DredgeFest California

KEY FINDINGS and RECOMMENDATIONS
DECEMBER 2016

Prepared by

Brett Milligan
Rob Holmes
Gena Wirth
Tim Maly

Portions of this document were provided in an earlier draft to DFCA participants. Sean Burkholder and Justine Holzman contributed significantly to the preparation of that draft, particularly what is now sections 03 and 05 in this document.

Drawings

Many of the drawings in this document were prepared by the DRC's 2016 summer intern-collaborators, working under the supervision of Gena Wirth. They are:

Nick Shannon
Kate Lenahan
Michael Biros
Crystal Xing

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DFCA Workshop Collaborators

Mario Accordino
Alexandra Zahn
Paul McBride
Andrew Prindle
Brittany Gray
Alejo Kraus-Polk
Paige Courtney
Jinhee Ha
Kate Granlund
Jamie Phillips
Nico Wright
William Reinhardt
Jackson Blalock
Johanna Hoffman

DFCA Workshop Leaders

Neeraj Bhatia
Richard Hindle
Justine Holzman
Forbes Lipschitz
Halina Steiner
Nicholas Pevzner
Steph Carlisle
Meg Studer
Brennan Cox
Gena Wirth
Kees Lokman
Derek Hoeferlin
Matthew Seibert

DFCA Experts, Reviewers, and Tour Guides

Janet Bennett, Dutra Dredge Museum
Bryan Brock, CA Dept of Water Resources
Steve Carroll, Ducks Unlimited
Warner Chabot, San Francisco Estuary Institute
Jessica Davenport, Delta Stewardship Commission
John Durand, UC Davis
Bill Fleenor, UC Davis
Joseph Gailani, U.S. Army Corps of Engineers, Engineer Research and Development Center
Brenda Goeden, San Francisco Bay Conservation and Development Commission
Eric Joliffe, U.S. Army Corps of Engineers, S.F. District
Edward Keller, U.S. Army Corps of Engineers, S.F. District
Thomas Kendall, U.S. Army Corps of Engineers, S.F. District
Jim Levine, Montezuma Wetlands
Jeremy Lowe, San Francisco Estuary Institute
Lester McKee, San Francisco Estuary Institute
Elizabeth Murray, U.S. Army Corps of Engineers, Engineer Research and Development Center
Dan Ray, Delta Stewardship Commission
Diana Sokolove, San Francisco Planning Department

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Dredge Research Collaborative

The Dredge Research Collaborative is an independent 501c3 nonprofit organization that investigates human sediment handling practices through publications, an event series, and various other projects. Our mission is to advance public knowledge about sediment management; to provide platforms for transdisciplinary conversation about sediment management; and to participate in envisioning and realizing preferred sedimentary futures.

DredgeFest is a roving event series, with the first four editions of DredgeFest spanning the four coasts of the continental United States.

DredgeFest California was a week-long event (June 13th-19th, 2016) about the human manipulation of sediments in California's Bay-Delta, from navigational dredging for the Port of Oakland to the construction of levees in the watery tracts of the delta. It was a transdisciplinary encounter between government agencies, designers, theorists, academics, corporate practitioners, industry experts, students, and the public. It situated sedimentary management in the context of critical current local conversations and issues, including climate change, sea-level rise, wetland restoration, the cultural landscape heritage of the Bay-Delta, and public waterfront access.

http://dredgeresearchcollaborative.org/

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DredgeFest California

DredgeFest California
KEY FINDINGS and RECOMMENDATIONS

EXECUTIVE SUMMARY

The following findings and recommendations have been synthesized from the work of DredgeFest California, a week-long event held in the Bay Area in July 2016. They draw on the work done by five teams across five days of design workshops, discussions with many different experts, two days in the field with the DredgeFest California public tours, and the background research conducted by the Dredge Research Collaborative prior to the event. Each recommendation summarizes a key principle that we believe should guide the design, planning, and management of sediment in the Bay-Delta. The abbreviated findings below are expanded on in Section 04 of this document.

1 Recognize and Quantify the Sediment Shortfall

Where, how, and how much sediment enters the Bay-Delta has radically changed over time due to human intervention and engineering. Having peaked during the gold rush era at exponetially higher rates, sediment flows today have returned to historic levels. But today we need more sediment than ever to restore the region's wetlands and to adapt to accelerated sea level rise that will cause the migration of the Bay-Delta's shorelines. Thus the Bay-Delta needs an accurate sediment budget. Wider recognition that there is a significant shortage will help drive efforts to document the situation, which will in turn help us better understand not only how urgent the problem really is, but precisely what its contours are.

2 Value Sediment

For the past 150 years dredged material was generally treated as spoils—a waste product to be disposed of. Today, more people, companies, and agencies understand that this material is a valuable resource. But design, policy, and markets have yet to fully adapt. Sediment must be recognized and valued as a crucial and limited resource, and steps must be taken to redesign both rules and landforms to better capture and make use of that value.

3 Treat Sediment as Critical Infrastructure

The landscapes that depend on sediment, such as shorelines, beaches, and wetlands, are increasingly valued, and the importance of sediment supply for sustaining them is increasingly well understood. Paradoxically, these landscapes are both particularly vulnerable to and especially critical for dealing with the consequences of climate change, particularly sea level rise. Sedimentary infrastructure is capable of aggregating, expanding, and adapting to novel conditions. This flexibility will be needed as we seek to adapt to and mitigate anthropogenically-accelerated change.

4 Consider Sedimentsheds

We commonly use the physiographic units of watersheds and subwatersheds in design, environmental planning, and engineering disciplines as an effective way to structure our efforts according to hydrological patterns and processes. We need to do the same for sediment. Studies, thinking, and plans that account for only a portion of the sedimentshed risk making decisions that benefit that portion at the expense of the whole, or missing opportunities and benefits visible only from a broader vantage

5 Design Holistic Sediment Systems

Dredging is a key part of a larger group of technologies, actions, and practices that speed up and slow down the movement of sediments. Like the flow of water, the flow of sediment has been dramatically altered by human action. Dams, river canalization, agricultural development, and upstream urbanization have all modified both flows in tandem. Infrastructure can and should be designed to jointly accommodate the distribution of these critical resources.

6 Design for Local Conditions, Design for Change

The amount of sediment available to the Bay-Delta is inadequate, but this regional problem risks masking a network of local conditions that must be considered with care and precision. The edge conditions of the Bay and Delta are highly variable. The variability of local conditions and the innately dynamic nature of the coast both demand a diverse, flexibly-deployed toolkit of new infrastructures, operations, and practices.

7 Match Sediment to Situations

Sediments vary widely in what they are, such as particle composition and potential contaminants. Gravels, sands, and fines all lend themselves to some applications while being useless for others. The choreography of sediment is more complex than simply directing volumes of supply to meet volumes of demand or need. We must match the right kinds of sediments to the right places.

8 Re-examine the Goal of Restoration at a Time of Great Change

While the nature of the Bay-Delta's emerging sediment shortfall is just beginning to be discussed, contested, and grappled with, it is clear that, relative to historic conditions, the Bay-Delta is radically altered, and continues to change rapidly. Accelerated climate change and sea level rise can be expected to continue. We need to move beyond the past as precedent to more successfully prepare for a very different future.

9 Develop New Technologies

Historically, technological innovation, such as the customization of clamshell dredgers for the Delta, has played a formative role in the Bay-Delta. Going forward, technological innovation will be necessary to address new challenges and conditions. These technologies will need to be multifunctional, addressing diverse ecological, economic and sociopolitical criteria. Technological innovation will require investment, incentivization, experimentation, and monitoring.

10 Evolve Policy and Planning to Meet New Conditions and Priorities

The emergent shortfall of sediment in the Bay-Delta presents a broad range of policy and regulatory challenges as we shift from a paradigm of excess to a paradigm of shortage. The risk is that policy and its subsequent regulation, notoriously slow to adapt, will not change at a pace that enables the long term success of the region's sediment-dependant ecosystems. Well-crafted policy and regulations have the potential to incentivize multifunctional projects that meet economic, social and ecological goals.

11 Organize Sediment Publics

Sediment is political. Sediment management decisions are made in a political context and are affected by both political values and political power. Climate change has the potential to significantly exacerbate existing inequalities in coming decades, and the political effects of sediment will need to be considered alongside technical, design, and engineering questions. We recommend strategically building an informed, active, and broad constituency for sediment which recognizes its foundational role in the future of the Bay-Delta.

DredgeFest California

APPROACH

The work of the participants at DredgeFest California was informed by our reading of the sedimentary situation in the Bay-Delta, which is outlined in this section. After an introduction that briefly lays out the challenge that defined the workshops, an essay, "The Pulse, the Sink, and the Shortfall", provides a compressed overview of the past several centuries of sedimentary history in the Bay-Delta. A statement then outlines the significance of the concept of the "dredge cycle", our theoretical tool that situates dredging within the wider array of means that humans use to speed up and slow down the movement of sediments. Finally, the bulk of the section addresses "scales of study" — the geographic extents and thematic focuses that defined the event's three workshop tracks. For each of those scales, a combination of mappings and text summarizes key research and knowledge concerning the existing sedimentary conditions of the Bay-Delta.

The Pulse, the Sink and the Shortfall: How We Got to Now

The following essay provides a comprehensive and condensed overview of the Bay-Delta's sedimentary history over recent centuries. Originally published: Milligan, B., Maly, T., & Holmes, R. (2015) The Pulse, the Sink, and the Shortfall. *Ground Up 04: Out West*. Revised May 25th, 2016.

The great sediment pulse began in 1852. These were the dying days of the California Gold Rush. San Francisco — a settlement of about 200 residents in 1846 — had exploded to a population of about 36,000 in 1852.[1] They had come to look for gold or to profit off of those looking for gold. Wells Fargo was founded in 1852. Mining was changing, professionalizing, and new engineering techniques were being brought to bear. Upstream in the Sacramento valley, there wasn't much gold for panning in the rivers anymore, but there was still gold in the hills. And so the rivers were turned on the hills. Water was gathered in great basins, fed through pressurized hoses and directed at gold-bearing upland paleogravels. The technique is called hydraulicking or hydraulic mining. Entire hillsides of the Sierra Nevada range were washed into sluices and sieved for metal. By the mid 1880s, it is estimated that more than 340 millions tons of gold had been extracted in this way, bringing with it vital tax income for a country fighting and then recovering from a civil war.

The rest of the debris got washed into the rivers where it choked navigable channels, worsened floods, and buried farmland. In 1882, a man with farmland near Marysville sued the largest mining operation in the region.[2] In 1883, Edwards Woodruff v. North Bloomfield Mining and Gravel Company went to trial. In 1884 Judge Lorenzo Sawyer handed down a decision that ended hydraulic mining and led to the creation of the California Debris Commission.[3] It is a landmark environmental court case. But the pulse did not end.

Formation

Geologists and geomorphologists describe the Bay-Delta as "well advanced", a description which refers less to the region's urbane qualities or hi-tech industries, and more to the magnitude of human alteration and development of the estuary. By "well-advanced", they are referring to our hydrological and earthen signature upon the place. The typical design pattern is disruption (mining, deforestation, agriculture, urbanization) that increases the sediment load, followed by dams, water diversions, and river management that reduce variability and thus sediment supply, and finally restoration of damaged habitat.[4] The Bay-Delta, as a unique geographic feature, is radically different from what it was less than 200 years ago. How did we get to where we are?

The whole Bay-Delta system is relatively young, having formed sometime between 6-10,000 years ago. San Francisco Bay is a drowned valley,[5] carved out by rivers now below sea level. The delta part of the Bay-Delta sits fully 50 miles from the coast of California. It is confined by the parallel Coast Range to the west and Sierra Nevada to the east. Where most deltas grow from one source river, broadening out towards the ocean, this delta broadens landward.[6] By most standards it isn't really a delta at all, just an accumulation of sediment at the headwaters of a very large estuary.

The delta used to be something like a migratory inland sea, or a 12,000 square mile floodplain that the entire central valley basin drained into via the Sacramento and San Joaquin Rivers. This porous landscape of tidal wetlands would expand and contract in tandem with California's wildly fluctuating climate and precipitation. Inverted deltas, such as the Bay's, tend to fill in with sediment over time, and the delta was a generator of peat soils which steadily accumulated within its shifting labyrinth of waterways. Mariners used to get lost in this maze.

People have lived in the area for a long time. When Gilbert was sent to assess the fallout from hydraulicking, he used the presence of enormous shellmounds and their relation to tide lines as a marker to help estimate the extent of subsidence or uplift.[7] These mounds were often 20 or 30 feet tall. The biggest, the Emeryville Shellmound, was reported as being over 60 feet high and surrounded by a network of smaller mounds, a testament to thousands of years of food and ritual. In the 1920s, a dance hall was built on its peak, affording partygoers an excellent view of the bay. Today, it is the site of a shopping mall.

Disruption (1850-1915)

The gold rush and following mining activity seems to be the first pivotal anthro-sedimentary event in California. The liquified hillsides were guided into wooden sluice boxes where gold, with the help of

Introduction / DredgeFest CALIFORNIA

San Francisco Bay is the largest estuary on the U.S. West Coast, and the 2nd largest in the United States; combined with the contiguous Sacramento-San Joaquin Delta it covers a total surface area of ~4100 km2 and a watershed area of ~162,000 km2. It contains several economically significant harbors ($20 billion worth of cargo annually) in one of the most developed regions of the United States, with a surrounding population of over seven million people. San Francisco Bay and the adjoining Delta are among the most human-altered estuaries and hydrologic systems, respectively, in the world. Major historical changes were driven by the extensive hydraulic mining influx of sediment in the late 19th century, massive alteration of the drainages entering San Francisco Bay in the 20th century, and the enormous amounts of sediment removed throughout the San Francisco Bay Coastal System from the early part of the 20th century to the present.

- Sediment transport in the San Francisco Bay Coastal System: An overview by Patrick L. Barnard, David H. Schoellhamer, Bruce E. Jaffe, Lester J. McKee. 2013

The Challenge

Sediment is critical to the present and future health of California's Bay-Delta. It is the physical infrastructure that underlies its many ecologies and economies. As the 2015 State of the Estuary report by The San Francisco Estuary Partnership notes, *"Like freshwater, sediment is a precious resource that is essential for keeping the Estuary healthy."*

But the Bay-Delta currently has a shortfall of this land-making resource. Upriver dams have trapped sediment. Levees, bank armoring, and river straightening have cut off wetlands and floodplains while accelerating the movement of sediment, preventing it from building new substrate. The Bay's coastal wetlands, which are critical to sea-level rise adaptation, have new sedimentary needs, potentially requiring as much as 200 million cubic yards of sediment over the next 15 years to effectively restore them to established Baylands ecosystem goals,[1] and this projection does not even account for the ongoing and longer-term need for sediment to maintain marsh elevations with respect to sea level rise. In the Delta, many of its levees are now protecting subsided "islands" that are up to 20 feet below sea level, stressing the levees — and with them local communities, ecologies, and the role of the Delta as conduit for southern California's water supply. Sediment, including dredged material, is one of the primary materials available to meet these current and future challenges.

The nature of the Bay-Delta's emerging sediment shortfall is just beginning to be discussed, contested, and grappled with. Its realization will affect policy, dredging operations and priorities of future investments and research. Its implications extend across economic, ecological, cultural and political domains. But the Bay-Delta is not alone in this situation and the challenges it presents. Sediment deficit in deltas and estuaries around the world, due to human influences, has been observed as an empirical phenomenon by scientists and geographers. Yet we are challenged in understanding the scope and magnitude of this shortfall. Is it a shortfall, which entails a deficit of some previous expected amount? Or more of an early sign of a very new Bay-Delta that is soon to be, regardless of what we do? There is no clear historic baseline around which to station our efforts, as the Bay Delta is too radically altered for such a comparison to be effective or realized. Moreover, determining future needs is complicated by how little we know, with certainty, of how accelerated climate change and sea level rise is going to physically manifest — and at what rate. As an example, in the course of our assembling this document, sea level rise predictions for the S.F. Bay nearly doubled with the publication of findings from new models.

The intent of DredgeFest California was to foreground sediment and earthworks as essential infrastructure in determining what the future of the Bay-Delta will be like. They are critical factors in coastal and deltaic resilience. Recognizing the importance of mud, sand and silt, we sought to better understand the qualities and parameters of its potential shortfall in the Bay-Delta, examine how we might act, and identify key questions to ask and pursue going forward.

Notes:

1. San Francisco Bay Sediment – Challenges and Opportunities, BCDC, 2015

^ San Francisco Bay, South
image: NASA EO

mercury, could be sieved out of the geologic slurry. In all, over 850 million cubic meters of sediment was flushed into the San Francisco Bay. This is approximately eight times the amount of rock and dirt moved during the construction of the Panama Canal[8] and roughly eight times the annual pre-pulse volume.

The loosened debris ranged in size from silt and sand in suspension (called "slickens"), to gravel, cobbles, and boulders. Writing in 1917, geologist Grove Karl Gilbert explains where it went. "Much of it escaped from the mountains altogether and found eventual lodgment in the Great Valley of California or in the tidal waters of San Francisco Bay and its dependencies. The coarser stuff tarried by the way, building up alluvial deposits on the lower hill slopes, in the flatter creek valleys, and in the river canyons."[9] A great flood followed in 1862 which built a coalition of alarmed riparian landholders: "the evils cited by them included the burial of alluvial farming lands by the flood of debris, the obstruction to navigation from shoaling of Sacramento and Feather rivers, and the raising of the flood levels of the valley streams whereby the area of periodic inundation was increased and protection against inundation became more difficult and expensive."[10]

Rivers such as the Yuba and Sacramento were silted in with this accelerated pulse of sediment, vastly decreasing their capacity. Between 1849 and 1879, the Sacramento river bed was raised so far that low water levels rose nearly six feet and tidal influence, which had been around two feet, shrank to two inches. Though hydraulicking was banned in 1884, it did not end the pulse. It takes indeterminate time for sediment, gravel, and rocks to make their way through a river system, especially a broad shallow one like the Bay-Delta. Once the source of sediment was cut off, the disruption began to falter, but the further downstream you are, the longer the effects persist. In San Francisco Bay, the effects are measurable to this day.[11]

Reclamation (1850-present)

At the same time that miners were washing hillsides out to sea, homesteaders were seeking to expand their holdings and to protect themselves and their investments from devastating floods. Left to its own devices, the delta would have seen regular flooding which both nourished the soils and redrew channels. They had two problems to solve. The first was protecting arable land from floods, especially from floods that buried the fields in mining debris when the waters receded. The second was deepening channels to maintain shipping pathways.

Beginning in the 1850s, farmers and towns began to build networks of channels and levees. They first built by hand, largely using the labor of Chinese immigrants. Much as with their colleagues upstream, the settlers soon began to mechanize. Though they experimented with dipper, hydraulic pipelines, and bucket ladder dredges, it was the clamshell dredge that would prove best suited to the task.

A clamshell dredge looks like a pair of monstrous jaws hanging off the end of a boom arm. When the jaws drop and hit the bottom, they snap shut. If the bottom consists of soft clay and sand, they grab a great deal of it. The jaws are winched up and liquid is allowed to drain away. The boom swivels easily, allowing the jaws to deposit the dewatered material precisely. Together, these features make the clamshell dredge particularly suited to cutting channels and building levees as part of the same operation. As versatile landscape machine, the clamshell dredge could also be used to clear brush and trees and to roughen surfaces so that deposited dredge material would adhere better.[12] From the 1900s to around 1915, the size of typical boom arms for Delta-Bay clamshell dredges grew from 100' to 230'.[13] People often describe the delta as being a series of islands protected by levees, but that implies the dry land is above the water level. It is not. The work of the dredgers gave us a dike and polder landscape, with the levees holding water back from subsiding farmland.

Reclamation and hydraulicking overlapped and the two practices entered into a feedback loop. The levees protected the farmlands from flooding that was made worse by the hydraulicking. But the raised terrain cut the river off from its floodplains, so the surplus sediment was stuck in the watercourse instead of being spread over the landscape. This contributed to making flooding worse and to sending more sediment downstream into the bay.

In 1983, The Bay Delta system of levees consisted of "well more than a billion cubic yards of dredged material."[14] Today, that number is certainly higher and rich peat soils continue to sink.

Surplus (1850-1950)

All told, the period from the mid 1800s to the mid 1900s was a period of net sediment deposition. As the hydraulicking-driven pulse continued to make its way through the system, it was joined by a second, smaller pulse. It was about 60% the size of the great pulse, and likely driven by urbanization adjacent to the bay and the expansion of agricultural land use in the Sacramento and San Joaquin Valleys.[15] As the pulse made its way through the Delta and out to the ocean, it raised the entire profile of the bay, shifting the shoreline out west, pushing back the Pacific Ocean and creating new beaches and marshlands.

Deficit (1950-present)

Starting around the 1950s, the trends reverse. Dams, river bank protections, and flood management have all combined to produce net erosion in the Bay-Delta system.[16]

Dams starve the system by trapping sediment. As the water slows on entering a reservoir, it drops the

sedimentary load into these anthropogenic deltas. Between 1950 and 1975, California's reservoir capacity, already growing, had doubled.[17] Again, the construction of levees disconnects rivers from their floodplain, preventing sediment from getting to those lands. The straightening of these water courses as well as erosion control bank protection further accelerates flows of water during sediment-laden storm events (the opposite effect that dams have), thus forcing sediment downstream.

Historically, the Sacramento River was the largest source of sediment for the Bay-Delta estuary. But between 1957 and 2001, it lost half its supply due to dams and other infrastructure[18], thus contributing gravely to net erosion. Slowly, the landscape is washing away. Compounding that deficit, the anthropogenic pulse of sediment induced by hydraulic mining has mostly passed through the Bay Delta (roughly 100 years or so), leaving us with an unprecedented shortage of sediment supply in the watershed.

Choreographing Sedimentary Futures

The challenges and transformations experienced in the Bay-Delta demand new forms of geographic description and design research to explore how sediments and hydrological processes are choreographed at regional scales. "Every year, an average of 3-6 million cubic yards of sediments must be dredged to maintain safe navigation in and around San Francisco Bay."[19] This dredging is necessary to allow massive container ships to continue to ply ports. Oakland's channels were recently deepened from a depth of 42' to 50'. San Francisco, Sacramento, and Stockton channel deepening looms as ship sizes and drafts continue to increase. Where these channels cut through the Delta, salinity intrusion into the waterways will follow, with cascading effects on already stressed aquatic habitats.

In the Delta, many researchers argue that the network of levees protecting subsided land has become more prone to failure. "Most levees were poorly constructed on weak, seismically unstable foundations. They are the descendents of originally small, private structures that have been expanded to cope with gradual land subsidence, sea level rise, and erosion."[20] Some economic analysis suggests that it is no longer cost effective to maintain them all, though that analysis is intensely debated. Decisions about the future of the levees are deeply political, tied to how one values the relative benefit accrued by not only local residents and landowners, but also the Bay area cities and southern Californians who consume Delta water exports. Investment schemes may be able to maintain the reclaimed Delta or triage may be performed, which would determine what earthworks would remain and what tracts would be transformed into novel open water ecologies. In light of these wicked problems, where do we go from here?

In many regions, dredged material is now valued as a land-making resource rather than a waste product, or "spoils", as it used to be called. In the Bay-Delta, the combination of sedimentary shortfalls, land subsidence, and climate change make this particularly apparent, suggesting a future where dredged material becomes a desperately needed resource; where levees, shorelines, and wetlands all compete for access. In the San Francisco Bay, approximately one-third of all dredged material is currently 'beneficially reused',[21] meaning that it is intentionally placed as a resource. In the Delta that percentage is higher, but much smaller in overall quantity. Intelligence and design foresight have accrued within sediment management. Where and how dredged material is displaced and replaced will in turn change the character of the complex processes of deposition and erosion that shape the region and its watery edges.

But even if every last cubic yard of dredged material was beneficially reused in the Bay-Delta today, it wouldn't come close to addressing the magnitude of the current and emerging sedimentary shortfall. We must examine broader design schemes and scenarios for the future. This is why DredgeFest is about dredging, but also about much more than dredging.

Notes:

1. Per U.S. census data. See SFGenealogy.com. San Francisco History - Population. http://www.sfgenealogy.com/sf/history/hgpop.htm

2. Gilbert, Grove Karl. 1917. Hydraulic-mining Debris in the Sierra Nevada. US Government Printing Office.

3. Woodruff v. North Bloomfield Mining Gravel Co., et als, Circuit Court, District of California

4. Barnard, P.L., Schoellhamer, D.H., Jaffe, B.E. & McKee, L.J., 2013, Sediment transport in the San Francisco Bay Coastal System: An overview, Marine Geology, 345, pp. 3-17.

5. Gilbert, 1917

6. Whipple AA, Grossinger RM, Rankin D, Stanford B, Askevold RA. 2012. Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

7. Gilbert, 1917

8. Ibid

9. Ibid

10. Ibid

11. Sommer, Lauren. Clear Waters, Cloudy Future for California Wetlands. national Public radio, 2010 http://www.npr.org/templates/story/story.php?storyId=128113664

12. Thompson, John and Edward A. Dutra. The Tule Breakers. The Story of the California Dredge. Stockton Corral of Westerners, University of the Pacific, 1983.

13. Ibid

14. Ibid

15. Schoellhamer, David H., Scott A. Wright, and Judith Z. Drexler. 2013. Adjustment of the San Francisco estuary and watershed to decreasing sediment supply in the 20th century. Marine Geology 345:63-71.

16. Ibid

17. Ibid

18. Ibid

19. United States Environmental Protection Agency, San Francisco Bay Long Term Management Strategy for Dredging (LTMS), http://www.epa.gov/region9/water/dredging/ltms/

20. Suddeth, Robyn J, Jeff Mount, and Jay R Lund. 2010. Levee decisions and sustainability for the sacramento-san joaquin delta. San Francisco Estuary and Watershed Science 8 (2).

21. US Army Corps of Engineers, Dredged Material Management Office (DMMO) Dredging and Placement of Dredged Material in San Francisco Bay January-December 2014 Report, 2014 http://www.spn.usace.army.mil/Portals/68/docs/Dredging/Annual%20Reports/2014%20DMMO%20Annual%20Report.pdf

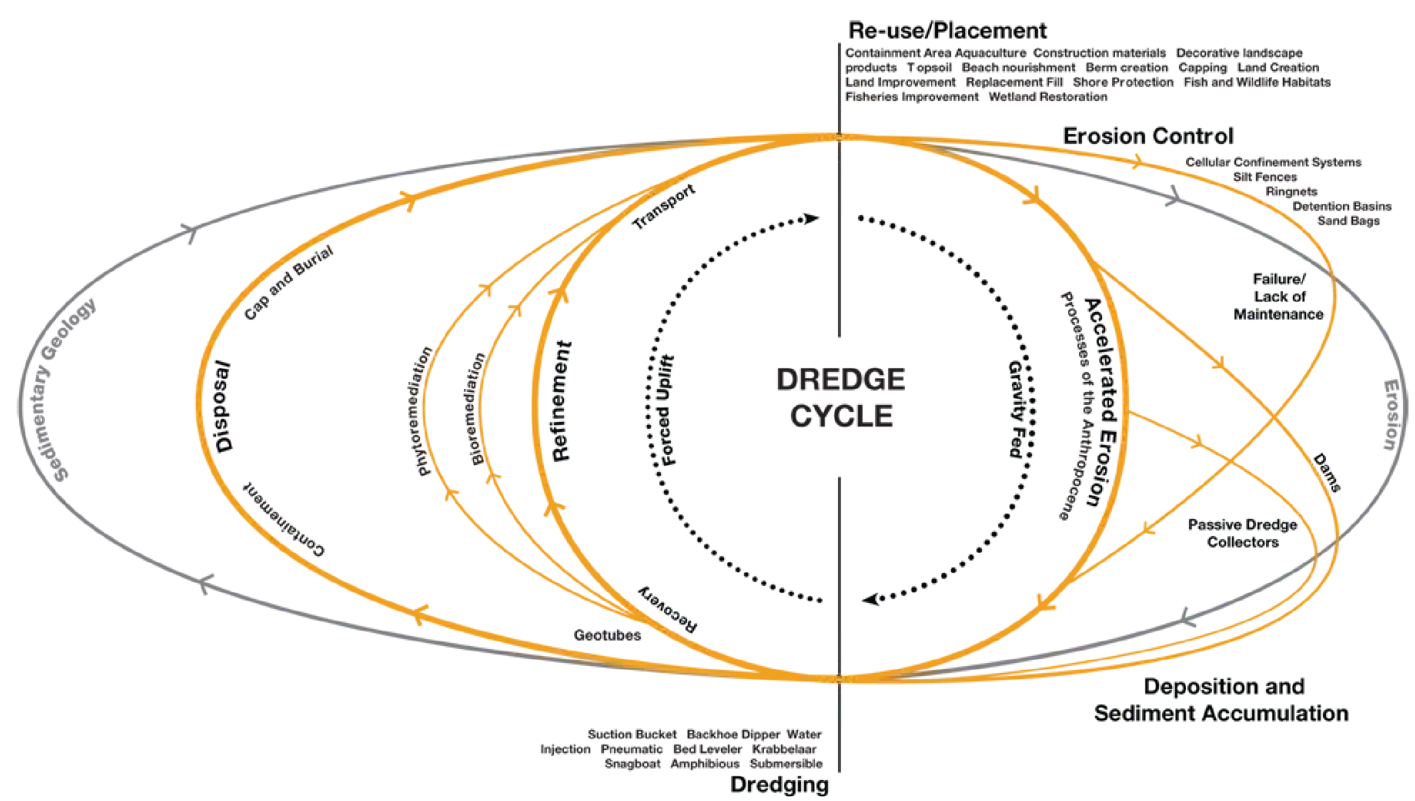
^ Clamshell dredge
Image: UC Berkeley, Bancroft Library

The Dredge Cycle

We, the Dredge Research Collaborative, refer to the myriad ways in which we affect and manipulate sediments and geological processes as the dredge cycle. Dredging is a critical activity in this realm; a switching point between processes driven by gravity and the heavy work of uplifting material and placing it elsewhere. But dredging is just one moment in the dredge cycle, which encompasses a more extensive range of anthropogenic sediment handling practices. It includes both intentional actions (such as dredging), as well as unintentional aggregate forces playing out across aquatic and terrestrial landscapes.

Over the last 6,000 years there has been a steady and exponential expansion in the amount of earthen material altered by human actions. Today we affect hydrogeological processes more than at any other time in history, mainly by accelerating and decelerating flows of these materials and by physically altering their composition. The combined influences of land reclamation, global agriculture, deforestation, mining, urbanization, and earth-moving irrevocably drags geology into our orbit, from dams trapping enough sediment to produce seismic events to erosion control silt fences preventing sedimentary flows from escaping construction sites. Like the analogous rock, water, and wind cycles, the Dredge Cycle has become ubiquitous, operating wherever humans alter sediments' migrational trajectories.

The DredgeFest California design workshops were focused on the workings of the dredge cycle within the sediment shed of the Bay-Delta region. They were aimed at generating innovative design and landscape planning to advance strategies for where that sediment can come from, how it can be delivered, and how it should be utilized.

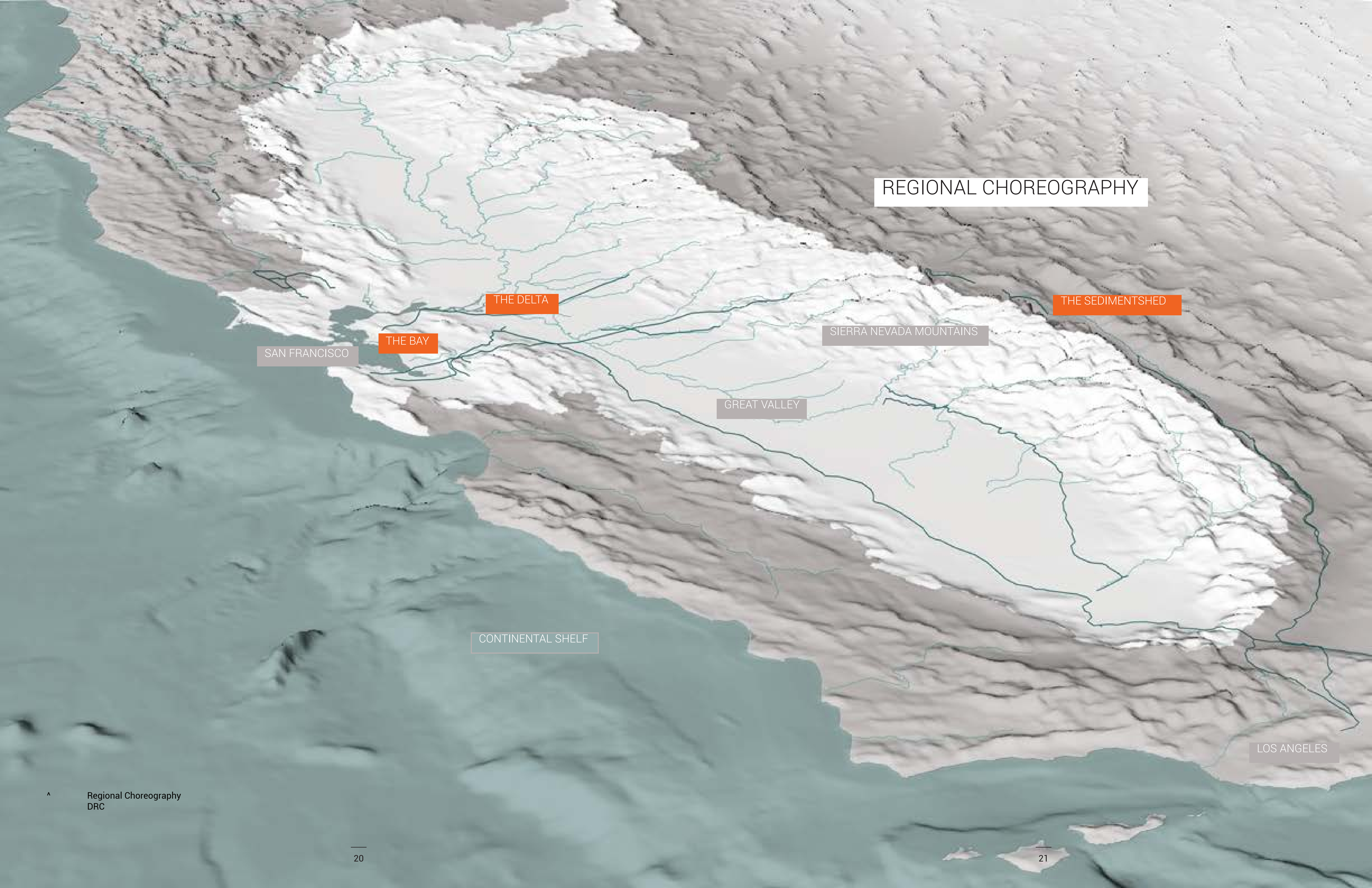


^ The Dredge Cycle / DRC

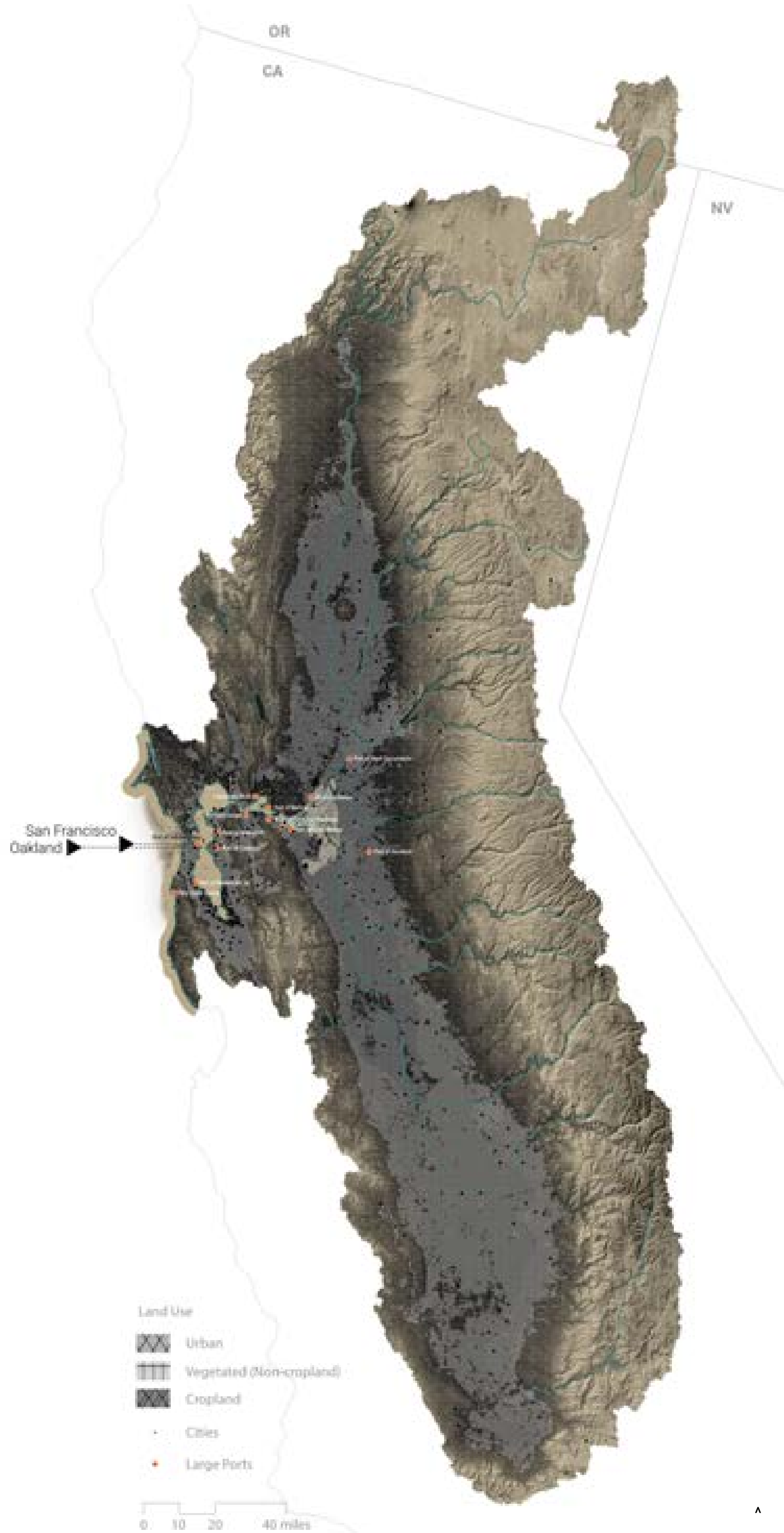
DredgeFest
California

SCALES OF STUDY

The workshops were divided into three scales of study, dealing with the Bay, the Delta, and the choreography of sediment at a regional scale.



^ Regional Choreography
DRC



Agriculture

Urban Areas

Vegetative Cover

^ Regional Choreography
DRC

Regional Choreography

Over the past two centuries, the Bay-Delta's geomorphology has been radically transformed. The Bay-Delta's history of alteration can be roughly divided into three phases[1].

First, there was a massive pulse, as Gold Rush hydraulic mining, agriculture, and development mobilized a vast volume of sediment, pushing it into the Bay-Delta's waterways, where it slowly migrated into the Bay. Before the pulse, the sediment supply from the Delta to the Bay was estimated to be 1.5 Mm3/year (1.3 Mt/year). Between 1849 and 1914, though, the total sediment load spiked to an average of 13.5 Mm3/year (11.5 Mt/year). The 1884 peak was even higher. This sediment moved very slowly through the Bay-Delta. Though sediment load steadily declined throughout the first half of the twentieth century, it still averaged 6.6 Mm3/year (5.6 Mt/year) from 1909 to 1966[2].

Second, dams were built, waterways channelized, and banks stabilized, all to manage water, but also unintentionally reducing the variability and volume of sediment supply. Dams and flood control bypasses trap sediment while stabilized or channelized waterways produce less erosion. This happened largely in the middle portion of the 20th century. Now that the pulse is reaching the end of its seaward migration, these alterations have helped produce a significant shortage of sediment in the watershed. Suspended sediment loads from the Sacramento River have been halved.[3] In recent years, the mean sediment load entering the Bay from the Delta has been only 0.9 Mt/year[4], not only less than the pulse condition, but also less than the pre-modification condition.

Moreover, the Bay's sediment supply has been radically localized. In the early 20th century, the waterways of the Delta (primarily the Sacramento and San Joaquin Rivers, with the Sacramento carrying seven times as much as the San Joaquin) accounted for 86% of the sediment load entering the Bay. Today, local tributaries—small waterways within the watershed of the Bay itself—account for over half of the Bay's sediment supply[5], at a mean annual load of 1.4 Mt/year[6].

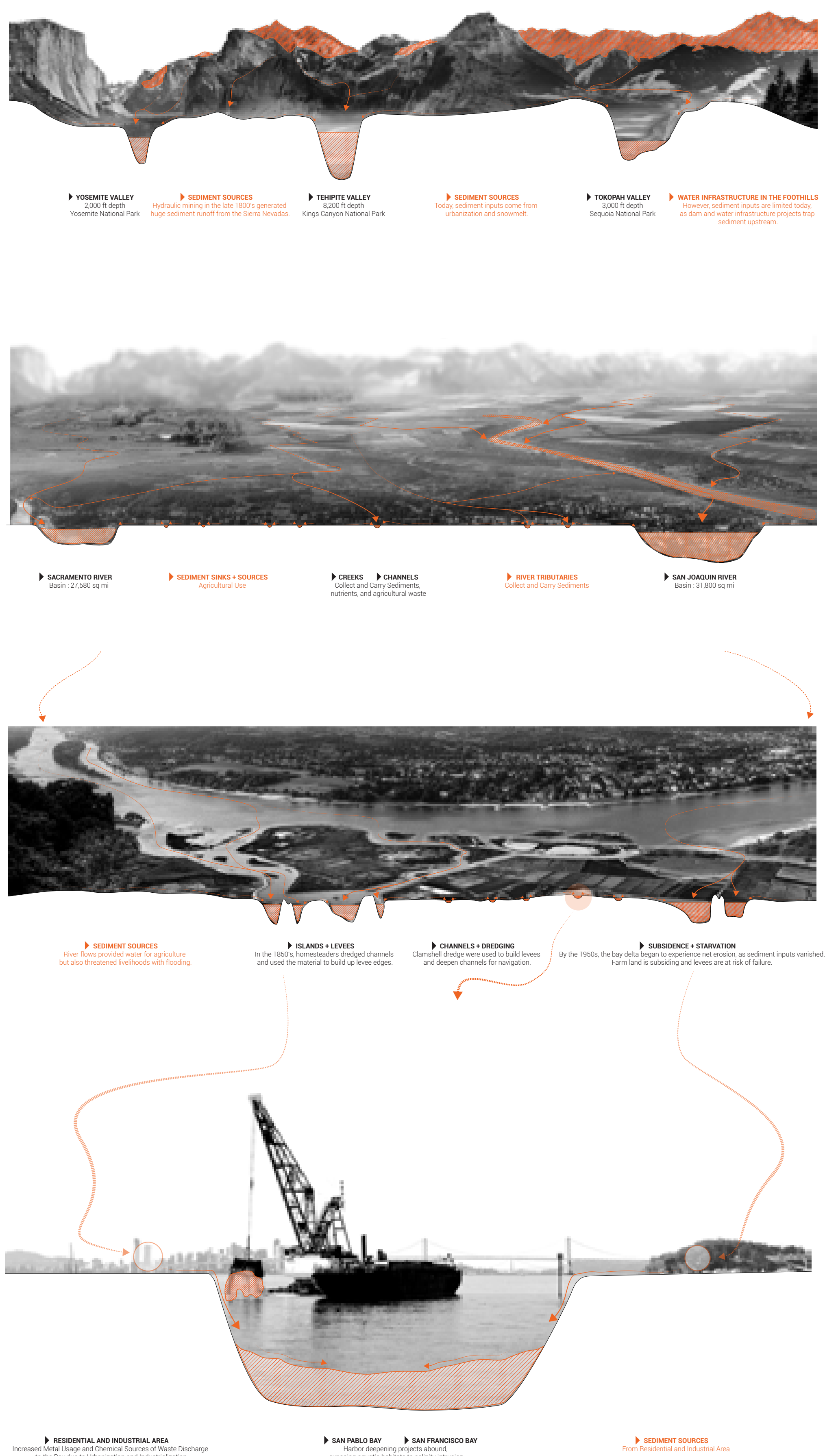
Today, we are in a third phase described as a "stationary altered regime"[7], which is marked by a deep shortage in the Bay-Delta of sediment. Wetlands, in particular, are capable of accreting rapidly enough to keep up with sea level rise, but they need enormous volumes of sediment in order to do so:

"Wetlands are particularly vulnerable, as they would require a total sediment input (i.e., organic matter and inorganic sediment) of up to 10.1 Mm3/year (~2.6 cm/year) by 2100 to keep pace with the higher projections of sea level rise: presently only as much as 0.4 Mm3/year is actually being deposited… the brackish and freshwater tidal wetlands, in particular, will be additionally stressed by higher salinities and temperatures, leading to lower plant productivity and correlative organic inputs to the wetland, requiring even higher rates of mineral sediment inputs for the wetland to keep pace with sea level rise."[8]

The 1999 and 2015 Baylands Goal Reports have set a goal of restoring 100,000 acres of wetlands in San Francisco Bay. With sea level rise looming (and expected to accelerate towards the latter half of this century), the sooner this can be accomplished, the less sediment will be required. Marshes accrue sediment and produce organic material, thus making them potentially more adaptable to sea level rise if they have been restored. But to even reach the Baylands goal in the next fifteen years, it has been estimated that 153 Mm^3 of sediment will be required—an annual amount nearly equal to the average sediment load during the Gold Rush.

Sediment availability is also critical for the Delta. "Deposited sediment creates and sustains the Delta landscape, including habitats such as tidal marsh, floodplain, open channels, and flooded islands"[9]. Like the Bay's wetlands, Delta wetlands face the challenge of accreting as sea level rises. But significant volumes of sediment are also needed in the Delta to maintain, replace, and upgrade the levees that protect tracts, particularly subsided tracts. During the period 1900-2000, subsidence created approximately 2.5 billion cubic meters of anthropogenic accommodation space in the Delta[10]. Without sufficient sediment supply, innovative approaches, such as sediment traps that would passively accrete earthworks, are crippled. This is the same sediment that is needed in the Bay, so trapping the sediment upstream in the Delta could have potential adverse effects on downstream shorelines.

In short, the challenge that the Bay-Delta faces is in large part a problem of inadequate sediment supply. The core question for Regional Choreography was: how can the distribution of sediments across the region be re-choreographed in order to address current and projected shortfalls? And what might be the consequences or byproducts—spatial, environmental, cultural—of that mobilization and delivery?



^ Sediment dynamics in the California Bay-Delta sediment shed / DRC

Dammed reservoirs are the most obvious large-scale source of additional sediment. For instance, “three of the largest dams in the Sacramento River watershed (Oroville, Folsom, and Englebright)...[have] impounded 85 Mm^3 of sediment”[11]. Today, most discussion of action of sedimented dams in California has focused on other issues related to reservoir sedimentation, including upstream flooding, dam safety, and fish passage[12]. Globally, reservoir sedimentation is often considered problematic because of loss of reservoir capacity, but total loss in California has been fairly low: an estimated 2.1 billion m^3 of trapped sediment has resulted in a loss of only 4.5% of total reservoir capacity[13].

Kondolf et al 2014 provides a classification of “strategies that both prolong reservoir life and benefit downstream reaches by mitigating the sediment starvation that results from sediment trapping”. A wide array of approaches can be used to mitigate sedimentation and downstream starvation. Some strategies involve designing or managing dams so as to reduce sedimentation in reservoirs, by either bypassing the dam or helping sediment to pass through it. Other strategies can be employed when sedimentation has already occurred, typically through either mechanically excavating the reservoir (including dredging) or manipulating reservoir hydrology so that its waterflow flushes sediment[14]. However, mercury contamination is a significant issue in the sediments that are trapped in reservoirs within the Bay-Delta watershed (Martin 2014), suggesting that there may be significant environmental impediments to remobilizing sediments trapped in Bay-Delta watershed reservoirs. Dredging provides another possible source. Approximately 2.3-4.6 Mm^3 of sediment is dredged annually in the Bay-Delta for channel maintenance. In 2014, approximately ⅓ of sediment dredged in the Bay was “beneficially reused”, primarily for wetland restoration. Most of the remaining sediment was suitable for similar uses, but was instead dumped in open-water disposal areas for cost reasons.

Beyond reservoirs and dredging, other options for increasing sediment load in the Bay-Delta include levee modifications, channel modifications, remediating mercury-laden hydro-mining sediment, and mining/excavation.

One of the major difficulties in developing a viable regional choreography of sediments for the Bay-Delta is the significant gaps that exist in present knowledge of the geography of sediment. “There has been no comprehensive study of the anthropogenic drivers of sediment supply, so determination of their relative importance is difficult.”[15] Data collection on sediment volumes in reservoirs, specifically, and data collection on sedimentation, generally, is extremely weak. There is a lack of “long-term, accurate” sediment data, which makes sediment management decision-making difficult[16]. Minear and Kondolf 2009 is the best existing estimate of the volumes of sediment held in reservoirs behind dams in California. However, the model that it uses is “appropriate for detecting regional trends and highlighting reservoirs potentially at risk of sedimentation but would not give accurate estimates of sedimentation within individual reservoirs”.

As a result, this workshop was not only oriented towards proposing futures, but also towards identifying questions. The choreography team’s work probed relationships between sediment sources and deficits across the entire estuary watershed, while considering the potential effects of drivers such as shifting regional weather patterns, long-term technological innovation, and state and national policy climates to better understand how these cumulatively shape the trajectory of sediments within the Bay-Delta’s watershed. Key research questions included: what drivers of change are most relevant to the development of regional choreography? What gaps in knowledge need to be resolved? What scenarios are worth exploring? This track’s work was informed by the Bay and Delta tracks and provides broader context for them.

Notes:

1. Schoellhamer, David H., Scott A. Wright, and Judith Z. Drexler. 2013. Adjustment of the San Francisco Estuary and watershed to decreasing sediment supply in the 20th century. Marine Geology 345: 63-71

2. Barnard, P.L., Schoellhamer, D.H., Jaffe, B.E. & McKee, L.J., 2013, Sediment transport in the San Francisco Bay Coastal System: An overview, Marine Geology 345: 3-17

3. Barnard et al, 2013

4. McKee, L.J., M. Lewicki, D.H. Schoellhamer, and N.K. Ganju. 2013. Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. Marine Geology 345: 47-62

5. Barnard et al, 2013

6. McKee et al, 2013

7. Schoellhamer et al, 2013

8. Barnard et al, 2013

9. Schoellhamer et al, 2012

10. Mount J and Twiss R. 2015. Subsidence, Sea Level Rise, and Seismicity in the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science 3:1.

11. Barnard et al, 2013

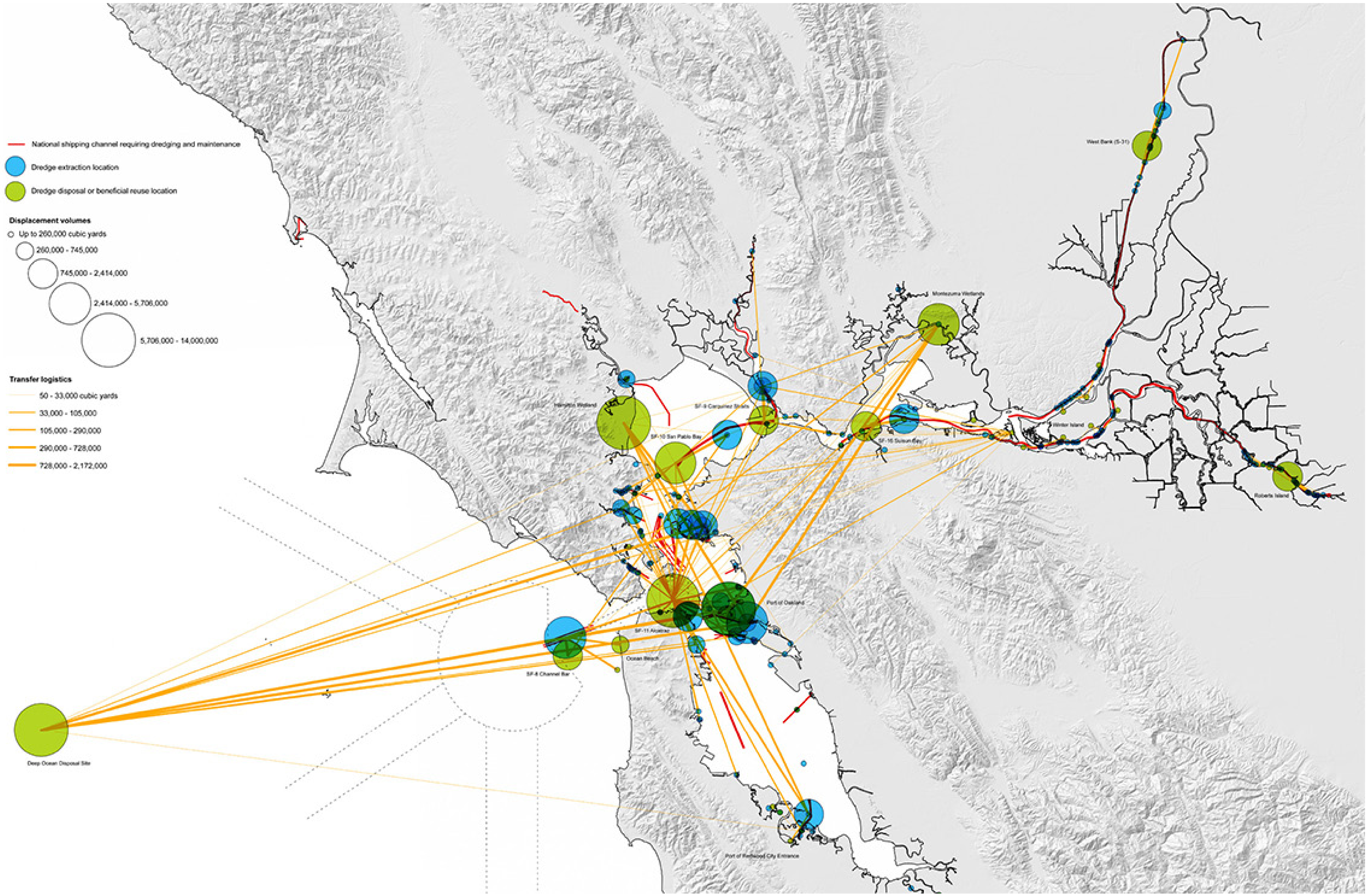
12. Kondolf, Mathias. 2014. Sustainable sediment management: the key to the future. International Water Power & Dam Construction: October 2014.

13. Minear, J. Toby and G. Matt Kondolf. 2009. Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California. Water Resources Research: 45.

14. Kondolf, G.M. et al. 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth’s Future 2

15. Schoellhamer et al, 2012

16. Kondolf et al 2014



^ Bay/ Delta Navigational Dredging Operations, 2000-2013. Data from USACE San Francisco and Sacramento Districts / DRC

Dams
Dams in the Bay-Delta watershed currently trap virtually all sediment that enters their reservoirs. Existing dams could be removed, retrofitted, or maintained/operated in new ways. Existing dams are significantly aged, and their remaining lifespans are uncertain. Relatively few locations remain for new dam construction in the watershed, though any new dams that are built should be better designed. If existing dams were removed or retrofitted to allow sediment to pass, major uncertainties exist as to where that sediment would go and if it could make it to desirable downstream locations, given that historic sediment pathways and high level water flows no longer exist in the Bay-Delta.

Levees
Dikes and levees occur throughout the Bay, Delta, and upstream. (Note: the 'levees' of the Delta are technically dikes, since they are always holding back water, but are referred to as levees out of convention.) They separate river flows from floodplains, which during storm events preventing sediment-laden water from reaching marshes and floodplains. At the same time, they keep more sediment within the channel, producing potential for channel infill or downstream deposition. A variety of options exist for modifying levees to achieve desired hydrological and sedimentary effects, including removal, setbacks, gating, and intentional breaches. Like dams in the watershed, many levees, particularly within the Delta, are aging and in need of upgrades to meet current standards.

Channels
The channels of the Bay-Delta watershed have been extensively modified, in terms of width and depth (often through dredging), path (straightening and shortcutting), and channel armoring (frequently with riprap). Path changes and channel armoring tend to significantly reduce the capacity of a waterway to pick up sediment through bank erosion. Some major constructed channels exist, such as the Sacramento Deep Water Ship Channel. The way that minor storm channels meet open water in the Bay is also particularly important for affecting deposition rates. There are currently pilot projects around the Bay that experiment with re-engineering these channels or turning them back into proper floodplains ("flood control 2.0"), in order to more deliberately convey sediment to where it's needed, treating it as a resource rather than a maintenance problem.

Dredging
Dredging is driven by a combination of sedimentation rates in channels (requiring maintenance dredging) and port infrastructure upgrades (requiring channel deepening or new channels). The 'beneficial reuse' of dredged material, which includes placement in wetland sites in order to simulate or stimulate accretion, has

^ Folsom Dam
Image: USACE

become widely accepted as a practice within the Bay area. Other forms of beneficial reuse are on the horizon, such as "strategic placement", entailing strategic in-bay placement which uses landscape processes, such as currents and tides to carry sediment to where it is needed. The primary barriers to increasing the percentage of dredged material that is beneficially reused are regulatory, financial, and logistical.

Flood Control

Historically, the demand for flood protection has driven many of the modifications that have affected the distribution of sediment in the Bay-Delta watershed, such as flood bypass channels, which trap sediment, and levees, which disconnect floodplains from waterbodies. The provision of flood protection remains an important consideration in both any future modifications, particularly those that would affect federal flood control projects, and planning for sea-level rise. California has the most erratic and variable climate in the United States, which makes it simultaneously prone to drought and flooding.

Availability of Mined and/or Excavated Sediment

A variety of sources for mined and/or excavated sediment exist within the Bay-Delta watershed. 'Dirt brokers' have begun to match construction projects with excess sediment with sites that have sedimentary deficits, through the SediMatch exchange. Large infrastructure projects, such as the Delta's Twin Tunnels, also have the potential to generate significant volumes of sediment that will need to be placed somewhere. Large volumes of hydraulic mining waste sediments, which are contaminated with mercury, still exist below the dams and upstream from the Bay-Delta. This sediment could potentially be remediated in-situ (if an economical technique to remove or recover the mercury was developed) and then bulldozed into the river, where it would travel downstream. The major challenge of this would be flood control concerns (blocking the channel and having sufficient flow in the river (generally lessened by dams) to transport it. As mentioned under dams, major uncertainties exist around mobilizing sediment downsteam, given alterations in channels and regulated water flows. While more speculative, intentional sediment mining of the Coast Ranges, which would replay the hydraulic mining of the Gold Rush, but in search of sand and silt, rather than gold, is also a possibility.

Technology

Technological change has the potential to significantly affect many of the other drivers listed here, through innovations such as remediation strategies that could increase the viability of contaminated sediments as a resource, new dredging and conveyance methods that could reduce costs and increase the viability of intentional sediment mining, or the use of distributed and/or remote sensing techniques to increase understanding of the distribution and propensities of sediment throughout the watershed.

Policy, Regulations, Plans, and Incentives

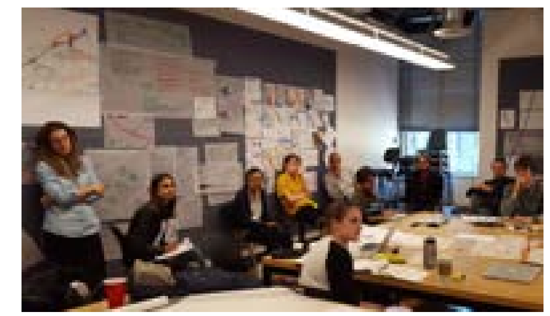
Each of the other drivers is entangled with an array of policies, regulations, plans, and incentives, which are mechanisms through which various stakeholders exert power and manipulate sediment.
Dredging, for instance, is heavily influenced by the EPA's "long term management strategies" (LTMS). The Bay already has a LTMS, which many see a need to revise significantly in light of the present sediment shortage. It was initially created during 'mudlock', when there was a shortage of disposal sites, and when in-bay disposal was considered bad. A new LTMS is expected soon for the Delta. Generally, the local regulatory environment is extensive and cumbersome, and is having difficulty pivoting from the 'filling of the bay' sedimentary excess of the 20th century toward the sedimentary deficit of the 21st, where sediment is increasingly considered a valuable resource. The USACE is bound by the "Federal Standard", which generally mandate for the least costly dredged material disposal or placement alternative that is consistent with sound engineering practices and meets all federal environmental requirements. If this policy were to be revised or superseded it could impact beneficial reuse practices significantly. Also, new business models will likely be needed, such as one in which restoration projects pay for the sediment they need (potentially through measures such as AA), justified and evaluated through the ecosystem services (and dollars) those projects will generate.

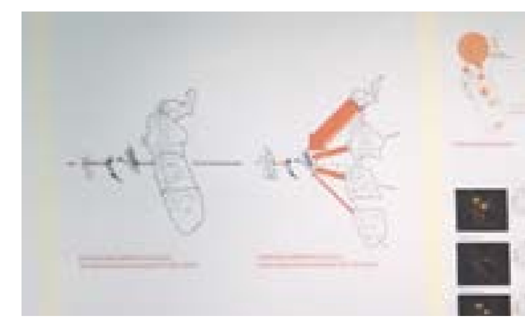
Investment

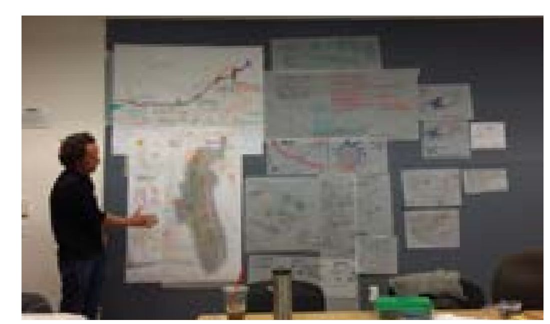
The amount of funding dedicated to sedimentary infrastructure projects is a significant variable. In general, the long-term trend in federal investment in infrastructure has been significantly downward. Efforts are underway to increase investment in sedimentary infrastructure in the Bay-Delta, but the success of those efforts is as yet uncertain. Cultural and political responses to the tangible effects of climate change may also play a significant role in determining levels of investment.

Accelerated Erosion

The rate of erosion throughout the watershed is heavily impacted by anthropogenic factors, including land use and erosion control practices. Trends toward increasing population and expanding urbanization tend to increase erosion, through development and construction. Agriculture, which is one of the primary land uses in the basin, is also a significant contributor to accelerated erosion. While accelerated erosion may seem like a positive trend relative to the sedimentary deficit of the Bay-Delta, it is generally considered a significantly negative trend which should be mitigated







as much as possible, because of the status of soil as a non-renewable resource. Intentionally accelerating erosion in order to feed the Bay-Delta is unlikely to be a wise strategy.

Climate Change

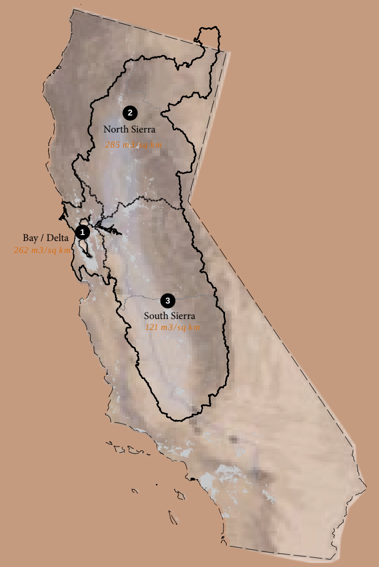
Generally considered to be an accelerating trend, climate change's net effects on sedimentation are uncertain, due both to a lack of research on the specific consequences of various climate change effects and the uncertain rate and intensity of those effects. Sea-level rise increases the need for sediment to enable wetlands to accrete upward and landward. Increased drought, drier conditions, and increased temperatures are considered likely over time, promoting vegetation die-off and increasing erosion rates within the watershed. Severe storms and forest fires are both expected to occur more frequently, and will increase the mobilization of sediment. Climate change is also likely to have indirect effects on sedimentation by affecting land use patterns and population migration, particularly in the longer term.

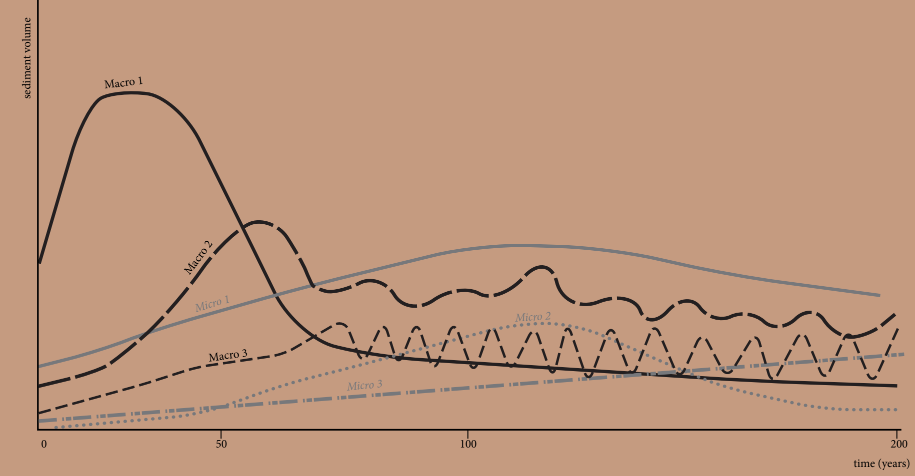
Water Exports

The demand for freshwater exports, primarily from the Sacramento River, has driven many of the hydrological modifications to the Delta, and consequently affected sedimentation patterns. The need to supply water for exports also prevents "wasteful" discharges of high flows from dams, which could send huge amounts of sediment downstream (though this wouldn't affect sediment behind dams, unless the dams are retrofitted). Historically, most sediment load is carried in high flow events. Water management for exports has flattened water volumes, preventing high flow events.

Note: In building a model of sedimentation in the Delta, Schoellhamer et al (2012) do not include climate change or consumptive water use as significant drivers, because current peak flow events are far from fully laden with sediment: "thus, human activities that alter watershed sediment supply are likely to have a greater effect on river supply to the Delta than those that modify the flow regime (most activities influence both). In accord with this philosophy, we have not included two anthropogenic drivers that primarily affect flow regime: climate change and consumptive water use".

Derek Hoeferlin, Kees Lokman, Matthew Seibert, Jackson Blalock,
Johanna Hoffman, William Reinhardt, Nick Shannon



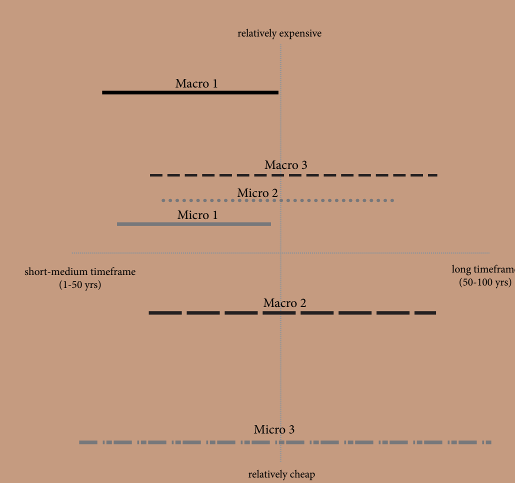


SEDIMENT MOBILIZATION METHODS

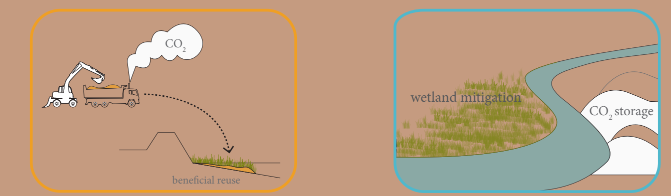
MACRO Methods	PRINCIPLE DRIVERS
1: Direct Transport of Entrapped Sediments Behind North Sierra Dams *Enables immediate mobilization of large amounts of sediment*	Accelerated Sea Level Rise + Funding
2: Dam Removals in North + South Sierra's *Enables medium-term mobilization of large amounts of sediment followed by small amounts of sediments based on seasonal rainfall pulse*	Infrastructural Obsolesence + Political Climate
3: Dam Retrofits in North + South Sierra's *Enables immediate mobilization of small-medium amounts of sediment based on seasonal rainfall pulse*	Funding + Infrastructural Obsolesence

MICRO Methods	
1: Dam Removals and Retrofits in Bay/Delta *Enables immediate mobilization of small amounts of sediment, followed by influx of sediments based on seasonal rainfall pulse*	Funding + Infrastructural Obsolesence
2: Accelerated Bay Lands Mining *Enables increased mobilization of small-medium amounts of sediment*	Political Climate
3: Dirt Brokering in Bay/Delta *Enables immediate relocation of small amounts of sediment in near, medium and longterm*	Regulatory Incentives

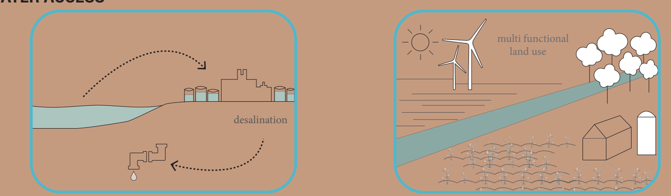
TIME / COST



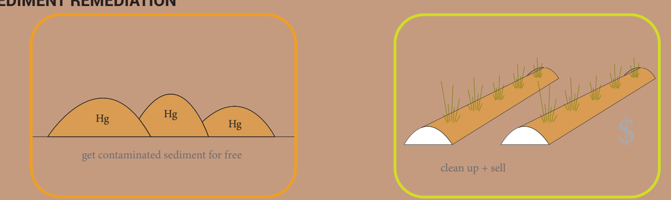
CARBON OFFSET



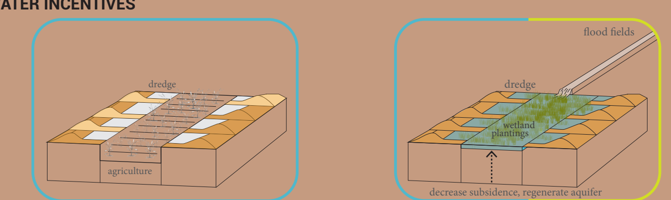
WATER ACCESS



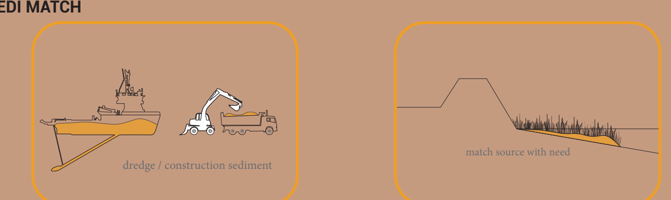
SEDIMENT REMEDIATION



WATER INCENTIVES

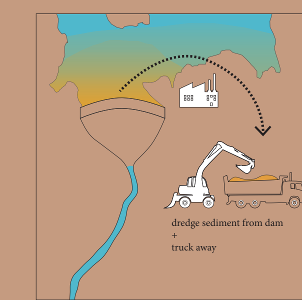


SEDI MATCH

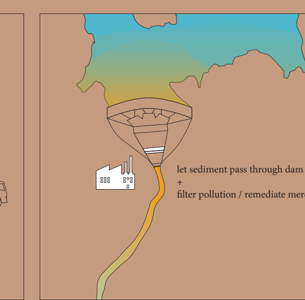


MEGA Regional Choreography

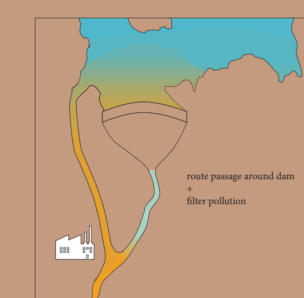
TRUCK AWAY



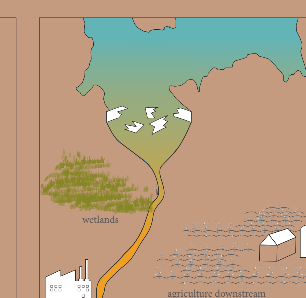
RETROFIT + PUSH THROUGH

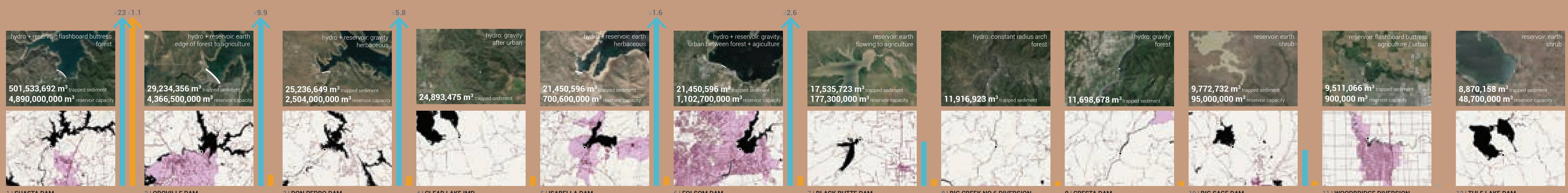


BYPASS

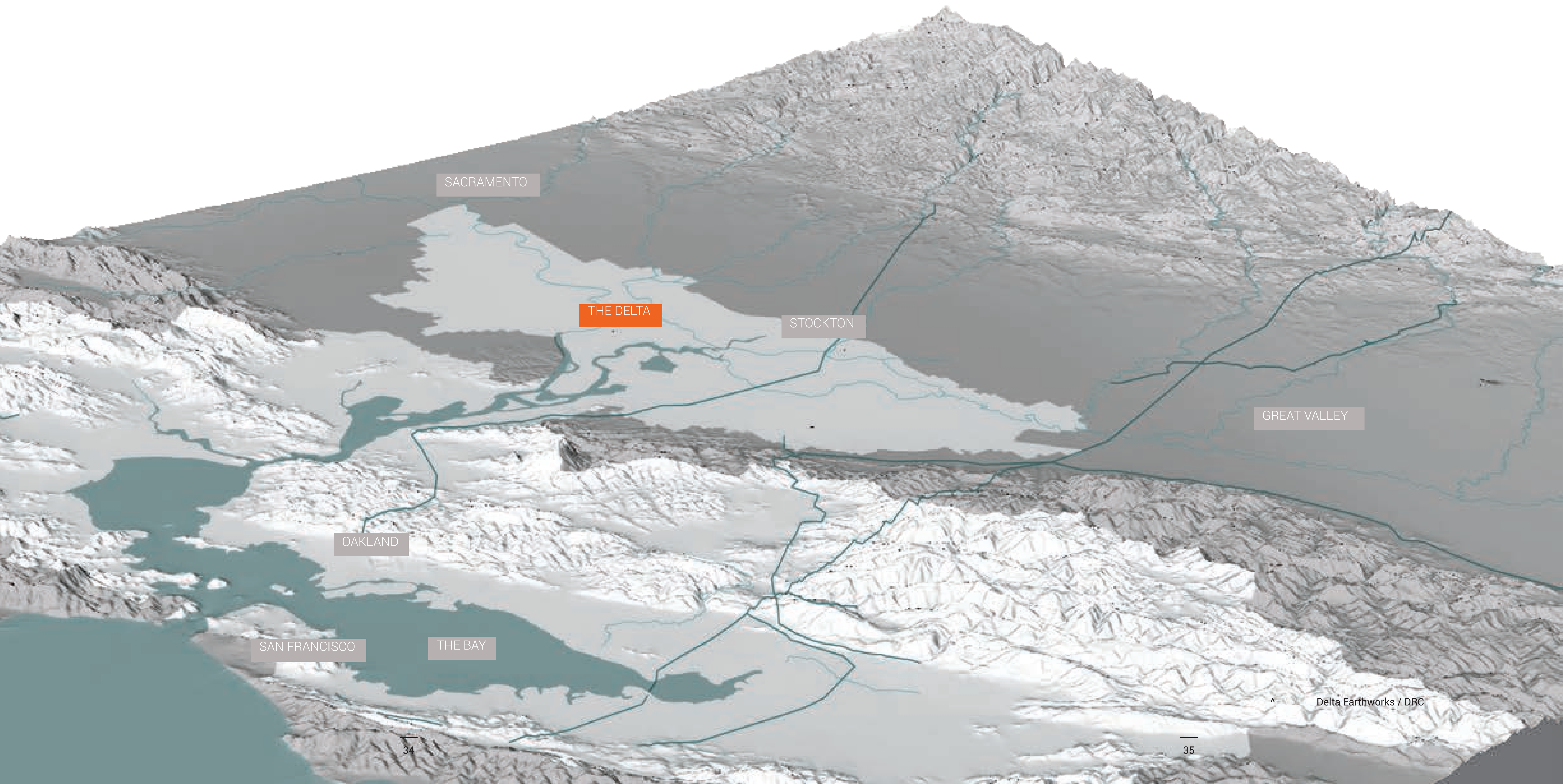


REMOVE DAM

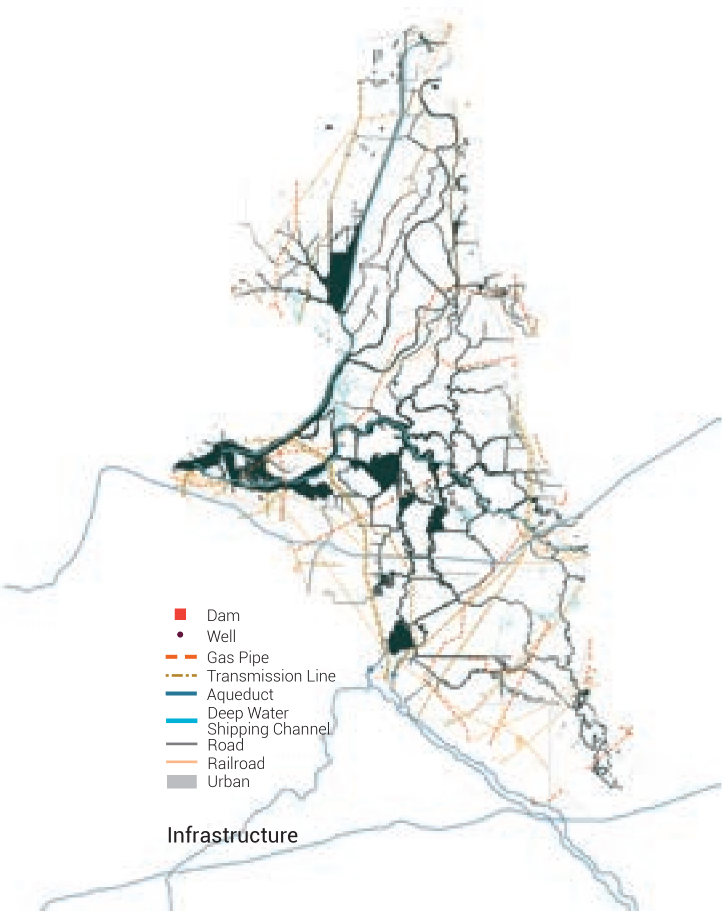




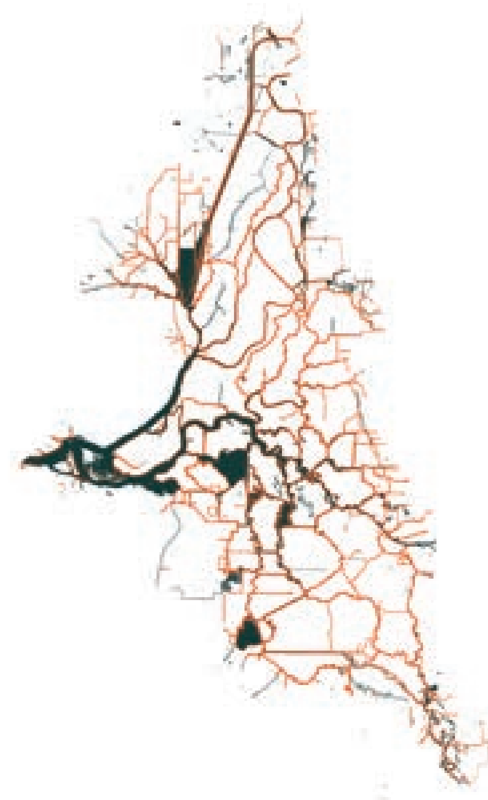
DELTA EARTHWORKS



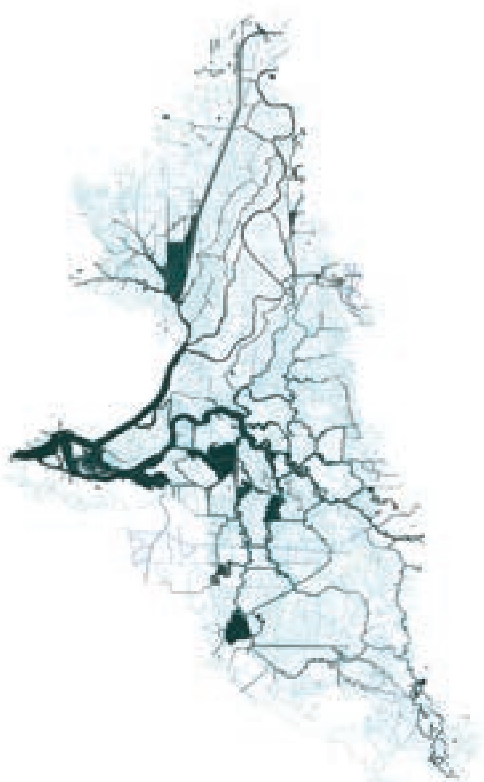
^ Delta Earthworks / DRC



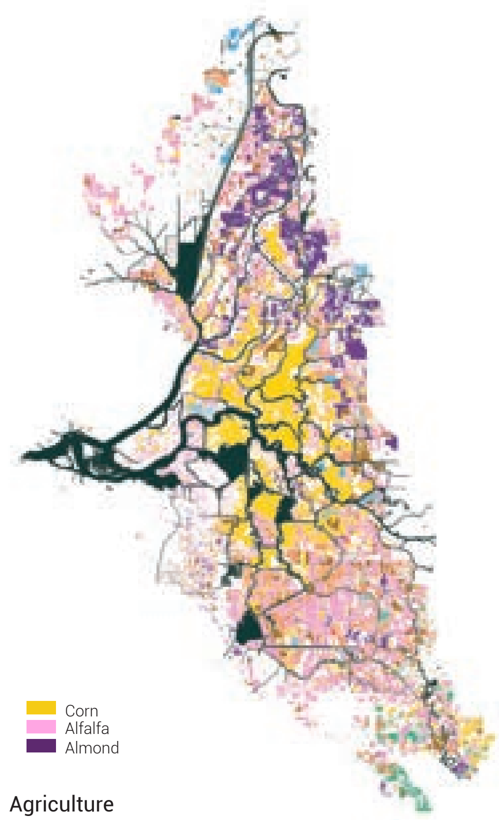
Infrastructure



Levees



Irrigation Canals



Agriculture

^ Delta Studies
DFCA Delta Workshop

Delta Earthworks

The California Delta of today is completely different from the marshy, migratory inland sea it used to be just a hundred and fifty years ago. Its physical geography of is unique, as it sits inland from the Bay, miles away from the ocean—an inverted Delta. Most of the Central Valley and the western slope of the Sierra Nevadas drain into the California Delta, periodically flooding it entirely. The Delta was one of the United States' first large-scale land reclamation projects. At that time, "reclamation" meant the grand experiment of converting wetlands (considered pestilent wastelands) to agricultural production.

The sequence of human-induced geologic events that led to the Delta's reclamation are unique. As homesteaders began to settle the area, the Delta was inundated with mobilized fragments of the Sierra Nevada foothills generated by hydraulic gold mining. These sediments were washed downstream by unusually wet winters. This slurry filled in the Delta's channels and caused an environmental crisis while providing ready-made material to build larger and more extensive levees. These were more stable than the smaller peat soil levees that preceded them and formed their foundation. The Delta as one sees and experiences it today—a dyke and polder working landscape akin to the Netherlands—was fashioned by this industrial combination of hydraulic mining followed by clamshell dredging. It is a massive constructed earthwork.

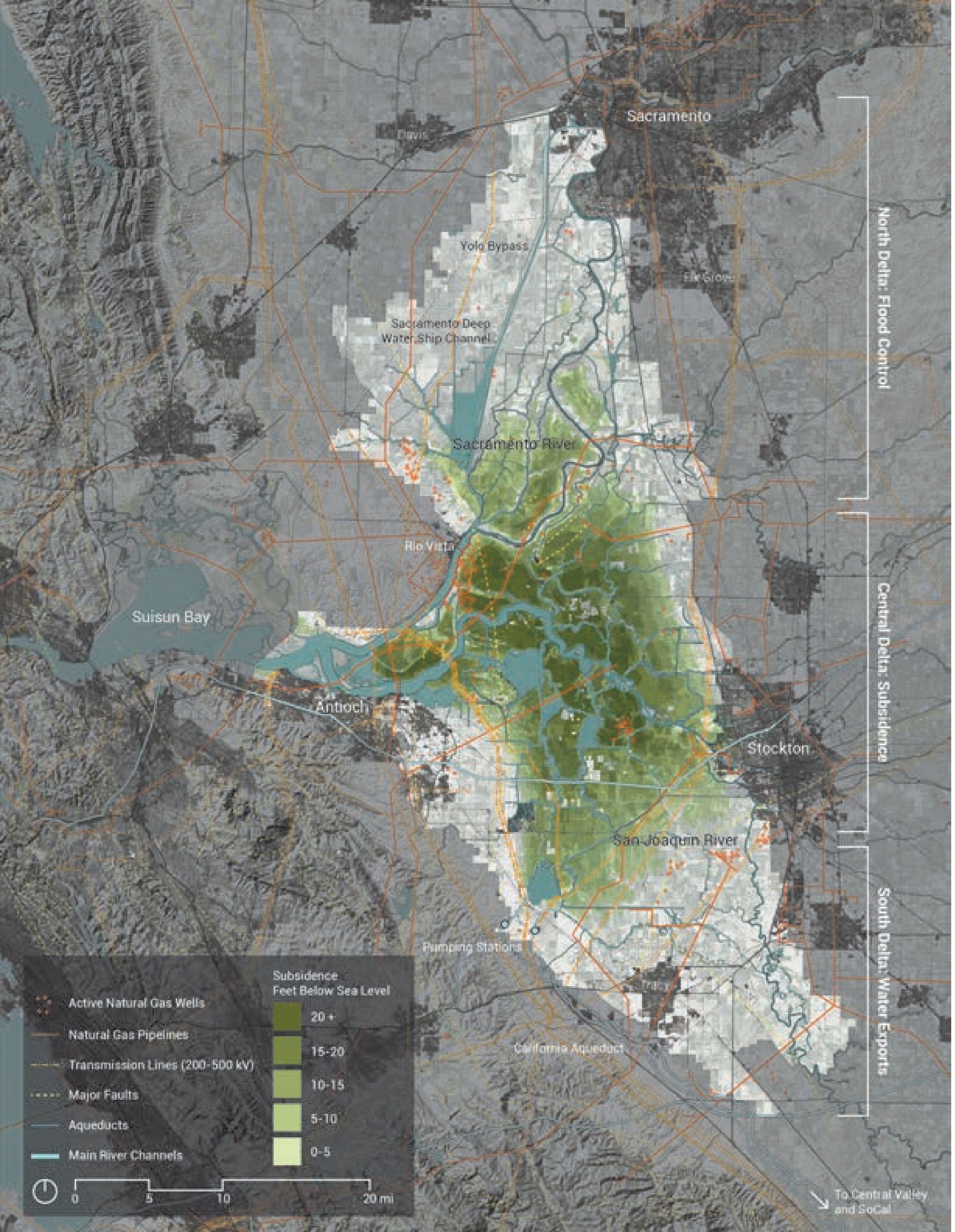
The Delta's 1,100 mile network of levees is its infrastructural backbone, which has continued to mold the form and functioning of the region. Since reclamation, the levees have been refined, breached, repaired, augmented and diversified. Around the middle of the 20th century, the Delta's levees assumed another critical function: water conveyance infrastructure. Since the 1950s the Delta has been a central hub in the state's water infrastructure system—one of the largest in the world.
The levees' transformative effect on the Delta itself (combined with altered water flows due to exports) includes enormous ecological ramifications, such as near total loss of former tidal and other wetland habitats (98% eradication) and in-tandem changes in species composition and extinctions. These changes are not easily reversible. If the Delta's levees were breached now, whether through deliberate effort or inadvertent failure, they would leave behind something radically different than what existed before them: rather than marshes, much of the Delta would be an inland sea due to the subsidence of the landscape's peat soils.[1]

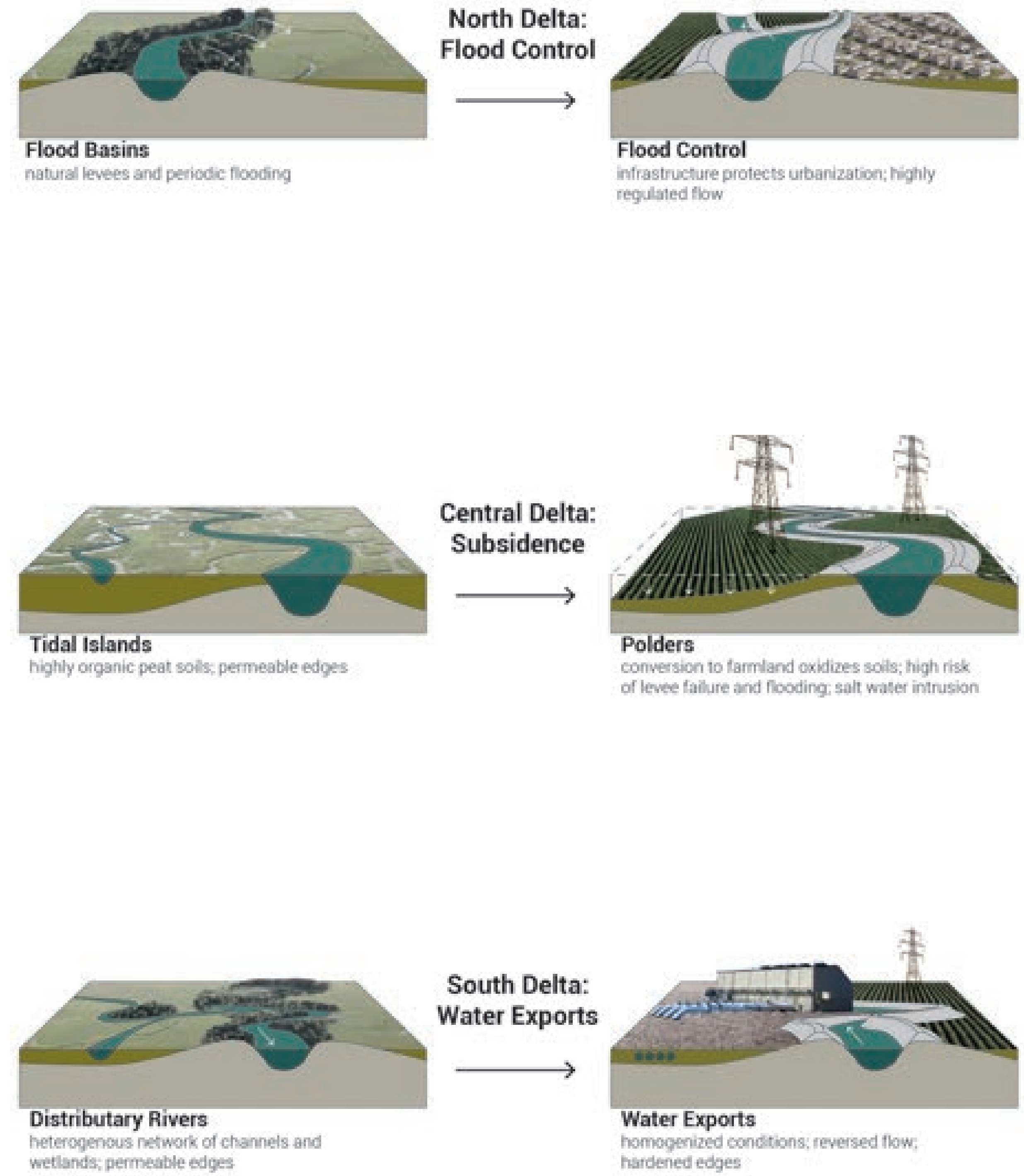
Further breaches are not unlikely. The sustainability of this earthen network is highly indeterminate. It is dependent on variables such as the work and dedication of local reclamation districts, federal and state funding, the burrowing habits of rodents, tree roots, and vastly different seismic and geotechnical stability projections. Its future will be shaped by the state's current levee prioritization study, which seeks to define decision-making metrics through flood risk and economic value assessments, and which of a dizzying array of plans and proposals for the Delta's future are implemented.

This uncertainty plays out within the context of a web of interconnected interests. The Delta Reform Act of 2009, legislation that currently guides state action in the Delta, defined "a more reliable water supply" and "protecting, restoring, and enhancing the Delta ecosystem" as "co-equal goals", to be achieved with a sensitivity to the "unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place". Yet how these values, as held by those who live, work and play there, are incorporated into projections and future protocols is unclear at best.

This is one example of how the Delta presents a range of 'wicked problems.' Coined by planners Horst Rittel and Melvin Webber, wicked problems are inherently ill-defined and never completely solvable, since solutions to them "rely upon elusive political judgment for resolution." The very formulation of a wicked problem is situated within and contingent on a meshwork of complexities and geopolitics. Thus "the process[es] of formulating the problem and of conceiving a solution (or re-solution) are identical, since every specification of the problem is a specification of the direction in which a treatment is considered."[2] Scientists and planners working in the Delta have come to embrace this understanding of the Delta's challenges:

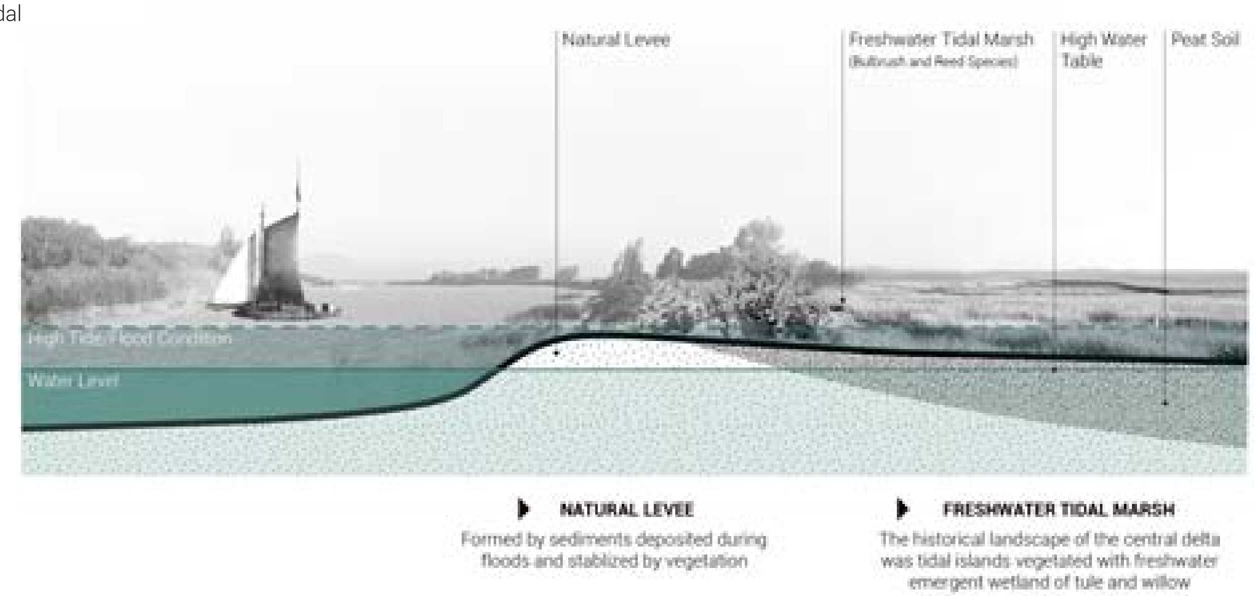
"If the problem were just about allocating freshwater flows, it might be solvable. Add in the complexity of moving water through a hydrologically and hydrodynamically complex Delta and it becomes complicated. Add the uncertainty of ecological responses and the institutional complexity of many actors with many visions and the problem becomes wicked. Then add the ever-changing water supply and ecological and economic contexts within which decisions must be made, and the problem becomes devilishly wicked."[3]



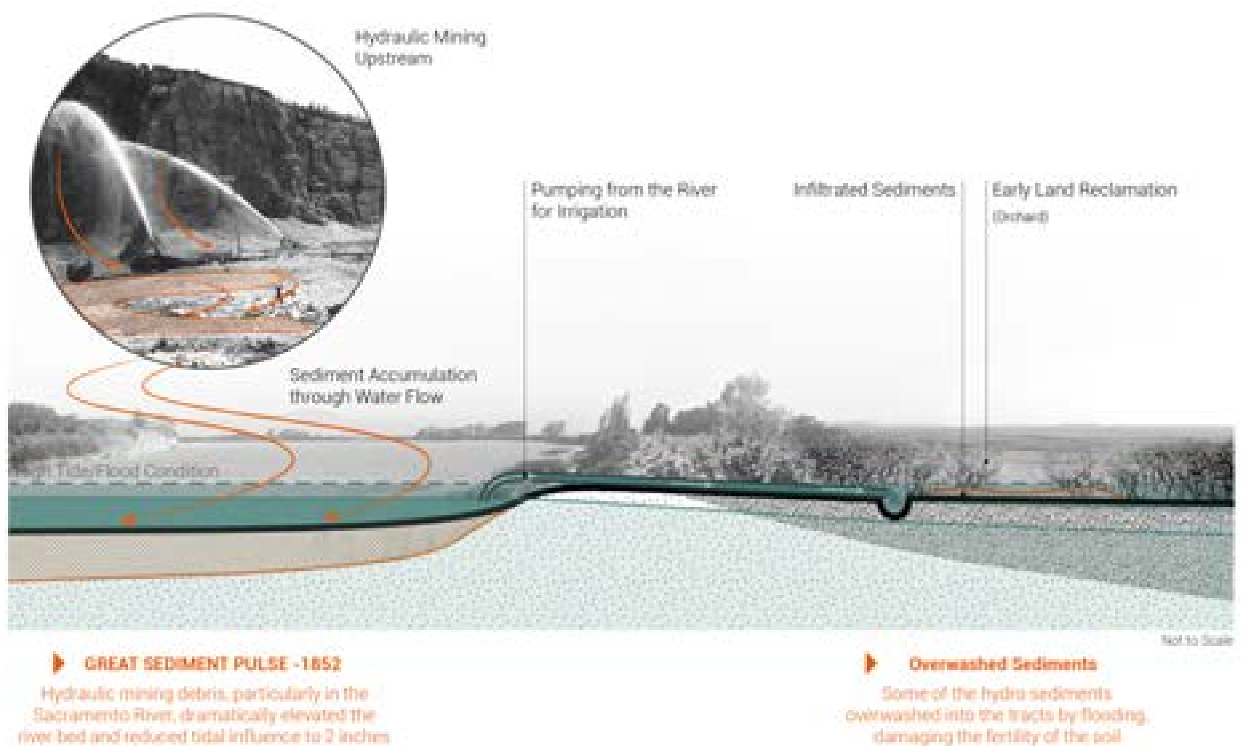


^ Delta Conditions
DRC

Before 1848
Historical Delta Ecology
Low Bank Islands with Constantly Flooded Tidal Wetlands



1848-1894
Hydraulic Mining & Agricultural Expansion
Increase of Sediment in Waterways due to Hydraulic Mining



^ Delta Sections
DRC

Given these challenges, the Delta has been the subject of intensive research—particularly by engineering, physical sciences, and biological sciences—as well as become a repository of propositions and plans for its future. In the resources section for this track, we have provided links to studies that have explored potential levee and water conveyance engineering options for the Delta. We also provide a listing of specific design and planning schemes that might be enacted, such as the California Waterfix, a current proposition to route water exports through two 40 diameter excavated tunnels (thirty miles in length), one hundred and fifty feet below the surface of the Delta. This proposition could be passed within the next year and would be one of the largest infrastructural projects in the U.S. Or, it might not pass, and would join the graveyard of failed Delta infrastructural propositions.

The Challenge

We deployed scenario planning as a method to look beyond the "tunnel" vision of the current moment to explore a broader range of plausible futures for the Delta. For this workshop, we looked fifty years into the future to envision what the Delta's infrastructural earthworks might be and the types of landscapes, ecologies and social conditions they might generate. The Delta is a place of accelerated landscape change, as clearly demonstrated by its recent cultural and environmental history. Fifty years from now, the Delta will likely be something very different yet again, regardless of what courses of action are taken.

The question asked of this workshop was what qualities that future Delta might exhibit and how might we act upon its earthworks to guide it towards more preferred outcomes, keeping in mind that "preferred" outcomes are inherently situated and political, as the Delta cannot be all things to all stakeholders.

Four scenarios (found in the appendix of this document) were provided to help envision vastly different ways the Delta could plausibly develop between now and 2066, based on different ways the drivers of change structuring them could play out. These scenarios are deliberately exploratory rather than normative, meaning they don't describe or privilege preferred futures or define what should be. Rather they attempt to provide a glimpse into vastly different conditions that could be fifty years from today. As such, they provide a platform; a basis for review and discussion of more normative design schemes that were generated in the workshop.

Design teams in this track were asked to propose innovate strategies for future earthworks and infrastructural retrofits in the Delta informed by the range of future possibilities presented across four scenarios. Myriad uncertainties facing the Delta's infrastructure are presented within them, including water exports, climate change, regional urbanization, rapid ecological change, potentially disastrous earthquakes, and flood protection needs.

How each team chose to respond to these scenarios was open-ended and up to them, both in terms of the methods of their design approach and what aspects of the challenge their team decided to focus on. Teams were not locked into any particular scenario. The only requirement was that each team's proposal address the broad thematic question of the workshop: what could the future of these earthworks be? How do you act now to affect what the earthworks might be in the future?

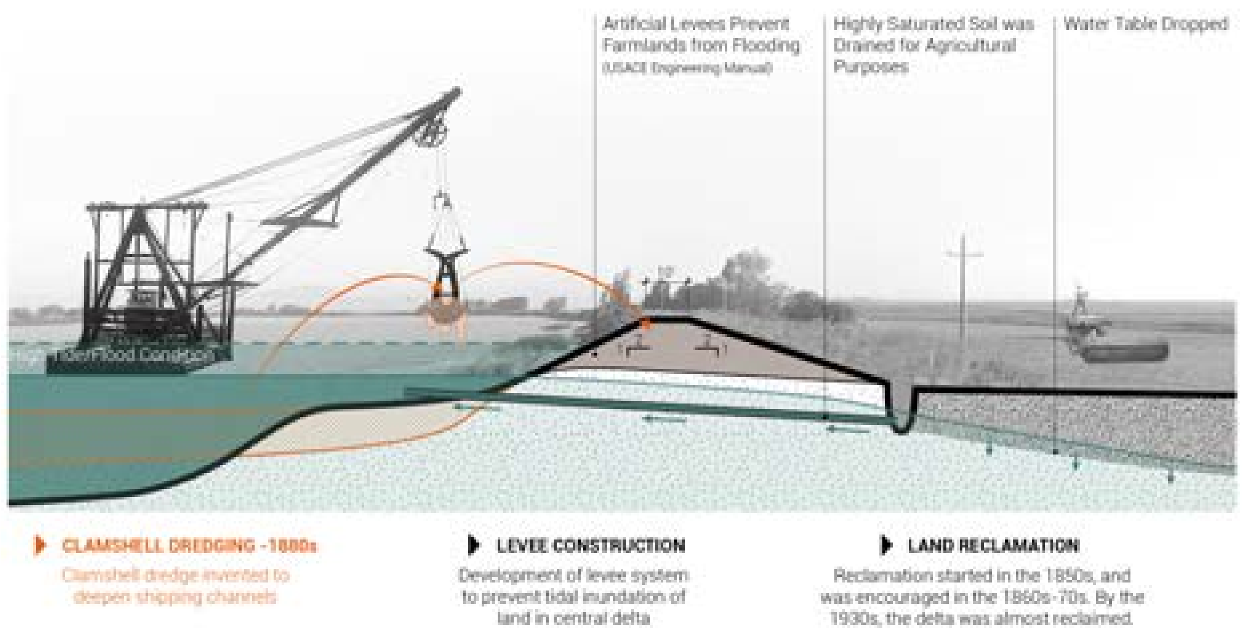
Notes:

1. Rittel H, Webber M, "Dilemmas in a general theory of planning", Policy sciences, vol. 4, no. 2.

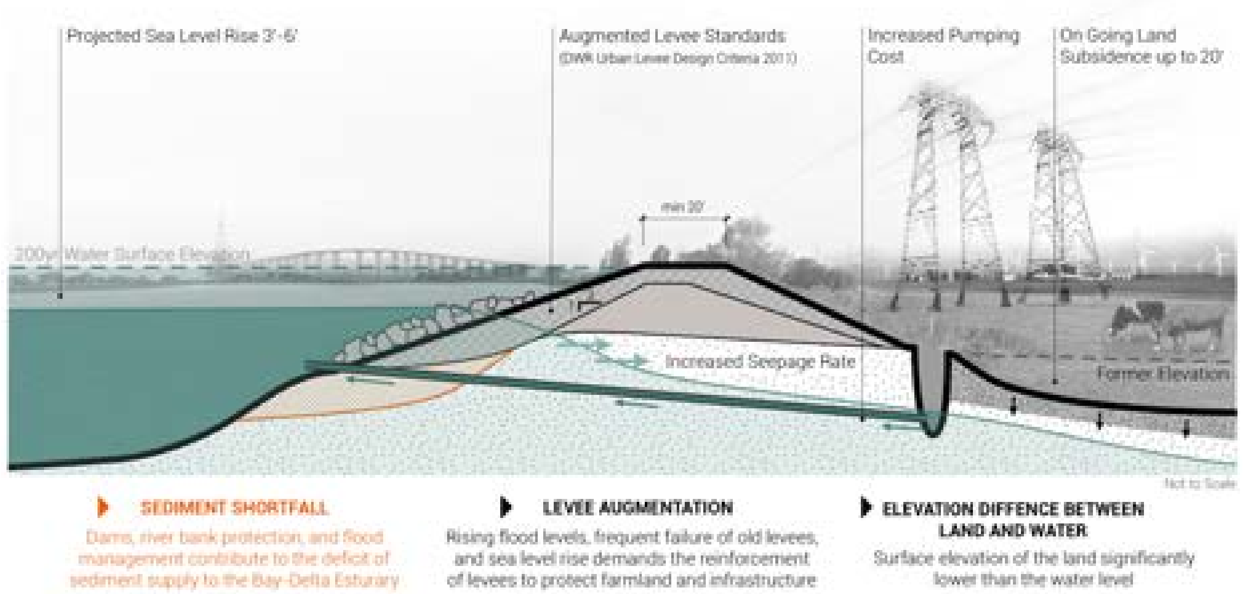
2. Ibid.

3. S. Luoma et al., "Challenges Facing the Sacramento–San Joaquin Delta: Complex, Chaotic, or Simply Cantankerous?", San Francisco Estuary and Watershed Science, vol. 13, no. 3, 2015.

1850s-Present
Dredging & Land Reclamation
Agriculture, Dredge, and Levee Building



1900s-Present
Land Subsidence & Adaptation
Ongoing Subsidence and Severe Loss of Wetlands



^ Delta Sections
DRC

DELTA EARTHWORKS DRIVERS OF CHANGE

Environmental Disaster and Accelerated Change

Includes not only events traditionally understood as 'natural disasters', such as earthquakes (which are likely in the Delta due to fault lines), storms, and droughts, but also longer and slower environmental events with potentially detrimental consequences for the Delta, such as anthropogenic climate change and alien species invasions. High incidence of disasters would be stressful for the Delta's levees, ecosystem, and inhabitants. Effects on the levees themselves are sometimes direct: a single earthquake could collapse multiple levees, flooding subsided tracts. Other effects are more indirect: for instance, climate change stresses the ecosystem through effects such as sea level rise (affecting salinity gradients) and rising temperatures, endangering Delta species; endangered species, in turn, result in the issuance of biological opinions by the courts which restrict water exports; and those exports are, presently, the primary reason for outside investment in Delta infrastructure.

For example, drought:
Long term effects/changes:
http://www.hcn.org/issues/48.3/a-dry-future-weighs-heavy-on-california-agriculture
What if the Drought continues:
http://www.ppic.org/main/publication_quick.asp?i=1160

Investment

Refers to the level of investment in the Delta, particularly its extensive infrastructure. The Delta's levees, and the repairs, maintenance and upgrades they require, are currently funded through a combination of the local reclamation districts (of which there are over 50), the state of California (through subventions and incentive programs) and federal funding (for federal flood control levees and some standard upgrades). Future investment in the Delta's levees are uncertain and controversial for a variety of ecological, economic and political reasons. Current investments in the Delta's levees are coupled with water exports, since the levees are needed to convey water through the Delta to the pumps for export to the southern portion of the state. These exports support urban and agricultural economies far beyond the Delta. If the state's water exports were decoupled from the Delta (via other technology, or reduction in exports themselves), the level of investment in its levees is likely to be significantly reduced. Locally, the Delta's levees protect not only communities, farms, and private landowners, but also a thick web of other infrastructure in the region, such as power lines, cell towers, rail, natural gas fields and storage basins, pipelines, ports, and deep water shipping channels.

For example:
Delta Levees Investment Strategy:
http://deltacouncil.ca.gov/delta-levees-investment-strategy

Water Exports

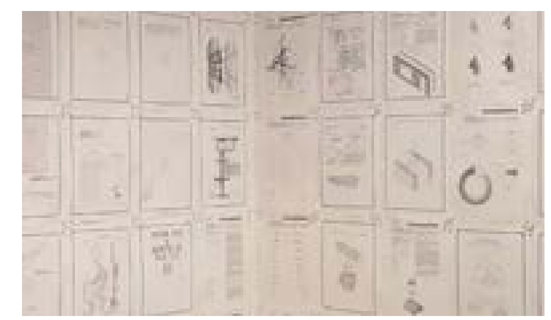
Since the construction and operation of California's State Water Project and the Central Valley Water Project (federal), circa late 1950s-early 60s, the Delta has become a central and controversial hub in California's vast water infrastructure. Both of these projects rely on the Delta's levees to protect water conveyance routes through the Delta to pumping plants, which in turn deliver water exports to city centers and to the southern, more arid half of the state. Re-plumbing the Delta for water exports has radically altered water flows in the Delta. Simultaneously, water infrastructure has combined with other anthropogenic influences — nutrient loading from agriculture, pollutants, channel modification and deepening, upstream diversions, and dam infrastructure — to also transform the Delta's ecology, which is now perceived to be in a state of crisis, as evidenced through extinctions and endangered species listings. Between a myriad of users and mandated flow requirements for those endangered species (encapsulated in "biological opinions" issued by Federal agencies, which state whether or not an action is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat.), the state's water is significantly "over-allocated", which means that there are more rights and demands on supply than there is actual water. Drought and climate change are expected to further reduce supply. At the same time, groundwater regulation is coming on line, reducing the availability of one alternative to Delta exports. As a result, the state is being forced to look at new solutions to this complex of situations centered around limited water resources.

For example:
How exports may change:
http://onthepublicrecord.org/2015/03/27/how-will-3-million-acres-of-irrigated-land-go-out-of-production/

New groundwater regulations: "Land retirement is coming to California agriculture."
http://www.sacbee.com/news/state/california/water-and-drought/article46665960.html

Technology

Technology refers to techniques, skills, methods and processes for producing, affecting and doing things. It includes both hardware (pipelines, sensors, dams, excavators) and software (ways of working, algorithms, protocols for action). For the scenarios, technology spans across ecological interventions, civil engineering, earthworks, increased water efficiency and recycling, to name a few. Some technology — for instance, sensate geotextiles that enable the realtime monitoring of seismic conditions within levees — may be employed within the Delta itself, while others, such as



^ Delta Workshop
DFCA

desalination, would be employed outside the Delta but have a significant effect on the Delta. Technological innovation is affected by levels of investment (for research and prototyping), laws and regulations (creating of new markets, such as carbon mitigation), and governmental policies.

For example:
How water may be exported through (around) the delta in the future:
The Delta Tunnels/Waterfix
http://www.californiawaterfix.com/

Alternatives to the tunnels
http://valleyecon.blogspot.com/2015/10/digest-version-of-my-delta-tunnels.html?spref=tw

In Delta Water Storage:
Delta Wetlands Project
http://www.sfgate.com/science/article/Southern-California-water-giant-agrees-to-buy-6878573.php
http://www.mercurynews.com/drought/ci_29612906/delta-islands-sold-big-water-agency

Water recycling
https://www.newsdeeply.com/water/op-eds/2016/05/25/recycled-water-key-to-californias-water-security

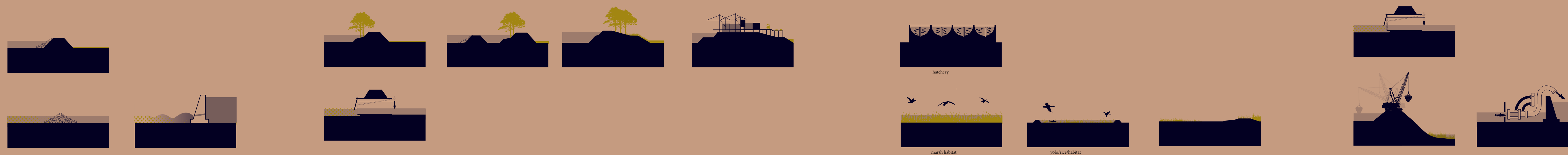
Temporary and removable levees
http://www.sfestuary.org/salt-field-ii/

Experimentation with multifunctional levees
http://www.water.ca.gov/floodsafe/fessro/environmental/dee/map_2012.cfm

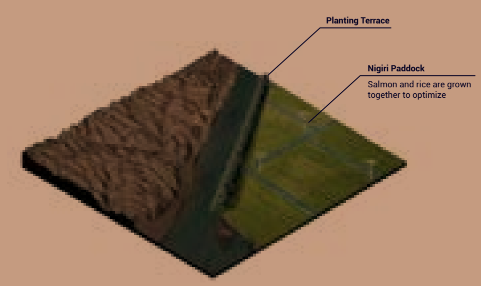
Urbanization
The Delta is surrounded by cities and expansive urbanized areas, including Sacramento, Stockton, Antioch and the greater Bay Area. California has been consistently growing in population for decades and continues to do so, placing greater urbanization pressure on the Delta. The Delta itself, the massive reclaimed floodplain of the Sacramento-San Joaquin Rivers is subject to land use policies that control and restrict development. In the primary zone, no urban expansion is allowed. In the secondary zones, which lie at the Delta's periphery, restrictions are looser and more contested. As a driver, urbanization is closely tied to state and national economic climates, population trends (in-migration versus exodus), and the regulatory climate (affecting change or stasis in land use policies).

Delta's Primary and Secondary Zones:
http://www.delta.ca.gov/res/docs/map/Black_and_White_Map.pdf

Forbes Lipschitz, Halina Steiner, Justine Holzman, Brittany Gray,
Andrew Prindle, Alejo Kraus-Polk, Yifang Xing



WATER MACHINE



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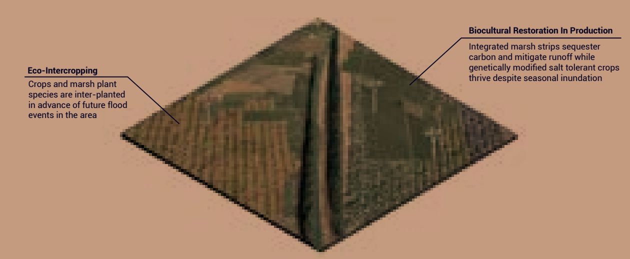

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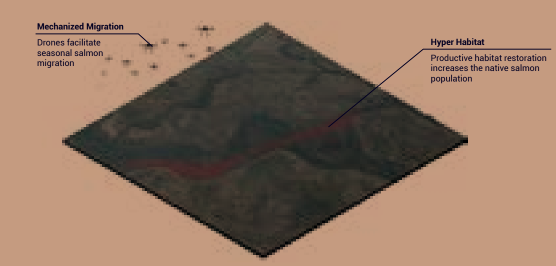

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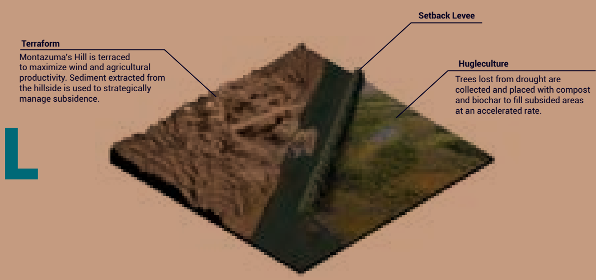
THE NEW DEAL



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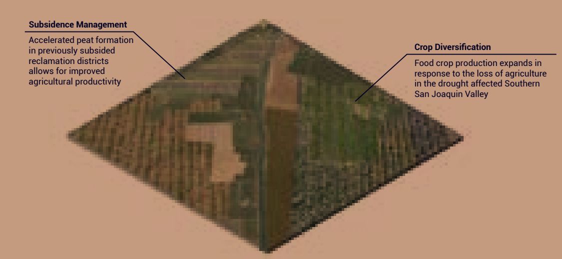

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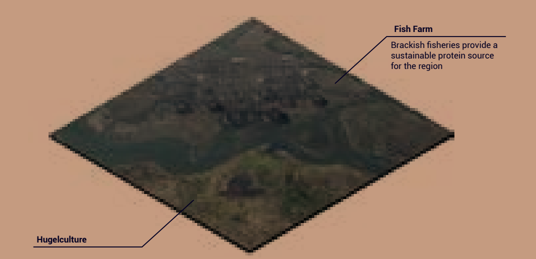

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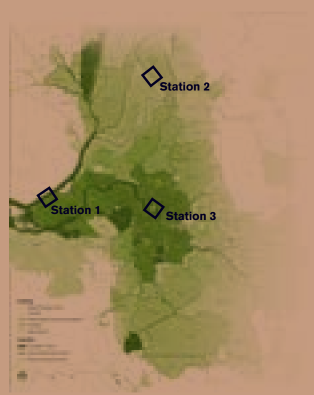
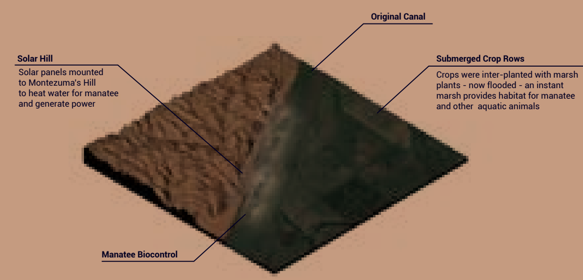


FERAL BAY



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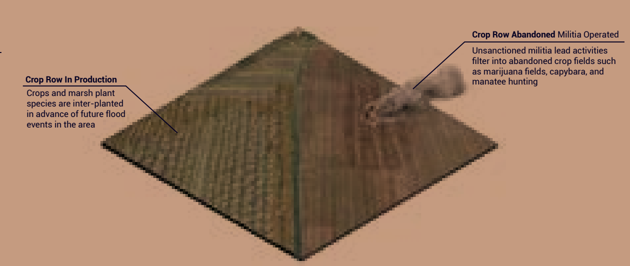

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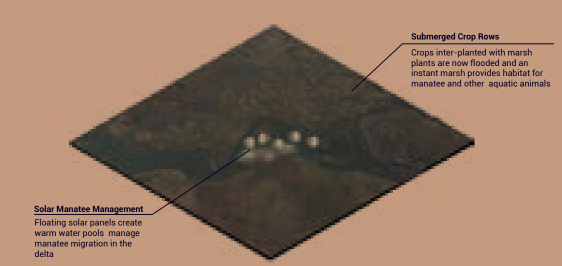

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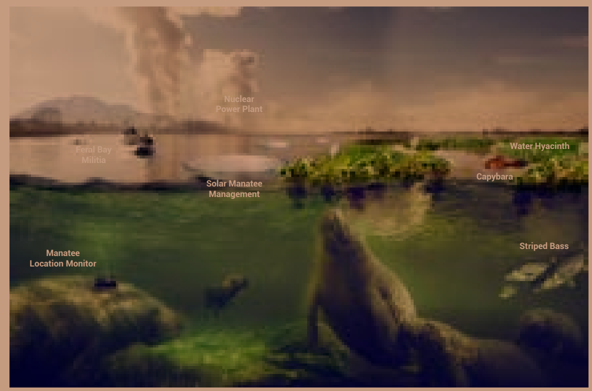
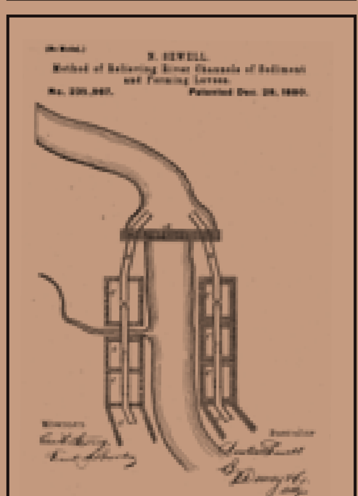
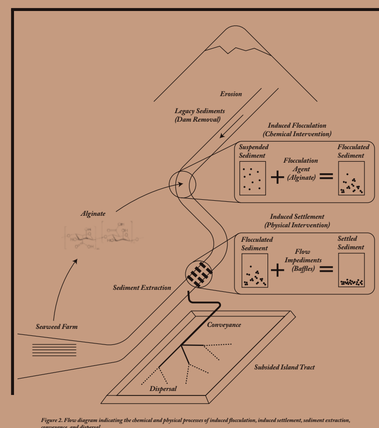
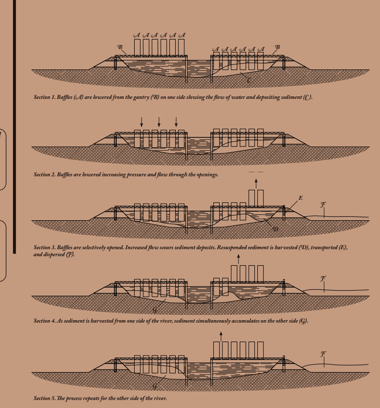








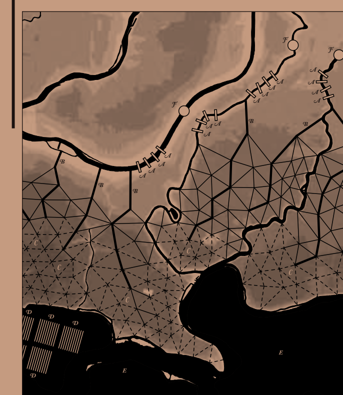
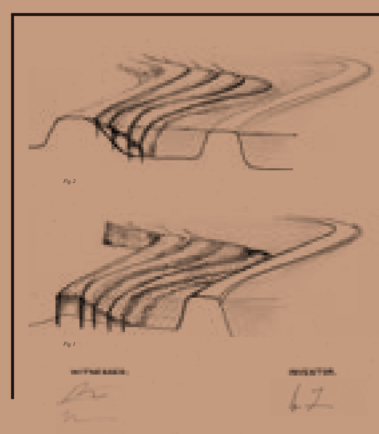
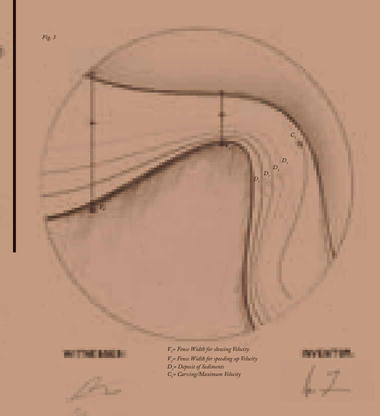
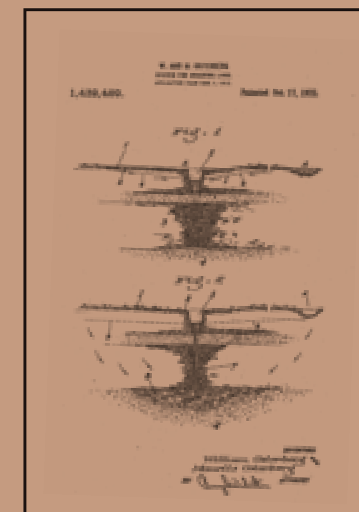
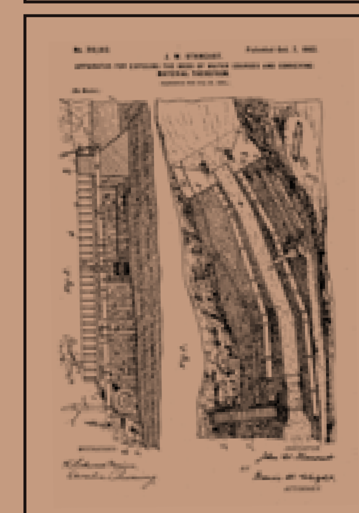


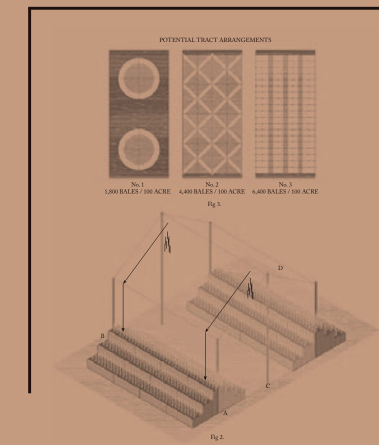
Figure 7. Triangular lattice landscape reinforcement structures of sediment extraction (A), conveyance (B), and dispersal (C). Seaweed farms (D) take advantage of saline conditions of the inland sea (E) and provide a source of alginate to induce sediment flocculation upstream of sediment extraction sites (F).

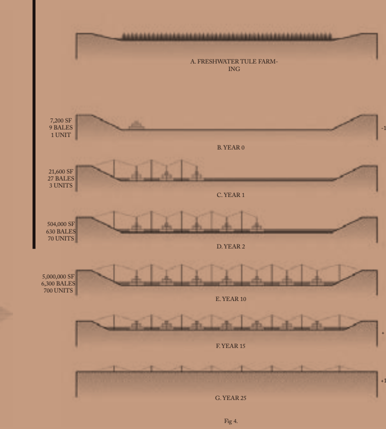


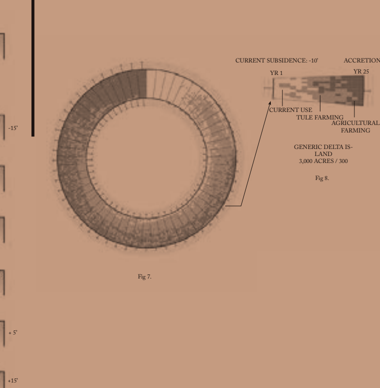


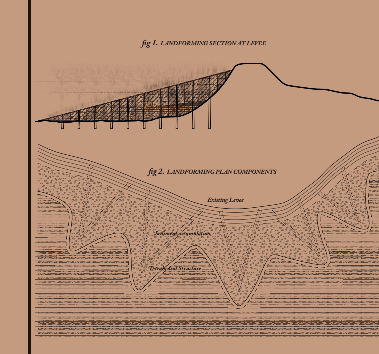


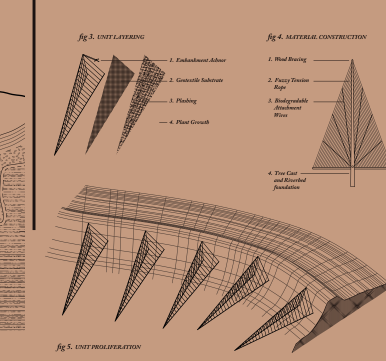


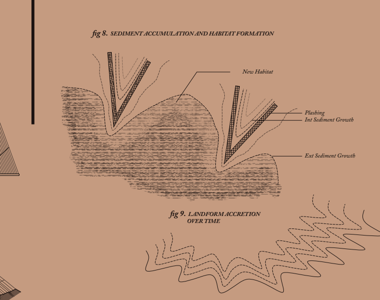




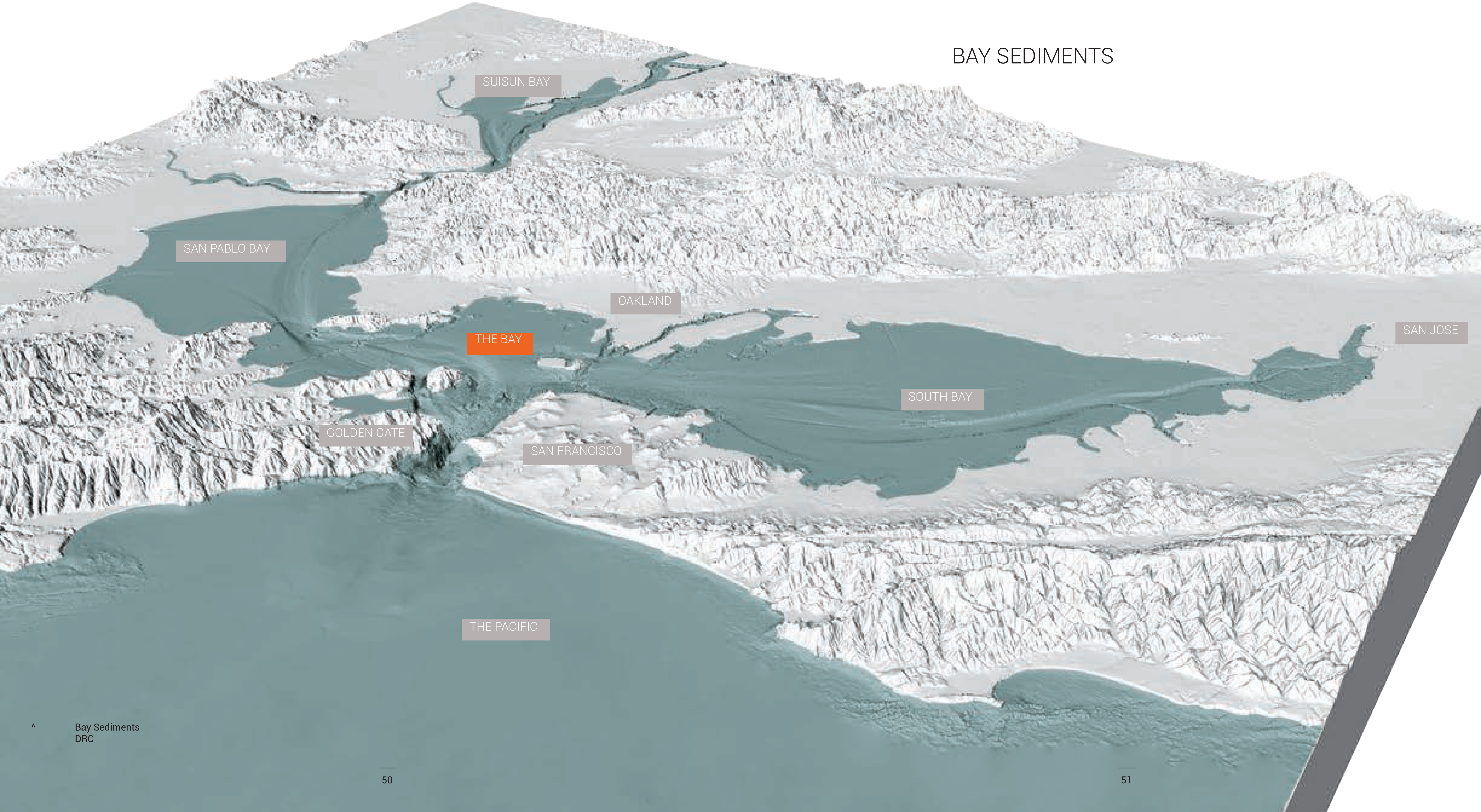




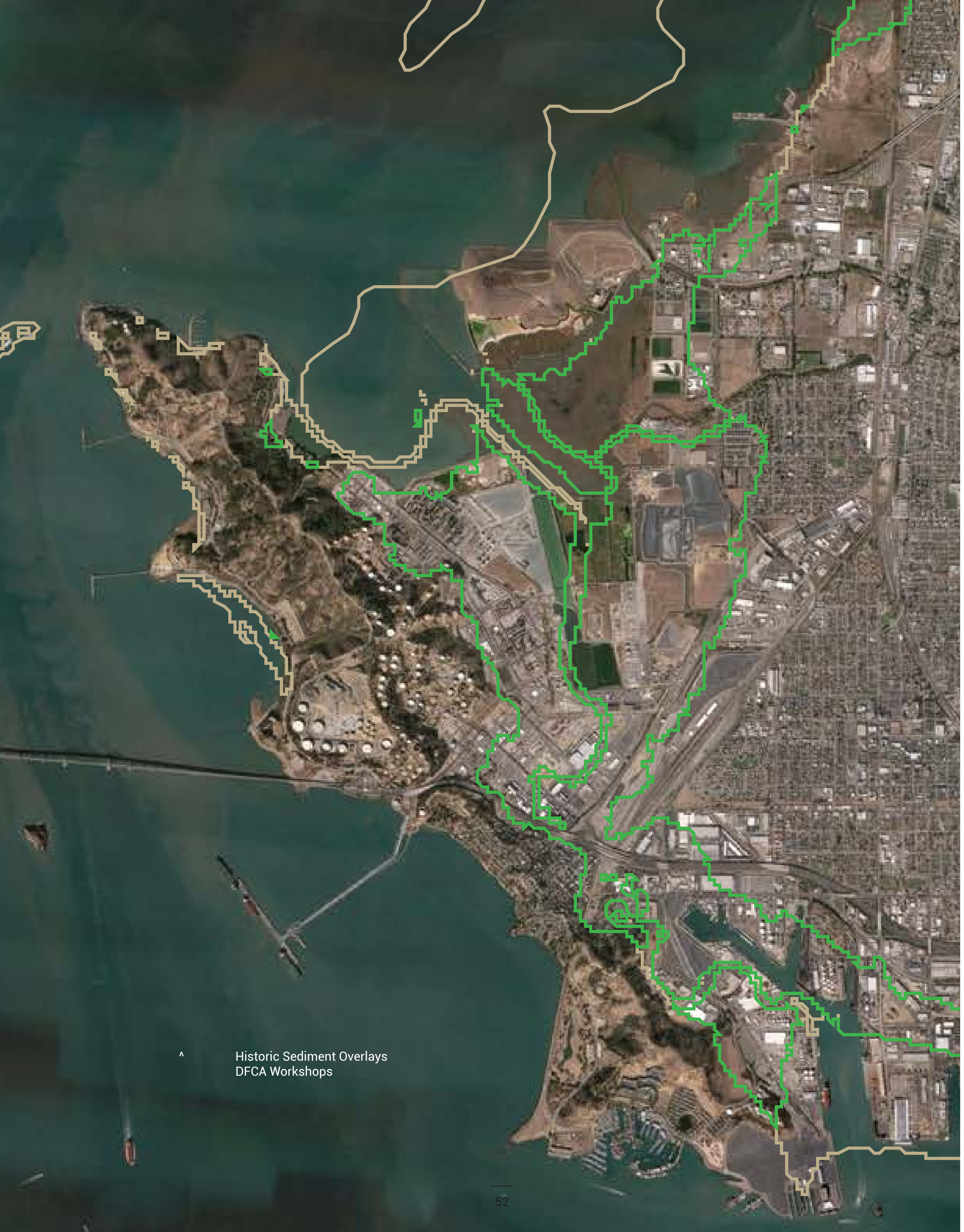




BAY SEDIMENTS



^ Bay Sediments
DRC



^ Historic Sediment Overlays
DFCA Workshops

Bay Sediments

The work of the Bay Sediments track focused on design proposals for bay and coastal management of sediment in the context of adaptation to accelerated sea-level rise, wetland restoration, maritime economies, the cultural landscape heritage of the Bay, and public waterfront access. Geographically, the track focused on the future of the Baylands ecosystem.

"The lands that lie between the maximum and minimum elevations of the tides over multiyear cycles, including those areas that would be covered by the tides in the absence of levees or other unnatural structures. The baylands ecosystem, as defined by the Goals Project, includes the baylands and their adjacent waters and lands, and their associated communities of plants and animals."[1]

San Francisco Bay is faced with the threat of accelerated sea level rise due to climate change. Historically, changes in water level that would have led to drops in elevations of marshlands were offset by the increased sediment load because of the Gold Rush pulse. That pulse is nearly over (it's an asymptotic process). There is a very good overview of the history in Sediment transport in the "San Francisco Bay Coastal System: An overview."[2]

San Francisco Bay is a much more comprehensively studied and planned situation than many other estuaries. At the high level, the 1999 Baylands Ecosystem Habitat Goals and the 2015 Science Update act as guiding ecological principles for intervention in the region. Many people understand that sediment projects have the potential to not only satisfy immediate economic needs, like the provision of navigation through channel dredging, but also to create additional long-term value for the cultural, ecological, and economic contexts that they are embedded in. A lot of proposals already exist for creative uses of dredged material. The barriers to beneficial reuse practices are often primarily regulatory, financial, or logistical, rather than a lack of interest or design intent.

The Crisis

"Between 1800 and 1998, 79 percent of tidal marshes (150,000 acres) and 42 percent of tidal flats (21,000 acres) were lost to diking and filling." This causes many serious problems for the users of the Bay. It means a loss of habitat for both native species and game species (bass, waterfowl). It means a loss of wetland buffers that reduce the impacts of storm events, increasing risk to all kinds of residential, industrial, and infrastructural landscapes.

In 1999, the Baylands Ecosystem Habitat Goals recommended restoring tidal marsh from the 40,000 acres at the time to about 95,000 to 105,000 acres in the future.[4] The recommendations call for a diverse mosaic of habitats including:

- Many large patches of tidal marsh connected by corridors to enable the movement of small mammals and marsh-dependent birds.
- Several large complexes of salt ponds managed for shorebirds and waterfowl.
- Extensive areas of managed seasonal ponds.
- Large expanses of managed marsh.
- Continuous corridors of riparian vegetation along the Bay's tributary streams.
- Restored beaches, natural salt ponds, and other unique habitats.
- Intact patches of adjacent habitats including grasslands, seasonal wetlands, and forests.[5]

In the intervening years, the situations has only gotten more complex. The Baylands Ecosystem Habitat Goals Science Update 2015 puts it like this:

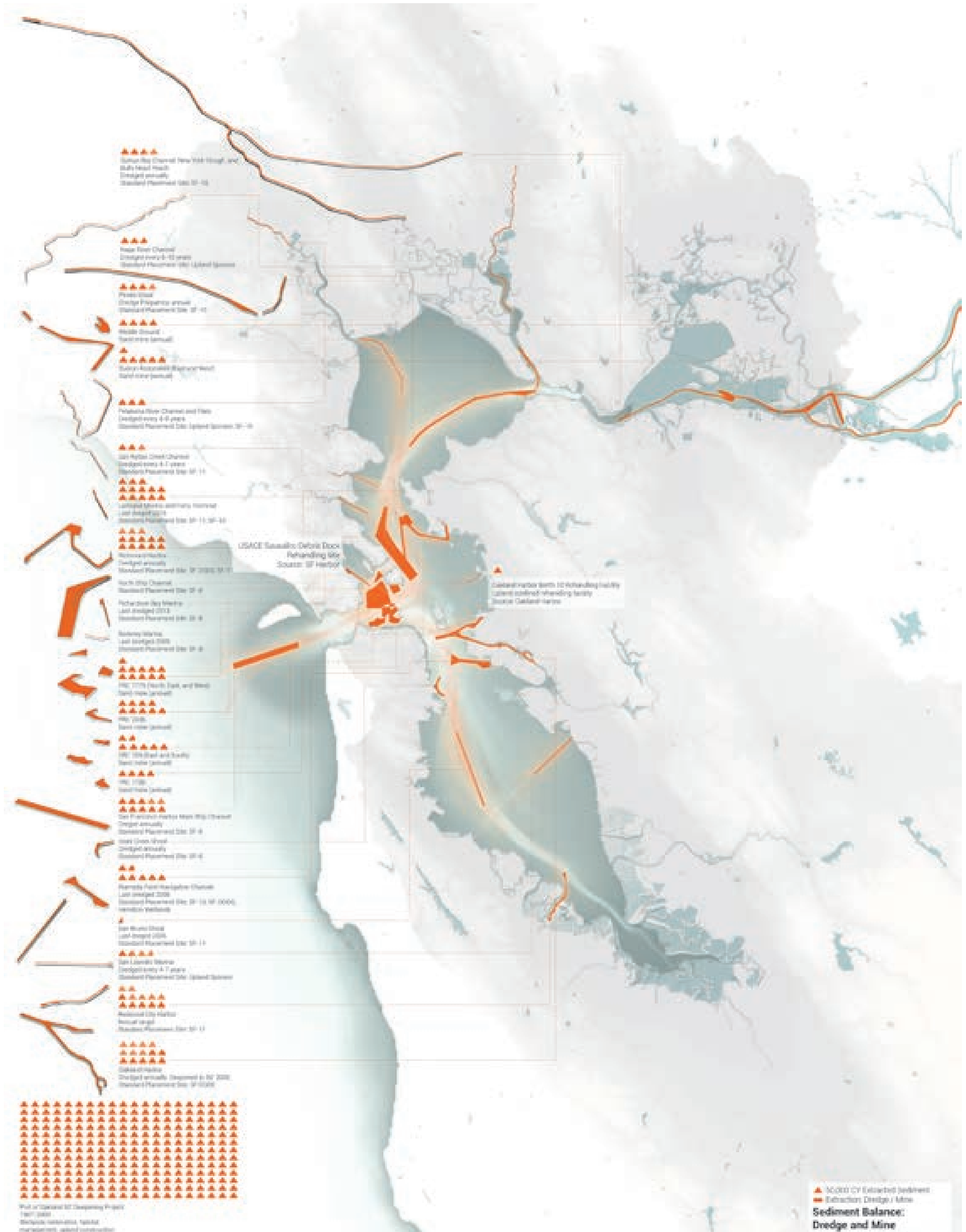
"The sea level is rising, weather patterns are shifting, and the sediment supply that has helped nourish the baylands since the Gold Rush appears to have been exhausted.

…

Projections show that if we don't act, rising seas and greater erosion will cause the baylands to shrink. We would lose the protection these wetlands provide to our shoreline by buffering storm waves, and the cost-effectiveness of a natural infrastructure that adjusts as sea levels rise. The bay would fundamentally change, with hardened edges and little vegetation."[7]

If the wetlands around the Bay can be nourished quickly enough in the short term, the report projects, then they will grow fast enough to keep pace with sea level rise and, though there will be some migration, the wetlands will remain. If the stakeholders do not act, then a feedback cycle of erosion and storm events will strip away all the soft landscapes. All that will be left is seawalls and other hard infrastructure, which is much more fragile and hard to maintain.

But that's just a general overview. Bay wetlands vary significantly in the amount of sediment available to them, based on general location and upstream conditions (i.e. urbanization cutting off or redirecting sediment supply to them). Some marshes will be more prone to persist than others. Some marshes are next to broad, gentle inclines and have plenty of room to migrate—others are up against rban areas, infrastructure or steep slopes with nowhere to go.



There are questions about planning for where wetlands will move into (such as acquiring land), rather than universally trying to counter accelerated sea level rise with diminished sediment (we can't save all of them that way). Knowing this could lead to more sophisticated responses of where to allocate limited supplies of dredge. These could be different scenario factors and design trajectories.

The Challenge

We deployed scenario planning as a method to look beyond the "tunnel" vision of the current moment to explore a broader range of plausible futures for the Bay. For this workshop, we looked fifty years into the future to envision what the Baylands might become and the types of landscapes, ecologies and social conditions they might generate. The Bay is a place of accelerated landscape change, as clearly demonstrated by its recent cultural and environmental history. Fifty years from now the Bay will likely be something very different yet again, regardless of what courses of action are taken.

The question asked of this workshop was what qualities that future Bay might exhibit and how might we act to guide Baylands towards more preferred outcomes, keeping in mind that "preferred" outcomes are inherently situated and political, as the Bay cannot be all things to all stakeholders.

Four scenarios (found in the appendix) were provided to help envision vastly different ways the Bay could plausibly develop between now and 2066, based on different ways drivers of change structuring them could play out. These scenarios are deliberately exploratory rather than normative, meaning they don't describe or privilege preferred futures or define what should be. Rather they attempt to provide a glimpse into vastly different conditions that could be fifty years from today. As such, they provide a platform; a basis for review and discussion of more normative design schemes generated in the workshops.

Design teams in this track were asked to propose innovative strategies for coastal retrofits in the Bay informed by the range of future possibilities presented across four scenarios. Myriad uncertainties facing the Bay's habitats and infrastructure are presented within them, including sea level rise, climate change, regional urbanization, rapid ecological change, and sediment supply.

How each team chose to respond to these scenarios was open-ended and up to them, both in terms of the methods of their design approach and what aspects of the challenge the team decided to focus on. Teams were not locked into any particular scenario. The only requirement was that each team's response address the broad thematic question of the workshop: what could the future of the Baylands be? This question includes not only in the design of processes of accretion and ecological function, but also related matters such as the role of Baylands in the Bay's maritime economy, the cultural landscape heritage of the Bay, and public waterfront access. How do you act now to affect what the Baylands might be in the future?

< Bay Sediment Extraction
DRC

Notes:

1. San Francisco Bay Area Wetlands Ecosystem Goals Project, The Baylands and Climate Change: What We Can Do - Baylands Ecosystem Habitat Goals Science Update 2015, 2015

2. Barnard PL, Schoellhamer DH, Jaffe BE, McKee LJ, Sediment transport in the San Francisco Bay Coastal System: An overview, 2013

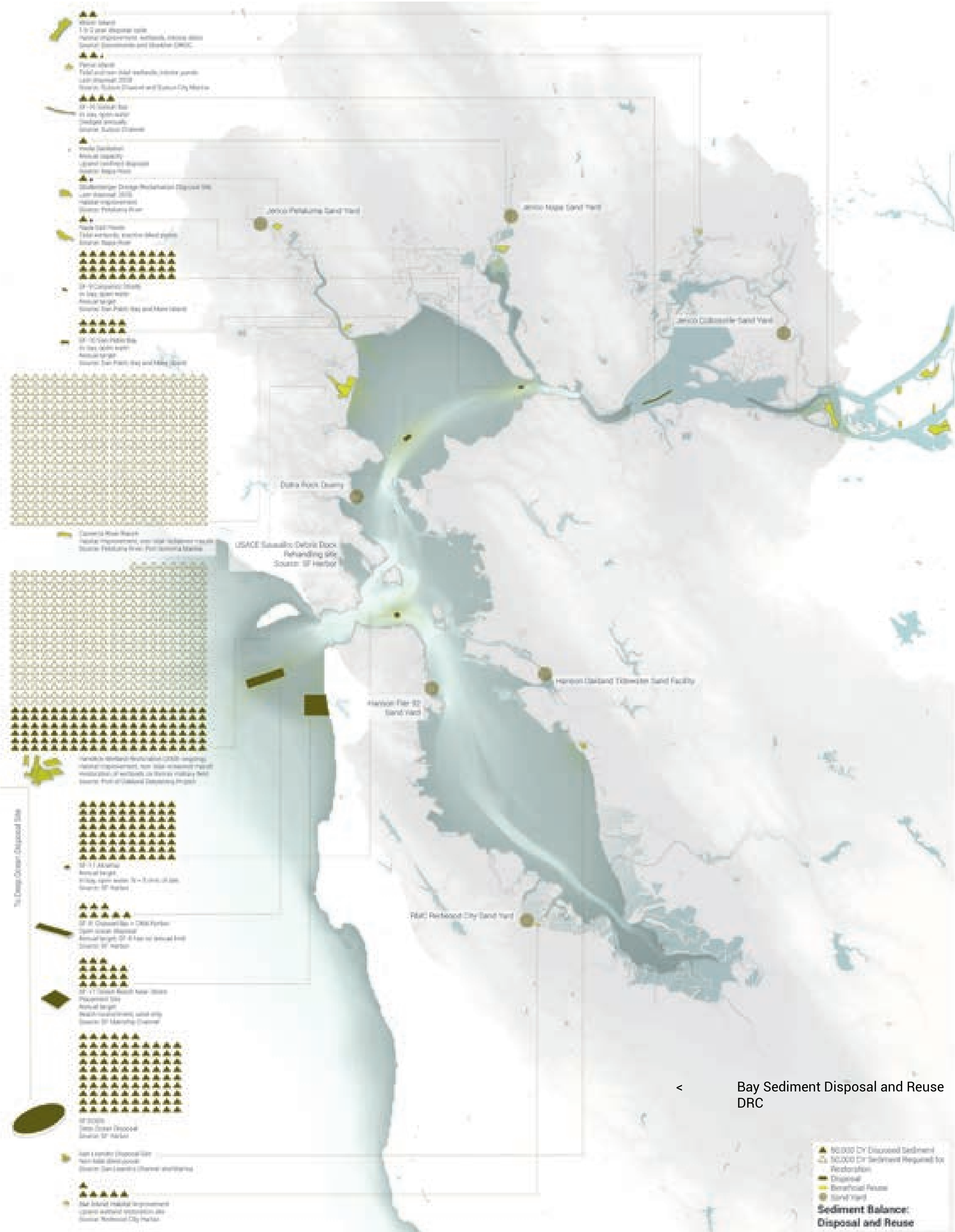
3. San Francisco Bay Area Wetlands Ecosystem Goals Project, The Baylands and Climate Change: What We Can Do - Baylands Ecosystem Habitat Goals Science Update 2015, 2015

4. Monroe M, Olofson PR, Collins JN, Grossinger RM, Haltiner J, Wilcox C, Baylands Ecosystem Habitat Goals, 1999

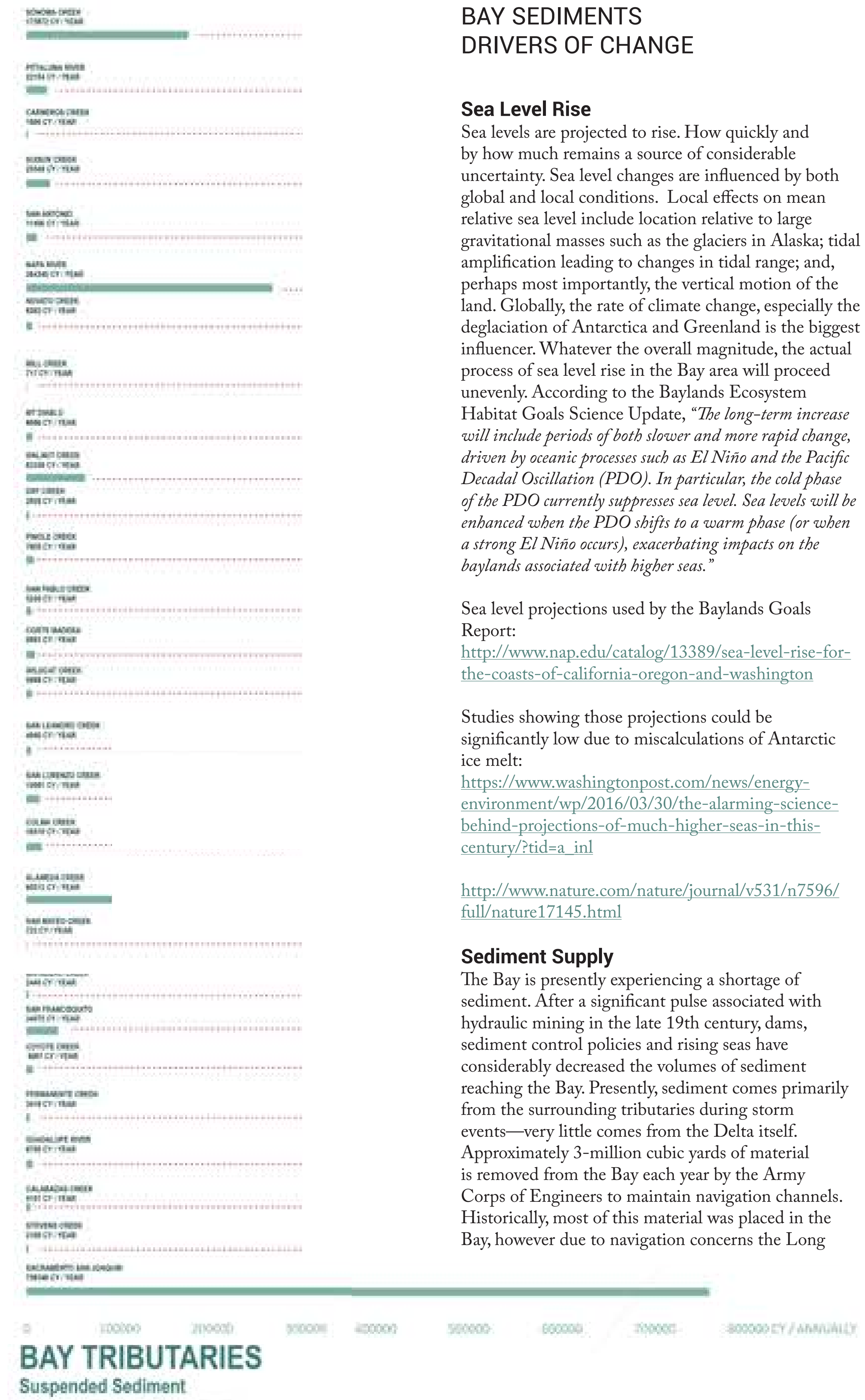
5. Ibid

6. San Francisco Bay Area Wetlands Ecosystem Goals Project, The Baylands and Climate Change: What We Can Do - Baylands Ecosystem Habitat Goals Science Update 2015, 2015

7. Ibid



< Bay Sediment Disposal and Reuse
DRC



BAY SEDIMENTS
DRIVERS OF CHANGE

Sea Level Rise

Sea levels are projected to rise. How quickly and by how much remains a source of considerable uncertainty. Sea level changes are influenced by both global and local conditions. Local effects on mean relative sea level include location relative to large gravitational masses such as the glaciers in Alaska; tidal amplification leading to changes in tidal range; and, perhaps most importantly, the vertical motion of the land. Globally, the rate of climate change, especially the deglaciation of Antarctica and Greenland is the biggest influencer. Whatever the overall magnitude, the actual process of sea level rise in the Bay area will proceed unevenly. According to the Baylands Ecosystem Habitat Goals Science Update, *"The long-term increase will include periods of both slower and more rapid change, driven by oceanic processes such as El Niño and the Pacific Decadal Oscillation (PDO). In particular, the cold phase of the PDO currently suppresses sea level. Sea levels will be enhanced when the PDO shifts to a warm phase (or when a strong El Niño occurs), exacerbating impacts on the baylands associated with higher seas."*

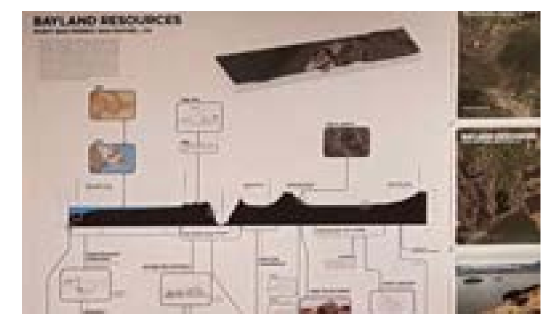
Sea level projections used by the Baylands Goals Report:
http://www.nap.edu/catalog/13389/sea-level-rise-for-the-coasts-of-california-oregon-and-washington

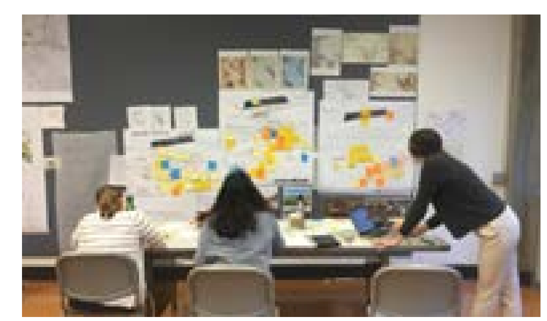
Studies showing those projections could be significantly low due to miscalculations of Antarctic ice melt:
https://www.washingtonpost.com/news/energy-environment/wp/2016/03/30/the-alarming-science-behind-projections-of-much-higher-seas-in-this-century/?tid=a_inl

http://www.nature.com/nature/journal/v531/n7596/full/nature17145.html

Sediment Supply

The Bay is presently experiencing a shortage of sediment. After a significant pulse associated with hydraulic mining in the late 19th century, dams, sediment control policies and rising seas have considerably decreased the volumes of sediment reaching the Bay. Presently, sediment comes primarily from the surrounding tributaries during storm events—very little comes from the Delta itself. Approximately 3-million cubic yards of material is removed from the Bay each year by the Army Corps of Engineers to maintain navigation channels. Historically, most of this material was placed in the Bay, however due to navigation concerns the Long





< Bay Sediment Workshop
DRC

Term Sediment Management plan now requires larger volumes to be placed in the open sea (about 50% of it). This material could easily be used for in-bay marsh creation or other projects. The re-working of tributaries feeding the Bay (such as removal of levees to reconnect tributaries with the marsh plain) could be another possible sediment source, as could removing sediment from behind the dams in the Delta, or large regional excavation/mining projects. At present, few of these projects have begun or are under serious consideration, as the Bay faces it largest sediment deficit in over 200 years.

It is this sediment that is necessary for the continued development and building of the tidal marshes around the Bay. These marshes and mudflats protect upland areas by reducing storm surge while also providing valuable and vanishing habitat. Sediment inputs are a key component to the health and well-being of both human and non-human ecosystems within the Bay Area.

Podcasts on the sediment situation in the SF Bay:
http://yourwetlands.org/podcasts.php#floodcontrol20whatrolesediment

Development/Investment

Refers to the level of investment in the Bay, as a shorthand for the general amount of resources available to enact local policy agendas, whatever their flavor. Where Sea Level Rise and Sediment Supply represent external factors that happen to the Bay, Development/Investment reflects the ability of Bay stakeholders to respond the situation and shape their destiny. Investment can take many forms. In the case of these scenarios, increased investment and development pressures tend to correlate with growth in human population around the Bay. More people generally represents additional increases in tax revenue from both property and industrial development and more popular pressure to enact change in one way or another. As a timely example, Measure AA is a $12-per-year parcel tax passed on a 2016 ballot that is projected to generate $500 million over 20 years for critical tidal marsh restoration projects around San Francisco Bay.

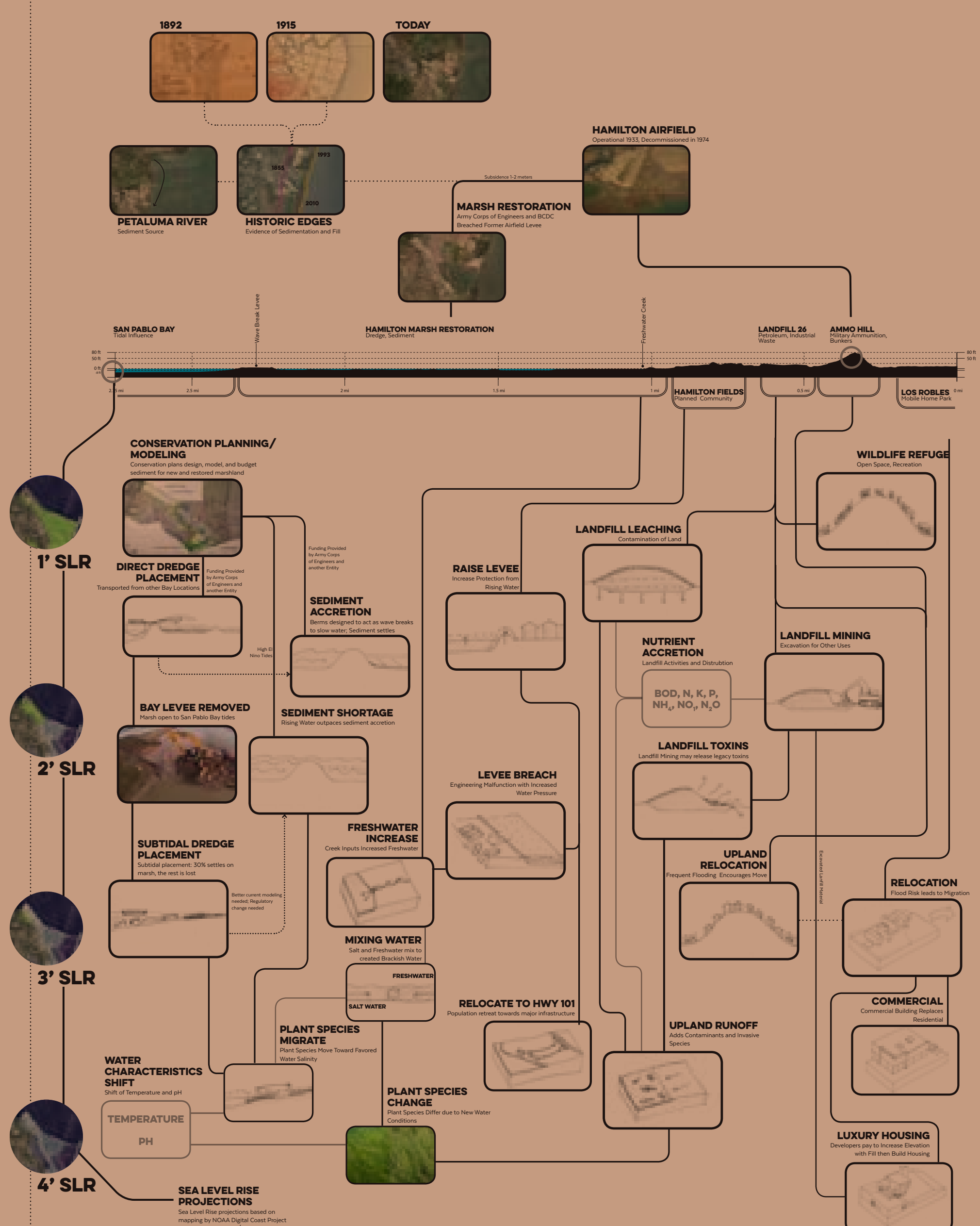
Projections assume that the Bay area could grow at a rate of over 80,000 residents per year over the next 25 years but California is no stranger to large migrations and depending on economic and environmental conditions, everything from a population explosion to a climate refugee crisis are imaginable.

http://votersedge.org/ca/en/ballot/election/area/39/measures/measure/1975?election_authority_id=49

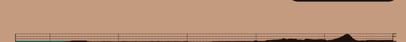
Nicholas Pevzner, Steph Carlisle, Meg Studer, Paige Courtney, Jinhee Ha, Kate Lenahan

BAYLAND RESTORATION
HAMILTON AIRFIELD: NOVATO, CA

Hamilton is located off the shore of San Pablo Bay in the city of Novato, California. This site is first characterized by its in-progress marsh restoration project in the location of the former Hamilton Airfield. The Hamilton Airfield was considered "surplus" and decommissioned in 1974. The former site included an airstrip, landfill, ammunition storage bunkers, and hangars. It is surrounded by relatively low-lying mixed income housing immediately adjacent to the restoration site. Since the levee breach upon completion of the restoration project, the wetland area has been accreting sediment via tidal inflow from San Pablo Bay.



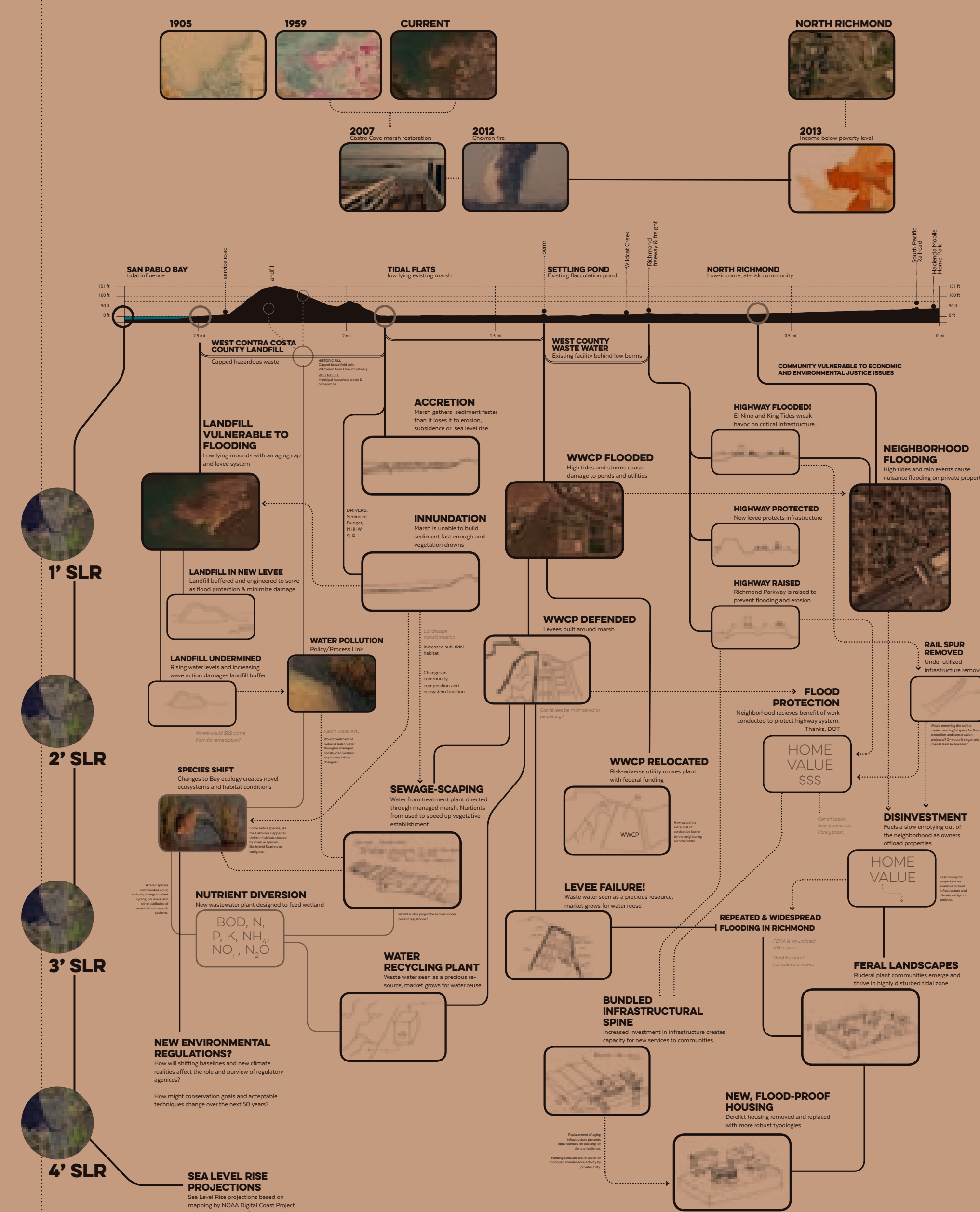
NOTES/COMMENTS/KEY FACTOIDS



BAYLAND INDUSTRY
NORTH RICHMOND + CASTRO COVE: RICHMOND, CA

North Richmond and Castro Cove are low-lying areas susceptible to flooding and saltwater intrusion, industrial contamination, and infrastructural impairment. Future changes on this site will call into question what assets require protection, and who ultimately is responsible for this work. Industry, infrastructure, communities and private devleopment are woven together in a fabric of interdependency, though values and priorities may differ dramaticly.

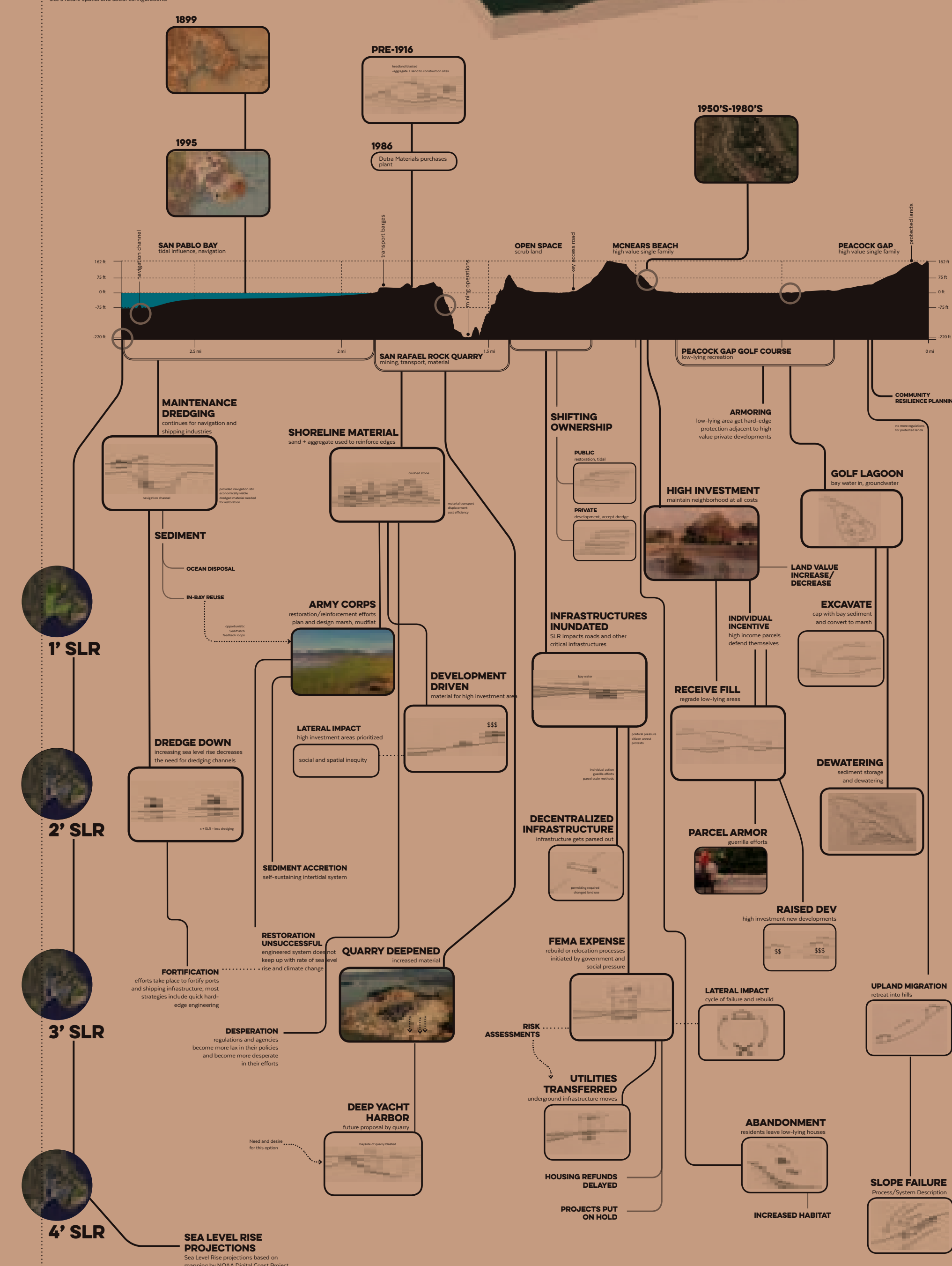
South of San Pablo Bay, industry has created two edges: first, the shoreline around Castro Cove, and second, the urban edge in North Richmond. Alongside other industrial usses, the Chevron oil refinery began construction in 1901, infringing upon the historic tidal flat at Castro Cove. By mid-century, the West Contra Costa County landfill had extended the shoreline into subtidal habitat to the west, and West County Wastewater had established a treatment plant to service the county's growing populations to the east. North Richmond has been saddled with the double burden of environmental pollution and social inequality. Over the 20th century, Chevron and other industrial facilities were found to have discharged hazardous substances into the cove, initiating a cleanup in 1987. Contaminated sediments were excavated and capped, restoring the tidal flat between the boundaries of the landfill and wastewater plant.



NOTES/COMMENTS/KEY FACTOIDS

BAYLAND RESOURCES
POINT SAN PEDRO: SAN RAFAEL, CA

Point San Pedro in San Rafael, California is a mix of elevated industrial lands and low-lying areas, which house high value residential development and recreation. If the last hundred years of site development were largely driven by the accumulation of capital through resource extraction and land development, the next hundred years will likely be concerned with the preservation of these assets. Future changes in San Rafael will continue to bring multiple constituencies into confrontation or collaboration, including neighborhoods, land owners, industry and a variety of local, state and federal agencies charged with maintaining key infrastructure. Availabilty of resources and their distribution, as well as investment prioritization, will contribute to the site's future spatial and social configurations.



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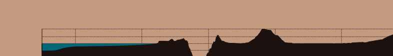
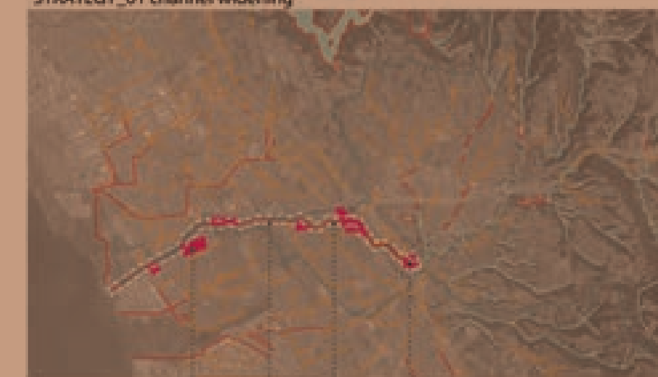


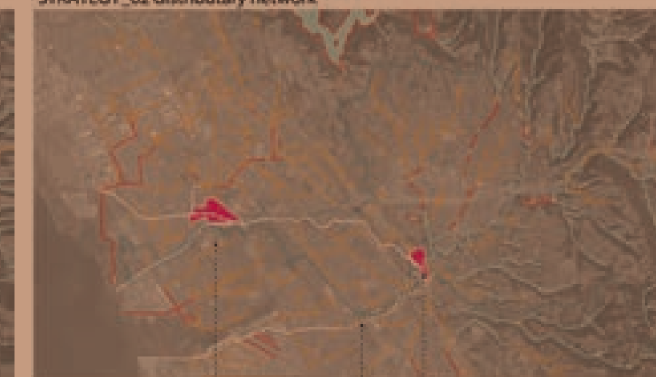
BAY SEDIMENTS / WORKSHOP RESULTS

Gena Wirth, Brennan Cox, Kate Granlund, Jamie Phillips, Nico Wright

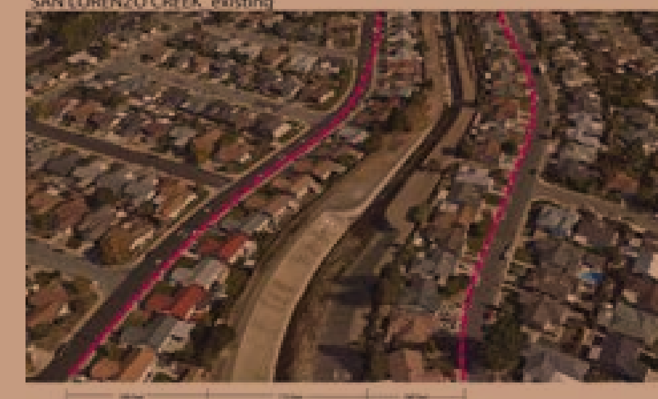
STRATEGY_01 channel widening



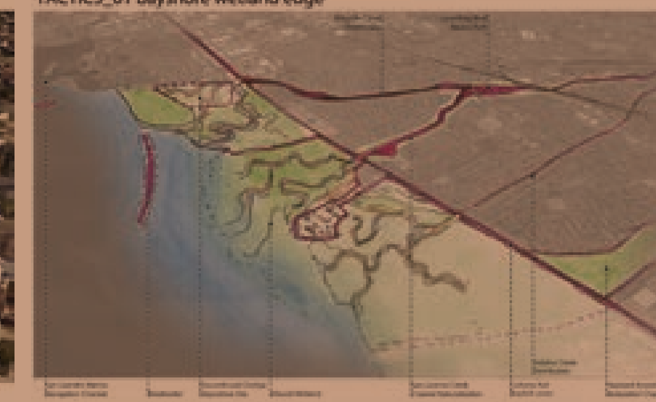
STRATEGY_02 distributary network

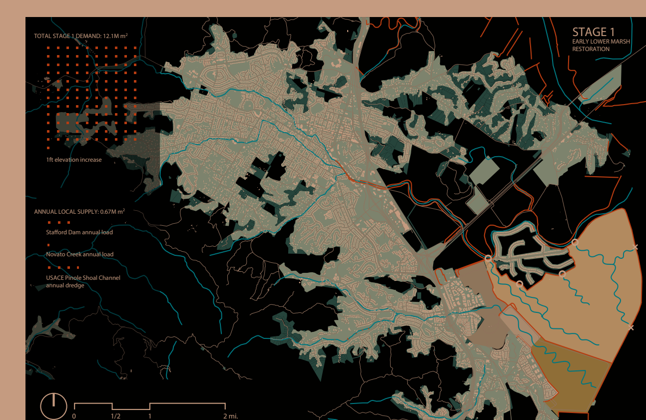


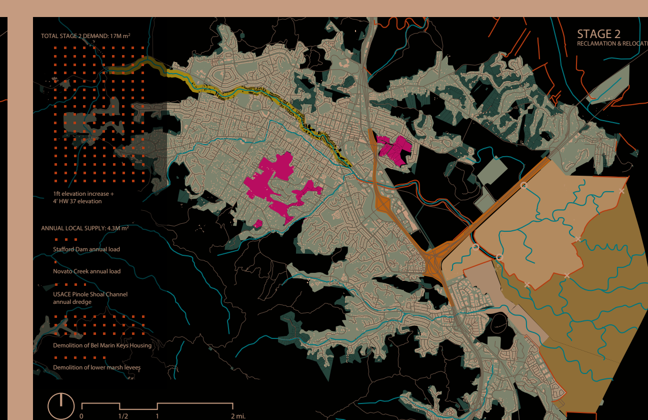
SAN LORENZO CREEK_existing

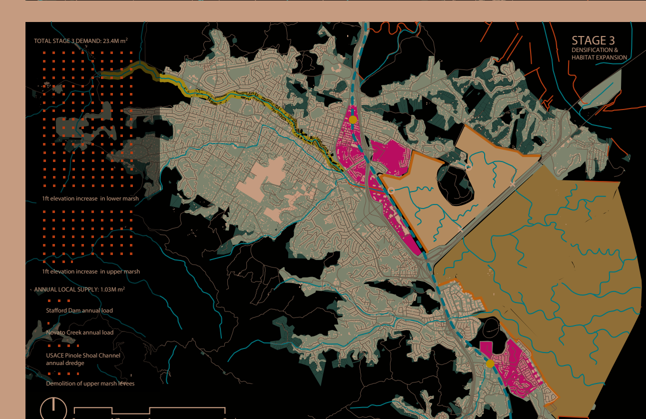


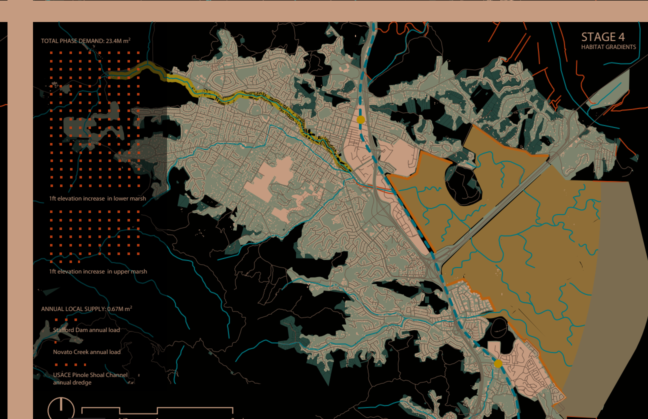
TACTICS_01 bayshore wetland edge











DredgeFest California

KEY FINDINGS

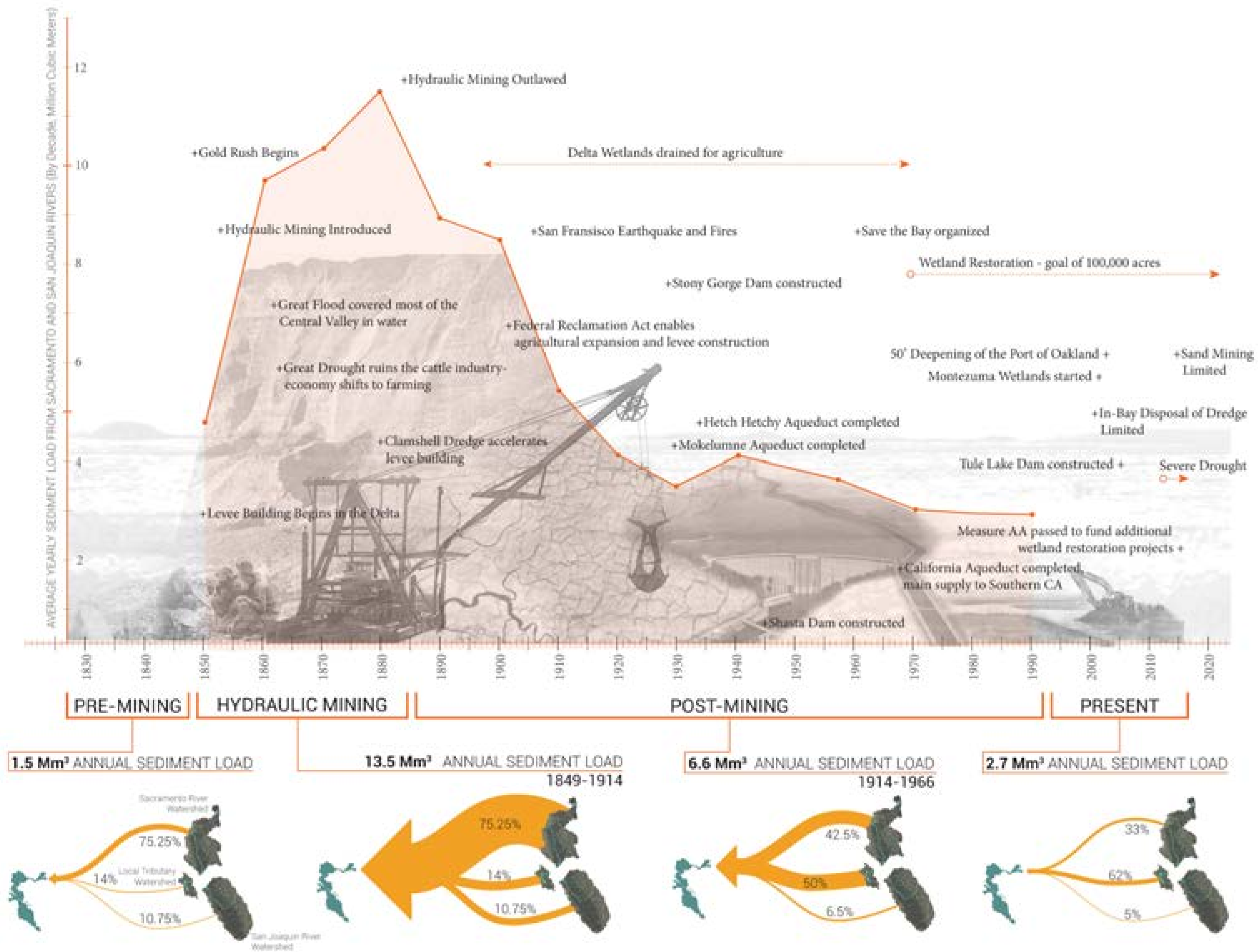
The following findings and recommendations have been synthesized from the work done by the design teams in the workshops, discussions with many different experts, our two days in the field with the DredgeFest California tours, and the background research conducted by the Dredge Research Collaborative before and after DredgeFest California.

1 RECOGNIZE AND QUANITFY THE SEDIMENT SHORTFALL

At a general level, the past 150 years of human impact on sediment flows in the Bay-Delta is well documented. First, hydraulic gold mining and settlement-driven clearcutting sent an unprecedented pulse of sediment into the Bay-Delta. Then, multiple dams throughout the upland portions of the watershed began to capture sediment while a variety of other infrastructures, such as levees and storm channels, redirected sediments away from where they are needed. Today, rising sea levels threaten to wash away vulnerable wetlands and breach critical levees.

According to some estimates, the Bay's coastal wetlands could require as much as 200 million cubic yards of sediment over the next 15 years to effectively restore them to established Baylands ecosystem goals, and this projection does not even account for the ongoing and longer-term need for sediment to maintain marsh elevations with respect to sea level rise. This need stands in sharp contrast to the amount of sediment flowing into the Bay-Delta today. Where and how sediment enters the Bay-Delta has also radically changed. Currently only an estimated 40% of sediment comes to the Bay via the Delta and its massive watershed, down from an estimated 80-90% in the past. 60% now flows into the Bay from local tributaries.

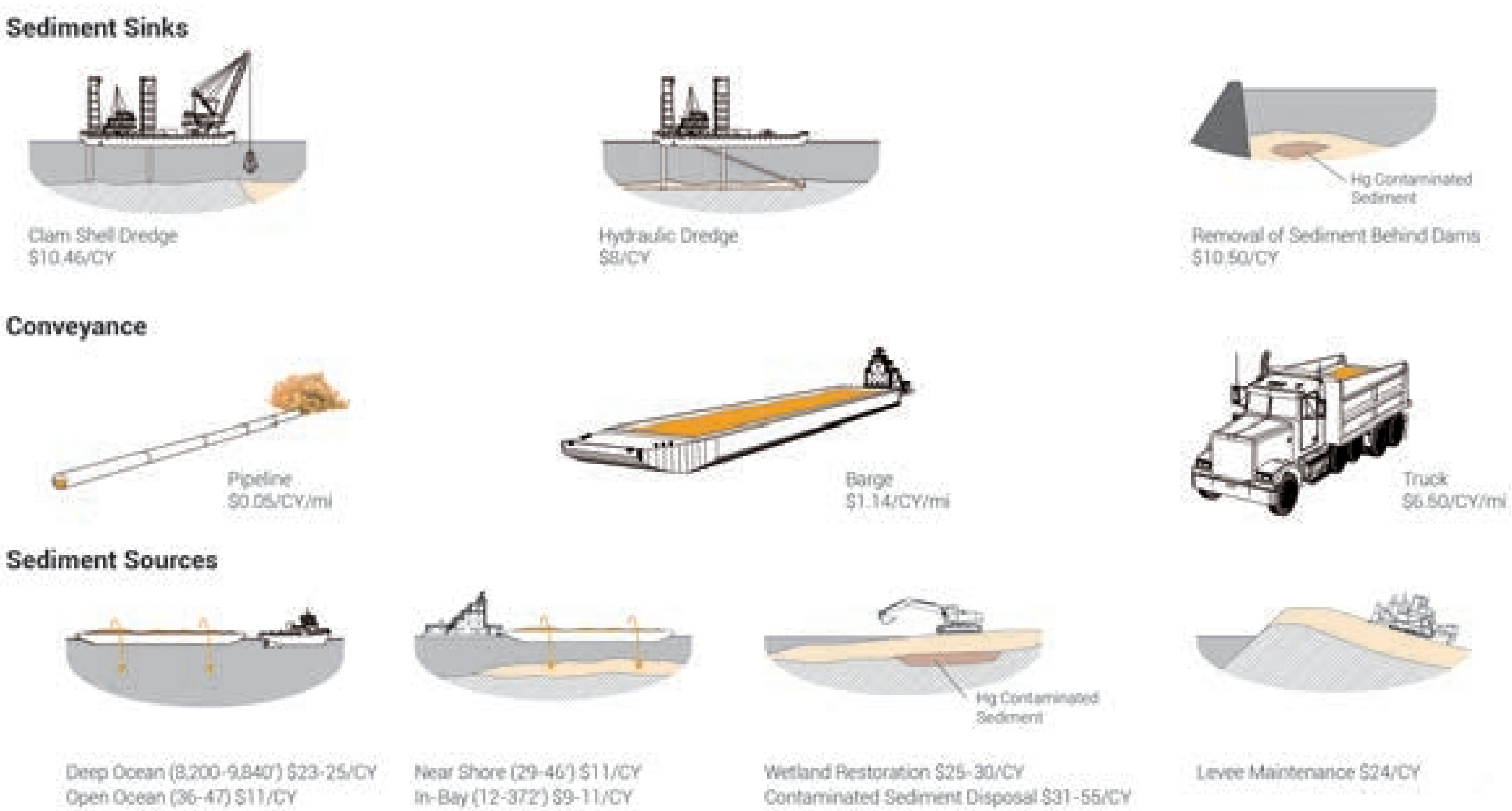
But these are only estimates. The Bay-Delta needs an accurate sediment budget that can account for the highly variable flows of material. Where does it come from and where does it end up? Wider recognition that there is a big problem will help drive efforts to more comprehensively document the situation, which will in turn help us better understand not only how big and urgent the problem really is, but precisely what its contours are.

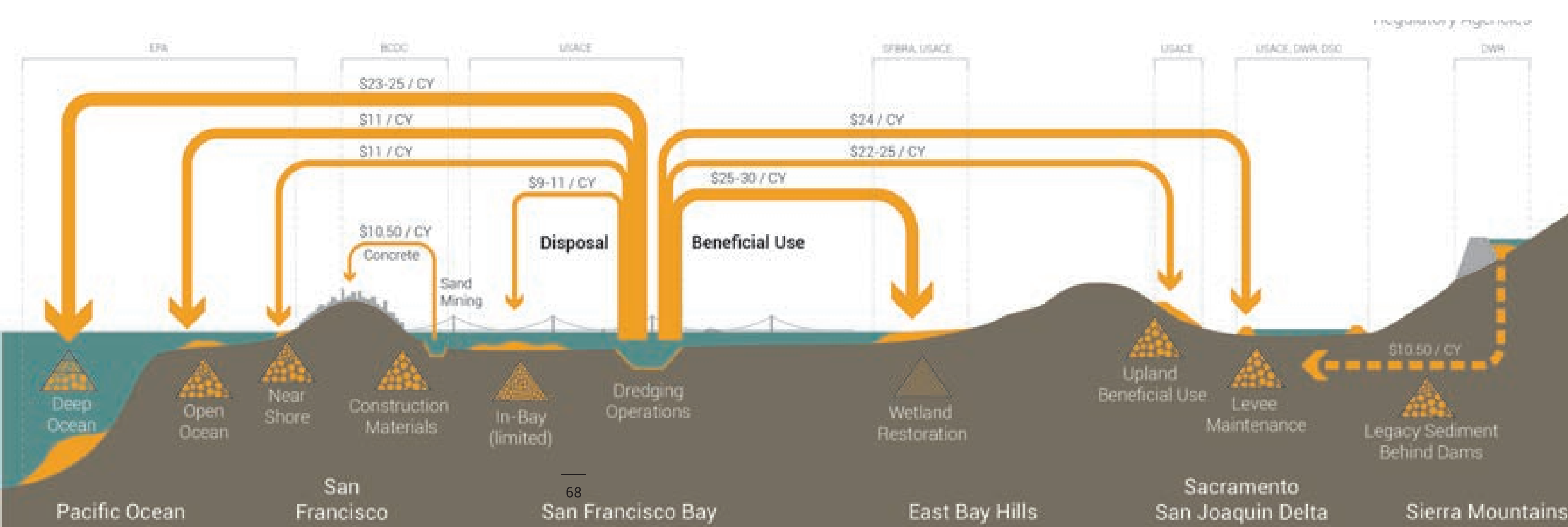


Sediment sources and sinks of the San Francisco Bay watershed have been dramatically altered over time and the Bay's exact sediment budget, as currently understood, has many unknowns. This graph uses two primary sources* to highlight trends in sediment loading in the bay over time. Hydraulic mining resulted in a huge surplus of sediment in the watershed, in contrast to today, where we face a deficit due to sediment being trapped upstream by dams. In recent history (roughly the past 60 years), small bay tributaries have come to provide more sediment to the bay than what comes from the much larger San Joaquin and Sacramento watersheds. Sediment loading estimates have a margin of error of up to 50%, and thus total sediment loading today is within the realm of what it is was prior to the mining and reclamation era. / DRC

*Barnard, P.L., Schoellhamer, D.H., Jaffe, B.E. and McKee, L.J., 2013. Sediment transport in the San Francisco Bay coastal system: an overview. Marine Geology, 345, pp.3-17.

*McKee, L.J., Lewicki, M., Schoellhamer, D.H. and Ganju, N.K., 2013. Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. Marine Geology, 345, pp.47-62.





2 VALUE SEDIMENT

For the past 150 years dredged material was generally treated as spoils—a waste product to be disposed of. Today, more people, companies, and agencies understand that this material is a valuable resource.

But dredging economies, policy regimens, and market incentives have yet to fully adapt to the new valuation of sediment and dredged materials in light of the shortfall, restoration imperatives, and sea level rise adaptation. Despite growing recognition that sediment is critical to protecting and nourishing shorelines, sediment is still not valuable enough to 'move twice'. No cost-effective mechanism for storing and retrieving sediment has been developed. So if it is to be used beneficially, it generally must be used when it is dredged. This demands coordination across projects, and whether sediment gets used or lost is often up to accidents of history. Was this restoration project approved in time to take sediment from that dredging job? Was supplemental funding available at the crucial moment? Regulations designed to protect habitat in the Bay have previously prevented sediment from being placed in open water, even if it may ultimately lead to wetland and aquatic ecosystem benefit. The "Federal Standard" requires that the USACE use the cheapest disposal option that meets applicable federal environmental regulations. This results in hundreds of cubic yards being sent out to sea to be dumped by barge at a designated offshore disposal site. Consequently, a great deal of available sediment in the Bay-Delta system is not re-used or applied to maximal benefit. In 2013, more than half of dredged sediment was lost in this way—and even more was lost to hardened shorelines and waterways that sluice sediment-rich flows out to open water or trap them behind reservoir dams.

Policy and markets must catch up to reality. Sediment must be recognized and valued as a crucial and limited resource, and steps must be taken to redesign both rules and landforms to better capture and make use of that value.

Sediment is valued, administered and handled according to its geophysical qualities, its location, and regulatory and market forces. It can perceived of as waste that must be properly disposed of and/or a resource that can be beneficially used. / DRC

3 TREAT SEDIMENT AS CRITICAL INFRASTRUCTURE

California is not alone in increasingly valuing sediment. This shift is in line with a broader national trend, as the importance of sediment is increasingly recognized in regions as diverse as the Great Lakes and the Mississippi River Delta. This is not only as a result of shortfalls, but also because the landscapes that depend on sediment, such as shorelines, beaches, and wetlands, are increasingly valued, and the importance of sediment supply for sustaining them is increasingly well understood.

Sediments are always part of larger ecosystems composed of biotic and abiotic materials. In these ecosystems, sediment is an essential component of—and substrate for—many critical ecological processes, particularly at land-water interfaces. California's water infrastructure, the Delta's reclaimed farmlands and restored tidal marshes, Oakland's port, the South Bay's salt ponds, the Don Edwards National Wildlife Refuge, and countless living and working communities are all built or dependent on the movement, management and sculpting of sediments.

Today, the landscapes that rely on sediment as infrastructure are growing in importance because they paradoxically are both particularly vulnerable to and especially critical for dealing with one of the most pressing issues of the 21st century: the consequences of climate change, particularly sea level rise. These landscapes have been made vulnerable due the ways in which we have confined them and reduced their sediment supply.

Unlike the critical infrastructures of previous generations of design—dams, levees, channels, and so on—intentional sedimentary infrastructure is capable of aggregating, expanding, and adapting to novel conditions. This flexibility will be needed as we seek to adapt to and mitigate anthropogenically-accelerated change. The crucial infrastructural role of sediments in the future of the Bay-Delta needs to be recognized and incorporated into policy and planning at all levels. It must also guide the valuation of sediment.

CASE STUDY // HAMILTON WETLANDS RESTORATION.

Between 2008 and 2013, approximately 6 million cubic yards of sediment were piped from the Port of Oakland's Harbor Deepening Project onto this 2,600 acre site. Previously farmland and a military airfield, the land subsided over time, requiring the addition of dredge to amend the site to current marsh elevations in the bay. The restoration required its own substation to power, and consumed 8 million gallons of water a day to slurry material through the pipeline. The final design includes a wildlife corridor with maximized transition zone, as well as seasonal and tidal wetland zones.

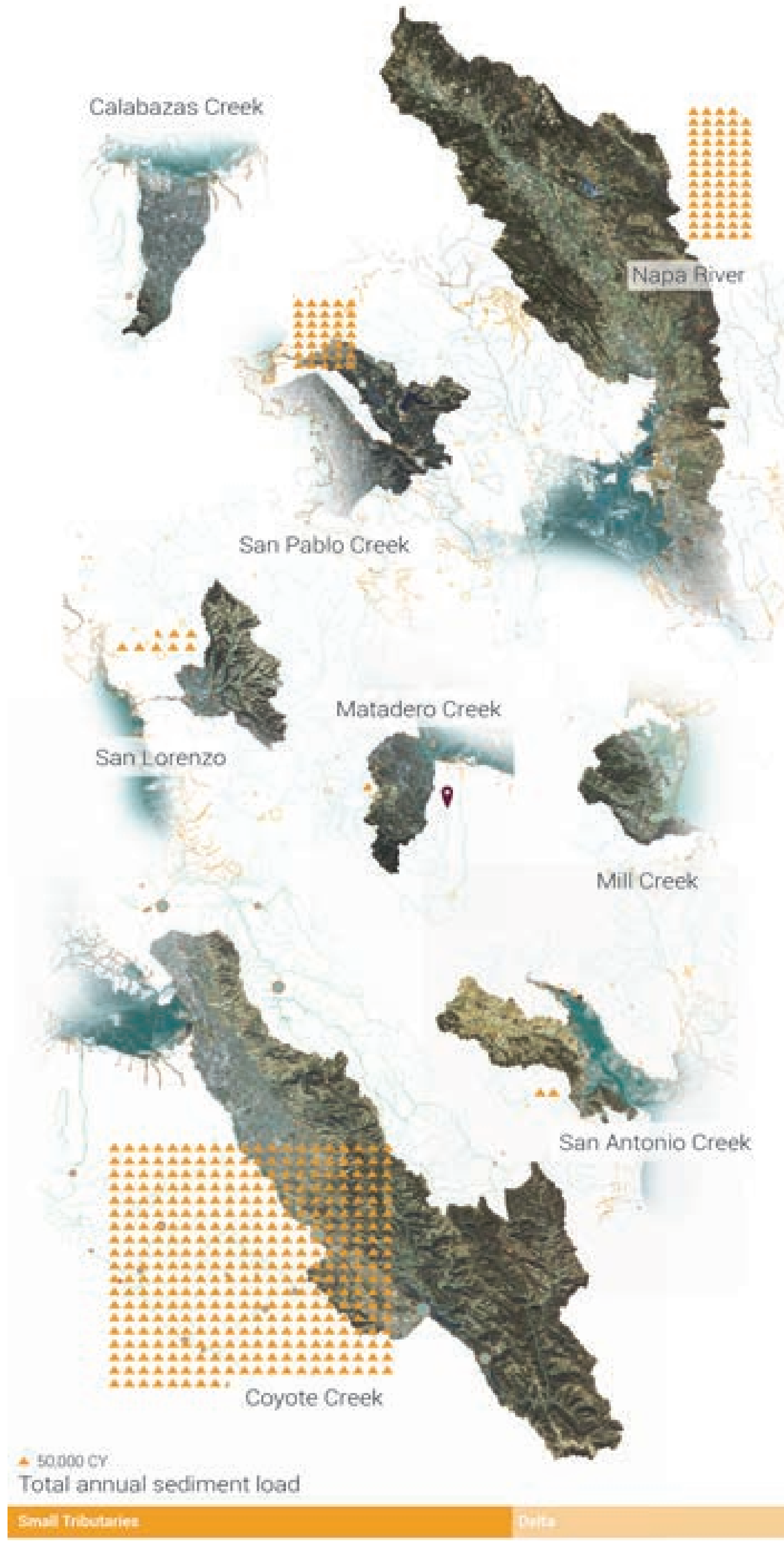
4

CONSIDER SEDIMENTSHEDS

We commonly use the physiographic units of watersheds and subwatersheds in design, environmental planning, and engineering disciplines as an effective way to structure our efforts according to hydrological patterns and processes. We need to do the same for sediment.

Watersheds nest in scale, beginning with local creeks and streams and aggregating into larger units involving whole river systems and their basins. Generally, a sedimentshed is co-extensive with the associated watershed, insofar as both are primarily determined by topography. However, infrastructures may alter the effective extent of either, sometimes causing them to diverge. For instance, landforms like dams and bank armor might effectively cut a region out of the sedimentshed while still allowing water to flow.

Considering the sedimentshed of the San Francisco Bay should begin with the the local tributaries of the Bay that now provide over half of all the sediment entering it, and then expand outward to include the entire basin that feeds into the Bay-Delta, stretching east to the Sierras, north to Oregon, and south into the Central Valley. Sediment design and management should span these scales. Studies, thinking, and plans that account for only a portion of the sedimentshed risk making decisions that benefit that portion at the expense of the whole, or missing opportunities and benefits visible only from a broader vantage.



The Bay's tributaries—small but numerous—are now known to account for the majority of the total annual sediment load (Barnard 2013). Subject to diverse conditions of social context, land use, and ecology, through careful management they exhibit significant potential to help meet sediment demand in the years to come. / DRC

$7.4 B to dredge sediment // **43 year** supply for the bay

$180 M to dredge sediment // **1 year** supply for the bay

$345 M to dredge sediment // **2 year** supply for the bay

$449 M to dredge sediment // **2.9 year** supply for the bay

$557 M to dredge sediment // **3.2 year** supply for the bay

$82 M to dredge sediment // **.5 year** supply for the bay

5 DESIGN HOLISTIC SEDIMENT SYSTEMS

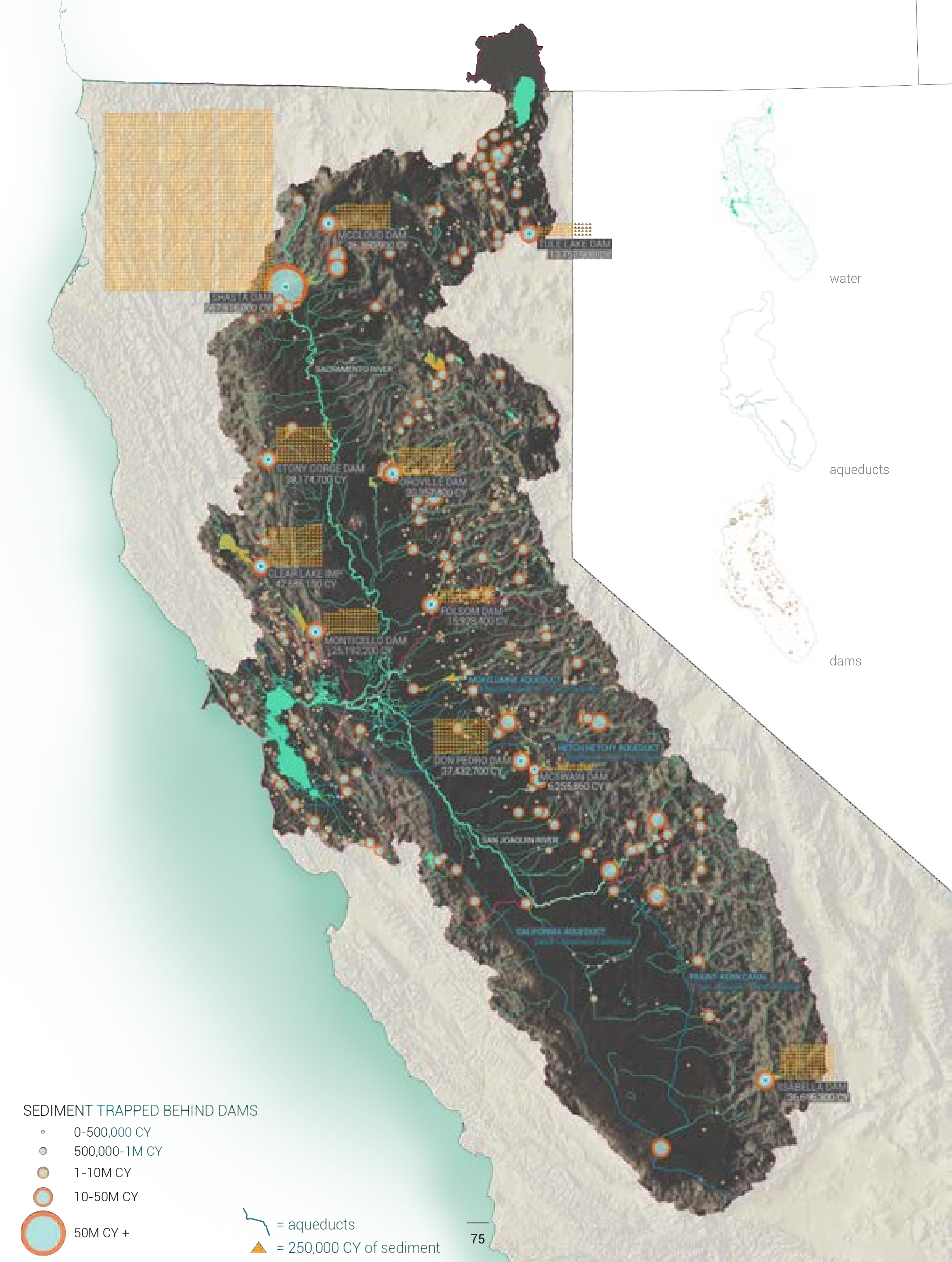
Dredging is a key part of a larger group of technologies, actions, and practices that speed up and slow down the movement of sediments. Like the flow of water, the flow of sediment has been dramatically altered by human action over time. Dams, river canalization, agricultural development, and upstream urbanization have all modified both flows in tandem. By considering the entire sedimentshed, it becomes clear that elements of this network not ordinarily considered to be part of sediment management must be taken into account.

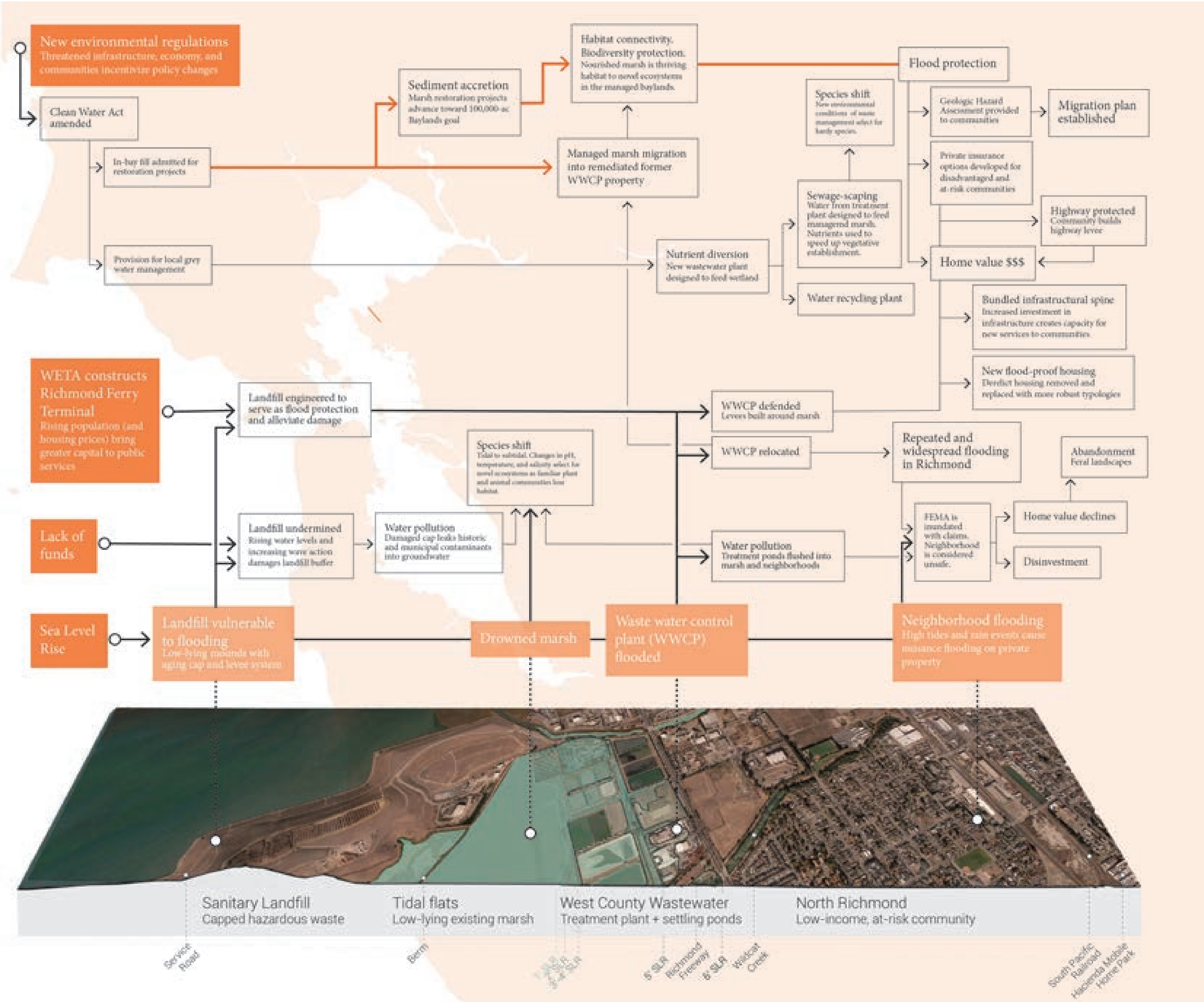
In particular, sediment and water must be considered together, systemically and holistically. Dams, which are constructed to control floods, create power, and supply communities with fresh water, have the unintended effect of trapping sediment. Levees that control floodwaters also often separate wetlands from the waterbodies that provide them with sediment. Arroyos and stream paths that once held and moved sediment have been converted to concrete-lined flood control channels, designed to whisk dangerous flood waters away from adjacent communities as fast as possible. The alteration of the Delta to serve as a switching station for water being diverted to central and southern California has also radically altered sedimentary processes. The potential future alteration of dams to increase sediment supply to the Bay-Delta could have major effects on water supply. Such examples show the limited function of systems designed to accommodate water alone. Infrastructure can and should be designed to jointly accommodate the distribution of these critical resources.

The fragmentation of regulatory and planning authority over these realms—water, sediment, ecology, infrastructure, human settlement—is a significant barrier to holistic design. It is important to conduct further research into opportunities to prevent siloing and integrate decision-making.

The dams in the regional sediment shed trap sediment, which reduces the reservoir capacity and takes the sediment out of the natural flow to the Bay. This sediment has the potential to meet the sediment needs of the Bay, but raises issues of transportation, contamination, and remediation.

The regional sediment shed contains natural water systems of the Sacramento and San Joaquin rivers, and man-made water conveyance infrastructure (irrigation and drinking water) that have been heavily altered by humans and changed the sediment flows to the Bay. / DRC





6 DESIGN FOR LOCAL CONDITIONS, DESIGN FOR CHANGE

The amount of sediment available to the Bay-Delta is inadequate, but this regional problem risks masking a network of local conditions that must be considered with care and precision. The edge conditions of the Bay and Delta are highly variable.

Try as we might to hold them in place, banks and shorelines are never static—constantly subject to erosion or accretion. Even armored edge conditions must be reinforced and rebuilt. As these facts are increasingly recognized, the predominance of hard, static engineering solutions is ending as we attempt to better design with dynamic environments.

Doing this requires an intimate understanding of local conditions. Some shorelines might migrate relatively easily, where others are constrained by geography, history, and nearby land use. In some places, shorelines might tend to accrete where we'd prefer them to erode. In other places, shorelines tend to erode, where we'd prefer that they accrete (given sea level rise and the sediment shortfall, the Bay-Delta has far more of these).

What makes a given stretch of land valuable? When might improvements be made through small interventions? What major works are called for? What happens if nothing is done? How does it relate to neighbouring tracts both along the shore and upland? How might changes here cascade and radiate out to affect the region as a whole? How might changes elsewhere impact conditions here?

These questions and more must be asked and answered, over and over again, section by section in recognition that the variability of local conditions and the innately dynamic nature of the coast both demand a diverse, flexibly-deployed toolkit of new infrastructures, operations, and practices.

In light of the complexity and plurality of the bay's edge conditions, local decisions about value—of infrastructure, ecology, economy, and community—will determine where the future shoreline may fall. These decisions may be dynamic, feeding into one another, as ecological and infrastructural defense often goes hand-in-hand with social protection. / DRC

7 MATCH SEDIMENT TO SITUATIONS

Sediments vary widely in what they are, such as particle composition and potential contaminants. Gravels, sands, and fines all lend themselves to some applications while being useless for others.

Nourishing the Bay's mudflats requires fine grained silt, while reconstructing Pleistocene Dunes near Antioch requires sand. Building and repairing levees works best with custom blends of clay and sand, such as those produced at Decker Island by mining the spoils of historic Sacramento River dredging projects. As seen in the Montezuma Wetlands, even contaminated sediments can find a role to play if they are properly placed and managed.

Consequently, even if we could guarantee an availability of the right volume of sediment for every significant need, without knowing its qualities, we could not promise to address the Bay-Delta's shortfalls. The choreography of sediment is more complex than simply directing volumes of supply to meet volumes of demand or need. We must match the right kinds of sediments to the right places.

CASE STUDY // MONTEZUMA DISPOSAL SITE AND WETLAND RESTORATION.

Jim Levine, owner of Montezuma Wetlands, privatized the movement of sediment dredged by the ACOE to incentivize the beneficial reuse of otherwise undervalued material. His team's goal is to restore more than 1,800 acres of wetlands through the placement of 20 million cubic yards of dredged sediment. This was made possible through the procurement of an offloader on-site to maximize the efficiency of the placement process. Cover (clean) and noncover (slightly contaminated) sediment are pumped through a network of pipes to phased restoration sites. Once the marsh elevations are established, the levees will be breached to bring in the tides for the the development of intertidal marsh.

8 REEXAMINE THE GOAL OF RESTORATION AT A TIME OF GREAT CHANGE

The nature of the Bay-Delta's emerging sediment shortfall is just beginning to be discussed, contested, and grappled with. Its resolution will affect policy, dredging operations and priorities of future investments and research. Its implications extend across economic, ecological, cultural and political domains.

Often, when people talk about managing sediment in the Bay-Delta watershed, it is done through the language of 'restoration'. To talk of restoration is to have a baseline condition to which you want to return. But to what baseline should the Bay and the Delta be returned?

The challenge of understanding the nature of the Bay-Delta's shortfall illustrates the difficulty of setting restoration goals. Is it a shortfall, which entails a deficit of some expected amount? Or more of an early sign of a very new Bay-Delta that is inevitably emerging? There is no clear historic baseline around which to station our efforts, as the Bay-Delta is too radically altered for such a comparison to be effective or realized. Moreover, determining future needs is complicated by how little we know, with certainty, of how accelerated climate change and sea level rise is going to physically manifest, and at what rate.

Given these novel conditions, "baselines" and "restoration" targets are tricky to apply in a real on-the-ground manner, or may become entrenched in protocols that hinder innovation and adaptation to accelerated change. In many situations there is a need to move beyond the past as precedent to more successfully prepare for a very different future. In particular, how the sediment shortfall is interpreted and encountered will strongly affect the policy, economics and management of sediment in the Bay-Delta. Incentivising more projective research to model, spatialize, and lend more specificity to the qualities and parameters of this shortfall should be a priority in future planning and design efforts.

Comparison of annual sediment sources for capture (bay-scale tributaries and dredge projects) versus annual needs for Baylands restoration. / DRC

9 DEVELOP NEW TECHNOLOGIES

Historically, technological innovation has played a formative role in the Bay-Delta. For instance, the reclaimed California Delta of today is a technological artifact. Its network of earthen levees was constructed by massive clamshell dredgers customized to the Delta's unique geography. Going forward, technological innovation, such as further expanding levee standards in the Delta or redesigning the storm channels of the Bay's tributaries to direct sediment flows to where they are most needed, will be necessary to address new challenges and conditions.

Future technologies will need to respond to a broader set of performance criteria. Rather than being precisely engineered to a single function, these technologies will need to be multifunctional, and able to perform across diverse ecological, economic and sociopolitical criteria.

Technological innovation is not limited to 'hardware' or machines, such as advances in hydraulic suction dredgers and excavators. It equally includes the 'software' of new practices, methods and protocols. Today we can point to a variety of new technologies being deployed in the Bay-Delta, such as horizontal levees, temporary salinity barriers, setback levees to reclaim floodplain habitat and flood capacity, and subsidence reversal achieved through the controlled manipulation of water regimens. Landscapes being utilized as experimental test sites can be approached as new technological investments, such as the constructed earthworks at Sears Point in San Pablo Bay, which were designed to passively accumulate sediment, and Montezuma Wetlands, a new model for beneficial reuse in terms of material practices, sustainable economics and public-private organizations.

In order for technological innovation to happen it will require investment, incentivization, experimentation, and monitoring to assess and improve upon how these technologies perform.

Technological innovations have reconfigured landscapes by prescribing new devices and methods of intervention that are applied at the scale of the site, but have implications at the scale of the region. Effectively these technologies establish territory. The patent is the language by which these technologies are communicated.

CASE STUDY // FIELD TECHNIQUES

Dr. Joseph Gailani (Research Hydraulic Engineer, USACE) researches dredge material management and sediment transport in San Francisco Bay's restored tidal wetlands. This research evaluates the marshes' capacity to accrete sediment on the basis of particle properties and processes of aggregation. Dr. Gailani has developed both laboratory and field techniques to measure the capacity of wetland soils to facilitate wetland formation. SEDFLUME, a sediment transport model, tests the erosion potential of core samples at varying flow rates. At Hamilton Bay, he has established monitoring platforms to collect further data on sediment processes such as suspension, settling velocity, transport, composition, flocculation, and consolidation. Fine-grained sediments, either sourced from dredge materials or transported tidally into Hamilton Bay, are known to better cohere as aggregates and reduce erosion, highlighting their potential for marsh nourishment and restoration.

Elizabeth Murray (Engineering Research and Development Center, USACE), presented research on the effects of berm shape on wave energy reduction in the restored tidal wetland sites of Sears Point (bottom aerial) and Hamilton Bay (top aerial). Both restorations tested unique berm formations to stimulate sediment accretion, employing natural processes to maximize overall benefit. Sears Point uses on-site materials to build a field of mounds, with the intent that patterns of water circulation and sediment accretion would emerge as the marsh develops. In contrast, Hamilton Bay utilizes linear berms that were modeled and optimized to slow incoming waves, allowing sediment to settle and accrete. The linear berms deployed at Hamilton Bay are more effective in attenuating wave energy, while the mounds of Sears Point better sustain vegetation.

10

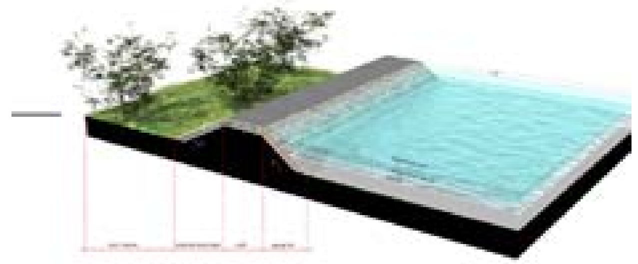
EVOLVE POLICY AND PLANNING TO MEET NEW CONDITIONS AND PRIORITIES

Policy and regulations play a dominant role in how sediment is managed and how it will be managed in the future. They determine what design options are allowable and which are not. They also affect which courses of action are economically viable through the sculpting of incentives and disincentives.

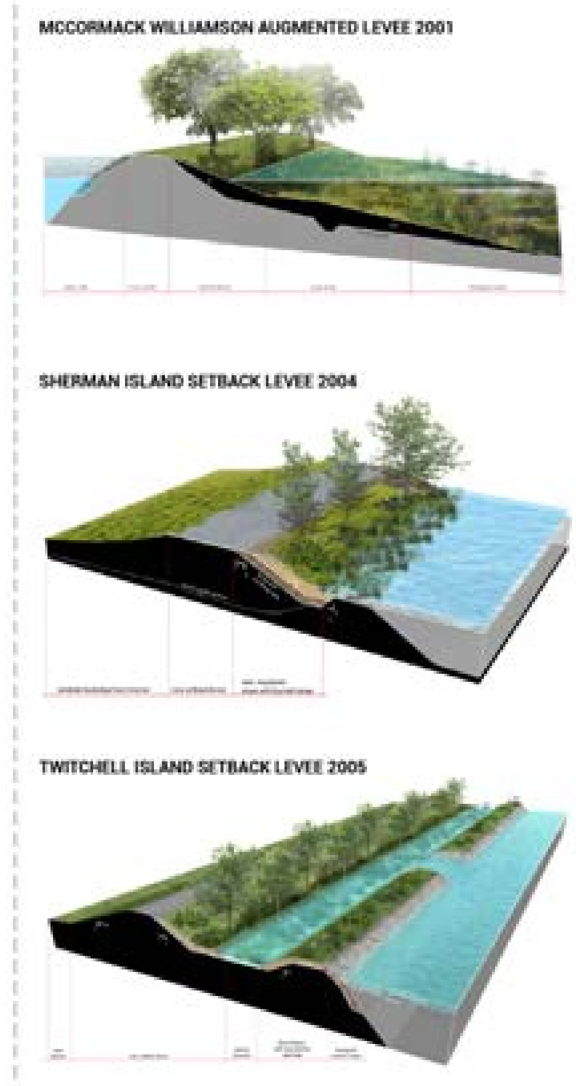
The emergent shortfall of sediment in the Bay-Delta presents a broad range of policy and regulatory challenges, as it introduces a paradigm that differs significantly from the 1980's "mudlock" crisis and the ecological damages caused by filling in the bay's edges. Since then, disposal has been superseded as the dominant sediment management issue by the recognition of sediment as a valuable, limited resource. However, the multi-stakeholder regulatory and policy environment has, understandably, yet to fully track with new conditions, new science, and new environmental priorities. This friction between the need to innovate and the need to regulate can be seen in current pilot projects like strategic placement, which has the potential to increase the application of beneficial reuse of dredged material, but technically runs against previous thinking and regulations regarding in-bay disposal. We need regulations to protect the environment and to avoid short-term damage that could negates long-term benefit.s The risk is that policy and its subsequent regulation, notoriously slow to adapt, will not change at a pace that enables the long term success of the region's sediment-dependant ecosystems. If policy and regulation continue to devalue sediment and conservatively limit experimentation in placement techniques, it is unlikely that sediment-dependant ecosystems, like the Bay's wetlands, will be able to adapt to climate change.

If policy and regulations are able to adapt to the pressing needs of the sediment shortfall, they also have the potential to incentivize innovative and multifunctional projects that meet economic, social and ecological goals. The recent passage of Measure AA presents such an opportunity in the Bay for effective policy to support the design and building of the future's baylands. Similarly, in the Delta, cost share incentives by state government are fostering the design and implementation of more polyfunctional levees.

Policy and regulations shape the physical landscape over time. The drawings at right showcase the history of levee regulations and standards that have created the edge conditions of today. in the Delta Policies leave a physical legacy for decades. How can they be adapted to meet the needs of the 21st century? / DRC

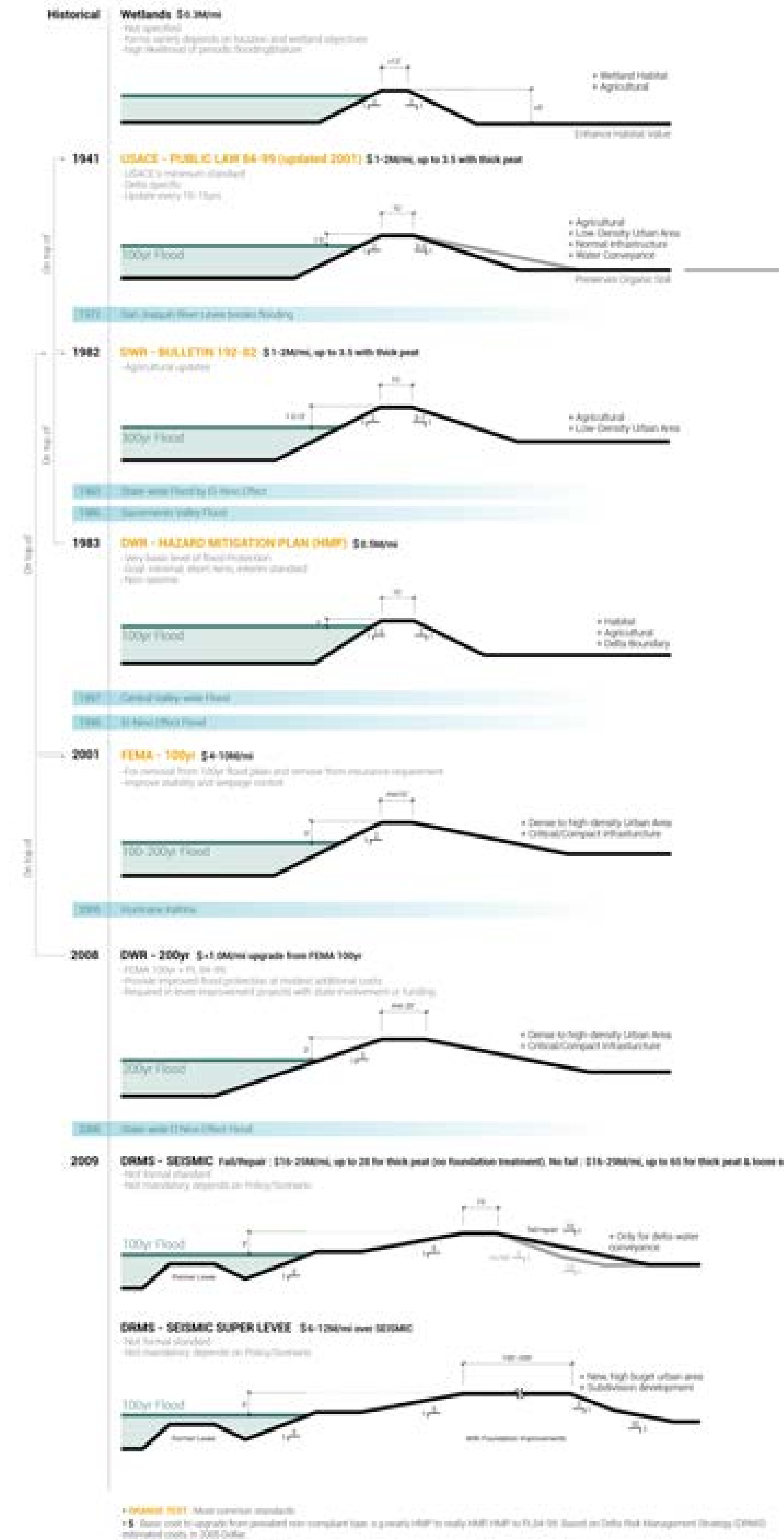


Variations (project-specified)



LEVEE STANDARD INVENTORY

Timeline



11 ORGANIZE SEDIMENT PUBLICS

Sediment is political. Sediment management decisions are made in a political context and are affected by both political values and political power. In the Bay-Delta, a multitude of agencies, stakeholders, private corporations, and public institutions are interwoven into these realms. This often has the effect of paralyzing decision making. Moreover, as in any political context, power is not distributed equally: some actors are advantaged, while others are disadvantaged; some voices are heard, while others are not.

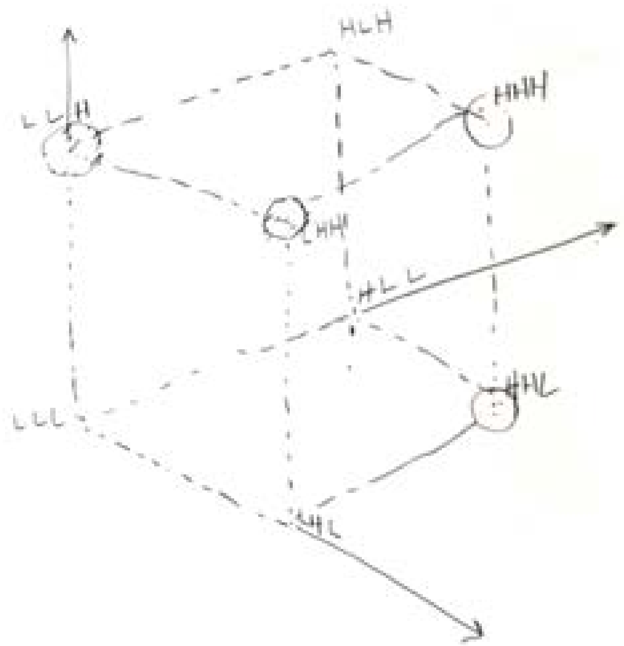
The movement of sediments also has political effects. In communities—both coastal and upland—the effects are not distributed equitably. With limited resources, where should they be applied? What geographies merit protection and where will we retreat and relinquish land? Who has the clout to promote or prevent unusual coastal construction? Where should potentially hazardous infrastructures be built, and how are their toxic legacies managed? Historically, the consequences of environmental degradation and disasters have most impacted communities with the least political power.

Climate change has the potential to significantly exacerbate existing inequalities in coming decades, and—given the role that sediment will play in building capacity to adapt to and mitigate the consequences of climate change—the political effects of sediment will need to be considered alongside technical, design, and engineering questions.

We recommend strategically building an informed, active, and broad constituency for sediment which recognizes its foundational role in the future of the Bay-Delta. This will have the effect both of distributing the effects of sediment management more equitably and of building the momentum that is needed to address the scale and scope of the challenges that the region faces.

DredgeFest California

APPENDIX



^ blank scenario cube .

// THE WORKSHOPS

Over five days, designers, local stakeholders, experts (from academia, industry, and government), and students came together to envision and respond to future sedimentary scenarios for the Bay-Delta.

The scenarios we worked with were:

- constructed through a scenario planning process, which considered the interaction of multiple factors driving change in the Bay-Delta
- evaluated through spatial modeling — the use of transdisciplinary design to test the consequences of scenarios, focusing on spatial outcomes while bridging between technical concerns and political, cultural, and social consequences
- used to inform design responses that propose innovative alternatives for sediment supply, transport, and placement and the future configuration of earthworks

The workshops consisted of five teams working in three tracks:

Regional Choreography
The choreography team probed potential relationships between sediment sources and sediment deficits across the entire estuary watershed, while considering the potential effects of external drivers such as shifting regional weather patterns, long-term technological innovation, and state and national policy climates. Its work was both informed by the Bay and Delta tracks and provides broader context for them.

Bay Sediments
The two Bay teams focused on scenarios for bay and coastal management of sediment in the context of adaptation to accelerated sea-level rise, wetland restoration, maritime economies, the cultural landscape heritage of the Bay, and public waterfront access. They aimed to demonstrate that sediment projects have the potential to not only satisfy immediate economic needs, like the provision of navigation through channel dredging, but also to create additional long-term value for the cultural, ecological, and economic contexts that they are embedded in.

Delta Earthworks
These two teams proposed innovate strategies for future earthworks and infrastructural retrofits in the Delta, informed by a set of scenarios described and spatially modeled by members of the Dredge Research Collaborative. Proposals responded to the myriad uncertainties facing the Delta's infrastructure, including water exports, climate change, regional urbanization, rapid ecological change, potentially disastrous earthquakes, and flood protection needs.

SCENARIO PLANNING: WHY SCENARIOS?

Scenario planning is a method to play out hypothetical sequences of events in order to focus attention on causal relationships and decision making. Scenarios are a tool for fostering dialogue and exploring "the gentle art of reperceiving", wherein we might discover our biases, blind spots, and where further research might be warranted. Scenarios are constructed by first identifying the scope of the scenarios, such as the extent of the geography, a time interval, and the relevant issues. Related stakeholders, trends and uncertainties are identified and then, in brief, you work through iterations of how these variables could interact and play out over time.

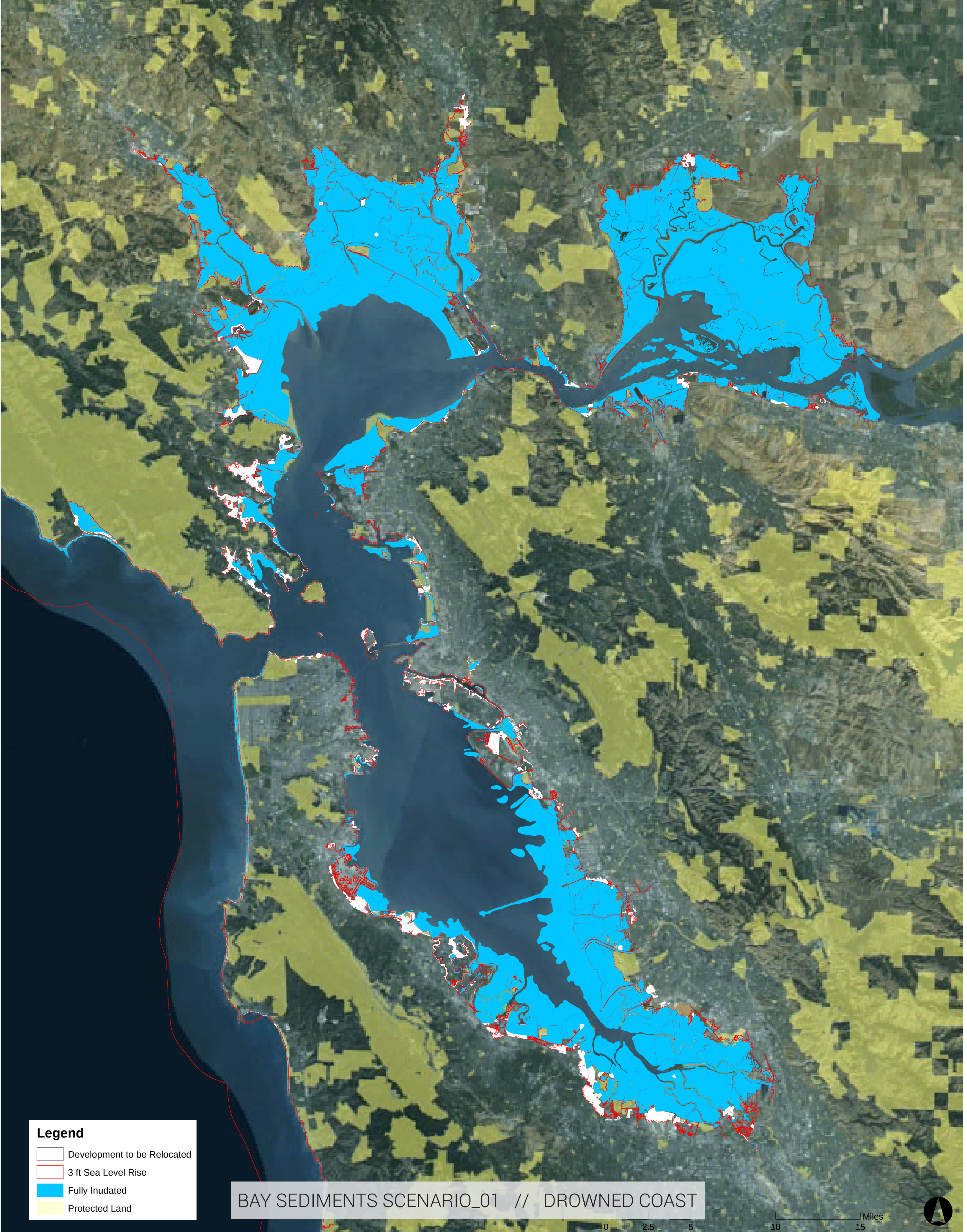
In scenario planning literature there is a key distinction made between normative scenarios and those that are exploratory. Normative scenarios depict futures that should be, identifying and striving for desirable and preferred future outcomes. In contrast, exploratory scenarios attempt to envision a fuller range of plausible futures, irrespective of their normative value, with the goal of better understanding what could happen.

The scenarios found later in this document for the Bay and Delta are exploratory. They do not articulate normative pathways or outcomes, and thus do not define a direction for design work. They are not a brief. Rather, teams were given free reign to choose how they formulate design proposals addressing their track's thematic, informed by the range of future outcomes presented by the scenarios. This is where the normative aspect of design begins to emerge: What did a team respond to and why? What did it privilege or augment? What did it sideline or ignore? All this is apparent in the decisions each team made, given the backdrop of the scenarios, and forms a basis for review and discussion.

Exploratory design scenarios emerged after World War II, most famously with Herman Kahn's cold war political strategizing and Shell Oil's successful corporate wagering. These actors envisioned futures to inform how they (or we) could act in the present. We gave the Bay and Delta workshop teams a simialr challenge: how could we develop more design sophistication and intelligence in articulating futures, particularly when those futures are marked by accelerated rates of landscape change and complex political realities?

The Regional Choreography team's situation was different. It was supplied with a list of drivers of change relevant to sediment supply and distribution within the entire Bay-Delta watershed. Because of the geologic scale of their subject matter, the scope of geography and time for Regional Choreography is much greater—up to 200 years into the future. Existing research and speculation related to their task was slim, in contrast to the Bay and the Delta (one of the most exhaustively studied estuaries in the world). Thus their task, in terms of scenario planning, was to begin to assemble the basis of scenarios by determining the relevancy and importance of these drivers and how they might interact and change over the course of timelines identified.

The two sets of four scenarios provided to each Bay and Delta tracks follow in this appendix. Each set of scenarios was initially read by the workshop participants in conjunction with an overall evaluation of their track's situation (see Section 03 Scales of Study), summary of drivers of change (see Section 03 Scales of Study), and associated bibliographies (Appendix, following the scenarios).



BAY SEDIMENTS SCENARIO_01 // DROWNED COAST

Overview

- High Sea Level Rise - approximately 3'(steady) - with projected rise to 6' by 2100
- Low Sediment Supply - decreasing with sea level rise - one weather-associated pulse late in scenario
- Low Development/Investment - region is slow to act on recommendations in the early period - catch up efforts are hampered by economic difficulties

Rising sea levels threaten habitat with little sediment available to reconstruct marshes. A Migration Plan begins to coordinate coastal retreat and habitat protection and provision.

Narrative

The bleakest climate change predictions become reality. Sea-level rise occurs at a steady clip, reaching the upper levels of current prediction windows by 2060. There is no dramatic crisis in the early days and calls to rally around the various marshland restoration efforts fall flat. Persistent regulatory and financial barriers mean that most efforts remain stuck in the proposal stage, and as a whole the Bay area fails to act. Aside from a few pilot projects, marshlands continue to gradually erode and disappear. By the mid-2030s it becomes obvious to many that living along the coast is foolhardy and very little development happens there. However, of those who already have a home on the shore, few are willing to move out of harm's way. Instead, a process of fortification to protect existing assets begins. Some of those assets might be better understood as liabilities—particularly the vast network of yet-to-be remediated military facilities, industrial sites. and landfills along the shore. Fears grow regarding what will happen if/ when they become inundated.

Seeing the looming crisis, the State of California had enacted a "Migration Plan" in 2029 to begin planning for the upland migration of both people and habitat. Thousands of "Migration Transects" are measured and modeled around the Bay. Remote aerial sensing of vegetation productivity, topography, connectivity, and landuse explores possible corridors and conflicts. Within this program comes the assessment of landuse based on "mobility." Infrastructural uses that are physically tied to other geographies such as freeways and electrical infrastructure are deemed "immobile", as are military facilities considered too large or dangerous to relocate. Industrial facilities that are highly dependent on infrastructure but that could conceivably be unplugged and relocated elsewhere are considered "quasi-mobile", as are landfills that in extreme conditions could be excavated and moved. Residential and commercial uses are seen as transitory and are deemed "mobile" by the project. They are typically the first regions to be assessed and transformed. The process is highly politicized, with accusations of corruption and the favoring of various communities dogging every step of the process, particularly in the face of the levee-effect caused by the protection of infrastructure deemed "immobile", which exacerbates the issue of flooding in areas seen as transitory.

By 2035, physical changes begin to occur based on the new zoning and development regulations required under the Migration Plan. Federal funding is found for a reasonable number of large projects, partially under the guise of a stimulus package, that attempt to knit together a "braided" retreat of both habitat and human occupation. This comes by way of both strategic siting and the removal of obstacles to upland migration.

Higher water levels generate reductions in maintenance dredging needs and non-existent development along the coast has reduced sediment from accelerated erosion to almost zero. The beneficial use of sediment is all but abandoned, because there is little clean fill to be had. The dredging that does occur in the region is focused on a backlog of maintenance and repair and is used for the the fortification of "immobile" assets. Owing to necessity and its condition as an "immobile" piece of infrastructure the Port of Oakland remains productive and is the focus of a good deal of protective construction, as it is seen by many as one of the essential "lifelines" to the region. It is one of the primary recipients of the small amount of dredged material available.

Meanwhile, San Francisco is going through a bust period. Significant losses in the tech sector combined with the migration mandate have encouraged many to either stay away or move to other locations (both industry and associated residential). The general economic chaos has meant less development pressure and many landowners have lept at the chance to offload underwater (financially) property before it becomes underwater (literally). This process is aided by California state buyouts funded through programs such as Measure AA for those selling their properties for the enhancement of habitat migration routes.

By 2040 most of the marshes have drowned and many diked baylands are being over-washed by both diurnal tides and storm surges, rendering them useless as habitat. The primary exception is the continued raising and re-plumbing of the salt ponds in South Bay, facilitated by sediment brought in from private upland sources.

By 2066, the sea has swallowed a good percentage of the Baylands, and is converting upland areas into the Baylands of the future. Development pressure slowly resumes based on this new striated infrastructure.

BAY SEDIMENTS SCENARIO_02 // ARMORED SHORE

Overview

- High Sea Level Rise - starts slow and then accelerates to approximately 3' - with projected rise to 6' by 2100
- Low Sediment Supply - decreasing with sea level rise - one rain-associated pulse late in scenario
- Mid Development/Investment - attempts to invest in the future prove to be inadequate - region struggles to adapt

Sea-level rises slowly and then accelerates in the late 2030s. Many marshes are washed away and habitat suffers. Planners, racing the tides, fall back to older protection schemes, relying on coastal armoring rather than soft infrastructures to hold back the waves.

Narrative

Sea level rise begins slowly in the first three decades, appearing to be in line with the low end of projections, leading to a feeling of safety and predictability.
The region continues to do well economically and significant development pressure continues to be placed on coastal areas of the Bay. In light of the seemingly slow advance of the sea, communities are fashioned among soft infrastructure projects in many locations, fortified by sediment meant to "seed" mudflats and marshes and encourage them to capture sediment and generate more structure for themselves over time. Maintenance dredging and the capture of the enhanced erosion-sediment associated with waterfront development provides enough material for most of these operations. By 2030, things in the Bay region appear to be well developed and situated.

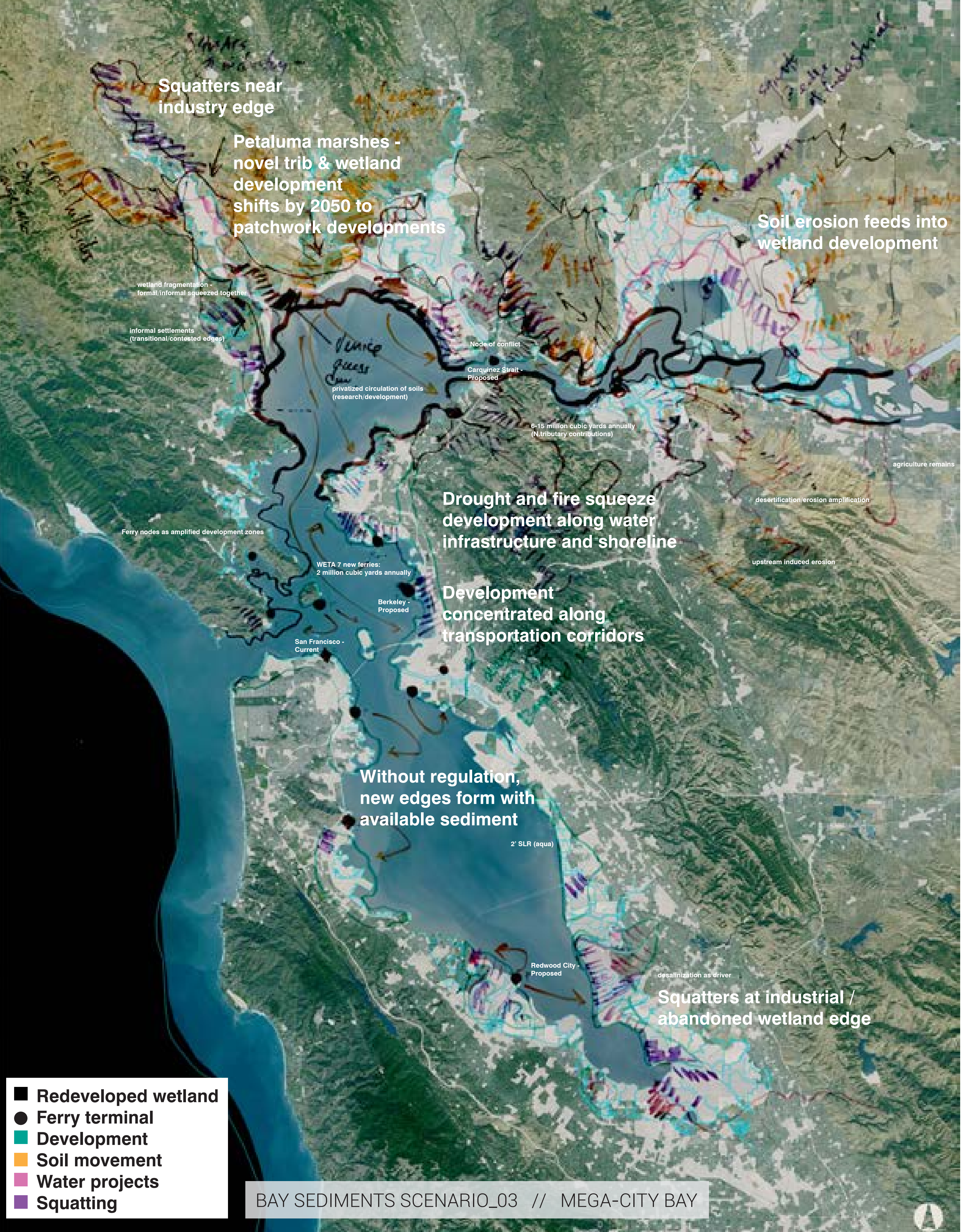
However, by 2035 the cold phase of the Pacific Decadal Oscillation comes to an end. A large increase in sea levels, combined with a series of strong storms in the late 2030s, catches the region off guard. Each storm inflicts significant damage which is not fully repaired before the next one hits. Most marshes are quickly saturated and many are drowned. Residential developments are inundated by a series of storm surges. Several new developments are all but total write-offs and it becomes clear that all the coastal regions are at risk. Some of the most impacted communities in the South Bay include areas on the eastern shore in Union City that are protected by failing diked wetland and the relatively unprotected Foster City on the western shore. In the San Pablo Bay, low-lying areas such as Mare Island and Gallinas are also significantly damaged.

These conditions do not quell the development pressure in the region as a whole, and a resistant attitude develops among residents, adamant to "see this out", no matter what. A sprint to structure the coast in a manner that can accommodate development occurs in spite of all habitat concerns. In some places, encampments of residents and industries remain as veritable islands, unable or unwilling to move out of the way of the rising waters. This stubbornness is contrasted by a significant level of abandonment in other areas by those who could leave or had no choice after the storms.

Making matters worse ecologically, the Bay's rapid cycles of boom and bust and a number of pro-development, pro-austerity, anti-green governments at the State level mean that habitat restoration efforts essentially grind to a halt during the crucial early years of the shift. Ideologues determined to "starve the beast" of the civil service simply fail to fund the projects necessary to address the 1999 Baylands Goals. During the good times, environmentalism is criticized for slowing development. During the bad times, it is a luxury San Francisco can't afford, particularly in the panic-mode present after the storms.

Unwilling to test unproven techniques, and wary of the failures of the soft infrastructure projects built in the early decades, the region responds to these challenges by falling back to hard-edge engineering. Emergency projects build seawalls, breakwaters and riprap. This proves to be an expensive and intensive process, particularly considering that all materials for the construction work must be imported. As sea levels continue to rise, more and more steel, concrete and stone must be dumped into the water to protect valuable human habitat on land. Essential infrastructure, private industry, military outposts and sites of "cultural" heritage are all prioritized. In many cases it is deemed cheaper to relocate and develop on newly constructed high ground along the coast than to repair and reconstruct many of the flood-damaged regions of the Bay. These areas are cleaned to the best possible standard and left as architectural graveyards, slowly consumed by the sea.

By 2060, the Bay consists of a highly structured series of coastal communities, held together by a network of protected legacy infrastructures. Many of the low-lying areas of the Bay have been abandoned and most of the wetlands were squeezed out between the rising ocean and the newly armored shore. The new ecological landscape of the Bay is slowly taking shape in the abandoned tracts of land along the shore.



BAY SEDIMENTS SCENARIO_03 // MEGA-CITY BAY

Overview

- Mid Sea Level Rise - 2'
- High Sediment Supply - WETA expansion, Maintenance Dredging of eroded sediment from tributaries + suspended sediment catchment from tributary sediment pulses.
- High Development/Investment - The Bay experiences a population explosion

Large amounts of sediment available to expand coastline for future development. Large megastructures / protection not necessary for sea level defense. A march back to the coast is observed and conflicts between development and habitat protection become serious.

Narrative

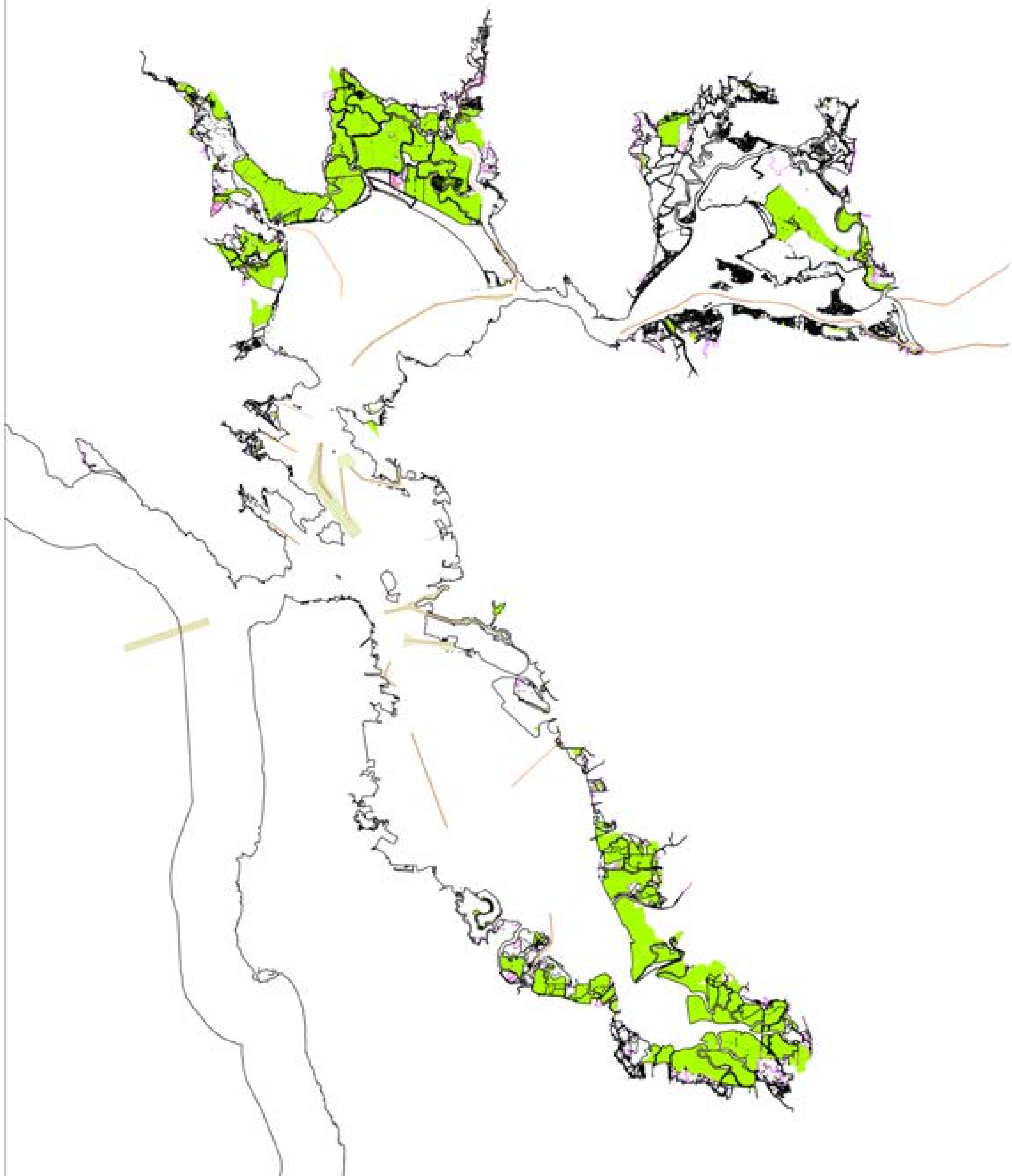
While sea-level rise tends towards the middle of long-term projections, climate change has had much more detrimental effects on the Western United States. A massive drought begins in 2025 and lasts for almost a decade, outstripping all gains from water conservation efforts undertaken in response to the drought of the 2010s. California experiences a great migration as those relying on groundwater for drinking or irrigation are forced to areas with better water availability. The Bay is one such destination—its favorable climate and new desalinization processes attract climate refugees from across the West. Approximately half of the of these new residents enter with jobs in the growing fields of technology, commerce, medicine, and ecosystem management. The rest congregate in large-scale informal settlements in under-managed areas of the region.

Development along the coast becomes rapid and, at times, ill-conceived. Increased erosion produces chronic sediment pulses during sporadic and localized heavy rain events throughout the region. In addition, the growing population places pressure on public transit and the WETA ferry system sees a huge jump in popularity, leading WETA to construct the 7 terminals currently under consideration by 2040 and to begin the study of more possible sites. Many of these new facilities are in the more shallow reaches of the Bay, thus requiring maintenance dredging themselves (in addition to the excavation needed to construct them initially). This process generates approximately 2 million cu/yds annually, however this material is removed by private contractors through WETA and is not federally managed. This material is typically "donated" to the new satellite communities served by WETA, many of which are dependent upon ferries as the only reliable transport to and from the urban centers of the Bay.

The growing population and loss of developable land encourage a series of experimental projects along many of the Bay's tributaries. These projects look to re-design the routes of these tributaries in ways that might generate increased sediment loads from areas where erosion is to be encouraged. In 2025 a collection of "sediment banks" along or around tributaries are identified and sediment is intentionally eroded from them into the Bay with the intention of relieving some of the sediment starved conditions there. The first of these is created along the Petaluma River, which immediately begins conveying increased sediment loads into the San Pablo Bay. Deemed a success, other projects are initiated along the Sacramento River, delivering sediment to the Suisun and San Pablo Bays. The more urbanized South Bay is less fortunate from this process, and sees little change in its sediment content under the sediment bank project. In general however, sediment loads in the Bay as a whole increase and dredged sediment volumes increase from 6 million cu yds in 2020 to 15 million by 2050. Much of this excavated material is used for development, but the suspended material in the northern bays is captured to create/grow tidal wetlands.

The relationship between development and habitat along the coast becomes contentious, with informal settlements slowly invading loosely-regulated marshlands, and other habitat areas at risk from planned development. In these cases, marshlands are considered in the planning phases of many projects, but are seldom realized as planned. Instead of a network of connected systems, a patchy and idiosyncratic collection of marshland habitats is developed due to the specific nature of development plans. In some plans, marshlands are seen as recreational, others as token habitat for animal observation.

Technological development and research associated with sediment management and beneficial use is focused on ideas associated with bearing capacity, admixing, and the remediation necessary to make the material structural for development. The funding available for these operations is significant and progress is made.



BAY SEDIMENTS SCENARIO_04 // HABITAT WONDERLAND

BAY SEDIMENTS SCENARIO_04 // HABITAT WONDERLAND

Overview

- Low Sea Level Rise - 0.8'
- High Sediment Supply - maintenance dredging, WaterFix excavation material, reconfiguration of tributaries
- Low Development/Investment - The Bay sees no significant population growth/development pressures and remediation plans are allowed to progress steadily.

Generous amounts of sediment and lower than expected rates of sea level rise allow existing habitats to be bolstered, fortified and expanded into areas not needed for development.

Narrative

Sea-level rise has occurred at a rate in the lower range of the prediction models. With little concern of the slowly rising sea, all work within the Baylands becomes less fraught with uncertainty. Drought conditions in southern California into the 2020s lead to a huge federal works and research project on the subject of desalination. Scientific breakthroughs and a concurrent investment in new infrastructure means that a new desalination industry comes online in a big way. This allows many who would have otherwise fled in search of water to remain invested in their initial urban regions and agricultural practices. In the Bay region, favourable rainfall and snow patterns in the Sierra Nevadas and Yosemite mean that the region requires little of the new water infrastructure.

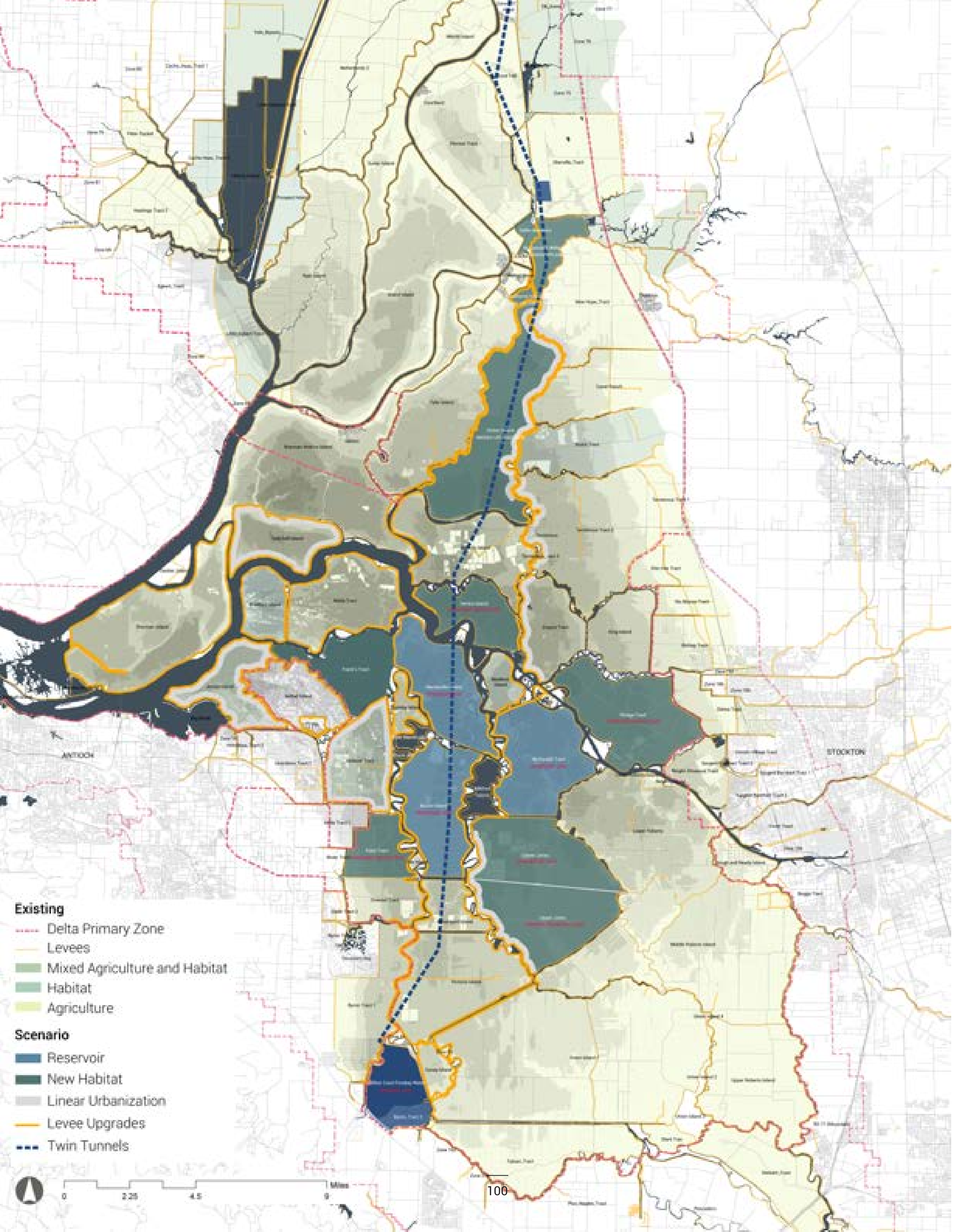
Thus a more water-stabilized California emerges and development patterns respond with strong intensification in the suburban regions at the periphery of water distribution systems. This process result in a less intense pattern of development along the shores of the Bay in favor of more inland suburban development. Developments in autonomous automobiles and other forms of personalized mass transit only encourage this trend.

A number of factors combine to make the Bay region rich with sediment. First, the surrounding watersheds continue to generate sediment flows into the Bay system and maintenance dredging of the bay for maritime commerce still occurs, generating 6-million cu yds per year of sediment. However, urban sediment control regulations and habitat creation have reduced the sediment inputs occurring day-to-day. By the end of 2050, this has dropped to 2-million cu yds per year.

Secondly, in the Delta, WaterFix is authorized but lags behind schedule due to flooding in the 2020s. Completed in 2038, this project generates over 30 million cu yds of material. Project "Eco-restore" is pressured to expand and consider the Bay-Delta system as a whole rather than as two isolated contexts. It is joined with the Baylands project and jointly funded. Through a somewhat obfuscated process, the 30-million cu/yds is determined to be more valuable to the Bay than the Delta. From 2019 to 2035 excavated material is barged down the Sacramento and Joaquin rivers for use in habitat creation and protection projects in the Bay. Advertised as "the golden soil of salvation" for Baylands habitat, press and research attention is directed to this volume and its use, and competition within the Bay for the sediment ensues. This moment in the late 2030s marks the crescendo of sediment-use technology in the region with demonstration dikes and test marshes splattered around the Bay, all showcasing what amazing things the soil could be used for.

Environmental augmentation of the Baylands take several forms. The first is cheap and strategic modifications to diked areas such as the relocation of outlet pipes or planned breaches of dikes due to the slowly rising water levels. The second is the seeding (both passive and active) of mudflats and marshes to help hold/build sediment and vegetation. The last is physical planning for migration upland, although this process requires little sediment and is not taken very seriously due to the sediment-heavy restoration occurring in the existing Baylands and the slow rate of sea-level rise.

By the end of the 2050s, many of the habitat goals of the Baylands portion of the Baylands/Eco-restore habitat targets have been met. The Baylands exist as an almost contiguous network of tidal and non-tidal ecosystems, some well planned and constructed, others, particularly the demonstration studies that failed to generate enough attention, already beginning to fail. At this point the lack of attention paid to the Delta is also proving to be obvious, and a tremendous mistake. By 2060 a huge shift in funding takes place and the Baylands, working under the assumption of continued O+M funding for the indefinite future is forced to use what it has created up to that point with no foreseeable future funding as the state attempts to resuscitate the failing Delta.



DELTA EARTHWORKS SCENARIO_01 // WATER MACHINE

Overview

- Medium Disaster - earthquakes late in the scenario
- High Investment
- High Water Exports - maintained through implementation of WaterFix
- Medium-High Urbanization - focused along new earthworks
- High Technology

Heavy investment is made in Delta infrastructure, with the primary goal of ensuring the stability of water exports. Climate change and earthquakes stress this water machine. Land use in the Delta fragments and diversifies, with some tracts surviving essentially intact while others are converted to novel uses ranging from open deep-water habitats to linear urbanization along super-levees.

Narrative

In the coming decades, California moves forward with a centrist, technocratic approach to managing environmental change, prioritizing the stability of natural resources as economic inputs. Government intervention occurs and there is a significant increase in infrastructure funding focused primarily on market continuity and maximizing the wellbeing of individuals and corporations with existing stakes. The 'California model' becomes paradigmatic, and is broadly shared by many other states and the federal government.

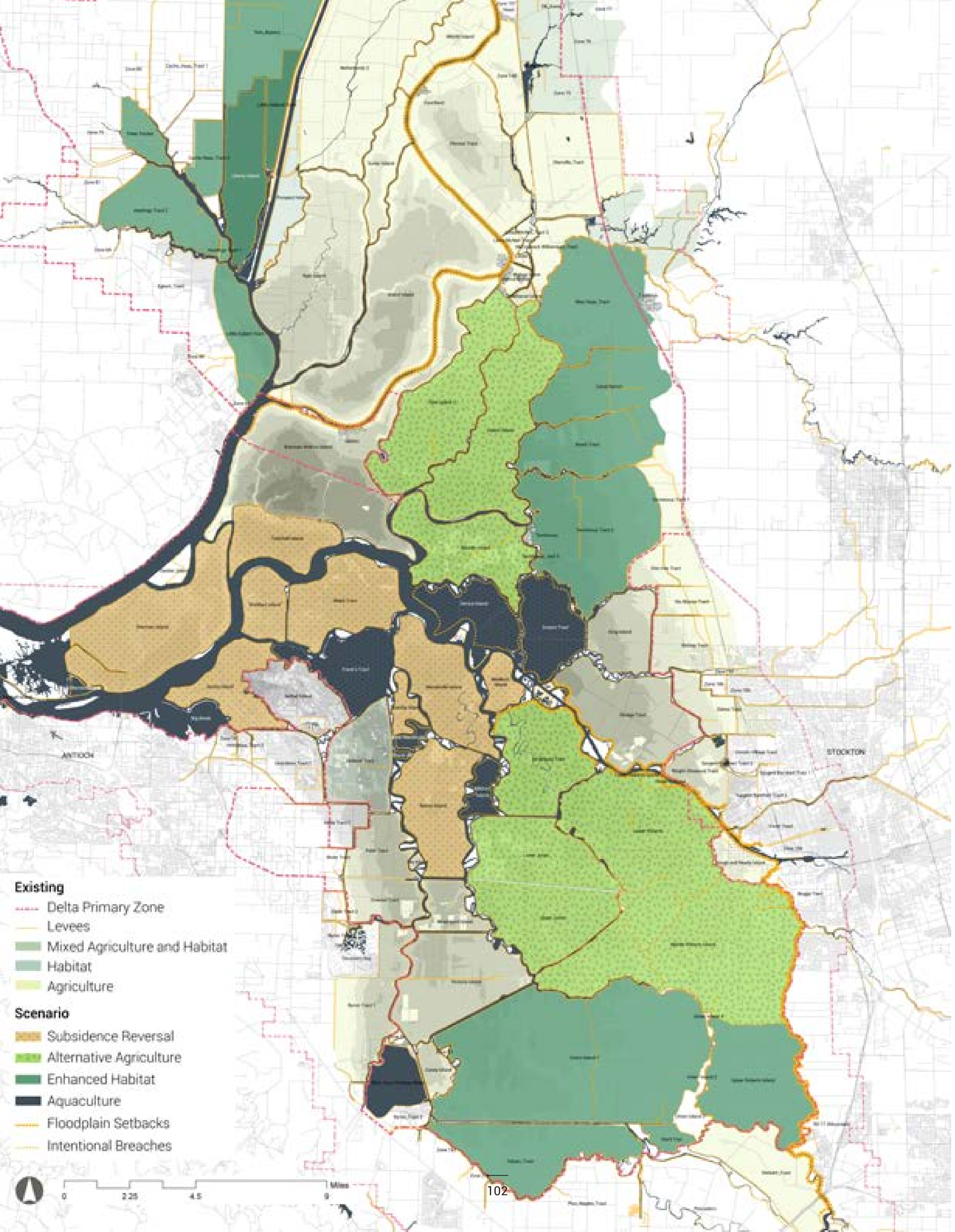
Despite controversy and significant opposition, California's government is able to prevail in pushing for the construction of the twin tunnels/WaterFix proposal. Ground is broken in 2017 and the tunnels are complete and operating by 2035, a mere three years late though significantly over budget. This infrastructure's water export reliability derives from the capacity to alternate between northern intakes (tunnels) and southern pumps (Tracy, Harvey O. Banks pumping plant), depending on environmental conditions related to water quality and the migratory presence of endangered aquatic species, so through-delta conveyance remains an infrastructural concern.

Investment in Delta levees becomes highly strategic and non-uniform. Levees for the western tracts are prioritized and repaired as needed, because they are most critical for maintaining low salinity for through-delta conveyance. Similarly, levees along the primary routes of through-delta conveyance continue to be prioritized as more robust super-levees. New forms of linear urbanization are permitted along these super-levees, thus supporting investment in the infrastructure. The strategic reuse of excavated tunnel material is prioritized to reinforce levees or reverse subsidence, as is the beneficial reuse of dredged material within the Delta from channel maintenance and deepening. Levees that are not critical for water conveyance suffer from a lack of federal and state investment.

Meanwhile, climate change continues unabated, driven in part by economic growth that continues to be powered by fossil fuels. Sea level rise in particular overshoots expected ranges as Arctic glaciers melt more rapidly than anticipated. By 2040 saltwater increasingly intrudes further and further up the Delta, pushing the X2 salinity barrier further east into the Delta. High water exports to central and southern California continue, even as desalination technologies and new forms of water-limited agriculture begin to proliferate, as both regions have continued to experience economic growth and accompanying urbanization.

Subsidence continues in the central, western, and northern Delta. Some of subsided tracts in the south are converted into freshwater storage, leading to the reinforcement of levees around these new reservoirs. Extreme seasonal floods occur in 2041 and 2044, as occasional deluges punctuate the general trend toward decreased annual precipitation. A major earthquake strikes in the early 2050s. This stresses the levee system and leads to dispersed breaches in the non-prioritized levees, which go unrepaired, as continued climate change forces greater and greater selectivity in the construction and maintenance of increasingly overmatched infrastructures. However, each flooded tract is intensely monitored. These accumulating failures spur conversion of these open water areas into experimental ecological habitats, laced with robotics, genetically-modified species, and sophisticated environmental sensors, in an attempt to build some semblance of both stable ecosystem function and a new economy of corporate fisheries.

By 2066, the Delta is nearly unrecognizable, a cyborg matrix of contrasting infrastructures and landscapes. The armored super-levees of the water machine host new communities on their banks. The machine is supplemented by storage tracts, which help to regularize the volumes of water exports. These well-funded areas contrast with both remnant patches of the old twentieth-century agricultural Delta, whose aging levees are vulnerable to further quakes and floods, and the novel open deep-water habitats that dominate the non-conveyance portions of the western and central Delta.



DELTA EARTHWORKS SCENARIO_02 // THE NEW DEAL

Overview

- Medium Disaster - a twenty-year drought in early years
- Low Investment - until economy recovers from drought
- Low Water Exports
- Low Urbanization
- High Technology

A multi-decade drought radically alters California and, with it, the Delta. The Delta's role as water supply infrastructure declines and California relies on both other sources and reductions in consumption to manage the loss of exports from the Delta. When the drought ends, the Delta evolves in a new direction, managed as a productive, economically-viable novel ecology.

Narrative

Global climate shifts — more or less following current change projections — alter the geography of farming and other land uses in the United States. The most influential of these changes in California is the continuation of the current drought through 2035. There are occasional wet years, which keep stakeholders invested well into this drought, but, overall, California goes dry: on average receiving only 30% of the precipitation it did in the 20th century. Climate designers and political interests endlessly debate if the prolonged drought is due to anthropogenic climate change or is an intrinsic longue durée element of California.

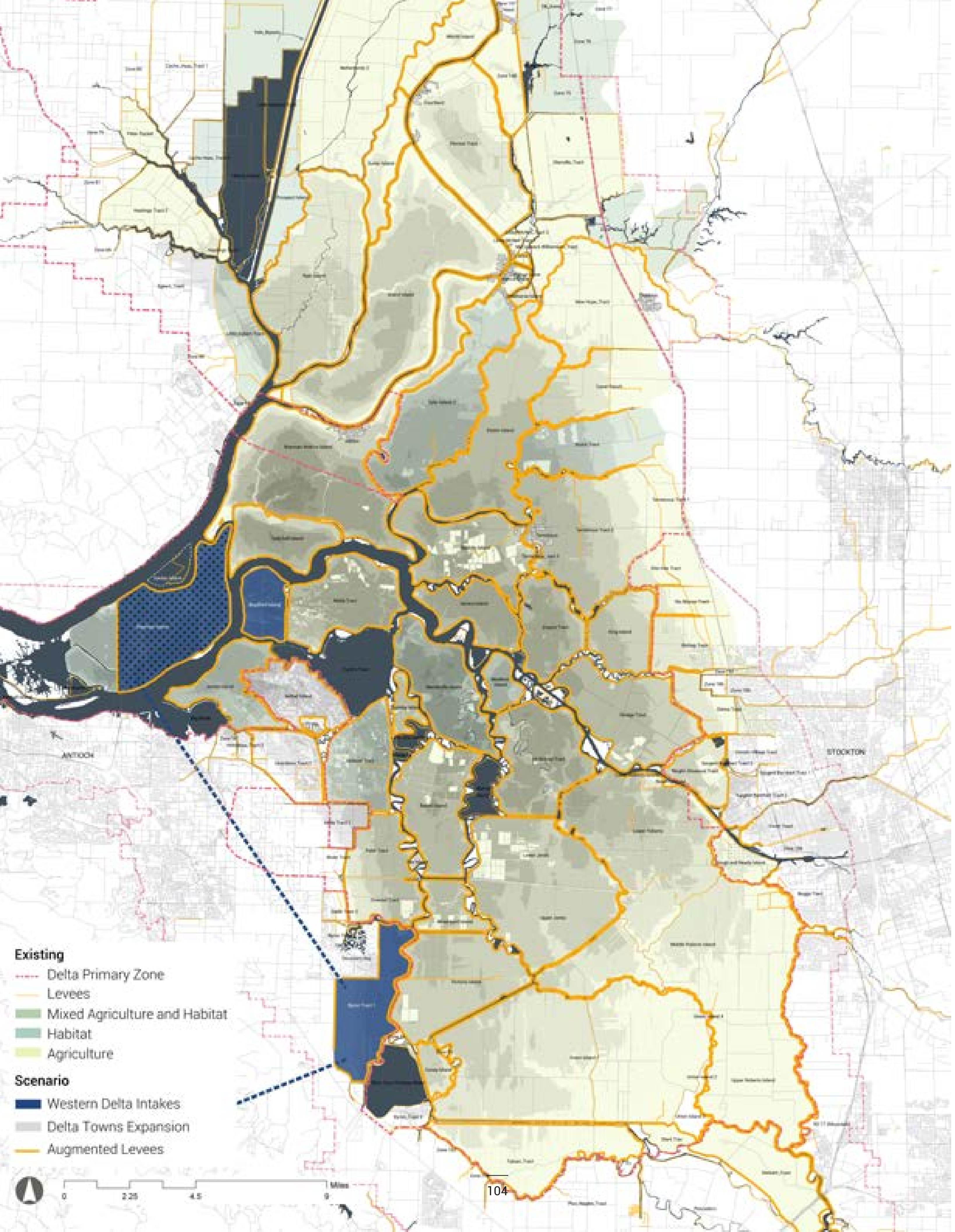
Over the next decade, entrenched battles over ever-diminishing and over-allocated resources steadily proliferate. Ecological demands, enforced through the issuance of biological opinions by the courts, battle cities and corporate agricultural lobbies over water allocations. Skirmishes flare up and Delta militias emerge, but scarcity ensures that there are no clear victors.

By 2026, the ecological ramifications of the drought are widely manifest in the Delta. Native aquatic species, depleted before the drought, largely go extinct. Terrestrial species and migratory birds fare nearly as badly. Large forest fires rip through the Sierra Nevada Mountains, consuming diseased forests and leaving the western slopes bare and exposed. A severe storm in the spring of 2027 sends a large pulse of sediment into the state's reservoirs, significantly reducing their capacity and causing two large dam failures. No major earthquakes occur in the Delta, though, and the levee system remains largely intact. Farming has continued in the Delta throughout this time, though in a reduced fashion due to shortages of available, clean water.

Over the course of the drought, Southern California and other importers eventually relinquish their reliance on Delta water due to sheer deprivation, rather than compromise. Twenty years of diminished and unreliable deliveries effectively crush these markets, which are forced to move on, as do many Californians. Southern California does its best to adapt, but the state experiences an unprecedented exodus to wetter and more reliable climates in the other regions of the country (as does the entire Southwestern United States). As the effects of climate change become increasingly evident nationwide (circa 2035), public opinion steadily shifts in favor of mitigating global climate change and adapting to its consequences through changes in human settlement patterns and more effective uses of natural resources, rather than intensification of infrastructures. Managed retreat and strategic degrowth are favored over fortification. With a diminished tax base, California, a former leader in this realm, struggles to keep pace with the rest of the nation. But the state's long push toward reduction of water consumption for residential, industrial, and remaining agricultural uses remains relatively constant and overall, effective. Combined with long-term technological investment, desalination technology and municipal-scale water recycling enters wide use, and becomes increasingly affordable, helping to reduce southern California's water import dependency.

By 2038, the drought has abated and the Bay-Delta estuary begins to see more water passing through its waterways than it has in a half century, due to highly reduced exports. The Delta's hydrology is again characterized by patterns of seasonal flux in both water level and salinity gradient. Upstream diversions increase slightly, taking up some of this slack, but the Delta is now able to operate more as an autonomous net user, rather than a net exporter.

Combined with regional sustainability mandates and eco-markets that have become viable and lucrative on a global scale, by 2050 the Delta begins to evolve differently. With the historic remnants of the former delta long gone, the Delta is again re-engineered, but this time as a state-of-the-art designed ecology that couples economic productivity with polyfunctional ecosystem services, rewilding and climate change adaptation. The Delta is now "farmed" in a different and more expansive manner. New markets emerge and new forms of productive land use colonize the Delta. Tule farms take advantage of intensified interest in wetland carbon markets and are employed in long-term subsidence reversal schemes. Legal marijuana cultivation, favored for its adaptability to wet conditions, replaces illegal cultivation, and expands its footprint, though the overall agricultural footprint is much smaller than in the present. Traditional agriculture is transformed, favoring shifts that emphasize wildlife-friendly practices. The Delta's remnant network of levees and other infrastructure is liberally re-calibrated to suit these new protocols and market objectives.



DELTA EARTHWORKS SCENARIO_03 // AUGMENTED EARTHWORKS

Overview

- Low Disaster
- High Investment
- High Water Exports
- Medium Urbanization - highest in Delta legacy towns
- Medium Technology

The existing earthworks of the Delta are upgraded and augmented. Water exports from the Delta continue, through the construction of a new conveyance intake in the western Delta. The communities of the Delta flourish, protected by this new infrastructure and fed by the combination of old agricultural economies with booming tourism and recreation.

Narrative

The physical drivers of change that negatively impact the Delta—land subsidence, sea level rise, seismicity, regional climate change, alien species—have a relatively mild impact on the Delta over the next two decades (2015-2035). Global climate change and sea level rise continue, but only reaching the lower bounds of predicted change. Precipitation regimes continue to shift, but not so rapidly as to make adaptation infeasible. Alien species continue to spread into the Delta, but most of the additional exotic species that might yet arrive, such as white bass, grass carp, zebra mussel, Asian fish tapeworm, fail to make an appearance.

Meanwhile, at regional, state, national, and even international levels, policy climates shift to favor pre-emptive mitigation and adaptation. (This reinforces the effect of low disasters: global policy changes bend the curve of climate change downward; effectively enforced state and national regulations mitigate against species invasions.) The global economy booms, and California, with strong tech and ecotech sectors, benefits heavily. In-migration and urbanization continues, strengthening the tax base. Recognizing the decaying state of the nation's infrastructure, infrastructural redevelopment is made a nationwide policy, and California leads the way with a set of major state-level initiatives which include rebuilding existing and constructing new Delta infrastructure.

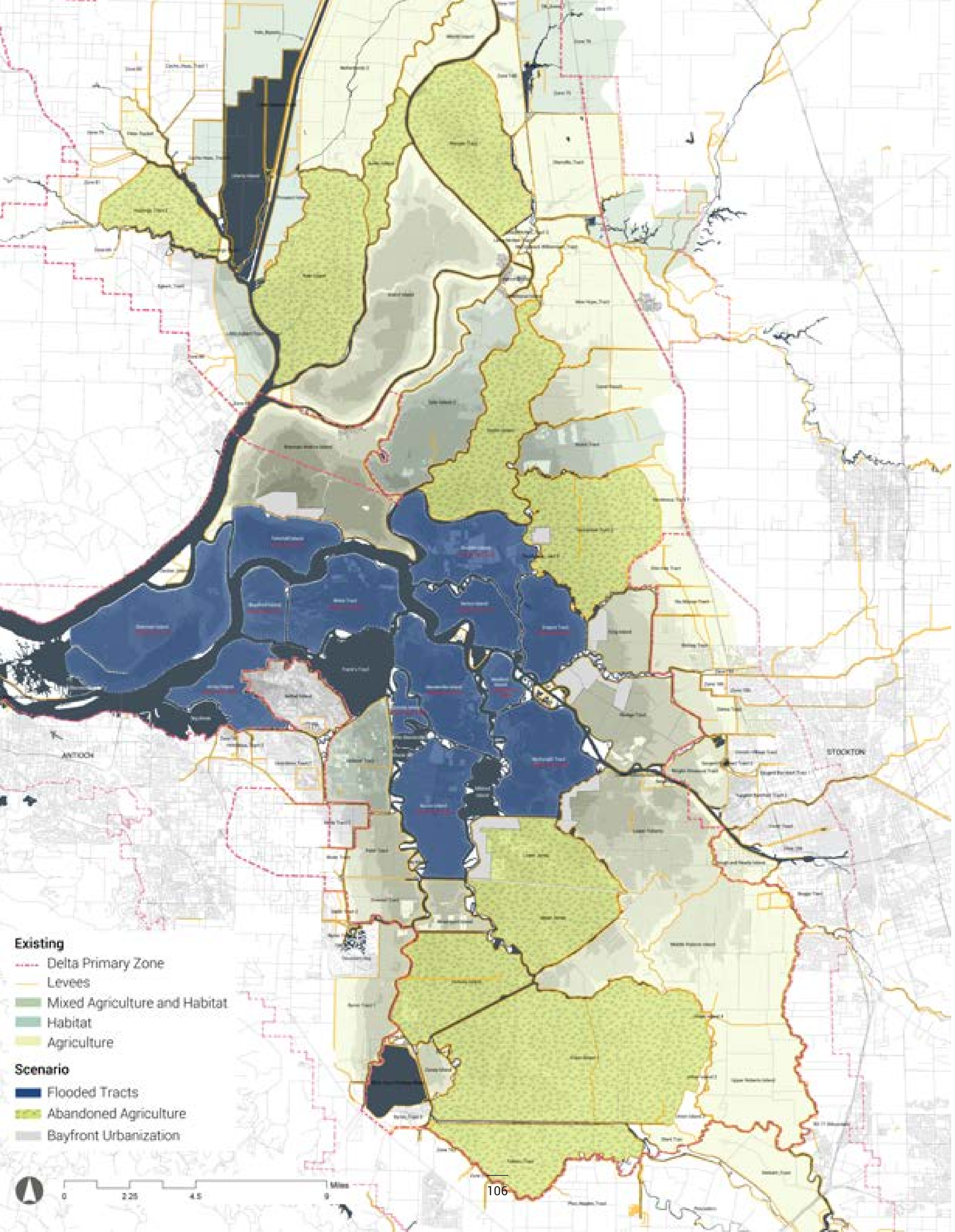
This climate of adaptation is multifaceted, acknowledging that accommodations must be made for ecosystem health in order to achieve other priorities that include the continuation of water exports (the legislative coequal goals of the Delta persist). This is achieved in two ways.

First, there is more uniform and robust investment in the Delta levee system. These investments advance state policies that require and incentivize improvements in the ecological function of levees in tandem with maintenance and improvements in flood resiliency. Accordingly, the Delta comes to exhibit the maturation of over a century of levee construction, culminating in a system of diversified and polyfunctional earthworks. These civil works expand and augment the material and ecological thresholds between land and water. Rather than focusing on taking entire tracts out of production, ecological function is obtained through setback allocations distributed throughout the linear network of waterways. In some cases the shape of the network is changed - such as the chaining together of some tracts to make this effort more feasible.

The second adaptation is a western Delta conveyance model that is approved and constructed at a fraction of the cost of the former WaterFix proposal (The western Delta conveyance option becomes popular in the wake of the failure of the tunnels proposal). With the western Delta conveyance, water can only be pumped out of the Delta in wetter years, but during those wetter years greater volumes of water can be pumped and stored for future use. Thus, in order to maintain even export levels, new water reservoirs are constructed in the south Delta, with even more further to the south.

These infrastructural investments beget further investment. Desired ecological benefits from levee retrofits manifest and prove economically worthwhile via sustained exports. Recreation on the naturalized and more aesthetically pleasing waterways booms, as does agriculture and tourism, attracted to the uniqueness of the Delta's cultural landscape, which stands in ever-greater contrast to the expanding ring of urbanization that surrounds it. Within this National Heritage Area, Delta legacy towns come to serve as new and expanded hubs for tourism and a revived local economy.

In later years (2040-2066), desalination advances ("desal light") reducing the need for freshwater at the point of water draw (at the same time as sea level rise makes this a necessity), permitting the Delta to trend towards greater and greater levels of salinity fluctuation over time, which further benefits desirable species. Agricultural and urban users in the Central Valley and southern California begin to transition to lower and lower levels of per capita water use, but this is counteracted by population growth in the region, so total water exports remain fairly level.



DELTA EARTHWORKS SCENARIO_04 // FERAL BAY

Overview

- High Disaster
- Low Investment
- Low Water Exports
- Medium Urbanization - late in scenario
- Low Technology

Unexpectedly rapid climate change and another major American housing market collapse preclude investment in the infrastructure of the Delta. A combination of earthquakes and storms inundates multiple islands in the core of the Delta, which becomes an inland sea. Eventually, this inland sea is colonized through a re-commoning of the Delta and the urbanization of the new baylands around its edges.

Narrative

Efforts to mitigate global climate change fail—spectacularly. A rift develops between more and less industrialized nations, with the latter intensifying use of fossil fuels to spur economic development and the former unwilling to lead on climate change without globe-wide participation. In the United States, a left-wing government of climate hawks is blamed for the devastating 2022 recession, and replaced in a sweeping electoral rout by a right-wing government split between climate doves counseling adaptation-only and outright climate change denialists. It takes multiple electoral cycles for globally-coordinated efforts at climate governance to re-emerge.

In the near-term, the recession is accompanied by another housing collapse, which halts any fledging efforts to urbanize the periphery of the Delta and ensures there is no pressure to urbanize the primary zone. Delta infrastructure is similarly neglected due to lack of available funds; even minimal levee upgrades are sidelined.

Meanwhile, global climate change intensifies and its pace accelerates. Propelled by a glacial melt feedback cycle, sea level rise far exceeds the upper bounds of current projections, Salinity intrusion into the Delta likewise intensifies, and the estuary—at least insofar as it is defined by salinity gradient—migrates upriver. Snowpack in the upper portions of the Delta's watershed continues to decline. The annual pulse of meltwater arrives in the Delta earlier due to increased temperatures.

The combination of salinity and erratic, declining water supply reduces the export capacity of the Delta, both directly and indirectly. It not only directly reduces the available volume of freshwater, but also exacerbates species declines in the Delta, leading to the issuance of biological opinions (which declare the ecological impact of these actions) which further reduce exports.

A major earthquake (8.5) in 2031 causes multiple levee breaches, which inundates Sherman and Twitchell Island, fully disrupting water exports to the south. The State scrambles to find funding to repair the levees and momentarily succeeds in securing federal assistance, only to have a 200-year storm event just one month later that inundates three more deeply subsided islands. This cluster of disasters instigates a general lack of confidence and a broad exposé of the current degraded state of the levees. Federal support wanes and repair efforts are abandoned. Water exports grind to a halt and the core of the Delta becomes an inland sea.

This combination of factors makes investment in the Delta ever more unlikely. Through the 2040s and 2050s, neglect begets neglect, and levees continue to collapse on the expanding edge of the sea, flooding more islands. With the wider state's interest in the Delta as water supply greatly reduced, adequate funding to repair most of the collapsed levees isn't available, so more and more of the Delta's land area shifts to open water. These navigable waterways inadvertently rewild and there is a re-commoning of the Delta as a public zone where people recreate, live and engage in a broad variety of unregulated activities and small-scale economies. Sufficient law enforcement in this spreading inland sea is impractical. The Delta is essentially left to its own devices ecologically, as environmental restoration efforts across the country collapse under the fiscal weight of dealing with climate change adaptation—now, belatedly, a national and international priority.

The Delta's inland sea initially hosts a novel ecology of aquatic weeds and non-native fish and invertebrates. The striped bass fishery, as well as other new imports, proliferates. Remnant levees are opportunistically utilized as structures for these fisheries and fish farms. As sea levels rise the waters become brackish and more of an extension of the San Francisco Bay (2055). The ecology of the Delta shifts in tandem. The new waterfronts of this bay – the Delta's eastern secondary zones – become desirable for new urban developments, coinciding with the state's economic recovery around 2065.

Download Readings and Resources from Dropbox

The best two papers for getting an overview of this topic are Barnard et al 2013 and Kondolf 2014. This section focuses on research that directly addresses regional movements of sediment. Much of the material in the individual Bay and Delta reading lists, such as the *Baylands Ecosystem Habitat Goals Science Update* and PPIC's *Envisioning and Comparing Futures for the Sacramento-San Joaquin Delta*, is also relevant to Regional Choreography, even though it is confined in scale to either Bay or Delta.

The best overview of the physical geography of the Bay-Delta's watershed, how it has been altered, and the current design issues is found in **Marine Geology #345 (November 2013): A multi-discipline approach for understanding sediment transport and geomorphic evolution in an estuarine-coastal system: San Francisco Bay.**

In particular:
P Barnard, D Schoellhamer, B Jaffe, L McKee "Sediment Transport in the San Francisco Bay Coastal System: An overview" (Marine Geology #345, November 2013)
This paper is one of few that looks at sediment transport in the bay and delta together instead of examining them distinct entities. Presents approximately 20 papers on sediment transport research and identifies data gaps.

The Bay in Regional Context
L. McKee, M. Lewicki, D. Schoellhamer, N. Ganju "Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California" (Marine Geology #345, November 2013)
Discusses how the main upland/watershed sources of sediments in the Bay-Delta have shifted dramatically due to anthropogenic changes. Most sediment used to enter the Bay-Delta from the Sacramento and San Joaquin Rivers, particularly the Sacramento River. Today, most sediment entering the bay comes from the small, local tributaries that feed directly into it. This illustrates the importance of small watersheds and the effect of Sacramento-San Joaquin dams, which effectively block sediment transport from 48% of watershed area.

The Delta in Regional Context
Schoellhamer, Wright, and Drexler, "Conceptual Model of Sedimentation in the Sacramento-San Joaquin River Delta" (San Francisco Estuary & Watershed Science, Oct 2012)
Provides a way of understanding how the Delta fits into the larger picture of regional choreography.

Dams and Reservoirs
Martin, "No Joy in Mudville: Amid Drought, California's Reservoirs are Clogged with Gunk" (California Magazine, 2014)
An interview with Kondolf is the primary source for this readable, succinct summary of the situation behind California's dams.

Kondolf, "Sustainable sediment management: the key to the future" (International Water Power & Dam Construction, October 2014)
A good introduction to Kondolf's research, as it condenses and reviews other articles that Kondolf has been involved in writing, including Minear and Kondolf (2009) and Kondolf et al (2014). Covers sedimentation of dams in California, strategies for designing dams to avoid accumulation, and the global impacts of sedimentation in dam reservoirs.

Minear and Kondolf, "Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California" (Water Resources Research 45, 2009)
The best existing estimate of the volumes of sediment held in reservoirs behind dams in California, but the model that it uses is "appropriate for detecting regional trends and highlighting reservoirs potentially at risk of sedimentation but would not give accurate estimates of sedimentation within individual reservoirs".

Kondolf et al, "Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents" (Earth's Future 2, 2014)
This article considers the regional management of sediment across a variety of global examples, providing a particularly helpful summary of the primary approaches to improving sediment management at dams that have been explored or employed globally.

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Poignant Overview of the Sedimentary Challenge facing the Bay
In Search of Mud to Save San Francisco Bay (Scientific American)
http://blogs.scientificamerican.com/guest-blog/in-search-of-mud-to-save-san-francisco-bay/
"To restore the region's salt marshes, scientists and engineers need to get their hands on huge quantities of the messy stuff."

Relevant Bay Planning Frameworks and Documents
Baylands Ecosystem Habitat Goals Science Update (2015)
Titled "The Baylands and Climate Change: What We Can Do", this is *"an update to the 1999 Baylands Ecosystem Habitat Goals, which for the first time set comprehensive restoration goals for the San Francisco Bay estuary. Produced by a collaborative of 21 management agencies working with a multi-disciplinary team of over 100 scientists, it synthesizes the latest science—particularly advances in the understanding of climate change and sediment supply—and incorporates projected changes through 2100 to generate new recommendations for achieving healthy baylands ecosystems."*

Baylands Ecosystem Habitat Goals (1999)
See where it all began. This is the report that the Science Update is updating. Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.

US Army Corps of Engineers, EPA, Bay Conservation and Development Commission, others (2001)
Long-Term Management Strategy for the Placement of Dredged material in the San Francisco Bay Region
The stated goals of the LTMS are to *"(1) Maintain in an economically and environmentally sound manner those channels necessary for navigation in SF Bay and Estuary and eliminate unnecessary Dredging (2) Maximize the use of dredge material as a beneficial resource and (3) Establish a cooperative permitting framework"*.

The Dredge Material Management Office (DMMO) http://www.spn.usace.army.mil/Missions/DredgingWorkPermits/DredgedMaterialManagementOffice%28DMMO%29.aspx
"A joint program of the San Francisco Bay Conservation and Development Commission(BCDC), San Francisco Bay Regional Water Quality Control Board (RWQCB), State Lands Commission(SLC), the San Francisco District U.S. Army Corps of Engineers (COE), and the U.S. Environmental Protection Agency (EPA). Its purpose is to cooperatively review sediment quality sampling plans, analyze the results of sediment quality sampling and make suitability determinations for material proposed for disposal in San Francisco Bay. The Goal of this interagency group is to increase efficiency and coordination between the member agencies and to foster a comprehensive and consolidated approach to handling dredged material management issues." The office's annual reports contain detailed information regarding how and where dredged material is being reused in the Bay Estuary.

SediMatch
http://www.sfei.org/projects/sedimatch-web-tool#sthash.qKczv621.dpbs
"SediMatch is a collaborative program to bring together the wetland habitat restoration and the dredging communities to discuss challenges and find mutually beneficial strategies to increase reuse of dredged sediment at habitat restoration sites. Goals are 1) to create healthy habitats while maximizing beneficial reuse of sediment; 2) to develop an easily accessible database where sediment needs can be matched with surplus sediment; and 3) to provide opportunities for collaboration. SediMatch is designed to meet goals related to Flood Control 2.0 by creating an easily accessible framework and information source for match-making between restoration projects and navigational and flood protection dredging projects and other "sediment suppliers" that can be implemented throughout the region to meet current and future sediment supply needs."

Water Emergency Transportation Authority (WETA)
https://sanfranciscobayferry.com/node/429
"The 2016 WETA Strategic Plan presents a vision for the next 20 years of ferry service in the San Francisco Bay Area. This plan comes at a pivotal period in WETA's history. Rising ridership driven by a strong regional economy with focused job growth in San Francisco has made the ferry more popular than ever. Pre-existing services in Vallejo, Alameda and Oakland have transitioned smoothly from city-run services to WETA operations. The first new terminal built in the Bay Area in decades – in South San Francisco – is thriving after an initial ramp up period. Funded projects such as the North Bay and Central Bay maintenance facilities as well as expansion of the downtown San Francisco terminal and a new terminal in Richmond are all in the final design or construction phase. And finally, expansion candidate terminals throughout San Francisco Bay are seeking funding to enter project implementation."

Bay Sediment and Shoreline Studies
L. McKee, M. Lewicki, D. Schoellhamer, N. Ganju. Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. http://www.sciencedirect.com/science/article/pii/S0025322713000297
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Bay Sediment and Shoreline Studies
L. McKee, M. Lewicki, D. Schoellhamer, N. Ganju. Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. http://www.sciencedirect.com/science/article/pii/S0025322713000297
Discusses how the main upland/watershed sources of sediments in the Bay-Delta have shifted dramatically due to anthropogenic changes. Most sediment used to enter the Bay-Delta from the Sacramento and San Joaquin Rivers, particularly the Sacramento River. Today, most sediment entering the bay comes from the small, local tributaries that feed directly into it. This illustrates the importance of small watersheds and the effect of Sacramento-San Joaquin dams, which effectively block sediment transport from 48% of watershed area.

Shifting Shores: marsh expansion and retreat in San Pablo Bay. San Francisco Estuary Institute (2015)
This report examines historical shoreline change in San Pablo Bay with the goal of increasing understanding of the rate, distribution, and mechanisms of marsh edge shoreline dynamics and the ways they are likely to respond to local actions. It describes and illustrates several types of shoreline edges, and provides recommendations for next steps in tracking shoreline change.

National Research Council (2012)
Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future

Current Engineering, Restoration and Beneficial Reuse of Dredge Projects
Flood Control 2.0
http://www.sfei.org/projects/sedimatch-web-tool#sthash.nJw51wXg.1jwClvH6.dpuf
"Flood Control 2.0 is a project funded by the US EPA San Francisco Bay Water Quality Improvement Fund, and will develop a set of innovative approaches for bringing environmental benefits and cost-savings to flood protection infrastructure along the San Francisco Bay shoreline. The strategy has two complementary approaches that transform costly trapped sediment in local flood control channels into a resource: channel redesign where sufficient adjacent land use flexibility exists, and sediment redistribution for highly constrained channels."

Sonoma Baylands
http://www.thebayinstitute.org/page/detail/117
Sonoma Baylands was among the first restoration projects to use dredged bay mud to raise the bottom elevation of a subsided landscape to create tidal wetlands, thus setting a precedent for later projects.

South Bay Salt Ponds
http://www.southbayrestoration.org/Project_Description.html
"The South Bay Salt Pond Restoration Project is the largest tidal wetland restoration project on the West Coast. When complete, the project will restore 15,100 acres of industrial salt ponds to a rich mosaic of tidal wetlands and other habitats."

Hamilton Wetlands
http://hamiltonwetlands.scc.ca.gov/
Transformation of a former North Bay military airbase into tidal wetlands using material dredged from the Oakland Harbor Deepening Project.

Sears Point Restoration
http://www.sfbayjv.org/project-sears-point-wetland-restoration-san-pablo-bay.php
Recently completed restoration project in the North Bay. Uses sculpted landforms to attempt to augment sedimentation.

Cullinan Ranch
http://www.restorecullinan.info/home.htm
"The Cullinan Ranch Restoration Project will restore over 1500 acres of tidal wetlands in the San Pablo Bay National Wildlife Refuge. Once complete, the site will be open to the public to explore on foot, bicycle or kayak." This project will take about 60 years to complete, dependent on how much dredged material it receives and rates of sea level rise.

Previous and Current Design Efforts
Rising Tides Competition (2009)
www.risingtidescompetition.com/risingtides/Home.html
In 2009, the San Francisco Bay Conservation and Development Commission (BCDC) held an open international design competition for ideas responding to sea level rise in San Francisco Bay and beyond.

Bay Area Resilient by Design (in planning)
http://sf-planning.org/bay-area-resilient-design-challenge
Well-funded and resourced design competition for the Bay styled after NY/NJ's Rebuild by Design.

Download Readings and Resources from Dropbox

General Introduction to the Delta, its history and its challenges

Delta Primer, Jane Wolff, 2003 (see PDF compilation)
"The California Delta is one of the most contested landscapes in the United States. Critical to the ecology and economy of California, it is the largest estuary on the west coast and the centerpiece of the vast system that delivers water to Los Angeles. Delta Primer organizes documentary stories about this complicated landscape according to four ideas of the place: that it is a garden, a machine, a wilderness, and a toy. This book represents these ideas in photographs, a brief history, a lexicon and a separate deck of narrative playing cards" - William Stout Publishers

The Delta as Wicked Problem
Both of these essays provide a comprehensive overview of the complexity of current social, ecological economic and political challenges facing the California Delta.

The Devil is in the Delta
https://www.planning.org/planning/2012/jan/waterwarriorsside1.htm

Challenges Facing the Sacramento–San Joaquin Delta: Complex, Chaotic, or Simply Cantankerous
http://resources.ca.gov/docs/DeltaChallenges-v13.pdf

Reclamation and the Ecological Transformation of the Delta

Changing ecosystems: a brief ecological history of the Delta
http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/sldmwa/moyleetal2010.pdf
Provides a concise narrative of the environmental history of the Delta

A Delta Transformed: Ecological Functions, Spatial Metrics, and Landscape Change in the Sacramento-San Joaquin Delta, 2014, SFEI
http://www.sfei.org/documents/delta-transformed-ecological-functions-spatial-metrics-and-landscape-change-sacramento-san
This document compares reconstructions of historical Delta ecology to the present-day Delta to identify potential opportunities to restore ecological functions. It seeks to do this "not by replicating the historical Delta, but by creating viable habitat mosaics with the vision of how they connect at the landscape scale". The document includes extensive maps that detail the ways in which the delta has been transformed. Excellent source both for understanding what the pre-reclamation Delta landscapes were like and how radically different they are today.

Current Delta Planning Frameworks and Documents

The Delta Plan
http://deltacouncil.ca.gov/delta-plan-0
"The Delta Plan is a comprehensive, long-term management plan for the Delta. Required by the 2009 Delta Reform Act, it creates new rules and recommendations to further the state's coequal goals for the Delta: Improve statewide water supply reliability, and protect and restore a vibrant and healthy Delta ecosystem, all in a manner that preserves, protects and enhances the unique agricultural, cultural, and recreational characteristics of the Delta." The Delta Plan is the current plan of all Delta plans. It became effective in 2013, but is still being revised and contested.

Delta Levees Prioritization Study (Ongoing)
http://deltacouncil.ca.gov/delta-levees-investment-strategy
This study will "combine risk analysis, economics, engineering, and decision-making techniques to identify funding priorities and assemble a comprehensive investment strategy for the Delta's levees." How performance metrics are being articulated and measured are controversial, as is the assessment of "beneficiaries" of the infrastructure. Arcadis and the Rand Corporation are the lead consultants on the project.

Delta Economic Sustainability Plan (ESP)
http://www.delta.ca.gov/Economic%20Sustainability%20Plan.htm
Delta residents and communities are often sidelined or overshadowed in discussions of the future of the Delta, due their small constituency in comparison to the state's water exporters and ecological recovery mandates. The Delta Protection Commission is the agency charged with representing in-Delta interests and drafting the ESP, which provides information and recommendations that inform policies concerning the socioeconomic sustainability of the Delta region itself. Ch. 5 of the ESP focuses specifically on the Delta's levees and their potential future.

Other Delta Future Envisioning Efforts

Public Policy Institute of California's reports: Envisioning Futures for the Sacramento-San Joaquin Delta
http://www.ppic.org/main/publication.asp?i=671

Comparing Futures for the Sacramento-San Joaquin Delta
http://www.ppic.org/main/publication.asp?i=810
"Sacramento-San Joaquin Delta is widely perceived to be in crisis today: its levee system is fragile, many of its native species are declining rapidly, and it lacks strong governing institutions to deal with its problems. In its current state, the Delta is unsustainable for almost all stakeholders. This report provides a comprehensive, scientifically up-to-date analysis and outlines several alternative management strategies for the Delta."

Geography and "Delta as Evolving Place"
"Delta as Evolving Place" is codified in CA Water Code §85054. The phrase is a planning conundrum fitting of the Delta that has yet to find real traction in policy and definition.

Settlement Geography of the Sacramento San Joaquin Delta, John Thompson (1956)
Stanford PhD thesis. Definitive, all 550 pages. Examines how the Delta was settled and reclaimed, via means that were, at the time, generally more technologically advanced than those of other deltas of the world.

Delta Narratives
http://www.delta.ca.gov/Delta_Narratives.htm
The Delta Narratives was a "collaborative project involving regional academic and cultural institutions, that sought to communicate the historic and cultural importance of the Delta region in California's—and America's—history, through multi-format educational exhibits within and around the Delta."

The Econocene and the Delta
https://escholarship.org/uc/item/4h98t2m0
"Considering the 50-fold increase and the globalization of economic activity during the 20th century, we are now in the Econocene: an era where our economy has become the major driver of rapid global change. Managing the California Delta will require policies that facilitate looking ahead and continually working with change rather than looking back and trying to secure a static past. Simply making modest adjustments in the current science–policy interface will be insufficient. Impractical changes—that is, those well beyond existing practice—are called for across the public, private, and non-governmental sectors."

Design and engineering plans active or recently active in the Delta

WaterFix ("The tunnels" or "Twin tunnels")
https://www.californiawaterfix.com/
Plan to convey water beneath the Delta (rather than through it) via the tunneling of two underground 40' diameter pipes.

Peripheral Canal
https://en.wikipedia.org/wiki/Peripheral_Canal
Predecessor to the tunnels proposal, would route water exports through a new canal along the eastern edge of the Delta. It was voted down in 1982.

EcoRestore
https://www.gov.ca.gov/docs/Delta_Fact_Sheets_4.30.15.pdf
Plan to fast track ecological restoration projects in the Delta

Levee Islands and Levee Feasibility Study (USACE and CA Dept of Water Resources)
http://www.spk.usace.army.mil/Portals/12/documents/civil_works/Delta/DILFS/Delta%20Study%20Draft%20Integrated%20FSEIS.pdf
Proposed beneficial reuse as subsidence reversal and land-building technique in the Delta

Delta Wetlands Project
https://www.newsdeeply.com/water/articles/2016/04/27/jeff-mount-the-mysteries-of-delta-islands-sale
Proposal to build leveed water reservoirs in the Delta on subsided tracts. Also seen as a controversial land grab by southern California water interests. Sale and transfer of these lands just recently occurred.

Yolo Bypass/Nigiri Project
https://watershed.ucdavis.edu/project/nigiri-project-growing-rice-and-salmon-floodway
Design of a leveed, multifunctional floodway in the North Delta. Choreographs flood control with fish and wildlife habitat, farming, hunting and recreation.

Subsidence Reversal: Twitchell Island
http://escholarship.org/uc/item/5j76502x
http://www.capradio.org/articles/2013/07/02/carbon-farming-in-the-delta/

Subsidence Reversal: Sherman Island
http://escholarship.org/uc/item/3tk650qh#page-1
http://www.water.ca.gov/floodsafe/fessro/docs/west_farming.pdf
Subsidence reversal is an emerging set of practices aimed at raising elevations of subsided lands (subsidence is the gradual sinking of an area of land, an occurrence that is common in wetland or peat soils, such as the Delta's, when they are reclaimed or exposed to air). Subsidence reversal can be cross-programmed with other forms of landscape productivity, such as carbon sequestration, wildlife habitat, aquaculture, and new modes of farming.

THE DREDGE RESEARCH COLLABORATIVE

Sean Burkholder (@seanburkholder) has spent the last decade dealing with projects of particular relevance to the Great Lakes region including urban vacancy, infrastructural re-purposing and dredge material management. He is currently an assistant professor in the Department of Architecture at the University at Buffalo.

Brian Davis (@faslanyc) is an assistant professor of landscape architecture at Cornell University. He teaches design studios as well as classes on construction technology and Latin American landscapes. His research looks at the relationship between landscapes and instruments, with a particular geographic focus in Latin America and New York State.

Rob Holmes (@rbhlms) is an assistant professor of landscape architecture at Auburn University. His research focuses on designed responses to reciprocal relationships between urbanization, infrastructural networks, and large-scale anthropogenic landscape change.

Justine Holzman (@JustineHolzman) is an adjunct assistant professor in the School of Landscape Architecture at the University of Tennessee, Knoxville and a research affiliate for the Responsive Environments and Artifacts Lab at Harvard. This summer she was in residence at the Isabella Stewart Gardner Museum as the 2016 Maeder-York family fellow in Landscape Studies.

Tim Maly (@doingitwrong) is a writer and design journalist whose work focuses on the near future of design, architecture, and infrastructure. He is a Fellow at Harvard's metaLAB and a Lecturer in Industrial Design at the Rhode Island School of Design. His writing has appeared in *Wired*, *The Atlantic, Volume*, and *Urban Omnibus*.

Brett Milligan (@freeassocdesign) is an assistant professor of landscape architecture and environmental design at the University of California, Davis. His research focuses on land-water interfaces and California's Bay-Delta, seeking to meld ecological and infrastructural performance with aesthetics and expanded forms of public engagement.

Gena Wirth (@genevawirth) is the Design Principal at SCAPE Landscape Architecture in New York City. Her work focuses on climate change resilience, infrastructural landscapes for people, and the role of ecology in the urban realm.

2016 DRC Intern-Collaborators
Michael Biros
Kate Lenahan
Nick Shannon
Crystal Xing

DredgeFest California