerushes, pennywort (*Hydrocotyle* sp.), Elephant-ear (*Colocasia esculenta*) and alligatorweed (*Alternanthera philoxeroides*). Other common plants are bullwhip, giant cutgrass (*Zizaniopsis miliacea*), fourchette (*Bidens laevis*) and cattail (*Typha* sp.). Fresh marshes are often very diverse with different species of grasses and broad-leaved annuals waxing and waning throughout the growing season. Chabreck (1972) documented 93 species of plants occurring in the fresh marshes of coastal Louisiana. Some fresh marshes, on the other hand, consist of nearly pure stands of maidencane. Aquatic plants commonly found in fresh marsh waters are duckweed (*Lemna minor*), coontail (*Ceratophyllum demersum*), Eurasian watermilfoil, southern naiad, water hyacinth (*Eichornia crassipes*), pondweeds (*Potamogeton* spp.), white waterlily (*Nymphaea odorata*), elodea (*Elodea canadensis*), hydrilla (*Hydrilla verticillata*), water celery, water shield (*Brasenia shreberi*), fanwort (*Cabomba caroliniana*), and American lotus (*Nelumbo lutea*). Fresh marsh salinity rarely increases above 2 ppt, with a year-round average of approximately 0.5-1 ppt. Freshwater marshes support extremely high densities of wildlife, such as migratory waterfowl. However, because of saltwater intrusion, freshwater marshes have undergone the largest rate of reduction in acreage of any of the marsh types in Louisiana over the past few decades.

The primary focus of Chabreck's (1972) and Chabreck and Linscombe's (1978, 1988, 2001) classification is the vegetative species of the natural marshes and interior water bodies of the coastal area. However, it is important to recognize that within or adjacent to those broadly delineated zones of marsh habitat types, other wetland areas with distinctive surface features and vegetative communities occur in association with the marshes. These include swamp and wetland forest, scrub/shrub, beach/barrier island, upland and other habitat. The following are descriptions of other major habitat types that compose and illustrate the diversity of the LCA (Ecosystem Restoration Study, Volume 2: Programmatic Environmental Impact Statement, November 2004).

<u>Wetland Forests</u>
Of the wetland forests in the Study area, the three major communities are swamp forest, bottomland forest, and wet pine flatwood forest. Cypress and cypress-tupelo swamp contains a mixture of bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), and swamp red maple (*Acer rubrum* var. *drummondii*) along with various understory plant species (Craig et al., 1987). Swamps with fairly open canopies sometimes support fresh marsh and scrub/shrub species as groundcover. Very often the water surface in cypress-tupelo swamps is covered by common duckweed, alligatorweed, and sometimes water hyacinth. Coastal swamp forests generally occupy the area between fresh marshes and developed areas of higher elevation. Bald cypress may occur in the upper end of interdistributary basins provided freshwater conditions are maintained year round. Cypress swamps may also border interdistributary ridges as a transition zone from higher elevation bottomland hardwood forests to lower elevation marshes. Healthy cypress

swamps occur only in fresh water areas experiencing minimal daily tidal action and where the salinity range does not normally exceed 2 ppt. Salinities of 3 ppt or higher may cause significant stress and mortality of cypress. However, short-term exposure to such salinities may be tolerated if the salts do not penetrate into and persist in the soil.

The bottomland hardwood forests and wet pine flatwoods occur only in fresh areas. Bottomland hardwood forests exist primarily in broad floodplains and distributary ridges of the Atchafalaya River and on the distributary ridges of the Mississippi River. Common tree species include sugarberry (*Celtis laevigata*), water oak (*Quercus nigra*), live oak (*Quercus virginiana*), nuttall oak (*Quercus nuttallii*), overcup oak (*Quercus lyrata*), bitter pecan (*Carya aquatica*), black willow (*Salix nigra*), American elm (*Ulmus americana*), swamp red maple, box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), and bald cypress (Craig et al., 1987).

Wet pine flatwoods are generally found on poorly drained flats and depressional areas in the "Florida Parishes" (Smith 1996). Common tree species include slash pine (*Pinus elliottii*), longleaf pine (*Pinus palustris*), water oak, laurel oak (*Quercus laurifolia*), sweet bay (*Magnolia virginiana*), and sweetgum (*Liquidambar styraciflua*). Wet pine flatwoods also contain a very diverse herbaceous community that can include many state rare species, and within in the coastal area, may include the threatened and endangered species Louisiana quillwort (*Isoetes louisianensis*).

Upland Forests

The three major communities of upland forest in the coastal area include chenier/maritime forest, mixed hardwood forest, and mixed pine-hardwood forest (Craig et al., 1987). Chenier/maritime forest occurs on abandoned beach ridges composed primarily of sand and shell. Common tree species include live oak, sugarberry, swamp red maple, sweetgum, and water oak. Red mulberry (*Morus rubra*), toothache-tree (*Zanthoxylum clava-herculis*), and sweet acacia (*Acacia farnesiana*) also occur on these elevated platforms. These ancient beaches were stranded behind prograding shorelines built during periods of sedimentation fed by the Mississippi River.

Mixed hardwood forest occurs adjacent to small stream floodplains in uplands protected from fire; common tree species include American beech (*Fagus grandifolia*), southern magnolia (*Magnolia grandiflora*), white oak (*Quercus alba*), Shumard oak (*Quercus shumardii*), sweetgum, and swamp white oak (*Quercus michauxii*).

Mixed pine-hardwood forest occurs on moist sites in the upper coastal area; common tree species include loblolly pine (*Pinus taeda*), sweetbay, southern magnolia, and red bay (*Persea borbonia*).

Scrub-Shrub

Scrub-shrub habitat is found along bayou ridges and on dredged material embankments, and is typically bordered by marsh at lower elevations, and by cypress-tupelo swamp or bottomland hardwoods (in fresh areas) or developed areas at higher elevations. Scrub-shrub communities are found throughout the coastal wetlands with their dominant species and community composition associated with the respective habitat type with which it occurs.

Scrub-shrub communities occurring in saline habitat include those dominated by black mangrove (*Avicennia germinans*) on flooded saltmarsh edges and barrier islands, or by marsh elder (*Iva frutescens*) and eastern baccharis (*Baccharis halimifolia*) on low ridges, bayou banks, and spoilbanks and other disturbed areas. Brackish scrub-shrub wetlands are also dominated by eastern baccharis and marsh elder, although wax myrtle (*Morella cerifera*, formerly *Myrica cerifera*) is common on low ridges, bayousides, and spoilbanks as well. Typical scrub-shrub vegetation in intermediate and fresh areas includes elderberry (*Sambucus canadensis*), wax myrtle, buttonbush (*Cephalanthus occidentalis*), rattlebox (*Sesbania drummondii*), Drummond red maple (*Acer rubrum var. drummondii*), Chinese tallowtree, marsh elder, and eastern baccharis. Dwarf palmetto (*Sabal minor*) and prickly pear cactus (*Opuntia spp*.) are common in the understory of Chenier/maritime forest. Yaupon (*Ilex vomitoria*), dwarf palmetto, swamp privet (*Forestiera acuminata*) and Virginia willow (*Itea virginica*) also occur in thickets and the understory of swamps and bottomland hardwood forests.

Other Wetland Communities

Other less well-known unique wetland communities found within the above habitat types in this ecoregion include barrier island communities, maritime forests, floating marsh/scrub, and submergent estuarine vascular vegetation (SAV). SAV communities are extremely important breeding areas for many fish species and support tremendous numbers of wintering diving ducks. SAV is a critical food source for many species and foraging and hiding ground for others. It provides habitat for myriad animals, including juveniles of many commercially and recreationally valuable species. Aquatic species affect water quality through nutrient uptake and storage, binding of sediments by their roots, and trapping of particles within their leaf canopy. With growth of lush aquatic vegetation, these mechanisms drive the area towards a condition of clear water, lowering nutrients for algae growth and concentrations of suspended sediment in the water column. SAV requires sunlight to photosynthesize, thus murky water caused by silt, turbidity, color, or phytoplankton is stressful. SAV is intolerant of changes in salinity, toxicity, and water clarity and can be used to document changes within the ecosystem.

Streams and Rivers

The Deltaic and Chenier Plains contain all or part of ten hydrologic regions including Pontchartrain, Pearl, Breton Sound, Barataria, Terrebonne, Atchafalaya, Teche/Vermilion, Mermentau, and Calcasieu/Sabine basins and the Mississippi River Delta. Each of these is influenced to varying degrees by the timing, magnitude, duration and frequency of freshwater inflows from streams and rivers, and the nutrients and sediments associated with those inflows.

The Mississippi River and its distributaries historically provided immense volumes of land-building sediment and nutrients throughout Louisiana’s coastal areas. For the last several thousand years, the dominance of the land building or deltaic processes resulted in a net increase of more than four million acres of coastal wetlands. In addition, there was the creation of an extensive skeleton of higher natural levee ridges along the past and present Mississippi River channels, distributaries, and bayous in the Deltaic Plain and beach ridges of the Chenier Plain.

The Mississippi River has an annual average flow rate of 495,000 cubic feet per second (cfs) (14,000 cubic meters per second) and a freshwater discharge onto the continental shelf of 470,000,000 acre feet (580 cubic kilometers) per year. Today, most of the Mississippi River's fresh water, with its nutrients and sediment, flows directly into the Gulf of Mexico, largely bypassing the coastal wetlands. Deprived of landbuilding sediment, the wetlands are damaged by saltwater intrusion and other causative factors associated with relative sea level change and land subsidence, and will eventually convert to open water as the plants that define the surface of the coastal wetlands die off. Once the coastal wetlands are denuded of vegetation, the fragile substrate is left exposed to the erosive forces of waves and currents, especially during tropical storm events.

There are 10 major navigation channels, both deep draft and shallow draft, within the Louisiana coastal area. While these channels support the local, regional, and National economies, they also serve as conduits for saltwater intrusion in some areas and barriers to the distribution of freshwater, sediment, and nutrients to wetland habitats in other areas.

Canals

A vast network of canals, pipelines, and production facilities has been created to service the oil industry. Canals that stretch from the Gulf of Mexico inland to freshwater areas allow saltwater to penetrate much farther inland, particularly during droughts and storms, which has had severe effects on freshwater wetlands. Dredged material banks, which are much higher than the natural marsh surface, and the many smaller canals dredged for oil and gas exploration, alter the flow of water across wetlands. This hydrological alteration changes important hydrogeomorphic, biogeochemical, and ecological processes, including chemical transformations, sediment transport, vegetation health, and migration of organisms.

Because of the presence of dredged material banks, partially impounded areas have fewer but longer periods of flooding and reduced water exchange when compared to unimpounded marshes (Swenson and Turner 1987). This results in increased waterlogging and frequently in plant death. Importantly, dredged material banks also block the movement of sediment resuspended in storms, which play a major role in sustaining land elevations (Reed et al. 1997). By altering salinity gradients and patterns of water and sediment flow through marshes, canal dredging, which mostly occurred between 1950 and 1980, not only directly changed land to open water, but also indirectly changed the processes essential to a healthy coastal ecosystem. Elevated dredged material embankments may provide important wildlife refugia during storm events and valuable habitat for neotropical migratory birds, and the value of this habitat should be considered as restoration of these areas occurs (LCA 2004).

External Drivers

The combination of subsidence and sea level rise is an important non-societal driver affecting coastal features, and will act independently of other societal-driven stressors. Subsidence and sea-level rise are likely to cause the landward movement of marine conditions into estuaries and coastal wetlands (Day and Templet 1989, Reid and Trexler 1992). Societal-driven external drivers in coastal Louisiana include water management, land use and development, levees, locks/dams and navigation. Water management practices, including modification of river discharge, have resulted in drastic modifications to estuarine ecosystems (LCA 2004). These changes have caused large fluctuations in the location, volume, timing, and frequency of freshwater and sediment inflow to the ecosystem and, in turn, have had an impact on the ecology of the estuarine ecosystem through alteration of salinity zonation, spatial arrangements of wetland building and loss rates.

Climate change has been tied to RSLR, but could influence other factors that affect Louisiana's wetlands. There is widespread consensus today in the international scientific community that the world's atmosphere is warming. The Intergovernmental Panel on Climate Change, 2007,[1] reports that global average temperature has increased by about 1 degree F in the last 140 years, and is expected to rise by 2.5 to 10.4 degrees F by the end of this century. Uncertainty remains regarding the effects of this change on patterns of precipitation. The two climate models generally used by scientists differ dramatically on projections of rainfall. Because fresh water is an essential ingredient for the survival of wetlands, this will be a key issue for future restoration projects. Predictions of storm patterns are also uncertain. Even if the frequency and intensity of storms remain constant, those considered minor by current standards could have major consequences in Louisiana as rising sea levels intensify tidal surge, erosion, flooding and saltwater intrusion.

Ecological Stressors

Altered Hydrology, Water Quality and sediment delivery**.** Natural processes alone are not responsible for the degradation and loss of wetlands in the Mississippi River delta plain. Natural levees created by seasonal flooding of the river would invariably influence the path and flow of river waters. The seasonal flooding of river waters provided a seasonal input of sediment providing a renewable resource of substrate and nutrients for habitat behind the natural levees. As natural levees accreted in height and size, the location and course of distributaries, river meanders, and river channels would change over a geologic scale of time (beyond multiple human lifespans). Nowhere has this change been exacerbated more than by the construction of flood protection levees on top of existing natural levees within the watershed of the Mississippi River especially in coastal Louisiana. Seasonal flooding that once provided sediments and nutrients critical to the

[1] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of WorkingGroup I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning,Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

healthy growth of wetlands of coastal Louisiana has been virtually eliminated by the addition of an extensive levee system, on top of the natural levee system, extending in part from the Old River Control Structure to Venice Louisiana, a distance of approximately 310 miles (500 kilometers); sediment carried by the river is now discharged far from the coast, thereby depriving wetlands of vital sediment. Altered hydrology and water quality is one predominant stressor on the ecosystem, taking the form of cumulative effects of levees, canals, and other physical alterations. This causes changes in quantity, timing, and quality of flows to the ecosystem, in addition to harm to wetlands and ground-water resources. Throughout the coastal wetland complex, an extensive system of dredged canals and flood-control structures, constructed to facilitate hydrocarbon exploration and production as well as commercial and recreational boat traffic, has enabled salt water from the Gulf of Mexico to intrude brackish and freshwater wetlands. Moreover, forced drainage of the wetlands to accommodate development and agriculture also contribute to wetlands deterioration and loss. Altered hydrology and water quality is exacerbated by physical changes made within the Mississippi River watershed that includes numerous large hydropower dams and reservoirs and flood control, land use patterns, agricultural practices and navigation projects.

<u>Altered Estuarine Salinity.</u>
Construction of flood protection levees, hydropower dams and reservoirs along the Mississippi River and its distributaries have had a system level impact on salinities. Construction of deep-draft and other navigation channels, pipeline canals, and oilfield canals have exacerbated those ecosystem level impacts. Additionally, forced drainage projects have altered the timing and location of freshwater inputs from adjacent distributary ridges and developed areas. Development and enhanced drainage of developed areas has also accelerated freshwater inputs into the coastal ecosystem. Canal-related hydrologic alterations allow those freshwater inputs to be quickly discharged from coastal wetlands and rapidly replaced with Gulf waters.

<u>Physical Alterations.</u>
In addition to the construction of flood control levees and canals of various sizes, the hydrology of coastal wetlands has also been altered through construction of highway embankments, railroad embankments, local flood protection levees, and impoundments. Levee failure of agricultural impoundments has resulted in creation of large open water lakes due to the oxidation and accelerated subsidence of the once drained soils. Extensive networks of oil and gas field canals have also altered hydrology and water quality resulted in substantial direct impacts to wetlands through dredging and dredged material placement impacts.

<u>Herbivory.</u>
During the 1930's, nutria (*Myocastor coypus)* were accidentally released into the coastal wetlands. Since then their population has rapidly expanded and their grazing and foraging for plant roots have been a major contributor to wetland losses. Although native, muskrats eat-outs may also result in significant local impacts to area marshes. Although eat-outs may recover under some conditions, tropical storm impacts on an eat-

out area may overnight convert such an area to permanent open water conditions (USGS 2000).

Invasive Species

Invasive plant species increase and spread rapidly because the new habitat into which they are introduced is free of insects and disease that are natural controls in their native habitats. The aggressive spread of invasive species decreases stands of native plants in many areas, rapidly altering ecosystem function. Different ecosystem types vary in the species that pose problems and the degree to which they are currently impacted or threatened by invasive species (USGS, 2000). Disturbed ecosystems are more vulnerable to invasive species than stable ecosystems. In coastal Louisiana, water hyacinth (*Eichhornia crassipes*), alligator weed (*Alternanthera philoxeroides*), and hydrilla (*Hydrilla verticilata*) are aquatic vegetative species that have long been considered invasive. More recently, common salvinia (*Salvinia minima*), giant salvinia (*Salvinia molesta*), and variable-leaf milfoil (*Myriophyllum heterophylum*) have become invasive, displacing native aquatics and degrading water and habitat quality. Invasive aquatic species interfere with drainage and flood control, and impede navigation and recreation activities (Westbrooks 1998). Chinese tallowtree (*Triadica sebifera*, formerly *Sapium sebiferum*) and sea-side cedar (*Tamarix gallica*) rapidly colonize higher disturbed open ground areas and interrupt natural succession of native prairie, scrub-shrub and woody species because of their tolerance to flooding and salt stress. Escaped populations of Chinese tallowtree have established extensive, self-replacing monocultures that have radically altered ecosystems (USGS 2000). Barrow et al. (2000) illustrates how the invasive tallowtree, in crowding out native species, provides less value to the foraging of migrating avian species. Cogongrass (*Imperata cylindrica*) is a fast-growing perennial grass that is infesting Gulf coast wetlands, savannas, and forests. Considered one of the top ten weeds in the world, cogongrass invades dry to moist natural areas and forms dense colonies with extensive root/rhizome systems that displace native plant and animal species. Cogongrass has been recorded as occurring in parts of Louisiana (Center for Aquatic & Invasive Plants 2000), but recently has been found to be locally severe in a very small number of areas (J. Pitre, USDA NRCS, 2002 – personal communication).

Storms

Wetlands already weakened by extreme weather conditions may be more vulnerable to damage from subsequent events as plant communities become stressed beyond their ability to recover or shift toward communities with more tolerant species. Hurricanes impact coastal vegetation communities with saltwater intrusion and flooding from storm surges. Hurricanes also cause immediate physical damage to emergent wetlands as increased wave action and currents cause tearing or uprooting of the live mat and substrate loss, and high winds sheer limbs and fell trees in wooded areas. Storms deposit smothering mats of wrack and detritus over large areas, causing temporary or permanent shifts in plant community composition. The erosion and breaching of emergent lands also deteriorates its buffering function that protects low-energy hydrologic regimes where aquatic vegetative communities may thrive.

Drought

Prolonged periods of drought can also impact coastal vegetation. In 2000, coinciding with the drought period, damage or dieback was reported in areas of unprecedented size in the Terrebonne and Barataria saline marshes. Areas sustaining the worst damage during this "brown marsh" phenomenon suffered complete dieback of above and belowground plant material and conversion to unvegetated mud flats (Linscombe et al., 2001). In addition, Visser et al. (2002), in comparing 1997 and 2000 vegetation survey data, found that salinity increases across all marsh types occurred. The response of estuarine plant communities to the hydrologic changes brought about by the 1999-2000 drought may provide a preview of changes in estuarine plant communities as global sea-level change causes marine intrusion into estuaries to increase (Visser et al., 2002). More recently, a severe nine-month drought following the 2005 hurricanes Katrina and Rita allowed for prolonged inundation of gulf-strength surge waters and its deep infiltration into marsh soils. One year post-storm, soils salinity levels in many coastal areas remain significantly increased (pers.comm. Jerry Daigle, USDA NRCS; Steyer et al., in prep.).

Important Linkages

One approach to restore Coastal Louisiana is to reverse the original alteration of the marsh landscape by removing man made levees and other hydrological constraints, filling in the extensive network of artificial channels, and letting the unconstrained physical processes re-create the wetlands, ridges and other features over time. This "idealized" approach is not possible for three main reasons:

1. The physical processes that formed the marsh are quite different than those operating now. For example, sediment loads in the Mississippi, Atchafalaya and other gulf tributaries is much lower now than in recent history and RSLR is greater and projected to increase with global climate change.

2. There are significant human constraints that limit the ability to restore natural processes. These include land development and property boundaries that define and limit how areas may evolve, flood protection requirements, and the presence of public infrastructure and travel corridors (including navigation channels and canals). Natural levees within the watershed of the Mississippi River especially coastal areas would still create a barrier limiting distribution of sediments into wetland areas. Dams that trap sediments, reservoirs that alter hydrology, basin land use practices and other related factors distributed over the entire drainage may also effectively constrain opportunities. However, ongoing research is in process to ascertain sediment loads/budgets of the Mississippi River in order to assist in development of future strategies to utilize existing resources in the river.

3. The economic investment in restoration is usually directed towards achieving restoration goals within a quick timeframe. Conversely, recovery through the restoration of key processes may require decades or even centuries to fully realize benefits. This may also mean trade-offs between created/restored landscape features that increase or

accelerate system sustainability versus the desire to allow unconstrained “natural” evolution.

PLAN FORMULATION

The aim of the LACPR was to formulate and justify a comprehensive plan that integrates coastal restoration with multiple lines of defense against hurricane surge risk for coastal Louisiana. Because of the complexity and size of the planning area, there may be hundreds of possible combinations of structural, nonstructural, and restoration measures that could be combined into alternative plans. In order to maintain the transparent problem-solving and opportunity focus of the analysis, it was essential to reduce the number of alternatives under consideration for LACPR to a manageable number.

The HET was charged with using measures contained in the Louisiana State Master Plan as the basis for formulation and evaluation of coastal restoration alternatives.

Early in the plan formulation process, the LACPR *Plan Formulation Atlas* presented three of the State Master Plan alternatives in addition to a fourth alternative developed by the HET. The “State Coastal Alternative 3” from the *Plan Formulation Atlas* is closest to the coastal restoration plan presented in the final State Master Plan and was carried forward as an alternative to be evaluated under LACPR as described in this appendix. The HET alternative “Coastal Alternative 4” from the *Plan Formulation Atlas* was carried forward as well as an alternative representing the LCA Plan that best meets the planning objectives (Plan PBMO).

Two additional alternatives were developed by the HET with the specific aim of sustaining the wetland area over a 100-year timeframe. Both alternatives achieve this aim through the restoration of coastal features (barrier islands, ridges, land bridges and marsh) in combination with Mississippi River diversions in PUs 1, 2 & 3a. The difference between the alternatives is in the design and operation of the diversion structures. One alternative incorporates the use of small to medium diversions operated on a relatively consistent basis, whereas the other alternative uses medium to large diversions with the capability for periodic (every four or five years) large pulsed flows. In PU 3a, an additional diversion alternative (PU3a R2) was included that involves the management and re-distribution of seasonally available Atchafalaya River fresh water from various points along the GIWW. To achieve “maximum sustainability” in the remaining planning units, one alternative employs heavy use of dedicated dredging to restore or sustain marsh with shoreline protection to reduce shoreline erosion. The other alternative also employs heavy use of dedicated dredging to restore or sustain marsh, but does not employ shoreline protection which significantly impacts the aim of reaching no net loss. The alternatives are summarized in Table 2.

Screening, Formulation and Prioritization Process

A two step screening and formulation process was utilized to develop the viable coastal restoration alternatives.

Two-Tiered Screening and Formulation Process

- **Tier 1 - Initial Screening of Measures and Formulation of Alternatives** eliminated coastal restoration measures that were not essential to sustaining the integrity of the landscape. The remaining measures were grouped (utilizing different rationales) to formulate five primary coastal restoration alternatives in each planning unit using several.
- **Tier 2 - Screening of Alternatives and Selection of a Representative Alternative** evaluated the five primary coastal restoration alternatives and selected the alternative that best represented the landscape and met the criteria of sustaining the existing landscape.

Tier 1: Initial Screening of Measures and Formulation of Alternatives

The HET considered implementing measures identified during the development of the State Master Plan. A range of features were considered that could maintain or restore natural deltaic processes and hydrology in coastal Louisiana; these included diversions off the Mississippi River, marsh creation, ridge or chenier (oak ridges) restoration and barrier islands restoration. These features were prioritized according to the anticipated degree of basin-level benefits they would provide. Factors considered for prioritization included:

- Distance to sediment sources, both riverine and offshore
- Availability of freshwater for sustainability
- Existing structures to aid in sediment confinement during construction
- Average depth of open water areas
- Land/water distribution
- Need for shoreline protection
- Preferred sediment grain size for restoration
- Processes responsible for wetland loss
- Measure of local subsidence
- Potential fisheries impacts
- Measure of flood and infrastructure protection provided by site
- Proximity of pipeline right-of-ways and access for construction
- Overlap with LCA/CWPPRA projects

Ultimately, prioritization was made primarily on the contribution of the measures to sustaining the integrity of the most critical estuarine regions in each hydrologic basin. Highest priority was given to measures that would restore and/or maintain critically important landscape features or marsh areas. Because construction of the most critically important measures would require more sediment than was readily available in many cases, the HET subdivided many of the marsh polygons from the State Master Plan into smaller units that could be prioritized separately. Additional marsh creation areas or erosion reducing measures not identified in the State Master Plan were also developed and applied to coastal restoration alternatives R1, R2, and R4, which are described below. Those marsh creation measures assigned the lowest priority were excluded from further analysis.

Five primary alternatives were identified for further analysis following screening of the first tier. See **Table 2** below:

Alternative Rationale	PU 1	PU2	PU3a	PU3b	PU4
Alternative relies on small to medium diversions off the Mississippi River. In PU 1 and 2, the diversions are steady state; PU3a diversions could be either steady state or "pulsed".	R1	R1	R1	NA	NA
Alternative relies on medium to large diversion "pulsed" flows off the Mississippi River.	R2	R2	NA	NA	NA
Alternative relies on diversions or water management off the GIWW	NA	NA	R2	NA	NA
Bank-line stabilization combined with dedicated marsh creation.	NA	NA	NA	R1	R1
Dedicated marsh creation without bank-line stabilization.	NA	NA	NA	R2	R2
State Master Plan	R3	R3	R3	R3	R3
Other coastal restoration measures not identified in the State Master Plan or modifications to the State Master Plan (R3).	R4	R4	R4	R4	R4
Louisiana Coastal Area (LCA) *Plan that Best Meets the Objectives*.	R5	R5	R5	R5	R5

NA – Not Applicable

Table 2. Coastal restoration alternatives developed for initial screening.

Each of the alternatives developed focus on the use of measures that contribute to estuarine maintenance at a basin scale, namely freshwater diversions, marsh creation using dredged material, ridge/Chenier restoration, and barrier island restoration.

Tier 2: Screening of Alternatives and Selection of a Representative Alternative

In the second tier of screening, each alternative as shown in **Table 2** above was subjected to a performance analysis over a 100 year period. The value generated was a simple gross maximum acreage of wetlands restored and/or sustained for each alternative by planning unit over 100 years. The acreages calculated from the analysis at various points in time were used to develop a performance trend for each alternative. The alternatives that resulted in negative acreages, indicating an inability to achieve coastal restoration goals, were dropped from further consideration. These were alternatives R4 and R5 for Planning Units 1 and 2 and alternatives R2, R3, R4 and R5 for Planning Units 3a, 3b and

4. The alternatives remaining for further consideration included R1, R2, and R3 in Planning Units 1 and 2 and R1 in Planning Units 3a, 3b, and 4. From the remaining alternatives in Planning Units 1 and 2, one alternative was chosen as a representative landscape coastal restoration alternative to be carried forward into the analysis in order to reduce the number of alternative combinations. Both alternatives achieve restoration of coastal features the difference between them being the design and operation of the diversion structures.. **Table 3** provides a summary of the coastal restoration alternatives carrier forward for further consideration.

PU	Alternatives Meeting Restoration Goals	Representative Alternatives	Representative Alternatives
1	R1, R2, R3	R2	Combination of medium to large river diversions operated with periodic large pulses and prioritized marsh creation measures to achieve sustainability.
2	R1, R2, R3	R2	Combination of medium to large river diversions operated with periodic large pulses and prioritized marsh creation measures to achieve sustainability.
3a	R1	R1	Variously sized Mississippi River diversions with prioritized MC measures to achieve sustainability.
3b	R1	R1 .	Alternative relies heavily on dedicated dredging to create a significant amount of wetlands in addition to shoreline protection to minimize wave/wake induced erosion.
4	R1	R1	Alternative relies heavily on dedicated dredging to create a significant amount of wetlands in addition to shoreline protection to minimize wave/wake induced erosion.

Table 3. Summary of coastal restoration alternatives**.**

The representative alternatives described above were combined with alternatives for structural and nonstructural storm damage reduction for analysis using a multi-criteria risk-informed decision framework, wherein stakeholders had the opportunity to weigh the importance of plan components. Uncertainty is explicitly included in the analysis through scenario analysis and the use of uncertainty estimates for the plan metrics. The principal factors around which scenarios were developed for the LACPR include:

a) Relative sea level rise, and
b) Redevelopment patterns within local communities in South Louisiana.

Two relative sea level rise rates were determined by combining the IPCC “medium” sea level rise projection and the NRC sea level rise rates with local subsidence rates. The two relative sea level rise rates are then combined with two levels of regional redevelopment (societal and economic recovery from Hurricanes Katrina and Rita) to form the four LACPR scenarios.

Alternative Formulation Process Overview

In developing alternatives, the HET considered numerous coastal restoration features that were developed in several collaborative venues, including the State Master Planning

Process and LCA. These features represented the initial array of management measures considered for inclusion in the LACPR, and they were augmented with features that have been proposed under other programs or separately identified by the HET. The HET utilized the factors identified below in the Tier 1 screening process to assess and prioritize each feature, and generated information regarding sediment availability to assess the feasibility of implementation of various alternatives.

Sediment availability from dredging operations (including routine O&M and possible additional borrow sources) and potential production rates from dredging for each planning unit were considered constraints in formulating alternatives involving beneficial uses of dredged material. A flow rate of 525,000 cfs between the months of December and May (normal peak flow periods) was assumed as an upper limit for Mississippi River Diversions to be used in planning until more detailed assessments can be completed to assess the diversion capacity with regard to associated flooding, navigation and environmental impacts. This flow rate was utilized in the LCA report and PEIS. The maximum flow rate for the Mississippi River below New Orleans is 1,250,000 cfs. The limit established in the LCA report was 45%, 525,000 cfs is approximately 42% of the maximum flow rate.

Given the above information and the objectives and principles previously discussed, the HET assessed each potential diversion site to determine the discharge magnitude and operations necessary to support the marsh community in the area influenced by the diversion such that maximum sustainability of wetlands was achieved. The deficit between the diversion benefits and overall wetland losses in each basin were then offset using dredged material beneficially to construct new wetlands, and other restoration measures. Where a marsh creation area would be located within a diversion influence area, that diversion was sized to sustain both the restored marsh and the marsh existing at baseline (year 2010).

Constraints

The development and evaluation of restoration alternatives within coastal Louisiana was constrained by several factors. Foremost among these factors was the fundamental premise that restoration of deltaic processes would be accomplished, in part, through reintroductions of riverine flows, but that natural and historical deltaic processes associated with the Mississippi River would not be fully realized. The availability of freshwater, primarily water transported down the Mississippi River, was considered a planning constraint because minimum levels or water flows are required to maintain navigation and flood control, and limit saltwater intrusion. The availability of sediment for restoration efforts was also considered a planning constraint for this study because there is not an unlimited, easily accessible, and low-cost source for restoration efforts.

Given the Congressionally-mandated time frame, hydrologic modeling and other intensive evaluations of measures and alternatives was not possible. Instead, relatively simple and rapid assessment methods were required.   Consequently, the evaluation represents a limited programmatic assessment of the benefits and impacts of alternatives.

Time constraints also limited the ability to obtain and incorporate extensive external input and data into the assessment of measures and evaluation of restoration alternatives.

Another significant constraint is the scientific and technological uncertainties inherent in large-scale aquatic ecosystem restoration projects. The HET maintains that implementation of the LACPR must be accompanied by a concerted research and technology development program to address these uncertainties, and that this is consistent with our recommendations for an adaptive management program for LACPR. These needs are discussed in later sections of this report.

Measures

Among the many measures considered in the development of the State Master Plan, the HET considered those measures that would significantly contribute to estuarine maintenance processes at a basin scale to be of greatest importance. Given the effects of subsidence and RSLR, sediment inputs and restoration of natural wetland maintenance processes were considered to be essential for achieving the highest degree of ecosystem sustainability possible. Restoration of natural deltaic processes through diversions of Mississippi River freshwater, nutrients, and sediment were considered essential for the restoration of self-sustaining coastal wetlands. Marsh creation measures strategically located to provide basin or subbasin-level benefits were also considered. Similarly, natural landscape features such as ridges, cheniers, and barrier islands were considered, provided those landscape features contributed substantially to the maintenance of desirable system hydrology.

After assessing shoreline erosion rates and the impacts associated with 100 years of continued erosion, some proposed bank stabilization measures were dropped from further consideration if deemed to be of little system-level benefit. Some water control structures and other measures were dropped from further consideration for similar reasons if not located in a rapidly deteriorating area or if not of a scale to provide significant benefits to a rapidly deteriorating area.

Sediment Demanding Measures

The HET considered implementation of marsh creation measures identified during the development of the State Master Plan. Measures that would restore and/or maintain critically important landscape features or marsh areas were given highest priority. Because construction of the most critically important measures would require more sediment than was readily available in many cases, the HET subdivided many of the marsh polygons from the State Master Plan into smaller units that could be separately prioritized, permitting inclusion of as many of those critically important measures as possible in any given year.

Principles:

- Create-recreate strategic marsh and/or landscape features to achieve synergies with diversions and other measures to maximize natural wetland sustainability and reduce costly long-term artificial maintenance.

- Use of external sediments is preferred rather than sediment taken from within the basin to avoid adverse indirect impacts, to avoid tidal prism increases, and to improve opportunities for natural marsh sustainability through the resuspension of sediments from open water areas. Use of in-basin borrow would not be precluded, but should be planned in a manner that avoids or minimizes adverse impacts to the greatest degree possible after external available sediments have been exhausted.

- When hydraulically dredged, sediments from saline sources should be used on barrier islands or in saline marshes to reduce salinity related impacts to wetland vegetation.

- To maximize the value provided by the use of the existing limited sediment supply, restoration and maintenance of rapidly subsiding marshes or coastal landscape features may be given lower priority compared to areas/features subsiding less rapidly, unless those features provided necessary ecosystem or hurricane protection functions.

- Determine annual sediment quantities available to coastal hydrologic basins in order to develop the most effective and strategic use of that material within each basin.

- Because of sediment availability constraints, and the cost for replacing eroded sediments, erosion protection measures may be required to help maintain marshes or recreated natural landscape features that are subject to erosional losses.

The following table (table 4) presents the HET-prioritized list for marsh and landscape feature creation using dredged material. The table presents the features sorted in priority order by planning unit, with a simple sorting algorithm using structural importance first, lifespan second, and synergy with diversions as the third criterion. Criteria scoring range from 0 – 3, with a value of 3 reflecting the highest degree of importance, longest life, or greatest synergy.

Table 4. Marsh Creation Priorities		**Sorting Criteria**			
		Structural	Function	Syn w	
PU	**Creation & Protection Features**	Import.	Lifespan	Divs	acres
1	East Orleans landbridge MC & SP	3	1	1	**7,996**
1	Breton Sound strategic MC	2	3	1	**10,365**
1	Biloxi Marshes (north + south) MC	2	2	0	**33,553**
1	Breton Sound MC	1	2	1	**52,099**
1	Bayou Terre Boeuf MC	1	2	0	**4,214**
1	Bayou LaLoutre Ridge	1	1	1	**- - - - -**

1	Central Wetlands MC	0	3	1	**4,467**
1	Labranche Marshes MC	0	3	0	**3,298**
1	Chanduleur Islands	0	3	0	
1	Golden Triangle MC	0	2	0.5	**2,614**
2	Barataria Bay Rim MC red (segs # 1,2,7,8,9)	3	3	1	**1,317**
2	Bar. MC: Red polys - SE Little Lake (8,19,11-17)	3	3	1	**22,573**
2	E.Grand Terre to Shell Is. Restoration	3	3	0.5	- - - - -
2	Shell Is to Sandy Point restoration	3	3	0.5	- - - - -
2	Barataria Landbridge MC	3	2	1	**29,031**
2	Grand Isle + W.Grand Terre restoration	3	2	0	- - - - -
2	Cheniere Caminada Beach restoration	3	1	0	- - - - -
2	Bar. MC: Orange polys - nr Little Lake (7,9)	2	2	1	**9,468**
2	Barataria Bay Rim MC orange (segs 4-6, 10-15)	2	2	0.5	**2,221**
2	Bayou L'Ours Ridge	2	2	0	- - - - -
2	Cheniere Caminada Ridges Restoration	2	1	0	- - - - -
2	Bayou Dupont Ridge	1	3	1	- - - - -
2	Bayou Grande Cheniere Ridge	1	2	1	- - - - -
2	Barataria Bay Rim MC blue (segs 3, 16-23)	1	2	0.5	**2,536**
2	Bar. MC: Blue polys - lower Laforuche (1-6)	1	2	0.5	**27,687**
2	Lower Bayou Lafourche Ridge	1	2	0	- - - - -
2	Bar. MC: Grn polys - E of BWW (18-30)& L.Salvdr.	0	3	1	**32,466**
2	Bayou Long Fontanelle Ridge	0	3	0.5	- - - - -
2	Bayou Barataria Ridge	0	2	0	- - - - -
3a	3DR-east red polys (9,10,11,16,19,21,22,28)	3	3	1	**31,006**
3a	Terr Bay N. Rim (JeanCh. To B.Terr)	3	3	1	**1,042**
3a	South Caillou Lake Landbridge MC (polys 20-22)	3	3	0.5	**6,237**
3a	Timbalier Islands Restoration	3	3	0	- - - - -
3a	Isle Derniers Restoration	3	2	0	- - - - -
3a	DuLarge-Grand Caillou Landbridge MC	2	3	1	**1,170**
3a	Small Bayou la Pointe Ridge	2	3	1	- - - - -
3a	3DR-east orange polys (S1,13,17,20,29,30)	2	3	0.5	**22,521**
3a	Bayou DuLarge Ridge	2	2	1	- - - - -
3a	3DR-west green polys (1,2,3,4,8)	2	2	0.5	**5,678**
3a	South Caillou Lake Landbridge MC (polys 19,23,24)	2	2	0	**13,727**
3a	Bayou Pointe au Chene Ridge	2	2	0	- - - - -
3a	3DR -east blue polys (8)	1	3	1	**2,563**
3a	3DR-west blue polys (5,6,7)	1	3	0	**4,212**
3a	Terr Bay N. Rim (Pt.Chen to JeanCh.)	1	2	1	**524**
3a	Margaret's Bayou Ridge	1	2	1	- - - - -
3a	Terr Bay N. Rim (Lafch to Pt.Chene)	1	1	1	**525**
3a	Terr Bay N. Rim (B.Terr to west end)	1	1	0	**1,067**
3a	Bayou Terrebonne Ridge	0	3	0	- - - - -
3a	3DR-east green N polys (2,7,12,14)	0	2	1	**8,741**
3a	3DR-east green S polys (N1,3,4,5,6,15,16,18,23-27)	0	2	0	**19,634**
3b	Penchant Basin Tidal MC	3	3	1	**8,207**
3b	Mauvois Bois - Marmande Ridges	3	2	0	- - - - -
3b	Barrier Reef (Pt au Fer to Eugene Island)	2	3	1	**

3b	Pointe au Fer Island MC	2	2	0	**1,462**
3b	Marsh Island MC	2	2	0	**7,883**
3b	Avoca Island MC	0	1	0	**1,445**
3b	Lower Atch. River MC	0	1	0	**1,526**
3b	Lower DuLarge Ridge MC (PU3b only)	0	1	0	**35**
4	South Pecan Island MC	1	3	1	**6,851**
4	South Grand Chenier MC	1	3	1	**5,575**
4	Northwest Calcasieu MC	1	3	1	**23,187**
4	East Calcasieu Lake MC	1	3	0	**11,141**
4	Chenier Reforestation/Restoration	0	1	0	**161**

Freshwater Diversions

Note: See Attachment E for additional information on diversions in PUs 1 & 2

The HET considered those diversions identified during the development of the State Master Plan, plus additional diversions identified during other recent restoration planning efforts. Existing diversions (Davis Pond and Caernarvon) and siphons were considered to be part of the overall diversion plan and were assumed to operate at their maximum discharge potential. In addition to constant (non-pulsed) operation, the HET also evaluated one pulsed operation alternative where one high discharge year was followed by 4 or 5 consecutive low-discharge years. This alternative was evaluated as a means of providing for both estuarine-dependent fisheries and periodic introductions of large quantities of suspended sediment into the receiving area marshes.

Principles:

- Baseline wetland loss between 1978 and 2006 (data provided by the USGS through satellite imagery) were determined via a linear trendline through the 1978 to 2006 data in order to avoid bias due to excessive hurricane-related 2005 wetland losses and to compensate for water level effects during satellite overflights.

- Based on preliminary estimations, the maximum diversion discharge from the Mississippi River is approximately 525,650 cfs. The HET developed a low-flow diversion alternative which would discharge a total of 153,000 cfs (alternative R4). The State's Preliminary Draft Master Plan consists of a medium discharge alternative with a maximum total Mississippi River discharge of 251,000 cfs. The LCA Plan 10130 (PBMO) represent medium high maximum diversion amounts of 438,000 cfs and the R1 Plan (steady flow diversions only from December through May) represent medium high maximum diversion amounts at 331,000 cfs.

- Within each basin, the HET determined how much discharge would be needed to achieve maximum sustainability to ascertain whether that alternative would exceed the allowable diversion total (525,650 cfs). Consequently, the total diversion discharge amounts of alternative plans R1 and R2 can be compared to the 525,650 cfs limit to evaluate the practicality of those alternative plans.

- determined which diversion would maintain the most critical marsh area within that basin. The second most critical marsh area was identified and a second priority diversion site identified to benefit it. Any remaining discharge to be allocated would be diverted at that location in amounts that would maintain that marsh area. This process was repeated again if unallocated basin flows are available.

Priorities are based on the potential for diversions to provide long-term maintenance of marshes that are of critical importance for basin hydrology. Unless otherwise specified, this prioritization does not consider diversion size/discharge, but it is assumed that the diversion should be sized to effectively maintain those critically important marsh and/or landscape features. The diversions listed below are in descending priority (table 5).

Table 5. Diversion priorities by basin.

Basin/Priority	PU	Diversion
Pontchartrain		
1	1	Violet*[5]
2	1	Maurepas swamp diversions (Hope Canal & Blind River)
3	1	LaBranche
4	1	Bonnet Carret
Bret[6]on Sound		
1	1	Caernarvon and/or White's Ditch[7]
2	1	American Bay
3	1	Bayou Lamoque
4	1	other lower river diversions
Barataria		
1	2	Myrtle Grove
2	2	Port Sulphur
3	2	upper basin swamp diversions
4	2	Davis Pond reauthorization
5	2	Buras
6	2	Fort Jackson
7	2	Bayou Lafourche 1,000 cfs siphon/pump

* *Recent WRDA 2007 legislation passed by Congress, authorized the construction of a diversion at or near Violet, Louisiana. All future alternative investigations and analysis will need to include the Violet Diversion as part of the FWOP condition*

Stabilization and Water Control Measures

[5] Violet or more efficient violet alternatives would be ranked highest, but because of the inefficiencies restored by discharge into the MRGO and Lake Borgne, Violet and/or the alternatives should not be sized to sustain the east Orleans landbridge.

[6] Proposed under Coast 2050. The HET believed a diversion American Bay to relatively inefficient for land building and marsh maintenance. Higher ranked diversions would provide more wetland benefits nd more storm protection benefits.

[7] Increased discharge at Caernarvon and/or a new diversion at Whites Ditch would provide maximum benefits to the Breton Sound estuary.

Stabilization Measures

In all of the planning units, but not all alternatives, stabilization measures were included in order to decrease erosion rates of existing wetlands. Combined with other measures, stabilization measures could reduce wetland loss rates significantly. The amount of wetlands potentially sustained is no more evident than in PU4[8], where shoreline erosion plays a large role in wetland loss rates. Stabilization measures typically include, but are not limited to, stone rip-rap along or in front of a shoreline or the use of oyster shell or reefs in front of critical areas as a means to reduce wave energy before reaching a wetland.

PU1 - Shoreline stabilization features could be placed on the perimeter of wetland areas that front the high energy open water of the Gulf of Mexico. Interior wetlands are sustained through diversions or dedicated dredging for marsh creation.

PU2 – Shoreline stabilization features might include fronting existing barrier islands with some type of rip-rap, but perhaps more importantly, critical marsh areas exposed to the high energy fetch of Barataria Bay. The goal is to prevent the inward degradation of wetlands, in order to reduce loss rates and enhance the sustainability success of diversions and mechanical wetland restoration.

PU3a - Shoreline stabilization features could include fronting existing barrier islands with some sort of rip-rap, but perhaps more importantly, critical marsh areas exposed to the high energy fetch of Terrebonne Bay. The goal is to prevent the inward degradation of wetlands, in order to reduce loss rates and enhance the sustainability success of diversions and mechanical wetland restoration.

PU3b – Shoreline stabilization features could include lining the perimeter of wetland areas that are exposed to the high energy open waters of the Gulf of Mexico and the interior high energy fetch of Vermilion Bay. A fair amount of this planning unit is experiencing growth through prograding deltas off of the Atchafalaya River and the Wax Lake Outlet.

PU4 – Shoreline stabilization features could include extensive shoreline protection measures along the Gulf coast shoreline of the planning unit, inland waterways, and large inland lakes/bays. Without significant shoreline protection measures in place, the ability to achieve coastal restoration goals in this planning unit are greatly diminished. Other measures that are available for other planning units are not necessarily available in PU4 because of the great distance from a major riverine input source or through current basin management practices for agricultural purposes.

Water Control Measures

[8] In PU4 the difference with and without shoreline stabilization measures, a amount of approximately 30,000 acres would be lost over the next 100 years.

This can be briefly described as implementing measures that re-distribute or restore hydrologic conditions to move freshwater (and associated nutrients/sediments) back into a particular system. This option is limited to the availability of freshwater sources (i.e., PU3a) and existing infrastructure obstacles that would have to be addressed and overcome (major highways, interior drainage, waterways, etc.).

Scenario Development and Application

The principal factors around which scenarios are being developed for the LACPR are: sea level rise, subsidence, population growth rates, and redevelopment patterns within local communities in south Louisiana. The scenarios under development combine two levels of relative sea level rise with two levels of regional redevelopment (societal and economic recovery from Hurricanes Katrina and Rita).

The HET determined that regional redevelopment patterns were unlikely to influence restoration outcomes, so the only scenario driver assessed by the HET was RSLR. The future acreage of wetlands and the spatial integrity index are both influenced by RSLR, so alternate outcomes were assessed for each condition. Ecosystem restoration measures are not located in areas where regional redevelopment (and new regional development) is anticipated to occur.

Alternative Descriptions

The measures used for the LACPR coastal restoration alternatives are summarized below. Figures illustrating coastal restoration alternatives are included in Attachment A.

LACPR Coastal Restoration Plan Alternative Measures for Planning Unit 1

PU1 R1 - December through May "Steady" Diversion Alternative (Attachment A – Figure A-1 PU1 R1)

- 1-1 Blind River Diversion - flows for sustaining entire south Maurepas swamp split between Blind River and Hope Canal
- 1-2 Hope Canal Diversion - flows for sustaining entire south Maurepas swamp split between Blind River and Hope Canal
- 1-3 LaBranche Diversion – diversion directly into LaBranche wetlands to sustain those wetlands
- 1-4 Bayou Bienvenu Diversion – to reduce East New Orleans landbridge loss rates by 50%
- 1-5 East New Orleans land bridge Marsh Creation – 7,996 acres @ 900 acres/year
- 1-6 Bayou LaLoutre Diversion – (In lieu of Violet) sized to sustain the Biloxi Marshes
- 1-7 Biloxi Marshes Shore Protection – 254,500 linear feet of protection around outer perimeter
- 1-8 Biloxi Marshes Marsh Creation – 33,553 acres of marsh creation with armored containment dikes where not already provided by Biloxi Marshes Shore Protection measure
- 1-9 Bayou Terre aux Boeufs Diversion - flows to sustain marshes between MRGO and Bayou Terre aux Boeufs
- 1-10 Bayou Terre aux Boeufs Marsh Creation – 2,591 acres in upper basin
- 1-11 Breton Sound Strategic Land Bridge – a band of marsh from MRGO to Miss. River (14,579 acres) plus marsh creation along either side of Bayou LaLoutre
- 1-12 Caernarvon Diversion – sized to sustain all marshes between Bayou Terre aux Boeufs and the Miss. River
- 1-13 Caernarvon Area Marsh Creation – Marsh creation along protection levee from Big Mar south to Pheonix (4,936 acres)
- 1-14 Bayou Lamoque Diversion – to sustain receiving area marshes
- 1-15 Grand Bay Diversion – sized to sustain receiving area marshes

PU1 R2 – Pulsed Diversion (one heavy flow year out of 5) Alternative (Attachment A – Figure A-2 PU1 R2)

- 2-1 Blind River Diversion - flows for sustaining entire south Maurepas swamp split between Blind River and Hope Canal
- 2-2 Hope Canal Diversion - flows for sustaining entire south Maurepas swamp split between Blind River and Hope Canal
- 2-3 LaBranche Diversion – diversion directly into LaBranche wetlands to sustain those wetlands
- 2-4 Bayou Bienvenu Diversion – to reduce East New Orleans landbridge loss rates by 50%
- 2-5 East New Orleans land bridge Marsh Creation – 7,996 acres @ 900 acres/year
- 2-6 Bayou LaLoutre Diversion – (In lieu of Violet) sized to sustain the Biloxi Marshes
- 2-7 Biloxi Marshes Shore Protection – 254,500 linear feet of protection around outer perimeter
- 2-8 Biloxi Marshes Marsh Creation – 33,553 acres of marsh creation with armored containment dikes where not already provided by Biloxi Marshes Shore Protection measure
- 2-9 Bayou Terre aux Boeufs Diversion - flows to sustain marshes between MRGO and Bayou Terre aux Boeufs
- 2-10 Bayou Terre aux Boeufs Marsh Creation – 2,591 acres in upper basin
- 2-11 Breton Sound Strategic Land Bridge – a band of marsh from MRGO to Miss. River (14,579 acres) plus marsh creation along either side of Bayou LaLoutre
- 2-12 Caernarvon Diversion – sized to sustain all marshes between Bayou Terre aux Boeufs and the Miss. River
- 2-13 Caernarvon Area Marsh Creation – Marsh creation along protection levee from Big Mar south to Pheonix (4,936 acres)
- 2-14 Bayou Lamoque Diversion – to sustain receiving area marshes
- 2-15 Grand Bay Diversion – sized to sustain receiving area marshes

PU1 R3 – State Master Plan Alternative (Attachment A – Figure A-3 PU1 R3)

- 3-1 Maurepas Shoreline Protection
- 3-2 Blind River Diversion @ 5,000 cfs[2]
- 3-3 Hope Canal Diversion @ 5,000 cfs[2]
- 3-4 Jefferson Parish Marsh Creation – 3,226 ac
- 3-5 St. Tammany Marsh Creation – 325 ac
- 3-6 East New Orleans Landbridge Marsh Creation – 7,996 ac
- 3-7 Central Wetlands Marsh Creation - 3,298 ac
- 3-8 Lake Borgne Marsh Creation – 4,357 ac
- 3-9 Biloxi Marsh Creation – 52,000 ac
- 3-10 Mississippi River Gulf Outlet Shoreline Protection
- 3-11 Golden Triangle Marsh Creation
- 3-12 Violet Diversion @ 50,000 cfs[2]
- 3-13 Caernarvon Freshwater/Sediment Introduction @ 8,500 cfs[2]
- 3-14 Breton Marsh Creation – 38,000 ac
- 3-15 White’s Ditch Diversion @ 15,000 cfs[2]
- 3-16 Bayou LaLoutre Ridge Restoration
- 3-17 Bayou Lamoque Diversion @ 15,000 cfs[2]

[2] Maximum diversion discharge

PU1 R4 - HET Alternative (Attachment A – Figure A-4 PU1 R4)

- 4-1 Blind River Diversion @ 1,000 cfs[2]
- 4-2 Hope Canal Diversion @ 1,000 cfs[2]
- 4-3 Bonnet Carre Freshwater/Sediment Introduction @ 13,000 cfs[2]
- 4-4 St. Tammany Parish Marsh Creation – 325 ac
- 4-5 New Orleans East land bridge Marsh Creation – 7,996 ac
- 4-6 Central Wetlands Marsh Creation – 4,467 ac
- 4-7 South Lake Borgne Marsh Creation – 4,357 ac
- 4-8 Biloxi Marsh Creation - 33,561 ac
- 4-9 Golden Triangle Marsh Creation – 2,614
- 4-10 Violet Diversion @ 15,000 cfs[2]
- 4-11 Breton Landbridge Marsh Creation – 3,671 ac
- 4-12 Caernarvon Freshwater Divesion @ 8,000 cfs[2]
- 4-13 Bayou Lamoque Diversion @ 12,800 cfs[2]

- 4-14 Benny 's Bay Diversion @ 20,000 cfs[2]
- 4-15 Ridge Restoration

[2] Maximum diversion discharge

PU1 R5 –LCA PBMO Alternative (Attachment A – Figure A-5 PU1 R5)

- 5-1 Increase Amite River influence by gapping spoil banks on diversion canals
- 5-2 Convent/Blind River Diversion @ 5,000 cfs[1]
- 5-3 Hope Canal Diversion @ 1,000 cfs[1]
- 5-4 Authorized opportunistic use of the Bonnet Carre Spillway
- 5-5 Sediment Delivery via pipeline at LaBranche Marsh Creation – 2,434 ac
- 5-6 Marsh nourishment/creation on the New Orleans East land bridge – 1,080 ac
- 5-7 Post authorization change for diversion of water through Inner Harbor Navigation Canal
- 5-8 Rehabilitate Violet Siphon for enhanced influence into Central Wetlands
- 5-9 Mississippi River Gulf Outlet (MRGO) Environmental Features and Salinity Control Study
- 5-10 Reauthorization of the Caernarvon Freshwater Diversion (optimize for marsh creation)
- 5-11 White's Ditch Diversion @ 10,000 cfs[1]
- 5-12 American/California Bay Diversion @ 110,000 cfs[1]
- 5-13 Bayou Lamoque Diversion @ 12,000 cfs[1]

[1] 50% duration discharge

LACPR Coastal Restoration Plan Alternative Measures for Planning Unit 2

PU2 R1 - December through May "Steady" Diversion Alternative (Attachment A – Figure A-6 PU2 R1)

- 1-1 Lagan Diversion – sized to sustain a portion of upper basin swamps
- 1-2 Edgard Diversion - sized to sustain remaining Lac des Allemands portion of upper basin wetlands
- 1-3 Davis Pond Freshwater Diversion reauthorization - run full discharge only Dec-May
- 1-4 Naomi Diversion – sized to sustain receiving area
- 1-5 Myrtle Grove Diversion – sized to sustain receiving area
- 1-6 Strategic Marsh Creation in lower basin – 22,573 acres @ 900 ac per year
- 1-7 North Bay Rim Marsh Creation/Protection – 3538 acres along northern border of Barataria Bay @ 900 ac per year
- 1-8 West Point a la Hache Diversion – sized to sustain receiving area
- 1-9 Port Sulphur Diversion – sized to sustain receiving area
- 1-10 Buras Diversion – sized to sustain receiving area
- 1-11 Fort Jackson Diversion – sized to sustain receiving area
- 1-12 Barrier Islands Restoration – 15,029 acres @ 900 acres/year

PU2 R2 – Pulsed Diversion (one heavy flow year out of 5) Alternative (Attachment A – Figure A-7 PU2 R2)

- 2-1 Lagan Diversion – sized to sustain a portion of upper basin swamps
- 2-2 Edgard Diversion - sized to sustain remaining Lac des Allemands portion of upper basin wetlands
- 2-3 Davis Pond Freshwater Diversion reauthorization - run full discharge one year out of 5 years
- 2-4 Naomi Diversion – sized to sustain receiving area
- 2-5 Myrtle Grove Diversion – sized to sustain receiving area
- 2-6 Strategic Marsh Creation in lower basin – 22,573 acres @ 900 ac per year
- 2-7 North Bay Rim Marsh Creation/Protection – 3538 acres along northern border of Barataria Bay @ 900 ac per year
- 2-8 West Point a la Hache Diversion – sized to sustain receiving area
- 2-9 Port Sulphur Diversion – sized to sustain receiving area
- 2-10 Buras Diversion – sized to sustain receiving area
- 2-11 Fort Jackson Diversion – sized to sustain receiving area
- 2-12 Barrier Islands Restoration – 15,029 acres @ 900 acres/year

PU2 R3 – State Master Plan Alternative (Attachment A – Figure A-8 PU2 R3)

- 3-1 Two upper basin swamp diversions each @ 5,000 cfs[2]
- 3-2 Pipeline Conveyance Marsh Creation (90,070 acres total)
- 3-3 Gulf Intracoastal Waterway (GIWW) Shoreline Protection
- 3-4 Davis Pond Freshwater Diversion Reauthorization
- 3-5 Myrtle Grove diversion @ 15,000 cfs[2] w/marsh creation
- 3-6 West Point a la Hache Freshwater/Sediment Introduction @ 15,0000 cfs[2]
- 3-7 Bayou Lafourche Freshwater/Sediment Introduction @ 1,000 cfs[2]
- 3-8 Bayou Lafourche Ridge Restoration
- 3-9 Bayou L'Ours Ridge Restoration
- 3-10 Bayou Grand Chenier Ridge Restoration
- 3-11 Caminada Cheniers Ridge Restoration
- 3-12 Bayou Dupont Ridge Restoration
- 3-13 Bayou Barataria Ridge Restoration
- 3-14 Caminada-Shell Islands Barrier Island Restoration – 3,438 ac
- 3-15 West Bay Freshwater/Sediment Introduction @ 50,0000 cfs[2]
- 3-16 Barrier Island Restoration – 4,414 ac

[2] Maximum diversion discharge

PU2 R4 - HET Alternative (Attachment A – Figure A-9 PU2 R4)

- 4-1 Landbridge Marsh Creation – 60,106 ac
- 4-2 Bay-rim Marsh Creation – 6,074 ac
- 4-3 Reauthorize Davis Pond Freshwater Diversion
- 4-4 Myrtle Grove Diversion @ 2,000 cfs[2]
- 4-5 Bayou Dupont Ridge Restoration
- 4-6 Bayou Barataria Ridge Restoration
- 4-7 Bayou Long Fontanelle Ridge Restoration
- 4-8 Bayou Lafourche Ridge Restoration
- 4-9 Bayou L'Ours Ridge Restoration
- 4-10 Bayou Grand Chenier Ridge Restoration
- 4-11 Caminada Cheniers Ridge Restoration
- 4-12 Fort Jackson Freshwater/Sediment Introduction @ 15,000 cfs[2]
- 4-13 West Bay Freshwater/Sediment Introduction @ 50,000 cfs[2]
- 4-14 Bayou Grand Liard Ridge Restoration
- 4-15 Caminada-Shell Islands Barrier Island Restoration – 3,438 ac
- 4-16 Barrier Island Restoration – 6,142 ac

[2] Maximum diversion discharge

PU2 R5 –LCA PBMO Alternative (Attachment A – Figure A-10 PU2 R5)

- 5-1 Edgard Freshwater/Sediment Introduction @ 1,500 cfs[1]
- 5-2 Donaldsonville Freshwater/Sediment Introduction @ 1,000 cfs[1]
- 5-3 Reauthorize Davis Pond Freshwater Diversion
- 5-4 Wetland creation and restoration feasibility sites Marsh Creation – 26,562 ac
- 5-5 Pikes Peak/Lagan Freshwater/Sediment Introduction @ 1,500 cfs[1]
- 5-6 Myrtle Grove @ 5,000 cfs Marsh Creation[1]
- 5-7 Ft. Jackons/Boothville Freshwater/Sediment Introduction @ 60,000 cfs[1]
- 5-8 Miss. R. Delta Management Study Freshwater/Sediment Introduction
- 5-9 Third Delta Freshwater/Sediment Introduction
- 5-10 Barrier Shoreline Restoration feasibility study – 10,396 ac
- 5-11 Lac Des Allemands Diversion

[1] 50% duration discharge

LACPR Coastal Restoration Plan Alternative Measures for Planning Unit 3a

PU3a R1 – Mississippi River Diversions Alternative (Attachment A – Figure A-11 PU3a R1)

- 1-1 HNC Lock Multi-purpose Operation
- 1-2 Convey Atchafalaya River water via GIWW
- 1-3 Lapeyrouse Canal diversion
- 1-4 Blue Hammock diversion
- 1-5 Upper Lake Boudreaux Basin Mississippi River Diversion
- 1-6 East Terrebonne Mississippi River Diversion
- 1-7 Grand Bayou & Jean LaCroix Basins Mississippi River Diversions
- 1-8 Pipeline Conveyance Marsh Creation (92,174 acres)
- 1-9 North Terrebonne Bay Rim Marsh Creation (3,158 acres)
- 1-10 DuLarge to Grand Caillou Landbridge Marsh Creation (1,170 acres)
- 1-11 South Caillou Lake Landbridge Marsh Creation (19,964 acres)
- 1-12 Isles Dernieres Restoration
- 1-13 Timbalier Islands Restoration

PU3a R2 – GIWW Diversions Alternative (Attachment A – Figure A-12 PU3a R2)

- 2-1 HNC Lock Multi-purpose Operation
- 2-2 Convey Atchafalaya River water via GIWW
- 2-3 GIWW By-Pass Channel
- 2-4 Lapeyrouse Canal diversion
- 2-5 Blue Hammock diversion
- 2-6 Pipeline Conveyance Marsh Creation
- 2-7 North Terrebonne Bay Rim Marsh Creation
- 2-8 DuLarge to Grand Caillou Landbridge Marsh Creation
- 2-9 South Caillou Lake Landbridge Marsh Creation
- 2-10 Isles Dernieres Restoration
- 2-11 Timbalier Islands Restoration

PU3a R3 – State Master Plan Alternative (Attachment A – Figure A-13 PU3a R3)

- 3-1 Caillou Lake Landbridge Marsh Creation – restore 19,964 acres @ 1,800 acres/yr
- 3-2 Pipeline Conveyance Marsh Creation – restore 77,828 acres @ 1,800 acres/yr
- 3-3 HNC Bankline Protection
- 3-4 GIWW Bankline Protection
- 3-5 Restore the Bayou DuLarge Ridge
- 3-6 Restore the Small Bayou LaPointe Ridge
- 3-7 Restore the Mauvois Bois Ridge
- 3-8 Restore the Bayou Terrebonne Ridge
- 3-9 Restore the Bayou Pointe au Chene Ridge
- 3-10 HNC Lock Multi-purpose Operation
- 3-11 Convey Atchafalaya River water via GIWW
- 3-12 Blue Hammock Bayou Freshwater Introduction (features in PU3b, benefits in PU3a)
- 3-13 Freshwater Introduction from Barataria via GIWW
- 3-14 Chacahoula Basin Plan
- 3-15 Water Management Plan for Upper Terrebonne Basin
- 3-16 Isles Dernieres and Timbalier Islands Restoration

PU3a R4 - HET Alternative (Attachment A – Figure A-14 PU3a R4)

- 4-1 Isles Dernieres and Timbalier Islands Restoration
- 4-2 Caillou Lake Landbridge Marsh Creation – restore 19,964 acres @ 1,800 acres/yr
- 4-3 Bayou DuLarge to Grand Caillou Landbridge Marsh Creation -
- 4-4 Pipeline Conveyance Marsh Creation – restore 90,127 acres @ 1,800 acres/yr
- 4-5 Maximize Beneficial Use

- 4-6 Terrebonne and Timbalier North Bay Rim Bank Protection
- 4-7 HNC Critical Areas Bank Protection
- 4-8 GIWW Critical Areas Bank Protection
- 4-9 South Lake Decade Bank Protection
- 4-10 Restore the Bayou DuLarge Ridge
- 4-11 Restore the Small Bayou LaPointe Ridge
- 4-12 Restore the Bayou Terrebonne Ridge
- 4-13 Restore the Bayou Pointe au Chene Ridge
- 4-14 HNC Lock Multi-purpose Operation
- 4-15 Convey Atchafalaya River water via GIWW
- 4-16 Blue Hammock Bayou Freshwater Introduction (features in PU3b, benefits in PU3a)
- 4-17 Houma By-Pass Channel to Improve and Increase Freshwater Introduction
- 4-18 South Lake Decade Freshwater Introduction
- 4-19 Penchant Plan
- 4-20 Chacahoula Basin Plan

PU3a R5 –LCA PBMO Alternative (Attachment A – Figure A-15 PU3a R5)

- 5-1 Bayou DuLarge-Bayou Grand Caillou Landbridge Marsh Creation – restore 1,170 acres
- 5-2 Caillou Lake Landbridge Gulf Shoreline Protection (33,137 linear feet)
- 5-3 HNC Lock Multi-purpose Operation
- 5-4 Bayou Lafourche 1,000 cfs Pump/Siphon (Benefits in PU2)
- 5-5 Convey Atchafalaya River water via GIWW
- 5-6 Blue Hammock Bayou Freshwater Introduction (Benefits in PU3a)
- 5-7 Penchant Basin Plan (Benefits in PU3b)
- 5-8 Isles Dernieres and Timbalier Islands Restoration

LACPR Coastal Restoration Plan Alternative Measures for Planning Unit 3b

PU3b R1 – Marsh Creation with Shoreline Protection (Attachment A – Figure A-16 PU3b R1)

- 1-1 Penchant Basin Plan
- 1-2 Convey Atchafalaya River water via GIWW
- 1-3 Relocate the Navigation Channel through Lower Atchafalaya River Delta
- 1-4 Increase Sediment Transport down the Wax Lake Outlet
- 1-5 Barrier Reef from Eugene Island to Pointe au Fer Island
- 1-6 Blue Hammock Bayou Freshwater Introduction (benefits in PU3a)
- 1-7 Gulfshore Protection at Pointe au Fer Island
- 1-8 Freshwater Bayou Bank Protection, Belle Isle to Lock
- 1-9 Southwest Pass Bank Protection
- 1-10 Marsh Island Shoreline Protection
- 1-11 Gulfshore Protection from Freshwater Bayou to Southwest Pass
- 1-12 Shoreline Protection at Vermilion Bay & West Cote Blanche Bay
- 1-13 East Cote Blanche Bay Shore Protection
- 1-14 Bayou Decade Area Marsh Creation (5,870 acres)
- 1-15 Brady Canal Area Marsh Creation (2,731 acres)
- 1-16 Pointe au Fer Island Marsh Creation (1,462 acres)
- 1-17 Marsh Island Marsh Creation (7,883 acres)
- 1-18 Wax Lake Outlet Delta Marsh Creation (4,736 acres)
- 1-19 Bayou Penchant Area Marsh Creation (6,554 acres)
- 1-20 Terrebonne GIWW Area Marsh Creation (3,977 acres)

PU3b R2 – Marsh Creation without Shoreline Protection (Attachment A – Figure A-17 PU3b R2)

- 2-1 Penchant Basin Plan
- 2-2 Convey Atchafalaya River water via GIWW
- 2-3 Relocate the Navigation Channel through Lower Atchafalaya River Delta
- 2-4 Increase Sediment Transport down the Wax Lake Outlet

- 2-5 Barrier Reef from Eugene Island to Pointe au Fer Island
- 2-6 Blue Hammock Bayou Freshwater Introduction (benefits in PU3a)
- 2-7 Bayou Decade Area Marsh Creation (5,870 acres)
- 2-8 Brady Canal Area Marsh Creation (2,731 acres)
- 2-9 Pointe au Fer Island Marsh Creation (1,462 acres)
- 2-10 Marsh Island Marsh Creation (7,883 acres)
- 2-11 Wax Lake Outlet Delta Marsh Creation (10,536 acres)
- 2-12 Bayou Penchant Area Marsh Creation (12,954 acres)
- 2-13 Terrebonne GIWW Area Marsh Creation (11,055 acres)
- 2-14 Avoca Island Marsh Creation (1,445 acres)
- 2-15 Lower Atchafalaya River Marsh Creation (1,526 acres)

PU3b R3 – State Master Plan Alternative (Attachment A – Figure A-18 PU3b R3)

- 3-1 Barrier Shoreline Restoration: Point Au Fer Island
- 3-2 Convey Atchafalaya River Water Eastward via GIWW to Benefit Eastern and Lower Terrebonne Marshes
- 3-3 Bankline Stabilization of Freshwater Bayou from Belle Isle Bayou to Freshwater Bayou Canal Lock
- 3-4 Increase Sediment Transport Down Wax Lake Outlet
- 3-5 Southwest Pass Shoreline Stabilization
- 3-6 Barrier Shoreline Restoration: Freshwater Bayou to South Point/Marsh Island
- 3-7 Bankline Protection for Gulf Intracoastal Waterway (GIWW)
- 3-8 Raynie Marsh Restoration
- 3-9 Convey Atchafalaya River Water Westward via GIWW
- 3-10 Marsh Restoration Using Dredged Material at Weeks Bay
- 3-11 Marsh Restoration Using Dredged Material at Marsh Island
- 3-12 Marsh Restoration Using Dredged Material at Point Au Fer
- 3-13 Stabilize Shoreline of Vermilion, East and West Cote Blanche Bays
- 3-14 Freshwater Introduction into Central and Lower Terrebonne Marshes
- 3-15 Fortify Spoil Banks of GIWW and Freshwater Bayou
- 3-16 Marsh Creation near Lower Atchafalaya River

PU3b R4 - HET Alternative (Attachment A – Figure A-19 PU3b R4)

- 4-1 Marsh Creation via Beneficial Use near the Lower Atchafalaya River (2,970 acres)
- 4-2 Marsh Creation via Beneficial Use on Pointe au Fer Island (4,763 acres)
- 4-3 Gulfshore Protection at Pointe au Fer Island
- 4-4 Marsh Island Shoreline Protection
- 4-5 Restore the Mauvois Bois Ridge
- 4-6 Increase Sediment Transport down the Wax Lake Outlet
- 4-7 Convey Atchafalaya River water via GIWW (Bayou Shaffer Diversion)
- 4-8 Penchant Basin Plan
- 4-9 Barrier Reef from Eugene Island to Pointe au Fer Island
- 4-10Blue Hammock Bayou Freshwater Introduction (benefits in PU3a)

PU3b R5 –LCA PBMO Alternative (Attachment A – Figure A-20 PU3b R5)

- 5-1 Shoreline Protection along East Cote Blanche Bay
- 5-2 Pointe au Fer Island Shore Protection
- 5-3 Point Chevreuil Jetty-Reef
- 5-4 Relocate the Navigation Channel through Lower Atchafalaya River Delta
- 5-5 Increase Sediment Transport down the Wax Lake Outlet
- 5-6 Modification of Old River Control Structure Operation Study (not shown on map)
- 5-7 Penchant Plan
- 5-8 Blue Hammock Bayou Freshwater Introduction (benefits in PU3a)
- 5-9 Convey Atchafalaya River water via GIWW (Bayou Shaffer Diversion)

LACPR Coastal Restoration Plan Alternative Measures for Planning Unit 4

PU4 R1 – Marsh Creation with Shoreline Protection (Attachment A – Figure A-21 PU4 R1)

- 1-1 Marsh Creation at Mud Lake (5,669 acres)
- 1-2 Marsh Creation at South Grand Chenier (8,575 acres)
- 1-3 Marsh Creation at South Pecan Island (9,851 acres)
- 1-4 Marsh Creation at East Pecan Island (7,184 acres)
- 1-5 Marsh Creation at No-Name Bayou (2,151 acres)
- 1-6 Marsh Creation at NW Calcasieu Lake (23,187 acres)
- 1-7 Marsh Creation at East Calcasieu Lake (14,141 acres)
- 1-8 Marsh Creation at Black Bayou (4,769 acres)
- 1-9 Marsh Creation at Gum Cove (3,261 aces)
- 1-10 Marsh Creation at Cameron Meadows (1,293 acres)
- 1-11 Marsh Creation at Central Canal (120 acres)
- 1-12 GIWW bank stabilization
- 1-13 Grand Lake bank stabilization
- 1-14 White Lake bank stabilization
- 1-15 Gulf Shoreline Stabilization (Sabine River to Calcasieu River
- 1-16 Gulf Shoreline Stabilization (Calcasieu River to Freshwater Bayou

PU4 R2 – Marsh Creation without Shoreline Protection (Attachment A – Figure A-22 PU4 R2)

- 2-1 Marsh Creation at Mud Lake (5,669 acres)
- 2-2 Marsh Creation at South Grand Chenier (8,575 acres)
- 2-3 Marsh Creation at South Pecan Island (9851 acres)
- 2-4 Marsh Creation at East Pecan Island (7,184 acres)
- 2-5 Marsh Creation at No-Name Bayou (3,151 acres)
- 2-6 Marsh Creation at NW Calcasieu Lake (29,187 acres)
- 2-7 Marsh Creation at East Calcasieu Lake (14,141 acres)
- 2-8 Marsh Creation at Black Bayou (4,769 acres)
- 2-9 Marsh Creation at Gum Cove (3,261 aces)
- 2-10 Marsh Creation at Cameron Meadows (1,293 acres)
- 2-11 Marsh Creation at Central Canal (18,216 acres)
- 2-12 Marsh Creation at Sweet Lake (3,527 acres)

PU4 R3 – State Master Plan Alternative (Attachment A – Figure A-23 PU4 R3)

- 3-1 GIWW bank stabilization
- 3-2 Restore the Mermentau Lakes Basin Integrity
- 3-3 Grand Lake bank stabilization
- 3-4 White Lake bank stabilization
- 3-5 Freshwater Bayou bank stabilization
- 3-6 Calcasieu Pass Salinity Control Structure
- 3-7 Gulf Shoreline Stabilization (Sabine River to Calcasieu River)
- 3-8 Gulf Shoreline Stabilization (Calcasieu River to Freshwater Bayou)
- 3-9 Marsh Creation (12,427 acres)
- 3-10 Beneficial Use of Calcasieu Ship Channel Dredged Material (34,908 acres)
- 3-11 Sabine Pass Salinity Control Structure
- 3-12 Fortify Spoil Banks of GIWW & Freshwater Bayou
- 3-13 Stabilize Calcasieu Lake Shoreline
- 3-14 Stabilize Sabine Lake Shoreline
- 3-15 Mermentau Basin Watershed Management Plan
- 3-16 Sabine Basin Watershed Management
- 3-17 Strategic Water Control Structures along Highways 82 and 27

PU4 R4 - HET Alternative (Attachment A – Figure A-24 PU4 R4)

- 4-1 Marsh Creation & Terracing northwest of Calcasieu Lake (22,262 acres) and East Calcasieu Marsh Creation (10,848 acres)
- 4-2 Gulf Shoreline Protection – Sabine River to Calcasieu River – critical areas only

- 4-3 Gulf Shoreline Protection – Calcasieu R. to Freshwater Bayou – critical areas only
- 4-4 Grand Lake Bank Protection – critical areas only
- 4-5 White Lake Bank Protection – critical areas only
- 4-6 GIWW Bank Stabilization – critical areas only
- 4-7 Use old Calcasieu Lock for Evacuation of Excess Water
- 4-8 Restore-Reforest Chenier Ridges

PU4 R5 –LCA PBMO Alternative (Attachment A – Figure A-25 PU4 R5)

- 5-1 Salinity Control Structure at Oyster Bayou
- 5-2 Salinity Control Structure at Long Point Bayou
- 5-3 Salinity Control Structure at Black Lake Bayou
- 5-4 Salinity Control Structure at Alkali Ditch
- 5-5 Modify existing Cameron-Creole Watershed Control Structures
- 5-6 East Sabine Hydrologic Restoration
- 5-7 Salinity Control Structure at Black Bayou
- 5-8 Sabine Pass Salinity Control Structure
- 5-9 Freshwater Introduction at Pecan Island
- 5-10 Freshwater Introduction at Rollover Bayou
- 5-11 Freshwater Introduction at Highway 82
- 5-12 Freshwater Introduction at Little Pecan Bayou
- 5-13 Freshwater Introduction at South Grand Chenier
- 5-14 Black Bayou Bypass Culverts
- 5-15 Gulf Shoreline Stabilization – protect 12,865 acres of land
- 5-16 Calcasieu Ship Channel Beneficial Use – restore 17,620 acres
- 5-17 Chenier Plain Freshwater Management and Allocation Reassessment (not shown on map)

The State of Louisiana's Preliminary Draft State Master Plan changed during its review and approval process. The need to develop information regarding proposed coastal restoration measures and conduct the appropriate evaluations, precluded the HET from waiting until all revisions were completed before beginning to evaluate the State Master Plan. Alternative 4 was developed by the HET concurrently with the development of the draft State Master Plan. Alternative 4 was developed to identify and evaluate measures that differed from measures previously considered during that Master Plan development effort. Given the extensive amount of work conducted to develop LCA alternative comprehensive plans, the HET felt that the State's most preferred comprehensive alternative (Plan 10130 or the Plan that Best Meeting the Objectives) should be evaluated even though the LCA study did not explicitly include the hurricane protection goals that are part of the LACPR effort.

Additional Alternatives

The HET felt that a sustainable coastal ecosystem is essential to achieving sustainable hurricane protection and therefore decided that the two new alternative plans would generally represent alternative ways of achieving coastal wetland sustainability on a basin level basis (excluding the present Mississippi River Delta wetlands). Consequently, development of plans that would only reduce wetland losses were precluded from consideration. Where possible, restoration of natural land-building and wetland maintenance processes were considered by the HET as essential for achieving a sustainable coastal wetland ecosystem. Where diversions were not possible, marsh creation could potentially offset ongoing wetland losses and thereby achieve maximum sustainability. Because potential impacts to some commercially and recreationally important estuarine-dependent fish and shellfish resources resulting from large-scale diversions might be the greatest impediment to achieving restoration of ecosystem sustainability, the HET decided that the two additional restoration plans should investigate alternative diversion operation schemes to reduce those impacts, while still seeking to achieve no-net coastal wetland loss.

PUs 1, 2, & 3a (the "Deltaic Plain Provinces") – Additional Alternatives

One of those new alternative plans would limit diversion discharges to December through May of every year. Such operations were anticipated to improve recruitment of post-larval and juvenile white shrimp, compared to continuing diversion discharges through June or July, the period of maximum recruitment into coastal estuaries. The concept for the other alternative diversion operation plan was modeled after fisheries responses to flood water discharges through the Bonnet Carre Floodway. Although fisheries are severely impacted during the discharge year, the following years have often exhibited exceptionally high fisheries production, due in part to the nutrient inputs and resulting increased productivity levels throughout the ecosystem. To periodically simulate this effect, and to introduce needed sediments into the coastal ecosystem, the HET considered conducting a year of high-flow diversions once in 4 years and once in every 5 years. To avoid and/or minimize fisheries impacts during the low-flow years, and to allow sufficient time for oyster production and to rebound after high-flow year impacts, the HET decided that this alternative would incorporate one high flow year in every 5 years. To determine discharges during high and low flow years, the HET evaluated the relative sizes of high-flow year diversions when high flow diversion levels were 2 times and 3 times that of the annual Dec-May diversion alternative. Based on that assessment, the HET decided that the "3 times" alternative would reduce low-flow year diversion quantities more than would the "2 times" alternative, and thereby would minimize fisheries impacts during the low-flow years. Compensation for fisheries impacts during the high-flow years would, therefore, be more effectively achieved during the low-flow years under the "3 times" alternative than under the "2 times" alternative.

Dec-May Diversion Alternative (PUs 1 & 2 - R1). This plan was developed to achieve coastal ecosystem sustainability on a planning unit basis in a manner that reduces some impacts to estuarine-dependent fish and shellfish resources. It employs use of multiple, various-sized, strategically located diversions that incorporate sufficient operational flexibility so that operation can be adapted to changing environmental conditions. Those diversions would be operated at maximum discharge, every year only during the December through May period. Sufficient marsh creation measures have been proposed to achieve basin-level wetland sustainability. Where marsh creation areas are located within diversion influence areas, those diversions have been sized to sustain both the restored and existing marsh areas.

Pulsed Diversion Alternative (PUs 1 & 2 - R2). This plan was developed to achieve coastal ecosystem sustainability on a planning unit basis under medium future sea-level rise conditions, in a manner that reduces some impacts to estuarine-dependent fish and shellfish resources. It employs use of multiple, various-sized, strategically located diversions that incorporate sufficient operational flexibility so that operation can be adapted to changing environmental conditions. Those diversions would be operated year-round at maximum discharge, one year out of 5. During the four low-flow years, discharge levels would be restricted to minimize adverse impacts to estuarine-dependent fisheries.

Mississippi River Diversions (PU3a R1) As in PUs 1 & 2, this plan was developed to achieve coastal ecosystem sustainability on a planning unit basis in a manner that reduces some impacts to estuarine-dependent fish and shellfish resources. It employs use of multiple, various-sized, strategically located diversions that incorporate sufficient operational flexibility(operated December through May) so that operation can be adapted to changing environmental conditions. Sufficient marsh creation measures have been proposed to achieve basin-level wetland sustainability. Where marsh creation areas are located within diversion influence areas, those diversions have been sized to sustain both the restored and existing marsh areas.

GIWW Diversions (PU3a R2) Although the largest practical GIWW diversions were included, those diversions provided minimal benefits due to their relatively small size and lack of suspended sediment carried by the GIWW. However, while the title suggests the utilization of diversions, it actually employs the use of multiple, various-sized, strategically located water management structures or the re-routing of channels to re-distribute water through the planning unit in an effort to restore historic hydrologic flows through the ecosystem. This alternative would also incorporate sufficient operational flexibility so that operation can be adapted to changing environmental conditions. Because an unrealistically large amount of marsh creation would be needed to achieve basin-level maximum sustainability, the HET decided to limit marsh creation to the acreage proposed under the R1 alternative. Consequently, this altenrnative fails to achieve no-net loss.

PUs 3b & 4 (the "Chenier Plain") – Additional Alternatives

Transitioning from the Deltaic Plain to the Chenier Plain presented a difficult challenge in identifying restoration measures for PUs 3b, & 4. PU3b & 4 is an area of transition between the two coastal geographic regions. It is close enough to the Mississippi River to still use it as a resource, but far enough away to make implementation of the same diversion concepts as in PUs 1& 2 (steady or pulsed flow) extremely difficult. The concept for all planning units in the Chenier Plain can best be described as focusing on restoration of disrupted water flows through water management and dedicated dredging for marsh restoration.

Marsh Creation in PUs 3b & 4 (R1) with shoreline protection These plans were also developed to achieve coastal ecosystem sustainability on a planning unit basis in a manner that reduces some impacts to estuarine-dependent fish and shellfish resources. Unlike all of the other planning units, these plans relied entirely upon dedicated dredging with shoreline protection, to reduce erosion, to reach sustainability. Sufficient marsh creation measures have been proposed to achieve basin-level wetland sustainability.

Marsh Creation in PUs 3b & 4 (R2) without shoreline protection These plans were also developed to achieve coastal ecosystem sustainability on a planning unit basis in a manner that reduces some impacts to estuarine-dependent fish and shellfish resources. Unlike all of the other planning units, these plans relied entirely upon dedicated dredging without shoreline protection, to reduce erosion, to attempt to reach sustainability. The net result is that sustainability is not reached due to the limited availability of additional resources, such as the ability to divert water from an outside source (i.e., PUs 1, 2, & 3a). While the amount marsh creation proposed was an attempt at reaching basin-level sustainability, the rate of land loss overcomes most large scale marsh creation efforts.

Identification/location of measures for additional alternatives

Figures for planning units described in this section can be found in Attachment A to this Appendix

In PU1 and PU2, diversion locations identified during the State's Master Plan development work, the Coast 2050 Report, the Coastal Wetlands Planning, Protection and Restoration Act were considered as candidate diversion locations. Based on previous existing evaluations and HET opinions, maximum influence area polygons were determined for each diversion in a manner that generally avoided overlapping polygons (Figure 3). For those few areas not sustained by diversions, marsh creation measures were proposed to offset wetland losses in those areas.

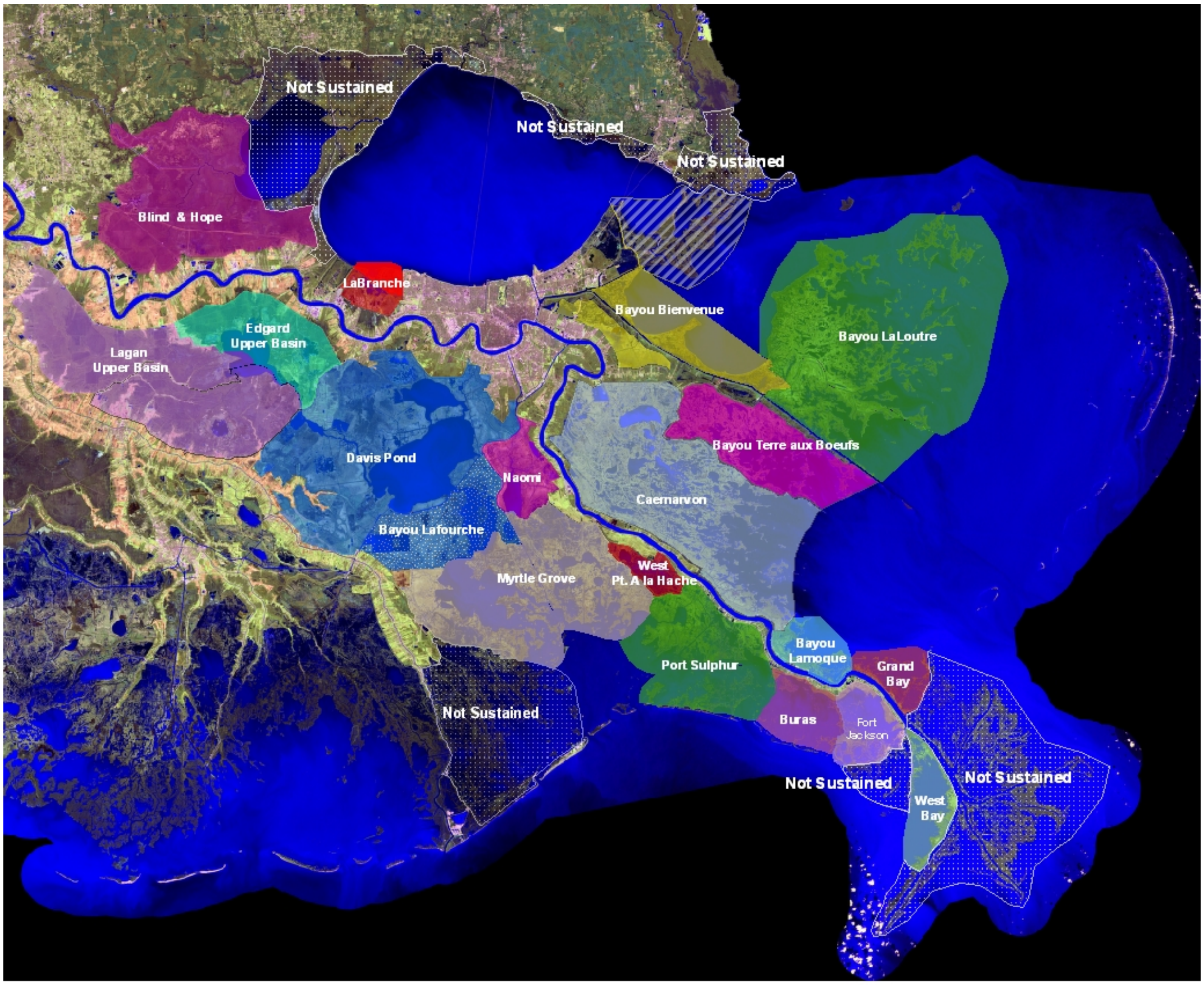


Figure 3. Map showing influence areas (colored and labeled) within PU1 and PU2 that could be sustained by diversions planned as part of alternatives R1 and R2. Hatched areas depict loss rates reduced by half and not totally sustained by a diversion

In each of the additional restoration alternatives, no new measures were proposed within the active Mississippi River Delta. Given the very high subsidence rates there and the continually decreasing suspended sediment loads in the Mississippi River, the HET assumed that the delta would be an inefficient location for use of the limited and continually decreasing suspended sediment resource. The HET, therefore, gave higher priority to restoration of Pontchartrain, Breton Sound, and Barataria Basin wetlands. As a general principle, the HET preferred upper basin introduction locations where introduced water, sediments, and nutrient could benefit as much of the wetland watershed as possible and where retention rates of sediment and nutrient resources would be maximized.

More details regarding measures are provided below. For alternatives R1 and R2 in PUs 1 and 2, the diversion measures differ only in diversion operation as described above. Otherwise, the measures contained in the additional diversion alternatives are identical.

Details regarding PU1 Measures within additional Alternatives

Additional alternatives rely upon eight freshwater/sediment diversions with additional marsh creation by other means (i.e., dedicated dredging, beneficial use of dredged material, etc), although the operations of the diversions differ. An overview of the diversions and marsh creation features follows.

Diversions:
Blind River/Hope Canal Diversions - To determine the sizes of these diversions, the flow from a single diversion needed to sustain the entire south Maurepas swamps (Amite/Blind Coast 2050 mapping unit) was allocated 50% to the Blind River Diversion location and 50% to the Hope Canal location.

Labranche Wetlands Diversion - Compared to the diversion of water through the Bonnet Carre Spillway and into Lake Pontchartrain, the HET decided instead to propose a small diversion or siphon directly into the deteriorating Labranche Wetlands. Such a diversion directly into the Labranche Wetlands would be much more effective in restoring/sustaining that area than would a diversion into the Lake where the Labranche Wetlands would receive only an indirect effect via tidal exchange with Lake Pontchartrain through Bayou Labranche.

Bayou Bienvenue Diversion - This diversion was developed to target marshes on the east New Orleans landbridge, a critical outer line of defense for New Orleans. Because of the inefficiencies associated with diverted sediments being lost to the MRGO and Lake Borgne, the flows needed to sustain the landbridge were deemed to be excessive. The HET, therefore, concluded that the goal of this diversion should be to reduce landbridge losses by half, and that marsh creation would offset the remaining losses. Because the Central Wetlands and the Golden Triangle marshes are closer to Bayou Bienvenue than the east New Orleans landbridge, they would receive a proportionally greater benefit. Not only would losses be prevented in those areas, but those areas would experience net wetland acreage increases. Because Bayou Bienvenue is closer to the Golden Triangle marshes and the east New Orleans landbridge marshes, the HET felt that it would be a more effective location than the often proposed Violet Canal location.

Bayou LaLoutre Diversion - This diversion targets the Biloxi Marshes and was developed to provide a more effective alternative to the Violet Canal diversion where a substantial amount of the diverted sediment would be lost to the MRGO and Lake Borgne. The Bayou LaLoutre Diversion would have to include a leveed conveyance channel from the Mississippi River across the MRGO, and directly into Bayou LaLoutre. It is sized to sustain the Biloxi Marshes, which together with the east New Orleans landbridge, provide an important outer line of defense for New Orleans and surrounding communities. Inclusion of a shore protection measure along the outer perimeter of the Biloxi Marshes reduces wetland losses that must the addressed by this diversion, thereby reducing the proposed diversion discharge.

Bayou Terre aux Boeufs Diversion – Because Bayou Terre aux Boeufs ridge prevents the Caernarvon Diversion from benefiting the marshes located between the MRGO and Bayou Terre aux Boeufs, the HET proposed a new diversion to achieve the sustainability of this isolated wetland subbasin area. Delivery of riverine freshwater, nutrients, and sediments to this location would require construction of a leveed conveyance channel and could be constructed in combination with the above-mentioned Bayou LaLoutre Diversion

Caernarvon Diversion Diversion – This diversion was sized to sustain all marshes between Bayou Terre aux Boeufs and Mississippi River. This flow could be distributed between the existing Caernarvon and other upper basin locations including Whites Ditch.

Bayou Lamoque Diversion - This diversion was sized to sustain the wetland area extending downriver from Bayou Lamoque. This diversion would be better located downriver in the center of the receiving area where it would discharge into protected bays rather than at Bayou Lamoque where diverted water would be discharged directly into unsheltered open water.

Grand Bay Diversion - This diversion was sized to sustain the area downriver of the Bayou Lamoque benefited area. The diversion should be located at a site to maximize distribution of benefits throughout the designated benefited area.

<u>Marsh creation:</u>

Five areas of marsh creation are proposed for PU 1[9]:

East NO Landbridge	- restore 7,996 acres @ 900 ac/year
Biloxi Marshes	- restore 33,553 acres @ 900 ac/year
Bayou Terre aux Boeufs	- restore 2,591 acres @ 900 ac/year
Breton Sound Strategic Landbridge	- restore 14,579 acres @ 900 ac/year
Caernarvon Area	- restore 4,936 acres @ 900 ac/year

Biloxi Marshes Shore Protection - To reduce wave-related erosion of the outer Biloxi Marshes, a 254,000 linear feet of shoreline protection is proposed along the outer perimeter of the Biloxi Marshes. Additionally, the containment dikes associated with the proposed marsh creation areas would also include shore protection, where not provided by the above-mentioned perimeter shore protection measures.

Details regarding PU2 Measures within additional alternatives

Additional alternatives rely upon nine freshwater/sediment diversions augmented by marsh creation, although the operations of the diversions differ. An overview of the diversions and marsh creation features follows.

<u>Diversions:</u>
Lagan Diversion – This diversion was sized to sustain a portion of the upper-most portion of the basin's swamps

[9] The number, 900 ac/yr is an assumed average productivity rate of a mechanical dredge. This table is intended to show an estimated scale at which desired marsh creation acreages would be restored assuming a particular production rate.

Edgard Diversion – This diversion was sized to sustain wetlands within the Lac des Allemands area.

Davis Pond Freshwater Diversion - This diversion was assumed to consist of the existing diversion operating at full discharge capacity, except that the in the Dec-May Diversion Alternative, it would only flow during that period, and during the Pulsed Diversion Alternative, it was assumed to flow year-round at full capacity during the one high-flow year. Otherwise, during the low-flow years, it was assumed to have a maximum discharge of 500 cubic feet per second (cfs).

Naomi Diversion – The HET assumed that the operation of this existing siphon has been of sufficient duration for the wetland benefits to be incorporated into the wetland loss rates derived from the 1978-2006 wetland acreage data. Consequently, the flows identified in this evaluation would be discharges needed to achieve sustainability of the benefited area in addition to that of its historic operation.

Myrtle Grove Diversion – This diversion was sized to sustain the benefited area.

West Pointe a la Hache Diversion - The HET assumed that the operation of this existing siphon has been of sufficient duration for the wetland benefits to be incorporated into the wetland loss rates derived from the 1978-2006 wetland acreage data. Consequently, the flows identified in this evaluation would be discharges needed to achieve sustainability of the benefited area in addition to that of its historic operation.

Port Sulphur Diversion - This diversion was sized to sustain the benefited area.

Buras - This diversion was sized to sustain the benefited area.

Fort Jackson - This diversion was sized to sustain the benefited area.

Marsh creation measures:

Three areas of marsh creation are proposed for PU 2:

North Bay Rim marsh creation	- restore 3,538 acres @ 900 ac/year
Barataria Landbridge marsh creation	- restore 22,573 acres @ 900ac/year
Barrier Island Restoration	- restore 15,029 acres @ 900ac/year

Details regarding PU3a Measures within the new Alternatives

Additional alternatives rely upon freshwater diversions augmented by marsh creation, although the operations of the diversions differ. An overview of the diversions and marsh creation features follows.

Diversions:
The obstacle presented for this planning unit is the lack of resources to carry out effective restoration measures. It is far from any direct source of renewable sediment resources as compared to PUs 1 & 2 or 3b of which all are directly connected to or within a distance to resources that can contribute to sustainability goals.

Mississippi River Diversions – This diversion was sized to influence the areas of Grand Bayou/Jean LaCroix, east of Bayou Terrebonne, and upper Lake Boudreaux. Although the size of the diversion was determined, the locations of the diversion at the river and the diversion channel have not been determined.

GIWW diversions - While the title suggests the utilization of diversions, it actually employs the use of multiple, various-sized, strategically located water management structures or the re-routing of channels to re-distribute water through the planning unit in an effort to restore historic hydrologic flows through the ecosystem. This alternative would also incorporate sufficient operational flexibility so that operation can be adapted to changing environmental conditions. Sufficient marsh creation measures have been proposed to achieve basin-level wetland sustainability.

Multi-purpose HNC Lock Operation – This measure would employ utilization of the proposed Houma Navigation Channel lock to redirect freshwater into areas of marsh in the vicinity. Minor flows would be directed into Lower Bayou Grand Caillou, Bayou Dulac to Lake Quitman, and Falgout Canal to Lake Decade. This would be a water management operation similar to methods employed under the GIWW diversion alternative.

Houma By-Pass Channel – Because the existing GIWW is very constricted in downtown Houma, a new unconstricted channel would be constructed east of Houma off of the GIWW that would run westward and south of Houma and then connecting back into the GIWW west of the Houma Navigation Channel. The resulting increased GIWW flows would be re-directed through Grand Bayou, St. Louis Canal, Humble Canal, and Bayou Chauvin. Infrastructure obstacles and land rights acquisition present a challenge for the constructability of this measure.

Marsh creation and other measures:

Four areas of marsh creation are proposed for PU 3a:

Pipeline Conveyance	- 92,174 acres
North Terrebonne Bay Rim	- 3,158 acres
DuLarge to Grand Caillou Landbridge	- 1,170 acres
South Caillou Lake Landbridge	- 19,964 acres

Details regarding PU3b and 4 Measures within additional alternatives

Unlike other planning units, PU 3b and PU 4 rely heavily on shoreline stabilization and dedicated marsh creation to maximize sustainability.

Shoreline Stabilization:

Sites for strategic shoreline stabilization have been identified throughout each of the alternatives. The intent is combining shoreline stabilization dedicated dredging

Marsh creation:

Nine areas of marsh creation are proposed for PU 3b:

Bayou Decade Area	- 5,870 acres
Brady Canal Area	- 2,731 acres
Pointe au Fer Island	- 1,462 acres
Marsh Island	- 7,883 acres
Wax Lake Outlet Delta	- 10,536 acres
Bayou Penchant Area	- 12,954 acres
Terrebonne GIWW Area	- 11,055 acres
Avoca Island Marsh Creation	- 1,445 acres
Lower Atchafalaya River Marsh Creation	- 1,526 acres

Eleven areas of marsh creation are proposed for PU 4:

Mud Lake	- 5,669 acres
South Grand Chenier	- 8,575 acres
South Pecan Island	- 9851 acres
East Pecan Island	- 7,184 acres
No-Name Bayou	- 3,151 acres
NW Calcasieu Lake	- 29,187 acres
East Calcasieu Lake	- 14,141 acres
Black Bayou	- 4,769 acres
Gum Cove	- 3,261 aces
Cameron Meadows	- 1,293 acres
Central Canal	- 18,216 acres
Sweet Lake	- 3,527 acres

Diversion Modeling, Assumptions and Inputs

The NRCS-Boustany model (2007) presented a screening level model for assessing both the nutrient and sediment benefits of flow diversions over long time scales. ERDC adapted the Boustany (2007) model to include daily variation in sediment processes in order to optimize diversion structure design and operation. The adapted Boustany model[10] was used to provide rough estimates of receiving area benefits for each year of the 100-year timeframe during past sea level rise conditions and future medium-increase RSLR conditions. An overview of the model is provided in Attachment C. Model benefits are based in part on Mississippi River discharge and the corresponding suspended sediment concentration which vary with discharge. The riverine hydrograph, in combination with diversion operation assumptions, are the key factors determining how much flow and sediment enters the diversion receiving area. Details regarding model inputs are discussed below.

A. Mississippi River Hydrograph

Excluding diversion structure operations, diversion discharges are determined primarily by the riverine hydrograph. To reduce the time required for assessing diversion benefits, it was decided to select a single annual hydrograph to assess all proposed diversion measures. To avoid intentionally biasing diversion discharges, an average hydrograph was selected from Tarbert Landing annual hydrographs 1980-2005. This was done averaging 26 years of daily discharges to obtain an index of the average annual discharge.

[10] Quantifying Benefits of Freshwater Flow diversion to Coastal Marshes: Theory and Applications, S. Kyle McKay, J. Crag Fischenich, S. Jarrell Smith, and Ronald Paille (2008)

Among the years where the annual average discharge index was within 5% of the 26-year average, the 1994 Tarbert Landing hydrograph (figure 4) was selected as its hydrograph shape most closely resembled the shape of the average hydrograph.

B. Diversion Discharges
Total diversion discharges presented in this section represent a “what-if” scenario for sensitivity analysis and plan formulation and are not necessarily indicative of a realistic end-state. Diversion discharge is determined by Mississippi River stage at the diversion structure. Because continuous stage and/or flow data from each proposed diversion location was not available, diversion discharges were related to river discharge at Tarbert Landing. According to operation records of the Caernarvon Freshwater Diversion structure (Nov. 1992 through 2006), that diversion has operated an average of 246 days a year. Lacking data to make similar determinations for many of the proposed diversion locations, all evaluated diversions were assumed to operate only during the 246 days of highest river discharges.

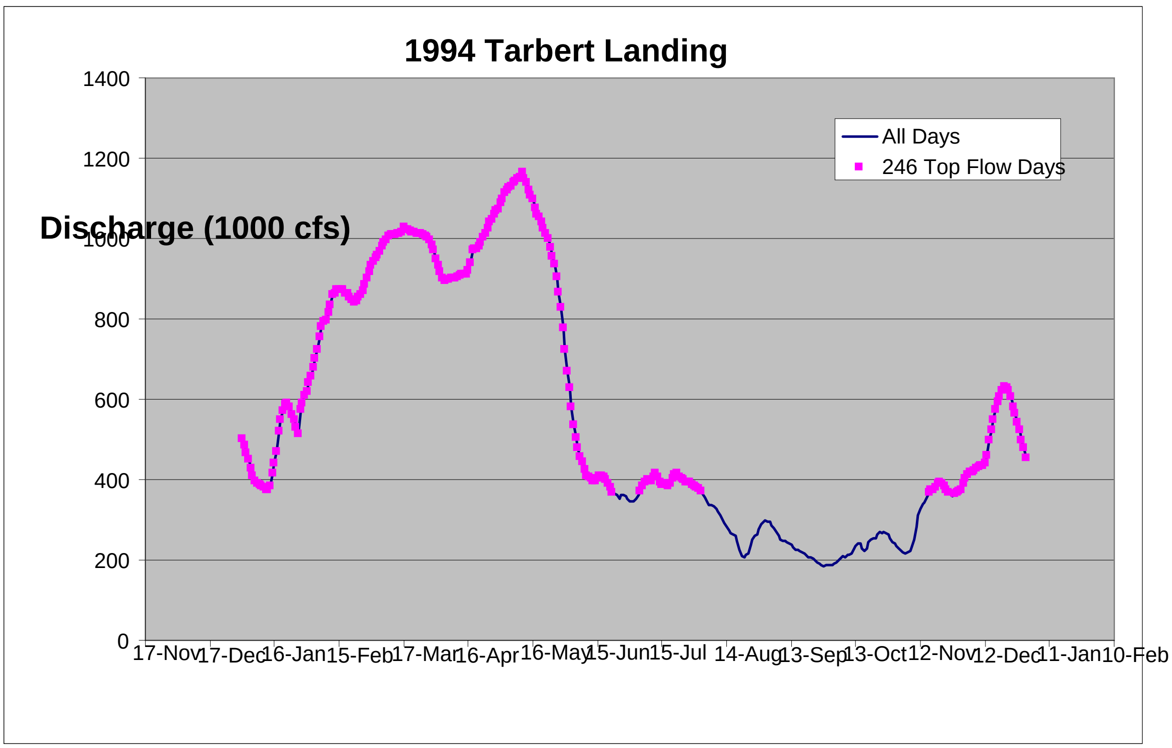


Figure 4. Mississippi River discharge at Tarbert Landing (1994).

Tarbert Landing 1994 daily discharge values were then sorted. The highest 246 discharge values were assumed to be sufficiently high to allow discharges through all evaluated diversion structures and the lower 119 values assumed to be too low to allow diversion discharges. To determine actual discharge through each proposed diversion structure, the data set of daily operation records (Nov. 1992 through 2006) for the Caernarvon Freshwater Diversion Structure was examined. A subset of Caernarvon dates and discharges was restored for only those days when all gates were fully open. Those discharges were assumed to represent the maximum discharge potential of the Caernarvon structure.

Those records reveal that discharges much higher than the structure's 8,000 cfs design discharge, which is both the 50% duration discharge and its maximum design flow capacity, could be obtained during medium to high Mississippi River stages (one daily discharge in excess of 10,000 cfs is present in the records). Because suspended sediment concentrations are greatest during high river discharge periods, the HET decided that restoration would be more effectively achieved if the design of new diversion structures did not cap diversion discharges at their 50% duration discharge. Therefore, the Caernarvon full-flow discharges were converted into percentages relative to its 50% duration flow design capacity of 8,000 cfs. Viewed in this manner, actual Caernarvon discharges have reached 126% of its design flow. A first degree polynomial equation was developed using Tarbert Landing discharge to predict percent of design discharge at Caernarvon (see equation 1). Because discharges at 126% of the design discharge occurred at a modest river discharge of <400,000 cfs, it was assumed that the Equation 1 could be used to predict diversion flows in excess of 126%.

Equation 1. *Caernarvon Design Discharge = 0.0019 (Tarbert Landing Discharge) – 0.226*

Using the 1994 Tarbert Landing data as input into Equation 1, Caernarvon discharges would reach 199% of the design discharge. A frequency analysis was conducted to lump Caernarvon discharges in 5 sub-groupings or bins according to the average percent discharge per bin. See Table 6.

Table 6. Discretization of Caernarvon discharges

Percent Discharge	Count
0.61931	97
0.92293	32
1.22655	12
1.53017	58
1.83379	47

According to Equation 1 presented above, the river discharge was used to determine percent of diversion design discharge according to the percent discharge values listed in Table 6. As a result, diversion discharges ranged from zero (actually 0.0001% was used) up to 183% of design discharge. Discharge at 183%[11] of design was used to describe the maximum discharge and the 100% design discharge was used to describe the average diversion discharge.

Equation 1 was used to predict discharge for all proposed diversions, and allowed those diversions to reach 183% of their design discharge. For the existing Davis Pond and Caernarvon structures, however, discharges were capped at their 50% duration design flows (10,650 cfs and 8,000 cfs, respectively).

For the Caernarvon Diversion, Naomi Siphon, and West Pointe a la Hache Siphon, it was assumed that benefits of their past discharges were reflected in the wetland loss rates determined for their respective influence areas. Consequently, estimates at Naomi and West Pointe a la Hache represent discharges in addition to past discharges. Unless

[11] Calculations conclude that the discharge rate can be significantly increased through an existing structure; in actuality, structural modifications would be necessary for safe operation and to reduce the risk of structural failure.

otherwise noted, the benefits associated with reauthorization of the Caernarvon Diversion to full-flow capacity was represented by maximum discharges of 6,163 cfs – the difference between its design capacity and its 1,837 cfs average annual maximum discharge. Similarly, for reauthorization of the existing Davis Pond Diversion, past average annual maximum discharges were estimated as 1,727 cfs such that reauthorization would only provide an additional maximum discharge of 8,923 cfs.

C. Mississippi River Suspended Sediment Concentration
Because sediment availability has been continually decreasing over the last 50 years, current data was needed to reflect those changes. Although good continuous total suspended solids (TSS) data exists for Tarbert Landing, the TSS concentrations are much reduced at locations below New Orleans. A sediment rating curve for Belle Chase (1991-2004) was used to determine quantities of sediment in the river at varying discharges (Snedden et al. 2006).

D. Mississippi River Nutrient Concentrations
The model applies a mean annual concentration for total nitrogen and phosphorus. Based on available historic records for the Mississippi River, the mean value was determined to be 1.7 mg/l and was used for all diversion analyses. The value assumed to range from 0.8 to 2.6 mg/l in the uncertainty analyses.

E. Diverted Suspended Sediment Characteristics
Monitoring data, obtained from the Caernarvon Diversion Structure's outfall channel, was used to characterize sediments being discharged via all evaluated diversions (Snedden et al. 2006).

F. Determining Wetland Loss Rates
Under the LCA project, the coastal wetland ecosystem was divided into approximately 160 units or polygons. Wetland acreage data for each polygon was obtained from the USGS. Assuming that the higher loss rates during the 1950s and 1960s would not be representative of future loss rates, wetland acreage data from 1978 through 2006 were used to develop loss rates for projecting throughout the future 100-year timeframe. Examination of those data reveal that although in some areas losses appeared to have either increased or decreased, the majority of polygons exhibited constant (linear) loss rates throughout the 1978 to 2006 period. Therefore a linear equation was developed for each polygon to estimate polygon acreages throughout the 100-year timeframe.

G. Determining Wetland Loss Rates with Future Increased RSLR
The HET determined it would be necessary to make preliminary projections regarding the implications of RSLR to land loss rates in order to assist in alternative formulation, and to determine how those impacts will be quantified. The methodology employed to make those projections is addressed in Attachment 2. Restoration alternatives R1 and R2 were designed to achieve sustainability under the increased RSLR scenario. Consequently, under the lower wetland loss rates of the existing RSLR scenario, those alternatives achieve net land gains.

H. Diversion Benefited Areas
Based on personal experience and involvement with previous diversion evaluation efforts, HET members made subjective determinations regarding potential maximum wetland areas that might be benefited by specific proposed diversions.

I. Receiving Area Depth
Based on personal experience and available data, HET members estimated average depths within diversion influence polygons.

J. Receiving Area Nutrient Retention
Using previously determined estimates of nutrient retention, diversion discharge, and receiving area characteristics, the HET made estimates of anticipated average nutrient retention.

K. Receiving Area Sediment Retention
A module of the diversion benefits model calculates sediment retention within the project area based on settling velocities, sediment particle size, receiving area water volume and depth. This module was used to estimate sediment retention rates for all diversions. However, for the Bayou Bienvenue diversion, the retention module was used to calculate sediment retention in a step-wise manner. Sediments not retained in the Central Wetlands were then assumed to be available to the MRGO. Sediments not retained in those areas were then assumed to be available to Lake Borgne. Remaining sediments were then assumed to be available to the Lake Borgne & Golden Triangle area marshes. Remaining sediments were then assumed to be available to the east New Orleans landbridge marshes.

For the LCA Plan measure known as “Opportunistic Use of the Bonnet Carre Spillway,” the benefits assessment made through the Coastal Wetland Protection and Restoration Act Program was used. That methodology did not include use of the above-mentioned sediment retention module.

L. Bulk Density of New Marshes
The diversion benefits model allows the user to select bulk density typical of fresh or brackish marshes. To be conservative, the higher brackish marsh bulk density value was used for all evaluated diversions.

M. Receiving Area Maximum Tidal Velocity
Lacking velocity data for all evaluated diversion receiving areas, velocities were estimated to be 1.2 to 1.4 feet per second in receiving areas close to the Gulf. Velocities in middle basin areas were estimated to range from 0.5 to 1.0 feet per second, and upper basin velocities were estimated to be less than 0.5 feet per second.

N. Flocculent Percent Deposition
Since deposition of flocculants occurs where suspended sediments encounter saltwater, percent flocculent deposition was assumed to be roughly proportional to salinity. Given that salinity data was not available for all diversion receiving areas, habitat type maps were used as a guide to average salinities, such that flocculent deposition was typically estimated to be approximately 70% in saline marshes, 30-50% in brackish marshes, and 10-20% in upper basin fresh marshes.

Sediment Availability

The HET ascertained that sediment availability is a key limiting factor in any coastal restoration effort, however given the time constraints for the LACPR analysis; a significant effort such as developing a comprehensive sediment budget could not be completed. However, a study conducted by Thorne, et al entitled *Current and Historical Sediment Loads in the Lower Mississippi* is currently underway. A regional sediment budget study has been proposed that would be applicable to all regional projects such as the ongoing levee work, CWPPRA, LCDA and LACPR. This study is anticipated to take a couple years to complete. The NRC Report (May 2008) and Day et al. (2007) estimate that the volume of sediment necessary to counter the effects of relative sea level (RSL) rise is 24,000 km^2 times a 10 cm rise in RSL. **Preliminary results of the Thorne et al. study conclude that there is more than ample sediment available in the Mississippi to sustain existing wetland acreages.**

It was not possible for the HET to duplicate the current sediment budget efforts in time to inform planning decisions for the LaCPR report due in December, 2008. None the less, the HET was able to make reasonable assumptions regarding sediment needs and availability without knowledge of the full sediment budget.

The HET established an objective to achieve "maximum sustainability" to the greatest degree possible. To accomplish this they determined that the sediment need is equivalent to what is required to replace lost resources (marsh, barrier island, and coastal ridges). The HET then applied the land loss rates from USGS data (Barras 2006)[12] to the land features in the project GIS. Losses were computed on an annual basis using a linear loss rate function for a period of 100 years to establish the future without project condition. The acreage of marsh loss computed above was multiplied by the depth to determine a volume of loss. To determine the quantity of sediment lost in tons, the volume was multiplied by the sediment bulk density, which varies depending upon the salinity. Thus, the amount of sediment needed to offset a 1km^2 marsh is simply a function of the marsh height and the sediment bulk density.

Table 7 provides example quantities for three depths and two salinity conditions. The figures in the table reflect the quantity of sediment within a mature marsh. The actual amount of material required to restore the marsh may be considerably greater than this value because sediment retention is not 100 percent. Retention rates vary depending upon site conditions as well as the method used to construct the marsh.

Depth	Weight (tons) of Sediment	
(ft)	Intermediate	Brackish
0.5	50400	100800
3.0	215000	349400
6.0	917300	1152500

Table 7. Sediment quantities (by weight) in 1km^2 of coastal marsh.

Losses in each planning unit were offset using a combination of freshwater diversions and mechanical placement of dredged material. The approaches for accomplishing this were detailed in the previous section and attachments C, E, and F.

[12] Barras, John A. 2006. Land area change in coastal Louisiana after the 2005 Hurricanes: A Series of Three Maps. U.S. Geological Survey Open-File Report 06-1274.

The sediment requirements for marsh creation/protection can be demonstrated to be less than the availability based upon the relatively conservative assumptions applied in the analyses. The HET formulated alternatives to meet the objective to achieve "maximum sustainability" by a stepped approach wherein the use of diversions at select sites were first evaluated and optimized, and additional losses beyond those compensated by diversions and/or shoreline protection measures, were offset using mechanical sediment placement.

To assess the potential for marsh creation using freshwater diversions, a desktop model (modified Boustany model, 2008) that accounts for both the creation of new marsh and the reduction in losses to existing marsh as a function of the sediments and nutrients delivered by the diversion was developed and applied. Several assumptions were made in the model analyses, and these are detailed in Attachment C. The USACE identified 525,000 cfs as an upper limit for Mississippi River Diversions to be used in planning until more detailed assessments can be completed to assess the diversion capacity with regard to associated flooding, navigation and environmental impacts. For alternative R1, PU1 and PU2 maximum Mississippi River discharge would equal approximately 331,000 cfs. The PU3a Mississippi River diversions would total 76,000 cfs. Therefore, the total Mississippi River maximum discharge in alternative R1 = 407,000 cfs.

The sediment volumes associated with those discharges were determined by applying sediment rating curves developed from measured data at the gaging stations on the Mississippi, Atchafalaya, and Calcasieu Rivers to the volume of diverted water. Table 8 shows the corresponding sediment volumes for the most sediment-demanding alternatives (R1 and R2).

Table 8. Mean annual diverted sediment volumes (CY) by Planning Unit for alternatives R1 and R2.

Planning Unit	Alternative R1	Alternative R2
PU1	28,650,000	27,012,000
PU2	11,895,000	11,243,000
PU3a	12,413,000	1,937,000
PU3b	677,000	677,000
PU4	0	0
Total	53,635,000	40,869,000

Sediment availability from dredging is unknown. Estimates of annual dredging volumes for the lower Mississippi River obtained by the HET range from 40 to 140 MCY in the period since 1970. The average for this time period is about 79 MCY. According to LCA (2004), 44 MCY of an annual 70 MCY of dredging is suitable for beneficial use. The HET determined that no more than 30 MCY of dredged material could be relied upon as an annual average, although a higher yield may occur in some years. For this effort, the HET worked with Corps staff to determine supplemental sediment quantities available by dredging water bottoms within the estuaries and from nearshore waters for situations where in-shore dredge material was not readily available.

In addition to material availability, the total number of dredges available and the production rate for any single dredge were considered limiting factors. Because of Jones

Act restrictions, it was assumed that the number of available dredges would be limited to nine. Dredge production for offshore and back-bay work assumed = 20K cyds/day x 365 days = 7.3M cyds/yr. It was assumed that 1.0 M cyds = 124 acres x 5 feet of fill (placed in 3 feet of water). Therefore, 7.3M cyds/yr x 124 ac/M cyds = 900 ac/yr production for one dredge (in shallow water locations).

Table 9 shows the average annual dredging volumes needed to offset losses not addressed by the diversions. In all cases, annual dredging is highly variable, but the number of required dredges is never greater than six, and the maximum volume dredged in any single year is less than 44 MCY.

Table 9. Average annual dredging quantities by planning unit for alternatives R1 and R2.

Planning Unit	Alternative R1	Alternative R2
PU1	3,423,000	3,423,000
PU2	2,616,000	3,043,000
PU3a	9,084,000	9,084,000
PU3b	2,678,000	4,473,000
PU4	6,468,000	8,776,000
Total	24,269,000	28,789,000

Table 10 is a summary of estimated dredging volumes necessary to offset projected barrier island and shoreline losses over 50 and 100 year planning horizons. Total acreages for barrier island restoration over the 100-yr project life are the same for Alternatives R1 and R2. Estimated sediment volumes for those island/headland measures are based on applying different fill density classifications (land, fractured, open water) developed according to design templates for 20- and 50-year project lives given the TY 0 condition of the various islands/headlands. The land change analysis that was conducted on a polygon level does not allow differentiation on a island level within polygons. Therefore, average cy/ac/polygon and average cy/ac/PU were calculated if there were multiple islands/headlands within a polygon. The existing conditions were assumed to degrade to a point and then restoration of those lost acres would occur. Lost acres were summed over the 50 and 100 year intervals as reported in Table 10. However, fill volume estimates were derived by back calculating the fill density in cubic yards per acre from a fill density based on a planform that initially would be restored to an optimal level (i.e., up front) then be allowed to degrade.

Site	50-yr Creation (ac)	100-yr Creation (ac)	Applied Fill Density (cy/ac)	50-yr Volume.	100-yr Volume.
PlaqBarS	2,700	5,400	4,566	12,328,200	24,656,400
GrandTIs	900	1,800	856	770,400	1,540,800
ChenCam	2,700	7,829	1,227	3,312,900	9,606,183
PU2 Subtotal	6,300	10,169		16,411,500	35,803,383
Timbaliers	1,800	5,400	4,478	8,060,400	24,181,200

Dernieres	1,800	4,700	2,220	3,996,000	10,434,000
PU3a Subtotal	3,600	10,100		12,056,400	34,615,200
Total				28,467,900	70,418,583

Table 10. Summary estimates for barrier island and shoreline fill volumes to restore acreages that would be lost over 50 and 100 year planning horizons in order to maintain baseline conditions.

METRICS

Performance metrics were developed within the risk informed decision framework that were used to evaluate plans to establish the degree to which they satisfy the planning objectives. The performance metrics are considered indicators of the state of complex systems. They are indicative – but not definitive – gauges, and consequently must be interpreted with their limitations in mind. The list of environmental metrics being developed to conduct plan evaluations are presented in Table 13.

Four environmental metrics were developed early in the process; however, two were dropped from the multi-criteria decision analysis because they had no affect on the outcome of the rankings (i.e. results were the same with or without the metric). The two metrics dropped were wetlands sustained/restored and spatial integrity. These two environmental metrics[13] were used to prioritize and identify restoration plans. The two metrics that were utilized in the MCDA to evaluate the LACPR alternatives were: (1) direct wetland loss impacts and (2) indirect impacts from structural measures. Table 11 below lists the metrics, and the following sections describe each metric as well as the data sources, uncertainty, and scale of application.

[13] The indirect impacts and direct wetland impact metrics are applicable to structural alternatives (proposed levees), whereas the remaining metrics are applied to the coastal restoration features.

Table 11 - Environmental Metrics

Planning Account	Planning Objective	Metrics	Units	Description	Data Source
Environmental Quality	Promote sustainable coastal ecosystem	Spatial Integrity (area, edge, shape, connectivity and interspersion	Unitless (scaled 0-1)	The size, shape, density, configuration and structure of patches across a landscape affect fundamental ecosystem processes, which determine the trajectories of ecological condition. Spatial integrity refers to undivided, contiguous space. A fragmented landscape (one containing several discrete patches of land or many inclusions of water) has less spatial integrity than a landscape containing fewer patches or inclusions. Land loss rates have been observed to vary substantially with spatial integrity. Typically, more aggregated landscapes display a higher probability of retaining land as compared to the more disaggregated landscapes. These trends were utilized to form a Landscape Stability Index which ranges from 0 to1, with probability of land retention increasing as the index approaches 1. The Landscape Stability Index places emphasis not only on the amount of land built, but the spatial configuration of that land.	Models, empirical data, maps and expert opinion
	Restore and sustain diverse fish and wildlife habitats	Direct Wetland Impacts	Acres	Many of the proposed levee alignments cross wetlands and result in the direct loss of those wetlands occupied by the footprint of the levee and adjacent borrow areas. The magnitude of the impact is a function of the levee alignment and the level of risk reduction, which influences levee base width. The potential direct wetland losses are calculated by simply overlaying the footprint of a given levee and associated borrow areas on the existing coastal landscape, assuming that all construction impacts occur simultaneously. These simplifying assumptions produce acreages of potential adverse direct wetland impacts. A high weighting penalizes plans that have significant wetland loss associated with levee construction.	Models, empirical data, maps and expert opinion
		Wetlands Created and/or protected	Acres	This metric is the direct measure of gain of wetlands restored and those existing wetlands protected form further degradation. A high weighting rewards plans that have significant wetland creation and/or protection compared to the anticipated loss of wetlands projected over the period of analysis in the no action scenario.	Models, empirical data, maps and expert opinion
	Reduce Impacts	Indirect Impacts	Unitless	This metric compares levee alignments and their potential indirect impacts (both positive and negative) to wetlands and other aquatic resources. Indirect impacts considered include (1) hydrologic changes, (2) effects on fisheries, (3) potential to induce development in wetlands, and (4) consistency with coastal restoration. Rankings range from +8 to -8, with a positive ranking meaning that there is the potential for beneficial effects to wetlands. Other factors being equal, it is assumed that the greater the acreage of wetlands that would be enclosed within a proposed levee system, the greater the potential for adverse indirect impacts. If, for example, a levee were to be built on an existing barrier (such as a levee, road, or distributary ridge), the risk for further hydrologic alteration is, in general, minimal. If a levee were built through a wetland area with limited or no existing barrier, the risk of hydrologic disruption would be far greater. A moderate adverse ranking for hydrologic impacts, for example, does not necessarily mean that a particular alignment does not have the potential for significant adverse hydrologic impacts. It simply means that the potential adverse hydrologic impacts of that alignment are substantially below what might be expected for other potential alignments in that planning unit. Fishery impacts refers to potential increases/reductions in fish access and in fish habitat. Induced development refers to the potential increase or decrease in wetland areas with significantly improved hurricane risk reduction and which are susceptible to residential, recreational and/or commercial development. Ecological sustainability/consistency (with coastal restoration) refers to the extent to which the proposed levee is or is not likely to be consistent with existing and future coastal restoration projects, particularly river reintroduction projects (a.k.a. diversions).	Expert opinion and pertinent scientific literature
	Sustain the unique heritage of coastal Louisiana by protecting cultural resources	Archaeological sites protected	Number of sites	The number of archaeological sites protected. Archaeological sites include locations with artifacts and other materials from people and cultures from the prehistoric and historic past. Archaeological sites may include the remains of buildings, trash pits, hearths, pottery, and tools (stone, metal, and other materials). A higher weighting for this metric indicates a preference for minimizing disturbance.	Survey and register
		Historic Properties Protected	Number of Properties	The number of historic properties include properties eligible or listed on the National Register and National Historic Landmarks. While archaeological sites may fall into any of these categories, structures form an overwhelming majority. In general, cultural resources in these categories must meet criteria defined at a local or national level to be included. Examples of historic resources in this category include Fort Jackson, Oaklawn Manor, Jackson Square, and the Garden District. A higher weighting for this metric indicates a preference for minimizing disturbance.	Survey and register

Restoration Metric: Wetland Acreage

Several wetland functions that produce benefits to coastal populations can be directly related to the total acreage of wetlands, including storm impact buffering, floodwater storage, nutrient, sediment and contaminant absorption, provision of wildlife habitat, and biological productivity and diversity. Given Louisiana's coastal wetland loss crisis, we propose to use the total wetland acreage over time as a primary metric for alternative comparison. In a self-sustaining coastal ecosystem, wetland acreage would remain roughly constant and the corresponding storm surge threat would also remain relatively constant, all other factors being equal. The accounting includes benefits due to mechanical marsh creation and diversion of sediments and nutrients.

The following figures (Figures 5 - 12) show the computed total wetland acreages for each of the alternatives evaluated, as well as the FWOP in all planning units. For each alternative, two projections are presented, representing the two SLR projections assessed by the HET.

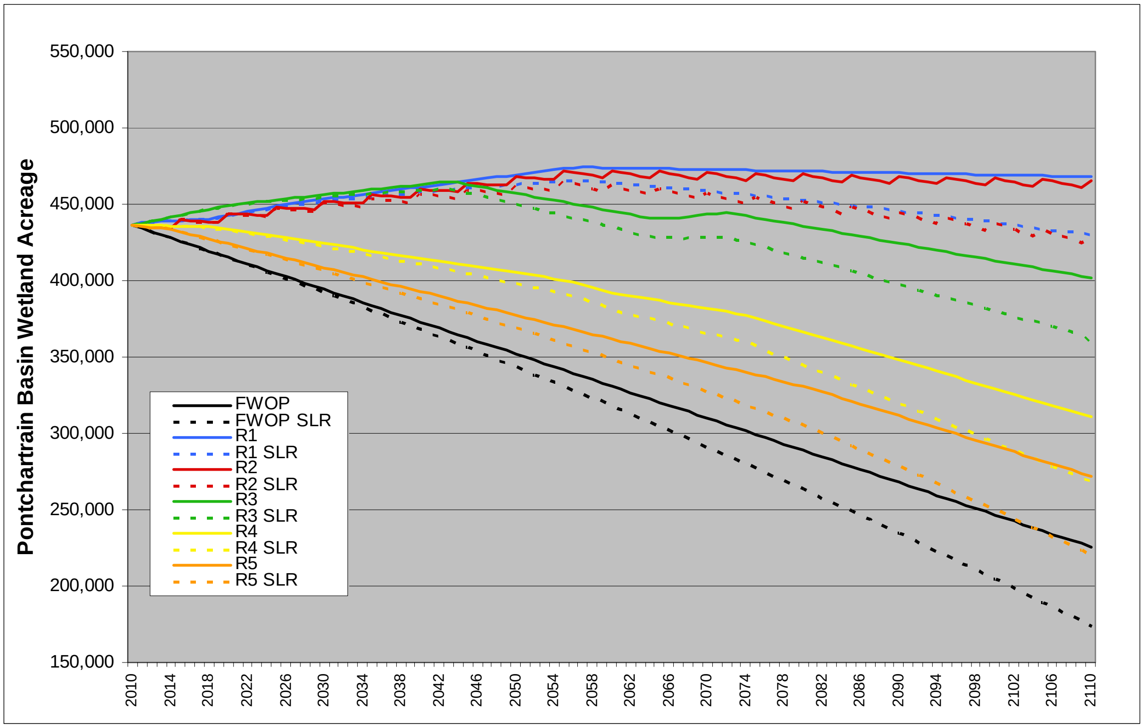
Ideally, future wetland acreage would be determined by wetland type (which could be summed) to provide additional insight into potential impacts or benefits of the proposed restoration measures. Unfortunately, the time constraints preclude use of sophisticated modeling techniques to predict acreages of future habitat types at the end of the 50-year planning horizon or a 100-year timeframe.

Adjustments to the baseline wetland acreages to account for levee impacts will be made on the basis of the direct footprint of the levee and any needed borrow area. These estimates were generated by the USACE for the HET. Adjustments are also made to account for mechanical marsh creation on the basis of the prioritizations discussed earlier in the document, and available sediment within each planning unit. Adjustments in annual acreages are also made on the basis of freshwater diversion benefits, as computed by a modified NRCS model that is discussed in Attachment C.

Future with Project (FWP) – Coastal Wetland Restoration Results for PU1

In PU1, Alternatives R1 and R2 sustain the Breton Sound and Pontchartrain Basin wetlands (Figures 5 & 6), but not that of the PU1 portion of the Mississippi River Delta. Because of the high subsidence rates in the Delta, the HET decided not to include any new restoration measures there and instead focused restoration measures in lower subsidence rate areas where benefits would be provided over a longer period of times. Consequently over the entire planning unit, R1 and R2 achieve sustainability only under the existing RSLR scenario but not under the medium RSLR increase scenario (Figure 5).

Figure 7. Predicted Pontchartrain Basin wetland restoration plan results.



Extensive future wetland losses in the Pontchartrain Basin make sustainability difficult to achieve. Possibly contributing to those high wetland losses is the uncertainty associated with the Maurepas Swamps wetland loss rate. The loss rate used was derived through the LCA Study and was not determined through satellite imagery since such rates are not well suited to forested wetland areas such as this. Better wetland loss rates in forested wetlands are needed to reduce uncertainty and improve restoration planning.

The existing I-10 earthen embankment through the Maurepas Swamp may preclude Mississippi River diversions of the magnitude needed to achieve sustainability of those swamps as proposed in Alternatives R1 and R2. More investigations are therefore needed to determine the extent of diversion that I-10 would allow and if insufficient, then solutions to this problem would be needed to achieve sustainability of those swamps.

Because the Biloxi Marshes and on the East Orleans Landbridge are somewhat distant from the Mississippi River and are bordered by lakes and bays which tend to capture diverted sediments, a Violet diversion over 100,000 cfs would be needed to achieve sustainability of those areas via Mississippi River diversions. This was considered to be impractical, hence, extensive use of shoreline protection and marsh creation measures was proposed in R1 and R2 to reduce and offset the high loss rates in those areas. However, if substantial synergistic effects of the proposed wetland restoration measures occur, then a reduction in scale or scope of those measures may be possible. Re-establishment of ideal conditions for oyster production to facilitate creation of oyster reef wave breaks may provide a less costly alternative means of achieving shoreline protection for the Biloxi Marshes.

The proposed 110,000 cfs diversion with sediment enrichment at American Bay provides substantial land-building benefits and is responsible for the superior performance of the R5 Alternative (Figure 4). However, American Bay is an inefficient location for landbuilding, the land created would provide little hurricane protection for New Orleans and adjoining communities, and dedicating such a large volume of river water at that location may preclude opportunities to sustain other more critically important marshes.

Figure 6. Predicted Breton Sound Basin wetland restoration plan results.

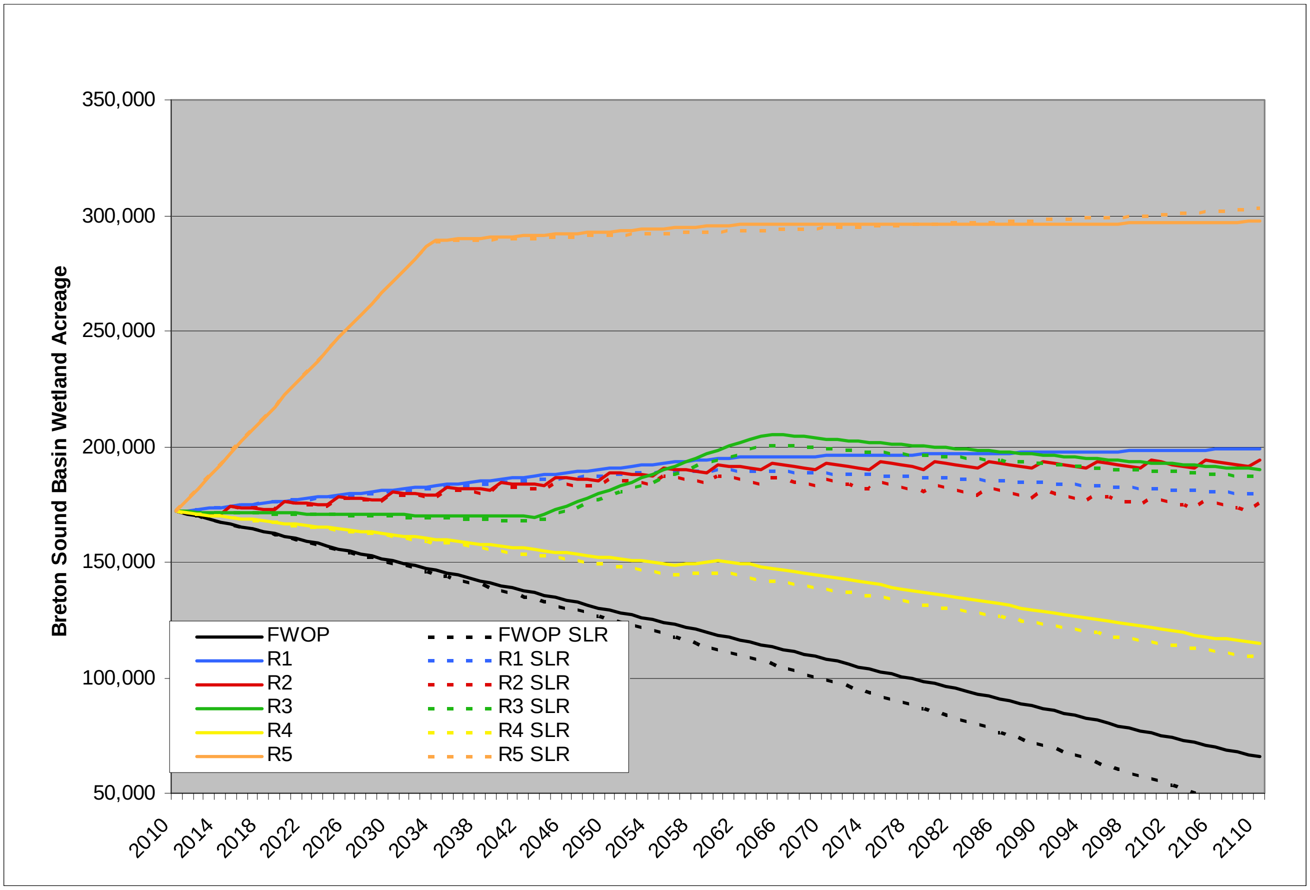
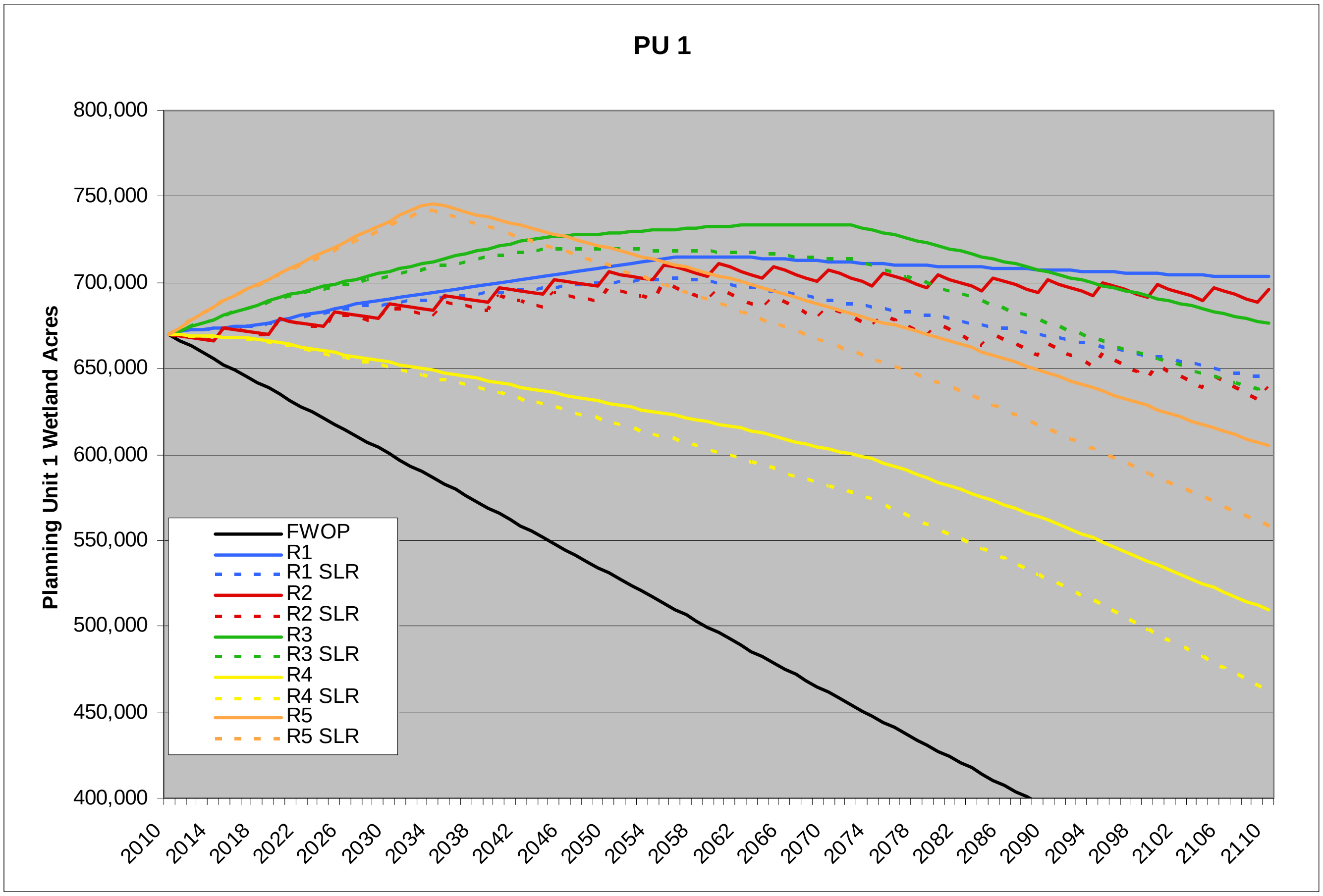


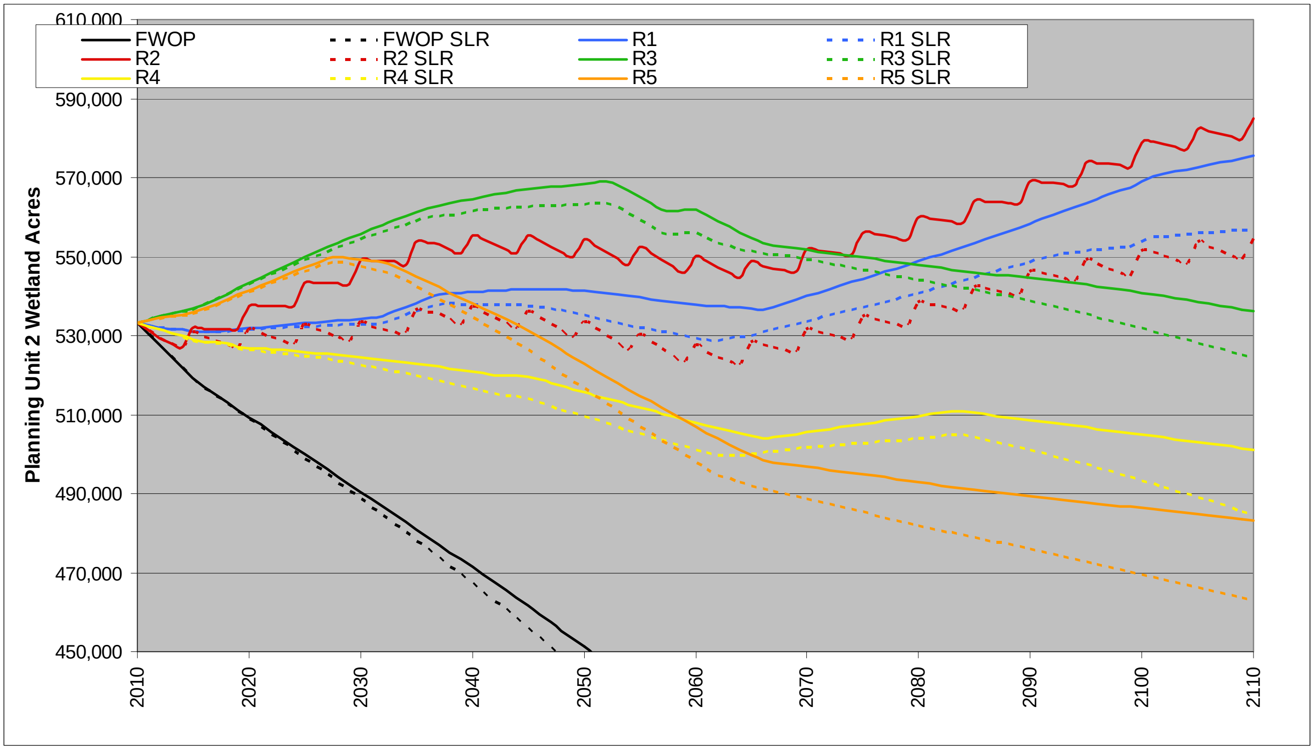
Figure 7. Predicted PU1 wetland restoration plan results.



<u>FWP – Coastal Wetland Restoration Results for PU2</u>

Ongoing wetland gains in the Mississippi River Delta portion of PU2 result in net wetland gains when included with restoration measures in the Barataria Basin portion of the planning unit (Figure 6). However, when sustainability is considered for the Barataria Basin alone (Figure 7), only R1 and R2 are able to achieve sustainability under the medium RSLR increase scenario.

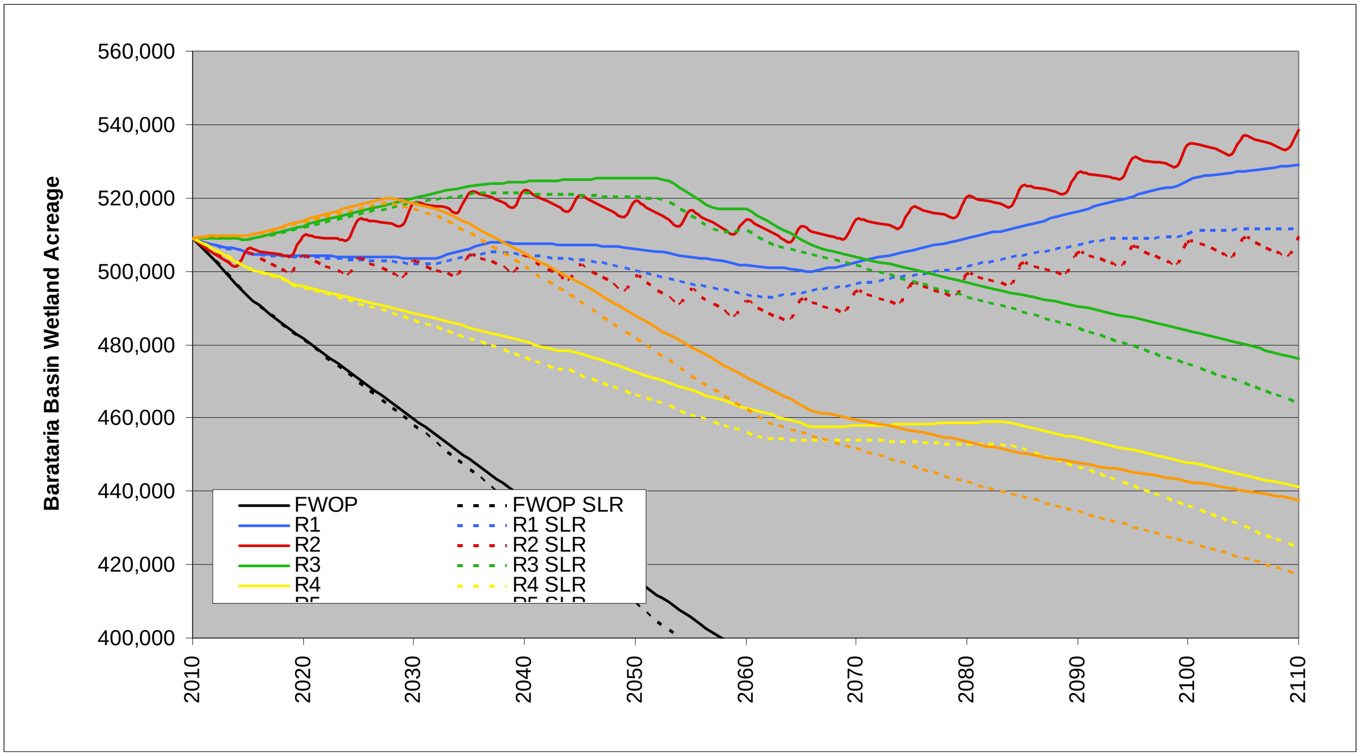
Figure 8. Predicted PU2 wetland restoration results.



In Alternatives R1 and R2, it was assumed that the extreme southwestern portion of the basin could not be sustained via diversions (area southwest of the Bayou L'Ours Ridge). However, the evaluation of those alternatives did not capture the likely reduction of loss rates in that area due to indirect diversion effects. Hence, the need to incorporate marsh creation to offset wetland losses not eliminated by diversions might be reduced. Also, the synergistic effects of the diversions into that basin may provide additional benefits that the analyses could not capture.

The Kraemer Ridge located in the upper basin swamps may isolate the swamps south of that ridge from benefits associated with the proposed upper basin diversions at Lagan and Edgard. In Alternatives R1 and R2, it was assumed that measures would be undertaken to ensure that those isolated swamps received sufficient benefits to eliminate wetland losses. As in PU1, a more accurate assessment of forested wetland loss rates is needed to appropriately plan and design diversions to sustain those upper basin swamps.

Figure 9. Predicted Barataria Basin wetland restoration results.



The ability to sustain the upper basin swamps may also be impacted by the combined effects of the existing hydrologic constriction at Bayou Des Allemand, the Highway 90 embankment across the basin, and potential diversion-related flooding of developed areas not currently protected by forced drainage systems.

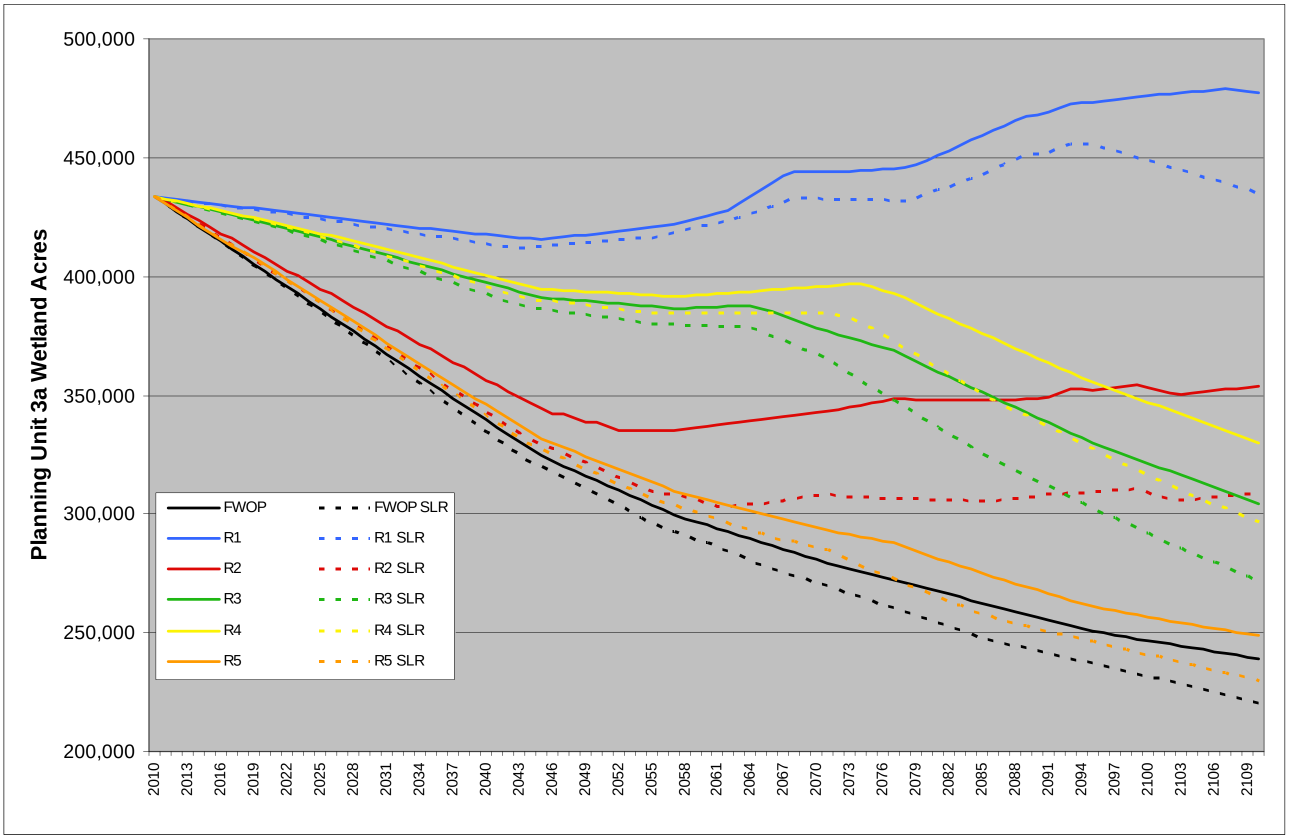
Maintenance of the marshes along the northern edge of Bartaria Bay was considered to be a critical restoration need for the entire basin. Loss of those marshes might allow saltwater impacts to cause wetland losses in currently stable fresh marsh areas. Maintenance and restoration of those bay-edge marshes would likely require erosion prevention measures as well as marsh creation as proposed in Alternatives R1, R2, and R4.

Restoration and maintenance of the barrier islands were also considered to be a critical need for the entire basin. That work could be achieved through deposition of hydraulically dredged sediments. A sediment diversion at Buras or Fort Jackson, to introduce sand into the litteral drift ecosystem may provide an alternative to mechanical barrier island maintenance as proposed via the R4 Alternative's 60,000 cfs diversion at Fort Jackson.

<u>FWP – Coastal Wetland Restoration Results for PU3a</u>
In Planning Unit 3a, sustainability was achieved only with the more effective Mississippi River Diversion Alternative (R1). Nevertheless, over 120,000 acres of marsh creation was needed to offset wetland losses in portions of the area not benefited by those diversions. The combined benefits of the many smaller GIWW diversions in Alternative R2 were much less effective in reducing wetland loss (Figure 8). Rather than propose an excessive and unrealistic amount of marsh creation to offset the remaining wetland losses, it was decided to include only the R1 marsh creation measures. In PU3a therefore, the R2 Alternative does not achieve sustainability. These evaluations illustrate the difficulties associated with achieving effective coastal wetland

restoration in PU3a. More work, specifically hydrologic modeling, is needed to assess the feasibility and extent of benefits of some of the larger measures and the combined benefits of all measures in PU3a.

Figure 10. Predicted PU3a wetland restoration results.



Although introduction of Mississippi River to portions of eastern Terrebonne could sustain that most rapidly deteriorating part of PU3a, construction of such a feature would be very difficult and costly. If that were not feasible or affordable, increasing Atchafalaya River freshwater inputs would be next best alternative, although unlikely to achieve sustainability. The more effective Atchafalaya River introduction options, however, may aggravate existing backwater flooding problems in the vicinity of Amelia and in Lake Verret Basin. Hence, that flooding problem would likely have to be resolved before those aggressive Atchafalaya introduction alternatives could be implemented.

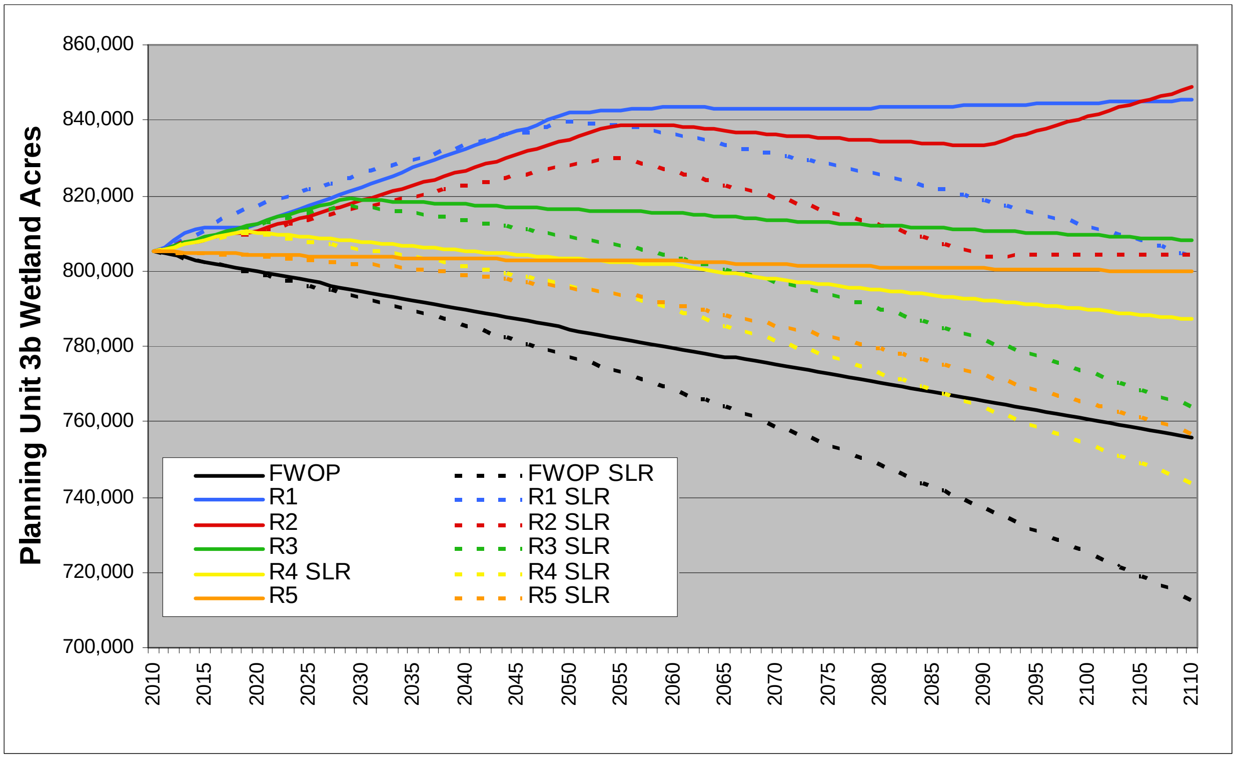
Those more aggressive Atchafalaya River introduction options, in combination with a GIWW conveyance channel south of Houma and other distribution channels, offer possibilities for substantially reducing wetland losses. The amount of water that could be introduced by such a combination of measures cannot be accurately determined at this time. Hydrologic modeling of such an alternative is needed to better assess the potential effectiveness of those options.

FWP – Coastal Wetland Restoration Results for PU3b & 4

Restoration plans in Planning Unit 3b included a number of small diversions from the GIWW, Bayou Penchant, and other local water bodies, in combination with shore protection and marsh creation measures (Figure 9). Hydrologic modeling of those larger measures is needed to better assess freshwater introduction opportunities for moving Atchafalaya River water and sediments to the critically important tidal marshes protecting the flotant marshes of the Penchant Basin.

Some plans also included several large-scale water/sediment management measures in Atchafalaya Bay. Benefits for those measures were obtained through evaluations made via the Coastal Wetlands Planning, Protection and Restoration Act program. A further assessment of benefits that might be obtained by such measures is needed, especially when combined with measures to provide synergistic opportunities. Those measures, such as the proposed reconstruction of the barrier reef from Pointe au Fer Island to Eugene Island, might have much greater benefits than anticipated as well as sizeable indirect benefits to western Terrebonne and other marshes.

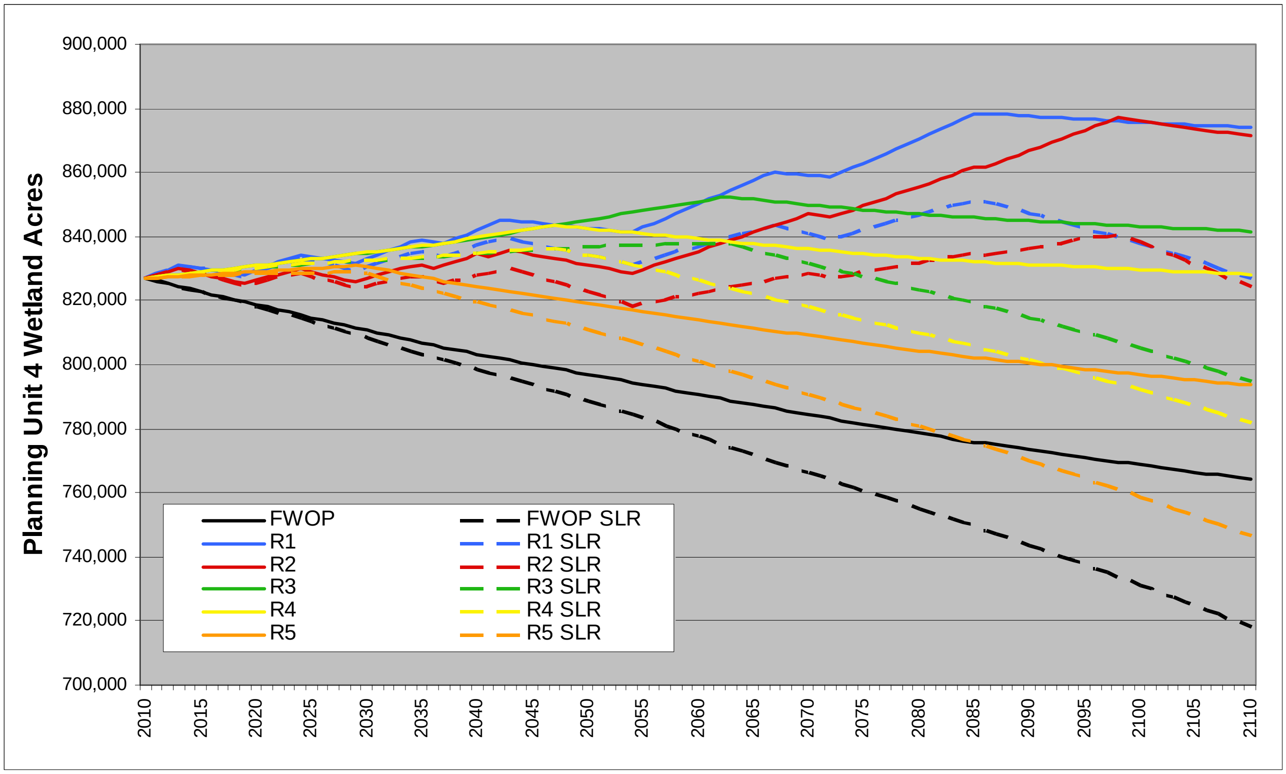
Figure 11. Predicted PU3b wetland restoration results.



In PU4, few details were available regarding aspects of proposed water management and salinity control measures. Lacking those details and suitable methods for assessing their benefits, the evaluation of alternative restoration plans in those areas was limited to the benefits achieved through shore protection and marsh creation measures (Figure 10). More detailed information, together with a method for assessing the effects of water and salinity management measures, would facilitate restoration planning and may reduce the need to rely strictly on shore protection and marsh creation measures.

The beneficial use of all maintenance dredged material is an obvious restoration measure in PU4. The mining of dredged material located in upland disposal sites may also offer an opportunity to restore marsh without the impacts associated with mining of lake bottoms. In PU4 and coastwide, an assessment of the relative cost-efficiency of shore protection to prevent wetlands losses versus marsh creation to replace lost marshes would facilitate restoration planning.

Figure 12. Predicted PU4 wetland restoration results.



Wetland Loss Rate Determination Methods.

To provide estimates of future wetland sustainability, loss rates were applied to existing and new wetland areas. Wetland acreage data (1956 to 2006) were obtained from the USGS, for a number of polygons across the coast. The 1956 and 1978 acreage data were obtained via map digitization and not from satellite imagery as were the data from later years. Because the 1978 to 2005 period did not include the rapid losses during the 1960s and 1970s, it was believed to better represent anticipated future losses. Therefore wetland acreage during the 100-year timeframe (2010-2110), was determined by extrapolation of the 1978-2006 loss rate. Although projecting acreage over the 100-year timeframe introduces enormous uncertainty, doing so is very valuable to illustrate where the current wetland loss trends are leading and to compare results among the various plans.

When extrapolating a loss rate over such a long period of time, the end result may vary significantly depending on how that rate is applied. The compounding rate (typical of the current CWPPRA program), may result in a reduction of losses over 100 years. However, plots of actual wetland acreage over the past 50 years reveals that losses have been quite linear and have not exhibited a decreasing trend. In fact, some areas exhibit a slight increasing loss trend (Figure 11).

For many of the polygons, the 50 years of wetland acreages were slightly better represented by a polynomial curve than by a linear line (Figure 12 & 13). However, when the polynomial curve was extended over the 100-year timeframe, it occasionally resulted in very unlikely scenarios. Hence, the polynomial equations were deemed to be not suitable for making 100-year projections. Given the uncertainties in future wetland loss rate changes, and the observed linear loss trends over the last 50 years, the HET decided to apply the 78-06 loss rate as a linear rate based on 1978 acreages.

Figure 13. Compounded Wetland Loss Rate

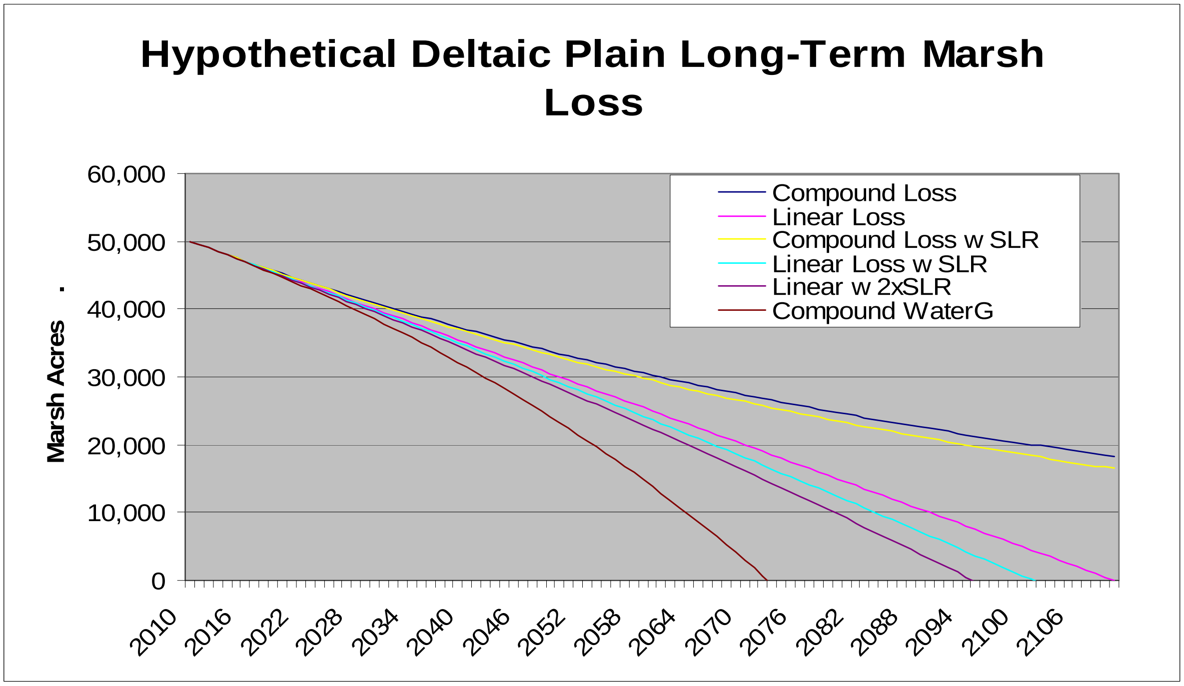


Figure 14. Example uncertainty in loss rate functions.

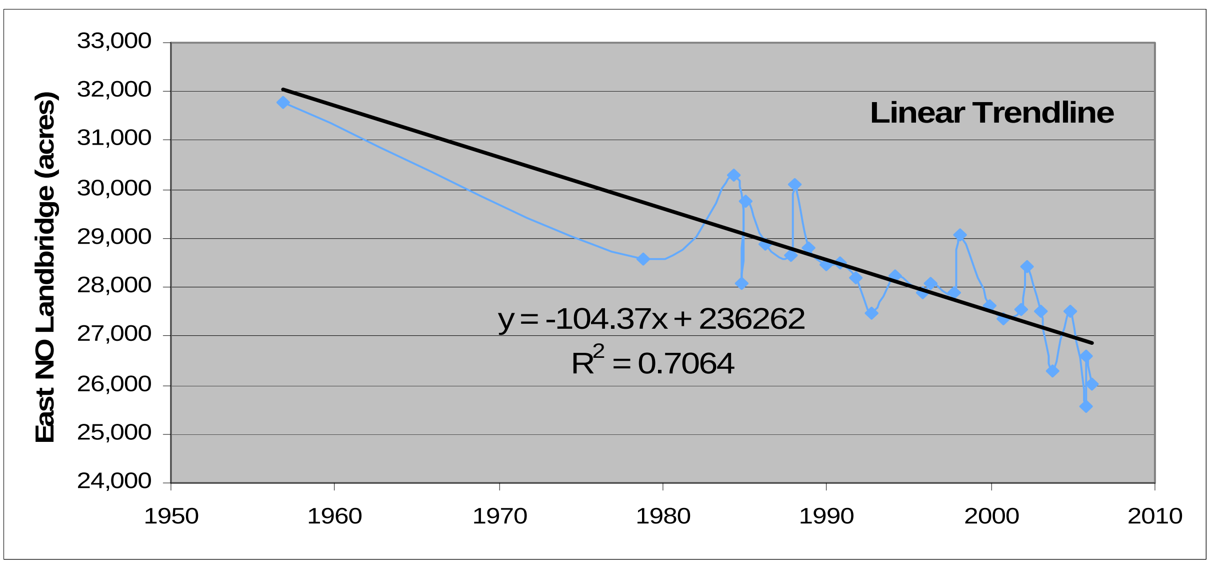
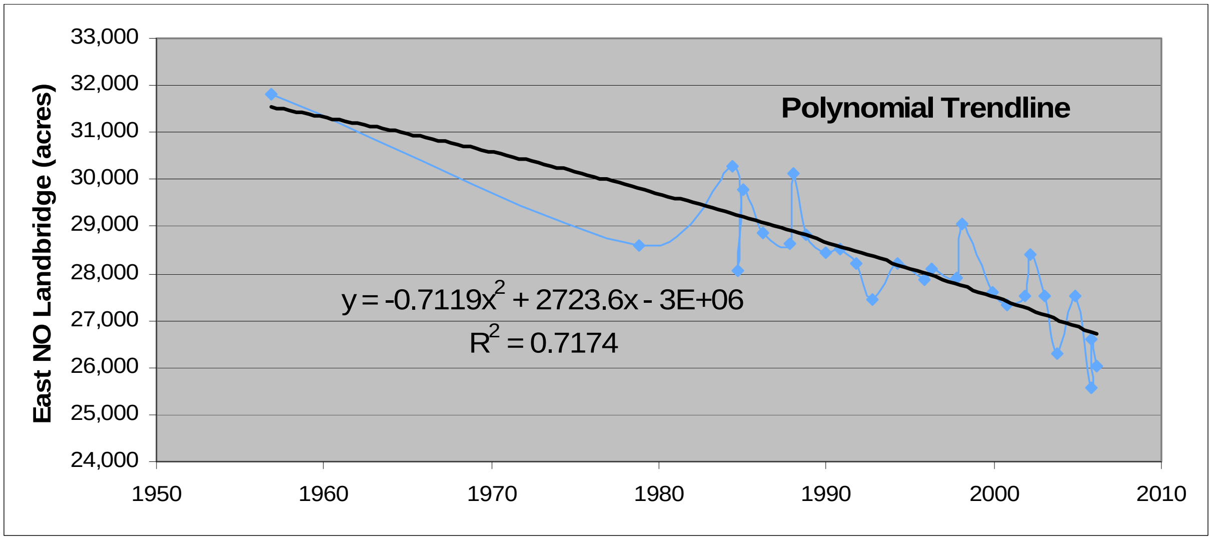


Figure 15. Trendline fits to measured wetland acreages.



Wetland acreage measurements from satellite imagery exhibit variations depending on water levels when sampled. To reduce this error, 1978 to 2006 loss rates were obtained from a linear regression over that period rather than from the actual data. This was especially useful in the Breton Sound Basin, which suffered extensive hurricane-related wetland losses during the later part of 2005 (see Figure 14). Use of the regression line to calculate wetland loss rates minimizes the substantial effect those hurricane impacts would otherwise have had on the loss rate.

Figure 16. Adjusted regression fit to Breton Sound.

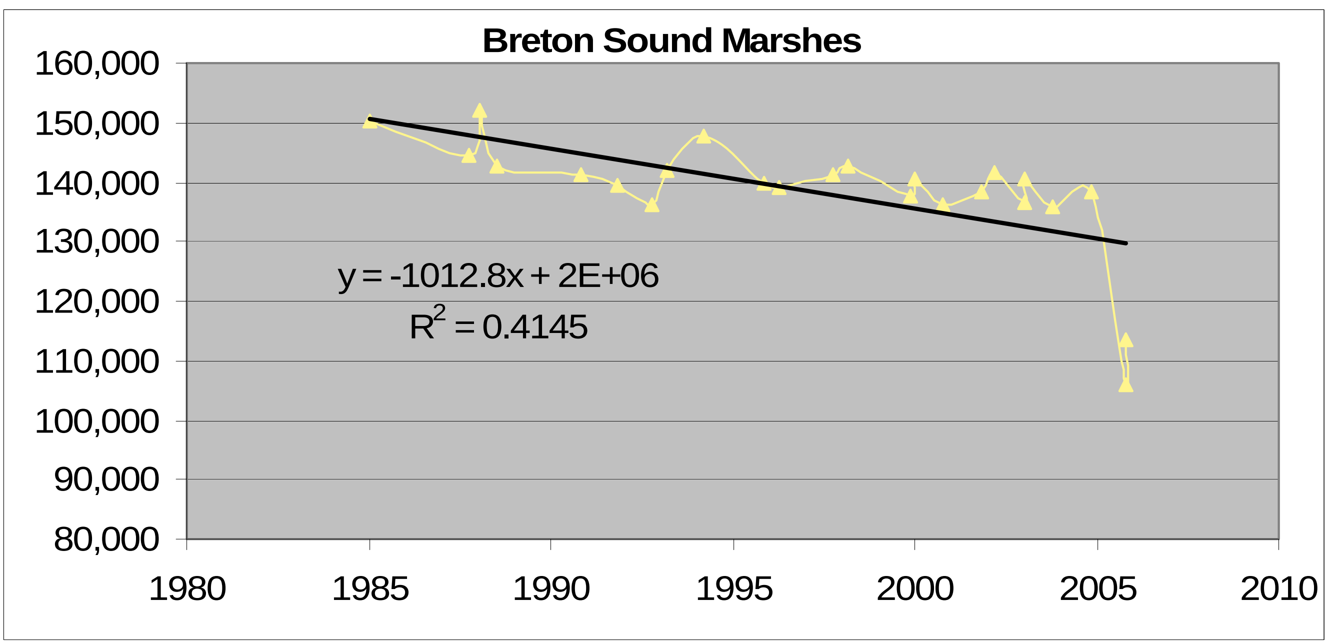


Table 12. Partial List of Uncertainties Affecting Wetland Acreage Projections.

Wetland Loss Rate Uncertainties
Subsidence rate changes
Sea level rise rate changes
Future hurricane effects
Satellite imagery-methodology issues
Loss rate extrapolation methodology
Synergistic and complimentary wetland restoration benefits
Diversion Benefits Assessment Uncertainities
Future Mississippi River suspended sediment quantity and quality
Location-related effects on duration of diversion discharges
Location-related effects on duration of diversion discharges
Sediment introduction characteristics of individual diversions
Diversion discharge estimates
Riverine nutrient flux
Suspended sediment deposition within diversion receiving areas
Nutrient retention with diversion receiving areas
Resuspension and removal of deposited subaqueous sediments
Anthromorphic-related inefficiencies in deltaic landbuilding
Nutrient-related benefits to emergent marshes
Sediment distribution throughout receiving area

Restoration Metric: Spatial Integrity Index

(Note: All Figures and Tables referred to in this section are presented in Attachment D)

Introduction

Principles of landscape ecology assert that landscapes are a mosaic of patches that can be defined by their structure, their function and change (Forman 1995). Our conceptual approach defines the landscapes in each of the principal hydrologic basins of the Louisiana coast by their structure (meaning the spatial relationship among distinct wetland patches or their elements and other key physical features such as barrier islands, ridges, and tributaries), their function (meaning the flow of mineral nutrients, water, energy, or species among component patches or between landscapes), and change (meaning the temporal alterations in the structure and function of landscapes or their components).

Our premise is that the structure, function and change of patches across landscape mosaics affect fundamental ecosystem processes, which determine the trajectories of ecological condition. Therefore, the quantification of landscape structure and measurements of change to that structure are important precursors to understanding functional effects of change (Tischendorf 2001). At the site scale, the structure of a wetland patch can be related to topography and other spatial attributes such as channel density and pattern and heterogeneity of vegetation types. At the landscape scale, the spatial configuration of wetland patches—e.g., their size, shape and connectivity—and the composition and connectivity of surrounding open water areas are the key components of structure.

One method to quantify structure employs the use of spatial "metrics" (Wu et al. 2000). Spatial structure metrics can be linked to function through a variety of analyses including regression-based and other types of statistical models and sensitivity analyses (Tischendorf 2001). For example, a tidal marsh-dependent vertebrate species might require connectivity with other wetland patches for dispersal and recruitment purposes, or may experience higher rates of predation in marshes with a high ratio of edge to interior habitat. Measurement of landscape context metrics may reveal adjacent land uses as potential stressors, or hint at exchange rates across ecotones.

For the LACPR, spatial characteristics will be calculated for important wetland features at the site and landscape scales and tied to ecological functions through hypotheses supported by conventional landscape ecology theory. It is anticipated that studies will be conducted to better link the spatial metrics and key functions, and that future revisions to the spatial model may be required. Remotely sensed satellite and low-altitude aerial photographic data combined with spatial data analysis tools in ARCGIS will be used for the assessment. This approach has proven successful in measuring broad scale landscape patterns and correlating such patterns with ecological functional changes (Kelly 2001).

Numerous spatial metrics have been used to characterize various landscape attributes and, by inference, important ecological processes. They can be categorized as follows:
(a) area metrics, (b) core area metrics, (c) patch density and size metrics, (d) edge metrics, (e) shape metrics, (f) diversity metrics, and (g) connectivity/interspersion metrics. Since many spatial metrics are highly correlated, an appropriate number of metrics each representing area, edge/shape, and connectivity/interspersion will be used in discriminating alternative plans. It will be necessary to relate the metrics to important processes or characteristics so that they can be interpreted for weighting the alternative plans. The table below establishes some of the potential inferences from each metric.

Metric	What is Measured	Related Processes/Conditions
Area	Composition	Stability/resiliency; Geomorphic process (if temporal assessment applied); Productivity
Edge/Shape	Configuration	Primary productivity; Hydropattern (applied to open water pathways); Stability/resiliency
Connectivity/ Interspersion	Configuration	Local spatial variability (diversity)

Table 13. Spatial Integrity Metrics and Related Processes/Conditions.

These metrics, and particularly interspersion, are highly scalable and determining the appropriate scale of application will be necessary. The large ecological gradients in the eastern basins may require division into smaller units (e.g. fresh/intermediate vs. brackish/saline) for landscape metric characterization.

Several trade-offs may be embedded within individual metrics. For example, edge and interspersion could both be used to assess wetland fragmentation. While this may result in higher primary productivity, it may also eventually lead to more rapid wetland losses. This suggests a careful evaluation of the metric sets and, where possible, identification of important thresholds or trade-offs.

Although the intent of the spatial integrity metric is to compare alternative plans, it may be possible to also refine the models so that they provide some predictive capability. Valid comparison to reference wetlands is difficult, but correlations between spatial metrics and ecosystem services may be developed over time, provided the appropriate data collection and analyses are conducted.

This study proposes to identify and test a variety of spatial metrics and incorporate them in a spatially-explicit model to assess historic trends. The historic trend output would then be used by the LACPR HET team to (1) support projections of "future without" and "future with" alternative landscape configuration patterns and (2) determine which restoration alternatives promote the greatest ecological sustainability.

Approach

Study Area

This study utilized the LACPR planning unit boundaries minus fastlands as the overall spatial extent (Figure 1). The spatial boundaries upon which the metrics were run are $4km^2$ grids. The boundaries of these 2km x 2km tiles are consistent with the original Louisiana Coastal Area (LCA) grid. Based on these spatial designations, a total of 8,437 tiles were evaluated in the study area using both grid-based and landscape-scale fragmentation analyses. The landscape-level metrics and analyses were used to assess more general trends in landscape configuration by planning unit.

Landscape Metrics

FRAGSTATS (McGarigal and Marks, 1995) is a software program designed to compute a wide variety of landscape metrics for categorical map patterns. This program was utilized because of its well tested utility as a packaged management tool and because it provides the greatest likelihood of product reproducibility. FRAGSTATS uses a grid-based approach, which is commonly not suitable for class scale determinations on entire landscapes; however it can provide class-level metrics, classification and assessments through individual non-related grid tiles. Historically, FRAGSTATS has been used for habitat suitability, change, and connectivity dynamics for forested ecosystems. Although there is very limited scientific literature on the study of marsh fragmentation and classification using FRAGSTATS, the authors have tested the use of this program to evaluate marsh breakup patterns in Terrebonne Parish, Louisiana under a saltwater intrusion scenario (Steyer et al., in prep), and feel it is appropriate for this study.

Landscape Classification

The Spatial Integrity Index (SII) developed as part of this study utilized a land-water classified image and a two-part classification system to support projections of landscape change as influenced by restoration alternatives. The two levels used in this system to denote landscape structure are: (1) *category*: ratio of water to land, and (2) *configuration*: marsh water area, shape and connectivity. This classification system (modified from Dozier, 1983) assigns values 1-10 to represent percentages of water. In this study, we represent the 10 classes of water as follows:

- Category 1, 0% to <5% water within marsh,
- Category 2, 5% to <15% water,
- Category 3, 15% to <25% water,
- Category 4, 25% to <35% water,
- Category 5, 35 to <45% water,
- Category 6, 45 to <55% water,
- Category 7, 55 to <65% water,
- Category 8, 65 to <75% water,
- Category 9, 75 to <85% water, and
- Category 10, >85% water.

The system subclasses utilized are identical to Dozier (1983) and are designated by the configuration of water bodies in the marsh. Class “A”, are configurations that are typically large water, (in relation to percent water class) and have connected water patches with linear edge. Class “B”, are configurations that are typically small (as related to associated percent water class) disconnected patches with a more random distribution, and fewer instances of connection. Class “C”, are configurations that are a combination of both class “A” and class “B” (with discernible regions of both). Figure 2 illustrates the SII class system. The numerical precursor denotes the amount of each tile occupied by water (increasing toward class 10) and the spatial configuration of water and land patches in each tile represented by A, B and C.

Due to considerations of data availability and time periods of interests, four dates of classified TM Landsat Thematic Mapper satellite imagery were selected for this examination. The classified land:water images utilized in this methodology were taken from existing data analyses described in Morton et al. (2005), Barras (2006), and Barras et al. (in-prep) using the same standardized methodology. The imagery and data utilized, from 1985, 1990, 2001 and 2006, were collected under similar water level and seasonal conditions.

To determine the appropriate grid scale required for maximizing the accuracy of SII classification, 4 km^2 and 16 km^2 raster grids were evaluated. These grid scales were identified because they were coarse enough to permit the extensive computer processing, and fine enough to not bias the classification. To standardize the tiling origin, and alleviate potential shift error, the project vector grid origin was based on an established grid system developed by Twilley and Barras (2003) for the Louisiana Coastal Area Ecosystem Restoration Study. Each land-water image was tiled using a geoprocessing routine to expedite the preparation and extraction of all raster grids or “tiles”. Each tile was then processed using FRAGSTATS and analyzed at the class metric level (i.e., statistics computed for every patch type or class in the landscape), and at each designated grid scale. Tiles were sorted by adjusted water percentages (recalculated category class, excluding "other" class), and by preliminary configuration thresholds (established to assess suitable metrics and metric combinations). Countless arrangements of metrics and metric combinations were selected and tested against configuration definitions. Category and configuration class output were assessed for accuracy of the computer generated classification. This method was used to evaluate all potential metrics, fit value thresholds to visually derived SII, and select adequate scale of tile. It was determined that the classifications based on the 4 km x 4 km extracted tile were often overwhelmed by large open water bodies, contained multiple SII classes, and were therefore too large to accurately classify the landscape. Conversely, the 2 km x 2 km tile system consistently classified the landscape correctly and thus was selected for this study.

The following landscape metrics which represent area, edge/shape, and connectivity/interspersion were selected after careful consideration of previous landscape fragmentation and configuration study metrics and evaluation of selected metrics toward meeting study goals.

Percentage of landscape occupied by water (PLDW) quantifies the proportional abundance of water within each patch type in the landscape. It is measured as the percentage of the landscape comprised of the corresponding class.

Number of patches of water (NPW) of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. It is measured as the number of patches of the corresponding class.

Patch density (PDW) of water has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. It is measured as the number of patches of the corresponding class divided by total landscape area.

Largest patch index (LPIW) of water at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. It is measured as the percentage of total landscape area comprised by the largest class.

Edge density of land (EDL) equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2). Edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.

Normalized Landscape shape index (NLSI) provides a simple measure of class aggregation or clumpiness. It is measured as the class perimeter length divided by the minimum perimeter needed for maximum aggregation.

Patch cohesion index of water (COHW) measures the physical connectedness of the corresponding patch type. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected.

Aggregation index of water (AIW) is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map.

Modified Simpson's diversity index (MSIDI) belongs to a general class of diversity indices to which Shannon's diversity index belongs. The Modified Simpson's diversity index evaluates whether any 2 classes selected at random would be different patch types.

Landscape Evaluation

The SII was used to examine multiple restoration alternatives, and project future landscape pattern under those scenarios. The restoration alternatives that were presented for evaluation are as follows:

- R1, (Figures 3a - 3e);
- R2, (Figures 4a - 4e);
- R3, (State Master Plan, Figures 5a - 5e);
- R4, (Figures 6a - 6e); and
- R5, (LCA Plan Best Meeting Objectives, Figures 7a - 7e).

Each of these alternatives was based on a low sea-level rise scenario. The diversion, marsh creation and barrier island measures of these plans were the primary features modeled in this application based on the initiation data provided by the HET team. Features such as shoreline stabilization, ridge restoration and gapping banks were assumed to have little effect on land change and configuration.

In order to provide a baseline of comparison, a “future without project (FWOP)” predictive scenario was created. While multiple “future without” scenarios have been developed in recent years, most project land loss or gain with little or no attention to the spatial pattern of that land. The LCA land loss polygons described in Barras et al. (2003) were updated for the current trend of land loss generated from 13 dates over the timeperiod 1978 – 2006. Polygons not evaluated for land loss trends under Barras et al (2003) were incorporated under the current analysis using the 1985-2006 data. The LCA polygon trend data set was rasterized at a 25x25 meter cell size to create a raster index file containing each loss polygon identified using a unique integer id (Figure 8). The Leica Imagine "Summary" function was then used to compare the raster index LCA loss unit file to each Landsat Thematic Mapper satellite classified land-water coastal mosaic and simplified historical habitat land-water coastal dataset to identify land-water acreage for each dataset by LCA trend polygon. To establish the FWOP scenario at year 50, a linear regression fit was applied to the data (Paille et al., in-prep). This FWOP scenario defined the total remaining acres in each of 183 polygons across the study area annually through year 2060 (50 year projection). The acreage by polygon was then merged with the tile grid in order to determine future acreage by tile. The composition of tiles in 2006, as well as trajectory of change over the 1985-2006 time period, was utilized to drive assumptions as to the spatial configuration of future acreage. All 8 metrics were run and evaluated by planning unit for years 2006, 2010, 2020, 2030, 2040, 2050, and 2060 to remain consistent with the LACPR land change evaluations.

Upon completion of the FWOP scenario, the restoration alternatives were evaluated. For each alternative, shape boundaries of all restoration measures were overlaid on the 2 km x 2 km grid. Tiles that were influenced by restoration measures were assigned new spatial configurations estimated based on land:water acreage provided by Paille et al., in-prep). Tiles affected by a restoration measure were compared to the same tile under the base year 2010 of the FWOP scenario for examination of effects. Details of the modeling approach are provided later in this document.

Determining future spatial configurations of restored landscapes with any degree of certainty is impossible at this time. The science has not evolved enough to support strong linkages between pattern and process that this level of assessment needs. A multiple lines of evidence approach was utilized that includes identifying historic patterns as a predictor of future change, identifying natural analogs that represent the types of restoration proposed, and using rules to drive configuration changes based on hypotheses of how spatial metrics and SII classes are linked to key functions provided by different categories of restoration measures.

In order to conduct the multiple lines of evidence approach, we identified eight categories of restoration measures that were common to the three restoration alternatives and considered them based on their location within the coastal landscape (high energy versus low energy). The categories are (1) freshwater diversions, (2) freshwater diversions coupled with marsh creation, (3) sediment diversions, (4) marsh creation coupled with shoreline stabilization, (5) marsh creation, (6) shoreline stabilization, (7) ridge restoration, and (8) barrier island restoration. Rules or hypotheses were then established that define how these restoration measures influence spatial configurations based on conventional landscape ecology theory and existing scientific literature or best professional scientific judgment. The existing scientific knowledge that helped frame our hypotheses are identified below.

Existing Scientific Knowledge:

- Suspended sediments increase and organic content decreases with increasing connectivity to riverine sources.
- Sedimentation rates in salt marshes vary as a function of either the distance from tidal channels or with flow distance between marsh and larger bodies of water.
- Sedimentation rates are inversely related to distance from marsh edge when sediment supplies are available to marsh.
- Sedimentation rates are positively related to hydro period (inundation duration) when sediment supplies are available to marsh.
- There are tradeoffs between hydro period and sedimentation. Increasing hydro period (to support sedimentation) beyond plant community thresholds will decrease productivity.
- Dissolved nutrient availability to marshes generally increases with greater connectivity to riverine sources and greater residence time of water.
- Sedimentation rates are positively related to plant stem density under normal conditions. Sedimentation by large storms may impact this relationship.

- Connectivity is a function of habitat type, drainage density, waterway orientation and levee height.
- Marshes tend to aggrade where fluvial flow becomes unconfined and degrade away from such sources.
- The flux of energy and nutrients across an ecotone depends on the surface area of the wetland contact zone.
- High river discharge coupled with southerly wind conditions can lead to sheet flow and sedimentation on the marsh.
- Storm surge breaks in barrier islands occur where the island width is least; so increasing island width not only minimizes the effects of storm surge, but also traps the sand as it rolls over the island.

Hypotheses

- Freshwater Diversions into existing patchy marsh will favor deposition of both organic and fine inorganic material and slowly increase sediment platform elevation. Large diversion flows or pulses into upper basins may result in transition to less fragmented classes due to the development of flotant. RULE: Existing marsh patches (B and C classes) will expand along their edges (stay within class or B go to C class) and small marsh patches will not coalesce unless large pulses or high diversion flows are employed (C class can go to A class, but is dependent on distance from source).
- Freshwater Diversions into large contiguous marsh creation patches will maintain contiguous marsh integrity by providing necessary sediment and nutrients to sustain the marsh. RULE: A class remains A class if sustained by diversion.
- Sediment Diversions into existing patchy marsh with low land:water ratios and slow currents will facilitate coarse and fine sediment deposition onto subaqueous habitats (e.g. bay bottoms), increasing their elevation and ultimately transforming them to subaerial marsh platforms (near field effect – extent dependent on diversion size/sediment content). RULE: Existing marsh patches will expand along their edges as adjacent ponds are infilled with sediment, and marsh patches will coalesce nearest the diversion. This effect might be greatest in class B and C. Increased channelization in near field will route flows and decrease sediment retention.
- Marsh creation will form contiguous marsh, and therefore increase the flow resistance on the marsh platform and thus concentrate flow in developed channels while maintaining large marsh patches. RULE: Marsh creation projects produce class A patterns immediately, with immediate formation of marsh channels, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.
- Marsh creation will form contiguous marsh, and coupling with shoreline stabilization will only change land:water acreage and not configuration (except immediately adjacent to shoreline stabilization). Therefore, increase in the flow resistance on the marsh platform will concentrate flow in developed channels while maintaining large marsh patches. RULE: Marsh creation projects produce class A patterns immediately, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.

- Shoreline stabilization will only change land:water acreage (from reduced shoreline erosion) and not change configuration. RULE: Trajectory of change from 1985-2006 by planning unit by marsh type will be applied to future condition.
- Ridge restoration will enhance skeletal network for water distribution within planning units, but no effect on pattern can be predicted. RULE: Trajectory of change from 1985-2006 by planning unit by marsh type will be applied to future condition.
- Barrier Island restoration will form contiguous back barrier marsh that may be enhanced by island rollover, but also susceptible to significant erosion during storm events. RULE: Marsh creation projects produce class A patterns immediately, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.
- Ecosystem performance and species survival are enhanced when external (storms) and internal (water flow) pulses are coupled.

Some of the assumptions made in applying the hypotheses in this application are:

- The effects of protection structures (levees) on water transport and flow, and how that process influences spatial configuration of the landscape was not addressed. It is anticipated that there will be non-linear responses in the landscape to these engineering features.
- Freshwater diversions will be operated in a manner that will not cause persistent flooding and impacts to the marsh landscape.
- No rapid subsidence collapse of the marsh landscape as described by Morton et al (2005) will occur again.
- Patchiness of vegetation is strongly dependent on propagation patterns (local reproduction strategies) of individual plant species within a marsh community type, but this will not be addressed.
- Build up of new land or the development of open water is a balance between net inputs of suspended sediments and organic production and outputs due to subsidence and export of eroded sediments.
- Primary productivity and, hence, stem density is enhanced with increased dissolved nutrient availability when nutrients are limited. This assumption does not take into account some evidence that belowground productivity will be reduced with increased nutrients nor that nutria may prefer higher nutrient plants.
- The remaining coastal landscape is more resilient to wetland loss (harder to lose) than the marsh that has been already lost, however it will be treated the same.
- Internal and external pulses were not coupled, therefore the effects of levees and shoreline stabilization on back marsh spatial integrity was not captured by spatial integrity metrics.
- Channel infilling will continue only until an equilibrium condition is reached based on the flow rates (tidal or diversion velocities) and the stability of the vegetation/soil matrix of the marsh.
- High discharge freshwater diversions or pulsed diversions will provide sedimentation on the marsh surface, but will also experience erosion in areas closest to the diversion.
- Barrier Island widths when restored will be maintained to eliminate island breaching during large storms.

These hypotheses need to be tested in order to better link the spatial metrics to key functions. As an initial test of the hypotheses, SII classes should be calculated for natural analogs representing some of the categories of restoration measures. In coastal Louisiana, there are few restoration projects that have been constructed and in place for a sufficient period of time to assess spatial change. The projects suggested for this evaluation are Sabine Refuge 1993, 1996, 1999 and Bayou Labranche 1994 representing marsh creation; Naomi 1993, West Pt ala Hache 1993, and Caernarvon 1991 representing freshwater diversion in broken marsh; West Bay 2003 representing sediment diversion into open water; and Wax Lake Outlet 1973 representing natural delta development.

Modeling Approach

FWOP

The foremost premise upon which the model operates is an assumption that different SII classes change in variable patterns. Observation of historic trends (1985 to 2006) will be used to determine how resistant A, B and C classes are to change, and how they vary by water class as well as across planning units. These spatial and categorical delineations will be utilized to drive future projections.

The mean change over time for each of the 8 spatial configuration metrics were calculated for every possible combination of planning unit (PU) and SII class. Any PU_SII class combination which did not occur during the observation period was assigned the average of a similar PU_SII class combination; however, this occurred infrequently. An assumption of linearity of change was then utilized (due to time constraints) and mean metric change was converted to a change rate on an annual basis. These change rates then formed “lookup tables” upon which the model draws (Appendix A of Attachment D).

Future projections (2010 – 2060) are based on land area change provided by Paille et al. (in prep), where the model attempts to reflect the land change data, driving the classification into the numeric portion of the SII class (1, 2, 3, 4, 5, 6, 7, 8, 9, 10). Land change projections were conducted on larger polygons than the 4 km^2 tiles used in this analysis. Therefore, tiles were assigned to polygons based on a majority rule. For FWOP projections, land gain or loss rates (in each 10-yr period) were then assigned to each tile in a polygon and projected future land area was calculated.

The spatial configuration portion of the SII class was calculated for each of the 8 metrics based on the lookup table value of the starting time period PU_SII class. Those tiles which experienced land gain utilize gain rates and loss tiles utilize loss rates. The annualized rate was first calculated for 4 years to achieve a 2010 projection. The 2010 SII class was then assigned based on the newly calculated spatial configuration metrics.
The process then iterates for the next 10-yr period based on the new SII class lookup value. The year 2010 served as our base year for the projection of future change.

Alternatives Assessment

The presence of hypothetical diversions and marsh creation measures in the alternatives required additional approaches for creating projections. As with the FWOP scenario, net benefit acreage for each of the measures that comprise the restoration alternatives was provided by Paille et al. (in-prep), and the model seeks to reflect those data. Net benefit acreage was again assigned to larger polygons, so tiles were assigned to polygons based on a majority rule. The model seeks to first distribute that benefit acreage appropriately throughout the tiles based on the type of restoration measures; however each type was modified differently based on the rules that were previously described.

Benefit area assignments were defined for marsh creation measures, marsh creation measures sustained by diversion measures, and diversion measures. The approach for each is defined as follows:

Marsh Creation Benefit Area Assignment

- Total available water area was assessed for all tiles in a given polygon.
- This figure was then multiplied by 0.7 as a result of the desire to implement marsh creation projects in a 70/30 land/water ratio.
- The resulting acreage was the maximum available area to be built, which was then compared to the Paille et al. (in-prep) benefit acreage for that 10-yr period.
- All cells were brought to the highest land acreage possible and assigned a spatial configuration class of "A". The mean metrics for the class were assigned.
- If the maximum available area was less than that of the benefit acres provided, that benefit could not be reflected.
- If the marsh creation project was not sustained by a diversion, it was subjected to 10-yrs of loss spatial configuration change rates and the process repeated for the next 10-yr period.

Marsh Creation (sustained by diversion) Benefit Area Assignment

- The benefit area was assigned in the same manner as other marsh creation projects, however the sustaining effect of the diversion was assumed to keep the spatial configuration as an "A" class.

Diversion Benefit Area Assignment

- Diversion land building was excluded in SII classes 1 and 10.
  - The assumptions here being that a diversion will not build a tile to any more than 95% land, and open water is very difficult to alter and build land.
- Diversion benefits were commonly assigned to large polygons, requiring a means of further discriminating where benefits occurred.
- Diversion "Zones of Influence" polygons were often found to not contain enough available water area to reflect the land benefit acreages provided.
- A shortest distance to diversion methodology was utilized where:
  - The cell which was closest to a diversion would first be subjected to gain rates as assigned by PU_SII class for a ten year period;
  - The model would then check that increase in acreage against the total benefit provided. If more benefit needed to be assigned, the next closest cell would receive benefits;
  - Once all benefits were assigned, the model would exit the loop and move on to the next diversion.

- A 20km threshold was also utilized as the maximum distance a diversion could assign benefits to avoid situations in which the benefit acreage criteria was not met, and consequently land building occurs at distances it logically could not benefit.
- If the benefit acreage can not be completely assigned within those restrictions (available tiles SII classes 2-9, within 20km) those benefits could not be reflected.

The LACPR HET will ultimately be responsible for placing value judgments on what type of spatial pattern is more beneficial from an overall ecosystem sustainability perspective. A reproducible numeric approach was developed for each selected metric (percentage of landscape occupied by water, edge density of land, and patch cohesion), where the average values calculated from each of the four dates of imagery (1985, 1990, 2001 and 2006) were averaged across all dates to determine rankings by SII. The SII rankings were then assigned an index value from 0 – 1 based on equal distribution across the 24 SII classes. These values were then used to calculate average values for each metric by PU. This type of ranking system may prove valuable to facilitate the comparison and interpretation of results; otherwise evaluation of positive or negative effect for particular processes as represented by a specific SII (i.e., fisheries utilization vs. land stability) will be a subjective determination by the LACPR HET.

Results & Discussion

The results and discussion presented in this draft report are going to concentrate on change assessments for PU's 1, 2, 3a, 3b, and 4 between two historic time periods (1985 and 2006) and two future dates (2010 and 2060) even though multiple dates were assessed. Additionally, results will focus on the metrics "Percentage of Landscape Occupied by Water", "Edge Density of Land", and "Patch Cohesion" as metrics that best represent the functions land stability, fisheries utilization, and hydrologic connectivity, respectively.

Classification Change

Historic Evaluation

The SII was calculated for 8,437 tiles coastwide for 1985, 1990, 2001 and 2006, and the spatial representation of the data from 1985 and 2006 are shown in Figures 9 and 10, respectively. The darker saturations/intensities (within a particular color) represent A classes, which denote large, contiguous patches of land and at least one large, contiguous patch of water. The intermediate saturations/intensities (within a particular color) represent C classes, which denote some fragmented patches of land and at least one large, contiguous patch of water. The light saturations/intensities (within a particular color) represent B classes, which denote a disaggregated configuration of land and water patches occurring throughout the tile.

Preliminary observations of these data suggest that the classification system accurately classified the amount of each tile represented by water. Overlays of these results with the original land:water classification by Barras (2006) showed a significant match. The SII also appear to match up fairly well with long term personal observations. As an initial sensitivity analysis, an evaluation of PU's 1 and 2 (Figures 11 – 12) and PU's 3a, 3b, and 4 (Figures 13 - 14) was conducted to corroborate results from this study with detailed pre and post-hurricane observations and data collection that was conducted in 2004, 2005 and 2006 throughout coastal

Louisiana. The lighter saturation/intensities in upper Breton Sound in PU1 and in Cameron Creole Watershed in PU4 in 2006 are confirmed B classes. Preliminary data comparisons of configuration classes in PU's 2, 3a and 3b were inconclusive. A more detailed sensitivity analysis needs to be conducted in the future.

The coastwide evaluation of SII changes from 1985 to 2006 is presented in Table 1. This matrix shows that over 58% of the coastwide tiles classified remained unchanged over this 21 year period. More importantly, it shows that tiles that started out as either class 1 (solid land) or class 10 (solid water) remained stable and didn't change class over the timeperiod. The data also show that generally A classes are most stable over time, followed by C classes and B classes. The percent of the A classes that remained unchanged, regardless of the water class in the tiles, always exceeded that of the B and C classes. Additionally, as water classes increase, the B classes that remain unchanged decrease. These findings suggest that the general trend of most stable to least stable is class A to C to B. When this evaluation was conducted at the planning unit (PU) scale, all planning units followed this general trend. Results from PU's 1, 2, 3a, 3b and 4 are included in Tables 2 - 6. It is interesting to note that PU1 had the greater amount of percent unchanged tiles (70.8%) whereas PU4 had the least (41.67). The result in PU4 may be reflecting the change in solid land (class 1) to water classes that is associated with impacts from Hurricane Rita. Further investigation into why there are large differences in the amount of percent unchanged tiles between PU's is needed.

<u>FWOP</u>

The FWOP SII was projected for 2010 and 2060 and is shown for PU's 1-2 in Figures 15 and 16. The greatest change over this time period is reflected in the increase in open water (higher SII classes), that visually match the land loss estimates provided by Paille et al. (in-prep). The large open water projected by 2060 is primarily in the marshes adjacent to the Gulf of Mexico in PU's 1 and 2, adjacent to large existing water bodies in PU1, and in interior marshes in central Barataria Basin in PU2. Figure 17 illustrates this point by showing that the middle and lower portions of PU's 1 and 2 are completely dominated by water. The SII change matrices also reflect the increase in water from 2010 to 2060. Planning unit 1 (Table 7) is dominated by a 1 category increase in water and a large shift in A classes to C classes. The matrix for PU2 (Table 8) illustrates 1-3 category increases in water (primarily 2 category), reflective of the higher landloss rates in PU2. The configuration of the remaining landscape is dominated by larger water patches in Barataria and Breton Sound and a greater disaggregation of land in lower Pontchartrain Basin (Figure 18). Planning units 1 and 2 have a slightly greater connectivity between water patches in the lower basin and a greater connectivity in the upper basin, as reflected in the patch cohesion metric in Figure 19.

The FWOP SII projections for 2010 and 2060 for PU's 3a, 3b and 4 are shown in Figures 20 and 21. The areas showing the highest SII classes reflecting increases in open water visually match those estimates provided by Paille et al. (in-prep) and Barras et al. (2003). The areas projected to continue to fragment and/or convert to open water include, but are not limited to, the landscape between Lake Boudreaux and Bayou LaFourche in PU 3a, North of Lake Mechant in PU 3b, and Grand Chenier and south White Lake in PU 4. The landscape west of Calcasieu Lake does not reflect well the losses projected from Barras et al. (2003). This area (other than the southwest region) shows higher percentages of water in 2010 than in 2060 (Figure 22), which suggests either an error in the model or that the polygon size and associated land loss rate applied from Paille et al. (in-prep) needs to be adjusted. The matrix for PU3a (Table 9) illustrates 1-3 category increases in water, consistent with the highest landloss rates found in this PU (Figure 22 and 23). Planning unit 3b, which includes a land building area in the Atchafalaya delta, and PU4 have slightly greater connectivity between water patches, as reflected in the patch cohesion metric in Figure 24, but also a smaller change in water category classes as compared to the higher loss areas in PU's 2 and 3a (Tables 10 & 11). A limitation of the projections is they assume that trajectories of land change and land configuration in the past (1985 – 2006) will be the same in the future. Refinements to address this assumption and a more detailed sensitivity analysis will be conducted in the future.

Alternatives Assessment

The alternatives assessment focused on evaluations of each of the alternatives at 2060 as compared to the FWOP condition. In PU's 1 and 2, all of the alternatives had greater spatial integrity than the FWOP condition (Figure 16). Most restoration measures within all of the plans are clearly identifiable. The R1 and R2 diversion and marsh creation measures increased the spatial integrity significantly in upper Breton Sound, the east flank of the Barataria Basin and the Barrier Islands (Figure 26). The R3 diversion and marsh creation measures increased the spatial integrity significantly in the Biloxi marshes, the east and west flanks of the Barataria Basin, the upper birdsfoot delta, and the Barrier Islands (Figure 27). The R4 diversion and marsh creation measures increased the spatial integrity similarly to R3 except had less spatial integrity in the upper Breton Sound and upper birdsfoot delta (Figure 28). The heavy influence of diversions and limited marsh creation is evident in the spatial integrity patterns of alternative R5 (Figure 29).

Planning units 3a, 3b and 4 also had greater spatial integrity than the FWOP condition for all alternatives (Figure 21). The influence of marsh creation features on the landscape, especially in PU3a - upper Terrebonne Basin are obvious (Figures 30 – 33), and when combined with freshwater influence from the GIWW, show the greatest spatial integrity (Figure 31). The R5 alternative in PU3a limited the use of marsh creation and showed the greatest water classes in 2060 (Figure 34). The differences in spatial integrity among alternatives in PU3b and PU4 were barely recognizable, primarily due to the use of protection features, which are not captured by the model, and small benefit areas associated with marsh creation and freshwater introduction features.

The individual SII change matrices between 2010 and 2060 for each of the alternatives can be found in Appendix B. A summary of those matrices are provided by category (water class; Figures 35 and 36) and by configuration class (Figures 37 and 38). Though categories 1 and 10 are end members which signify extremes in the category class spectrum and are therefore important to the overall average change in classification, their frequency and resistance to change, both require and enable their exclusion from select summary statistics and figures. In PU1, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R3 followed by R1 and R2 then R4 > R5 > FWOP (Figure 35). There was little difference in the occurrence of A classes at year 2060 between all alternatives except R5 (Figure 37). In PU2, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R1, followed closely by R2 and R3 with the least land classes in R5 > R4 > FWOP, however the increase in water classes 6 – 9 do not show FWOP as the greatest. This decline in FWOP classes 6 – 9 was expected since a higher percentage of tiles converted to class 10 in FWOP than in any other plan. The greatest number of A classes and fewest number of B and C classes are found in R3.

In PU3a, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R3 followed closely by R1, R2 and R4 then R5 > FWOP (Figure 36). There was little difference in the occurrence of A classes at year 2060 between all alternatives except R5 (Figure 38). In PU3b and PU4, a trend of declining frequency in water classes as you gain more water was distinct (Figure 36). This is evident of natural land building that occurs in the Atchafalaya delta in PU3b and lower land loss rates in PU4. The results across all PU's illustrate that you lose a higher percentage of B classes in FWOP and that a large number of C classes are converted to A classes by marsh creation and diversion measures.

The ability to discern the influences of restoration measures on specific functions, and therefore compare each alternative was captured through a change analysis by metric between FWOP and each alternative. This approach shows only the influences of the restoration measures that comprise each of the alternatives, with no change represented outside of these areas. The change in percentage of landscape occupied by water metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 39 – 43 and in PU's 3a, 3b and 4 in Figures 44 - 48. The change in the edge density of land metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 49 – 53 and in PU's 3a, 3b and 4 in Figures 54 - 58. The change in the patch cohesion of water metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 59 – 63 and in PU's 3a, 3b and 4 in Figures 64 - 68. These figures provide a visualization of how particular functions as represented by the metrics are maintained in 2060 by the different alternatives. The details of how individual metrics change among alternatives and FWOP between 2010 and 2060 are included in Figures 69 - 74 and Tables 12 - 14. In PU's 1 and 2, the general pattern in 2060 is that R3 has the smallest percentage of landscape occupied by water, followed by R1 and R2, then the most water in R4 < R5 < FWOP. In PU3a, R4 has the smallest percentage of landscape occupied by water. The patterns in PU3b and PU4 are similar with R3 having the smallest percentage of landscape occupied by water, followed by R1 < R2 < R4 < R5 < FWOP. Alternative R5 had the greatest amount of water at year 2060 across all PU's. The amount of edge metric represented in Figures 71 & 72 must be interpreted carefully because edge density increases when SII classes 1 – 5 degrade and then edge density declines when you increase the amount of SII classes 6 – 9. All PU's show declines in edge density over time except in PU3b, where active land building (Atchafalaya delta) and large marsh creations into previous large open water areas increase edge. Cohesion values represent in part how water bodies coalesce over time as land is lost. Across all PU's, R3 generally had the lowest cohesion of water values whereas R5 and FWOP had the highest values.

Index values were created for each metric to calculate an average value for each metric by PU to support a further evaluation of alternatives. It is important to note with regard to interpretation of R1 and R2, that the model is incapable of appropriately projecting the differential effects of the operation schemes which distinguish these alternatives from each other. As the locations of diversions and marsh creation features are held constant, leaving only the net land area benefits to vary among the plans, we expected and indeed saw nearly identical results for these plans.
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A land stability index was generated from the percentage of landscape occupied by water and the number of unchanged tiles (Figures 75 and 76, Table 15). Though it may be intuitive to believe this occurs as a result of these plans building the most land, it is not necessarily the case. The land stability index places emphasis not only on the amount of land built, but the spatial configuration of that land. Also, the results of the spatial integrity model utilized in this analysis are highly dependent upon the spatial distribution of restoration features throughout a landscape. The greatest land stability was found in R3 for alternatives PU1 and PU2; R4 in PU3a; R1 in PU3b; and R1 and R3 in PU4. In general, it appears that R1, R2 and R3 seem to have employed a greater number of small to medium diversions, spaced strategically throughout the PU with significant marsh creation. A diversion strategically placed to influence large areas of degraded, fragmented marsh will often have more beneficial results than a diversion placed in close proximity to large amounts of open water. This occurs as a result of multiple assumptions built into the spatial integrity model. First, diversion benefits are only allowed within a 20km distance of the diversion. Second, benefits are not allowed to be assigned to "open water" (Class 10) or tiles containing more than 95% land (Class 1). The combination of these assumptions can lead to situations where the model is incapable of assigning land building benefits. Placement is also of the utmost importance with regard to marsh creation projects. Marsh creation projects are assumed to be installed as "A" configuration classes (typically containing large amounts of aggregated land). Therefore, a marsh creation project which falls on top of areas which are already highly aggregated will have less beneficial influence than one placed in highly disaggregated areas. This is reflected in PU2 where R3 employed the greatest amount of marsh creation and had the greatest land stability at 2060. The R5 alternative in PU4 shows a significant increase in land stability from 2010 to 2040. This finding is contrary to what we would expect and may be reflective of how benefits (land loss rate reductions) were assigned associated with salinity control features in this alternative and the large polygon size that represents this area.

The edge utilization index was calculated from the edge density of land metric (Figures 77 and 78, Table 16). The results from PU's 1, 2 and 3a reflect the large contiguous marsh patches created initially followed by there disaggregation over time and creation of more edge. Alternative R5 which employed the least amount of marsh creation across PU's, showed high edge utilization values. This is suggestive of fewer A classes and a greater amount of B and C classes. The highest wetland loss areas are found in PU's 2 and 3b and this is reflected in very low values of edge utilization in 2060, apparently from small water patches coalescing into large water patches. There is an increasing trend in edge utilization in PU's 3b and 4 over time. This may be reflective of a less patchy landscape and more stable landscape in 2010 that then degrades over time. The low initial edge utilization index value of R5 in PU4 is consistent with the problem findings addressed in the land stability index.

The cohesion of water patch metric was used to generate the hydrologic connectivity index (Figures 79 and 80, Table 17). The FWOP reflects that as you lose land, there is a greater connectivity between water patches, and therefore high index values. The R4, R5 and FWOP alternatives had the highest values in PU's 1, 2, 3b and 4. This may be indicative of PU1 and PU2 starting out in a more deteriorated condition, such that new land building contributes to the large increase in cohesion of water patches. In PU3b and PU4, all alternatives decrease over time. The cohesion of water patch trend most commonly reflects that C classes are higher than A classes which are higher than B classes

The results from all of the metrics suggest that the geographic location of features is highly influential on model output. In many ways, placement of restoration features has a larger influence on the values of spatial integrity metrics than does cfs load or net acres of benefit. It may be important to place larger emphasis on feature location in future plan development efforts.

Future Plans

The conception, creation, and implementation of this model took place in a very short timeframe. Minimal time was afforded for further investigations of historical trends and in depth assessments of the validity of model's assumptions and/or methodologies. Easy approaches were, at times, selected over more rigorous approaches due to time constraints and the lack of the scientific backing to draw on. Therefore, future study of the assumptions and methodologies is encouraged to increase the validity and value of the results.

One such assumption warranting further investigation are the rates of change projected for various restoration features. The model currently utilizes rates of change based on tiles experiencing land gain from a variety of sources during the 1990-2001 period. This approach excludes an ability to incorporate variable patterns of change which may result from features with variable design and operation schemes. For example, rates of spatial pattern change are exactly the same for a 1,000 cfs diversion as that of an 80,000 cfs diversion (until land gain projections are met). Similarly, the model currently assumes a steady and pulsed diversion operation scheme will affect spatial pattern in the same manner. Realistically, benefits and change in spatial pattern will probably vary with operation scheme, cfs load and other factors. Therefore, further investigation into these variables is considered vital to the utility of projections of spatial pattern under different restoration strategies.

Another issue in need of future study would be incorporation of bathymetric depth as a variable affecting the likelihood and magnitude of change, not only in terms of land gain, but the spatial pattern of that gain. One assumption that affects model output routinely is the restriction of diversion land building benefits in open water tiles (Class 10). This assumption is logical in most cases, in that a $4km^2$ area of open water is unlikely to experience land gain. These tiles are usually deep and subjected to sufficient energy to maintain them as open water. There are a few cases however, where shallow open water, protected from wave energy, should be considered viable candidates to receive land building benefits from diversions. Therefore, incorporation of depth dependency may also improve the value of results.

A constant threshold distance of 20km is currently utilized to prevent diversion benefits beyond a reasonable distance. This distance was commonly utilized in LCA and was agreed upon as a maximum distance at which you could expect benefits by a panel of experts. This assumption needs to be tested. Although one would expect a majority of the benefits to occur closest to the diversions, there is uncertainty regarding the distance from source that freshwater, sediment, and nutrient benefits are provided.

Investigation of boundary condition effects on the spatial integrity model also warrants further investigation. Boundary conditions may affect specific metrics primarily due to the Euclidean geometry of square tiles. This study utilized 4km^2 tiles in an attempt to alleviate boundary conditions as much as possible. Boundary condition effects could be reduced further by using a moving window analysis to assess patterns; however it is computationally intensive. Removing the potential influence of boundary condition effects may enable assessment of finer scale patterns, and thereby provide more accurate projections at finer scales.

Structural Metric: Direct Wetland Impacts

A direct wetland impact is the acreage directly lost or impacted by construction of structural alternatives (i.e., levees). It is a straightforward number that could eventually be used to determine the amount and, depending on habitat impacted, quality of habitat that needs to be replaced or restored through mitigation. This is not a measure of direct impacts due to non-structural or coastal restoration alternatives.

Methodology

To understand the full range of potential environmental effects from structural hurricane risk reduction measures (e.g., levees) both direct and indirect environmental effects must be assessed. For LACPR, the potential direct impacts to wetlands from the footprint of levees and associated borrow sites have been estimated using what is being called a "max-gross" approach. With the max-gross approach there is no consideration of temporal aspects such as background wetland loss rates and phased levee construction. The potential direct wetland losses (and associated mitigation needs) are calculated by simply overlaying the footprint of a given levee and associated borrow areas on the existing coastal landscape, assuming that all construction impacts occur simultaneously. The max-gross approach uses these simplifying assumptions to produce acreages of potential adverse direct wetland impacts.

Table 14 Direct Wetland Impacts for Structural Alternatives (acres)

PU1	
Structural Alternatives	Direct Impacts
LP-a-100-1	4,200
LP-b-400-1	3,600
LP-a-100-3	6,000
HL-a-100-3	5,500
LP-a-100-2	1,000
HL-a-100-2	4,100
LP-b-1000-1	3,700
HL-b-400-2	4,200
LP-b-400-3	7,500
HL-b-400-3	5,100
LP-b-1000-2	9,100

PU2	
Structural Alternatives	Direct Wetland Impacts
WBI-100-1	0
G-100-1	1,000
R-100-2	700
R-100-3	1,000
WBI-400-1	3,700
R-100-4	1,600
R-400-2	4,400
G-100-4	2,200
R-400-3	4,700
R-400-4	5,300
R-1000-4	6,800
G-400-4	7,400
PU3a	
Structural Alternatives	Direct Wetland Impacts
M-100-1	4,900
M-100-2	4,200
G-400-2	5,300
G-1000-2	6,600
PU 3b	
Structural Alternatives	Direct Wetland Impacts
G-100-1	2,300
F-100-1	2,500
F-400-1	3,900
F-1000-1	5,200
RL-100-1	900
RL-400-1	1,700
PU4	
Structural Alternatives	Direct Wetland Impacts
G-100-1	2,200
G-100-2	1,800
G-400-3	2,500
G-1000-3	2,500
RL-100-1	100
RL-400-1	100

Structural Metric: Indirect Impacts to Wetlands

(Note: Tables are presented in Attachment C)

Methodology

Given constraints in time and resources, the LACPR Habitat Evaluation Team (HET) did not think it possible to accurately quantify potential indirect impacts to wetlands and other aquatic resources from the structural hurricane risk reduction measures under consideration. Instead, the HET decided to qualitatively describe and compare the potential indirect impacts (both positive and negative) of the various proposed structural measures. The HET developed an indirect impacts ranking matrix which covers four categories of potential indirect impacts: Hydrologic Impacts, Fishery Impacts, Induced Development, and Ecological Sustainability/Consistency with coastal restoration. Using best professional judgment based on field experience and knowledge of pertinent scientific literature, the HET rated the various structural measures according to the following key:

- **"+2" indicates a relatively high potential for *positive* indirect impacts.**
- **"+1" indicates a relatively moderate potential for *positive* indirect impacts.**
- **"0" indicates relatively low to no potential for indirect impacts.**
- **"-1" indicates a relatively moderate potential for *adverse* indirect impacts.**
- **"-2" indicates a relatively high potential for *adverse* environmental impacts.**

Unlike the max-gross assessment of direct wetland impacts, the indirect impacts matrix does not provide an absolute measurement; rather, it describes how a particular alignment is expected to perform relative to other alignments and existing conditions in the same planning unit. Thus, the matrix is a tool for comparing levee alignments in terms of potential indirect impacts, as opposed to assessing mitigation needs. A moderate adverse ranking for hydrologic impacts, for example, does not necessarily mean that a particular alignment does not have the potential for significant adverse hydrologic impacts. It simply means that when comparing one alignment to another, the potential adverse hydrologic impacts of that alignment are substantially below what might be expected for other potential alignments in that planning unit.

Assumptions Regarding "Leaky Levees":

Both the State of Louisiana and the USACE are considering levee alignments that would enclose large wetland areas (e.g., alignments that parallel the Gulf Intracoastal Waterway [GIWW] in the Barataria Basin). Proponents believe that such levees can be built to minimize adverse impacts to the coastal ecosystem by incorporating gates and other structures to maintain or even restore natural hydrologic processes. Such levees are commonly referred to as "leaky levees"; as they would remain open to tidal flow at certain locations until a storm approaches.

In assessing the potential indirect effects of alignments that would enclose wetlands, the HET had to decide whether to assume that proposed leaky levees can and would be built to substantially minimize indirect impacts to the coastal ecosystem or whether in some cases such alignments pose a serious threat to the aquatic environment. There is much scientific information regarding the potential for levees and other unnatural linear barriers (such as spoil banks) to adversely affect coastal wetlands. However, there is little to no scientific information to substantiate the theory that leaky levees can actually accomplish the goal of minimizing adverse indirect impacts to wetlands, particularly in the complex and dynamic hydrologic settings in which such levees would be built. *Given what is known about the potential negative effects of building barriers through aquatic ecosystems and the lack of understanding of how to minimize such impacts, the HET assumed that certain leaky levees may pose a serious risk of indirect adverse impacts to wetlands and other aquatic resources.*

In applying this assumption, the HET considered the amount of wetlands that would be enclosed by the proposed levee. Other factors being equal, the HET assumed that the greater the acreage of wetlands that would be enclosed within a proposed levee system, the greater the risk (or potential) for adverse indirect impacts. All other factors are not, however, equal. The analysis of the potential effects of leaky levees is complicated by the fact that the corridors upon which such levees would be built range in the extent of existing hydrologic obstruction. If, for example, a levee were to be built on an existing barrier (such as a levee, road, or distributary ridge), the risk for further hydrologic alteration is, in general, minimal. (In such cases, there may even be an opportunity to restore natural hydrology, with limited risk of further hydrologic disruption.) On the other hand, if a levee were built through a wetland area with limited or no existing barrier, the risk of hydrologic disruption would be far greater.

Thus, in addition to the extent of wetlands that would be enclosed, the HET also considered the extent of existing hydrologic obstruction in the corridor through which the levee would be built. The HET assumed, for example, that a levee alignment along Highway 90 in Barataria Basin would not have the greatest potential for hydrologic and fishery impacts (despite enclosing a large acreage of wetlands), because the existing highway and adjacent railroad already substantially block flow across the area (with the exception of Bayou Des Allemands). By comparison, the GIWW does not appear to obstruct hydrology to the same extent. (There are numerous cuts in the GIWW spoil bank, in addition to the passes at Bayou Perot and leading into Bayou Barataria.) Accordingly, a levee along Highway 90 would have substantially less potential for adverse indirect hydrologic impacts than would an alignment along the GIWW in Barataria Basin. (This risk is compounded by the fact that a GIWW alignment would enclose a far larger area of wetlands and open water.)

Critics of these assumptions might argue that leaky levees could theoretically be designed to mimic or even restore natural hydrology. In this sense, leaky levees could present an opportunity to both build structural hurricane protection and address coastal restoration needs. The HET does not necessarily challenge the conceptual basis for such a position. (Indeed, the HET acknowledges such potential in cases such as a Highway 90 alignment in Barataria Basin.) Rather, the HET questions whether there is sufficient knowledge to successfully design and build such levees in more complex situations. In the Barataria Basin, for example, we do not adequately understand the existing hydrology (basin-wide modeling for the Donaldsonville to the Gulf hurricane protection study is still being developed), nor do we know how much river water would ultimately need to be reintroduced for that basin to be sustainable. Future sea level rise, subsidence, storm intensity, and rainfall patters are also uncertain. Given these and other uncertainties, it would be premature to assume that certain leaky levee alignments could be built in a way that adequately minimizes the potential for adverse environmental impacts.

<u>Categories of Potential Indirect Impacts</u>

(1) Hydrologic Impacts

This refers to potential changes such as reduced or increased impoundment; reduced or increased sheet flow; and reduced or increased salinities. The following factors were considered in estimating the extent (positive or negative) of the potential hydrologic impacts:

- Extent to which the proposed levee alignment is located on an existing hydrologic barrier or disruption, and the extent to which that barrier would likely be maintained, increased, or reduced.

- Number of inlets/outlets through the area that would be traversed by the proposed levee alignment (includes major and minor channels and areas where sheet flow may occur), and the extent to which these inlets/outlets would likely be maintained, increased, or reduced.

- Amount of enclosed wetlands. (Indicates potential for impoundment/drainage problems, for example.)

(2) Fishery Impacts

This refers to potential reductions in fish access due to increased velocities and/or physical barriers; increases in fish access due to removal of obstructions; and/or reductions or increases in fish habitat. The following factors were considered in estimating the extent (positive or negative) of the potential impacts to fisheries:

- Extent to which area that would be enclosed currently supports fisheries or could support fisheries with improvements in access and/or habitat.

- Extent to which fish access would increase or decrease in area enclosed by the levee.

- Amount of fish habitat that would be enclosed or otherwise affected by the levee.

(3) Induced Development

This refers to the potential increase or decrease in wetland areas with significantly improved hurricane risk reduction and which are susceptible to residential, recreational and/or commercial development. Areas susceptible to residential development have or will have auto access and are near or adjacent to areas of current or likely foreseeable future residential growth. Areas susceptible to commercial development have or likely will have significant access to navigation, rail, and/or highway transportation and are in a position to support economic activities typical of the area (e.g., oil and gas support). Areas susceptible to recreational development are areas that are desirable given location and ease of access to popular recreational activities (such as fishing).

It is recognized that unlike traditional forced drainage systems, “leaky levees” would not be designed to drain wetland areas. Nevertheless, the presence of a “leaky levee” would substantially reduce the risk of flooding from storm surges in enclosed areas. Such reduced risk could facilitate the development or expansion of local forced drainage systems and/or the filling of wetlands in the absence of forced drainage.

As with the other elements of the indirect impacts rankings, induced development rankings are relative to other levee alignments and existing conditions in the same planning unit. A negative score indicates that the given alignment has a relatively greater potential to encourage future development in wetlands (thereby leading to further wetland loss and increased assets at risk of flooding). A positive score indicates a potential to encourage or direct future development towards higher and safer ground.

(4) Ecological Sustainability/Consistency (with coastal restoration)

This refers to the extent to which the proposed levee is or is not likely to be consistent with existing and future coastal restoration projects, particularly river reintroduction projects (a.k.a. diversions). This also refers to the extent to which the proposed levee may or may not be located in a potentially sustainable environment. The following factors were considered in determining consistency with coastal restoration:

- Extent to which additional up-basin river re-introduction projects have been identified in coastal plans such as CWPPRA, Coast 2050, LCA, BTNEP CCMP, and/or LACPR itself, and the technical and budgetary challenges of designing the proposed levee and structures to accommodate such increased flows.

- Size of wetland area above the proposed levee alignment and hydrologic structures

Compensatory Wetlands Mitigation

Note: At a later date, a final determination will be made on the applicability of the following LACPR mitigation discussion, as it relates to current USACE policy, for projects that contain an ecosystem restoration component.

Introduction

The term *compensatory mitigation* generally refers to actions taken to offset environmental impacts by replacing or providing substitute resources or environments. National policy on compensatory mitigation for wetlands and other aquatic resources comes primarily from the Clean Water Act (CWA) Section 404 regulatory program. For the purposes of CWA Section 404, compensatory mitigation is the restoration, creation, enhancement, or in exceptional circumstances, preservation of wetlands and/or other aquatic resources for the purpose of compensating for unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved. In this context, compensatory mitigation is critical to National policy goal of achieving no net loss of wetlands and aquatic resources.

The various structural hurricane risk reduction measures under consideration in the LACPR study will inevitably result in unavoidable impacts to wetlands and other aquatic resources. In these cases, compensatory mitigation would be needed to ensure that such unavoidable impacts are fully offset, consistent with the policy of no-net-loss. This section describes in general the policies and assumptions that should be used to identify and implement appropriate, practicable, and effective compensatory mitigation measures for such unavoidable impacts. This section is not an exhaustive list of all the specific actions necessary for successful compensatory mitigation. Rather, it is intended to highlight some of the key issues pertaining to compensatory mitigation in the context of LACPR and coastal Louisiana.

Assumptions

- Compensatory mitigation actions for LACPR will comply with the policies and standards used for the CWA Section 404 program. (Section 2036 of WRDA '07 mandates that mitigation plans for water resources projects comply with the mitigation standards and policies established pursuant to the regulatory programs administered by the Secretary.).

- Acres of mitigation required (ratio) will vary depending upon quality functions and values of acres impacted, quality of acres of mitigation area. Furthermore the quantity of acres required to meet mitigation requirements will fluctuate depending upon length of the project analysis period (i.e., 50 or 100 years).

- Sediment sources for mechanical marsh creation should come from the least environmentally damaging sites (i.e., place highest priority on mining sediment from outside the system such as the rivers or offshore)

- Compensatory mitigation for LACPR projects will be conducted in advance or concurrent with implementation of the structural hurricane risk reduction projects for which the mitigation is required.

- Notwithstanding the need for flexibility and a watershed approach to designing compensatory mitigation (see below), it is generally not appropriate to offset wetland impacts in one planning unit (or basin) through compensatory mitigation actions in another planning unit.

- Impacts to wetlands outside of existing levee systems will not be offset by compensatory mitigation projects within existing levee systems.

- No mitigation credit should be given for theoretical benefits to wetland areas enclosed within the levee system unless there is definitive, quantitative information to support such claims. For example, mitigation credit should not be given for assumed salinity reductions in wetlands enclosed within levee systems.

Site Selection (on-site)

In 2001, the National Research Council (NRC) recommended the use of a watershed approach for decisions regarding compensatory mitigation (www.nap.edu/books/0309074320/html/). This recommendation is based in part on the finding that there are circumstances in which on-site mitigation may not be either practicable or environmentally preferable. In coastal Louisiana, such flexibility and watershed-based planning may provide opportunities to complement existing or planned coastal restoration projects. A watershed approach to compensatory mitigation site selection in coastal Louisiana would include consideration of:

- the environmental conditions and needs of the entire basin or planning unit, as well as restoration opportunities to meet such needs;
- trends in wetland loss by type;
- functional lifespan and potential sustainability of the mitigation area;
- structural importance of the mitigation area; and
- potential synergies with other coastal restoration projects.

Such a watershed approach does not in any way preclude mitigation at or near the site of the impact. Indeed, there may be cases where such traditional on-site mitigation is preferable. For example, it may in some instances be preferable to create a marsh buffer in front of a new or improved levee.

Mitigation Type

Generally in-kind compensatory mitigation is preferable to out-of-kind compensation because it is most likely to compensate for the specific functions, services, and values lost at the impact site. In-kind means a resource type that is structurally and/or functionally similar to the impacted resource type. The compensatory mitigation project site must be ecologically suitable for providing the desired aquatic resource functions. In striving for in-kind compensation within the planning unit approach, implementation of mitigation could be sequenced so mitigation is constructed by habitat as it is impacted annually by constructing structural storm protection.

Due to the uncertainties with salinity gradient changes and associated habitat switching with the 100 year planning horizon, some consideration may be given at this pre-feasibility level of allowing fresh marsh to be compensated for intermediate marsh or visa versa and brackish marsh compensated for saline marsh or visa versa. This potential assumption is based on the uncertainties in the potential spatial changes in the landscape and somewhat similar functions these marsh types provide.

Amount of Compensatory Mitigation

Federal policy on compensatory mitigation calls for a minimum of one for one functional replacement (i.e., no net loss of values), with an adequate margin of safety to reflect the expected degree of success associated with the mitigation plan.

The basis of this Federal mitigation policy is Federal Regulation Vo.73, No. 70, published Thursday April 10, 2008 and codified in 33 CFR Parts 325 and 332 and 40 CFR Part 230. The regulations state "(1) If the district engineer determines that compensatory mitigation is necessary to offset unavoidable impacts to aquatic resources, the amount of required compensatory mitigation must be, to the extent practicable, sufficient to replace lost aquatic resource functions. In cases where appropriate functional or condition assessment methods or other suitable metrics are

available, these methods should be used where practicable to determine how much compensatory mitigation is required. If a functional or condition assessment or other suitable metric is not used, a minimum one-to-one acreage or linear foot compensation ratio must be used.
(2) The district engineer must require a mitigation ratio greater than one-to-one where necessary to account for the method of compensatory mitigation (e.g., preservation), the likelihood of success, differences between the functions lost at the impact site and the functions expected to be produced by the compensatory mitigation project, temporal losses of aquatic resource functions, the difficulty of restoring or establishing the desired aquatic resource type and functions, and/or the distance between the affected aquatic resource and the compensation site. The rationale for the required replacement ratio must be documented in the administrative record for the permit action".

Since the earlier 1990 Memorandum of Agreement between the EPA and the Department of the Army, the Corps and various resource agencies involved in compensatory mitigation have often used acreage ratios of greater than 1:1, particularly in cases where there is a temporal lag in the development of wetland functions at the mitigation site and/or where there is uncertainty regarding the likelihood of the mitigation being fully successful.

Various national and local policy precedents exist for use of ratios and ratios higher than one to one. Local precedents include requests by commenting agencies on civil works projects (e.g., Morganza to the Gulf, proposed procedures for 3rd and 4th supplemental Acts), use under the CWA Section 404 Program. Analysis conducted thus far for Task Force Guardian and now being used for the 3rd and 4th Supplemental Appropriations work are using ratios both less than and greater than 1.5:1 which were approximated based on previous and generic functional based analyses to reserve sufficient mitigation funds.

Examination of the Corps national statistics for the CWA Section 404 program (from 1993 to 2000), indicates that the average mitigation ratio is closer to 2:1. Specifically, 42,000 areas of mitigation were required for 24,000 acres of impacts. Despite a nearly 2:1 ratio, the National Academy of Science still concluded that it is questionable whether the goal of no-net-loss is being reached.

EPA Region 4 has developed mitigation guidance, which provides recommended ratios including why these ratios are usually greater than 1:1.
http://www.epa.gov/region4/water/wetlands/technical/mitigation.html

In the case of LACPR, the level of data available and time allotted renders a functional based assessment impracticable at this point in the process, except of course for cases where such work has already been completed for previously authorized project components (e.g., MRGO closure). Additionally, the development of compensatory mitigation for LACPR can be expedited through up-front agreement on the amount and type of compensatory mitigation to be implemented to offset unavoidable adverse impacts to wetlands. Doing so would allow the Corps to more readily incorporate the potential costs of mitigation for various alternatives under consideration, and it could reduce the time needed to develop and implement final mitigation plans on a project-by-project basis.

Function-based ratio estimator example

In addition to adjust for temporal losses (time to implement) and limited success, some mitigation may be function inequivalent to the habitat it is compensating for. As an example, some studies have demonstrated constructed marsh is approximately half as productive as natural marsh for economically-important crustacean shellfish species (e.g., brown shrimp, white shrimp, and blue crab) for at least the first five to ten years after construction (Minello and Webb 1997, Rozas and Minello 2001). However, some of the same studies have documented that restored marsh is similar in productivity for finfish soon after construction (Minello 2000). To offset this loss of shellfish productivity, an increase of approximately 50 percent in terms of acreage would be appropriate based on the need to restore at least one acre of marsh for every acre impacted to compensate for finfish productivity and two acres of marsh for every one impacted to compensate for shellfish productivity.

Quality-based ratio estimator example

For the purposes preliminary cost estimating under the 3rd and 4th supplemental, a mitigation ratio was assigned to each area of wetland impact identified that corresponds to the estimated quality of habitat impacted. The ratios below are based on the professional judgment of New Orleans District Environmental staff, which relied on earlier examples of mitigation for estimating appropriate ratios.

Bottomland Hardwood Habitat Quality Ratios

- High Quality (upland) – 1 acre impacted: 4.5 acres mitigated
- High Quality (wet) - 1 acre impacted: 3 acres mitigated
- Medium Quality- 1 acre impacted: 2 acres mitigated
- Low quality- 1 acre impacted: 1 acre mitigated

Timing

Construction of mitigation should be in advance of or concurrent with the activity causing the authorized impacts to avoid temporal loss of aquatic resources. Authorizations of any measures to implement (i.e., feasibility, preliminary engineering and design, and construction) should include funds for the commensurate mitigation. Cost share agreements and programming of funds under the agreements should enable concurrent mitigation.

Cost

The full cost of compensatory mitigation must include not just project implementation, but also monitoring, long-term management, and contingency funds. For forested wetland mitigation projects, costs typically include land acquisition, hydrologic improvements (e.g., removing ditches, grading), planting, vegetative management (e.g., invasive control), monitoring, contingencies (such as replanting), and long-term stewardship. Marsh mitigation projects would typically entail marsh creation via mechanical placement with dredges or with river diversions. Marsh is restored in areas where it does not currently exist, often on state-owned water bottoms. Therefore, no real estate costs are usually associated with marsh mitigation. However, marsh creation via mechanical dedicated dredging is an intense construction process, usually involving the pumping or trucking and placing of fill material as well as planting of marsh vegetation; thus, the construction cost over the first ten years of the project is much higher for marsh than for bottomland hardwood. Marsh creation with diversion also has a high initial cost for construction of the diversion structure, but takes many years to realize marsh creation.

The following is a copied break-down of the costs of mitigating one acre of wetland by wetland type as derived and used for Task Force Guardian and expected use for 3rd and 4th Supplemental Appropriations flood protection work (2007 MVN Environmental Whitepaper). "Estimated costs were derived from recently conducted mitigation activities. Real costs were based on the actual purchase price of bottomland hardwoods adjacent to the Bayou Sauvage National Wildlife Refuge as part of the mitigation associated with work completed by Task Force Guardian (TFG). The cost of marsh creation per acre and bottomland hardwood management were derived from figures provided by the US Fish and Wildlife Service planning-aid report, developed as part of an interagency team effort lead by Corps to assist MVN staff in determining impacts and mitigation needs associated with Task Force Guardian efforts.

Bottomland Hardwood forest
<u>Costs per acre for mitigation</u>: $37,000 per acre

- $35,000 Real Estate cost per acre. Based upon TFG cost estimates for Bottomland Hardwood impacts in Orleans Parish 2006 and includes fees typically associated with land acquisition such as title searches, closing costs, recording fees, etc.
- $1,200 construction costs per acre. Year 1 to 10 of project.
- $800.00 O&M and monitoring cost per acre for 50 year life of project.

Tidal Emergent Marsh, Fresh Water Marsh, Salt Water Marsh
<u>Cost per acre for mitigation</u>: $80,000

- $0 Real Estate cost per acre
    - This cost assumes mitigation on state water bottoms, which will not always be possible. CEMVN RE has estimated marsh real estate at $500 per acre historically in those cases where non-state water bottom is acquired.
- $79,000 construction cost per acre.
- $1,000 for O&M and monitoring cost per acre for 50 year life of project."

Financial Assurances, Long-Term Stewardship, and Adaptive Management

Sufficient financial assurances should be provided to ensure a high level of confidence that the compensatory mitigation will be successfully completed. Sediment availability and practicable construction schedules based on equipment availability will directly limit the amount and rate at which impacts occur and could be offset. Due to the large amount of impacts and complexity of mitigation needs, sufficient funds for all anticipated impacts should be set provided in legislative appropriations at the same time activities are authorized from which the impacts would occur. Project sponsors should set aside these funds upfront.

Estimates of mitigation funding needs should include resources for additional measures that may be needed to ensure success of the compensatory mitigation project. With forested wetland mitigation, for example, it is not unusual for replanting to be needed due to higher than expected planting mortality. Such contingency funds can and should be released as the mitigation project meets specified performance thresholds. For example, once an adequate amount and diversity of trees become well established in a forested mitigation site, it is less likely that replanting will be needed.

Success Criteria, Monitoring, Reporting, and Adaptive Management

Compensatory mitigation plans should contain specific, measurable criteria for assessing whether mitigation is succeeding. Success criteria typically address hydrologic conditions (e.g., whether or not the mitigation area has self-sustaining wetland hydrology), vegetative success (considering both quantity and type), and in some cases factors pertaining to fish and wildlife usage.

Monitoring should be designed to provide both a general overview of how the mitigation project is or is not working, as well as measuring progress relative to the specific success criteria discussed above. Monitoring it typically more frequent in the first five years of the mitigation project, after which monitoring intervals can increase. For example, a typical forested wetland mitigation project might entail monitoring at years one, three, five, and ten, with reports every five years thereafter. Additional monitoring may be needed in cases where success criteria are not being met and remedial actions are needed. Monitoring reports should be made available to the resource agencies to help evaluate the effectiveness of the compensatory mitigation project, and to help determine whether corrective actions are needed.

Restoration and Structural Metric: Fisheries Impacts

The economic and ecologic value of Louisiana's coastal fisheries is nationally important and therefore it is desirable to have an assessment of fisheries impact to inform the plan formulation process for LaCPR. Specifically, an assessment method and resultant metric is desired to inform the Multi-Criteria Decision Analysis (MCDA) for both structural and restoration measures. Fundamental limitations exist both in terms of the specificity of measures and alternatives and the degree of understanding of relative effects on fisheries production. This is complicated in that migratory pathways within planning units, the limits of habitat support functions, and the effects of hurricane protection structures on fisheries are not fully understood. Further confounding and equally, if not most, challenging is the relative value of fisheries habitat varies spatially by species and life-stage of species.

With respect to restoration measures, various matrices could and should be developed because changes occurring under the no-action or various action alternatives create unique challenges for fisheries management. However, only qualitative data are available at this time. Thus, the limited information and time do not allow for quantitative analysis, although available information can inform the planning process, managers, and decision makers of what is needed. The following is a cursory list of suggestions and characterizations of details on fisheries impacts associated with restoration rather than measurable input metrics for MCDA. The development of those metrics is not possible at this time given the current project schedule and planning process.

No Action

The project area supports one of the most productive fisheries in the Nation. However, it is believed that with no action, sharp declines in fisheries productivity are likely (Minello et al. 1994; Rozas and Reed et al.1993). Impacts to fisheries resulting from the implementation of each plan will vary depending on the features included in the selected plan, species-specific habitat, prey, spawning requirements, and current conditions in the Deltaic and Chenier Plain estuaries." (LCA, FPEIS November 2004)

Louisiana is second only to Alaska in terms of commercial fisheries production and home to three of the top six commercial fishing ports in the country. Louisiana's recreational harvest is second only to Florida among the states surveyed by the NOAA Fisheries recreational survey. In recent years Louisiana landed significant portions of the total U.S. commercial harvest, including, 37% of the shrimp, 35% of oysters, 60% of Gulf menhaden and 27% of blue crab, 56% of black drum, 26% of mullet, 28% of all snapper species, and 31% of yellowfin tuna. Louisiana-based recreational anglers caught high proportions of the U.S. recreational harvest, including, 49% of black drum, 73% of red drum, 28% of sheepshead, 32% of southern flounder, and 71% of spotted seatrout from the states surveyed by the Marine Recreational Fishery Statistical Survey (MRFSS).

The relative production of deteriorating marsh in Louisiana is often very high, but this condition is not sustainable. Steep declines in fish production have been forecast for the next century (Thomas 1999). This is particularly important for the resource users who are satisfied with "current conditions" in terms of fish production. In order to maintain current conditions for fish production major habitat restoration actions are required.

"Indirect impacts to fisheries may result from the expected continuation of land loss and further loss of habitat supportive of estuarine and marine fishery species. In the short-term, land loss and predicted relative sea level changes are likely to increase open water habitats available to marine species, except in the active deltas of the Atchafalaya and Mississippi Rivers; and areas otherwise influenced by river flow, such as, the Caernarvon and Davis Pond Freshwater Diversions, and to a lesser extent, Pointe a la Hache and Naomi Siphons. In the long-term, as open water replaces wetland habitat and the extent of marsh to water interface begins to decrease, fishery productivity is likely to decline (Minello et al. 1994; Rozas and Reed 1993). This may already be happening in the Barataria and Terrebonne estuaries. Browder et al. (1989) predicted that brown shrimp catches in Barataria, Timbalier, and Terrebonne Basins would peak around the year 2000 and may fall to zero within 52 to 105 years." (LCA FPEIS, November 2004)

This goal of maintaining or restoring some desired ecological baseline and associated fish production is challenging due to the uncertainties in possible endpoint outcomes. As described by Cowan et al. 2006, two examples include regime shift (bottom-up process driven) and man-induced changes in ecosystem function (top-down effects). Although responses of Louisiana coastal fisheries from regime shifts (e.g., climate variability) are unknown, restoration efforts may produce a nearly linear response in efforts to restore ecosystem function including fisheries productivity. A more challenging endpoint possibility is that a shift in the ecological baseline could result from top-down habitat modification effects through restoration. Mechanisms for this second scenario possibly include habitat reduction and change to reorganization of food webs, but regardless of the mechanisms, top-down forcing with ecosystem or landscape level attempts in restoration may be less likely to return to a state that resembles "pristine" that are similar to the level of fishery productivity provided by the pre-disturbed conditions. Despite these uncertainties there is reason to forge ahead with optimism if efforts include investigations on the potential effects on fisheries and means for adaptive management of both the process and potential structure operations.

Action Alternatives

General alignments and restoration
Leaky levee concept
Diversions- freshen

General characterizations of impacts by restoration method are listed in Table 15 & 16.

Coastal restoration projects attempting to address the loss of estuarine habitat with a number of techniques may produce localized to widespread changes in fisheries production and distribution (Thomas 1999).

Public perception difficulties with restoration efforts arise from misunderstandings of the nature of estuarine functions, particularly of the importance of nursery habitat and of the value of low-salinity marshes as nursery habitat (Thomas 1999).

Significant improvement in the outlook for estuarine fish habitat in Louisiana will require long-term and large-area vision from managers and the public (Thomas 1999).

Resource displacement can result in increased harvest costs, and basin-scale changes may be particularly hard for resource users who are satisfied with the current conditions
Harvesters have demonstrated reluctance, and may lack the financial flexibility, to forfeit expected current catches for predicted enhancement of long-term fisheries production (Thomas 1999).

Diversions
Degree of displacement depends on the species and life stage-specific variables, structure location, flow-rate, and env. conditions (Caffey and Schexnayder 2002)

Salinity reductions result in a seaward shift of the optimal harvest zones form brown shrimp. Some displacement of white shrimp and blue crab landings. Meanwhile, low salinity marsh restored by diversions may expand the nursery required for the development of brown and white shrimp (Caffey and Schexnayder 2002).

Large-scale diversions can cause a range of temporal and spatial impacts to various fisheries. The ultimate merit of diversions on fisheries should not be measured by short-run impacts alone (Caffey and Schexnayder 2002).

<u>Mechanical vs. Diversions</u>

Mechanical – rapid marsh creation and relatively little fish production but

- High or low mechanical marsh creation – realize land gain rapidly, but spatial and landscape benefits are limited
- Dredge fleet limited
- Not sustainable; no net loss of wetlands and associated levels of fish production would have to be maintained via dedicated dredging unless creation sites are located to enable synergy with diversions
- Relatively no landscape displacement impacts to fish displacement or production and associated users

Diversion – slow marsh response, but

- High diversion = may displace valuable estuarine less valuable fisheries; however process will create sustainable low-salinity nursery grounds for valuable estuarine fisheries
- Low diversion =smaller displacement due to changes in salinity regimes, smaller increase in fuel, time, and refrigeration needs on fishing industry)

- Those techniques include the types of measures included in this plan: marsh creation and freshwater diversions. Changing the distribution and timing of freshwater inputs and the configuration of land and water will change the distribution of estuarine organisms and thus the economics of estuarine fisheries in coastal Louisiana.

Operation of structures may be the most critical component of any diversion plans; a closer adherence to natural cycles of high and low flow would lessen fisheries impact

<u>What is Needed</u>

Topics, associated data, and available resources to compile and evaluate the outcome and effects in alternatives analysis is needed to inform this process and to inform managers and decision makers. Establishment of an understanding, or a more complete understanding, of fundamental processes is needed for many habitat stability, resiliency, and shifting response effects on fisheries productivity.

Inventory of needs and resources

1. Project-specific inferences – e.g., make inferences from the Caernarvon type impacts; analyze the LDWF Caernarvon data
2. Empirical analysis with LDWF fisheries independent data is one analytical option among others

3. Evaluate perturbations (productivity and driver mechanisms) from existing restoration along a gradient.
4. Evaluation of protection structure designs on fisheries.
5. Evaluate habitat shifting and structural complexity effects.
6. Refinement of measures including optimizing operation plans for structures and the commitment to adaptively managed the structures
7. Assessment of cumulative impact of alternative features (e.g., multiple diversions, etc.)
8. Identify other existing data sets, staff, or researchers that can facilitate these evaluations in necessary timelines

Table 15. Comparison of diversion impacts on fisheries.

Coastal Restoration Alternatives	Diversion Impacts	Comments
Alts 3, 4, and LCA Plan PBMO (see assumptions below this table)	Displacement and habitat preservation	
Non Pulsed (Dec-May unrestricted flow) (see assumptions below this table)	Displacement and habitat preservation	Salinity reductions result in a seaward shift of the optimal harvest zones form brown shrimp. Some displacement of blue crab landings. Impacts to American Oyster (see caption below this table)
Pulsed (1 unrestricted flow year out of 5) (see assumptions below this table)	Displacement and habitat preservation	Limited adverse fisheries impacts to once in five years; however depending on whether it was a high or low flow year, year class strength of most economically important estuarine dependent fisheries species would be adversely impacted Impacts to American Oyster (see caption below this table)

<u>American Oyster</u>

The amount of discharge with relatively numerous and large scale freshwater diversions in all alternatives would adversely impact growing conditions within a large area of oyster grounds. The diversions would have the potential to reduce salinities within receiving areas to levels, which are lethal to oysters across large areas of water bottom. As previously stated, this is partly dependent upon natural variations within water bodies; the size, location, and operation of the diversion structures; and the proximity of oyster grounds to the diversions.

Louisiana has a far more extensive and productive oyster lease program than any other state in the United States. Providing more than 35 percent of the Nation's oysters, any project that adversely impacts oyster resources in Louisiana would impact nationwide oyster harvest, in addition to reducing the contribution of this industry to the local, state, and national economy. Although in the long-term, oyster populations are anticipated to benefit from large-scale coastal restoration, significant impacts could affect the industry for the foreseeable future.

<u>Assumptions</u>

For alternatives R3, R4, and R5, the HET assumed unrestricted flows whenever the diversion would flow, but, based on past Caernarvon records, the HET assumed that all diversions would only flow for 246 days per year.

For alternative R1, the non-pulsed Dec-May diversion, the HET assumed unrestricted flows only during those months. Otherwise no flows at all - this would be more restrictive than the limiting of flows to only 245 days per year.

For alternative R2, the Pulsed 1 high flow year out of 5, the HET assumed unrestricted flow during the high flow year - as all flows are based on the 1994 Tarbert Landing hydrograph in which there is a Dec rise, there would be good diversion discharges during that month. During the low-flow years, flows would be restricted to much lower levels, but those flows would also be year-round when the river allows. Those flows would vary according to river stage. Note that in this alternative, there is still the assumption of only 246 days of flow per year for both high flow and low flow years.

Table 16. Adapted from LCA, FPEIS.

Items of consideration in the impact analysis of restoration opportunities on fisheries resources.	
Freshwater Diversions	Direct impacts to fisheries resulting from freshwater diversions include mortality due to burial or sudden salinity changes; injury or mortality due to increased turbidity (e.g., gill abrasion, clogging of feeding apparatus); modified behavior, and short-term displacement. Indirectly, fisheries may be displaced to offshore areas. Displacement is related to the timing and volume of freshwater input proposed. These projects prevent the loss of marsh, and generally improve conditions for SAV and other highly productive forms of EFH. As a result, project areas can maintain most of their current ability to support Council-managed species (such as white shrimp, brown shrimp, and red drum), as well as the estuarine-dependent species (such as spotted seatrout, gulf menhaden, striped mullet, and blue crab) that are preyed upon by other Council-managed species (such as mackerels, red drum, snappers, and groupers) and highly migratory species (such as billfish and sharks). Potential increases in submerged aquatics will increase the habitat required for juveniles to escape predation and therefore increase quality and habitat.
Dredging	These projects, or project components, would negatively impact benthic organisms and benthic feeders in the borrow and disposal areas. Sessile and slow-moving aquatic invertebrates would be disturbed by the dredge or buried by the dredged material. Dredging and disposal activities and the resultant increased turbidity would temporarily displace other fisheries, but these species are expected to return after dredging and disposal activities are completed. Impacts include smothering of non-mobile benthic organisms in dredged material deposition sites and increased turbidity in waters near the construction sites.
Salinity/water control structures	If water control structures are designed and operated to maximize marine fishery migratory opportunities, while minimizing the worst salt water events, these projects can slow the loss of emergent marsh without severely impacting marine fishery productivity. However, care must be taken to ensure the structures do not create conditions that would adversely impact marsh habitats supportive of marine fishery resources. Additionally, operational plans should incorporate provisions to ensure the structures are open during appropriate times to allow drainage, facilitate freshwater inflow, and allow the maximum possible marine fishery ingress and egress. Without these provisions, these projects can significantly reduce the marine fishery productivity of the project area, even if the structures help maintain marsh habitats; the maintained habitats would not support production of marine fishery species, if the species do not have access to those critical nursery and foraging habitats.
Beneficial Use/ Sediment Delivery/Marsh Creation, Restoration, or Nourishment	The use of dredged sediment would convert open water habitat to wetlands providing a more diverse habitat. The conversion would increase foraging, breeding, spawning, and cover habitat for a greater variety of fisheries species than would occur with no action, and potentially increase the marsh/water interface. The increased marsh/water interface is a greater benefit than marsh acres alone (Rozas and Minello 2001). Measures should be taken (i.e., creating tidal creeks and ponds) to maximize the fisheries productivity of the restored marsh areas.

	Nutrients and detritus would be added to the food web, providing a benefit to local area fisheries. Fisheries access features and structure operation plans would be necessary to facilitate ingress and egress of various fisheries species to restored wetlands within the proposed disposal areas. Short-term adverse impacts to fish would occur during the construction phase of these projects as a result of dredging activities (see dredging impacts).
Shoreline Protection/ Stabilization	Shoreline protection projects are likely to prevent the loss of marsh for protected areas. This helps maintain valuable fisheries habitat. Design of shoreline protection should incorporate low-sill openings, gaps, and/or allow historical channels to remain open for aquatic organism ingress and egress, and the adequate discharge of surface flow drainage.
Barrier Island Restoration	Barrier islands protect coastal marshes from storm surges and provide unique back barrier and sand bottom habitats. Barrier island restoration that involves supratidal vegetative plantings and sand retention structures alone will not directly affect fisheries species. However, the long-term impact to fisheries would be beneficial by maintaining the valuable habitats that would otherwise convert to open water. Restoration on a larger scale involving dredging of sand resources for placement on and around existing islands would impact the benthic areas of both the borrow and disposal areas. Subsequent benefits would result from the increase in back barrier shallow water and sand bottoms, and the increased protection to coastal marshes.

SCIENTIFIC ISSUES AND TECHNICAL UNCERTAINTIES

Although numerous scientific studies have been conducted within the Louisiana coastal environments, considerable uncertainty remains regarding key ecological processes and the efficacy of some of the proposed restoration measures. Limitations in analytical tools to assess ecosystem responses also exist, and were compounded by the relatively short timeframe in which the LACPR was formulated. These limitations and uncertainties substantiate the value of a truly adaptive approach to the LACPR, and suggest that some plan components require further and more detailed study prior to implementation. Demonstration projects based on sound scientific and technological theory and practice should be implemented in order to test the uncertainty in a controlled manner.

To meet that challenge, (1) mechanisms to fund a coordinated program of coastal investigations to understand the longer term dynamics of the system must be developed, (2) research and demonstrations that specifically advance restoration technology must be conducted, (3) usable databases must be developed, and (4) mechanisms to integrate research results into the planning and design of restoration projects must be developed.

<u>Research and Technology Development Needs</u>

(Subject to continued revision)

Although many studies have been conducted in the Louisiana coastal area, most were limited in geographic extent or technical scope. Therefore, while much has been learned from previous efforts, many scientific and technical uncertainties remain. Some areas of high uncertainty include:

- availability of sediment (riverine and offshore)

- subsidence rates and sea level rise
- benefits and impacts of pulsed freshwater diversions
- channel evolution in freshened areas
- effect of diversions on Mississippi River sediment transport
- over freshening of estuaries
- fisheries impacts associated with river diversions
- pipeline conveyance technologies and costs
- thin-layer sediment placement techniques
- salt transport inland with sediments from offshore
- benthic habitat impacts

Appendix A of the LCA Report (LCA 2004) outlines the R&D needs for coastal Louisiana as well as a general strategy for achieving those goals. Rather than reiterate those needs and strategy, the HET advocates the adoption of the LCA S&T Program as a model for LACPR.

To effectively use existing knowledge and gain the increased understanding necessary to deal with the issues described above, it is essential that appropriate predictive tools are developed. The tools include numerical modeling approaches to predicting patterns of water level, salinity, and sediment distribution. Hydrologic models, which specifically encompass flows across marsh surfaces and through channels and structures, must be developed. Ecological models must address marsh accretion (mineral and organic), nutrient budgets, and soil biogeochemical processes.

To fully achieve the ecosystem goals set forth in this plan, a better understanding of ecological and biogeomorphic processes and functions is needed. Critical questions still need answers, such as "What is the effect on ecosystem sustainability of a seasonal river diversion that increases the annual range of salinities within the receiving basin? How important to coastal marshes is nutrient input alone vs. freshwater and sediment delivery from the river? How does this vary with marsh type?"

Although the intent of the spatial integrity metric is to compare alternative plans, it may be possible to also refine the models so that they provide some predictive capability. Valid comparison to reference wetlands is difficult, but correlations between spatial metrics and ecosystem services may be developed over time, provided the appropriate data collection and analyses are conducted.

Demonstration and Evaluation Needs

Demonstration projects may be necessary to address uncertainties that would be identified in the course of individual project implementation or during the course of studies of large-scale and long-term restoration concepts. Nominated demonstration projects would be subject to review and approval of individual project feasibility-level decision documents by the Secretary of the Army. In addition to standard feasibility-level decision document information, the demonstration project feasibility-level documents would address: 1) major scientific or technological uncertainties to be resolved; 2) a monitoring and assessment plan to ensure that the demonstration project would provide results, and that those results contribute to overall LACPR effectiveness; 3) a lessons learned discussion and 4) transparent framework to distribute knowledge gained.

Clearly, there are still many restoration issues in coastal Louisiana that cannot be resolved without additional research. The research must then be integrated into the refinement of the strategies and the revision of the plan.

Monitoring and Adaptive Management Needs

In the long-term, success of the coastal restoration component of LACPR will be largely measured by the quantity, diversity, and quality of wetland acreage, and the resulting benefits from various services to Louisiana, the Gulf region, and the nation. These benefits include protection against storms and floods, production of fisheries and wildlife resources, protection of water supply and water quality, and support to regional economic activities such as oil and gas development, navigation, and recreation. Although the LACPR and other related efforts have attempted to quantify these potential benefits, considerable uncertainty remains. In addition, it is likely that new technologies, improved understanding of ecosystem processes, and other factors will lead to innovative approaches to coastal ecosystem restoration not contemplated in this study.

For these reasons, and to permit the assessment of the success of those plan components that are implemented, the LACPR must include a concerted monitoring and evaluation program that benefits from the monitoring efforts through adaptive management and improved techniques. The general restoration strategy identified by the HET is dependent on the overall input, movement, and circulation of water, sediment, and nutrients in each basin (although some measures can be implemented largely independently of these considerations), and early monitoring and evaluation efforts should focus on these processes.

Monitoring funds are routinely allocated for the life of constructed projects and monitoring plans for each project are developed to include statistical designs and the use of reference areas. Because of funding constraints, these monitoring efforts are limited to the environmental parameters expected to be affected by the projects and are confined to the area immediately affected by a project and an adjacent reference area if a suitable one can be located. As more projects are undertaken, monitoring databases for some essential variables such as water level and salinity data will cover extensive areas of the coast. These collective data will provide a good starting point to assess the cumulative spatial and temporal impacts of the numerous projects proposed as part of the LACPR.

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ATTACHMENTS

ATTACHMENT A – COASTAL RESTORATION MAPS
ATTACHMENT B – INDIRECT MATRIX TABLE
ATTACHMENT C – DIVERSION BUILDING MODEL
ATTACHMENT D - SPATIAL INTEGRITY FIGURES & TABLES
ATTACHMENT E – HET DIVERSION SUMMARY
ATTACHMENT F - WETLAND ACREAGE

ACRONYM LIST

BTNEP	Barataria-Terrebonne National Estuary Program
CEM	Conceptual Ecological Model
CWA	Clean Water Act
CWPPRA	Coastal Wetland Planning Protection and Restoration Act
EPA	Environmental Protection Agency
ERDC	Engineering Research Design Center
FPEIS	Final Programmatic Environmental Impact Statement
FTR	Final Technical Report
FWP	Future With Project
FWOP	Future Without Project
GIWW	Gulf Intracoastal Waterway
HET	Habitat Evaluation Team
LACPR	Louisiana Coastal Protection and Restoration
LCA	Louisiana Coastal Area
LDNR	Louisiana Department of Natural Resources
LDWF	Louisiana Department of Wildlife and Fisheries
MCDA	Multi-Criteria Decision Analysis
MOA	Memorandum of Agreement
MRFSS	Marine Recreational Fishery Statistical Survey
MRGO	Mississippi River-Gulf Outlet
MVN	Mississippi Valley Division, New Orleans District
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service
NPS	National Parks Service
NRC	National Research Council
NRCS	Natural Resource Conservation Service
NTP	Near-Term Plan
PBMO	Plan that Best Meets the Objectives
ppt	parts per thousand
PU	Planning Unit
RSLR	Relative Sea Level Rise
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service
WRDA	Water Resources Development Act

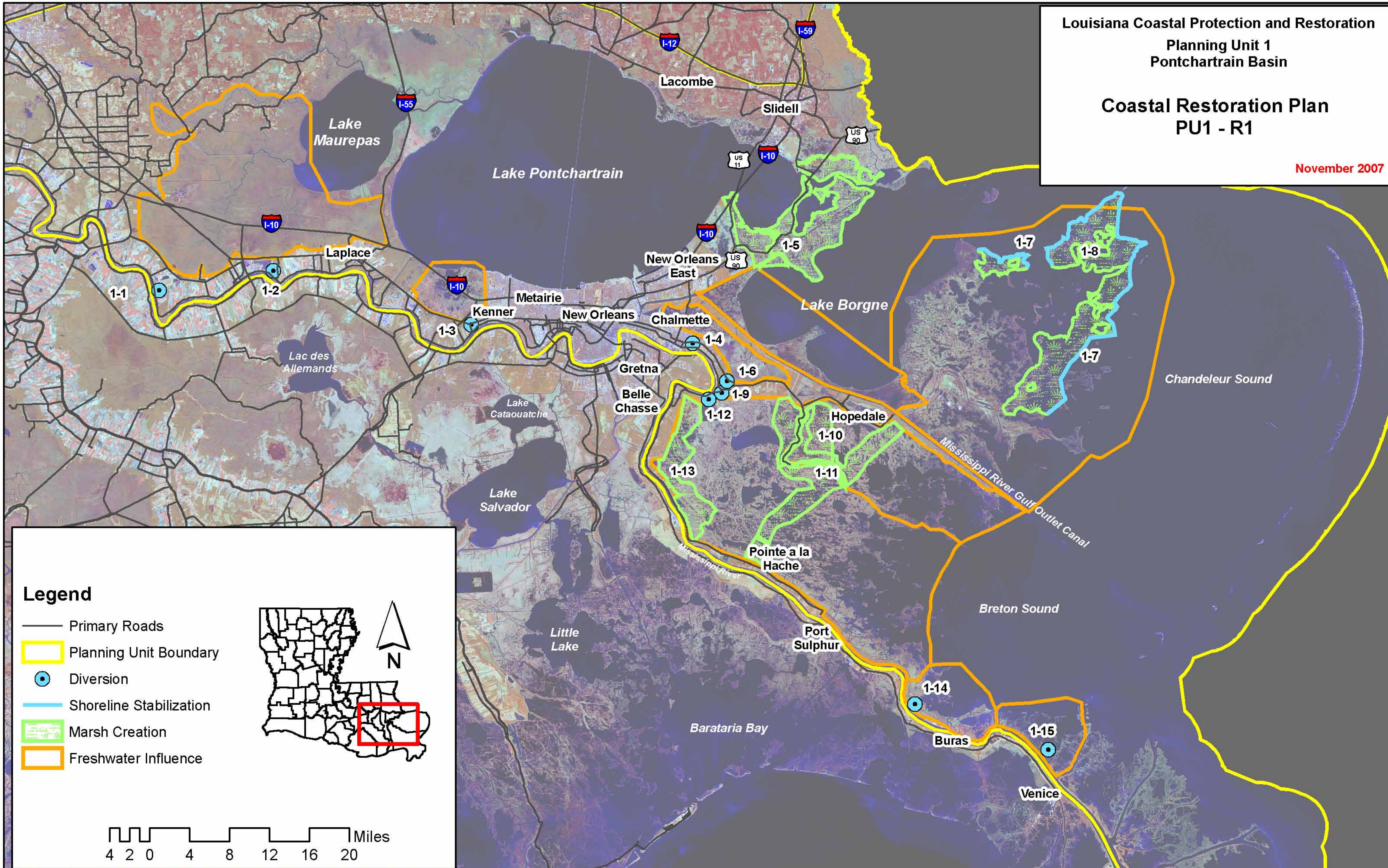
GLOSSARY

Brackish Marsh (BRM)	Intertidal plant community typically found in the area of the estuary where salinity ranges between 4-15 ppt.
Comprehensive	A combination of structural, non-structural and coastal restoration plans
Conceptual Ecological Model	non-quantitative planning tools that can be used to identify major stressors on a system, the effects of those stressors, and the best way to measure those effects (Ogden et al. 2005:795-809)
Deltaic Plain	The land formed and reworked as the Mississippi River switched channels in the eastern part of the Louisiana coastal area
Direct Impacts	Those effects that result from the initial construction of a measure (e.g., marsh destroyed during the dredging of a canal). Contrast with “Indirect Impacts.”
Diversion	A turning aside or alteration of the natural course or flow of water. In coastal restoration this usually consists of such actions as channeling water through a canal, pipe, or conduit to introduce water and water-borne resources into a receiving area.
Ecosystem	An organic community of plants and animals viewed within its physical environment (habitat); the ecosystem results from the interaction between soil, climate, vegetation and animal life.
Ecosystem Restoration	activities that seek to return a organic community of plants and animals and their habitat to a previously existing or improved natural condition or function.
Estuary	A semi-enclosed body of water with freshwater input and a connection to the sea where fresh water and salt water mix.
Estuarine	Related to an estuary.
Feature	A constructible increment of an alternative plan.
Fresh Marsh	Intertidal herbaceous plant community typically found in that area of the estuary with salinity ranging from 0-3 ppt.
Future With	Projection of conditions within a study area over the project life if the proposed plan is implemented
Future Without	Projection of conditions within a study area over the project life if the proposed plan is not implemented
Indirect Impacts	Those effects that are not as a direct result of project construction, but occur as secondary impacts due to changes in the environment brought about by the construction. Contrast with “Direct Impacts.”
Levee	A linear mound of earth or stone built to prevent a river from overflowing; a long, broad, low ridge built by a stream on its flood plain along one or both banks of its channel in time of flood.
Marsh Creation	To build wetland habitat by mechanical means
Maximum sustainability	greatest amount of measureable habitat that could be maintained
Pulsing	Letting a diversion flow periodically at a high rate for a short time, rather than continuously.
Relative Sea Level Change	The sum of the sinking of the land (subsidence) and eustatic sea level change; the change in average water level with respect to the surface.
Saline Marsh	Intertidal herbaceous plant community typically found in that area of the estuary with salinity ranging from 12-32 ppt.
Salt Marshes	See “Saline Marsh.”
Storm Surge	An abnormal and sudden rise of the sea along a shore as a result of the winds of a storm.
Subsidence	The gradual downward settling or sinking of the Earth’s surface with little or no horizontal motion.
Sustain	To support and provide with nourishment to keep in existence; maintain.

ATTACHMENT A

COASTAL RESTORATION MAPS

DECEMBER 2008



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Coastal Restoration Plan
PU1 - R1
November 2007
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Lake Pontchartrain
Lacombe
Slidell
Laplace
Metairie
Kenner
New Orleans
New Orleans East
Chalmette
Lake Borgne
Lac des Allemands
Lake Cataouatche
Gretna
Belle Chasse
Hopedale
Lake Salvador
Pointe a la Hache
Mississippi River Gulf Outlet Canal
Mississippi River
Chandeleur Sound
Breton Sound
Little Lake
Port Sulphur
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Marsh Creation
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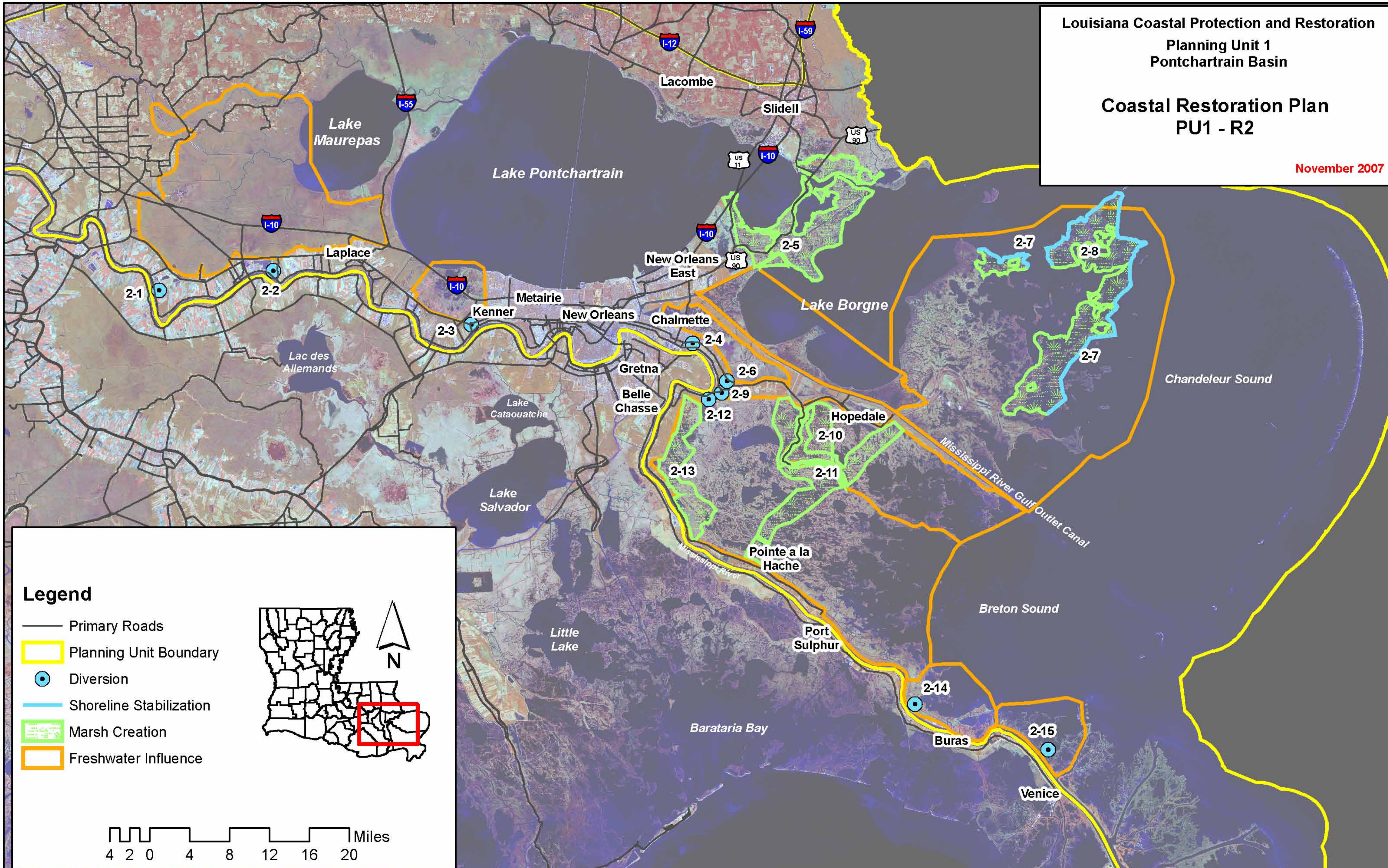

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Coastal Restoration Plan
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Shoreline Stabilization
Marsh Creation
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Lac des Allemands
Lake Cataouatche
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Chandeleur Sound
Mississippi River Gulf Outlet Canal
Pointe a la Hache
Mississippi River
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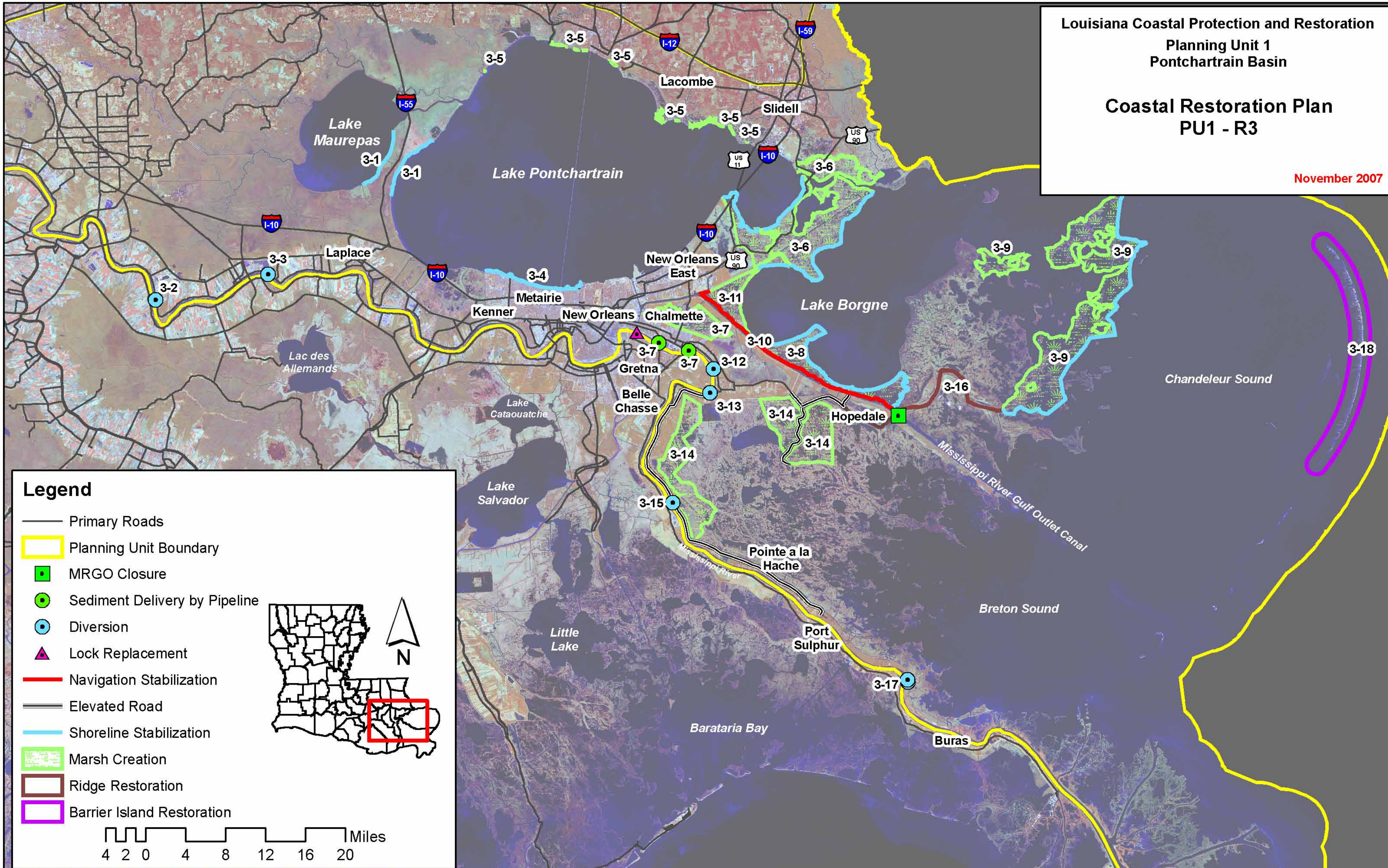

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Lake Salvador
Little Lake
Lacombe
Slidell
Laplace
Metairie
Kenner
New Orleans
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Pointe a la Hache
Port Sulphur
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Primary Roads
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MRGO Closure
Sediment Delivery by Pipeline
Diversion
Lock Replacement
Navigation Stabilization
Elevated Road
Shoreline Stabilization
Marsh Creation
Ridge Restoration
Barrier Island Restoration
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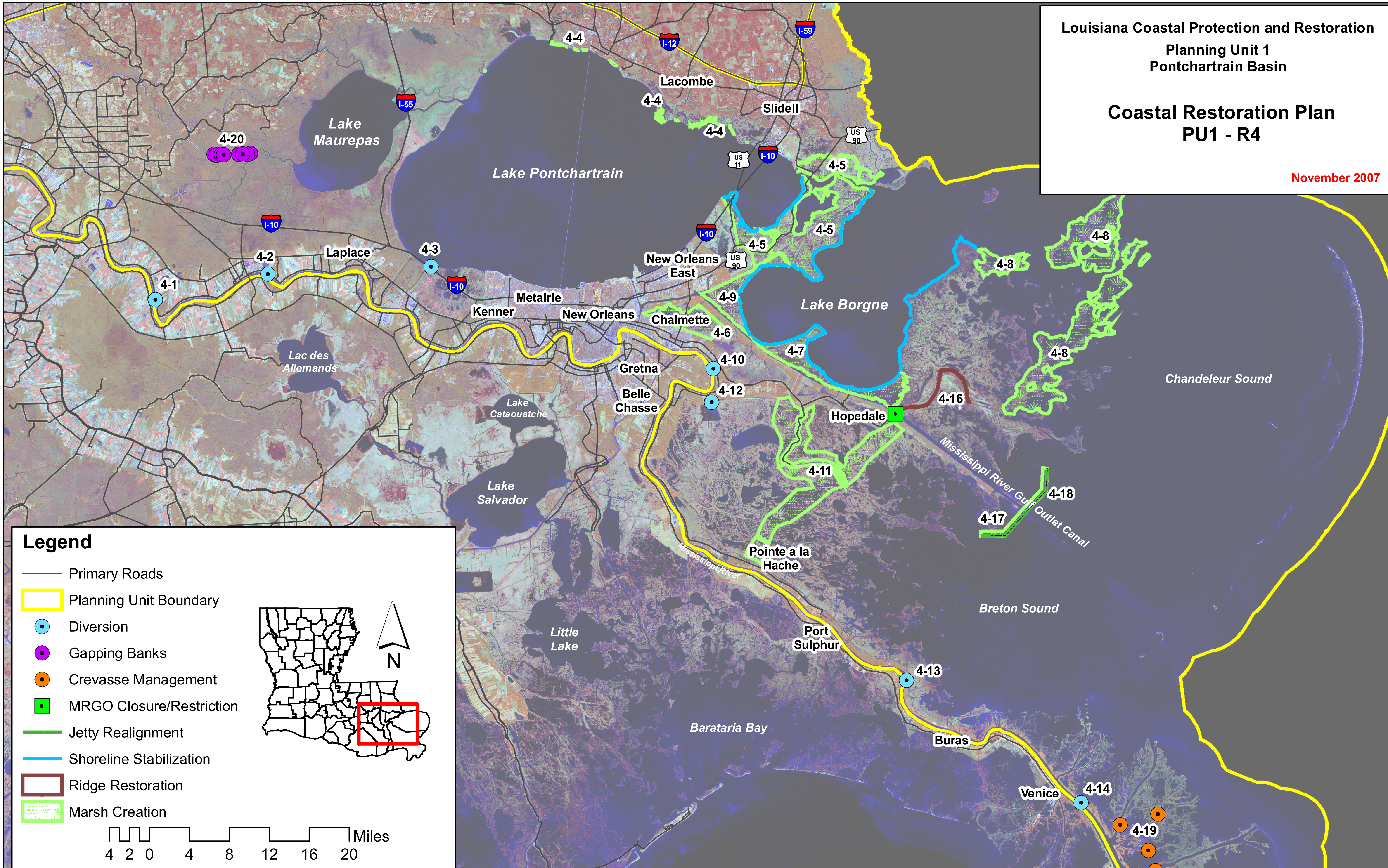

Louisiana Coastal Protection and Restoration
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November 2007
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Gapping Banks
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MRGO Closure/Restriction
Jetty Realignment
Shoreline Stabilization
Ridge Restoration
Marsh Creation
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Lake Borgne
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Breton Sound
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Belle Chasse
Hopedale
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Port Sulphur
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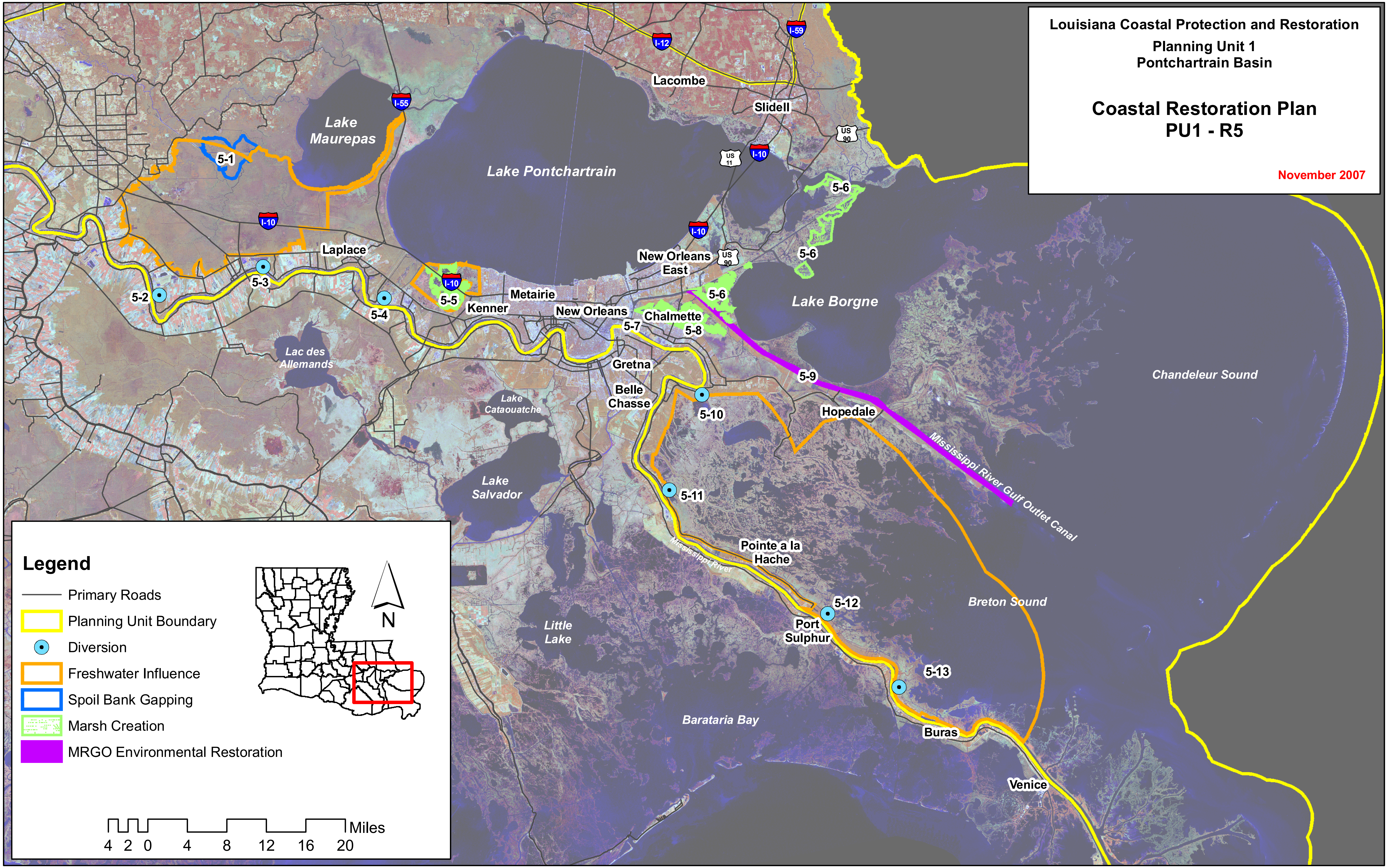

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New Orleans
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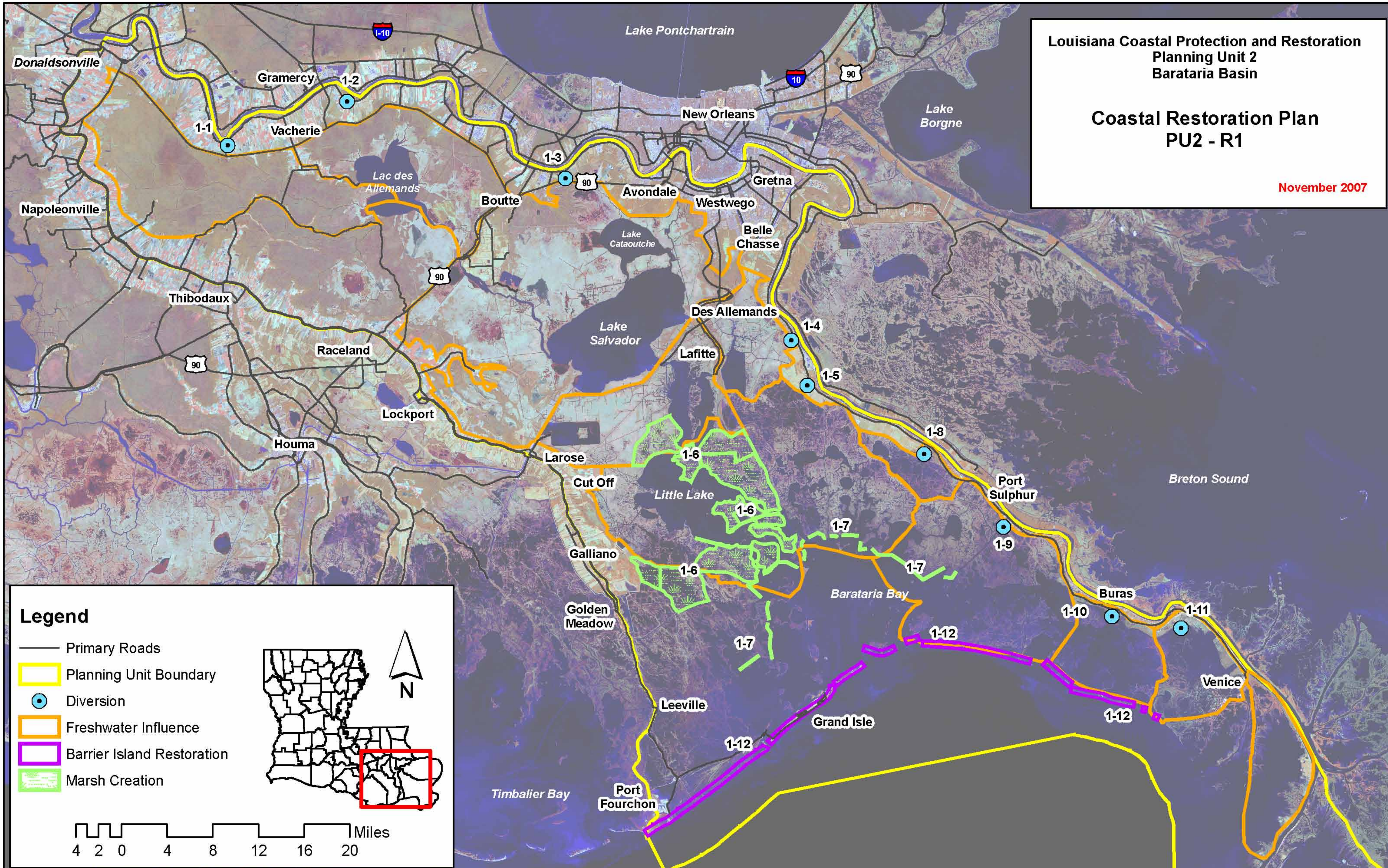

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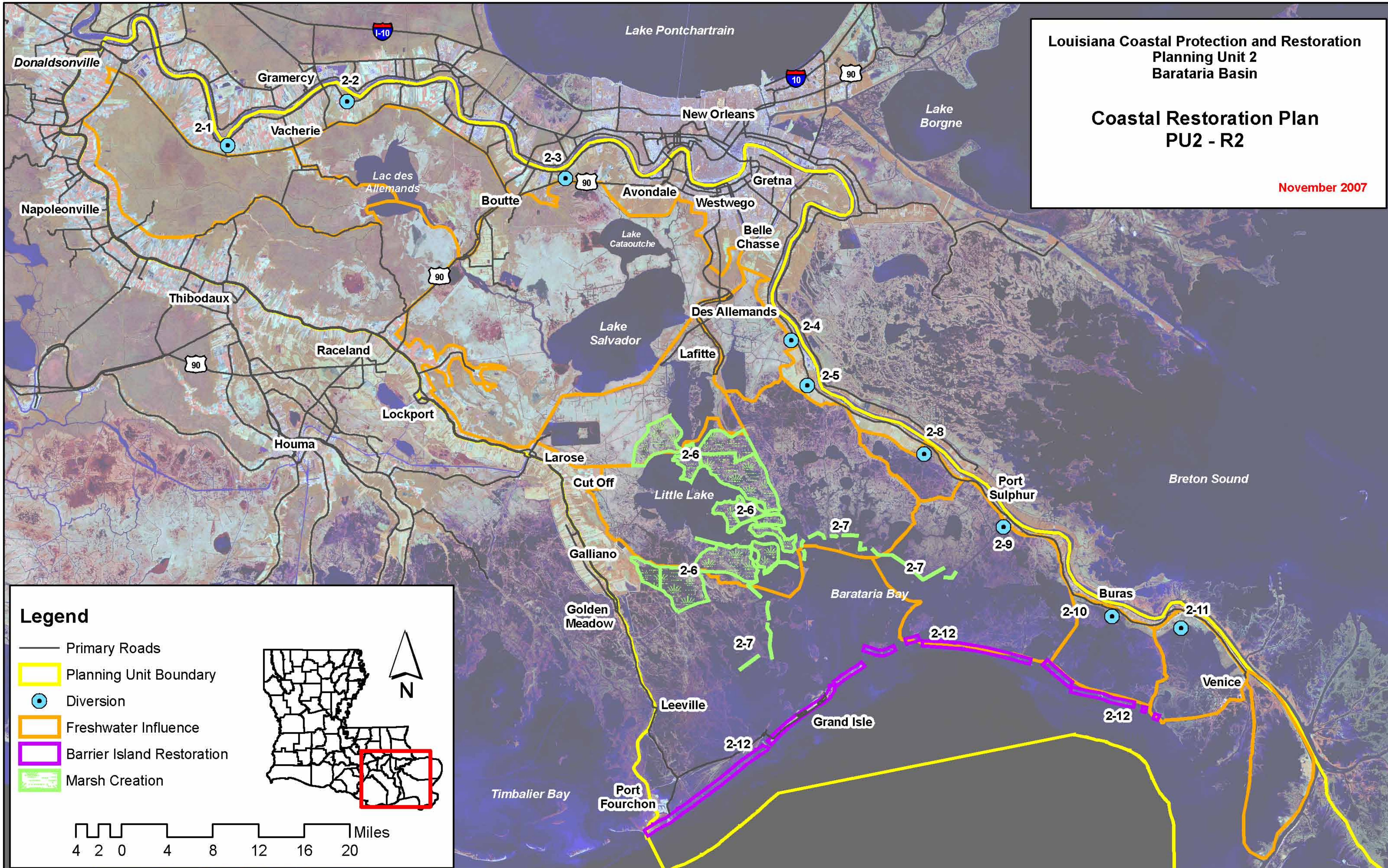

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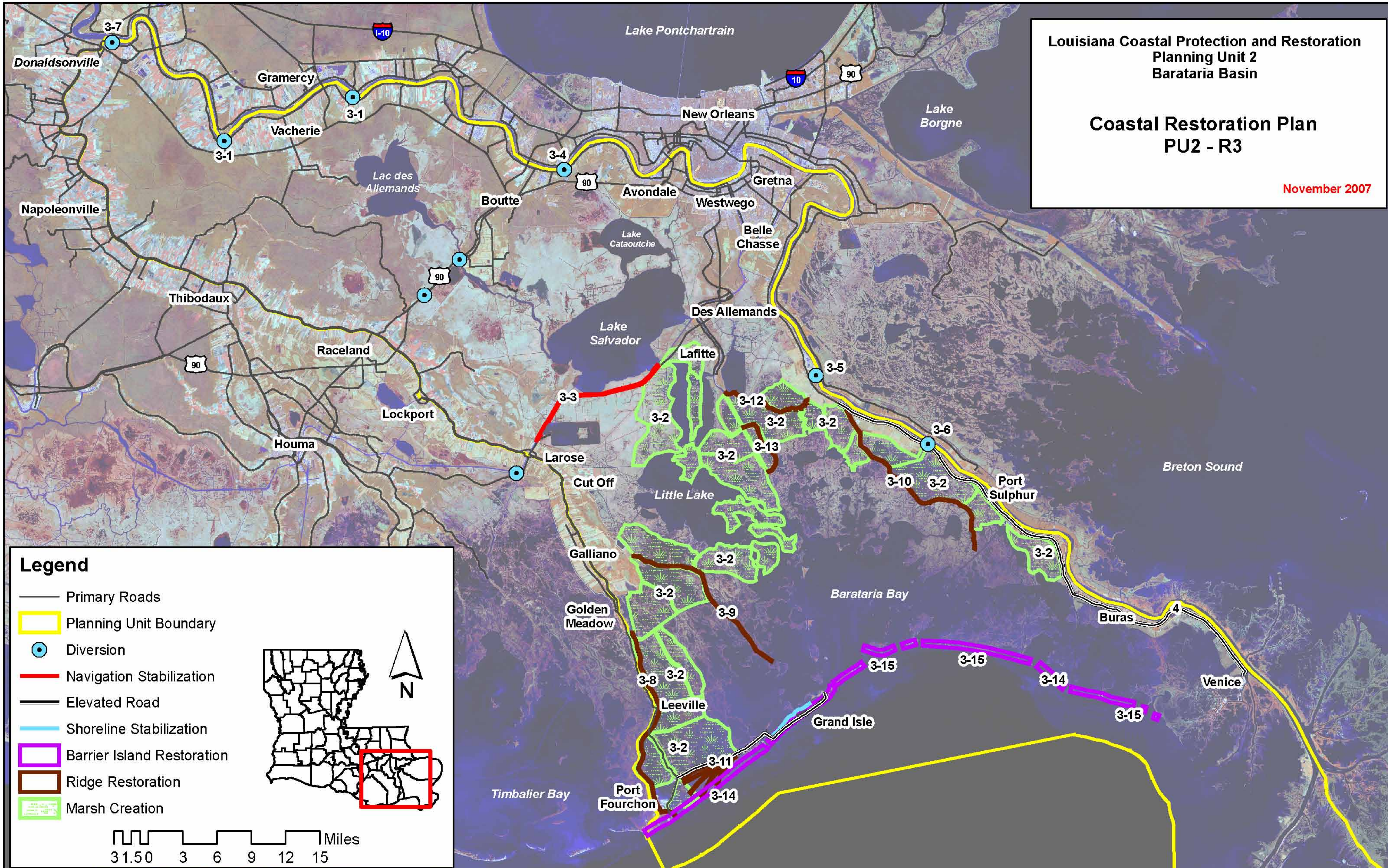

Louisiana Coastal Protection and Restoration
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Planning Unit Boundary
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Elevated Road
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Marsh Creation
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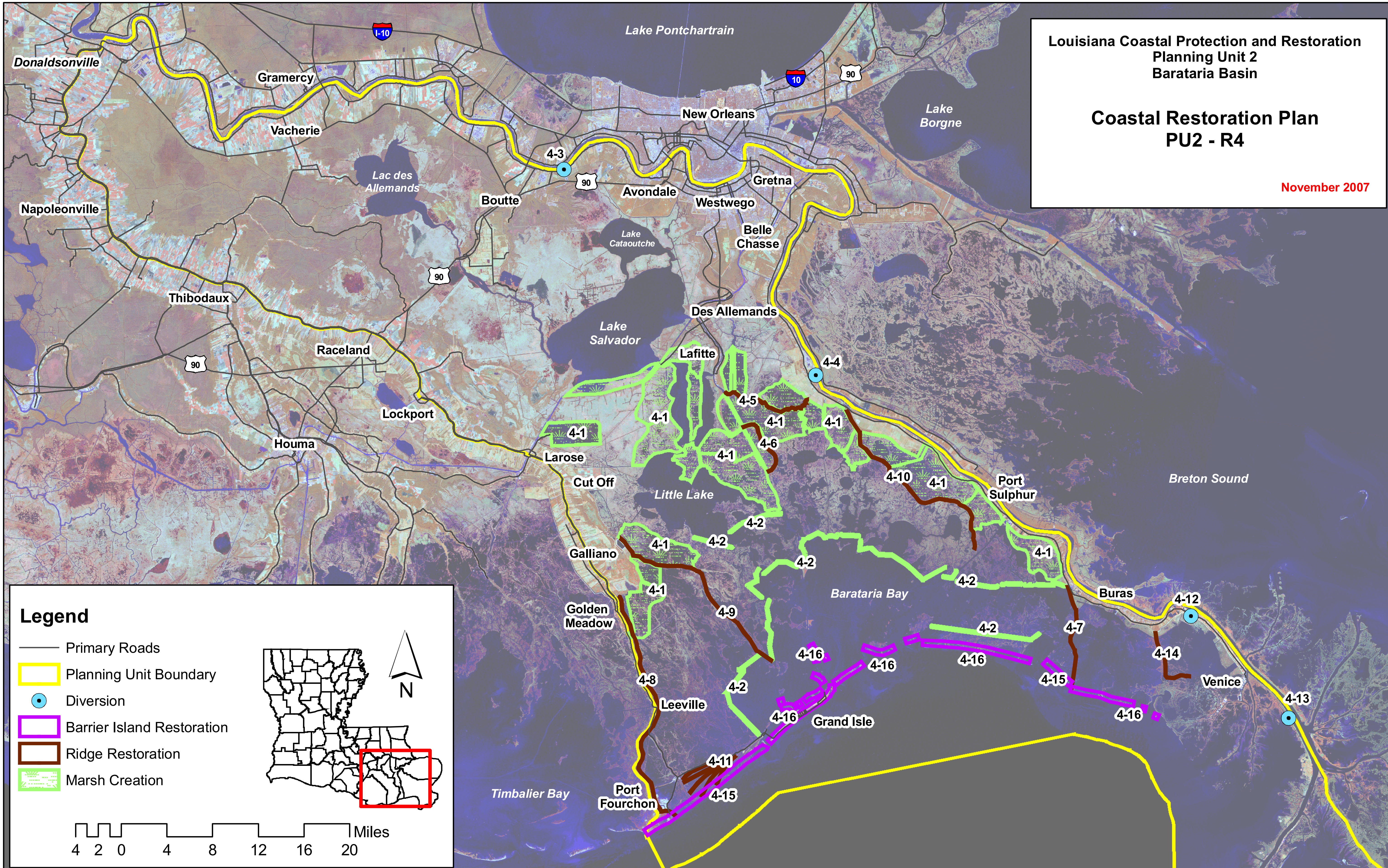

Louisiana Coastal Protection and Restoration
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Coastal Restoration Plan
PU2 - R4
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Planning Unit Boundary
Diversion
Barrier Island Restoration
Ridge Restoration
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Donaldsonville
Gramercy
Vacherie
New Orleans
Lac des Allemands
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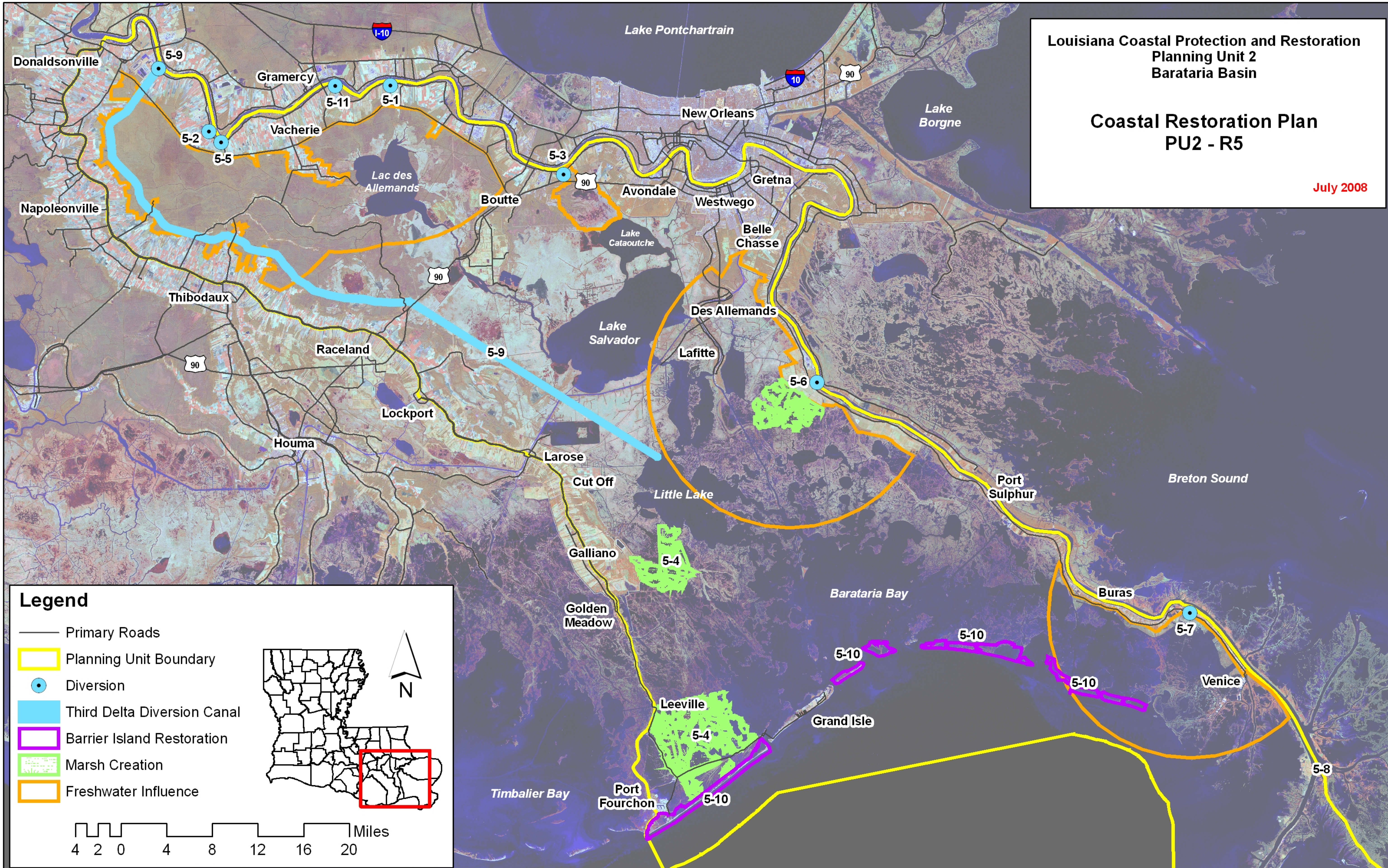
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Coastal Restoration Plan
PU2 - R5
July 2008
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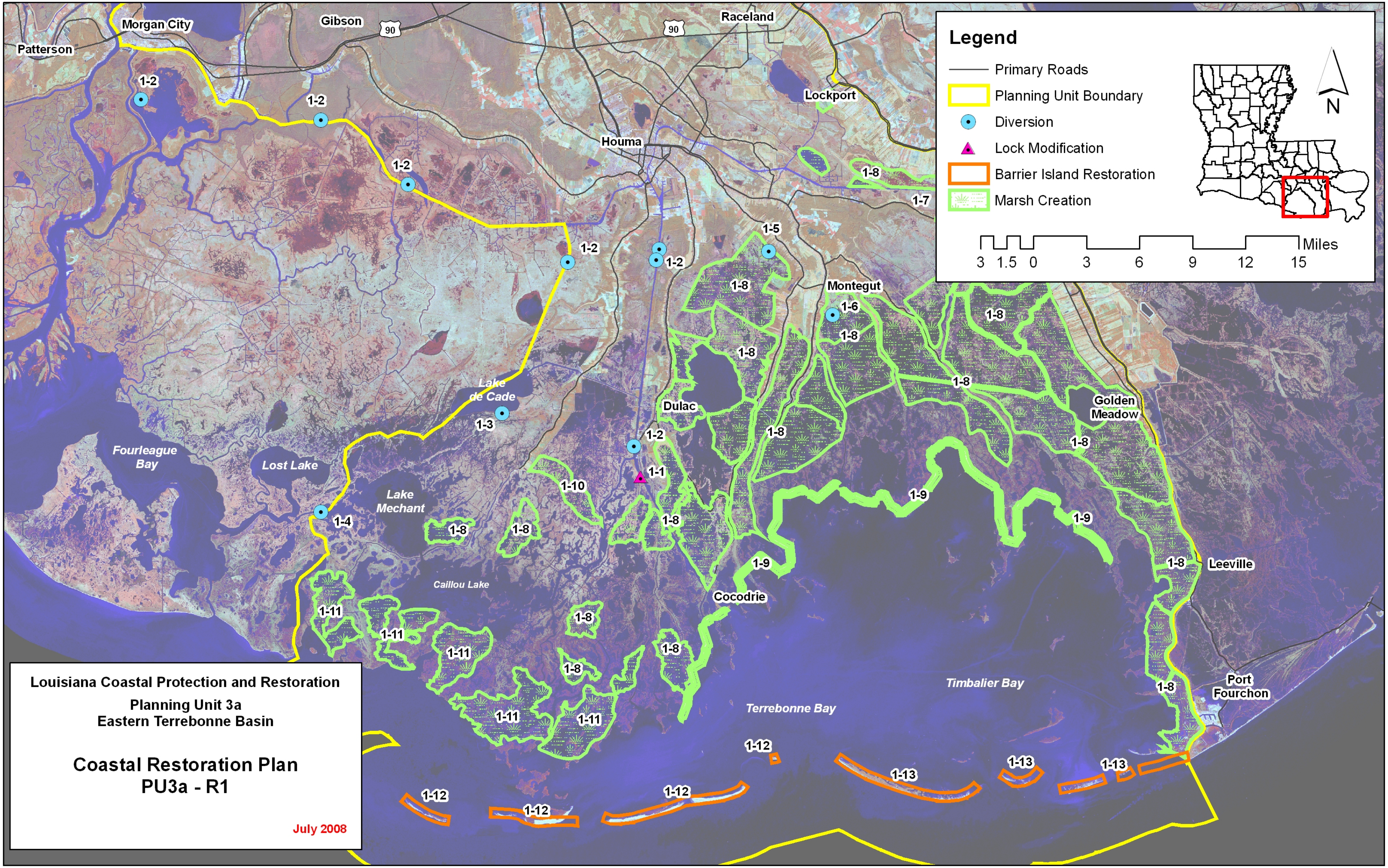
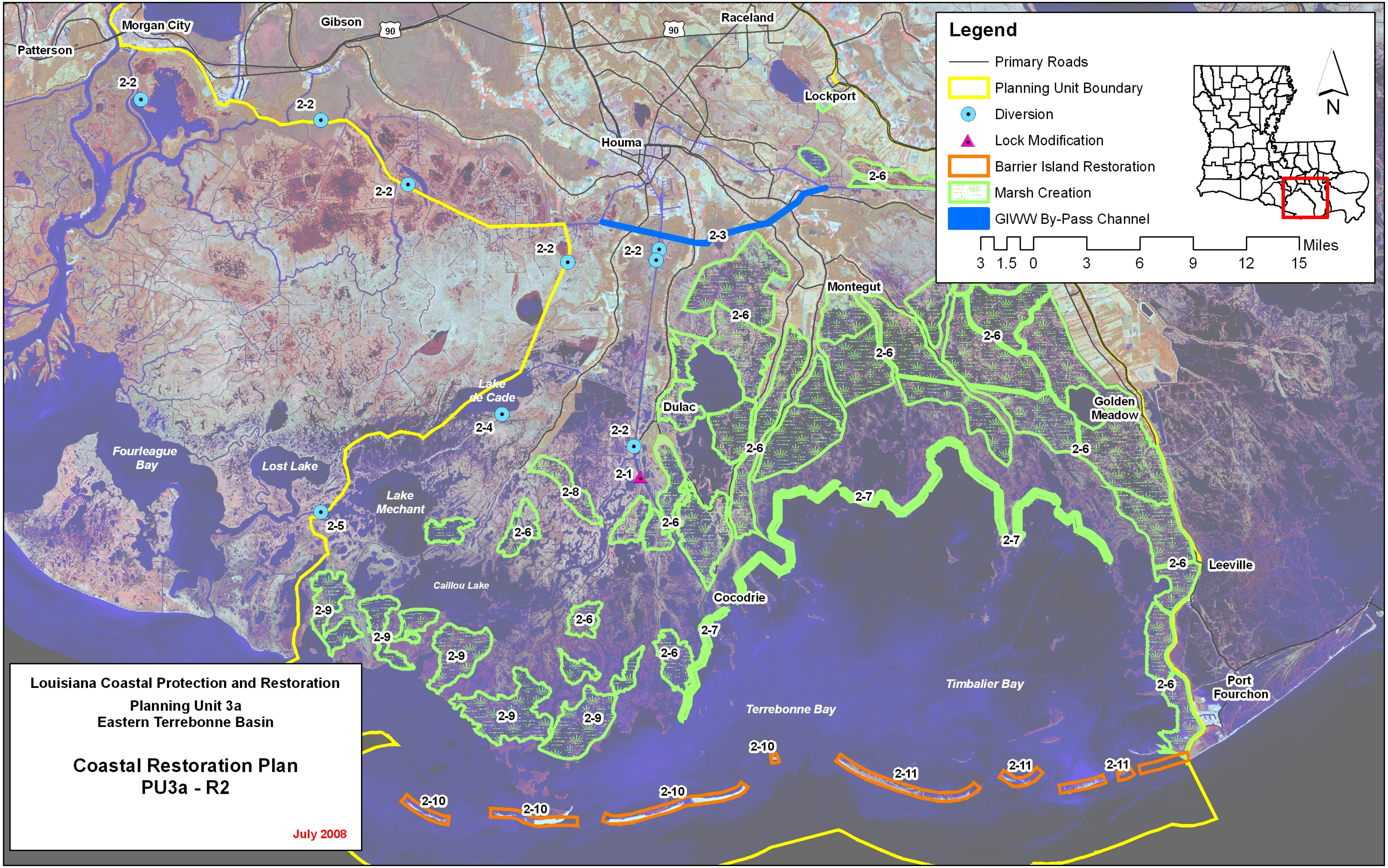


Louisiana Coastal Protection and Restoration

Planning Unit 3a
Eastern Terrebonne Basin

Coastal Restoration Plan
PU3a - R1

July 2008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Lock Modification
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Louisiana Coastal Protection and Restoration
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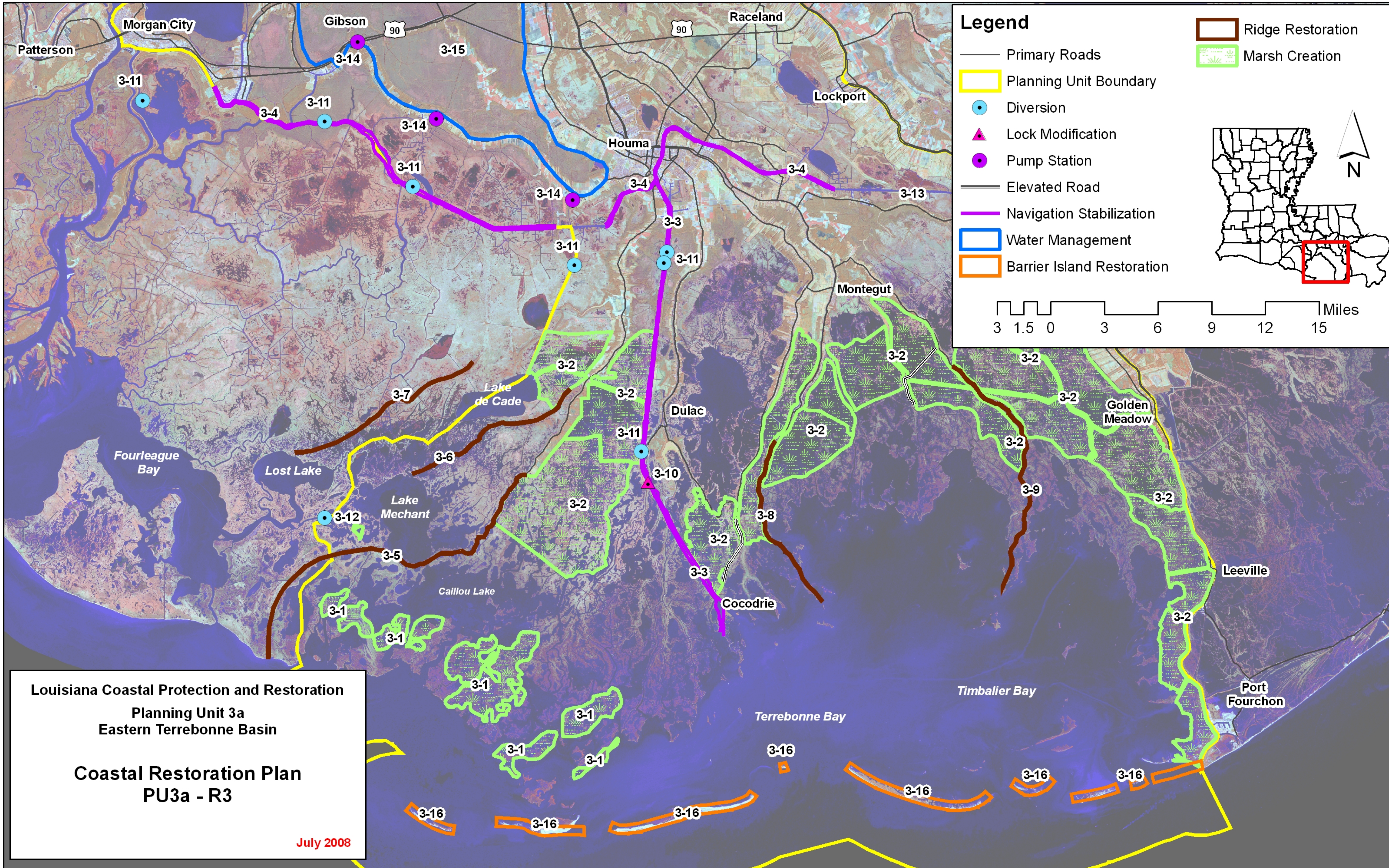
Coastal Restoration Plan
PU3a - R2
July 2008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Pump Station
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Navigation Stabilization
Water Management
Barrier Island Restoration
Ridge Restoration
Marsh Creation
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Louisiana Coastal Protection and Restoration
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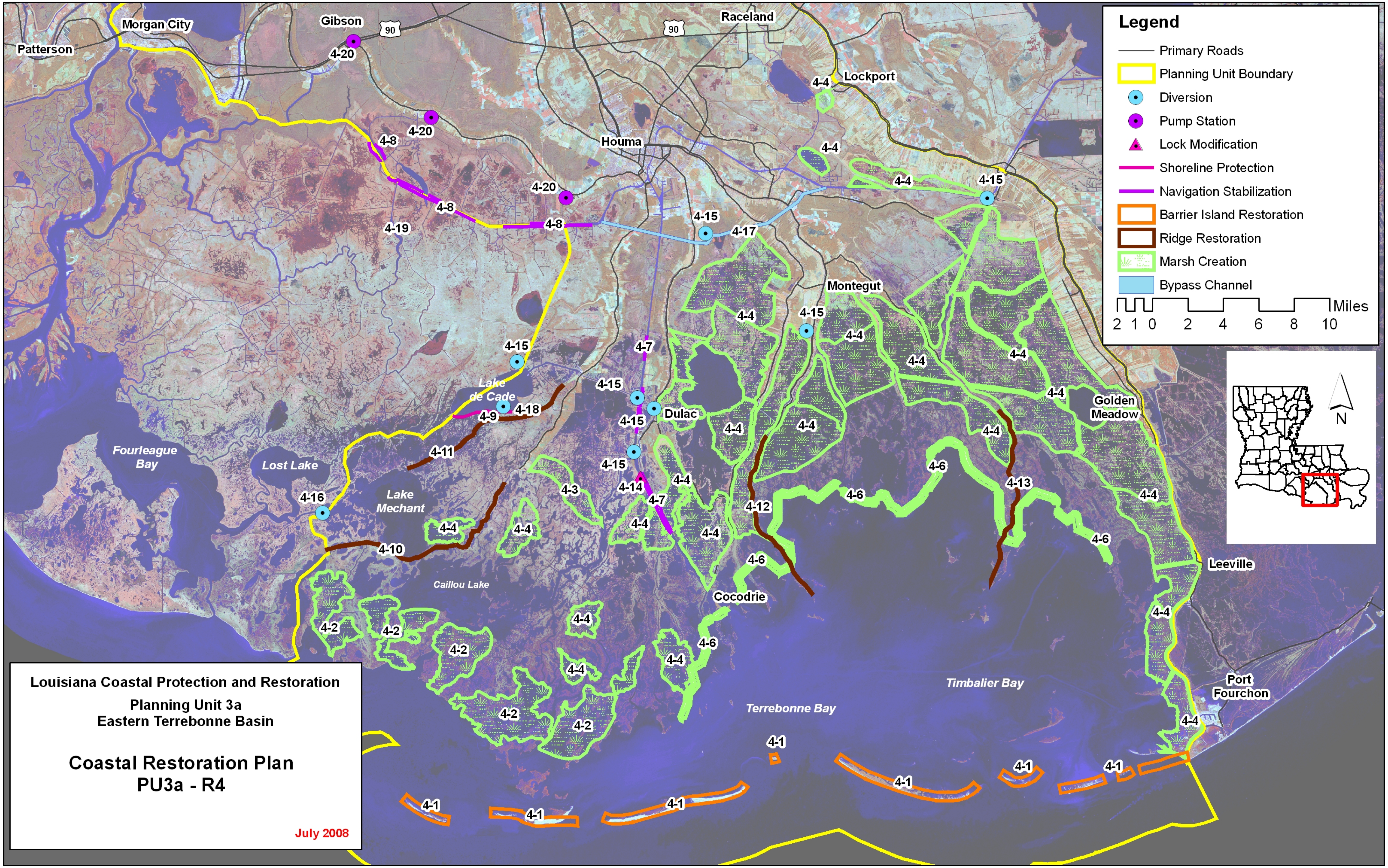
Coastal Restoration Plan
PU3a - R3
July 2008

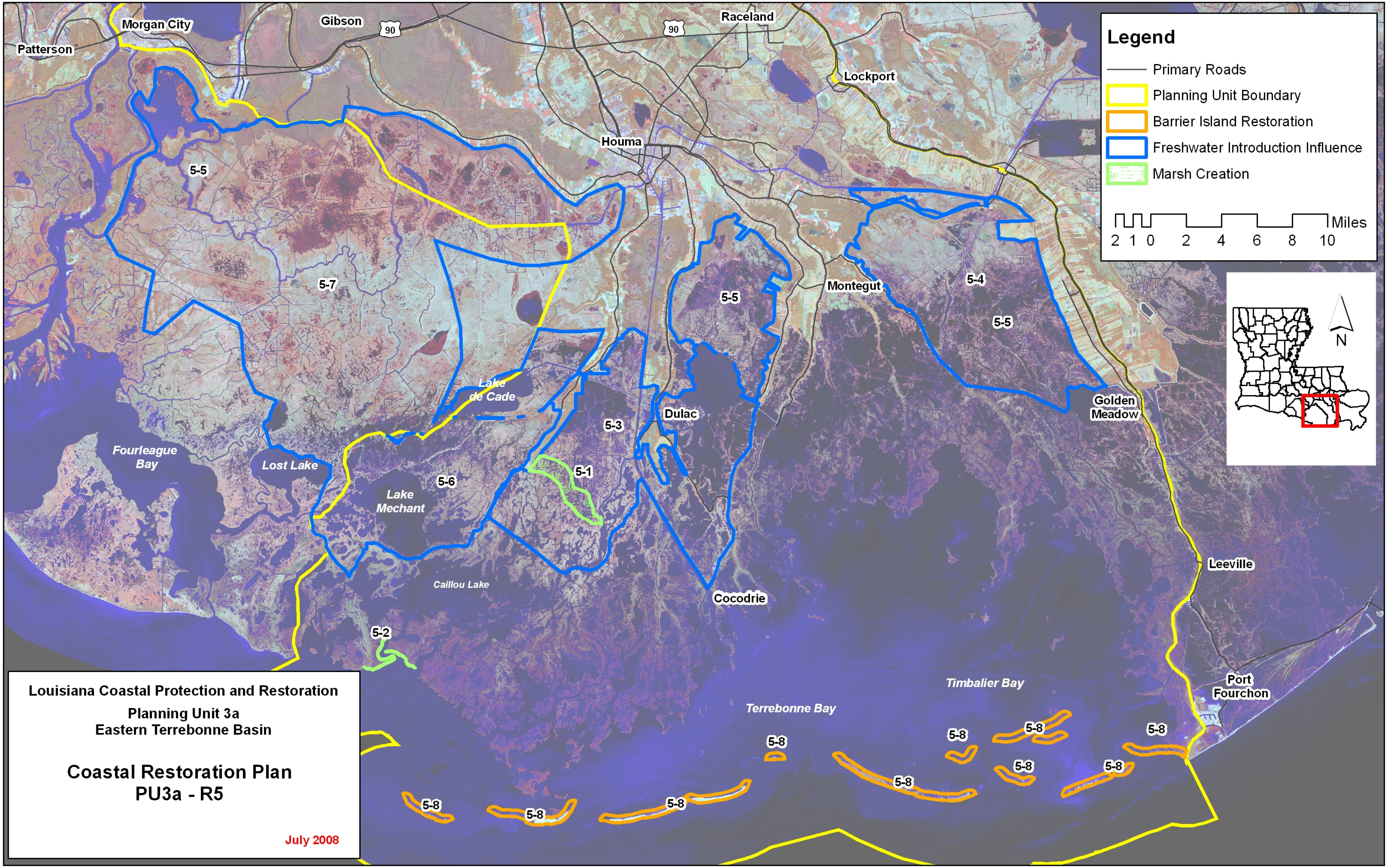


Louisiana Coastal Protection and Restoration

Planning Unit 3a
Eastern Terrebonne Basin

Coastal Restoration Plan
PU3a - R4

July 2008



Louisiana Coastal Protection and Restoration

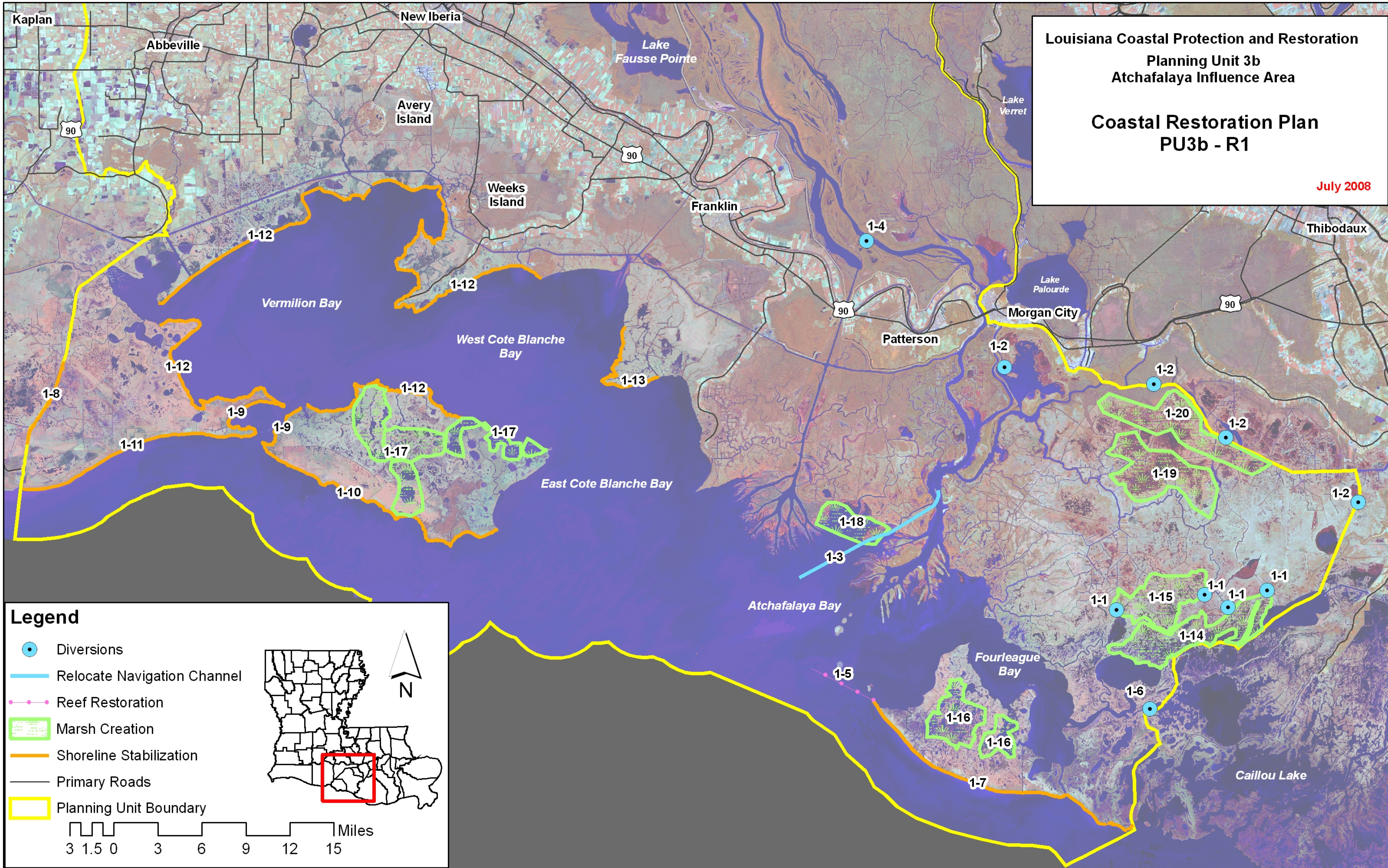
Planning Unit 3a

Eastern Terrebonne Basin

Coastal Restoration Plan

PU3a - R5

July 2008



Louisiana Coastal Protection and Restoration
Planning Unit 3b
Atchafalaya Influence Area
Coastal Restoration Plan
PU3b - R1
July 2008
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Abbeville
New Iberia
Lake Fausse Pointe
Avery Island
Weeks Island
Franklin
Lake Verret
Lake Palourde
Morgan City
Patterson
Thibodaux
Vermilion Bay
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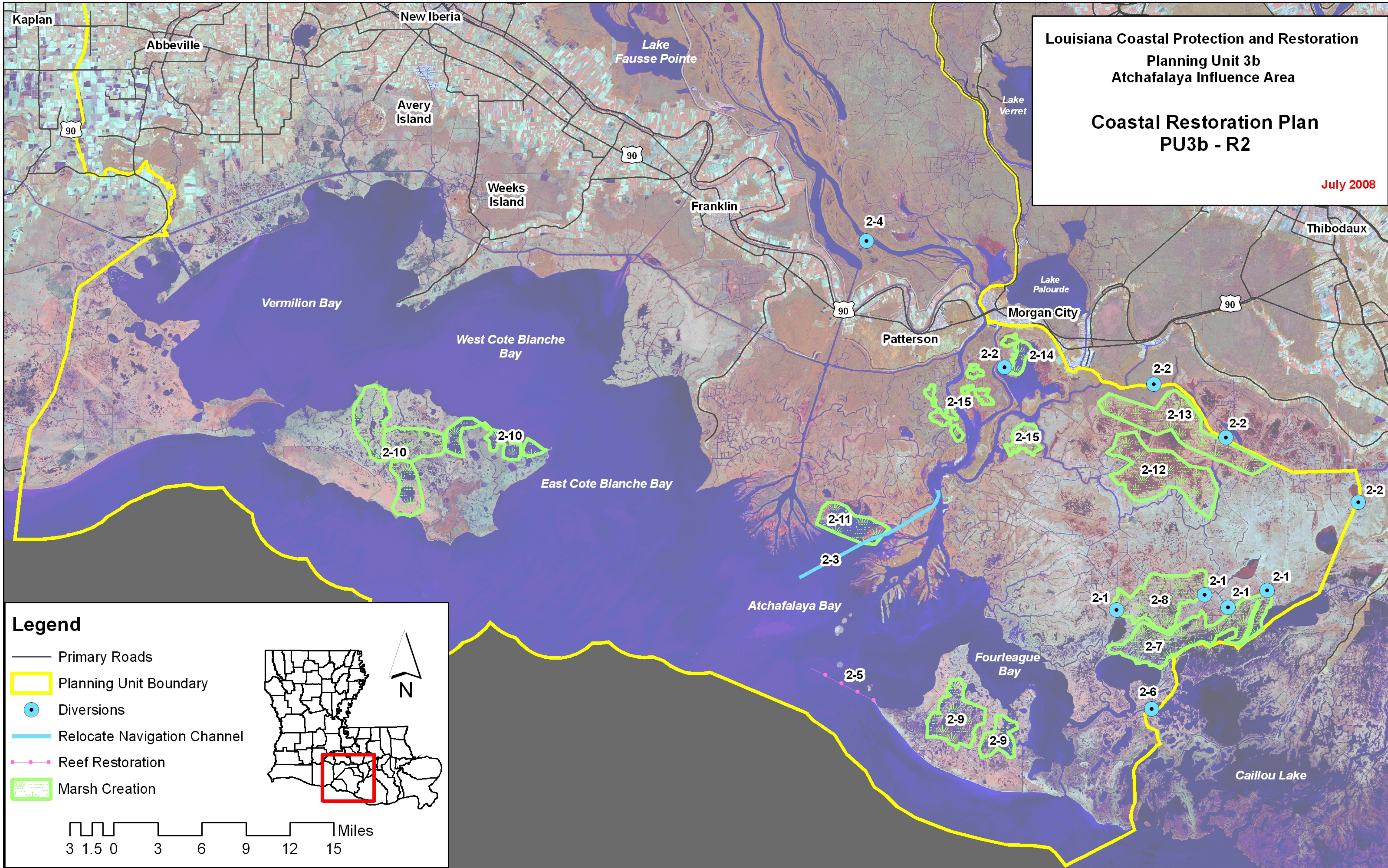

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PU3b - R2
July 2008
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Lake Fausse Pointe
Avery Island
Weeks Island
Franklin
Lake Verret
Lake Palourde
Morgan City
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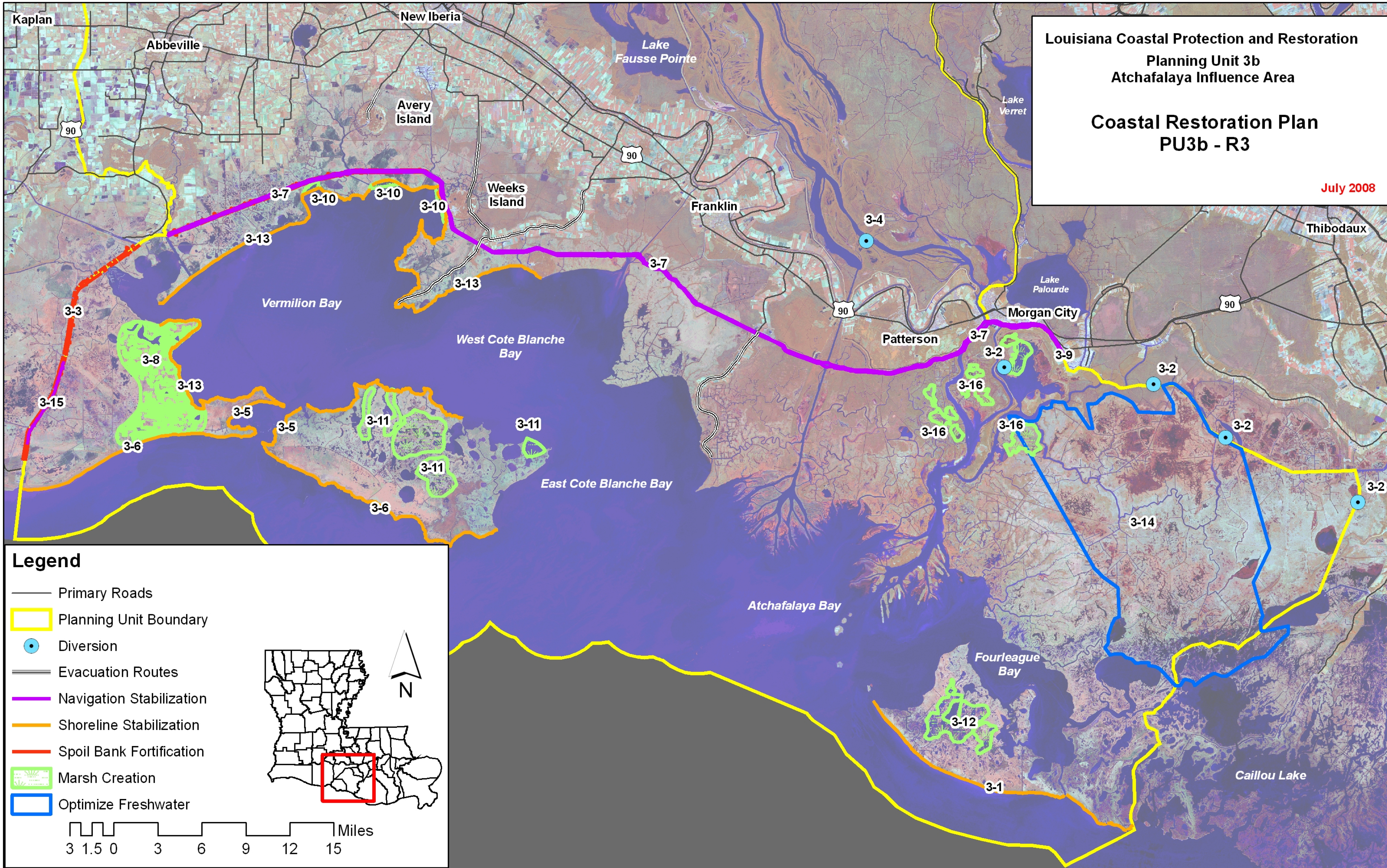

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Lake Verret
Lake Palourde
Morgan City
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Legend
Primary Roads
Planning Unit Boundary
Diversion
Evacuation Routes
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Shoreline Stabilization
Spoil Bank Fortification
Marsh Creation
Optimize Freshwater
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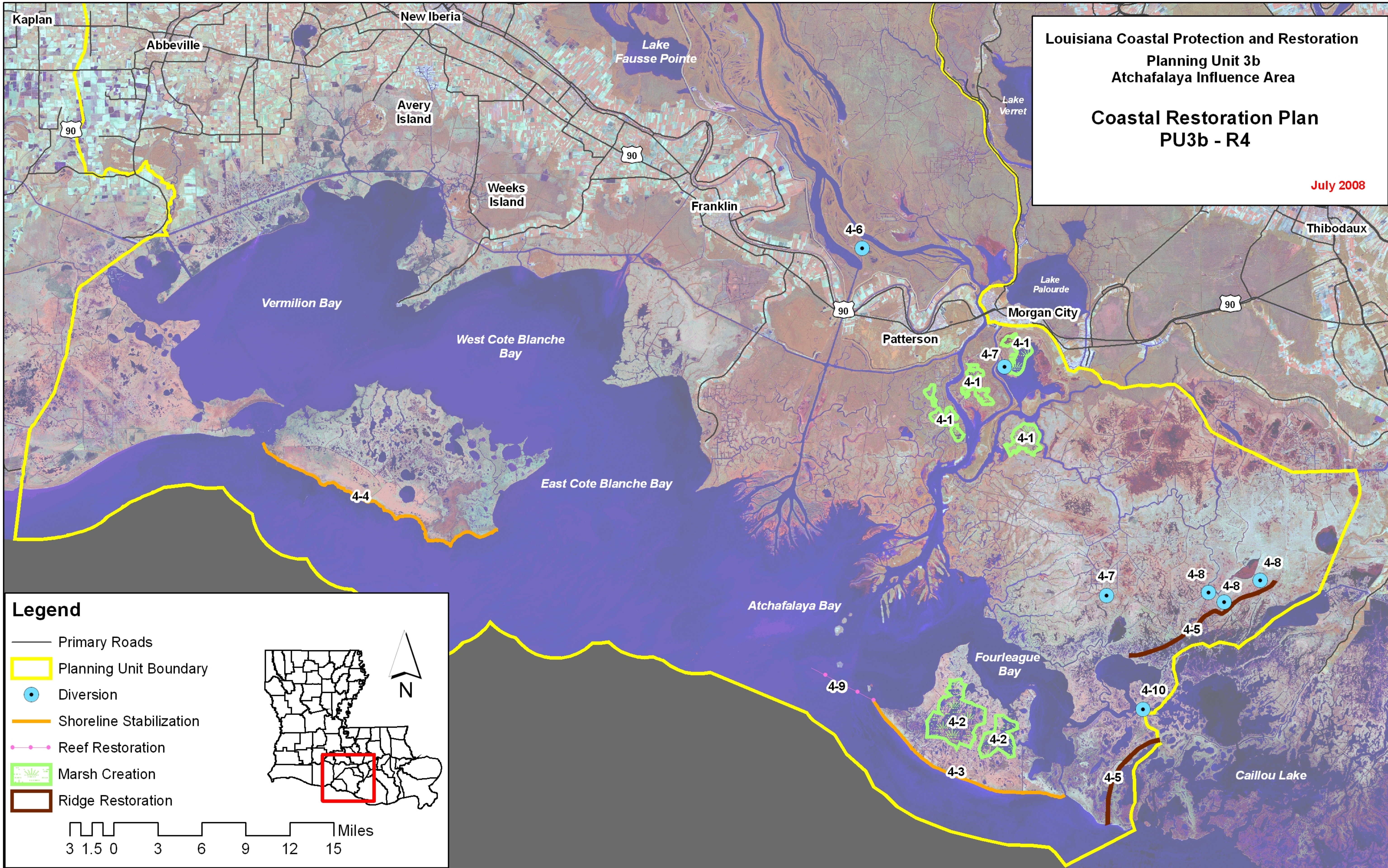

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Lake Fausse Pointe
Avery Island
Weeks Island
Franklin
Lake Verret
Thibodaux
Lake Palourde
Morgan City
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West Cote Blanche Bay
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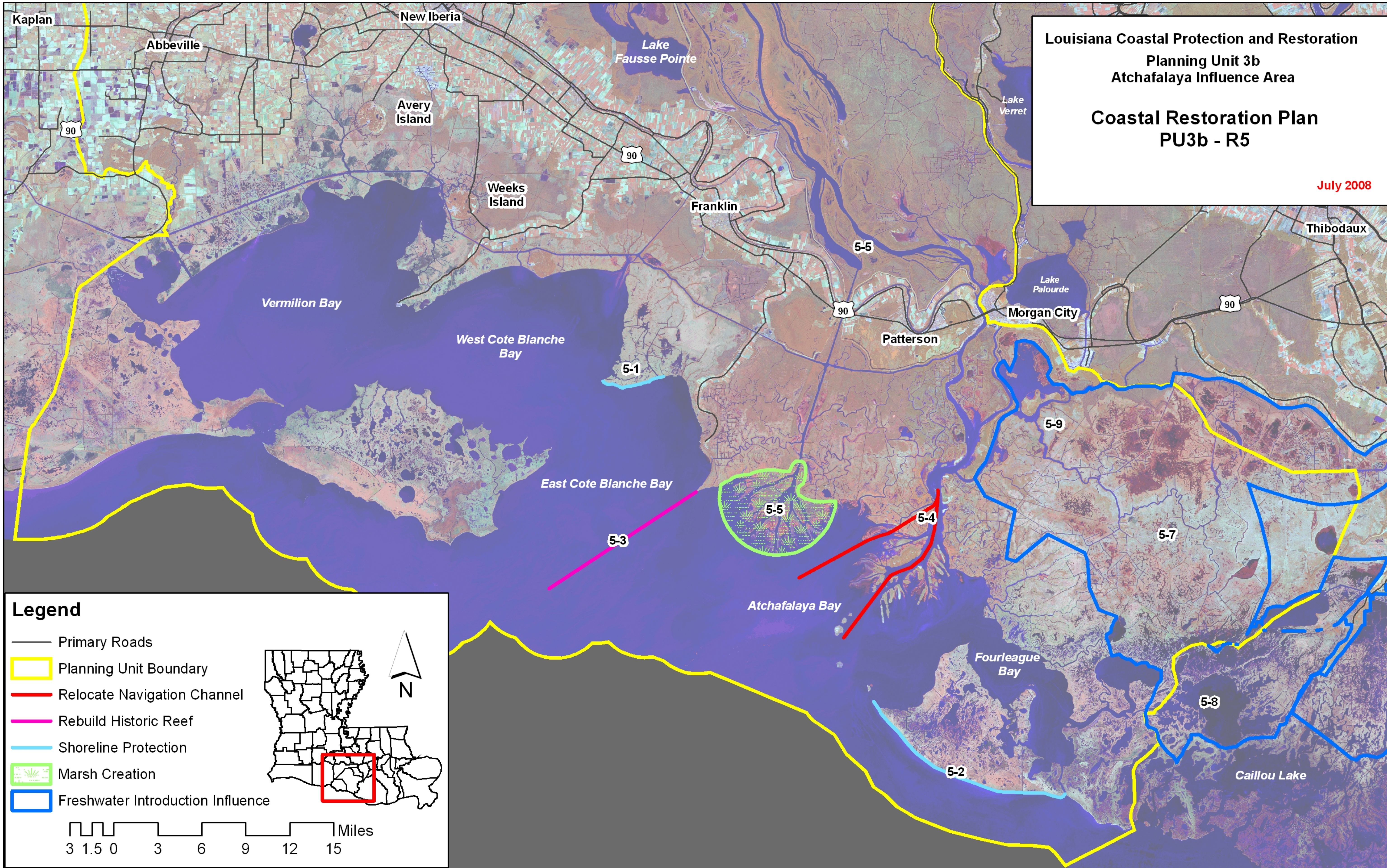

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Weeks Island
Franklin
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Thibodaux
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Morgan City
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Vermilion Bay
West Cote Blanche Bay
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Relocate Navigation Channel
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Shoreline Protection
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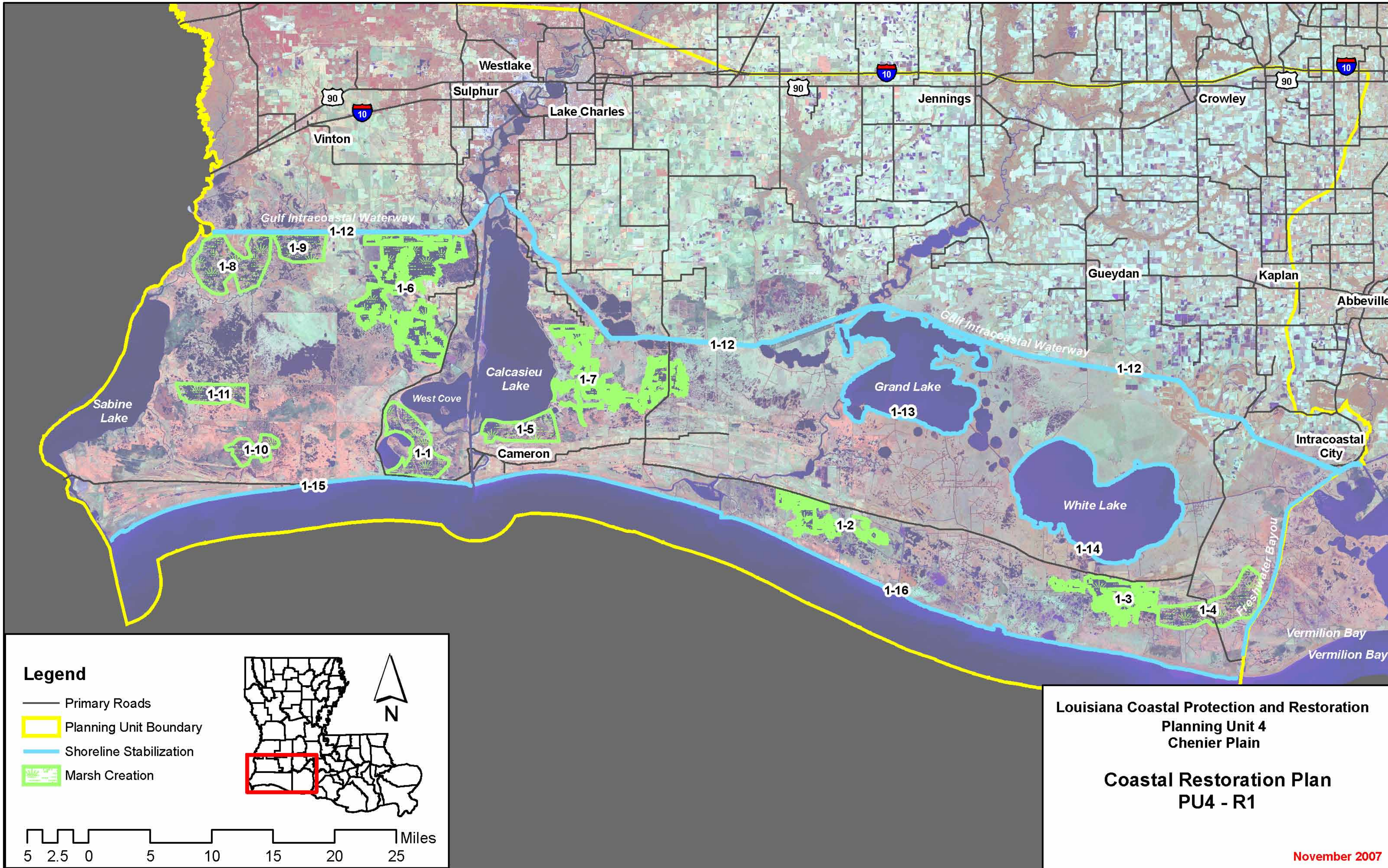
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Jennings
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Intracoastal City
Gulf Intracoastal Waterway
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Sabine Lake
Calcasieu Lake
West Cove
Cameron
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White Lake
Freshwater Bayou
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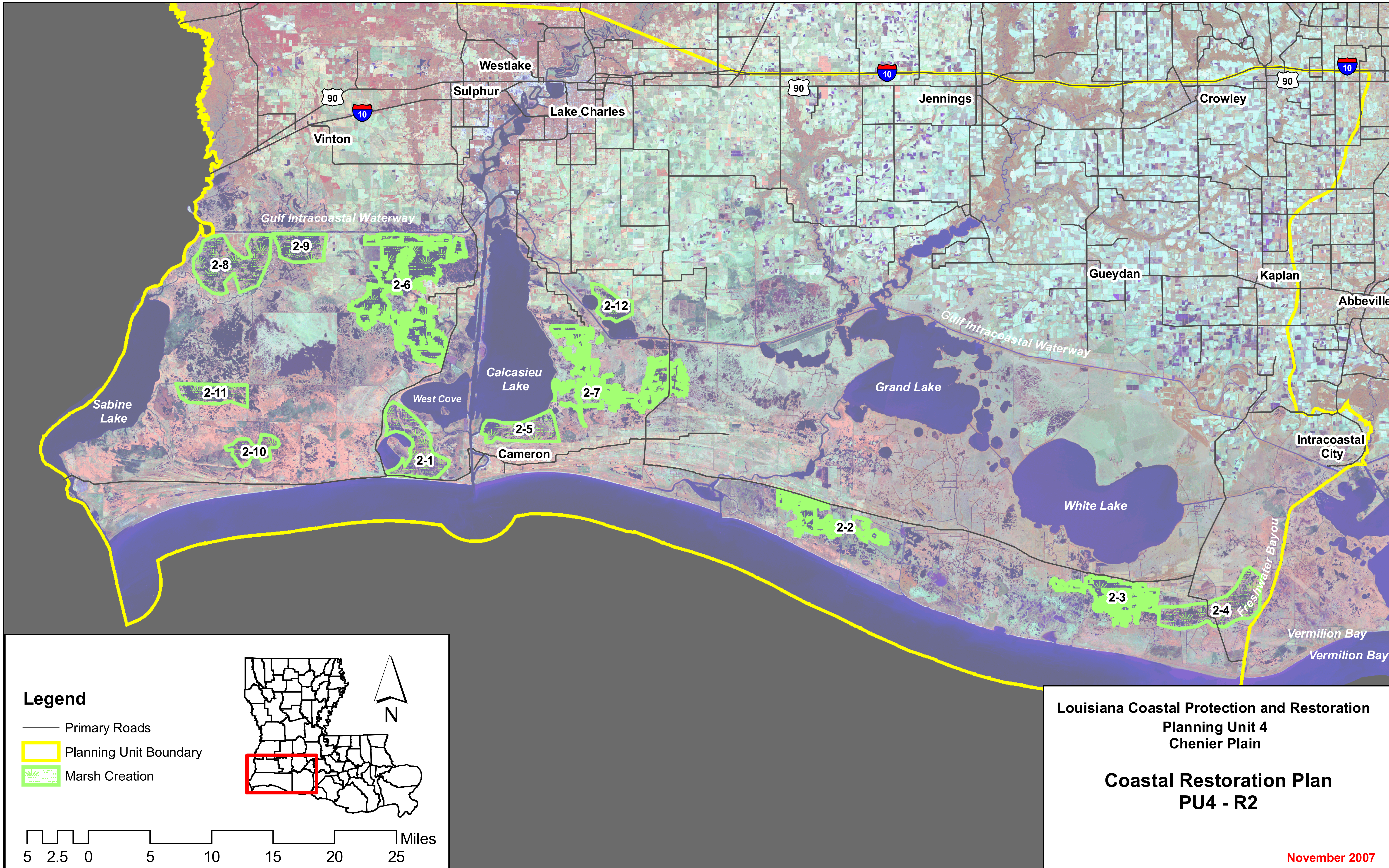
November 2007



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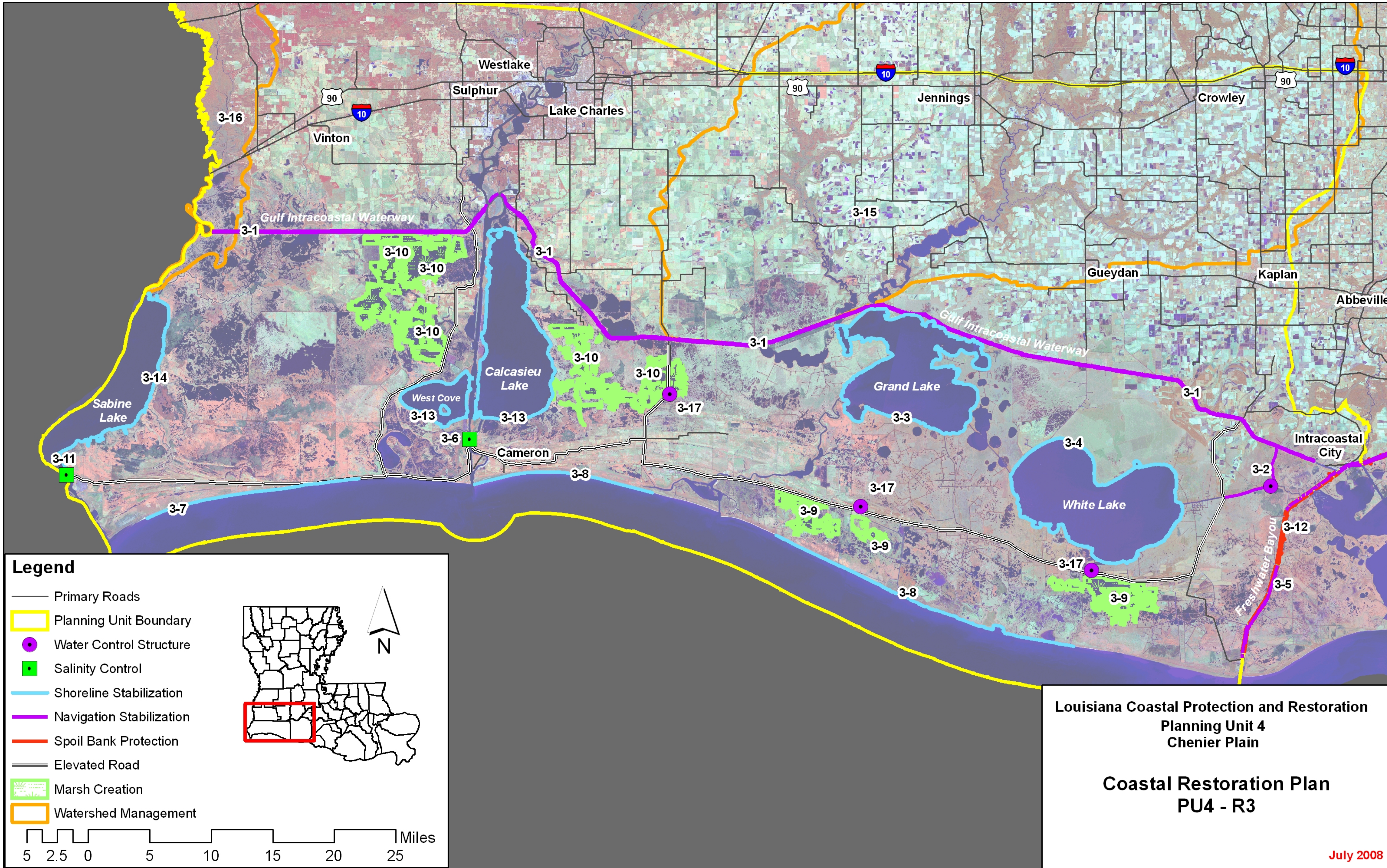
Planning Unit 4
Chenier Plain

Coastal Restoration Plan
PU4 - R2

November 2007



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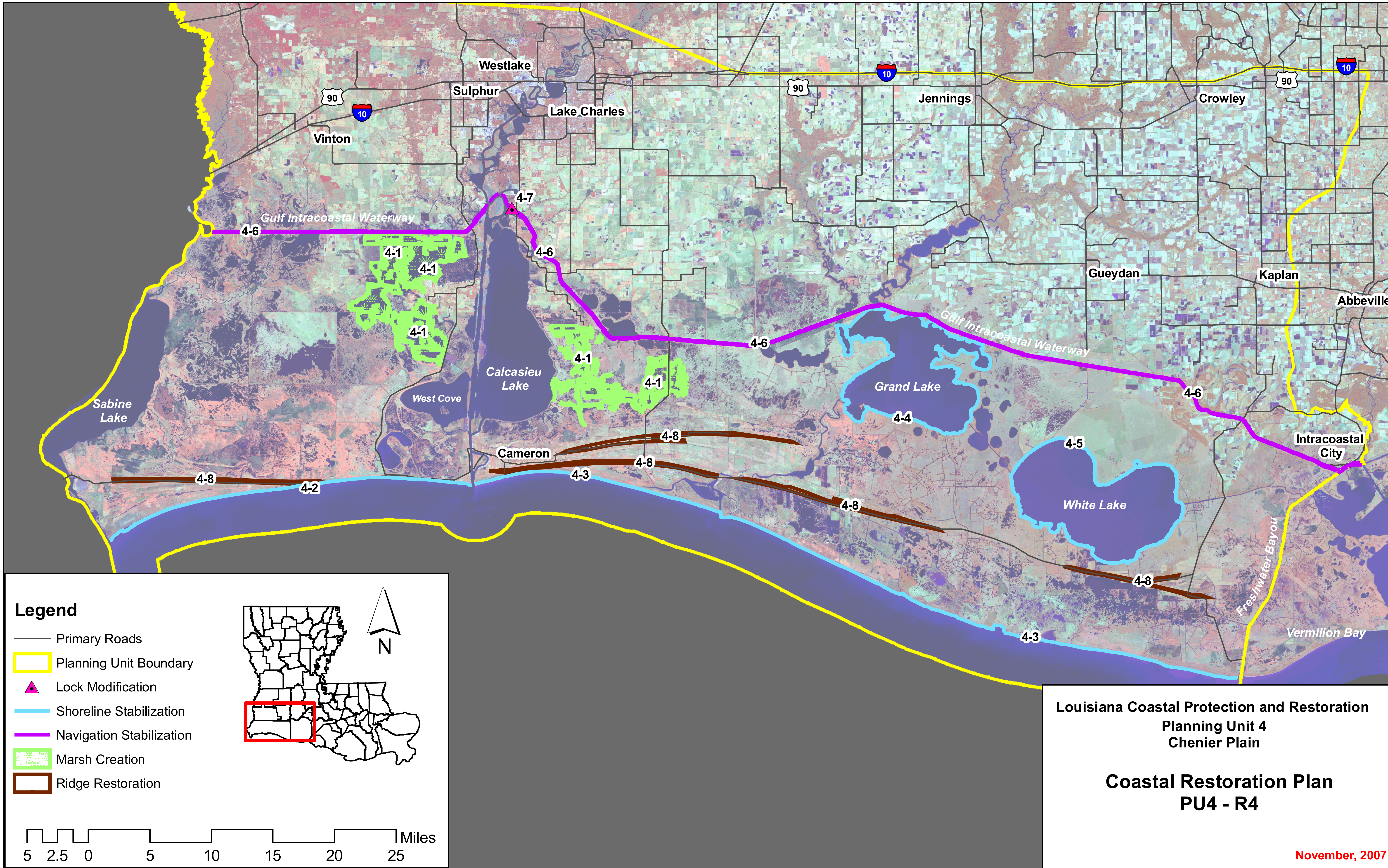
July 2008



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Intracoastal City
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Vermilion Bay
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Lock Modification
Shoreline Stabilization
Navigation Stabilization
Marsh Creation
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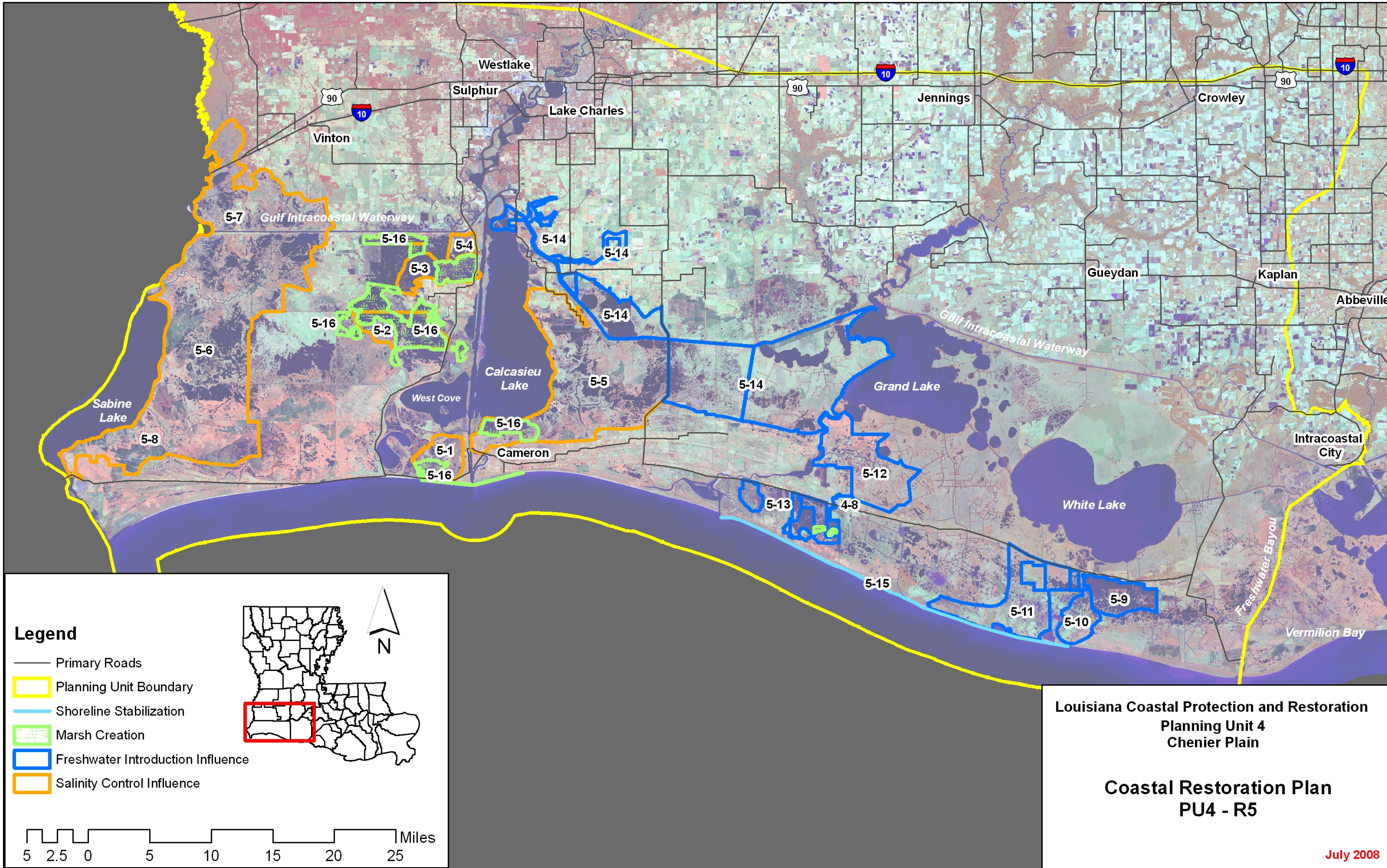
November, 2007



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Primary Roads
Planning Unit Boundary
Shoreline Stabilization
Marsh Creation
Freshwater Introduction Influence
Salinity Control Influence
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Louisiana Coastal Protection and Restoration
Planning Unit 4
Chenier Plain
Coastal Restoration Plan
PU4 - R5
July 2008

ATTACHMENT B

Indirect Impacts Matrix

December 2008

Planning Unit 1

Levee Alignment	Hydrologic Impacts	Fishery Impacts	Induced Development	Ecological Sustainability/ Consistency	Total Score
LP-a-100-1	-2[1]	-2[2]	-2[3]	-2[4]	-8
LP-b-400-1	-2	-2	-2	-2	-8
LP-a-100-3	-2	-2	-2	-2	-8
HL-a-100-3	-1[5]	0[6]	-1[7]	+1[8]	-1
LP-a-100-2	-2	-2	-2	-2	-8
HL-a-100-2	-1[9]	-1[10]	-1[11]	+1	-2
LP-b-1000-1	-2	-2	-2	-2	-8
HL-b-400-2	-1[12]	-1[13]	-1[14]	+1	-2
LP-b-400-3	-2	-2	-2	-2	-8
HL-b-400-3	-1	-1	-1	+1	-2
LP-b-1000-2	-2	-2	-2	-2	-8

[1] High potential to alter tidal flow in and out of Lake Pontchartrain, as well as drainage rates. *Such impacts could potentially be mitigated by designing the barrier in a way that does not change the cross sections at the passes.*

[2] High potential to affect fish ingress and egress due to changes in velocities and other factors. *Such impacts could potentially be mitigated by designing the barrier in a way that does not change the cross sections at the passes.*

[3] Could facilitate various types of development in wetlands along north shore of Lake Pontchartrain and around Lake Maurepas.

[4] High potential for basin-wide enclosure impacts. Could conflict with future up-basin diversions.

[5] Potential for adverse hydrologic changes due to Slidell ring levee.

[6] Slidell ring levee could adversely affect fisheries, but such impacts would be relatively minor compared to other levee alignments in this planning unit.

[7] Slidell ring levee could induce development in wetlands.

[8] Could facilitate river reintroduction projects by minimizing potential concerns with flood risks to developed areas.

[9] North shore levees could affect tributary flow into Lake Pontchartrain and could enclose some wetlands. South shore would be built on existing alignments.

[10] North shore levees could have adverse impacts on fisheries.

[11] North Shore levees could facilitate recreational and residential development in enclosed wetlands.

[12] The enclosure of the Golden Triangle is likely to adversely impact wetland hydrology.

[13] The enclosure of the Golden Triangle is likely to adversely impact fisheries.

[14] Slidell and North Shore levees could induce development in wetlands.

Planning Unit 2

Levee Alignment	Hydrologic Impacts	Fishery Impacts	Induced Development	Ecological Sustainability/ Consistency	Total Score
WBI-100-1	0	0	+1[15]	+1[16]	+2
G-100-1	-2[17]	-2[18]	-2[19]	-2[20]	-8
R-100-2	0[21]	0	+2[22]	+2[23]	+4
R-100-3	0	0	+2	+2	+4
WBI-400-1	0	0	+1	+1	+2
R-100-4	0	0	+2	+2	+4
R-400-2	0	0	+2	+2	+4
G-100-4	-2	-2	-2	-2	-8
R-400-3	0	0	+2	+2	+4
R-400-4	0	0	+2	+2	+4
R-1000-4	0	0	+2	+2	+4
G-400-4	-2	-2	-2	-2	-8
G-1000-4	-2	-2	-2	-2	-8

[15] Would direct future development towards higher ground, but would not to the same extent as the "Ridge" alignment.

[16] Could facilitate diversions and hydrologic restoration, though not as much as "Ridge" alignment.

[17] Existing hydrologic disruption caused by GIWW would likely be worsened unless numerous gates were installed. Potential to further restore basin-wide hydrology in future would be greatly reduced. Encloses greatest area of wetlands.

[18] Would enclose large estuarine area. The ability to maintain or enhance existing fishery access is highly uncertain. Would likely cause significant direct, indirect, and secondary impacts to fish habitat.

[19] Could induce commercial and/or recreational development in wetlands along Highway 90/I49, GIWW, Lake Salvador and vicinity. Forested wetlands north of Highway 90/I49 would be more susceptible to residential, commercial and recreational development.

[20] High potential for conflict with future up-basin diversions.

[21] Assumes that levee is built on upland side of wetland-upland interface.

[22] Would direct future development away from wetlands towards higher ground along the Mississippi River and Bayou Lafourche.

[23] Could facilitate diversions and hydrologic restoration by minimizing flood risk to developed areas.

Planning Unit 3a

Levee Alignment	Hydrologic Impacts	Fishery Impacts	Induced Development	Ecological Sustainability/ Consistency	Total Score
M-100-1	-2[24]	-2[25]	-1[26]	--2[27]	-7
M-100-2	-1	-1	-1	-1	-4
G-400-2	-2	-1	-2[28]	--2	-7
G-1000-2	-2	-1	-2	--2	-7

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[24] Potential for adverse impacts to wetlands enclosed within levee system due to altered hydrology. Such impacts could be further minimized by proper design, construction, and operation of water control features.

[25] This alignment would enclose large estuarine area. Could adversely affect fisheries ingress and egress into large estuarine area. Such impacts could be minimized by proper design, construction, and operation of water control features.

[26] This alignment could induce/facilitate commercial, residential, and recreational development in wetland areas behind levee.

[27] Potential for conflict with future diversions. (However, the Morganza to the Gulf alignment, the Bayou Black Ridge alignment, and the GIWW alignment could theoretically be designed, built, and operated in a way that could improve freshwater distribution.)

[28] Substantially reduced hurricane flooding risk could substantially induce development in wetlands in vicinity of Houma. Could be less negative or positive if the design is optimized.

Planning Unit 3b

Levee Alignment	Hydrologic Impacts	Fishery Impacts	Induced Development	Ecological Sustainability/ Consistency	Total Score
G-100-1	-2	-2	-2	-2[29]	-8
F-100-1	0	0	+1	+1	2
F-400-1	0	0	+1	+1	2
F-1000-1	0	0	+1	+1	2
RL-100-1	0	0	+1	+1	2
RL-400-1	0	0	+1	+1	2

[29] Levees would enclose marshes and may reduce freshwater flow and sediment input to enclosed and outside marshes via GIWW and other structures.

Planning Unit 4

Levee Alignment	Hydrologic Impacts	Fishery Impacts	Induced Development	Ecological Sustainability/ Consistency	Total Score
G-100-1	-2[30]	-1[31]	-1[32]	-1	-5
G-100-2	-2	-1	-1	-1	-5
G-400-3	-2	-1	-2	-1	-6
G-1000-3	-2	-1	-2	-1	-6
RL-100-1	0	0	0	0	0
RL-400-1	0	0	0	0	0
RL-1000-1	0	0	0	0	0

[30] Existing hydrologic disruptions caused by the GIWW would likely be worsened unless gates were installed. Potential to restore basin-wide hydrology in future would be reduced or eliminated.

[31] Could enclose estuarine habitat.

[32] Could induce commercial and/or recreational development in wetlands south of Highway 14.

ATTACHMENT C

Quantifying Benefits of Freshwater Flow Diversion to Coastal Marshes: Theory and Application

December 2008

Quantifying Benefits of Freshwater Flow Diversion to Coastal Marshes: Theory[a] and Applications[b]

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Keywords: wetland, Louisiana, accretion, uncertainty, organic, inorganic, coastal restoration, operation,

Abstract

The combination of relative sea level rise and river/marsh disconnection has created a deficit of available soil and accompanying land loss in a large portion of coastal Louisiana. The U.S. Congress recently charged the U.S. Army Corps of Engineers, State of Louisiana, and other federal and local agencies with restoring the coastal wetlands of Louisiana and Mississippi. Many alternative combinations of restoration measures have been proposed, and assessment of the advantages and disadvantages of these efforts must be made to determine the optimal design. One technique being applied for coastal restoration is the reconnection of rivers to coastal marshes through flow diversions.

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[a] Based on material from McKay, S.K., J.C. Fischenich, and S.J. Smith. (2008). "Quantifying Benefits of Flow Diversion to Coastal Marshes. I: Theory." In draft for submission to Ecological Engineering.
[b] Based on material from McKay, S.K., J.C. Fischenich, and R. Paille. (2008). "Quantifying Benefits of Flow Diversion to Coastal Marshes. II: Application to Louisiana Coastal Protection and Restoration." In draft for submission to Ecological Engineering.

Freshwater flow diversions offer significant nutrient and sediment inputs to marshes that induce both organic and inorganic accumulation of soil. Boustany (2007) presented a screening level model for assessing both the nutrient and sediment benefits of flow diversion over long time scales. This paper has presented the adaptation of Boustany's (2007) model to include daily variation in sediment processes in order to optimize diversion structure design and operation. The model was verified using an existing diversion to prove the ability of the model to track land evolution associated with flow diversion. This paper also demonstrates the application of the model to diversion operational and structural optimization.

Introduction

In the fall of 2005, Hurricanes Katrina and Rita awakened the United States public to the natural protection that coastal wetlands provide in reducing of the effects of hurricanes on coastal communities. In response to these catastrophic events, the U.S. Congress directed the U.S. Army Corps of Engineers (USACE) to "conduct a comprehensive hurricane protection analysis and design…to develop and present a full range of flood control, coastal restoration, and hurricane protection measures" (USACE, 2006). This paper focuses on interagency efforts to assess and weigh benefits of coastal restoration via freshwater flow diversion. The paper will focus on the development and adaptation of a screening level model to quantify the benefits of flow diversion to coastal marshes and will describe the assessment of various diversion operational and structural scenarios.

Coastal Marsh Accretion and Flow Diversion

The tidal marshes of coastal Louisiana are receding at alarming rates as high as 115 km^2/yr (Barras et al., 1994). Submergence of these valuable ecological assets (Figure 1) was once counteracted by vertical accretion due to the addition of freshwater, nutrient, and mineral inputs from riverine environments; however, eustatic sea level rise (ESLR) and basin subsidence now exceed the current rate of vertical accretion, and coastal marshes have been disconnected from their freshwater and sediment sources, distributary channels of the Mississippi and Atchafalya Rivers. ESLR has been attributed to global increase in ocean volume and has been estimated as 1.0-2.4 mm/yr (Church et al., 2001). Subsidence of the Mississippi delta has been attributed to multiple factors, namely: regional isostasy, faulting, sediment consolidation, and soil dewatering (Dokka et al., 2006). Previous researchers identified other potential sources of subsidence as groundwater and petroleum extraction (Morton et al., 2002); however, Dokka et al. (2006) renounce these hypotheses as unlikely due to the relative lack of groundwater extraction from the highly saltwater intruded groundwater table of most of southern Louisiana and the lack of coincidence between petroleum extraction and subsidence. The synergy of ESLR and basin subsidence has created an apparent local change in sea level known as Relative Sea Level Rise (RSLR) that has been measured in the Mississippi Delta at rates as high as 10 mm/yr (Snedden et al., 2007).

In addition to RSLR, the disconnection of coastal marshes from their sediment and nutrient source is equally disconcerting. Over geologic time scales, large-scale delta lobe switching has lead to alternating episodes of delta building and redistribution of sediment and nutrients throughout the coastal plain (Coleman, 1988; Coleman et al., 1998); however, in the last two centuries, the Mississippi River has been controlled by levees and other structures in order to maintain a consistent navigation channel for commerce and protect infrastructure against floods (Coleman et al., 1998; Parker et al., 2006). Presently, much of the sediment and nutrient load of the Mississippi River is discharged directly into the northern Gulf of Mexico through the birdsfoot delta, providing little benefit to protective delta building and contributing to an increasing zone of hypoxia near the river mouth (Mitsch et al., 2001). In addition to problems associated with fate of river sediment and nutrients, this disconnection starves coastal wetlands of historic nutrient and sediment inputs necessary for marsh sustainment. Although the relative importance of this multitude of factors has yet to be rigorously quantified throughout the Louisiana coastal plain, the combination of RSLR and river/marsh disconnection has led to high land loss rates and conversion of many freshwater marshes to shallow saltwater bays.

In recent years, freshwater flow diversions from river sources to coastal marshes have been offered as a tool for combating RSLR and disconnection of rivers and wetlands. In these diversions, river water is released into marshes to simulate flooding of a river onto its floodplain and increase hydrologic connectivity. Potential benefits have been observed from pulsing diversion discharges to simulate natural flood regimes (Day et al., 2003; Reyes et al., 2003; Snedden et al., 2007). Many studies have also shown that flow diversion is a plausible remedy to reconnect rivers to tidal marshes and deltas and induce organic and inorganic deposition (Parker et al., 2006; Snedden et al., 2007). An ancillary benefit of these flow diversions is potentially reduction of the nutrient loading to the Gulf of Mexico with associated reduction in the hypoxic zone (Lane et al., 1999; Mitsch et al., 2001).

Vertical accretion of marshes has been identified as highly dependent upon both inorganic and organic accumulation (Figure 2; Delaune et al., 1981; Nyman et al., 1993; Day et al., 1995; Reed, 1995; Foote and Reynolds, 1997; Nyman et al., 2006; Morris, 2007). Often accretion is only accounted for through sedimentation (e.g. Parker et al., 2006); however locations have been identified that depend more upon organic inputs than sediment inputs (Nyman et al., 2006). The characteristics of the receiving marsh and associated hydrologic connectivity are likely to influence whether inorganic or organic inputs control (Boustany, 2007). For instance, if a region is initially unvegetated, sediment inputs will be necessary to establish a soil platform for dense vegetative growth; however, once vegetation is well established, the vegetative inputs are likely to dominate while at the same time inducing higher retention of sediment in the process. This complex feedback system necessitates the inclusion of both inorganic (sediment) and organic (vegetative) inputs to any calculation of vertical accretion (Reed, 1995).

Vegetative accumulation in coastal marshes involves a delicate balance of above and belowground plant productivity (Gosselink, 1984; Edwards and Mills, 2005), salinity (Visser et al., 2004), nutrient availability (Delaune et al., 2005), flood frequency (Nyman et al., 2006), vegetation type (Gosselink, 1984), and seasonality (Visser et al., 2004), among other factors. Freshwater reintroduction has been shown to increase nutrient inputs to coastal marshes (Lane et al., 1999) and stimulate growth in these ecosystems (Cardoch et al., 2002), further causing vegetative inputs to contribute to accretion. In coastal Louisiana most marshes are nutrient limited (Nyman et al., 1990; Delaune et al., 2005), so the introduction of limiting nutrients such as nitrogen and phosphorous from flow diversion is a topic of great importance when considering flow diversion alternatives and benefits (Lane et al., 1999; Hyfield, 2004; Hyfield, 2008); however, excessive nutrient loading to coastal wetlands could potentially induce harmful water quality effects such as eutrophication (Delaune et al., 2005) or stimulation of invasive plant species (Carter and Bernard, 2007), so diversion of flow to coastal wetlands must be carefully balanced and planned.

The accretion of sediment on coastal marshes and deltas has also been studied extensively (Stumpf, 1983; Wang, 1997; Rybczyk and Cahoon, 2002; Reyes et al., 2003; Parker et al., 2006; Snedden et al., 2007). Relevant sedimentation processes have been identified as sediment loading from floods/diversions (Reed, 1995; Parker et al., 2006), sediment settling properties (Stumpf, 1983; Soulsby, 1997; Winterwerp and van Kesteren, 2004), tidal erosion (Stumpf, 1983; Wang et al., 1997), wind and storm induced erosion and deposition (Wang, 1997), sediment export through canals and bayous (Wang, 1997; Baustian and Turner, 2006), and vegetation induced settling (Gleason et al., 1979; Stumpf, 1983; Reed, 1995; Leonard and Luther, 1995).

Although flow diversions have proved useful for combating coastal land loss, the optimization of flow diversion locations and operation has been difficult due to the complexity in data needs of a coupled ecological and hydrodynamic model (Reyes et al., 2003; Delaune et al., 2003; Snedden et al., 2007). These complexities encourage the development of a simple, screening-level model that includes the effects of vegetation and sediment dynamics and allows for straightforward examination and optimization of flow diversion feasibility and operational benefits.

Boustany (2007) Landscape Evolution Model

Boustany (2007) developed a composite nutrient and sediment model to assess the feasibility of flow diversions and screen diversion alternatives under the Coastal Wetland Planning, Protection, and Restoration Act (CWPPRA; Boustany, Personal Communication). This model, herein referred to as the Boustany Model (BM), presents all benefits of flow diversion in terms of marsh area by assuming all nutrient and sediment benefits additive to the existing area and land change rate:

$$A_{i+1} = A_i + \delta_{nut} A_i + A_{sed}$$

Equation 1

Where A_i is the marsh area at time i, δ_{nut} is the fractional change in land area due to RSLR and river-marsh disconnection (value may be positive or negative) that has been adjusted to account for the benefits associated with nutrient addition, and A_{sed} is the area benefit of sediment addition.

The BM was developed to compare long term relative benefits of many flow diversion locations and was implemented with an annual time step to provide quick estimates of the potential benefits of diversions. The BM is sufficient for quick estimation of flow diversion benefits and initial screening of alternatives, but the LACPR program required greater temporal resolution in order to assess not only the relative benefits of diversion locations, but also the effects of diversion structure type, diversion operational regimes, and hydrologic variability. Ideally a detailed two- or three-dimensional model coupling nutrient and sediment processes would be used to account for the complex mechanisms governing coastal marsh accretion (Reyes et al., 2000; Dortch et al., 2007); however, the vast number of alternatives and short time scale of the LACPR report to Congress precluded development of such models for every alternative and marsh. As such, the BM was adapted to include processes deemed most critical to LACPR alternatives analysis. The following sections provide further details of the nutrient and sediment models implemented in the landscape evolution calculations, but the two major adaptations of the BM were:

- High temporal variability in sediment processes encouraged the refinement of the temporal resolution of the sediment model to include daily impacts of the diversion on the marsh.
- In order to maintain model simplicity, the BM required estimation of a number of parameters to account for nutrient and sediment processes (e.g. sediment retention and average annual suspended sediment concentration). The adaptation of the model has also included the calculation of many of these inputs in order to account for temporal variance, reduce data requirements, and minimize potential input errors.

Nutrient Benefits

Nutrient addition to coastal marshes has proven to be a source of vegetation stimulation and strengthening and biomass creation (Deegan et al., 2007). Boustany (2007) proposes a model that accounts for the ability of nutrients to stimulate vegetation to better resist erosional processes. This model determines the percent of the vegetated area that is strengthened from nutrient addition. This parameter is found by examining the annual nutrient requirements of the marsh relative to the nutrients loaded to the marsh.

The nutrients required by the marsh for vegetative growth are assumed to be the mass of the nutrients held in plant biomass. This quantity may be assessed by examining the rate of biomass production (annual primary productivity, P_r) and the percent of biomass containing these nutrients (γ). Since most Louisiana coastal marshes are nitrogen or phosphorous limited, Boustany proposes that the total concentration of nitrogen and phosphorous (*TNP*) be used to account for nutrient benefits.

$$LR_{req} = P_r \gamma_{TNP}$$

Equation 2

Where LR_{req} is the marsh required nutrient loading rate [$ML^{-2}T^{-1}$], P_r is primary productivity [$ML^{-2}T^{-1}$], and γ_{TNP} is the percent of plant biomass containing nitrogen and phosphorous [1].

The nutrient loading rate of the diversion to plant biomass, LR_{div}, may be calculated from the volumetric discharge of water to the marsh from the diversion, Q_{div} [L^3T^{-1}], the concentration of nutrients in the source water, C_{source} [ML^{-3}], the retention rate of nutrients in plant biomass, R_{nut} [1], and the vegetated marsh area, A_{veg} [L^2].

$$LR_{div} = \frac{Q_{div} C_{source}}{A_{veg}} R_{nut}$$

Equation 3

In addition to nutrient loading from the diversion, there is ambient nutrient loading to the marsh from other ongoing processes (e.g. atmospheric deposition, stormwater runoff, current plant decomposition, denitrification, etc.). These processes will be accounted for by a loading rate for background sources, $LR_{background}$. The net loading of nutrients to the marsh, LR_{net}, is therefore the sum of the background and diversion loading rates.

$$LR_{net} = LR_{div} + LR_{background}$$

Equation 4

From knowledge of the loading rates applied, LR_{net}, and required, LR_{req}, one may obtain the fraction of wetlands sustained by nutrient addition, E_s.

$$E_s = \frac{LR_{net}}{LR_{req}}$$

Equation 5

In this model, nutrients are assumed to be unable to freely construct land; however, they can reduce the loss rate by strengthening vegetated areas against erosion. This assumption produces conservative estimates of the organically-induced benefits of the diversion. For instance, in an environment with a low land loss rate, according to the model, the diversion could potentially reduce the land loss to zero; however, no land gain would be associated with organic inputs. The percentage of wetland sustained by nutrient addition serves as a reduction ratio to the land loss rate in the form of Equation 6.

$$\delta_{nut} = \begin{cases} \delta(1 - E_s) & For E_s < 1 \\ 0 & For E_s \geq 1 \end{cases}$$

Equation 6

Where δ is the land change rate prior to the diversion and δ_{nut} is the nutrient adjusted land change rate.

Sediment Benefits

The accumulation of diverted sediments is determined by a sediment budgeting model utilizing the input concentration of sediment from the source water and calculated hydrodynamics of the system to determine the quantity of diverted sediment retained in the marsh. As previously specified, the BM implemented sedimentation calculations on an annual timescale, and while this assumption is reasonable for preliminary screening of alternatives, further refinement is necessary for more detailed analyses of flow diversion benefits. The sediment model implemented herein relies on calculation of sediment inputs and sediment settling theory on a daily timescale over a single representative year and reapplies that year throughout the proposed project life cycle.

Sediment Input

In order to minimize costs and maximize benefits of flow diversion in coastal Louisiana, diversion structures often withdraw water from one of the region’s major rivers (e.g.

Mississippi, Atchafalya, Calcasieu). These rivers are located throughout the coastal plain, carry large water and sediment loads, and serve as a virtually infinite source of diversion resources.

River discharge and suspended sediment concentration have often been shown to be positively correlated (Mossa, 1996; Snedden et al., 2007). The relationship between discharge and sediment load may be determined by analytical and partially analytical models (e.g. Meyer-Peter Muller, Einstein, Yang; Richardson et al., 2001) or by empirical models for a given set of observed discharge and sediment concentration values (Mossa, 1996; Snedden et al., 2007). In coastal Louisiana, there exists enough recorded sediment discharge data to generate empirical models of sediment concentration for some of the major rivers of the region. For this analysis, a power function was found to provide enough resolution in sediment concentration variation (Equation 7). Table 1 presents a number of sediment ratings of this form for coastal Louisiana.

$$Q_{s,river} = a_1 Q_{river}{}^{a_2}$$

Equation 7

Where $Q_{s,river}$ is sediment load (ton/da), Q_{river} is river discharge (cfs), a_1 is a dimensional coefficient, and a_2 is a dimensionless coefficient. From this sediment rating, flow-averaged suspended sediment concentration of the river, C_{river}, may be calculated $\left(C_{river} = Q_{s,river} / Q_{river} \right)$ and transformed to the desired units.

Regardless of the model defining this relationship, the sediment concentration has been shown to be highly dependent upon discharge; therefore, in order to capture the temporal variance in sediment discharge through a diversion, the sediment concentration must vary with river discharge at an appropriate time scale (Snedden et al., 2007). For the purposes of this analysis, daily variation in discharge provides sufficient temporal resolution for accurate calculation of sediment loading to marshes by diversions.

One of the purposes for adapting the BM is the desire to examine relative diversion structure operation. In order to do this, daily estimates of diversion discharge are also required. These daily diversion discharges, Q_{div}, are combined with the daily predictions of river suspended sediment concentration, C_{river}, to determine the mass loading rate of sediment to the marsh, $Q_{s,div}$ (Equation 8). This increase in temporal resolution allows for examination of diversion discharge operation such that sediment benefits may be maximized by coinciding diversion discharges with periods of high river suspended sediment concentration.

$$Q_{s,div} = Q_{div} C_{river}$$

Equation 8

Sediment Retention

After sediment laden water has been diverted to a coastal wetland, a portion of the sediment load is expected to settle from suspension and deposit. Sediment that remains in suspension is then subject to being transported outside the system boundaries. Sediment retention defines the fraction of diverted sediments retained within the coastal wetland.

Retention is dependent upon system properties such as: wetland geometry, diversion discharge, tidal velocities (Stumpf, 1983), wind and storm events (Wang, 1997), settling velocity of diverted sediments (Soulsby, 1997; Winterwerp and van Kesteren, 2004), vegetation coverage (Stumpf, 1983), and canal-induced sediment import/export (Wang, 1997). The approach taken by Boustany (2007) is to apply retention factors estimated for other sites (e.g. Wax Lake Outlet) or allow the analyst to choose a retention factor based on knowledge of the receiving area and best professional judgment. Building upon the suggestion of Stumpf (1983), an alternative to this approach is to use a simple calculation which includes effects of wetland geometry, sediment properties, and flow hydrodynamics at the site. The effects of vegetation and channels are ignored in this analysis in order to maintain model simplicity; however, vegetation would likely increase roughness, reduce turbulence, and induce greater sediment deposition leading to conservatively low estimates of sediment retention, while the influence of channels may serve as pathways to sediment export and thus produce non-conservatively high estimates of sediment retention.

Consider suspended sediments in a water body. The time required for a given particle to settle from the water surface to the bed is given as:

$$T = \frac{H}{W_{s,eff}}$$

Equation 9

Where T is the time required for sediment to completely settle, H is the local depth, and $W_{s,eff}$ is the effective settling velocity of a specific sediment class.

As the particle settles, it is also transported by tidal and diversion currents, so the distance traveled by the particle is:

$$X = U_{div} T = U_{div} \frac{H}{W_{s,eff}}$$

Equation 10

Where U is the diversion induced mean velocity. As the averaging timescale of the model is greater than the tidal period and net tidal flow is zero, Equation 10 neglects the influence of tidal velocities, and the net displacement of water within the marsh is described by the diversion flow.

For this analysis the wetland is assumed to have rectangular planform and cross-sectional geometries described by the average length (L), width (B), and depth (H). The fraction of sediment retained in the wetland then becomes a function of wetland length relative to transport distance prior to full deposition of the sediment fraction in question (Stumpf, 1983). If all diverted sediment is retained within the system, the retention factor is 1. Since this analysis takes a macroscopic view of the total sediment retained in the system and location of deposit is not considered, the retention factor becomes 1 if the length of the wetland is greater than the transport length, and the retention of a given sediment particle class, R_j, may be expressed as:

$$R_j = \min\left(\frac{L}{X}, 1\right)$$

Equation 11

Due to variation in fall velocity with sediment size, coarse particles may be retained while fines are flushed from the system; therefore, the combined retention of the entire grain size distribution must be made. Retention over all sediment classes may be expressed as:

$$R_T = \sum R_j f_j$$

Equation 12

Where R_T is the combined total retention factor and f_j is the mass fraction associated with each sediment class.

Fall Velocity

A key element of the sediment budgeting model presented is the calculation of the effective fall velocity of a given sediment size class, which is a function of the fall velocity of that sediment in a static body of water, W_s, and the turbulence of the flow. Fall velocity of sediment is dependent upon both sediment properties (shape, size, density, concentration, ability to flocculate) and fluid properties (viscosity, density, temperature, salinity). In the natural environment, turbulence is generated by flow over the sediment bed. The presence of turbulence acts to vertically mix suspended sediments, which reduces the effective settling velocity of suspended particles. The steady-state vertical flux balance at a point in the water column is given by:

$$W_s C + K_z \frac{dC}{dz} = 0$$

Equation 13

Where C is the suspended sediment concentration, K_z is the vertical diffusivity, and z is the vertical distance from the bed.

For the purposes of this tool to estimate retention, it is convenient to combine the terms in Equation 13 to define an effective settling velocity (Equation 14).

$$W_{s,eff} C = W_s C + K_z \frac{dC}{dz}$$

Equation 14

Vertical diffusivity varies with turbulent intensity and height above the bed. Rouse proposes that diffusivity varies parabolically with height above the bed in the form (Richardson et al., 2001):

$$K_z = \kappa u_* z\left(1 - \frac{z}{H}\right)$$

Equation 15

Where κ is the von Karman constant (~0.4) and u_* is the total friction velocity (a measure of turbulent intensity).

Given the sediment flux balance in Equation 13, the vertical concentration profile is:

$$C = C_a\left(\frac{z}{z_a}\frac{H - z_a}{H - z}\right)^{-b}$$

Equation 16

Where b is the Rouse parameter $\left(b = {W_s}/{\kappa u_*}\right)$ and z_a is a reference height above the bed with a known sediment condition, C_a.

The turbulent shear velocity is estimated from the depth-averaged velocity by the logarithmic boundary layer (law of the wall) (Kundu, 1990).

$$u_* = \frac{U\kappa}{\ln\left(\frac{H/3}{z_0}\right)}$$

Equation 17

Where U is the daily mean wetland velocity with both tidal and diversion related components and z_0 is the hydraulic roughness length.

For the diurnal tidal cycle of coastal Louisiana, the tide is assumed to have approximately sinusoidal periodicity. The mean instantaneous wetland velocity can then be determined by considering both tidal and diversion components (Figure 3).

$$U_i = U_{div} + U_{\max,tide} \sin\omega = \frac{Q_{div}}{HB} + U_{\max,tide} \sin\omega$$

Equation 18

Where U_i is the instantaneous mean velocity with tidal and diversion components and $U_{max,tide}$ is the maximum tidal velocity (or tidal amplitude), and ω is tide phase.

For the use in the flow diversion model, the velocity is integrated over the tidal cycle (0 to 2π) to obtain the daily mean velocity, U.

$$U = \frac{1}{2\pi}\left\{U_{div}\left(2\omega_1 - \omega_0 - \omega_2\right) + U_{\max,tide}\left(\cos(\omega_2) - 2\cos(\omega_1) + \cos(\omega_0)\right)\right\}$$

Equation 19

Where ω_0 is the tide phase at zero up-crossing $\left(\omega_0 = \sin^{-1}\left({-U_{div}}/{U_{\max,tide}}\right)\right)$, ω_1 is the tide phase at zero down-crossing $\left(\omega_1 = \pi - \omega_0\right)$, and ω_2 is the completed tidal phase $\left(\omega_2 = \omega_0 + 2\pi\right)$ (Figure 3).

In order to estimate the shear velocity, the hydraulic roughness must also be estimated from local sediment grain size, form roughness, and vegetative coverage. In this analysis, a lumped parameter accounting for both grain size and form roughness is implemented based on marsh surface character (Table 2). Vegetative roughness is incredibly important in coastal marshes where emergent plants are encountered throughout the marsh, and although basing this parameter on bed material ignores the effects of vegetation, this will provide an estimate of sediment settling in open water and will therefore provide conservative estimates of settling in vegetated or partially vegetated marsh.

Combining Equation 13 – Equation 17, one may obtain an expression for the effective settling velocity of sediment in coastal marshes.

$$W_{s,eff} = W_s - bK_z\left(\frac{H - z_a}{z_a}\right)^{-b}\left(\frac{z}{H - z}\right)^{-b-1}\left(\frac{H}{(H - z)^2}\right)$$

Equation 20

For incorporation into the flow diversion model, vertical mixing has been computed at a height above the bed equal to 1/10 of water depth $\left(z = H/10\right)$ and z_a is approximated as 1/100 of the depth $\left(z_a = H/100\right)$. These values provide an estimate of the settling velocity of particles very near the bed that are assumed to settle. Insertion of these relations into Equation 20 yields:

$$W_{s,eff} = W_s - bK_z(99)^{-b}\left(\frac{1}{9}\right)^{-b-1}\left(\frac{0.81}{H}\right)$$

Equation 21

Where $K_z = 0.009\kappa u_* H$.

Net Sediment Benefit

By accounting for sediment loading to the marsh and sediment retention within the marsh, the mass loading rate of sediment retained in the marsh may be determined by:

$$Q_{s,net} = Q_{s,div} R_T$$

Equation 22

Where $Q_{s,net}$ is the net mass loading rate of sediment to the marsh.

This loading rate may then be used to calculate the net aerial sediment benefit due to flow diversion, A_{sed}, for a given time period.

$$A_{sed} = \frac{Q_{s,net}\, dt}{H\rho_{bd}}$$

Equation 23

Where dt is the time step (da) and ρ_{bd} is the average bulk density of the receiving area.

Bulk density in coastal marshes varies significantly with depth due to sediment consolidation. For our analysis, we assumed that the bulk density was a depth averaged value based on the depth of marsh being filled with sediment (i.e. flow depth, *H*). Bulk density profiles were obtained from literature (Nyman et al., 1990; Nyman et al., 1993; Delaune et al., 2003) and available data (Michael Channel, personal communication).

Application: Caernarvon Diversion and Breton Sound Estuary

In order to verify the ability of the model to account for landscape evolution due to flow diversion, the model was applied to an existing diversion structure and marsh, the Caernarvon Diversion to Upper Breton Sound Estuary (Figure 4). The Caernarvon Diversion is located on the east bank of the Mississippi River at river mile 81.5 (131.2 km) (approximately 12.5 river miles (20.1 km) downstream of New Orleans) and discharges Mississippi River water into Breton Sound through five 15-ft (4.57-m) box culverts with vertical lift gates (Lane et al., 1999; Snedden et al., 2007). The diversion was constructed between 1988 and 1991 and opened for operation in August of 1991 with goals of reducing the salinity in Breton Sound for commercial shell fisheries. An ancillary benefit of the diversion has been sediment and nutrient loading to the marsh and corresponding reduction in land loss (Snedden et al., 2007).

Upper Breton Sound is approximately 231 mi^2 (599 km^2) in area with a length of 18.8 mi (30.2 km) and a width of 12.3 mi (19.8 km). This estuary was historically an intermediate marsh, but due to RSLR and river/marsh disconnection, marsh salinity elevated to brackish conditions before the diversion became operational (Carter and Bernard, 2007). The current marsh is dominated by brackish species (e.g. *S. patens*) near the diversion and saline marsh species (e.g. *S. alterniflora*) far from the diversion (Snedden et al., 2007).

Breton Sound is hydrologically isolated from surrounding marshes by levees on both the eastern and western borders; therefore accounting for inflows and outflows to the marsh is relatively straightforward with water budgets for Upper Breton Sound revealing major hydrologic processes to be precipitation, evaporation, and freshwater diversion. Groundwater and stormwater inflows have been shown to be relatively small compared to precipitation and diversion (Hyfield, 2004).

In order to maximize the retention time of diverted water and induce desirable sediment settling and nutrient uptake, the State of Louisiana has initiated outfall management for the Caernarvon Diversion. Management actions have included restoration and backfilling of man-made canals, installation of control structures throughout the marsh (Carter and Bernard, 2007), and operational adjustment to test theories of marsh sedimentation processes (Snedden et al., 2007).

Snedden et al. (2007) have shown that a large majority (nearly 99%) of Caernarvon's discharge flows downmarsh through two major flow routes for low discharges. These authors indicate that below 3500 cfs, the diverted waters remain almost entirely in these canals. When diversion discharge exceeds this threshold value, diverted waters appear to exceed canal banks and flow over the marsh as sheet flow (Snedden et al., 2007). This indicates that large pulses of discharge may be more effective in distributing sediments throughout the estuary. These authors also applied a local river sediment rating based on near-surface suspended sediment concentrations of the Mississippi River approximately 5 mi (8 km) downstream of the Caernarvon structure at Belle Chase, Louisiana. By examining sediment loading rates through the diversion, these authors concluded that pulsing of discharges in phase with high river sediment concentrations not only induces sheet flow over the marsh, but also has the ability to load much greater quantities of sediment to the marsh (Snedden et al., 2007).

The Caernarvon Diversion provides an excellent test case for the model developed herein due to the variable discharge inputs and extensive knowledge of current system processes. Table 3 presents the inputs to the model for the Caernarvon Diversion and

Breton Sound. Many of these inputs have a significant amount of variability and have been presented with standard deviations in order to provide the reader with a scale of parameter uncertainty. When data was not available, parameters and ranges were estimated by best professional judgment. Since many of the input parameters contain a significant amount of uncertainty and forecasting land evolution in such a complex system is difficult, model uncertainty has been characterized by a Monte Carlo risk analysis. In this analysis, parameter uncertainty was estimated and assumed normal about the mean. Random errors were then introduced in each parameter for 10,000 calculations. Model results were computed with each set of randomly induced errors, and the range of area predictions was analyzed to determine 90% confidence intervals.

In order to apply the model to Breton Sound, the diversion and river hydrographs must be estimated to indicate marsh nutrient and sediment availability. The river hydrograph may be estimated by using a representative water year or by averaging flows for many years and determining mean daily discharges over a period of record. The diversion hydrograph may be estimated by applying historic operational records, assuming an input hydrograph, testing various operational theories (e.g. pulses timed with river discharge), or linking the discharge to the diversion structure type (e.g. diversion discharge dependence upon river stage using a weir equation). A sample representative diversion and river hydrograph are displayed (Figure 5) for operation of the Caernarvon structure in 1994. Both the diversion and river hydrographs for this year output very near average annual discharge volumes and the peak magnitudes of the hydrographs were well represented; therefore, for this analysis, the diversion and river hydrographs were assumed to be that of the 1994 calendar year for each year of the simulation.

Figure 6 presents the evolution of land area within Upper Breton Sound from before the diversion was opened (1 November 1990) until the end of 2006 (31 December 2006). This figure shows the observed values of marsh area along with estimates by the current model with associated parameter uncertainty alongside the Boustany Model. The estimated future without project (FWOP) is presented to provide the reader with the magnitude of marsh area benefit the Caernarvon Diversion is providing Breton Sound. Vertical lines indicate the beginning of diversion operation and hurricanes making landfall in Louisiana. It is clear that hurricanes create significant perturbations to the system; however, hurricanes may provide both import and export to a given marsh depending upon the location of landfall and are, for the purpose of this screening level model, assumed to create no net import or export of sediment over a long planning horizon.

In addition to model verification at Caernarvon, readers may be interested in the benefits provided by nutrient and sediment components separately; therefore Figure 7 presents the model predictions with nutrient only and sediment only scenarios for the Caernarvon Diversion application.

Optimization of Implemented Diversion

The focus of LACPR has been the analysis of alternatives and the decision support framework associated with choosing diversion sites and quantities. The land evolution model has been applied as tool for assisting in this framework and has provided relative benefits of various flow diversion sites and scenarios. The utility of the tool, however, has not yet been fully exploited. Following the narrowing of alternatives, the land evolution model may then be used in the initial optimization of the selected diversions by examining different operational and structural scenarios. This type of analysis has not yet been conducted for each of the alternatives of the LACPR, but this section provides a sample of how these analyses might be conducted for a given diversion site. The model will be applied to an existing diversion (Caernarvon) to assess the land gain benefits of six operational and five structural scenarios with near equal annual discharge volumes.

As previously stated, the Caernarvon Diversion discharges Mississippi River water to Upper Breton Sound through five 15 ft box culverts with vertical lift gates which can be used to control diversion discharges to the marsh. For this analysis the diversion is merely used to demonstrate the ability of the land evolution model to provide relative benefits of different operational and structural conditions. Table 3 provides the model inputs used for these optimization exercises. For these analyses, the 1994 Mississippi River hydrograph was found to be representative of the average annual discharge volume, peak magnitude, and seasonality of flow in the river and has been used throughout the duration of the model simulations in these exercises.

Operational Optimization of Gate Structures

The continuous hydrographic inputs of the model provide a tool for optimizing gate-type diversion operation to obtain the greatest land evolution benefits. In this section, the model will be applied to demonstrate the operational benefits for the six approximately equal-volume discharge scenarios that follow (Figure 8). These annual hydrographs were chosen based on previous research indicating that pulsing and timing of diversions may be critical to land evolution (Day et al., 2003; Snedden et al., 2007).

1. Historic operation based on 2003 operational conditions (a "pulsed" diversion year with a large portion of the annual sediment load derived from two two-week pulses)
2. Simulated operation with a large pulse of one-month duration timed *in phase* with high river sediment discharges
3. Simulated operation with a large pulse of one-month duration timed *out of phase* with high river sediment discharges
4. Simulated operation with a small pulse of six-month duration timed *in phase* with high river sediment discharges
5. Simulated operation with a small pulse of six-month duration timed *out of phase* with high river sediment discharges
6. Constant diversion discharge

Each of the annual hydrographs was input to the model, and land evolution estimates were made for a 50 year time period starting at the arbitrary starting date of January 1, 2001 (Figure 9). These results indicate that, for the inputs considered, the magnitude and timing of the diversion discharges is critical to suppression of the land loss rate. Therefore, for this hypothetical diversion scenario at Caernarvon, the diversion of flows could be altered to be in phase with high river sediment discharges and should occur from later winter to early summer (February – June). These periods of high sediment discharge may not, however, align with other project goals of a given diversion (e.g. reduction of salinity for maintenance of commercial fisheries). This analysis indicates a time period over which the greatest land evolution benefits may be obtained, and diversion operation may be optimized within that timeframe to include multiple project goals.

Structure Selection

Not only will operational considerations impact diversion benefits, but structure type will also have a drastic impact on the selection and operation of a given diversion. For instance, a gate-type structure (such as the one at Caernarvon) may be controlled to achieve the desired water and sediment discharges, but the cost and maintenance may be high. Whereas a broad-crested weir may have low cost, but control of diversion discharges is relatively minimal. A siphon is a third common diversion structure that may require significant maintenance and operational effort, but the suspended sediment concentration of the diverted water may be higher and the size gradation of the sediment diverted may be significantly larger inducing more land gain on both accounts. This section will demonstrate the ability of the model to assess land evolution by applying the model to the Caernarvon Diversion for the following five hypothetical structural scenarios:

1. Gate structure with pulsed operation based on the 2003 hydrograph
2. 100-ft wide broad-crested weir
3. 200-ft wide broad-crested weir structure
4. 1 – 15 ft siphon with a single short duration (113 day) discharge event
5. 1 – 6 ft siphon with continuous operation throughout the year

The weir structures have been assumed to behave as theoretical broad-crested weirs (Equation 24) and the discharge was determined based on the Mississippi River stage for the representative hydrograph (1994). The weir elevations were adjusted to produce annual discharge volumes approximately equal to the average annual diversion discharge volume from 1991-2006.

$$Q_{div} = C_{weir} B_{weir} \left(z_{river} - z_{weir} \right)^{3/2}$$

Equation 24

Where C_{weir} is a weir coefficient (~4.37 $ft^{0.5}/s$), B_{weir} is the width of the weir (ft), z_{river} is the elevation of the river for a given flow rate (ft), z_{weir} is the elevation of the weir (ft) (White, 2003).

In order to calculate the discharge of the diversion by siphoning, Bernoulli's equation was implemented (Equation 25). Frictional losses in the pipe were assumed negligible due to the qualitative nature of this analysis. As with the weir, the marsh elevation was optimized to produce annual discharge volumes approximately equal to the average annual diversion discharge volume from 1991-2006. Figure 10 presents diversion discharge hydrographs for the five scenarios considered.

$$Q_{div} = V_{siphon} A_{siphon} = \sqrt{2g\left(z_{river} - z_{marsh}\right)}\left(\frac{\pi d^2}{4}\right)$$

Equation 25

Where z_{marsh} is the elevation of the marsh and d is the pipe diameter.

The land evolution model was applied using these annual diversion hydrographs and the parameters from the Caernarvon Diversion (Table 3). The only alteration of the Caernarvon model inputs was the sediment rating curve and size fraction applied to the siphon calculations. A weir or gate structure diverts surface waters of the Mississippi River to the marsh, and the Belle Chase surface sediment rating presented in Table 1 was determined as such (Snedden et al., 2007), but a siphon could draw water from lower in the water column, producing a larger sediment concentration and a more coarse sediment size fraction. As such, the total sediment rating at Belle Chase was applied with an assumed size fraction distribution based on the observed fraction of silt and clay (f_{sand} = 0.12, f_{silt} = 0.44, f_{clay} = 0.44, f_{floc} = 0.3).

As evident by the land evolution calculations (Figure 11), the benefits of flow diversion are extremely sensitive to the size fraction and concentration of the river water diverted. Therefore, the choice of structure type from a land evolution perspective is overwhelmingly in favor of siphons which divert higher concentrations of coarser sediment. However, logistical difficulties associated with operation and maintenance of a siphon (e.g. maintaining head differential, priming the siphon, air intrusion) may eliminate this structure type from consideration in many instances. It is also important to note that the results presented herein likely offer overly optimistic benefits of siphon structures due to the exclusion of friction in the siphon and the use of the total suspended sediment rating at Belle Chase. Although the siphon will be able to draw water from lower in the Mississippi River water column than a gate or weir, in order to maintain appropriate pressure differential for flow to the marsh, the siphon inlet will likely be required to draw in the upper half of the water column where suspended sediment concentrations are lower. The land evolution benefits of a siphon may also be overshadowed by other project objectives which may be detrimentally impacted by high turbidity or suspended sediment concentrations, such as fisheries production and marsh vegetation stimulation.

Summary of Diversion Optimization

The purpose of this exercise was not to identify an operational condition or structural alternative that is ideal for all flow diversions in coastal Louisiana, but was instead to demonstrate the land evolution model's ability to maximize land gain benefits for various operational and structural alternatives. Land gain (or suppression of land loss) is often not the only objective in the large-scale, long-term projects of the LACPR, and many other factors may be included in the selection of a diversion operational or structural scheme, some of which include:

- Cost of diversion with both structural and operation/maintenance components
- Desire to control diversion releases
- Commercial fisheries impacts
- Public recreational land use patterns

Conclusions

This paper has presented the adaptation of a model for quantifying flow diversion benefits and demonstrated the model's ability to estimate the relative benefits of various flow diversion locations, structures, and operational regimes; however, the model results are limited due to the exclusion of a variety of important system processes. Some of the major assumptions and limitations of the model were:

- Benefits of flow diversion are independent (in reality the benefits are likely non-linearly coupled due to vegetation inducing sediment deposition and sedimentation increasing suitable habitat for vegetation)
- Nutrients serve as a reduction in land loss, not a source of land gain benefits (Deposition of particulate organic matter neglected)
- Spatial uniformity - vegetation, roughness, bulk density, and other parameters are highly heterogeneous in coastal marshes
- Temporal resolution is only represented intra-annually, not contiuously
- Rectangular wetland geometry
- No vegetative component to settling/roughness
- Organic accumulation is not considered as a function of time even through biomass production is highly seasonal
- No habitat switching with time
- Canals are not accounted for as a sediment loss mechanism
- Sheetflow was assumed for all diversion flow rates
- No sediment resuspension due to rainfall, tidal flows, waves, or hurricanes
- Uniform distribution of sedimentation.
- Nutrient recycling neglected

Although these assumptions significantly limit the model's ability to quantify the benefits of flow diversion, approximations had to be made due to the time and resource constraints under which the model was developed. Further refinement of model processes and algorithms are recommended and should address the above limitations specifically focusing on the following:

- Temporal distribution of nutrient benefits to account for seasonality and storage
- Nutrients as a source of benefit, not just a source of loss reduction. Refer to the organic accumulation models of Blum et al. (1978), Mitsch and Reeder (1991), and Reyes et al. (2000) for examples of organic benefit frameworks
- Nutrient retention calculations inclusive of marsh nutrient cycling processes (e.g. denitrification, burial)
- Division of nutrients – nutrients should be divided into individual components (e.g. nitrogen and phosphorous) due to marsh limitation to a single nutrient
- Salinity is roughly covered in the model by the adjustment of bulk density and primary productivity, but the parameter is not explicitly covered and habitat switching is not tracked
- Spatial complexity/geometry improvements
- Inclusion of coastal currents and erosion, major storm events, and wind erosion
- Better methods of accounting for hydraulic resistance

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Figures

Figure 1. Typical coastal Louisiana marsh community with a patchwork of dense vegetation and open water

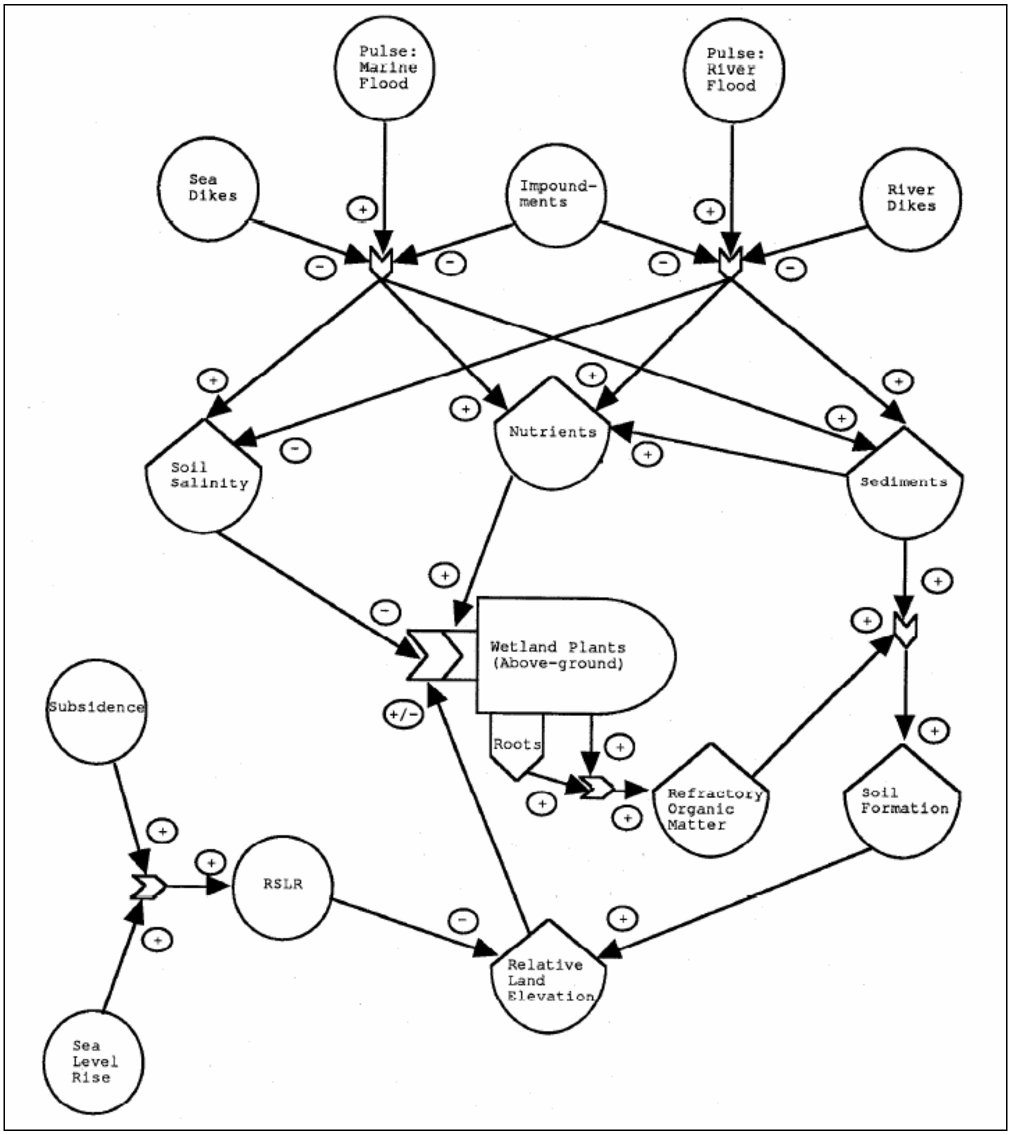

Figure 2. Conceptual model of coastal Louisiana marsh accretionary processes (from Day et al., 1995)

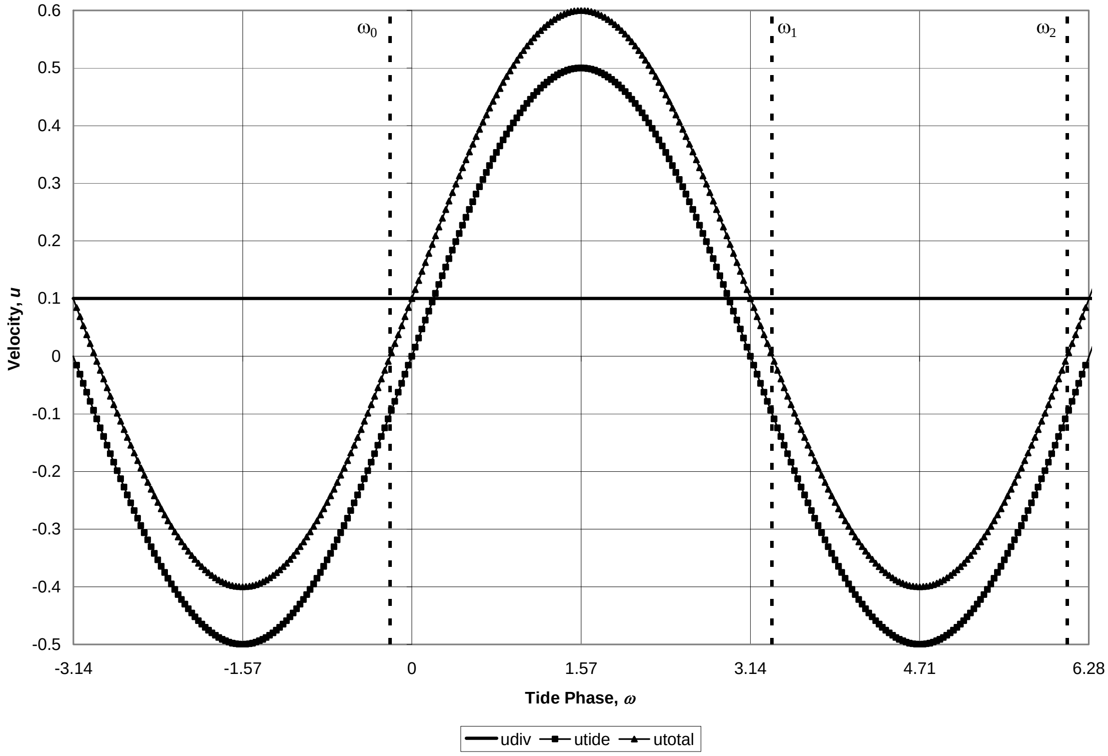

Figure 3. Wetland velocity with diversion and tidal components

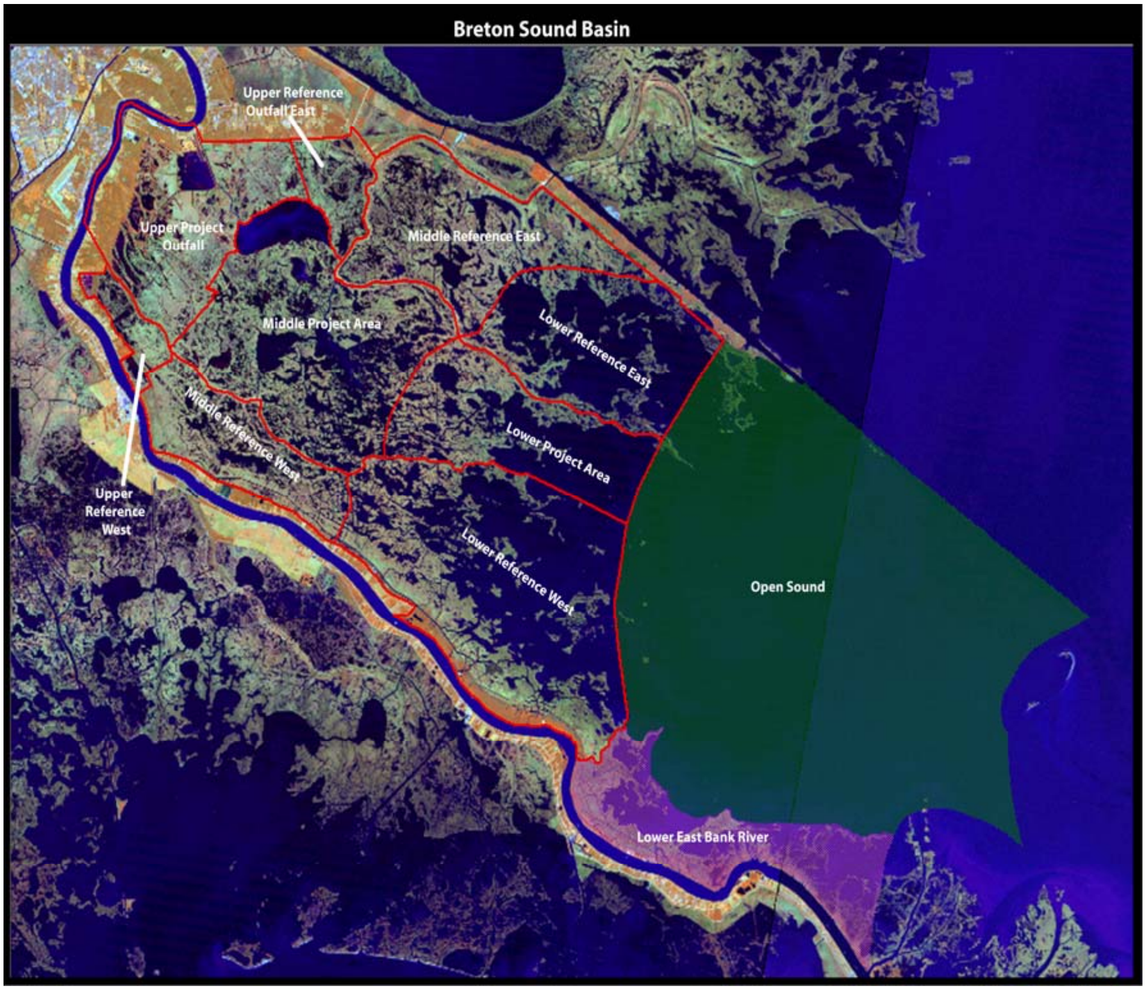

Figure 4. Aerial view of Breton Sound displaying Caernarvon Diversion and project division areas for tracking land evolution. In this analysis only the following areas were considered to be directly influenced by the Caernarvon Diversion in order to maintain relative uniformity in conditions: Upper Reference Outfall East, Upper Project Outfall, Upper Reference West, Middle Reference West, and Middle Project Area.

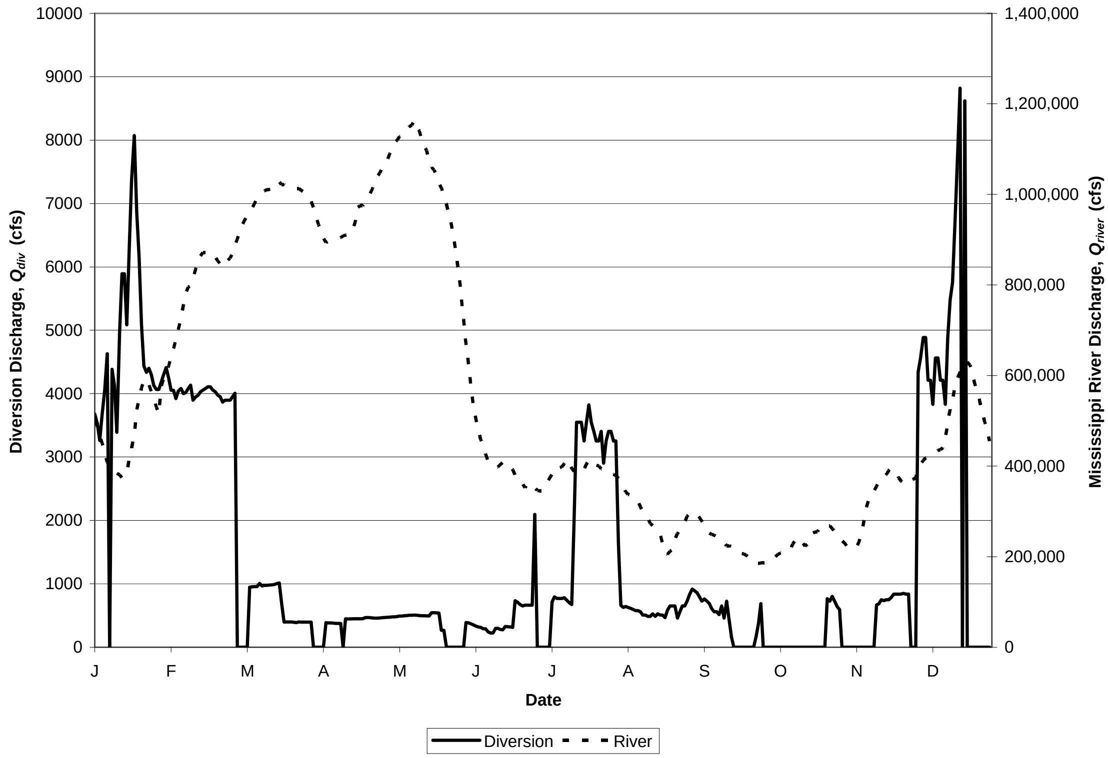

Figure 5. Representative diversion and river hydrographs for land evolution forecasting associated with the Caernarvon Diversion (1994 hydrographs)

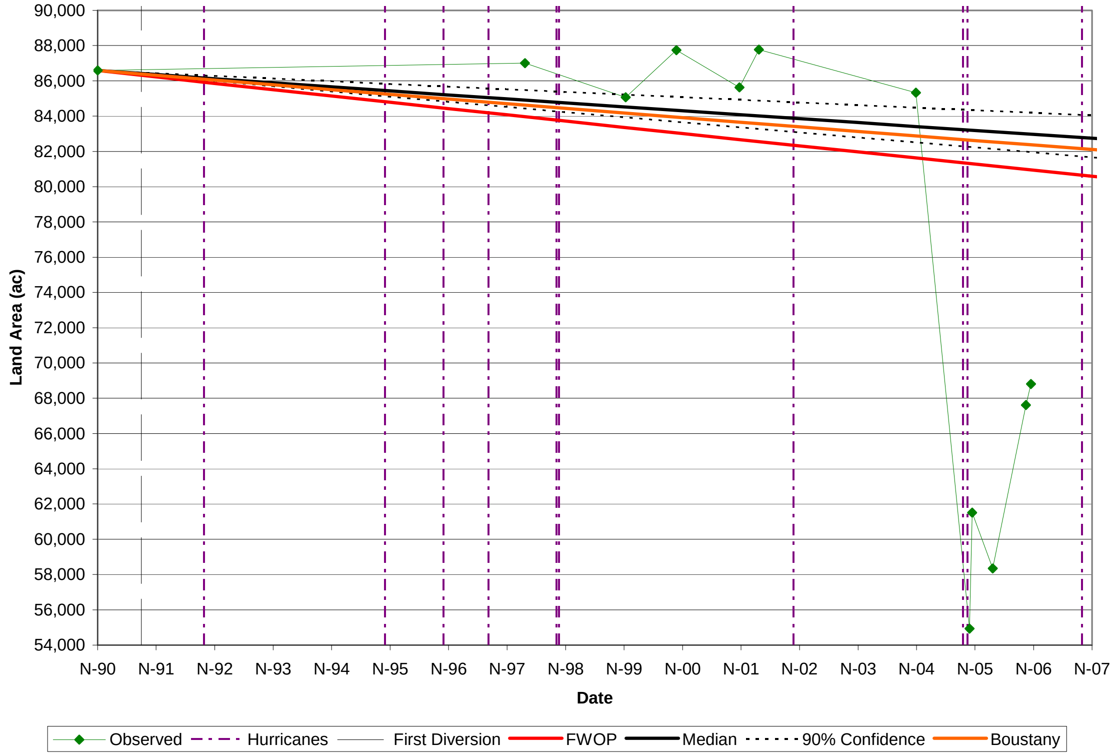

Figure 6. Marsh area prediction for the Caernarvon Diversion from 1990-2006 with observed acreages, model predictions with parameter uncertainty bounds, as well as the Boustany Model predictions

Figure 7. Marsh area prediction for the Caernarvon Diversion from 1990-2040 with isolated nutrient and sediment benefits

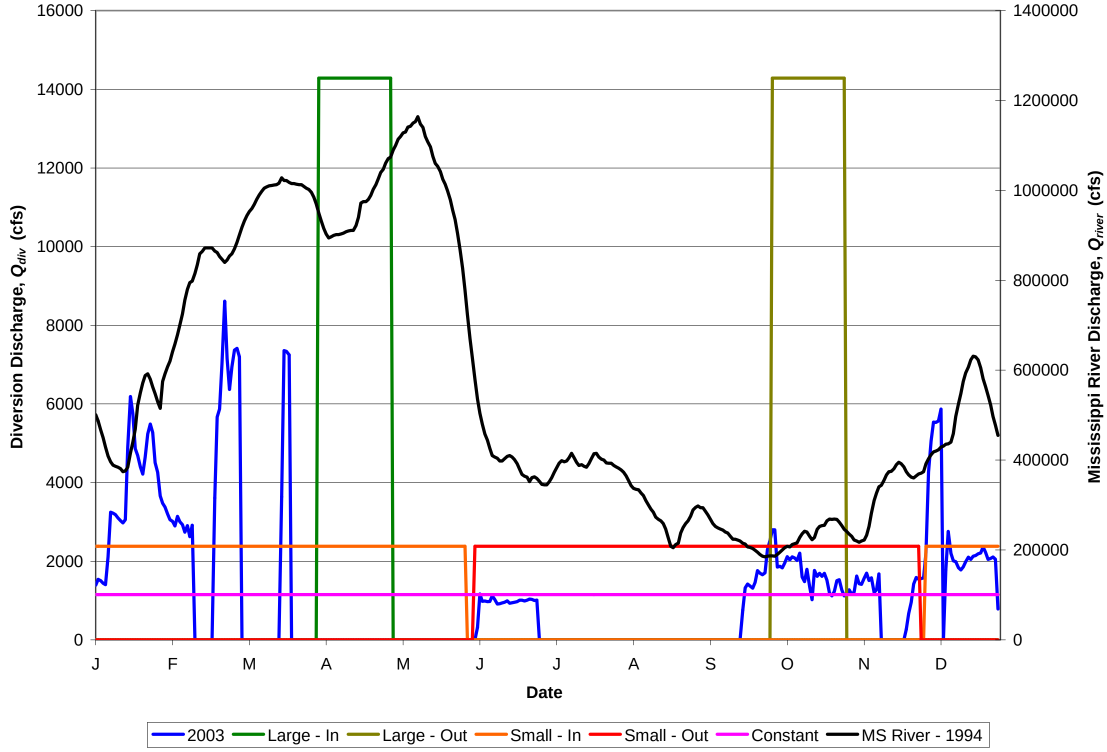

Figure 8. Hydrographs considered in Caernarvon Diversion operational optimization

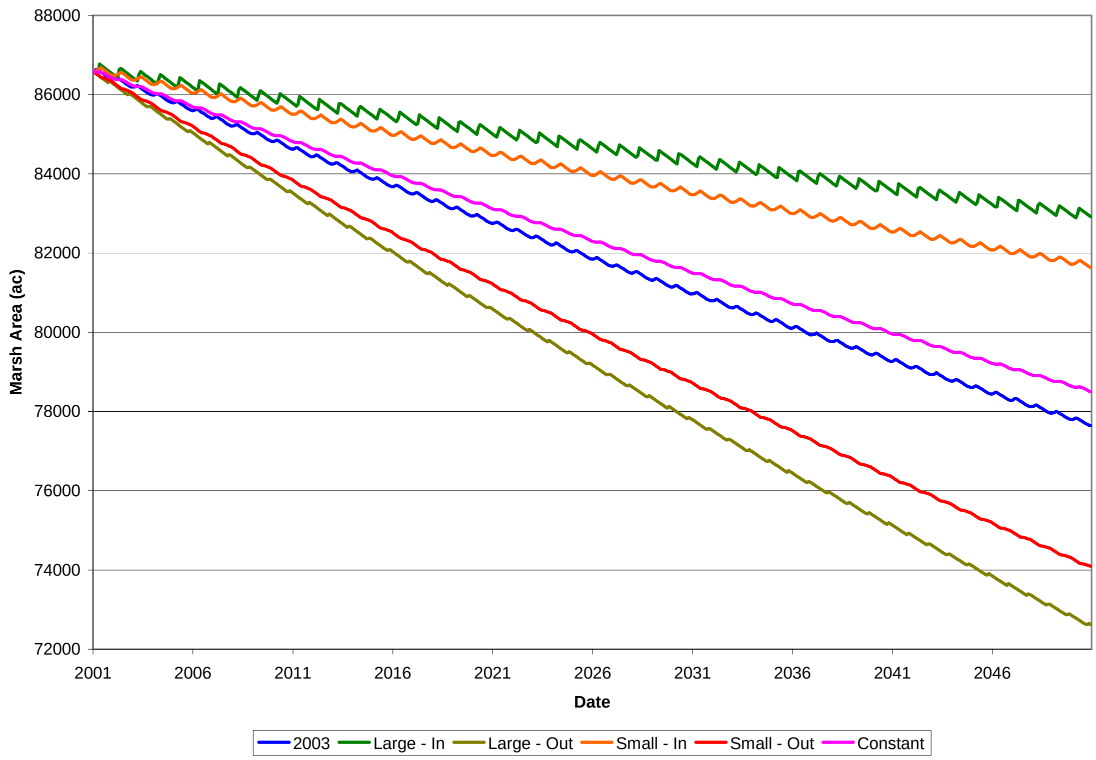

Figure 9. Land evolution predictions for multiple operational scenarios at the Caernarvon Diversion

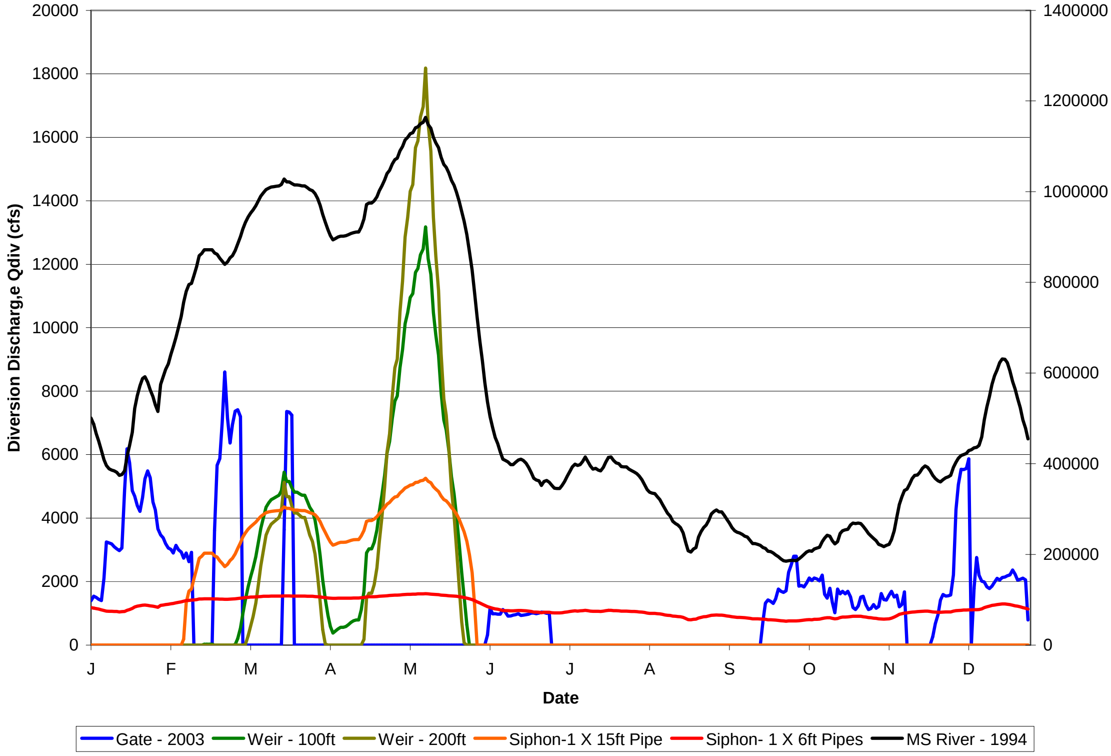

Figure 10. Calculated hydrographs for various structure types at the Caernarvon Diversion

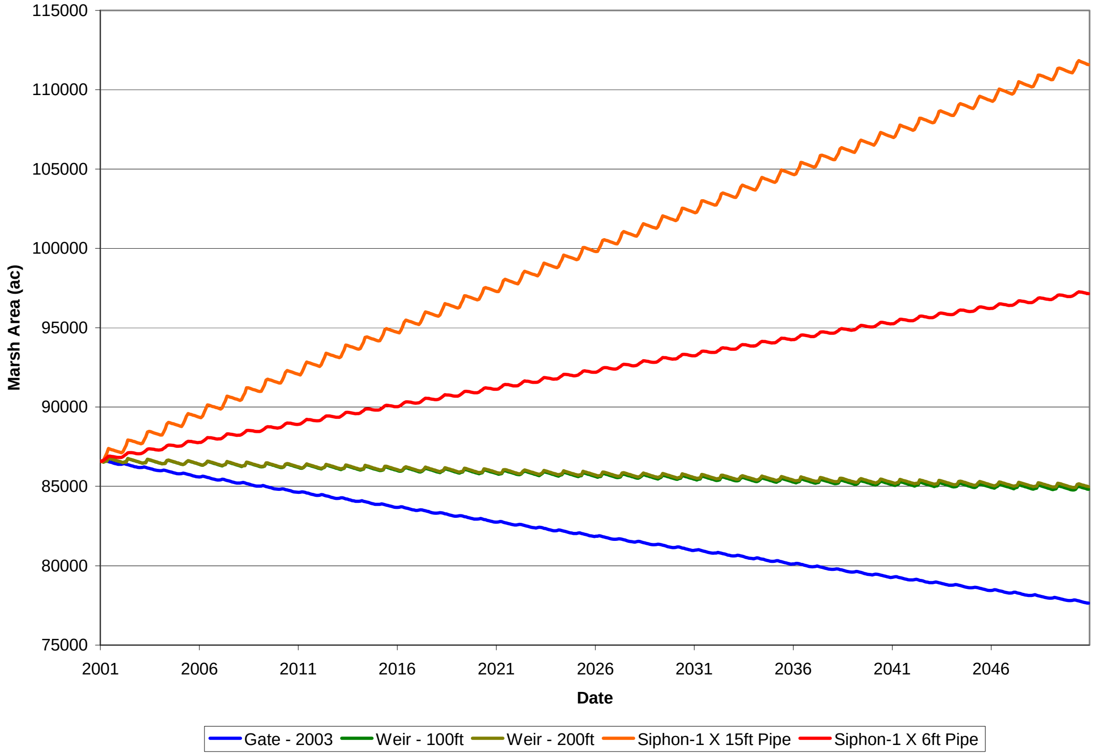

Figure 11. Land evolution predictions for various structure types at the Caernarvon Diversion

Tables

Table 1. Sediment Ratings for Rivers on the Louisiana Coastal Plain

River	Gauge Location	a_1	a_2	R^2
Mississippi	Belle Chase Surface*	3.205E-07	2.000	0.6648
	Belle Chase	1.237E-08	2.320	0.7302
	Tarbert - 1949-1975	1.192E-04	1.702	0.7945
	Tarbert - 1975-2007	7.096E-03	1.342	0.7689
	St. Francisville	6.501E-04	1.507	0.7357
Atchafalaya	Melville	4.941E-06	1.937	0.7764
	Simmesport	8.286E-04	1.563	0.8138

All ratings developed from suspended sediment concentrations and water discharges from USGS Website except "Belle Chase Surface"

*Surface concentrations of suspended sediment at Belle Chase and Tarbert's Landing Discharges (Snedden et al., 2007)

Table 2. Hydraulic roughness height as a function of bed material grain size

Channel Boundary	**Roughness Height, z_0[1]**		
	ft	**mm**	**m**
Mud	6.6E-04	0.2	2.0E-04
Mud/Sand	2.3E-03	0.7	7.0E-04
Silt/Sand	1.6E-04	0.05	5.0E-05
Sand (unrippled)	1.3E-03	0.4	4.0E-04
Sand (rippled)	2.0E-02	6	6.0E-03
Sand/Shell	9.8E-04	0.3	3.0E-04
Sand/Gravel	9.8E-04	0.3	3.0E-04
Mud/Sand/Gravel	9.8E-04	0.3	3.0E-04
Gravel	9.8E-03	3	3.0E-03

[1]Adapted from Soulsby (1983, Table 5.4)

Table 3. System properties and land evolution model parameters for the Caernarvon Diversion to Breton Sound Estuary

Parameter	Best Estimate	Approximate Standard Deviation
General System Properties		
Initial Land Area (ac)#	86,591	-
Project Area (ac)#	148,018	-
Average Water Depth, H (ft)*	3	0.5
Average Water Width, B (ft)	65,000#	1,000*
Maximum Tidal Velocity, $U_{tide,max}$ (ft/s)*	0.6	0.1
Roughness Height, z_o (ft)*	0.005	0.0005
Land Loss Rate (%/y)[1]	-0.42	0.042
Bulk Density, ρ_{bd} (g/cm^3)	0.26	-
Sediment Rating of Surface Concentrations of the Mississippi River at Belle Chase[2]		
Coefficient	3.205E-07	3.21E-08
Exponent	2.000	-
Size Fraction of Belle Chase Rating[2]		
Sand	0.01	0.0017
Silt	0.63	0.1050
Clay	0.36	-
Floc Fraction*	0.3	0.0667

Parameter	Best Estimate	Approximate Standard Deviation
Approximate Fall Velocity[3] (m/s)		
Sand	1.00E-02	8.33E-04
Silt	3.00E-04	2.50E-05
Clay	7.00E-06	5.83E-07
Floc Fraction	2.00E-04	4.00E-05
Marsh Nutrient Requirements		
Plant Productivity Rate, P_r (g/m^2yr)[*]	4,150	415
Percent of N and P in Plant Biomass, γ_{TNP}(%)[4]	0.72	0.072[*]
Nutrient Loading to Marsh		
Background Concentration of N and P, $C_{background}$ (mg/L)[5]	0.34	0.034[*]
Sourcewater Concentration of N and P, C_{source} (mg/L)[#]	2.28	0.5[*]
Nutrient Retention, R_{nut} (%)[*]	50	10

[1]Land loss rate calculated from observed marsh acreage from 1978-1990

[2]Data for rating and size fraction from Snedden et al. (2007)

[3]Calculated from method of Soulsby (1997)

[4]Foote and Reynolds (1997)

[5]Hyfield (2004)

[#]Available data

[*]Best professional judgment

Symbols

b = Rouse parameter
d = Diameter of siphon
f_i = Sediment size fraction i
g = Acceleration due to gravity
u_* = Shear velocity
x = Longitudinal or down-marsh coordinate
y = Horizontal or cross-marsh coordinate
z = Vertical coordinate
z_0 = Hydraulic roughness length
z_a = Reference depth
z_{river} = River stage
z_{marsh} = Marsh Elevation
z_{weir} = Weir Elevation
A = Marsh area
A_{veg} = Vegetated area of receiving area
A_{nut} = Total aerial nutrient benefit from flow diversion
A_{sed} = Total aerial sediment benefit from flow diversion
A_{siphon} = Cross-sectional area of siphon
B = Average marsh width
B_{weir} = Weir width
C = Suspended sediment concentration
C_a = Suspended sediment concentration at reference elevation z_a
C_{river} = Suspended sediment concentration of river
C_{source} = Nutrient concentration of source water
C_{weir} = Theoretical weir coefficient
E_{sus} = Percent of wetland sustained by nutrient loading
H = Average marsh depth
K_z = Vertical diffusivity
L = Average marsh length
LR_{req} = Marsh required nutrient loading rate
LR_{div} = Loading rate of nutrients from the flow diversion
$LR_{background}$ = Background loading rate of nutrients from preexisting marsh sources
LR_{net} = Net loading rate of nutrients from diversion and background sources ($=LR_{div} - LR_{background}$)
P_r = Primary Production
Q_{div} = Volumetric water discharge through diversion
$Q_{s,river}$ = Sediment discharge of river
$Q_{s,div}$ = Sediment discharge of diversion
$Q_{s,net}$ = Rate of sediment discharged to and retained in marsh
R_i = Sediment retention of size fraction i
R_T = Total sediment retention factor
T = Time required for particle settling
U = Daily mean velocity with tidal and diversion related components
U_i = Instantaneous mean velocity with tidal and diversion related components

U_{div} = Diversion induced velocity (= Q_{div} / HB)
$U_{max,tide}$ = Maximum tidal velocity (tidal velocity amplitude)
V_{siphon} = Velocity of flow in siphon
W_s = Natural settling velocity
$W_{s,eff}$ = Effective settling velocity due to natural settling and turbulence
X = Transport distance of suspended sediment
δ = Land change rate (% / time)
δ_{nut} = Nutrient suppressed land change rate (% / time)
γ_{nut} = Percent of plant biomass made up of nutrients
κ = von Karman's constant (0.4)
ω = Tide phase
ω_0 = Tide phase of the up-crossing zero velocity
ω_1 = Tide phase of the down-crossing zero velocity (=$\omega_0 + \pi$)
$\omega_2 = \omega_0 + 2\pi$

ATTACHMENT D

Spatial Integrity Figures and Tables

December 2008

Spatial Integrity Index
December 21, 2007

INTRODUCTION

Principles of landscape ecology assert that landscapes are a mosaic of patches that can be defined by their structure, their function and change (Forman 1995). Our conceptual approach defines the landscapes in each of the principal hydrologic basins of the Louisiana coast by their structure (meaning the spatial relationship among distinct wetland patches or their elements and other key physical features such as barrier islands, ridges, and tributaries), their function (meaning the flow of mineral nutrients, water, energy, or species among component patches or between landscapes), and change (meaning the temporal alterations in the structure and function of landscapes or their components).

Our premise is that the structure, function and change of patches across landscape mosaics affect fundamental ecosystem processes, which determine the trajectories of ecological condition. Therefore, the quantification of landscape structure and measurements of change to that structure are important precursors to understanding functional effects of change (Tischendorf 2001). At the site scale, the structure of a wetland patch can be related to topography and other spatial attributes such as channel density and pattern and heterogeneity of vegetation types. At the landscape scale, the spatial configuration of wetland patches—e.g., their size, shape and connectivity—and the composition and connectivity of surrounding open water areas are the key components of structure.

One method to quantify structure employs the use of spatial "metrics" (Wu et al. 2000). Spatial structure metrics can be linked to function through a variety of analyses including regression-based and other types of statistical models and sensitivity analyses (Tischendorf 2001). For example, a tidal marsh-dependent vertebrate species might require connectivity with other wetland patches for dispersal and recruitment purposes, or may experience higher rates of predation in marshes with a high ratio of edge to interior habitat. Measurement of landscape context metrics may reveal adjacent land uses as potential stressors, or hint at exchange rates across ecotones.

For the LACPR, spatial characteristics will be calculated for important wetland features at the site and landscape scales and tied to ecological functions through hypotheses supported by conventional landscape ecology theory. It is anticipated that studies will be conducted to better link the spatial metrics and key functions, and that future revisions to the spatial model may be required. Remotely sensed satellite and low-altitude aerial photographic data combined with spatial data analysis tools in ARCGIS will be used for the assessment. This approach has proven successful in measuring broad scale landscape patterns and correlating such patterns with ecological functional changes (Kelly 2001).

Numerous spatial metrics have been used to characterize various landscape attributes and, by inference, important ecological processes. They can be categorized as follows:

(a) area metrics, (b) core area metrics, (c) patch density and size metrics, (d) edge metrics, (e) shape metrics, (f) diversity metrics, and (g) connectivity/interspersion metrics. Since many spatial metrics are highly correlated, an appropriate number of metrics each representing area, edge/shape, and connectivity/interspersion will be used in discriminating alternative plans. It will be necessary to relate the metrics to important processes or characteristics so that they can be interpreted for weighting the alternative plans. The table below establishes some of the potential inferences from each metric.

Metric	What is Measured	Related Processes/Conditions
Area	Composition	Stability/resiliency; Geomorphic process (if temporal assessment applied); Productivity
Edge/Shape	Configuration	Primary productivity; Hydropattern (applied to open water pathways); Stability/resiliency
Connectivity/ Interspersion	Configuration	Local spatial variability (diversity)

These metrics, and particularly interspersion, are highly scalable and determining the appropriate scale of application will be necessary. The large ecological gradients in the eastern basins may require division into smaller units (e.g. fresh/intermediate vs. brackish/saline) for landscape metric characterization.

Several trade-offs may be embedded within individual metrics. For example, edge and interspersion could both be used to assess wetland fragmentation. While this may result in higher primary productivity, it may also eventually lead to more rapid wetland losses. This suggests a careful evaluation of the metric sets and, where possible, identification of important thresholds or trade-offs.

Although the intent of the spatial integrity metric is to compare alternative plans, it may be possible to also refine the models so that they provide some predictive capability. Valid comparison to reference wetlands is difficult, but correlations between spatial metrics and ecosystem services may be developed over time, provided the appropriate data collection and analyses are conducted.

This study proposes to identify and test a variety of spatial metrics and incorporate them in a spatially-explicit model to assess historic trends. The historic trend output would then be used by the LACPR HET team to (1) support projections of “future without” and “future with” alternative landscape configuration patterns and (2) determine which restoration alternatives promote the greatest ecological sustainability.

APPROACH

Study Area

This study utilized the LACPR planning unit boundaries minus fastlands as the overall spatial extent (Figure 1). The spatial boundaries upon which the metrics were run are

$4km^2$ grids. The boundaries of these 2km x 2km tiles are consistent with the original Louisiana Coastal Area (LCA) grid. Based on these spatial designations, a total of 8,437 tiles were evaluated in the study area using both grid-based and landscape-scale fragmentation analyses. The landscape-level metrics and analyses were used to assess more general trends in landscape configuration by planning unit.

Landscape Metrics

FRAGSTATS (McGarigal and Marks, 1995) is a software program designed to compute a wide variety of landscape metrics for categorical map patterns. This program was utilized because of its well tested utility as a packaged management tool and because it provides the greatest likelihood of product reproducibility. FRAGSTATS uses a grid-based approach, which is commonly not suitable for class scale determinations on entire landscapes; however it can provide class-level metrics, classification and assessments through individual non-related grid tiles. Historically, FRAGSTATS has been used for habitat suitability, change, and connectivity dynamics for forested ecosystems. Although there is very limited scientific literature on the study of marsh fragmentation and classification using FRAGSTATS, the authors have tested the use of this program to evaluate marsh breakup patterns in Terrebonne Parish, Louisiana under a saltwater intrusion scenario (Steyer et al., in prep), and feel it is appropriate for this study.

Landscape Classification

The Spatial Integrity Index (SII) developed as part of this study utilized a land-water classified image and a two-part classification system to support projections of landscape change as influenced by restoration alternatives. The two levels used in this system to denote landscape structure are: (1) *category*: ratio of water to land, and (2) *configuration*: marsh water area, shape and connectivity. This classification system (modified from Dozier, 1983) assigns values 1-10 to represent percentages of water. In this study, we represent the 10 classes of water as follows: Category 1, 0% – <5% water within marsh, Category 2, 5% – <15% water, Category 3, 15% – <25% water, Category 4, 25% – <35% water, Category 5, 35 – <45% water, Category 6, 45 – <55% water, Category 7, 55 – <65% water, Category 8, 65 – <75% water, Category 9, 75 – <85% water, and Category 10, >85% water. The system subclasses utilized are identical to Dozier (1983) and are designated by the configuration of water bodies in the marsh. Class "A", are configurations that are typically large water, (in relation to percent water class) and have connected water patches with linear edge. Class "B", are configurations that are typically small (as related to associated percent water class) disconnected patches with a more random distribution, and fewer instances of connection. Class "C", are configurations that are a combination of both class "A" and class "B" (with discernible regions of both). Figure 2 illustrates the SII class system. The numerical precursor denotes the amount of each tile occupied by water (increasing toward class 10) and the spatial configuration of water and land patches in each tile represented by A, B and C.

Due to considerations of data availability and time periods of interests, four dates of classified TM Landsat Thematic Mapper satellite imagery were selected for this examination. The classified land:water images utilized in this methodology were taken from existing data analyses described in Morton et al. (2005), Barras (2006), and Barras et al. (in-prep) using the same standardized methodology. The imagery and data utilized, from 1985, 1990, 2001 and 2006, were collected under similar water level and seasonal conditions.

To determine the appropriate grid scale required for maximizing the accuracy of SII classification, 4 km^2 and 16 km^2 raster grids were evaluated. These grid scales were identified because they were coarse enough to permit the extensive computer processing, and fine enough to not bias the classification. To standardize the tiling origin, and alleviate potential shift error, the project vector grid origin was based on an established grid system developed by Twilley and Barras (2003) for the Louisiana Coastal Area Ecosystem Restoration Study. Each land-water image was tiled using a geoprocessing routine to expedite the preparation and extraction of all raster grids or "tiles". Each tile was then processed using FRAGSTATS and analyzed at the class metric level (i.e., statistics computed for every patch type or class in the landscape), and at each designated grid scale. Tiles were sorted by adjusted water percentages (recalculated category class, excluding "other" class), and by preliminary configuration thresholds (established to assess suitable metrics and metric combinations). Countless arrangements of metrics and metric combinations were selected and tested against configuration definitions. Category and configuration class output were assessed for accuracy of the computer generated classification. This method was used to evaluate all potential metrics, fit value thresholds to visually derived SII, and select adequate scale of tile. It was determined that the classifications based on the 4 km x 4 km extracted tile were often overwhelmed by large open water bodies, contained multiple SII classes, and were therefore too large to accurately classify the landscape. Conversely, the 2 km x 2 km tile system consistently classified the landscape correctly and thus was selected for this study.

The following landscape metrics which represent area, edge/shape, and connectivity/interspersion were selected after careful consideration of previous landscape fragmentation and configuration study metrics and evaluation of selected metrics toward meeting study goals.

Percentage of landscape occupied by water (PLDW) quantifies the proportional abundance of water within each patch type in the landscape. It is measured as the percentage of the landscape comprised of the corresponding class.

Number of patches of water (NPW) of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. It is measured as the number of patches of the corresponding class.

Patch density (PDW) of water has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. It is measured as the number of patches of the corresponding class divided by total landscape area.

Largest patch index (LPIW) of water at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. It is measured as the percentage of total landscape area comprised by the largest class.

Edge density of land (EDL) equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2). Edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.

Normalized Landscape shape index (NLSI) provides a simple measure of class aggregation or clumpiness. It is measured as the class perimeter length divided by the minimum perimeter needed for maximum aggregation.

Patch cohesion index of water (COHW) measures the physical connectedness of the corresponding patch type. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected.

Aggregation index of water (AIW) is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map.

Modified Simpson's diversity index (MSIDI) belongs to a general class of diversity indices to which Shannon's diversity index belongs. The Modified Simpson's diversity index evaluates whether any 2 classes selected at random would be different patch types.

Landscape Evaluation

The SII was used to examine multiple restoration alternatives, and project future landscape pattern under those scenarios. The restoration alternatives that were presented for evaluation are (1) R1, (Figures 3a - 3e); (2) R2, (Figures 4a - 4e); (3) R3, (State Master Plan, Figures 5a - 5e); R4, (Figures 6a - 6e); and R5, (LCA Plan Best Meeting Objectives, Figures 7a - 7e). Each of these alternatives was based on a low sea-level rise scenario. The diversion, marsh creation and barrier island measures of these plans were the primary features modeled in this application based on the initiation data provided by the HET team. Features such as shoreline stabilization, ridge restoration and gapping banks were assumed to have little effect on land change and configuration.

In order to provide a baseline of comparison, a “future without project (FWOP)” predictive scenario was created. While multiple “future without” scenarios have been developed in recent years, most project land loss or gain with little or no attention to the spatial pattern of that land. The LCA land loss polygons described in Barras et al. (2003) were updated for the current trend of land loss generated from 13 dates over the timeperiod 1978 – 2006. Polygons not evaluated for land loss trends under Barras et al (2003) were incorporated under the current analysis using the 1985-2006 data. The LCA polygon trend data set was rasterized at a 25x25 meter cell size to create a raster index file containing each loss polygon identified using a unique integer id (Figure 8). The Leica Imagine "Summary" function was then used to compare the raster index LCA loss unit file to each Landsat Thematic Mapper satellite classified land-water coastal mosaic and simplified historical habitat land-water coastal dataset to identify land-water acreage for each dataset by LCA trend polygon. To establish the FWOP scenario at year 50, a linear regression fit was applied to the data (Paille et al., in-prep). This FWOP scenario defined the total remaining acres in each of 183 polygons across the study area annually through year 2060 (50 year projection). The acreage by polygon was then merged with the tile grid in order to determine future acreage by tile. The composition of tiles in 2006, as well as trajectory of change over the 1985-2006 time period, was utilized to drive assumptions as to the spatial configuration of future acreage. All 8 metrics were run and evaluated by planning unit for years 2006, 2010, 2020, 2030, 2040, 2050, and 2060 to remain consistent with the LACPR land change evaluations.

Upon completion of the FWOP scenario, the restoration alternatives were evaluated. For each alternative, shape boundaries of all restoration measures were overlaid on the 2 km x 2 km grid. Tiles that were influenced by restoration measures were assigned new spatial configurations estimated based on land:water acreage provided by Paille et al., in-prep). Tiles affected by a restoration measure were compared to the same tile under the base year 2010 of the FWOP scenario for examination of effects. Details of the modeling approach are provided later in this document.

Determining future spatial configurations of restored landscapes with any degree of certainty is impossible at this time. The science has not evolved enough to support strong linkages between pattern and process that this level of assessment needs. A multiple lines of evidence approach was utilized that includes identifying historic patterns as a predictor of future change, identifying natural analogs that represent the types of restoration proposed, and using rules to drive configuration changes based on hypotheses of how spatial metrics and SII classes are linked to key functions provided by different categories of restoration measures.

In order to conduct the multiple lines of evidence approach, we identified eight categories of restoration measures that were common to the three restoration alternatives and considered them based on their location within the coastal landscape (high energy versus low energy). The categories are (1) freshwater diversions, (2) freshwater diversions coupled with marsh creation, (3) sediment diversions, (4) marsh creation coupled with shoreline stabilization, (5) marsh creation, (6) shoreline stabilization, (7) ridge restoration, and (8) barrier island restoration. Rules or hypotheses were then established that define how these restoration measures influence spatial configurations based on conventional landscape ecology theory and existing scientific literature or best professional scientific judgment. The existing scientific knowledge that helped frame our hypotheses are identified below.

Existing Scientific Knowledge:

- Suspended sediments increase and organic content decreases with increasing connectivity to riverine sources.

- Sedimentation rates in salt marshes vary as a function of either the distance from tidal channels or with flow distance between marsh and larger bodies of water.
- Sedimentation rates are inversely related to distance from marsh edge when sediment supplies are available to marsh.
- Sedimentation rates are positively related to hydroperiod (inundation duration) when sediment supplies are available to marsh.
- There are tradeoffs between hydroperiod and sedimentation. Increasing hydroperiod (to support sedimentation) beyond plant community thresholds will decrease productivity.
- Dissolved nutrient availability to marshes generally increases with greater connectivity to riverine sources and greater residence time of water.
- Sedimentation rates are positively related to plant stem density under normal conditions. Sedimentation by large storms may impact this relationship.
- Connectivity is a function of habitat type, drainage density, waterway orientation and levee height.
- Marshes tend to aggrade where fluvial flow becomes unconfined and degrade away from such sources.
- The flux of energy and nutrients across an ecotone depends on the surface area of the wetland contact zone.
- High river discharge coupled with southerly wind conditions can lead to sheet flow and sedimentation on the marsh.
- Storm surge breaks in barrier islands occur where the island width is least; so increasing island width not only minimizes the effects of storm surge, but also traps the sand as it rolls over the island.

Hypotheses:

- Freshwater Diversions into existing patchy marsh will favor deposition of both organic and fine inorganic material and slowly increase sediment platform elevation. Large diversion flows or pulses into upper basins may result in transition to less fragmented classes due to the development of flotant. RULE: Existing marsh patches (B and C classes) will expand along their edges (stay within class or B go to C class) and small marsh patches will not coalesce unless large pulses or high diversion flows are employed (C class can go to A class, but is dependent on distance from source).
- Freshwater Diversions into large contiguous marsh creation patches will maintain contiguous marsh integrity by providing necessary sediment and nutrients to sustain the marsh. RULE: A class remains A class if sustained by diversion.
- Sediment Diversions into existing patchy marsh with low land:water ratios and slow currents will facilitate coarse and fine sediment deposition onto subaqueous habitats (e.g. bay bottoms), increasing their elevation and ultimately transforming them to subaerial marsh platforms (near field effect – extent dependent on diversion size/sediment content). RULE: Existing marsh patches will expand along their edges as adjacent ponds are infilled with sediment, and marsh patches will coalesce nearest the diversion. This effect might be greatest in class B and C.

Increased channelization in near field will route flows and decrease sediment retention.

- Marsh creation will form contiguous marsh, and therefore increase the flow resistance on the marsh platform and thus concentrate flow in developed channels while maintaining large marsh patches. RULE: Marsh creation projects produce class A patterns immediately, with immediate formation of marsh channels, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.
- Marsh creation will form contiguous marsh, and coupling with shoreline stabilization will only change land:water acreage and not configuration (except immediately adjacent to shoreline stabilization). Therefore, increase in the flow resistance on the marsh platform will concentrate flow in developed channels while maintaining large marsh patches. RULE: Marsh creation projects produce class A patterns immediately, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.
- Shoreline stabilization will only change land:water acreage (from reduced shoreline erosion) and not change configuration. RULE: Trajectory of change from 1985-2006 by planning unit by marsh type will be applied to future condition.
- Ridge restoration will enhance skeletal network for water distribution within planning units, but no effect on pattern can be predicted. RULE: Trajectory of change from 1985-2006 by planning unit by marsh type will be applied to future condition.
- Barrier Island restoration will form contiguous back barrier marsh that may be enhanced by island rollover, but also susceptible to significant erosion during storm events. RULE: Marsh creation projects produce class A patterns immediately, which are then subjected to change to class B or C based on trajectory of change from 1985-2006 by planning unit by marsh type.
- Ecosystem performance and species survival are enhanced when external (storms) and internal (water flow) pulses are coupled.

Some of the assumptions made in applying the hypotheses in this application are:

- The effects of protection structures (levees) on water transport and flow, and how that process influences spatial configuration of the landscape was not addressed. It is anticipated that there will be non-linear responses in the landscape to these engineering features.
- Freshwater diversions will be operated in a manner that will not cause persistent flooding and impacts to the marsh landscape.
- No rapid subsidence collapse of the marsh landscape as described by Morton et al (2005) will occur again.
- Patchiness of vegetation is strongly dependent on propagation patterns (local reproduction strategies) of individual plant species within a marsh community type, but this will not be addressed.
- Build up of new land or the development of open water is a balance between net inputs of suspended sediments and organic production and outputs due to subsidence and export of eroded sediments.

- Primary productivity and, hence, stem density is enhanced with increased dissolved nutrient availability when nutrients are limited. This assumption does not take into account some evidence that belowground productivity will be reduced with increased nutrients nor that nutria may prefer higher nutrient plants.
- The remaining coastal landscape is more resilient to wetland loss (harder to lose) than the marsh that has been already lost, however it will be treated the same.
- Internal and external pulses were not coupled, therefore the effects of levees and shoreline stabilization on back marsh spatial integrity was not captured by spatial integrity metrics.
- Channel infilling will continue only until an equilibrium condition is reached based on the flow rates (tidal or diversion velocities) and the stability of the vegetation/soil matrix of the marsh.
- High discharge freshwater diversions or pulsed diversions will provide sedimentation on the marsh surface, but will also experience erosion in areas closest to the diversion.
- Barrier Island widths when restored will be maintained to eliminate island breaching during large storms.

These hypotheses need to be tested in order to better link the spatial metrics to key functions. As an initial test of the hypotheses, SII classes should be calculated for natural analogs representing some of the categories of restoration measures. In coastal Louisiana, there are few restoration projects that have been constructed and in place for a sufficient period of time to assess spatial change. The projects suggested for this evaluation are Sabine Refuge 1993, 1996, 1999 and Bayou Labranche 1994 representing marsh creation; Naomi 1993, West Pt ala Hache 1993, and Caernarvon 1991 representing freshwater diversion in broken marsh; West Bay 2003 representing sediment diversion into open water; and Wax Lake Outlet 1973 representing natural delta development.

Modeling Approach

Future Without Project (FWOP)
The foremost premise upon which the model operates is an assumption that different SII classes change in variable patterns. Observation of historic trends (1985 to 2006) will be used to determine how resistant A, B and C classes are to change, and how they vary by water class as well as across planning units. These spatial and categorical delineations will be utilized to drive future projections.

The mean change over time for each of the 8 spatial configuration metrics were calculated for every possible combination of planning unit (PU) and SII class. Any PU_SII class combination which did not occur during the observation period was assigned the average of a similar PU_SII class combination; however, this occurred infrequently. An assumption of linearity of change was then utilized (due to time constraints) and mean metric change was converted to a change rate on an annual basis. These change rates then formed “lookup tables” upon which the model draws (Appendix A).

Future projections (2010 – 2060) are based on land area change provided by Paille et al. (in prep), where the model attempts to reflect the land change data, driving the classification into the numeric portion of the SII class (1, 2, 3, 4, 5, 6, 7, 8, 9, 10). Land change projections were conducted on larger polygons than the 4 km^2 tiles used in this analysis. Therefore, tiles were assigned to polygons based on a majority rule. For FWOP projections, land gain or loss rates (in each 10-yr period) were then assigned to each tile in a polygon and projected future land area was calculated.

The spatial configuration portion of the SII class was calculated for each of the 8 metrics based on the lookup table value of the starting time period PU_SII class. Those tiles which experienced land gain utilize gain rates and loss tiles utilize loss rates. The annualized rate was first calculated for 4 years to achieve a 2010 projection. The 2010 SII class was then assigned based on the newly calculated spatial configuration metrics. The process then iterates for the next 10-yr period based on the new SII class lookup value. The year 2010 served as our base year for the projection of future change.

Alternatives Assessment

The presence of hypothetical diversions and marsh creation measures in the alternatives required additional approaches for creating projections. As with the FWOP scenario, net benefit acreage for each of the measures that comprise the restoration alternatives was provided by Paille et al. (in-prep), and the model seeks to reflect those data. Net benefit acreage was again assigned to larger polygons, so tiles were assigned to polygons based on a majority rule. The model seeks to first distribute that benefit acreage appropriately throughout the tiles based on the type of restoration measures; however each type was modified differently based on the rules that were previously described.

Benefit area assignments were defined for marsh creation measures, marsh creation measures sustained by diversion measures, and diversion measures. The approach for each is defined as follows:

Marsh Creation Benefit Area Assignment

- Total available water area was assessed for all tiles in a given polygon.
- This figure was then multiplied by 0.7 as a result of the desire to implement marsh creation projects in a 70/30 land/water ratio.
- The resulting acreage was the maximum available area to be built, which was then compared to the Paille et al. (in-prep) benefit acreage for that 10-yr period.
- All cells were brought to the highest land acreage possible and assigned a spatial configuration class of “A”. The mean metrics for the class were assigned.
- If the maximum available area was less than that of the benefit acres provided, that benefit could not be reflected.
- If the marsh creation project was not sustained by a diversion, it was subjected to 10-yrs of loss spatial configuration change rates and the process repeated for the next 10-yr period.

Marsh Creation (sustained by diversion) Benefit Area Assignment

- The benefit area was assigned in the same manner as other marsh creation projects, however the sustaining effect of the diversion was assumed to keep the spatial configuration as an "A" class.

Diversion Benefit Area Assignment

- Diversion land building was excluded in SII classes 1 and 10.
  - The assumptions here being that a diversion will not build a tile to any more than 95% land, and open water is very difficult to alter and build land.
- Diversion benefits were commonly assigned to large polygons, requiring a means of further discriminating where benefits occurred.
- Diversion "Zones of Influence" polygons were often found to not contain enough available water area to reflect the land benefit acreages provided.
- A shortest distance to diversion methodology was utilized where:
  - The cell which was closest to a diversion would first be subjected to gain rates as assigned by PU_SII class for a ten year period;
  - The model would then check that increase in acreage against the total benefit provided. If more benefit needed to be assigned, the next closest cell would receive benefits;
  - Once all benefits were assigned, the model would exit the loop and move on to the next diversion.
  - A 20km threshold was also utilized as the maximum distance a diversion could assign benefits to avoid situations in which the benefit acreage criteria was not met, and consequently land building occurs at distances it logically could not benefit.
  - If the benefit acreage can not be completely assigned within those restrictions (available tiles SII classes 2-9, within 20km) those benefits could not be reflected.

The LACPR HET will ultimately be responsible for placing value judgments on what type of spatial pattern is more beneficial from an overall ecosystem sustainability perspective. A reproducible numeric approach was developed for each selected metric (percentage of landscape occupied by water, edge density of land, and patch cohesion), where the average values calculated from each of the four dates of imagery (1985, 1990, 2001 and 2006) were averaged across all dates to determine rankings by SII. The SII rankings were then assigned an index value from 0 – 1 based on equal distribution across the 24 SII classes. These values were then used to calculate average values for each metric by PU. This type of ranking system may prove valuable to facilitate the comparison and interpretation of results; otherwise evaluation of positive or negative effect for particular processes as represented by a specific SII (i.e., fisheries utilization vs. land stability) will be a subjective determination by the LACPR HET.

RESULTS & DISCUSSION

The results and discussion presented in this draft report are going to concentrate on change assessments for PU's 1, 2, 3a, 3b, and 4 between two historic time periods (1985 and 2006) and two future dates (2010 and 2060) even though multiple dates were assessed. Additionally, results will focus on the metrics "Percentage of Landscape Occupied by Water", "Edge Density of Land", and "Patch Cohesion" as metrics that best represent the functions land stability, fisheries utilization, and hydrologic connectivity, respectively.

Classification Change

Historic Evaluation
The SII was calculated for 8,437 tiles coastwide for 1985, 1990, 2001 and 2006, and the spatial representation of the data from 1985 and 2006 are shown in Figures 9 and 10, respectively. The darker saturations/intensities (within a particular color) represent A classes, which denote large, contiguous patches of land and at least one large, contiguous patch of water. The intermediate saturations/intensities (within a particular color) represent C classes, which denote some fragmented patches of land and at least one large, contiguous patch of water. The light saturations/intensities (within a particular color) represent B classes, which denote a disaggregated configuration of land and water patches occurring throughout the tile.

Preliminary observations of these data suggest that the classification system accurately classified the amount of each tile represented by water. Overlays of these results with the original land:water classification by Barras (2006) showed a significant match. The SII also appear to match up fairly well with long term personal observations. As an initial sensitivity analysis, an evaluation of PU's 1 and 2 (Figures 11 – 12) and PU's 3a, 3b, and 4 (Figures 13 - 14) was conducted to corroborate results from this study with detailed pre and post-hurricane observations and data collection that was conducted in 2004, 2005 and 2006 throughout coastal Louisiana. The lighter saturation/intensities in upper Breton Sound in PU1 and in Cameron Creole Watershed in PU4 in 2006 are confirmed B classes. Preliminary data comparisons of configuration classes in PU's 2, 3a and 3b were inconclusive. A more detailed sensitivity analysis needs to be conducted in the future.

The coastwide evaluation of SII changes from 1985 to 2006 is presented in Table 1. This matrix shows that over 58% of the coastwide tiles classified remained unchanged over this 21 year period. More importantly, it shows that tiles that started out as either class 1 (solid land) or class 10 (solid water) remained stable and didn't change class over the timeperiod. The data also show that generally A classes are most stable over time, followed by C classes and B classes. The percent of the A classes that remained unchanged, regardless of the water class in the tiles, always exceeded that of the B and C classes. Additionally, as water classes increase, the B classes that remain unchanged decrease. These findings suggest that the general trend of most stable to least stable is class A to C to B. When this evaluation was conducted at the planning unit (PU) scale, all planning units followed this general trend. Results from PU's 1, 2, 3a, 3b and 4 are included in Tables 2 - 6. It is interesting to note that PU1 had the greater amount of percent unchanged tiles (70.8%) whereas PU4 had the least (41.67). The result in PU4 may be reflecting the change in solid land (class 1) to water classes that is associated with impacts from Hurricane Rita. Further investigation into why there are large differences in the amount of percent unchanged tiles between PU's is needed.

Future Without Project (FWOP)

The FWOP SII was projected for 2010 and 2060 and is shown for PU's 1-2 in Figures 15 and 16. The greatest change over this time period is reflected in the increase in open water (higher SII classes), that visually match the land loss estimates provided by Paille et al. (in-prep). The large open water projected by 2060 is primarily in the marshes adjacent to the Gulf of Mexico in PU's 1 and 2, adjacent to large existing water bodies in PU1, and in interior marshes in central Barataria Basin in PU2. Figure 17 illustrates this point by showing that the middle and lower portions of PU's 1 and 2 are completely dominated by water. The SII change matrices also reflect the increase in water from 2010 to 2060. Planning unit 1 (Table 7) is dominated by a 1 category increase in water and a large shift in A classes to C classes. The matrix for PU2 (Table 8) illustrates 1-3 category increases in water (primarily 2 category), reflective of the higher landloss rates in PU2. The configuration of the remaining landscape is dominated by larger water patches in Barataria and Breton Sound and a greater disaggregation of land in lower Pontchartrain Basin (Figure 18). Planning units 1 and 2 have a slightly greater connectivity between water patches in the lower basin and a greater connectivity in the upper basin, as reflected in the patch cohesion metric in Figure 19.

The FWOP SII projections for 2010 and 2060 for PU's 3a, 3b and 4 are shown in Figures 20 and 21. The areas showing the highest SII classes reflecting increases in open water visually match those estimates provided by Paille et al. (in-prep) and Barras et al. (2003). The areas projected to continue to fragment and/or convert to open water include, but are not limited to, the landscape between Lake Boudreaux and Bayou LaFourche in PU 3a, North of Lake Mechant in PU 3b, and Grand Chenier and south White Lake in PU 4. The landscape west of Calcasieu Lake does not reflect well the losses projected from Barras et al. (2003). This area (other than the southwest region) shows higher percentages of water in 2010 than in 2060 (Figure 22), which suggests either an error in the model or that the polygon size and associated land loss rate applied from Paille et al. (in-prep) needs to be adjusted. The matrix for PU3a (Table 9) illustrates 1-3 category increases in water, consistent with the highest landloss rates found in this PU (Figure 22 and 23). Planning unit 3b, which includes a land building area in the Atchafalaya delta, and PU4 have slightly greater connectivity between water patches, as reflected in the patch cohesion metric in Figure 24, but also a smaller change in water category classes as compared to the higher loss areas in PU's 2 and 3a (Tables 10 & 11). A limitation of the projections is they assume that trajectories of land change and land configuration in the past (1985 – 2006) will be the same in the future. Refinements to address this assumption and a more detailed sensitivity analysis will be conducted in the future.

Alternatives Assessment

The alternatives assessment focused on evaluations of each of the alternatives at 2060 as compared to the FWOP condition. In PU's 1 and 2, all of the alternatives had greater spatial integrity than the FWOP condition (Figure 16). Most restoration measures within all of the plans are clearly identifiable. The R1 and R2 diversion and marsh creation measures increased the spatial integrity significantly in upper Breton Sound, the east flank of the Barataria Basin and the Barrier Islands (Figure 26). The R3 diversion and marsh creation measures increased the spatial integrity significantly in the Biloxi marshes, the east and west flanks of the Barataria Basin, the upper birdsfoot delta, and the Barrier Islands (Figure 27). The R4 diversion and marsh creation measures increased the spatial integrity similarly to R3 except had less spatial integrity in the upper Breton Sound and upper birdsfoot delta (Figure 28). The heavy influence of diversions and limited marsh creation is evident in the spatial integrity patterns of alternative R5 (Figure 29).

Planning units 3a, 3b and 4 also had greater spatial integrity than the FWOP condition for all alternatives (Figure 21). The influence of marsh creation features on the landscape, especially in PU3a - upper Terrebonne Basin are obvious (Figures 30 – 33), and when combined with freshwater influence from the GIWW, show the greatest spatial integrity (Figure 31). The R5 alternative in PU3a limited the use of marsh creation and showed the greatest water classes in 2060 (Figure 34). The differences in spatial integrity among alternatives in PU3b and PU4 were barely recognizable, primarily due to the use of protection features, which are not captured by the model, and small benefit areas associated with marsh creation and freshwater introduction features.

The individual SII change matrices between 2010 and 2060 for each of the alternatives can be found in Appendix B. A summary of those matrices are provided by category (water class; Figures 35 and 36) and by configuration class (Figures 37 and 38). Though categories 1 and 10 are end members which signify extremes in the category class spectrum and are therefore important to the overall average change in classification, their frequency and resistance to change, both require and enable their exclusion from select summary statistics and figures. In PU1, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R3 followed by R1 and R2 then R4 > R5 > FWOP (Figure 35). There was little difference in the occurrence of A classes at year 2060 between all alternatives except R5 (Figure 37). In PU2, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R1, followed closely by R2 and R3 with the least land classes in R5 > R4 > FWOP, however the increase in water classes 6 – 9 do not show FWOP as the greatest. This decline in FWOP classes 6 – 9 was expected since a higher percentage of tiles converted to class 10 in FWOP than in any other plan. The greatest number of A classes and fewest number of B and C classes are found in R3.

In PU3a, the alternative that maintained a majority of land (classes 2 – 5) at year 2060 was R3 followed closely by R1, R2 and R4 then R5 > FWOP (Figure 36). There was little difference in the occurrence of A classes at year 2060 between all alternatives except R5 (Figure 38). In PU3b and PU4, a trend of declining frequency in water classes as you gain more water was distinct (Figure 36). This is evident of natural land building that occurs in the Atchafalaya delta in PU3b and lower land loss rates in PU4. The results across all PU's illustrate that you lose a higher percentage of B classes in FWOP and that a large number of C classes are converted to A classes by marsh creation and diversion measures.

The ability to discern the influences of restoration measures on specific functions, and therefore compare each alternative was captured through a change analysis by metric between FWOP and each alternative. This approach shows only the influences of the restoration measures that comprise each of the alternatives, with no change represented outside of these areas. The change in percentage of landscape occupied by water metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 39 – 43 and in PU's 3a, 3b and 4 in Figures 44 - 48. The change in the edge density of land metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 49 – 53 and in PU's 3a, 3b and 4 in Figures 54 - 58. The change in the patch cohesion of water metric for Alternatives R1 – R5 are shown for PU's 1 and 2 in Figures 59 – 63 and in PU's 3a, 3b and 4 in Figures 64 - 68. These figures provide a visualization of how particular functions as represented by the metrics are maintained in 2060 by the different alternatives. The details of how individual metrics change among alternatives and FWOP between 2010 and 2060 are included in Figures 69 - 74 and Tables 12 - 14. In PU's 1 and 2, the general pattern in 2060 is that R3 has the smallest percentage of landscape occupied by water, followed by R1 and R2, then the most water in R4 < R5 < FWOP. In PU3a, R4 has the smallest percentage of landscape occupied by water. The patterns in PU3b and PU4 are similar with R3 having the smallest percentage of landscape occupied by water, followed by R1 < R2 < R4 < R5 < FWOP. Alternative R5 had the greatest amount of water at year 2060 across all PU's. The amount of edge metric represented in Figures 71 & 72 must be interpreted carefully because edge density increases when SII classes 1 – 5 degrade and then edge density declines when you increase the amount of SII classes 6 – 9. All PU's show declines in edge density over time except in PU3b, where active land building (Atchafalaya delta) and large marsh creations into previous large open water areas increase edge. Cohesion values represent in part how water bodies coalesce over time as land is lost. Across all PU's, R3 generally had the lowest cohesion of water values whereas R5 and FWOP had the highest values.

Index values were created for each metric to calculate an average value for each metric by PU to support a further evaluation of alternatives. It is important to note with regard to interpretation of R1 and R2, that the model is incapable of appropriately projecting the differential effects of the operation schemes which distinguish these alternatives from each other. As the locations of diversions and marsh creation features are held constant, leaving only the net land area benefits to vary among the plans, we expected and indeed saw nearly identical results for these plans.

A land stability index was generated from the percentage of landscape occupied by water and the number of unchanged tiles (Figures 75 and 76, Table 15). Though it may be intuitive to believe this occurs as a result of these plans building the most land, it is not necessarily the case. The land stability index places emphasis not only on the amount of land built, but the spatial configuration of that land. Also, the results of the spatial integrity model utilized in this analysis are highly dependent upon the spatial distribution of restoration features throughout a landscape. The greatest land stability was found in R3 for alternatives PU1 and PU2; R4 in PU3a; R1 in PU3b; and R1 and R3 in PU4. In general, it appears that R1, R2 and R3 seem to have employed a greater number of small to medium diversions, spaced strategically throughout the PU with significant marsh creation. A diversion strategically placed to influence large areas of degraded, fragmented marsh will often have more beneficial results than a diversion placed in close proximity to large amounts of open water. This occurs as a result of multiple assumptions built into the spatial integrity model. First, diversion benefits are only allowed within a 20km distance of the diversion. Second, benefits are not allowed to be assigned to “open water” (Class 10) or tiles containing more than 95% land (Class 1). The combination of these assumptions can lead to situations where the model is incapable of assigning land building benefits. Placement is also of the utmost importance with regard to marsh creation projects. Marsh creation projects are assumed to be installed as “A” configuration classes (typically containing large amounts of aggregated land). Therefore, a marsh creation project which falls on top of areas which are already highly aggregated will have less beneficial influence than one placed in highly disaggregated areas. This is reflected in PU2 where R3 employed the greatest amount of marsh creation and had the greatest land stability at 2060. The R5 alternative in PU4 shows a significant increase in land stability from 2010 to 2040. This finding is contrary to what we would expect and may be reflective of how benefits (land loss rate reductions) were assigned associated with salinity control features in this alternative and the large polygon size that represents this area.

The edge utilization index was calculated from the edge density of land metric (Figures 77 and 78, Table 16). The results from PU’s 1, 2 and 3a reflect the large contiguous marsh patches created initially followed by there disaggregation over time and creation of more edge. Alternative R5 which employed the least amount of marsh creation across PU’s, showed high edge utilization values. This is suggestive of fewer A classes and a greater amount of B and C classes. The highest wetland loss areas are found in PU’s 2 and 3b and this is reflected in very low values of edge utilization in 2060, apparently from small water patches coalescing into large water patches. There is an increasing trend in edge utilization in PU’s 3b and 4 over time. This may be reflective of a less patchy landscape and more stable landscape in 2010 that then degrades over time. The low initial edge utilization index value of R5 in PU4 is consistent with the problem findings addressed in the land stability index.

The cohesion of water patch metric was used to generate the hydrologic connectivity index (Figures 79 and 80, Table 17). The FWOP reflects that as you lose land, there is a greater connectivity between water patches, and therefore high index values. The R4, R5 and FWOP alternatives had the highest values in PU’s 1, 2, 3b and 4. This may be indicative of PU1 and PU2 starting out in a more deteriorated condition, such that new land building contributes to the large increase in cohesion of water patches. In PU3b and PU4, all alternatives decrease over time. The cohesion of water patch trend most commonly reflects that C classes are higher than A classes which are higher than B classes.

The results from all of the metrics suggest that the geographic location of features is highly influential on model output. In many ways, placement of restoration features has a larger influence on the values of spatial integrity metrics than does cfs load or net acres of benefit. It may be important to place larger emphasis on feature location in future plan development efforts.

Future Plans:

The conception, creation, and implementation of this model took place in a very short timeframe. Minimal time was afforded for further investigations of historical trends and in depth assessments of the validity of model's assumptions and/or methodologies. Easy approaches were, at times, selected over more rigorous approaches due to time constraints and the lack of the scientific backing to draw on. Therefore, future study of the assumptions and methodologies is encouraged to increase the validity and value of the results.

One such assumption warranting further investigation are the rates of change projected for various restoration features. The model currently utilizes rates of change based on tiles experiencing land gain from a variety of sources during the 1990-2001 period. This approach excludes an ability to incorporate variable patterns of change which may result from features with variable design and operation schemes. For example, rates of spatial pattern change are exactly the same for a 1,000 cfs diversion as that of an 80,000 cfs diversion (until land gain projections are met). Similarly, the model currently assumes a steady and pulsed diversion operation scheme will affect spatial pattern in the same manner. Realistically, benefits and change in spatial pattern will probably vary with operation scheme, cfs load and other factors. Therefore, further investigation into these variables is considered vital to the utility of projections of spatial pattern under different restoration strategies.

Another issue in need of future study would be incorporation of bathymetric depth as a variable affecting the likelihood and magnitude of change, not only in terms of land gain, but the spatial pattern of that gain. One assumption that affects model output routinely is the restriction of diversion land building benefits in open water tiles (Class 10). This assumption is logical in most cases, in that a 4km^2 area of open water is unlikely to experience land gain. These tiles are usually deep and subjected to sufficient energy to maintain them as open water. There are a few cases however, where shallow open water, protected from wave energy, should be considered viable candidates to receive land building benefits from diversions. Therefore, incorporation of depth dependency may also improve the value of results.

A constant threshold distance of 20km is currently utilized to prevent diversion benefits beyond a reasonable distance. This distance was commonly utilized in LCA and was agreed upon as a maximum distance at which you could expect benefits by a panel of experts. This assumption needs to be tested. Although one would expect a majority of the benefits to occur closest to the diversions, there is uncertainty regarding the distance from source that freshwater, sediment, and nutrient benefits are provided.

Investigation of boundary condition effects on the spatial integrity model also warrants further investigation. Boundary conditions may affect specific metrics primarily due to the Euclidean geometry of square tiles. This study utilized $4km^2$ tiles in an attempt to alleviate boundary conditions as much as possible. Boundary condition effects could be reduced further by using a moving window analysis to assess patterns; however it is computationally intensive. Removing the potential influence of boundary condition effects may enable assessment of finer scale patterns, and thereby provide more accurate projections at finer scales.

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FIGURES

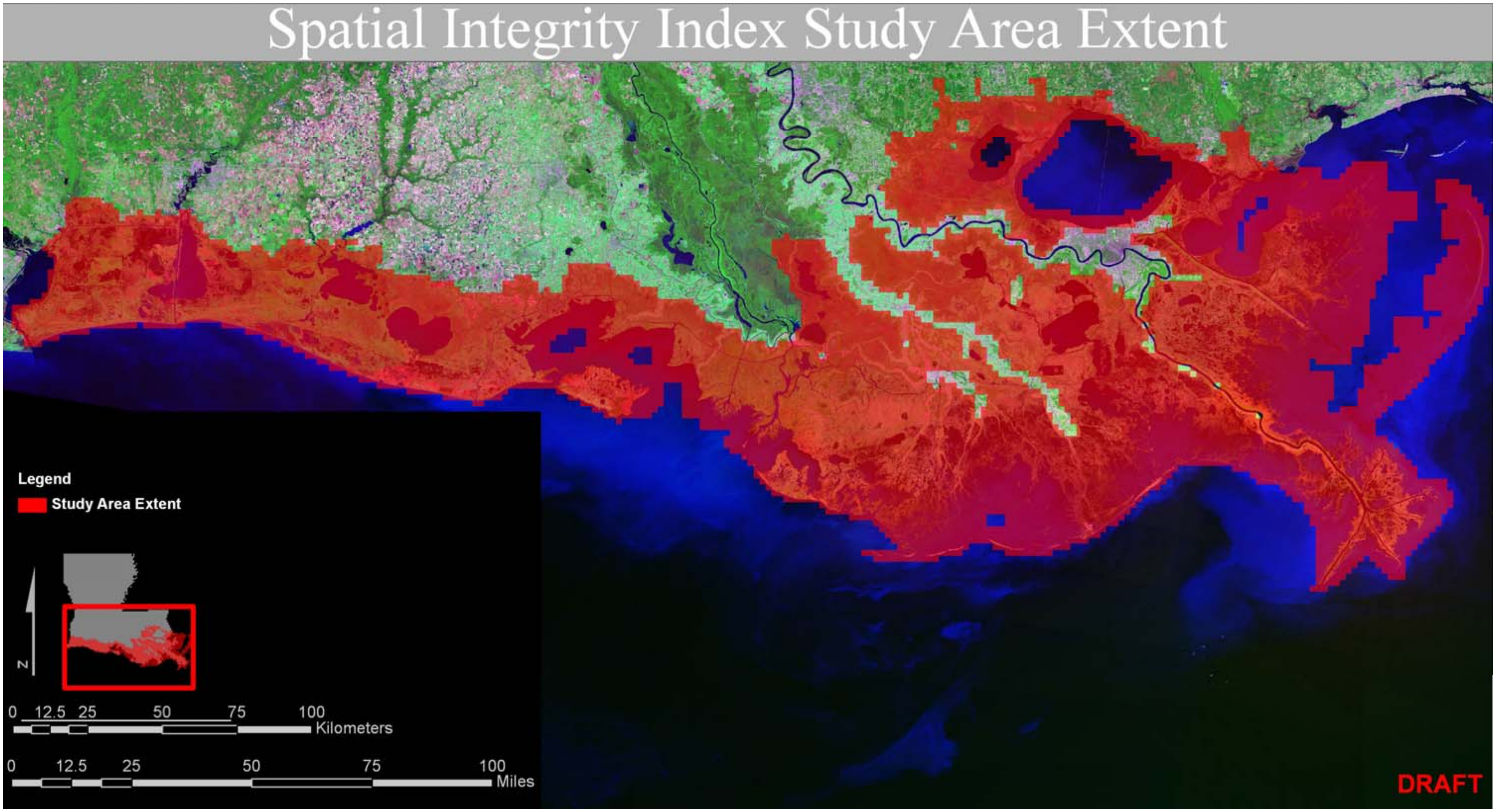


Figure 1. The overall spatial extent of the study area includes the LACPR planning unit boundaries minus fastlands.

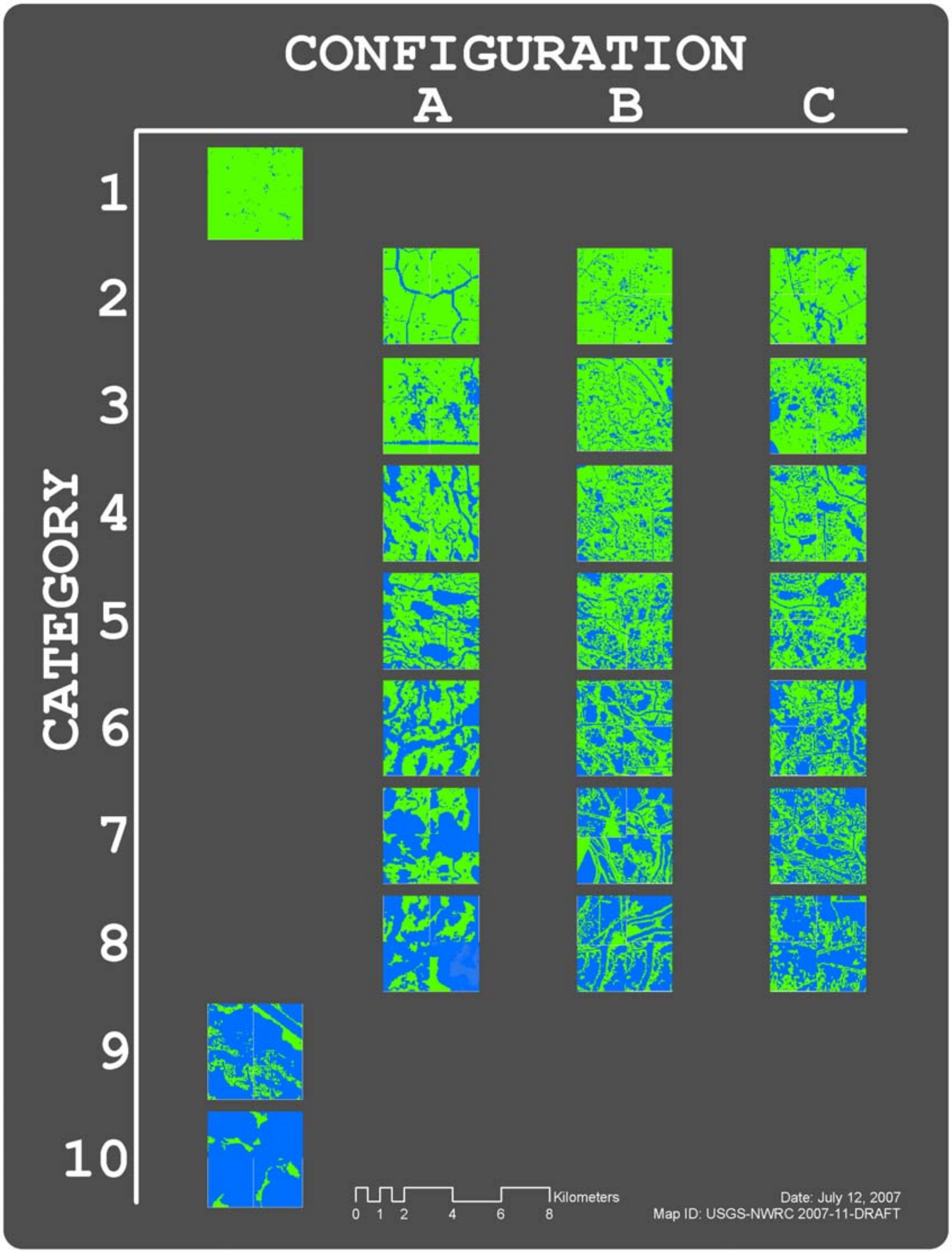


Figure 2. A representation of the spatial integrity index (SII) classification scheme modified from Dozier (1983) used for interpretation of classified TM landsat imagery. The numbers 1-10 represent percentages of water as: Class 1, 0%–<5% water within marsh, Class 2, 5%–<15% water, Class 3, 15%–<25% water, Class 4, 25%–<35% water, Class 5, 35–<45% water, Class 6, 45–<55% water, Class 7, 55–<65% water, Class 8, 65–<75% water, Class 9, 75–<85% water, and Class 10, ≥85% water. Letters A, B, and C are subclasses determined by configuration of water bodies in the marsh.

Figure 3a. Identified are the measures that comprise Alternative R1, May – December Medium Diversions – Planning Unit 1.

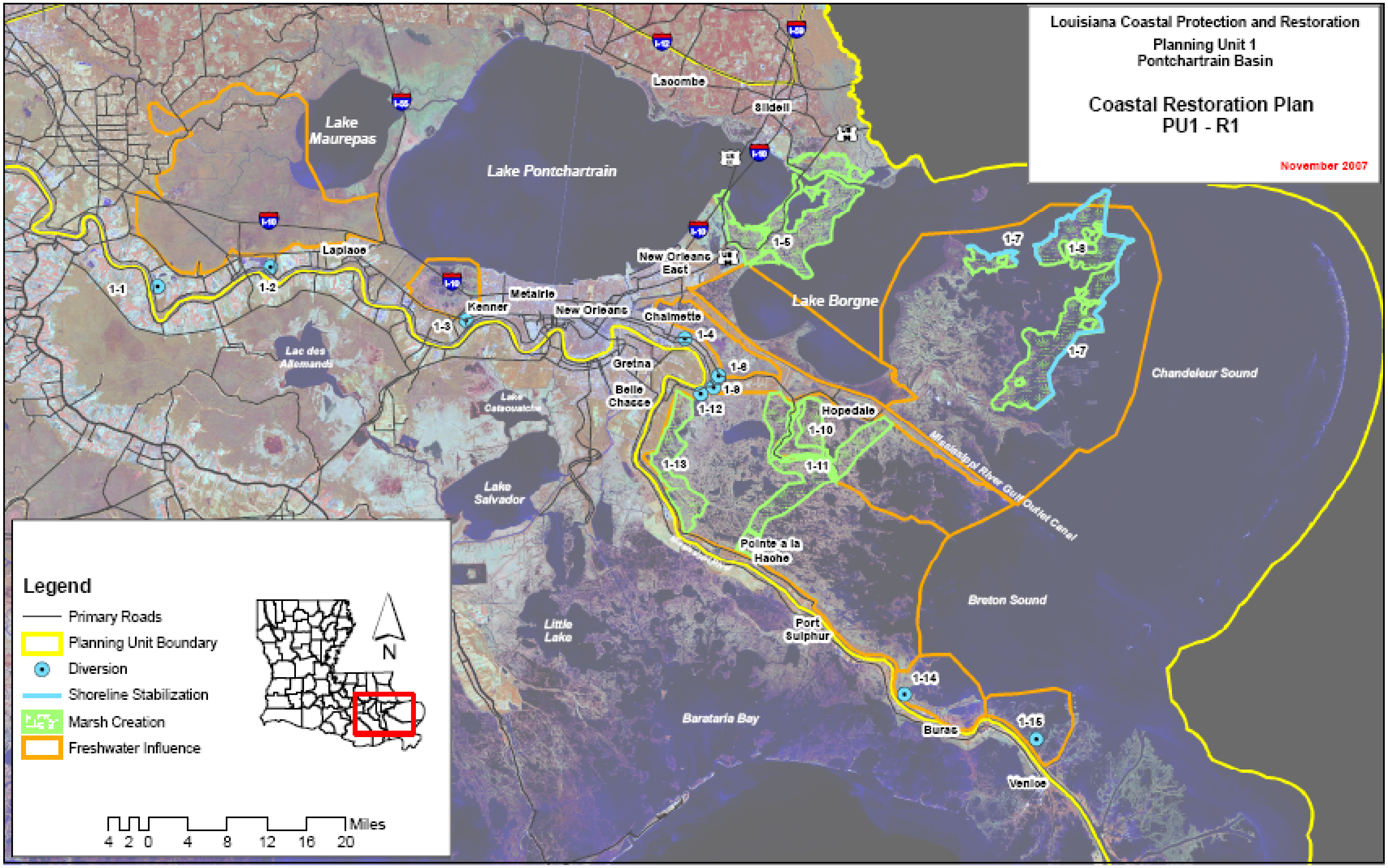


Figure 3b. Identified are the measures that comprise Alternative R1, May – December Medium Diversions – Planning Unit 2.

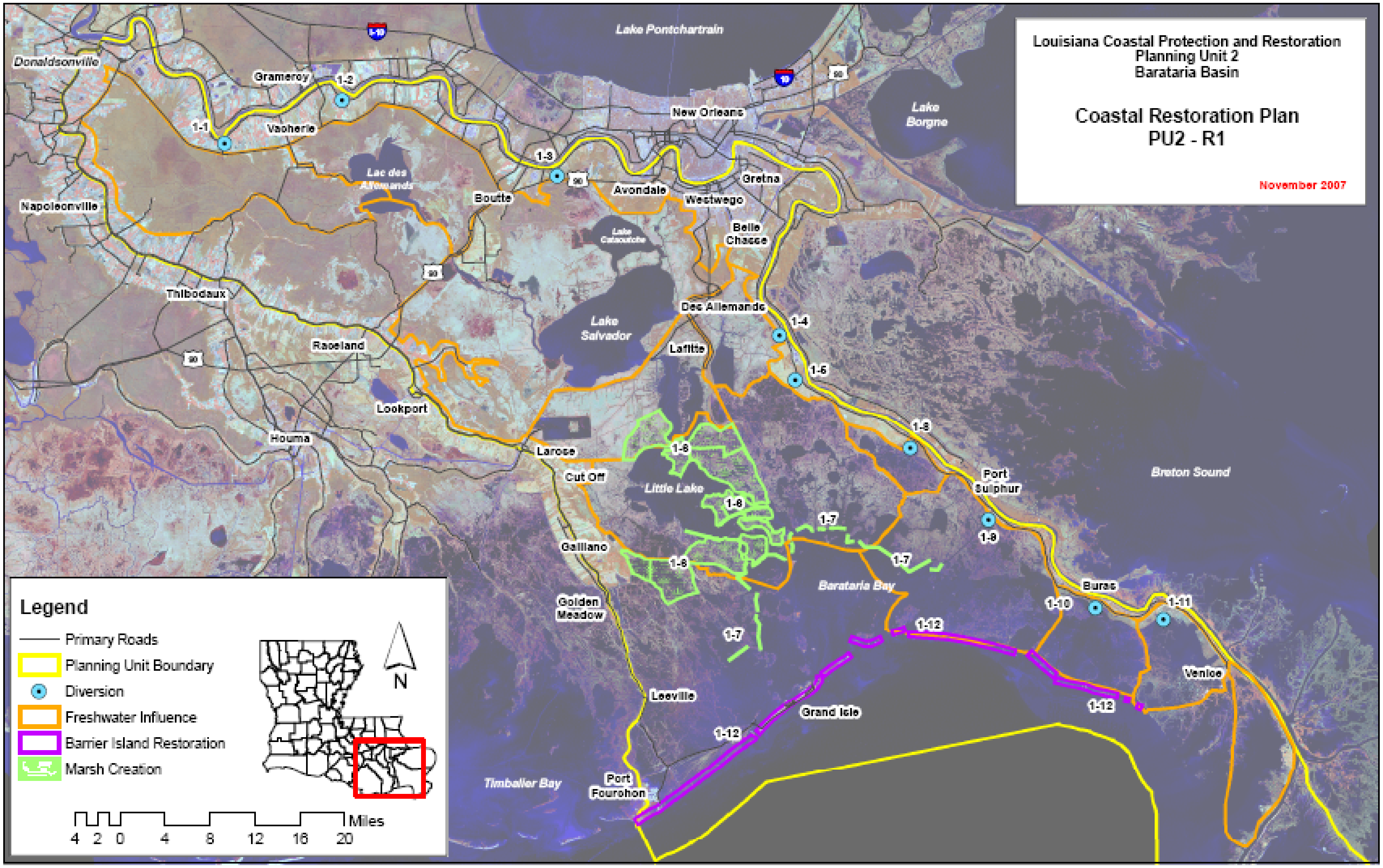


Figure 3c. Identified are the measures that comprise Alternative R1, Mississippi River Diversions – Planning Unit 3a.

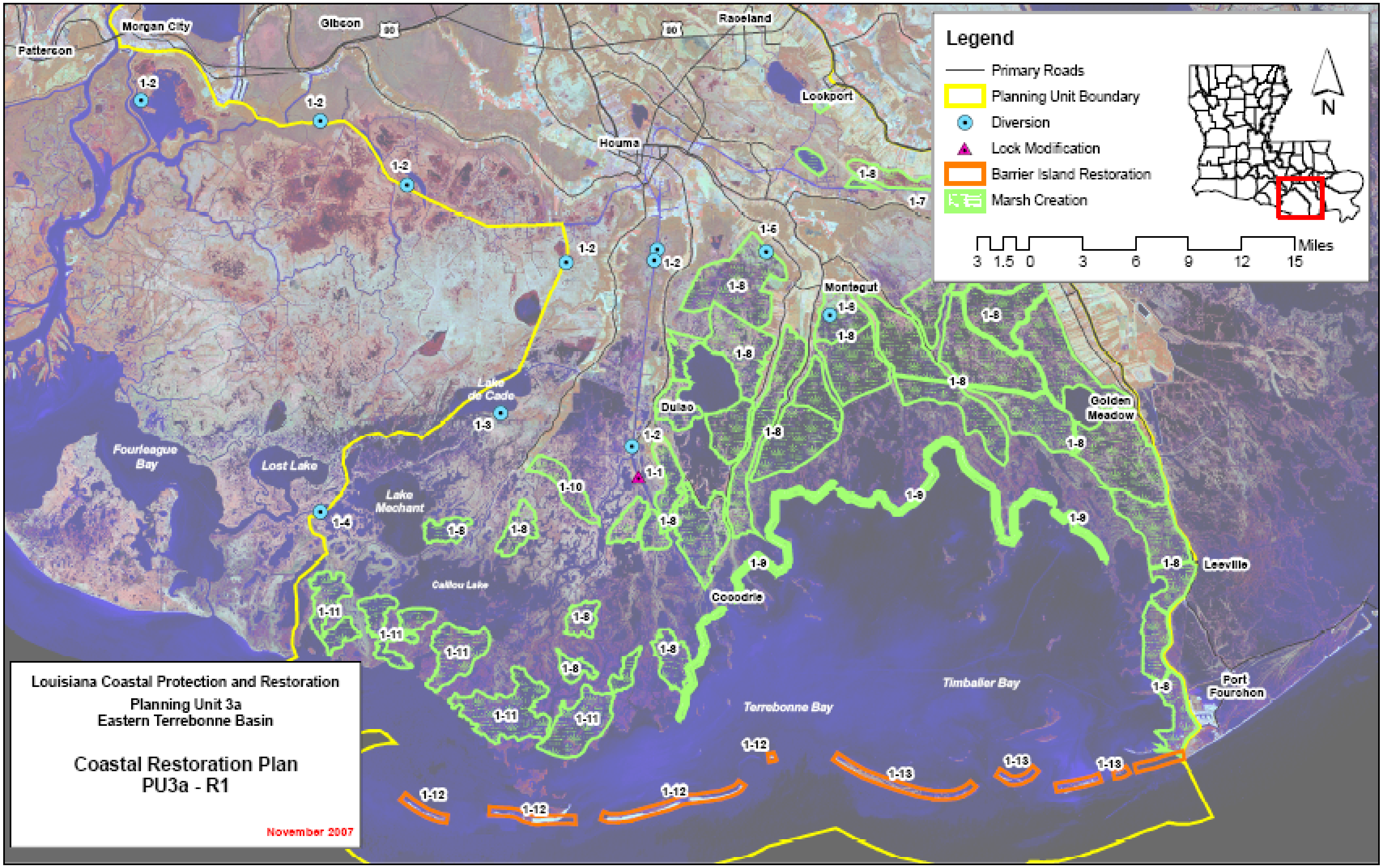


Figure 3d. Identified are the measures that comprise Alternative R1, GIWW Diversions With Shoreline Protection – Planning Unit 3b.

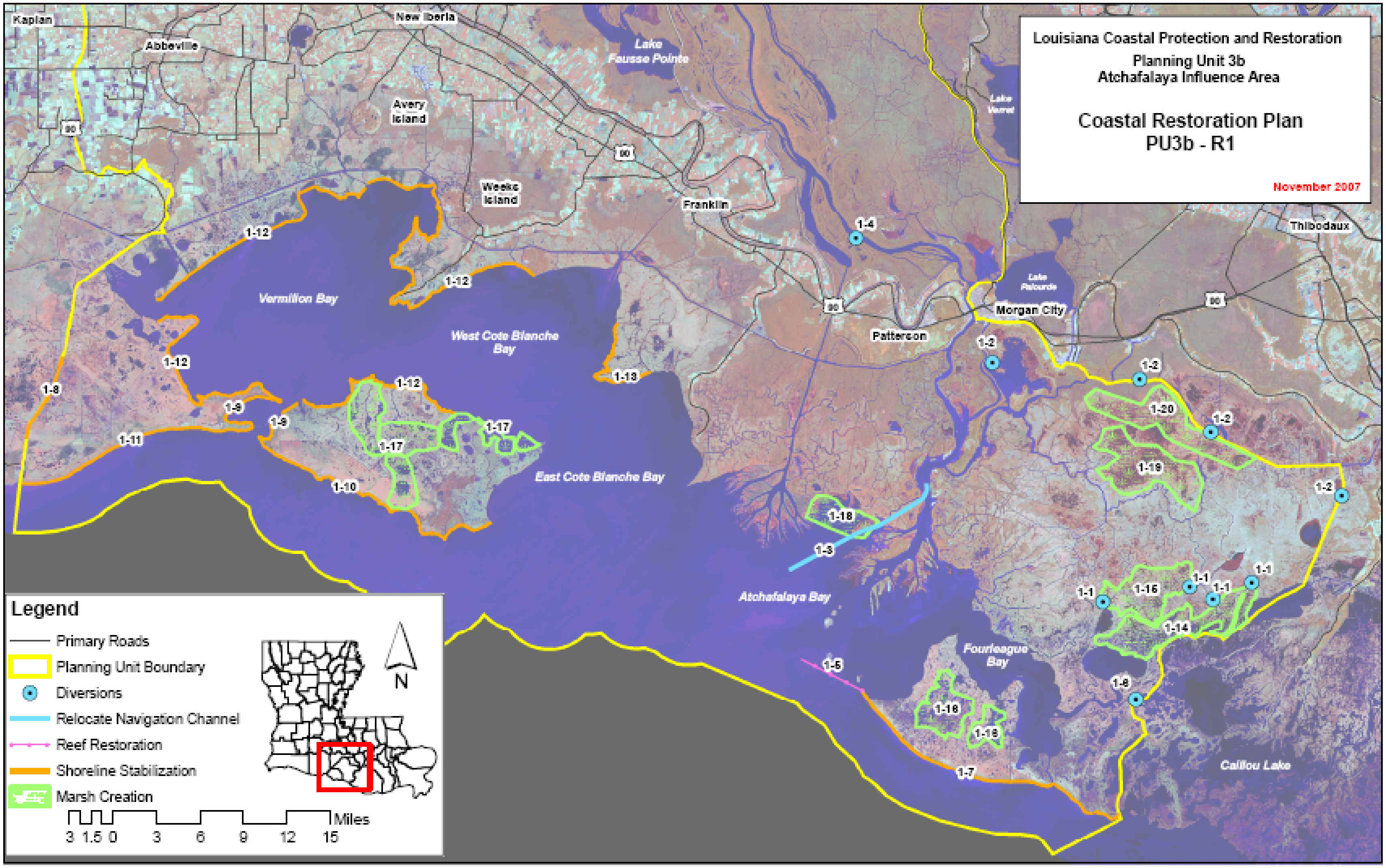


Figure 3e. Identified are the measures that comprise Alternative R1, Marsh Creation With Shoreline Protection – Planning Unit 4.

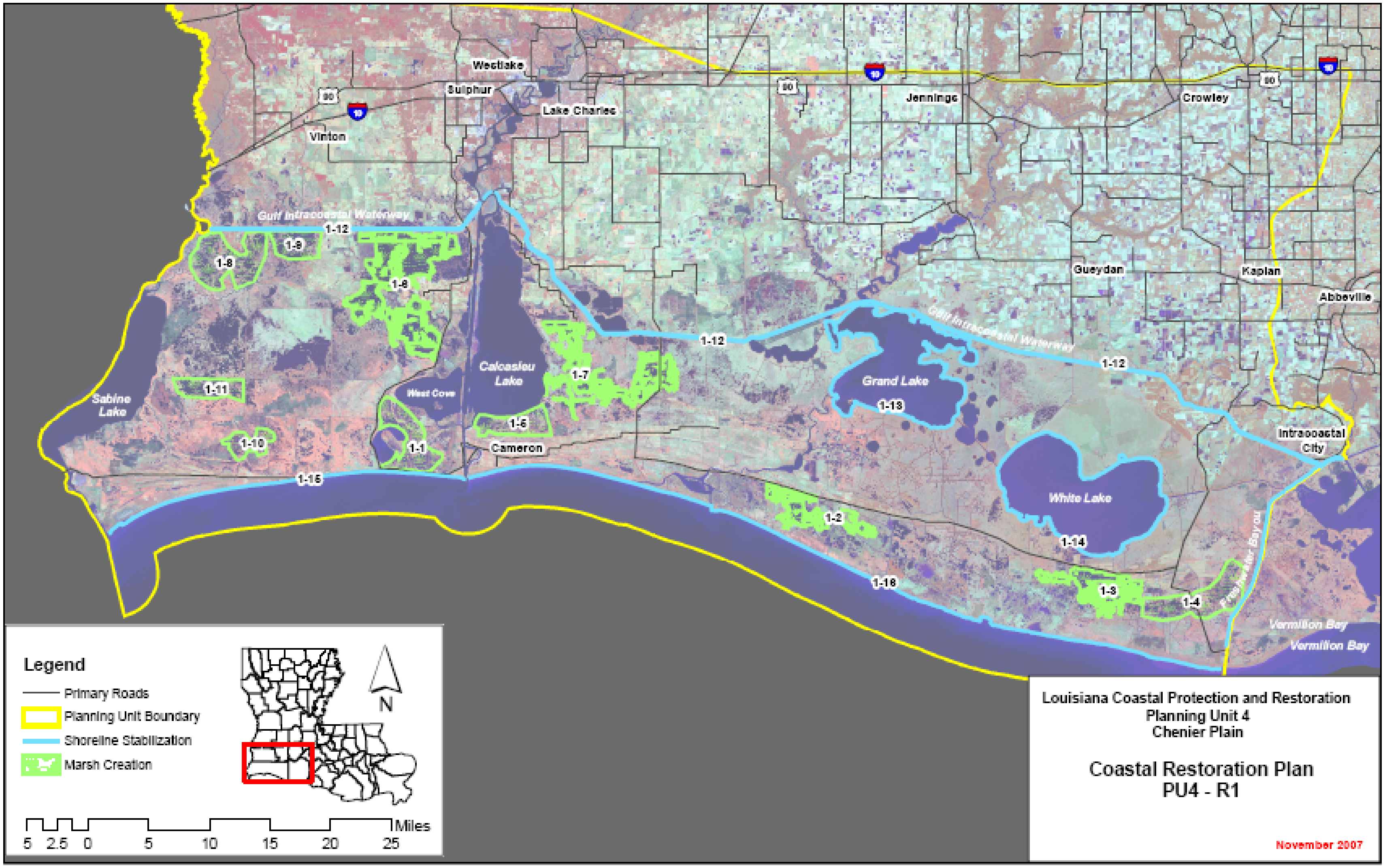


Figure 4a. Identified are the measures that comprise Alternative R2, Pulsed Diversions – Planning Unit 1.

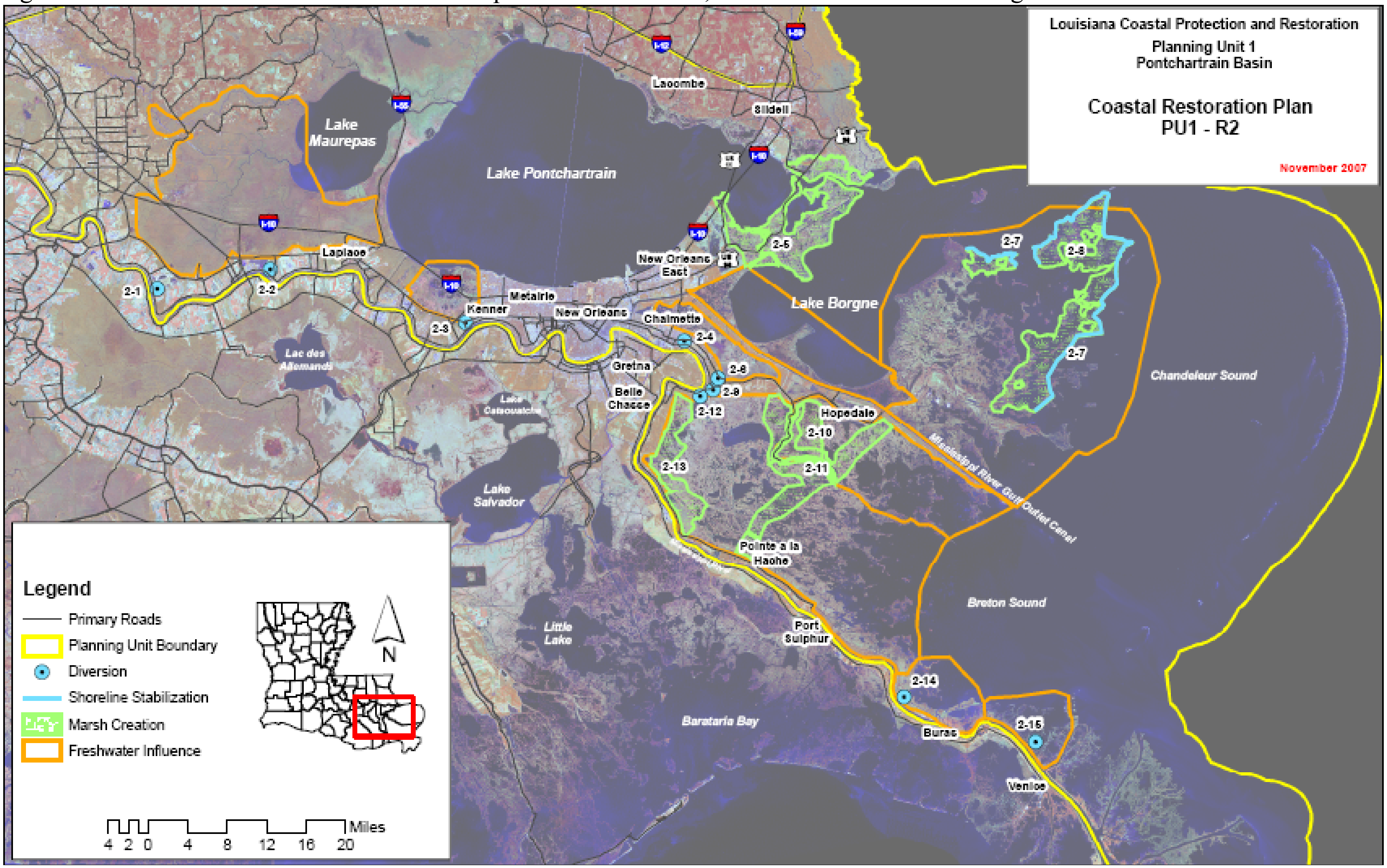


Figure 4b. Identified are the measures that comprise Alternative R2, Pulsed Diversions – Planning Unit 2.

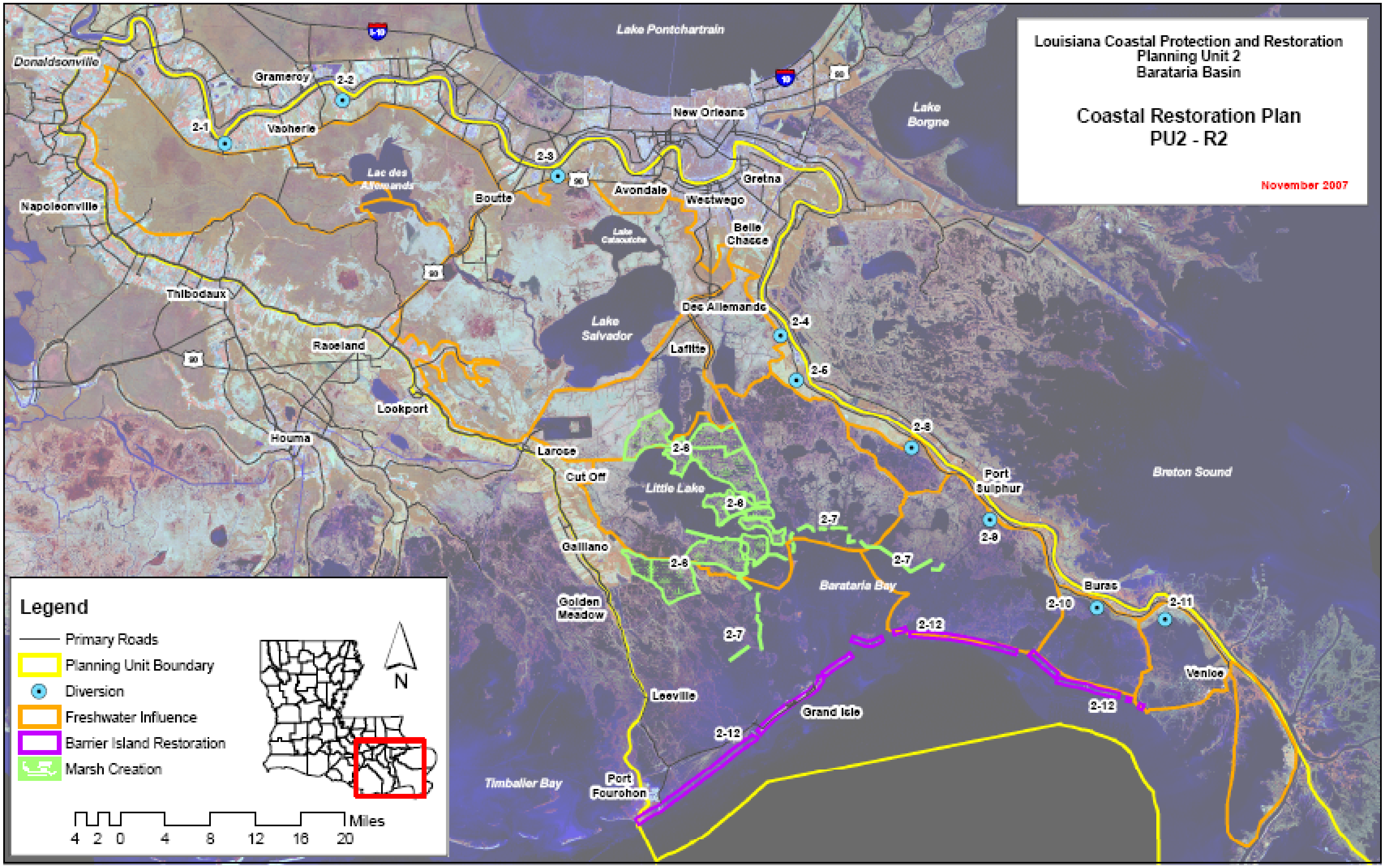


Figure 4c. Identified are the measures that comprise Alternative R2, GIWW Diversions – Planning Unit 3a.

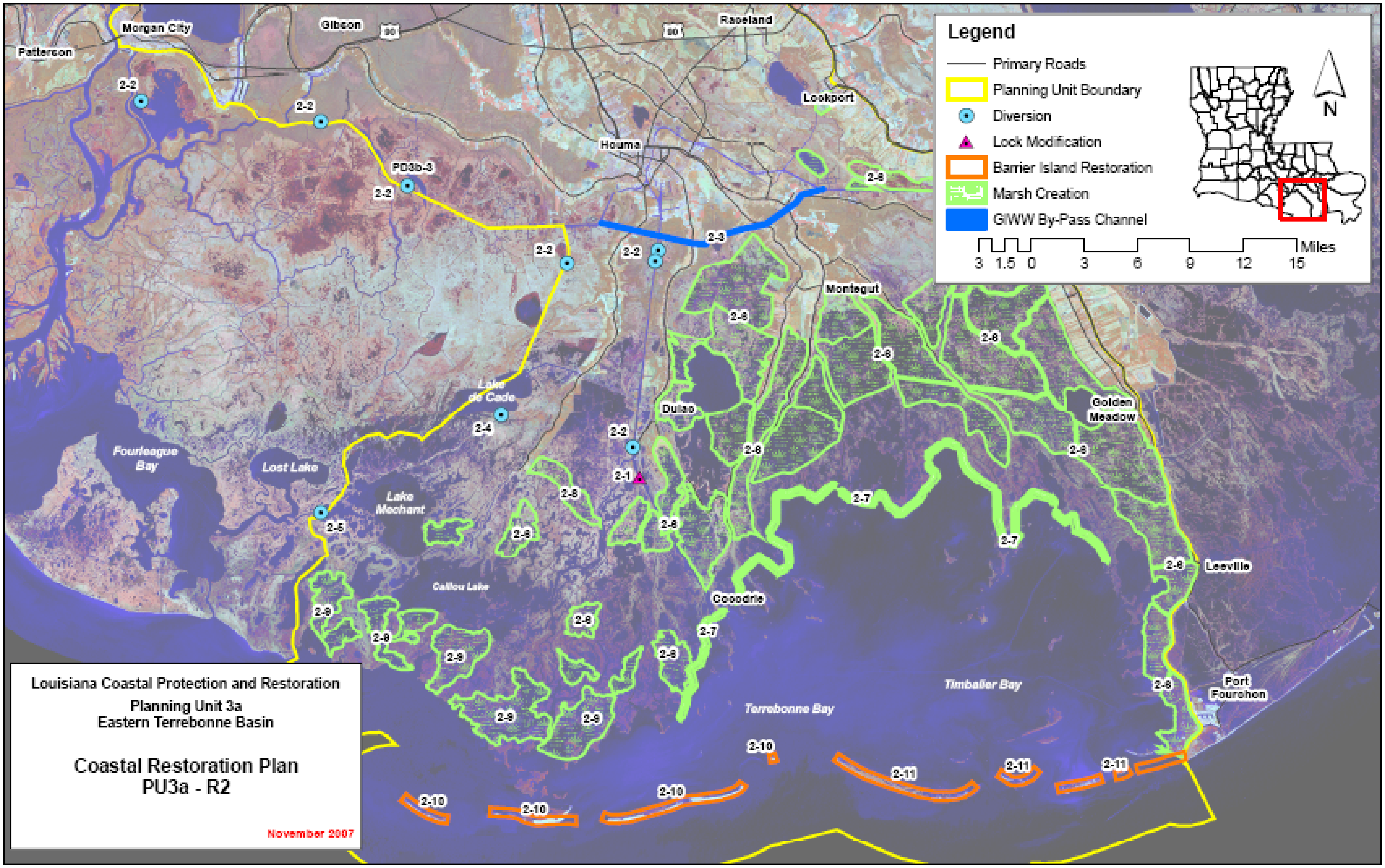


Figure 4d. Identified are the measures that comprise Alternative R2, GIWW Diversions With Marsh Creation – Planning Unit 3b.

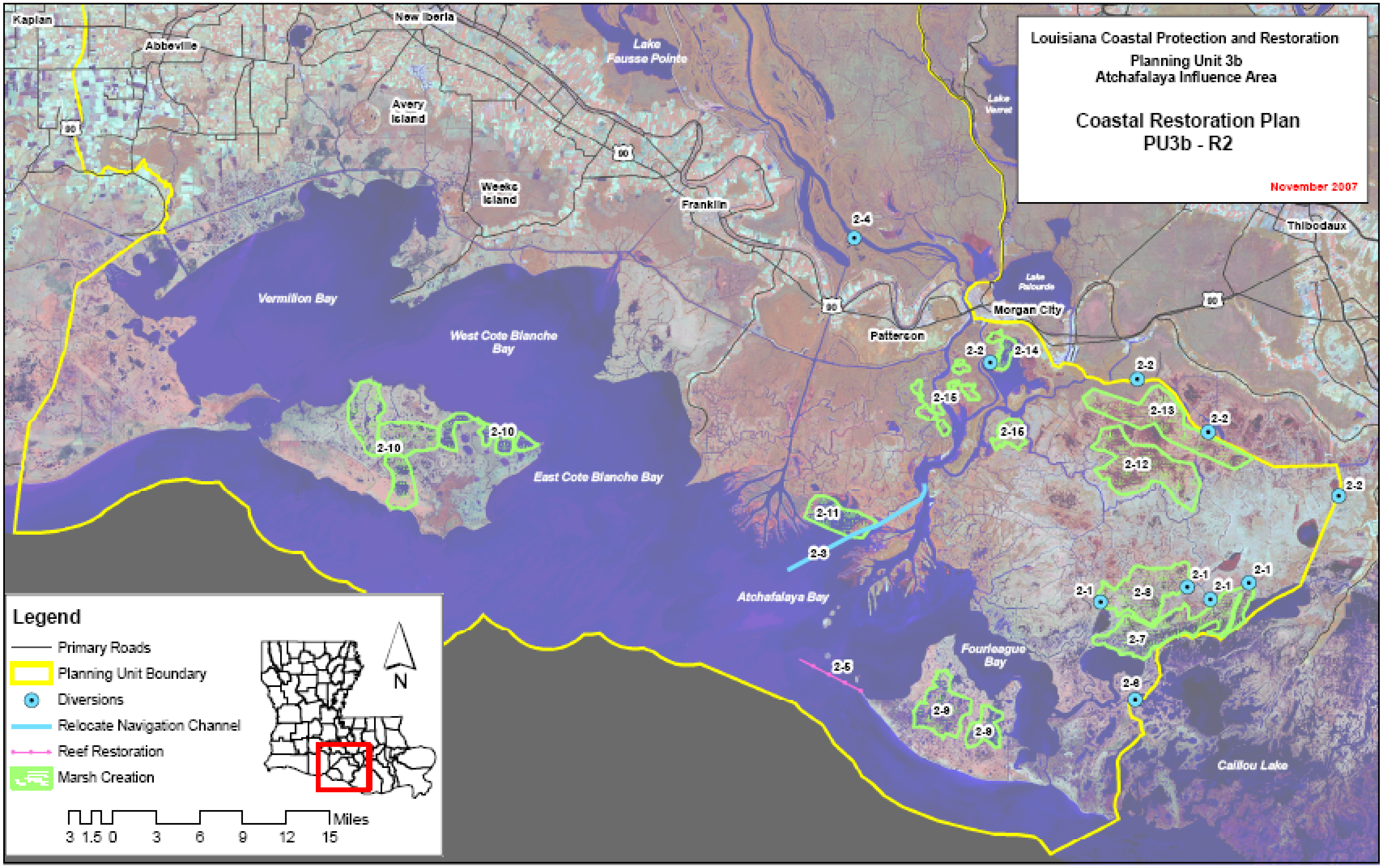


Figure 4e. Identified are the measures that comprise Alternative R2, Marsh Creation Without Shoreline Protection – Planning Unit 4.

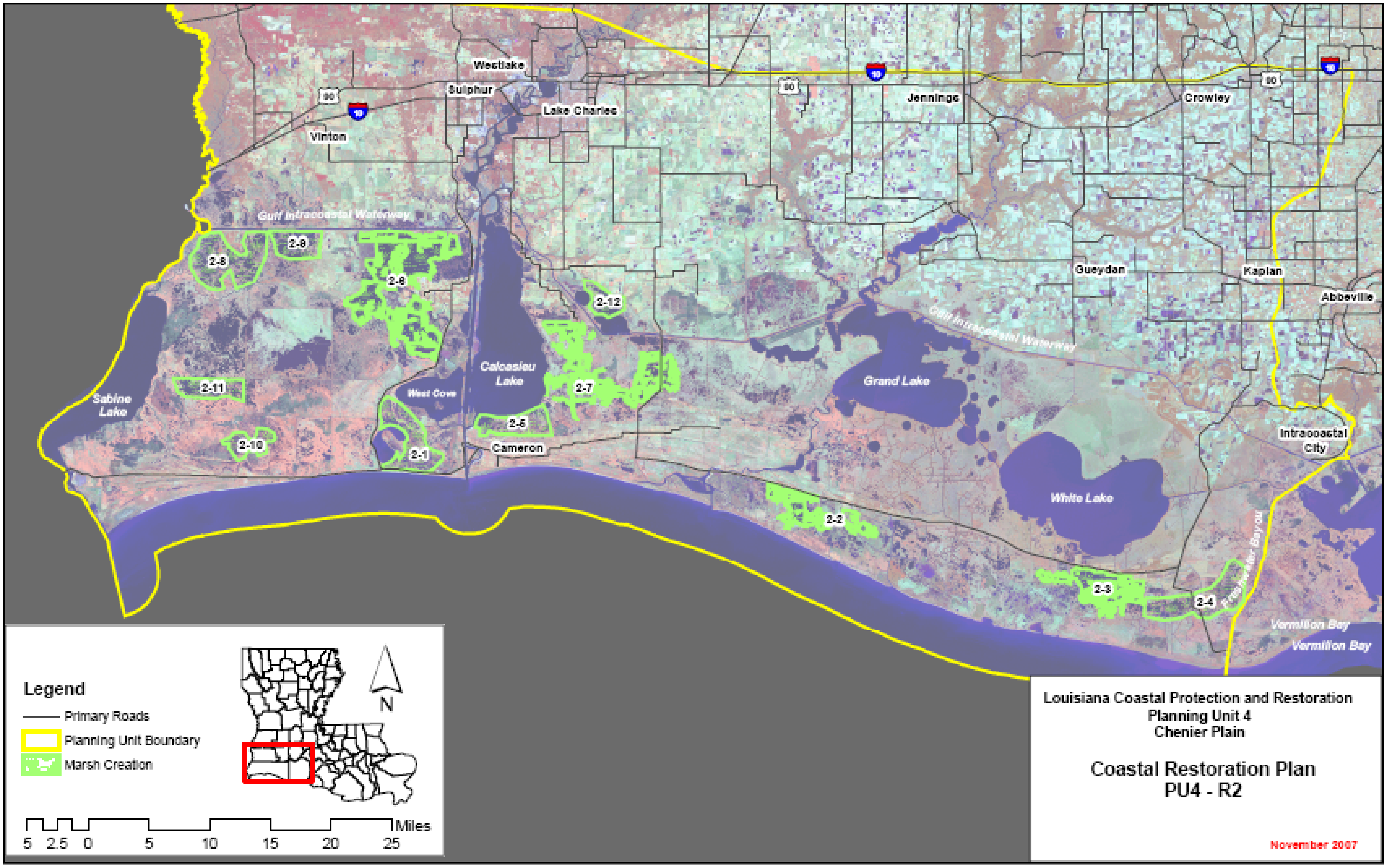


Figure 5a. Identified are the measures that comprise Alternative R3, State Master Plan – Planning Unit 1.

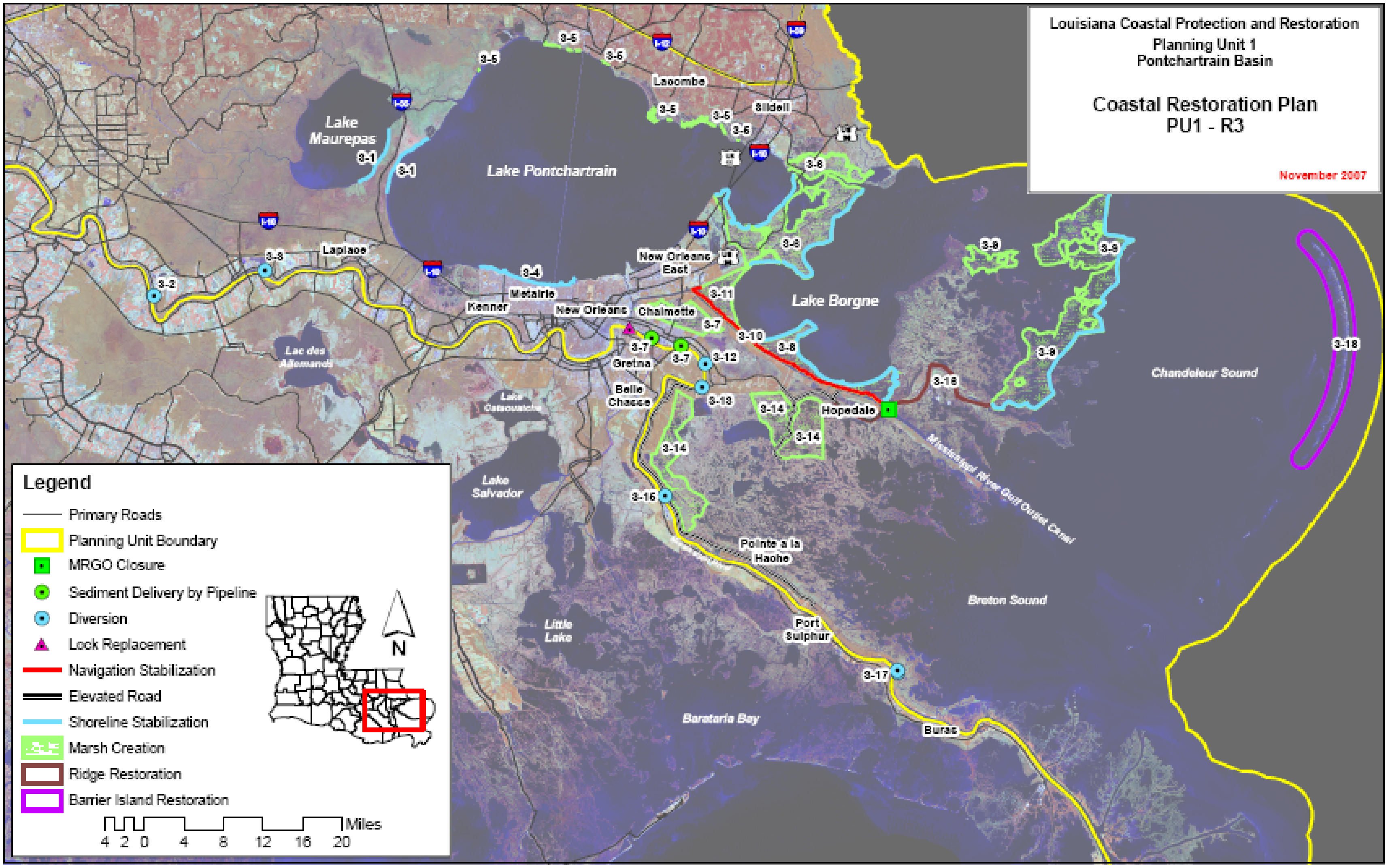


Figure 5b. Identified are the measures that comprise Alternative R3, State Master Plan – Planning Unit 2.

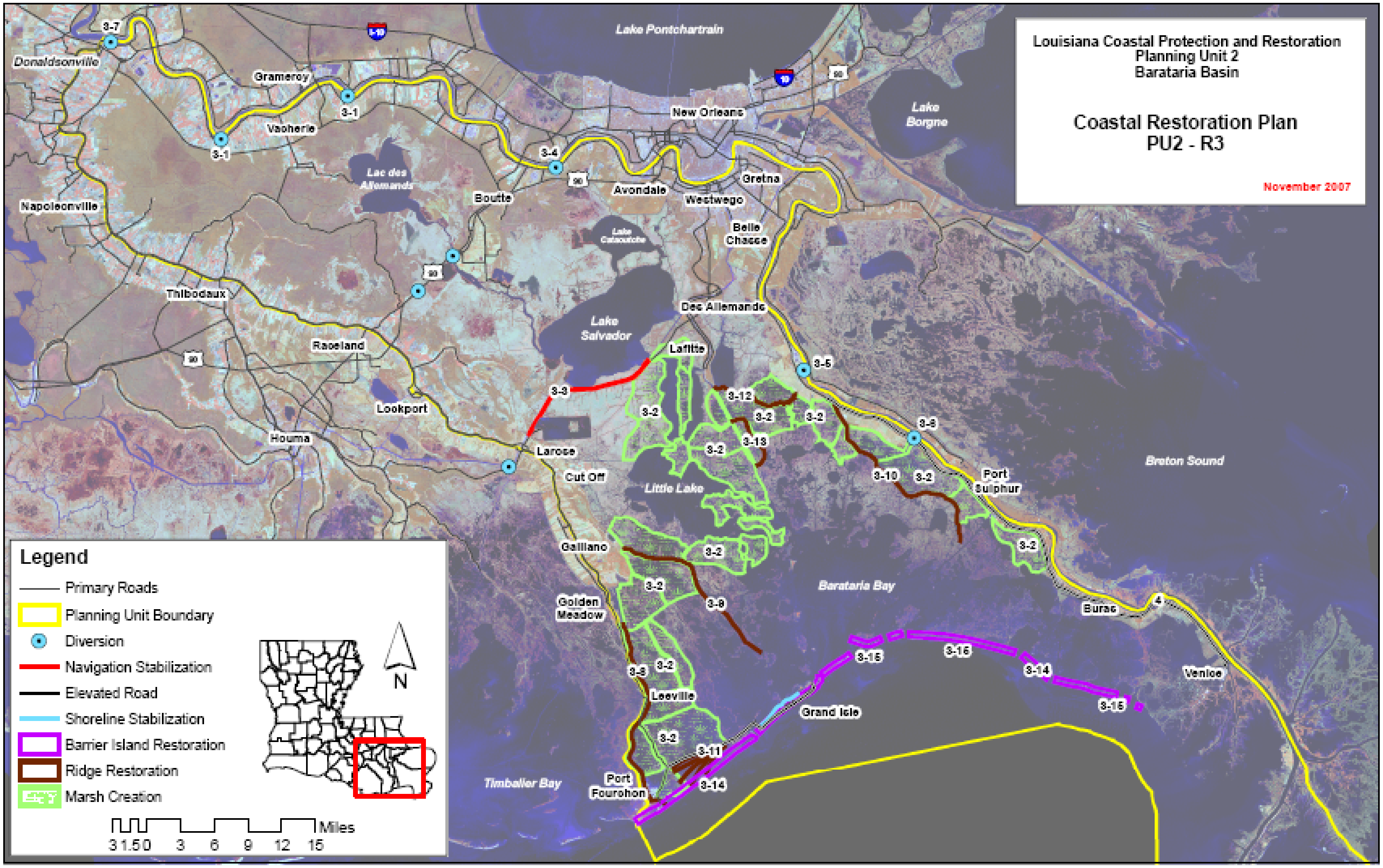


Figure 5c. Identified are the measures that comprise Alternative R3, State Master Plan – Planning Unit 3a.

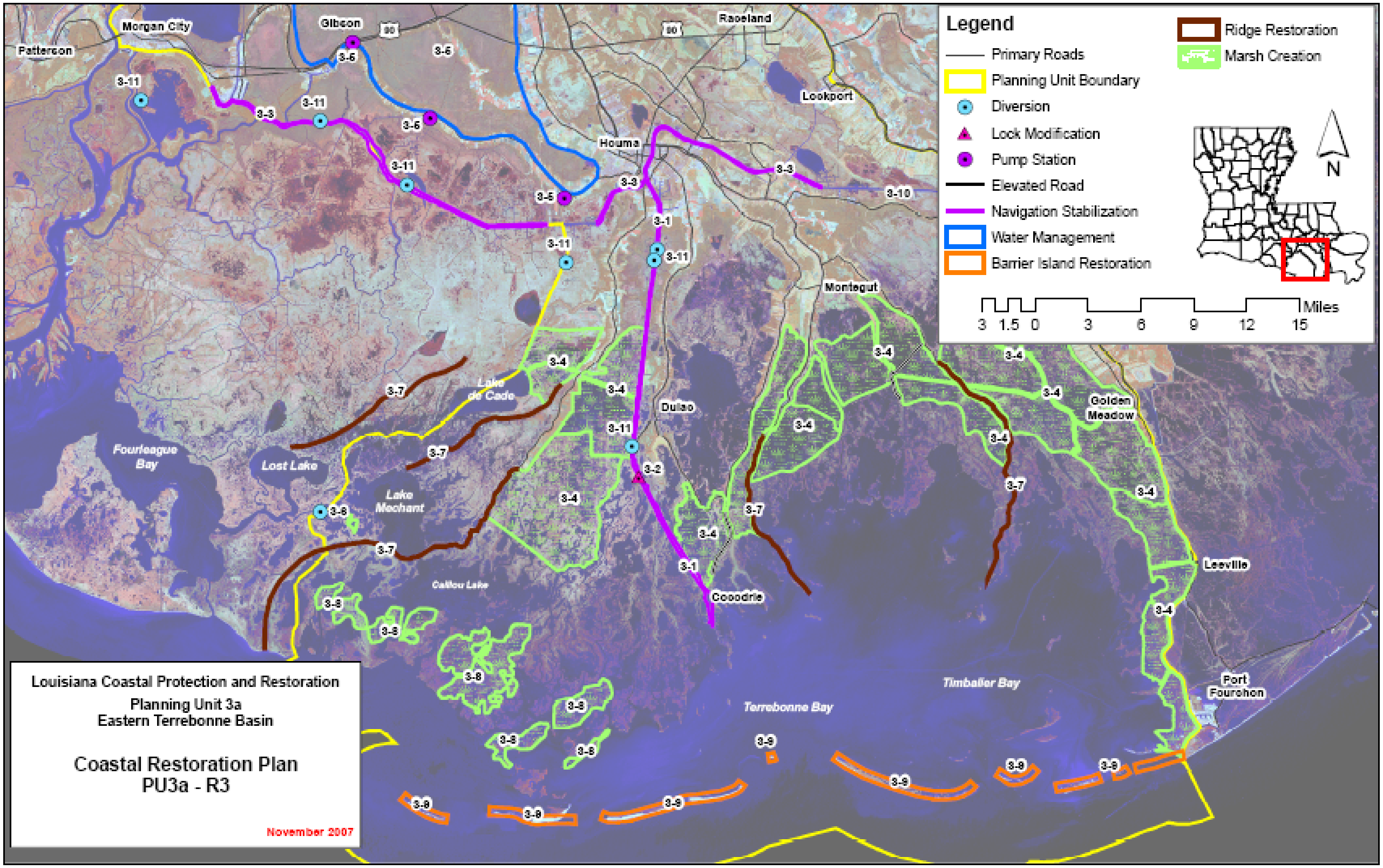


Figure 5d. Identified are the measures that comprise Alternative R3, State Master Plan – Planning Unit 3b.

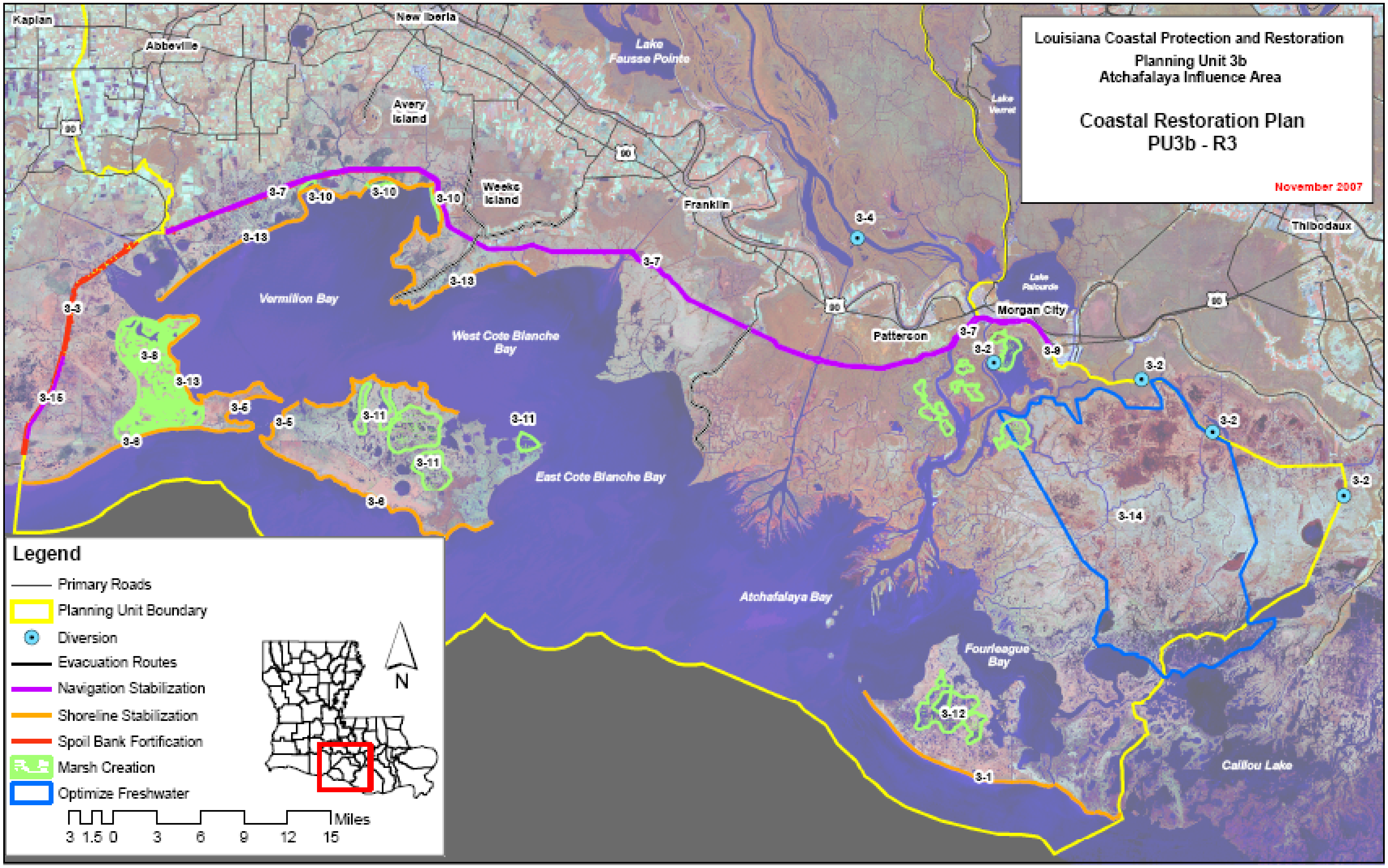


Figure 5e. Identified are the measures that comprise Alternative R3, State Master Plan – Planning Unit 4.

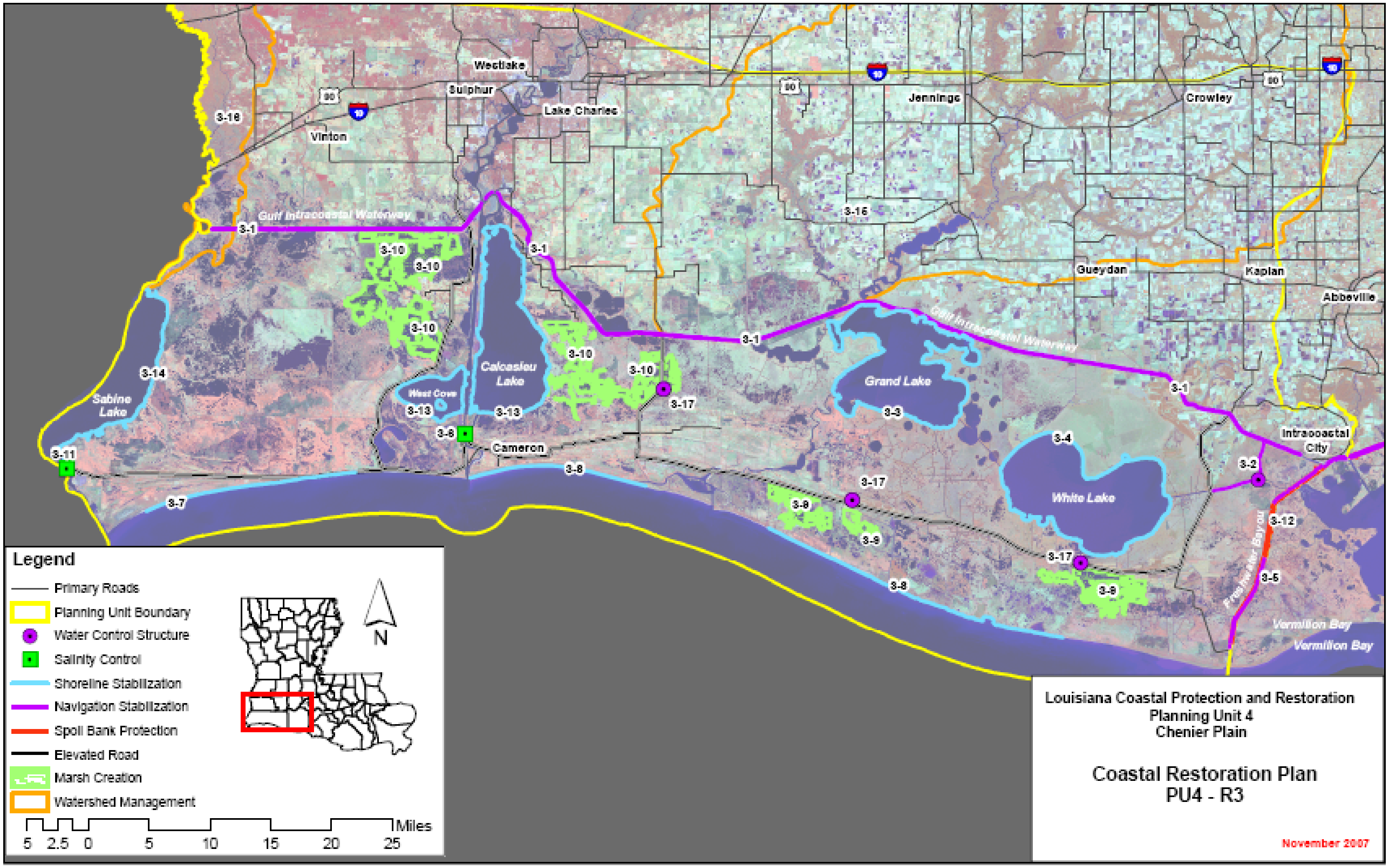


Figure 6a. Identified are the measures that comprise Alternative R4 – Planning Unit 1.

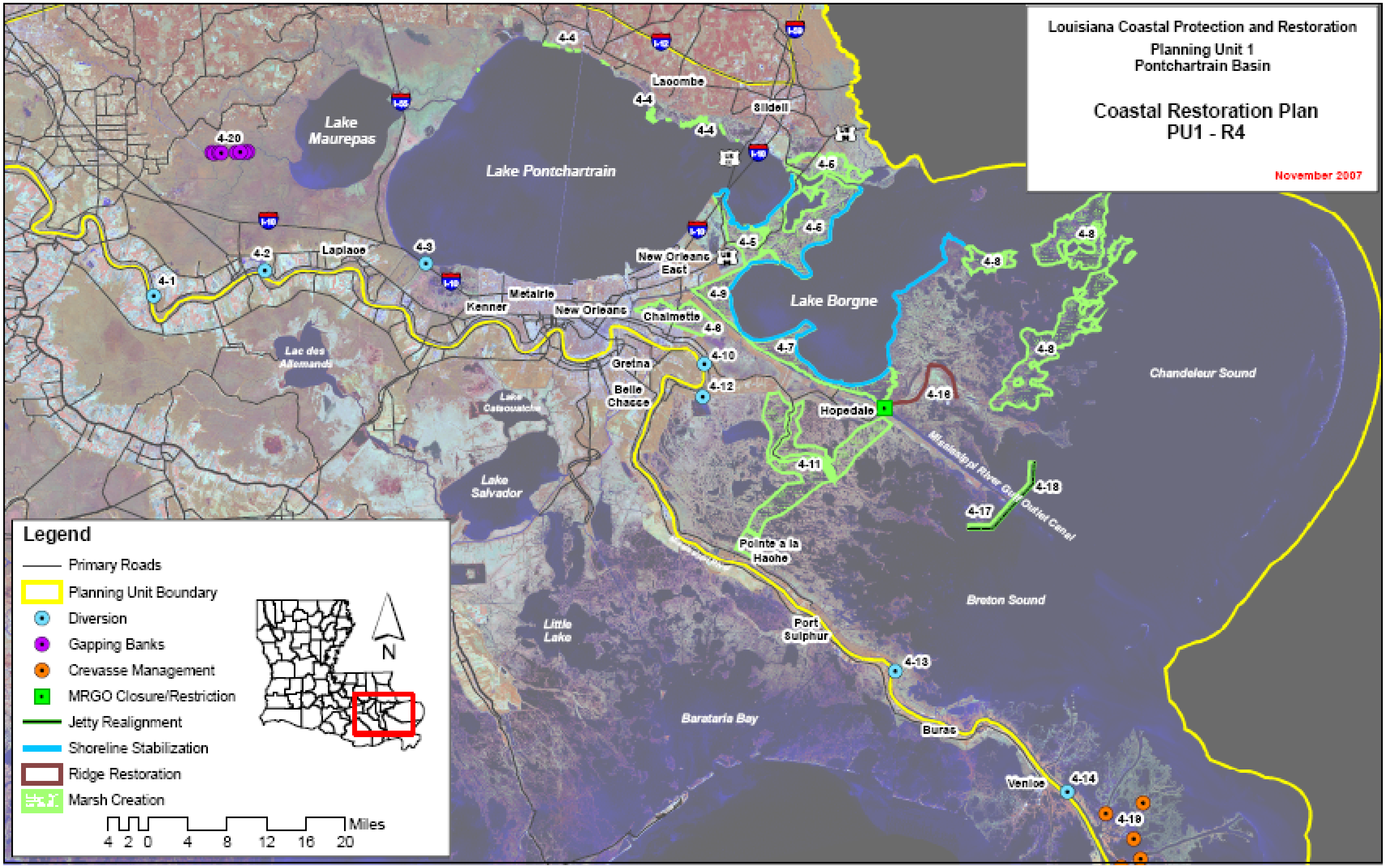


Figure 6b. Identified are the measures that comprise Alternative R4 – Planning Unit 2.

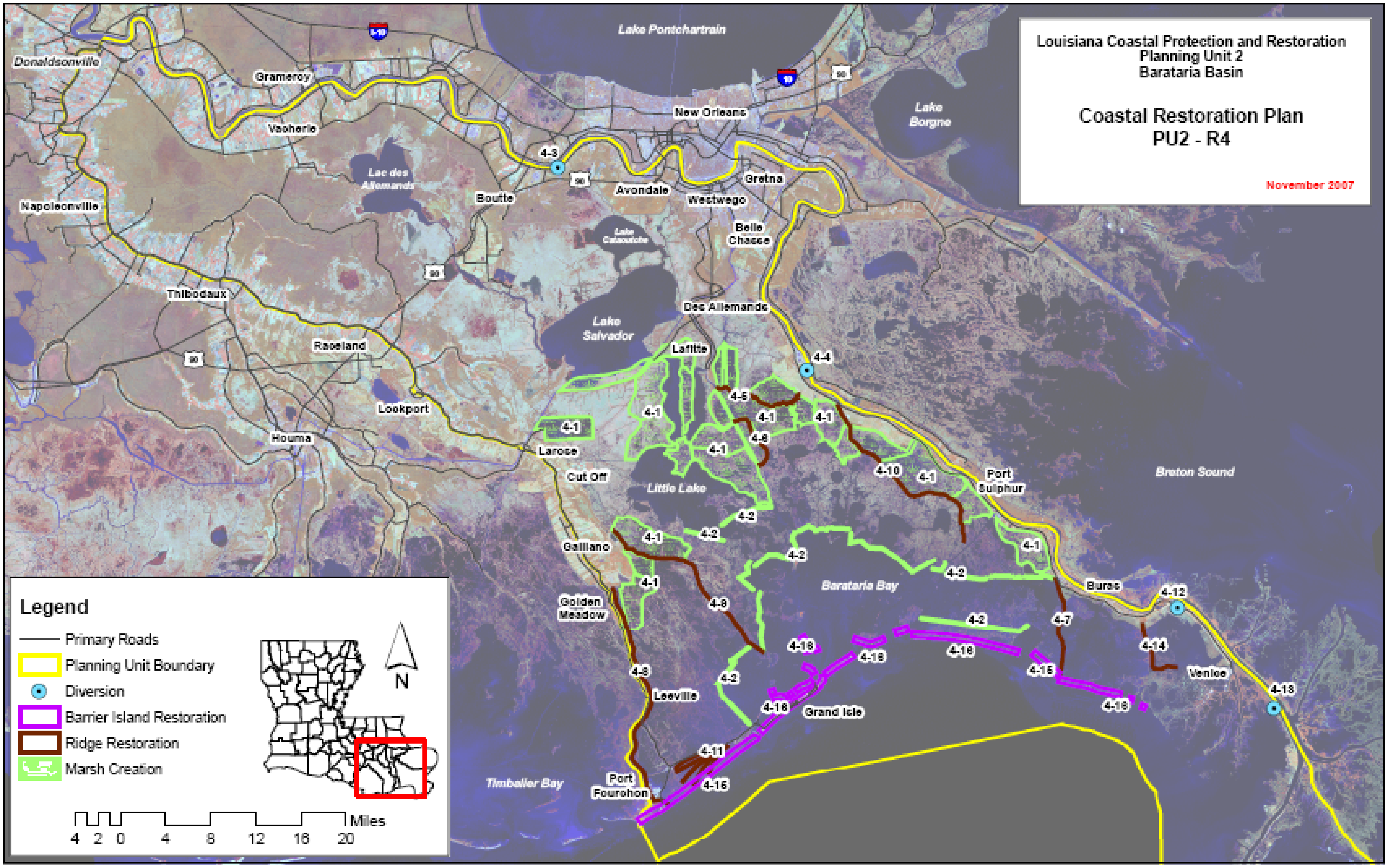


Figure 6c. Identified are the measures that comprise Alternative R4 – Planning Unit 3a.

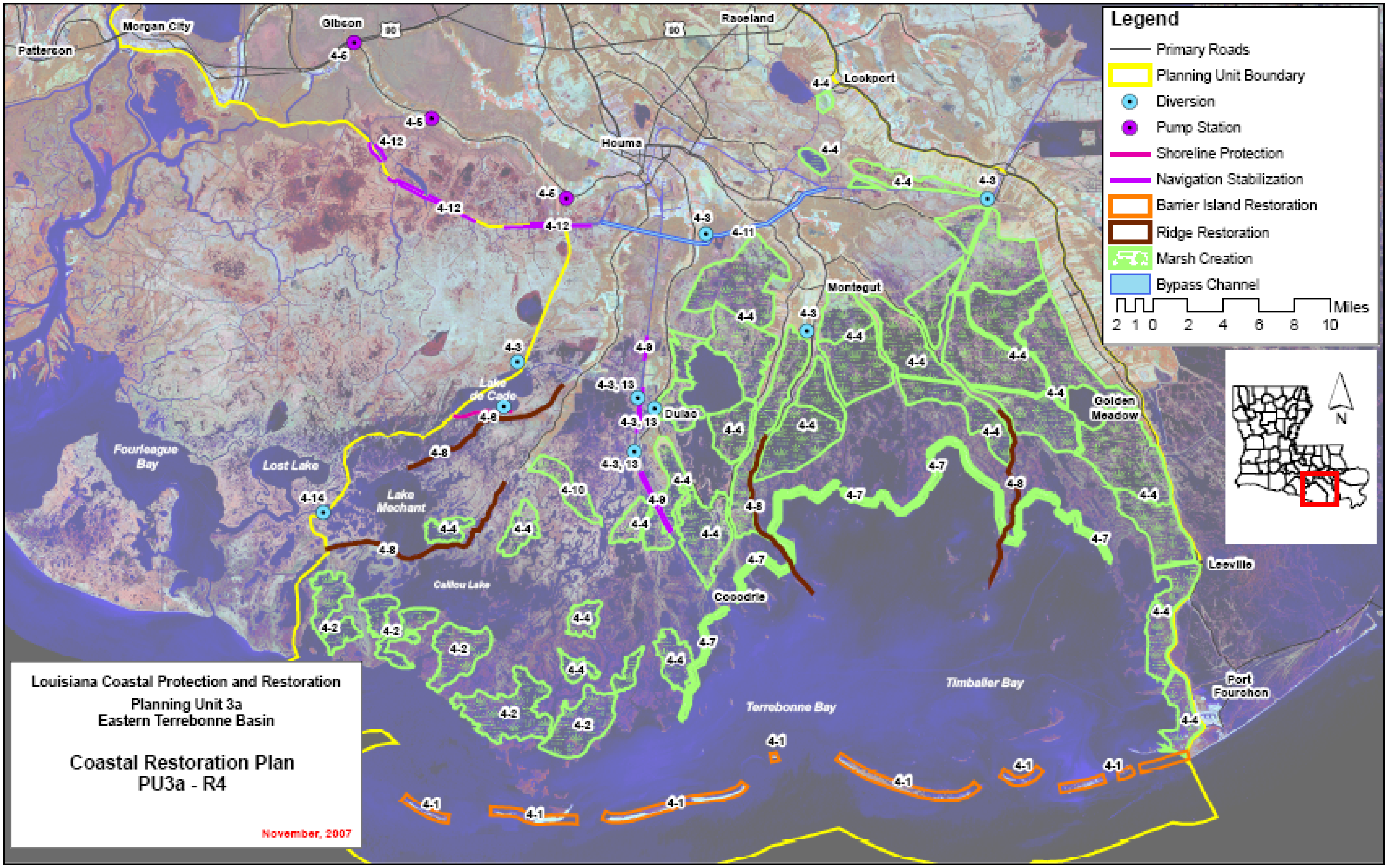


Figure 6d. Identified are the measures that comprise Alternative R4 – Planning Unit 3b.

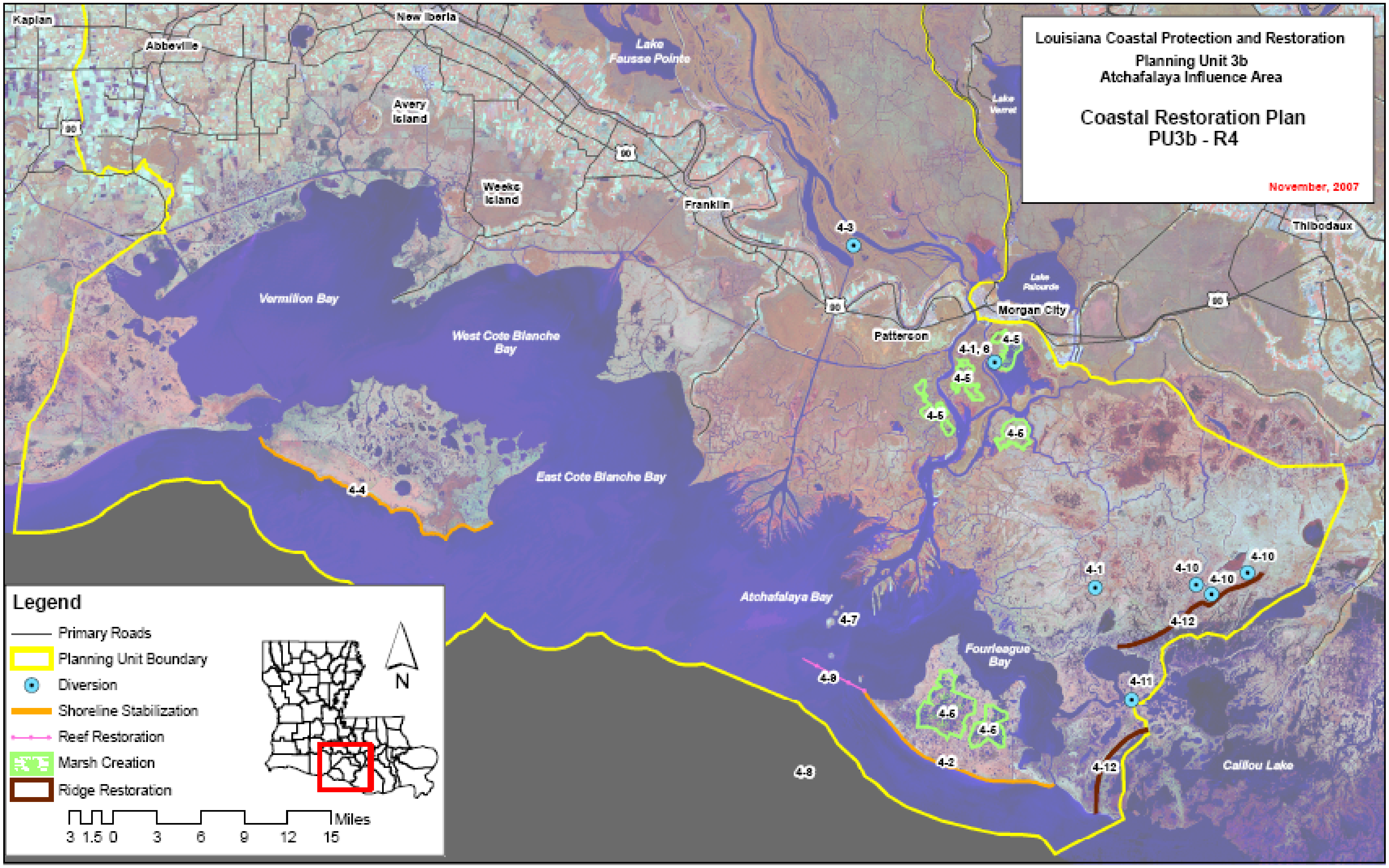


Figure 6e. Identified are the measures that comprise Alternative R4 – Planning Unit 4.

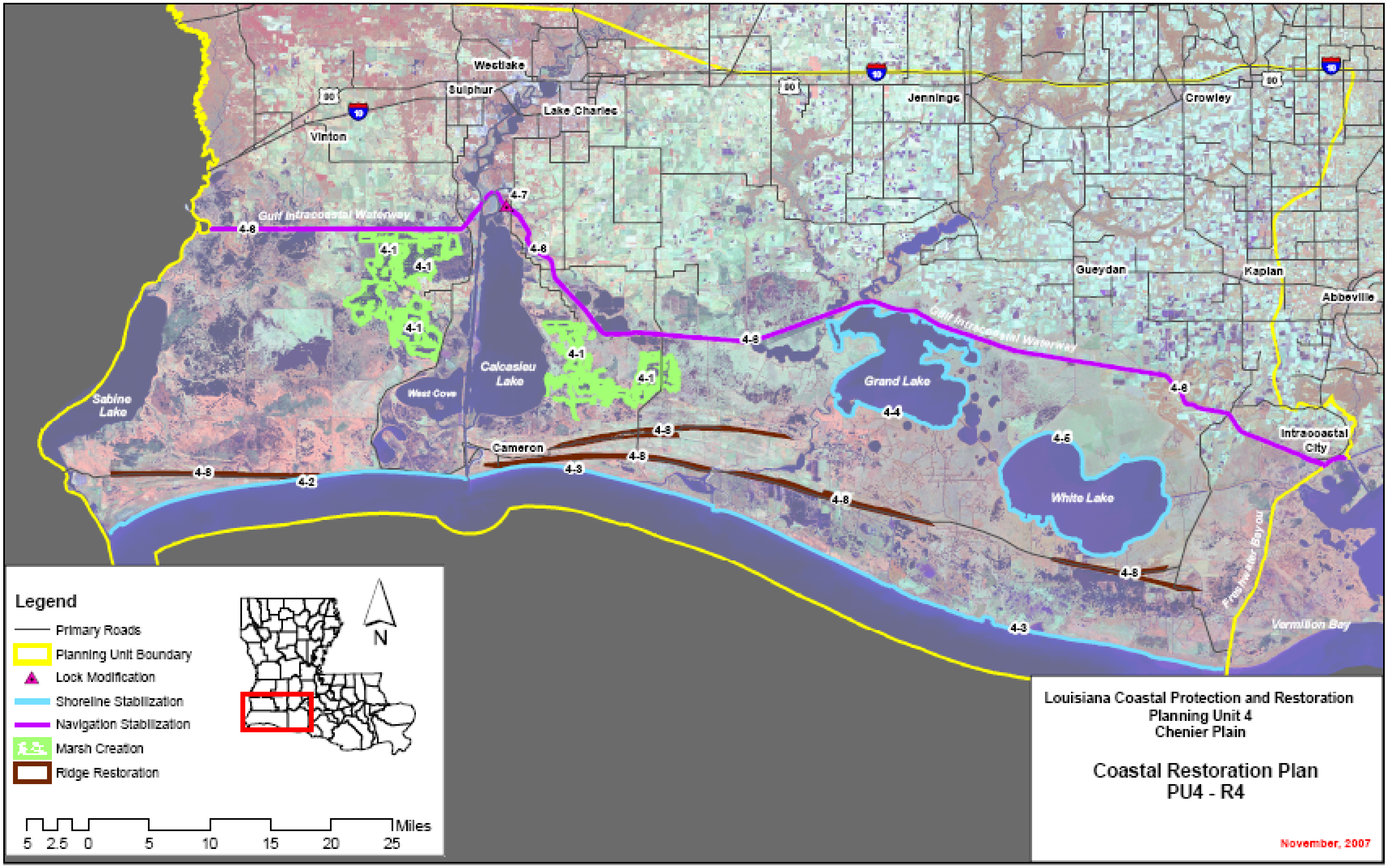


Figure 7a. Identified are the measures that comprise Alternative R5, LCA Plan Best Meeting Objectives – Planning Unit 1.

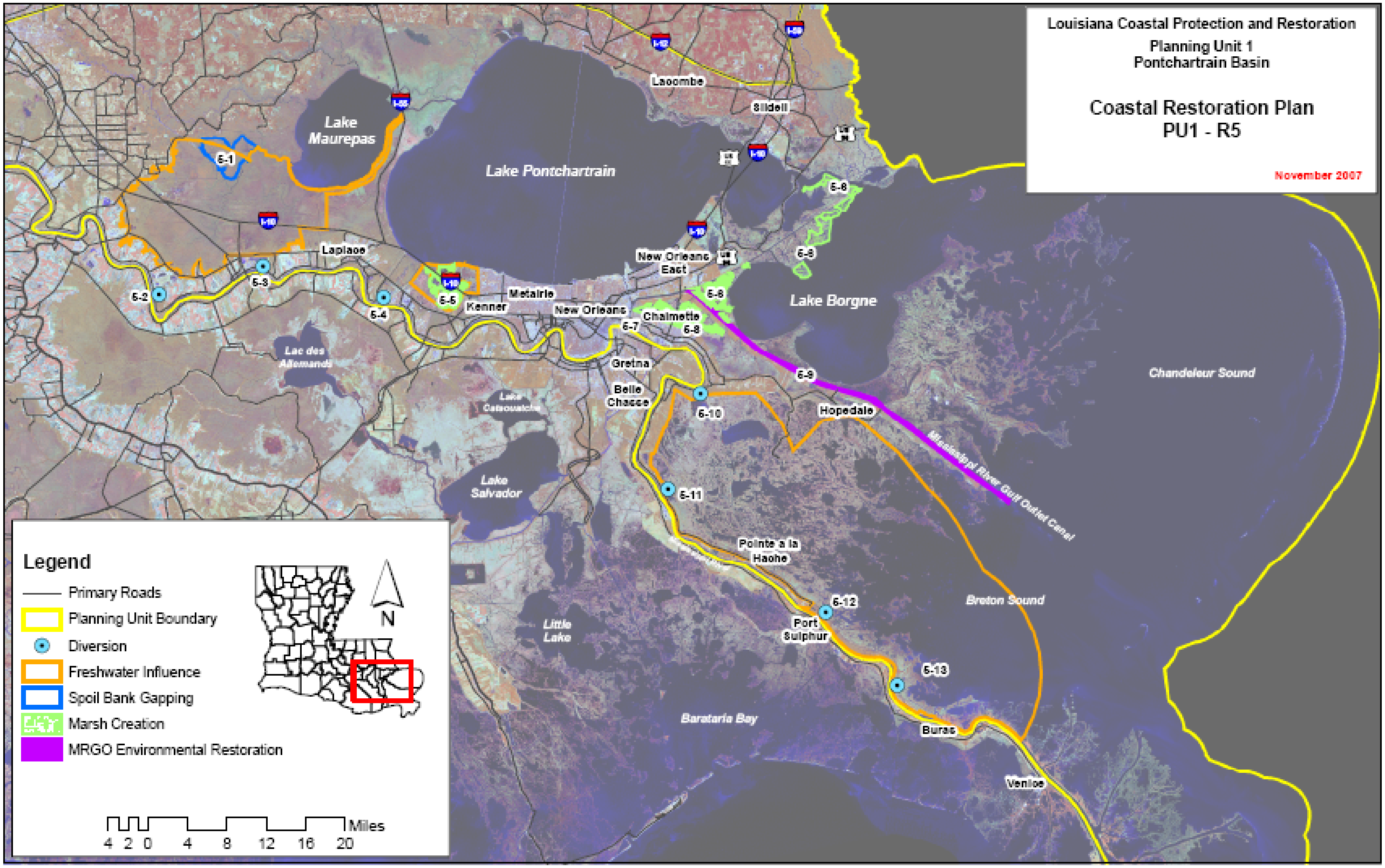


Figure 7b. Identified are the measures that comprise Alternative R5, LCA Plan Best Meeting Objectives – Planning Unit 2.

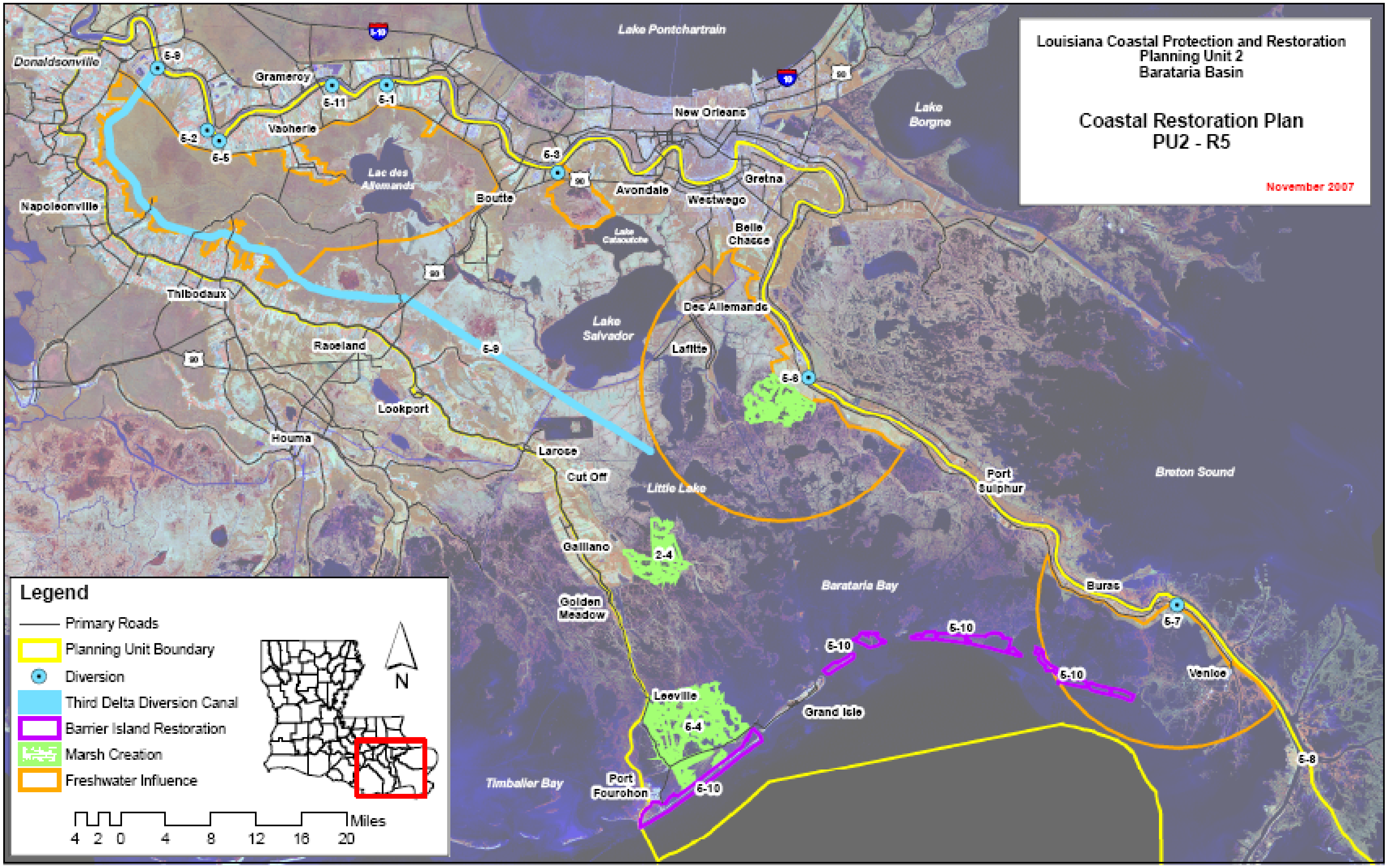


Figure 7c. Identified are the measures that comprise Alternative R5, LCA Plan Best Meeting Objectives – Planning Unit 3a.

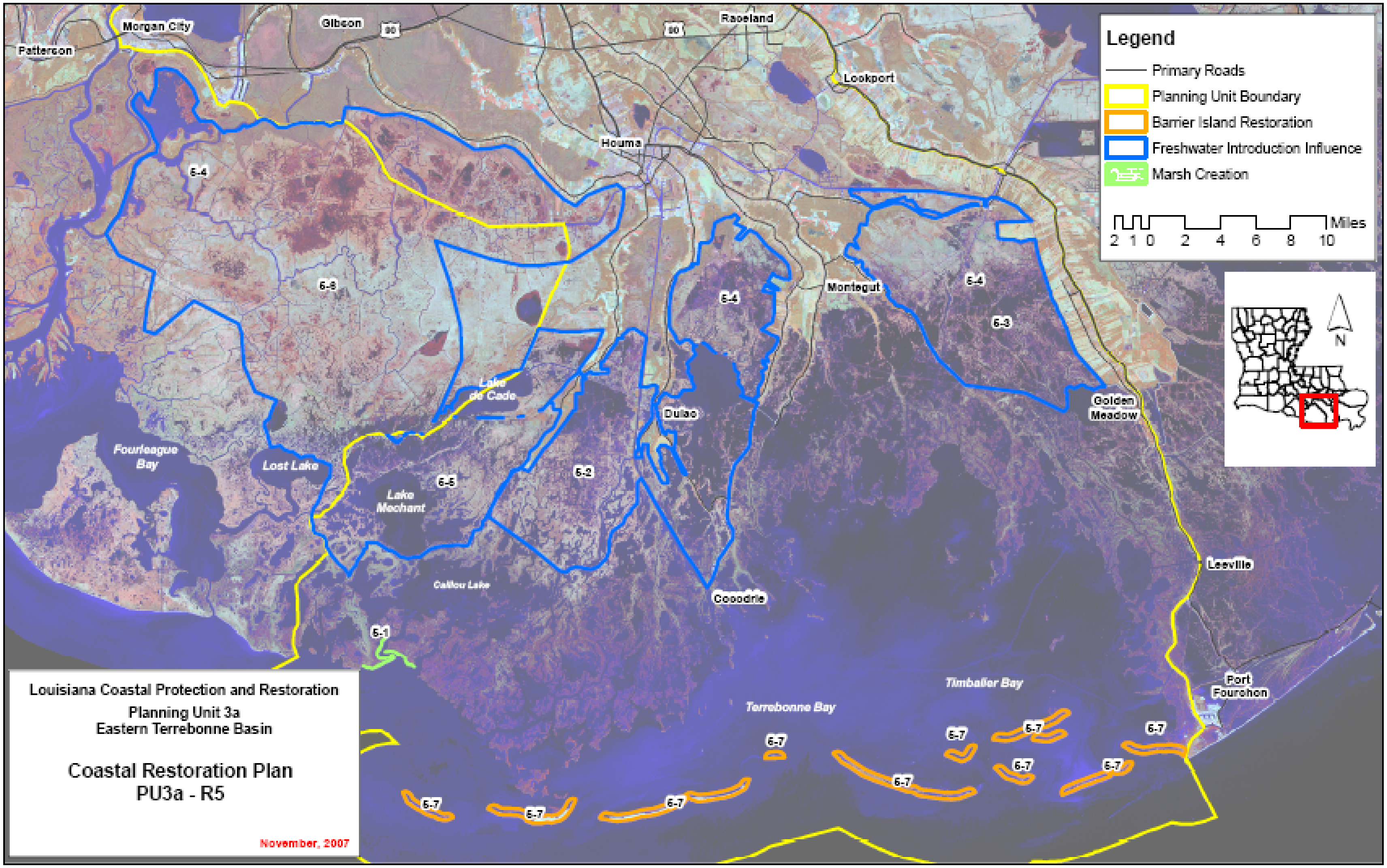


Figure 7d. Identified are the measures that comprise Alternative R5, LCA Plan Best Meeting Objectives – Planning Unit 3b.

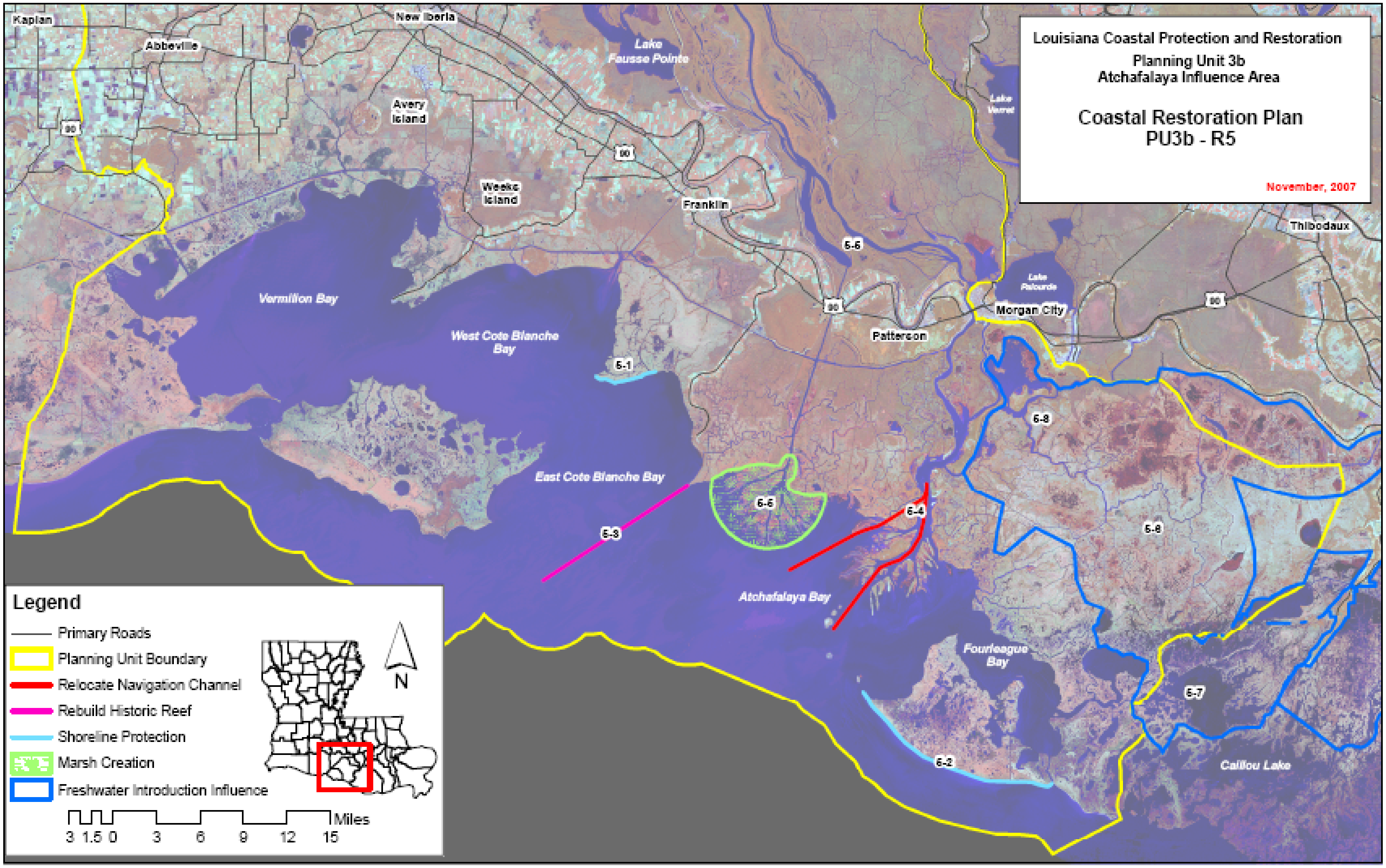


Figure 7e. Identified are the measures that comprise Alternative R5, LCA Plan Best Meeting Objectives – Planning Unit 4.

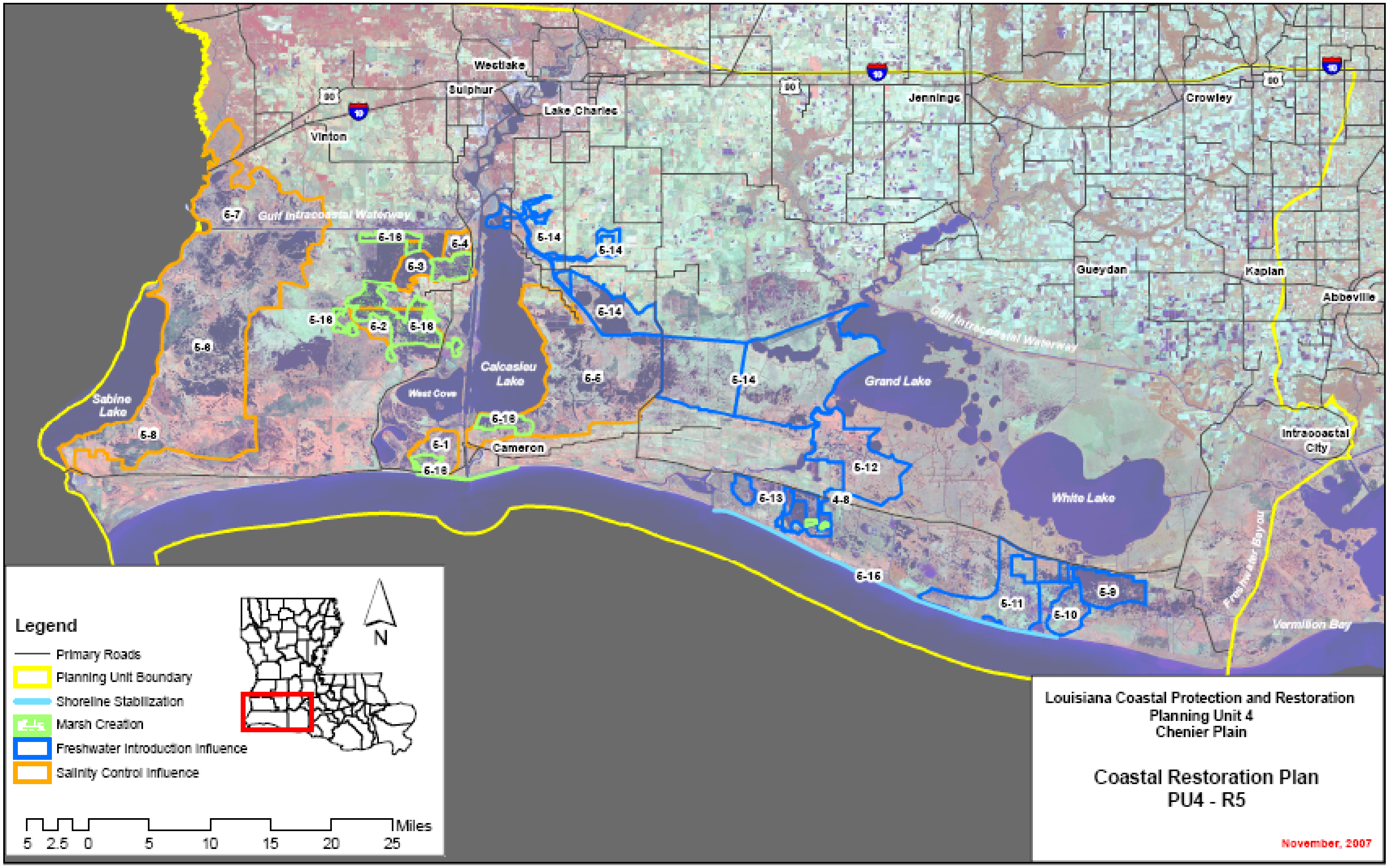
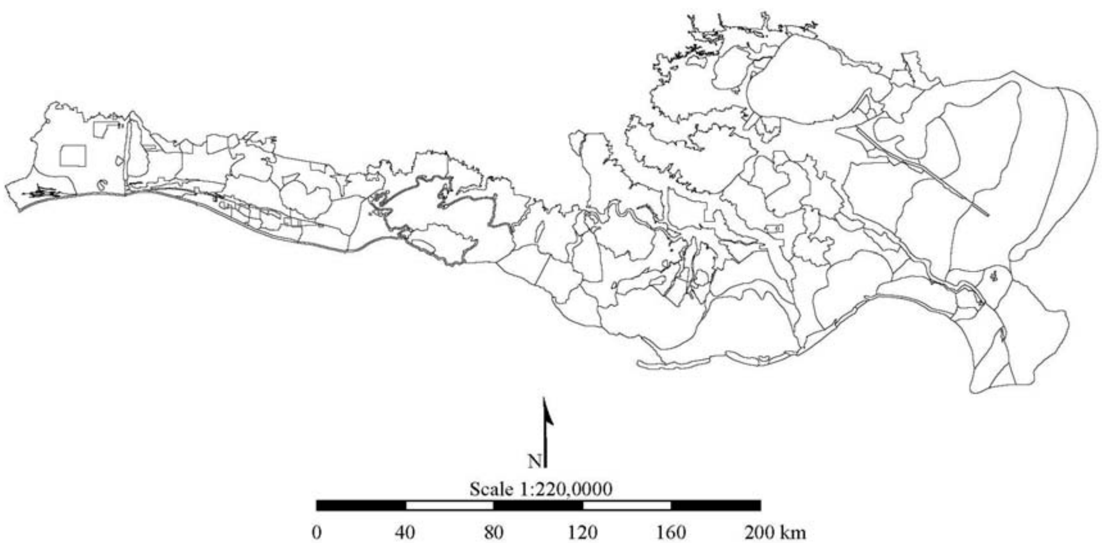


Figure 8. The LCA polygon trend data rasterized at a 25x25 meter cell size.



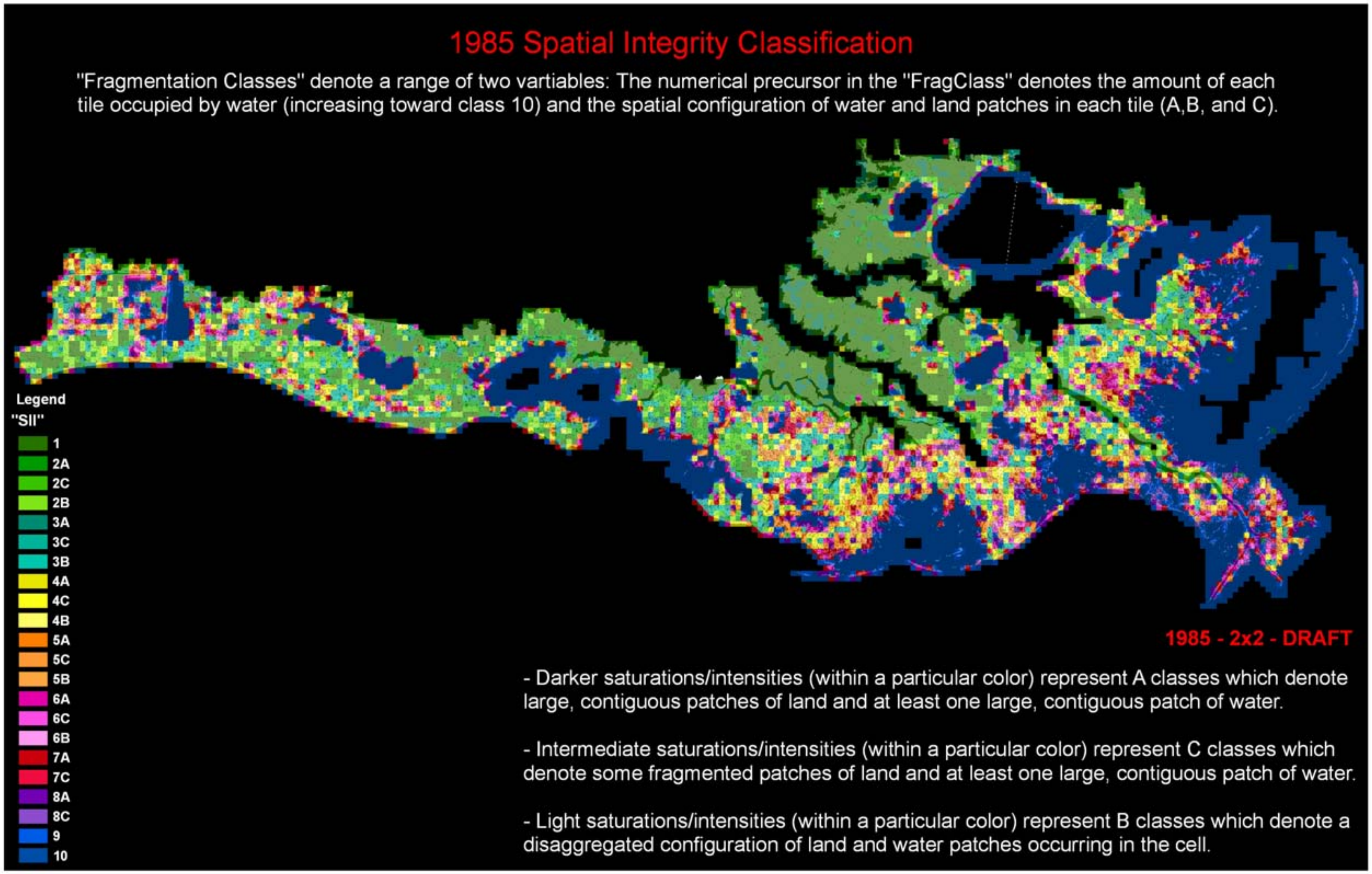


Figure 9. Coastwide spatial integrity index for 1985.

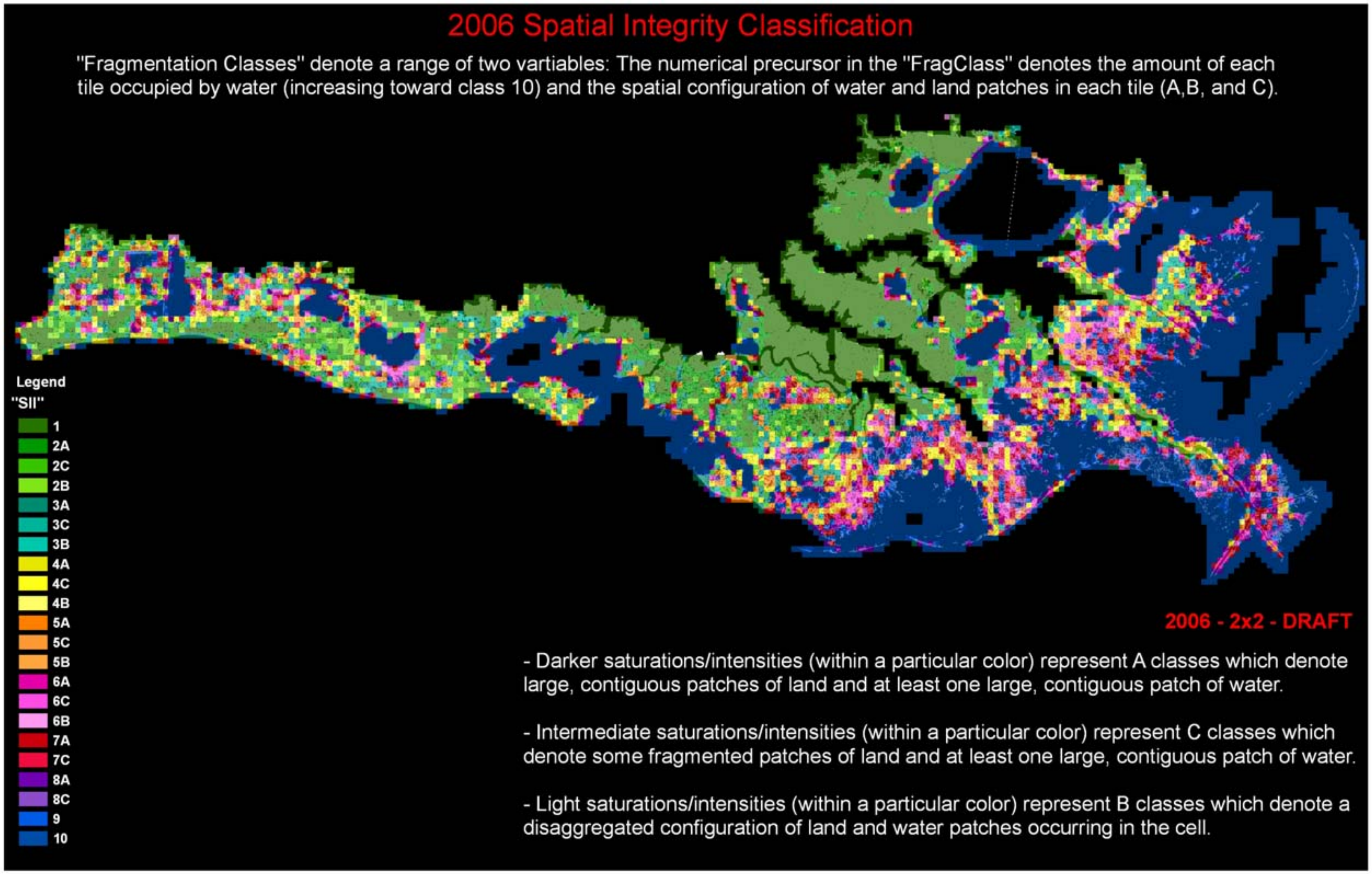


Figure 10. Coastwide spatial integrity index for 2006.

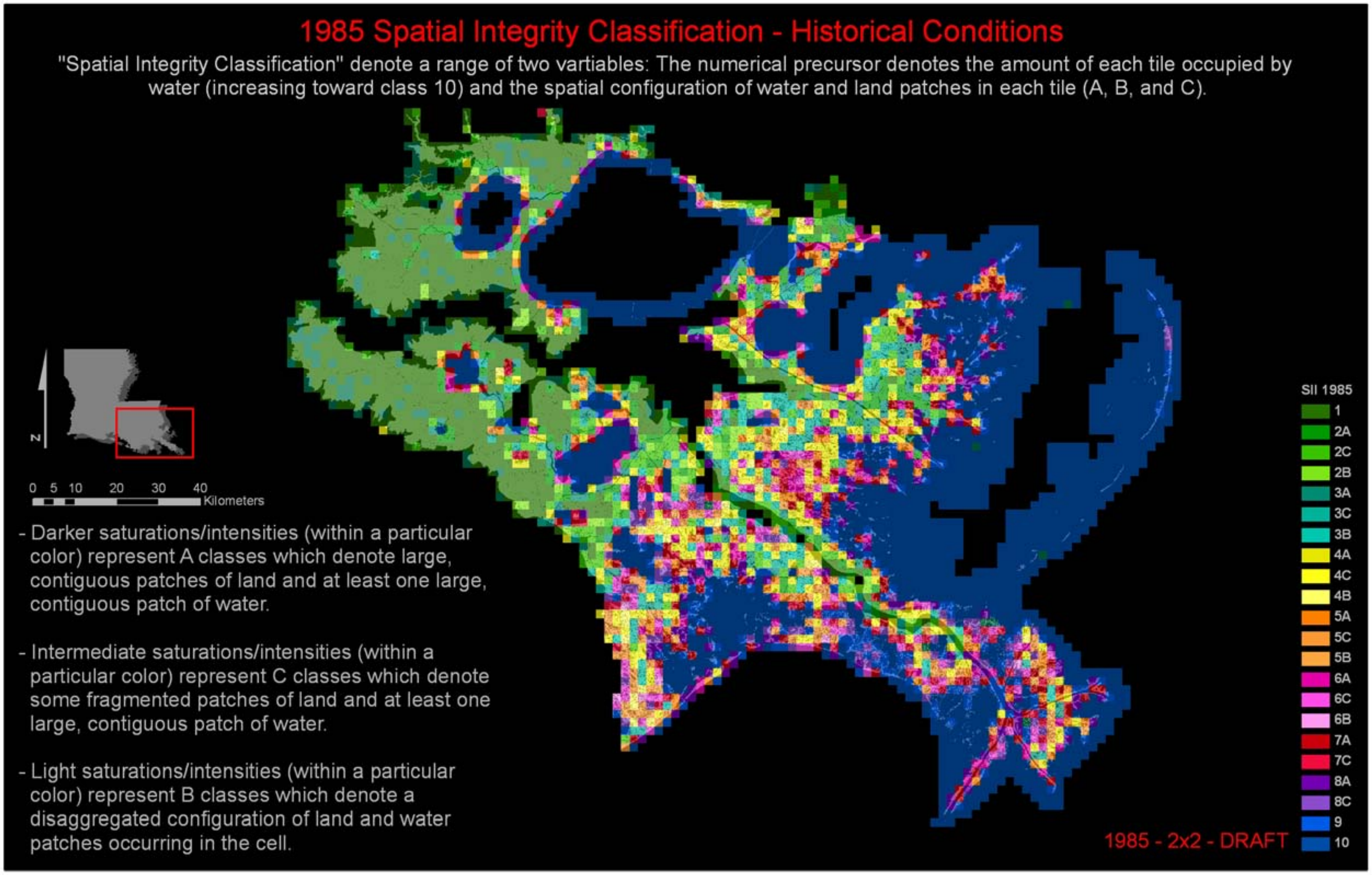


Figure 11. Spatial integrity index for 1985 for planning units 1 and 2.

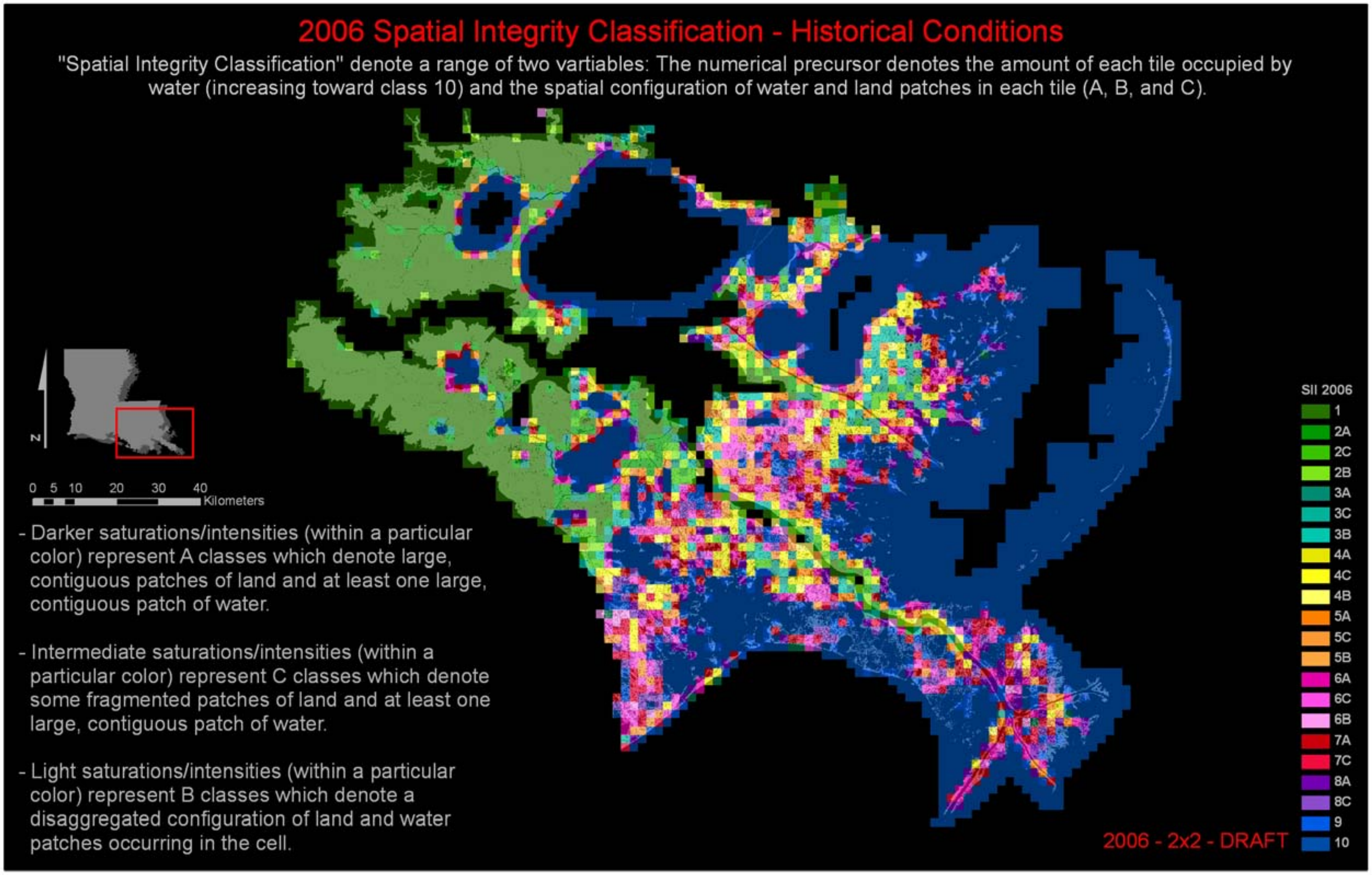


Figure 12. Spatial integrity index for 2006 for planning units 1 and 2.

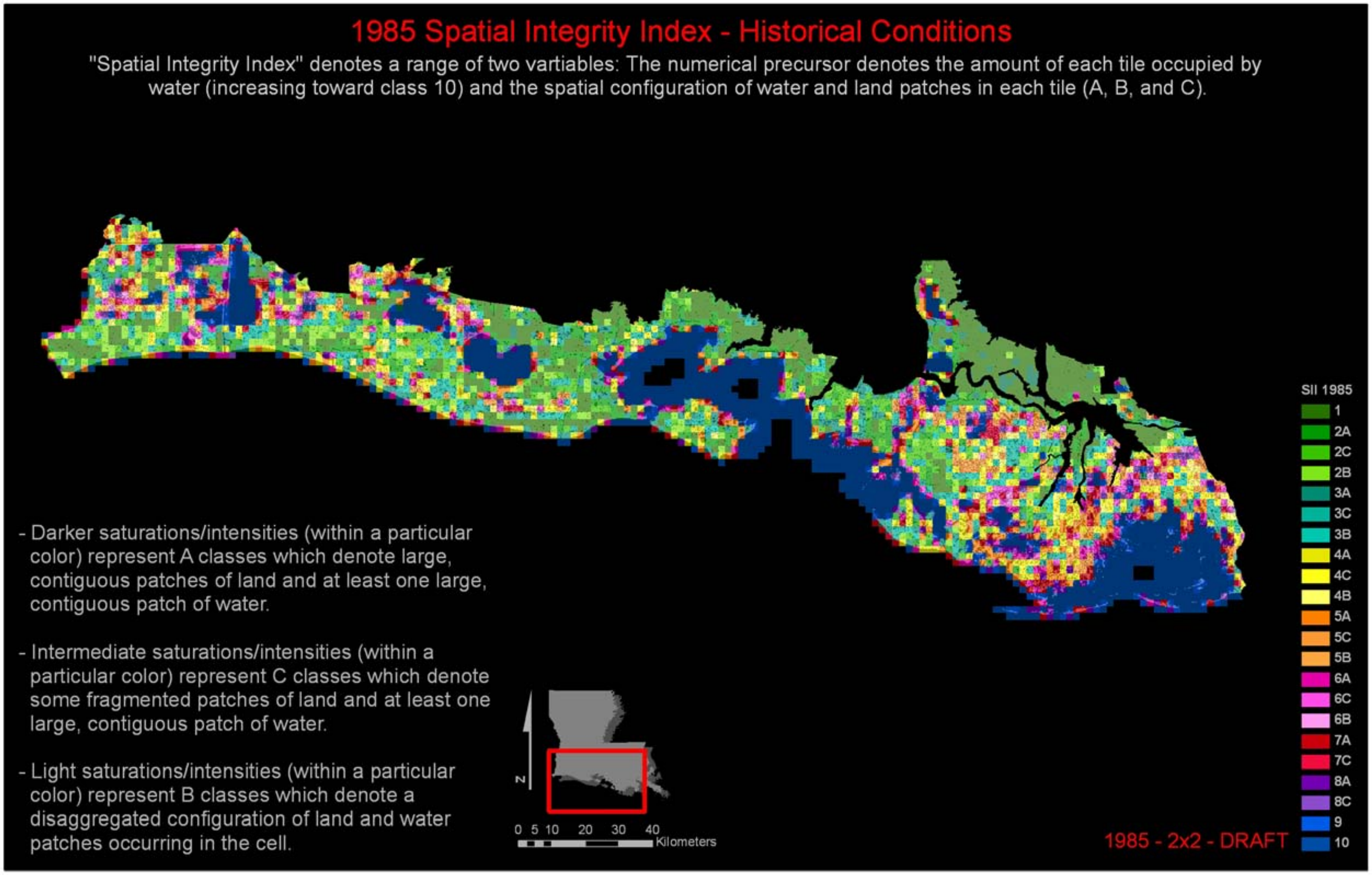


Figure 13. Spatial integrity index for 1985 for planning units 3a, 3b and 4.

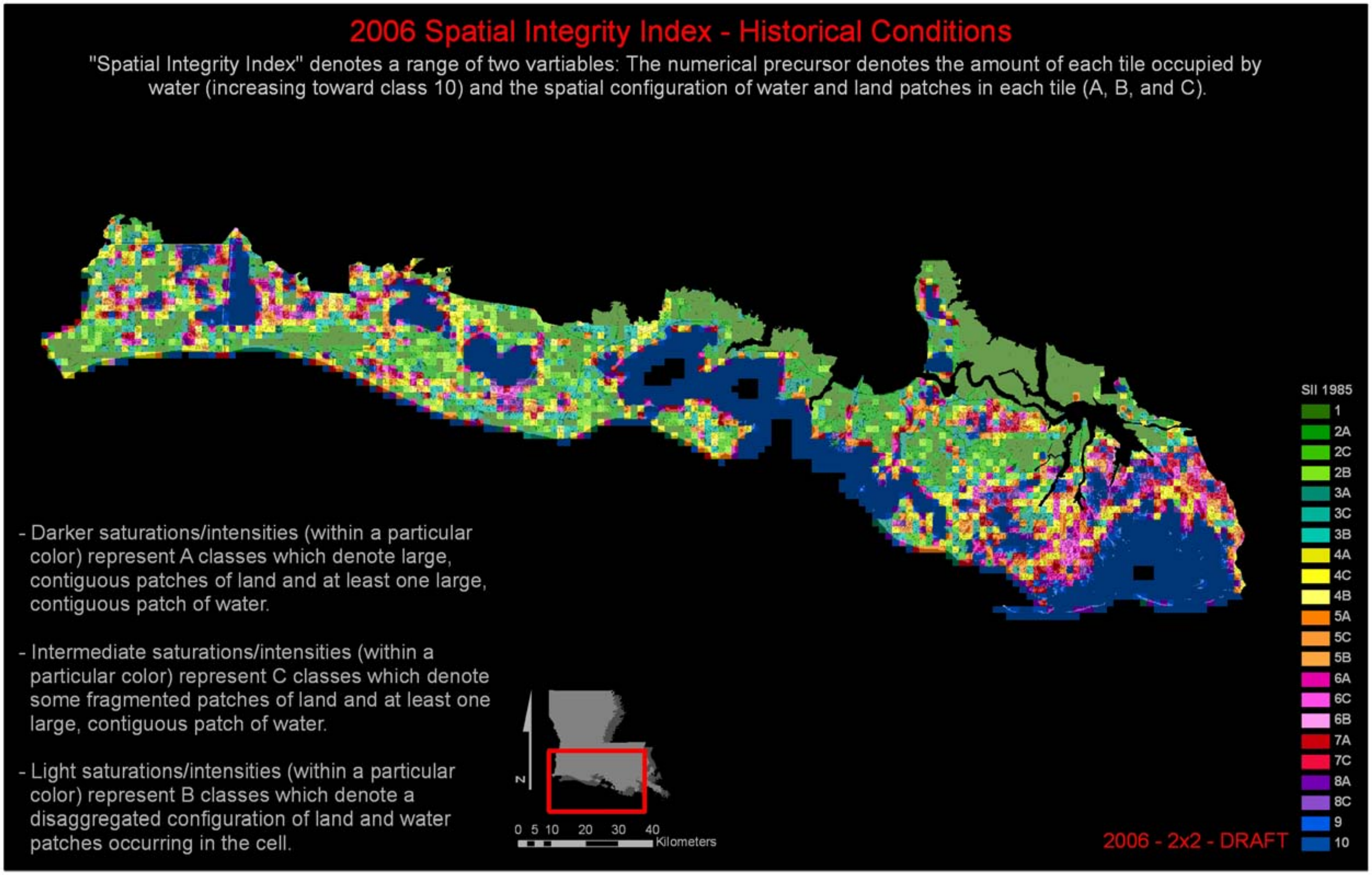


Figure 14. Spatial integrity index for 2006 for planning units 3a, 3b and 4.

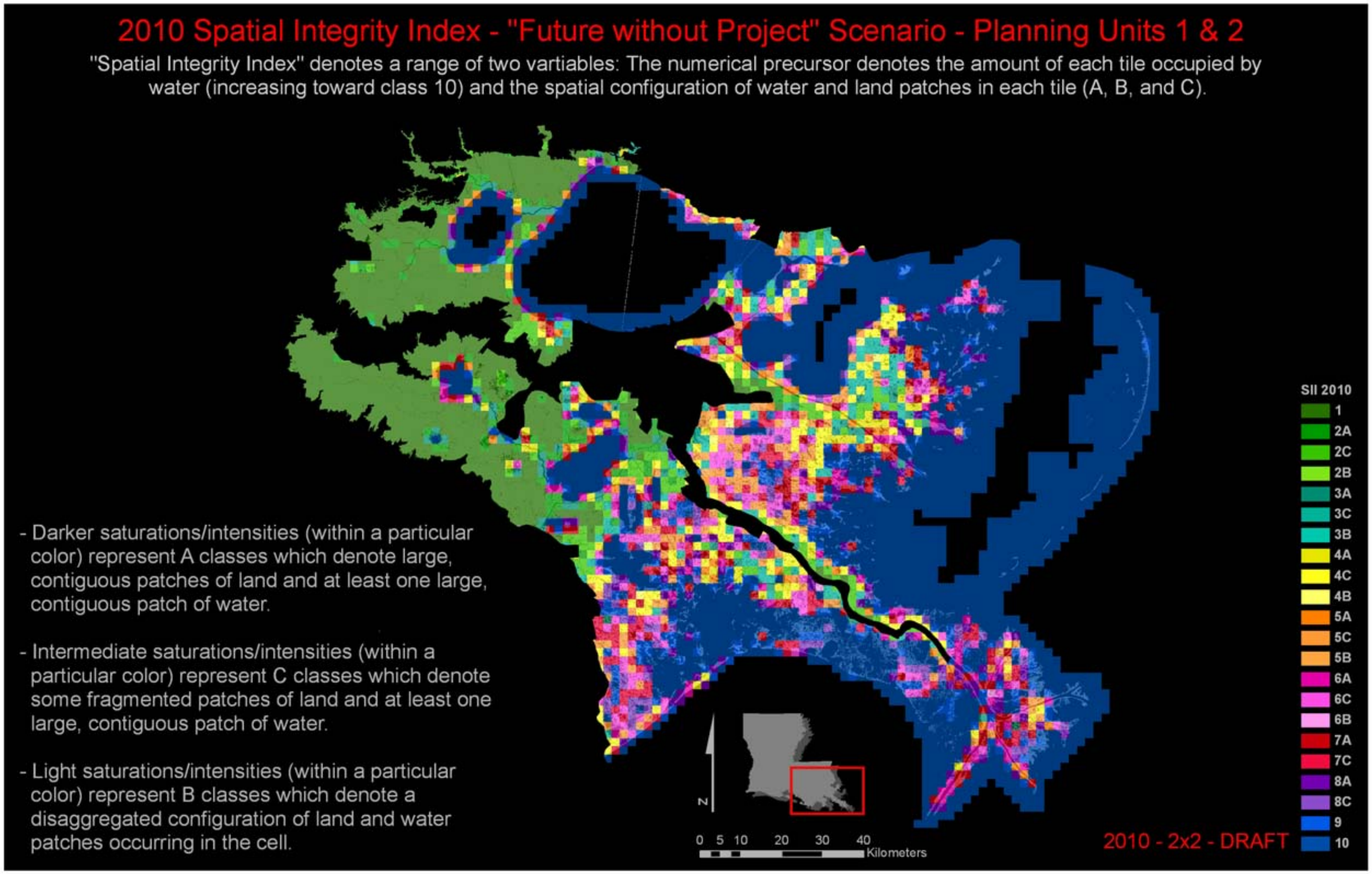


Figure 15. Spatial integrity index for 2010 for planning units 1 and 2.

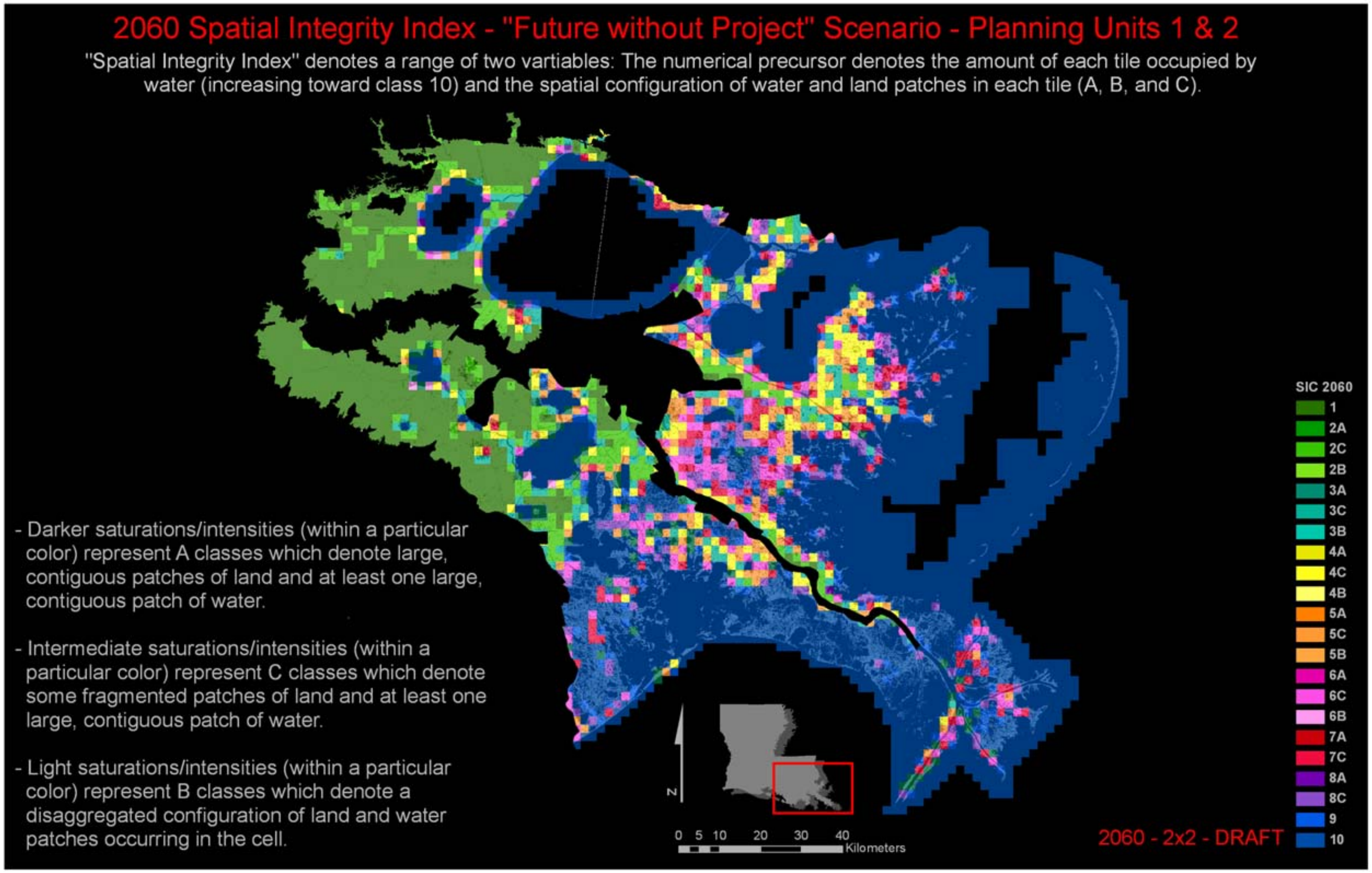


Figure 16. Spatial integrity index for future without project in 2060 for planning units 1 and 2.

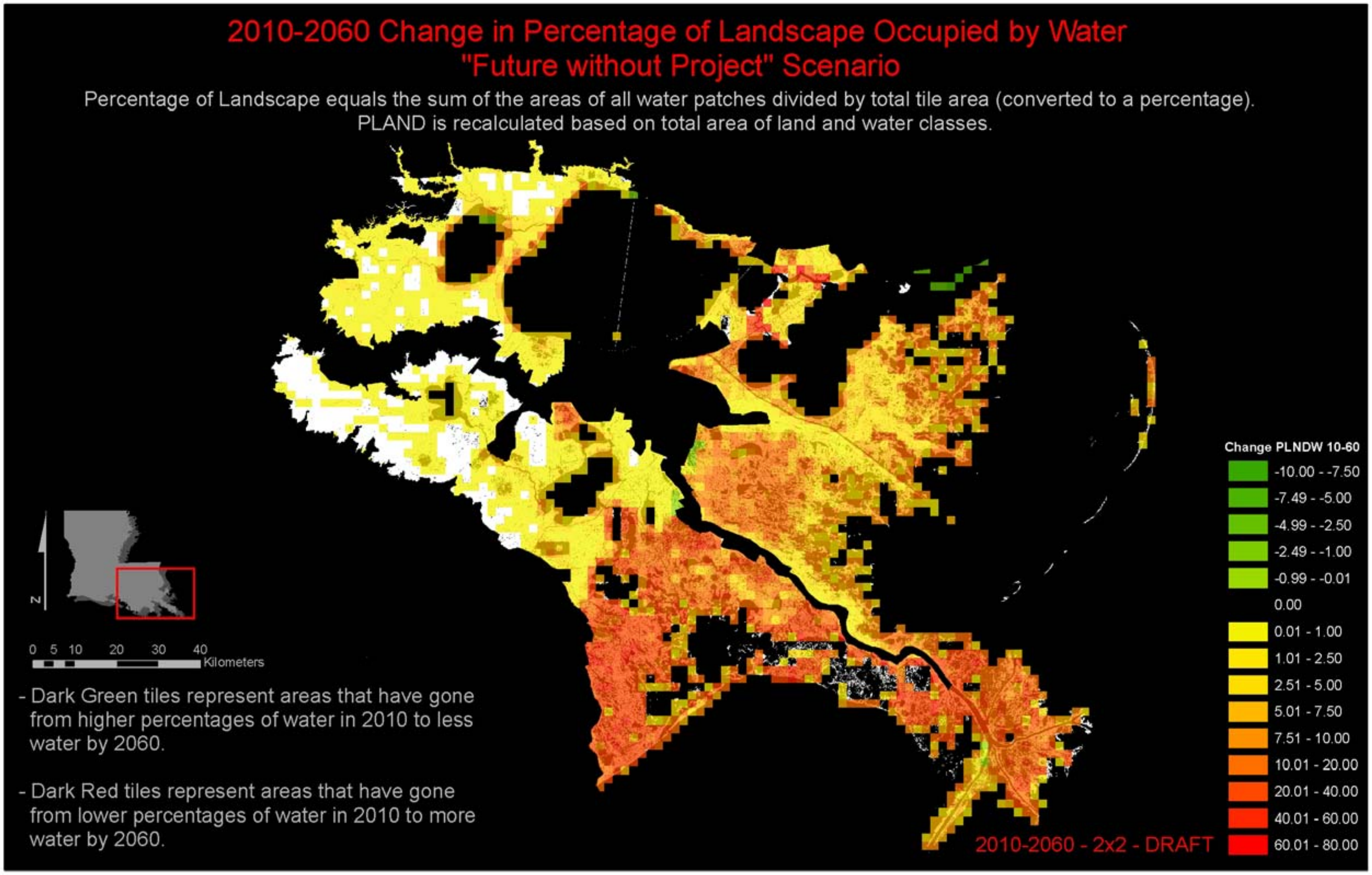


Figure 17. Percentage of landscape occupied by water metric for planning units 1 and 2 showing future without project changes projected between 2010 and 2060.

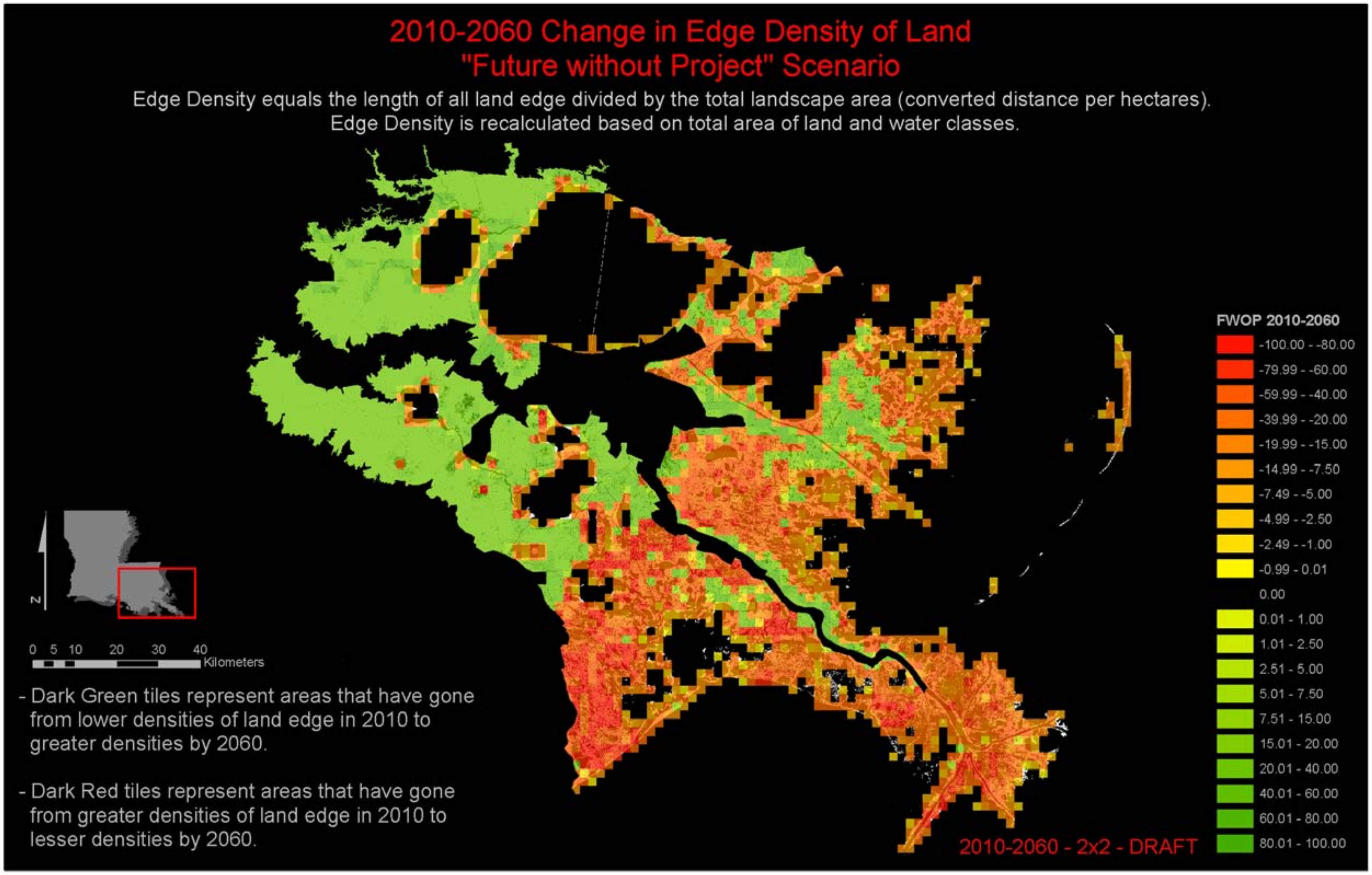


Figure 18. Edge density of land metric for planning units 1 and 2 showing future without project changes projected between 2010 and 2060.

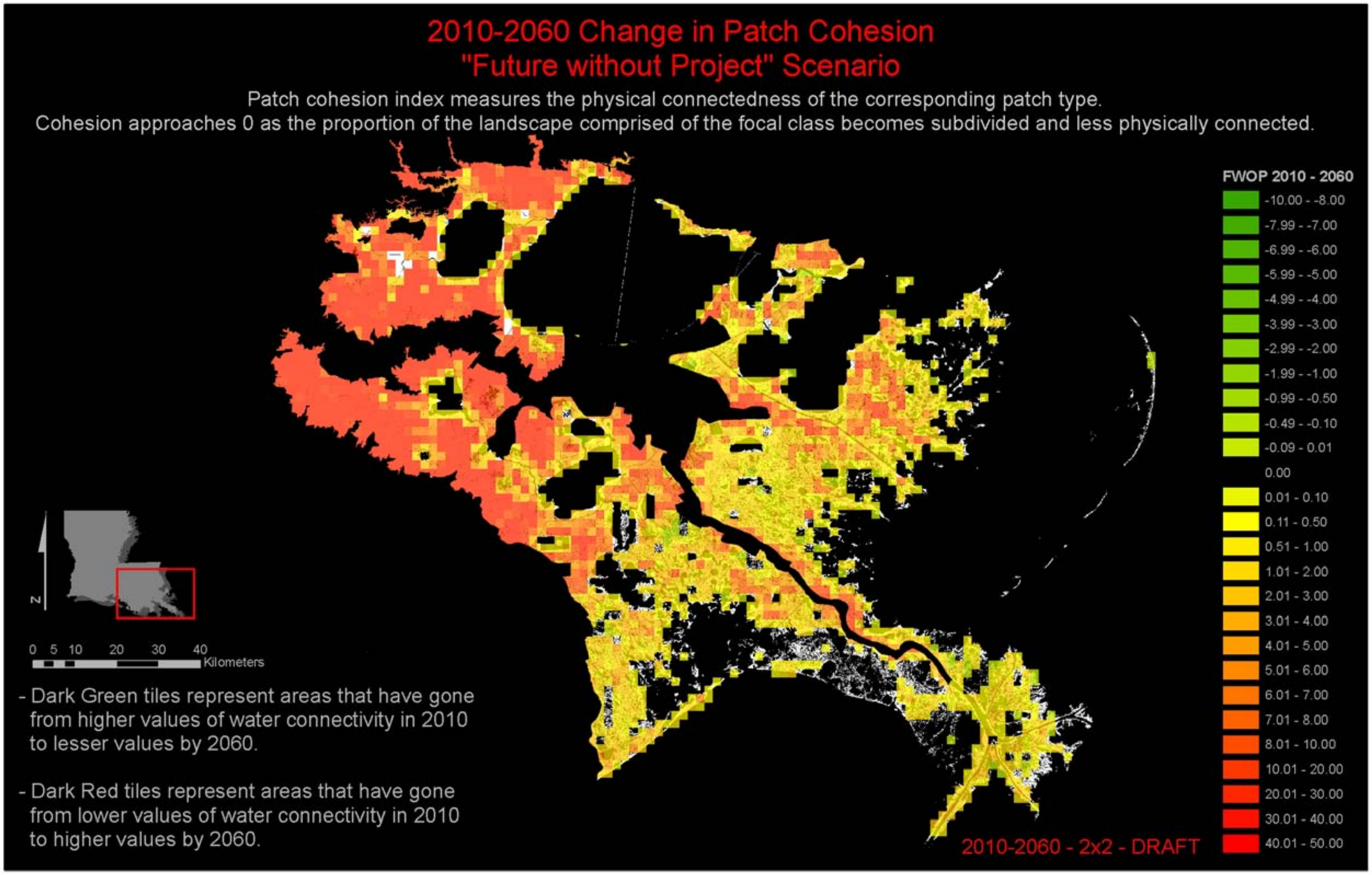


Figure 19. Patch cohesion metric for planning units 1 and 2 showing future without project changes projected between 2010 and 2060.

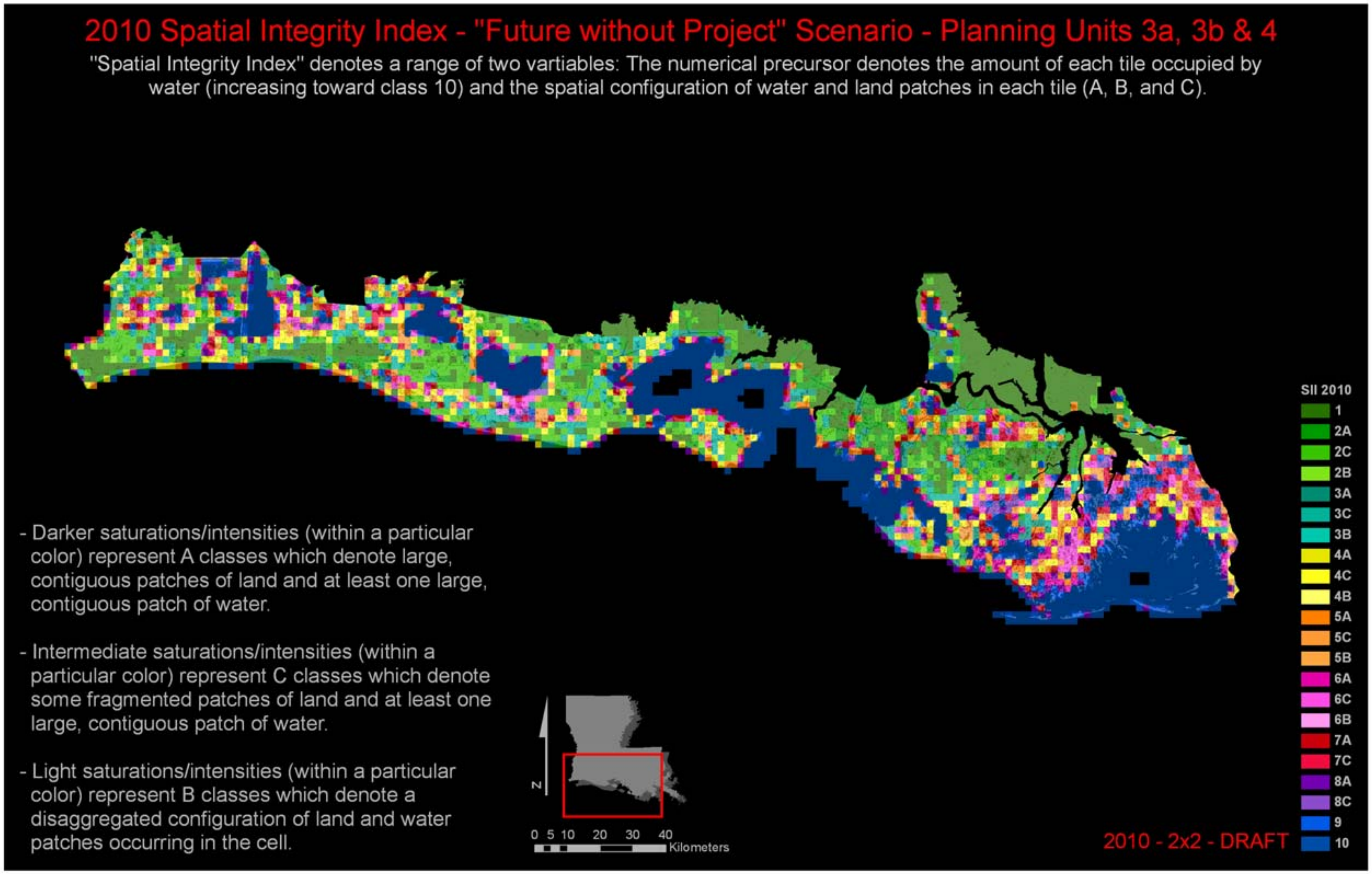


Figure 20. Spatial integrity index for 2010 for planning units 3a, 3b and 4.

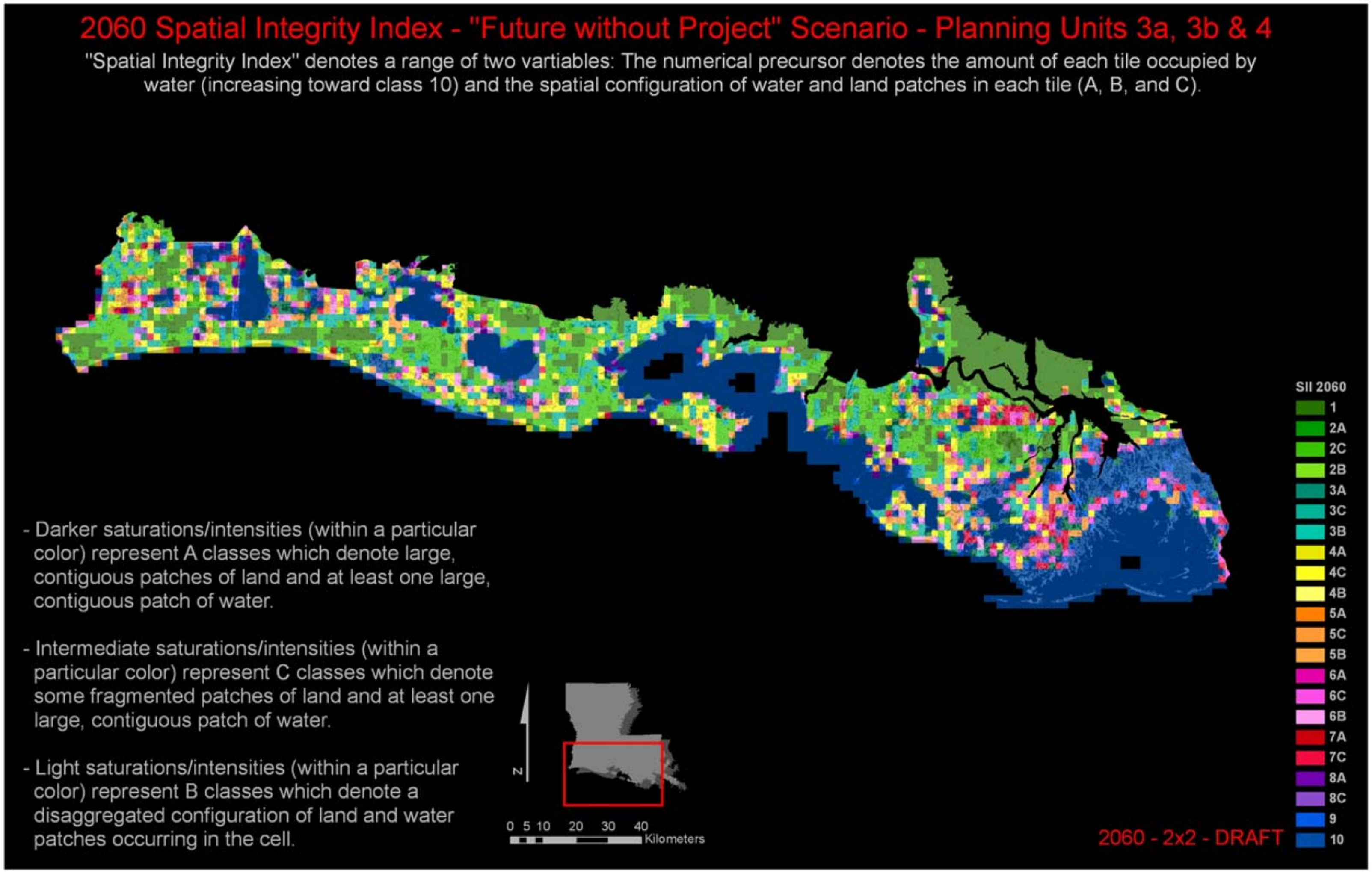


Figure 21. Spatial integrity index for future without project in 2060 for planning units 3a, 3b and 4.

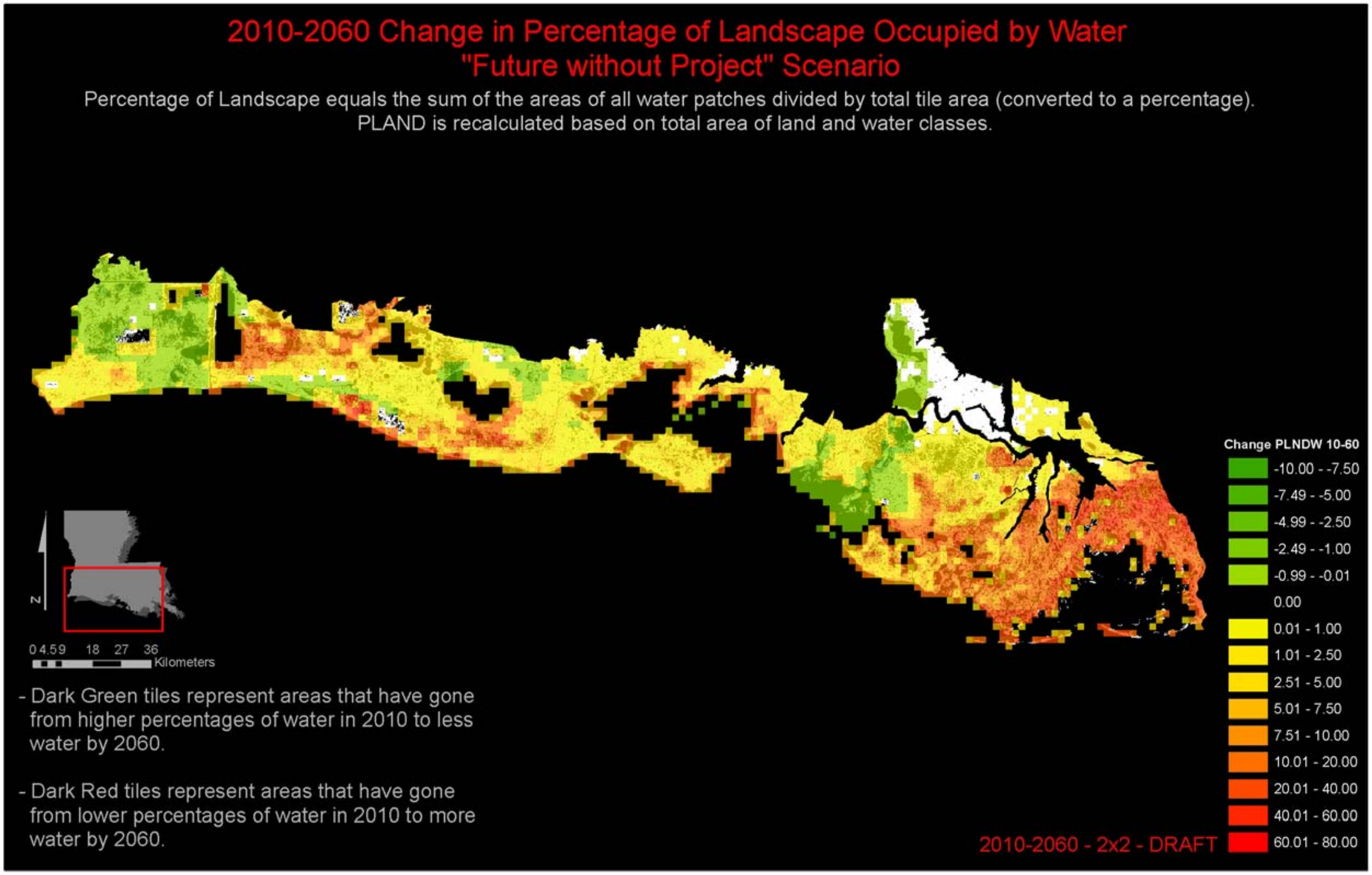


Figure 22. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing future without project changes projected between 2010 and 2060.

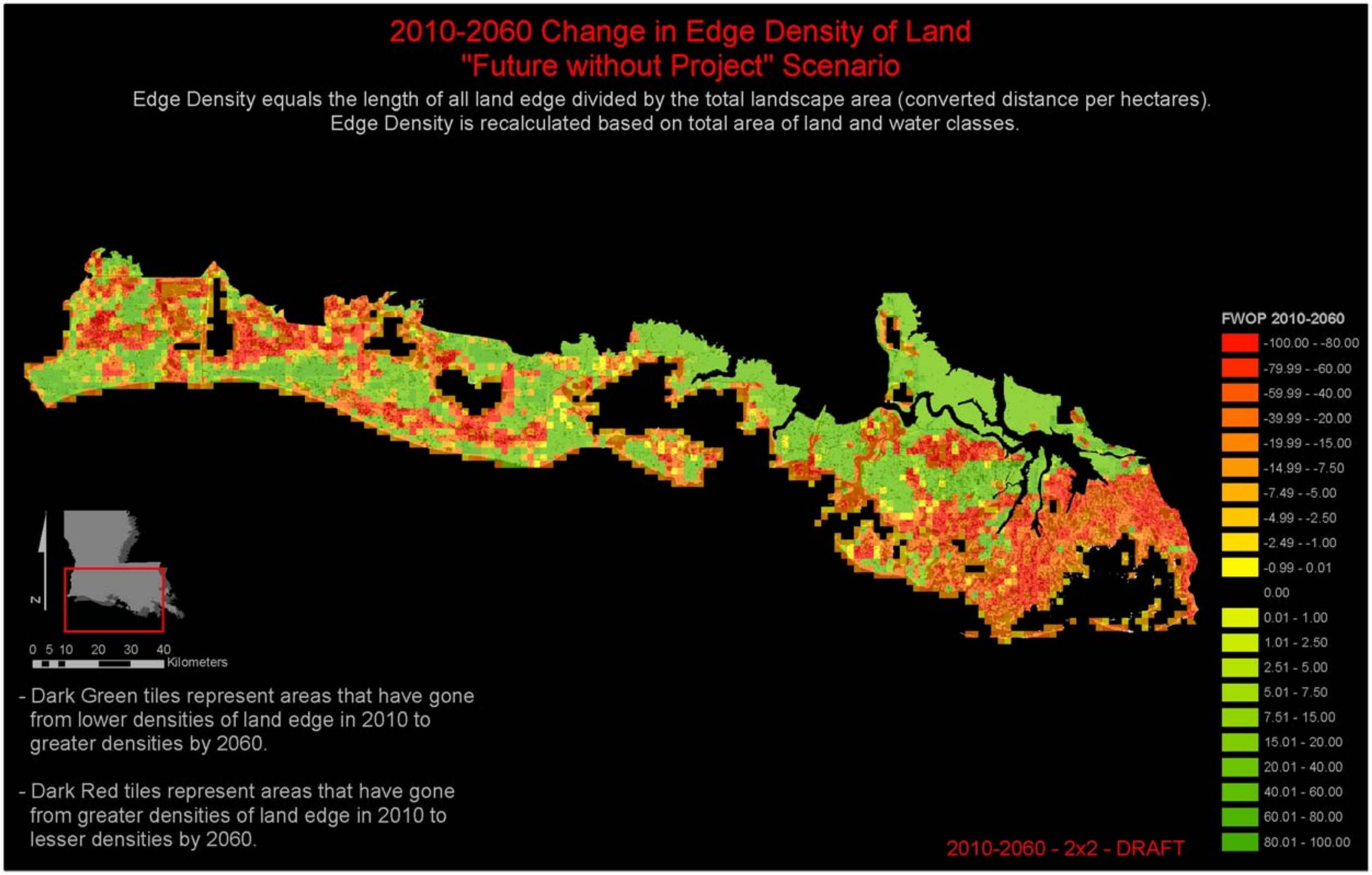


Figure 23. Edge density of land metric for planning units 3a, 3b and 4 showing future without project changes projected between 2010 and 2060.

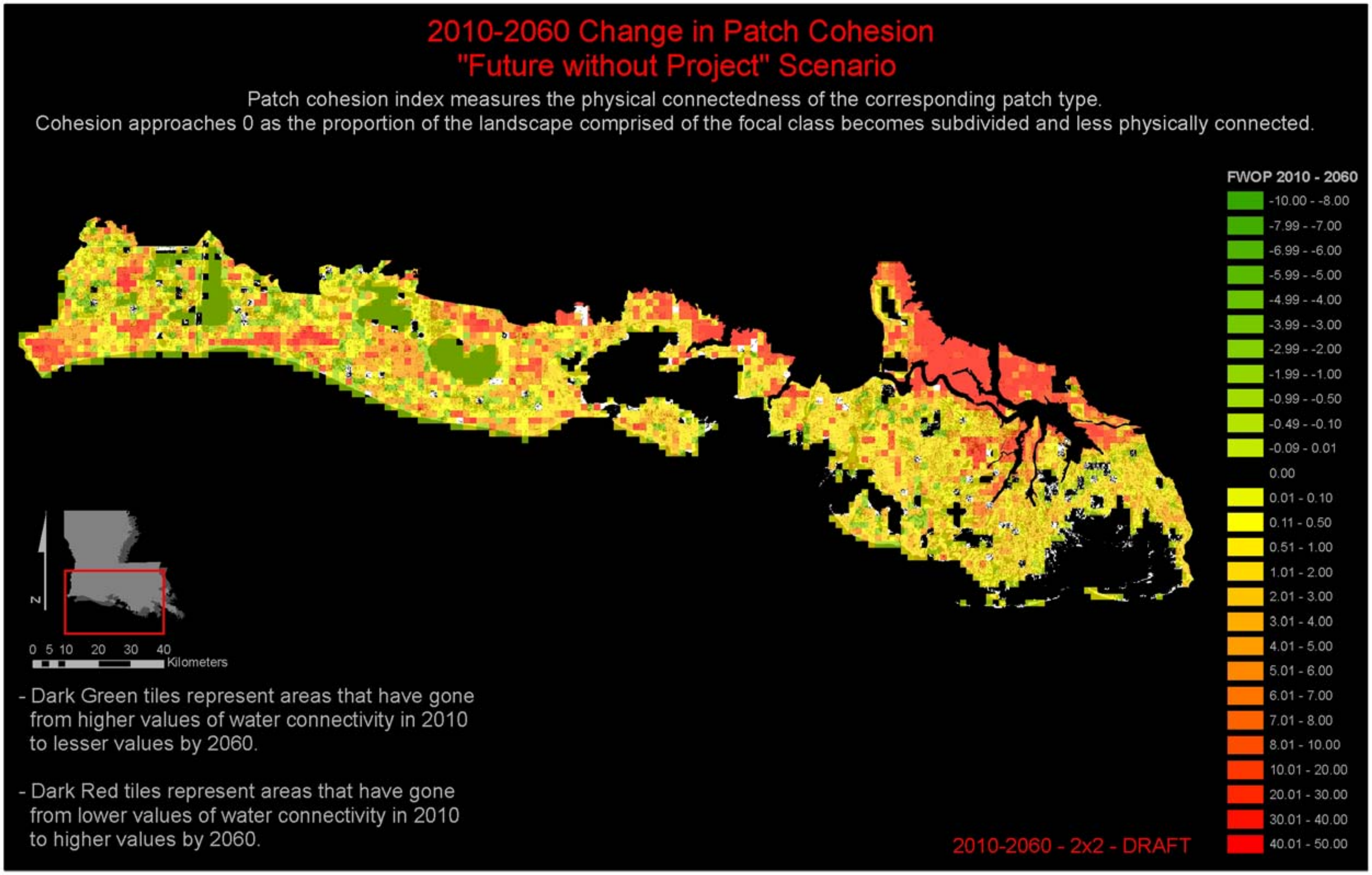


Figure 24. Patch cohesion metric for planning units 3a, 3b and 4 showing future without project changes projected between 2010 and 2060.

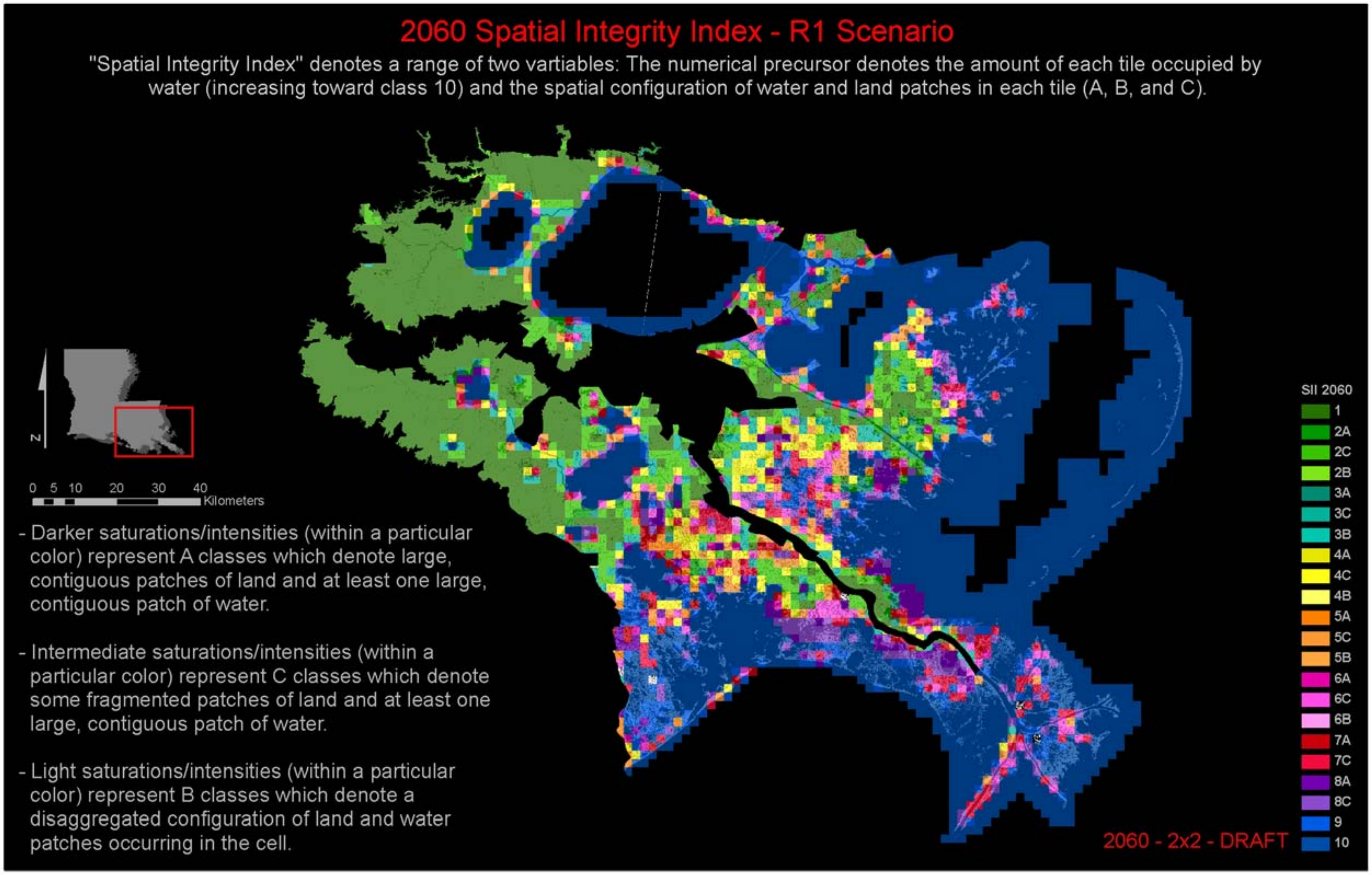


Figure 25. Spatial integrity index for Alternative R1 in 2060 for planning units 1 and 2.

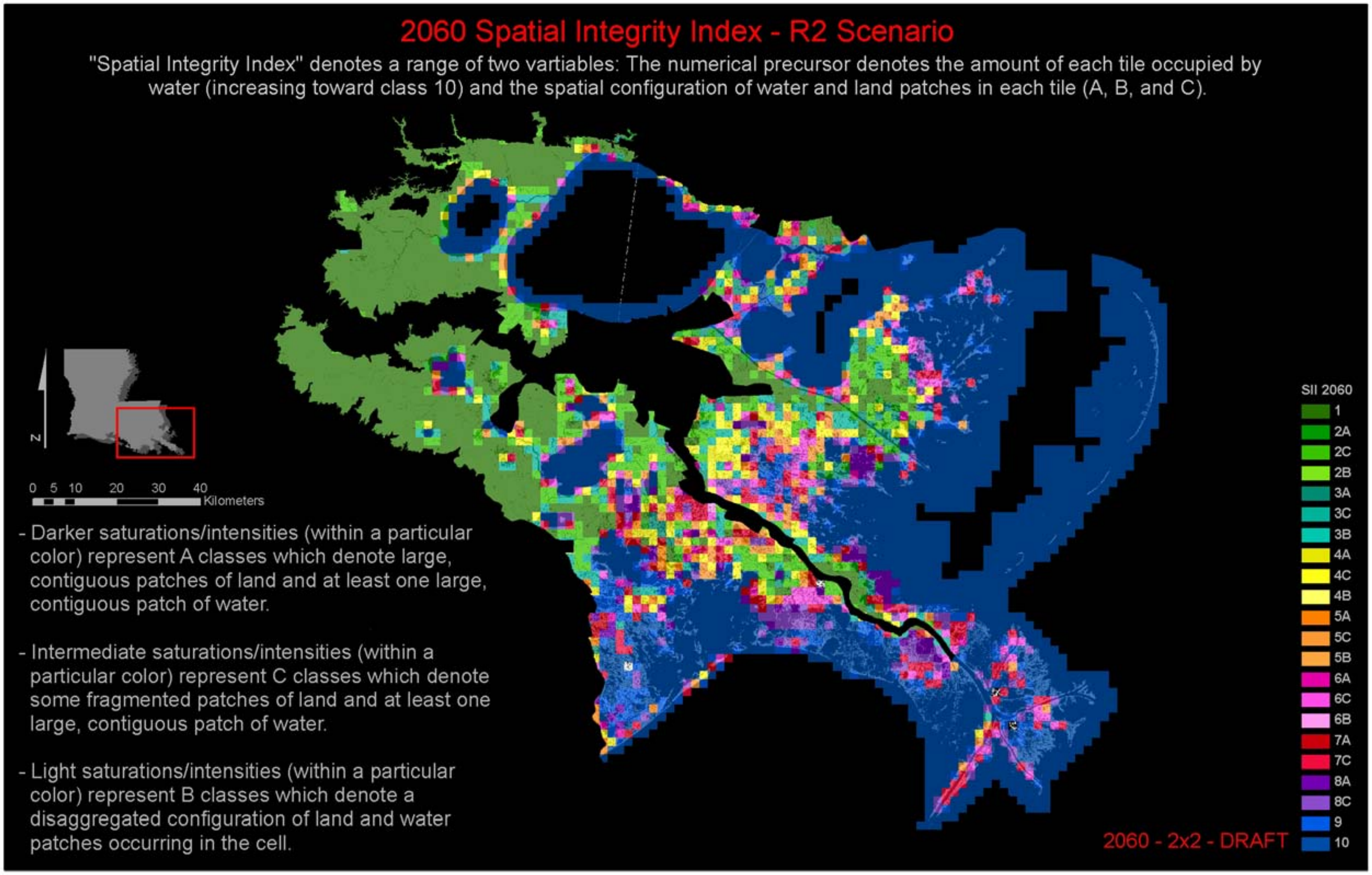


Figure 26. Spatial integrity index for Alternative R2 in 2060 for planning units 1 and 2.

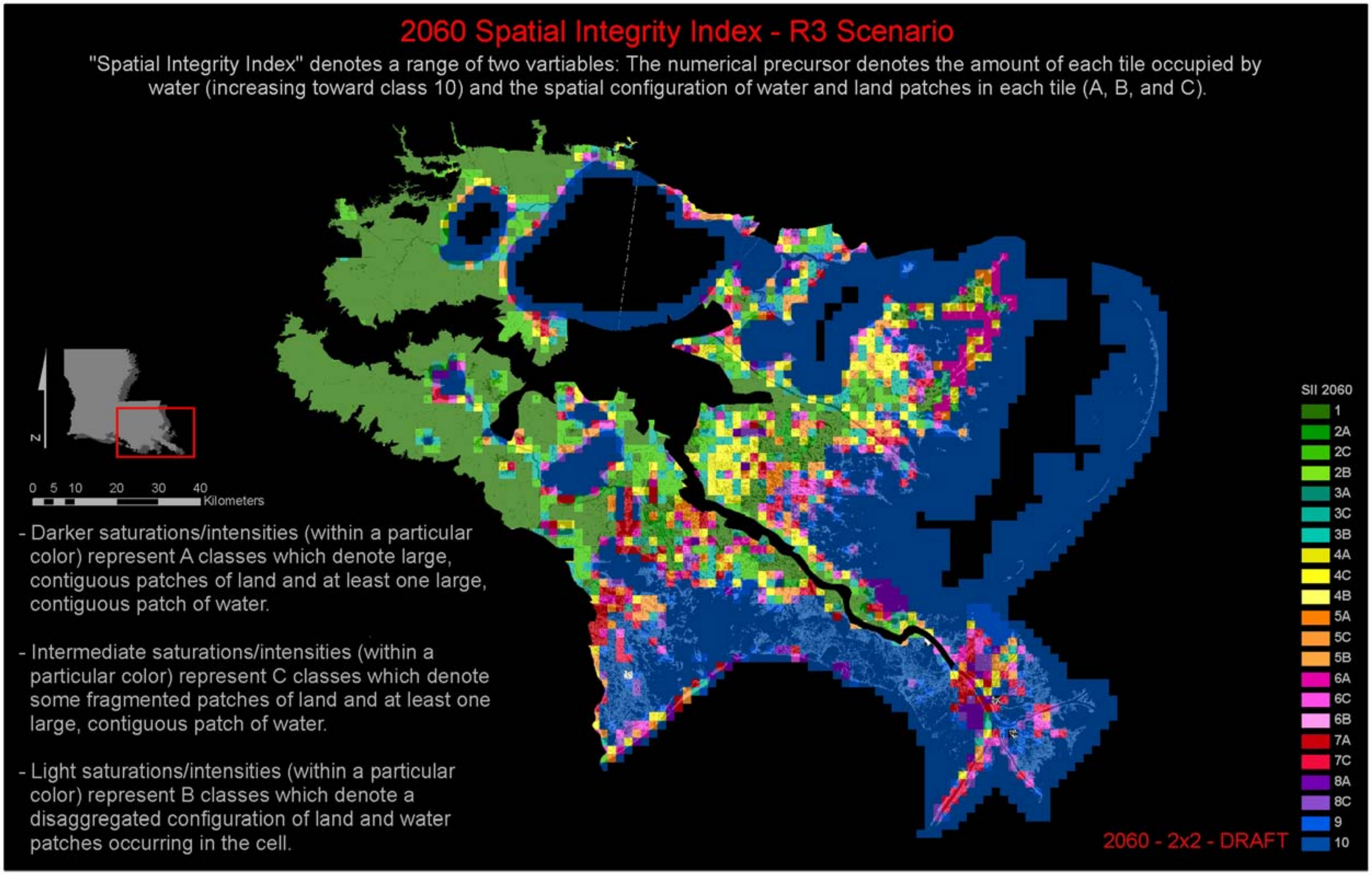


Figure 27. Spatial integrity index for Alternative R3 in 2060 for planning units 1 and 2.

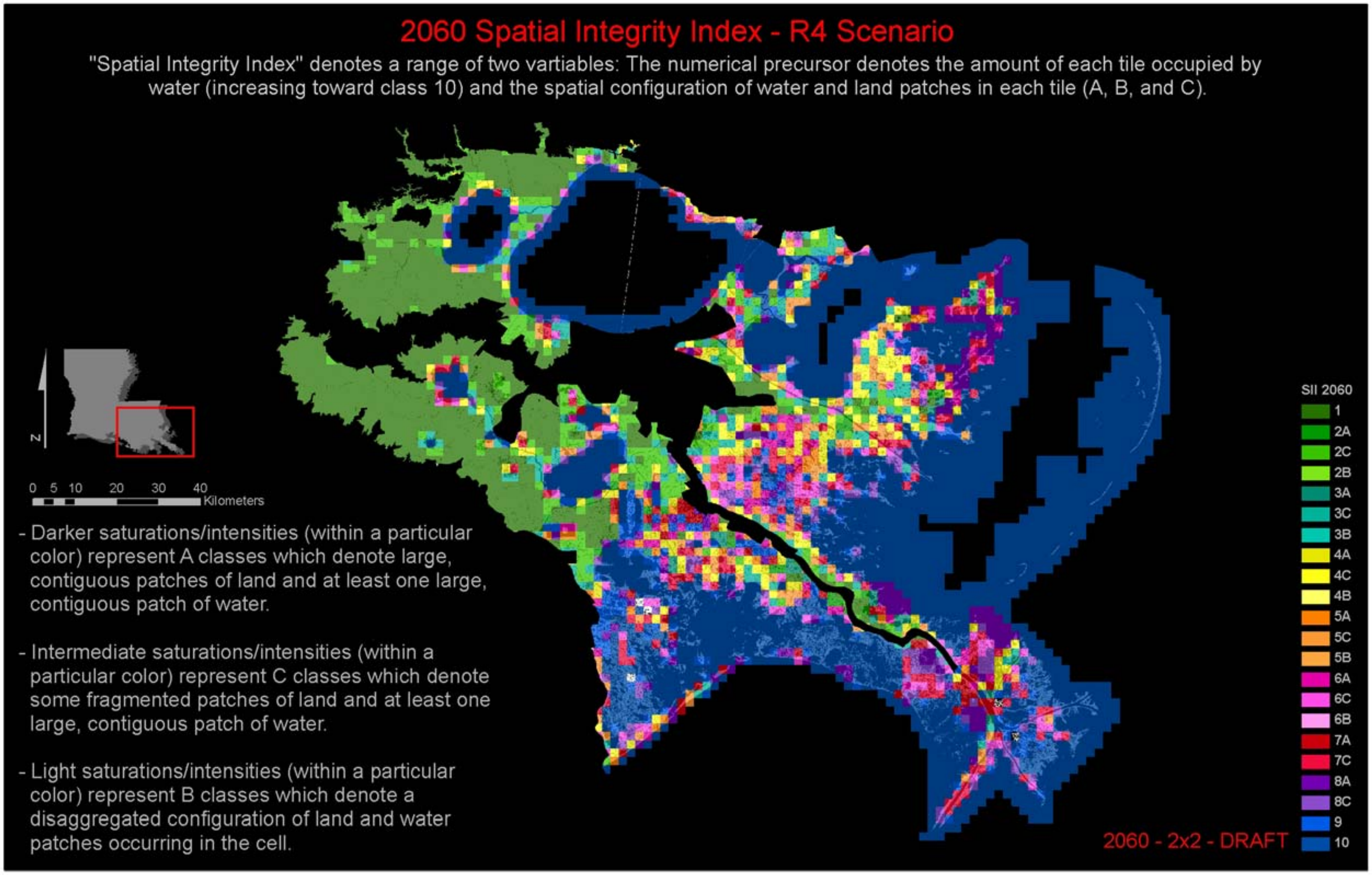


Figure 28. Spatial integrity index for Alternative R4 in 2060 for planning units 1 and 2.

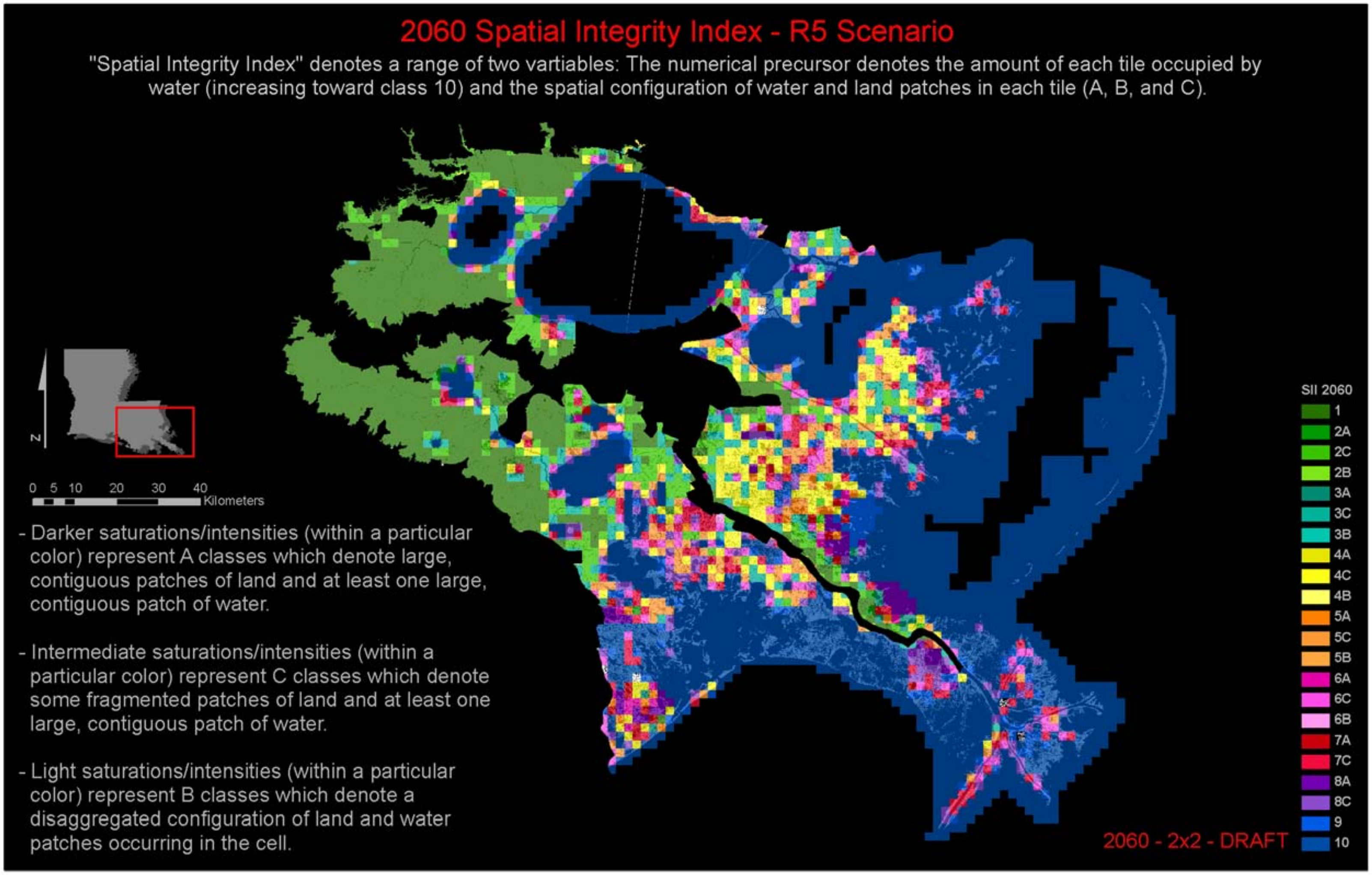


Figure 29. Spatial integrity index for Alternative R5 in 2060 for planning units 1 and 2.

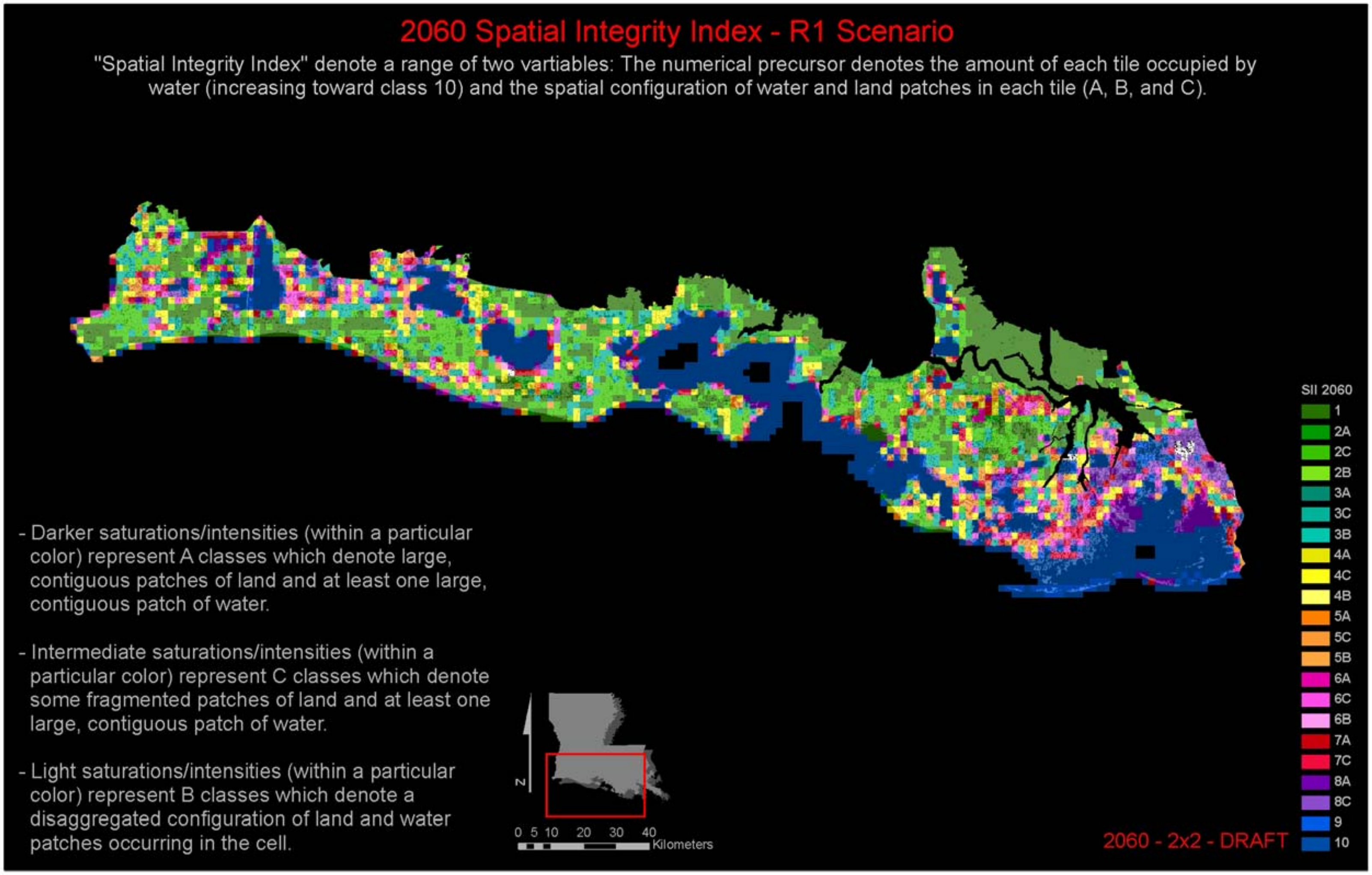


Figure 30. Spatial integrity index for Alternative R1 in 2060 for planning units 3a, 3b and 4.

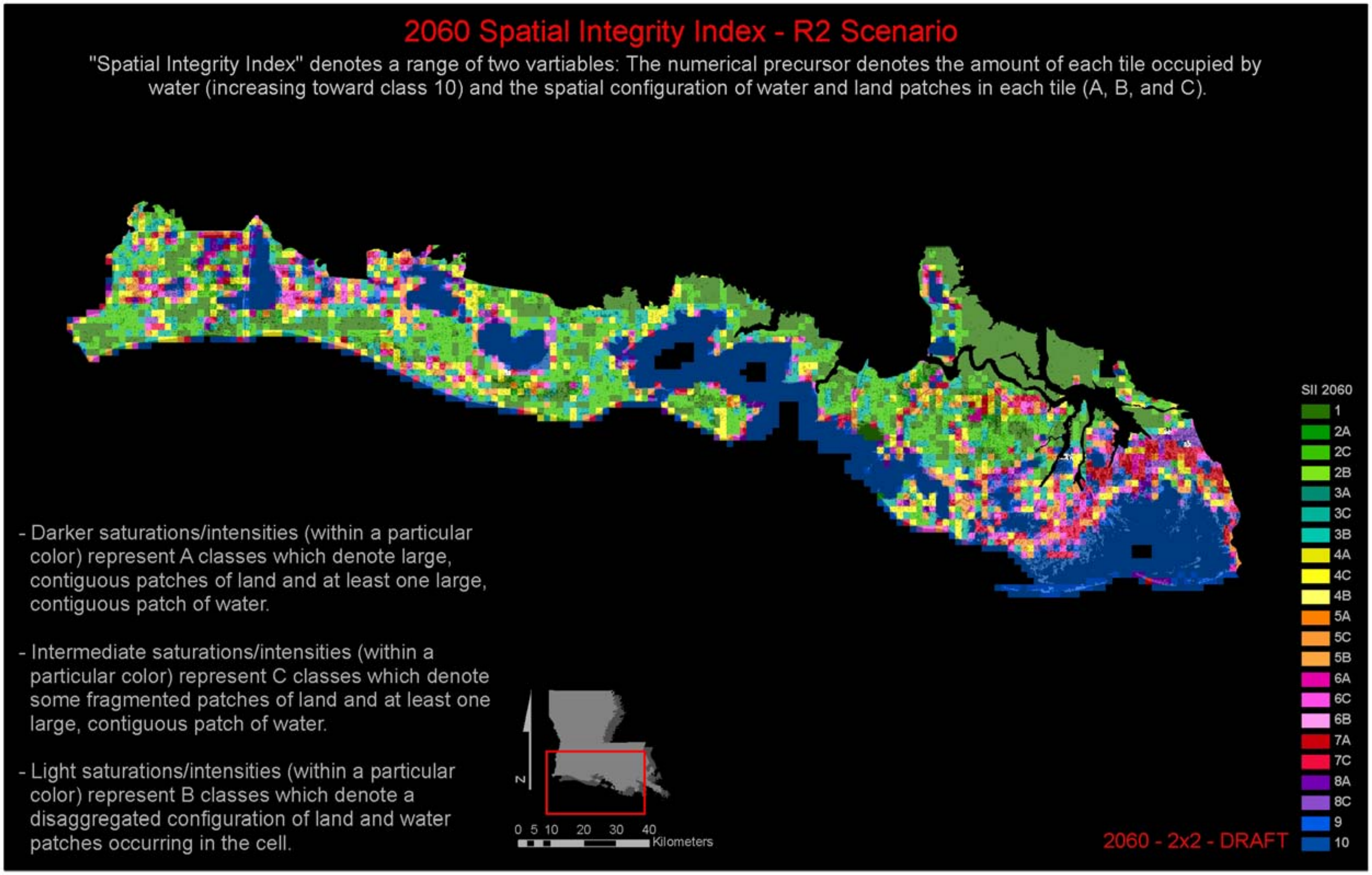


Figure 31. Spatial integrity index for Alternative R2 in 2060 for planning units 3a, 3b and 4.

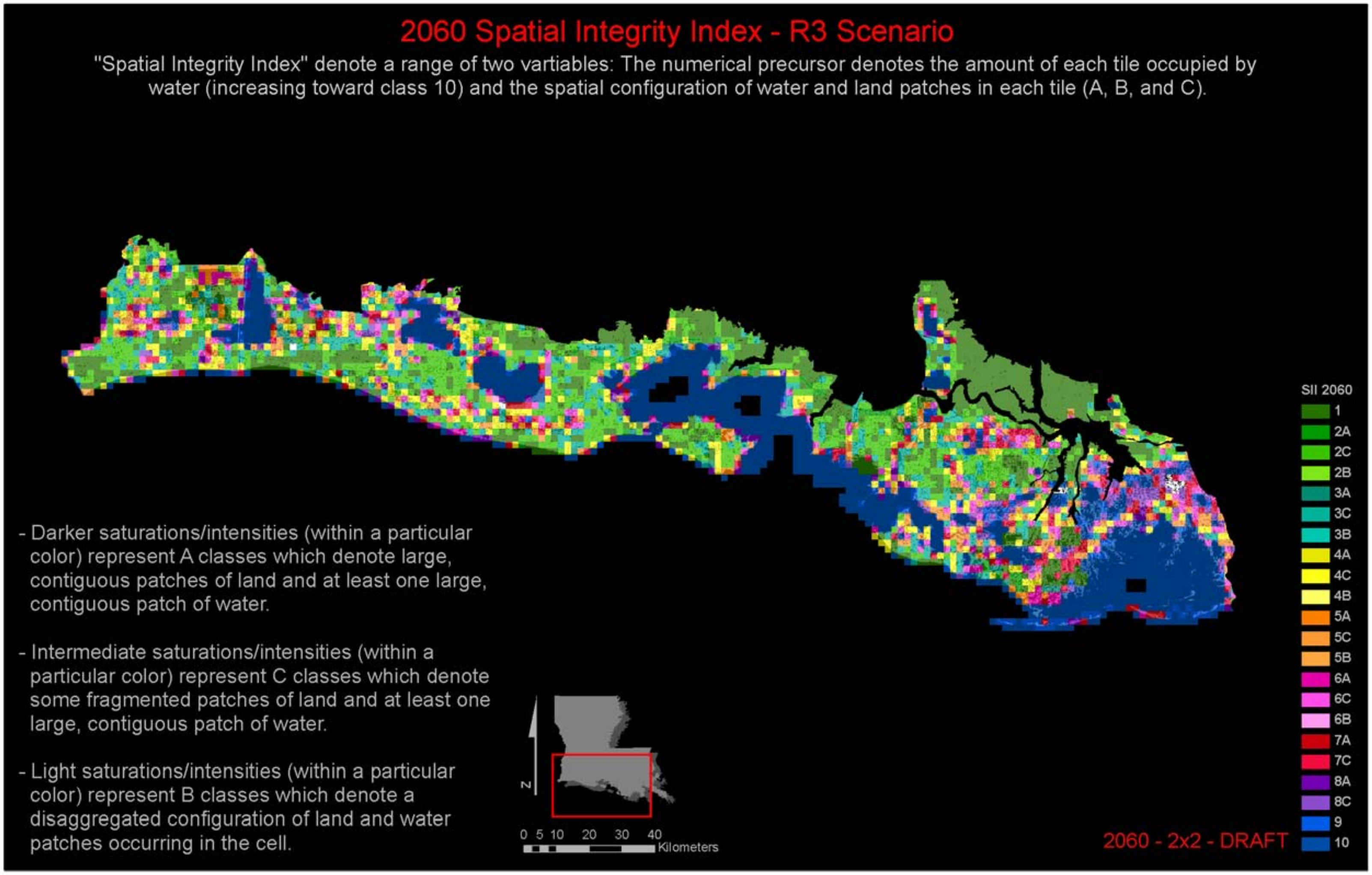


Figure 32. Spatial integrity index for Alternative R3 in 2060 for planning units 3a, 3b and 4.

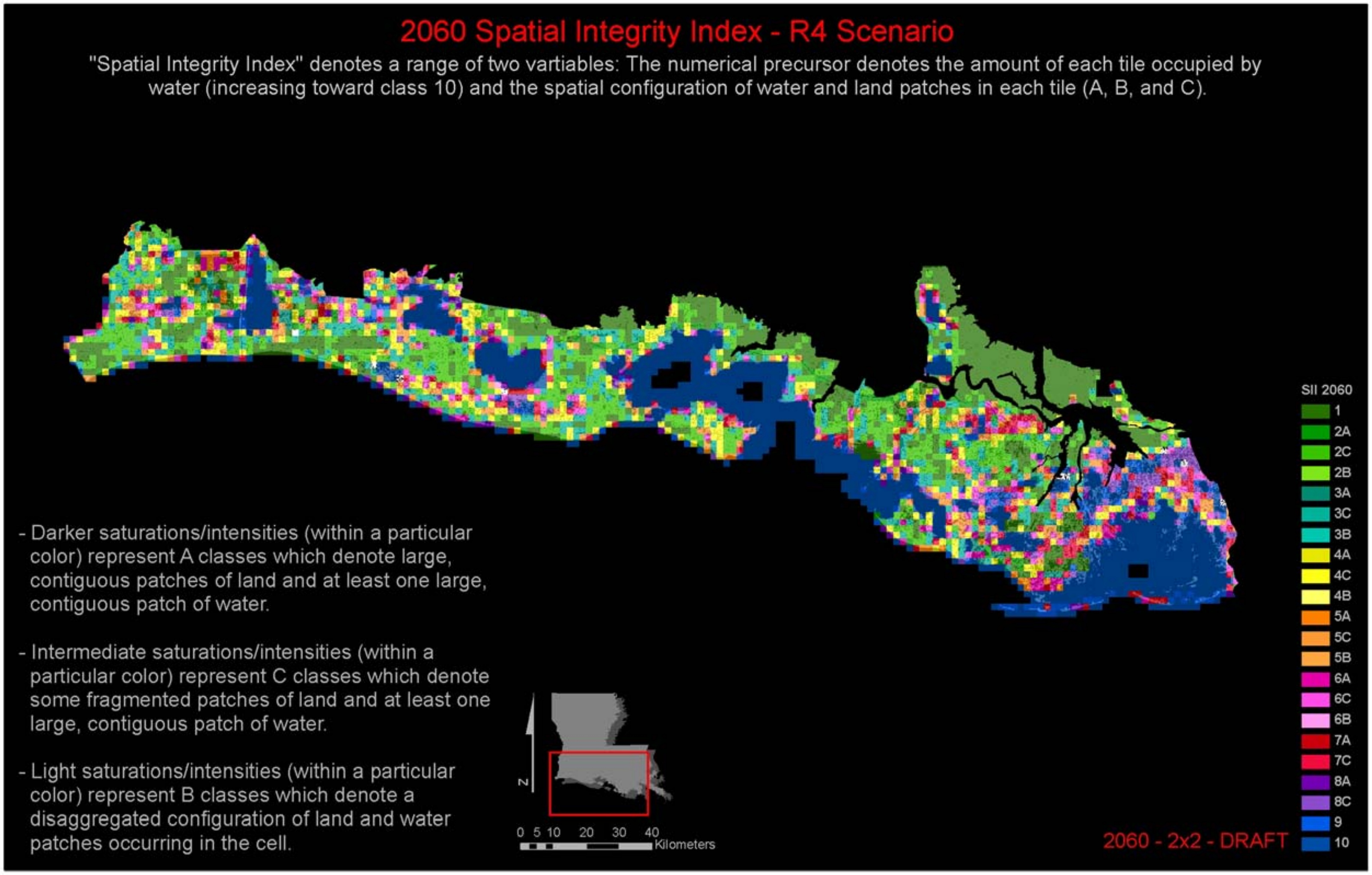


Figure 33. Spatial integrity index for Alternative R4 in 2060 for planning units 3a, 3b and 4.

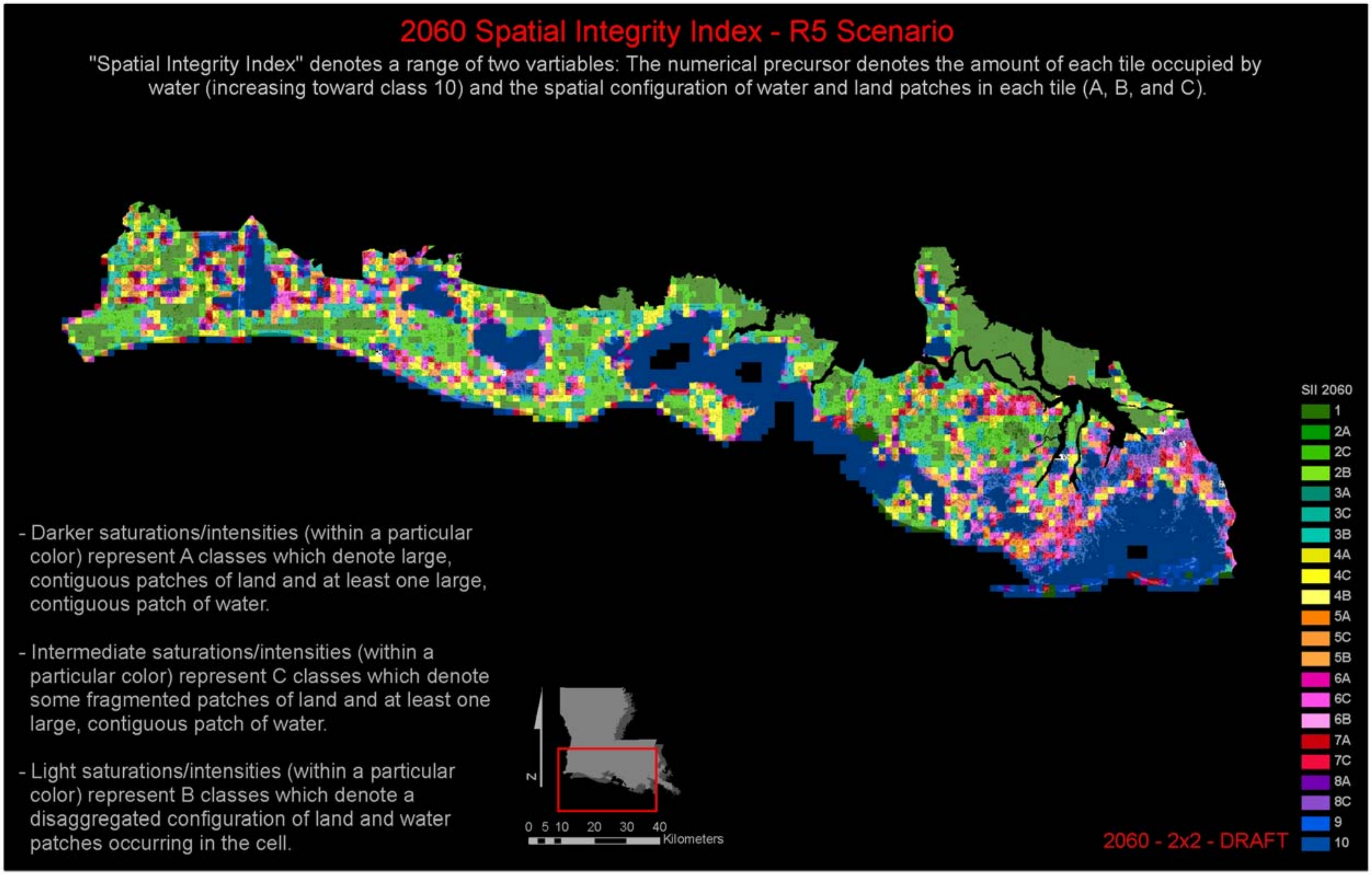
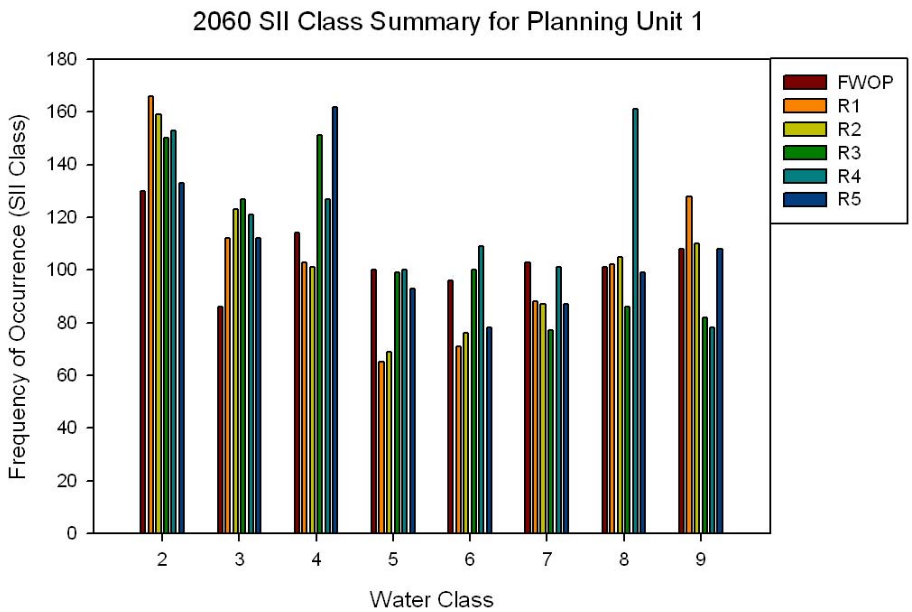


Figure 34. Spatial integrity index for Alternative R5 in 2060 for planning units 3a, 3b and 4.



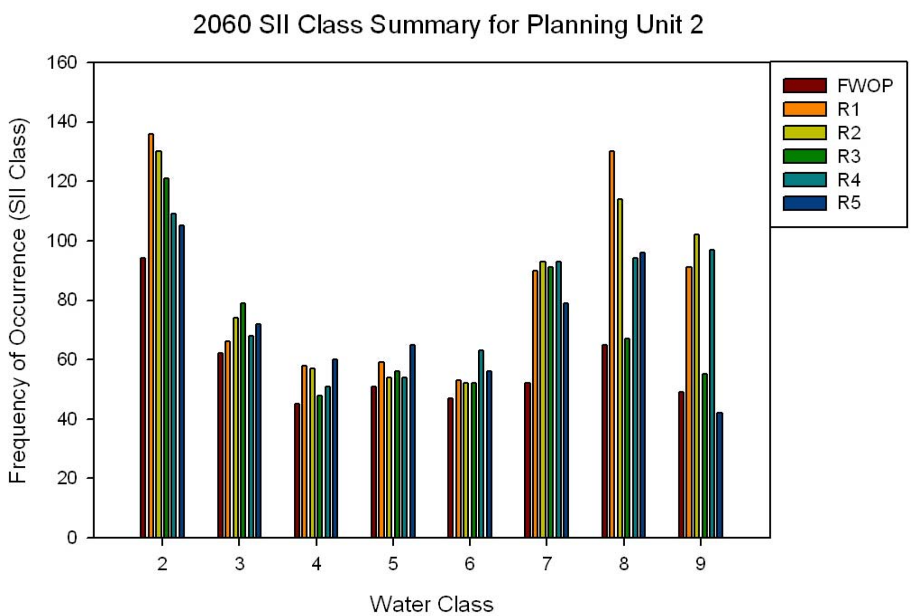


Figure 35. Spatial integrity index from 2060 summarized by individual water classes for planning units 1 and 2. Frequency represents counts of tiles in 2060 represented by the class.

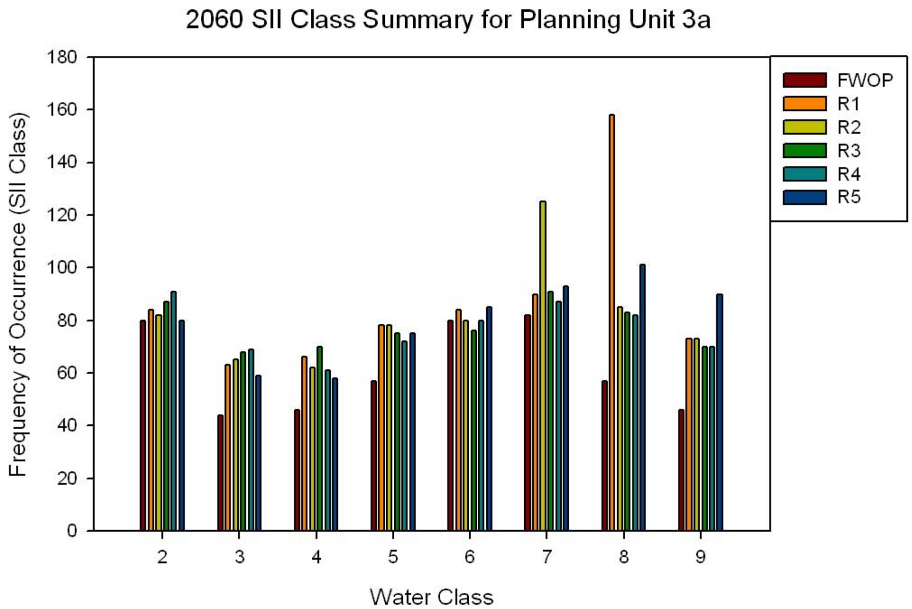


Figure 36a. Spatial integrity index from 2060 summarized by individual water classes for planning units 3a and 3b. Frequency represents counts of tiles in 2060 represented by the class.

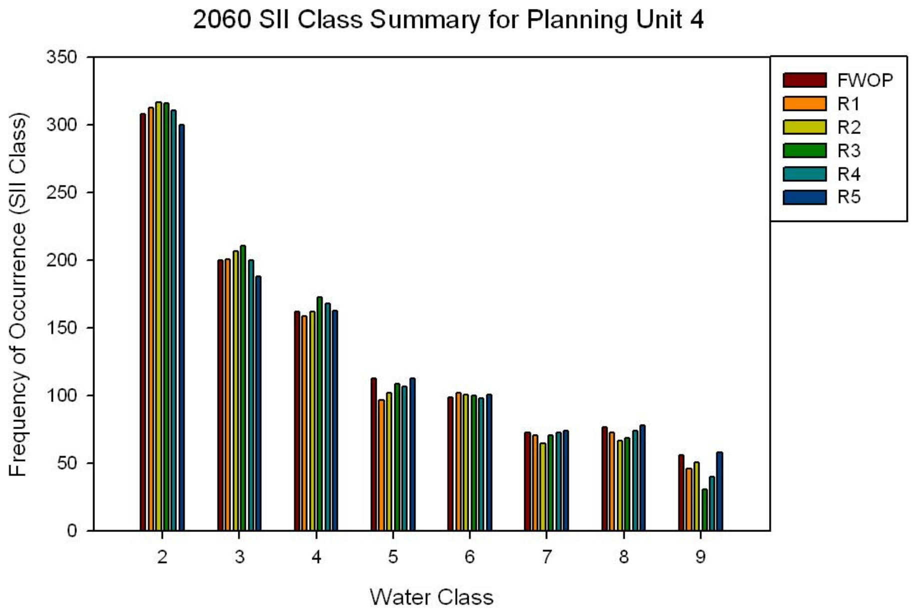
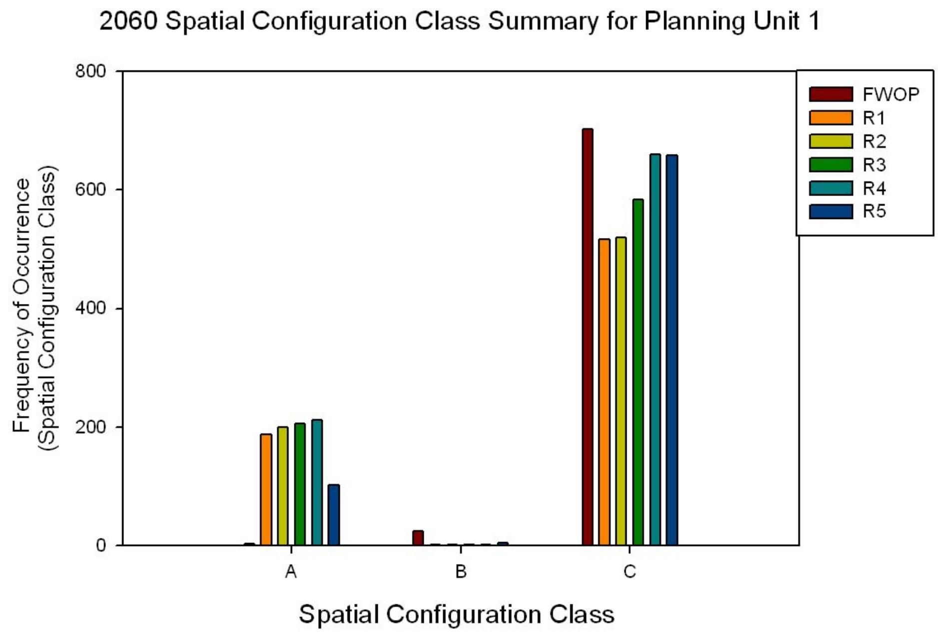


Figure 36b. Spatial integrity index from 2060 summarized by individual water classes for planning unit 4. Frequency represents counts of tiles in 2060 represented by the class.



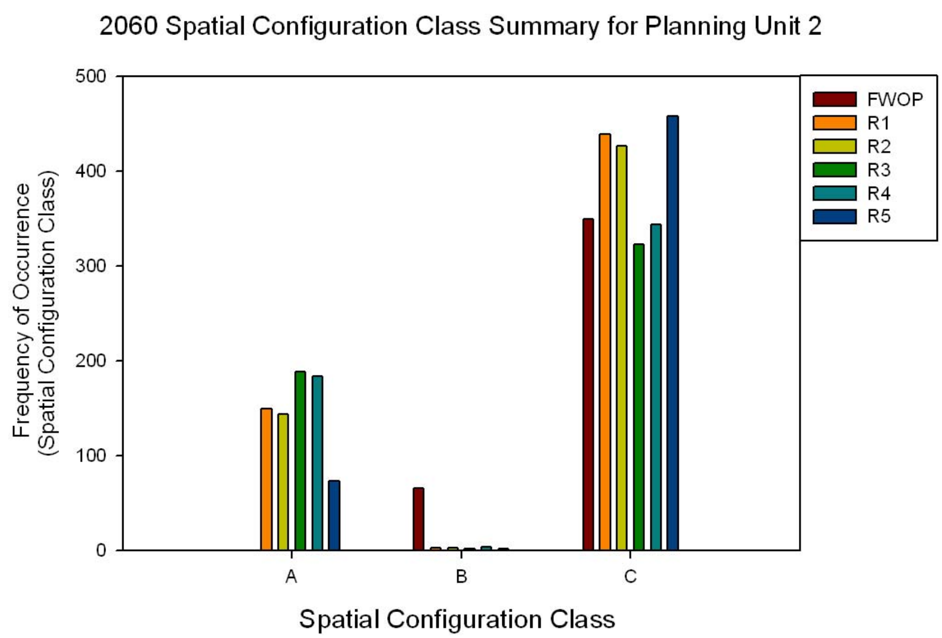
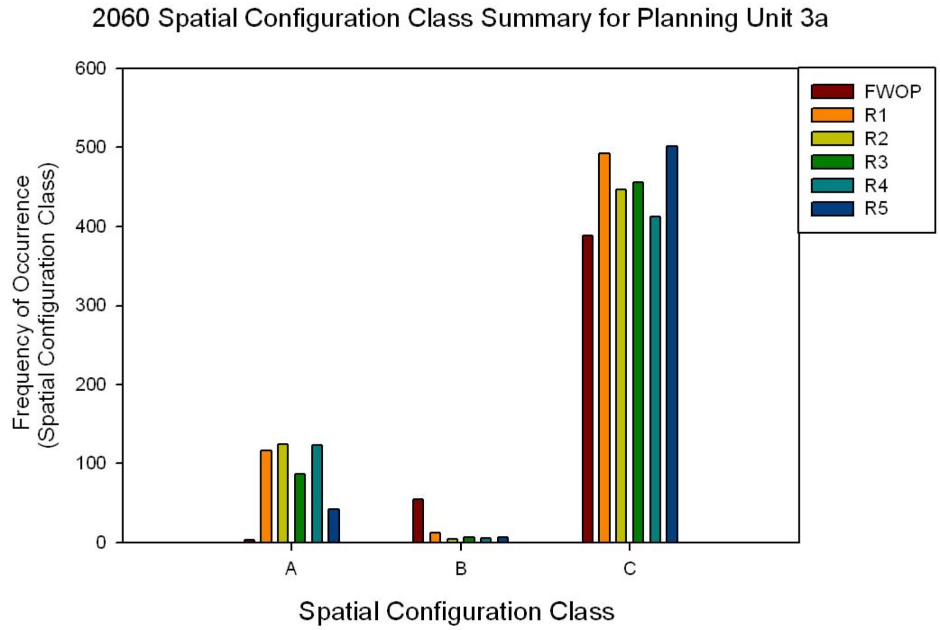


Figure 37. Spatial integrity index from 2060 summarized by individual configuration classes for planning units 1 and 2. Frequency represents counts of tiles in 2060 represented by the class.



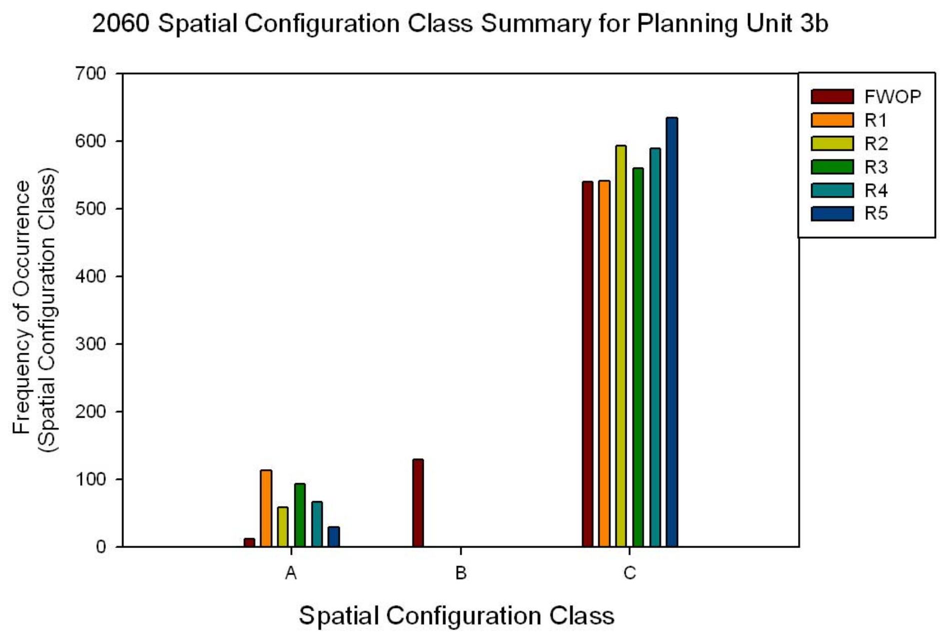


Figure 38a. Spatial integrity index from 2060 summarized by individual configuration classes for planning units 3a and 3b. Frequency represents counts of tiles in 2060 represented by the class.

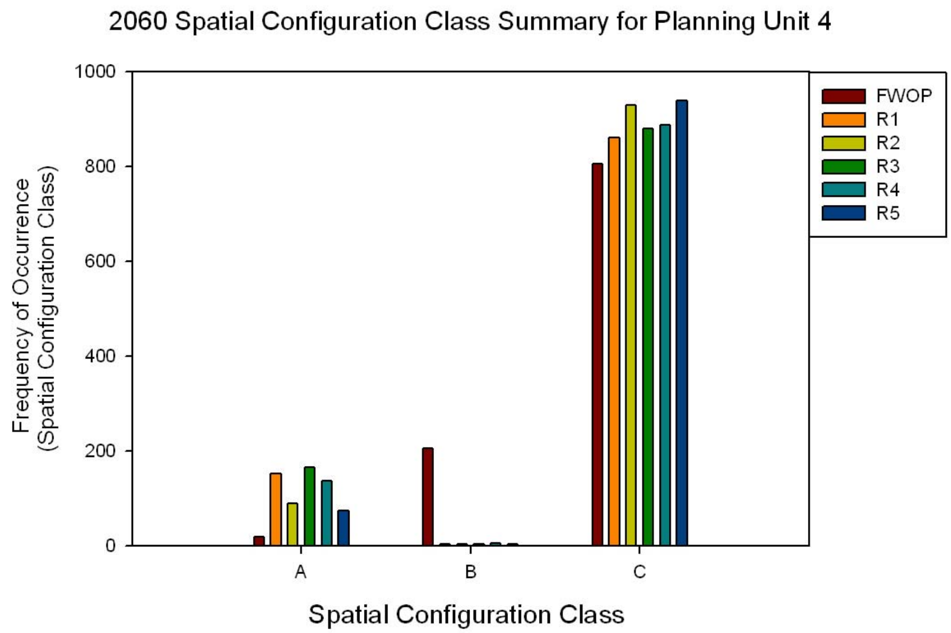


Figure 38b. Spatial integrity index from 2060 summarized by individual configuration classes for planning unit 4. Frequency represents counts of tiles in 2060 represented by the class.

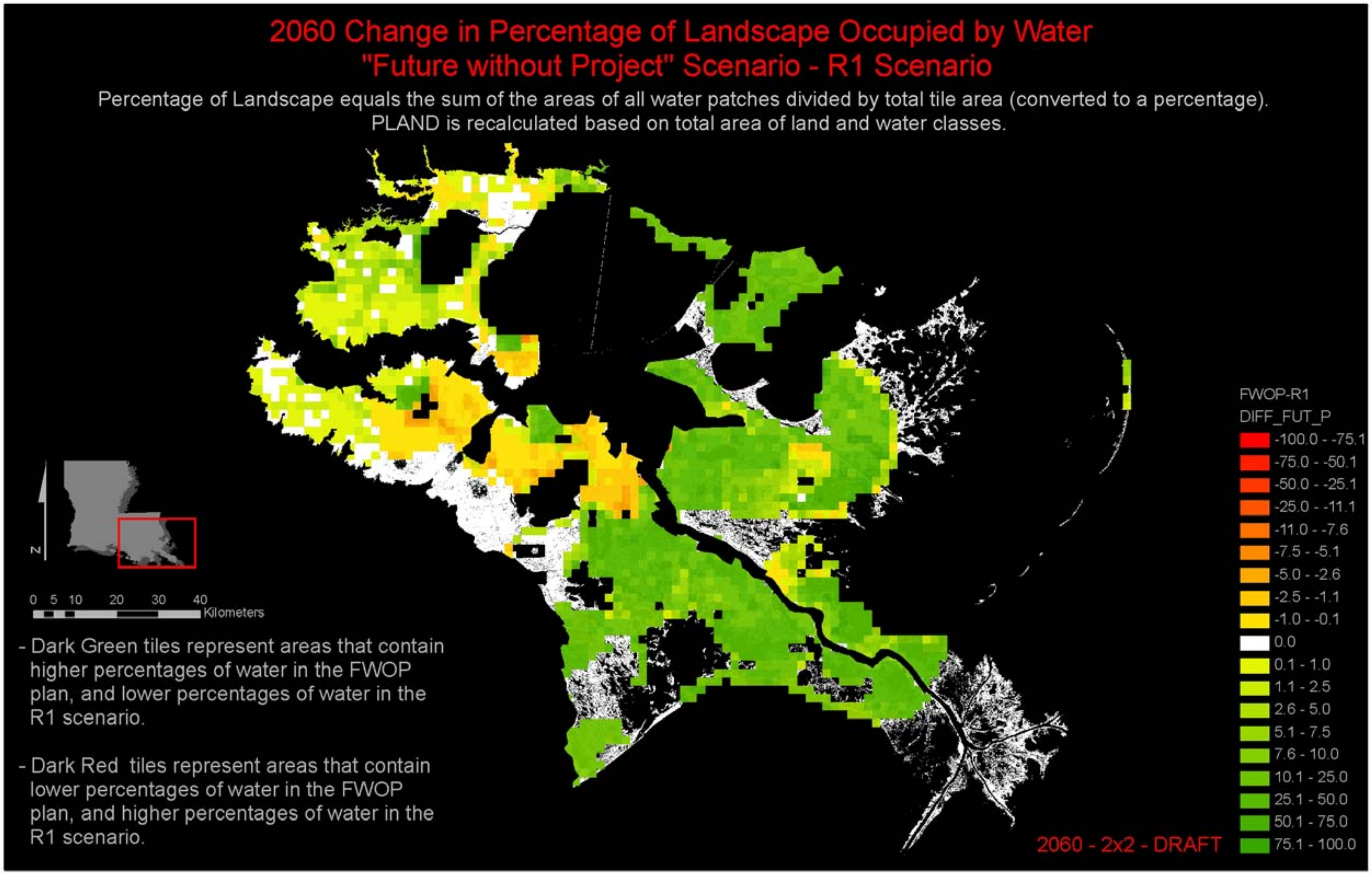


Figure 39. Percentage of landscape occupied by water metric for planning units 1 and 2 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

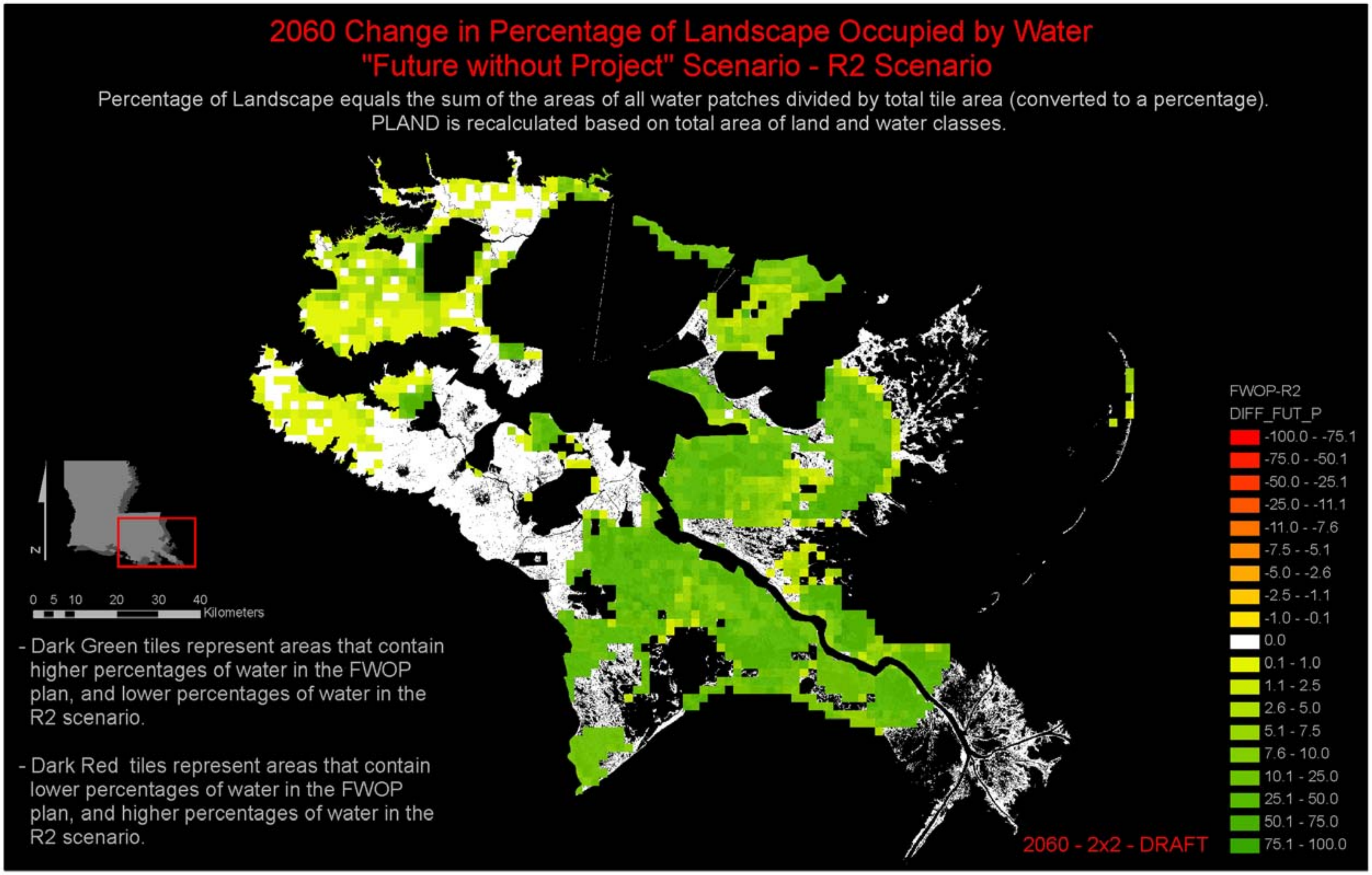


Figure 40. Percentage of landscape occupied by water metric for planning units 1 and 2 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

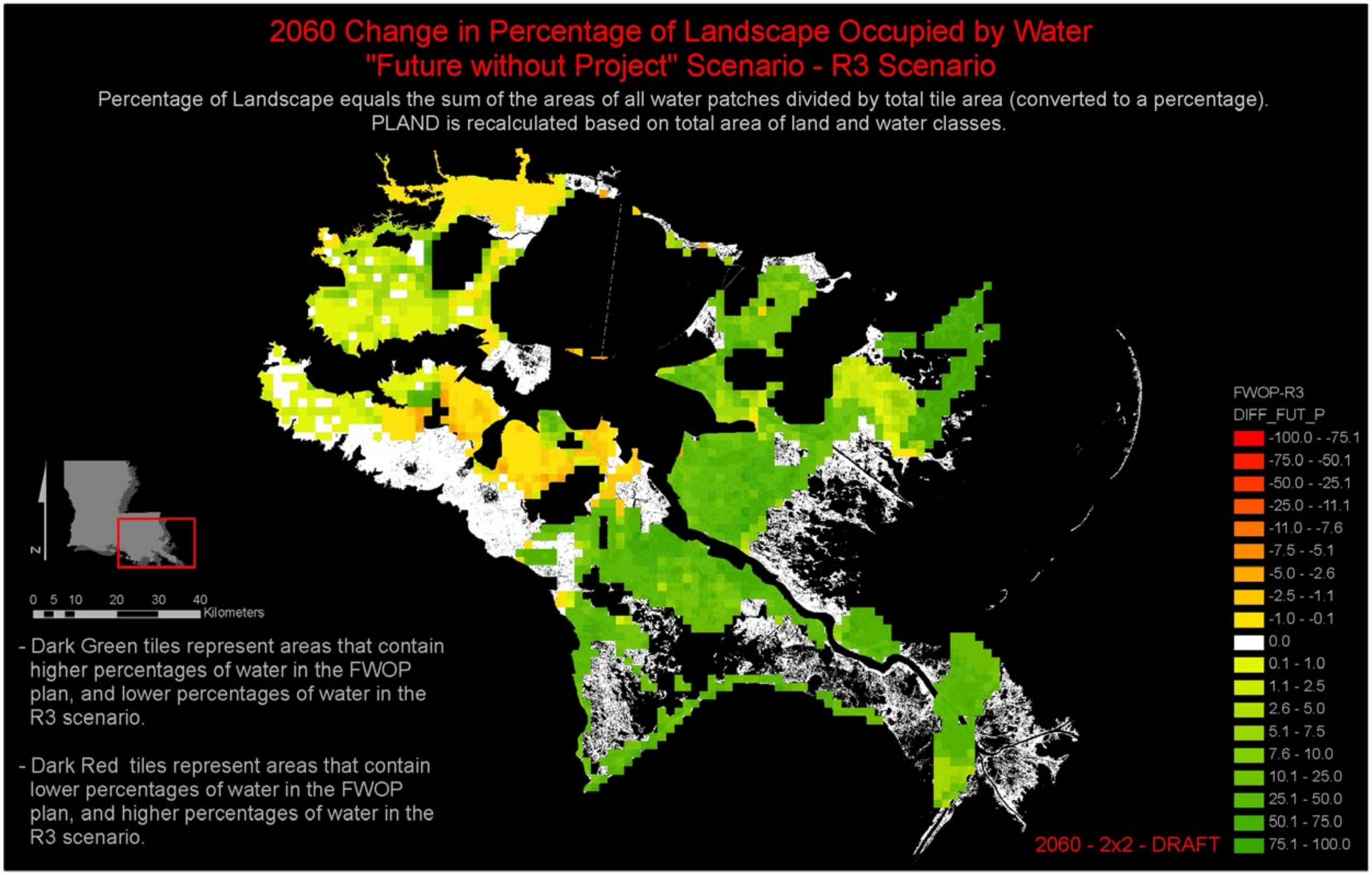


Figure 41. Percentage of landscape occupied by water metric for planning units 1 and 2 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

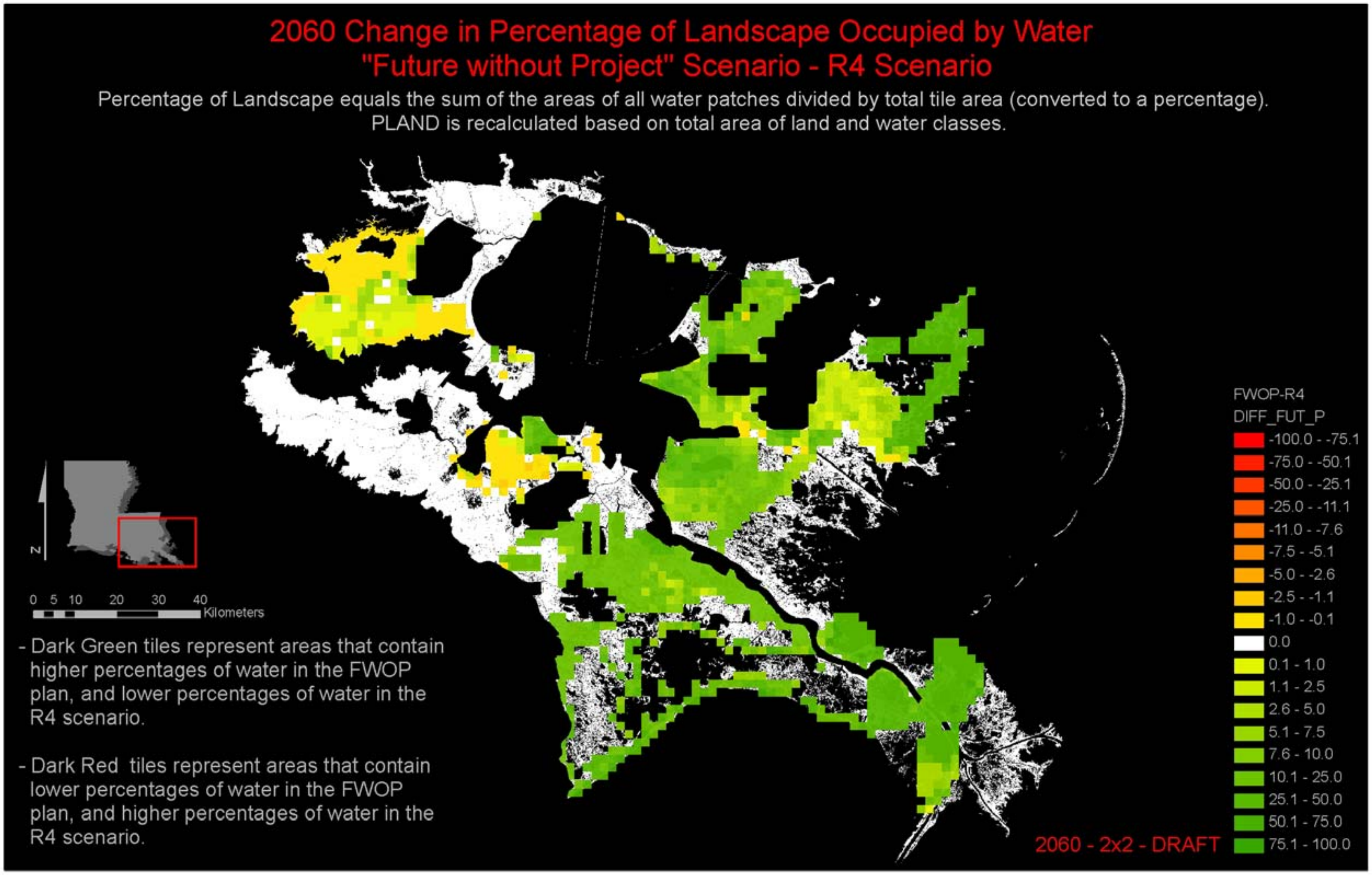


Figure 42. Percentage of landscape occupied by water metric for planning units 1 and 2 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

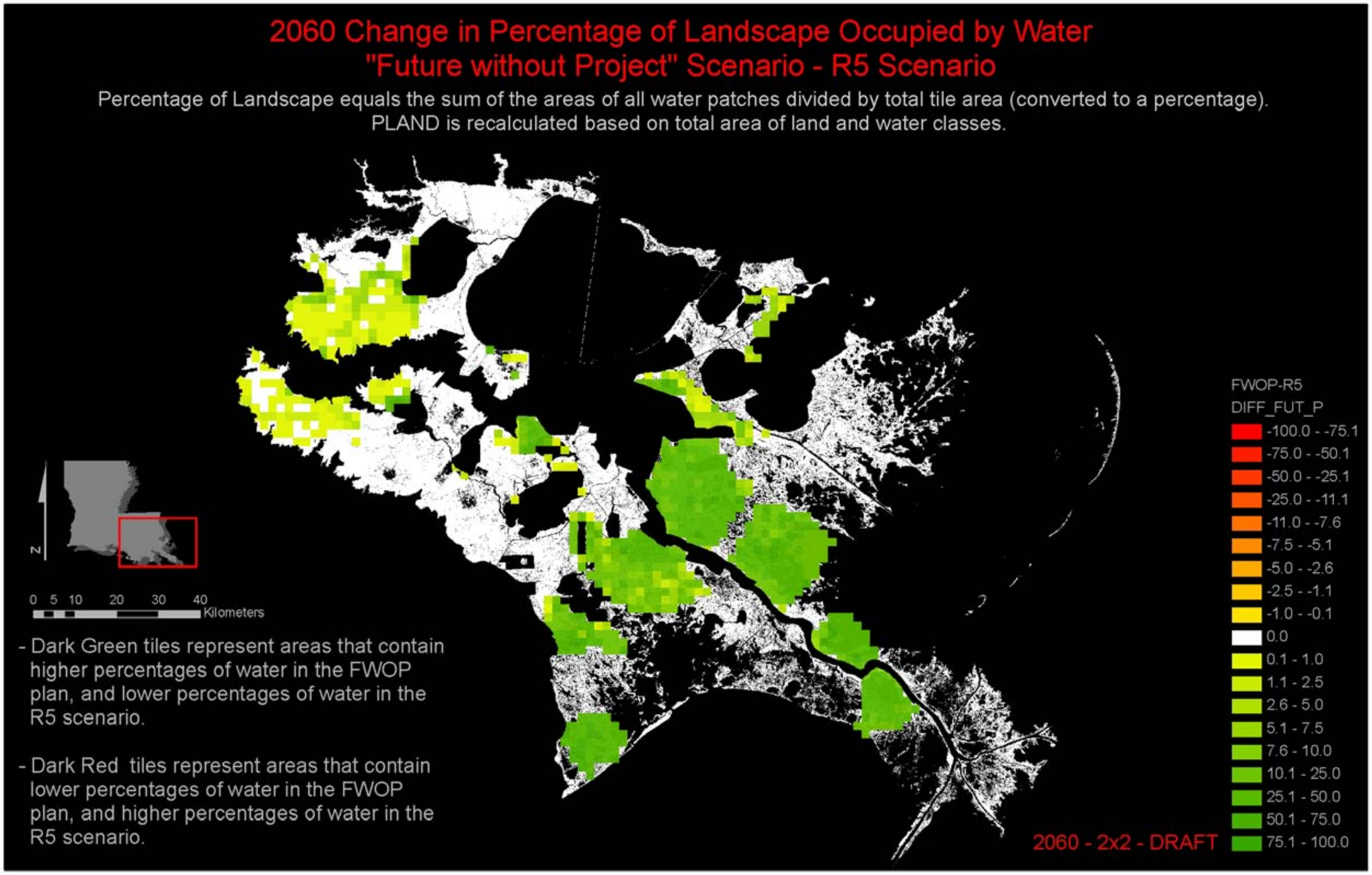


Figure 43. Percentage of landscape occupied by water metric for planning units 1 and 2 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

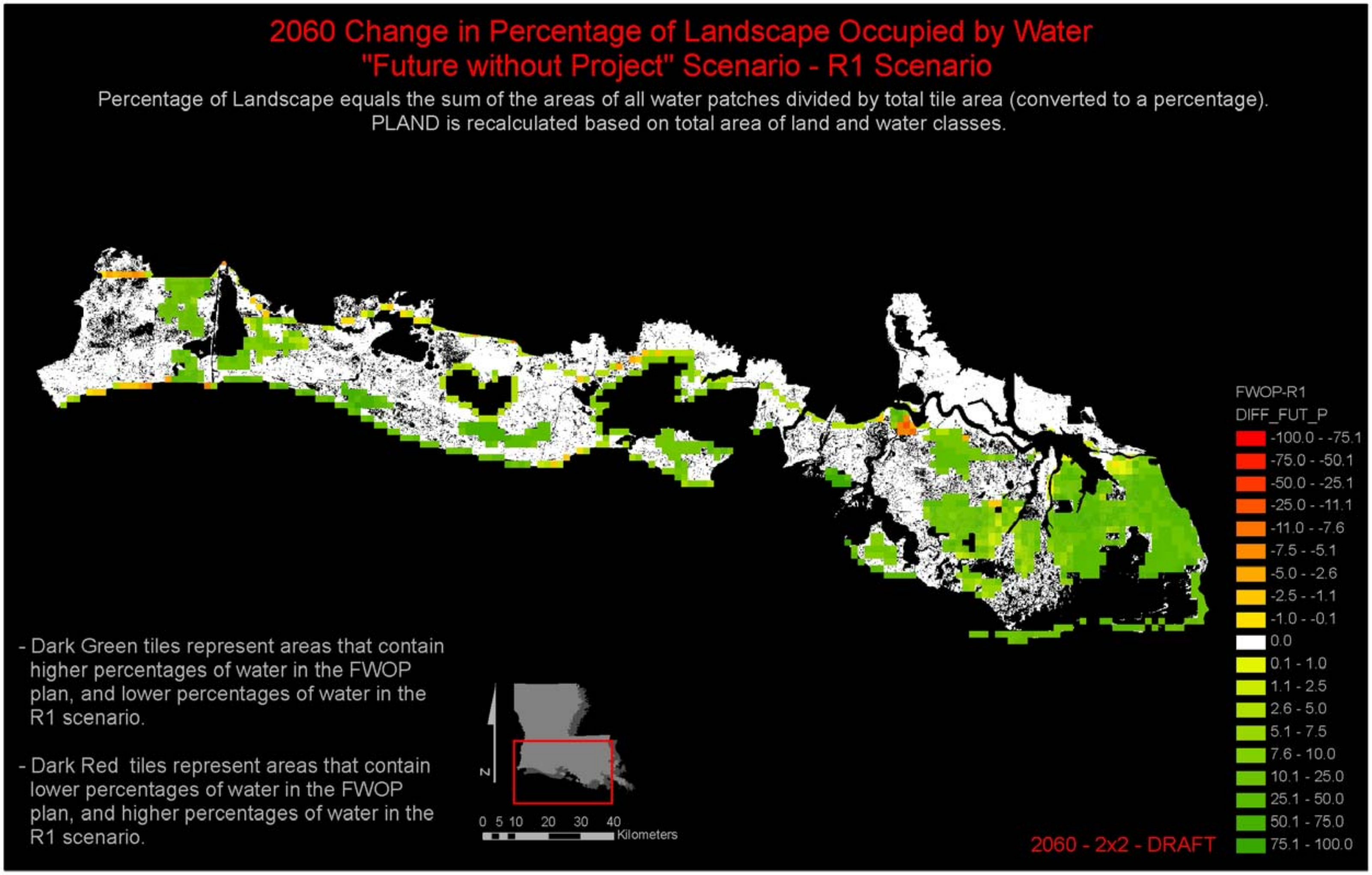


Figure 44. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

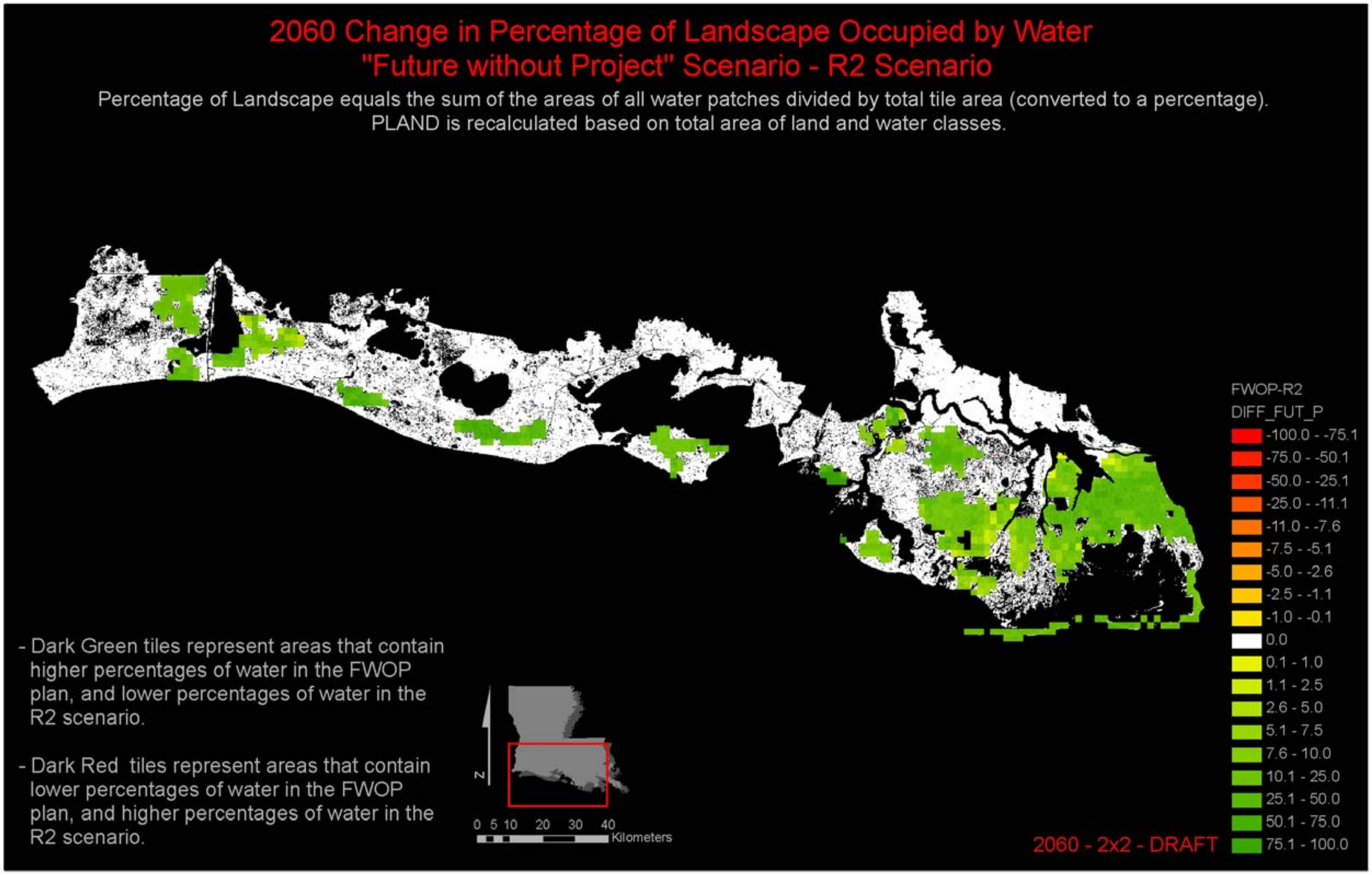


Figure 45. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

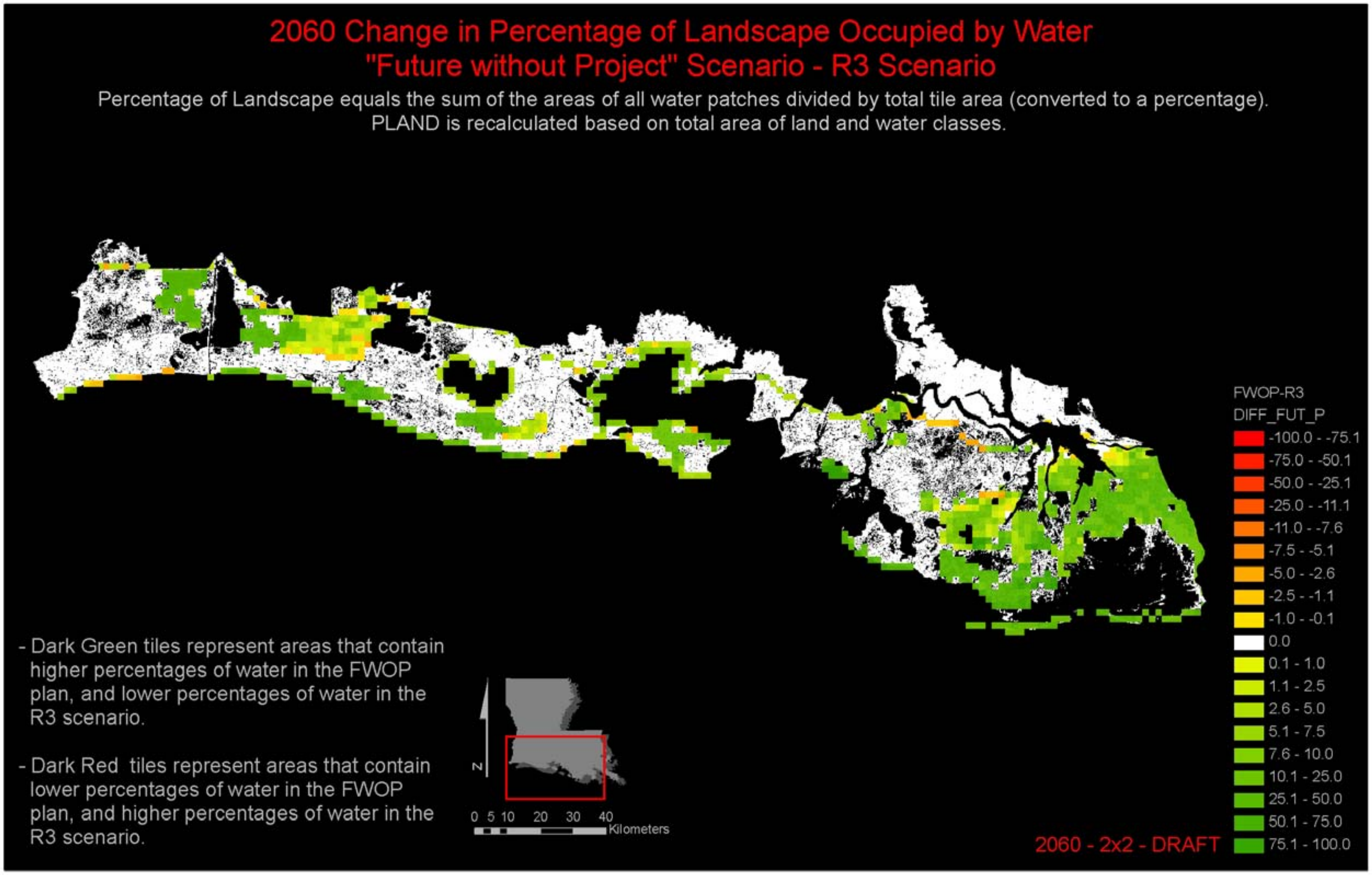


Figure 46. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

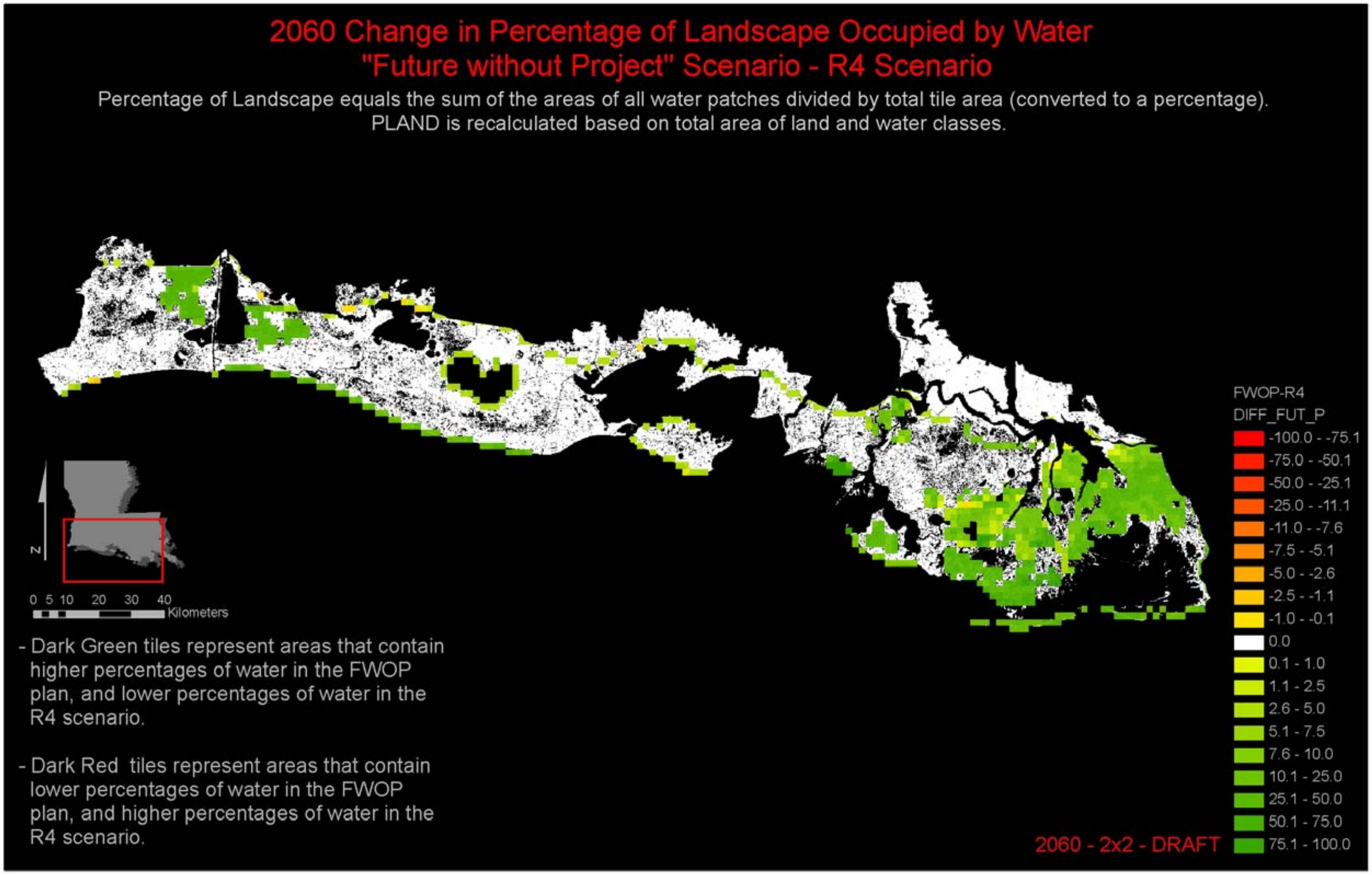


Figure 47. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

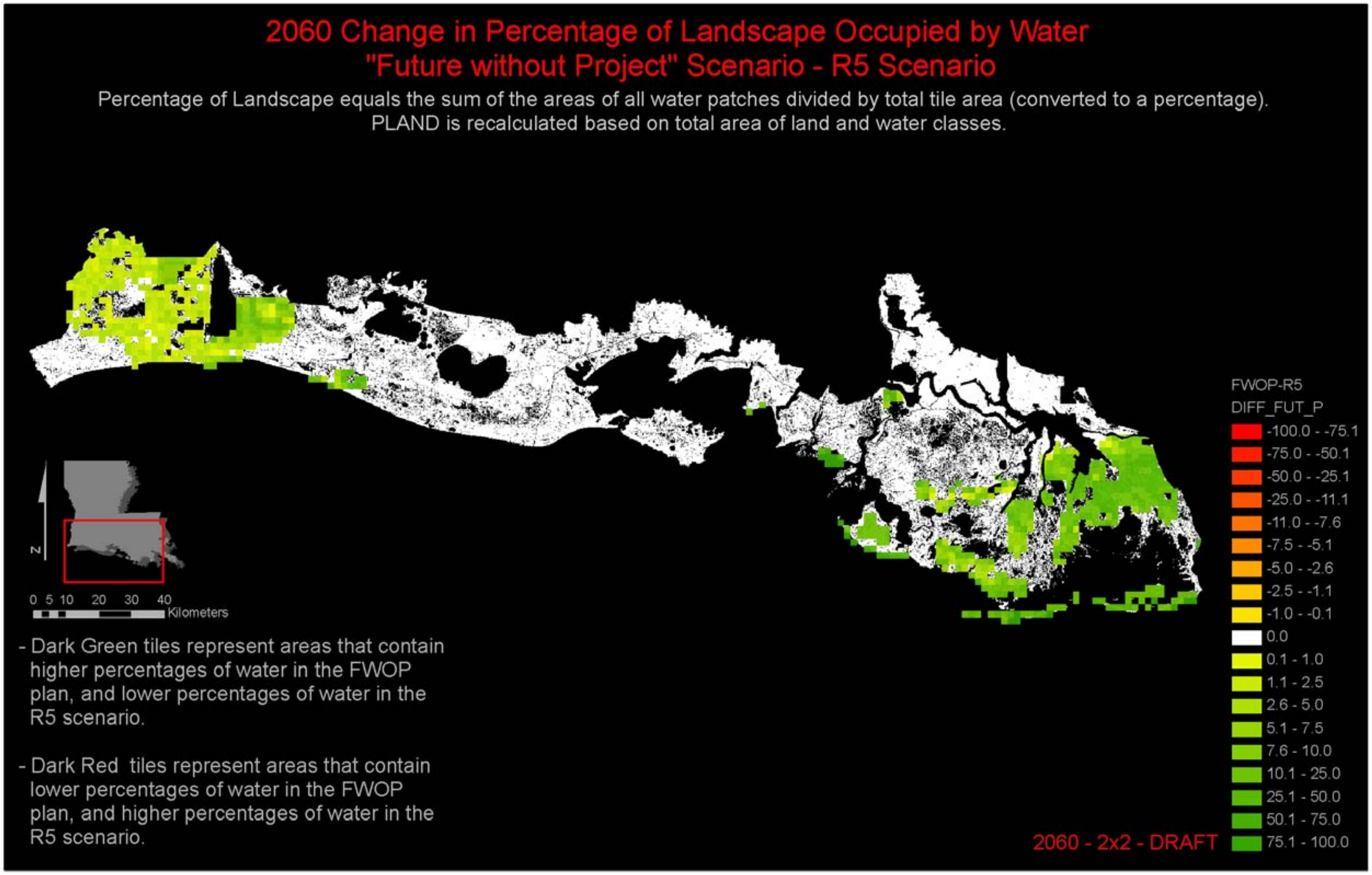


Figure 48. Percentage of landscape occupied by water metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

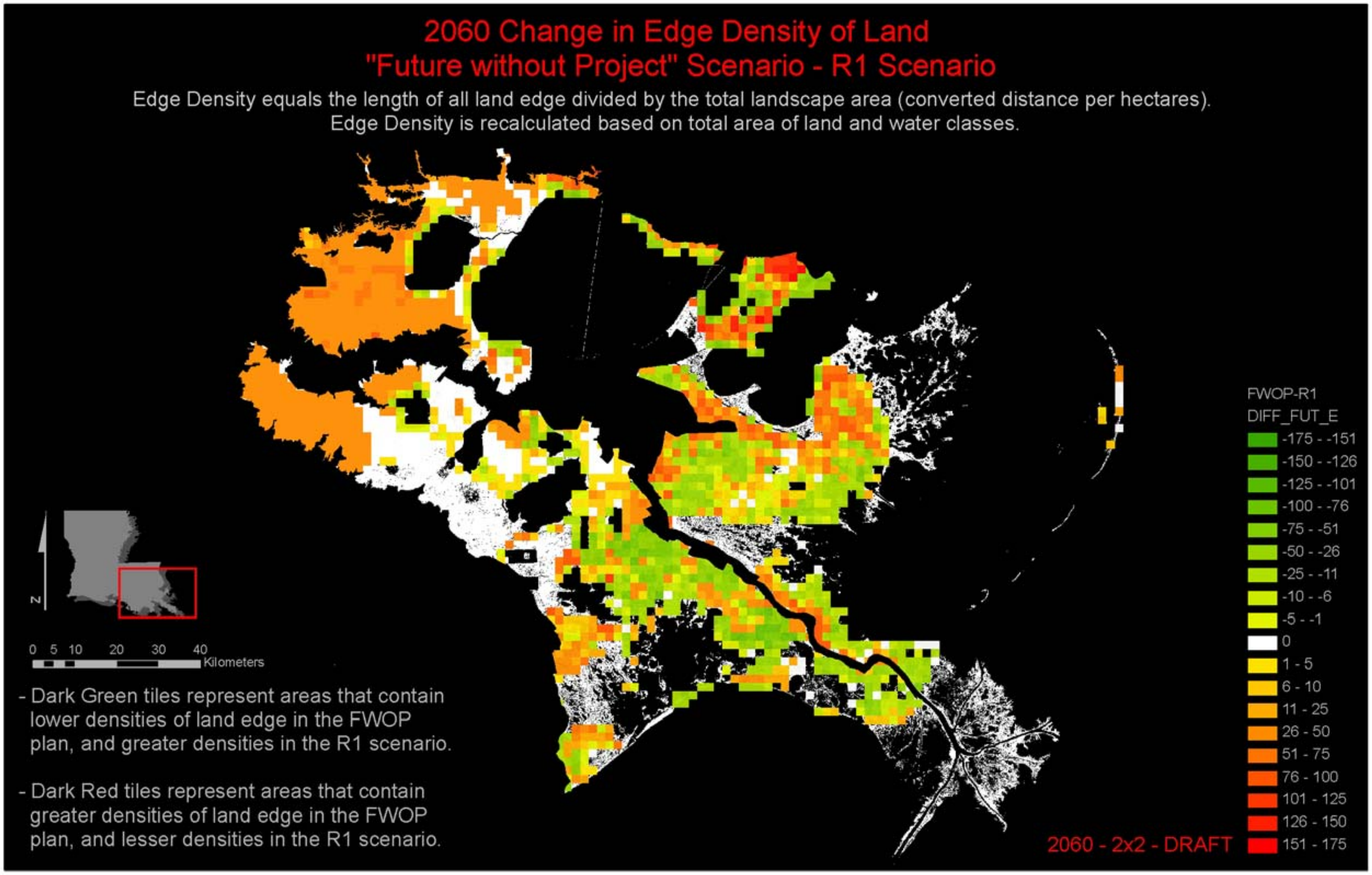


Figure 49. Edge density of land metric for planning units 1 and 2 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

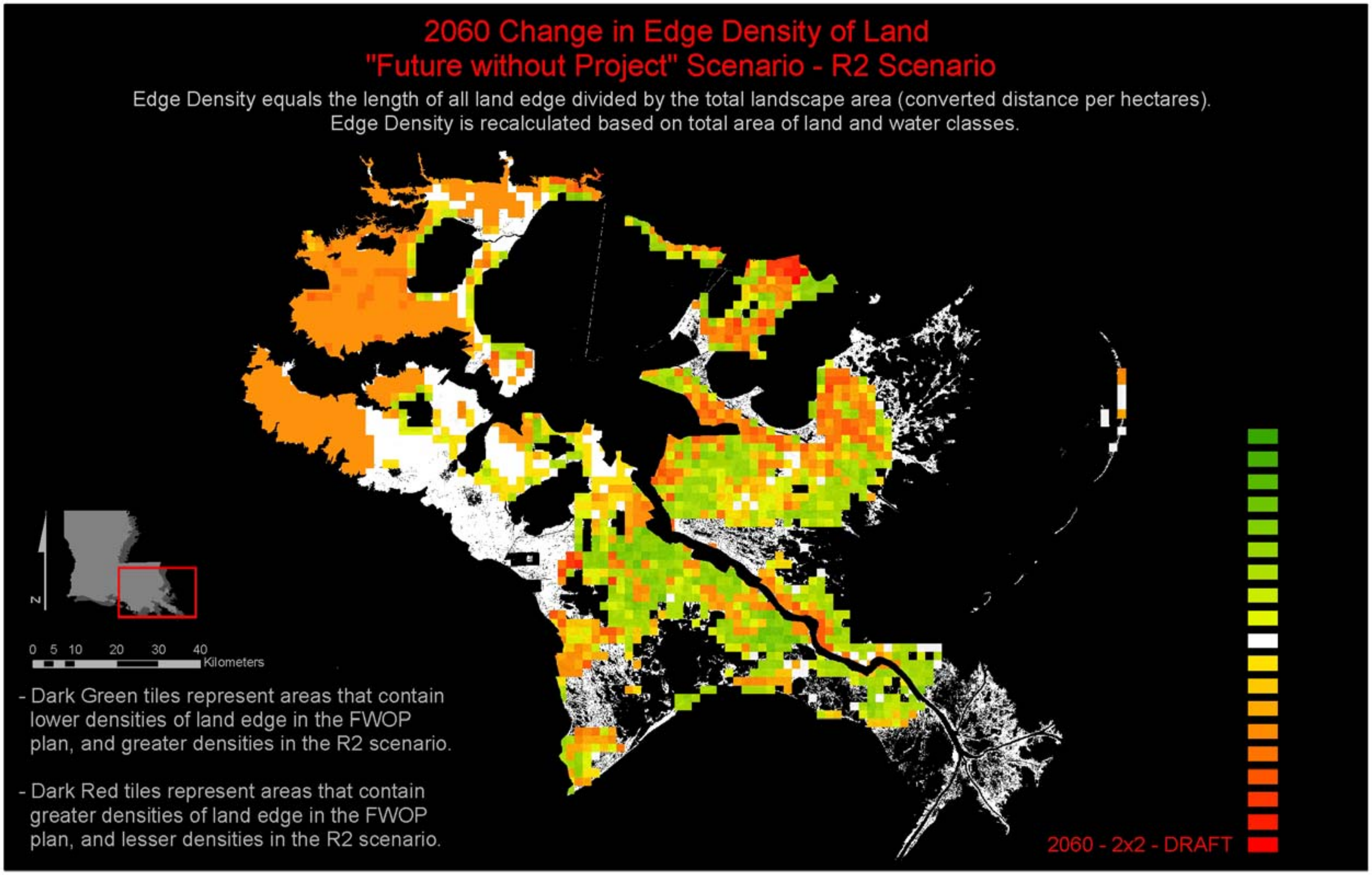


Figure 50. Edge density of land metric for planning units 1 and 2 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

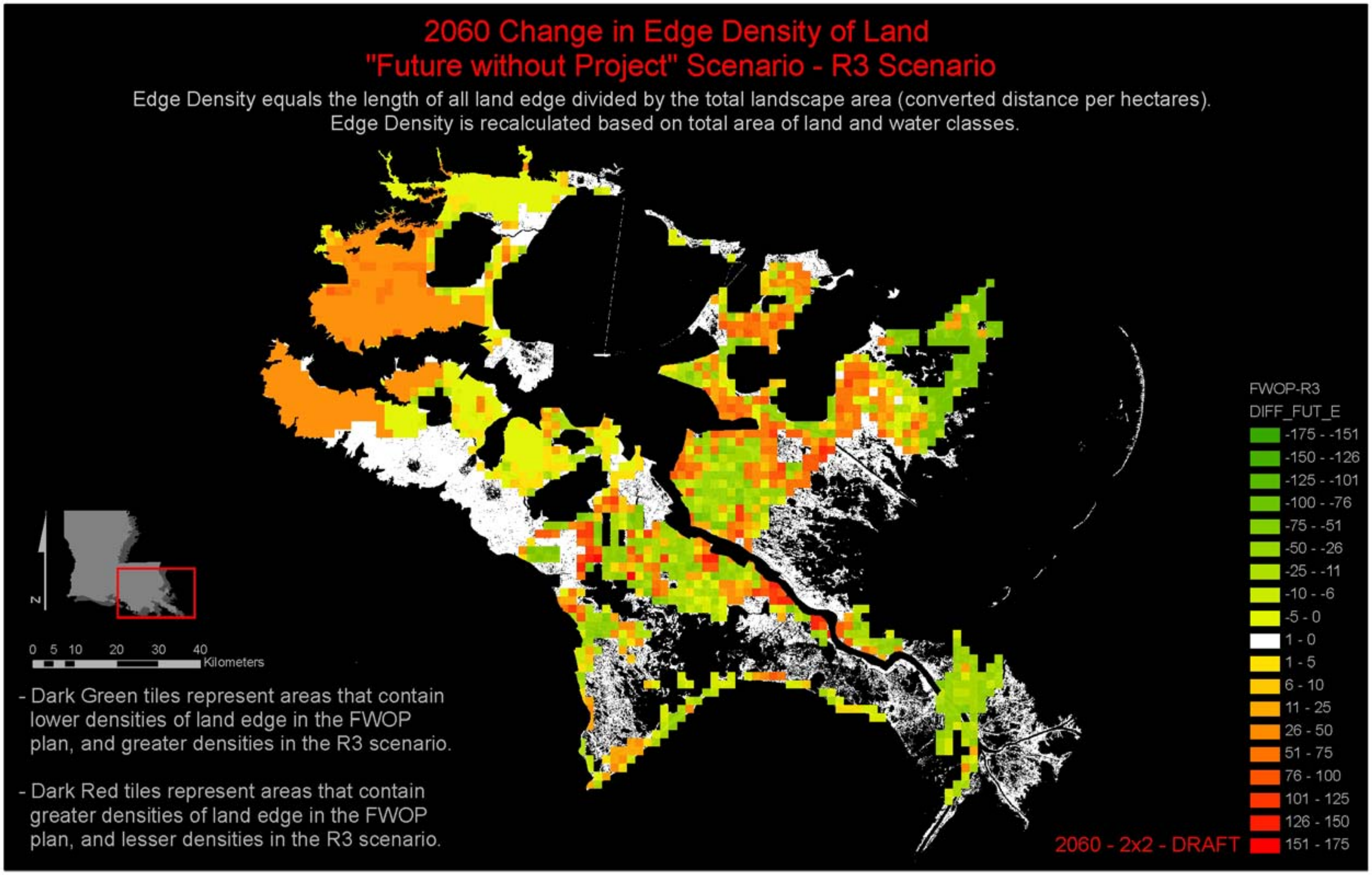


Figure 51. Edge density of land metric for planning units 1 and 2 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

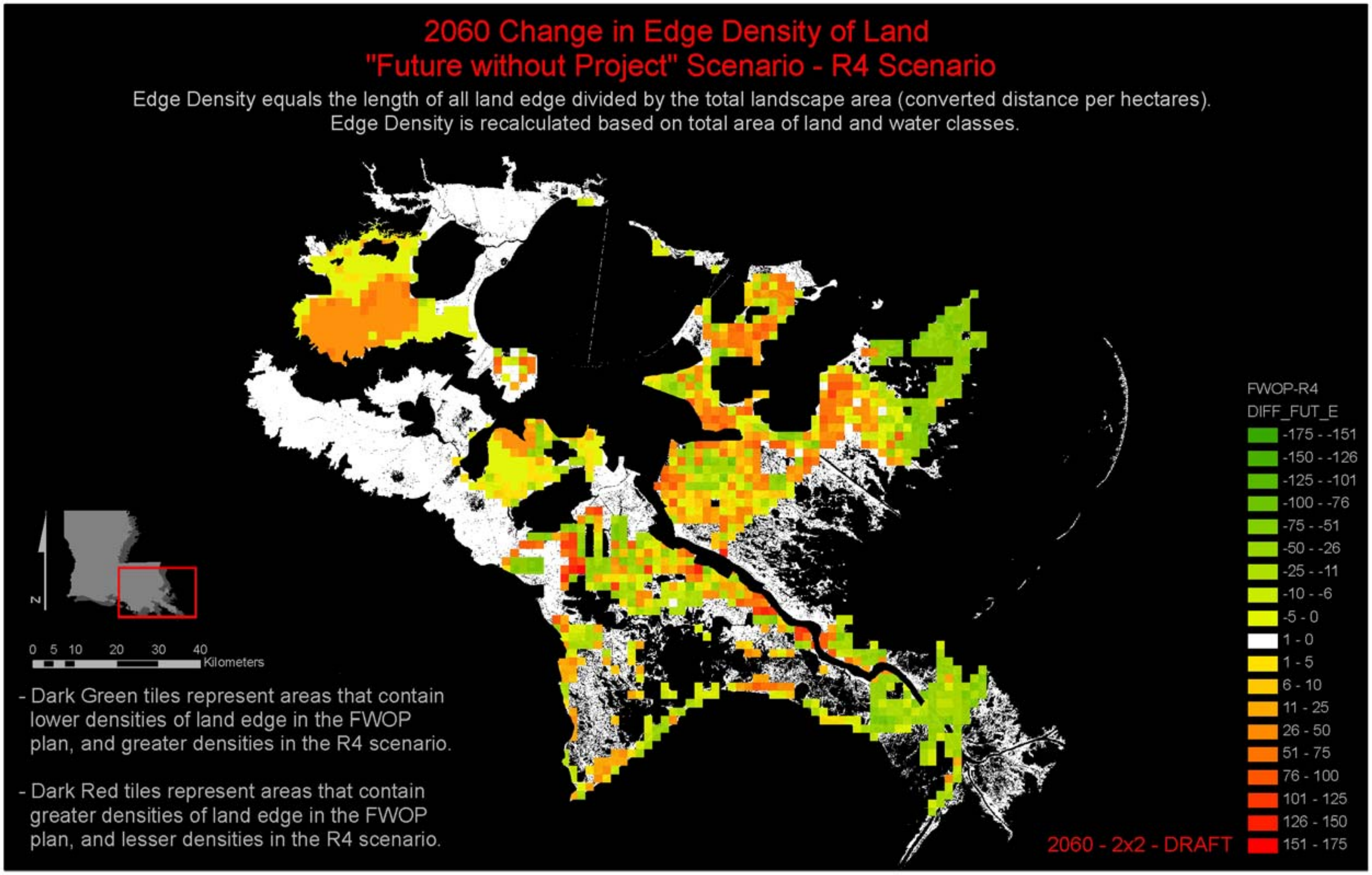


Figure 52. Edge density of land metric for planning units 1 and 2 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

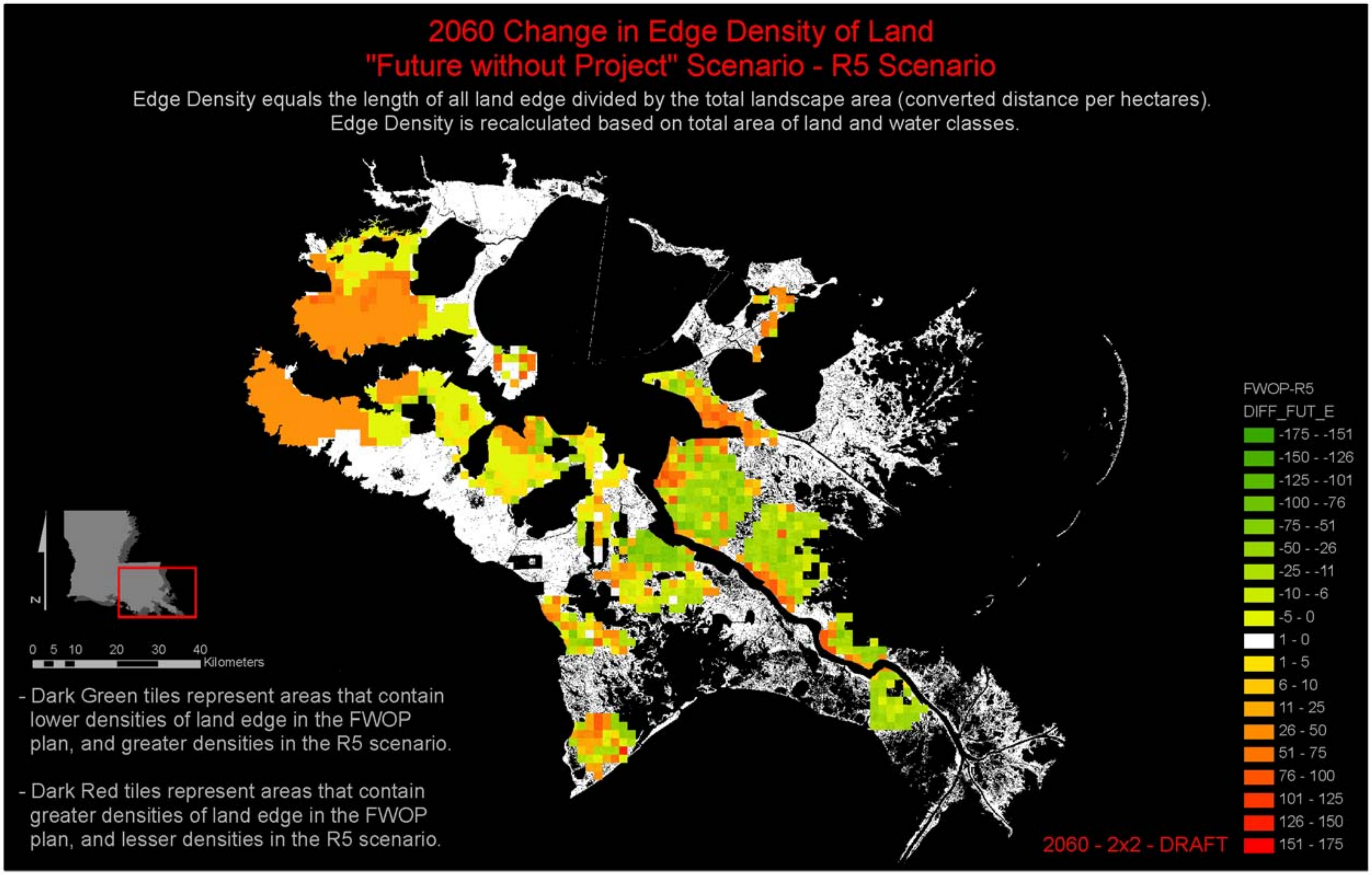


Figure 53. Edge density of land metric for planning units 1 and 2 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

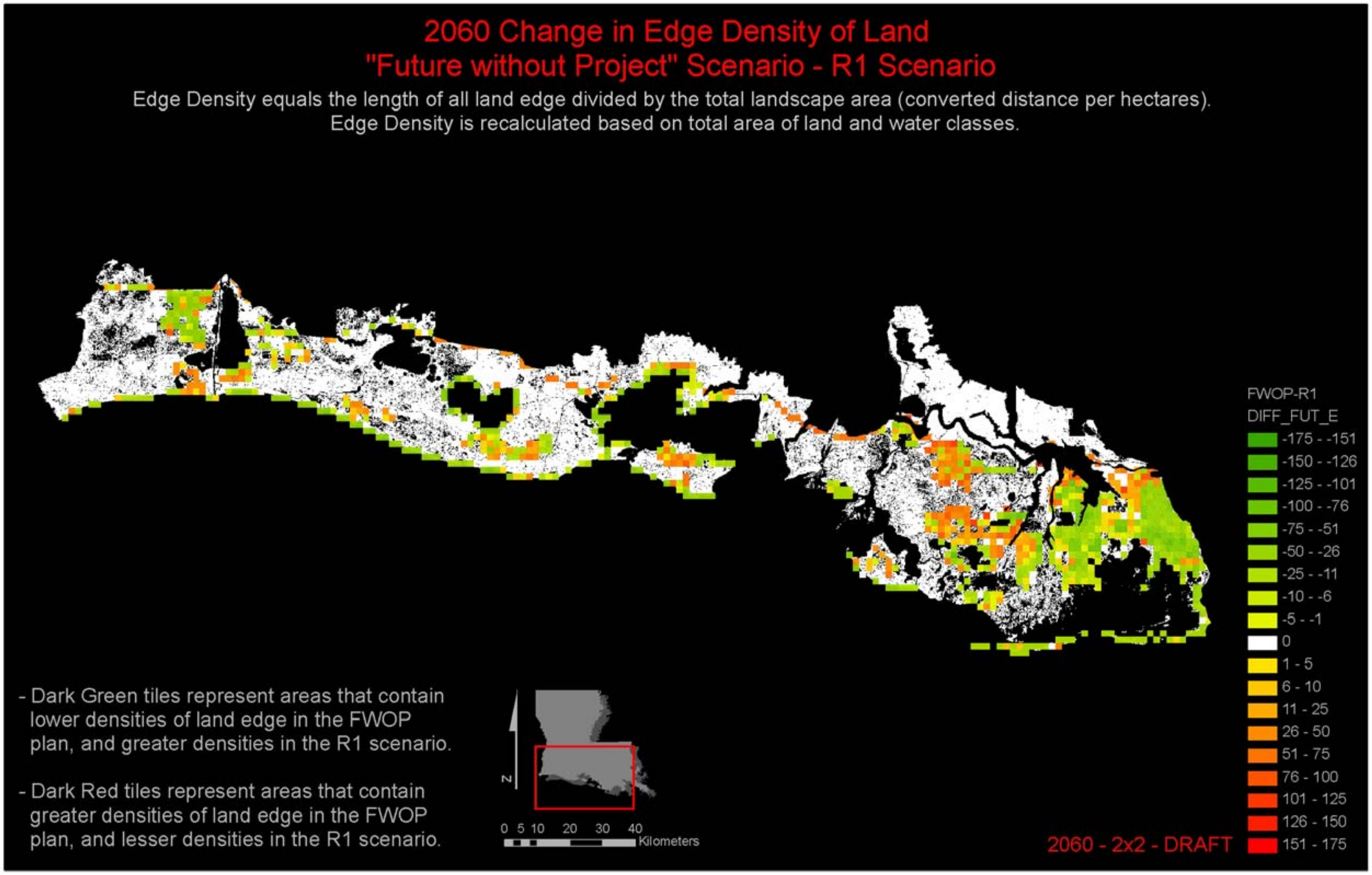


Figure 54. Edge density of land metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

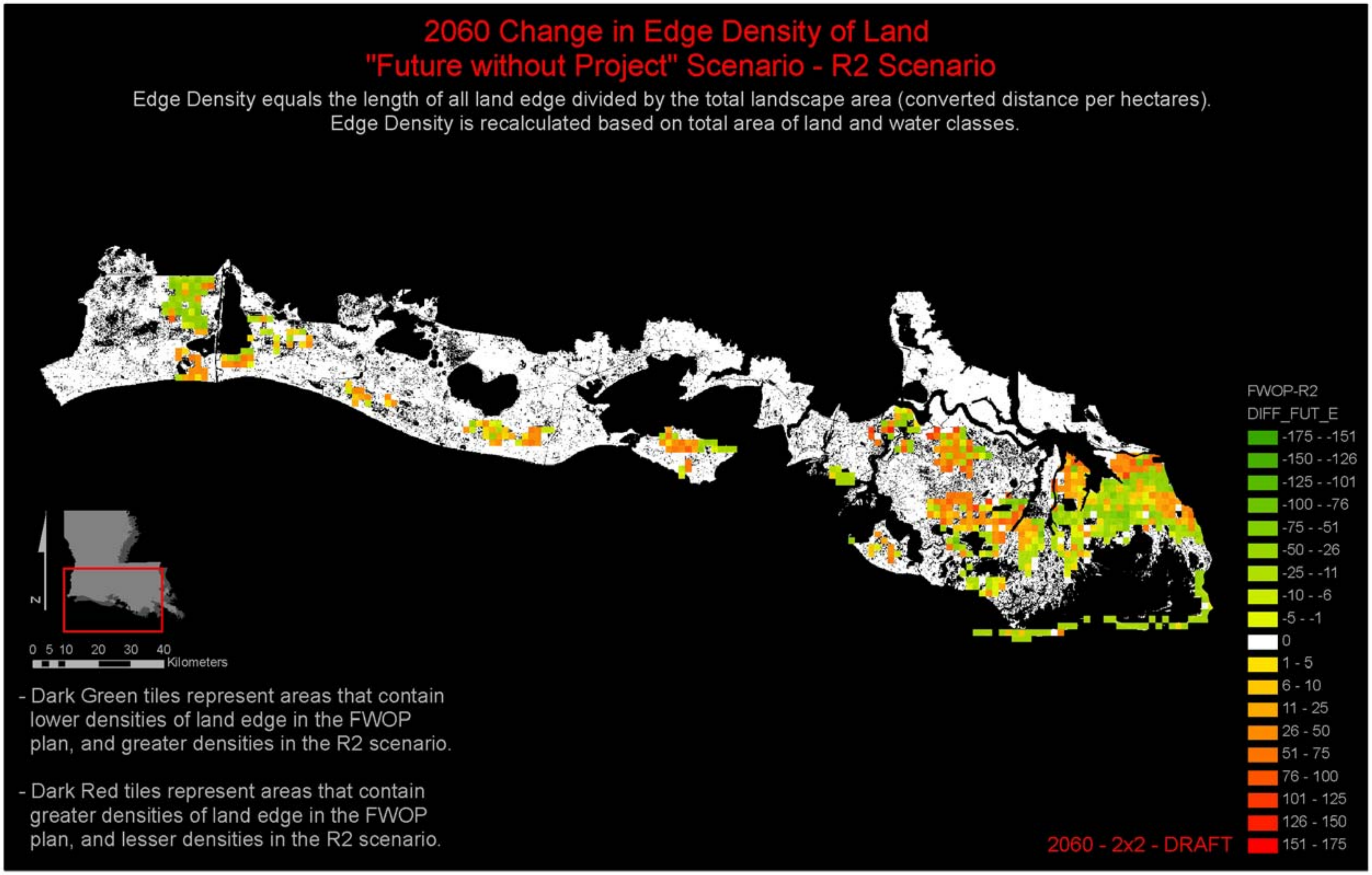


Figure 55. Edge density of land metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

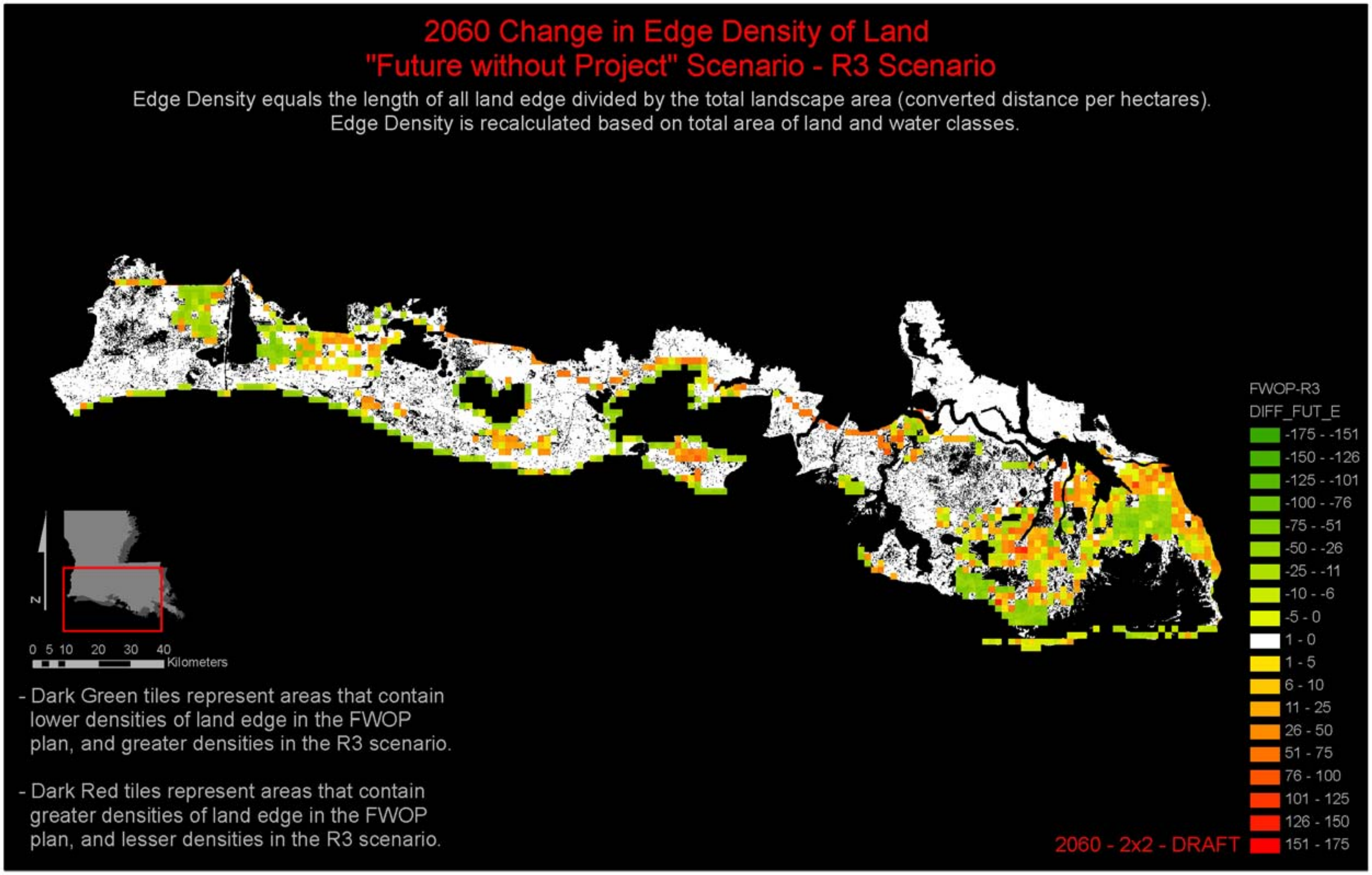


Figure 56. Edge density of land metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

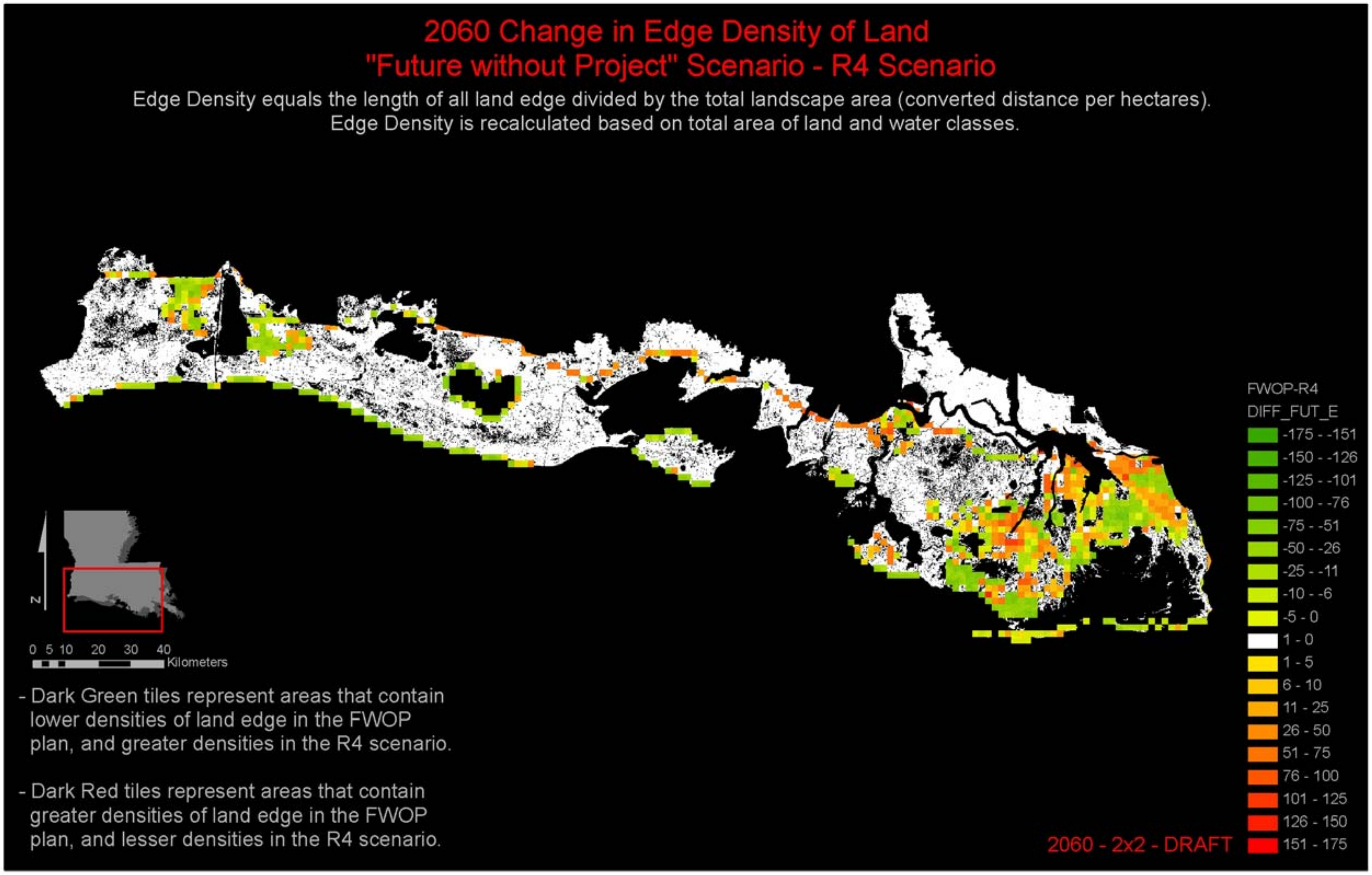


Figure 57. Edge density of land metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

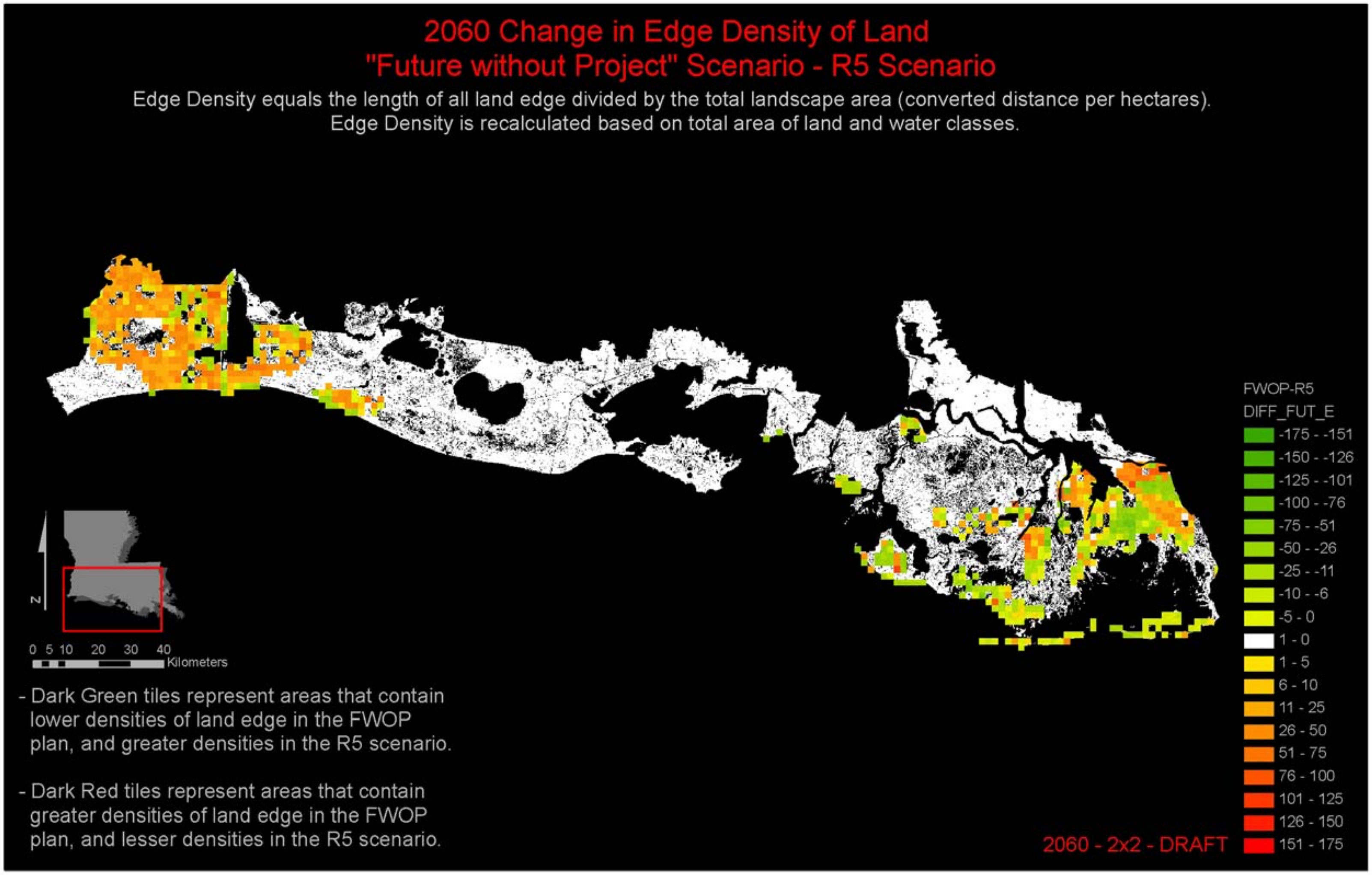


Figure 58. Edge density of land metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

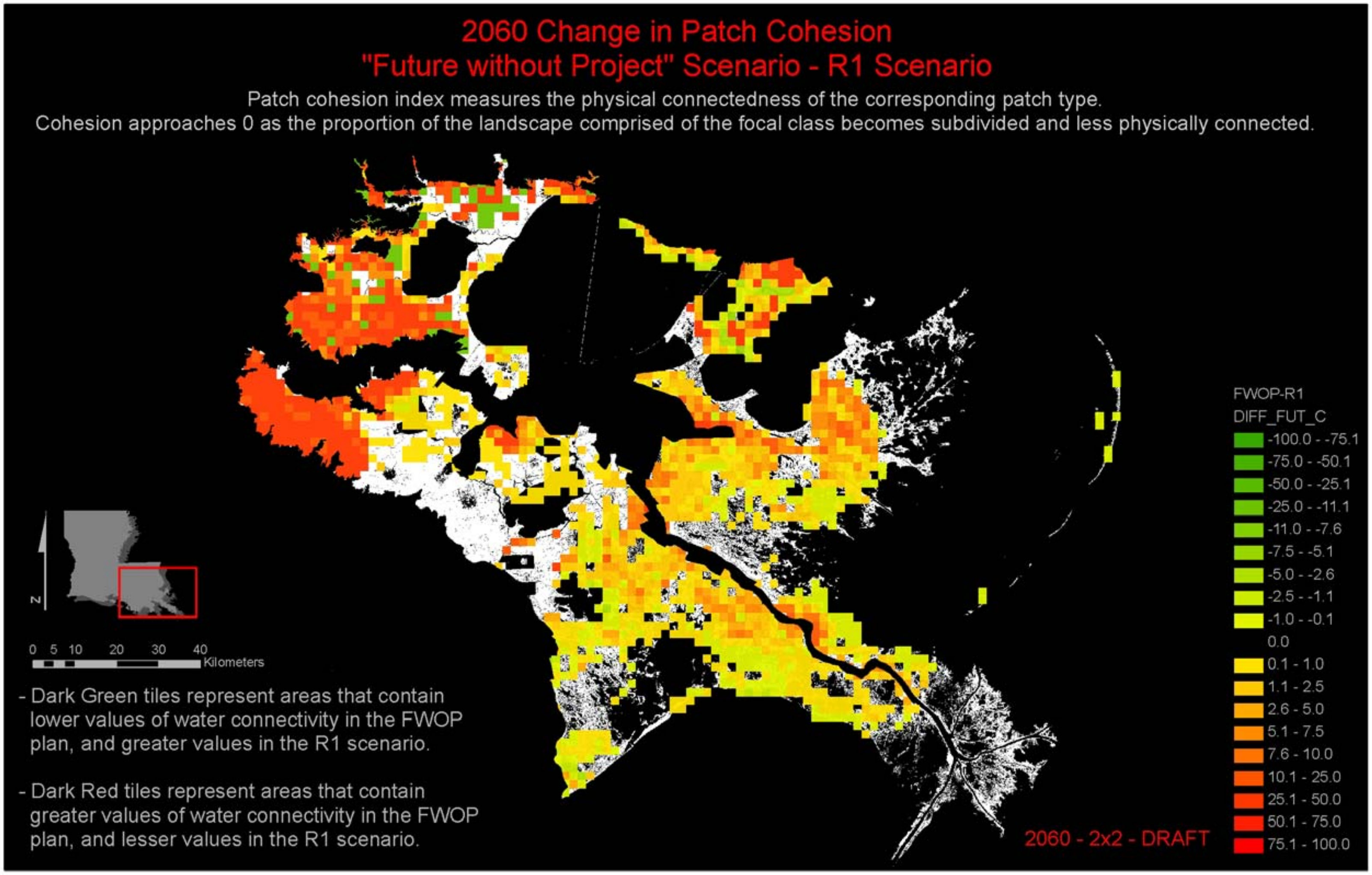


Figure 59. Patch cohesion metric for planning units 1 and 2 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

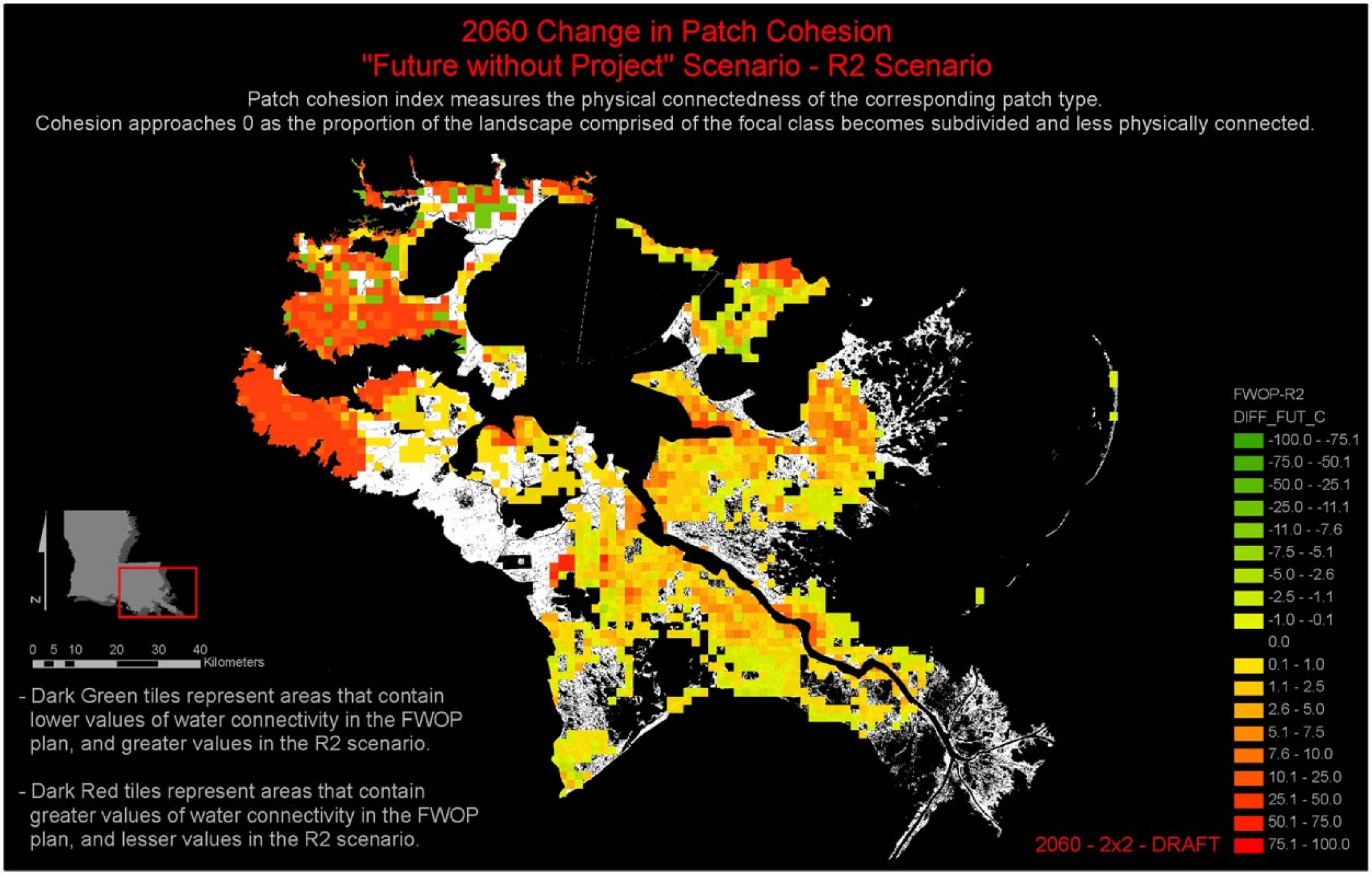


Figure 60. Patch cohesion metric for planning units 1 and 2 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

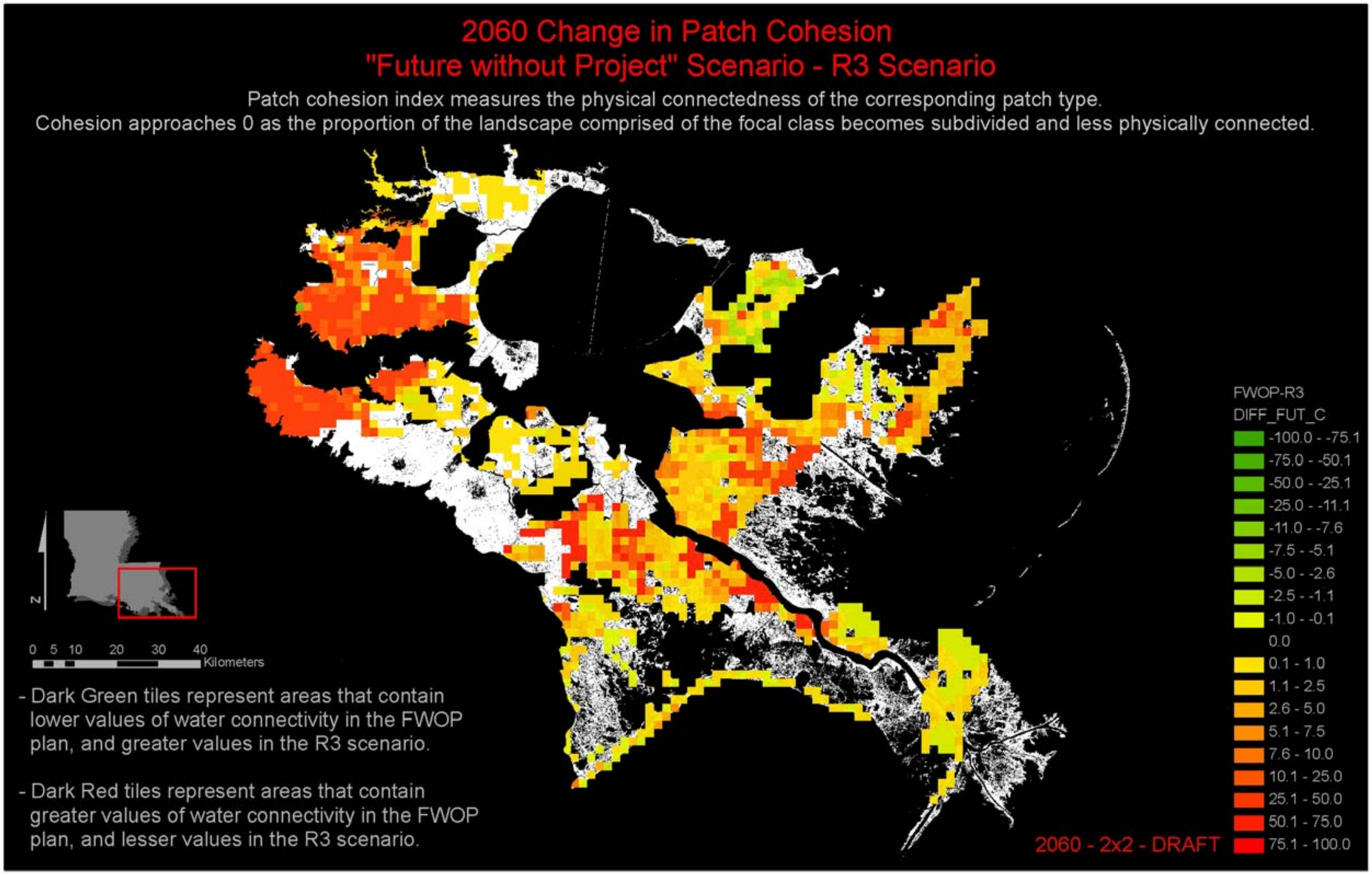


Figure 61. Patch cohesion metric for planning units 1 and 2 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

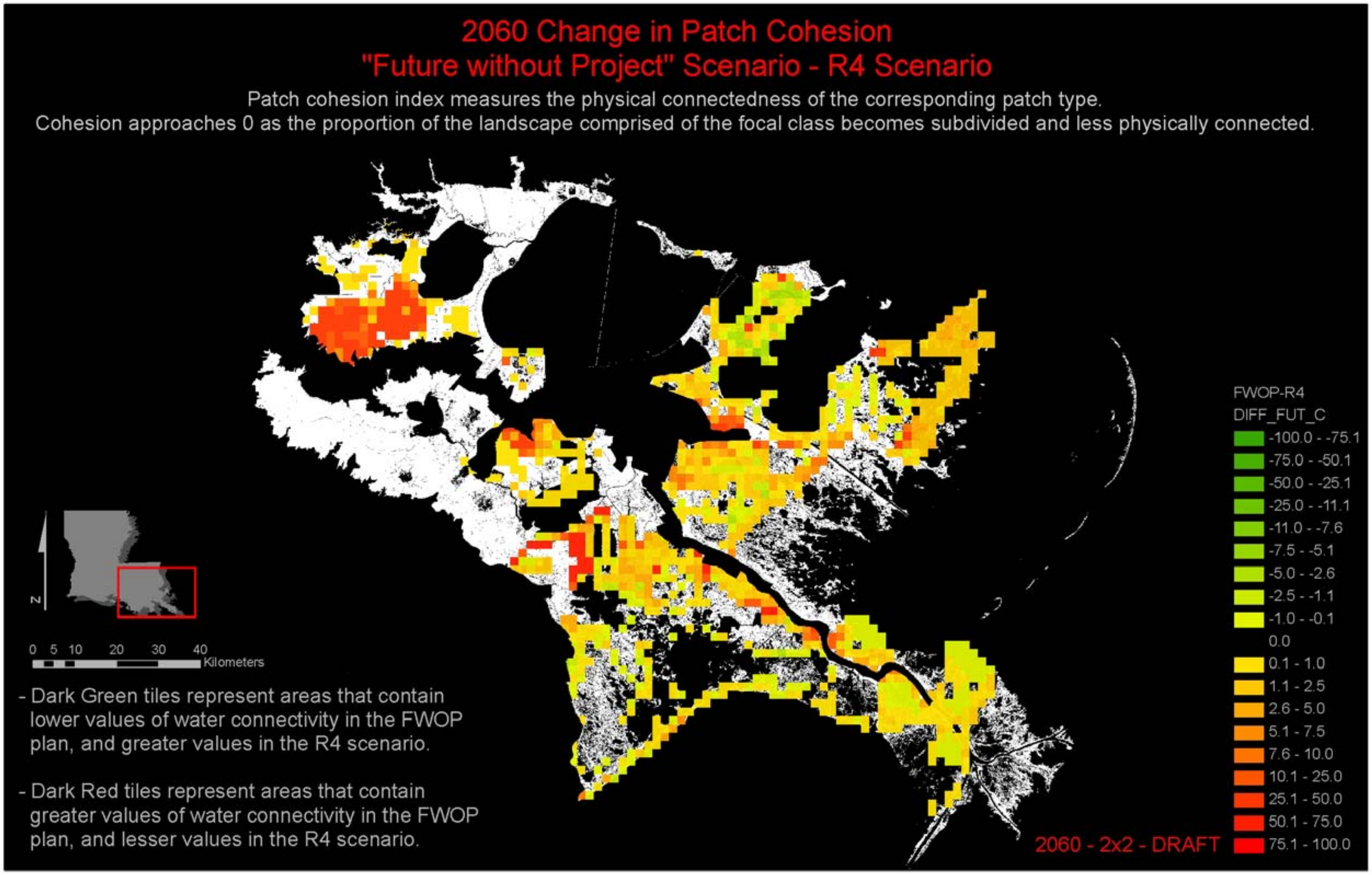


Figure 62. Patch cohesion metric for planning units 1 and 2 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

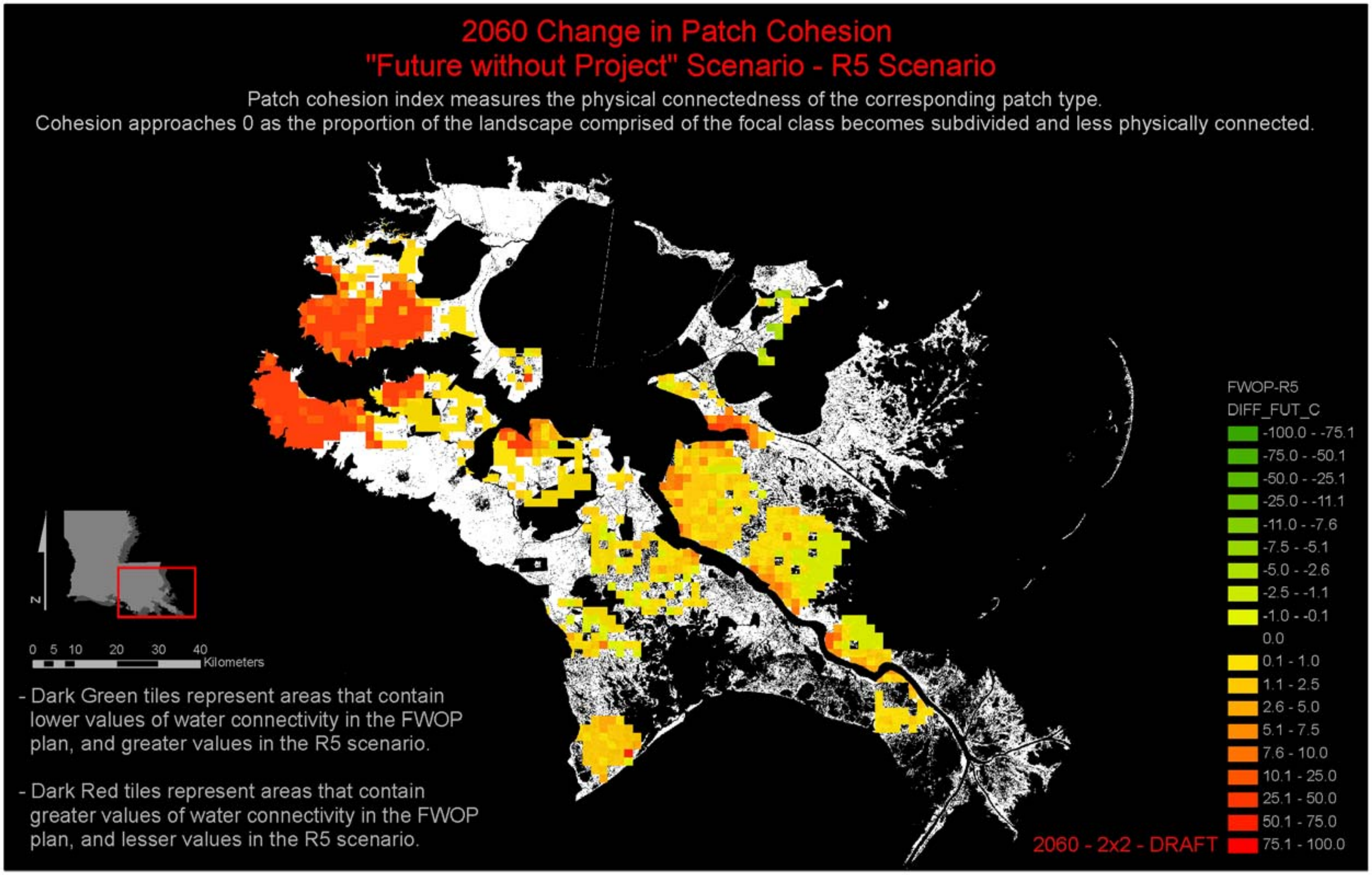


Figure 63. Patch cohesion metric for planning units 1 and 2 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

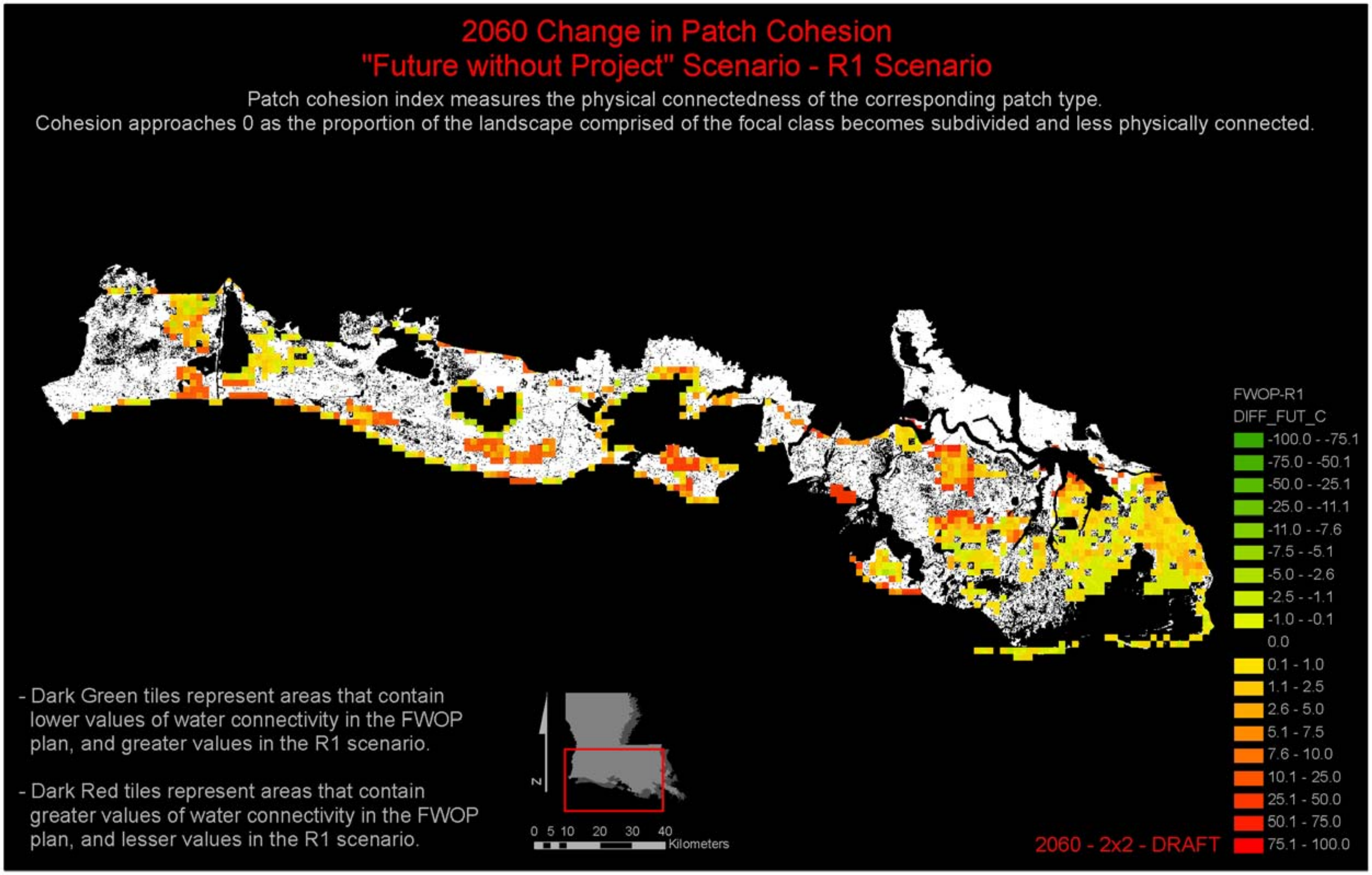


Figure 64. Patch cohesion metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R1 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

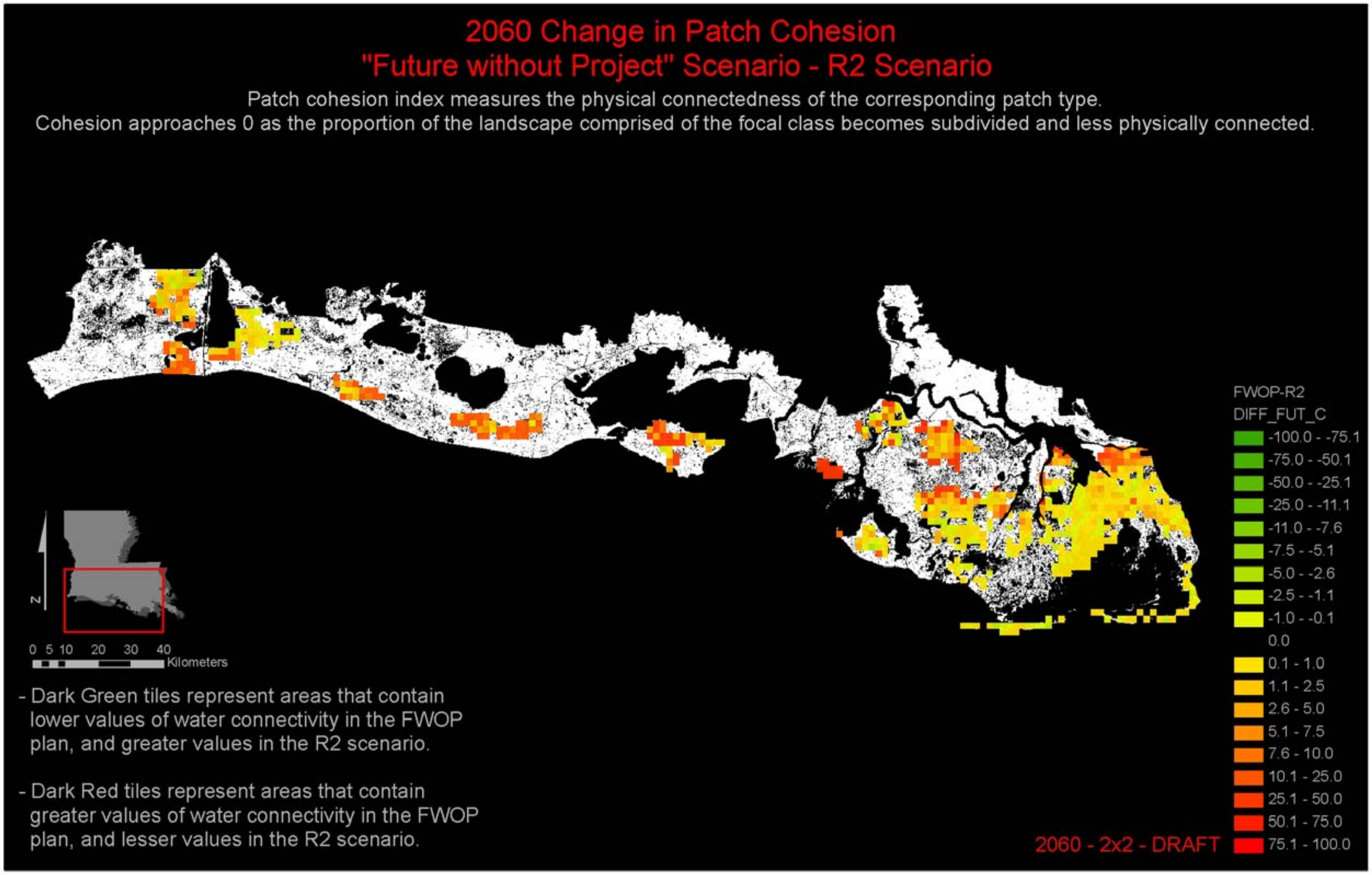


Figure 65. Patch cohesion metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R2 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

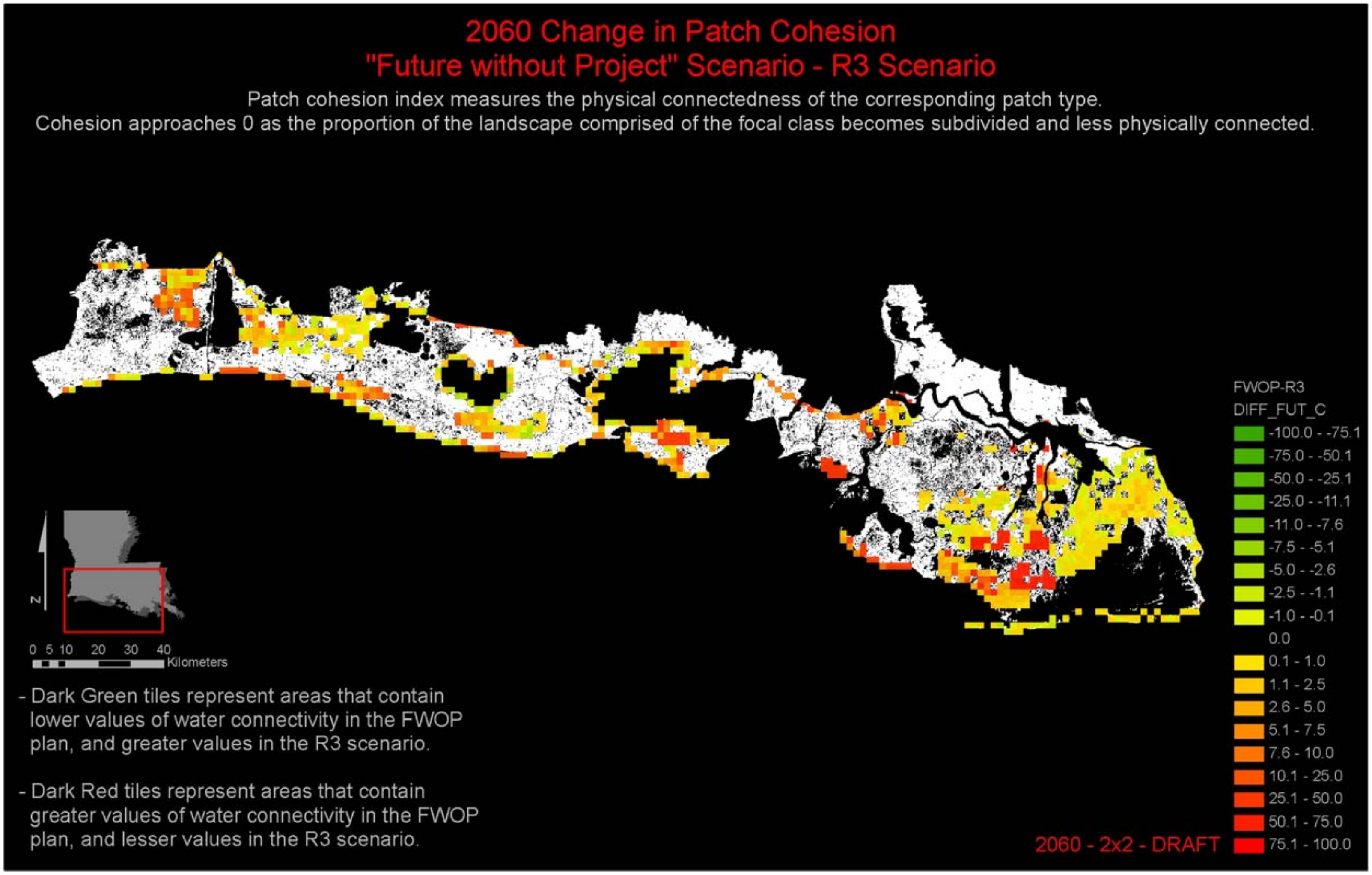


Figure 66. Patch cohesion metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R3 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

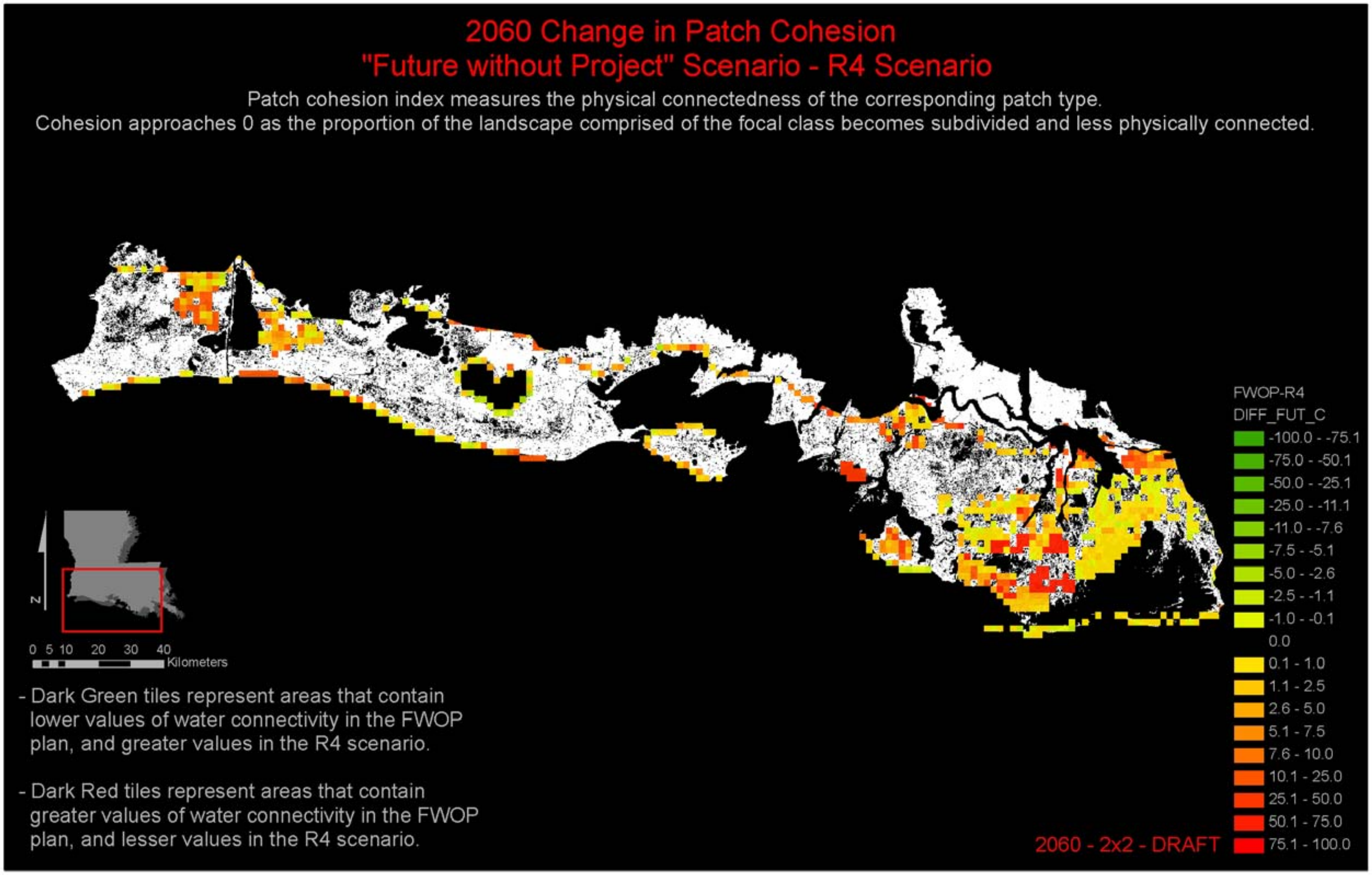


Figure 67. Patch cohesion metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R4 at 2060. Colored areas reflect influences of specific measures that comprise alternative.

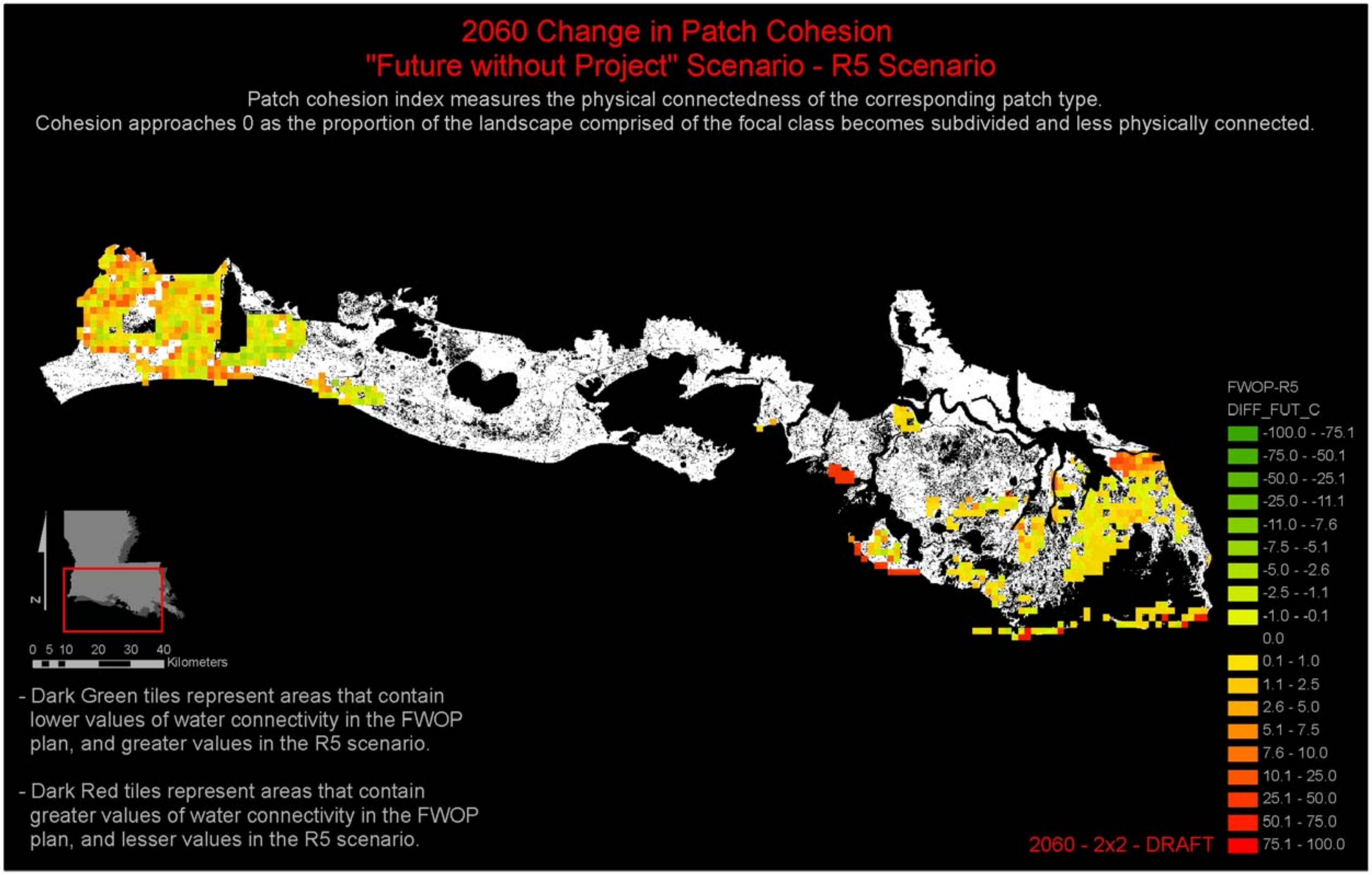
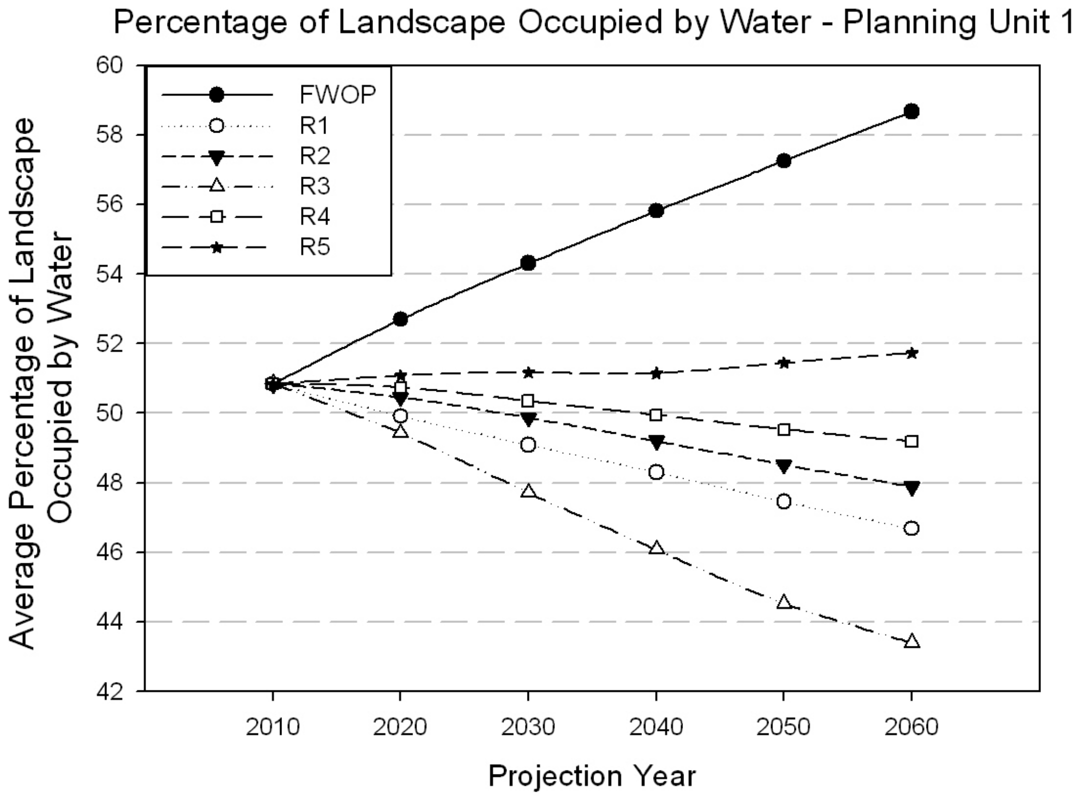


Figure 68. Patch cohesion metric for planning units 3a, 3b and 4 showing difference between future without project and Alternative R5 at 2060. Colored areas reflect influences of specific measures that comprise alternative.



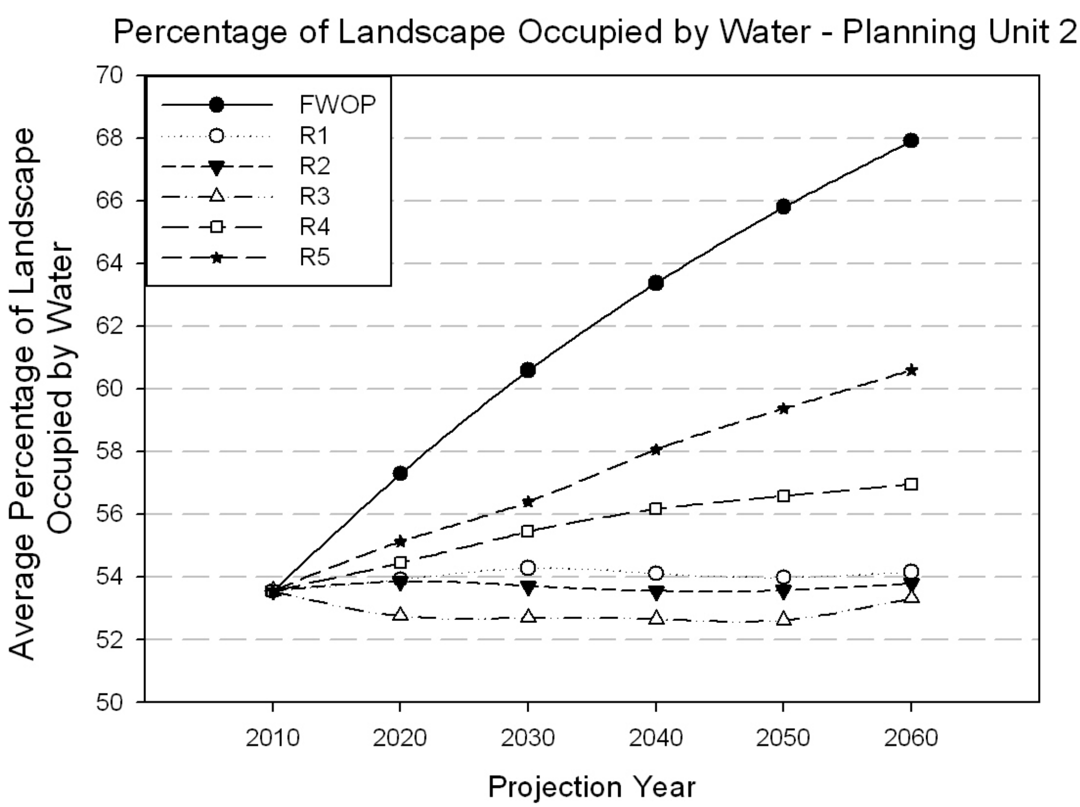
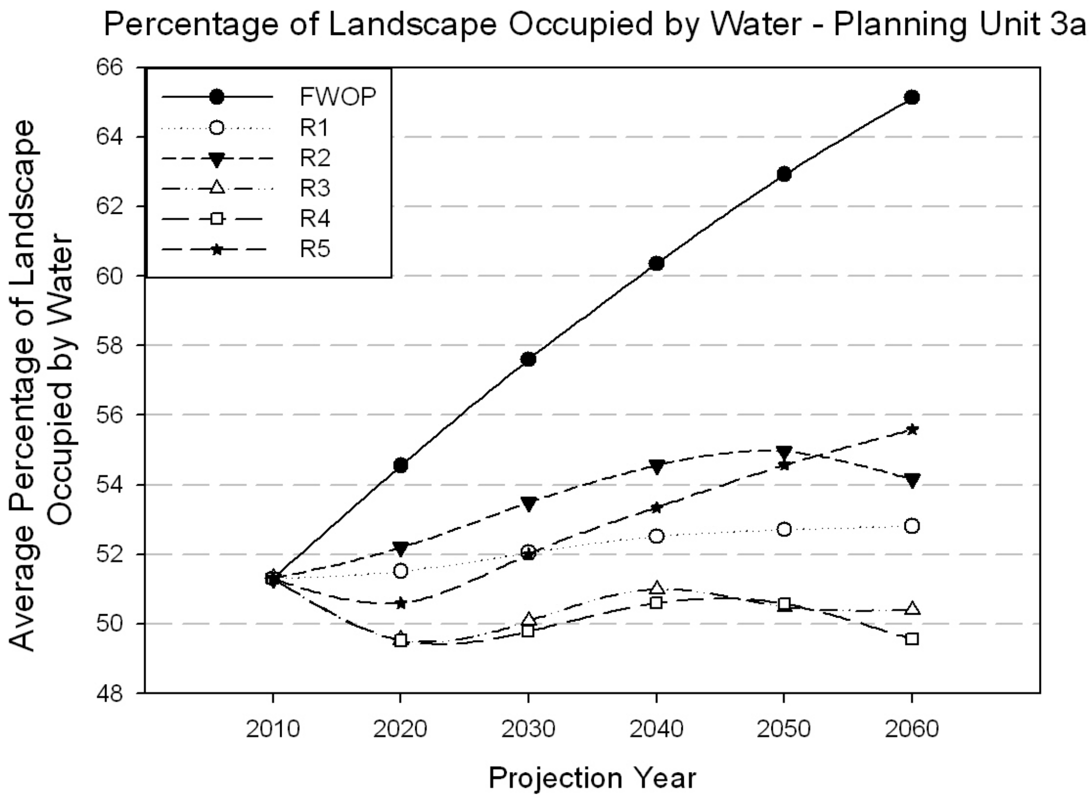


Figure 69. Projections of change in average percent of landscape occupied by water metric among alternatives from 2010 to 2060 in planning units 1 and 2.



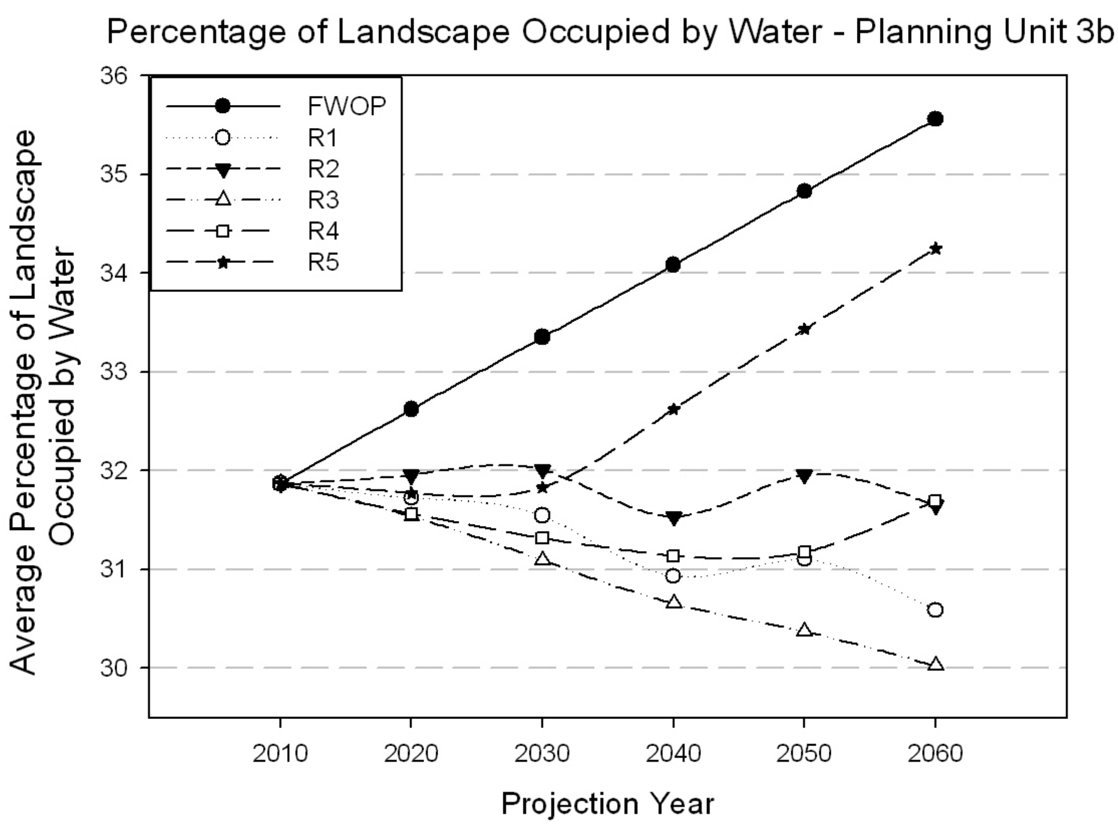


Figure 70a. Projections of change in average percent of landscape occupied by water metric among alternatives from 2010 to 2060 in planning units 3a and 3b.

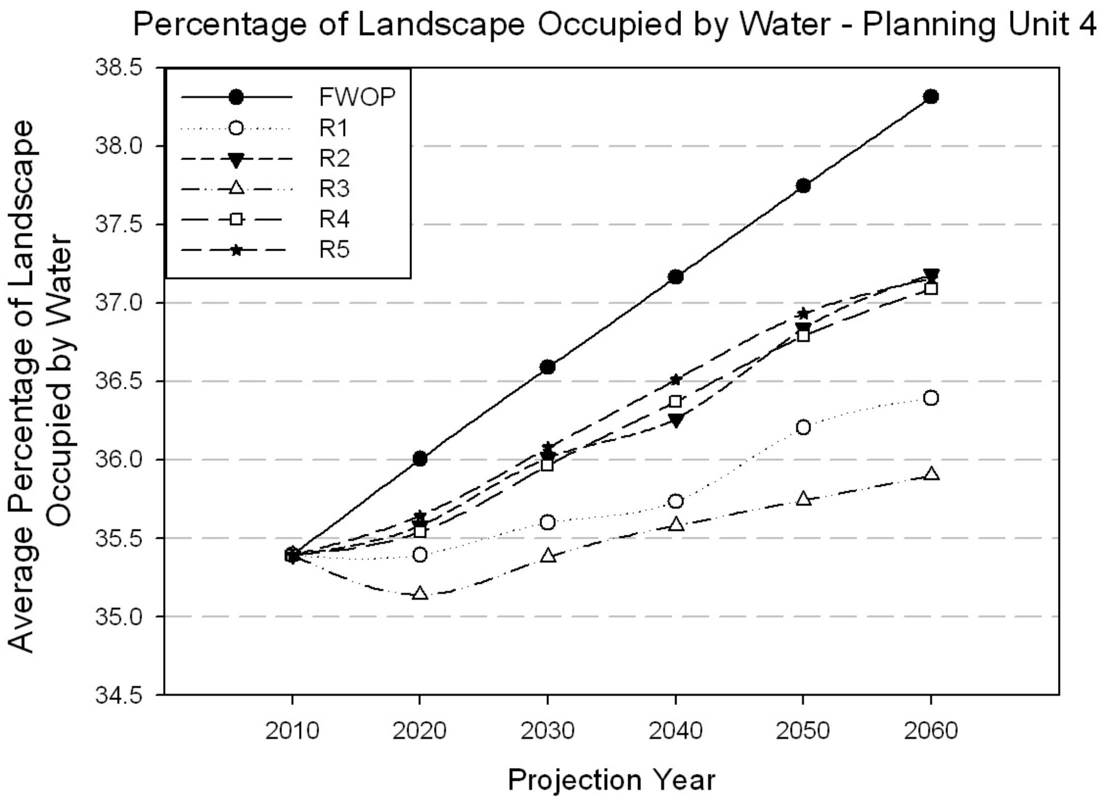


Figure 70b. Projections of change in average percent of landscape occupied by water metric among alternatives from 2010 to 2060 in planning unit 4.

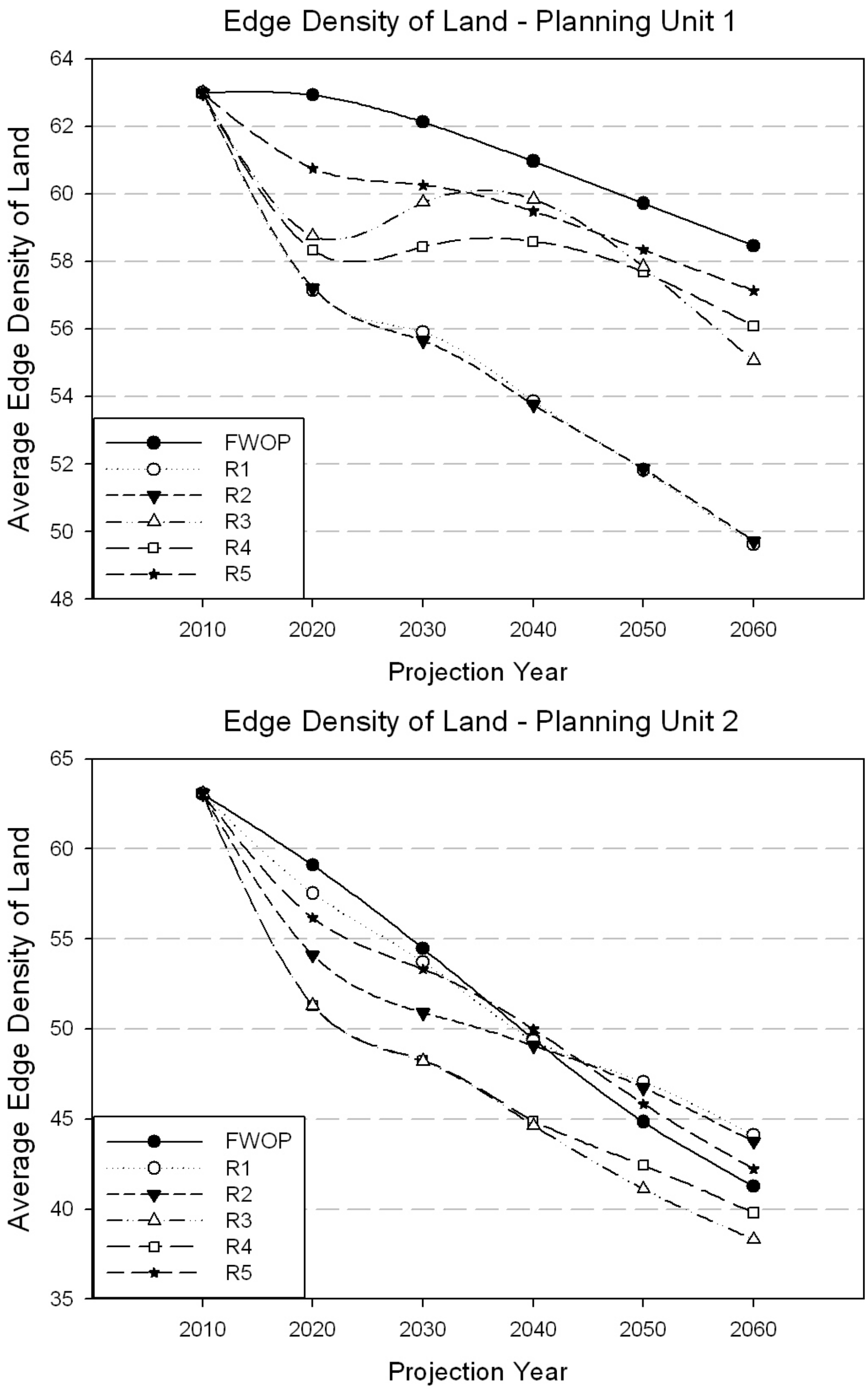


Figure 71. Projections of change in edge density of land metric among alternatives from 2010 to 2060 in planning units 1 and 2.

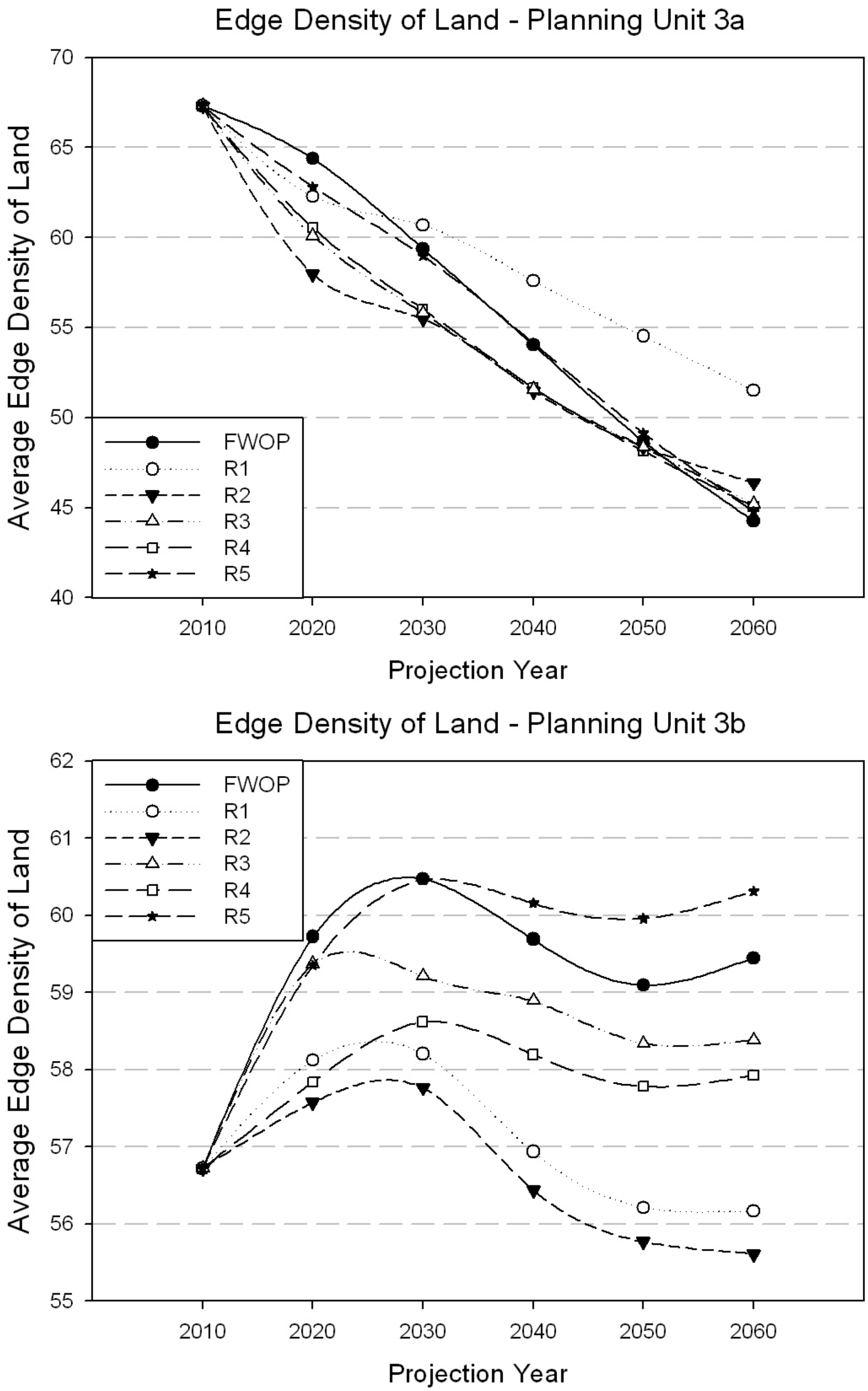


Figure 72a. Projections of change in edge density of land metric among alternatives from 2010 to 2060 in planning units 3a and 3b.

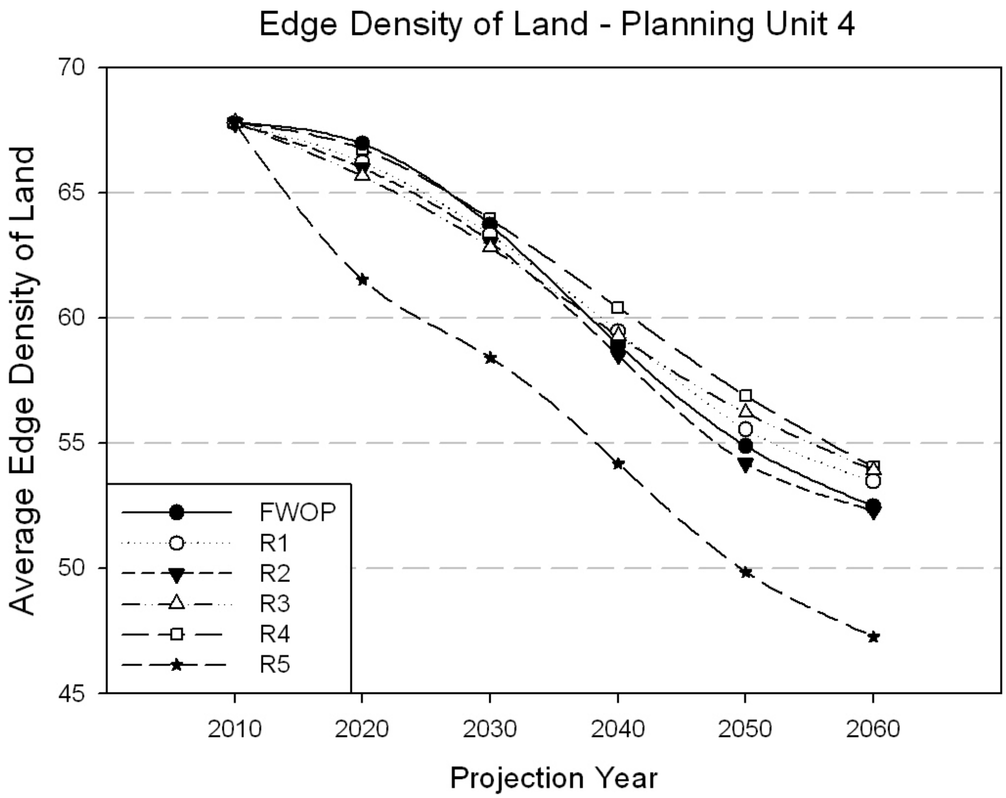


Figure 72b. Projections of change in edge density of land metric among alternatives from 2010 to 2060 in planning unit 4.

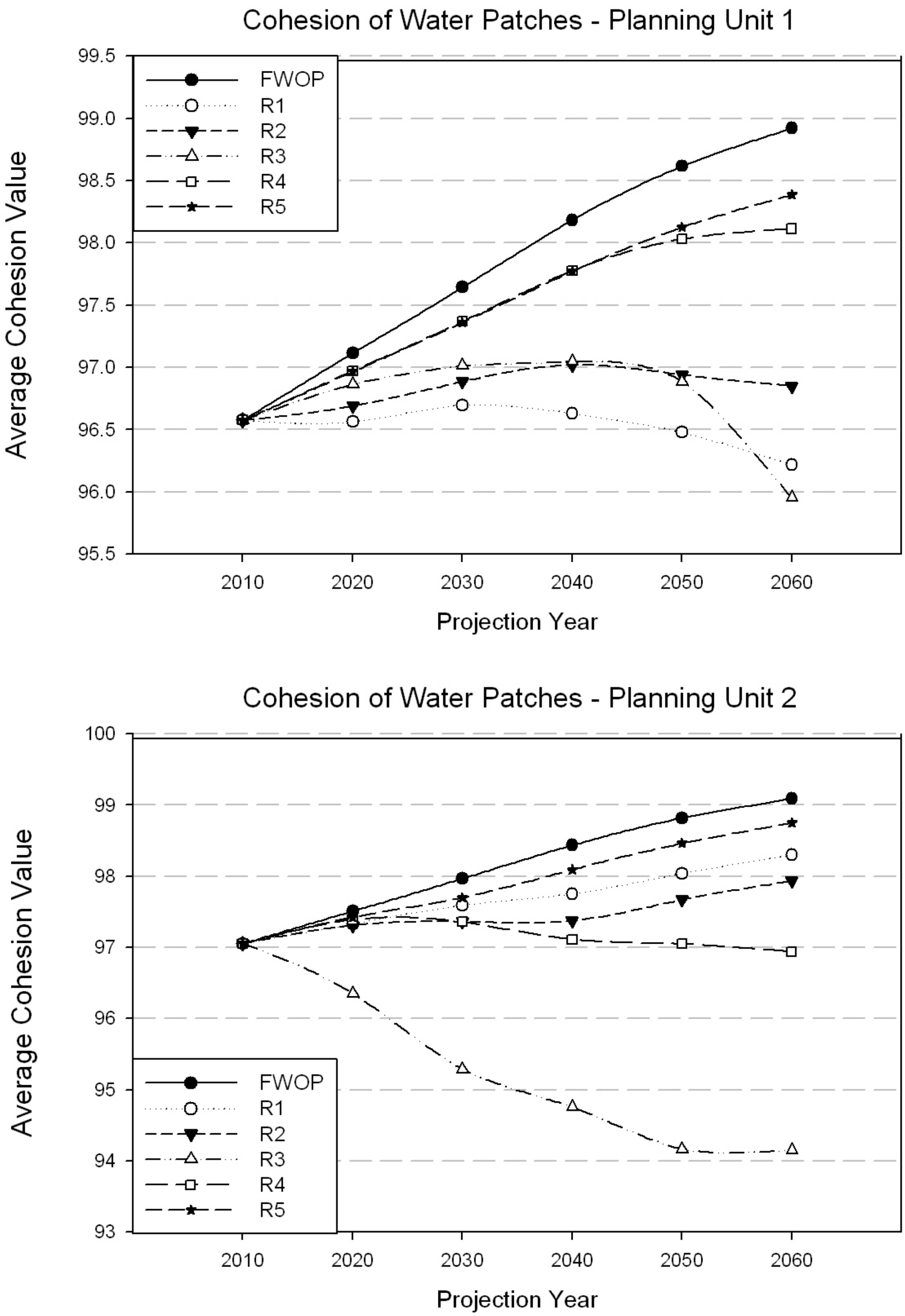
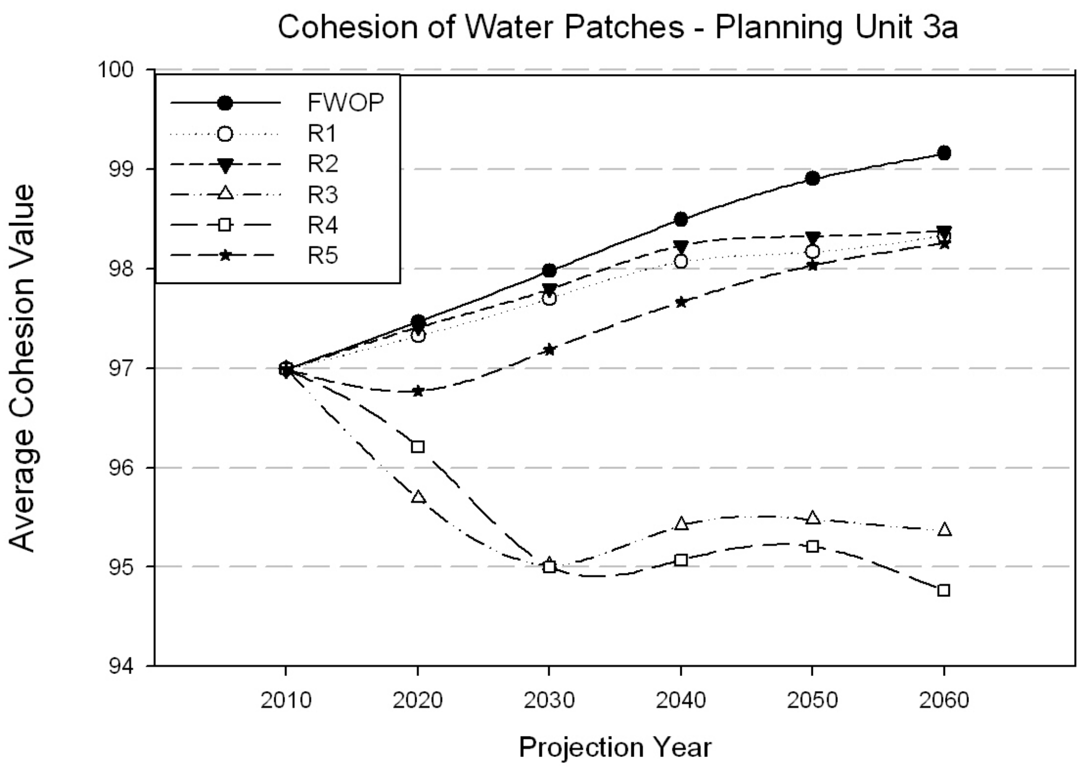


Figure 73. Projections of change in patch cohesion of water metric among alternatives from 2010 to 2060 in planning units 1 and 2.



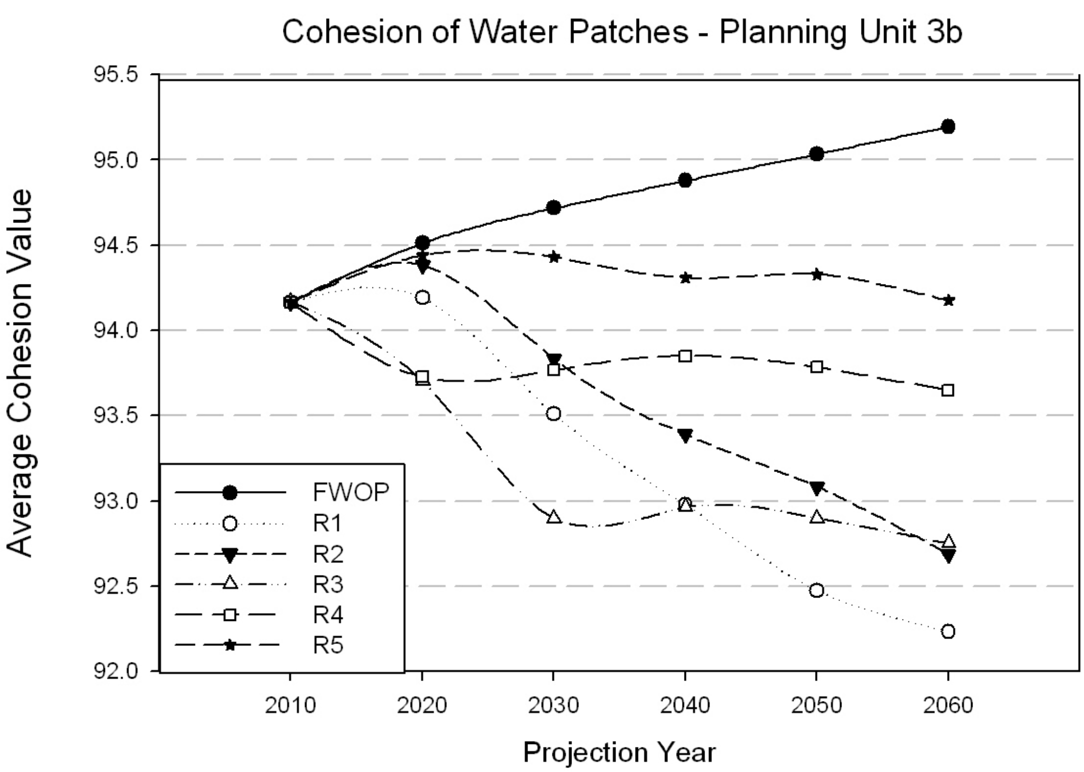


Figure 74a. Projections of change in patch cohesion of water metric among alternatives from 2010 to 2060 in planning units 3a and 3b.

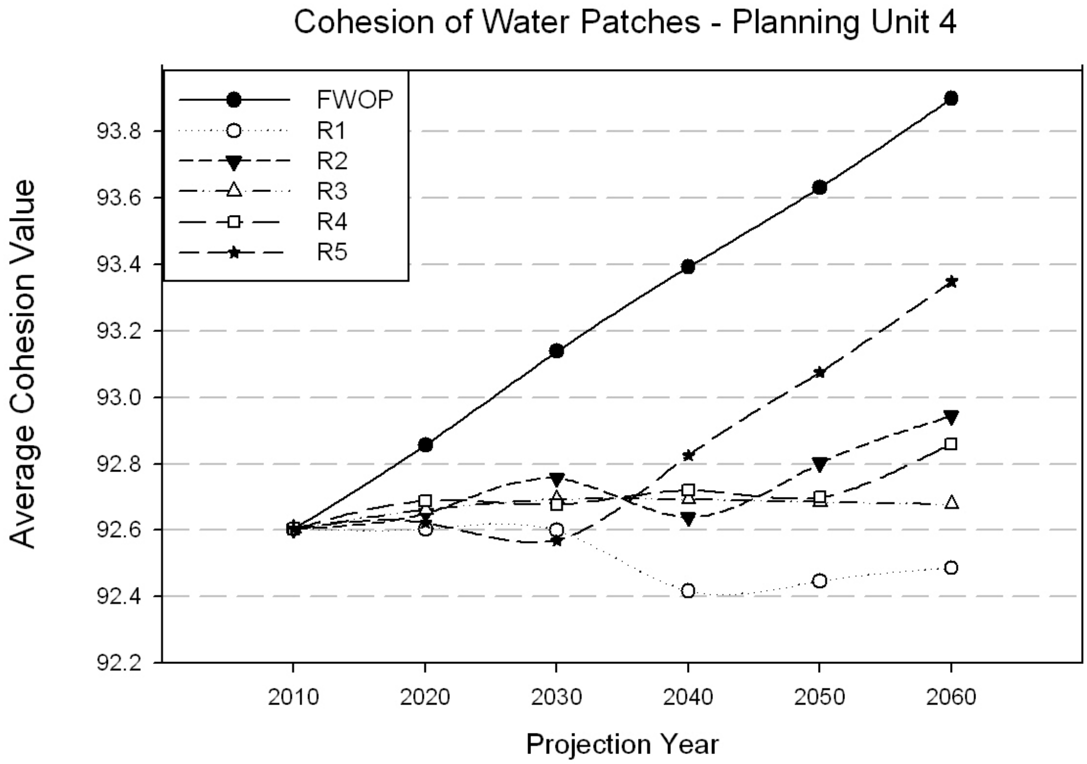


Figure 74b. Projections of change in patch cohesion of water metric among alternatives from 2010 to 2060 in planning unit 4.

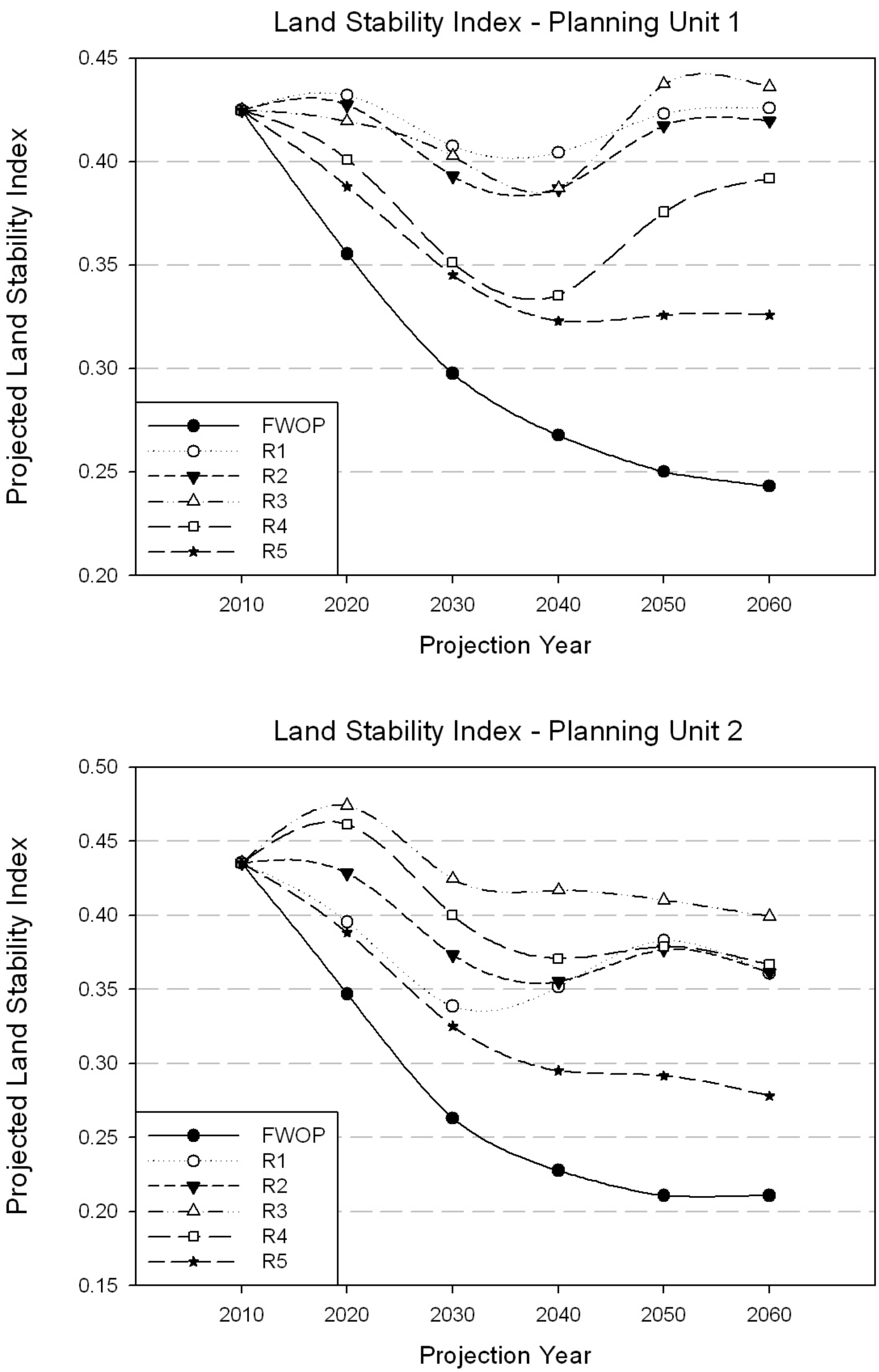


Figure 75. Projections of change in a land stability index among alternatives from 2010 to 2060 in planning units 1 and 2.

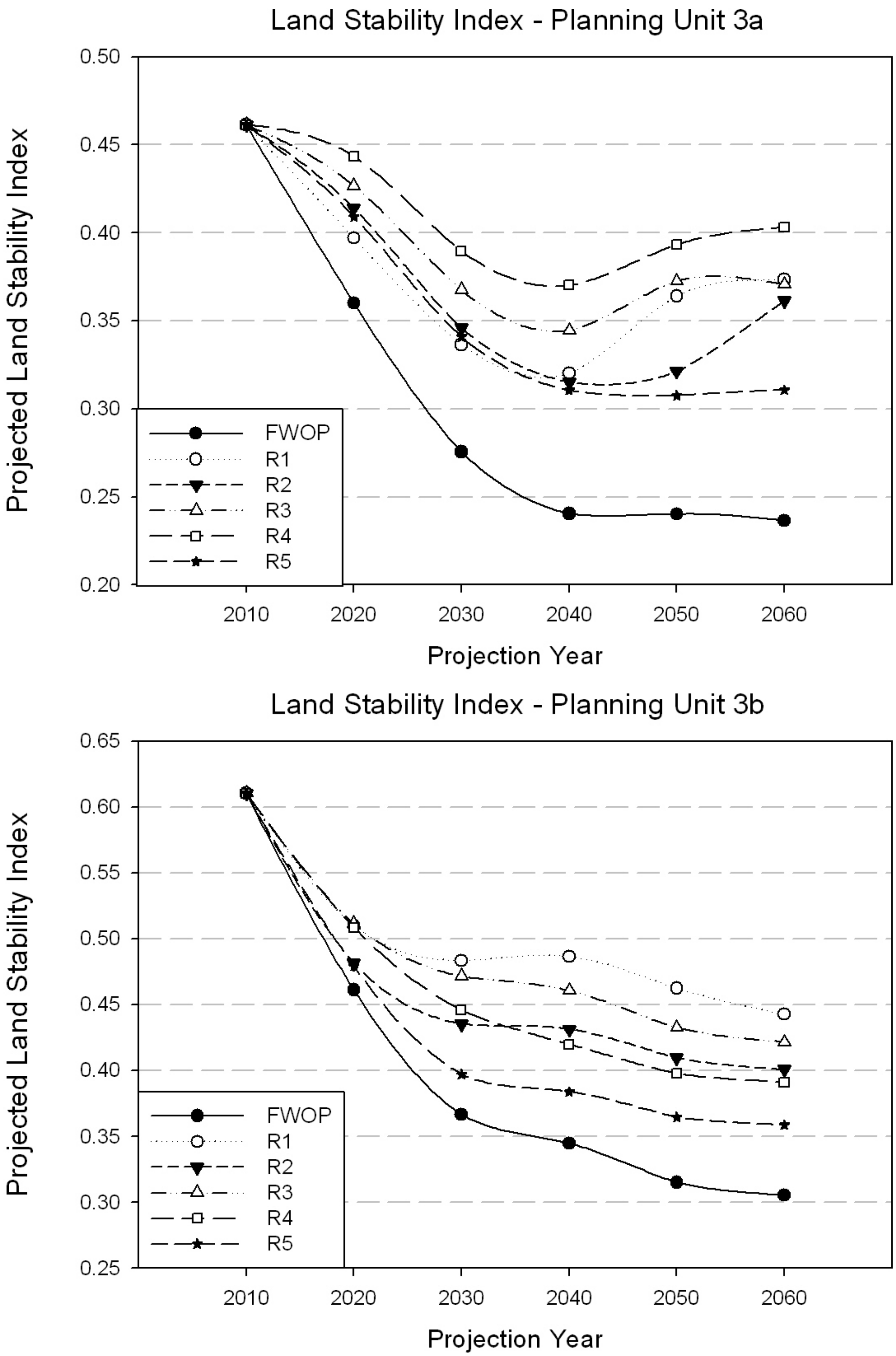


Figure 76a. Projections of change in a land stability index among alternatives from 2010 to 2060 in planning units 3a and 3b.

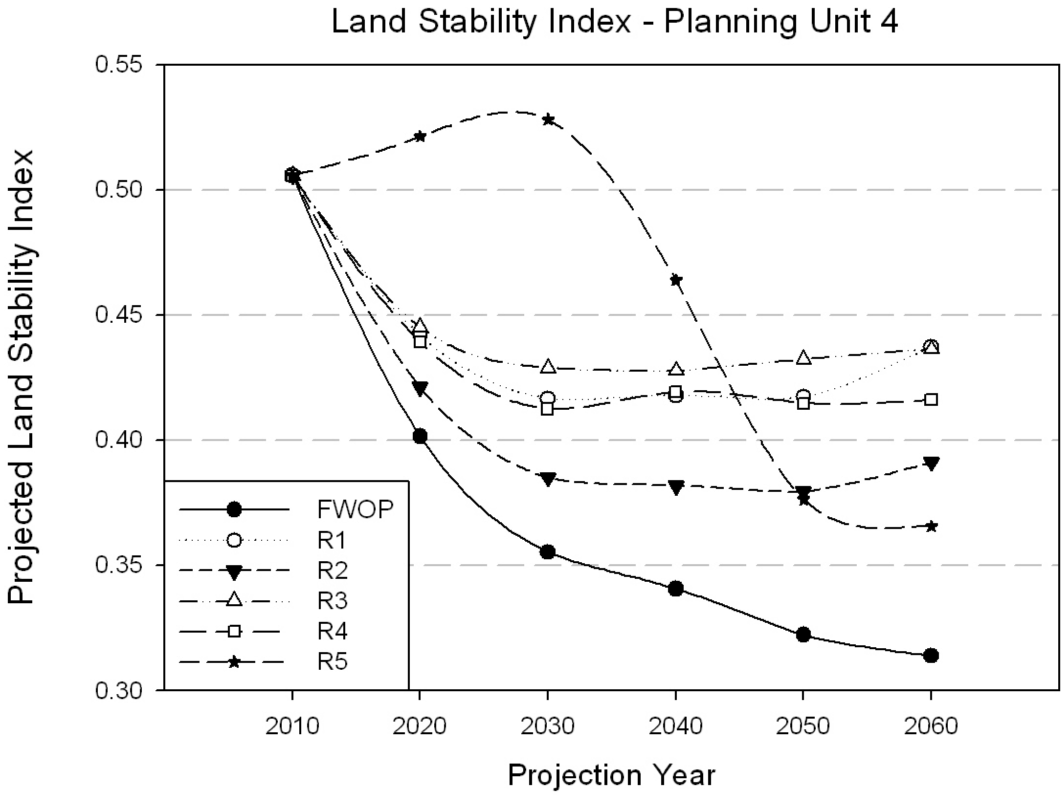


Figure 76b. Projections of change in a land stability index among alternatives from 2010 to 2060 in planning unit 4.

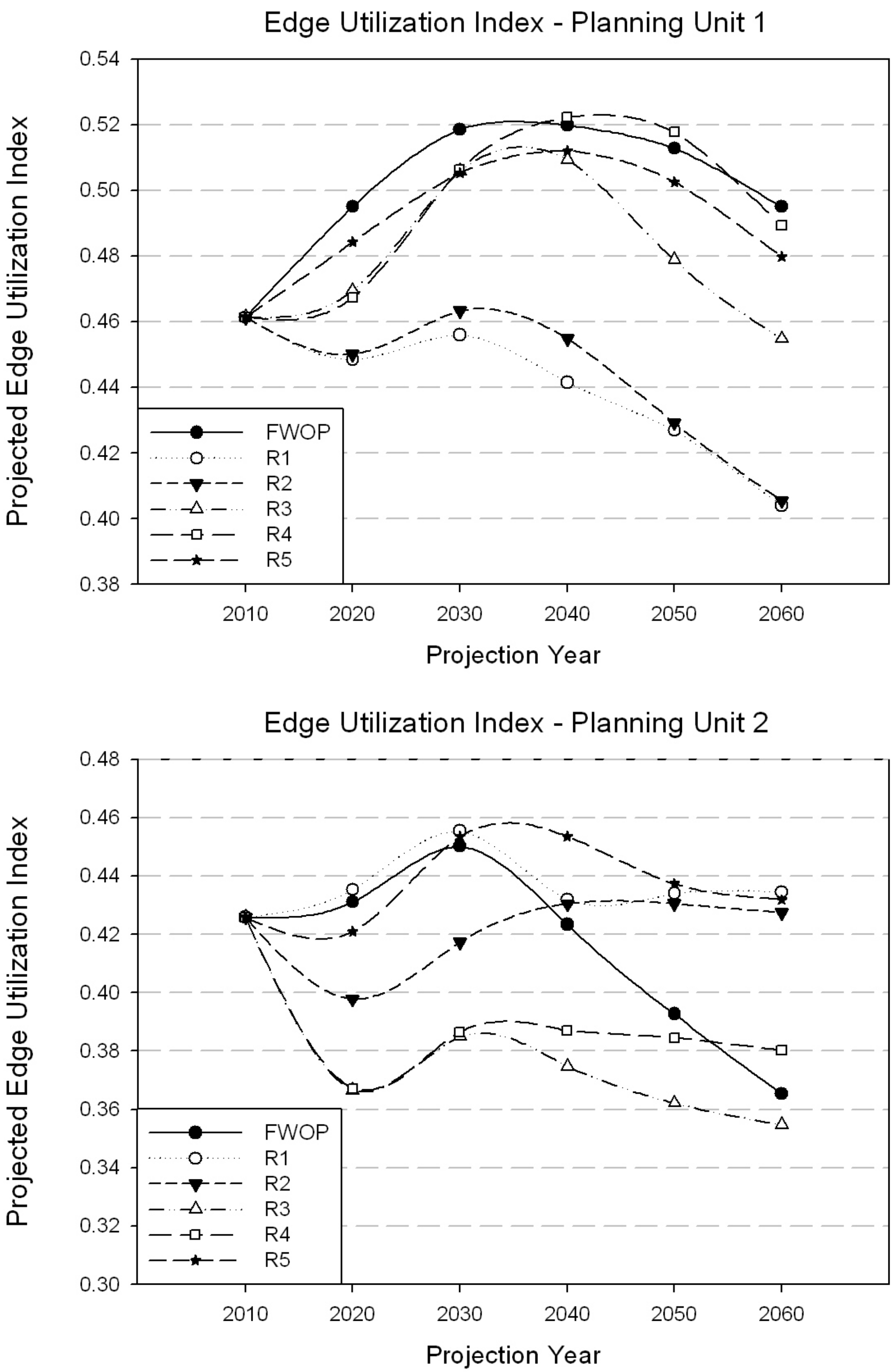
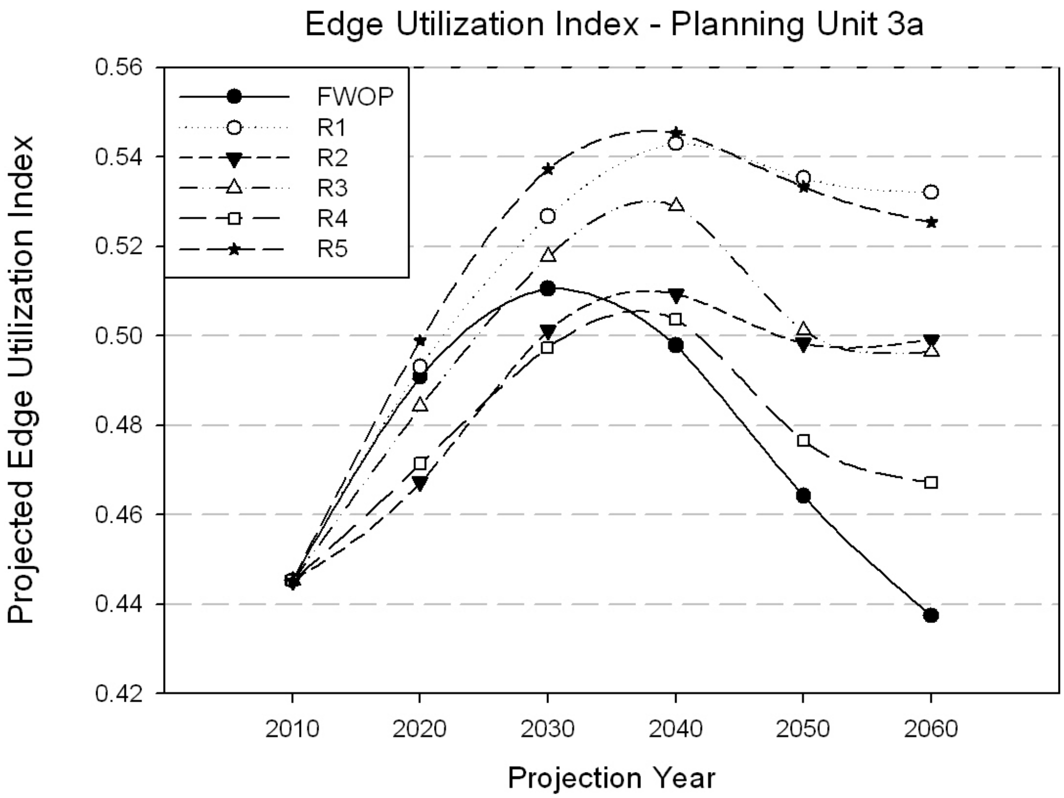


Figure 77. Projections of change in an edge utilization index among alternatives from 2010 to 2060 in planning units 1 and 2.



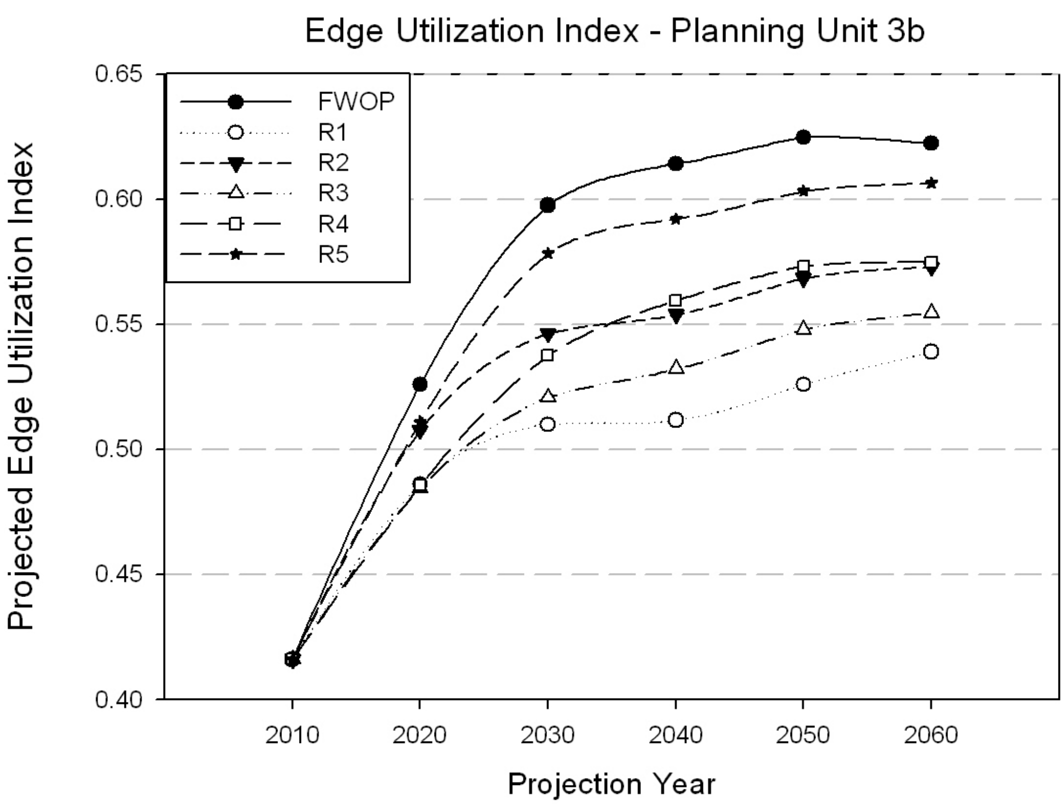


Figure 78a. Projections of change in an edge utilization index among alternatives from 2010 to 2060 in planning units 3a and 3b.

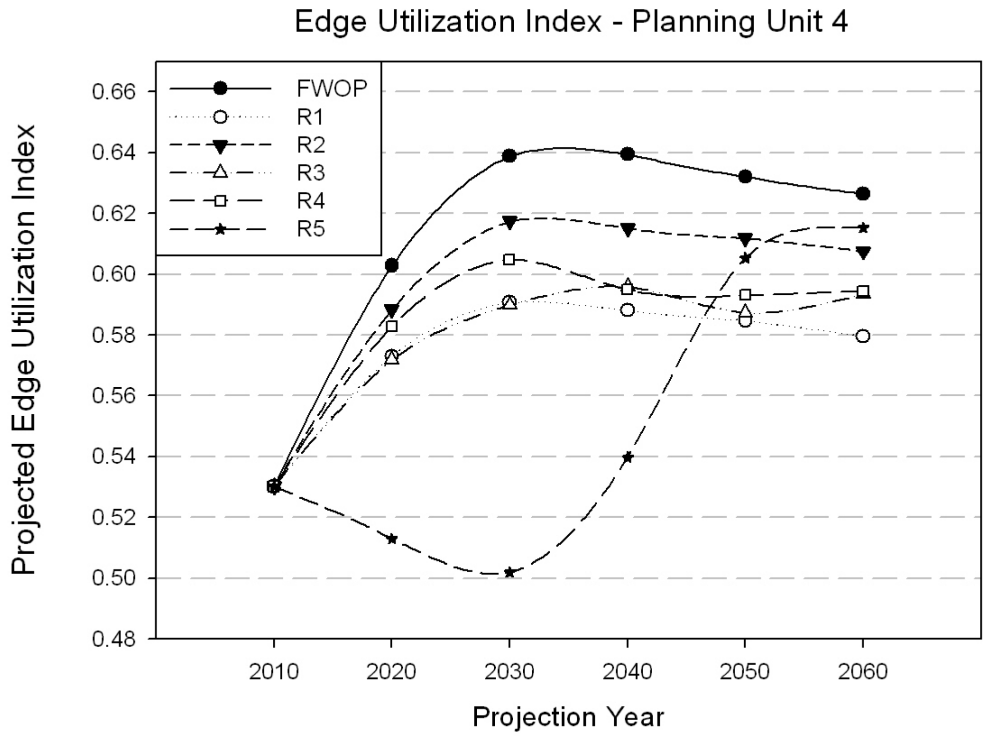
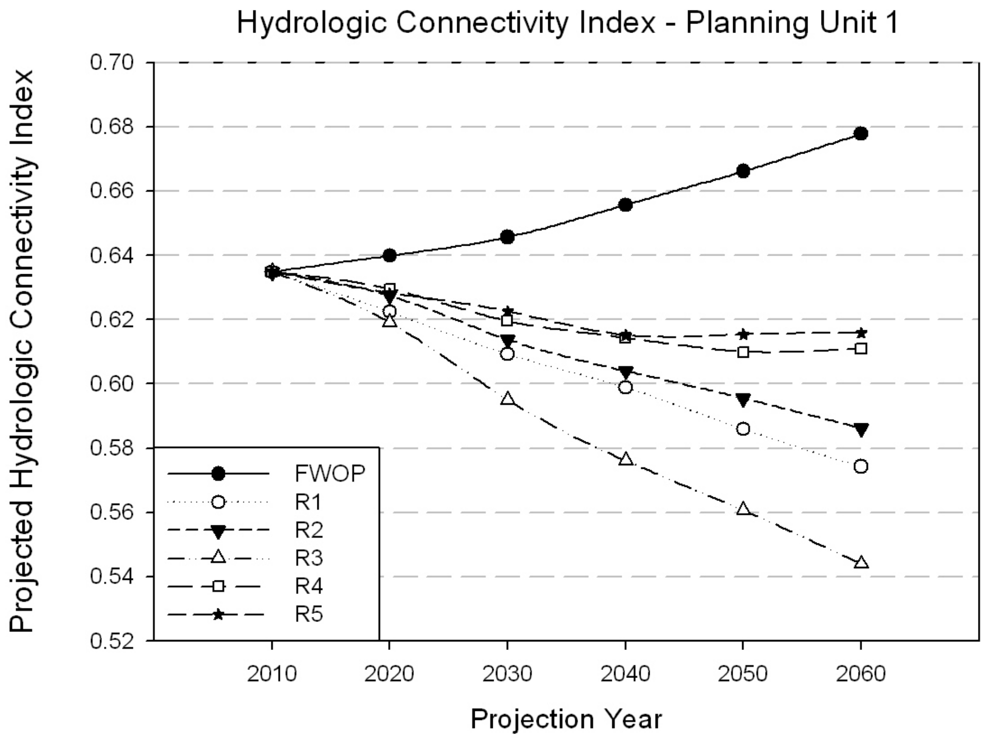


Figure 78b. Projections of change in an edge utilization index among alternatives from 2010 to 2060 in planning unit 4.



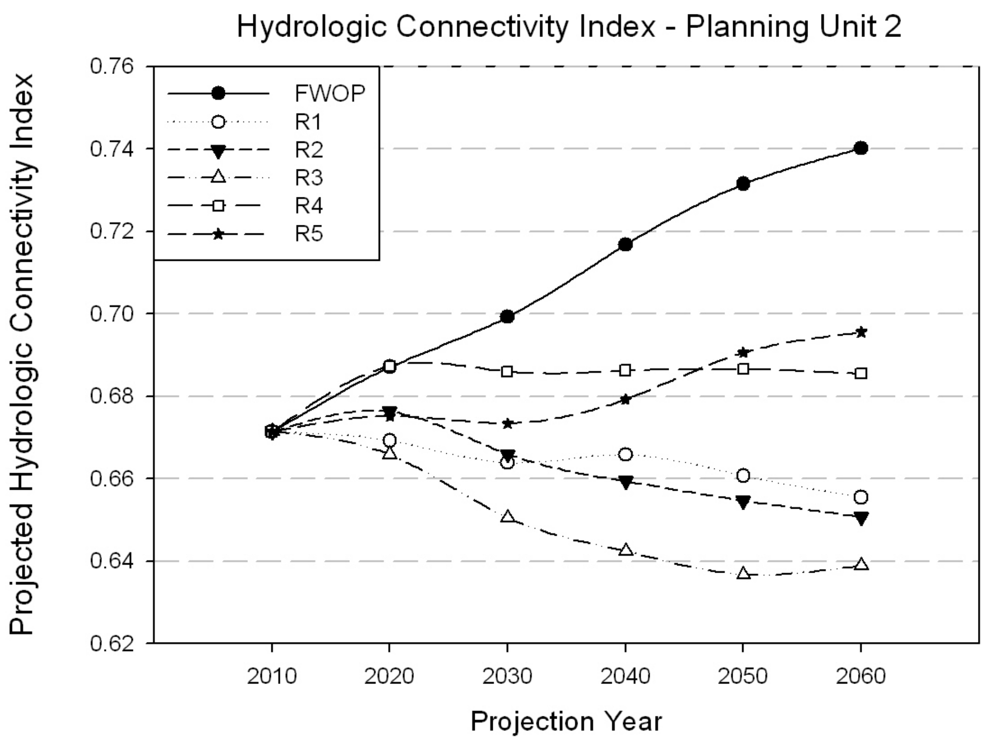
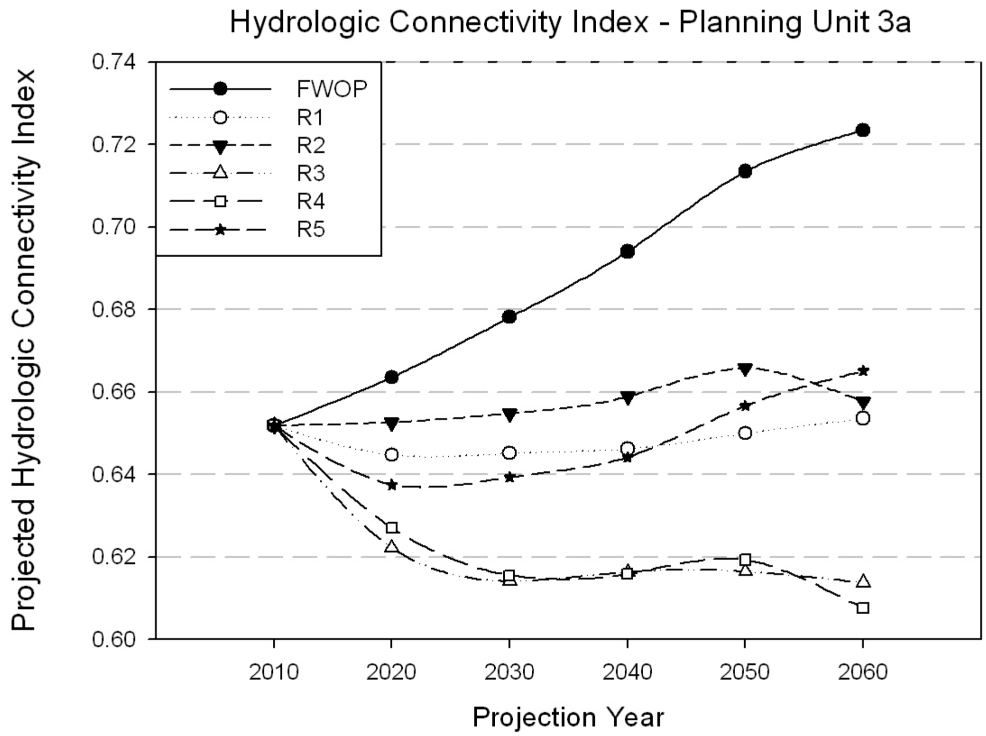


Figure 79. Projections of change in a hydrologic connectivity index among alternatives from 2010 to 2060 in planning units 1 and 2.



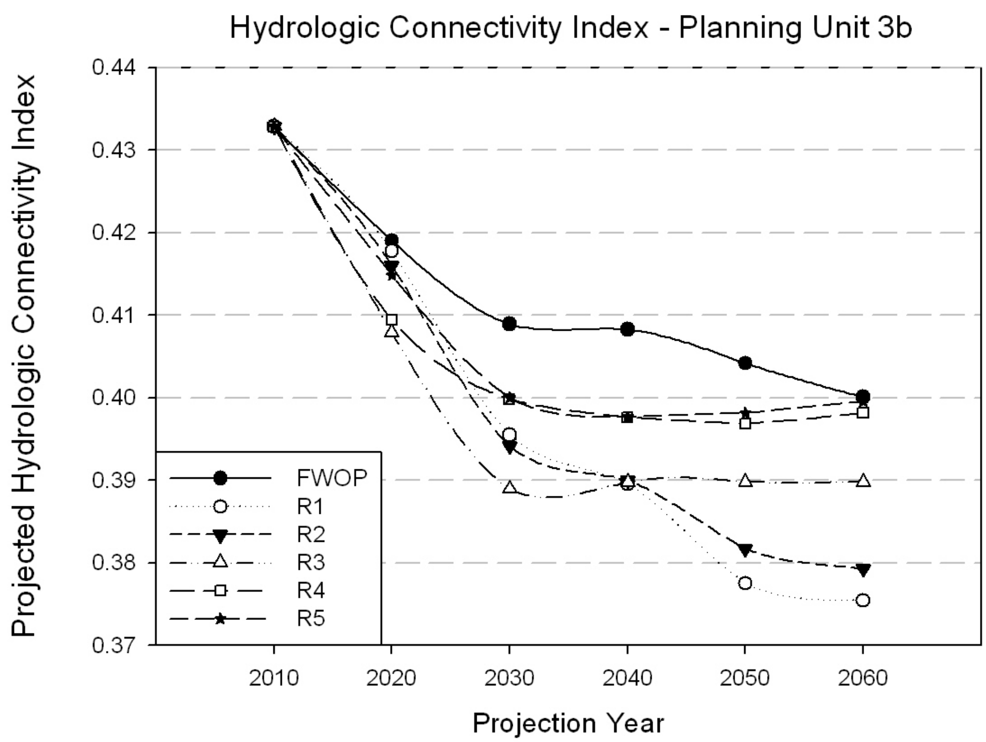


Figure 80a. Projections of change in a hydrologic connectivity index among alternatives from 2010 to 2060 in planning units 3a and 3b.

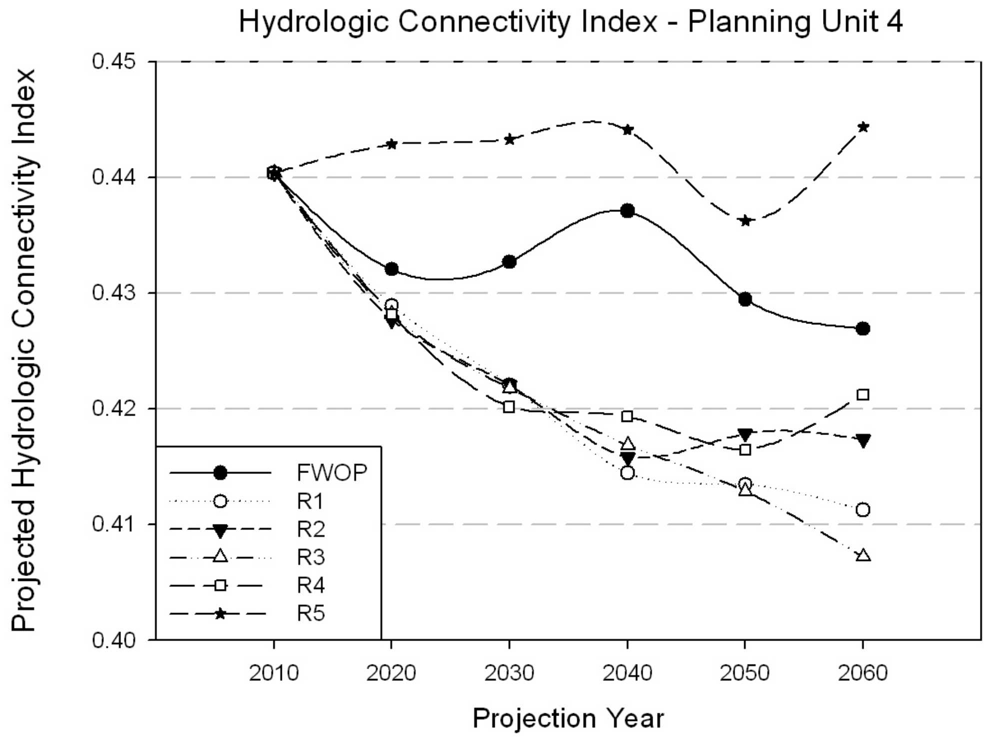


Figure 80b. Projections of change in a hydrologic connectivity index among alternatives from 2010 to 2060 in planning unit 4

TABLES

Table 1. Coastwide evaluation of spatial integrity index changes from 1985 to 2006.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 Coastwide

SII 1985 ↓ / SII 2006 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**1274**	42	44	34	12	1	17	0	0	5	3	0	3	0	0	2	0	1	4	0	0	3	0	0	1445	88.2
2A	71	**258**	10	35	56	2	20	6	2	5	2	2	2	2	0	1	0	0	1	0	0	0	0	0	475	54.3
2B	70	20	**39**	27	3	12	10	6	2	8	0	0	5	1	0	5	1	0	1	0	0	1	0	0	211	18.5
2C	68	77	33	**74**	19	21	32	2	2	11	3	2	5	1	1	3	0	0	1	0	1	2	0	0	358	20.7
3A	6	47	0	7	**162**	1	13	75	2	21	5	3	3	1	0	3	0	0	2	1	0	0	0	0	352	46.0
3B	6	7	9	11	1	**11**	12	2	10	9	1	4	10	1	0	6	0	0	3	0	0	2	1	0	106	10.4
3C	21	35	8	23	36	5	**56**	26	12	65	7	5	24	2	2	8	2	0	9	0	0	0	1	1	348	16.1
4A	3	8	0	1	23	2	1	**158**	0	21	82	5	33	14	1	15	4	0	3	2	0	2	0	3	381	41.5
4B	1	3	3	3	5	4	2	1	**6**	9	3	7	5	0	4	10	0	0	8	0	0	0	0	0	74	8.1
4C	2	14	3	7	14	0	12	5	3	**24**	9	4	50	1	2	38	5	1	13	4	0	3	1	1	216	11.1
5A	0	4	0	0	5	0	1	19	1	1	**109**	1	4	69	0	33	17	2	7	5	0	3	4	1	286	38.1
5B	0	2	0	1	0	1	4	3	4	3	1	**1**	2	1	2	12	1	1	11	2	0	5	4	0	61	1.6
5C	2	7	0	5	6	0	5	16	1	12	15	3	**21**	9	0	60	12	1	30	1	0	13	4	1	224	9.4
6A	0	0	0	0	2	0	0	3	0	0	16	1	0	**78**	0	5	75	0	14	12	0	3	11	2	222	35.1
6B	0	0	0	1	1	0	0	0	1	2	1	1	1	0	**1**	1	1	0	4	0	0	5	1	0	21	4.8
6C	1	1	0	1	2	2	0	4	2	7	11	2	12	14	1	**29**	15	0	37	5	0	30	16	7	199	14.6
7A	0	0	0	1	1	0	0	1	0	0	5	0	0	16	0	3	**72**	0	2	87	0	23	21	10	242	29.8
7B	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	**0**	2	0	0	2	0	0	7	0.0
7C	0	0	2	3	0	1	2	1	0	2	4	0	5	8	1	9	13	0	**28**	10	0	22	19	8	138	20.3
8A	0	0	0	0	1	0	0	1	0	0	2	0	1	7	0	0	9	1	2	**88**	0	0	83	30	225	39.1
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**0**	0	0	1	2	0.0
8C	0	0	0	0	0	0	1	0	0	0	3	0	0	2	0	0	5	1	14	12	0	**13**	40	29	120	10.8
9	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	7	0	2	20	0	3	**137**	179	354	38.7
10	0	0	0	0	1	0	0	1	0	0	0	0	0	2	0	0	3	0	0	6	0	3	28	**2331**	2375	98.1
Total of 2006	1525	525	151	234	350	63	189	330	48	205	282	41	186	234	16	244	244	8	198	255	1	138	371	2604	8442	

Overall percent unchanged = 58.87

Bold numbers in the diagonal represent number of unchanged SII.

Table 2. Evaluation of spatial integrity index changes from 1985 to 2006 in planning unit 1.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 PU-1

SII 1985 ↓ / SII 2006 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**362**	10	10	8	1	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	394	91.9
2A	7	**50**	1	13	16	1	8	2	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	102	49.0
2B	8	3	**7**	2	0	6	1	3	0	3	0	0	4	0	0	3	0	0	0	0	0	1	0	0	41	17.1
2C	9	5	3	**6**	5	9	13	1	1	3	1	2	2	0	0	2	0	0	0	0	0	0	0	0	62	9.7
3A	0	0	0	1	**37**	0	2	25	2	10	1	2	1	0	0	0	0	0	1	0	0	0	0	0	82	45.1
3B	0	0	0	2	0	**0**	3	0	2	1	0	1	2	1	0	4	0	0	0	0	0	2	0	0	18	0.0
3C	2	1	0	3	0	0	**7**	3	4	17	2	3	7	0	2	4	1	0	4	0	0	0	1	1	62	11.3
4A	0	1	0	0	0	0	0	**39**	0	4	31	3	12	3	1	8	1	0	1	1	0	2	0	2	109	35.8
4B	0	0	0	0	0	0	0	0	**0**	2	1	1	0	0	0	2	0	0	0	0	0	0	0	0	6	0.0
4C	0	0	0	0	0	0	2	1	0	**2**	2	2	11	0	0	8	3	0	0	1	0	1	1	1	35	5.7
5A	0	0	0	0	0	0	0	0	0	0	**27**	1	3	25	0	12	7	0	5	1	0	1	2	1	85	31.8
5B	0	0	0	0	0	0	0	0	0	1	0	**0**	1	0	0	0	0	0	0	2	0	0	1	0	5	0.0
5C	0	0	0	0	0	0	1	3	0	1	1	0	**3**	1	0	13	3	0	4	1	0	3	2	0	36	8.3
6A	0	0	0	0	0	0	0	0	0	0	1	0	0	**22**	0	3	28	0	9	5	0	0	2	1	71	31.0
6B	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	2	50.0
6C	0	0	0	0	0	1	0	0	0	2	0	0	2	0	0	**6**	3	0	8	2	0	5	2	1	32	18.8
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	2	**16**	0	0	27	0	13	6	4	73	21.9
7B	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	**0**	1	0	0	0	0	0	4	0.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2	2	0	**4**	3	0	3	3	0	21	19.0
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	**31**	0	0	33	12	80	38.8
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**0**	0	0	0	1	0.0
8C	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	3	3	0	**8**	7	4	28	28.6
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4	0	0	**45**	58	109	41.3
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	5	**1248**	1257	99.3
Total of 2006	388	70	21	35	60	17	39	77	9	47	69	16	50	62	6	70	70	1	42	83	0	40	110	1333	2715	

Overall percent unchanged = **70.76**

Bold numbers in the diagonal represent number of unchanged SII.

Table 3. Evaluation of spatial integrity index changes from 1985 to 2006 in planning unit 2.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 PU-2

SII 1985 ↓ / SII 2006 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**368**	4	3	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	378	97.4
2A	10	**36**	0	0	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	66.7
2B	12	1	**5**	5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	20.0
2C	11	15	2	**24**	2	4	7	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	35.3
3A	1	3	0	1	**24**	0	1	9	0	3	0	0	0	1	0	0	0	0	0	1	0	0	0	0	44	54.5
3B	1	0	0	0	1	**2**	2	0	3	2	1	0	2	0	0	1	0	0	1	0	0	0	0	0	16	12.5
3C	5	2	0	2	3	1	**9**	7	0	14	1	0	8	1	0	0	1	0	0	0	0	0	0	0	54	16.7
4A	1	1	0	0	3	0	1	**24**	0	3	9	0	5	4	0	1	1	0	0	1	0	0	0	1	55	43.6
4B	1	0	0	0	0	0	1	1	**1**	1	0	2	1	0	2	4	0	0	3	0	0	0	0	0	17	5.9
4C	1	1	0	1	2	0	1	0	0	**3**	3	1	16	0	2	12	1	0	6	1	0	1	0	0	52	5.8
5A	0	0	0	0	0	0	1	1	0	0	**12**	0	0	5	0	9	4	0	1	0	0	0	1	0	34	35.3
5B	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	1	7	0	0	5	0	0	3	1	0	19	0.0
5C	0	1	0	0	0	0	0	0	1	1	3	0	**2**	2	0	24	4	0	14	0	0	5	1	1	59	3.4
6A	0	0	0	0	0	0	0	1	0	0	1	0	0	**19**	0	1	13	0	3	2	0	1	1	0	42	45.2
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	1	0	1	0	0	3	1	0	6	0.0
6C	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	**5**	5	0	11	1	0	14	9	2	52	9.6
7A	0	0	0	1	0	0	0	0	0	0	1	0	0	5	0	0	**13**	0	0	22	0	5	3	1	51	25.5
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	1	0	0	1	0.0
7C	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	3	0	**6**	3	0	9	8	6	39	15.4
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	0	1	**18**	0	0	20	5	51	35.3
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	1	1	0.0
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	5	0	**1**	21	21	51	2.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	4	0	0	**31**	60	99	31.3
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	8	**314**	324	96.9
Total of 2006	411	64	10	37	40	7	28	43	6	31	33	3	35	46	5	65	56	0	52	60	0	43	105	412	1592	

Overall percent unchanged = 57.60

Bold numbers in the diagonal represent number of unchanged SII.

Table 4. Evaluation of spatial integrity index changes from 1985 to 2006 in planning unit 3a.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 PU-3A

SII 1985 ↓ / **SII 2006** →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**284**	7	6	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	302	94.0
2A	11	**35**	0	2	7	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	60.3
2B	8	2	**1**	2	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	6.3
2C	6	5	3	**8**	2	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	33	24.2
3A	1	2	0	1	**23**	0	1	18	0	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	52	44.2
3B	0	1	0	0	0	**1**	0	1	0	3	0	0	3	0	0	1	0	0	2	0	0	0	1	0	13	7.7
3C	3	3	1	3	4	0	**7**	8	3	16	1	1	8	0	0	1	0	0	1	0	0	0	0	0	60	11.7
4A	0	0	0	0	2	0	0	**29**	0	6	21	1	4	4	0	3	0	0	0	0	0	0	0	0	70	41.4
4B	0	0	0	0	0	0	0	0	**0**	1	1	3	1	0	1	3	0	0	5	0	0	0	0	0	15	0.0
4C	0	0	0	0	0	0	0	1	0	**7**	4	0	16	1	0	11	1	1	6	1	0	0	0	0	49	14.3
5A	0	1	0	0	0	0	0	0	0	0	**22**	0	0	30	0	3	2	1	1	4	0	1	0	0	65	33.8
5B	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	1	3	1	0	5	0	0	2	0	0	12	0.0
5C	1	1	0	0	1	0	0	1	0	1	5	0	**4**	5	0	15	4	1	11	0	0	3	0	0	53	7.5
6A	0	0	0	0	1	0	0	0	0	0	1	0	0	**10**	0	0	23	0	0	1	0	1	5	0	42	23.8
6B	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**0**	1	0	0	2	0	0	2	0	0	6	0.0
6C	0	0	0	0	0	1	0	0	1	1	0	1	0	2	0	**4**	3	0	9	2	0	9	5	2	40	10.0
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**	0	0	24	0	1	9	4	50	24.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	1	0	0	1	0.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	**4**	3	0	7	7	2	27	14.8
8A	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**7**	0	0	24	12	44	15.9
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	**1**	8	4	16	6.3
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**21**	42	64	32.8
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**276**	278	99.3
Total of 2006	314	57	11	18	41	7	17	58	5	39	57	7	39	52	2	47	48	3	47	45	0	28	82	342	1366	

Overall percent unchanged = **55.34**

Bold numbers in the diagonal represent number of unchanged SII.

Table 5. Evaluation of spatial integrity index changes from 1985 to 2006 in planning unit 3b.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 PU-3B

SII 1985 ↓ / SII 2006 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**153**	6	6	8	2	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	180	85.0
2A	22	**66**	3	8	14	1	3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	120	55.0
2B	14	0	**10**	6	0	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	27.8
2C	19	33	6	**19**	4	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	22.4
3A	1	20	0	3	**36**	0	5	16	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	43.9
3B	4	2	2	2	0	**2**	1	1	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	19	10.5
3C	8	18	3	4	15	0	**11**	2	1	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	72	15.3
4A	1	2	0	0	6	0	0	**26**	0	4	13	1	4	0	0	1	0	0	0	0	0	0	0	0	58	44.8
4B	0	3	2	2	1	0	0	0	**2**	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	12	16.7
4C	1	9	1	2	4	0	2	2	1	**4**	0	0	2	0	0	3	0	0	0	0	0	0	0	0	31	12.9
5A	0	1	0	0	3	0	0	1	0	0	**26**	0	0	4	0	1	0	0	0	0	0	0	0	0	36	72.2
5B	0	2	0	1	0	0	2	0	0	0	1	**0**	0	0	0	0	0	0	0	0	0	0	0	0	6	0.0
5C	1	5	0	3	3	0	3	5	0	2	2	0	**4**	0	0	1	0	0	0	0	0	0	0	0	29	13.8
6A	0	0	0	0	0	0	0	2	0	0	6	0	0	**13**	0	0	5	0	0	0	0	0	0	0	26	50.0
6B	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	1	0.0
6C	1	1	0	1	1	0	0	2	0	0	4	0	2	4	0	**0**	2	0	4	0	0	0	0	0	22	0.0
7A	0	0	0	0	1	0	0	1	0	0	2	0	0	1	0	0	**18**	0	0	10	0	4	1	0	38	47.4
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	0	0	0	0	0	1	0.0
7C	0	0	0	1	0	0	2	1	0	1	2	0	2	2	0	2	0	0	**4**	1	0	0	0	0	18	22.2
8A	0	0	0	0	0	0	0	1	0	0	2	0	0	2	0	0	0	1	0	**14**	0	0	4	0	24	58.3
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	1	0	**0**	1	0	7	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	3	0	1	**19**	14	43	44.2
10	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	2	0	0	2	0	1	8	**336**	352	95.5
Total of 2006	225	168	33	61	90	7	37	63	7	22	62	2	16	31	0	10	30	1	13	31	0	6	33	350	1298	

Overall percent unchanged = **58.78**

Bold numbers in the diagonal represent number of unchanged SII.

Table 6. Evaluation of spatial integrity index changes from 1985 to 2006 in planning unit 4.

Change Matrix (Historic): Spatial Integrity Index (SII) change count from 1985 to 2006 PU-4

SII 1985 ↓ / SII 2006 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 1985	% unchanged by SII
1	**107**	15	19	14	8	1	9	0	0	5	2	0	3	0	0	1	0	1	3	0	0	3	0	0	191	56.0
2A	21	**71**	6	12	14	0	4	3	1	3	1	1	1	1	0	1	0	0	1	0	0	0	0	0	141	50.4
2B	28	14	**16**	12	3	3	4	2	1	4	0	0	1	1	0	2	1	0	1	0	0	0	0	0	93	17.2
2C	23	19	19	**17**	6	2	7	1	0	5	2	0	2	1	1	1	0	0	1	0	1	2	0	0	110	15.5
3A	3	22	0	1	**42**	1	4	7	0	4	3	0	1	0	0	3	0	0	1	0	0	0	0	0	92	45.7
3B	1	4	7	7	0	**6**	6	0	3	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	40	15.0
3C	3	11	4	11	14	4	**22**	6	4	11	2	1	0	1	0	2	0	0	4	0	0	0	0	0	100	22.0
4A	1	4	0	1	12	2	0	**40**	0	4	8	0	8	3	0	2	2	0	2	0	0	0	0	0	89	44.9
4B	0	0	1	1	4	4	1	0	**3**	4	1	1	3	0	1	0	0	0	0	0	0	0	0	0	24	12.5
4C	0	4	2	4	8	0	7	1	2	**8**	0	1	5	0	0	4	0	0	1	1	0	1	0	0	49	16.3
5A	0	2	0	0	2	0	0	17	1	1	**22**	0	1	5	0	8	4	1	0	0	0	1	1	0	66	33.3
5B	0	0	0	0	0	1	2	3	4	2	0	**1**	0	0	0	2	0	1	1	0	0	0	2	0	19	5.3
5C	0	0	0	2	2	0	1	7	0	7	4	3	**8**	1	0	7	1	0	1	0	0	2	1	0	47	17.0
6A	0	0	0	0	1	0	0	0	0	0	7	1	0	**14**	0	1	6	0	2	4	0	1	3	1	41	34.1
6B	0	0	0	0	0	0	0	0	1	2	0	1	1	0	**0**	0	0	0	1	0	0	0	0	0	6	0.0
6C	0	0	0	0	1	0	0	2	1	4	6	1	8	4	1	**14**	2	0	5	0	0	2	0	2	53	26.4
7A	0	0	0	0	0	0	0	0	0	0	2	0	0	5	0	1	**13**	0	2	4	0	0	2	1	30	43.3
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	N/A
7C	0	0	2	1	0	1	0	0	0	0	1	0	2	4	0	2	6	0	**10**	0	0	3	1	0	33	30.3
8A	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	2	0	0	**18**	0	0	2	1	26	69.2
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	7	1	0	**3**	3	0	18	16.7
9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	8	0	2	**21**	5	39	53.8
10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	**157**	164	95.7
Total of 2006	187	166	76	83	119	25	68	89	21	66	61	13	46	43	3	52	40	3	44	36	1	21	41	167	1471	

Overall percent unchanged = **41.67**

Bold numbers in the diagonal represent number of unchanged SII.

Table 7. Future without project evaluation of spatial integrity index changes from 2010 to 2060 in planning unit 1.

Change Matrix (FWOP): Spatial Integrity Index (SII) count from 2010 to 2060 for PU-1

SII 2010 ↓ / SII 2060 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 2010	% unchanged by SII
1	**364**	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	386	94.3
2A	0	**0**	0	43	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0.0
2B	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
2C	0	0	0	**65**	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	79	82.3
3A	0	0	0	0	**0**	0	22	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0.0
3B	0	0	0	0	0	**0**	5	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	7	0.0
3C	0	0	0	0	0	0	**44**	0	0	32	0	0	1	0	0	0	0	1	0	0	0	0	0	1	79	55.7
4A	0	0	0	0	0	0	0	**0**	0	24	0	0	9	0	0	0	0	0	0	0	0	0	0	0	33	0.0
4B	0	0	0	0	0	0	0	0	**0**	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0.0
4C	0	0	0	0	0	0	0	0	0	**46**	0	0	42	0	0	3	0	0	0	0	0	0	0	0	91	50.5
5A	0	0	0	0	0	0	0	0	0	0	**0**	0	14	0	0	19	0	0	0	0	0	1	0	0	34	0.0
5B	0	0	0	0	0	0	0	0	0	0	0	**0**	3	0	0	5	0	0	0	0	0	0	0	0	8	0.0
5C	0	0	0	0	0	0	0	0	0	0	0	0	**29**	0	0	52	0	0	8	0	0	0	0	2	91	31.9
6A	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	2	5	0	2	16	0	1	6	1	2	35	0.0
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	0	0	1	0	1	0	0	0	3	0.0
6C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**9**	0	2	55	0	1	21	1	5	94	9.6
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	2	9	0	4	35	16	1	67	0.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	1	0	1	0.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**6**	0	6	13	11	5	42	14.3
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	8	46	20	77	3.9
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0**	18	21	40	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**13**	101	114	11.4
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1355**	1355	100.0
Total of 2060	364	0	0	130	0	0	86	0	0	114	0	1	99	0	2	94	0	8	95	3	14	84	108	1513	2715	

Overall percent unchanged = 71.23

Bold numbers in the diagonal represent number of unchanged SII.

Table 8. Future without project evaluation of spatial integrity index changes from 2010 to 2060 in planning unit 2.

Change Matrix (FWOP): Spatial Integrity Index (SII) count from 2010 to 2060 for PU-2

SII 2010 ↓ / SII 2060 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 2010	% unchanged by SII
1	**409**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	409	100.0
2A	0	**0**	0	46	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0.0
2B	0	0	**0**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
2C	0	0	0	**47**	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	75.8
3A	0	0	0	0	**0**	0	26	0	0	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	35	0.0
3B	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
3C	0	0	0	0	0	0	**17**	0	0	18	0	0	1	0	0	1	0	0	0	0	0	0	0	0	37	45.9
4A	0	0	0	0	0	0	0	**0**	0	11	0	0	13	0	0	3	0	0	0	0	1	0	0	0	28	0.0
4B	0	0	0	0	0	0	0	0	**0**	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0.0
4C	0	0	0	0	0	0	0	0	0	**8**	0	0	22	0	0	13	0	1	3	0	0	0	0	0	47	17.0
5A	0	0	0	0	0	0	0	0	0	0	**0**	1	9	0	0	7	0	0	2	0	0	1	0	1	21	0.0
5B	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	1	1	0	0	0	0	0	2	0.0
5C	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	13	0	0	9	0	3	10	3	1	42	7.1
6A	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	5	3	0	11	4	0	6	3	3	3	38	0.0
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	1	0	1	0.0
6C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	2	4	0	7	12	17	20	64	3.1
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	10	3	0	10	1	7	19	50	0.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	1	1	0.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	2	1	5	46	54	0.0
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	5	3	10	42	60	0.0
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	43	44	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	98	100	2.0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**444**	444	100.0
Total of 2060	409	0	0	94	0	0	62	0	0	45	0	1	50	0	5	42	0	26	26	0	34	31	49	718	1592	

Overall percent unchanged = **58.54**

Bold numbers in the diagonal represent number of unchanged SII.

Table 9. Future without project evaluation of spatial integrity index changes from 2010 to 2060 in planning unit 3a.

Change Matrix (FWOP): Spatial Integrity Index (SII) count from 2010 to 2060 for PU-3A

SII 2010 ↓ / SII 2060 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 2010	% unchanged by SII
1	**308**	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	314	98.1
2A	0	**0**	0	45	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0.0
2B	0	0	**0**	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0.0
2C	0	0	0	**24**	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	85.7
3A	0	0	0	0	**0**	0	25	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0.0
3B	0	0	0	0	0	**0**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
3C	0	0	0	0	0	0	**8**	0	0	16	0	0	3	0	0	0	0	0	0	0	0	0	0	0	27	29.6
4A	0	0	0	0	0	0	0	**0**	0	15	0	0	8	0	0	5	0	0	0	0	0	0	0	0	28	0.0
4B	0	0	0	0	0	0	0	0	**0**	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0.0
4C	0	0	0	0	0	0	0	0	0	**5**	0	0	32	0	0	27	0	1	0	0	0	0	0	0	65	7.7
5A	0	0	0	0	0	0	0	0	0	0	**0**	3	9	0	3	22	0	0	7	0	0	1	0	0	45	0.0
5B	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	3	0	2	0	0	0	5	0.0
5C	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	17	0	0	16	0	2	8	4	2	50	2.0
6A	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	2	1	0	11	12	0	4	4	9	3	46	0.0
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	0	0	0	0	0	0	0	0	1	0.0
6C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	8	12	0	5	9	8	11	54	1.9
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0**	4	2	0	5	7	5	21	45	0.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	N/A
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	2	2	8	30	47	10.6
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	1	1	3	33	41	7.3
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0**	5	25	31	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**	79	83	4.8
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**362**	362	100.0
Total of 2060	308	0	0	80	0	0	44	0	0	46	0	3	54	0	5	75	0	25	57	3	22	32	46	566	1366	

Overall percent unchanged = **52.78**

Bold numbers in the diagonal represent number of unchanged SII.

Table 10. Future without project evaluation of spatial integrity index changes from 2010 to 2060 in planning unit 3b.

Change Matrix (FWOP): Spatial Integrity Index (SII) count from 2010 to 2060 for PU-3B

SII 2010 ↓ / SII 2060 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 2010	% unchanged by SII
1	**200**	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	223	89.7
2A	0	**0**	0	98	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	115	0.0
2B	0	0	**0**	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0.0
2C	0	0	0	**104**	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130	80.0
3A	0	0	0	0	**0**	0	50	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0.0
3B	0	0	0	0	0	**0**	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.0
3C	0	0	0	0	0	0	**49**	0	0	21	0	0	2	0	0	0	0	0	0	0	0	0	0	0	72	68.1
4A	0	0	0	0	0	0	0	**0**	3	33	0	5	8	0	2	0	0	0	0	0	0	0	0	0	51	0.0
4B	0	0	0	0	0	0	0	0	**0**	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.0
4C	0	0	0	0	0	0	0	0	0	**23**	0	2	9	0	1	1	0	0	0	0	0	0	0	0	36	63.9
5A	0	0	0	0	0	0	0	0	0	1	**0**	25	5	0	19	4	0	1	1	0	0	0	0	0	56	0.0
5B	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	1	100.0
5C	0	0	0	0	0	0	0	0	0	0	0	11	**3**	0	5	1	0	1	1	0	0	0	0	0	22	13.6
6A	0	0	0	0	0	0	0	0	0	0	0	3	0	**0**	9	2	0	10	1	0	2	3	0	0	30	0.0
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	N/A
6C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	**3**	0	1	2	0	0	0	0	0	13	23.1
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	**0**	8	6	4	3	2	3	2	30	0.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	1	100.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**6**	0	1	1	0	1	11	54.5
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7**	1	0	18	7	33	21.2
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	N/A
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	**0**	0	1	5	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**14**	15	30	46.7
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**353**	355	99.4
Total of 2060	200	0	0	237	0	0	146	0	3	96	0	47	27	0	45	11	0	25	17	12	10	6	37	379	1298	

Overall percent unchanged = **58.86**

Bold numbers in the diagonal represent number of unchanged SII.

Table 11. Future without project evaluation of spatial integrity index changes from 2010 to 2060 in planning unit 4.

Change Matrix (FWOP): Spatial Integrity Index (SII) count from 2010 to 2060 for PU-4

SII 2010 ↓ / SII 2060 →	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C	9	10	Total of 2010	% unchanged by SII
1	**170**	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	187	90.9
2A	3	**0**	0	76	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83	0.0
2B	0	0	**0**	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.0
2C	1	0	0	**209**	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	235	88.9
3A	0	0	0	1	**0**	0	47	0	0	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	58	0.0
3B	0	0	0	0	0	**0**	10	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0.0
3C	0	0	0	1	0	0	**106**	0	0	31	0	0	3	0	0	0	0	0	0	0	0	0	0	0	141	75.2
4A	0	0	0	0	0	0	1	**0**	3	44	0	5	6	0	4	0	0	1	0	0	0	0	0	0	64	0.0
4B	0	0	0	0	0	0	2	0	**0**	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	11	0.0
4C	0	0	0	0	0	0	5	0	1	**62**	0	2	29	0	1	0	0	0	0	0	0	0	0	0	100	62.0
5A	0	0	0	0	0	0	0	0	1	1	**0**	20	11	0	7	4	0	5	0	0	0	0	0	0	49	0.0
5B	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	1	1	0	0	0	0	0	0	0	0	5	60.0
5C	0	0	0	0	0	0	0	0	0	0	0	19	**12**	0	20	5	0	4	3	0	1	0	0	1	65	18.5
6A	0	0	0	0	0	0	0	0	0	0	0	1	0	**0**	23	3	0	4	1	0	1	2	3	0	38	0.0
6B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	2	0	0	1	0	0	0	3	0.0
6C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	**4**	0	17	4	0	7	4	0	2	59	6.8
7A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	2	14	4	3	8	1	7	39	0.0
7B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**0**	0	0	1	0	0	1	3	0.0
7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	5	**7**	0	7	7	10	2	42	16.7
8A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	**12**	2	7	12	5	40	30.0
8B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	1	1	0.0
8C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	**1**	2	8	18	5.6
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	**25**	14	43	58.1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	**168**	171	98.2
Total of 2060	174	0	0	308	0	0	200	0	5	157	0	50	63	0	81	18	1	42	30	19	28	30	56	209	1471	

Overall percent unchanged = **52.96**

Bold numbers in the diagonal represent number of unchanged SII.

Table 12. Projections of change in percentage of landscape occupied by water metric among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Percentage of Landscape Occupied by Water											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		52.70	57.29	54.55	30.13	32.62	29.27	30.26	28.83	23.43	22.92
2030		54.31	60.59	57.60	30.83	33.35	29.92	31.67	30.04	23.82	23.56
2040		55.81	63.37	60.36	31.56	34.08	30.46	32.56	30.90	24.25	24.19
2050		57.25	65.80	62.92	32.31	34.83	30.90	33.17	31.59	24.70	24.85
2060		58.67	67.90	65.13	33.09	35.56	31.31	33.59	31.94	25.18	25.47
2010	R1	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		49.91	53.92	51.51	29.16	31.72	29.27	28.80	26.89	22.80	22.75
2030		49.09	54.28	52.05	28.07	31.54	30.17	29.34	26.87	22.83	23.04
2040		48.30	54.11	52.51	27.69	30.93	31.29	29.75	26.82	22.95	23.38
2050		47.45	53.99	52.71	27.09	31.10	32.48	30.31	27.00	22.96	23.80
2060		46.68	54.15	52.82	27.47	30.59	33.77	31.08	27.06	23.54	23.13
2010	R2	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		50.45	53.86	52.20	29.47	31.96	29.33	29.00	27.63	22.96	22.85
2030		49.87	53.71	53.50	28.70	32.01	30.23	29.66	28.30	23.13	23.24
2040		49.21	53.55	54.56	28.62	31.54	31.36	30.13	28.68	23.39	23.75
2050		48.52	53.57	54.97	28.27	31.96	32.52	30.74	28.96	23.54	24.22
2060		47.90	53.79	54.17	28.44	31.65	33.80	31.50	28.95	24.10	23.70
2010	R3	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		49.43	52.75	49.54	28.37	31.54	28.32	29.77	28.32	22.74	22.42
2030		47.71	52.69	50.09	27.80	31.09	28.26	31.54	29.43	22.91	22.07
2040		46.08	52.64	50.99	28.11	30.65	28.99	32.93	29.88	23.20	21.88
2050		44.53	52.63	50.49	28.50	30.37	29.97	34.22	30.23	23.64	22.08
2060		43.40	53.33	50.40	28.94	30.02	31.48	35.02	30.81	24.16	22.06
2010	R4	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		50.74	54.46	49.52	28.76	31.56	28.88	28.87	28.07	23.06	21.97
2030		50.35	55.45	49.80	29.01	31.32	28.70	29.83	29.57	23.24	22.20
2040		49.95	56.17	50.59	29.35	31.14	28.79	30.60	30.17	23.64	22.53
2050		49.53	56.58	50.58	29.74	31.18	29.12	31.33	30.55	24.19	23.07
2060		49.18	56.96	49.56	30.19	31.70	29.72	31.98	31.40	24.83	23.59
2010	R5	50.84	53.56	51.31	29.46	31.87	28.39	28.37	27.30	23.08	22.22
2020		51.08	55.13	50.60	29.47	31.77	28.93	29.60	27.04	22.88	22.54
2030		51.17	56.41	52.01	29.58	31.83	29.55	30.82	27.70	23.08	23.24
2040		51.15	58.06	53.35	29.81	32.62	30.31	31.50	28.23	23.50	23.74
2050		51.45	59.38	54.57	30.15	33.44	31.15	32.21	28.68	24.06	24.27
2060		51.73	60.60	55.60	30.58	34.25	32.07	32.85	29.03	24.70	24.78

Table 13. Projections of change in edge density of land metric among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Edge Density of Land											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		62.92	59.09	64.39	59.72	66.95	39.78	39.73	38.33	29.34	27.15
2030		62.13	54.48	59.37	60.47	63.71	41.54	39.25	37.75	31.25	27.23
2040		60.97	49.46	54.05	59.69	58.95	44.49	40.04	39.37	36.36	31.73
2050		59.72	44.84	48.67	59.09	54.89	48.35	41.89	43.29	42.42	37.11
2060		58.46	41.25	44.24	59.45	52.46	52.87	44.10	48.18	48.24	41.66
2010	R1	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		57.15	57.54	62.29	58.12	66.22	34.85	36.07	34.55	26.61	25.98
2030		55.90	53.72	60.68	58.20	63.31	34.54	36.12	34.25	29.03	26.19
2040		53.86	49.36	57.59	56.93	59.47	35.58	35.53	36.11	34.22	29.63
2050		51.82	47.06	54.51	56.21	55.55	36.95	36.98	39.37	40.14	34.52
2060		49.63	44.12	51.50	56.17	53.47	38.67	39.11	43.84	46.29	38.50
2010	R2	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		57.21	54.11	57.96	57.57	65.97	34.91	35.13	34.87	27.74	26.97
2030		55.65	50.91	55.47	57.76	63.03	35.23	34.97	34.86	30.47	27.00
2040		53.75	49.07	51.46	56.44	58.50	36.28	35.51	36.25	35.92	31.21
2050		51.86	46.73	48.37	55.77	54.20	37.23	36.93	38.59	41.89	36.56
2060		49.72	43.76	46.38	55.61	52.30	38.86	39.12	42.72	47.64	40.68
2010	R3	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		58.76	51.30	60.09	59.37	65.65	34.49	32.93	34.08	27.51	25.25
2030		59.75	48.20	55.79	59.21	62.80	34.76	32.63	34.76	29.82	25.33
2040		59.83	44.62	51.56	58.89	59.28	36.52	33.25	35.95	34.39	28.94
2050		57.83	41.11	48.34	58.34	56.21	38.85	34.92	38.60	40.23	33.52
2060		55.07	38.30	45.18	58.38	53.92	42.45	37.10	42.81	46.02	38.09
2010	R4	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		58.32	51.30	60.53	57.84	66.74	35.37	33.48	34.17	28.77	25.83
2030		58.43	48.25	56.01	58.62	63.94	35.82	33.69	34.92	30.84	25.97
2040		58.58	44.89	51.65	58.19	60.42	36.76	34.65	35.93	35.50	29.09
2050		57.68	42.42	48.12	57.78	56.88	39.43	35.94	38.43	41.12	34.05
2060		56.09	39.79	45.04	57.92	54.04	42.70	38.37	42.67	46.66	38.90
2010	R5	62.99	63.06	67.31	56.72	67.78	39.00	41.09	39.89	29.70	30.86
2020		60.75	56.16	62.82	59.35	61.53	37.17	36.33	33.97	28.44	26.39
2030		60.26	53.33	58.98	60.46	58.41	38.75	36.63	34.27	30.38	25.42
2040		59.49	49.98	54.14	60.16	54.19	41.25	37.74	36.03	35.35	29.21
2050		58.34	45.84	49.14	59.96	49.85	44.44	39.62	39.96	41.24	34.63
2060		57.14	42.21	44.77	60.31	47.27	48.03	41.99	44.95	47.10	39.32

Table 14. Projections of change in cohesion of water patches metric among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Cohesion of Water Patches											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		97.11	97.51	97.47	94.51	92.86	3.52	3.69	3.92	4.89	5.66
2030		97.64	97.97	97.98	94.72	93.14	3.01	3.31	3.38	4.84	5.35
2040		98.18	98.44	98.50	94.88	93.39	2.53	2.91	2.85	4.82	5.09
2050		98.62	98.82	98.90	95.04	93.63	2.13	2.55	2.41	4.80	4.87
2060		98.92	99.09	99.16	95.20	93.90	1.80	2.23	2.06	4.78	4.70
2010	R1	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		96.56	97.33	97.33	94.19	92.60	5.44	3.87	4.06	5.14	5.92
2030		96.70	97.59	97.70	93.51	92.60	5.63	3.68	3.65	7.16	5.90
2040		96.63	97.75	98.07	92.98	92.42	6.57	4.01	3.81	8.34	6.10
2050		96.48	98.04	98.17	92.47	92.45	7.63	3.83	4.98	9.24	6.24
2060		96.22	98.30	98.33	92.23	92.49	8.74	3.64	5.21	9.79	6.38
2010	R2	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		96.69	97.31	97.41	94.38	92.65	5.13	4.30	4.12	5.16	5.96
2030		96.89	97.36	97.80	93.83	92.76	5.31	5.00	3.78	6.99	5.81
2040		97.02	97.38	98.24	93.39	92.64	5.64	6.23	3.46	8.14	5.97
2050		96.94	97.67	98.32	93.08	92.80	6.38	6.05	4.72	8.76	5.93
2060		96.85	97.94	98.38	92.69	92.94	7.17	5.87	5.03	9.64	5.90
2010	R3	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		96.86	96.35	95.69	93.70	92.66	4.07	8.34	10.02	6.32	5.75
2030		97.01	95.29	95.02	92.90	92.69	4.34	11.99	12.57	8.44	5.67
2040		97.05	94.76	95.42	92.96	92.69	5.48	13.50	12.69	8.49	5.71
2050		96.89	94.16	95.47	92.90	92.68	6.59	15.08	13.08	8.78	5.95
2060		95.95	94.15	95.36	92.75	92.68	9.61	15.55	13.62	9.23	6.08
2010	R4	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		96.97	97.39	96.21	93.73	92.69	4.04	4.16	8.14	6.54	5.69
2030		97.37	97.36	95.00	93.77	92.68	3.67	5.90	12.22	6.85	5.74
2040		97.78	97.11	95.07	93.85	92.72	3.34	8.20	12.90	6.94	5.72
2050		98.03	97.05	95.20	93.78	92.70	3.58	9.24	13.04	7.33	5.87
2060		98.11	96.94	94.76	93.65	92.86	4.10	10.18	13.87	7.92	5.94
2010	R5	96.58	97.05	96.99	94.17	92.60	4.05	4.08	4.50	5.10	6.04
2020		96.97	97.42	96.77	94.44	92.62	3.85	3.73	6.82	5.01	5.94
2030		97.36	97.70	97.19	94.43	92.57	3.53	3.95	6.63	5.57	6.14
2040		97.77	98.10	97.67	94.31	92.83	3.24	3.68	6.48	6.33	5.84
2050		98.13	98.47	98.04	94.33	93.08	3.01	3.44	6.37	6.56	5.58
2060		98.39	98.75	98.26	94.18	93.35	2.82	3.22	6.30	7.35	5.36

Table 15. Projections of change in a land stability index among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Land Stability Index											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.36	0.35	0.36	0.46	0.40	0.28	0.29	0.28	0.27	0.22
2030		0.30	0.26	0.28	0.37	0.36	0.23	0.22	0.22	0.21	0.18
2040		0.27	0.23	0.24	0.34	0.34	0.20	0.19	0.18	0.19	0.17
2050		0.25	0.21	0.24	0.32	0.32	0.18	0.19	0.20	0.16	0.17
2060		0.24	0.21	0.24	0.31	0.31	0.18	0.20	0.20	0.16	0.17
2010	R1	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.43	0.40	0.40	0.51	0.44	0.32	0.31	0.29	0.29	0.25
2030		0.41	0.34	0.34	0.48	0.42	0.31	0.27	0.25	0.29	0.24
2040		0.40	0.35	0.32	0.49	0.42	0.32	0.28	0.23	0.29	0.25
2050		0.42	0.38	0.36	0.46	0.42	0.33	0.29	0.25	0.28	0.25
2060		0.43	0.36	0.37	0.44	0.44	0.34	0.28	0.25	0.28	0.26
2010	R2	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.43	0.43	0.41	0.48	0.42	0.32	0.32	0.31	0.28	0.24
2030		0.39	0.37	0.35	0.44	0.39	0.30	0.30	0.27	0.26	0.21
2040		0.39	0.36	0.32	0.43	0.38	0.31	0.29	0.24	0.26	0.22
2050		0.42	0.38	0.32	0.41	0.38	0.33	0.29	0.25	0.25	0.22
2060		0.42	0.36	0.36	0.40	0.39	0.34	0.29	0.26	0.24	0.23
2010	R3	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.42	0.47	0.43	0.51	0.45	0.31	0.34	0.31	0.30	0.25
2030		0.40	0.42	0.37	0.47	0.43	0.29	0.33	0.28	0.28	0.25
2040		0.39	0.42	0.34	0.46	0.43	0.29	0.33	0.26	0.28	0.24
2050		0.44	0.41	0.37	0.43	0.43	0.31	0.34	0.28	0.27	0.25
2060		0.44	0.40	0.37	0.42	0.44	0.32	0.34	0.28	0.26	0.25
2010	R4	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.40	0.46	0.44	0.51	0.44	0.30	0.34	0.32	0.30	0.25
2030		0.35	0.40	0.39	0.45	0.41	0.27	0.32	0.30	0.27	0.23
2040		0.34	0.37	0.37	0.42	0.42	0.25	0.31	0.29	0.26	0.24
2050		0.38	0.38	0.39	0.40	0.41	0.27	0.31	0.30	0.24	0.24
2060		0.39	0.37	0.40	0.39	0.42	0.28	0.31	0.30	0.24	0.24
2010	R5	0.42	0.44	0.46	0.61	0.51	0.31	0.32	0.32	0.30	0.28
2020		0.39	0.39	0.41	0.48	0.52	0.29	0.31	0.30	0.28	0.29
2030		0.35	0.33	0.34	0.40	0.53	0.27	0.26	0.25	0.23	0.29
2040		0.32	0.30	0.31	0.38	0.46	0.26	0.24	0.23	0.22	0.27
2050		0.33	0.29	0.31	0.36	0.38	0.26	0.25	0.23	0.21	0.21
2060		0.33	0.28	0.31	0.36	0.37	0.27	0.24	0.23	0.20	0.21

Table 16. Projections of change in an edge utilization index among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Edge Utilization Index											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.50	0.43	0.49	0.53	0.60	0.34	0.33	0.34	0.26	0.24
2030		0.52	0.45	0.51	0.60	0.64	0.34	0.34	0.35	0.25	0.24
2040		0.52	0.42	0.50	0.61	0.64	0.34	0.34	0.36	0.24	0.24
2050		0.51	0.39	0.46	0.62	0.63	0.34	0.34	0.36	0.24	0.23
2060		0.50	0.37	0.44	0.62	0.63	0.34	0.34	0.35	0.23	0.23
2010	R1	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.45	0.44	0.49	0.49	0.57	0.33	0.32	0.33	0.26	0.25
2030		0.46	0.46	0.53	0.51	0.59	0.32	0.32	0.33	0.26	0.26
2040		0.44	0.43	0.54	0.51	0.59	0.31	0.29	0.31	0.26	0.26
2050		0.43	0.43	0.54	0.53	0.58	0.31	0.29	0.31	0.27	0.27
2060		0.40	0.43	0.53	0.54	0.58	0.31	0.30	0.31	0.27	0.26
2010	R2	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.45	0.40	0.47	0.51	0.59	0.33	0.30	0.33	0.26	0.25
2030		0.46	0.42	0.50	0.55	0.62	0.32	0.30	0.33	0.25	0.25
2040		0.45	0.43	0.51	0.55	0.62	0.32	0.29	0.33	0.26	0.25
2050		0.43	0.43	0.50	0.57	0.61	0.31	0.29	0.32	0.26	0.25
2060		0.41	0.43	0.50	0.57	0.61	0.31	0.30	0.32	0.26	0.25
2010	R3	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.47	0.37	0.48	0.48	0.57	0.33	0.28	0.33	0.26	0.25
2030		0.51	0.38	0.52	0.52	0.59	0.32	0.29	0.33	0.26	0.25
2040		0.51	0.37	0.53	0.53	0.60	0.32	0.29	0.33	0.27	0.25
2050		0.48	0.36	0.50	0.55	0.59	0.31	0.30	0.32	0.26	0.25
2060		0.45	0.35	0.50	0.55	0.59	0.32	0.30	0.32	0.27	0.25
2010	R4	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.47	0.37	0.47	0.49	0.58	0.33	0.28	0.33	0.26	0.25
2030		0.51	0.39	0.50	0.54	0.60	0.33	0.29	0.34	0.26	0.25
2040		0.52	0.39	0.50	0.56	0.60	0.32	0.30	0.33	0.26	0.25
2050		0.52	0.38	0.48	0.57	0.59	0.32	0.30	0.32	0.26	0.25
2060		0.49	0.38	0.47	0.57	0.59	0.31	0.30	0.32	0.26	0.26
2010	R5	0.46	0.43	0.45	0.42	0.53	0.32	0.30	0.31	0.25	0.26
2020		0.48	0.42	0.50	0.51	0.51	0.33	0.31	0.32	0.25	0.26
2030		0.51	0.45	0.54	0.58	0.50	0.33	0.33	0.33	0.24	0.27
2040		0.51	0.45	0.55	0.59	0.54	0.33	0.33	0.32	0.25	0.25
2050		0.50	0.44	0.53	0.60	0.61	0.33	0.33	0.32	0.25	0.25
2060		0.48	0.43	0.53	0.61	0.62	0.33	0.34	0.32	0.25	0.26

Table 17. Projections of change in a hydrologic connectivity index among alternatives from 2010 to 2060 in planning units 1, 2, 3a, 3b and 4.

Average Hydrologic Connectivity Index											
Yr	Alt	Mn_PU_1	Mn_PU_2	Mn_PU_3a	Mn_PU_3b	Mn_PU_4	St.Dev.PU_1	St.Dev.PU_2	St.Dev.PU_3a	St.Dev.PU_3b	St.Dev.PU_4
2010	FWOP	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.64	0.69	0.66	0.42	0.43	0.30	0.30	0.28	0.27	0.27
2030		0.65	0.70	0.68	0.41	0.43	0.31	0.31	0.29	0.28	0.27
2040		0.66	0.72	0.69	0.41	0.44	0.31	0.31	0.30	0.27	0.27
2050		0.67	0.73	0.71	0.40	0.43	0.31	0.31	0.30	0.27	0.27
2060		0.68	0.74	0.72	0.40	0.43	0.31	0.31	0.30	0.26	0.27
2010	R1	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.62	0.67	0.64	0.42	0.43	0.31	0.30	0.28	0.27	0.27
2030		0.61	0.66	0.65	0.40	0.42	0.32	0.31	0.29	0.27	0.27
2040		0.60	0.67	0.65	0.39	0.41	0.32	0.31	0.29	0.27	0.27
2050		0.59	0.66	0.65	0.38	0.41	0.34	0.31	0.29	0.27	0.27
2060		0.57	0.66	0.65	0.38	0.41	0.35	0.32	0.29	0.27	0.27
2010	R2	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.63	0.68	0.65	0.42	0.43	0.31	0.29	0.28	0.27	0.27
2030		0.61	0.67	0.65	0.39	0.42	0.32	0.31	0.29	0.27	0.27
2040		0.60	0.66	0.66	0.39	0.42	0.32	0.32	0.30	0.27	0.27
2050		0.60	0.65	0.67	0.38	0.42	0.33	0.32	0.30	0.27	0.27
2060		0.59	0.65	0.66	0.38	0.42	0.34	0.33	0.29	0.27	0.27
2010	R3	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.62	0.67	0.62	0.41	0.43	0.30	0.30	0.29	0.27	0.26
2030		0.59	0.65	0.61	0.39	0.42	0.31	0.32	0.31	0.27	0.26
2040		0.58	0.64	0.62	0.39	0.42	0.31	0.33	0.31	0.27	0.26
2050		0.56	0.64	0.62	0.39	0.41	0.31	0.34	0.31	0.27	0.26
2060		0.54	0.64	0.61	0.39	0.41	0.33	0.35	0.32	0.27	0.26
2010	R4	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.63	0.69	0.63	0.41	0.43	0.30	0.29	0.29	0.27	0.26
2030		0.62	0.69	0.62	0.40	0.42	0.31	0.30	0.31	0.27	0.26
2040		0.61	0.69	0.62	0.40	0.42	0.31	0.31	0.32	0.27	0.26
2050		0.61	0.69	0.62	0.40	0.42	0.31	0.31	0.32	0.27	0.27
2060		0.61	0.69	0.61	0.40	0.42	0.31	0.32	0.32	0.28	0.27
2010	R5	0.63	0.67	0.65	0.43	0.44	0.30	0.29	0.27	0.27	0.26
2020		0.63	0.68	0.64	0.41	0.44	0.30	0.30	0.28	0.27	0.27
2030		0.62	0.67	0.64	0.40	0.44	0.31	0.31	0.29	0.27	0.27
2040		0.62	0.68	0.64	0.40	0.44	0.31	0.31	0.30	0.27	0.28
2050		0.62	0.69	0.66	0.40	0.44	0.32	0.31	0.30	0.27	0.28
2060		0.62	0.70	0.67	0.40	0.44	0.33	0.31	0.30	0.27	0.28

ATTACHMENT E

HET Diversion Summary Tables

December 2008

PU1	R1 (Dec-May)		R2 (Pulse Flow 5)				R3 (State Master Plan)		R4 (HET Alt)		R5 (LCA PBMO)	
			Low Flow Year		High Flow Year							
	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)
Pontchartrain Basin												
Bonnet Carre									7,104	13,000	*opport. use*	
LaBranche	403	737	138	253	1,209	2,212						
Blind River	6,604	12,085	2,121	3,881	19,812	36,256	2,732	5,000	546	1,000	5,000	9,150
Hope Canal	6,604	12,085	2,121	3,881	19,812	36,256	2,732	5,000	546	1,000	1,000	1,830
Violet Canal							27,322	50,000	8,197	15,000	250	458
Bayou Bienvenue	32,000	58,560	5,000	9,150	96,000	175,680						
Bayou LaLoutre	21,000	38,430	5,224	9,560	63,000	115,290						
basin subtotal	**66,611**	**121,897**	**14,604**	**26,725**	**199,833**	**365,694**	**32,787**	**60,000**	**16,393**	**30,000**	**6,250**	**11,438**
Breton Sound Basin												
B. Terre aux Boeufs	10,230	18,721	2,714	4,967	30,690	56,163						
Caernarvon	16,175	29,600	4,397	8,047	48,525	88,801	*4,372*	*8,000*	*4,372*	*8,000*	*8,000*	*8,000*
White's Ditch							8,197	15,000			10,000	18,300
Bayou Lamoque	7,348	13,447	7,912	14,479	22,044	40,341	8,197	15,000	6,995	12,800	12,000	21,960
American Bay											110,000	201,300
Grand Bay	3,358	6,145	971	1,777	10,074	18,435						
Benny's Bay	0	0	0	0	0	0	27,322	50,000	10,929	20,000	0	0
basin subtotal	**37,111**	**67,913**	**15,994**	**29,270**	**111,333**	**203,740**	**48,087**	**88,000**	**22,295**	**40,800**	**140,000**	**249,560**
PU1 TOTAL	**103,722**	**189,810**	**30,598**	**55,995**	**311,166**	**569,434**	**80,874**	**148,000**	**38,689**	**70,800**	**146,250**	**260,998**

Existing diversions assumed to operate at full capacity

Discharge in excess of existing full diversion capacity

PU2	R1 (Dec-May)		R2 (Pulse Flow 5)				R3 (State Master Plan)		R4 (HET Alt)		R5 (LCA PBMO)	
			Low Flow Year		High Flow Year							
	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)	Ave. Flow (cfs)	High Flow (cfs)
Barataria Basin												
Lagan	3,016	5,519	2,198	4,022	9,048	16,558	2,732	5,000			1,500	2,745
Edgard	3,533	6,465	967	1,773	10,599	19,396	2,732	5,000			1,500	2,745
Bayou Lafourche							1,000	1,000	186	*340*	1,000	1,000
Davis Pond	*10,650*	*10,650*	*273*	*500*	*10,650*	*10,650*	*5,820*	*10,650*	*5,820*	*10,650*	*10,650*	*10,650*
Naomi	1,091	1,997	328	600	3,273	5,990	*1,093*	*2,000*	*1,093*	*2,000*	*1,093*	*2,000*
Myrtle Grove	21,610	39,546	5,240	9,589	64,830	118,639	8,197	15,000	1,093	2,000	5,000	9,150
West Pointe-a-la-Hache	1,794	3,283	475	869	5,382	9,849	8,197	15,000	*1,093*	*2,000*	*1,093*	*2,000*
Pt. Sulphur-Homeplace	11,354	20,778	2,757	5,045	34,062	62,333						
Buras	3,803	6,959	1,315	2,406	11,409	20,878						
Fort Jackson	5,310	9,717	1,122	2,053	15,930	29,152			8,197	15,000	60,000	109,800
basin subtotal	**62,161**	**104,914**	**14,675**	**26,857**	**165,183**	**293,445**	**29,770**	**53,650**	**17,481**	**31,990**	**81,836**	**140,090**
Mississippi River Delta												
West Bay	*20,000*	*36,600*	*20,000*	*36,600*	*20,000*	*36,600*	**27,322**	**50,000**	**27,322**	**50,000**	*20,000*	*36,600*
PU2 TOTAL	**82,161**	**141,514**	**34,675**	**63,457**	**185,183**	**330,045**	**57,093**	**103,650**	**44,803**	**81,990**	**101,836**	**176,690**
TOTAL PU1 + PU2 Mississippi River Diversions	**185,883**	**331,324**	**65,273**	**119,452**	**496,349**	**899,479**	**137,967**	**251,650**	**83,492**	**152,790**	**248,086**	**437,688**
Existing Diversions	*30,650*	*74,250*	*20,273*	*37,100*	*30,650*	*47,250*	*11,284*	*20,650*	*12,377*	*22,990*	*40,836*	*59,250*

Existing diversions assumed to operate at full capacity

Discharge exceed maximum siphon capacity

Measure Description	Maximum PU3a and PU3b Diversion Discharges* R1 (cfs)	R2 (cfs)	R3 (cfs)	R4 (cfs)	R5 (cfs)
Multi-purpose HNC Lock operation					
Lower Bayou Grand Caillou	750	750	500	750	500
Bayou Dulac to L. Quitman		750	500	750	500
Falgout C. to L. Decade	500	500	250	500	250
Mississippi River Diversions					
Grand Bayou + Jean LaCroix	38,796				
East of Bayou Terrebonne	32,208				
Upper Lake Boudreaux	5,124				
FW Introduction via GIWW from Barataria					
Grand Bayou			1,000		
Convey Atch Water to N. Terrebonne					
Grand Bayou		6,000	4,000	6,000	4,000
St. Louis Canal		0	0	0	0
Humble Canal		500	500	500	500
Bayou Chauvin		500	0	500	0
Lower Bayou Grand Caillou	750	750	500	750	500
Bayou Dulac to L. Quitman		750	500	750	500
Falgout C. to L. Decade	500	500	250	500	250
Minors Canal w enlargement	2,000	2,000	1,000	2,000	1,000
Carencro Lake**	500	500	250	500	250
Avoca Island**	4,000	4,000	2,000	4,000	2,000
Blue Hammock Bayou	2,000	2,000	1,000	2,000	1,000
Penchant Basin Plan**					
Superior Canal	500	500	500	500	500
Brady Canal	500	500	500	500	500
Carencro Lake	500	500	250	500	250
Liners Canal enlargement	200	200	0	200	0
South Lake Decade (Lapeyrouse C.)	500	500	0	500	
Houma By-Pass Channel					
Grand Bayou		2,000	0	2,000	
St. Louis Canal		0	0	0	
Humble Canal		500	0	500	
Bayou Chauvin		500	0	500	
Totals	**89,328**	**24,700**	**13,500**	**24,700**	**12,500**

* *Listed inputs are in addition to any existing freshwater inputs*

** Benefits accrue to PU3b wetlands

ATTACHMENT F

WETLAND ACREAGE

December 2008

PU 1 2010 (Base Year) Acreage – 669,760										
Coastal Restoration Alternative	R1		R2		R3		R4		R5	
SLR	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium
2110 Acreage	703,154	643,822	695,902	639,096	676,224	630,920	509,472	462,883	605,278	557,992
% of Baseline Sustained	105%	96%	104%	95%	101%	94%	76%	69%	90%	83%

PU 2 2010 (Base Year) Acreage – 533,130										
Coastal Restoration Alternative	R1		R2		R3		R4		R5	
SLR	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium
2110 Acreage	575,497	557,009	584,871	554,796	536,034	524,359	501,080	484,671	483,199	463,040
% of Baseline Sustained	108%	104%	110%	104%	101%	98%	94%	91%	91%	87%

PU 3a 2010 (Base Year) Acreage – 437,585										
Coastal Restoration Alternative	R1		R2		R3		R4		R5	
SLR	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium
2110 Acreage	482,463	438992	358,976	312,590	304,868	271,860	330,057	296,670	250,140	231,140
% of Baseline Sustained	110%	100%	82%	71%	70%	62%	75%	68%	57%	53%

PU 3b 2010 (Base Year) Acreage – 805,137										
Coastal Restoration Alternative	R1		R2		R3		R4		R5	
SLR	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium	Existing	Medium
2110 Acreage	845,338	804,156	848,744	804,082	808,168	768,763	787,204	743,662	799,811	756,912
% of Baseline Sustained	105%	100%	105%	100%	100%	95%	98%	92%	99%	94%

PU 4 2010 (Base Year) Acreage – 827,003										
Coastal Restoration Alternative	**R1**		**R2**		**R3**		**R4**		**R5**	
SLR	**Existing**	**Medium**	**Existing**	**Medium**	**Existing**	**Medium**	**Existing**	**Medium**	**Existing**	**Medium**
2110 Acreage	**874,028**	**827,011**	**871,320**	**824,282**	**841,614**	**794,761**	**828,214**	**782,015**	**793,544**	**746,543**
% of Baseline Sustained	**106%**	**100%**	**105%**	**100%**	**102%**	**96%**	**100%**	**95%**	**96%**	**90%**