Multifunctional Subsidence Reversal

Crossprograming Restored Wetlands on Sherman Island

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Abstract

As the interface between land and water processes, deltas record activities and subsidence in the Sacramento-San Joaquin Delta mark the 150 years of agricultural land use. Hydrologic manipulation for agriculture and the subsequent oxidation of drained soils have caused the vertical deformation of the land's surface. Anthropocentric activities have manipulated the land for agriculture and redefined rivers for municipal water conveyance; both systems depend on the existing levees to remain intact. The levee system has been countlessly breached, and subsiding levee foundations, rising sea levels, and growing seismic risk further threaten their integrity. The agricultural practices which power the delta's economy have carved islands into polders.

To restore the delta and relieve dependence on the levee system, a series of studies conducted by USGS in conjunction with DWR suggest the feasibility of large-scale restoration before rising sea levels engulf the islands. Through reestablished freshwater emergent wetlands, subsidence reversal manipulates hydrology to rebuild soils by favoring natives with a rampant cycle of vegetative growth and decay. Although subsidence reversal buttresses infrastructure against catastrophic failure, converting prime agricultural land to wetlands seems economically wasteful. To further incentivize subsidence reversal, this study developed compatible programs.

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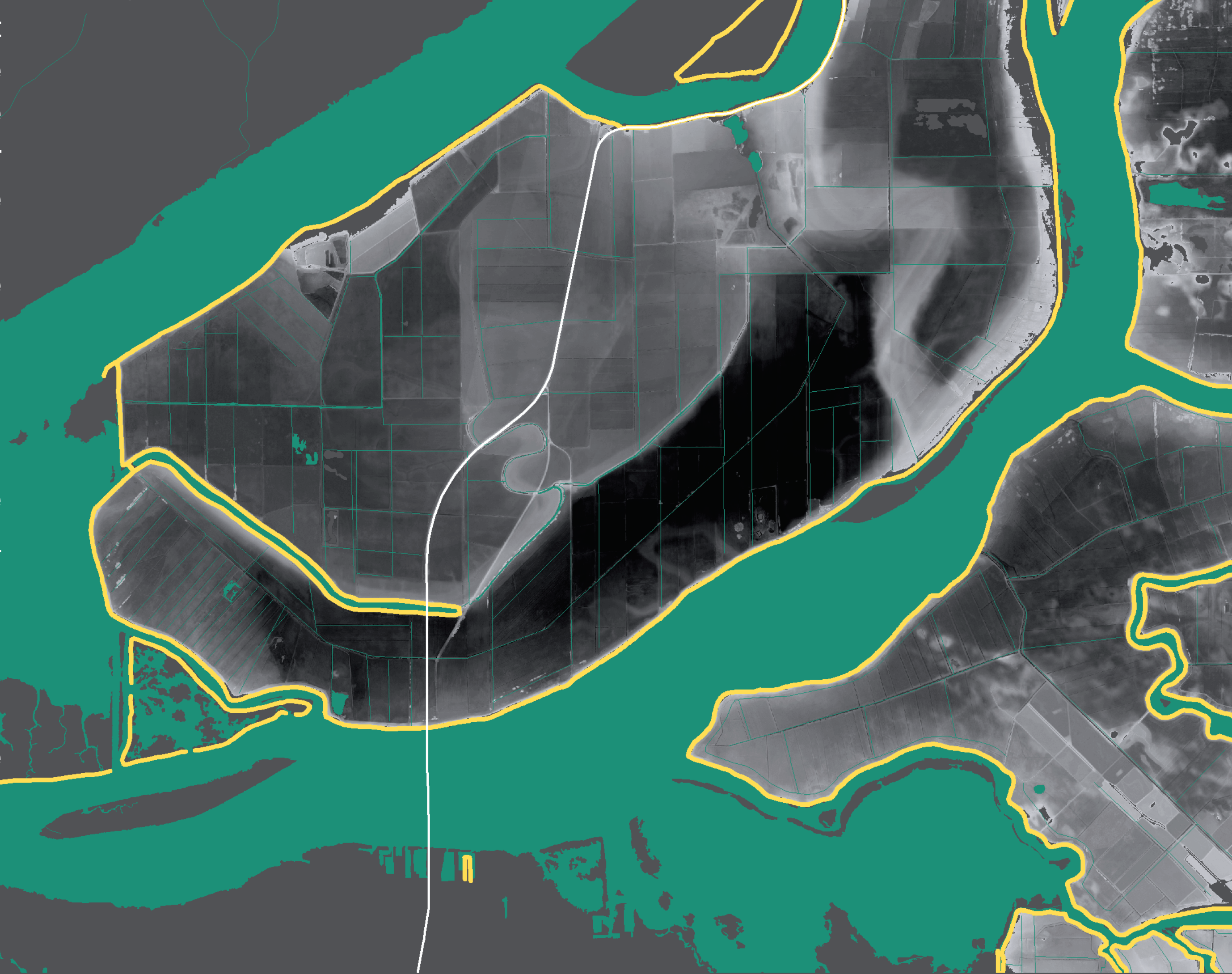
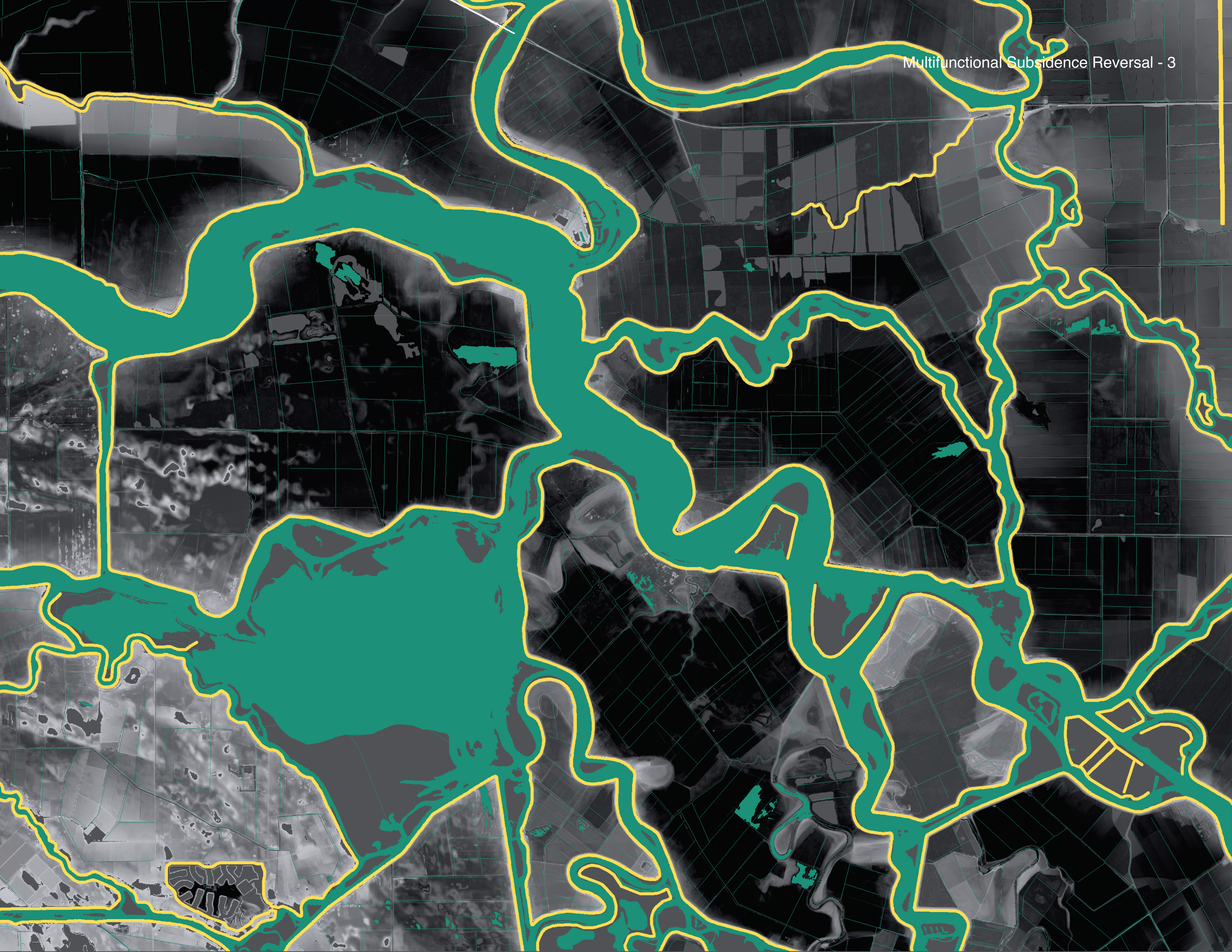
Figures

01 Introduction

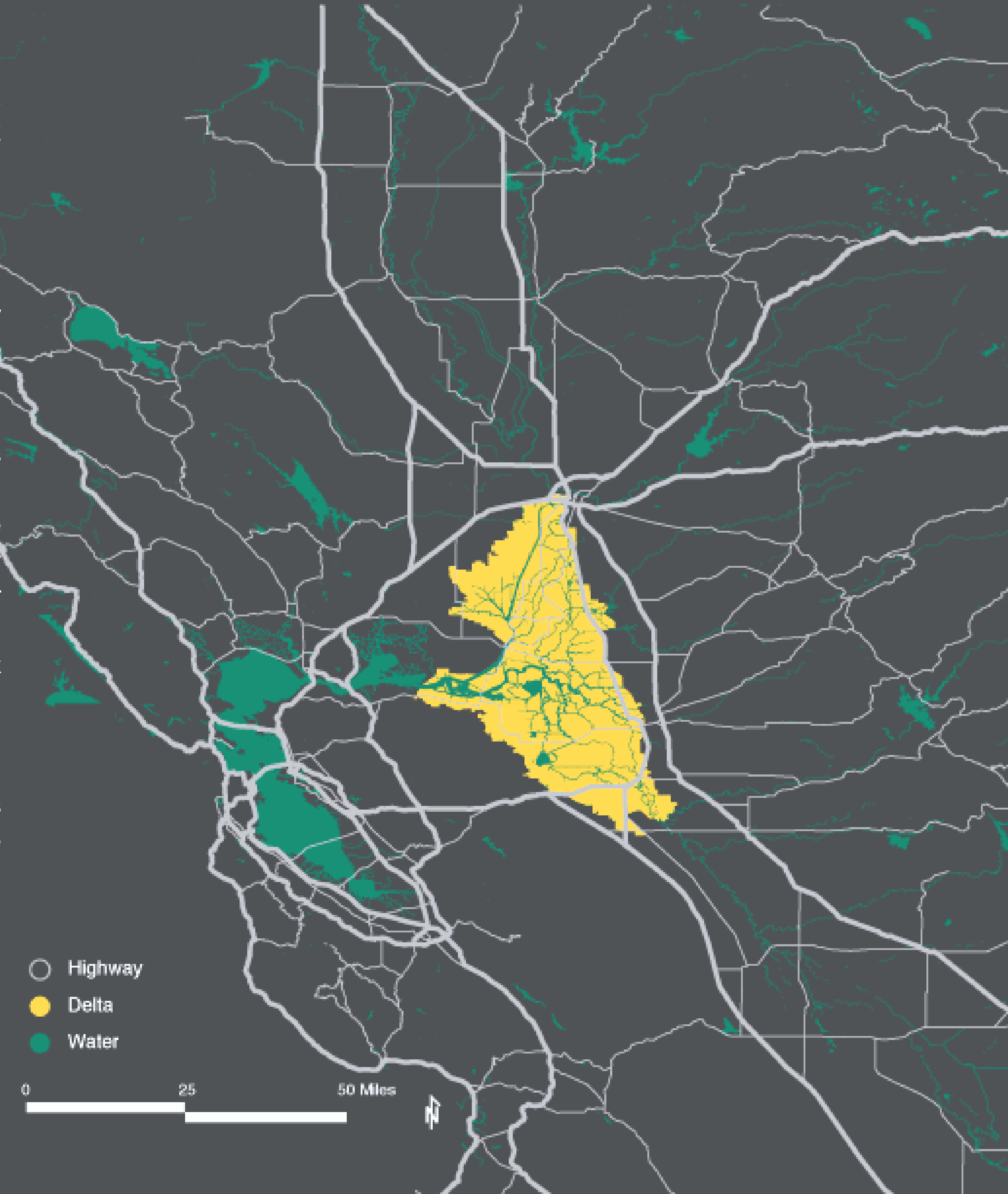
As the interface between land and water processes, deltas record activities through their landscape. Subsidence is sinking caused by hydrologic manipulation. In the Sacramento-San Joaquin Delta, the depth of the subsided islands mark the 150 years since major agriculture reclamation. These polders depend on the aging levee infrastructure to prevent inundation; however, if these levees are breached, saline water could migrate further inland and affect drinking water supplies for two-thirds of the state. In the face of weather weirding, sea level rise, and the potential for an earthquake, the subsided islands significantly risk affecting water infrastructure. Subsidence reversal mimics the high rate of sediment accretion of predevelopment conditions by recreating freshwater emergent wetlands. Subsidence reversal across the islands of the delta could remediate the soil degradation caused by the last 150 years of farming; however, converting prime agricultural land to wetlands is economically unappealing. The immediate loss of agricultural revenue marginalizes the long term costs avoided in the event of a levee breach. Currently, the farms in purple compose two-thirds of the delta and generate $800 million for region's economy. This design seeks to economically substantiate the proposal for subsidence reversal on Sherman Island with functions that incentivize land use conversion. How can subsidence reversal be designed to foster multiple functions?

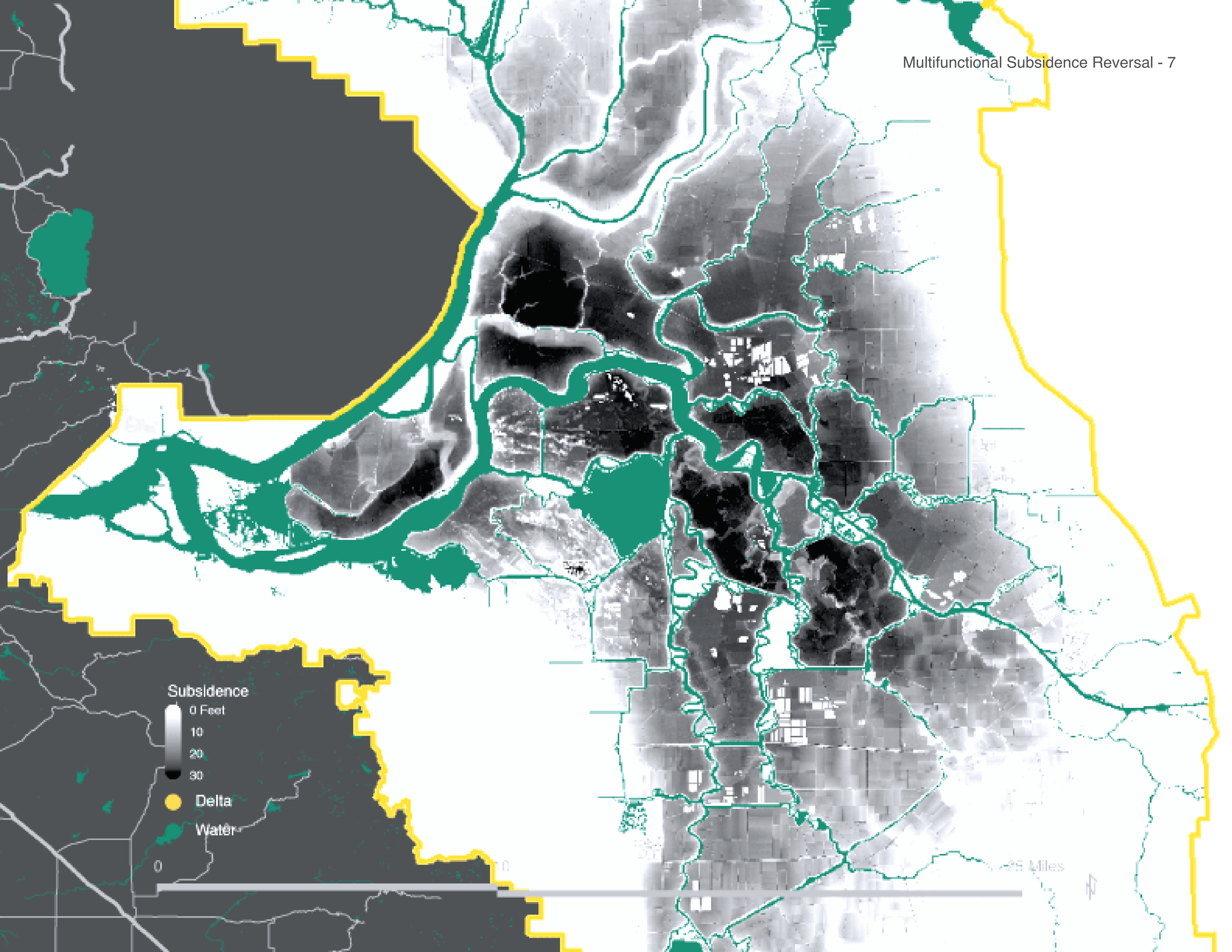




02 Problem Statement

Development redefined the Sacramento-San Joaquin Delta for agriculture and conveyance. Widespread land conversion from wetlands to farmland has dessicated the islands into polders. While the land surface of the polders can be raised by reverting farmland to wetlands, growing the surface of the islands above sea level would require decades to a century. Left to sink, the degrading levees of the sunken islands pose severe and growing risks to local and regional stakeholders. Subsidence is the deformation of land primarily caused by the removal and extraction of fluids, further exacerbated through oxidation, compaction and dissolution of soil. The land can sink both gradually and/or suddenly, and manifests as both vertical and horizontal displacement (Galloway & Burbey 2011). Subsidence over the past two centuries has created extensive risks that necessitate intervention. This study aims to design multifunctional subsidence reversal.

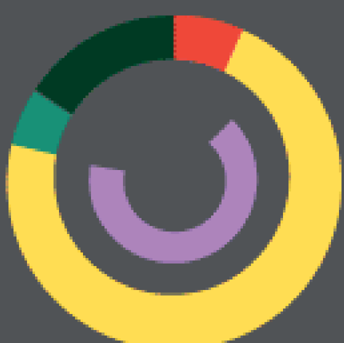


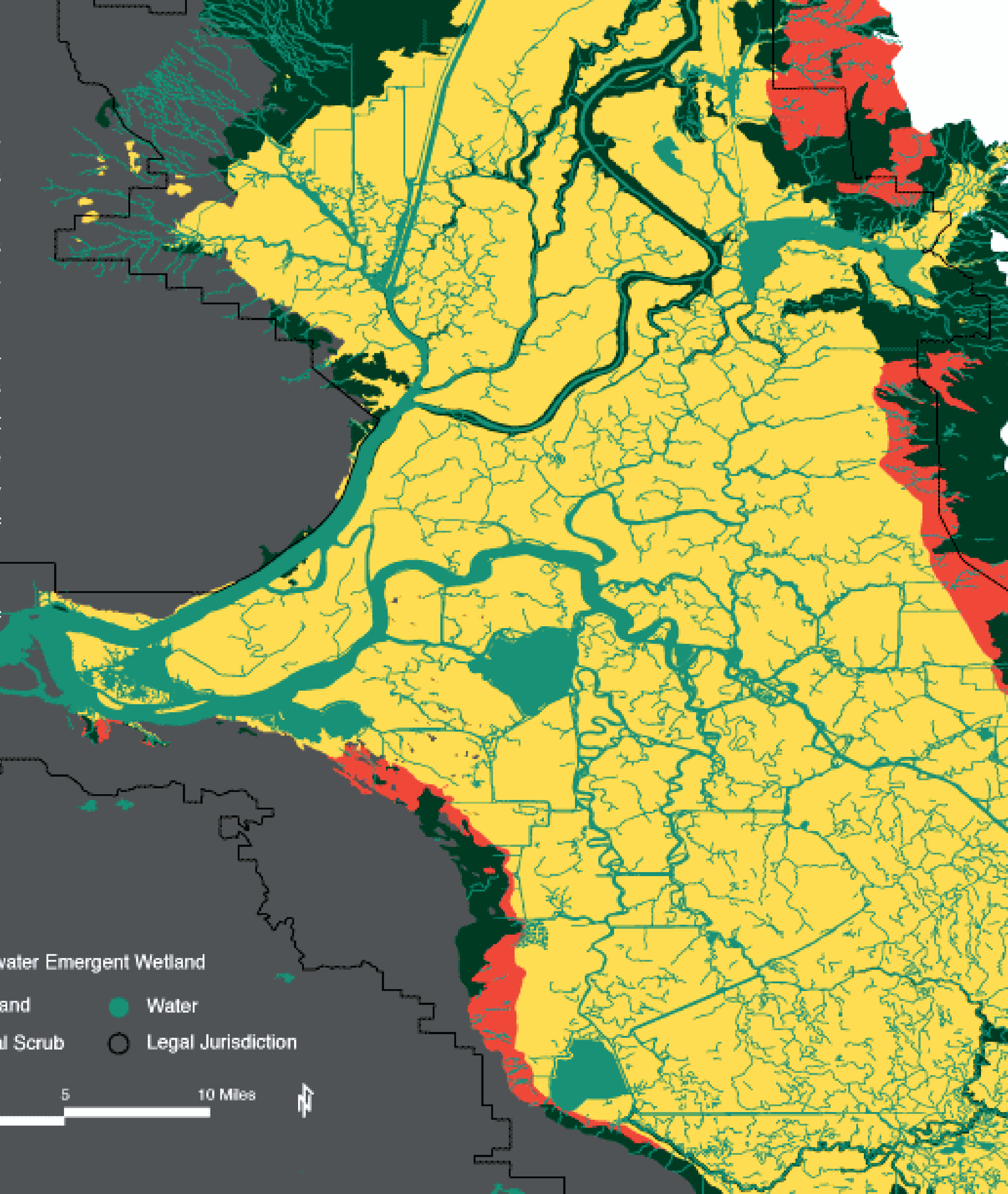


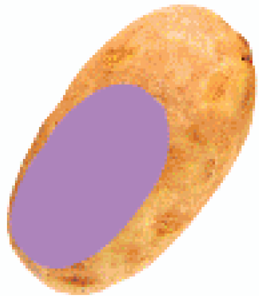
Subsidence
0 Feet
10
20
30
Delta
Water
0
10
25 Miles

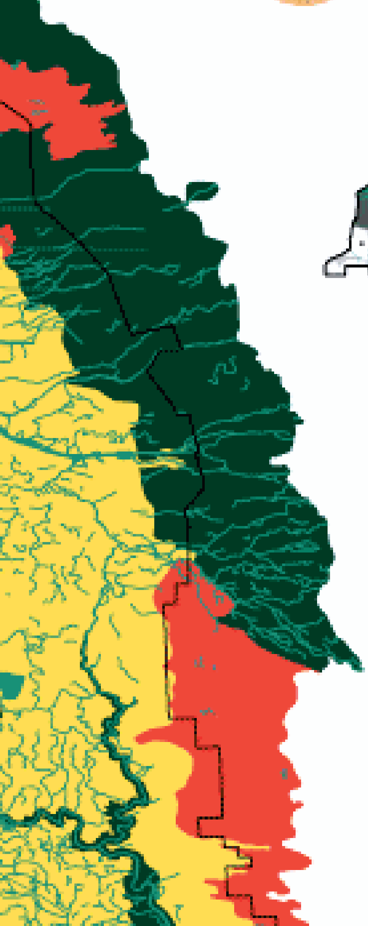
Prior to the Delta's development, the low-lying tidal marshes connected across sinuous channels and flooded seasonally. After sea-level rise stabilized 5,000 years ago, the delta balanced continued sea-level rise with rapid marsh growth and sediment accumulation. The bay-delta was a swampland of serpentine channels and low-lying islands no less than 5 feet above sea level (Cohen et al 1998). The freshwater outflows relative to the tidal flow fostered peat formation through marshes of tule.

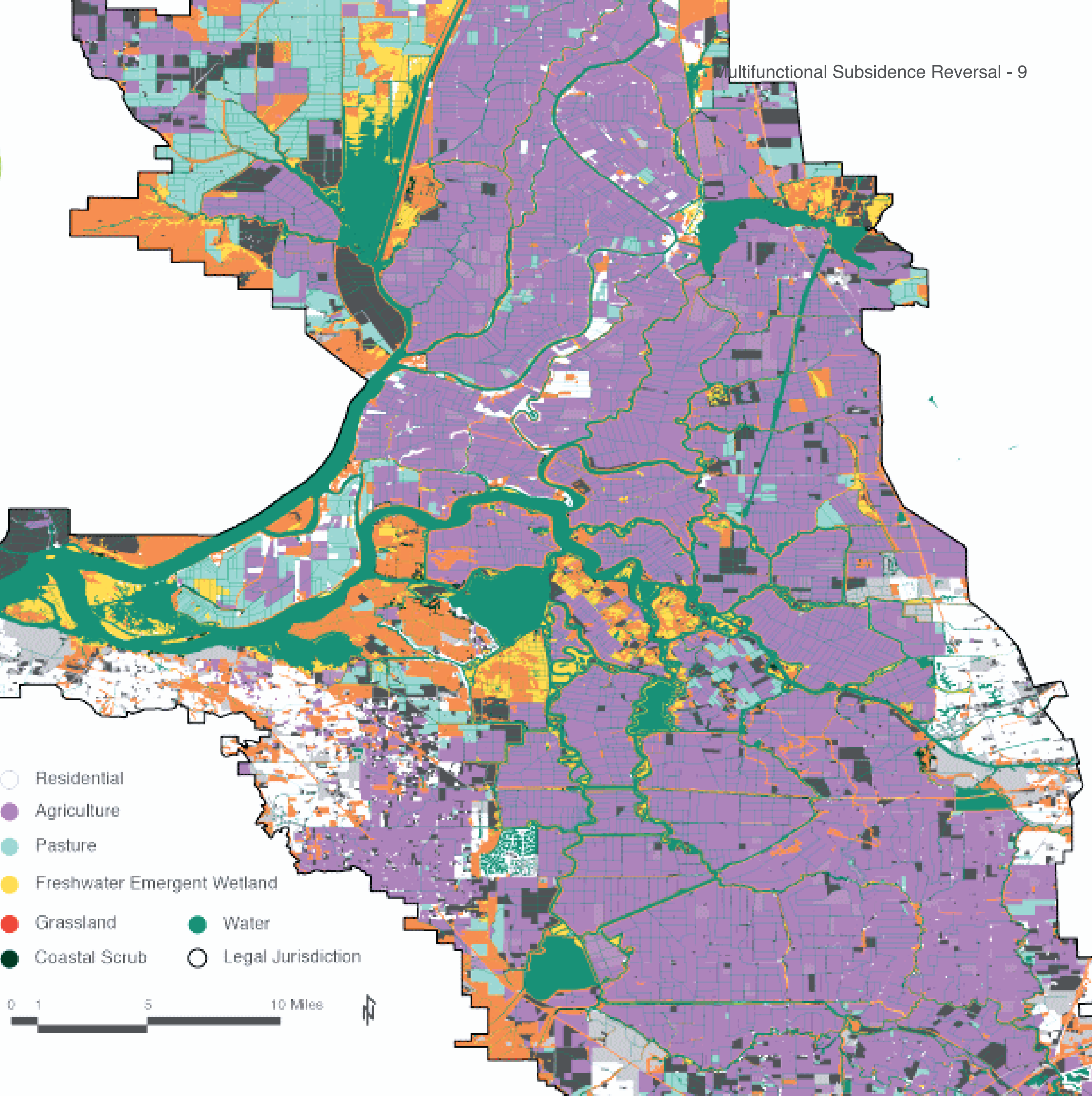
The 1849 Gold Rush brought an influx of American settlers which spurred the need for production. As a result, the Swamp and Overflowed Lands Act of 1850 catalyzed large-scale development of agriculture (Wolff 2003). The Swamp and Overflowed

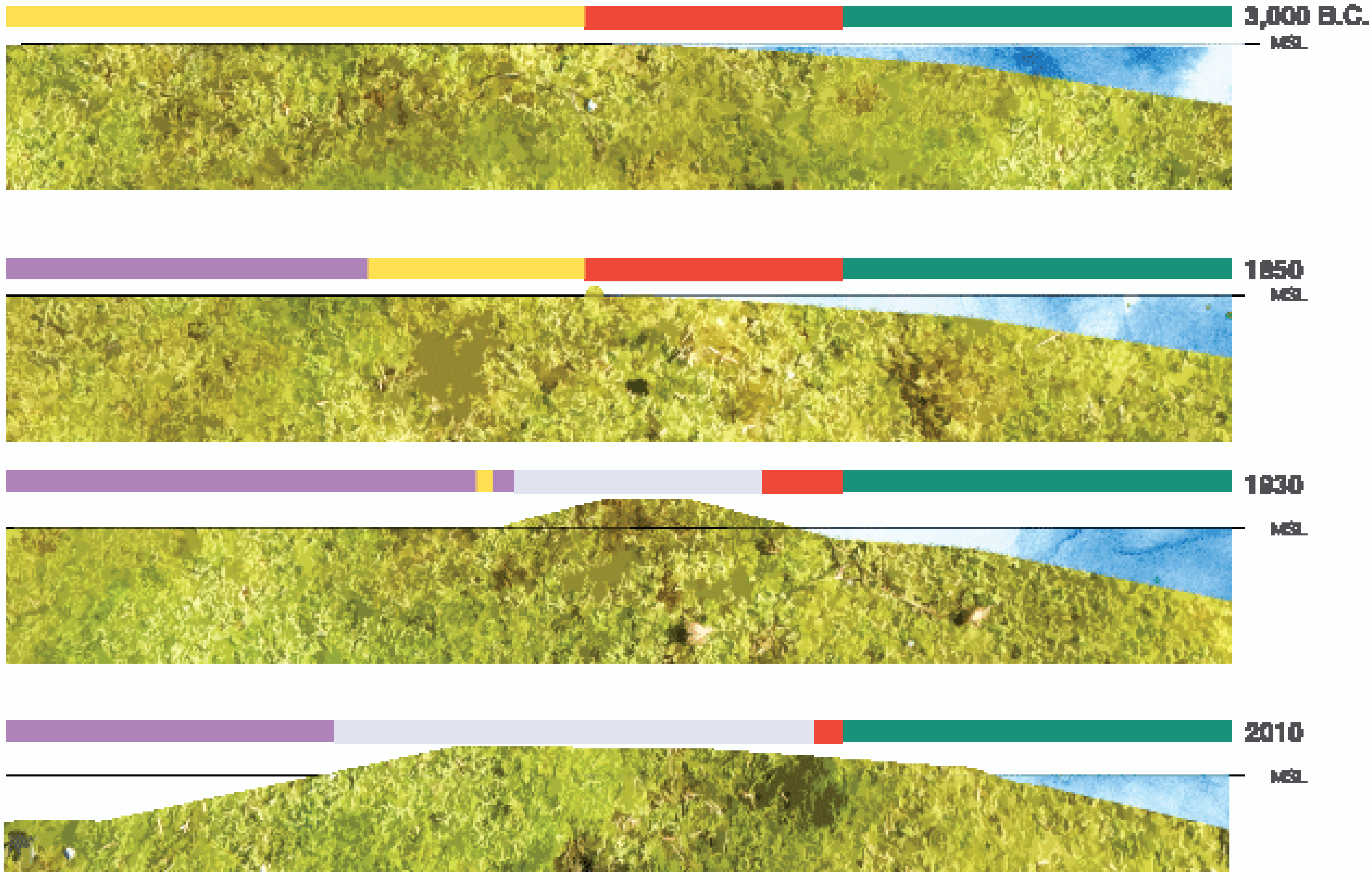









Residential
Agriculture
Pasture
Freshwater Emergent Wetland
Grassland
Water
Coastal Scrub
Legal Jurisdiction
0 1 5 10 Miles
N


3,000 B.C.
MSL
1850
MSL
1930
MSL
2010
MSL

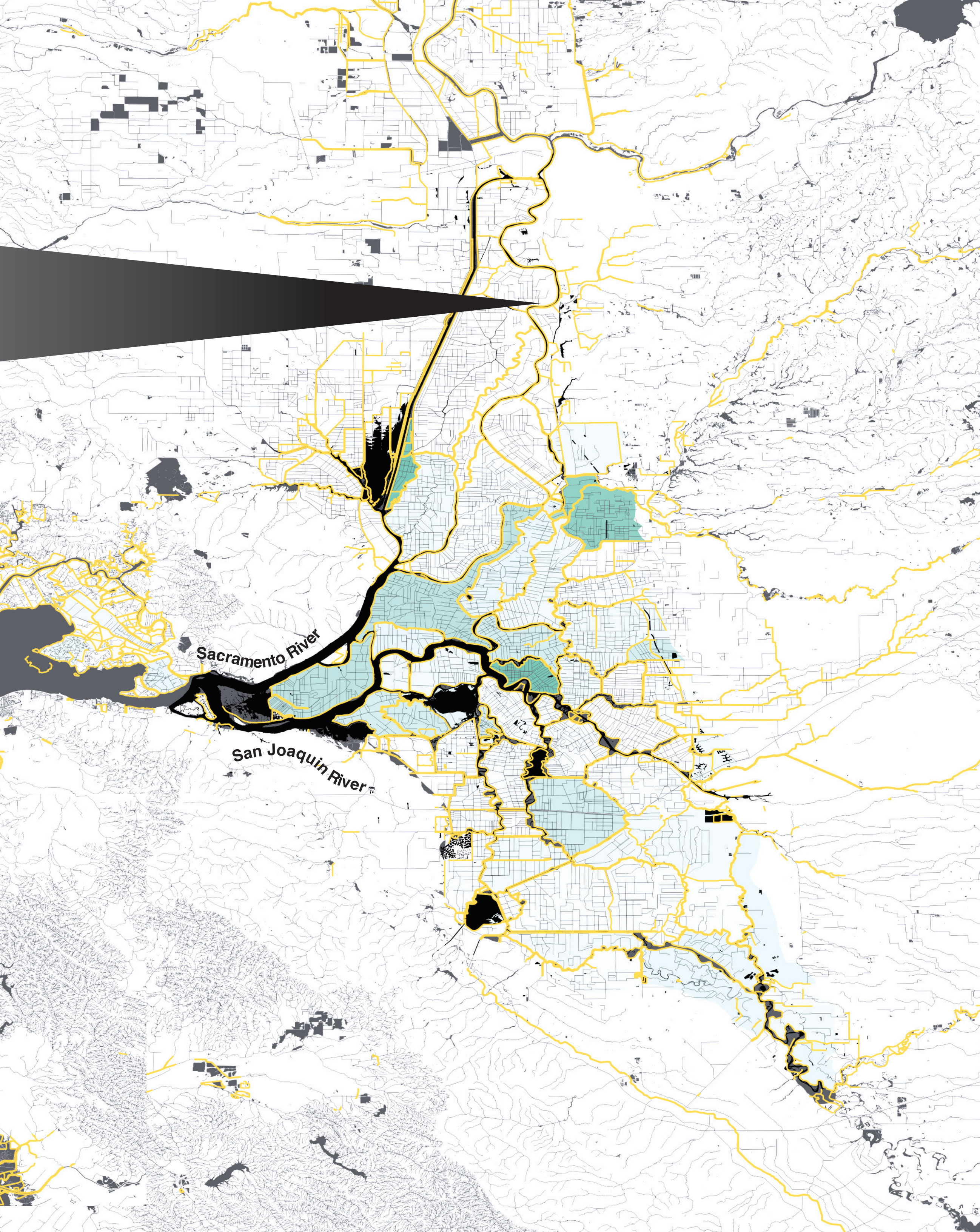
Lands Act redefined the delta by allocating portions of public swampland to speculators willing to drain the land. Through the late 1800's, the swamplands woven into the Sacramento-San Joaquin Delta were encircled with 3 to 4 foot high levees and drained for agriculture. Early agricultural use of the organically nutrient-rich peat and mud deposits yielded seemingly miraculous crops including 50 pound heads of cabbage and potatoes over 30 centimeters in circumference. The adjacent network of water channels provided convenient transportation of produce. The nutrient-rich soils provided astounding crops and the complex of water channels allowed easy access. Abetted by stupendous agricultural productivity and cheap transport, the region began to grow in notoriety for its agricultural prowess. The legislation transformed wetlands into farmland and the rivers into major shipping lanes. Draining swamplands for farming instigated subsidence in the Sacramento-San Joaquin Delta (Deverel & Rojstaczer 1996). Converting wetlands to dry conditions exposed the peat soils to oxygen and induced microbial oxidation. Through oxidation, the soil was spent and the surface of the land began to sink. Regardless, the agriculture grew to dominate the delta landscape.

As the interior of the island fell below sea level, the land surface met groundwater levels. To maintain suitable conditions for conventional agricultural production, irrigation ditches surround each field and maintain the groundwater level between 3 and 4 feet below surface level. In the late 1800's, the clamshell dredger collected alluvial material from shipping channels which was used to augment the levees; however, the increased volumetric capacity of the river caused water levels to rise and incite further flooding (Wolff 2003). By 1930, the levee system was completed and maintained around at an elevation of 10 to 15 feet by local owners and the Army Corps of Engineers (Cohen et al 1998). Following numerous episodes of floods, the remaining levees have been continually raised to resist high water events; however, Several of the levees breached by tides in the past century were never repaired and have remained inundated polders (Deverel & Rojstaczer 1996). Through the 1930's to the 1980's, federal, state, and local jurisdictions developed water conveyance infrastructure in the delta. Since the State Water Project and Central Valley Project, two-thirds of California's water supply passes through the delta.

The original levees lie between 16 to 26 feet below sea level (Cohen, D. A., Deverel, S.J., & Johnson, L.A. 1998) and have been maintained over the years to compensate for sinking. Despite efforts since the 1850's to develop robust protection, the probability of failure and the magnitude of inundation grows. A breach of the weakening levee system could salinate both local groundwater and regional surface water supplies. Saltwater intrusion endangers water supplies for many residents of California as well as agricultural productivity within the delta and Central Valley.

The islands of the Sacramento-San Joaquin Delta lie below sea level. “The Big Gulp” describes an event in the delta when several levees will be breached resulting in the inundation of islands and salinization of state water infrastructure. Water conveyance infrastructure relies on the levees and minimum freshwater outflows to preserve the salinity gradient across the bay-delta. The sunken islands pose a risk to the serviced population who depend on the levee system and hydrologic management of the saline-freshwater interface to prevent salinization of local and regional water supplies. Sea level rise necessitates buttressing fortifications while the peat and dredged alluvial material of the levees continues to oxidize and sink. As the levees degrade and sea levels rise, the effects of natural disasters increases. The decaying levees of the delta are susceptible to breaches in event of a large storm and/or an earthquake. Whether future sea levels, a large storm event or an earthquake cause major levee breaches first, the islands of the delta could flood.

Additional amounts of water are released from reservoirs during the dry season to



prevent saline water from entering the aqueducts (Roos & Vries 2011). About 70% of the inflow to the Sacramento-San Joaquin Delta comes from the Sacramento River and 20% comes from the San Joaquin River; the remaining fraction flows from the several east side rivers and a few smaller creeks (Roos & Vries 2011). Due to the density differences between ocean water and saline water, breached polders would predominantly fill freshwater. Losing immense volumes of freshwater from water channels would result in the migration of saline water to the east.

Subsidence of delta levees coupled with sea level rise within the bay augments the flood risk. After general stabilization 5,000 years ago, sea level has been rising since the late 19th century and accelerated through the 20th century due to anthropocentric catalysts. Further, contemporary local measures have demonstrated deceleration of rates for reasons unclear; however, evidence of unequal distribution of sea level rise may demonstrate a change in ocean pattern which could yield a dramatic surge or accelerated rate of rise through the next couple of decades (Roos &

Vries 2011). At localized scales, changes in tide gauge measurements represent both worldwide ocean rise as well as local tectonic movement; working off the assumption the San Francisco gauge has been at a relatively stable elevation for the past 100 years, Roos and Vries (2011) base measurements off the San Francisco tide gauge record. In 2009, the DWR prepared localized estimates combining the California Climate Action Team's 12 potential scenarios and further developed sea level rise projections. Based off their findings, the DWR operates at a design range of a 6 inches (0.15 m) to 1.3 feet (0.4 m) rise from 2000 to 2050 (OEHHA 2009). By 2100, sea levels are estimated to rise 8 inches (0.2 m) to 2 feet (0.61 m) above current levels; however these projections may not consider the accelerating rate of polar ice cap melting as buttresses to sea ice collapse (Roos & Vries 2011).

As sea levels rise and as the levees degrade over a long time scale, both the probability and severity of breaches during large storm events or an earthquake increases. Sea levels range between 1 foot daily due to tidal inundation, and the greatest risk of inundation occurs at high tide during storm events. Four factors determine the likelihood and/or severity of inundation in a storm event: river runoff, onshore winds, low barometric pressure, and high astronomical tide (Roos & Vries 2011).

To conclude, land conversion from inundated to dry conditions has degraded fertile soils and incited soil oxidation in the marshy peat islands of the delta. While the most sinking has occurred in the Central Valley, municipal water systems rely on the delta as a node. As California's population continues to grow and the severity of droughts increase, the demand for water will rise; however, the conveyance system in the delta is vulnerable to saltwater intrusion. Structural failure of the levees in the delta would endanger state drinking water supplies. As climate change progresses, the delta's ability to convey water is threatened by saltwater intrusion; furthermore, rising sea levels coupled with groundwater overdraft increases the probability of saline inundation into groundwater supplies. As soils oxidize, sea levels rise, levees subside, groundwater disappears, and saltwater migrates further the delta, the multiplicity of risks converge at the the delta and threaten water supplies and safety. As the weather weirding of climate change provokes greater variation in temperature and precipitation, larger populations rely on resources from aging infrastructure.

03 Purpose Statement & Research Question:
Substantiating Subsidence Reversal

The existing conditions began to develop over a century before subsidence was perceived or scientifically reviewed and the topography has shown that farming peat soils is liable to edaphic deterioration. Subsidence was instigated by conversion of non-tidal marsh to agricultural plots and will continue at a rate of 1 to 3 inches per year; however, subsidence reversal can halt subsidence and restore soils at an average rate of 1.5 inches (4 cm) per year (2008 Miller et al). The pre-development conditions thousands of years ago fostered ecologies capable of maintaining an elevation above sea level. Re-establishing non-tidal wetlands through managed hydrology accumulates sediment at rates capable of significant elevation gains over decades, and so, over time, a return to tidal marsh would protect the saltwater-freshwater interface by removing reliance on the levee system. By returning to a landscape of freshwater emergent wetlands, the delta could reverse subsidence and avoid associated risks; however, economic barriers prevent widespread conversion. In the face of weather weirding, sea level rise, and an earthquake, the subsided islands significantly risk affecting water infrastructure; however, the immediate costs marginalize the potential long term risks and/or benefits. Designing layered functions to subsidence reversal incentivizes land conversion. How can subsidence reversal foster multiple functions?

Through 1997 to 2006, subsidence reversal through managed palustrine wetlands demonstrated success across two 3 hectare wetlands. Freshwater emergent species readily colonize water shallower than 2 feet while invasives dominate depth between 5 and 15 feet where delta natives do not readily grow. Tule and cattail's fast cycle of growth and decay contributed the most to peat formation, and was informed by hydrologic patterns. With design depths of 0.82 feet (25 cm) and 1.80 feet (55 cm), the two wetlands demonstrated similar rates of reversal. The shallower wetland retained water for an average of 13 days and was homogeneously colonized by emergent wetland species. The deeper wetland retained water for an average of 6 days and developed varying patches of emergent wetland. This heterogeneity created spatially variable depths which augmented invasion by duckweed and other species; the topographic variety also created dense stands in deeper areas and thinner stands in the transition zones. These densely vegetated stands accumulated sediment at the greatest rates particularly in the portions isolated from the river water inlets. Across the transition zones and shallower wetland, sediment accumulated at intermediate rates. Unvegetated areas colonized by invasives in the deeper scenario had the lowest rates of accumulation. This method requires infrastructure such as berms, pumps, and weirs in order to manipulate hydrology. Water flows in through the gravity siphon pipe from the San Joaquin River at the southeast and southwest corners of the site and out through the adjustable weirs on the northern side. Across the two sites, the average sediment growth rate was 1.57 inches (4 cm); however, this ranged between 0.20 inches (0.5 cm) lost per year to 3.62 inches (9.2 cm) gained per year (2008 Miller et al).

In 100 years, Sherman Island would be barely above mean sea level accommodating for rise assuming a uniform growth rate of 1.57 inches (4 cm) each year. Higher growth rates could potentially fill Sherman Island in half the time. However, the levees are significantly likely to fail after 15 years. To restore islands above mean sea level before high probability of levee failure across the delta, reversal rates would to be at least 7.09 inches (18 cm) to 14.17 inches (36 cm) per year to accommodate the most subsided islands . Despite the likelihood of a breach, subsidence reversal would still delay and reduce flooding. Furthermore, if islands flooded, certain elevation gains could create a range where native plants can readily compete and do not encourage invasive growth (2010 Deverel & Leighton). In light of the uncertainty of long term risks and benefits, the immediate costs detract from present action. Differing priorities for the delta's land use prevent implementing subsidence reversal across the subsided islands. The Economic Sustainability Plan for the delta aims to achieve equality between economic and ecological goals and weighs economic sustainability with three metrics: agriculture; recreation and tourism; and infrastructure (2012 DPC). Subsidence reversal requires several costs and displaces the delta's current economic structure.

Creating and managing wetlands requires rights to the land and funds for operation. Although the state has been reclaiming areas since the 1930's, many parcels of the island are still privately owned and used for agricultural, residential, or other commercial purposes. Developing subsidence reversal projects would require ownership of or easements through remaining private land. In addition to initial construction, managing the siphons and weirs incur costs for labor and maintenance. Considering the temporal scale of subsidence reversal, budgeting for maintenance is crucial. The existing subsidence reversal projects do not adequately support the delta's current agriculturally based economy. Changing farmland to wetland removes the primary source of jobs and revenue from the delta and does not appeal to the region's economic goals.

However, research on compatible programs seek to fill this discrepancy. These programs include rice cultivation, a hybrid aquaculture and hydroponic scheme, a stewardship/demonstration project to

inform management practices, and habitat restoration. Existing subsidence projects predominantly operate on limited funding sources including grants and infrastructure bonds (2008 Brock); currently, a major source of revenue exists through the state cap and trade program. As carbon sinks, ARB has allocated $21 million to DFW to restoring 2,500 acres of wetlands over the 2014 through 2015 fiscal year. Of these funds, $10 million were allocated to Sherman Island under Reclamation District 341. Changing land use to freshwater emergent wetlands replaces jobs and revenue from farmland with carbon credits from wetlands. Rice paddies were shown to sequester more carbon than a degraded grazed peatland. Rice cultivation mitigates subsidence and preserves the site's agricultural heritage; however, this function was not chosen. While generating revenue, reversing subsidence and storing carbon, an aquaponics system was prioritized for it's significantly larger estimated profits. This research aims to further substantiate subsidence reversal by proposing an array of programs focusing on sustainable agriculture; recreation and tourism; and infrastructure.

To compare the benefits of the programs with the revenue losses from land conversion, this study will quantify the economic costs and/or benefits of each program. The business as usual scenario will serve as a baseline. As decades pass, the combination of continued subsidence and sea level rise will exaggerate the land-water relationship. The current levees occasionally seep water; buttressing levees when and where sand boils occur damper the situation. At greater depths, pumping from will gradually accrue significant costs. As the islands continue to sink, costs increase for individuals.

This research aims to program re-established nontidal wetlands to incentivize the change the land use of prime agricultural land to wetlands.

04 Research Design, Methods, & Data Collection

Sherman Island was once primarily freshwater emergent marsh until 1859, when settlers built the first 3 to 4 foot high and 8 foot wide levees which breached in 1861; another decade later, a new levee system was completed and failed in 1871, and 1874. The levees were fortified to stand 12 feet high and 120 feet wide, and ruptured again in 1876 and 1878 (2008 Angell). The original levees lie between 16 to 26 feet below sea level (Cohen, D. A., Deverel, S.J., & Johnson, L.A. 1998) and are maintained to compensate for sinking. Following another series of floods through 1930 to the early 1940's, the land was returned to the Army Corps of Engineers (Cohen et al 1998). Several breached levees have remained inundated on across Lower Sherman Island. Currently, the polder ranges between 15 foot high levees to depths of 25 feet where abandoned fields leased to ranchers rest below sea level. Sherman Island would hold the largest volume among the western islands--142 million cubic yards.

Separating the Sacramento and San Joaquin Rivers, a major levee breach would severely affect drinking water supplies. Three Mile Slough conveys freshwater through the Sacramento and San Joaquin Rivers along the northern perimeter of Sherman Island and dams artificially maintain the freshwater-ocean water interface. Levee failure would allow saline water to move further inland and complete inundation would first double the salinity in Contra Costa Water District and then increase the salinity of drinking water of state systems by 41%. As a result, the State Water Project, Central Valley Project, and local municipalities rely on Sherman Island's levee system. If an island flooded, it could take from 43 to 240 days to repair breaches and dewater the island which could cost from $136 to 276 million USD (DRMS 2008); as an island with one of the greatest volumes, Sherman Island would fall in the higher half of these brackets. These consequences would be most severe during the summer and/or drought.

Local assets to Sherman Island include a small population, few remaining tracts of agriculture, and energy infrastructure. Today, the majority of the land is owned by public agencies and uses as a pasture. The remaining land uses include residential, agriculture, and other commercial enterprises. About 110 people live on Sherman Island. The levees of Sherman Island also protect access and energy assets. The island sits on the southern tip of Sacramento County adjacent to San Joaquin, Yolo, Solano, Contra Costa and Alameda counties. Highway 160 traverses Sherman Island and serves as a major connection between Highways 8 and 80. The bridge in the north and the Antioch Bridge in the south provide vehicle access to Antioch and Rio Vista respectively. As a throughway for interstate commerce, closure of State Route 160 would cost $70,000 per day. Energy assets on Sherman island include electric transmission lines and natural gas pipelines. Three 500 kV transmission lines cross Sherman Island: the WAPA California Oregon Transmission Project, PG&E Table Mountain-Tesla line, and PG&E Vaca Dixon-Tesla line; a fourth decommissioned transmission line crosses the eastern side of Sherman Island. The DRMS reports a two month outage of two of the 500 kV lines would cost $42,000,000. Additionally, natural gas pipelines from Canada pass belowground.

This research aims to program the next proposed subsidence reversal wetland on Sherman Island by quantifying the profits.

05 Design Investigation and Analysis

Responding to the site conditions, the prototype aims to undo historic degradation and support hydrologic processes. The legacy of farming and pre-development history provide rich opportunities for site-specific applications. The Whale's Belly Wetland and Park provides programming that would offset the loss of agricultural revenues from converting farmland to wetlands.

While historically Sherman Island was owned by private farmers, the DWR and other CalFed agencies currently own 86% of the island. Since the majority of the land is owned by public agencies, public use of the land would be largely uncontested. The DWR received funds from the state Cap and Trade Program to mitigate carbon. Wetlands perform ecosystem services with an annual revenue of $14, 785 USD per hectare including an assumed rate of 4 cm/year for subsidence reversal. These ecosystem services include water filtration, flood protection, groundwater recharge, subsidence reversal, and carbon sequestration. Two subsidence reversal and carbon sequestration projects compose significant tracts of emergent wetland and seasonally flooded regions. Mayberry Farms and Whale's Mouth Wetlands were formed with ecological enhancements, but differ in size and management.

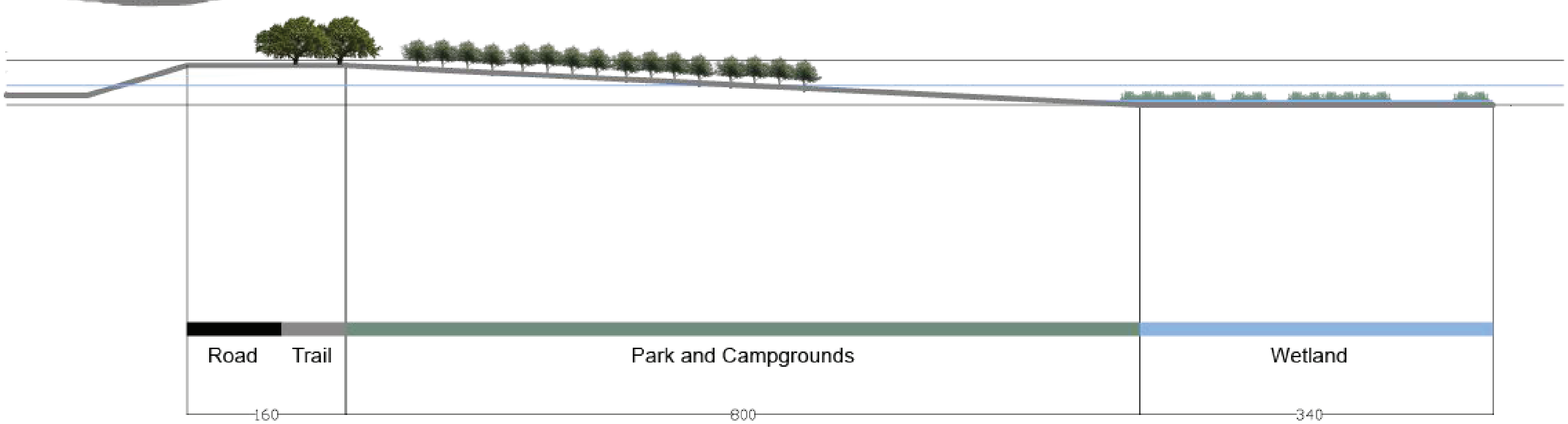
In 2010, Mayberry Farms was created as a demonstration of subsidence reversal and carbon sequestration to inform practices for the operators of private wetlands. Of the 307 acre site, 192 acres are emergent wetland and 115 acres are seasonally flooded wetlands; the inundated areas are separated into 7 management units using the 4 existing berms. To enhance the site for waterfowl hunting, loafing islands were included in the design. Construction cost $1.6 million USD and 191,717 cubic yards of soil were excavated. Currently, a local hunting club--Duck Unlimited leases the property from the state. Small teams of biologists and professionals from related fields from UC Berkeley has been working with the DWR researching GHG emissions to develop policy under CARB and methyl mercury levels for management by the Central Valley Regional Water Board. Between these two uses, up to 24 individuals may occupy the site. This project serves ecological, educational, and recreational purposes.

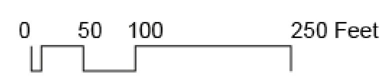
Whale's Mouth Wetland was restored in 2014 with similar project goals of subsidence reversal and carbon sequestration, but also addresses seepage and levee stability. Within a 977 acre conglomerate of parcels, the wetlands encompass 600 acres. Perimeter berms divide the site into smaller management units. Loafing islands, swales, potholes, and a transitional upland enhance the ecological services. Access into the site is limited by two vehicular gates on the eastern and western ends of the wetland. Otters and other species not designed for inhabit the site (2008 Brock).

The Aquaponics Water Management System hybridizes hydroponics and aquaculture within an enclosed flood storage zone. Byproducts of aquaculture fertilize the hydroponic system. The hydroponic rafts consist of film tubes, buoyant rafts, and anchors stabilizing position. The film tubes are PVC tubes with growing medium and holes eight inches apart to allow nutrient transport. Hydroponics can support many different types of vegetables including artichokes, arugula, asparagus, basil, beets, broccoli, brussel sprouts, cabbage, carrots, cauliflower, celery, cilantro, collards, eggplant, endive, garlic, lavender, leek, lettuce leaf, okra, onions, parsley, parsnips, peas, bell peppers, radishes, raspberries, spinach, strawberries, and tomatoes. The system would provide revenue through both agricultural yields and fish yields; agricultural yields range up to from $1,100 per year for onions and $88,000 per year for cilantro. Farming sturgeon could generate $8.5 million USD per year. This system would cost roughly $23 million and would break even after two and a half years (2011 Fischer et al).

Existing activities at the site include research and recreation such as kiteboarding, windsurfing, kayaking, boating, and waterfowl hunting. Access through Highway 160 and Sherman Island's location allows for great potential to recreation and tourism. Ecological enhancements for migrating waterfowl and birds also facilitates trails, camping, picnics, fishing birdwatching, and hunting. To host these activities, the levees were regraded with trails, campgrounds, picnic sites, fishing banks, and observation decks. Within the wetlands, trails would provide access to the wetlands.

1500 acres of wetlands would generate $8 million in ecological services. By designing the space to facilitate passive use recreation, Whale's Belly Wetland could tap into the projected 50% population growth from the surrounding counties and generate from 6 million dollars with half a million visitations to triple or quadruple (2012 DPC). In conjunction, a floating aquaculture and hydroponics system add value to the inundated areas. Aquaponics would generate up to $9 million each year with high profit crops such as cilantro. The combination of recreation and aquaponics could accrue about $15 million to $45 million while existing agricultural practices only generates about $900,000.


Road
Trail
Park and Campgrounds
Wetland
160
800
340


0
50
100
250 Feet

06 Reflection and Conclusion

The Sacramento-San Joaquin Delta has undergone a transformation in the past two hundred years. Pre-development, the inland delta was a tidal marsh that flooded seasonally. As Americans immigrated into the west, settlers converted the swamp for agriculture by erecting levees to drain the soil. The development of conveyance infrastructure repurposed the delta and it's water for anthropocentric use. The future of climate change entails of a rising sea level, and an increase in the number and severity of droughts. Subsidence stems from land management practices.

Groundwater mining and agricultural drainage have influenced subsidence. Overpumping of groundwater has led to the compaction of aquifer systems. Drainage of the delta marsh spurred the oxidation of peat soils. This phenomena have caused the islands of the delta to sink up to 15 feet in some areas. The impacts of subsidence in the Sacramento-San Joaquin Delta rests at the confluence of the levees, sea level rise, and water supply. Subsiding peat soils lower islands further below sea level and degrade the levees. As sea levels rise, the delta becomes more susceptible to flooding and saltwater intrusion further east. Repetitive droughts, intensive agricultural development, sea level rise, continuous population growth and rapid urbanization raise the the demand of water.

This research programs subsidence reversal to economically incentivize the landscape. By nesting programs with subsidence reversal, the intervention will substantiate the restoring wetlands on Sherman Island. However, this framework may be insufficient to offset revenue losses from conversion across the array of subsided islands in the delta where high value crops are grown. Through a wetland park and aquaponics system, implementing subsidence reversal across expanses of the delta becomes more feasible.

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