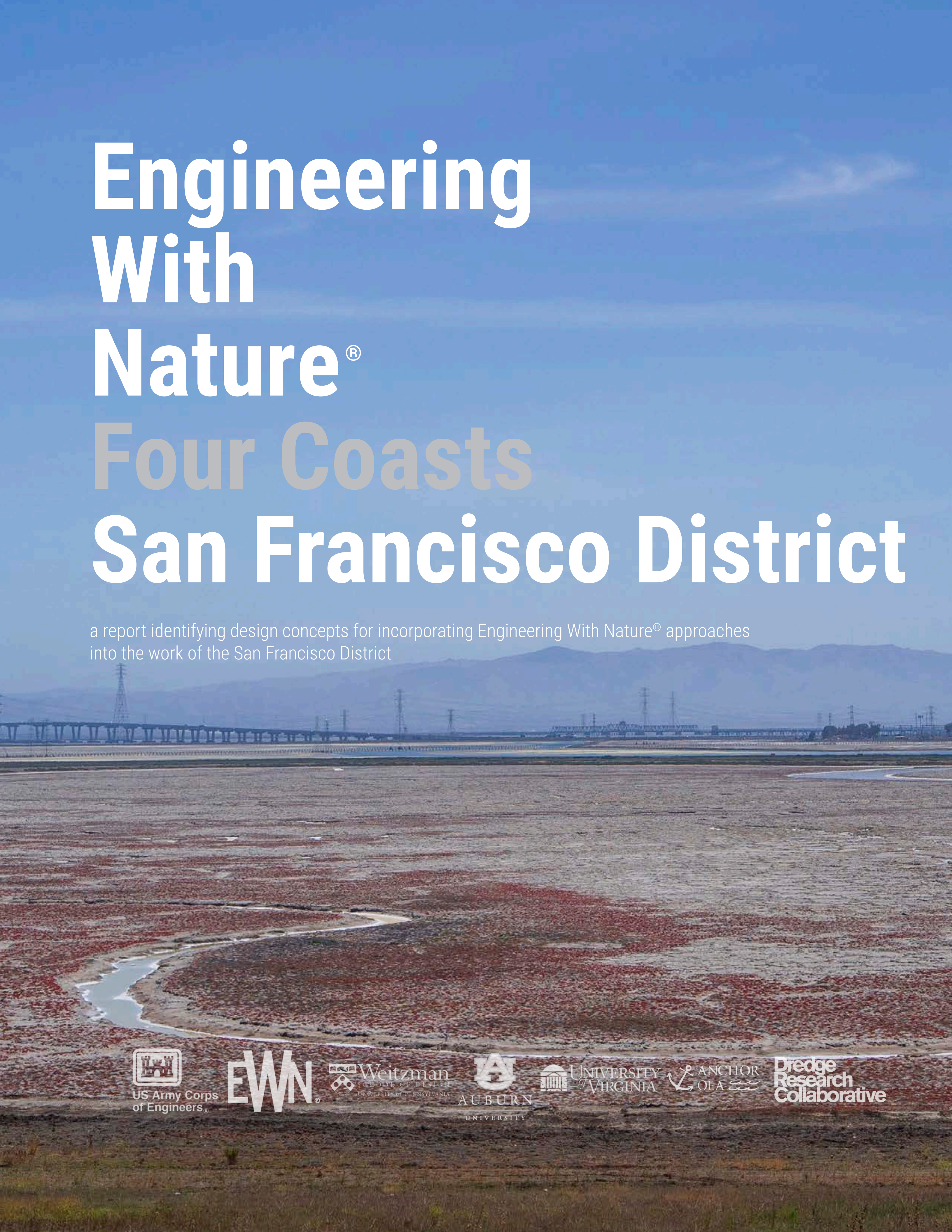
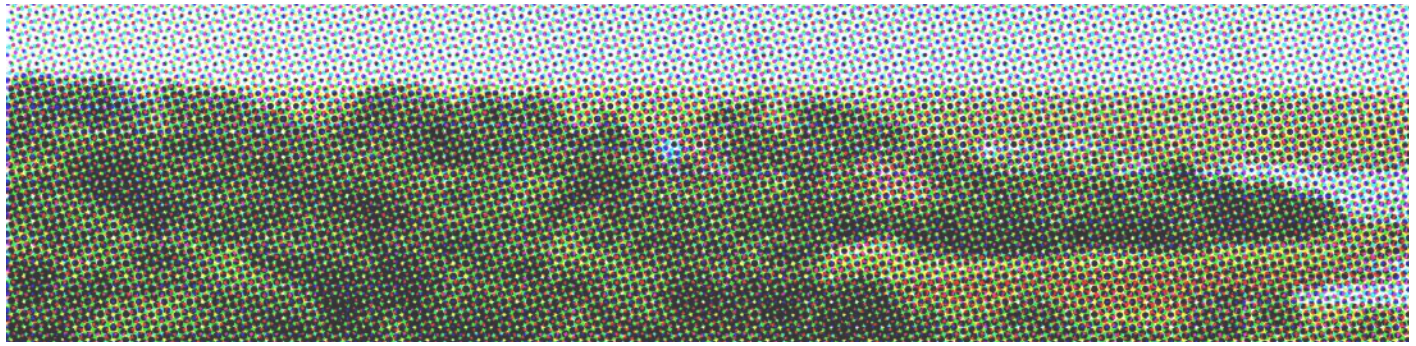


Engineering With Nature®
Four Coasts
San Francisco District

a report identifying design concepts for incorporating Engineering With Nature® approaches into the work of the San Francisco District

US Army Corps of Engineers®
EWN®
Weitzman School of Design University of Pennsylvania
Auburn University
University of Virginia
Anchor QEA
Dredge Research Collaborative



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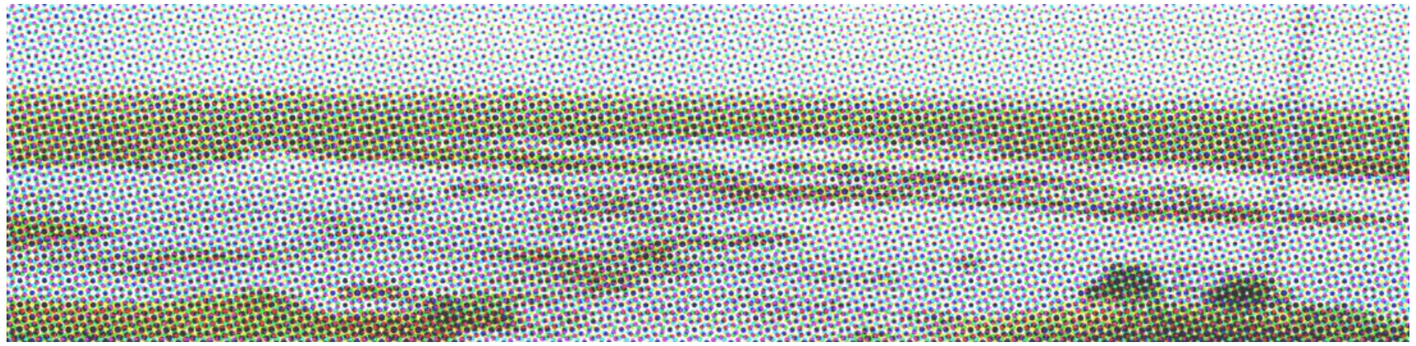

This report covers findings from research cooperative agreement W912HZ-20-2-0049 **Incorporating Engineering With Nature® (EWN®) and Landscape Architecture (LA) Designs into Existing Infrastructure Projects**, an agreement between the **U.S. Army Engineering Research Development Center** (ERDC) and **Auburn University** (AU).

This report has been prepared by the investigators at **Auburn University**, the **University of Virginia**, and the **University of Pennsylvania** in collaboration with **AnchorQEA** and consultants from the **Dredge Research Collaborative**; it also incorporates research and insights from ERDC's **Engineering With Nature®** project team.

Engineering with Nature® is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes.

Sustainable development of water resources infrastructure is supported by solutions that beneficially integrate engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management.

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. Its 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.

http://engineeringwithnature.org
http://dredgeresearchcollaborative.org/

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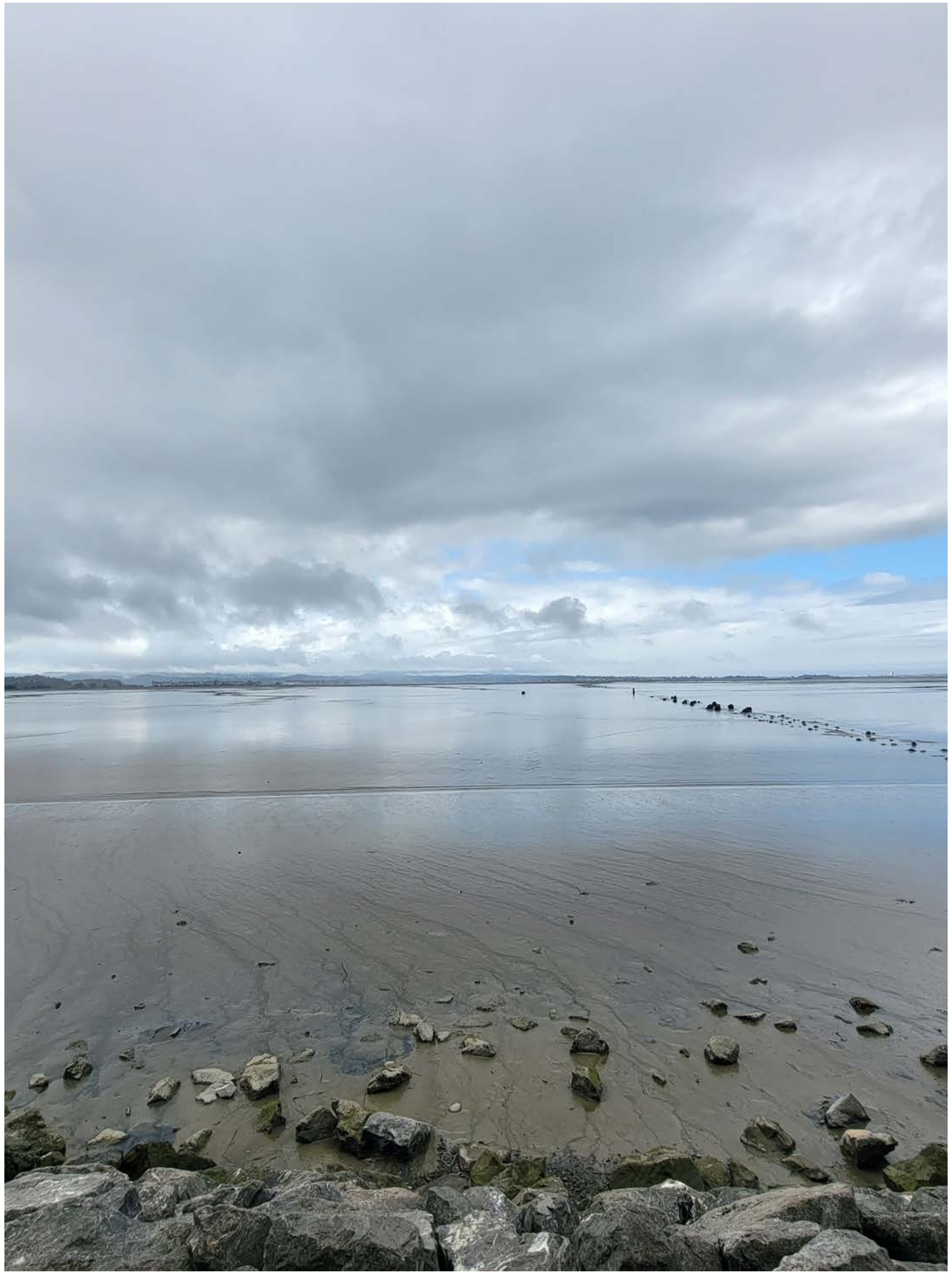


Executive Summary

The San Francisco District (SPN), which spans 900 miles of shoreline and includes three coastal watershed sub-regions, serves a population of over 6.7 million people, many of whom live near or around the San Francisco Bay, the largest estuary system on the Pacific Coast and home to a $68 billion maritime industry (itself about one-tenth of the region's GDP). In recent years, the District has overseen some of the largest wetland restoration projects on the West Coast, thus leading in efforts to beneficially reuse dredged material. However, climate change threatens the livelihood, economies, and ecologies of the region, as flooding events intensify and sea level rises. These risks were sadly underlined during the preparation of this report by serious flooding in March 2023 along the Pajaro River, which has been one of our study sites. A comprehensive, regional, and long-term approach is necessary to both adapt to and mitigate climate change impacts in the region. Through its established mission of navigation, flood risk mitigation, and ecosystem restoration, as well as its role as an EWN Proving Ground district, the San Francisco District is well-positioned to lead the way in addressing these issues. The following report documents five projects that incorporate innovative Engineering With Nature designs to support economic, ecological, and social resilience. SPN has a long history of innovation in EWN, and the included projects showcase both concepts developed by SPN and new concepts developed by the research team to support SPN's ongoing work.

The work summarized in this EWN-LA Four Coasts SPN report occurred between January 2022 and September 2023. The report is primarily organized by coastal watershed sub-regions: Northern Basin, San Francisco Bay, and Central Basin. After initial research and meetings with the EWN team and in coordination with the San Francisco District, five sites were selected that exemplify the particular challenges and opportunities within the three sub-regions. This initial research into the regional characteristics, including the specific issues and opportunities, and the subsequent site selection are summarized in *Part 1: San Francisco District*. *Part 2: Northern Basin* delves into the Northern Basin Region, specifically the Humboldt Bay Sediment Choreography Plan. *Part 3: San Francisco Bay* describes the San Francisco Bay estuary and three sediment-focused strategies, including strategic sediment movement in Marin County, strategic sediment placement in Eden Landing, and shoreline resilience in South Bay. Finally, *Part 4: Central Basin* relocates to the Central Coastal Basin, focusing on flood risk management and ecological complexity in the Pajaro floodplain expansion project. Collectively, these projects document SPN's current deployment of EWN and show some examples of how future EWN work could continue to evolve in the district.

Introduction

Engineering With Nature® (EWN) is a program based out of the USACE Engineer Research and Development Center (ERDC). This report has been produced as part of a larger collaborative research project, referred to as the Four Coasts project. In this project, the engineering firm Anchor QEA and a team of landscape architects affiliated with the Dredge Research Collaborative (DRC) were tasked by the USACE ERDC as part of the EWN program to work with Proving Ground districts along the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, and Great Lakes, collectively known as the four coastal regions, to identify key nature-based infrastructure opportunities. These collaborative partners selected three to five representative projects on each coast, with the projects ranging from the integration of natural and nature-based features (NNBF) to existing work to the advancement of new EWN opportunities that the project team has developed. This report documents in detail five such projects located within the bounds of the USACE San Francisco District (SPN).

EWN is the philosophy behind the "intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes" (Engineering with Nature).

In the EWN approach, sustainable development of water resources infrastructure is supported by solutions that beneficially integrate engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management.

EWN outcomes are "triple-win," which means that they systematically integrate social, environmental, and economic considerations into decision-making and actions at every phase of a project to achieve "innovative and resilient solutions" that are more socially acceptable, viable, equitable, and ultimately, more sustainable.
Four Coasts builds on and expands four years of earlier work in the EWN-LA initiative, which has engaged new and existing water resources infrastructure projects in districts ranging from Alaska to Florida, with the aim of supporting the deployment of EWN approaches through the application of the methods and knowledge of landscape architecture. As a field, landscape architecture is presently concerned with many of the same issues of infrastructural performance and potential that EWN is currently pursuing, including the re-imagination of traditional infrastructure to meet more diverse criteria encompassing engineering functions, ecological value, cultural significance, and aesthetic benefits (Spirn, 1984; Mossop, 2006; Orff, 2016; Belanger 2017). The landscape architecture work of this initiative has been led by members of the DRC, including Sean Burkholder, Brian Davis, Rob Holmes, Justine Holzman, Brett Milligan, and Gena Wirth, together with ORISE Fellow Tess Ruswick, supported by colleagues and students at our respective universities, which, over the lifespan of the initiative so far, have been Auburn University, the University of Pennsylvania, the University of Toronto, and the University of Virginia.

For the current Four Coasts project, the DRC landscape architects have worked collaboratively with engineers at Anchor QEA to ensure concepts are based on sound engineering principles. This collaboration allows for the development of unique infrastructure concepts through an iterative process of concept development, technical assessment, and refinement. Broadly, the engineers on the research team bring a precise and analytical approach based on values that can be quantified, while the landscape architects offer a synthetic approach that considers cultural values alongside environmental characteristics. This collaborative integration of engineering and landscape architecture promotes a holistic alignment in the development and visualization of EWN design concepts.

PART 1

SAN FRANCISCO DISTRICT

SAN FRANCISCO DISTRICT

DISTRICT OVERVIEW AND PROJECT SELECTION

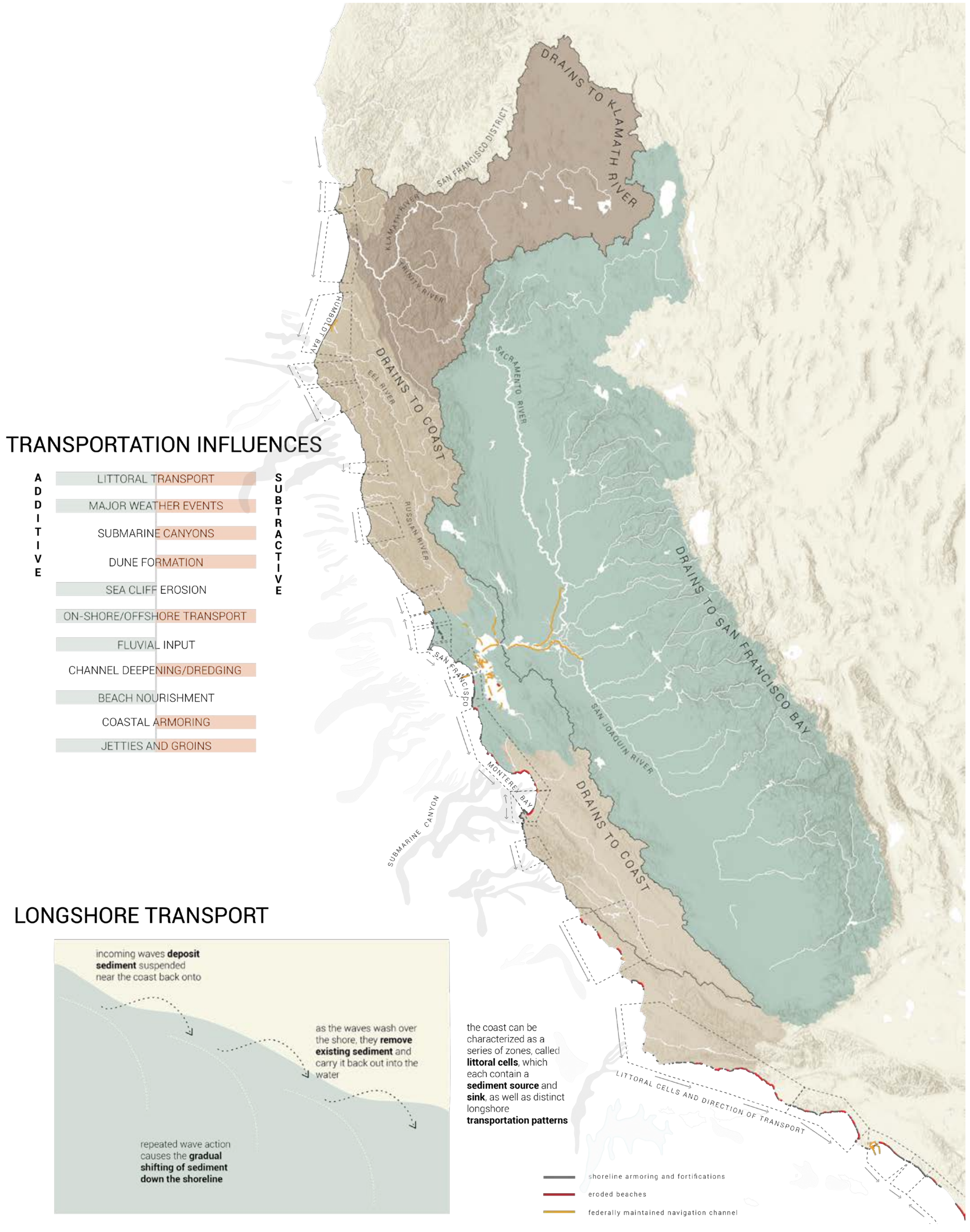
The San Francisco District (SPN) was established in 1866 and spans more than 600 miles along California's Pacific Coast. The District originally extended across the entire Pacific Coast west of the American Rocky Mountains. Today, SPN, located within the South Pacific Division, covers an area along California's coast stretching from the south-central region near Big Sur to just south of the border between California and Oregon. Due to its broad reach, the District had a hand in the development of almost every major fort and harbor at strategic points along this region.

SPN has an extensive history of work that is aligned with the EWN mission and values, an alignment that is recognized by its status as a Proving Ground for EWN projects. One such example of EWN at work within SPN is the substantial placement of dredged material to restore wetlands at locations like the Hamilton Wetlands, aligning the district's navigational dredging mission with both its ecosystem restoration mission and the broader goals of bayland restoration established by the Bay Area as a whole. Such placement accelerates natural processes of sediment deposition and aids in the proliferation of productive wetland habitat. With a set of diverse landscapes, communities, and vulnerabilities, the San Francisco District is poised to continue to collaborate with partners to evaluate and employ EWN methods and further the EWN mission.

In this introductory section, we describe some of the general conditions of the district as a whole, before discussing specific EWN opportunities in later sections.

1 DISTRICT OVERVIEW
COASTAL BASINS

Within this region, there are three distinct hydrographic zones: the Northern Coastal Basin, the San Francisco Bay Area, and the Central Coastal Basin. The Northern Coastal Basin region consists of mountains and hills extending to the ocean and contains multiple fluvial systems. This region is heavily forested, accounting for about half of the commercial forest land in California. To the south, the San Francisco Bay Area spans 6,100 square miles, including four distinct but interconnected bays: Lower San Francisco, San Francisco proper, San Pablo, and Suisun. This region includes many of the largest ports in California and the United States, including, but not limited to, the Ports of San Francisco, Oakland, Redwood City, and Richmond. The waterborne commerce through these and other Bay Area ports accounts for almost half of the waterborne commerce of the entire state. Finally, south of the Bay Area, the Central Coastal Basin consists of mountainous and rugged terrain that extends to the edge of the ocean. This area covers approximately 11,450 square miles.



TRANSPORTATION INFLUENCES

	ADDITIVE	SUBTRACTIVE
LITTORAL TRANSPORT	●	●
MAJOR WEATHER EVENTS	●	●
SUBMARINE CANYONS		●
DUNE FORMATION		●
SEA CLIFF EROSION	●	
ON-SHORE/OFFSHORE TRANSPORT	●	●
FLUVIAL INPUT	●	
CHANNEL DEEPENING/DREDGING		●
BEACH NOURISHMENT	●	
COASTAL ARMORING		●
JETTIES AND GROINS	●	●

LONGSHORE TRANSPORT

incoming waves **deposit sediment** suspended near the coast back onto

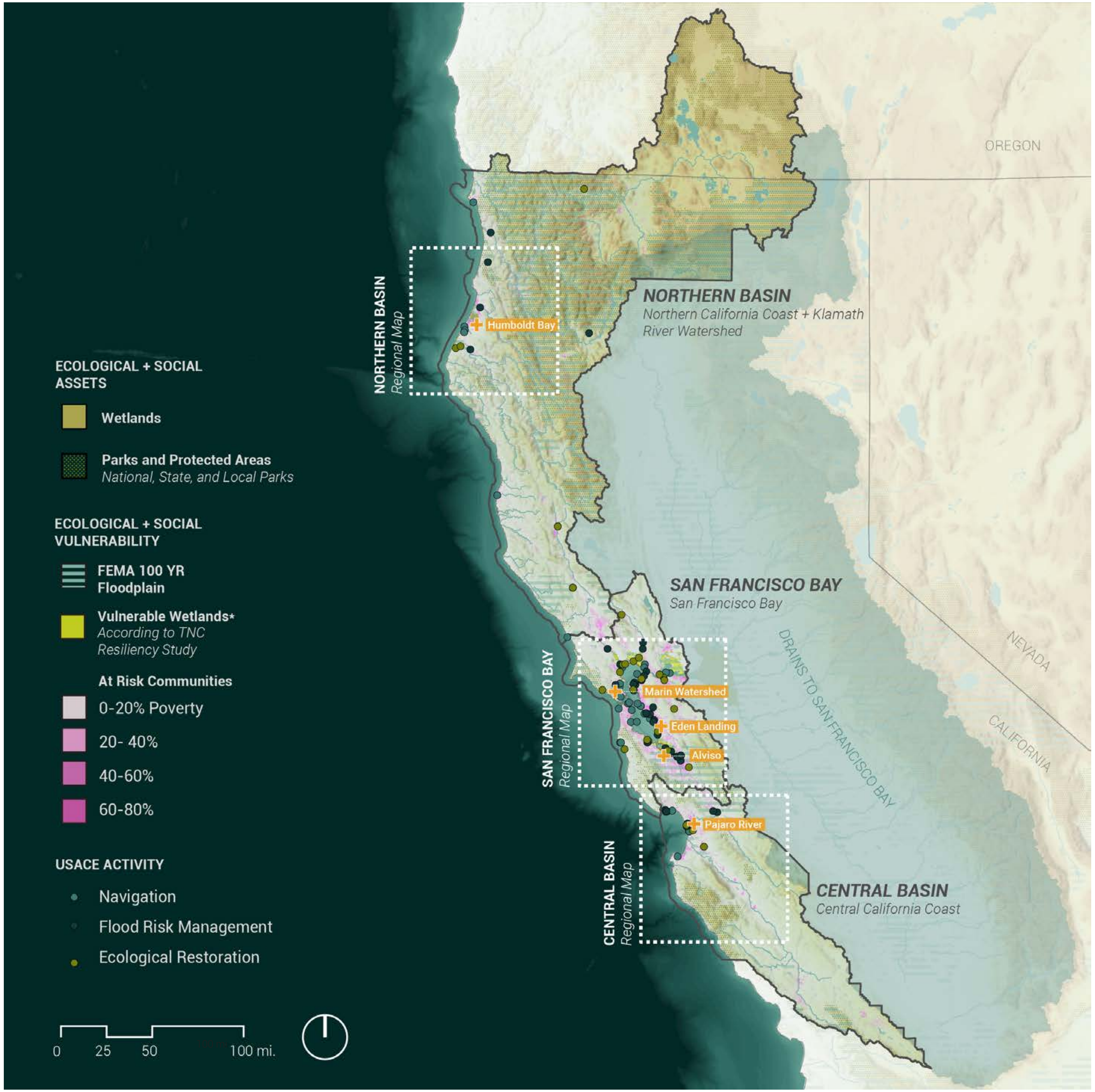
as the waves wash over the shore, they **remove existing sediment** and carry it back out into the water

repeated wave action causes the **gradual shifting of sediment down the shoreline**

the coast can be characterized as a series of zones, called **littoral cells**, which each contain a **sediment source** and **sink**, as well as distinct longshore **transportation patterns**

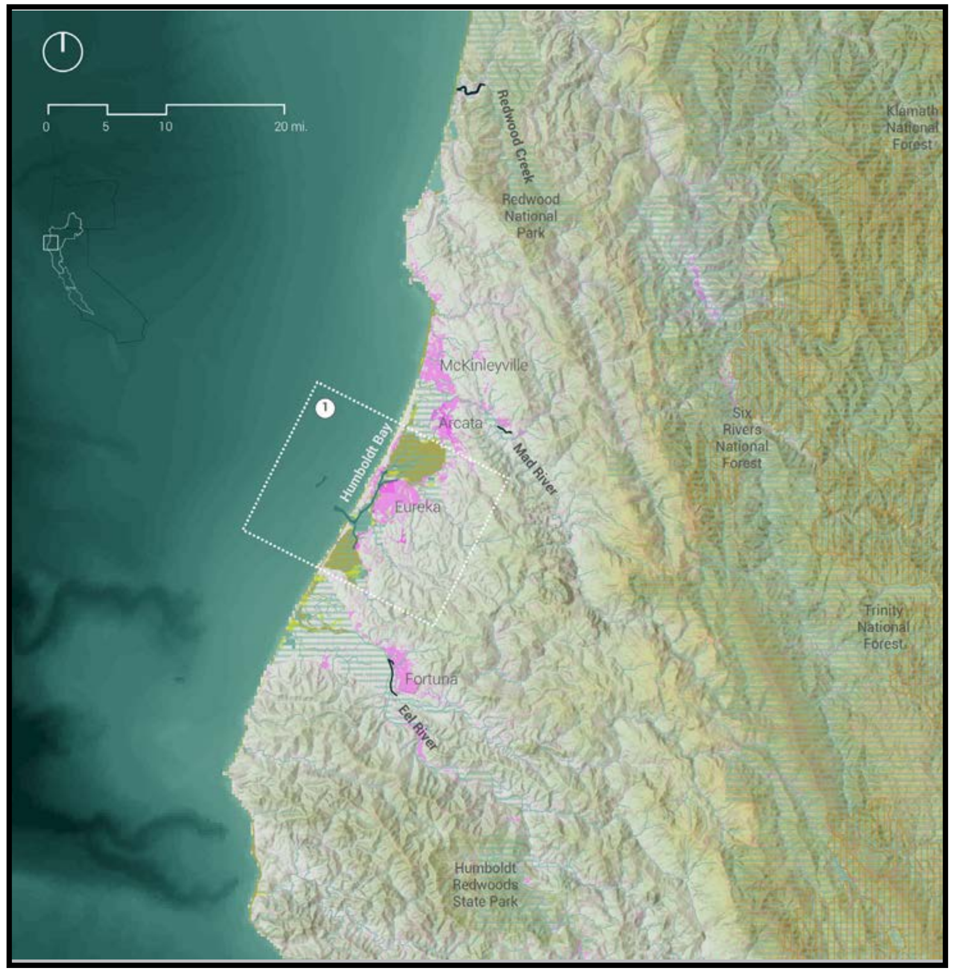
1 DISTRICT OVERVIEW
FOCUS PROJECTS

Five projects were selected for their diversity in terms of types and scales of nature-based infrastructures, timelines, phases, objectives, and representation of the aforementioned regions of the SPN District. Each seeks to highlight forward-thinking and innovative design concepts, some already in development by SPN, others building from the planning and operations of the District. These selected projects included a long-term Humboldt Bay Sediment Choreography Strategy (an intentional sequence of sediment strategies; see "Choreographing Sediment" in Holmes, Milligan, and Wirth 2024) in the Northern Basin region, three sediment-focused strategies for building up the Baylands in the San Francisco Bay Area, and a floodplain expansion project on the Pajaro River in the Central Coastal Basin. The following sections document these projects in detail, moving from north to south.



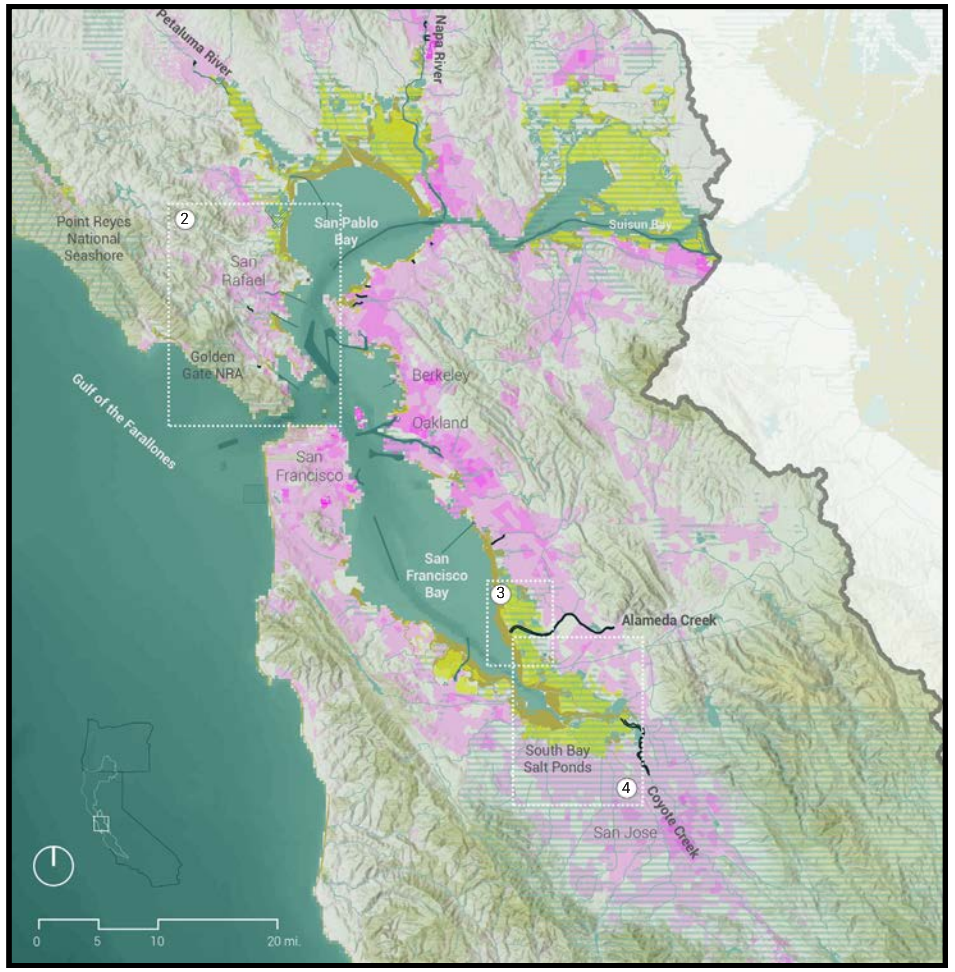
1 DISTRICT OVERVIEW
REGIONS

NORTHERN BASIN



① **SEDIMENT CHOREOGRAPHY** | HUMBOLDT BAY, CA

SAN FRANCISCO BAY

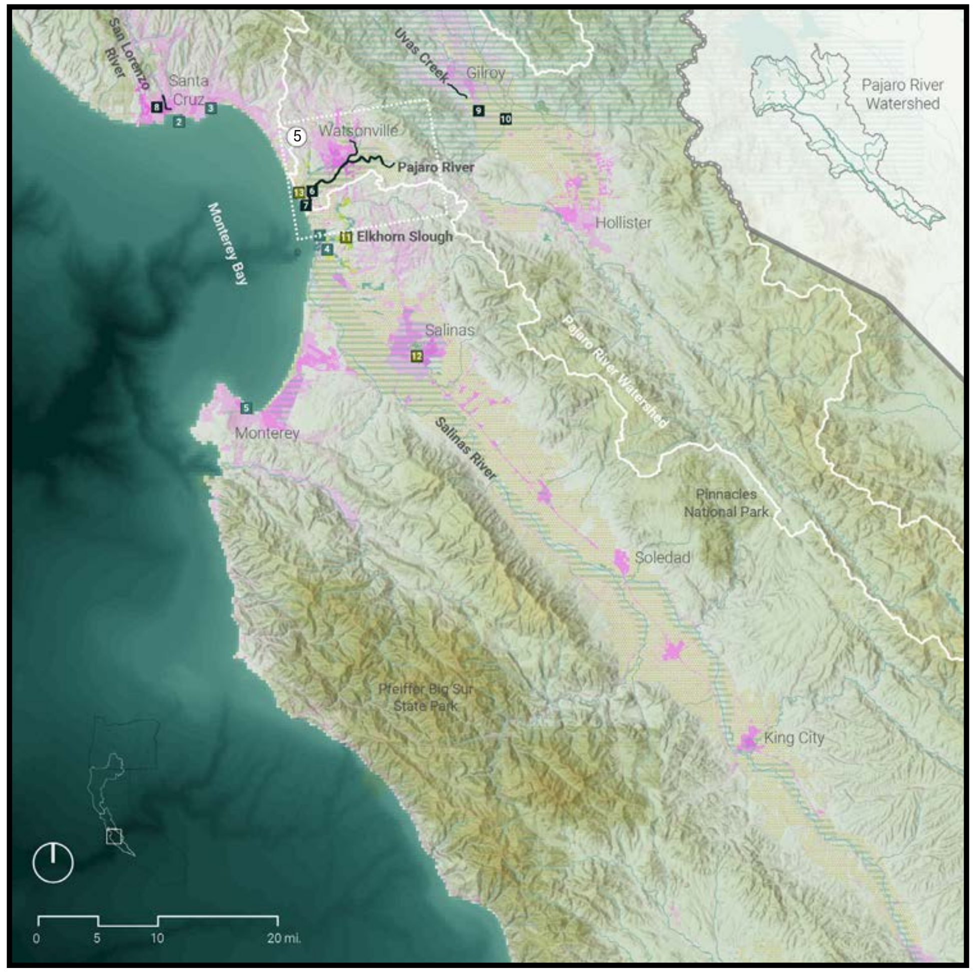


② **STRATEGIC SEDIMENT PULSE DREDGING**| MARIN WATERSHED, CA

③ **STRATEGIC SEDIMENT PLACEMENT** | EDEN LANDING, CA

④ **SOUTH SAN FRANCISCO BAY SHORELINE** | ALVISO, CA

CENTRAL BASIN



⑤ **FLOODPLAIN EXPANSION**| PAJARO RIVER, CA

PART 2

NORTHERN BASIN

NORTHERN BASIN
OVERVIEW

The northern section of the San Francisco District is predominantly forest, covering coastal areas and more mountainous inland regions. Coastal Redwood forests dominate within a narrow coastal belt extending not more than 50 miles inland. These famous ecosystems contain some of the tallest and oldest trees in the world and are kept moist by coastal fog and heavy winter rains. Inland, the rugged terrain of the Klamath Mountain Range supports extremely biodiverse temperate coniferous forests. Due to the presence of unique serpentine soils and a history of climatic stability, the mountainous ecoregion is home to many endemic species not found anywhere else in the world. The Klamath, Trinity, and Eel River Watersheds, among others, hydrologically connect the coast to the mountains, providing habitat for species such as salmon and trout, whose life cycles also connect mountains and coast.

Along the Pacific Coast north of San Francisco, several state and national parks protect sections of old-growth Coastal Redwood forest, including Redwood National Park and Humboldt Redwoods State Park. These public lands are accessible for hiking, camping, and, in some instances, boating and swimming. Much of the more inland temperate forests are protected by large connected National Forests, including Klamath National Forest, Six Rivers National Forest, and Shasta National Forest. These forests also welcome public recreation, such as hiking, camping, and fishing. The Pacific Crest Trail (PCT) passes through these National Forests, bringing hundreds of thru-hikers to the area each year.

The northern coast of California faces several social and environmental risks related to climate change. Although low-to-moderate intensity fires are a normal part of the region's ecosystem, high-intensity fires are increasingly becoming a threat to forest communities due to climate change-induced extreme heat and drought, which is compounding a history of forest fire suppression practices. These fires can lead to mountain slope failure and erosion issues, which creates downslope sediment transfer into the watershed. Rising sea levels are also causing erosion and threatening beaches and coastal communities, including the City of Eureka adjacent to Humboldt Bay. Many counties along California's coast have higher than average poverty rates, making them more vulnerable to these climate-related risks.

1 NORTHERN BASIN
USACE PROJECT FOCUS

The USACE manages several projects related to the watersheds of the northern California coast. Their work ranges from dams and levee maintenance for flood risk reduction, beach nourishment for erosion control, navigation dredging, and ecological restoration activities. Humboldt Bay is a significant hub of USACE activity, where California's northernmost deep-water port is supported by multiple projects aimed at maintaining navigable channels and managing shoaling and erosion.

ECOLOGICAL + SOCIAL VULNERABILITY

- ▤ **FEMA 100 YR Floodplain**
- 🟨 **Vulnerable Wetlands*** *According to TNC Resiliency Study*
- ▥ **Recent Large Fires** *According to CA Dept. of Forestry and Fire Protection*

Social Vulnerability Index

- ■ 0-20% Poverty
- ■ 20- 40%
- ■ 40-60%
- ■ 60-80%

ECOLOGICAL + SOCIAL ASSETS

- ■ **Wetlands**
- ▦ **Parks and Protected Areas** *National, State, and Local Parks*

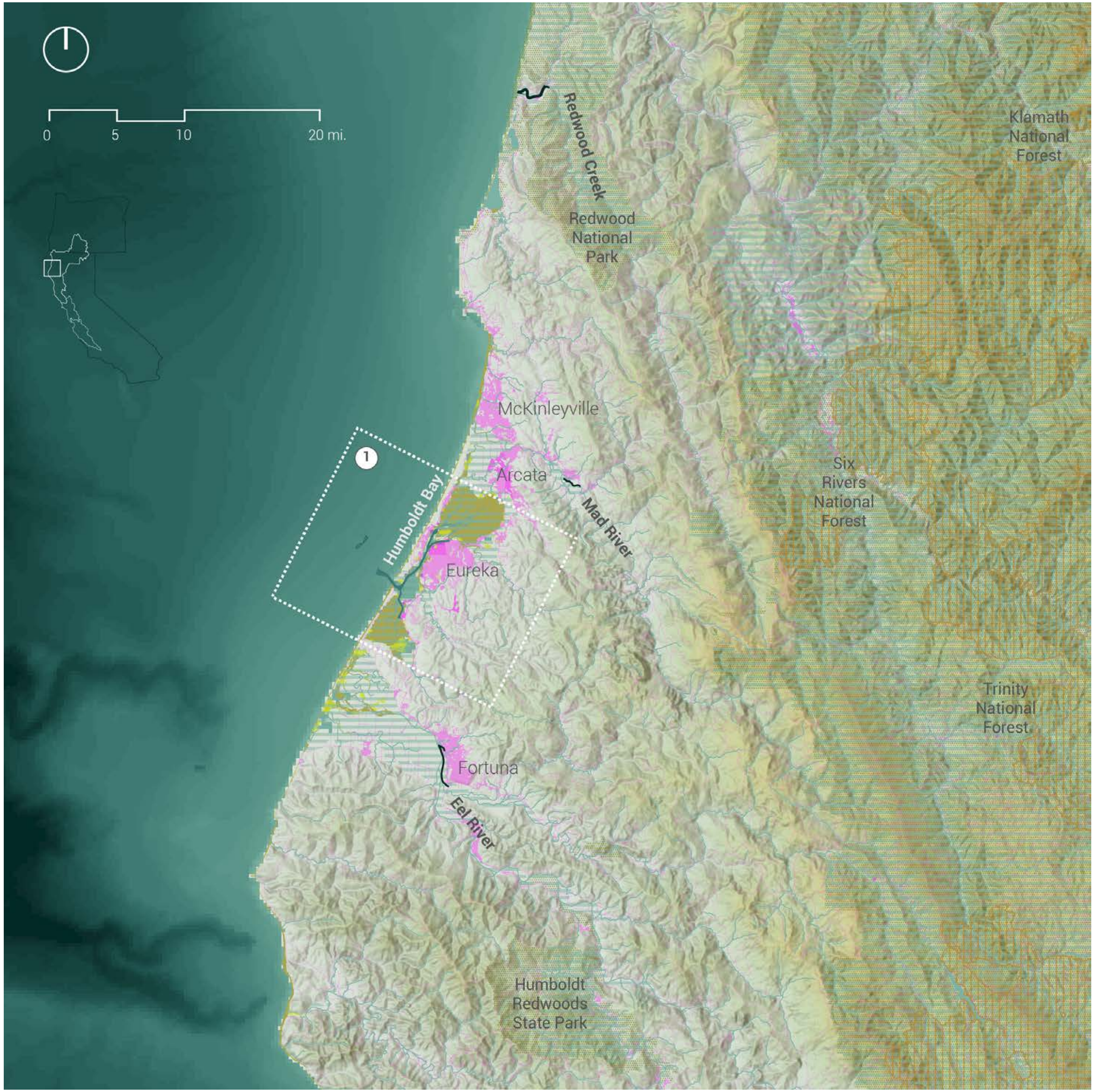
EWN-LA FOCUS FOCUS AREAS

- ① **Humboldt Bay** Sediment Choreography

USACE PROJECTS + OPERATIONS

- ■ **USACE Channel Areas**
- ▨ **USACE Placement Areas**
- — **USACE Levees**

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index- Overall.



SEDIMENT CHOREOGRAPHY
HUMBOLDT BAY

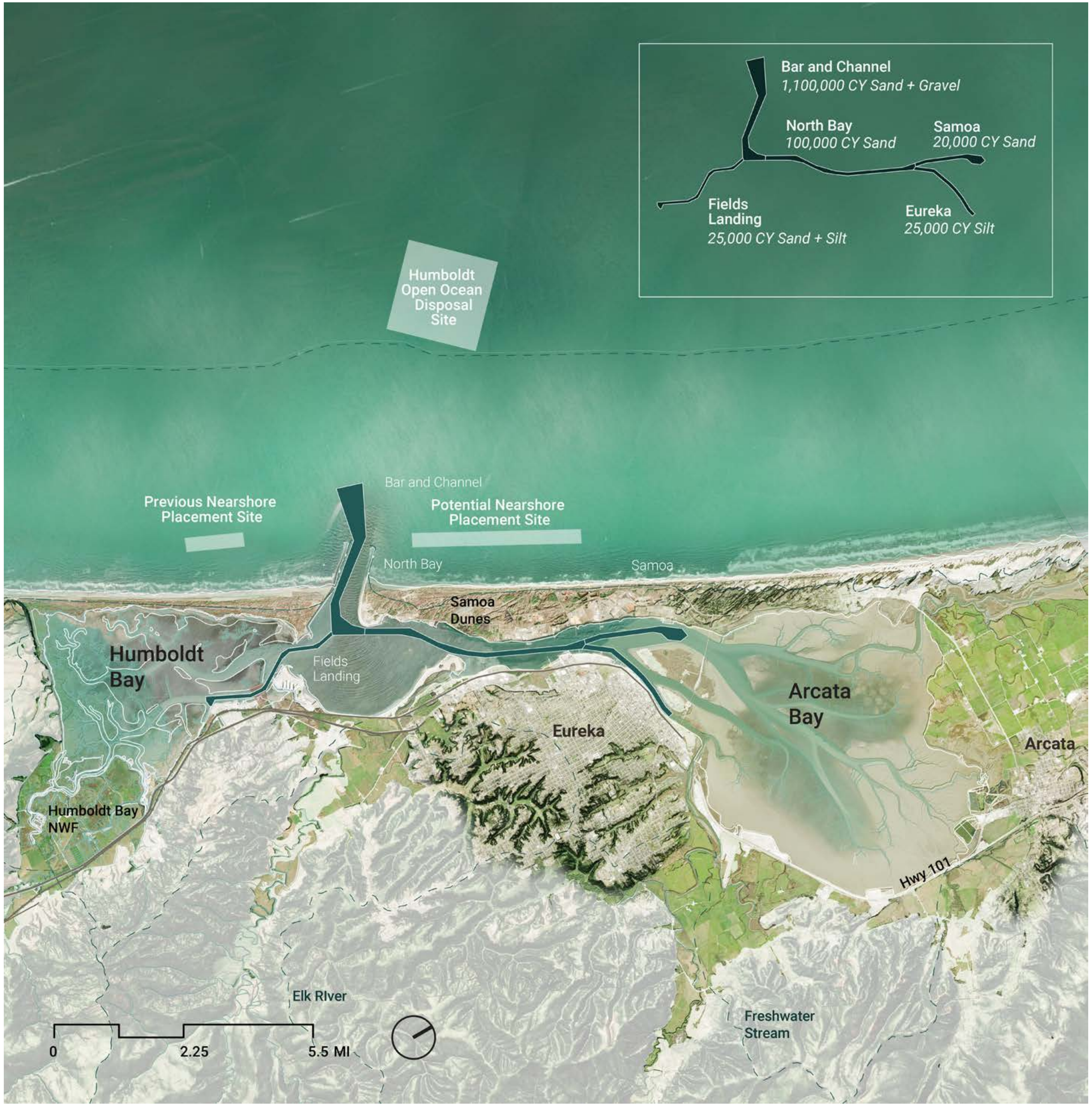
The Humboldt Bay region centers on the cities of Humboldt and Arcata, approximately 80 miles south of the California-Oregon border. This region is suffering from the loss of several habitats, the endangerment of coastal infrastructure, and accompanying emerging community vulnerabilities. This loss will continue accelerating with future sea level rise trends (Laird, 2018). Approximately 1 million CY of sediment is dredged from Humboldt Bay annually, and this dredged material is typically placed offshore with no discernible ecological benefit. In 2017, SPN released a report that outlined different placement options around the bay, including placement within the littoral zone, coastal dune enhancement, tidal marsh restoration, coastal infrastructure protection, dike rehabilitation, and recreational beaches within the bay (Coastal Regional Sediment Management Plan, 2017). Currently, there are plans for a pilot nearshore placement project just north of Humboldt Bay inlet (Humboldt Harbor and Bay Operations and Maintenance Dredging, 2021); however, the capacity for the pilot project is limited, and there are opportunities for more beneficial use projects elsewhere in the bay.

Careful choreography of beneficially used sediment can help to overcome the challenges posed by the logistical scale of operations in the bay while addressing issues produced by rapidly rising sea levels. The following "choreography", the intentional design of movements and steps to achieve these goals, seeks to build off the 2017 report to outline a phased and multi-faceted approach for utilizing dredged material around the bay for coastal infrastructure, wetland protection, beach nourishment, and habitat management. To accomplish these objectives, this sediment strategy outlines a combination of employed BU techniques, including feeder berms, thin layer placement, and direct placement, each requiring specific design and preparation to ensure maximum effectiveness. This strategy builds upon the options in the previous SPN report to outline a sediment choreography tied to dredging cycles, types of dredged material, site-specific requirements, and anticipated climatic risks. It aims to describe this choreography on a multi-decadal scale, putting material placement strategies and operational logistics into the context of long-term environmental change. Doing so for a region as extensive and dynamic as Humboldt Bay is a richly complicated undertaking, and this choreographic plan, which builds on existing District planning, outlines and begins to further study the issues and opportunities involved. Further efforts will be needed to advance concepts such as assessment of ecological impacts, hydrodynamic modeling, characterization of proposed placement areas to ensure placement of 'like on like' material, and cost estimating. In particular, the relative rates of sea level rise and subsidence versus accretion and habitat-building through beneficial use need to be carefully studied, in order to understand where sediment supply is adequate for adaptation purposes, and where other measures, including land use change, will need to be considered.

1 HUMBOLDT CONTEXT

SITE DESCRIPTION

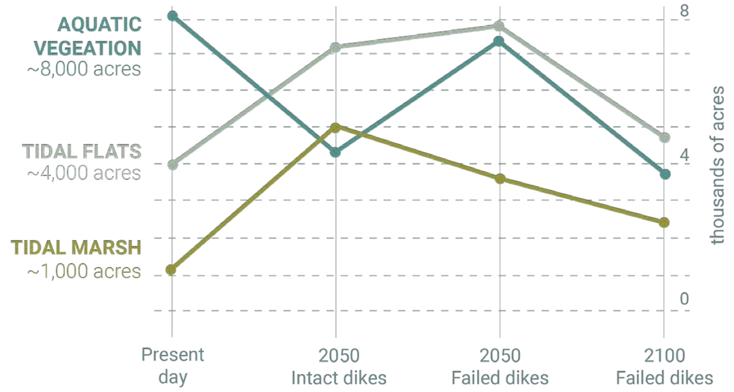
The sediments in Humboldt Bay are derived from three primary sources: fluvial runoff, oceanic (marine) input, and biological activity. (Pequegnat 1992). Fluvial runoff and biological activity essentially provide input directly to the bay. In contrast, oceanic input comes from adjacent watersheds, including the Eel and Mad Rivers, contributing sediment to the nearshore environment. Such nearshore sediment arrives in the bay through the strong forces of tidal interchange at the bay's mouth. During periods of high river discharge, the nearshore currents trend northerly, carrying the Eel River plume into the bay during flood tides, and some of these sediments settle in the bay during slack tides. The Mad River also contributes sediments similarly during periods of southward-flowing nearshore currents. However, the sediment load of the Mad River is only about 10% of that of the Eel River. Because the periods of southward flow do not coincide with periods of high river discharge, Mad River-sourced sediments to the bay are considered relatively low (Pequegnat, 1992). Compared to the Eel and Mad Rivers, the rivers and creeks that drain directly into Humboldt Bay have small watersheds and contribute a much smaller volume of sediment, most of which is finer material, unlike the sand and gravels in the nearshore



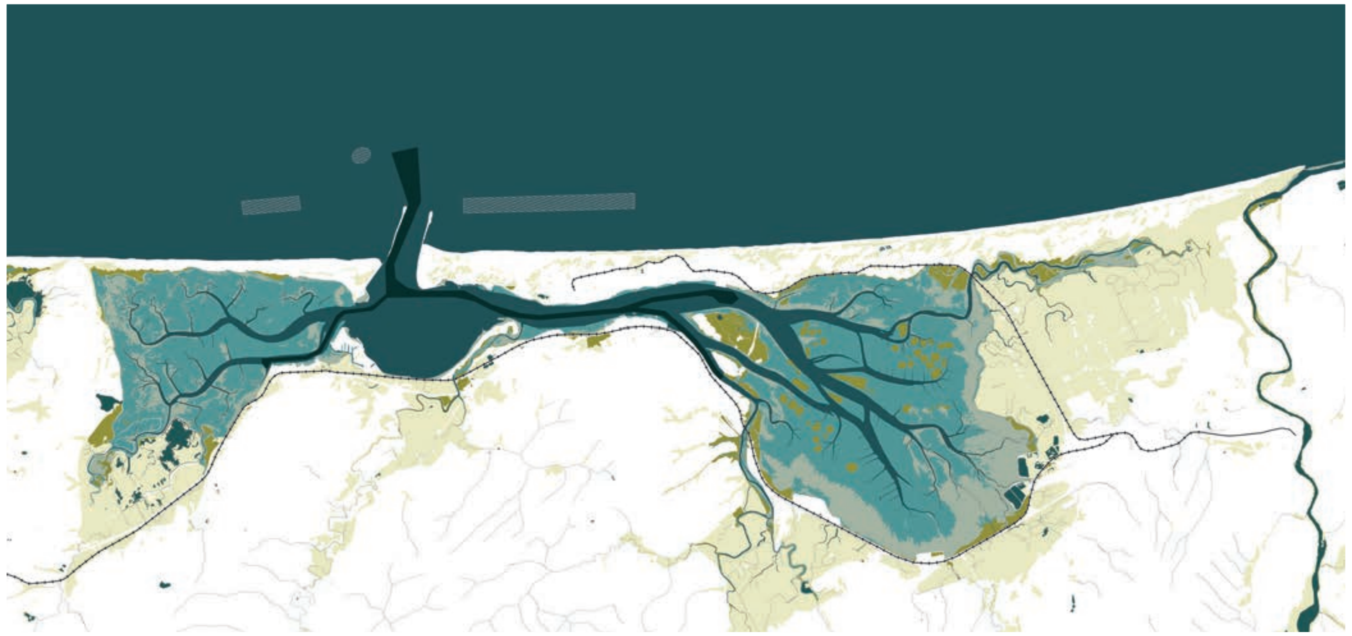
Dredging happens primarily at and near the entrance channel, though there are also smaller channels and basins within the bay proper. Of the total dredged volume removed, 90% is sand-sized or larger, and less than 10% is fines. Starting in 1990, that dredged material was placed outside of the Littoral Cell at the Humboldt Open Ocean Disposal Site (HOODS), the center of which is approximately 3.5 mi from the channel entrance (Coastal Regional Sediment Management Plan 2017). Repeated testing shows sediment from the Bar and Entrance Channel and the North Bay Channel exceeds 95% sand and gravel. Sediment from the Samoa Channel and its Turning Basin is greater than 85% sand and gravel. The Eureka Channel, Fields Landing Channel, and Turning Basin sediments are between 25 and 80% sand and gravel (Coastal Regional Sediment Management Plan 2017). Although there have been insufficient funds in recent years, when funding is available, USACE also dredges fine sediment from interior channels on the order of 100,000 CY per year. The fine sediment is also placed at HOODS. USACE annually dredges the Bar and Entrance Channel through the ebb shoal bar and between the two jetties. Until recently, the federal channels inside the bay were dredged annually, though now they are dredged less frequently because of funding limitations.

Multiple locations around the bay are vulnerable to rising water levels and land subsidence. Along the north bar, wave, and current erosion drive shoreline erosion. Within Arcata Bay, marsh and mudflat loss is detrimental to the environment by reducing habitat for aquatic and terrestrial species and impacting civic services, as portions of the wetland are incorporated into an innovative wastewater treatment facility. Highway 101, which runs adjacent to the bay, is highly vulnerable to RSLR and coastal erosion. It should be noted that a railroad corridor runs between Highway 101 and the bay, which could pose logistical challenges and potential opportunities to transport material. Within South Bay, the diking of wetlands for agriculture and ranching by Euro-American settlers was followed by a long period of subsidence, which has left these substantial wetlands well below marsh plane elevation, disconnected from tidal processes, and highly vulnerable to breaching.

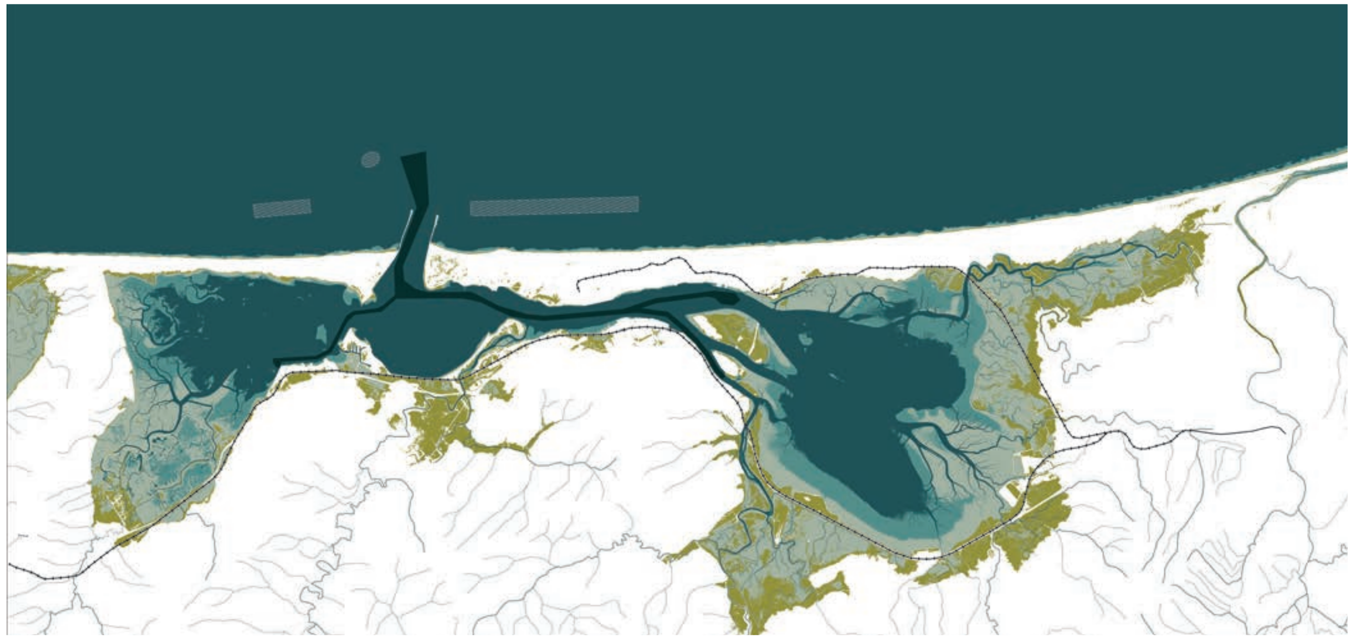
1 HUMBOLDT CONTEXT
SLR RISE + WETLANDS



■ Deep Water
■ Aquatic Vegetation
■ Tidal Flats
■ Tidal Marsh
■ Freshwater Wetlands



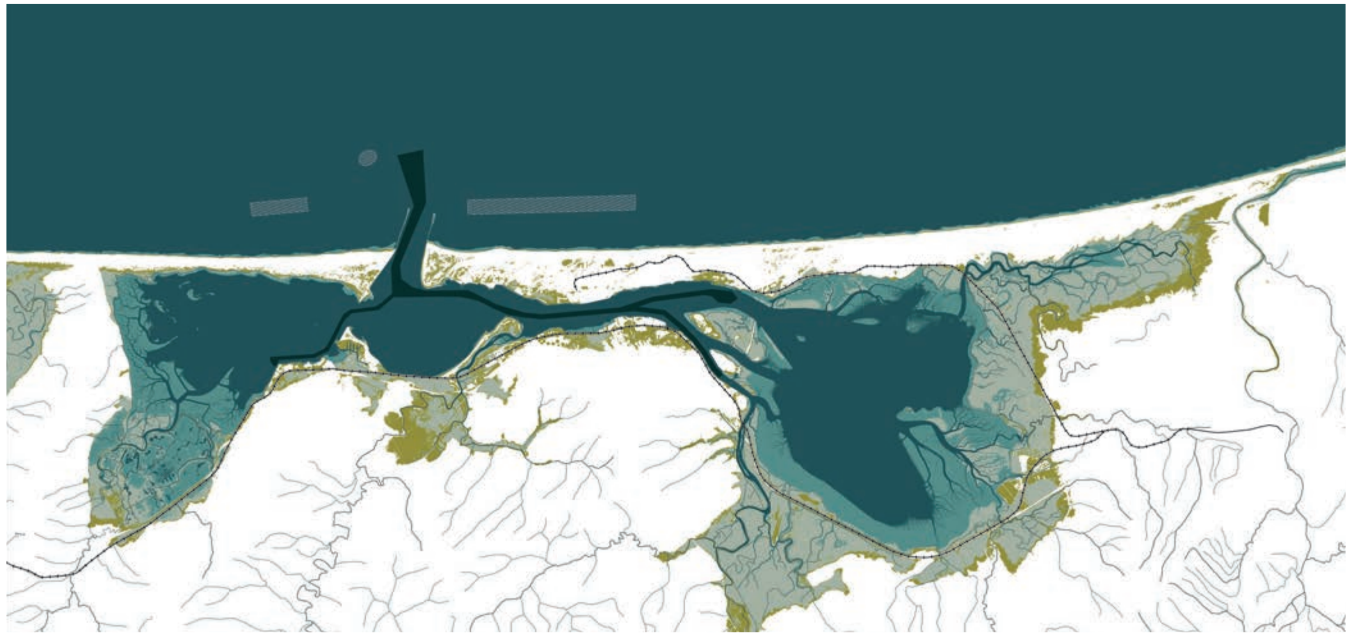
2020



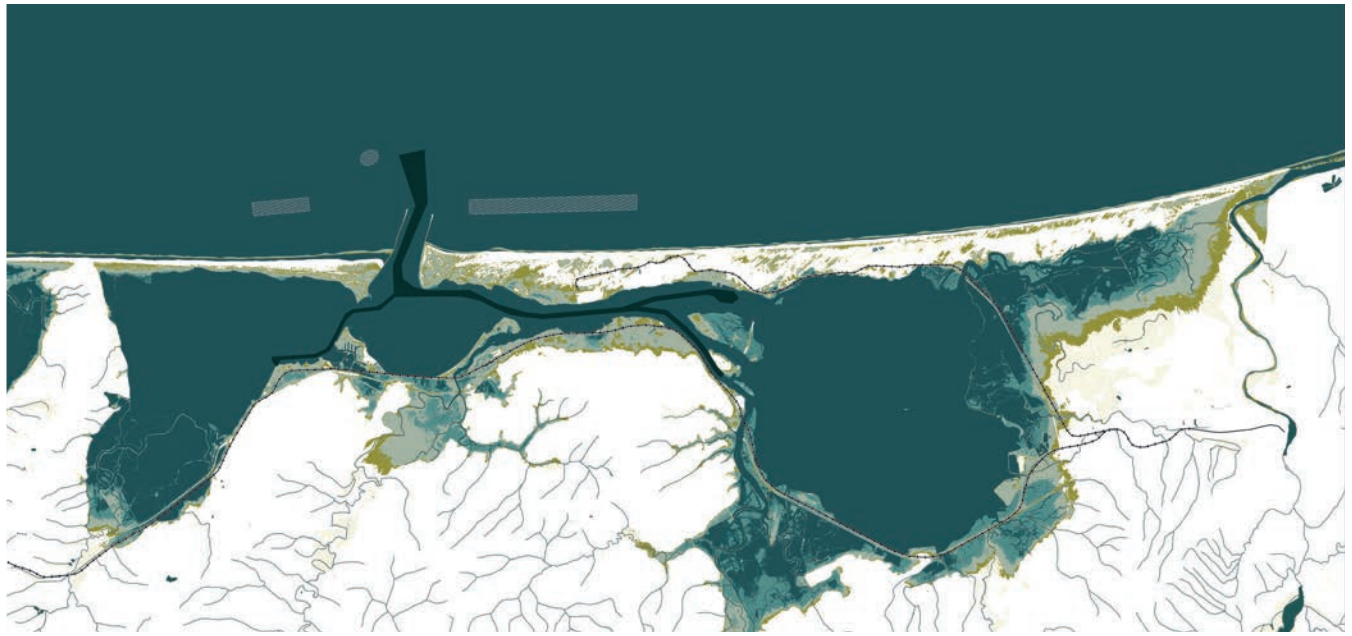
2050 WITH INTACT DIKES

Like most regions with substantial tidal habitats, the Humboldt Bay region faces the prospect of significant change in the coming decades.

The series of drawings below examine marsh habitat loss due to rising sea levels. The following drawings used the high projection for sea level rise in Humboldt Bay by Northern Hydrology and Engineering (NHE) for the North Spit tide gauge: 2030 (.9 ft), 2050 (1.9 ft), 2100 (5.4 ft) (NHE, 2014; Laird, 2018). The drawings did not consider supplemental beneficial use, natural sediment accretion, or subsidence. There is no projection of a scenario with intact dikes in 2100, because with this SLR rate, even intact dikes would be submerged in 2100. Ultimately, these drawings highlight the scale of the potential transformation faced by the diked and subsided baylands in both Humboldt and Arcata Bays.



2050 WITH FAILED DIKES



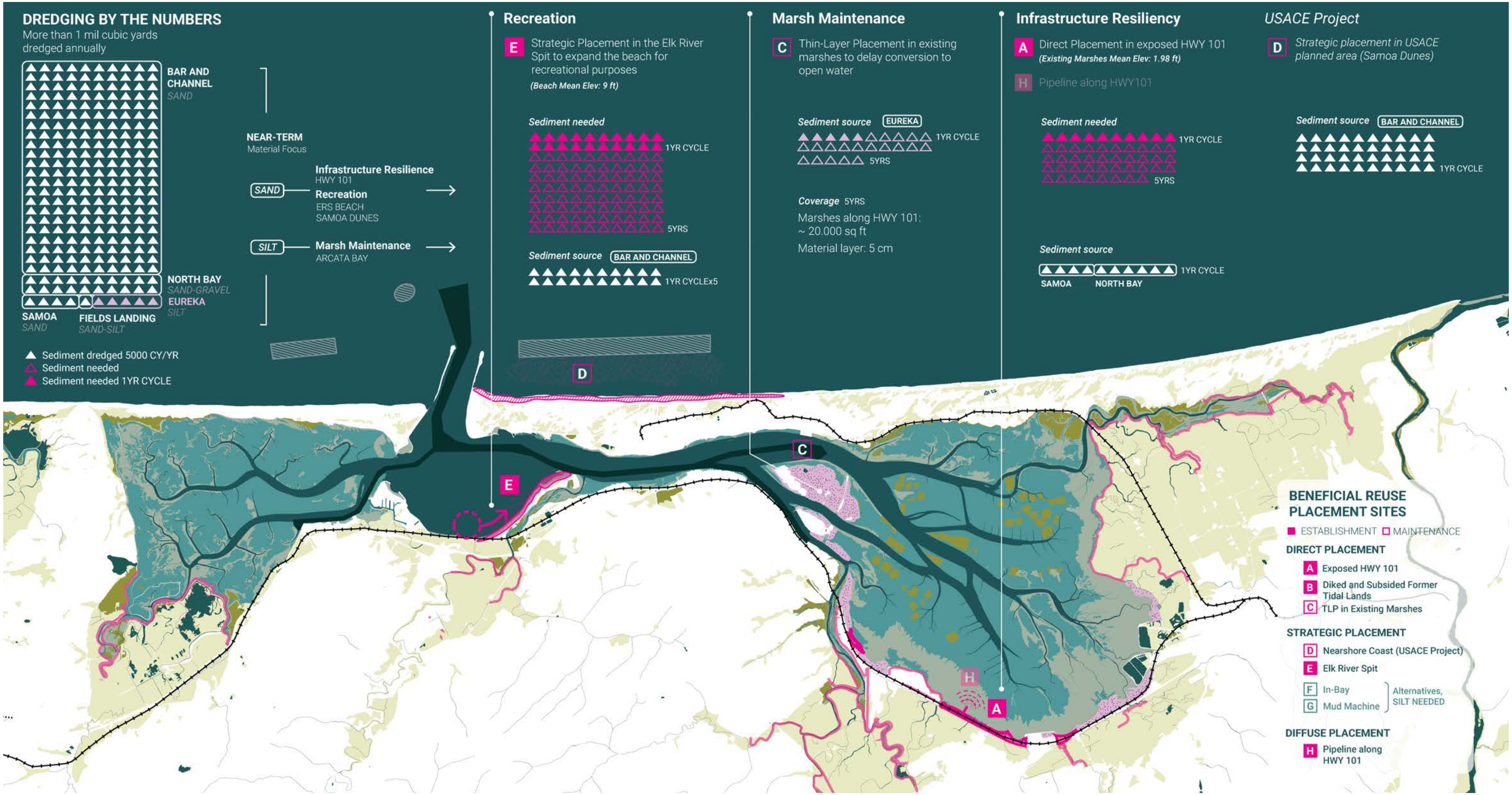
2100 WITH FAILED DIKES

2

SEDIMENT CHOREOGRAPHY SHORT TERM (NEXT 5 YEARS)

For the next five years, we recommend prioritizing (1) pilot projects that will inform future projects and (2) beneficial use projects in high-risk areas. Four such projects include sand engines on Elk River Spit, thin-layer placement on Arcata Bay islands, direct placement for marsh creation along Highway 101 (via a sediment pipeline following an abandoned rail corridor), and strategic placement along the coast. These pilots would utilize different placement techniques and sediment sizes to understand sediment movement in the bay. All four projects have additional recreational and restoration benefits to increase funding and partnering opportunities.

These drawings roughly quantify relationships between volumes of sediment dredged and the areas and elevations indicated. It is important to note that these estimates, being simple volumetric calculations worked out in GIS software, do not account for many of the dynamic processes impacting placed sediment in the bay environment, including settlement, subsidence, erosion, or natural accretion.

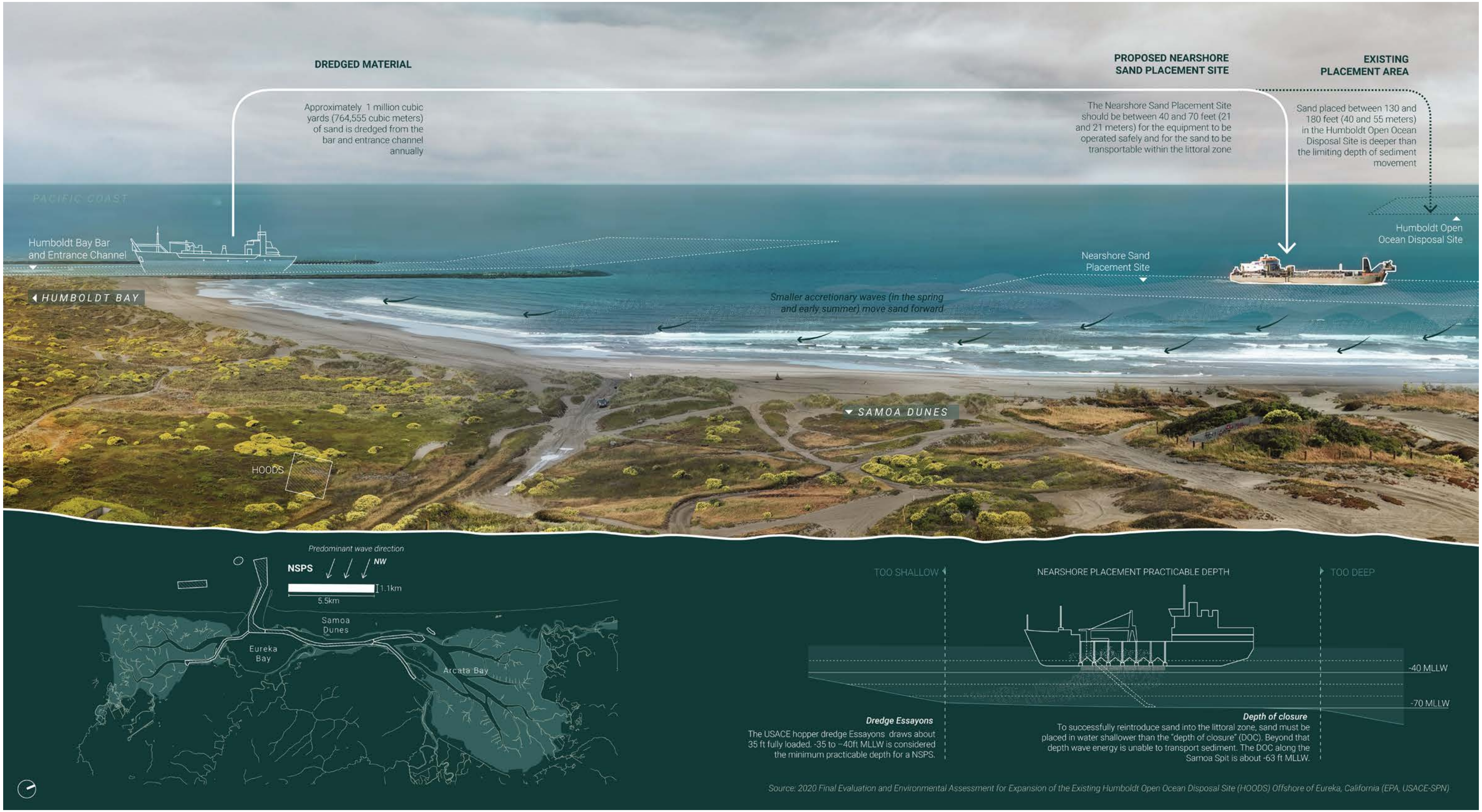


2

CHOREOGRAPHING SEDIMENT

NEARSHORE SAND PLACEMENT

The District has proposed a nearshore sand placement site offshore of Samoa Dunes, which would nourish the nearshore and beaches directly adjacent to and immediately north of the site (Humboldt Harbor and Bay Operations and Maintenance Dredging, 2021). This project, which is currently being worked through the permitting process, is the most immediately implementable of these several pilot projects and could inform regional beneficial use practices in the near future.



Approximately 1 million cubic yards (764,555 cubic meters) of sand is dredged from the bar and entrance channel annually

The Nearshore Sand Placement Site should be between 40 and 70 feet (21 and 21 meters) for the equipment to be operated safely and for the sand to be transportable within the littoral zone

Sand placed between 130 and 180 feet (40 and 55 meters) in the Humboldt Open Ocean Disposal Site is deeper than the limiting depth of sediment movement

Smaller accretionary waves (in the spring and early summer) move sand forward

Dredge Essayons

The USACE hopper dredge Essayons draws about 35 ft fully loaded. -35 to -40ft MLLW is considered the minimum practicable depth for a NSPS.

Depth of closure

To successfully reintroduce sand into the littoral zone, sand must be placed in water shallower than the "depth of closure" (DOC). Beyond that depth wave energy is unable to transport sediment. The DOC along the Samoa Spit is about -63 ft MLLW.

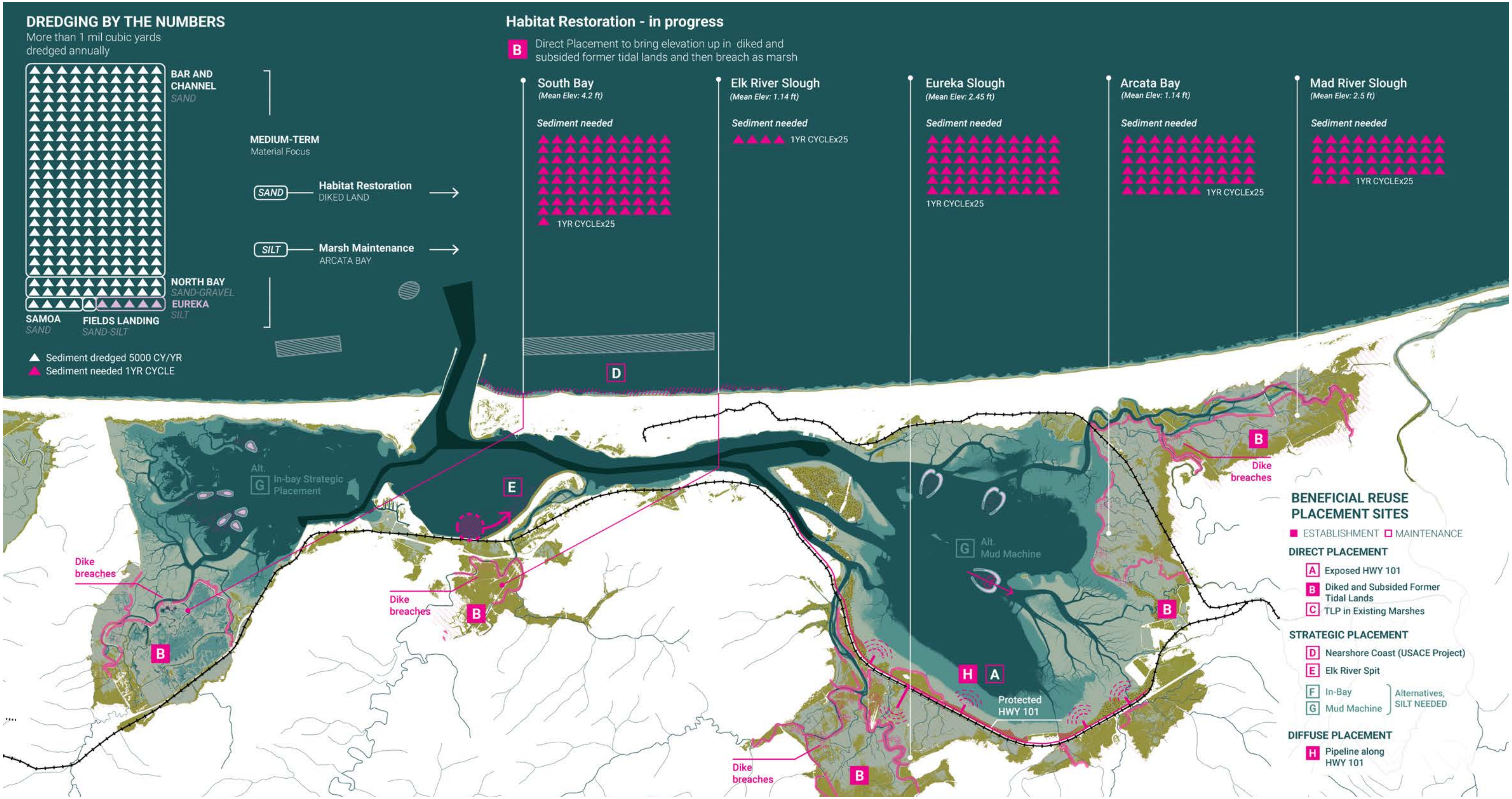
Source: 2020 Final Evaluation and Environmental Assessment for Expansion of the Existing Humboldt Open Ocean Disposal Site (HOODS) Offshore of Eureka, California (EPA, USACE-SPN)

2

SEDIMENT CHOREOGRAPHY

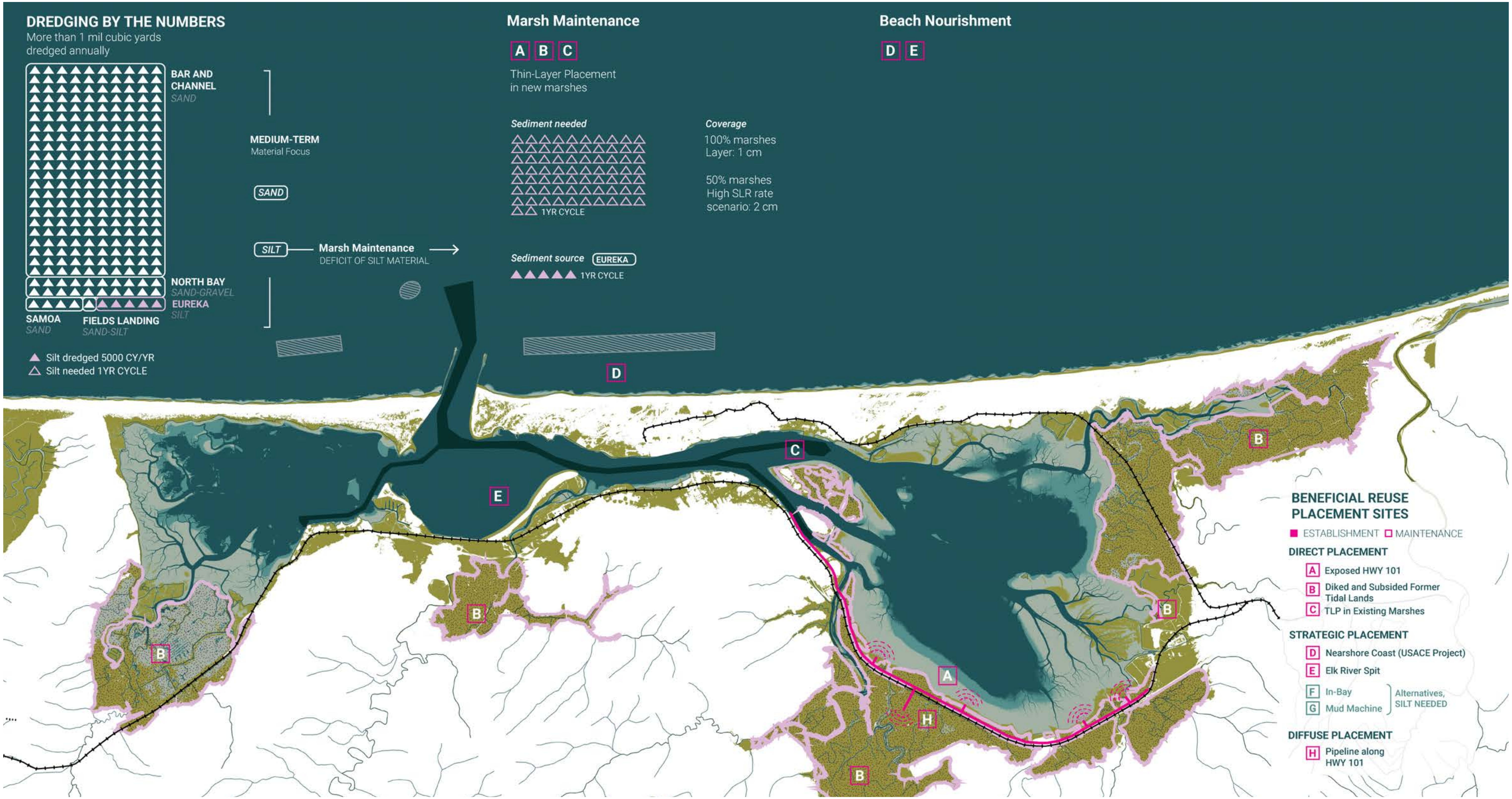
MEDIUM TERM (5-30 YEARS)

Lessons learned from the pilot projects could be leveraged to expand into a broader program of habitat restoration throughout the bay. A majority of the wetlands in the bay are diked, and as such, have dramatically subsided over the past one hundred years. While the bay's dredged material itself, comprised of mostly sands, is not ideal for wetland restoration, coarse material can used to bring the elevation up in diked and subsided former tidal lands, at which point the dikes could be breached, and tidal process could be restored to the wetlands. Doing this would require very large volumes of sediment; the map on this spread shows the volume of sediment dredged annually (in white) and the volumetric measurement of the area to be brought up to wetland elevation in annual terms across a period of 25 years (in pink). It does not account for subsidence, erosion, or natural accretion.



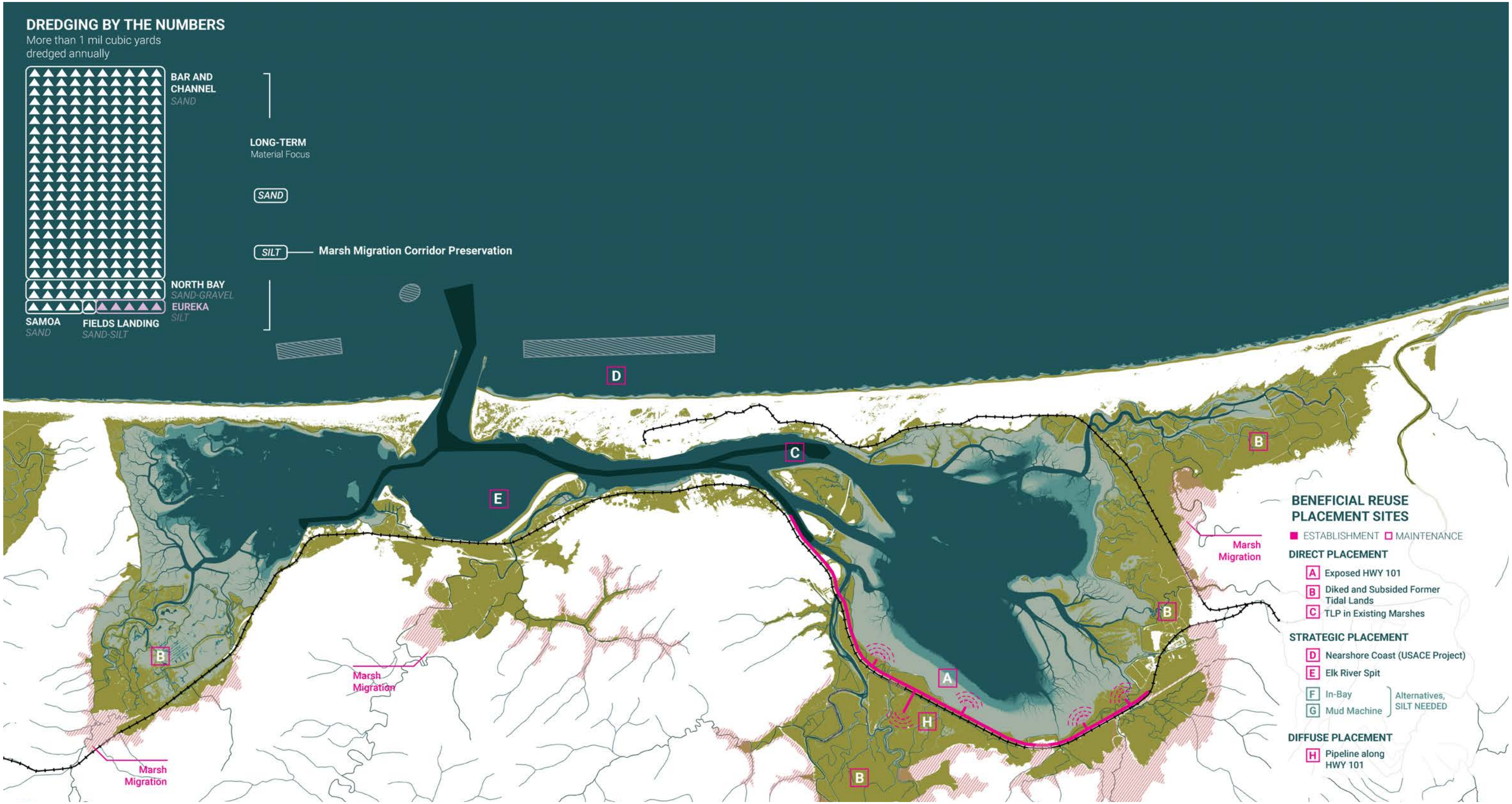
2 SEDIMENT CHOREOGRAPHY
LONG TERM (>30 YEARS)

After thirty years, once the previously diked wetlands are brought to marsh plane elevation and tidal processes are restored, thin-layer placement can be used to spray the finer material from the smaller dredging operations of in-bay channels onto the newly raised marsh lands, with the aim of enhancing their capacity to accrete and gain elevation as sea level rises. Unfortunately, as the volumetric comparison on this spread shows, the volume of fines available via current dredging activity is well below what would be required on an annual basis to maintain marsh elevation against sea level rise. (It is important to note, as stated earlier, that this analysis does not include the effects of natural accretive processes and tidal processes, which, depending on local rates, would reduce or potentially even eliminate the gap between the volume available and the volume needed.)



2 CHOREOGRAPHING SEDIMENT
MARSH MIGRATION

Marsh migration also has the potential to mitigate marsh loss throughout the bay. Effort should be made to secure lands adjacent to the current wetlands to allow for eventual marsh migration to occur. Long-term planning can identify potential sites to conserve and protect. This spread shows such potential areas based on adjacency to anticipated marsh locations and elevation alone; it does not incorporate an analysis of property ownership, infrastructure, or other barriers to marsh migration, nor does it attempt to analyze or prioritize the relative ecological or recreational value of potential migration lands.



2

CHOREOGRAPHING SEDIMENT

CONCLUSION

The aim of this choreography strategy is to show that the beneficial use of sediment has substantial potential to contribute to the long-term regional challenges faced by Humboldt Bay and its communities. Matching available sediment to anticipated needs will require further detailed analysis, including ecological and hydrological modeling, and it should incorporate an open, transparent public engagement process to ensure that community values and needs are understood, acknowledged, and incorporated into sediment design. Though such work has been beyond the scope of this study, we believe the study, and the District planning that it builds off, shows EWN techniques can be a key part of long-term climate adaptation and the pursuit of a rich, sustainable future for the Humboldt Bay region.

PART 3

SAN FRANCISCO BAY

SAN FRANCISCO BAY
OVERVIEW

The low-lying edges of the San Francisco Bay are generally known as baylands; this marshy fringe lies between the four large sub-bays and uplands (Goals Project, 2015). Though much of the baylands have been built on and developed into the dense urban settlements that ring the bay, the baylands still support a wide array of plant communities and wildlife, and regional conservation goals prioritize preserving, expanding, and regenerating these sediment-dependent landscapes. This is primarily motivated by the substantial degradation from human activity that the bay's habitats have experienced since Euro-American colonization. Despite such degradation, the San Francisco Bay still provides habitat to almost 500 animal species, including fish, birds, and mammals. For instance, as the entire Sacramento and San Joaquin watersheds drain into the bay, more than half of California's salmon population passes through the bay as part of their migration. The bay is also an important stopover and wintering spot on the Pacific Flyway, providing short or long-term habitat to roughly one million birds (San Francisco Environment Department).

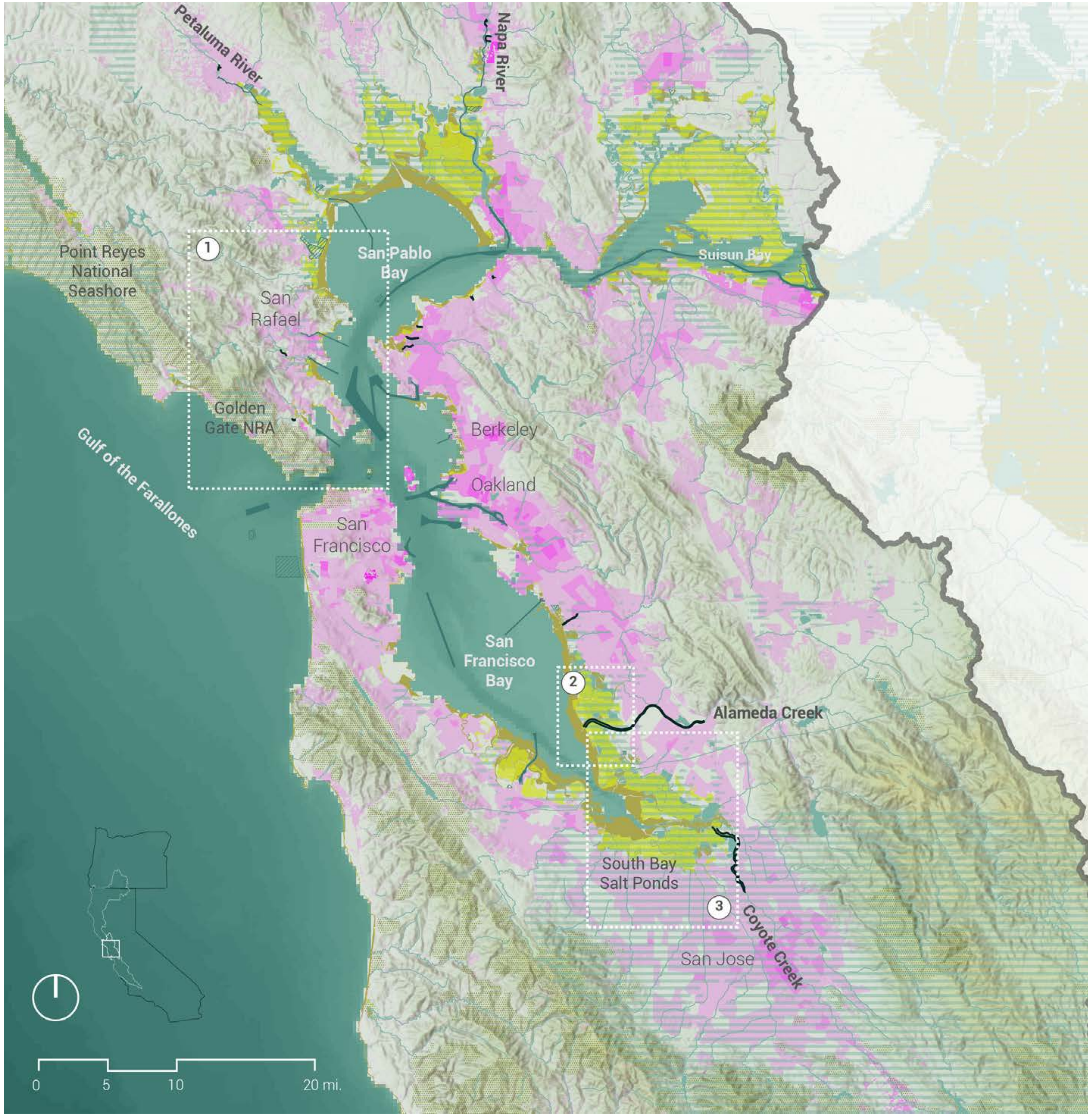
Though much of the population within this region resides in dense urban areas, large waterfront parks along the Pacific and San Francisco Bay coasts provide critical open greenspace and recreational opportunities. Golden Gate National Recreation Area and Point Reyes National Seashore are critical areas, stretching from downtown San Francisco to the natural beaches and rocky shores of Marin County. These and smaller parks lining the San Francisco Bay provide numerous trails for walking, hiking, and biking. Additionally, the San Francisco Bay is a popular destination for boating and fishing, with an abundance of marinas, yacht clubs, and boat ramps.

Large swaths of wetlands within the San Francisco Bay, San Pablo Bay, and Sacramento-San Joaquin Delta are considered vulnerable to climate change and rising sea levels. Losses of these areas would have ripple effects on the millions of birds, fish, and other animals that depend on them to survive. Additionally, the Bay Area is home to some of the state's most vulnerable populations, with over 35,000 unhoused individuals, and cities like Oakland, where poverty rates exceed 20% (Allen & Li, 2016). Moreover, crucial infrastructure, including wastewater treatment plants, highways, and ports, often occupies these low-lying regions, rendering them particularly exposed to escalating sea levels. The baylands provide a vital cushion against storms, wave action, erosion, and rising sea levels for infrastructure and coastal communities.

1

REGIONAL OVERVIEW
USACE PROJECT FOCUS

Most USACE activity in the San Francisco District occurs within this central region, particularly within the San Francisco and San Pablo Bays. Several major navigation channels are maintained within the bays and their tributaries, producing large quantities of dredged material. This material presents large-scale beneficial use opportunities, which the District has developed through innovative projects such as the Hamilton Airfield Wetlands Restoration. USACE also maintains levees designed for flood risk reduction on creeks and rivers feeding into the bays, including along Corte Madera Creek in Marin County, which is one of the study sites for the strategic sediment pulse dredging concept documented in this report, and Alameda Creek, which is the bay's largest tributary and a prime candidate for Creek-to-Bayland restoration, as identified in SFEI's Flood Control 2.0 study (Dusterhoff, 2017) and developed conceptually in the Resilient By Design Bay Area Challenge by the Public Sediment team (SCAPE, 2018). USACE also engages in large-scale wetland restoration in the baylands, such as the restoration of the South Bay Salt Ponds near Alviso.



ECOLOGICAL + SOCIAL VULNERABILITY

- ▤ **FEMA 100 YR Floodplain**
- 🟩 **Vulnerable Wetlands*** *According to TNC Resiliency Study*

Social Vulnerability Index

- ■ 0-20% Poverty
- ■ 20- 40%
- ■ 40-60%
- ■ 60-80%

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index- Overall

ECOLOGICAL + SOCIAL ASSETS

- ■ **Wetlands**
- ▒ **Parks and Protected Areas** *National, State, and Local Parks*

EWN-LA FOCUS AREAS

- ① **Marin Watershed** Strategic Sediment Pulse Dredging
- ② **Eden Landing** Strategic Sediment Placement
- ③ **Alviso** South San Francisco Bay Shoreline

USACE PROJECTS + OPERATIONS

- ■ **USACE Channel Areas**
- ▨ **USACE Placement Areas**
- — **USACE Levees**

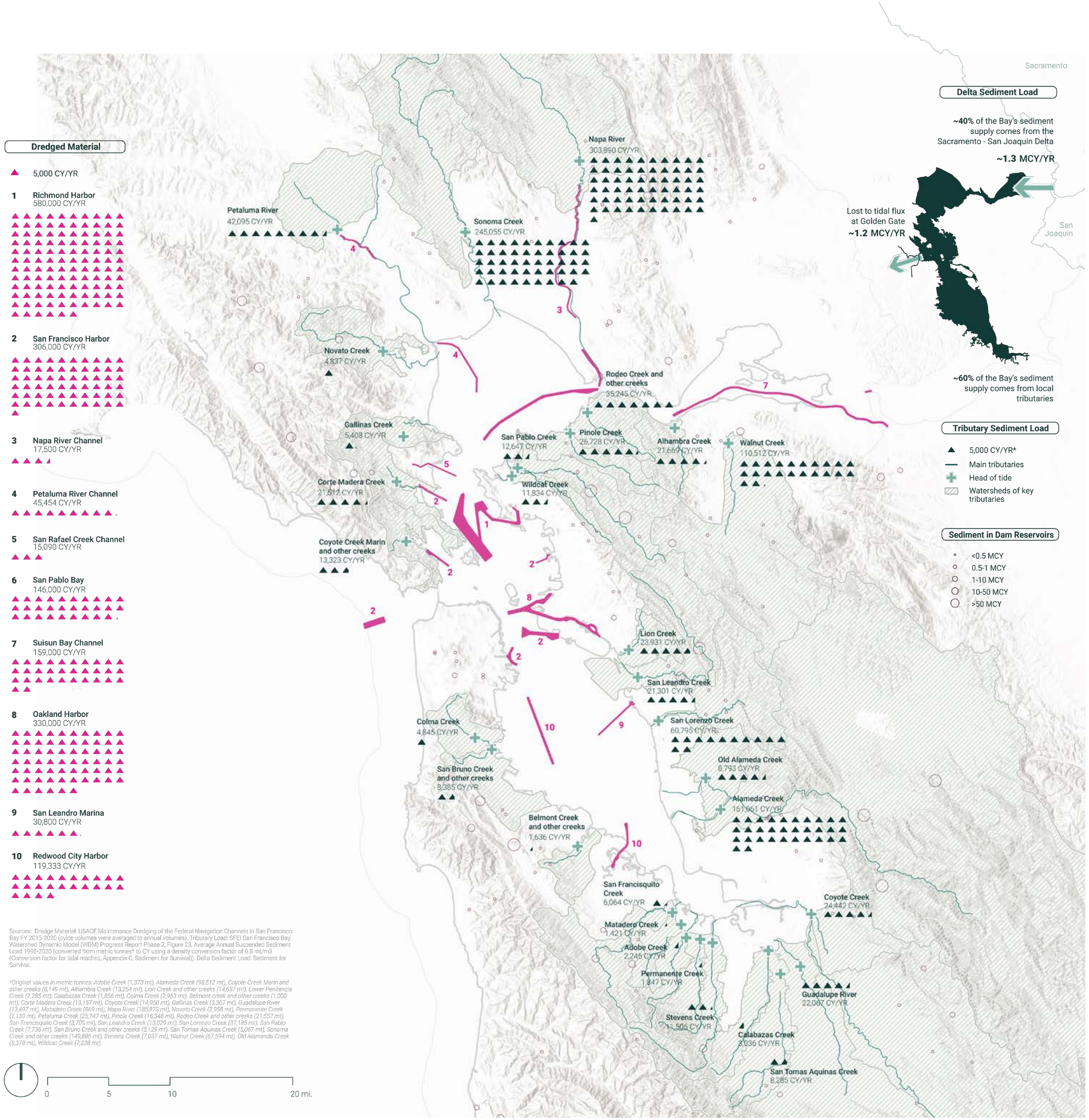
2

SEDIMENT STRATEGIES

SEDIMENT SUPPLY

The San Francisco Bay is the second largest estuary in the United States. When combined with the Sacramento-San Joaquin Delta, it expands over 1,500 square miles, and has a watershed area of over 60,000 square miles. Current sediment load has significantly decreased from peak historic levels, which were greatly influenced by mining and agriculture in the upstream watersheds (Barnard et al., 2013). The maintained channels (shown in pink at right) located throughout the bay further exasperate bay-wide sediment deficits, as much of the dredged sediment is placed upland or in deeper waters offshore, thus removing it from the system. As suspended sediment loads from the Delta have decreased, sediment supply from the small local tributaries has become increasingly important. Many of these tributaries are channelized and leveed, which both limits the capacity of sediment from their watersheds to enter the tributaries (shown in turquoise in the figure at right) and hinders what sediment they do carry from nourishing the tidal baylands, as the channelized rivers discharge their sediment to deeper portions of the bay, bypassing the nearby mudflats and marshes. The recent SFEI report "Conceptual Understanding of Fine Sediment Transport in San Francisco Bay" covers these dynamics in much greater detail (McKnight et al., 2023).

It is also important to note that, in order to facilitate comparison between different sources of sediment, this drawing shows each source in the same kind of unit (cubic yards per year). Doing so is only possible by converting tributary and delta sediment loads from metric tonnes (weight) to cubic yards (volume). This was done using a density conversion factor of 0.8 mt/m^3 (Dusterhoff et al. 2021); however, no conversion factor can be 100% accurate.



Sources: Dredge Material: USACE Maintenance Dredging of the Federal Navigation Channels in San Francisco Bay FY 2015-2020 (cylce volumes were averaged to annual volumes). Tributary Load: SFEI San Francisco Bay Watershed Dynamic Model (WDM) Progress Report Phase 2, Figure 23, Average Annual Suspended Sediment Load 1995-2020 (converted from metric tonnes* to CY using a density conversion factor of 0.8 mt/m3 (Conversion factor for tidal reaches, Appendix C, Sediment for Survival)). Delta Sediment Load: Sediment for Survival.

*Original values in metric tonnes: Adobe Creek (1,373 mt), Alameda Creek (98,512 mt), Coyote Creek Marin and other creeks (8,149 mt), Alhambra Creek (13,254 mt), Lion Creek and other creeks (14,637 mt), Lower Penitencia Creek (2,285 mt), Calabazas Creek (1,856 mt), Colma Creek (2,963 mt), Belmont creek and other creeks (1,000 mt), Corte Madera Creek (13,157 mt), Coyote Creek (14,950 mt), Gallinas Creek (3,307 mt), Guadalupe River (13,497 mt), Matadero Creek (869 mt), Napa River (185,873 mt), Novato Creek (2,958 mt), Permanente Creek (1,130 mt), Petaluma Creek (25,747 mt), Pinole Creek (16,348 mt), Rodeo Creek and other creeks (21,557 mt), San Francisquito Creek (3,709 mt), San Leandro Creek (13,029 mt), San Lorenzo Creek (37,185 mt), San Pablo Creek (7,736 mt), San Bruno Creek and other creeks (5,129 mt), San Tomas Aquinas Creek (5,067 mt), Sonoma Creek and other creeks (149,886 mt), Stevens Creek (7,037 mt), Walnut Creek (67,594 mt), Old Alamenda Creek (5,378 mt), Wildcat Creek (7,238 mt).

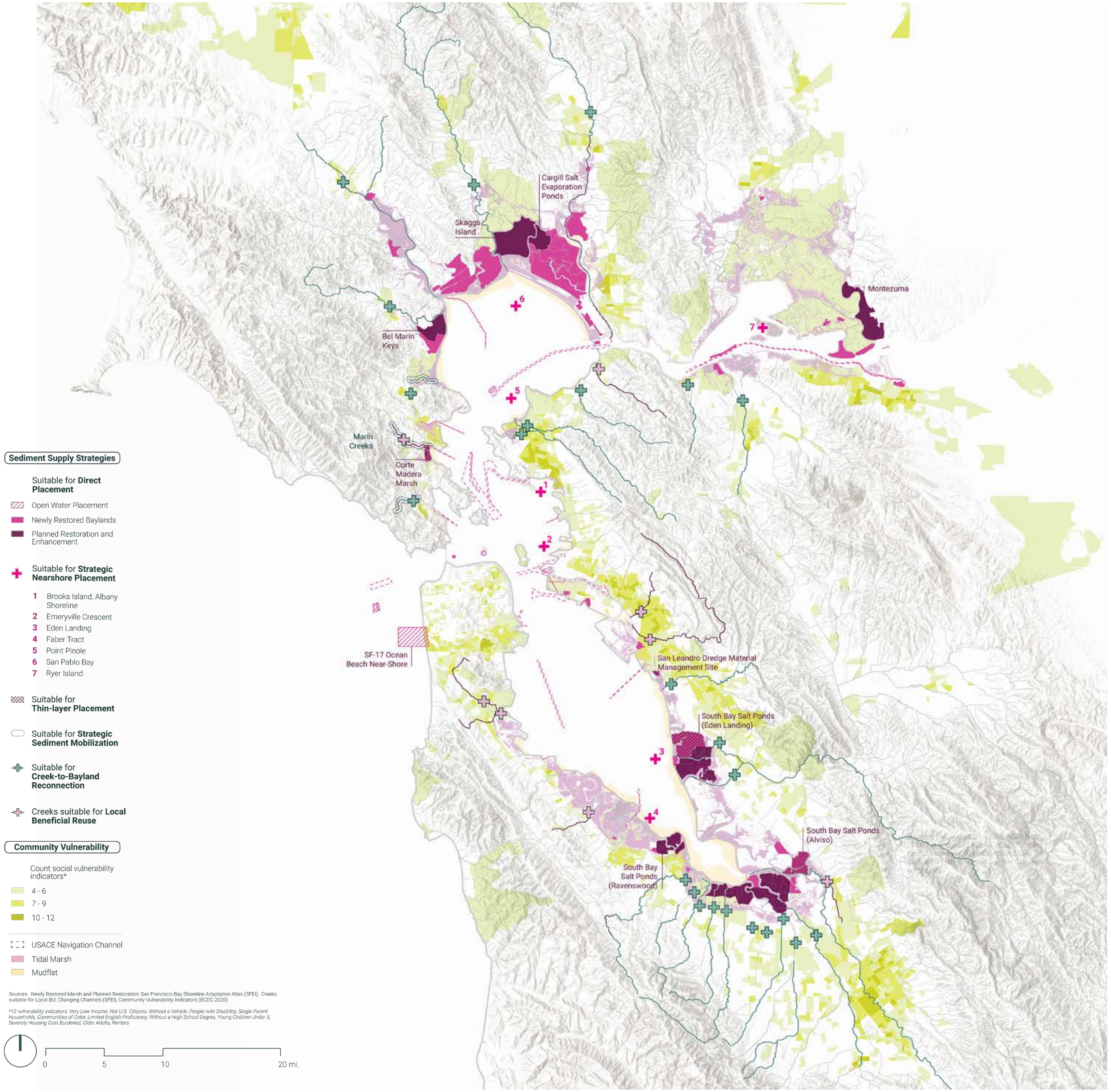
2

SEDIMENT STRATEGIES
SEDIMENT IN THE SYSTEM

Anthropomorphic changes over the past century have deprived the Bay Area's wetlands of sediment supply. As sea level rise is now accelerating bayland inundation and drowning, sediment has become an invaluable resource to combat bayland loss, build habitat, and protect Bay Area communities. Throughout the past century, dredged sediment has been placed in upland or offshore areas, thus removing valuable sediment from the bay system. Alternative placement techniques have been identified by the San Francisco District and its partners that would allow dredged sediment to be utilized in such a way that it would remain active within the system, able to nourish the baylands' tidal marshes and mudflats. These alternatives include direct placement, open water placement, strategic nearshore placement, thin-layer placement, strategic sediment mobilization, and local beneficial reuse. Certain characteristics of the projects, including sediment size, wetland type, wave environment, proximity to channels, and proximity to tidally connected marshes can be used to help identify and guide which technique would be best utilized.

In addition to navigation projects, USACE has also been involved in the channelization and construction of levees on the Bay Area's tributaries. These measures were implemented to mitigate flood risk, which is often substantial for communities built in the low-lying areas along the bay's shores. However, when implemented across the bay, these infrastructure projects have unintentionally but significantly decreased the riparian sediment supply to adjacent tidal marshes. Reconnecting rivers to the tidal marshes through dike and levee breaches will help deliver tributary sediment to where it is needed, supplementing techniques that rely on dredged sediment produced by navigation projects.

This map summarizes current thinking on how to organize and deploy these EWN techniques to collectively keep sediment in the system, where it can support the vitality of the baylands and the communities that ring the bay.



Sources: Newly Restored Marsh and Planned Restoration: San Francisco Bay Shoreline Adaptation Atlas (SFEI), Creeks suitable for Local BU: Changing Channels (SFEI), Community Vulnerability Indicators (BCDC 2020).

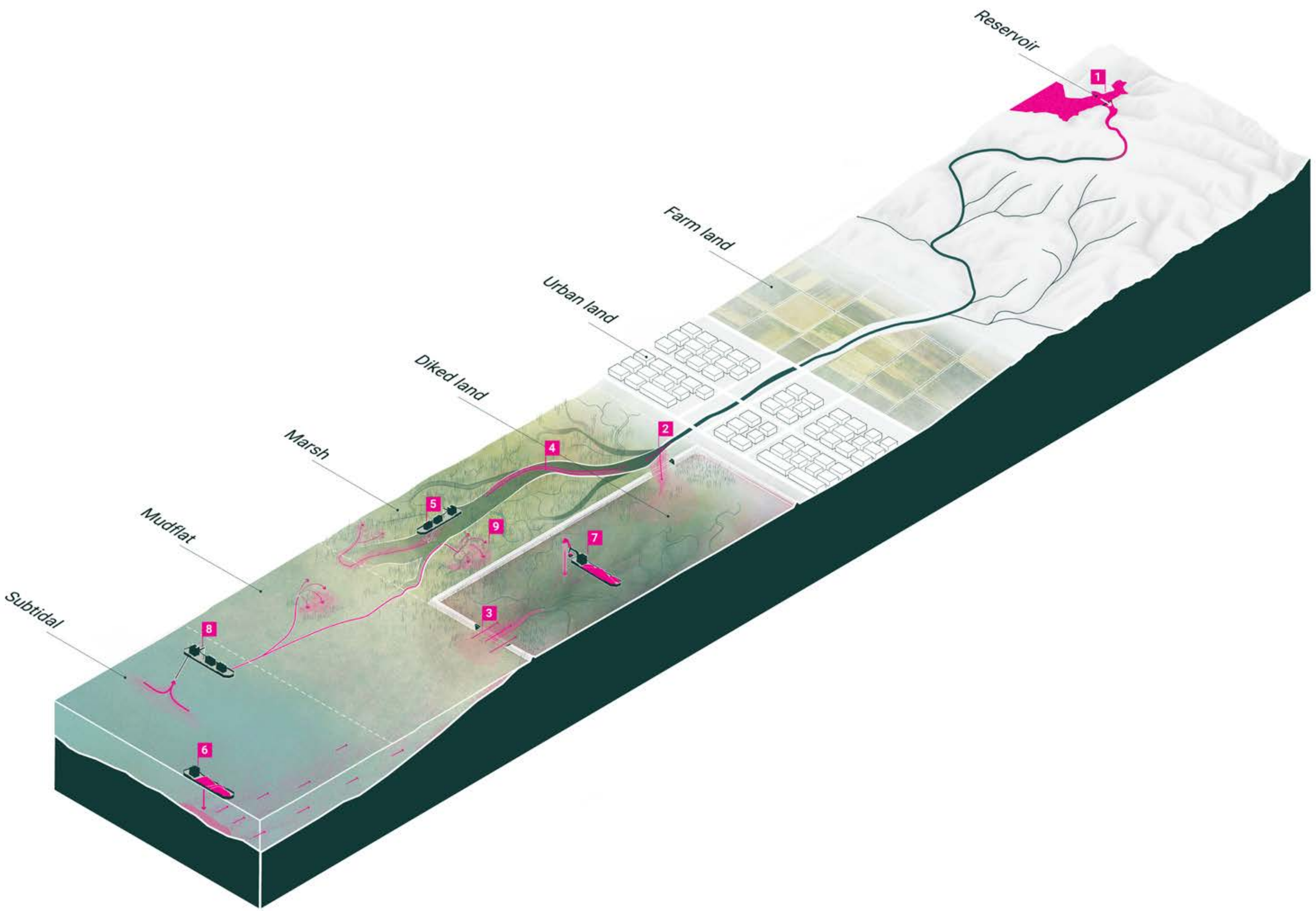
**12 vulnerability indicators: Very Low Income, Not U.S. Citizens, Without a Vehicle, People with Disability, Single Parent Households, Communities of Color, Limited English Proficiency, Without a High School Degree, Young Children Under 5, Severely Housing Cost Burdened, Older Adults, Renters*

2 SEDIMENT STRATEGIES
RESERVOIR TO BAY

These approaches for keeping sediment in the system can also be understood along an elevational gradient (Dusterhoff, 2021) and a natural-to-mechanical spectrum. This drawing shows this pair of ways of understanding the sediment technique toolkit.

From the moment sediment erodes in the watersheds of upland creeks to the point at which it discharges into the bay, opportunities exist to encourage and assist the natural tidal and riparian sediment transport processes. Holistic regeneration of the baylands requires working along the length of this elevational gradient, with Creek-to-Bayland connection a particularly important technique for connecting upland sources of sediment to the bay and its wetlands.

The natural-to-mechanical spectrum describes the amount of mechanical effort needed to restore certain lost or disconnected natural processes. These techniques fall broadly into three categories from least to most necessary mechanical effort: 1) remove obstructions to natural processes, 2) assist natural processes, and 3) replace natural processes. The EWN design concepts that follow in this section explore techniques that both involve the removal of obstructions to natural processes (breaching dikes in the South San Francisco Bay Shoreline Project) and assist natural processes (Strategic Sediment Pulse Dredging in Marin County and Strategic Placement at Eden Landing).



1 Reservoir Management
2 Creek-to-Bayland Reconnection
3 Breached Dikes

REMOVE OBSTRUCTIONS
TO NATURAL PROCESSES

4 Geomorphic Dredging
5 Strategic Sediment Pulse Dredge
6 Strategic Placement

ASSIST
NATURAL PROCESSES

7 Mechanical Placement
8 Hydraulic Placement
9 Thin Layer Placement

REPLACE
NATURAL PROCESSES

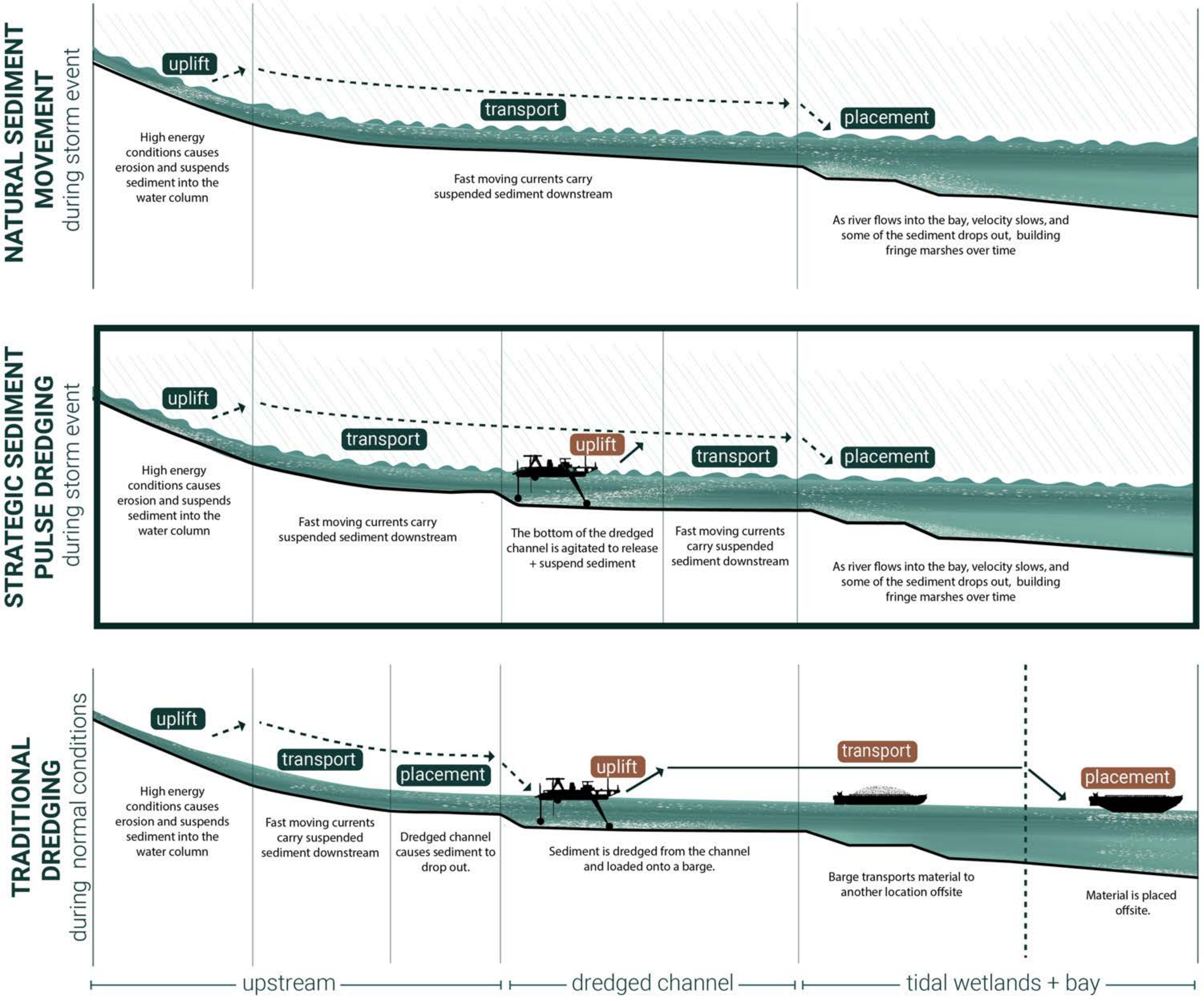
STRATEGIC SEDIMENT PULSE DREDGING

MARIN WATERSHED

Strategic sediment pulse dredging (SSPD) is a nature-based technique that takes advantage of naturally occurring, periodic high-flow events to transport sediment into the bay (Leventhal, personal communication, June 1, 2022). Under normal conditions, sediment in shallow upstream locations erodes and is carried by the water flowing through the creek until it naturally deposits near the mouth of the creek, where it impedes navigation and impacts watershed management. During high-flow events, the increased flow velocity can keep sediment in suspension to carry further into the bay before depositing. To take advantage of this natural process, sediment upstream in the canal can be agitated in coordination with the timing of high-flow events, increasing sediment in the water column when high flows are available to transport sediment out into the marsh, nearshore, and bay. By harnessing these natural forces, SSPD can bypass the need for transportation and placement of dredged materials along the marsh, which is costly, depends on fossil fuel energy, and is effort-intensive.

1 STRATEGIC SEDIMENT PULSE DREDGING
CONCEPT SECTIONS

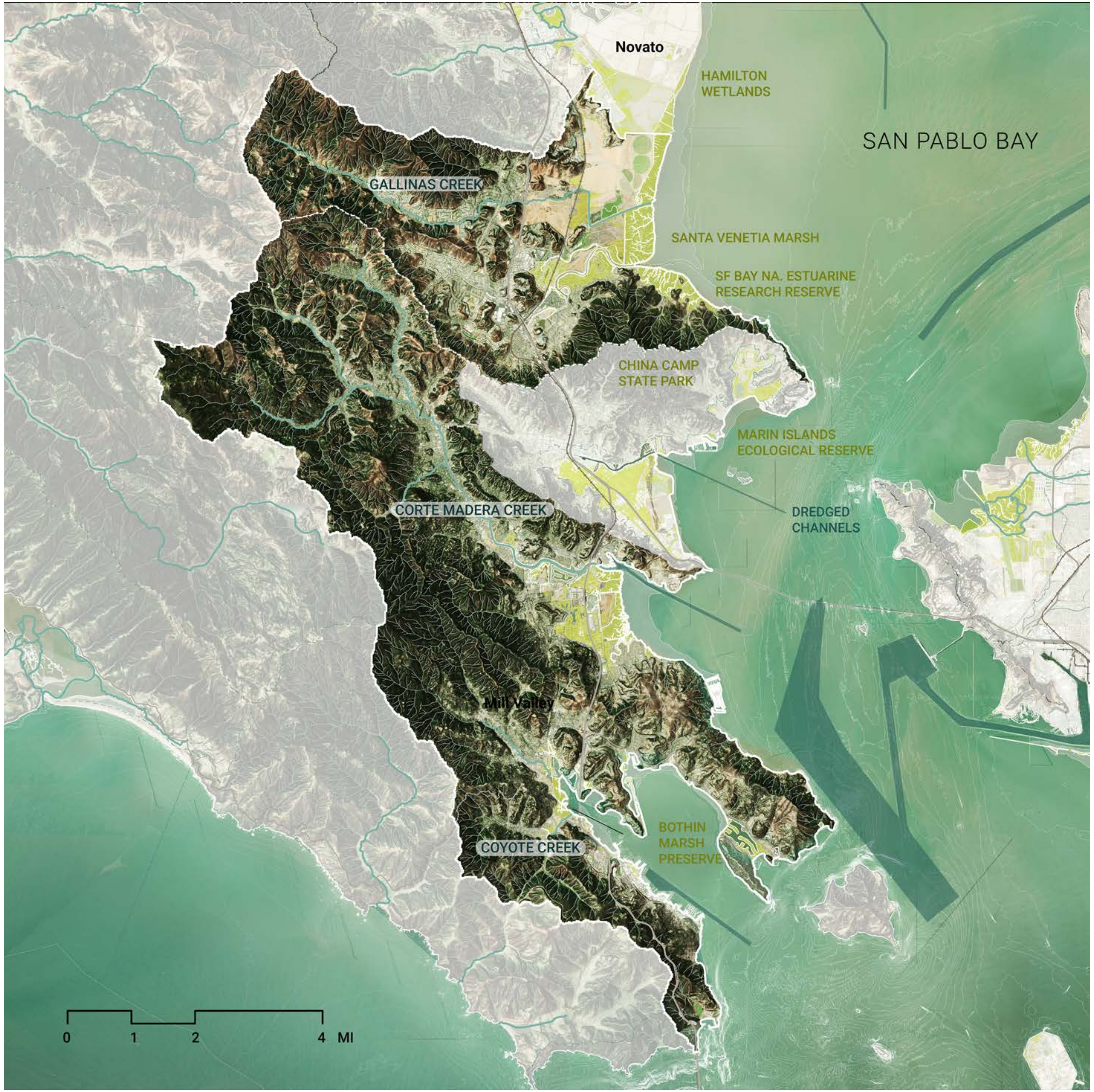
Strategic Sediment Pulse Dredging utilizes natural forces to effectively resuspend and flush sediment into the adjacent marshes and nearshore. By studying natural sediment pulses in a riverine system, SSPD can be timed to utilize these sediment pulses to deliver the sediment back into the nearshore. Mobilization would be performed by placing a dredge within the channel and hydraulically or mechanically agitating the sediment just prior to a high-flow event. This would increase the sediment load within the water column so that the natural high-flow event could carry the sediment to the mouth of the creek. While traditional dredging requires a multi-step operation to dredge, transport, and place material, strategic sediment pulse dredging harnesses natural forces to transport and place material, thus saving significant time and effort.

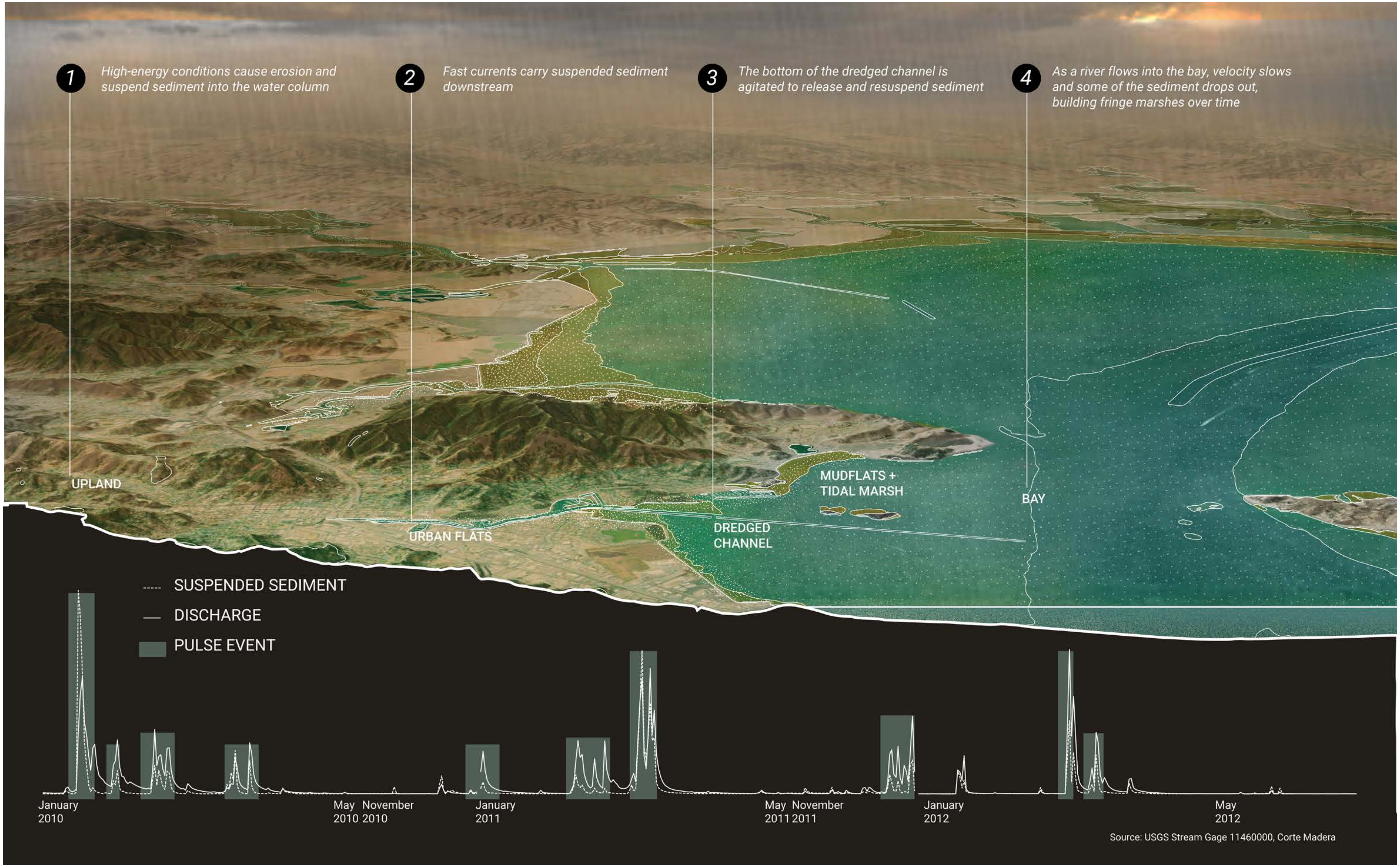


2

MARIN WATERSHED SITE CHARACTERISTICS

The watersheds within Marin County, located in the northwestern portion of the San Francisco Bay Area, are being used as a study area for this SSPD research, which both SPN and its local partners are exploring. Several large creeks within Marin County convey stormwater from within the Marin County watershed to San Francisco Bay, including Gallinas, Corte Madera, and Coyote Creeks. These creeks naturally carry sediment from the shallow upstream portions of the creek down to where they meet the bay, where this sediment is deposited, forming a fringe marsh habitat (Thorne, 2022). All three creeks in the study area empty into small sub-bays, which have a semi-protected wave environment that could encourage shorter sediment settling times. Bothin Marsh Preserve, Corte Madera Marsh State Marine Park, and McInnis Marsh border the mouth of these creeks and would benefit from added riparian sediment. Furthermore, because of their primarily recreational uses, these creeks are infrequently dredged by the USACE. Consequently, both the associated communities and the adjacent public marshlands are impacted by this sedimentation and would benefit from an EWN strategy that uplifts the sediment during a strategic flow event, transports material naturally beyond the creek mouth areas where sedimentation poses a challenge, and places the material where it is desirable.





1 *High-energy conditions cause erosion and suspend sediment into the water column*

2 *Fast currents carry suspended sediment downstream*

3 *The bottom of the dredged channel is agitated to release and resuspend sediment*

4 *As a river flows into the bay, velocity slows and some of the sediment drops out, building fringe marshes over time*

Source: USGS Stream Gage 11460000, Corte Madera

STRATEGIC PLACEMENT

EDEN LANDING

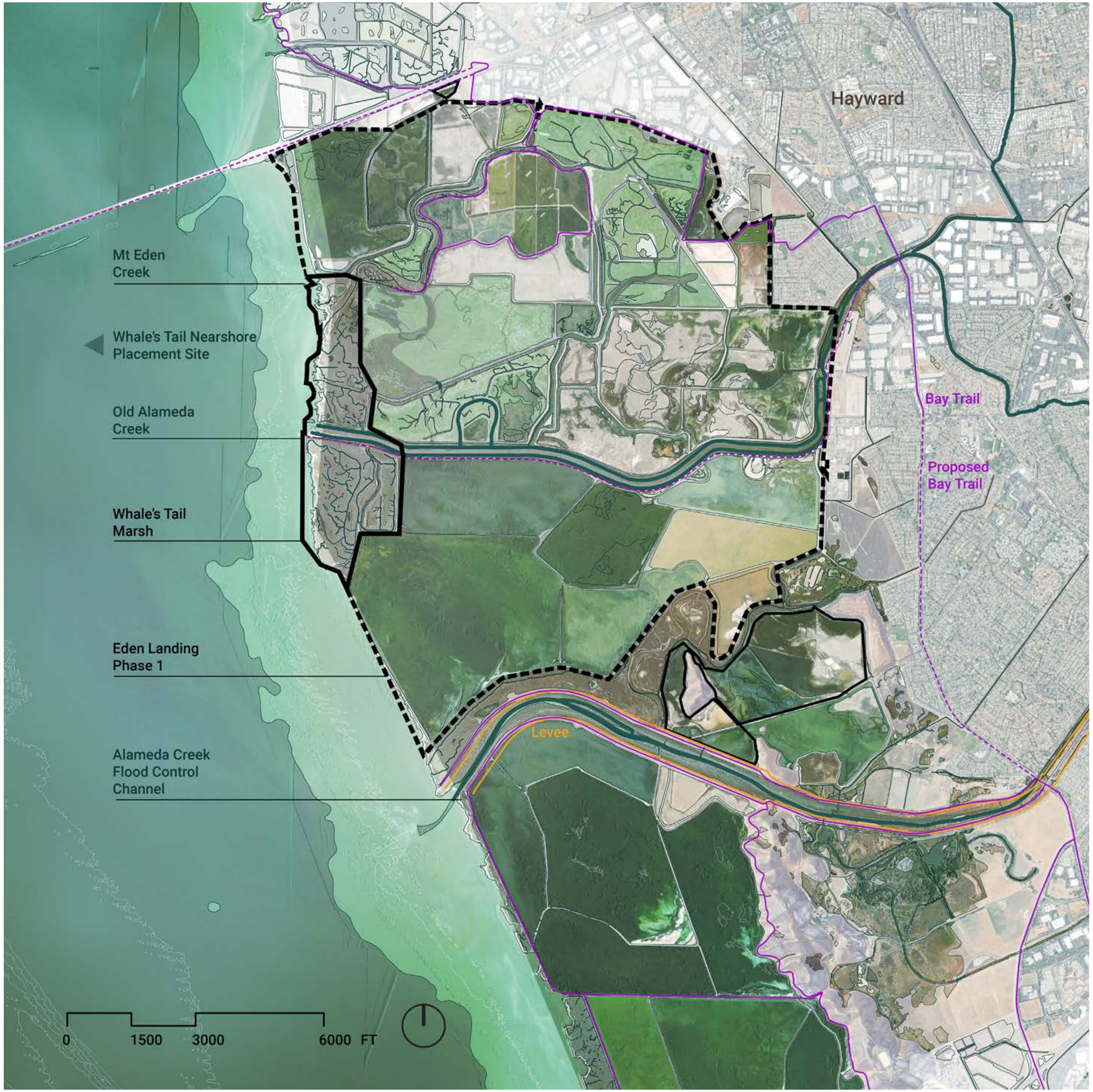
Strategic placement is the practice of utilizing hydrodynamic forces to disperse dredge material toward desired locations, nurturing sediment-starved nearshore and tidal marsh habitats (Gailiani et al., 2019). While the strategic placement of coarse sediment has been studied and documented, predominantly finer materials are far less practiced and understood. Because of its higher suspension time, muddier material can stay in the water column for much longer. It could lead to increased turbidity, commonly perceived as a negative despite evidence that many critical species require turbidity to survive (Gailiani et al., 2019). Another challenge to the perception of strategic placement surrounds the increased uncertainty in the outcomes caused by the increased suspension time. However, these finer materials are necessary for maintaining sediment loadings to wetlands and could help maintain necessary marsh elevations in the face of rising sea levels and marsh subsidence. Strategic placement of fines should be piloted and monitored to understand its effects more fully on nearby target locations. It could serve as a critical regional strategy in nourishing tidal marshes throughout the San Francisco Bay.

The Water Resources Development Act of 2016 (WRDA) established a pilot program to conduct projects for the beneficial use of dredged material. This program provided an opportunity, which continues to advance towards implementation, through the California State Coastal Conservancy (CSCC), San Francisco Bay Conservation and Development Commission (SFBCDC), and USACE San Francisco District's (SPN) Restoring San Francisco Bay's Natural Infrastructure with Dredged Sediment: Strategic Placement (Eden Landing Project) to pilot the strategic placement of materials in nearshore environments. The following pages contain drawings intended to document this advancing work and aid in communicating its significance.

1 EDEN LANDING CONTEXT

SITE CHARACTERISTICS

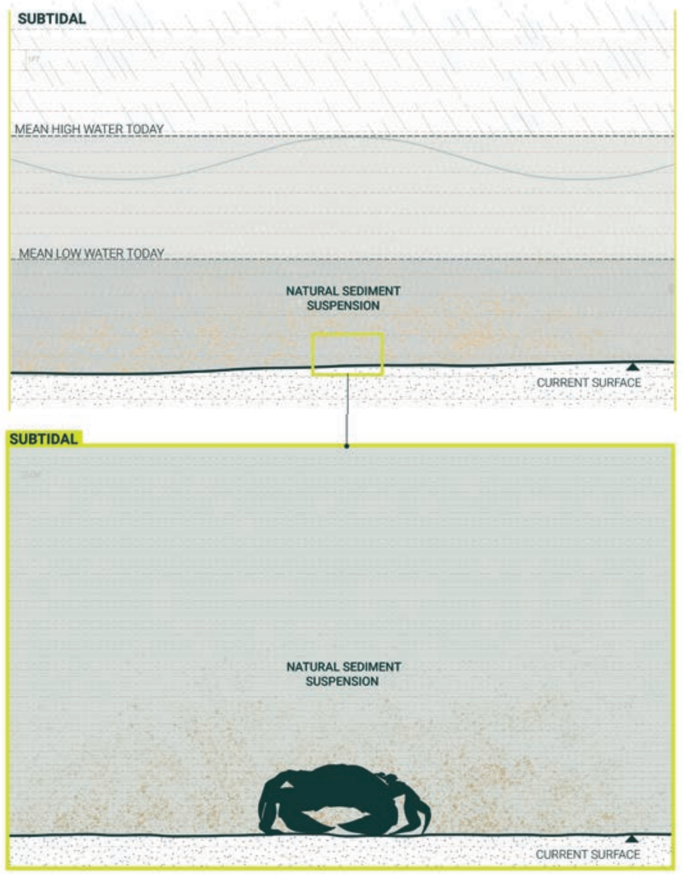
The San Francisco District has identified potential strategic placement sites based on a variety of criteria, including eroding or drowning marsh (due to lack of natural sediment supply), sufficient wind-wave action to resuspend sediment placed, proximity to a Federal Channel, open to tidal exchange, water shallow enough to get a scow close to shore, protection of disadvantaged communities, lower populations of critical species, and avoiding large eelgrass beds/nearshore reef projects (Strategic Shallow Water Placement Project to Restore San Francisco Bay's Natural Infrastructure. 2022). Based on these criteria and ongoing complementary efforts in Alameda Creek and at the Eden Landing Salt Pond Restoration (Public Sediment, 2018), the District selected Whale's Tail Marsh as a potential site for this pilot project. Whale's Tail Marsh is named after the two fan marshes formed from the sediment deposited as Alameda Creek and Mount Eden Creek drain into the bay. These two tidal creeks are adjacent to and connected to a network of recently tidally restored salt ponds, and, as such, any strategic placement conducted in the vicinity has the added benefit of potentially nourishing these areas as well.

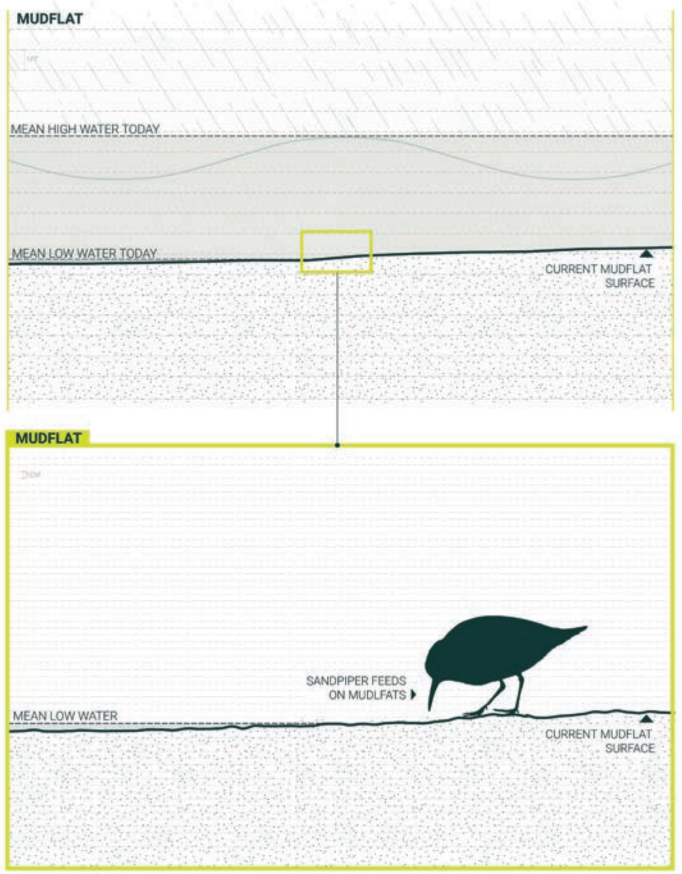


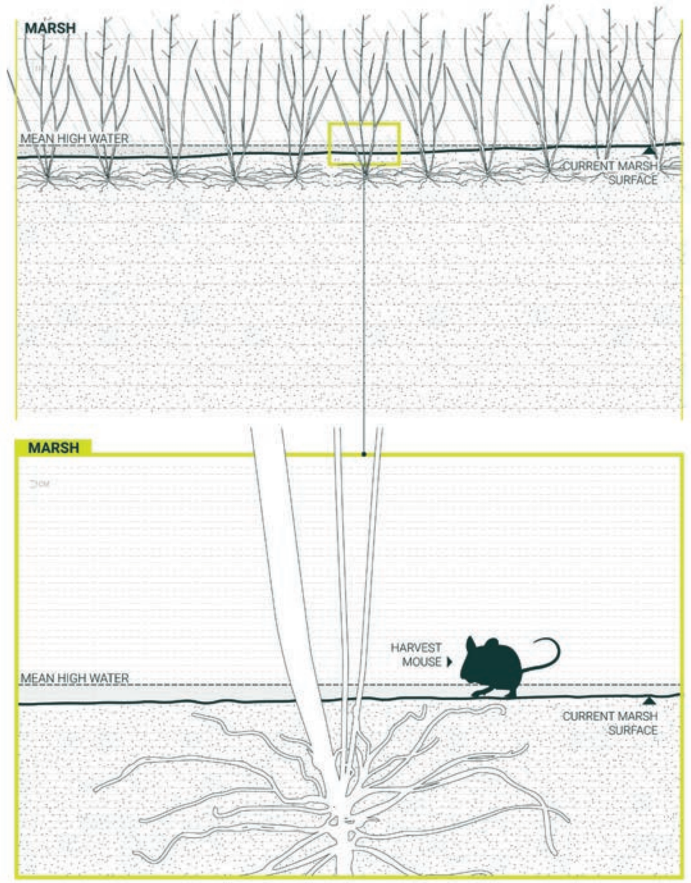
2

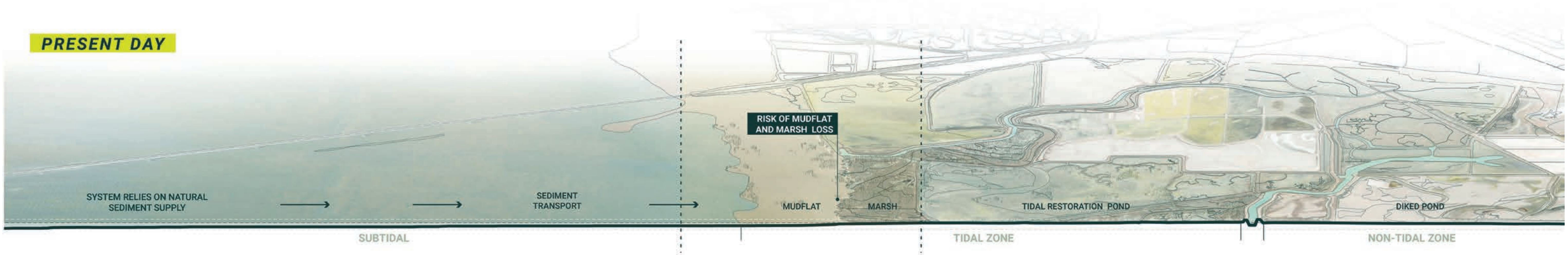
STRATEGIC PLACEMENT
PRESENT DAY

While Whale's Tail Marsh is an example of an older restored marsh in the Bay Area, having been restored to tidal action in 1930, the marsh is still at risk for drowning due to sea level rise if no action is taken to increase sediment supply. Currently, the marsh provides important subtidal, mudflat, and marsh habitat to important Bay Area species, such as the Dungeness Crab, snapper, and harvest mouse, respectively. By showing the marsh at the scale of the individual species, the importance of the sediment to the wetland becomes more fully realized.



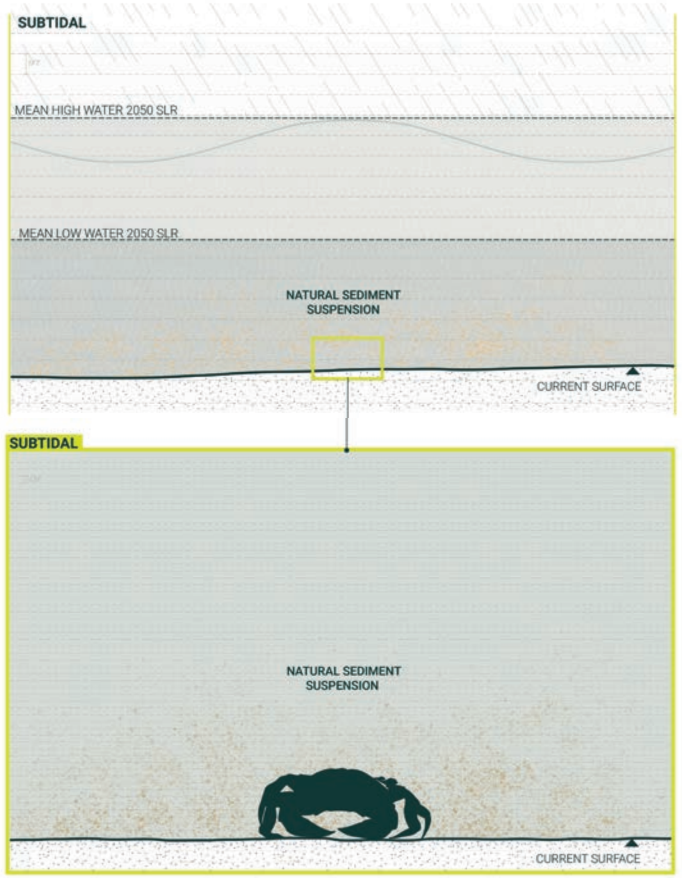


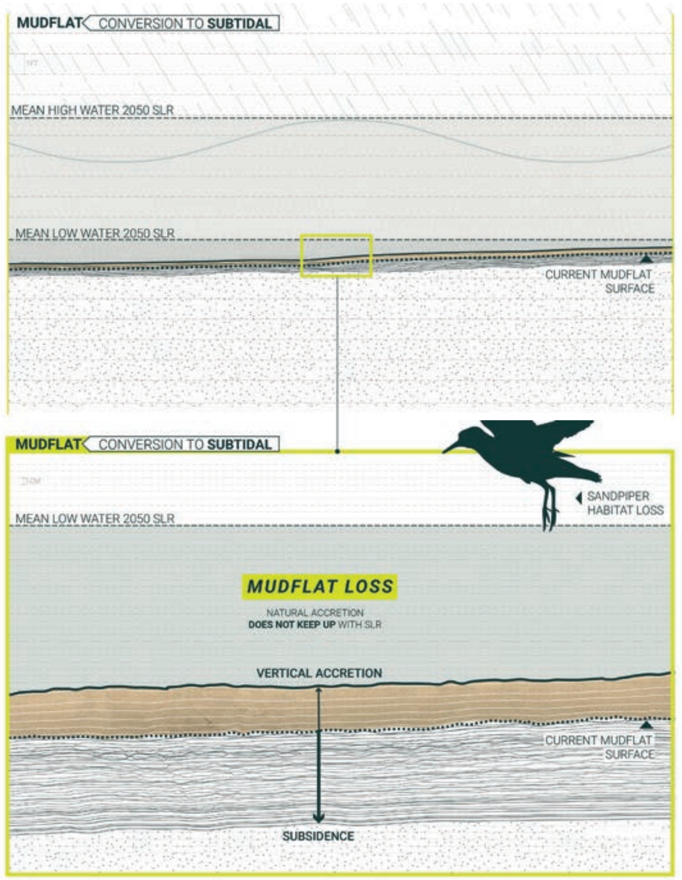


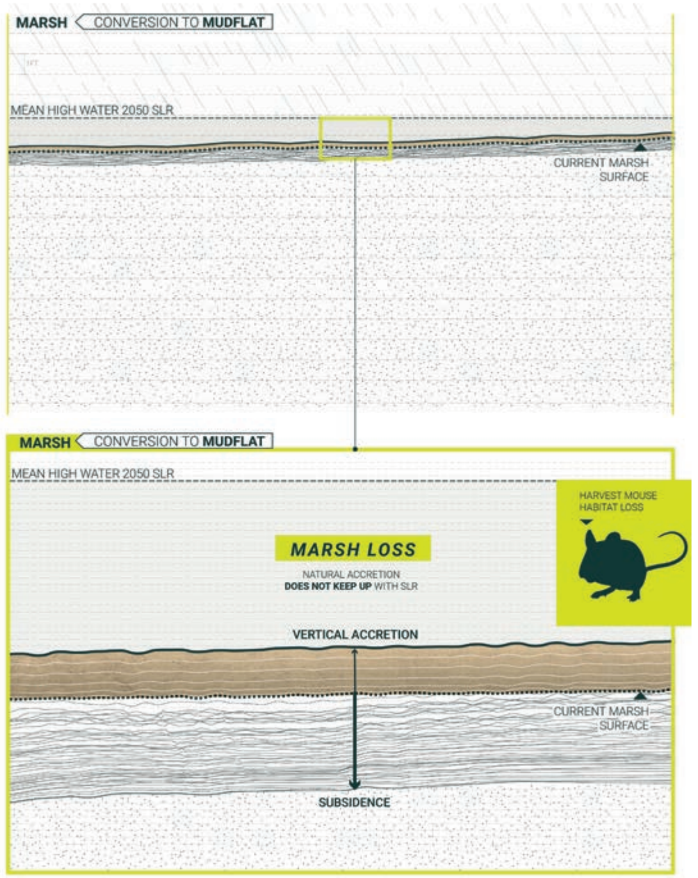


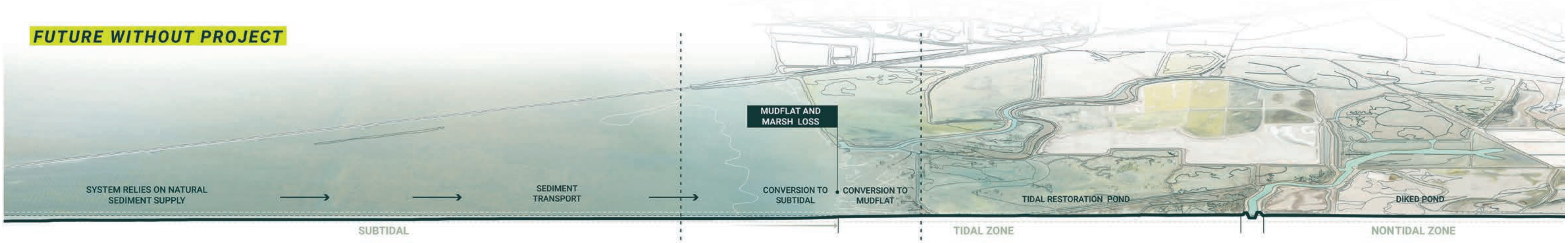
2 STRATEGIC PLACEMENT
FUTURE WITHOUT PROJECT

Marsh plants thrive in the tidal zone, above Mean Low Water (MLW) and below Mean High Water (MHW). As the sea level rises, marshes without adequate sediment supply (and without corridors to move landwards) risk downing. By 2050, under current high sea level rise projections, the current mudflats would be converted to subtidal habitat and the marshes to mudflats (NOAA Sea Level Rise Local Scenarios, Alameda, CA). This drawing assumes an elevation loss of -0.3 cm/yr, given the natural accretion of 0.2cm/yr and subsidence of .5cm/yr (Callaway, 2019; Shirzaei, 2018). These values are approximate, but appropriate given available data; they are used here for illustrative purposes, to depict the conceptual relationships between the processes shaping the baylands.







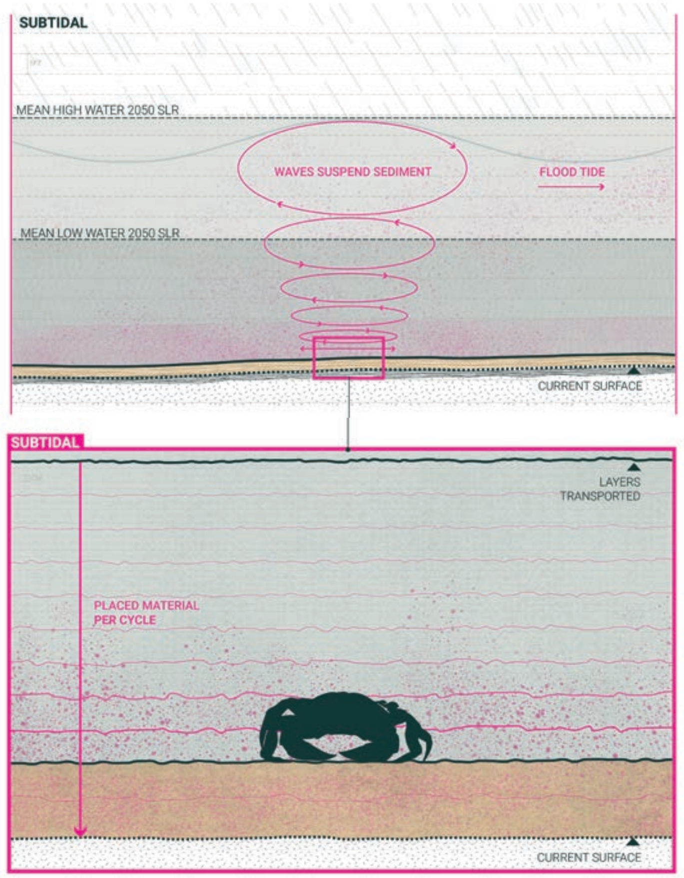


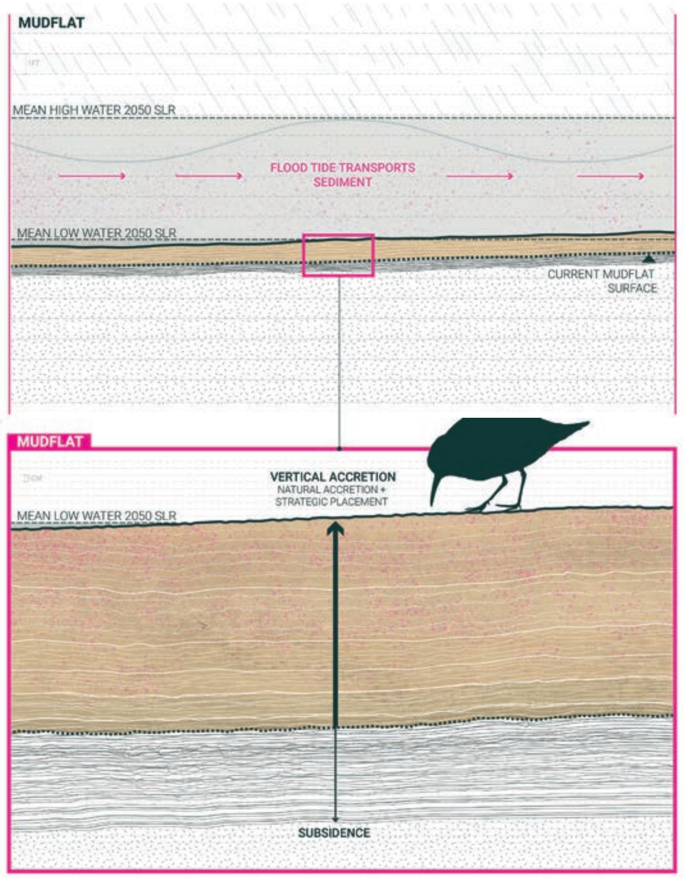
2 STRATEGIC PLACEMENT

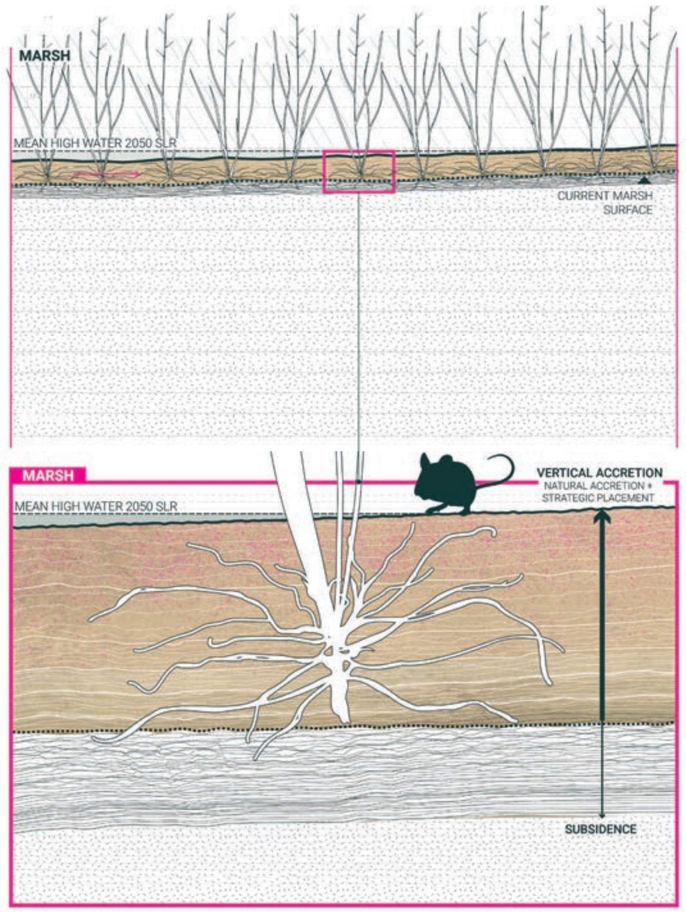
FUTURE WITH PROJECT

To compensate for SLR and subsidence-related elevation loss, the nearshore strategic sediment placement beneficially uses dredged material to reintroduce sediment. Monitoring material placement will help guide the amount and timing of material necessary for anticipated sea level rise. This drawing shows 1.5 cm/yr to keep accretion at pace with SLR and subsidence. This emphasizes the conceptual relationship between strategic placement and the maintenance of existing baylands.

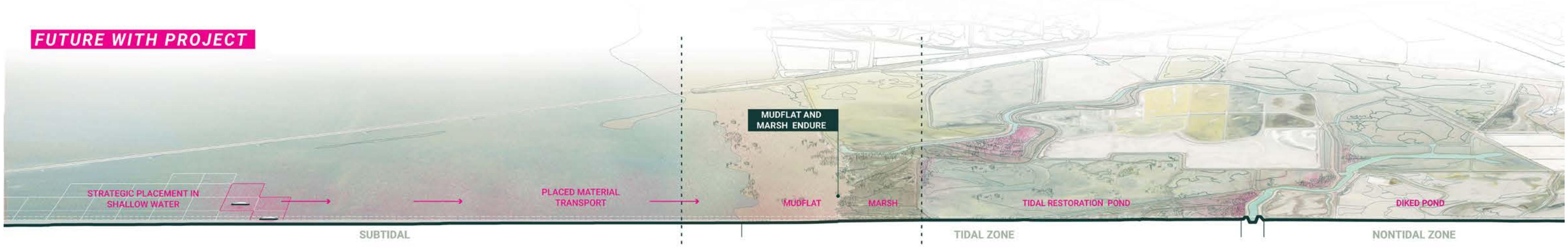
A pilot project will explore this potential technique, with the first placement scheduled for winter 2023, with monitoring extending a year post-placement to help guide the amount and timing of material necessary for anticipated sea level rise.

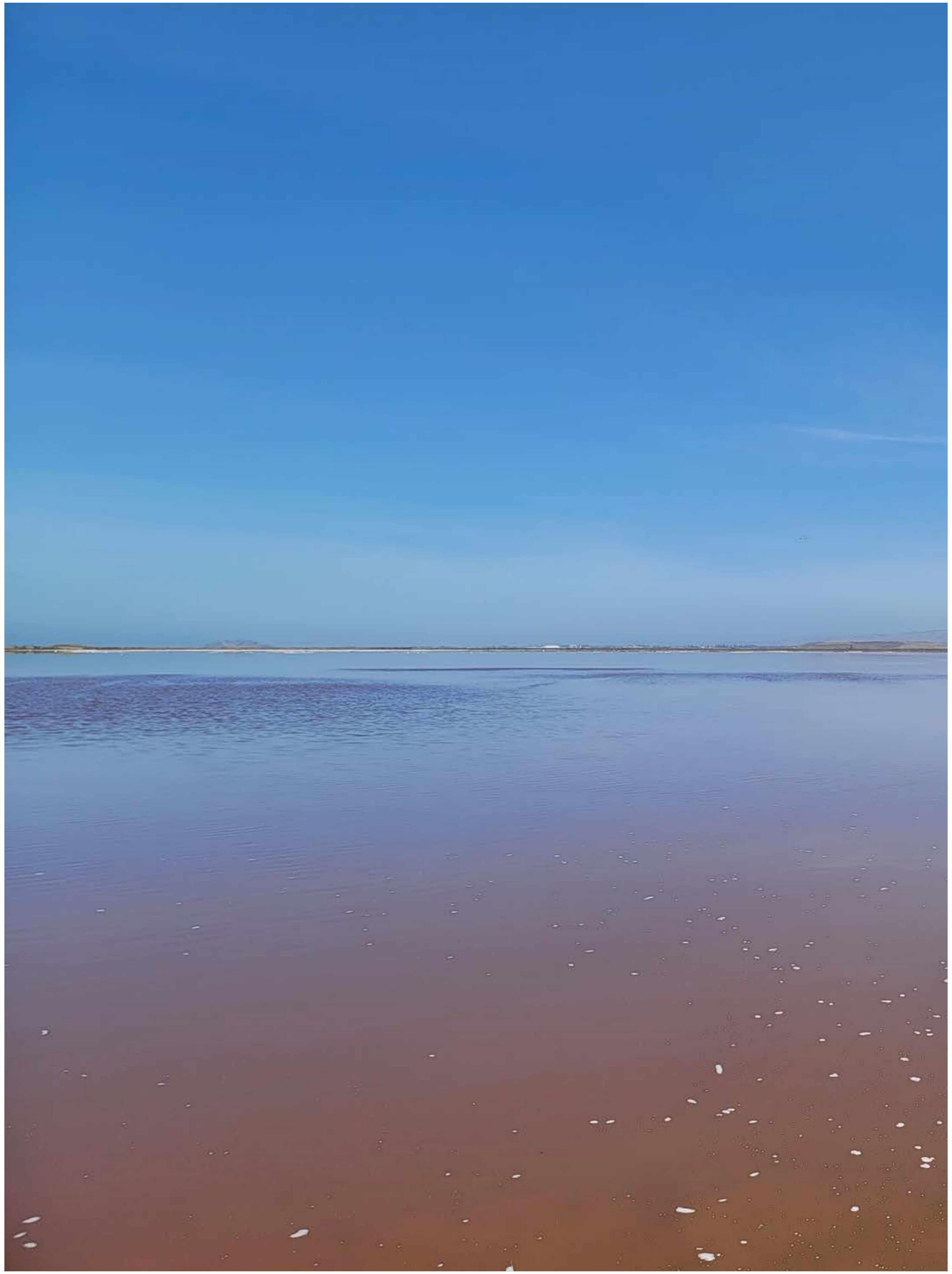






FUTURE WITH PROJECT





SOUTH SAN FRANCISCO BAY SHORELINE

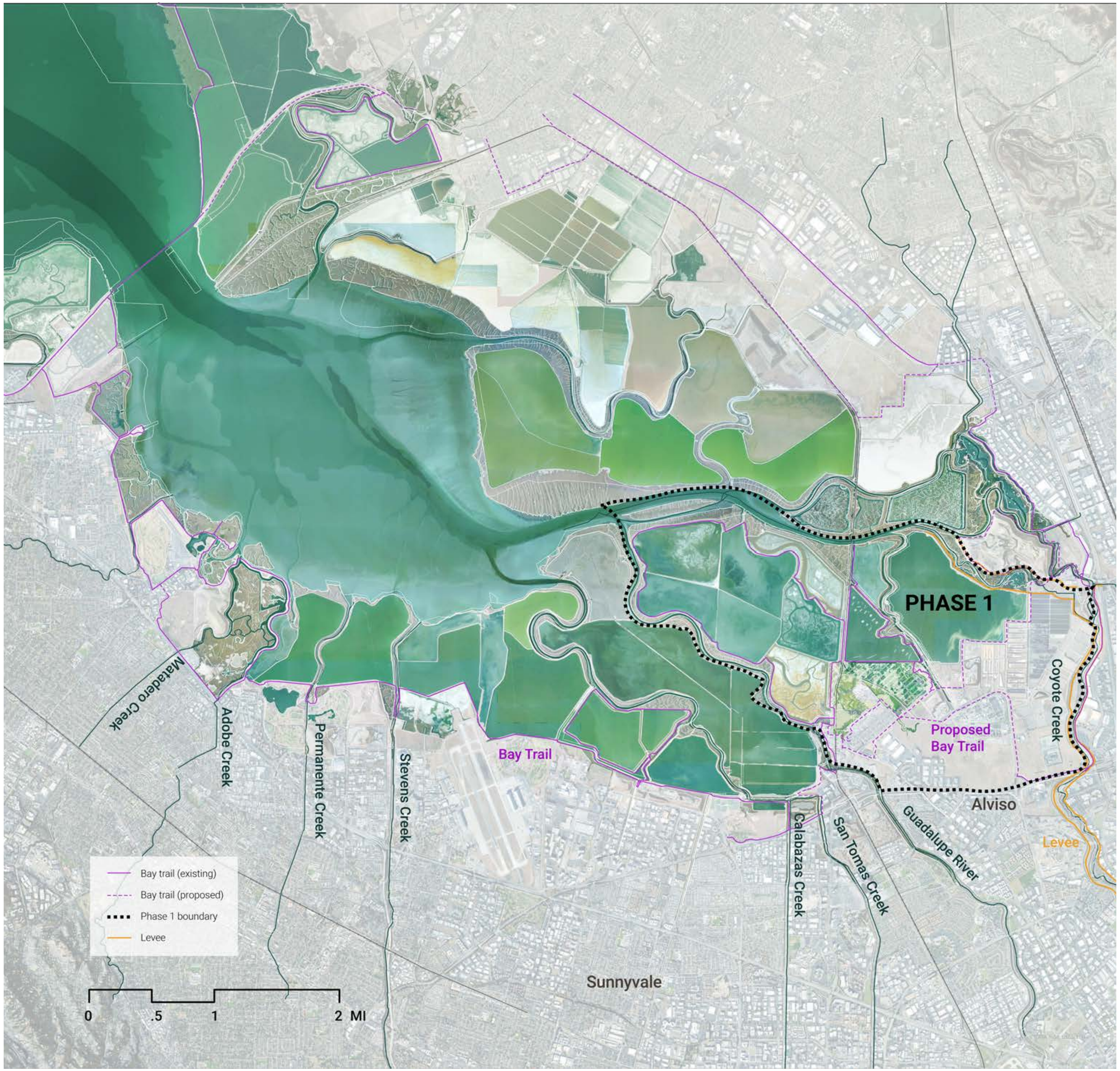
ALVISO COUNTY, CALIFORNIA

USACE's South San Francisco Bay Shoreline project is centered on the community of Alviso. The existing shorelines consist of a mosaic of diked salt ponds with a small levee between the ponds and upland Alviso. Based on the projected Relative Sea Level Rise (RSLR), it is expected that by 2067, the existing levee will be close to overtopping at Mean Lower Low Water (MLLW). This RSLR would put Alviso within the 100-year flood zone, potentially causing significant damage to the community during storm events and placing the area's immigrant and marginalized populations at risk. The planned South San Francisco Bay Shoreline project would build up a large levee between the salt ponds and the upland and systematically breach areas of the existing salt ponds to hydraulically connect them with the bay and convert them to salt marsh habitat. The following spreads show how parts of the shoreline project could eventually be integrated into a comprehensive system while adding an access and social component. A new trail system could incorporate Alviso's significant cultural and social history, though it would need to accomodate breaches in the dikes on the existing ponds. Moreover, phased implementation of recreational access could help educate and inform the public about the project timeline and the subsequent shifting landscape. It is important to note that the Shoreline project has continued to evolve since the work documented in this report was completed (in 2022-2023), and thus, while the following spreads are illustrative of the potential value of integrating a recreational access strategy into shoreline and similar projects, further refinement would be needed to align the details of design concepts with current planning and emerging conditions on the ground.

1

SOUTH SAN FRANCISCO BAY SITE CHARACTERISTICS

The South San Francisco Bay Shoreline project spans four miles of shoreline in Alviso and will restore approximately 3,000 acres of habitat. This large-scale effort provides an ideal opportunity to create a connected ecological and recreational landscape that serves the South Bay area. The cultural landscape protected by the bay is diverse, comprising the larger corporations of Silicon Valley, educational magnets like Stanford, and smaller disadvantaged communities like Alviso. Currently, the Bay trail winds around the dikes, providing miles of access to the salt ponds. The planned breaches will break up the continuous dike system, thus creating the need to anticipate and design a new trail system that works in conjunction with the levee and breached dikes. The EWN design concept plan shows how a new trail system could be situated on the newly built levees and how it could be phased to accommodate the planned breaches. Such a recreational plan could also incorporate and highlight the critical cultural and ecological history of the tidal marsh and adjacent communities. Educational materials could be provided to show the trail system plan, the phased approach, and the necessity of providing flood risk mitigation.



2 ALVISO LEVEE TRAIL
TIMELINE

Settled on Tamien Nation land, Alviso was founded on a floodplain, and, as such, the town has a complicated history with its location on the water, which has allowed it to flourish through maritime and manufacturing industries but also has been the cause of devastating flooding.

Pre 1800 — 1800 — 1850 — 1900 — 1925 — 1950 — 1975 — 2000

Settlement

Tamien Nation
Tamien Nation's traditional lands are within the Southern San Francisco Peninsula, including the now town of Alviso.

Ygnacio Alviso
In 1838, Governor Juan Bautista Alvarado granted Ygnacio Alviso over 6000 acres of land by Governor Juan Bautista Alvardo.

Incorporation of Alviso
The city of Alviso was founded in 1845 and incorporated on March 4, 1852 (one of the oldest towns in Santa Clara County).

New Chicago of the Far West
Street patterns and names still remain on remnants from the development from the "New Chicago" scheme

Maritime/ Railroad History

"Port of Unrealized Dreams"
Originally a boating and shipping port, it was the primary transportation link for San Jose and the only maritime center of Santa Clara County. Agricultural produce, hides and tallow from ranchos, and quicksilver from the Almaden mines" were transported through the port. Steamboats regularly traveled between SF and Alviso

Railroad Growth declined use of boating and shipping ports
The San Francisco-San Jose Railroad, which was later part of the Southern Pacific Railroad, built a direct line between San Jose and San Francisco, bypassing Alviso. However, in the 1880s, Alviso became a stop on the Newark line of Southern Pacific Railroad between San José and Oakland.

South Bay Yacht Club
Alviso was once the yachting company, led by the South Bay Yacht Club. Every spring, the start of the yacht season was celebrated with a flotilla of pennant-flying boats sailing out of the harbor, led by San José's elite. The clubhouse served as a vantage point for the spectacle, as guests could watch from the veranda to view the brightly-flagged boats.

Industry

Flour Alviso Mills
Founded in 1853- at its height was producing approximately 300 barrels of flour a day. Wheat production grew in San Joaquin Valley nearby, in turn transitioning Santa Clara Valley towards fruit production.

Bayside Canning Company
Bayside Canning Company, now one of the largest canneries in the US, was opened in 1906, Sai Yin Chew and his son, Thomas Foon Chew. Together, they operated the Chinese run cannery, known for paying generous wages and employing exclusively Chinese and Chinese Americans in the early nineteen hundreds.

Great Depression
During the The Great Depression, Alviso become well known for its dance halls and gambling establishments (thought of as uncivil during this era)

Hydrology

Founded on a Floodplain
In the towns early years, Alviso prospered, but its early development was limited by its flat, poorly-drained flood plain, as flood waters and high tides periodically inundated the town.

Significant Historical Flooding
Alviso experienced multiple significant floods from the Guadalupe River which occurred in 1862, 1895, 1911, 1955, 1958, 1963, 1969, 1982, 1986 and 1995.

Guadalupe River Siltation
By 1920, Alviso Slough and the Guadalupe River had become so heavily silted that Alviso harbor could no longer accommodate commercial vessels

Sewage Treatment Plant
San José annexed Alviso in 1968, all because of the sewage treatment plant that was necessary to support the growth of the future "Capital of Silicon Valley." While the larger city gained control over its destiny, those in the smaller community it absorbed have never believed that they received the benefits that being part of San José was supposed to provide.

1983 Flooding
In 1982 and 1983, El Nino storms, combined with a tidal surge, caused severe flooding in Alviso, placing the community under 10 feet of water. The flooding cause wide-spread devastation in the community, affecting both businesses and residents alike.

2

ALVISO LEVEE TRAIL
OVERALL PLAN

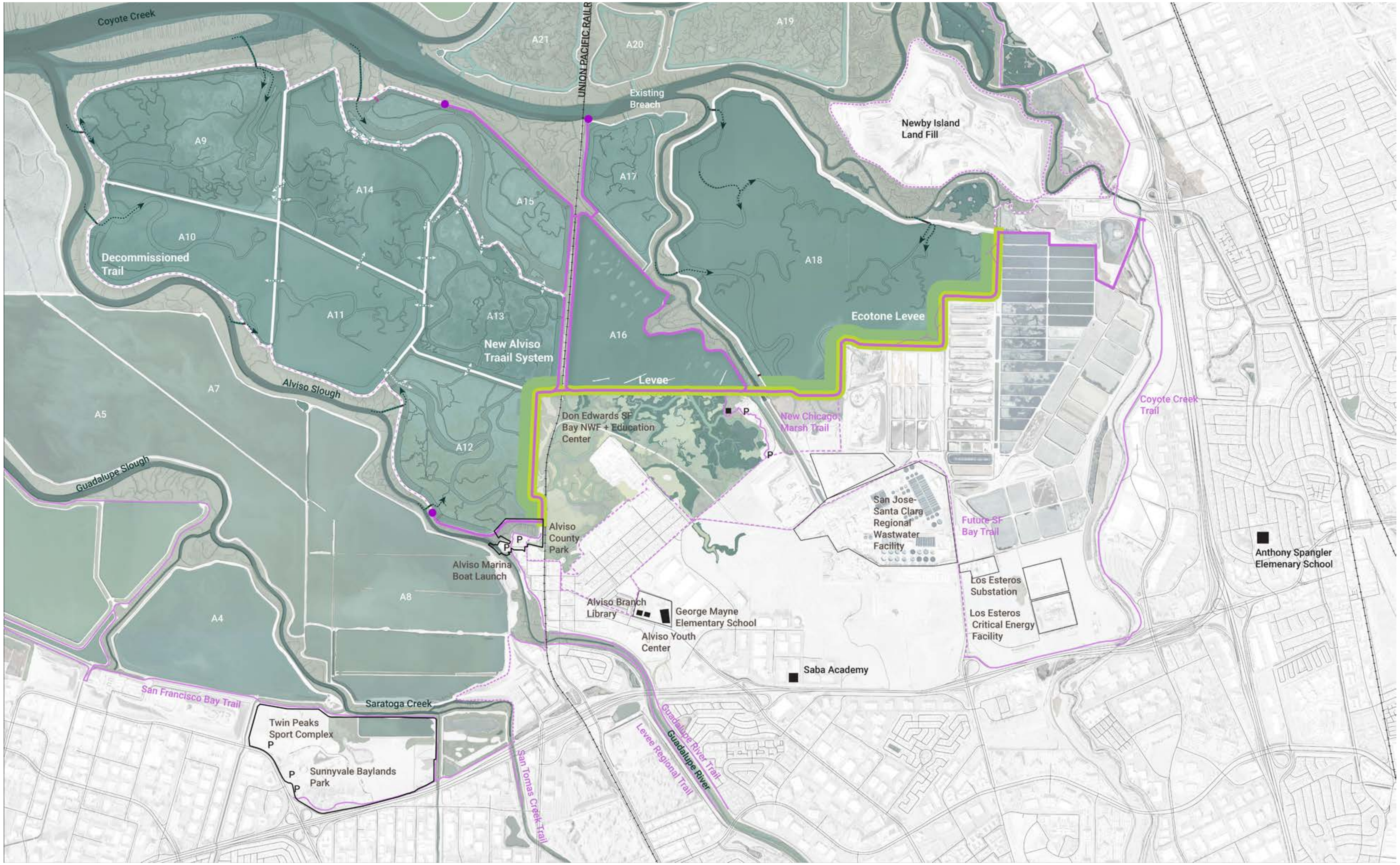
As the San Francisco District proceeds with the South San Francisco Bay Shoreline (South San Francisco Bay Shoreline Phase I Study, 2015), there will likely be valuable opportunities to maintain and add to the site's current recreational and ecological uses.

Three key elements could support a recreational access strategy here:

1) Provide educational materials to inform the public about how access may change as the project is implemented

2) Explain changes to the dike system through informative material that highlights the importance of the Shoreline project

3) Design a new recreational trail system with accompanying supplemental build features to highlight Alviso's ecological and cultural importance and supplement the ongoing ecological restoration work by USACE and associated agencies in the area.



Note that the Shoreline project has continued to evolve single the completion of drawings like this one, and further study would be necessary to adapt these concepts to the latest planning and implementation of the Shoreline project.

Trail Proposals

Existing- Prior to Shoreline 1 Proposal
— SF Bay Trail System
- - Thin-layer Placement

Proposed- Shoreline 1 Proposal
— Alviso Trail System
- - - Decomissioned Trail

Infrastructural Proposals

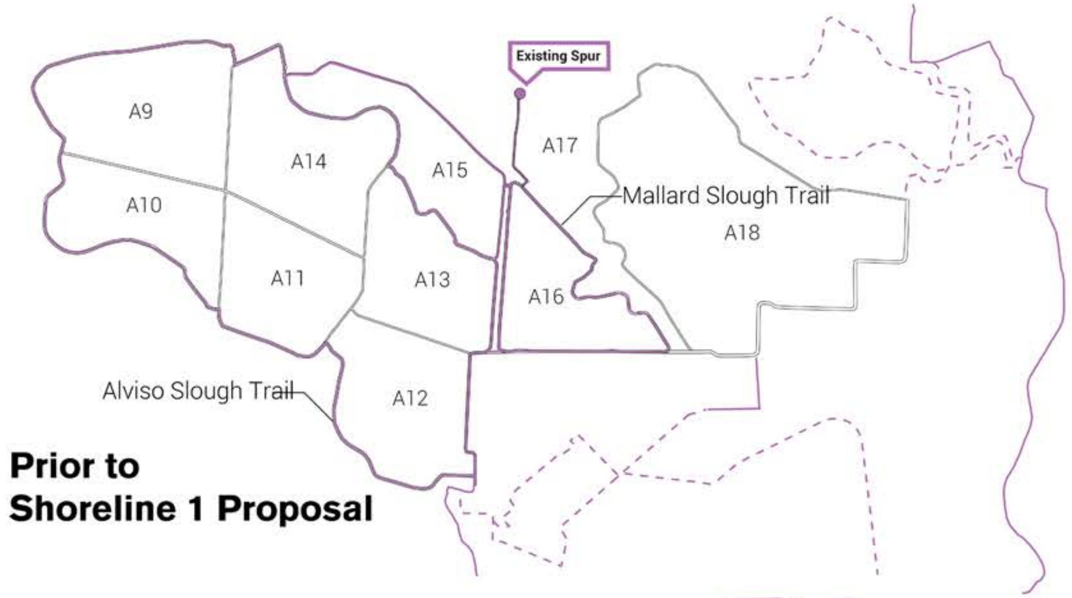
Levee Related
🟩 Ecotone Levee
🟩 Levee

Dike Related
↔ Internal Dike Breaches
↔ External Dike Breaches

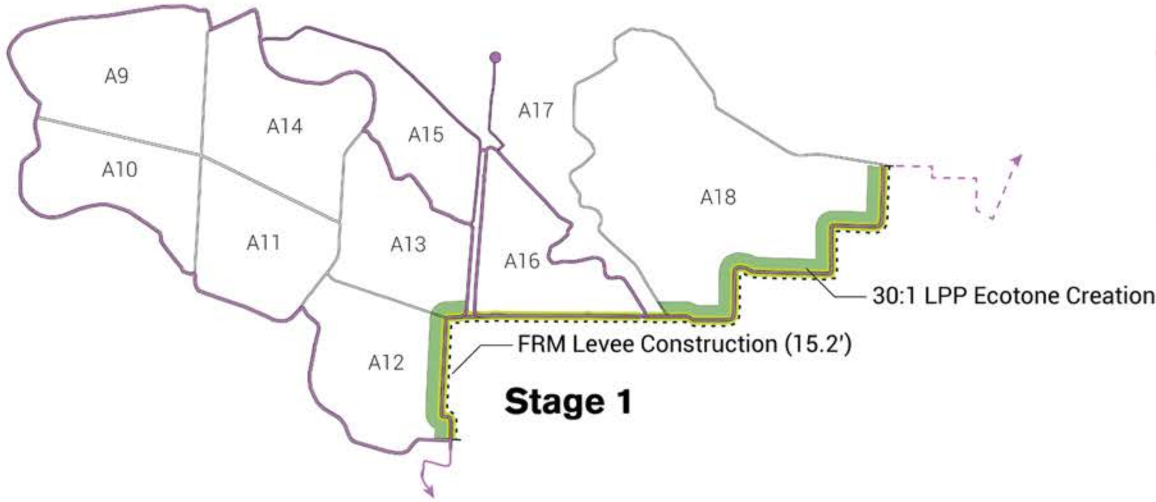
0 2000 4000 FT

2 ALVISO LEVEE TRAIL
STAGED APPROACH

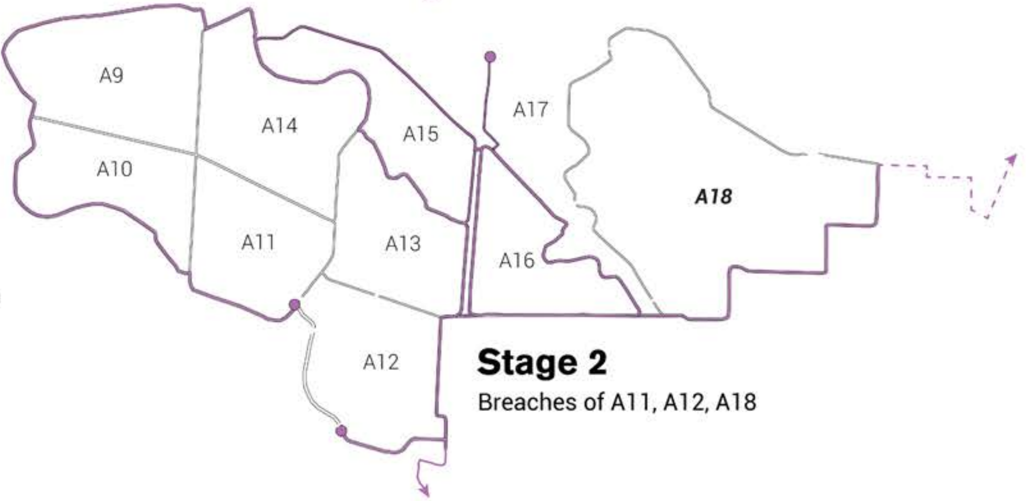
A phased approach could choreograph the addition of new trails and the decommissioning of old trails in coordination with planned levee breaches. Diagrams like these could be used to engage local communities in this planning process.



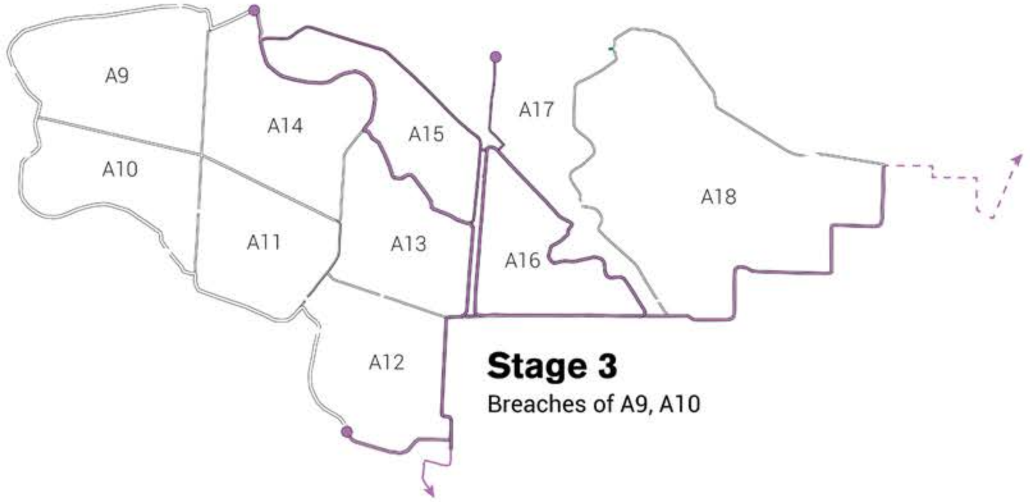
Prior to Shoreline 1 Proposal



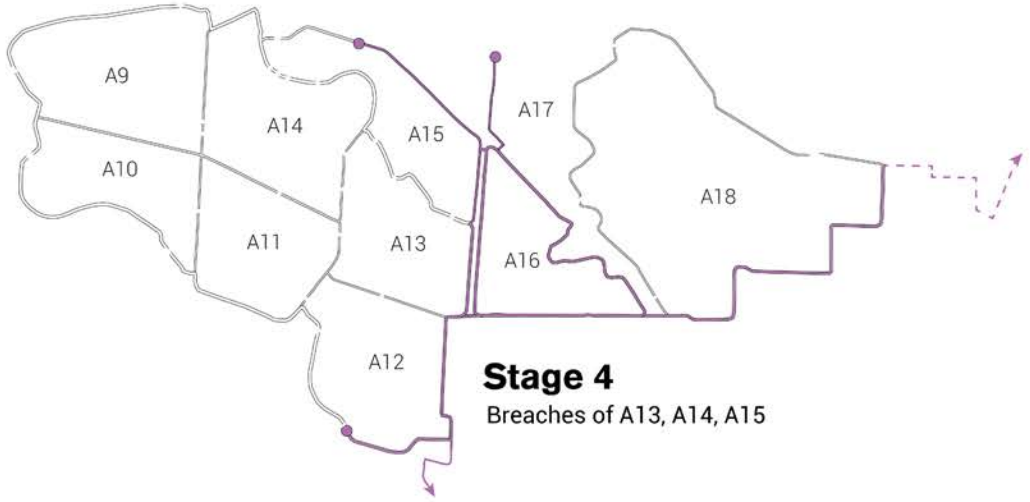
Stage 1



Stage 2
Breaches of A11, A12, A18



Stage 3
Breaches of A9, A10

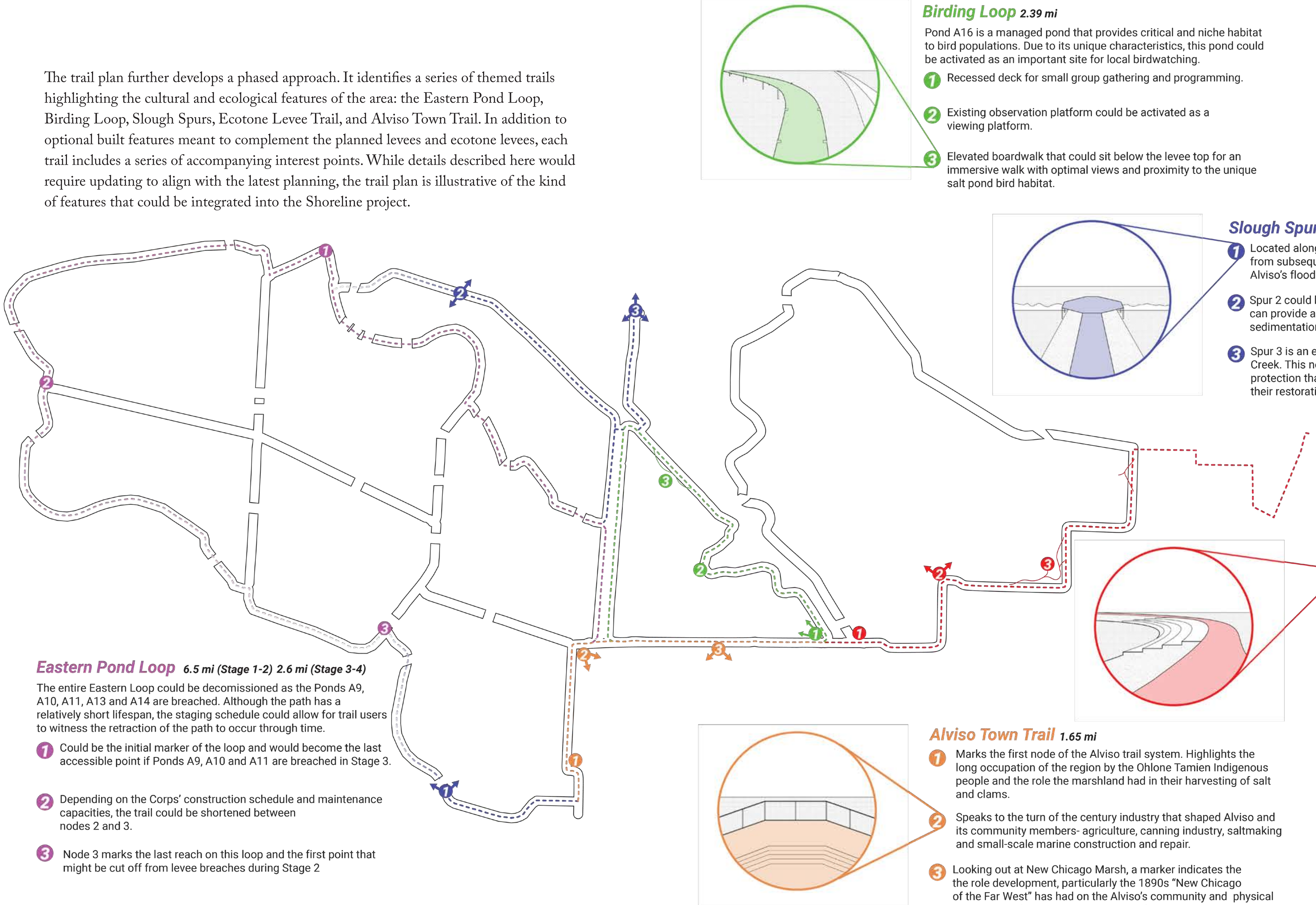


Stage 4
Breaches of A13, A14, A15

Note that the Shoreline project has continued to evolve single the completion of drawings like this one, and further study would be necessary to adapt these concepts to the latest planning and implementation of the Shoreline project.

2 ALVISO LEVEE TRAIL
ECOLOGICAL AND CULTURAL TRAIL PLAN

The trail plan further develops a phased approach. It identifies a series of themed trails highlighting the cultural and ecological features of the area: the Eastern Pond Loop, Birding Loop, Slough Spurs, Ecotone Levee Trail, and Alviso Town Trail. In addition to optional built features meant to complement the planned levees and ecotone levees, each trail includes a series of accompanying interest points. While details described here would require updating to align with the latest planning, the trail plan is illustrative of the kind of features that could be integrated into the Shoreline project.



Birding Loop *2.39 mi*

Pond A16 is a managed pond that provides critical and niche habitat to bird populations. Due to its unique characteristics, this pond could be activated as an important site for local birdwatching.

① Recessed deck for small group gathering and programming.

② Existing observation platform could be activated as a viewing platform.

③ Elevated boardwalk that could sit below the levee top for an immersive walk with optimal views and proximity to the unique salt pond bird habitat.

Slough Spurs *distance varies*

① Located along the Southern edge of A12 and potentially disconnected from subsequent trail early on (Stage 2), this spur focuses on Alviso's flood history, particularly the critical flood events of 1980.

② Spur 2 could be created at Stage 4 with the breaching of A15. This node can provide an overview of the historical tidal channels and natural sedimentation processes that existing prior to salt pond creation.

③ Spur 3 is an existing stretch of trail that extends towards Coyote Creek. This node can focus on the natural flood and erosion protection that marshlands provide and the importance that their restoration has on adjacent communities.

Eastern Pond Loop *6.5 mi (Stage 1-2) 2.6 mi (Stage 3-4)*

The entire Eastern Loop could be decomissioned as the Ponds A9, A10, A11, A13 and A14 are breached. Although the path has a relatively short lifespan, the staging schedule could allow for trail users to witness the retraction of the path to occur through time.

① Could be the initial marker of the loop and would become the last accessible point if Ponds A9, A10 and A11 are breached in Stage 3.

② Depending on the Corps' construction schedule and maintenance capacities, the trail could be shortened between nodes 2 and 3.

③ Node 3 marks the last reach on this loop and the first point that might be cut off from levee breaches during Stage 2

Ecotone Levee Trail *2.27 mi*

① Built-in seating marks the beginning of this trail with a general history on salt marsh restoration and the role of ecotone in providing important habitat and flood risk protection.

② Look-out ledge allows for a comprehensive view towards neighboring ponds and Coyote Slough, as well as a vantage point to look over the ecotone habitat.

③ Off-shoot trails on ecotone levee allows for an entrenching ecotone experience. Markers indicate the specificity of the salt marsh ecosystem, such as species ID and moments to identify zones of marsh that coincide with water levels.

Alviso Town Trail *1.65 mi*

① Marks the first node of the Alviso trail system. Highlights the long occupation of the region by the Ohlone Tamien Indigenous people and the role the marshland had in their harvesting of salt and clams.

② Speaks to the turn of the century industry that shaped Alviso and its community members- agriculture, canning industry, saltmaking and small-scale marine construction and repair.

③ Looking out at New Chicago Marsh, a marker indicates the the role development, particularly the 1890s "New Chicago of the Far West" has had on the Alviso's community and physical remnants such as street patterning and naming conventions.

Note that the Shoreline project has continued to evolve single the completion of drawings like this one, and further study would be necessary to adapt these concepts to the latest planning and implementation of the Shoreline project.

2 ALVISO LEVEE TRAIL

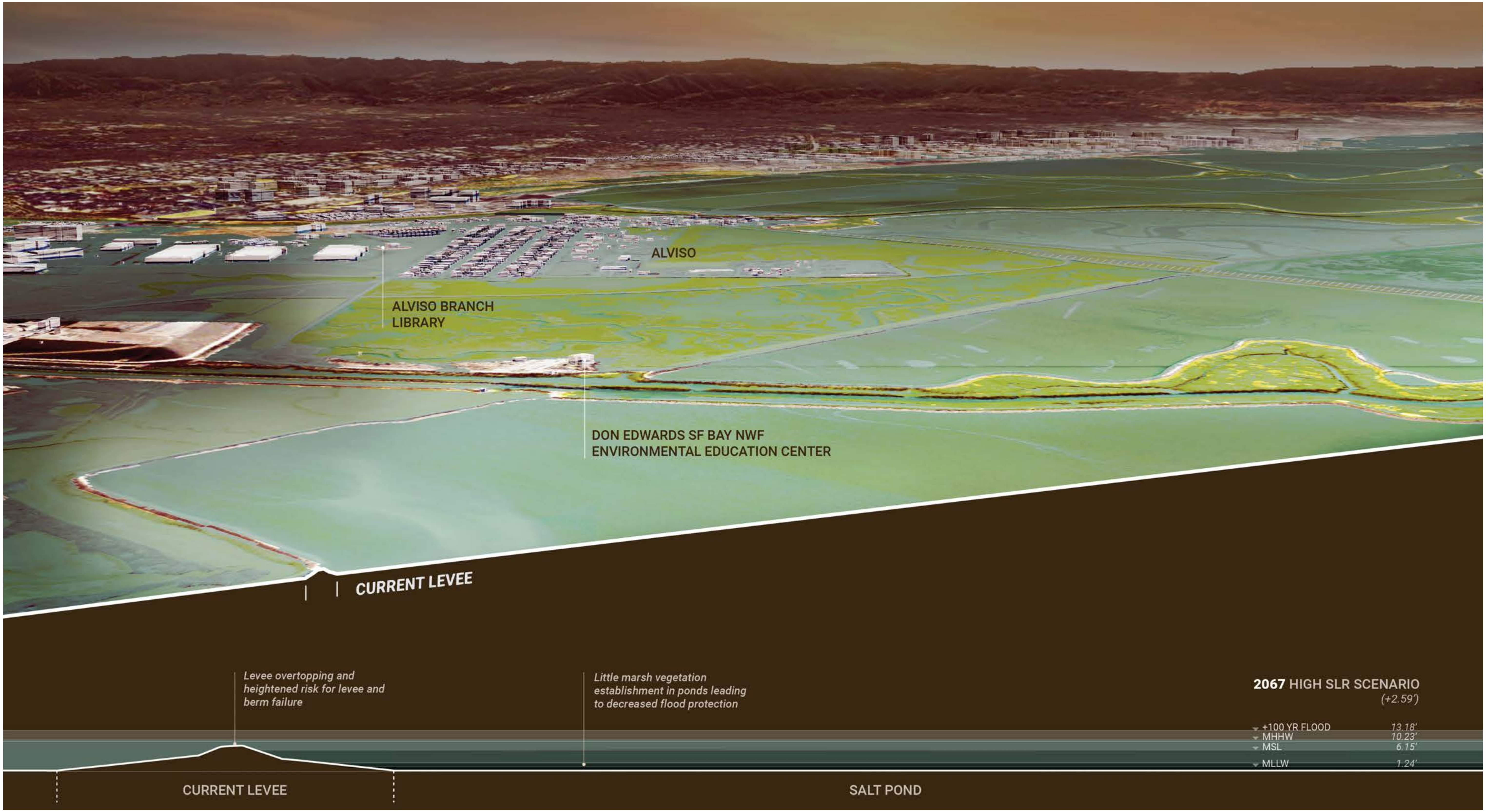
BIRD OBSERVATION DECK

An observation deck could look over both the bird pond and the restored salt ponds, allowing moments to appreciate the sublime beauty of the landscape and the associated flora and fauna.

3 SOUTH SAN FRANCISCO BAY SHORELINE

FUTURE WITHOUT DIKE BREACHES AND BUILT LEVEES

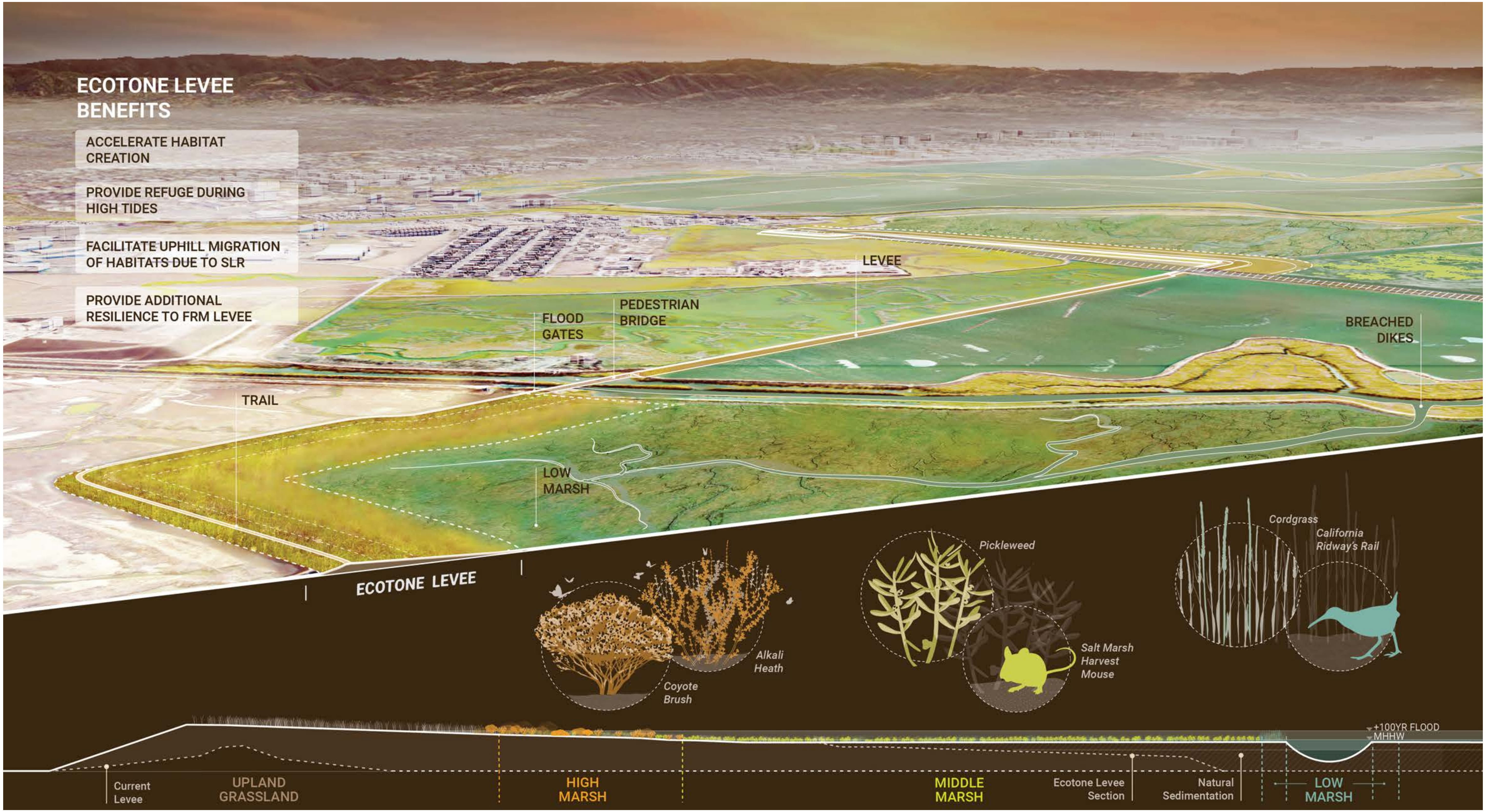
The following drawings envision two scenarios fifty years in the future: one with the South San Francisco Bay Shoreline project and one without the project. The current dikes risk overtopping and breaching without the project. Additionally, the salt ponds, isolated from tidal processes, become further subsided due to a lack of natural sediment supply (Appendix D1 To the Final South San Francisco Shoreline Study Feasibility Study and Environmental Impact Statement; Coastal Engineering and Riverine Hydraulics Summary, 2015).



3 SOUTH SAN FRANCISCO BAY SHORELINE

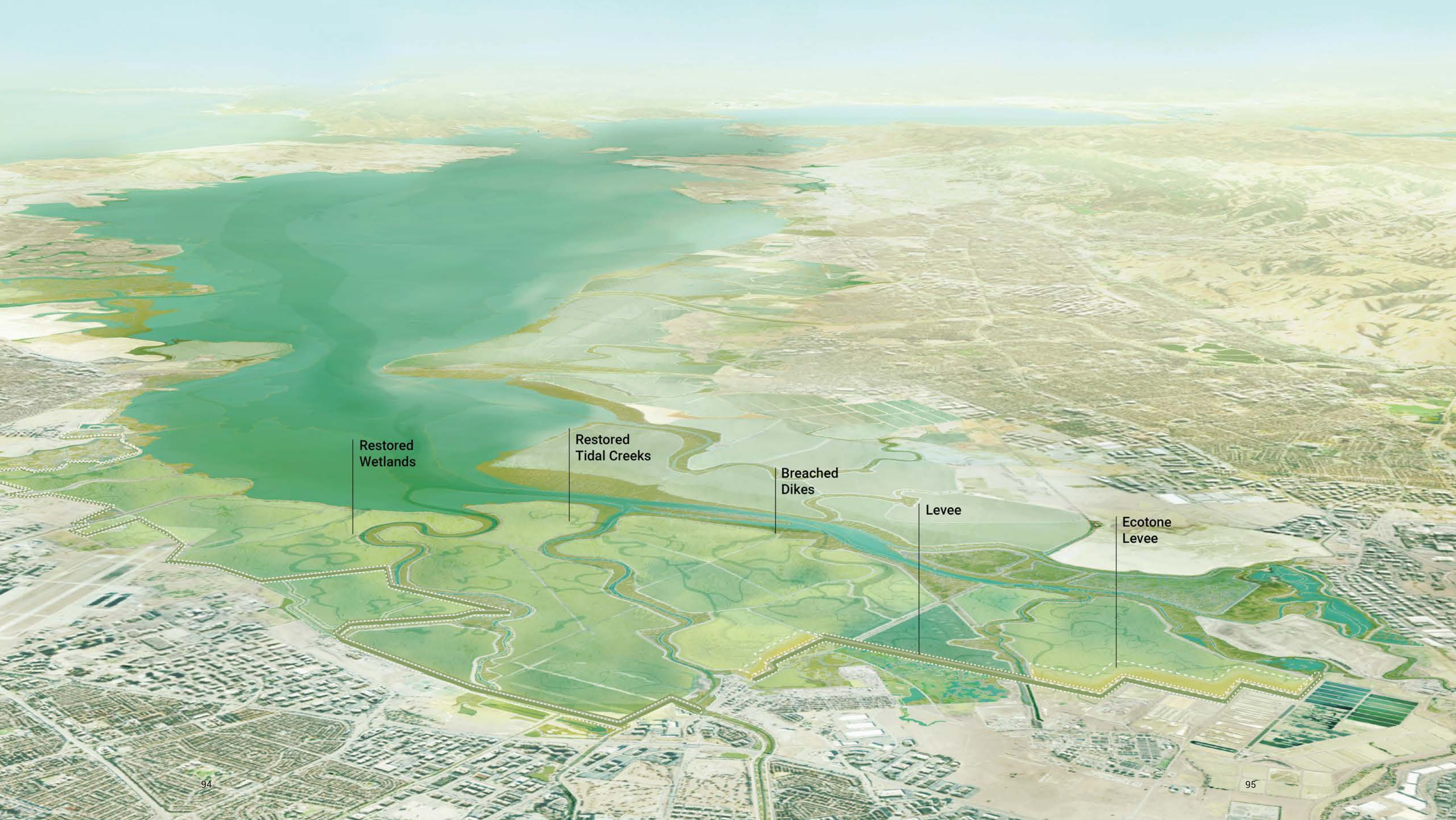
FUTURE WITH DIKE BREACHES AND ECOTONE LEVEES

In contrast, this drawing demonstrates the flood and sea level rise protection that an ecotone levee would afford the neighboring community of Alviso, as well as the ecological benefits of the project. The breached dikes would restore tidal and sedimentary processes to the salt ponds, allowing for sediment accumulation in the restored marsh. By creating topographic diversity and connection in an otherwise flat landscape, the levee would allow for future marsh migration to higher ground, mitigating some of the adverse effects of sea level rise on marsh loss.



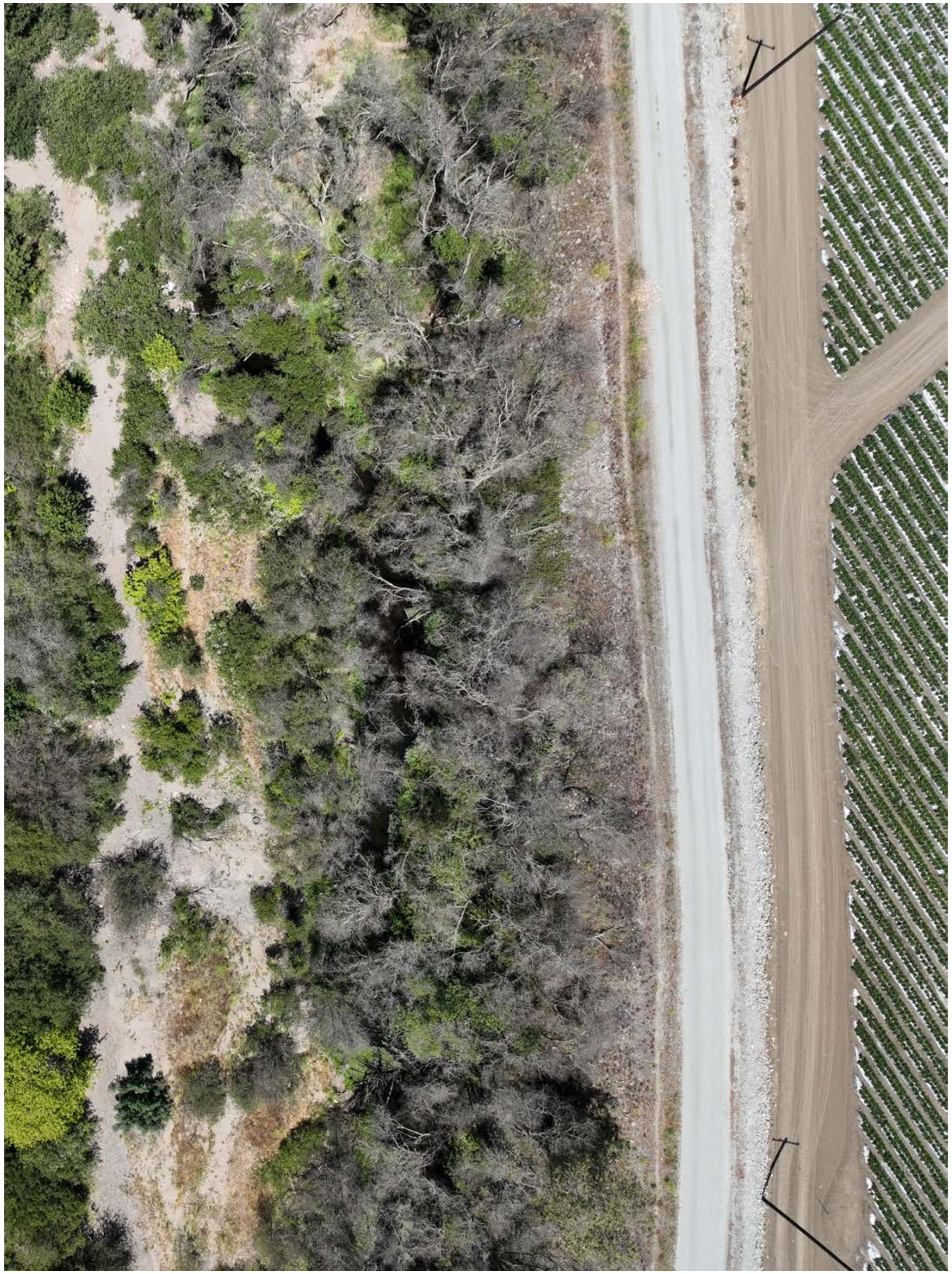
3 SOUTH SAN FRANCISCO BAY SHORELINE
ENTIRE SOUTH SAN FANCISCO BAY

In the future, ecotone levees could be extended further west, affording many South Bay communities flood risk management. Such an expansion project would convert thousands of acres of diked, subsided salt ponds into valuable tidal marsh habitat. Such a project could serve as a connecting landscape in the South Bay while offering protective, environmental, and recreational services to the adjacent communities.



PART 4

CENTRAL BASIN



CENTRAL BASIN

OVERVIEW

The Central California Coast is drained by a number of smaller rivers. Two that empty into Monterey Bay, the Pajaro and Salinas, have a significant impact on the inland ecology of this region, providing habitat corridors within an otherwise dry grassland environment. Closer to the Pacific coast, famous coastal redwood forests emerge in more moist environments. Several vulnerable species live or breed near the Pajaro River, including western pond turtles, pallid bats, and burrowing owls. Off the shore, Monterey Canyon makes Monterey Bay a hub of diverse and abundant aquatic life, ranging from kelp forests and bat rays to sea otters and dolphins.

The natural scenery of the Big Sur coastline, much of it protected by Pfeiffer Big Sur State Park, makes it one of the biggest tourist destinations in the country. In addition to scenic beaches, Pfeiffer Big Sur State Park, like the more inland Pinnacles National Forest, offers recreation in the form of hiking and camping. North of Big Sur, Monterey Bay provides additional recreational opportunities, especially for lovers of aquatic life. Monterey Canyon makes the bay a prime location for scuba diving and whale watching, and the Monterey Bay Aquarium is one of the largest public aquariums in the country.

The Salinas and Pajaro River valleys support a large amount of agricultural production, which presents a complicated set of social and ecological vulnerabilities. A significant amount of this agricultural land falls within the 100-year floodplain, making it at risk of flood damage. Additionally, the overuse of groundwater for irrigation, particularly in the Salinas Valley, is causing problematic saltwater intrusion. Within the Pajaro River, agricultural runoff, illegal dumping, and flood control levees threaten the waterway's ecological health. Many of the communities of agricultural workers are also socially vulnerable, facing high rates of poverty.

1 REGIONAL OVERVIEW
USACE PROJECT FOCUS

In the Central Basin region of the San Francisco District, the USACE's work includes the dredging of Moss Landing Harbor, a few ecological restoration projects, and the maintenance of several river levels for flood risk management. The Pajaro River is the most extensive levee system in the District, with over 20 miles of levees constructed on both sides.

ECOLOGICAL + SOCIAL VULNERABILITY

- ▤ **FEMA 100 YR Floodplain**
- 🟩 **Vulnerable Wetlands*** *According to TNC Resiliency Study*

Social Vulnerability Index

- ☐ 0-20% Poverty
- ☐ 20- 40%
- ☐ 40-60%
- ☐ 60-80%

Center for Disease Control Agency for Toxic Substances and Disease Registry. 2018. Social Vulnerability Index- Overall. Overall Social Vulnerability Map Service.

ECOLOGICAL + SOCIAL ASSETS

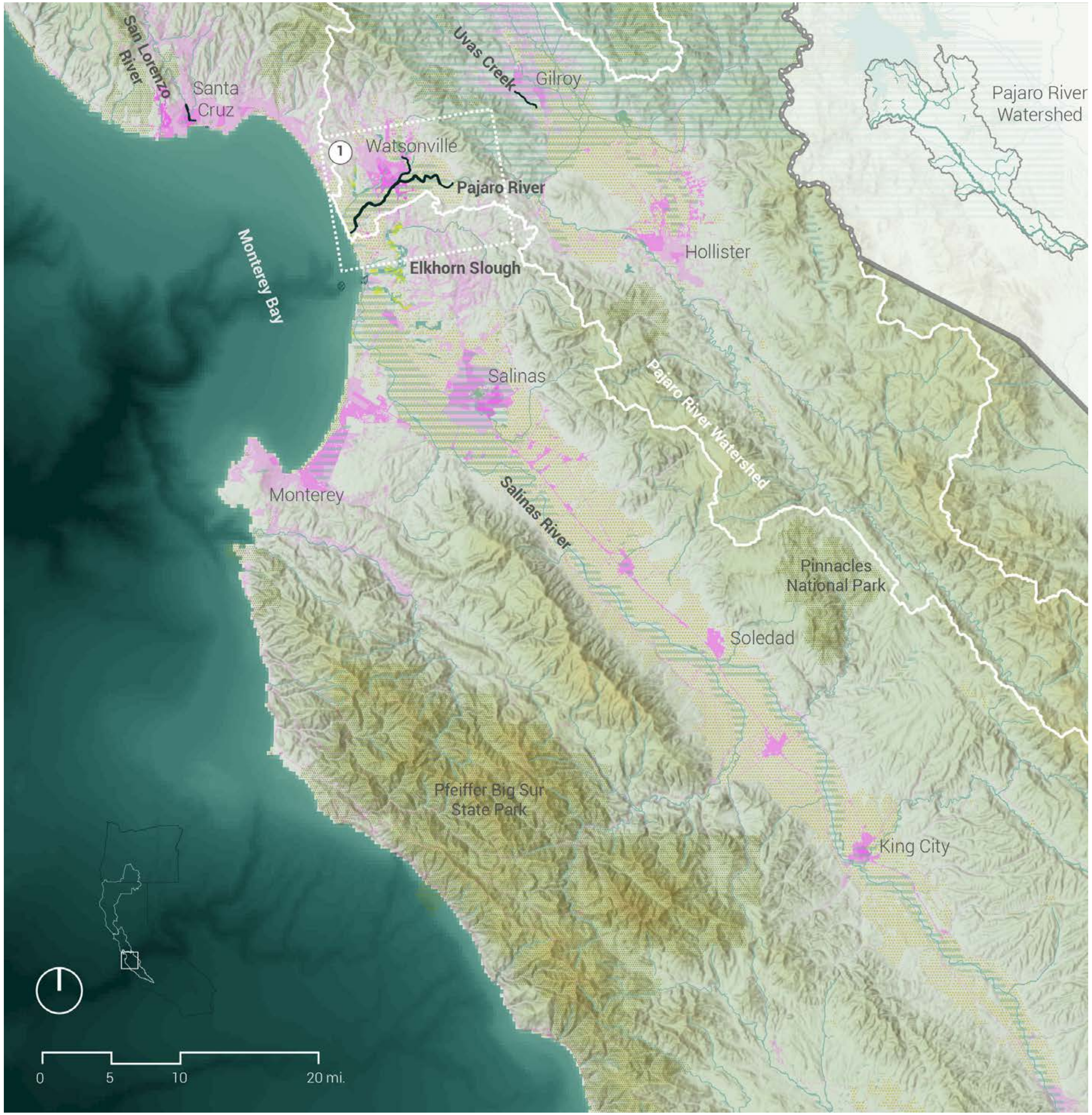
- ■ **Wetlands**
- ▦ **Parks and Protected Areas** *National, State, and Local Parks*
- ▦ **Crop Land**

EWN-LA FOCUS FOCUS AREAS

- ① **Floodplain Expansion** Pajaro River, California

USACE PROJECTS + OPERATIONS

- ■ **USACE Channel Areas**
- ▨ **USACE Placement Areas**
- — **USACE Levees**



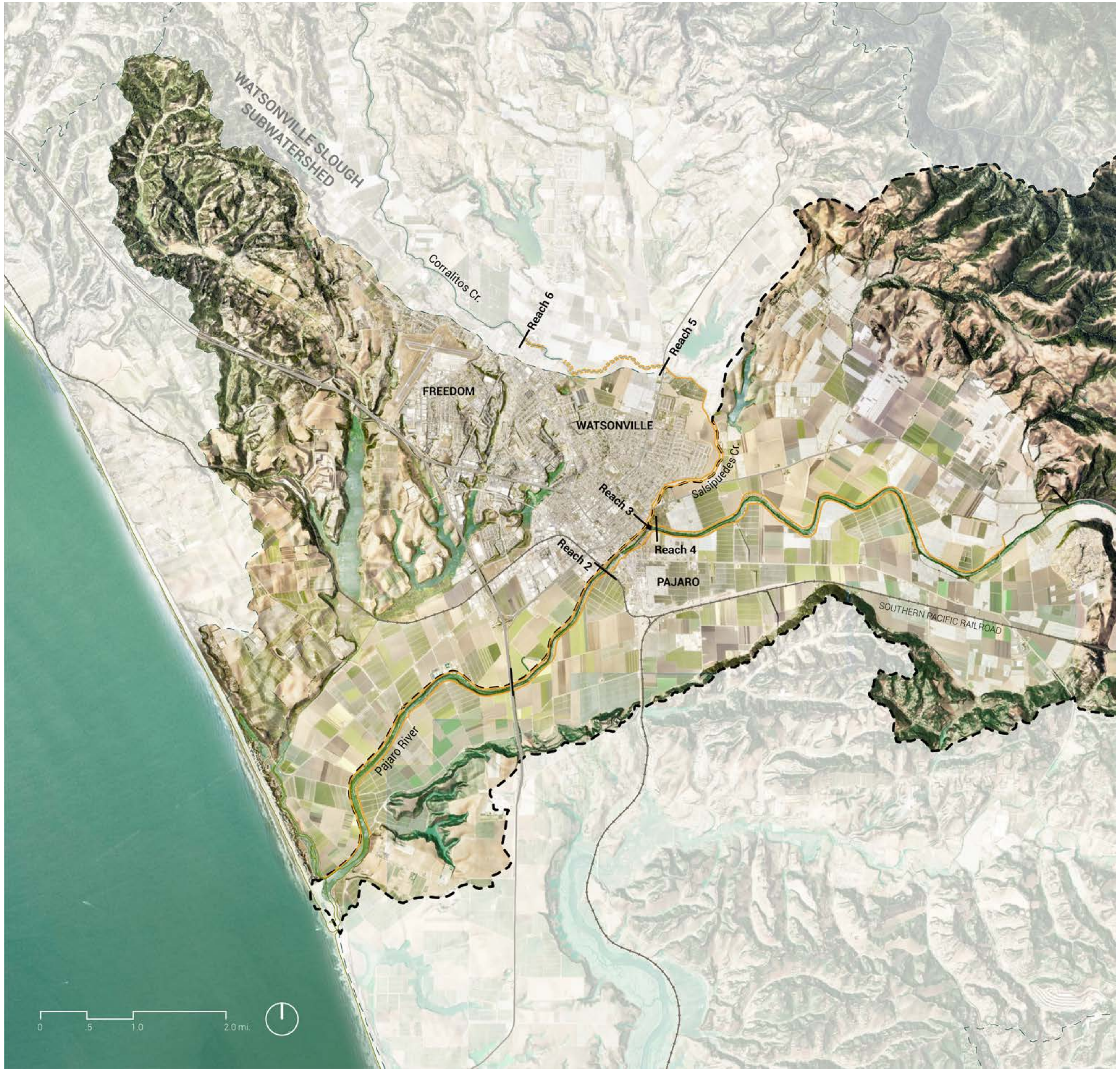
FLOODPLAIN EXPANSION

MONTEREY & SANTA CRUZ COUNTIES,CA

Existing levees along the Pajaro River require restoration and improvement to increase flood risk management. The Town of Pajaro, the City of Watsonville, and the surrounding areas have suffered multiple large-scale flood events, with the most significant events occurring in 1955, 1958, 1995, 1998, and 2023. The population impacted by flooding has a high level of social vulnerability and is economically disadvantaged (Pajaro River Flood Risk Management Project, 2019). The river segment near Pajaro and Watsonville consists of an incised channel disconnected from the surrounding floodplain. The USACE intends to offset the existing levees to increase the flood storage, which presents an opportunity to encourage river braiding and pooling of water during storm events within this expanded floodplain and facilitate enhanced geomorphic function. The urgency of providing increased flood storage was tragically underlined during the writing of this report when flood waters in March 2023 caused a levee failure that flooded homes and fields and displaced nearly 3,000 residents, drawing national attention to the Pajaro River and the ongoing levee setback project.

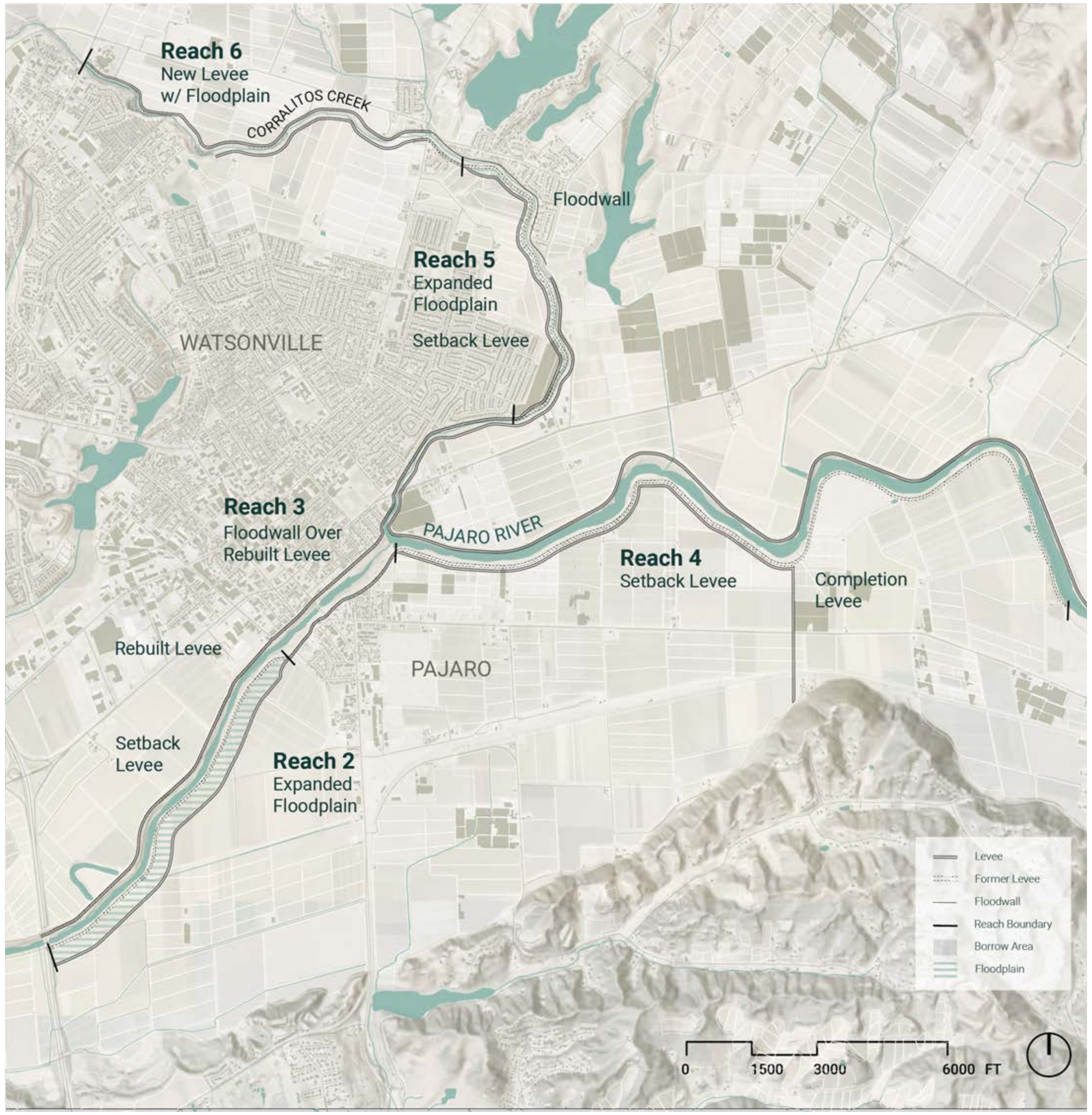
1 PROJECT OVERVIEW
SITE CHARACTERISTICS

The Pajaro River is a 30-mile-long river in the Central Coast region of California, forming the border between Santa Cruz and Monterey counties. The river discharges into Monterey Bay and runs adjacent to Watsonville and Pajaro, two underserved, agriculturally based communities. The current levee system, built in 1949, is located on both sides of the Pajaro River and along Salsipuedes Creek. Currently, there are no existing levees along Corralitos Creek. The stretch of levee along Salsipuedes Creek is the only levee reach that is publicly accessible and is heavily used by pedestrians and bicyclists.



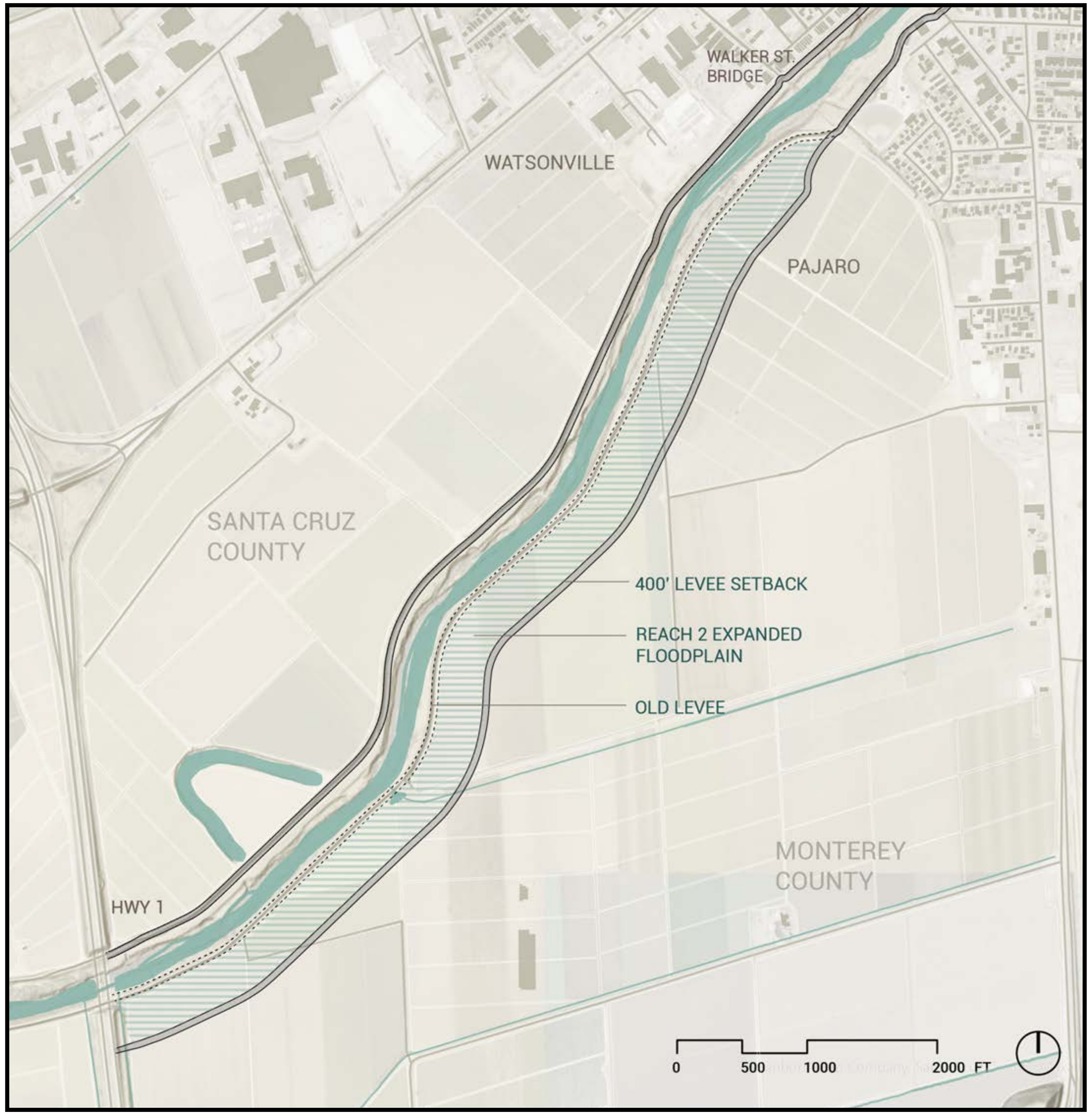
1 PROJECT OVERVIEW
USACE PROJECT

The Pajaro Levee Flood Risk Management project divided the study area into eight reaches based on the major confluences, land uses, and significant bridges. As shown on the map, the Tentatively Selected Plan (TSP) proposes flood risk management feature improvements on Reaches 2, 3, 4, 5, and 6, which include the demolition of the existing levees, and construction of a new setback, replacing a portion of an existing levee with a floodwall, rebuilding existing levees, and building a new levee or floodwall in other areas. The preferred plan, as outlined in the 2019 Pajaro General Reevaluation Report (GRR), calls for a 100' setback on both the Monterey and Santa Cruz sides of the river. Although the Reach 2 authorized project is for 100' setbacks on both sides, the VE Revision, as proposed by NFS, suggests a 400' setback on the Monterey County side. The following design proposal considers the VE Revision.



The concepts that follow focus on Reach 2. Reach 2 is located on the main stem of the Pajaro River and extends approximately one and a half miles from the west of Watsonville's city limits to Highway 1 Bridge. Both sides of this stretch of river border agricultural land, and while public access is limited, the proximity of the stretch to the city presents an opportunity to connect with the current Salsipuedes-Pajaro cycle trail, which runs along Reach 3 and Reach 5. In a recent habitat improvement project, Santa Cruz County Flood Control and Water Conservation District excavated floodplain benches throughout Reach 2 and Reach 4 (Pajaro River Bench Excavation Project, 2012). Since construction, there is evidence that the river has carved out pools and other microtopography. Accordingly, this project could serve as a model for more habitat improvements through this stretch.

The preferred plan, as outlined in the 2019 Pajaro General Reevaluation Report (GRR), calls for a 100' setback on both the Monterey and Santa Cruz sides of the river. Although the Reach 2 authorized project is for 100' setbacks on both sides, the VE Revision, as proposed by NFS, suggests a 400' setback on the Monterey County side. The following design proposal considers the VE Revision.



2

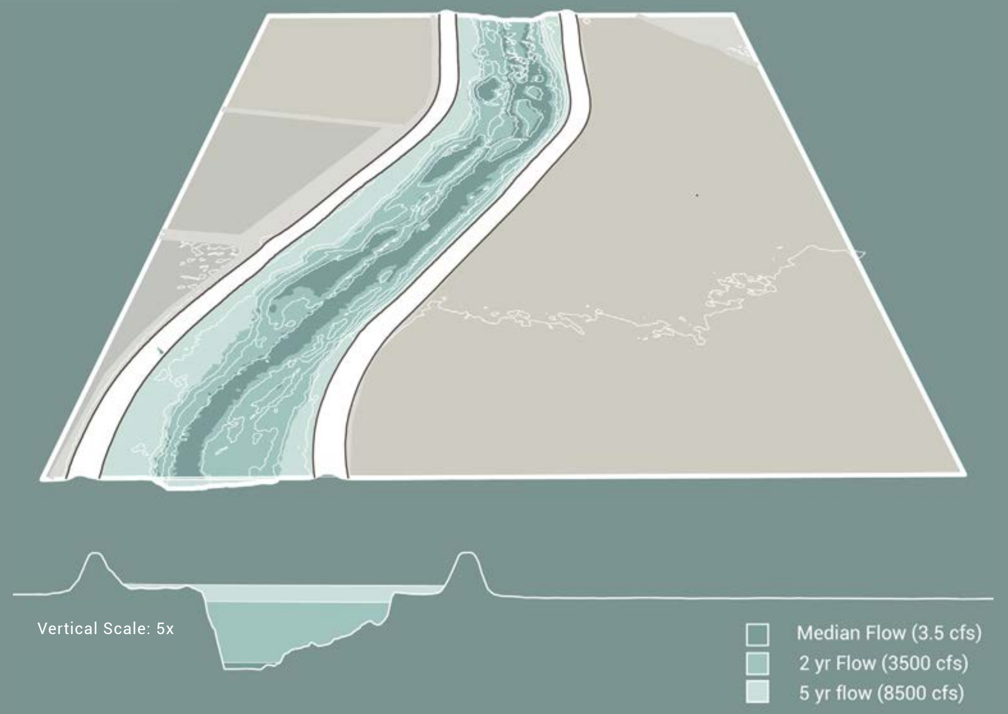
CONCEPT DEVELOPMENT
SETBACK OPTIONS: CURRENT

In addition to the flood risk management benefits, the General Reevaluation Report identified several ecological, hydrological, and recreational opportunities that have the potential to be studied and incorporated into the current plan. These opportunities included increasing habitat for special status and native species, restoring a more naturally functioning riverine system, improving water recharge, and increasing recreational benefits. Our findings suggest that all of these opportunities could be integrated into the risk management floodplain expansion for Reach 2.

At the right and on the following pages, a series of diagrams show the conceptual relationships between the current levee configuration, the proposed levee setback without any additional alterations to the floodplain, and two alternatives for building greater hydrological and ecological functions in the expanded floodplain.

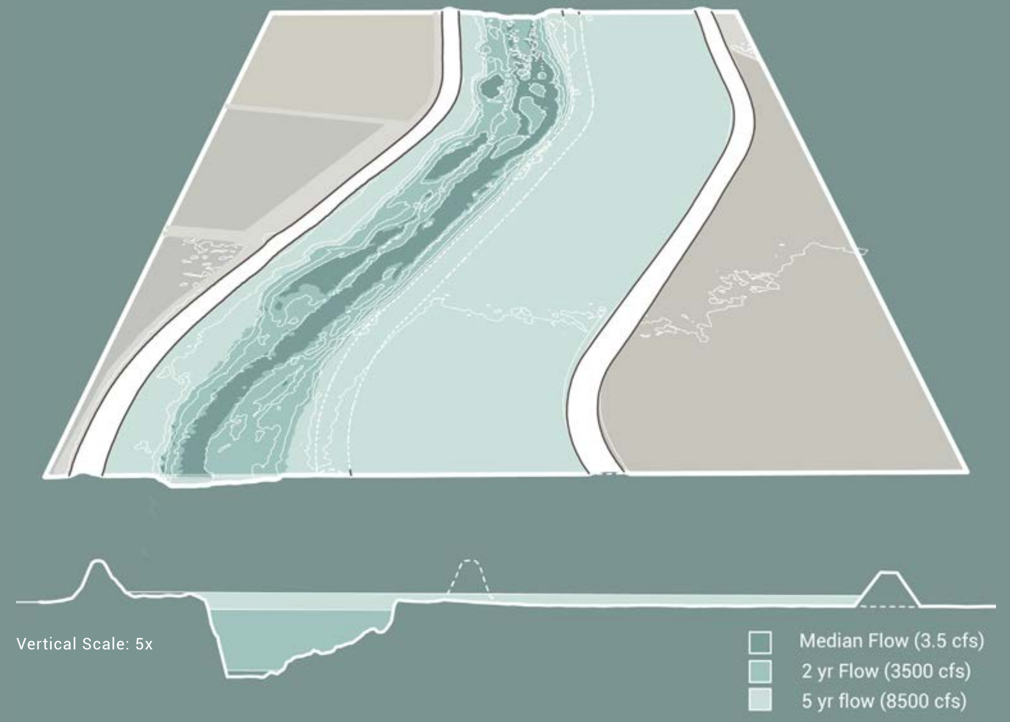
CURRENT

Current built levee conditions



LEVEE SETBACK

Conditions after removal of the current levee and construction of 400' levee setback



2 CONCEPT DEVELOPMENT
SETBACK OPTIONS: ALTERNATIVE

Two primary research questions informed the alternatives on the pages that follow. Within the river channel, can multi-thread channels, or a dynamic active channel be promoted? And, up in the river's floodplain, can topographic design encourage floodplain function that improves over time with flood events?

Anastomosing River

Based on the high sediment load and highly variable hydrological conditions, Pajaro River can be expected to act as the similar adjacent river, Salinas Creek, which exhibits anastomosing behavior (personal communication, Mark Strudley, June 6, 2022). Anastomosing rivers consist of multiple, semi-permanent interweaving channels. These channels may themselves be braided. Except for the bank excavation work, Reach 2 is incised, contained by steep banks that grade into the existing levees. A 400' levee setback would provide space to create floodplains and widen the channel, increasing critical habitat for native species. The widened channel could slow the flows sufficiently enough to cause gravel deposition, increasing spawning in the mainstem for Chinook Salmon. More diverse stands of vegetation could develop on the point bars on the inside bends, enhancing aquatic and riparian habitats. The multi-channeled river could serve the red-legged frog, which lays eggs in slow-moving/still waters.

The challenges of this concept stem from the fact that a mere levee setback will still have an incised channel disconnected from a floodplain in all but the largest storms. The channel's banks must be reworked into a desirable shape to achieve many potential ecological and social benefits of a wider channel and connected floodplain.

The 2012 bank excavation project demonstrates that this increased geometric complexity can be beneficial and maintain flood control function. However, that approach used mechanical means to reshape and reconnect the floodplain, which has significant upfront costs and ecological impacts. This study considered the possibility that the river might be put to work reshaping its floodplain, much like a natural system, This study considered the possibility that the river might be put to work reshaping its own floodplain, much like a natural system, perhaps even achieving the goal of anastomosing.

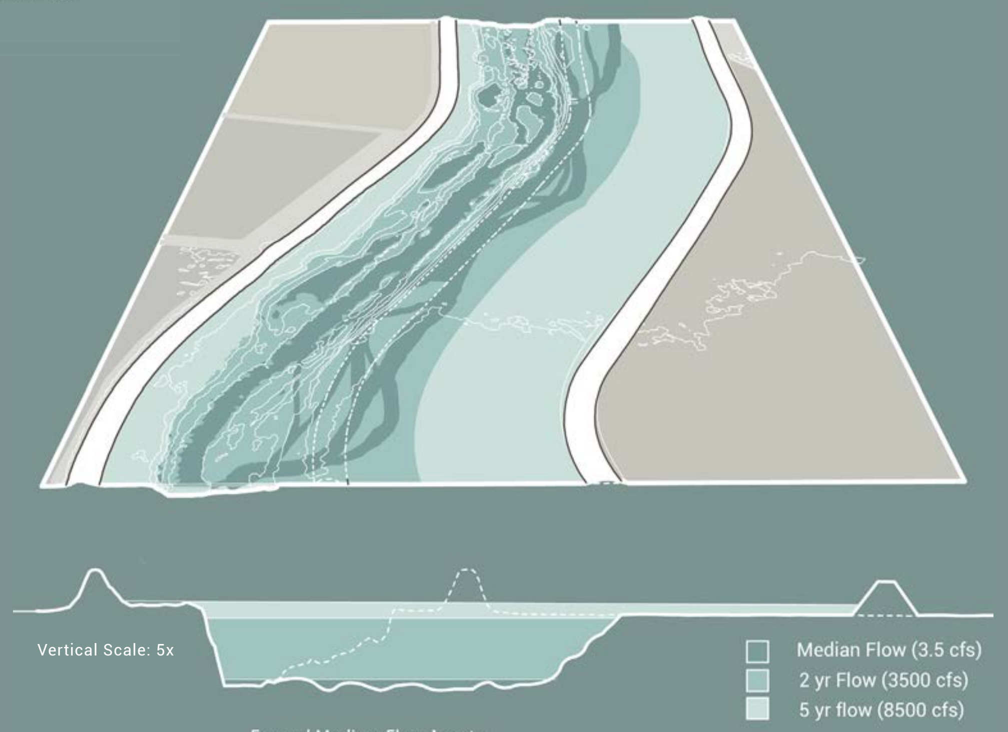
Floodplain Co-Design

Connecting the river to the floodplain during 2-year and 5-year flood levels would increase groundwater recharge, create microtopography, and improve the habitat value of the floodplain. A working assumption for this study was that these smaller storms influence the river morphology and habitat potential more because of their frequency. They should be considered in the design process along with the 100-year and 500-year storms studied for flood risk management.

As mentioned previously, Reach 2 has deeply incised and steep riverbanks. Because of these incised banks, more excavation work may be needed to reconnect the floodplain during these more common flood events. Therefore, studying the frequency of flood events related to the current topography within the levee setback area is important.

ANASTOMOSING RIVER

Alteration of floodplain to allow for the river to anastomse under medium flow



Expand Medium Flow Area to encourage anastomosing river

FLOODPLAIN CODESIGN

Alteration of floodplain to allow for floodplain activation under 2 yr flow conditions

3

COMPUTATIONAL MODELING

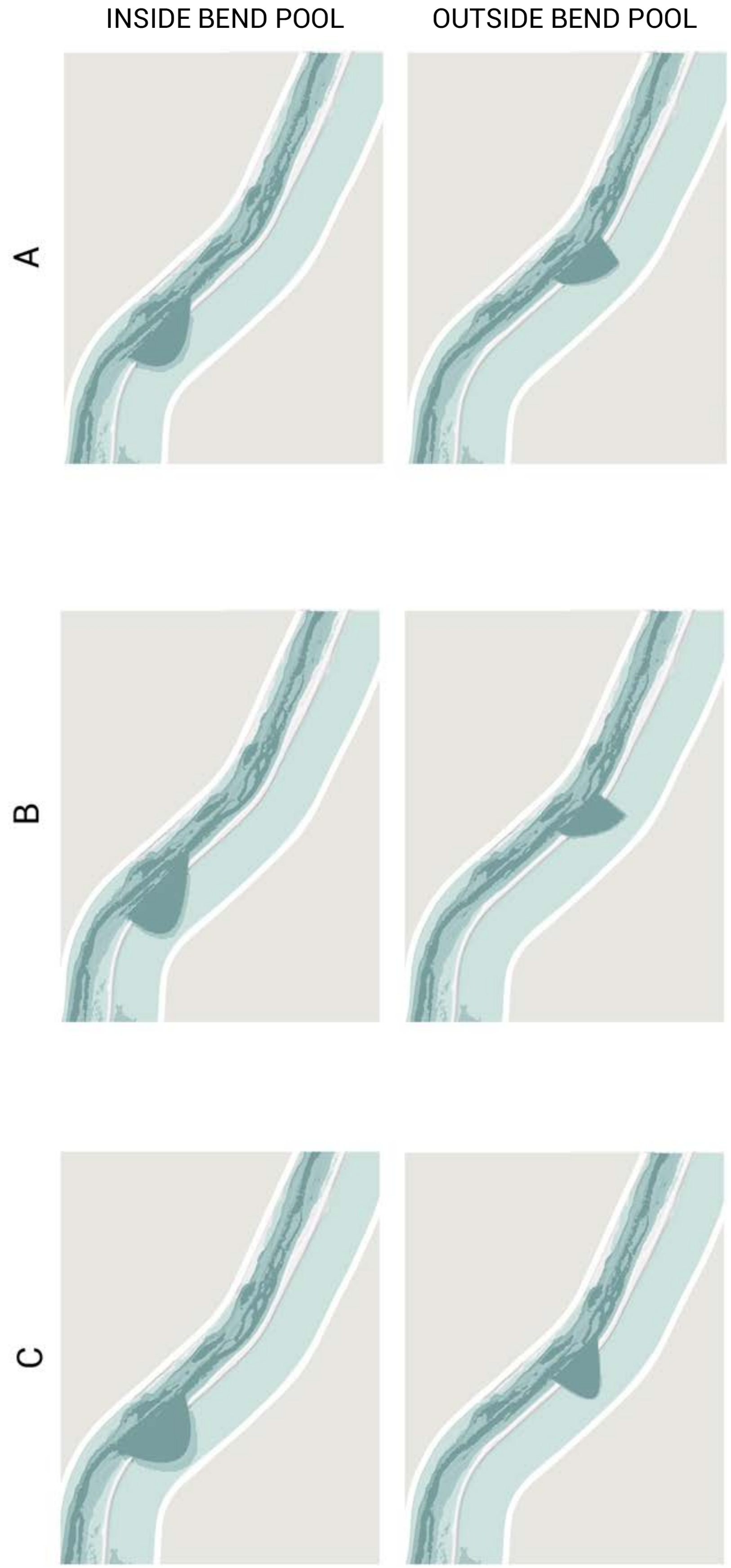
SET-UP: POOL FORMS

The following interventions were designed with the following goals: to either 1) lead to a more anastomosing river and 2) reconnect the floodplain. We aimed to find the minimum amount of mechanical excavation needed to encourage the river to redesign its floodplain within the safety parameters of the newly setback levee system. We proposed different formal concepts and explored their implication through the development of a HEC-RAS 2D model, physical qualitative model, and plan and section drawings.

Bend Pools

Pools on the inside or outside bends would excavate large areas on level with average water level. These pools were designed to help slow down water velocity in particular areas, potentially causing coarser material to drop out of the system. In response, bars could form in the areas, catalyzing the river to shift course and develop alternative routes. We studied both configurations with pools on the inside and the outside bends of Reach 2.

A stream table at the University of Virginia's Natural Infrastructure Lab was used for initial formal exploration.



3

COMPUTATIONAL MODELING
SET-UP: OTHER FORMS

Ribbon

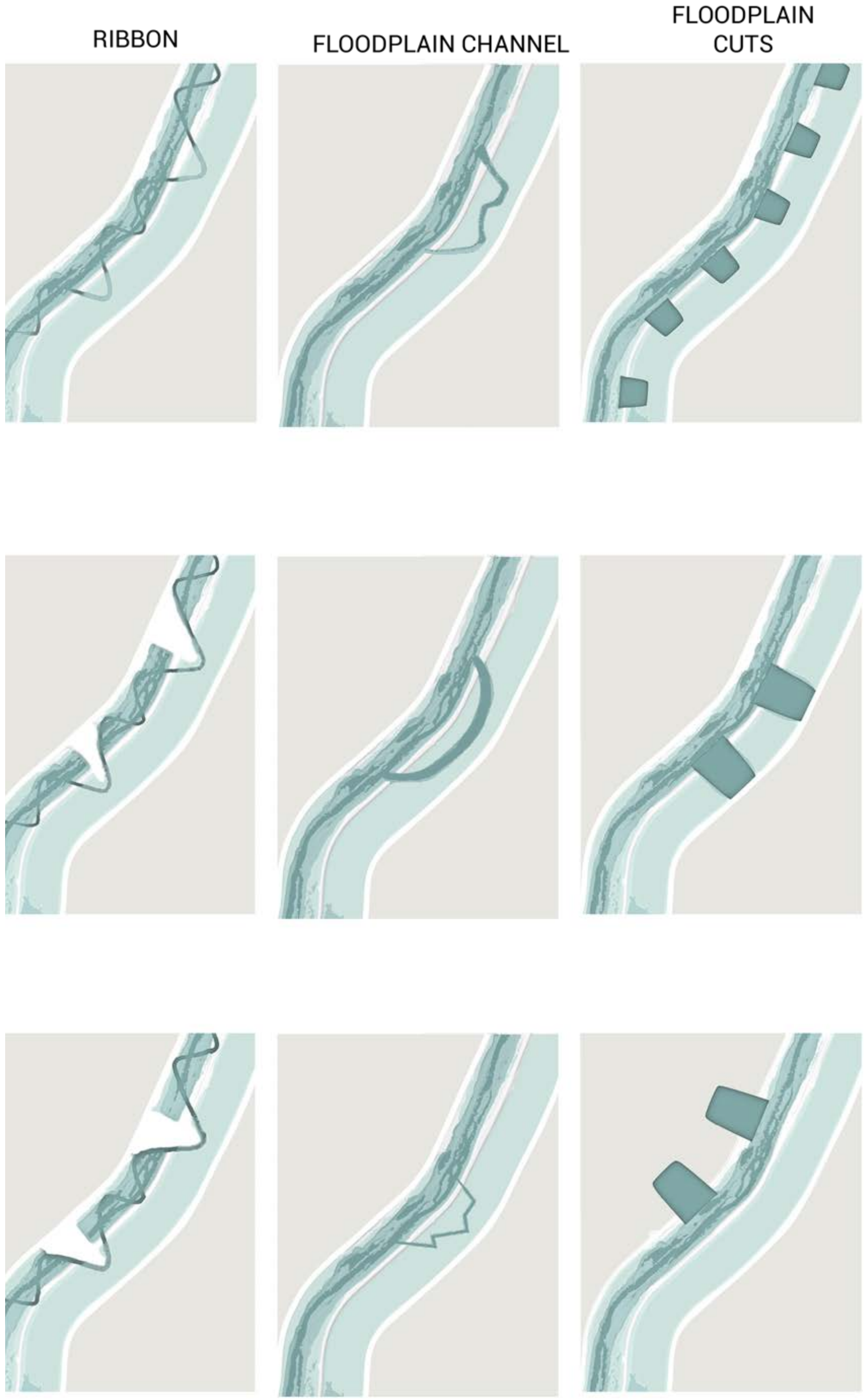
The Ribbon concept would excavate a continuous channel into the existing floodplain. This would necessitate additional excavation along the sides of the ribbon to lay back the slopes because of the excessive elevation difference between the existing channel and the floodplain. The Ribbon concept would create a secondary channel that fills with water and acts as a slow side channel. Modeling suggests that hot spots of shear stress would occur in points of divergence and convergence between the channel and the “ribbon,” likely creating localized erosion and morphological complexity at a desirable scale over time.

Floodplain Channel

This concept aims to identify an ideal location for an additional channel on the newly available floodplain side made accessible by the levee setback. It is a more localized version of the ribbon concept. For that reason, it may be cheaper and a better option to test the efficacy of the Ribbon concept to develop geometric complexity at no additional costs or increased risk.

Floodplain cuts

A series of cuts were created in the floodplain, which was made newly accessible to the river due to the levee setback. The formal logic of the cuts is very simple and efficient, with soil being removed from the pools and placed and shaped in the vestigial areas between the pools. This alternating geometry between high and low ground would create a high amount of edge condition and biological complexity. The simple geometry would be cost-effective to construct and would grow in complexity as the river erodes the hard edges and builds up new gravel beds in the pools over time. Though the excavations would all be similar, their relationship to the river currents and morphology would vary along the length of the channel, creating a range of complex environments from one simple move of earthmoving operations.

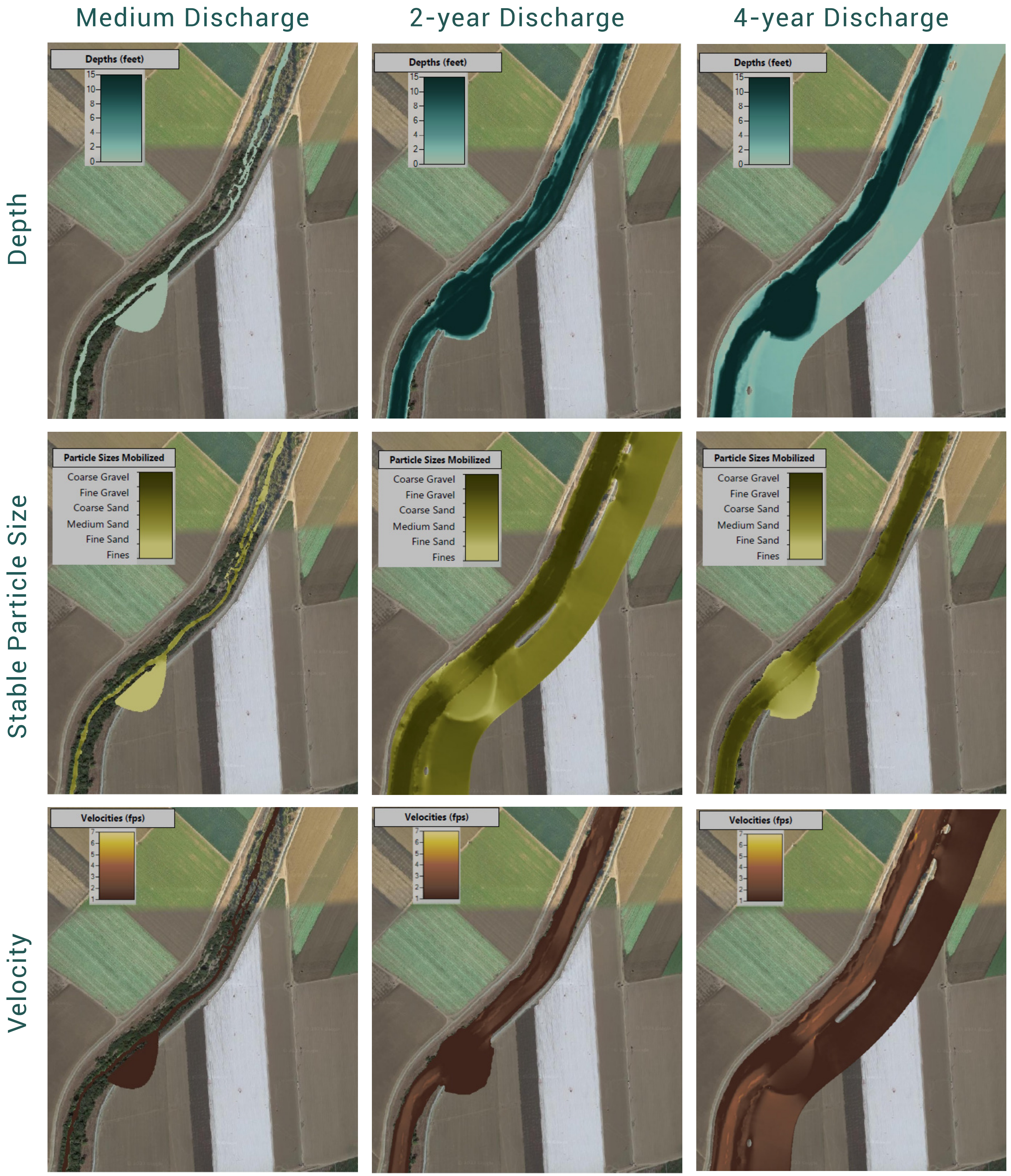


3 COMPUTATIONAL MODELING

INSIDE/OUTSIDE BEND POOL MODELING RESULTS

Computational modeling tested water depth, velocity, and particle mobility of each of the scenarios (See Appendix 1). Based on these models, the "inside bend pool" typology offered the most promising results towards achieving the long-term desired conditions of both an anastomosing river and a more frequently inundated floodplain. Velocity decreases at the site of the pool under both 2-year and 5-year flow conditions. These decreases correlate to the particle mobility results that show stable coarse sand and large-size particles adjacent to the pool feature, and stable fine to medium sized sand particles stable within the pool feature. As a result of the pool, the adjacent main channel would experience reduced velocity and bed shear stress and could result in the deposition of sediment within the channel, potentially causing the main channel to divert into the pool feature and increasing the complexity of the channel morphology.

Locating a newly excavated pool on the outside bend, "Outside Bend Pool", was also modeled in HEC-RAS, and could be used in conjunction with the "Inside Bend Pool" concept. This area would likely accumulate sediment during periods of low-flow and then be scoured during high discharge events. This may have the benefit of being self-maintaining for a longer period. The recommended plan on the following spreads shows this pairing of Inside Bend Pool and Outside Bend Pool.



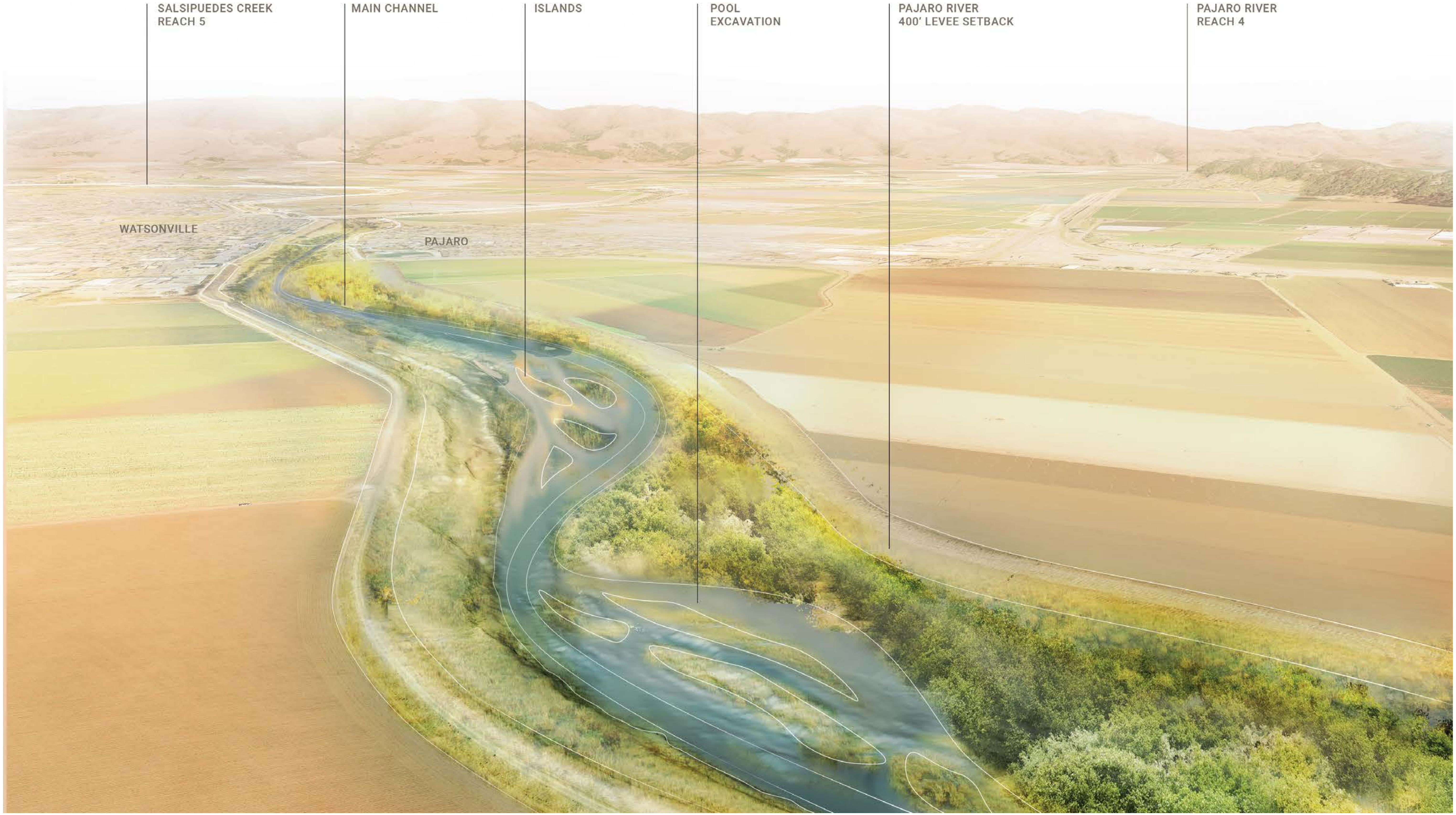
4 CONCEPT REFINEMENT

DEEP POOL PLAN

Based on the success of the modeling for the pool concepts and ongoing discussions with project partners, we developed a plan showing pools working together on the inside and outside bend of the Pajaro River just downstream of the towns. A series of deep pools are excavated into the expanded floodplain. Over time, the widened channel should cause sediment to deposit, resulting in a series of channels and islands. The steep slopes of the excavation cuts should erode and deposit more sediment into the system. Floods resulting from 2-year and 5-year storm events should reshape the steep slopes of the pools, eroding out benches and hummocks. The cobble islands with scattered trees should create habitat for chinook salmon and migrating steelhead while the red-legged frogs could lay their eggs in the formed slow-moving channels and pools that lie between.

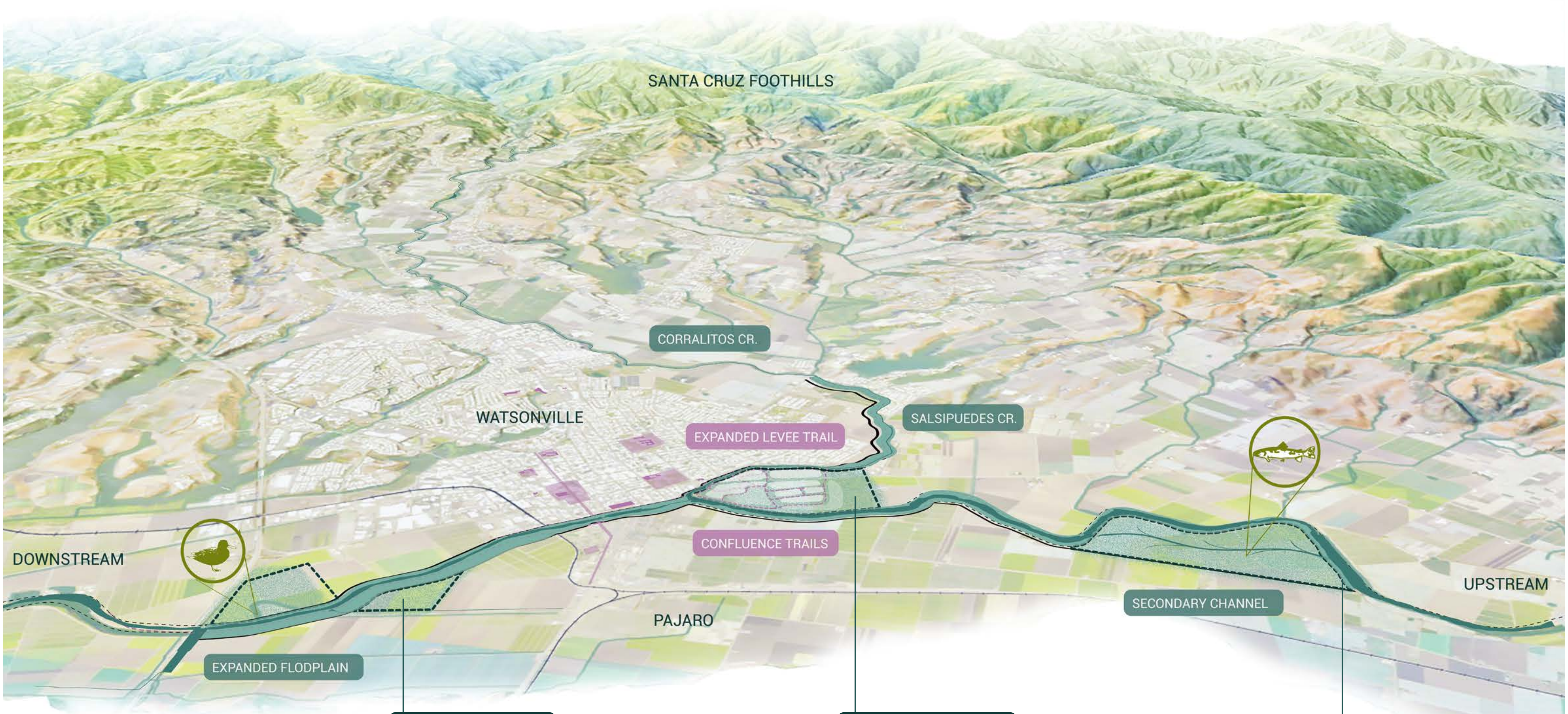
4 CONCEPT REFINEMENT

BIRD'S EYE RENDERING



5 EXPANDING BEYOND THE LEVEE
INNOVATIVE FRM APPROACHES

A holistic floodplain vision could expand to the larger Watsonville area, shaping a floodplain that expands beyond the levees. This vision suggests designating some areas to be more frequently flooded for recreational, ecological, and hydrological benefits. These floodable areas include various floodplain farms located along the main stem, a park located in the confluence, and a bypass located in a bend of the Pajaro River.



FLOODPLAIN FARMS

Encourage flodplain farms that balance arable land with groundwater recharge and habitat. Plant seasonal crops that can be inudated regularly to accomodate habitat for wintering waterfowl and spawning grounds for native fish.

Precedents: Yolo River Bypass

CENTRAL CONFLUENCE

Design floodable public space for Watsonville and Pajaro, located in the confluence of Pajaro River and Salispuedes Creek, which would allow for floodwaters to dissipate. This accessible and central public space could create direct river access for residents, as well as opportunites for other public space, including trails and sport fields.

Precedents: Bow River

PAJARO BYPASS

Design a "green river" bypass in order to create a seasonally flooded landscape for spanwing fish and migratory waterfowl. This bypass would help filter and clean water upstream of Watsonbille and Pajaro, increase groundwater recharge, and mitigate flood risk.

Precedents: Yolo River Bypass, Bow River, Napa River Restoration

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APPENDIX 1

PAJARO RIVER FLOODPLAIN EXPANSION– HYDRAULIC MODELING ANALYSIS

Prepared for:

US Army Corps of Engineers
ERDC
EWN

Prepared by:

ANCHOR QEA
Dredge Research Collaborative

1 INTRODUCTION

This report describes the hydraulic modeling analysis performed by Anchor QEA, LLC, to support the evaluation of conceptual design alternatives developed in conjunction with the Dredge Research Collaborative (DRC) as part of the Engineering with Nature (EWN) initiative funded by the U.S. Army Engineer Research and Development Center (ERDC), as part of the U.S. Army Corps of Engineers (USACE) San Francisco District Proving Ground initiative. The objective of the EWN project was to research and conceptualize potential natural and nature-based features (NNBF) for floodplain expansion between setback levees along a select reach of the Pajaro River (the River) in California to complement the Pajaro River Flood Risk Management (FRM) Project being implemented by USACE in Santa Cruz and Monterey Counties in California. Specifically, the EWN project objectives included researching potential river channel and adjacent floodplain geometry design options to increase hydrological and ecological benefits of the FRM project.

2 RIVER SETTING

The Pajaro River is a 30-mile-long river located in the Central Coast region of California, forming the border between Santa Cruz and Monterey Counties. The River is the largest coastal stream between San Francisco Bay and Monterey County and drains a watershed area equal to approximately 1,300 square miles. Several streams are tributaries to the Pajaro River, including the Salinas River, Salsipuedes and Corralitos Creeks, and Sargent Creek (Pajaro River Watershed 2014). The USACE FRM project area is located in the lower Pajaro River watershed and encompasses an area of approximately 10,000 acres, which includes the stream channels, active floodplains, and terraces along the Pajaro River and Salsipuedes and Corralitos Creeks. Figure 1 shows select designated river reaches within the FRM project area. The City of Watsonville, California, north of the Pajaro River, and the unincorporated Town of Pajaro, south of the Pajaro River, are the two urban areas within the project area. The EWN research project and hydraulic modeling analysis were located within Reach 2 of the project area, located downstream from the confluence of Salsipuedes Creek (see Figure 1).

In 1949, USACE built an earthen levee system along each bank of the lower Pajaro River and its tributaries. Since its construction, there have been four major floods that resulted in significant flooding caused by overtopping or breaching of the levees (1955, 1958, 1995, and 1998). Peak discharges for the four major post-construction floods exceeded the 19,000 cubic feet per second (cfs) design discharge upstream of Salsipuedes Creek confluence. The March 1995 storm was equivalent to a 15.4-year return-interval flow event and resulted in the greatest flood damage in the area when the levee was breached and the Town of Pajaro was inundated. The February 1998 storm is considered the flood of record and was equivalent to a 28.5-year return-interval flood event (USACE 2019). For comparison, the Flood Insurance Study (FIS) for Santa Cruz County, California, published by the Federal Emergency Management Agency (FEMA) lists the 10-year and 100-year discharges downstream of the Salsipuedes Creek confluence equal to 14,250 cfs and 43,600 cfs, respectively (FEMA 2017).

Two high-flow events occurred in early 2023. On January 10, 2023, a peak discharge of 10,500 cfs was recorded at U.S. Geological Survey (USGS) station 11159500 at Watsonville, California, approximately 0.2 mile upstream of Reach 2. On March 11, 2023, a peak discharge of 11,700 cfs was recorded at the USGS gage in Watsonville. These are both lower than the FEMA 10-year discharge of 14,250 cfs, but the March 2023 flow event resulted in the levee being breached approximately 4 miles upstream of the USGS gage at Watsonville and approximately 3 miles upstream of the Town of Pajaro (near the upstream end of Reach 4 shown in Figure 1). The breach resulted in flooding that forced a mandatory evacuation of Pajaro. Although the breach was upstream of this study, which is focused on Reach 2, the recent storms and flooding reinforce the importance of why these flood control systems are being evaluated.

The FEMA FIS shows that the 100-year floodplain extends well beyond the levee system (FEMA 2017). At the upstream end of Reach 2, the 100-year floodplain boundary is approximately 0.3 mile north of the Pajaro River and approximately 1.5 miles south of the Pajaro River. At the downstream end of Reach 2, the 100-year floodplain boundary is approximately 1.4 miles north of the Pajaro River and approximately 0.6 mile south of the Pajaro River (FEMA 2017).

Discharge data from 2019 through 2022 from USGS gage 11159500 at Watsonville shows that the flow in the lower Pajaro River is typically less than 100 cfs, with a median discharge of approximately 3.5 cfs.

3 HYDRAULIC ANALYSIS

As part of the FRM project, USACE intends to offset the existing levees along the Pajaro River to increase the flood storage, which presents an opportunity to encourage river anastomosing (i.e., multiple interweaving channels) and pooling of water during major storm events within this expanded floodplain and facilitate river channel migration. In Reach 2, USACE intends to offset the existing levee on the south side of the Pajaro River by 400 feet. As flow is conveyed through a channel, hydraulic characteristics such as water surface elevations and current velocities are affected by the geometry of the channel cross section. Hydrodynamic flows, particularly during high-flow events, can result in elevated current velocities and corresponding bed shear stresses. This EWN project concept aims to harness these typical characteristics for natural development of the system.

A hydraulic analysis was performed to assess the hydraulic characteristics of the project area during a range of flows, including predicted flow velocities and shear stresses for existing conditions and for several conceptual design alternatives. For all simulations (including the existing conditions), the hydraulic model geometry included the planned levee setback in Reach 2. The hydraulic analysis was performed using the USACE HEC-RAS model (USACE 2021). HEC-RAS is a public-domain, general-purpose model designed to assess flow in natural streams and channels. HEC-RAS version 6.1, released in September 2021, was used for all model simulations. A 2D, unsteady flow model was developed using the 2D RAS Mapper within HEC-RAS to represent river flows within the reach.

3.1 Model Boundary Conditions

The primary model boundary condition input for the hydraulic analysis was upstream discharge rates. To evaluate the performance of conceptual design NNBF alternatives, flow rates ranging from typical flows to more frequent return-interval events were considered appropriate, as the NNBF features are intended to increase hydrological and ecological benefits during typical and frequent flows. Less frequent extreme storm events were not considered appropriate conditions to evaluate the performance of the NNBFs because the area is inundated under extreme events.

A statistical analysis was performed to determine the median discharge for the Pajaro River using available 15-minute discharge data from 2019 through 2022 from USGS gage 11159500 at Watsonville. Figure 2 shows a cumulative frequency distribution of the measured 15-minute discharge data. As shown in Figure 2, the median discharge from 2019 through 2022 equaled approximately 3.5 cfs. This was considered to represent a typical flow condition in the Pajaro River.

Another statistical analysis was performed to estimate the 2-year and 5-year return-interval flow rates for the Pajaro River. The 2-year flow was selected to represent an approximate bank-full condition, and the 5-year flow was selected to represent a flow that would be out of bank but contained within the proposed offset levee system being constructed as part of the USACE FRM project. The statistical analysis was performed using 7 years of available annual peak streamflow data from USGS gage 11159500 at Watsonville (1912, 1913, 1972, 1973, 2019, 2020, and 2021) and the USGS PeakFQ program. PeakFQ estimates flood magnitudes and their corresponding variance for a range of annual exceedance probabilities using the log-Pearson Type III frequency distribution (Flynn et al. 2006). In addition to the USGS data, the statistical analysis used return-interval flow rates for the Pajaro River published in FEMA (2017) including the 10-, 50-, 100-, and 500-year return interval flow events. Table 1 shows the return-interval flow rates for the lower Pajaro River from FEMA (2017).

Table 1
Summary of FEMA Discharges

Flow Event	Discharge (cfs)
FEMA 10-year event	14,250
FEMA 50-year event	32,500
FEMA 100-year event	43,600
FEMA 500-year event	76,200

Note: Extreme event discharge data were obtained from the FEMA FIS report for Santa Cruz County, California, and Incorporated Areas, published in September 2017.

The FEMA return-interval flow rates were overlain on the PeakFQ results graph, and an estimated best fit line was plotted through the FEMA data to estimate the 2-year and 5-year flow rates (see Figure 3). As shown in Figure 3, the estimated 2-year and 5-year flows using the FEMA data fall within the PeakFQ 95% confidence limit. Table 2 summarizes the flow events that were evaluated using the HEC-RAS hydraulic model. These were considered an appropriate range of flow events that would be contained within the levee system to evaluate the EWN conceptual designs as the NNBF features are intended to increase hydrological and ecological benefits during typical and frequent flows, not during extreme events that inundate the area.

Table 2
Model Simulation Flow Conditions

Flow Event	Flow (cfs)
Typical	3.5
2-year	3,500
5-year	8,500

The downstream end of the model was specified as a Normal Depth Downstream Boundary, where the model computed a single water surface for the downstream boundary for each flow simulation. The water surface elevation was based on an estimated friction slope that was set equal to the estimated approximate slope of the river bottom near the downstream end of the model based on the available data. These data were considered appropriate for this hydraulic analysis, which is supporting a proof-of-concept level of analysis. Further field data collection to confirm bed elevations and slopes may be required during subsequent stages of design.

3.2 Model Mesh

A 2D model computational mesh was developed to cover the river reach of interest. Figure 4 shows the hydraulic model grid extents and the location of the USGS gage at Watsonville, just upstream of the model grid. As shown in Figure 4, the model grid covers Reach 2 and extends from the upstream model grid boundary located near the southwest border of Watsonville to the downstream model grid boundary located just upstream of the Cabrillo Highway Bridge (Route 1). Laterally, the model grid extents were set beyond the proposed levees on each side of the Pajaro River but not to cover the entire 100-year floodplain, as the selected flows would be contained within the designed levee system.

The model mesh resolution was spatially variable, with local refinements within the river channel and levees to accurately represent the topography and bathymetry within the River. The model mesh had an average cell size of approximately 10 feet by 10 feet. Additional refinements were made to the model cells within the river and levees to set them at an orientation that is normal to the direction of flow to more accurately represent the bends in the river compared to a uniform orthogonal grid with a single north-south orientation. Figure 5 shows an example of the model mesh cell resolution and orientation within the River and adjacent floodplain.

3.3 Model Elevation Data

A detailed elevation surface of the topography and bathymetry within the model mesh extents was developed by DRC based on a FEMA lidar data set and provided to Anchor QEA (OCM Partners, 2023). The model elevation surface had a dense spatial resolution to accurately define key features and flow paths within the River and the adjacent levees. As stated previously, the elevation surface in the hydraulic model included the proposed levee setback along the south side of the Pajaro River in Reach 2. The elevation data were projected horizontally to the North American Datum of 1983 State Plane California III FIPS 0403 (U.S. feet), and vertically to the North American Vertical Datum of 1988 (NAVD88; feet).

Figure 6 shows elevation contours within the model grid extents based on the high-resolution model elevation surface. Figure 6 also shows how the model geometry incorporated the planned levee setback in Reach 2. This approach enabled the evaluation and comparison of the EWN design concepts to the proposed long-term levee alignment and floodplain geometry. The USACE FRM project levee setback involves removing the existing levee on the south side of the River and increasing the distance from the River to the new levee with a setback of 400 feet.

3.4 Bed Roughness

Within Reach 2 of the Pajaro River, there are several types of channel bed, including sandy bottom, grass-covered areas, low-lying vegetation, and heavily wooded areas with trees. Each channel type provides a different resistance to flow and affects flow velocities and water surface elevations throughout the River. The HEC-RAS 2D User's Manual provides guidance for creating land cover files and selecting Manning's n values based on terrain descriptions and various National Land Cover Database land cover types (USACE HEC, 2023). Appropriate roughness values were defined throughout the model to accurately represent the channel bed and areas of vegetation within the River. Table 3 lists the types of channel bed and floodplain and the final Manning's n roughness values that were used in the hydraulic model.

Table 3
Manning's n Roughness Values

Channel or Floodplain Category	Manning's n Value
Developed High Intensity	0.16
Riparian Canopy	0.14
Vegetated Channel	0.09
Meadow with Vegetation	0.068
Cultivated Crops	0.035
New Forms	0.03

3.5 Model Data Comparison

Measured and predicted water surface elevations were compared to assess the performance of the existing-conditions hydraulic model and to refine the Manning's n values used in the model. For the 2-year flow simulation, the predicted water surface elevation at the upstream model boundary near Watsonville was compared to measured water surface elevations at USGS gage 11159500 at Watsonville, located approximately 0.2 mile upstream of the model grid boundary. The USGS gage was used for the model data comparison because it was the station closest to the model grid extents for which measured published water surface elevation data were available. As described in Section 2.2.1, the 2-year flow was estimated to equal 3,500 cfs. The available discharge data at USGS gage 11159500 showed a flow of 3,500 cfs occurred on February 18, 2019, at 5:15 a.m. (PST). The water surface elevation at the USGS gage at that time equaled 25.2 feet NAVD88. After refining the Manning's n values in the model, the predicted water surface elevation at the upstream model boundary for the 2-year flow condition equaled 25.3 feet NAVD88. This model data comparison was considered confirmation that the hydraulic model performance was appropriate for the hydraulic analysis.

3.6 Existing Conditions Results

Figures 7 and 8 show the water depth and velocity results for the typical flow condition. The figures show that water depths are less than 1 foot and velocities are less than 1 foot per second (fps) throughout Reach 2. The results are consistent with observations that the channel has large areas that are dry and does not encroach on the current levee structures. The typical flow results also confirm that the high-resolution elevation data and model mesh resolution used in the analysis successfully defined the thalweg of the River.

Figures 9 and 10 show the water depth and velocity results for the 2-year flow condition. As shown in the figures, the 2-year flow condition of 3,500 cfs produces an approximate bank-full condition in the River, where the flow is still within the riverbanks and not encroaching on the levees. Water depths throughout the model mostly ranged from approximately 7 to 12 feet, with select areas having water depths of 15 feet or greater. Velocities in the River ranged from approximately 1 to 2.5 fps.

Figures 11 and 12 show the water depth and velocity results for the 5-year flow condition. As shown in the figures, the 5-year flow condition of 8,500 cfs produces water surface elevations that exceed the River top-of-bank elevations and is contained between the levees. On the north side of the River, the levee is set close to the riverbank so the water is contained near the riverbank. But on the south side of the River, the new levee position with an increased setback from the River now shows an expanded floodplain, with the water reaching the new levee location. Water depths in the main channel mostly ranged from approximately 15 to 20 feet, and water depths in the southern floodplain between the river and the levee mostly ranged between approximately 1 to 2 feet. Velocities in the main channel mostly ranged from approximately 2 to 3 fps, with select areas having slightly higher or lower velocities. Because not all of the flow is being conveyed within the banks of the river for the 5-year flow event, the velocities did not significantly increase compared to the 2 year flow event. The flow is expanding laterally into the floodplain through a larger cross sectional area, which slows velocities in the main channel.

4 CONCEPTUAL DESIGN ALTERNATIVES MODELING

DRC developed several initial conceptual design alternatives to evaluate the potential for adding hydrological and ecological benefits into the expanded floodplain project area. Hydrological benefits considered included supporting the FRM and at minimum maintain required conveyance volumes, increasing sinuosity and length of the lower Pajaro River, increasing connectivity between the lower Pajaro River and historical floodplain, and facilitating lower Pajaro River channel migration. Ecological benefits considered included increasing habitat and species diversity in riparian and floodplain zones, targeting key and federally listed species (e.g., steelhead trout and red-legged frog).

The DRC performed physical modeling of various forms and geometries in a laboratory setting to identify and select alternatives to be evaluated with the hydraulic numerical model. The DRC developed five primary types of alternative river and floodplain geometries. The following are the names and a brief description of each alternative:

- **Inside bend pools**: areas cut into the inside bend of the riverbank adjacent to the main channel to expand the River cross section at that location and create an area of calmer water
- **Outside bend pools:** areas cut into the outside bend of the riverbank adjacent to the main channel to expand the River cross section at that location and create an area of calmer water
- **Ribbon:** a meandering channel cut throughout the main channel bed and into the existing floodplain to create more complexity and anastomosing throughout the active channel
- **Floodplain channels:** a channel cut through the floodplain to create an additional flow path where flow can divert from the active channel into the floodplain, then reconnect to the main channel
- **Floodplain cuts**: multiple areas excavated in the floodplain to form a series of deepwater pools that would be filled during higher flow events that overtop the main riverbanks

The hydraulic model was used to evaluate each alternative type for the same range of flow conditions as the existing conditions model as described in Section 2.2.1. The results of each flow simulation were compared for each conceptual design alternative to evaluate how each alternative affected water depths, flow velocities, and bed shear stresses throughout the area of interest. Variations of each alternative that included slightly different geometries were also evaluated (e.g., Inside Bend Pool A, B, and C).

To evaluate the potential for sediment transport, the critical shear stress required to initiate movement of different-size riverbed materials based on the Unified Soil Classification System (USCS) was computed using Shields parameter (van Rijn 1984a; van Rijn 1985b). The computed bed shear stresses from each model simulation were compared to the computed critical shear stresses for each range of USCS particle sizes to estimate the particle sizes that would be mobilized throughout the area of interest for each flow simulation. This analysis provides insight regarding how each conceptual design alternative may impact sediment transport patterns in the River.

4.1 Inside Bend Pool Alternative

Figure 13 shows the water depth results for an inside bend pool feature (Inside Bend Pool A alternative). Figure 14 shows a select cross section through the proposed feature to illustrate the geometry of the inside bend pool feature. As shown in the figures, the pool feature creates additional wetted area connected to the main channel that extends into the floodplain during the typical and 2-year flow conditions and creates an area of deeper water in the floodplain between the main channel and the setback levee under the 5-year flow condition.

Figure 15 shows the velocity results in the vicinity of the inside bend pool feature. As shown in the figure, under the 2-year and 5-year flow conditions, the expanded channel cross section at the pool feature causes a reduction in flow velocity in the main channel. For the 2-year flow, the velocity in the main channel drops from approximately 3 fps to less than 1 fps adjacent to the pool feature. For the 5-year flow condition, the velocity in the main channel drops from approximately 3.5 fps to approximately 1 fps adjacent to the pool feature.

Figure 16 shows the range of sediment sizes that would be mobilized in the channel and floodplain in the vicinity of the pool feature for each flow condition evaluated. As shown in the figure, the particle mobility results show patterns correlating to the velocity results with a reduction in the mobilized particle size at the same location the flow velocity is reduced in the main channel adjacent to the pool feature. For both the 2-year and 5-year flow conditions, the results indicate that coarse sand and larger-sized particles would be stable adjacent to the pool feature, and fine to medium-sized particles would be stable within the pool feature.

The reduced velocity and bed shear stress in the main channel adjacent to the pool feature may result in sediment settling out of the water column and depositing in the main channel adjacent to the pool feature. Deposition in the main channel could cause the main channel to divert into the pool feature, which could increase the complexity of the channel morphology.

Figures 17 through 22 show the water depth, velocity, and particle mobility results for the additional variation alternatives of an inside bend pool feature (i.e., Inside Bend Pool B and Inside Bend Pool C). Although the shape of the pool feature varied slightly between the different alternatives, the magnitudes and patterns of results were similar to those discussed for Inside Bend Pool A.

4.2 Outside Bend Pool Alternative

Figure 23 shows the water depth results for an outside bend pool feature (Outside Bend Pool A alternative) in the vicinity of the proposed feature. Figure 24 shows a select cross section through the proposed feature to illustrate the geometry of the outside bend pool feature. As shown in the figures, the pool feature creates additional wetted area connected to the main channel that extends into the floodplain under the typical and 2-year flow conditions and creates an area of deeper water in the floodplain between the main channel and the setback levee under the 5-year flow condition.

Figure 25 shows the velocity results in the vicinity of the outside bend pool feature. As shown in the figure, under the 2-year and 5-year flow conditions, the expanded channel cross section at the pool feature causes a reduction in flow velocity in the main channel. For the 2-year flow, the velocity in the main channel drops from approximately 2 fps to less than 1 fps adjacent to the pool feature. For the 5-year flow condition, the velocity in the main channel drops from approximately 3 fps to approximately 1 fps adjacent to the pool feature.

Figure 26 shows the range of sediment sizes that would be mobilized in the channel and floodplain in the vicinity of the pool feature for each flow condition evaluated. As shown in the figure, the particle mobility results show patterns correlating to the velocity results with a reduction in the mobilized particle size at the same location the flow velocity is reduced in the main channel adjacent to the pool feature. For both the 2-year and 5-year flow conditions, the results indicate that coarse sand and larger-sized particles would be stable adjacent to the pool feature, and fine to medium-sized particles would be stable within the pool feature.

The reduced velocity and bed shear stress in the main channel adjacent to the pool feature may result in sediment settling out of the water column or as bedload and depositing in the main channel adjacent to the pool feature. Deposition in the main channel could cause the main channel to divert into the pool feature, which could increase the complexity of the channel morphology. But the length of main channel that shows a reduced mobile particle size for the outside bend features evaluated is shorter than the length of main channel with reduced particle mobility created by the inside bend pool features evaluated. This could reduce the amount of sediment deposition in the main channel adjacent to the outside bend pool features compared to the inside bend pool features.

Figures 27 through 32 show the water depth, velocity, and particle mobility results for the additional variation alternatives of an outside bend pool feature (i.e., Outside Bend Pool B and Outside Bend Pool C). Though the shape of the pool feature varied slightly between the different alternatives, the magnitudes and patterns of results were similar to those discussed for Outside Bend Pool A.

4.3 Ribbon Alternative

Figure 33 shows the water depth results for an outside bend pool feature (Ribbon A alternative) in the vicinity of the proposed feature. Figure 34 shows a select cross section to illustrate the geometry of the proposed ribbon feature. As shown in the figures, the ribbon feature is intended to create additional wetted area connected to the main channel and introduce more complexity and sinuosity to the channel geometry under the typical flow condition. Under the 2-year flow condition, the ribbon feature creates additional wetted area that extends into the floodplain and creates areas of deeper water within the main channel. Under the 5-year flow conditions, the ribbon feature creates channeled areas of deeper water in the floodplain between the main channel and the setback levee under the 5-year flow condition.

Figure 35 shows the velocity results in the vicinity of the ribbon feature. As shown in the figure, the ribbon feature did not cause significant changes to flow velocity magnitudes or patterns in the main channel but did create channeled areas of flow in the floodplain, with velocities up to approximately 2 fps and 3 fps for the 2-year and 5-year flow conditions, respectively. Figure 36 shows the range of sediment sizes that would be mobilized in the channel and floodplain in the vicinity of the ribbon feature. As shown in the figure, the 2-year and 5-year flow results indicate that flows in the deeper channel areas in the floodplain could mobilize particle sizes up to coarse sand and fine gravel, respectively.

The ribbon feature introduces topographic and bathymetric diversity and complexity to the main channel geometry, which may provide increased habitat diversity. The increased complexity of the main river channel increases the sinuosity and anastomosing of the main channel.

Figures 37 through 42 show the water depth, velocity, and particle mobility results for the additional variation alternatives of a ribbon feature (i.e., Ribbon B and Ribbon C). One key difference between Ribbon A and the other two variations is that Ribbon B and Ribbon C included placing fill in the main river channel to encourage flow diversion into the channel areas in the floodplain. As shown in the figures, the fill in the main channel does result in the channel being fully diverted into the floodplain channel areas, which results in dry areas in the main channel and increased velocities within the floodplain channel areas capable of mobilizing coarse gravel-sized materials.

4.4 Floodplain Channel Alternative

Figure 43 shows the water depth results for a floodplain channel feature (Floodplain Channel A alternative) in the vicinity of the proposed feature. Figure 44 shows a select cross section through the proposed feature to illustrate the geometry of the floodplain channel feature. As shown in the figures, the floodplain channel feature does not modify the main channel but creates an additional flow path and wetted area connected to the main channel that extends into the floodplain, then reconnects with the main channel farther downstream. Under the typical flow condition, the floodplain channel does not have a significant impact on the results compared to existing conditions due to the low flows not diverting into the floodplain channel. Under the 2-year flow condition, the floodplain channel feature creates additional wetted area that extends the floodplain and creates areas of deeper water within the main channel. Under the 5-year flow conditions, the floodplain channel creates a channel of deeper water in the floodplain between the main channel and the setback levee.

Figure 45 shows the velocity results in the vicinity of the floodplain channel feature. As shown in the figure, under the typical flow condition there were minimal impacts to the velocities in the main channel. For the 2-year and 5-year flows, there were slight reductions in the main channel velocities near the floodplain channel feature. Within the floodplain channel, the 2-year and 5-year flows resulted in velocities up to approximately 2 fps and 3 fps, respectively, with localized areas of increased velocity (up to approximately 6 fps) at the narrow entry and exit points of the floodplain channel where it connected to the main channel.

Figure 46 shows the range of sediment sizes that would be mobilized in the main channel and floodplain in the vicinity of the floodplain channel feature. As shown in the figure, the 2-year and 5-year flow results indicate that flows in the deeper floodplain channel could mobilize particle sizes up to coarse sand and fine gravel, respectively.

Figures 47 through 52 show the water depth, velocity, and particle mobility results for the additional variation alternatives of a floodplain channel feature (i.e., Floodplain Channel B and Floodplain Channel C). The other variations have different floodplain channel shapes and widths than Floodplain Channel A. Though the shape of the floodplain channel varied, the overall magnitudes and patterns of results were similar to those discussed for Floodplain Channel A, with localized areas having more significant differences. For example, the wider cross section and rounder shape of the Floodplain Channel B alternative resulted in a more significant difference in the pattern and magnitude of reduced velocities in the main channel near the feature.

4.4 Floodplain Cuts Alternative

Figure 53 shows the water depth results for a floodplain cuts feature (Floodplain Cuts A alternative) in the vicinity of the proposed feature. Figure 54 shows a select cross section through the proposed feature to illustrate the geometry of the floodplain channel feature. As shown in the figures, the floodplain cuts feature does not modify the main channel but creates areas of deep excavation in the floodplain area that fill up under higher flows. Under the typical and 2-year flow conditions, the floodplain cuts feature is dry, as the water does not spill over the banks of the main channel for those flows. Under the 5-year flow conditions, the floodplain channel creates pools of deeper water in the floodplain between the main channel and the setback levee.

Figure 55 shows the velocity results in the vicinity of the floodplain cuts feature. As shown in the figure, under the typical and 2-year flow conditions there were minimal impacts to the velocities in the main channel, and there is no water in the floodplain cuts features. For the 5-year flow, there were slight reductions in the main channel velocities near the floodplain cuts features, and within the floodplain cuts features, velocities were less than 1 fps due to the cuts acting like separate disconnected pool features located in the floodplain.

Figure 56 shows the range of sediment sizes that would be mobilized in the main channel and floodplain in the vicinity of the floodplain cuts feature. As shown in the figure, the 5-year flow results indicate that, within the floodplain cut pools, fine sand-sized particles could be mobilized.

Figures 57 through 62 show the water depth, velocity, and particle mobility results for the additional variation alternatives of a floodplain cuts feature (i.e., Floodplain Cuts B and Floodplain Cuts C). The other variations have different floodplain cuts, channel shapes and widths, and number of cuts compared to Floodplain Channel A. Most notably, Floodplain Cuts B has two larger cuts compared to the several smaller cuts in Floodplain Cuts A and C and creates pools of deeper water in the floodplain between the main channel and the setback levee for both the 2-year and 5-year flow conditions.

5 SUMMARY

A hydraulic modeling analysis was performed to support the evaluation of conceptual design alternatives developed by the DRC to research potential river channel and adjacent floodplain geometry design options to increase hydrological and ecological benefits of the USACE FRM project along the Pajaro River. Five primary types of river channel and adjacent floodplain geometry conceptual design alternatives were evaluated: inside bend pools, outside bend pools, ribbon, floodplain channel, and floodplain cuts. Secondary variations of each primary alternative type were also evaluated. Although the performance and longevity of these features over their lifespan was not assessed as part of this effort, preliminary results showed that the conceptual design alternatives have the potential to create conditions that increase the hydrological and ecological benefits of the FRM project by maintaining or increasing conveyance volumes and by increasing channel complexity along the Pajaro River, connectivity to the adjacent floodplain, and habitat diversity through variations in topography and bathymetry. Future project phases should include evaluation and consideration of how the conceptual design alternatives may impact river morphology in the long term (e.g., how the channel may respond to erosion along the banks, channel migration, and potential impacts to levees).

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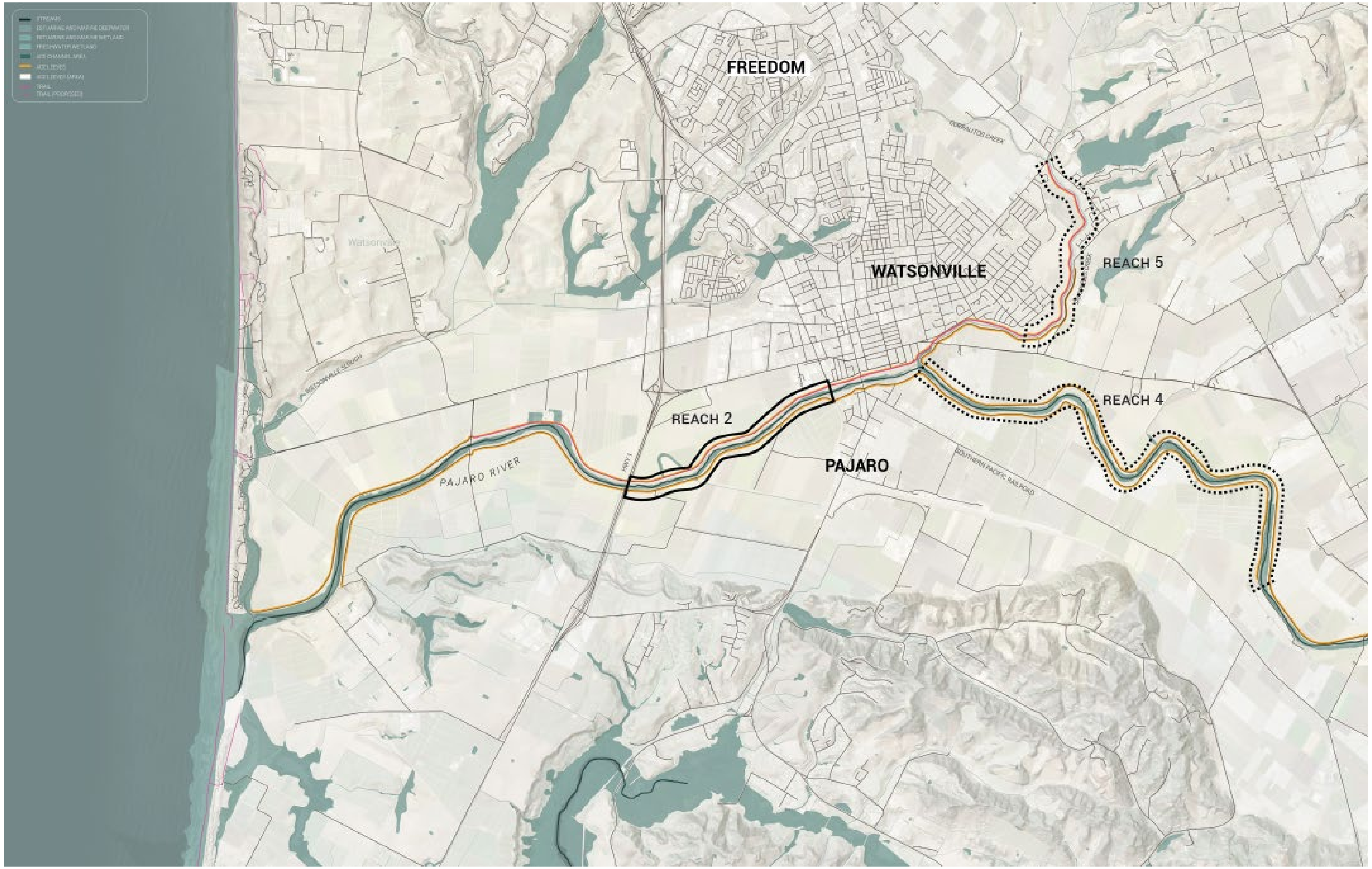
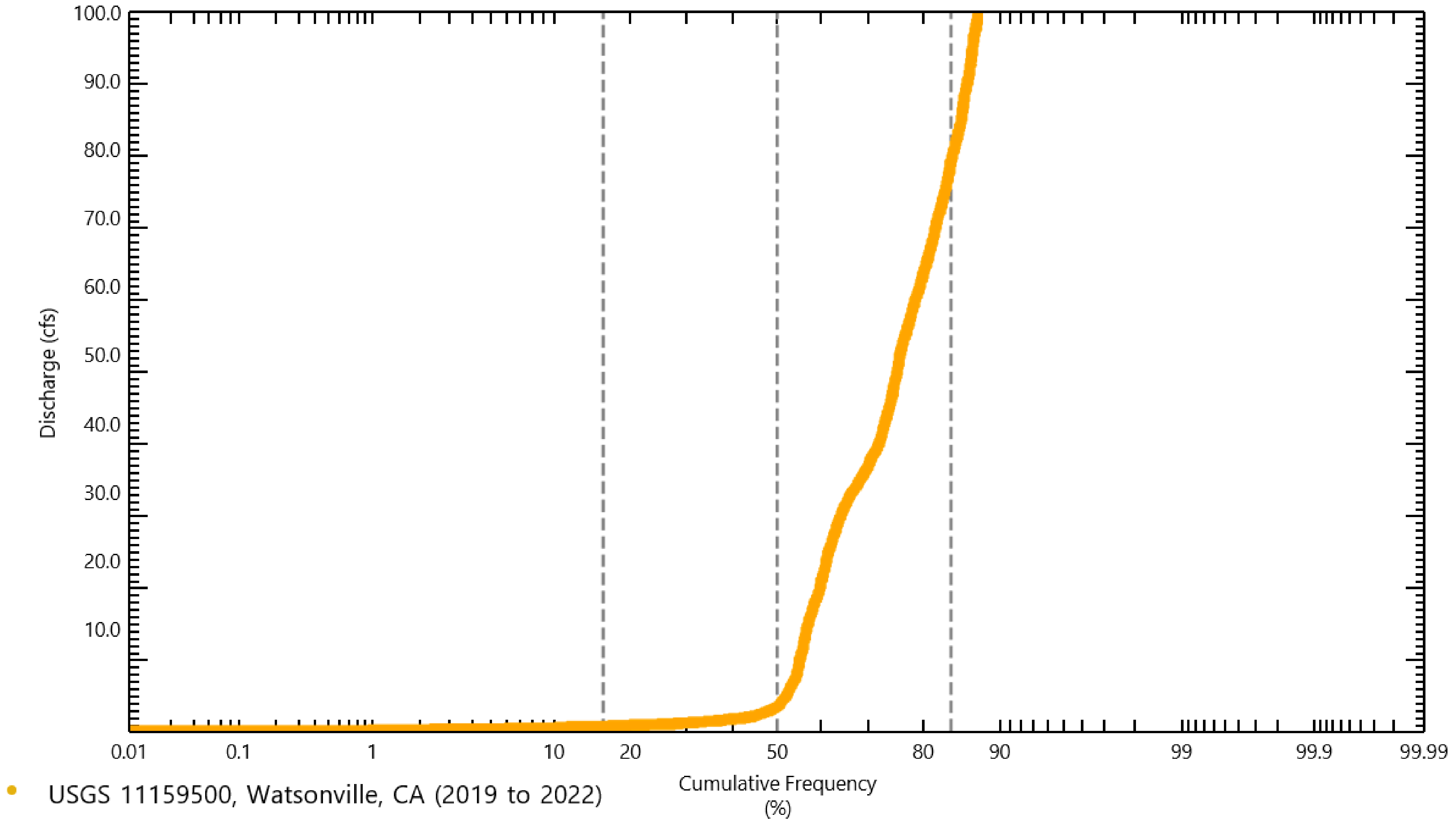
7 FIGURES



Note: River reaches shown are select reaches as defined by the U.S. Army Corps of Engineers as part of the Pajaro River Flood Risk Management Project Study.

Figure 1
Pajaro River Reaches Map



Note: cfs = cubic feet per second

Figure 2
Cumulative Frequency Distributions of Measured Discharge

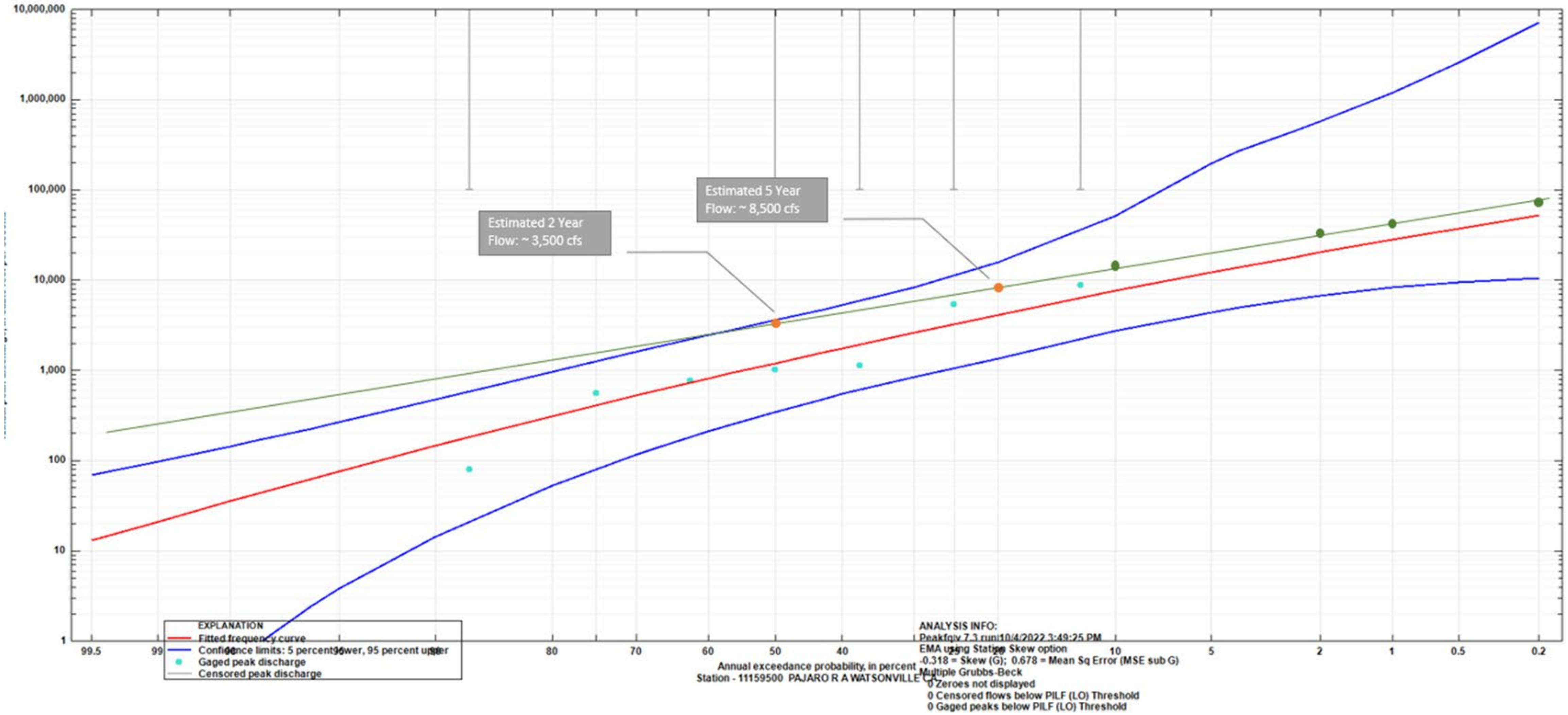


Figure 3
FEMA and USGS Flow Analysis

Figure 4
Computational Model Mesh Extents and USGS Gage Location

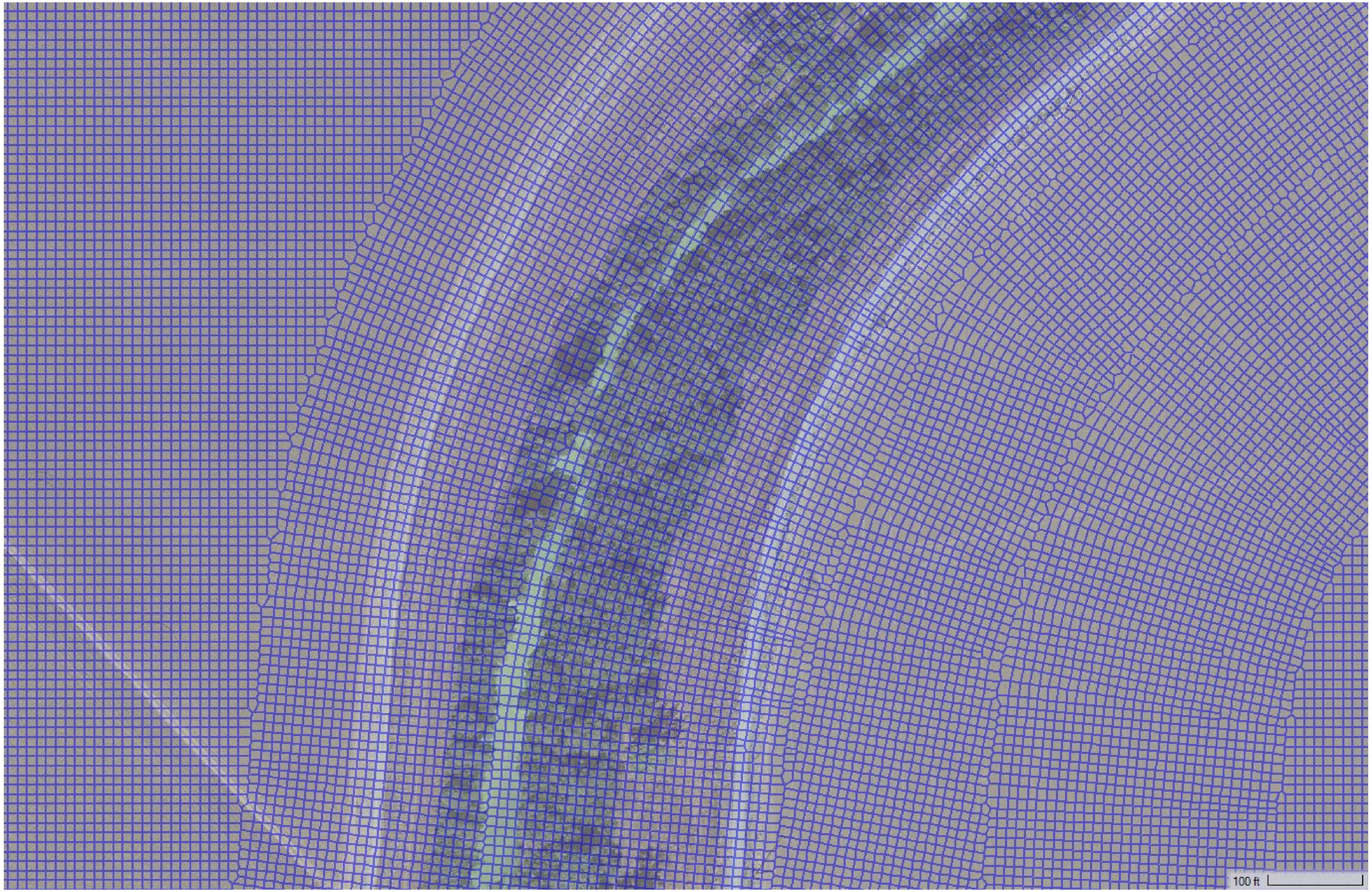


Figure 5
HEC-RAS Mesh Orientation and Resolution

Figure 6
Contour of Dike Offset

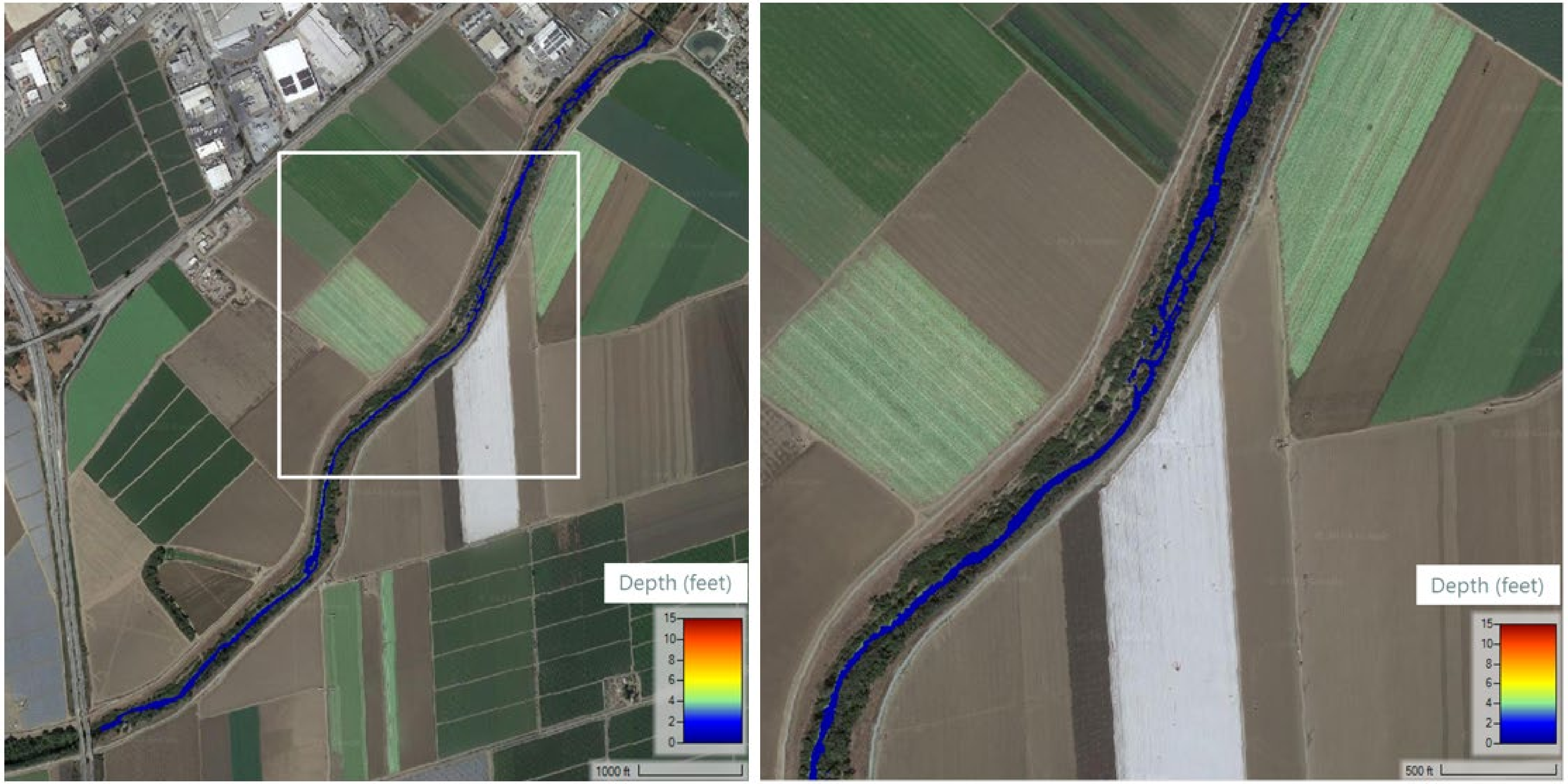


Figure 7
Median Discharge Depth Results

Note: fps = feet per second

Figure 8
Median Discharge Velocity Results

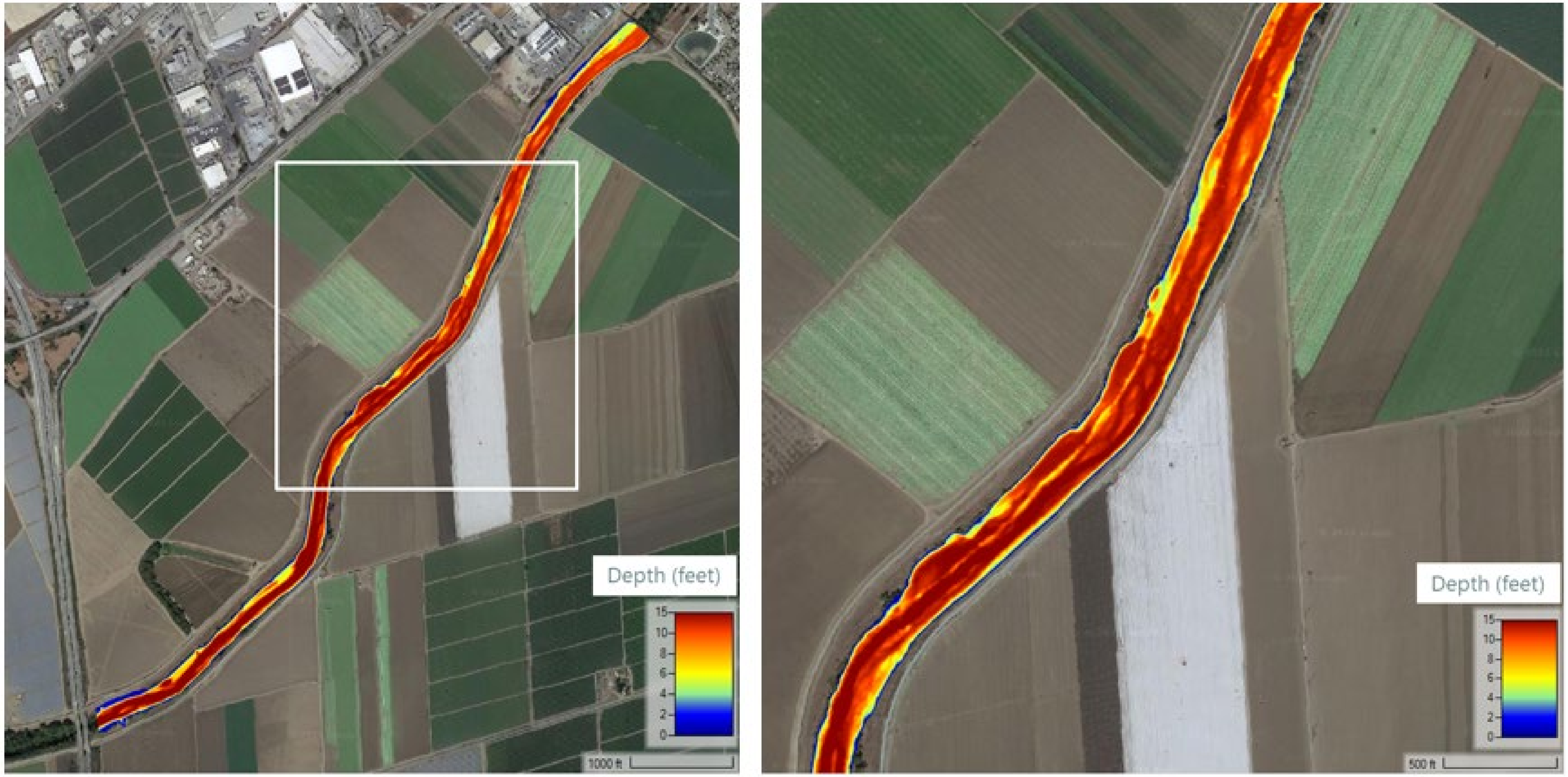


Figure 9
2-Year Discharge Depth Results

Figure 10
2-Year Discharge Velocity Results

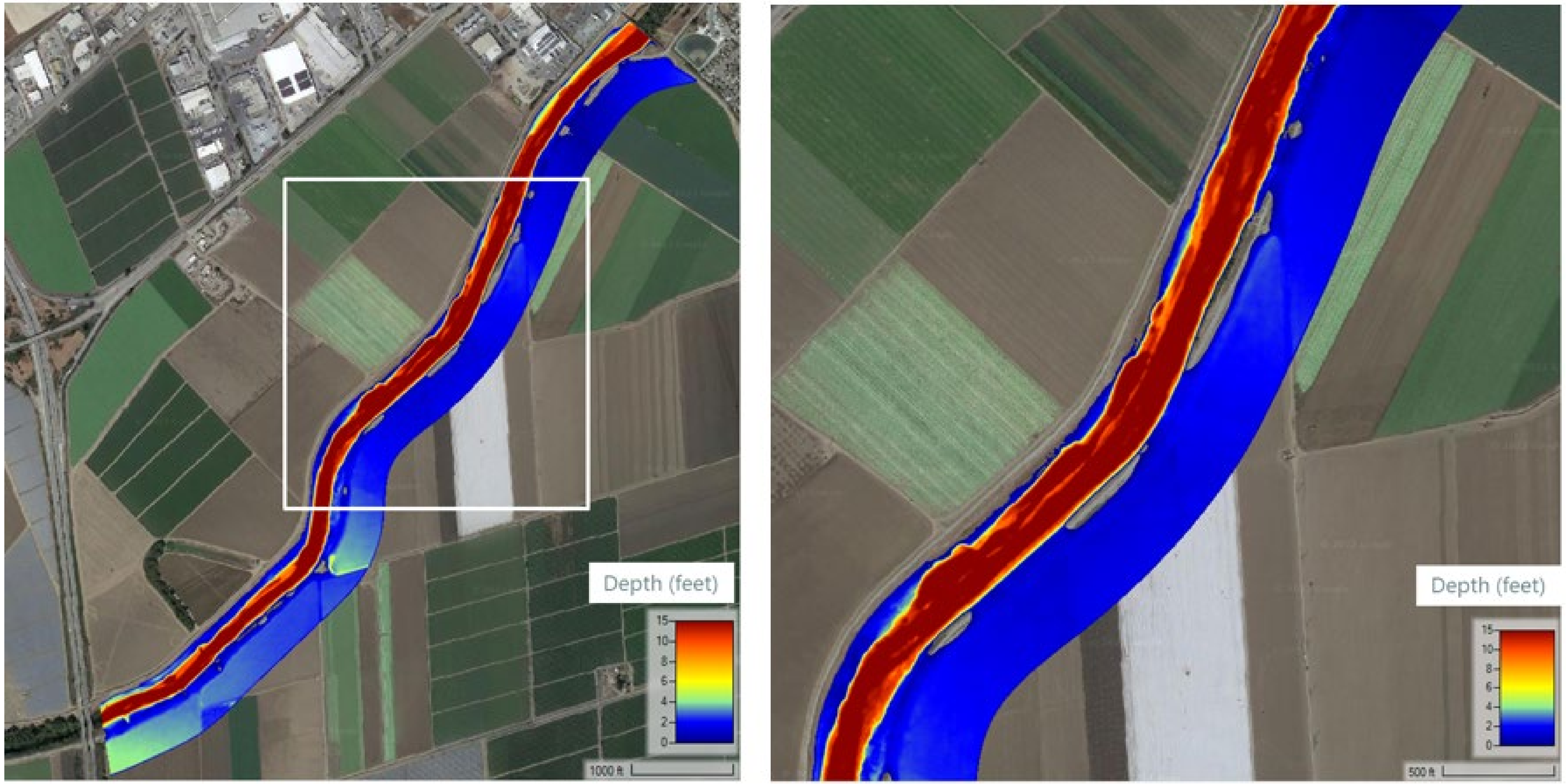


Figure 11
5-Year Discharge Depth Results

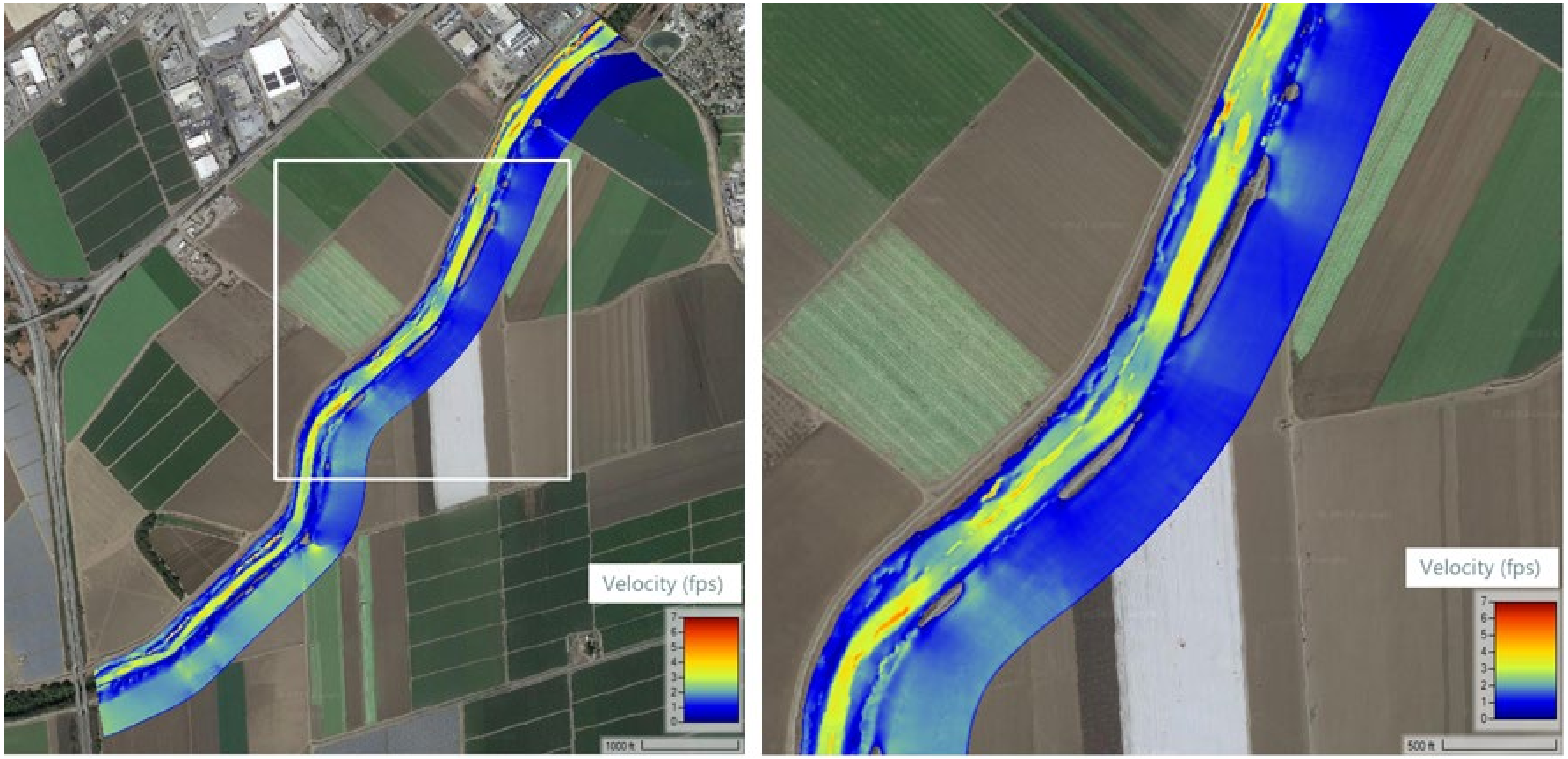


Figure 12
5-Year Discharge Velocity Results

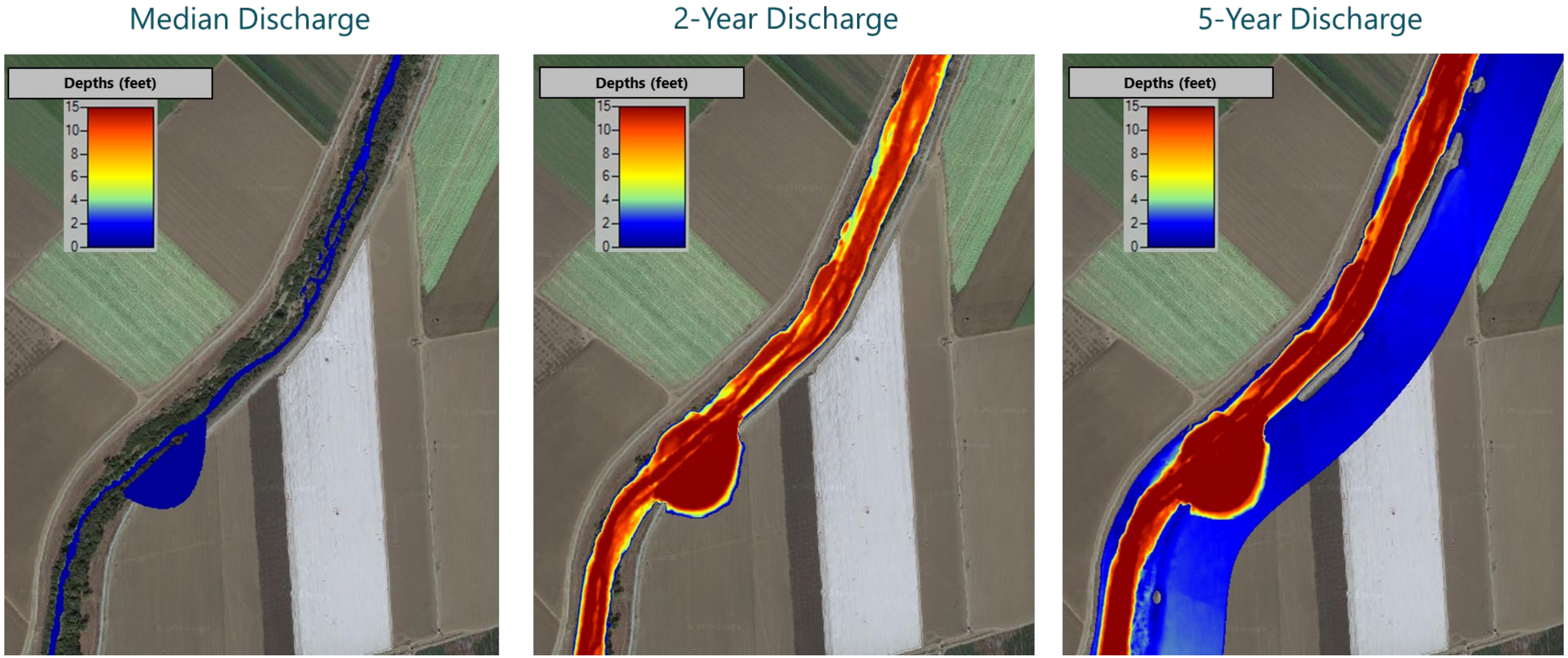
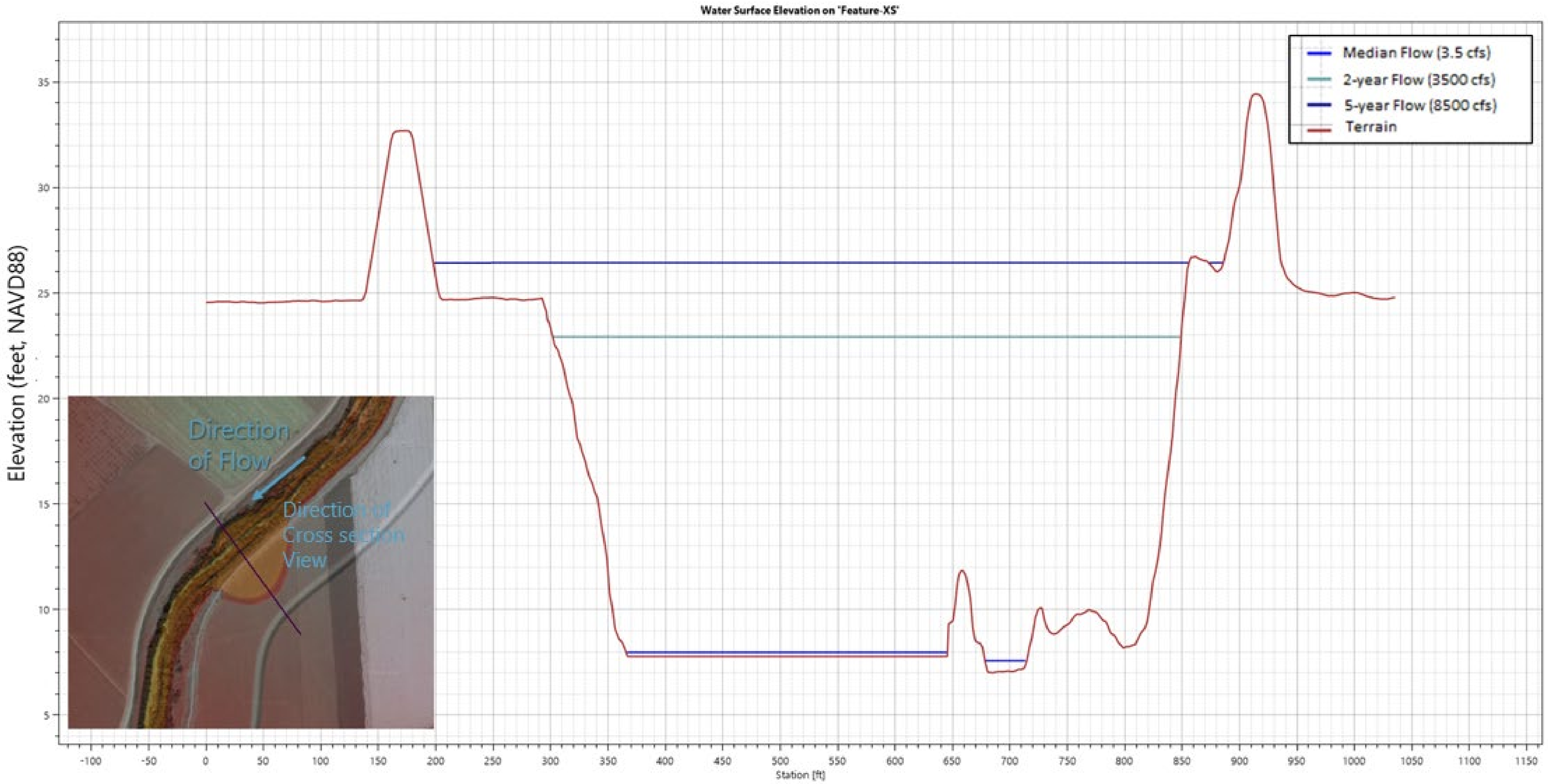
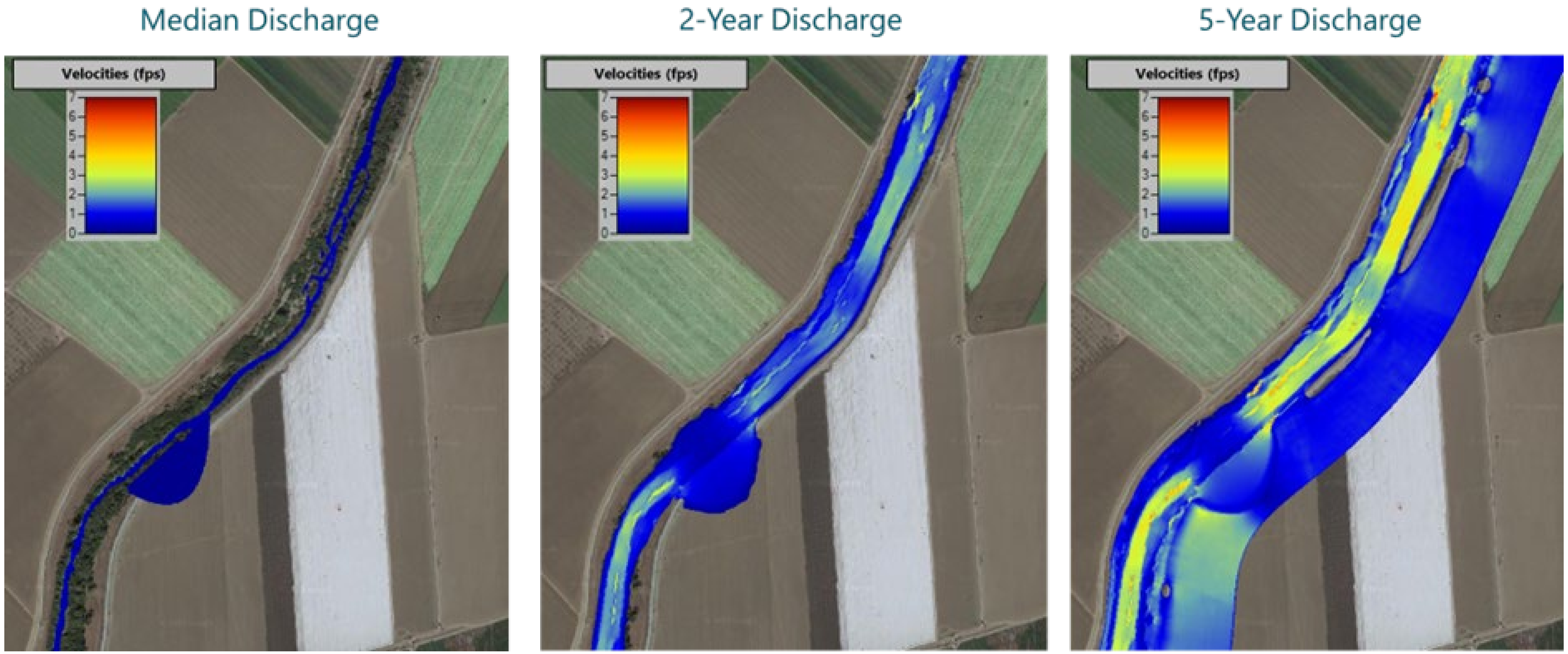


Figure 13
Inside Bend Pool A Depth Results



Note: Cross section shown is looking in downstream direction.

Figure 14
Inside Bend Pool A Depth Results Cross Section



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 15
Inside Bend Pool A Velocity Results

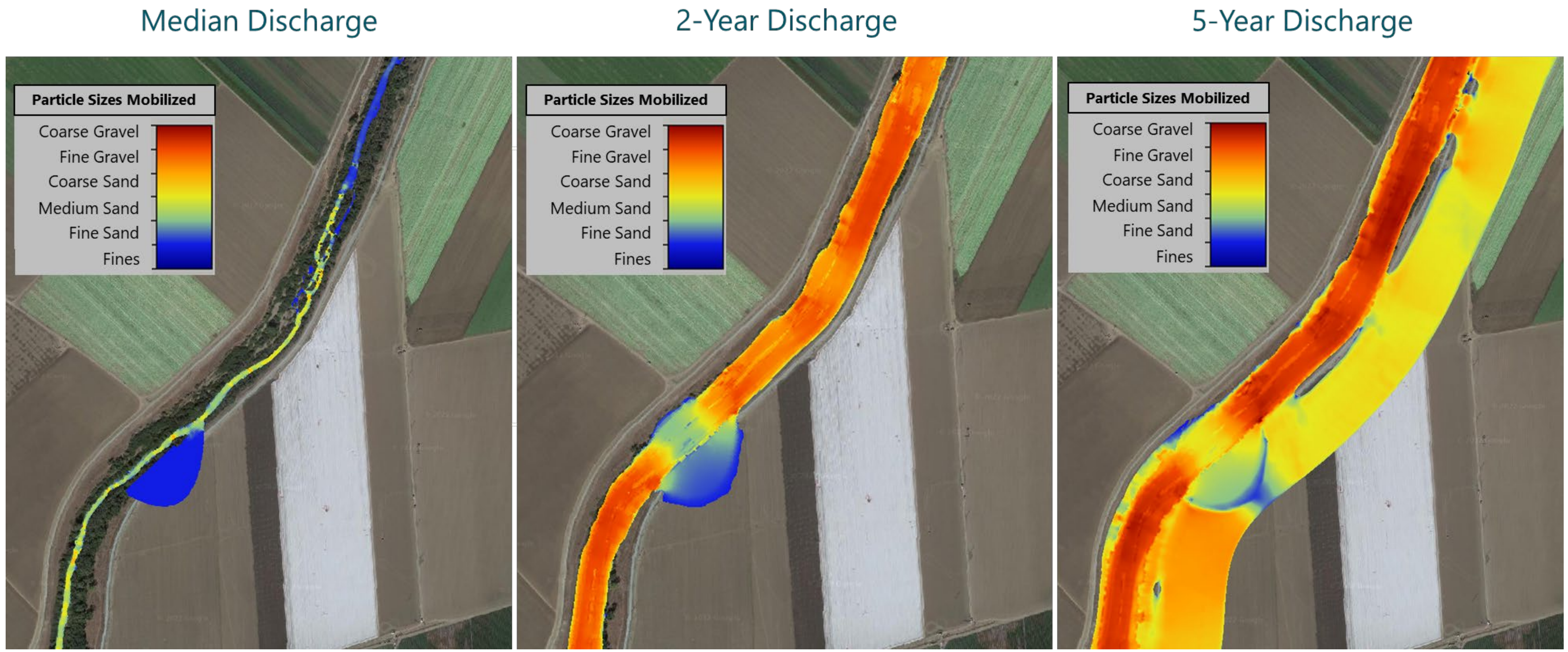


Figure 16
Inside Bend Pool A Stable Particle Size Results

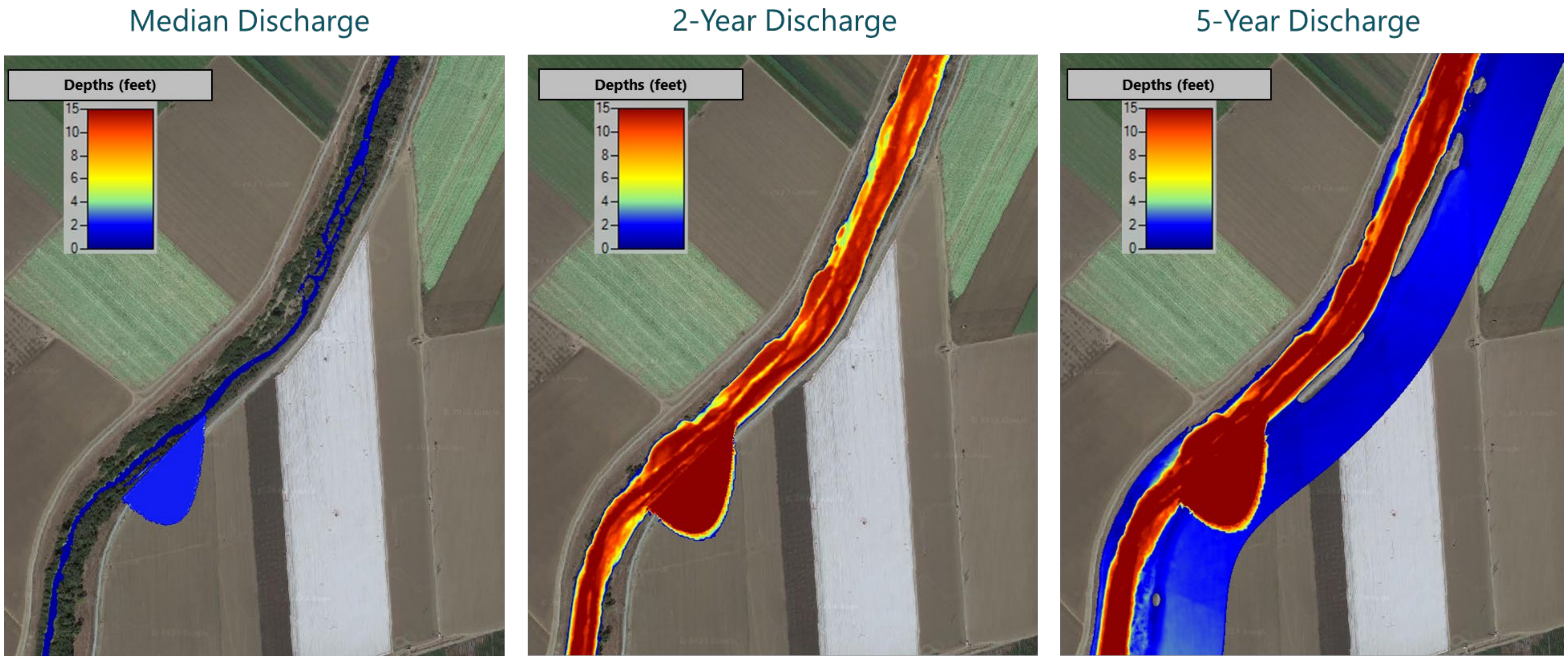
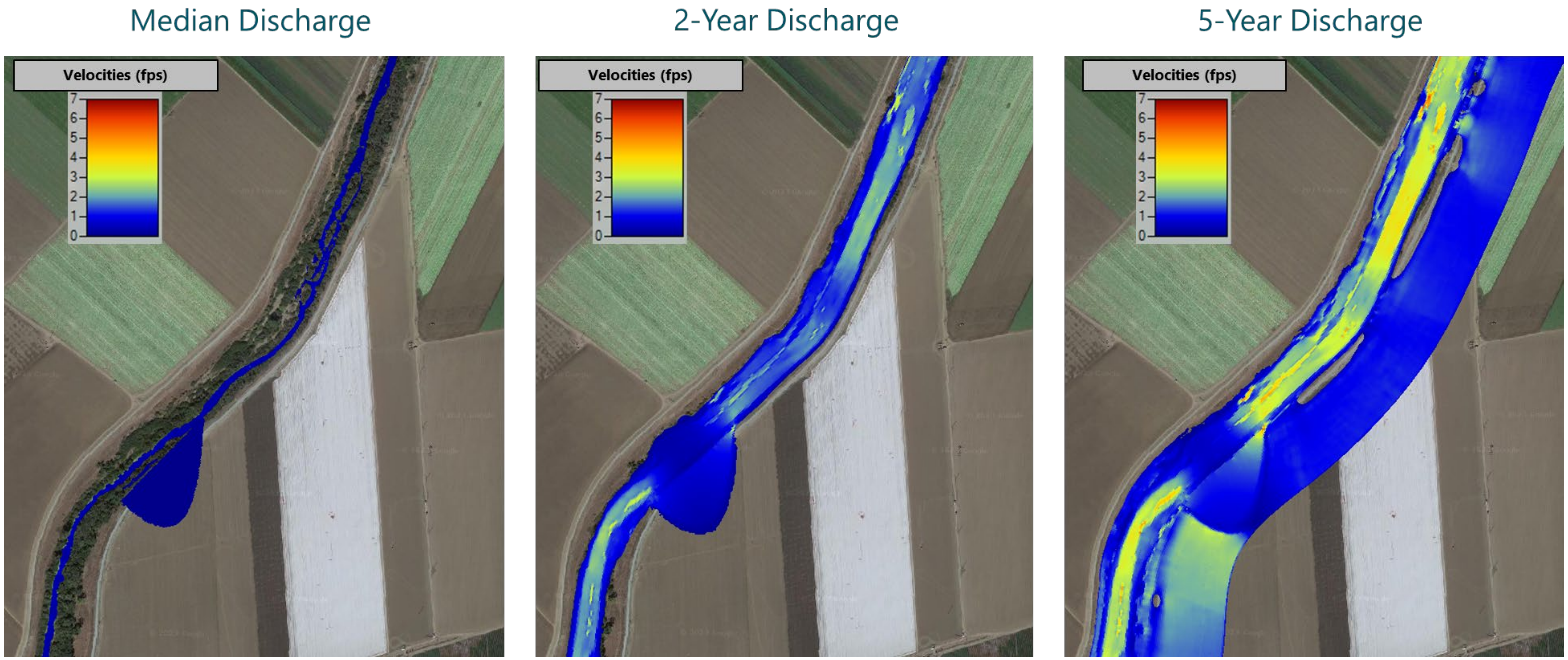


Figure 17
Inside Bend Pool B Depth Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 18
Inside Bend Pool B Velocity Results

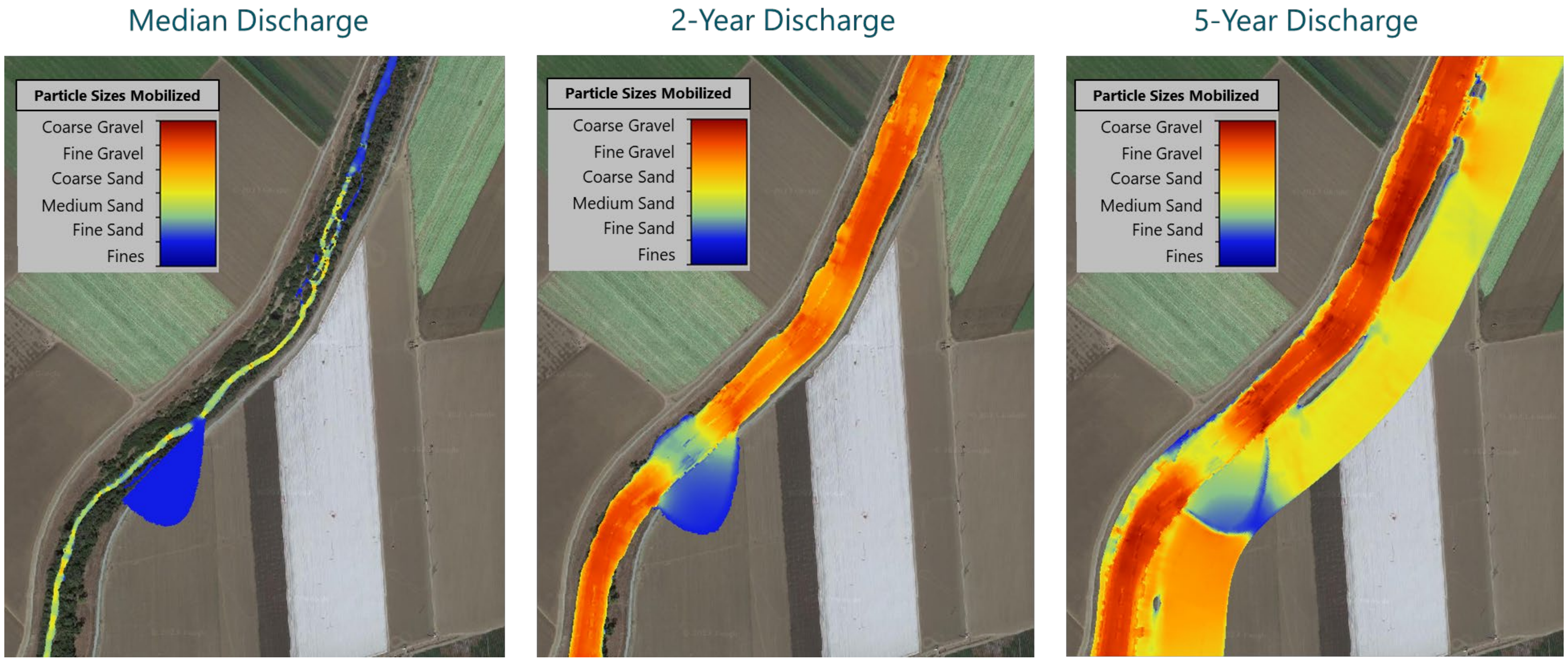
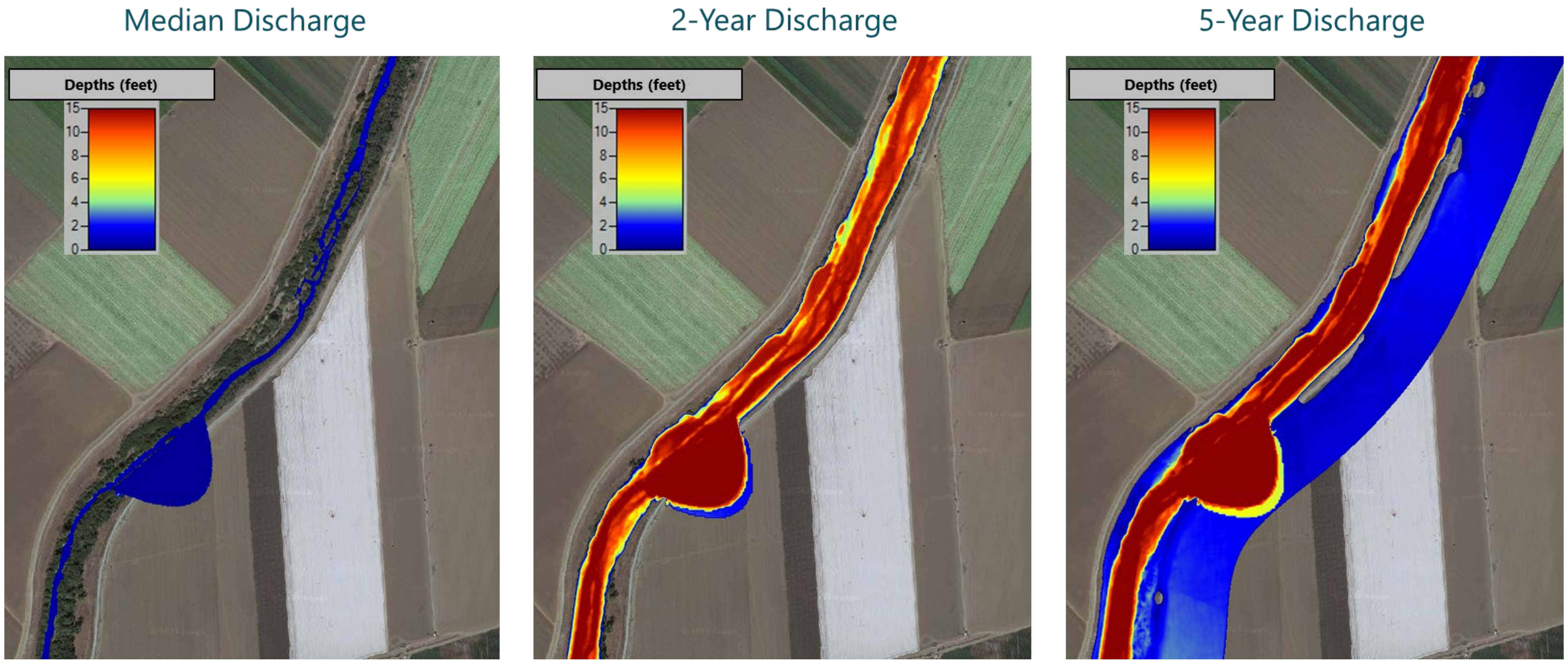


Figure 19
Inside Bend Pool B Stable Particle Size Results

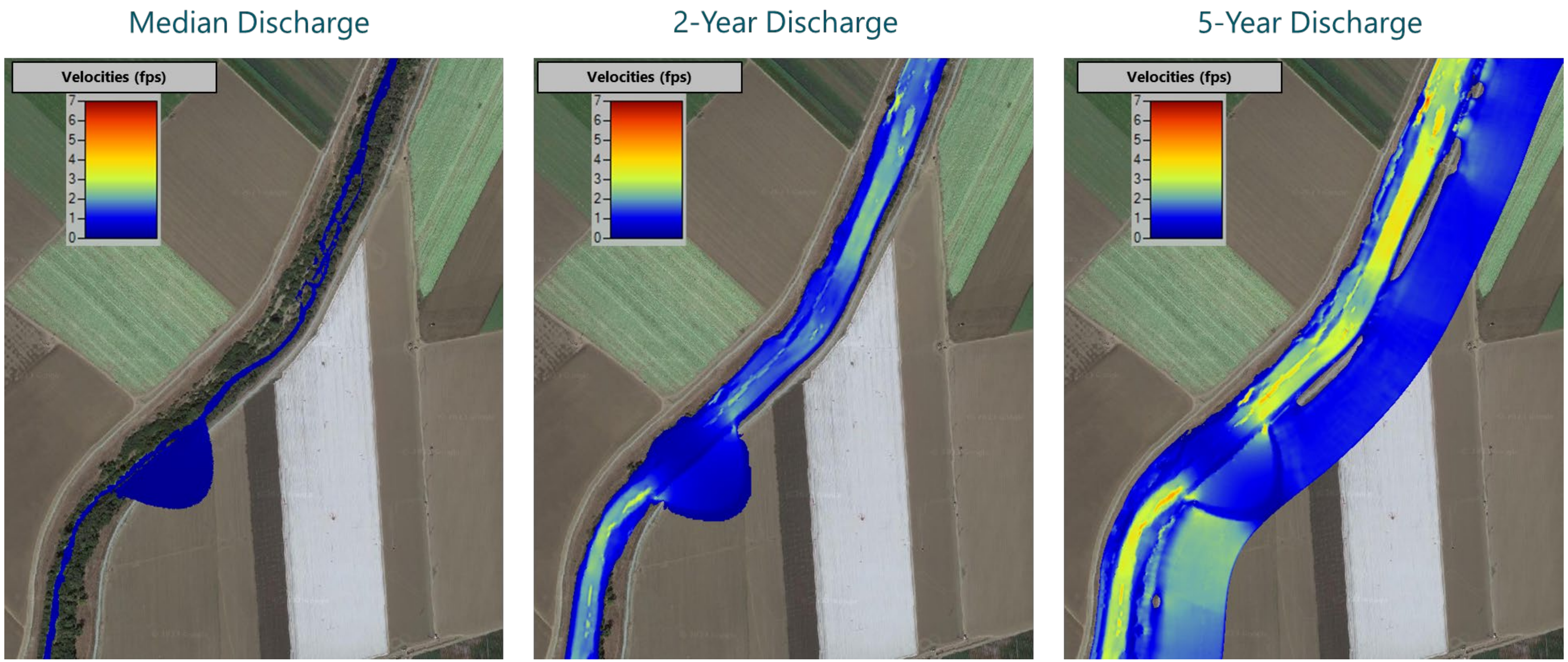


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 20
Inside Bend Pool C Depth Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 21
Inside Bend Pool C Velocity Results

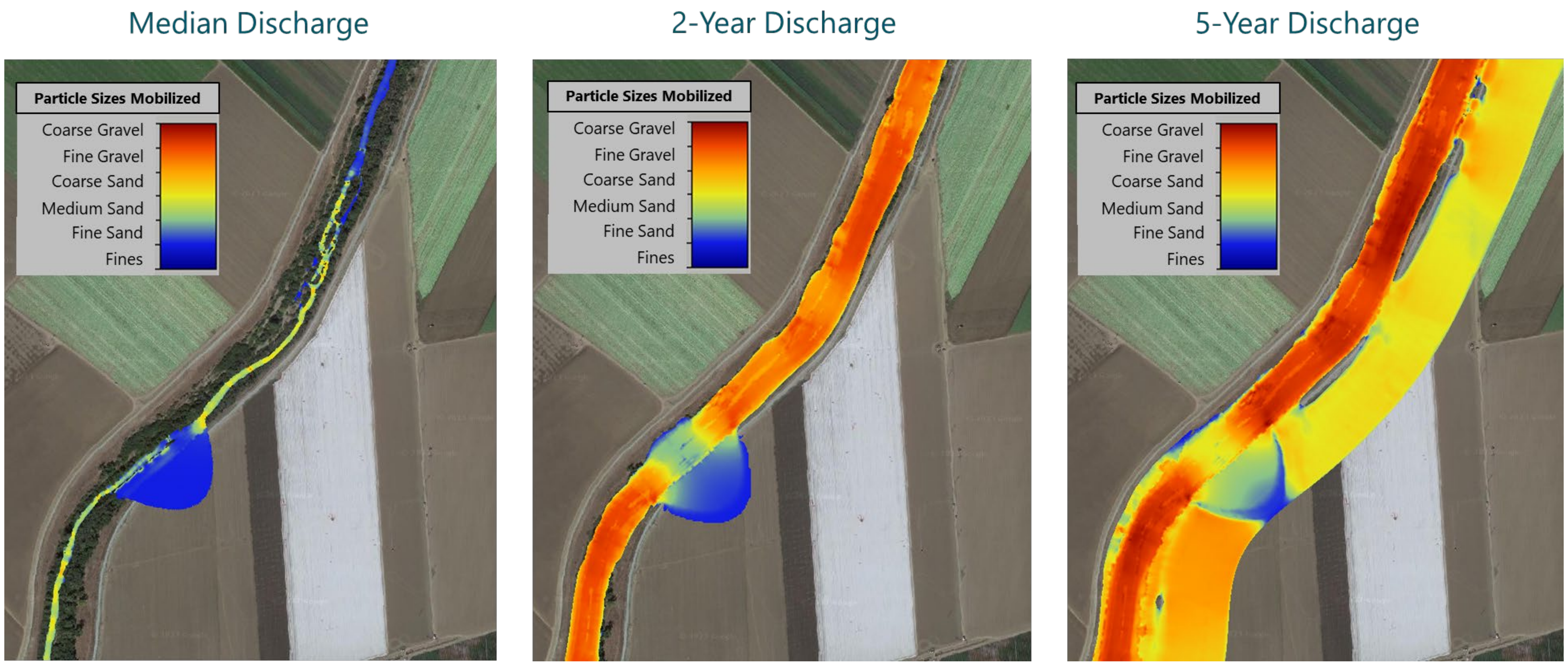
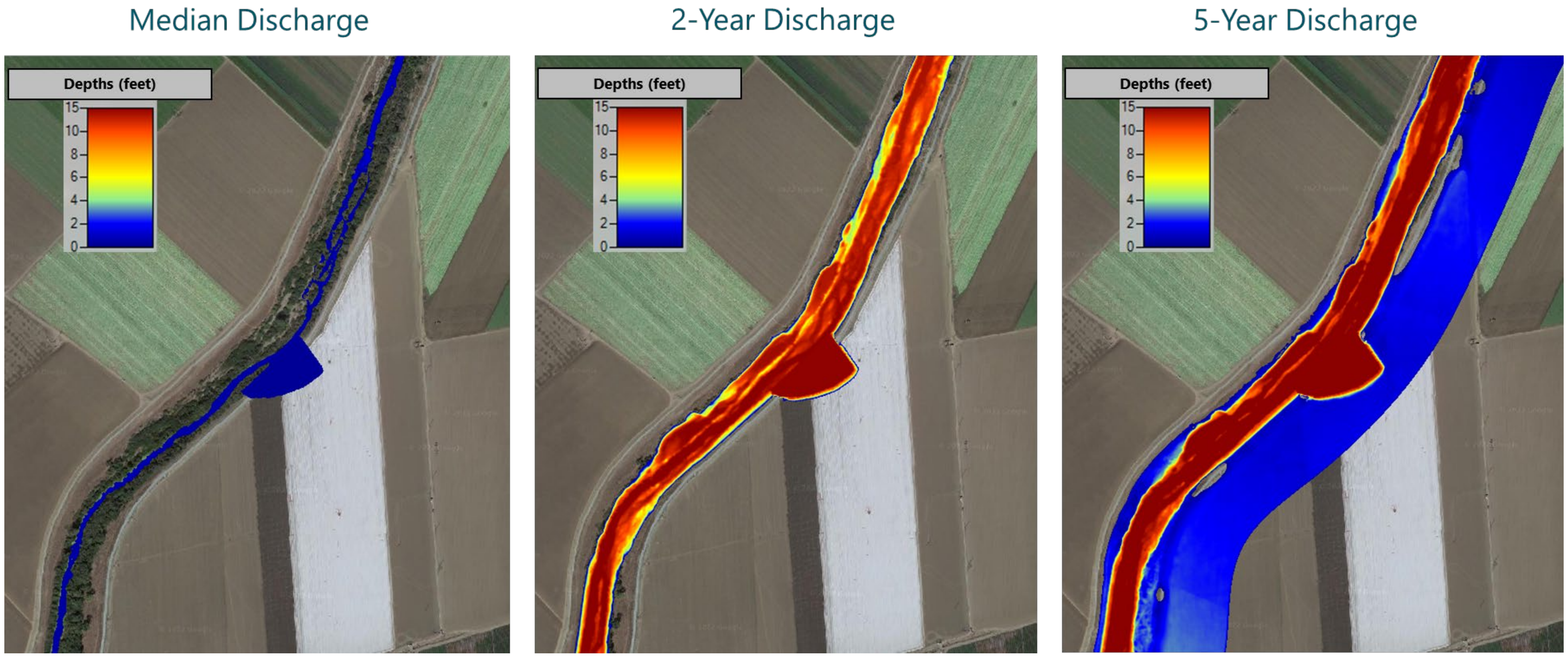


Figure 22
Inside Bend Pool C Stable Particle Size Results

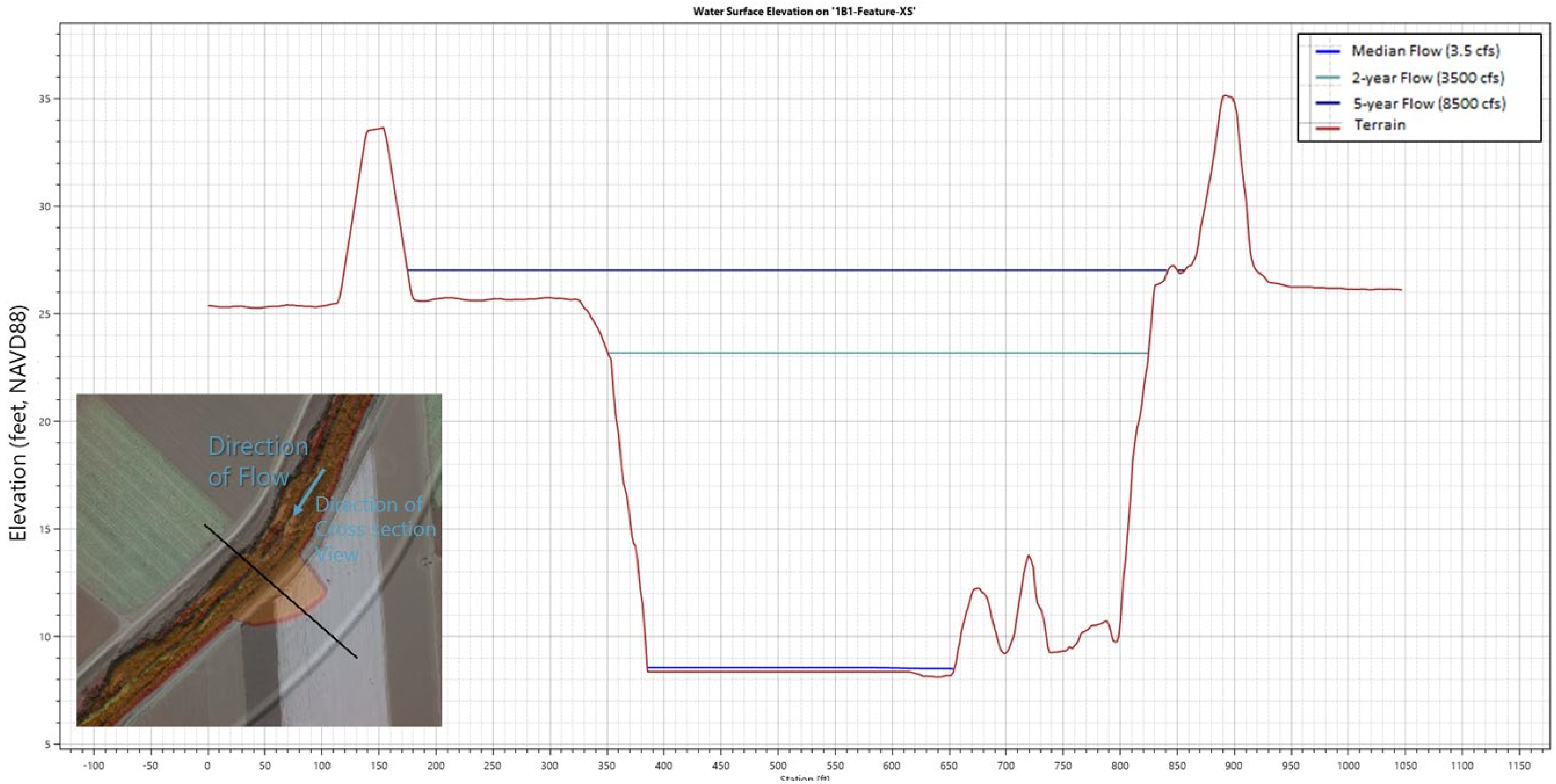


Median Discharge

2-Year Discharge

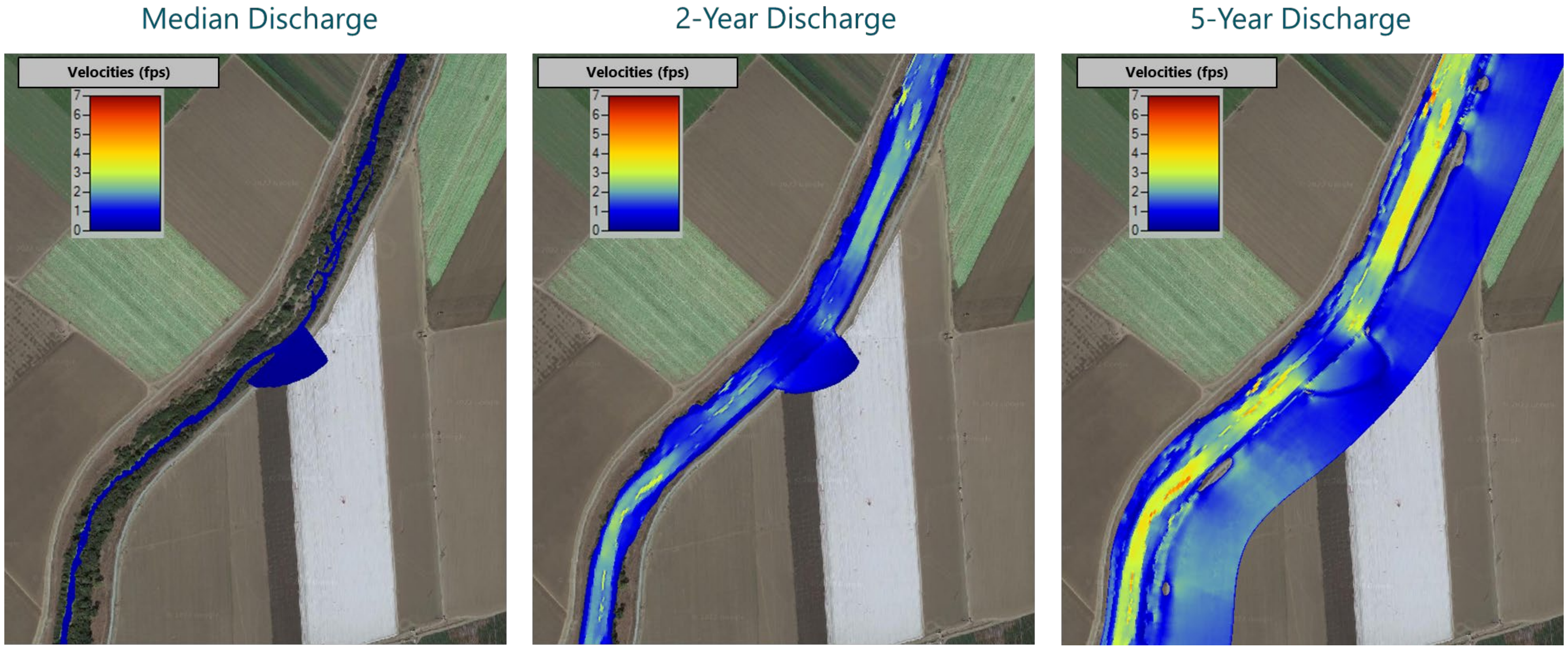
5-Year Discharge

Figure 23
Outside Bend Pool A Depth Results



Note: Cross section shown is looking in downstream direction.

Figure 24
Outside Bend Pool A Depth Results Cross Section

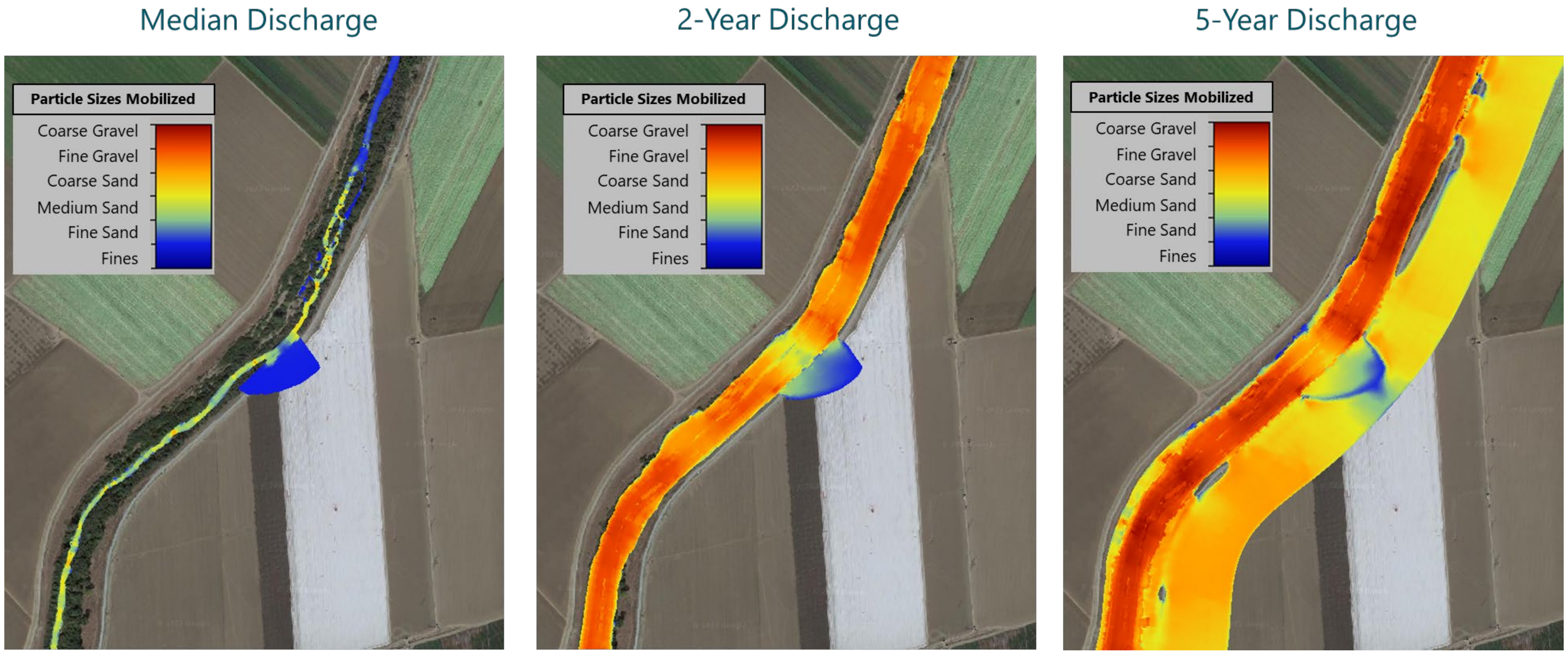


Median Discharge

2-Year Discharge

5-Year Discharge

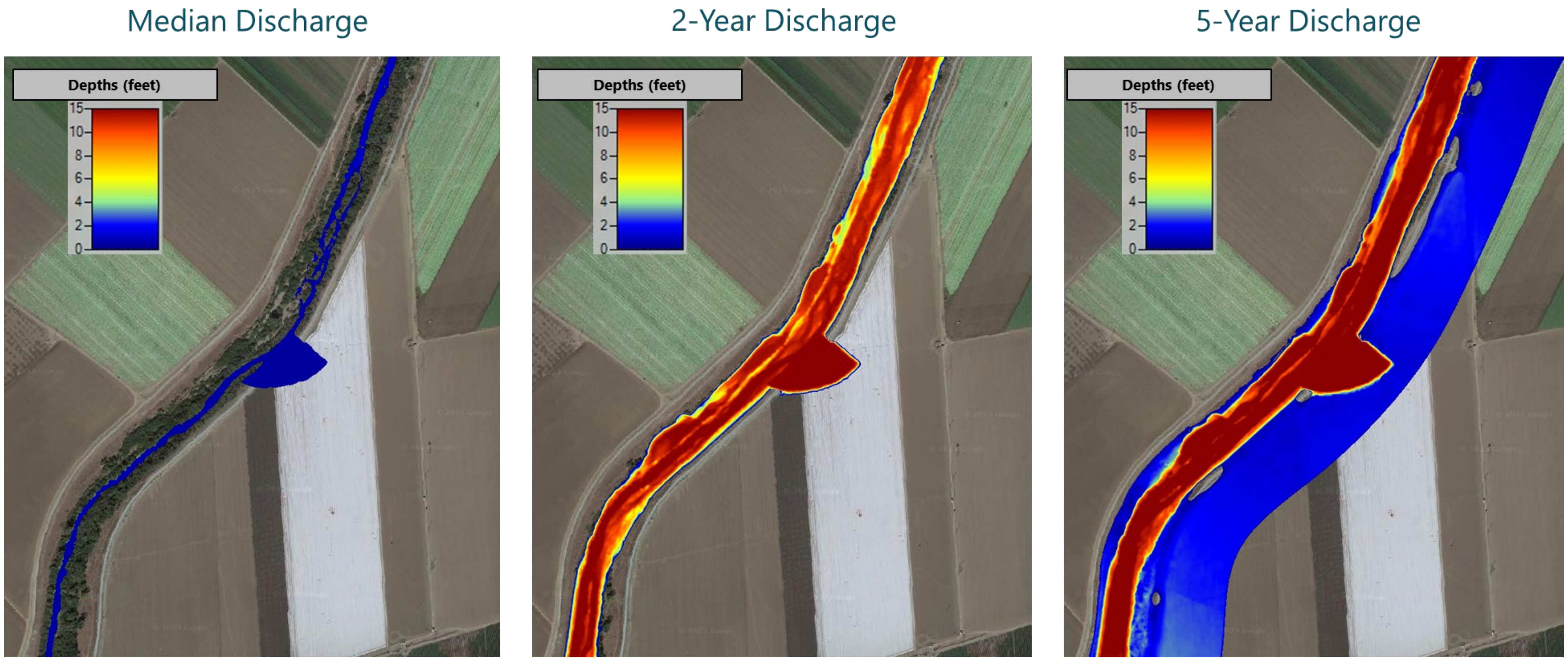
Figure 25
Outside Bend Pool A Velocity Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 26
Outside Bend Pool A Stable Particle Size Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 27
Outside Bend Pool B Depth Results

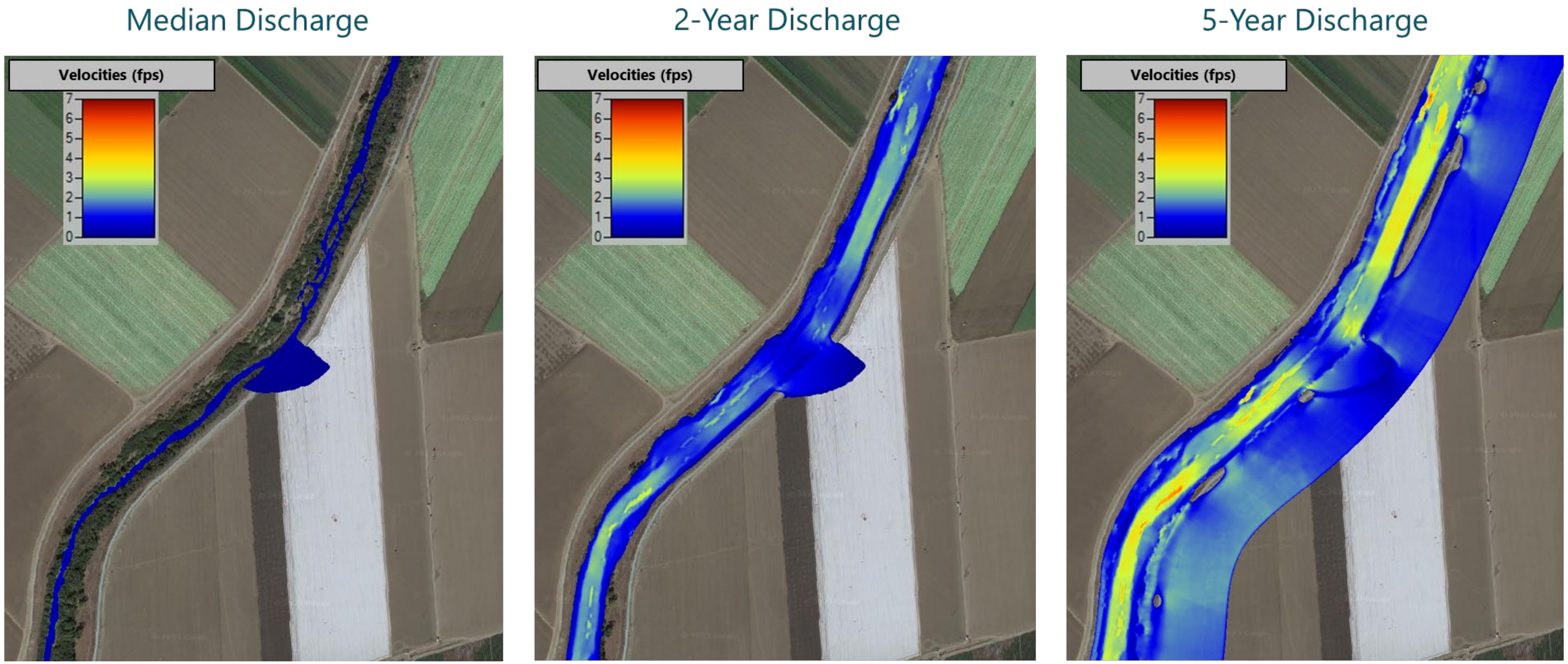
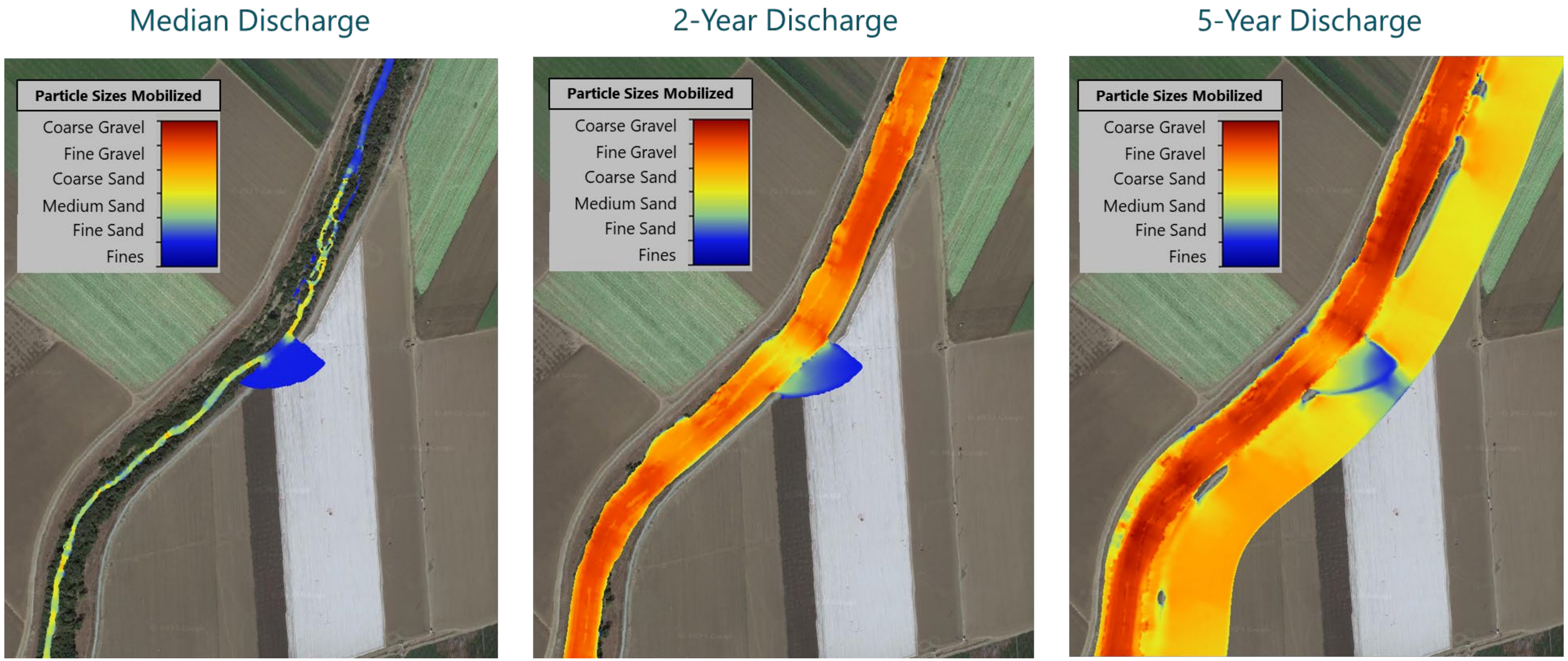


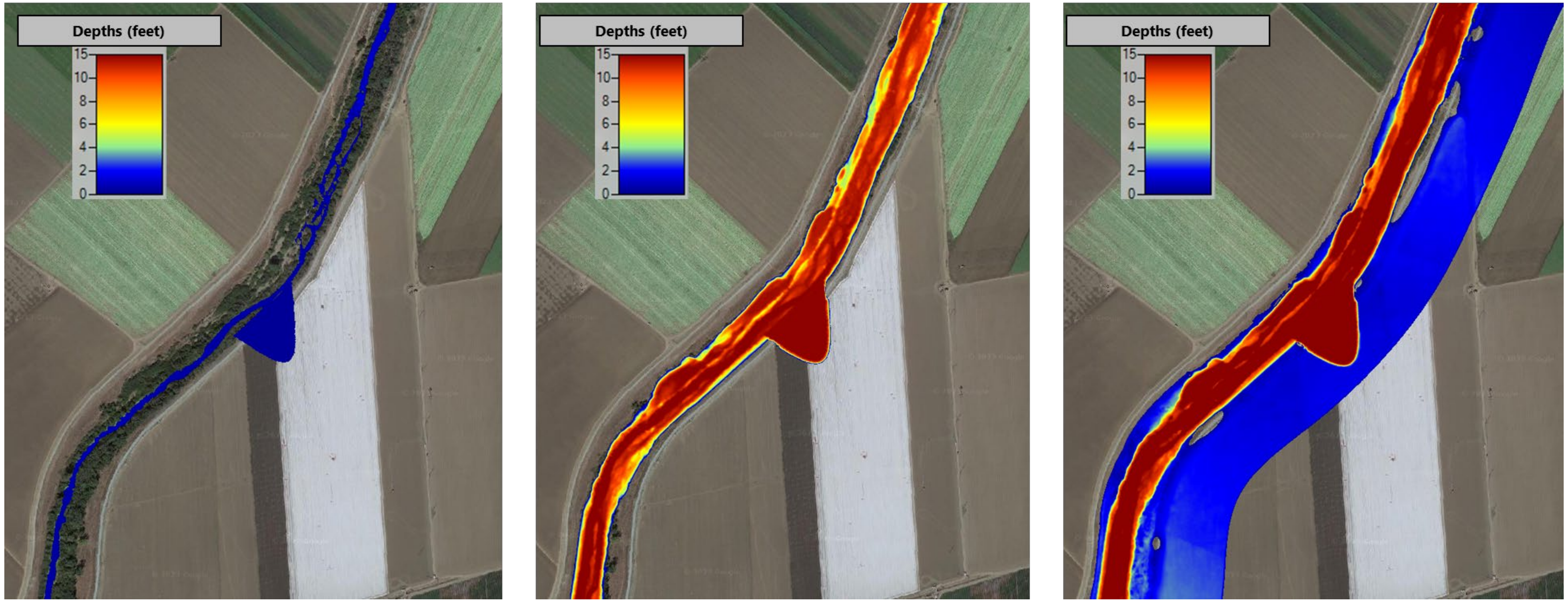
Figure 28
Outside Bend Pool B Velocity Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 29
Outside Bend Pool B Stable Particle Size Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 30
Outside Bend Pool C Depth Results

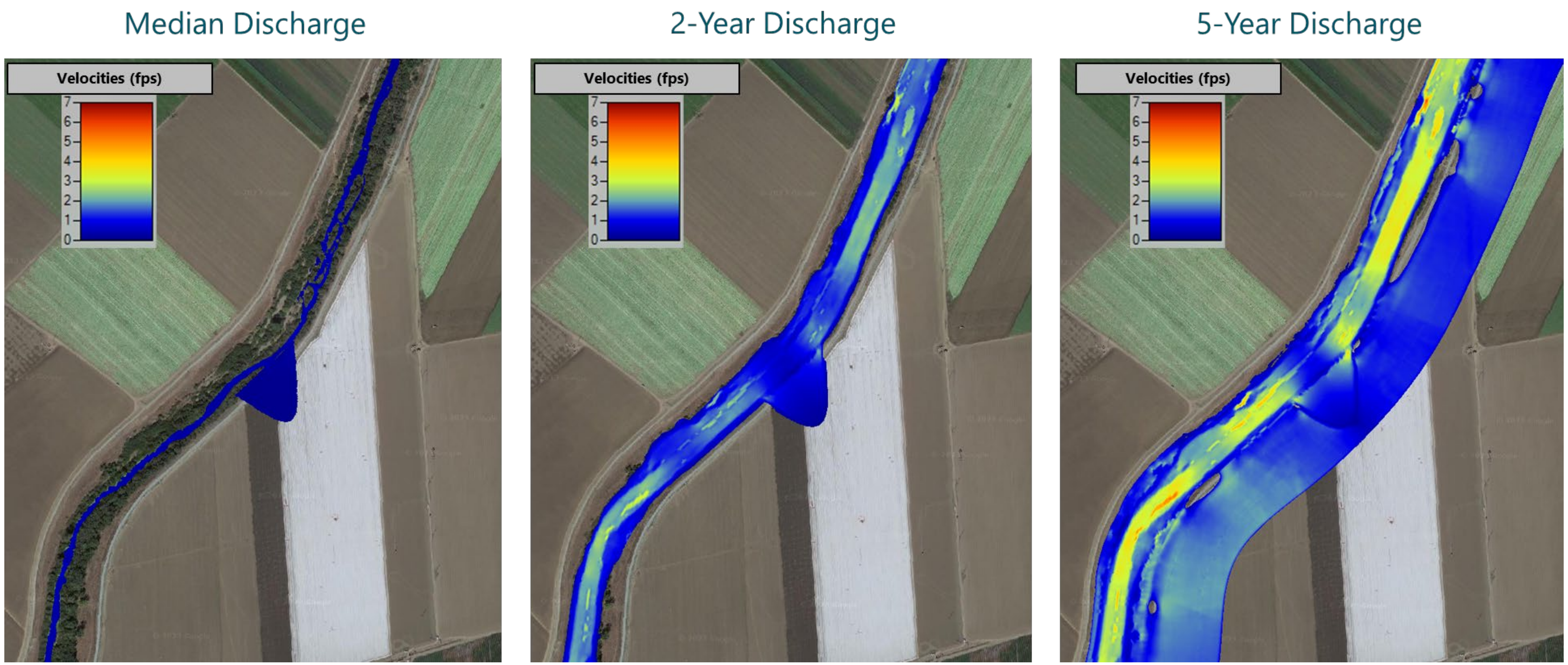


Figure 31
Outside Bend Pool C Velocity Results

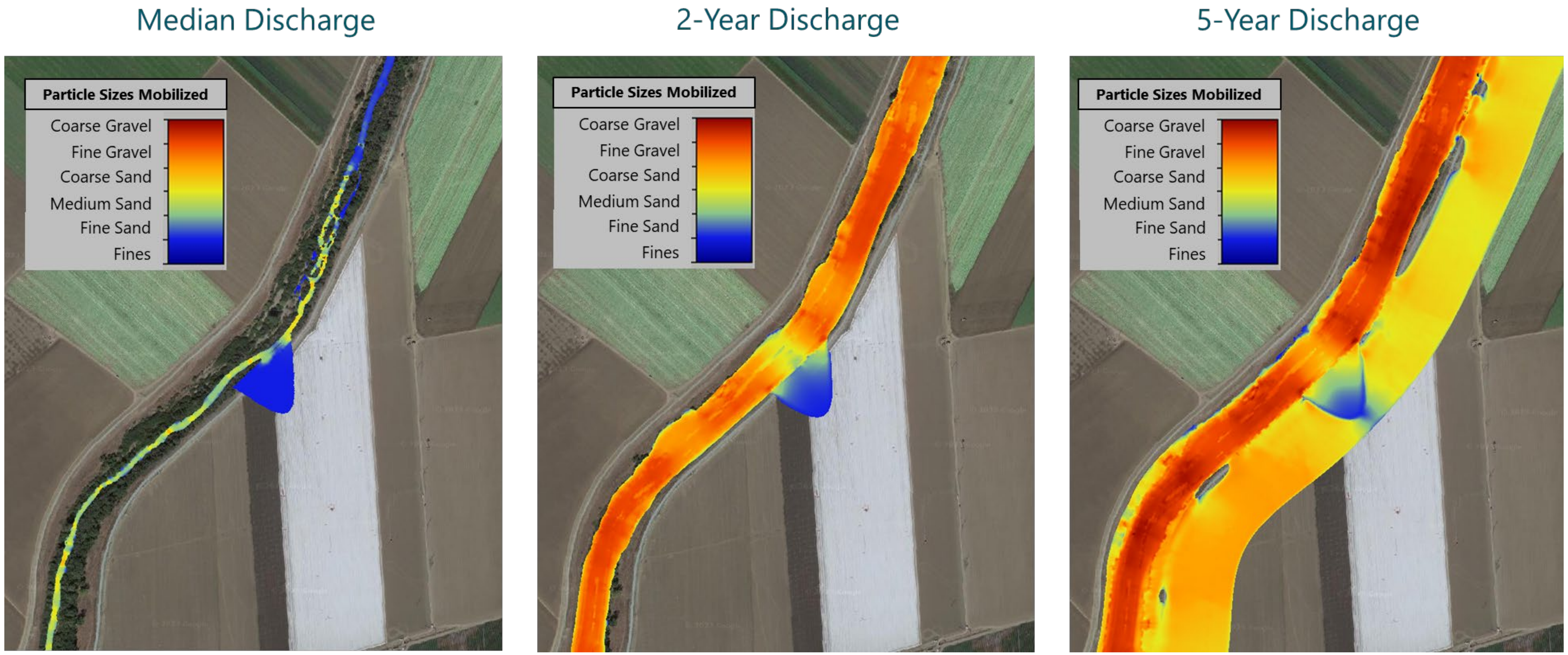


Figure 32
Outside Bend Pool C Stable Particle Size Results

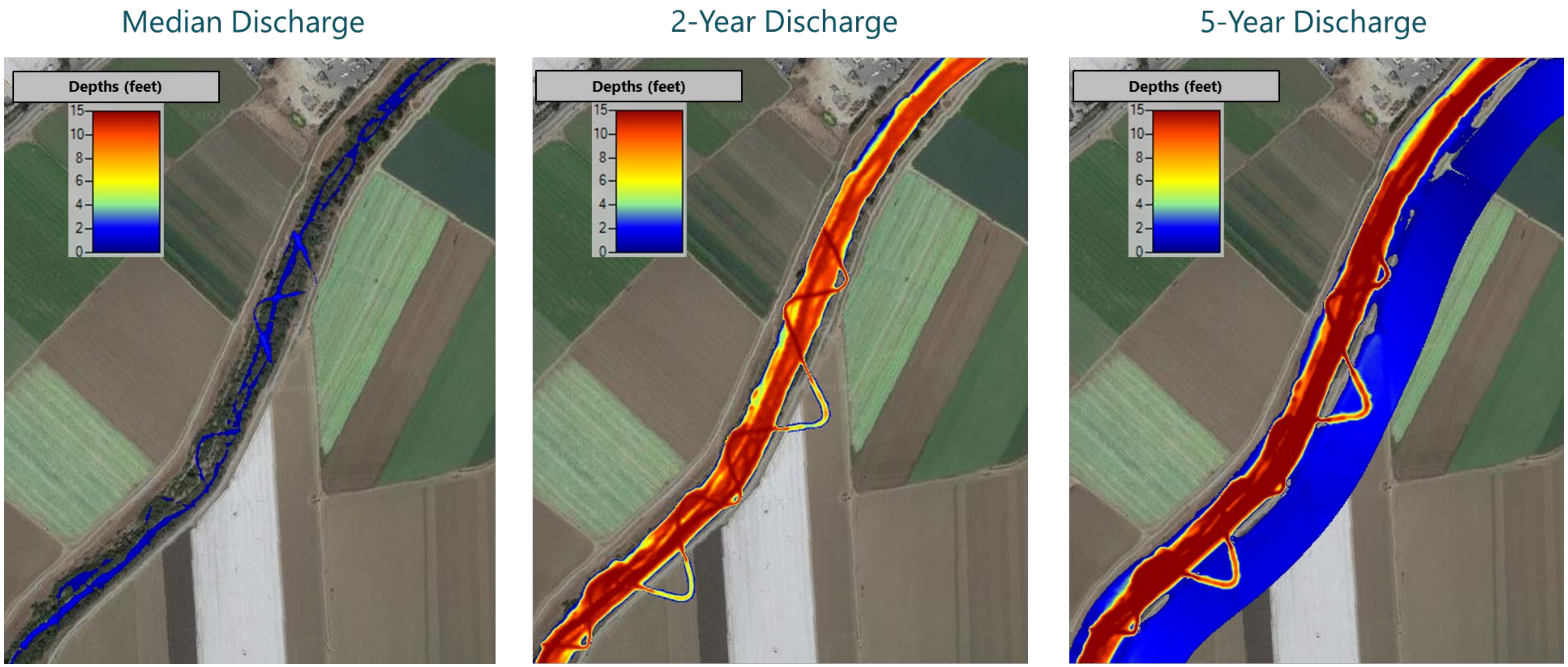
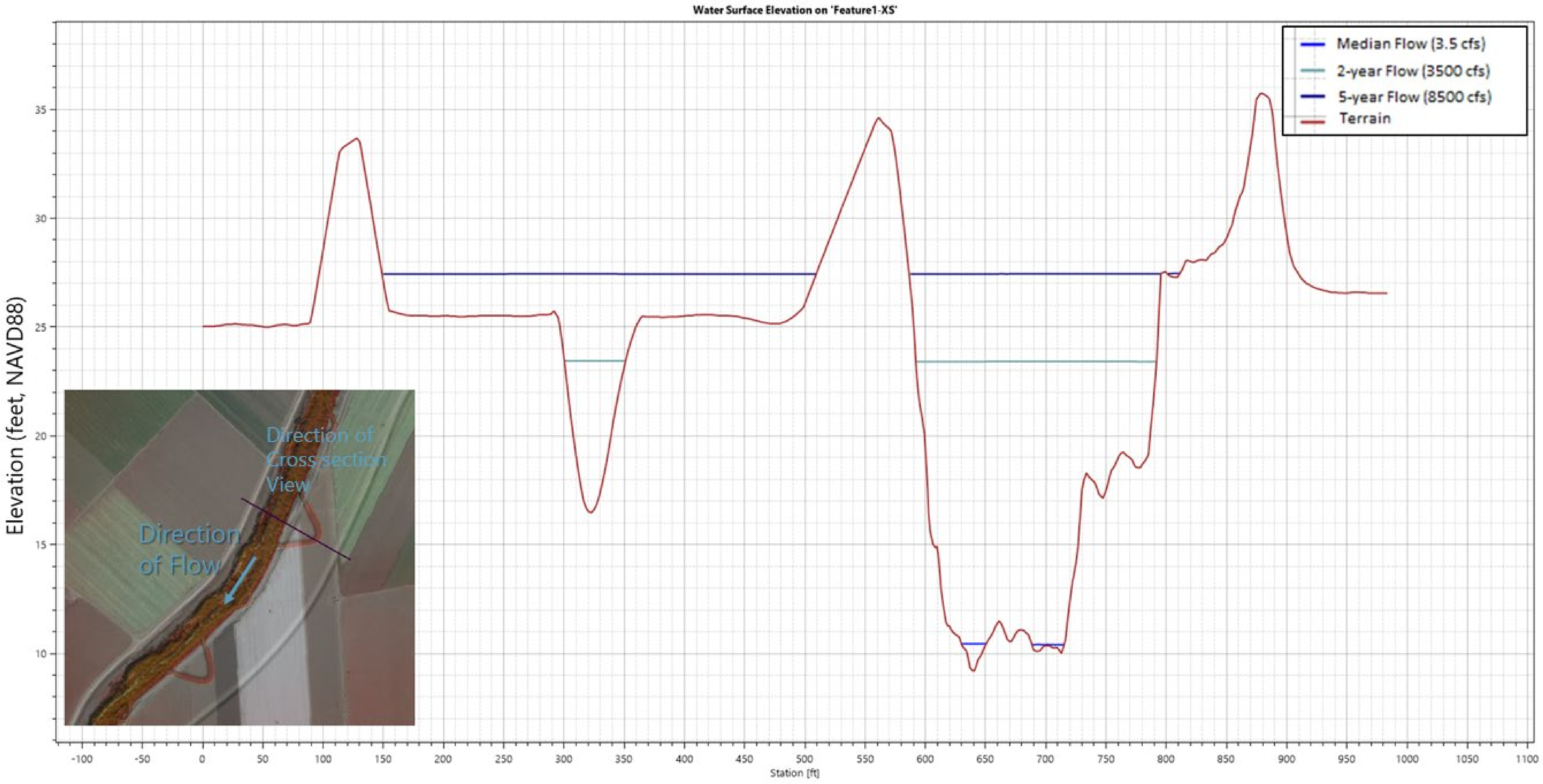
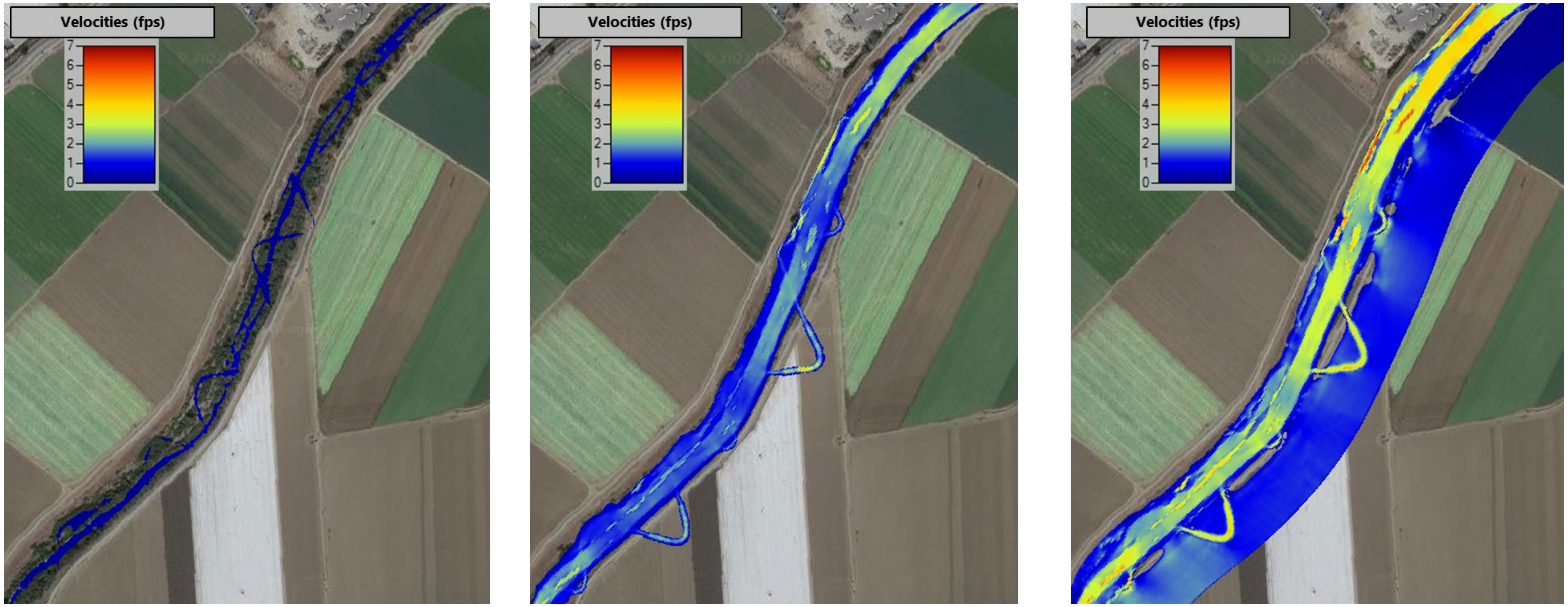


Figure 33
Ribbon A Depth Results



Note: Cross section shown is looking in downstream direction.

Figure 34
Ribbon A Depth Results Cross Section

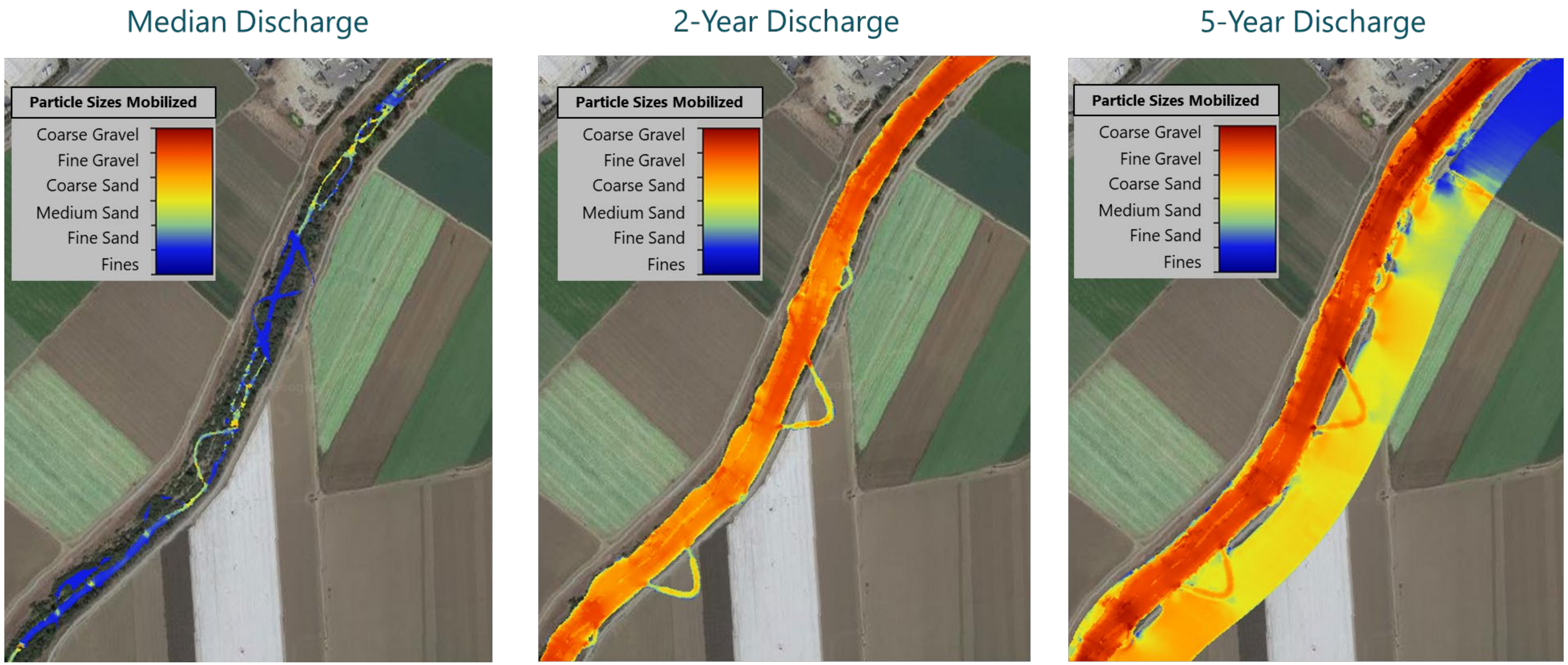


Median Discharge

2-Year Discharge

5-Year Discharge

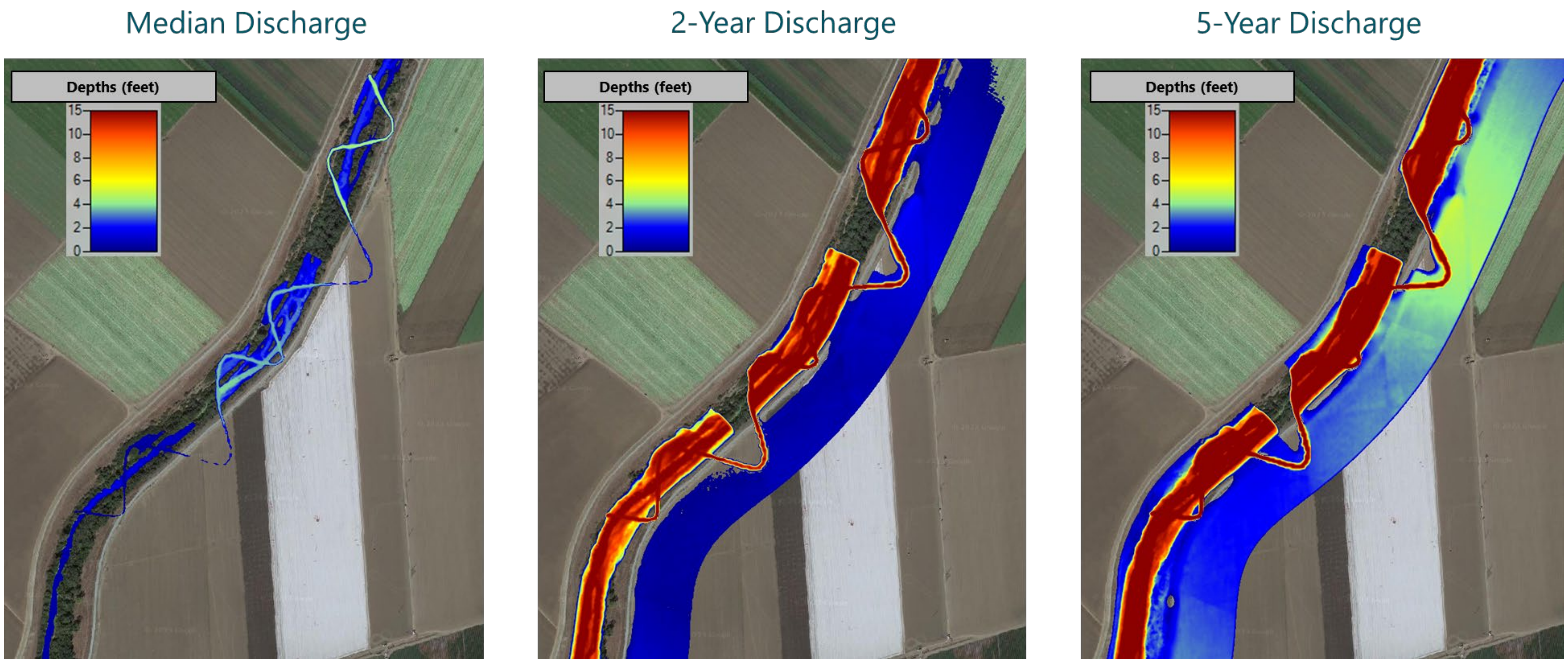
Figure 35
Ribbon A Velocity Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 36
Ribbon A Stable Particle Size Results

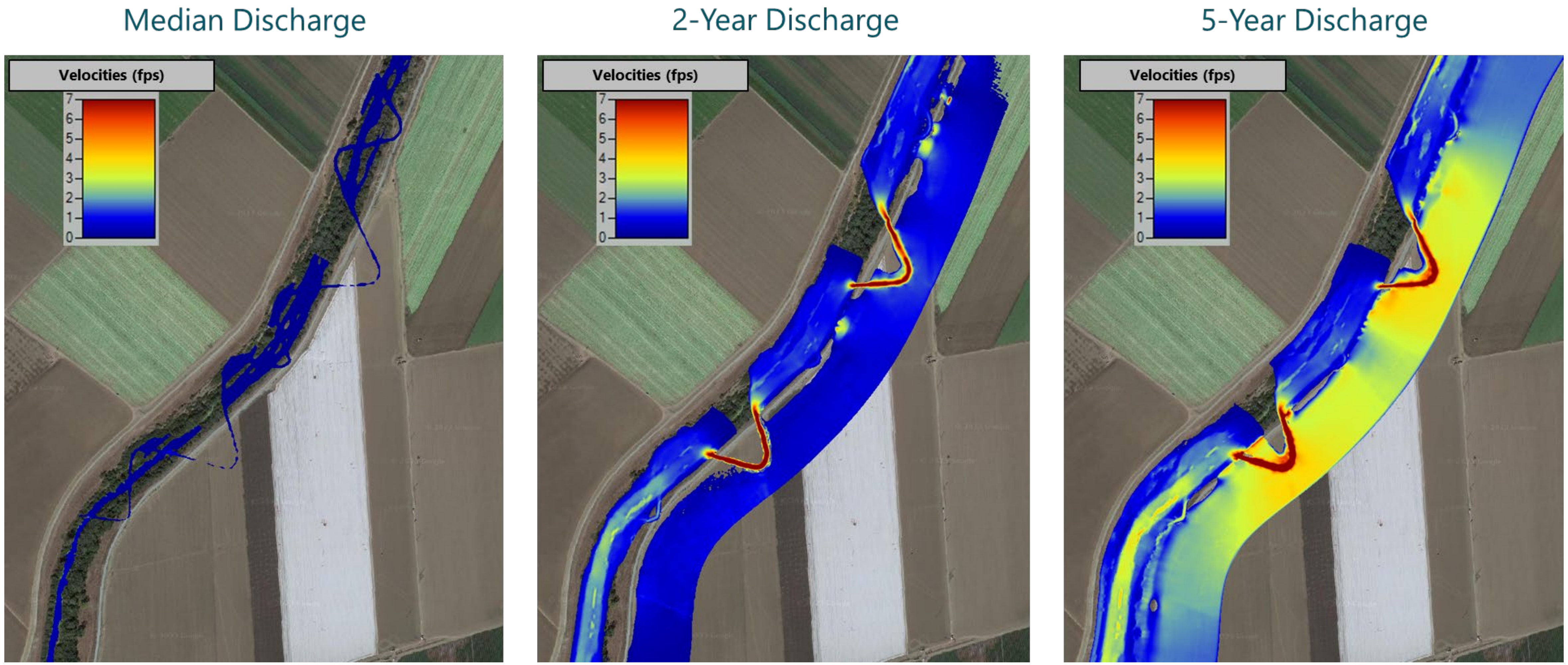


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 37
Ribbon B Depth Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 38
Ribbon B Velocity Results

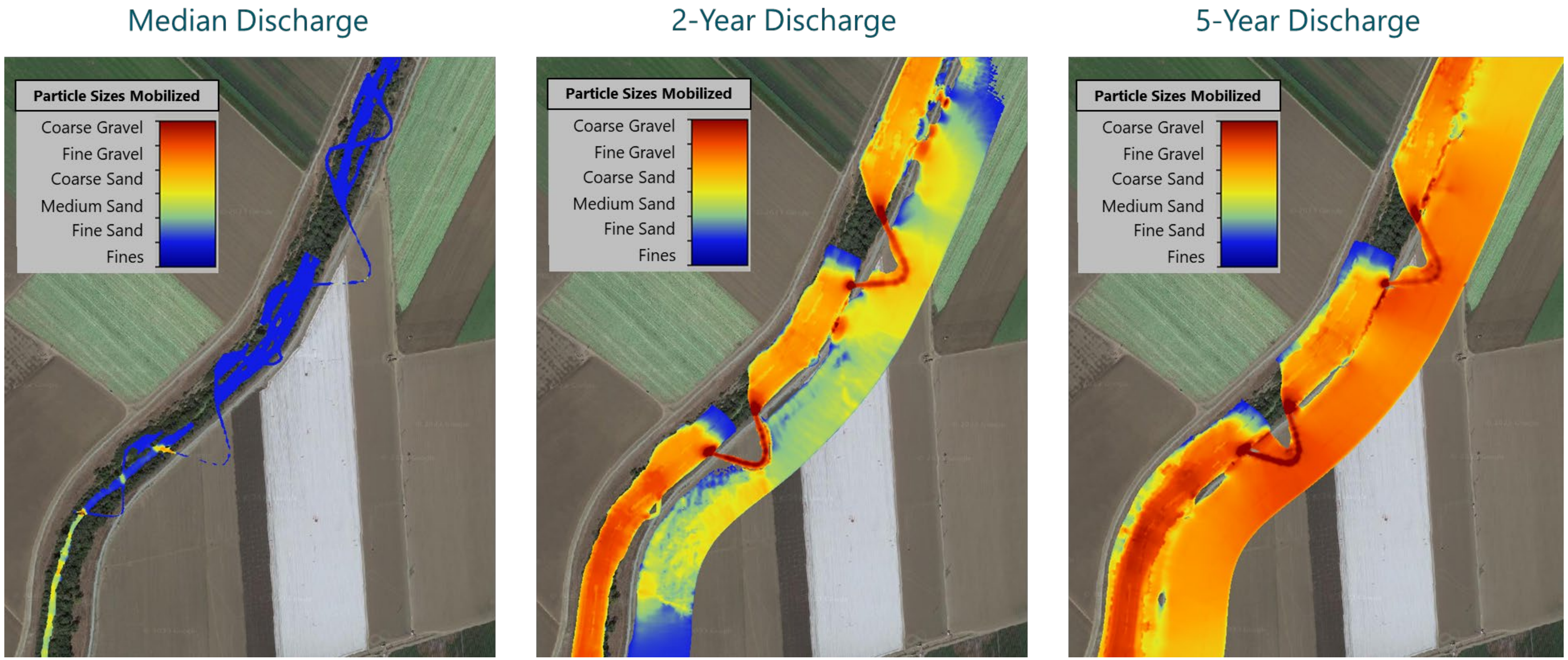
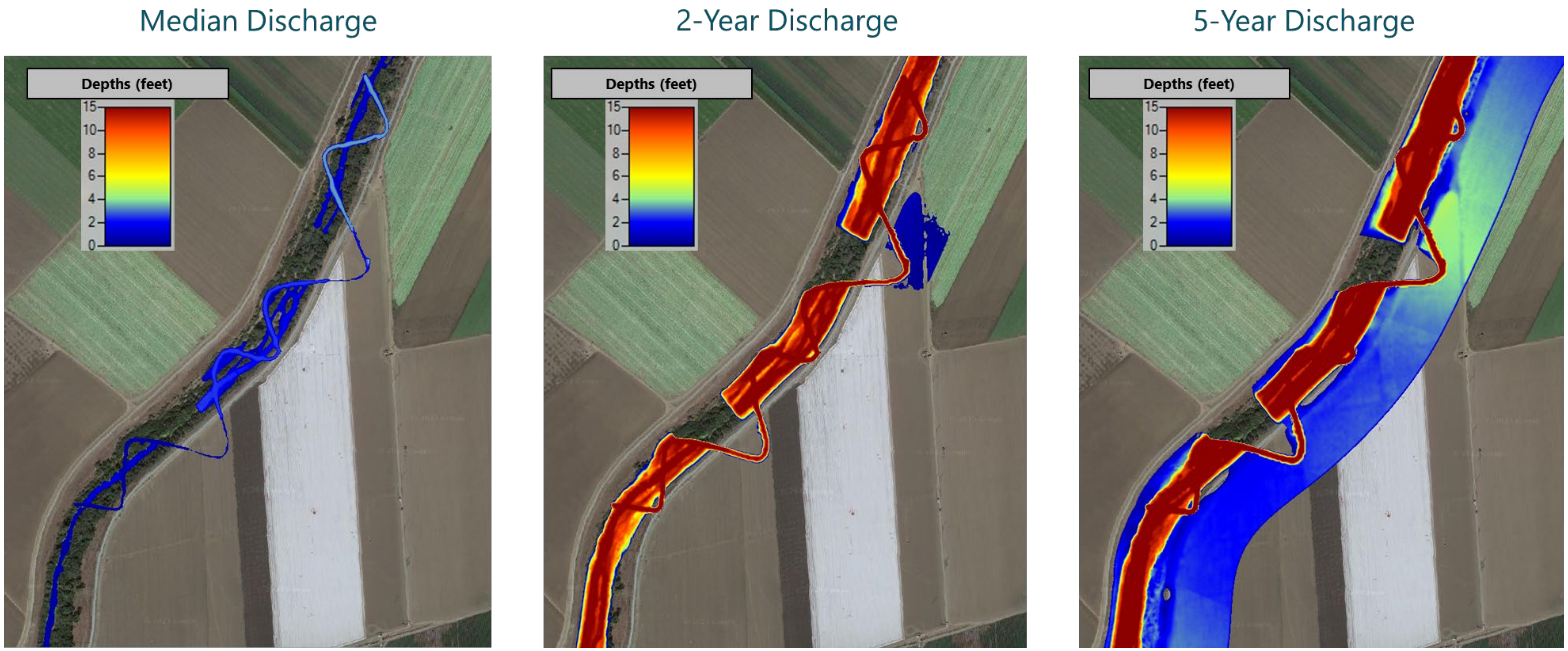


Figure 39
Ribbon B Stable Particle Size Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 40
Ribbon C Depth Results

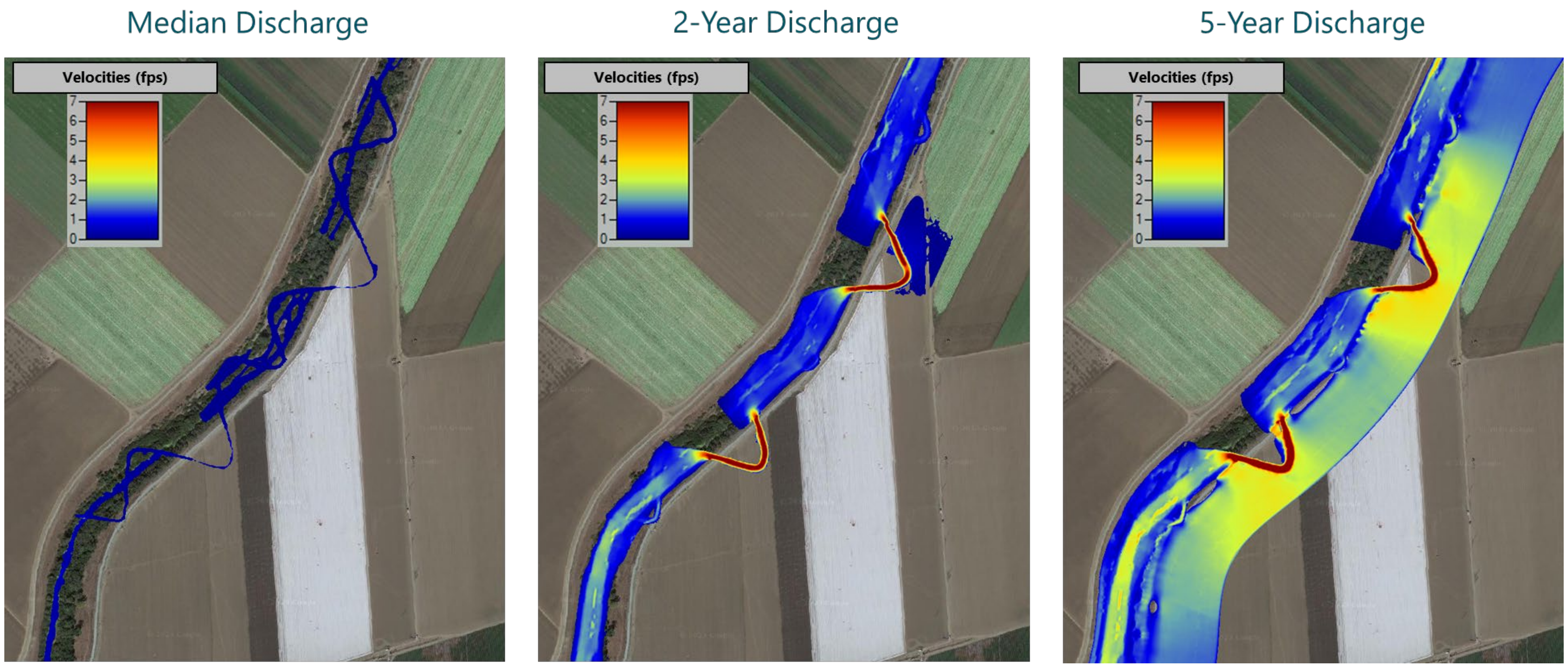
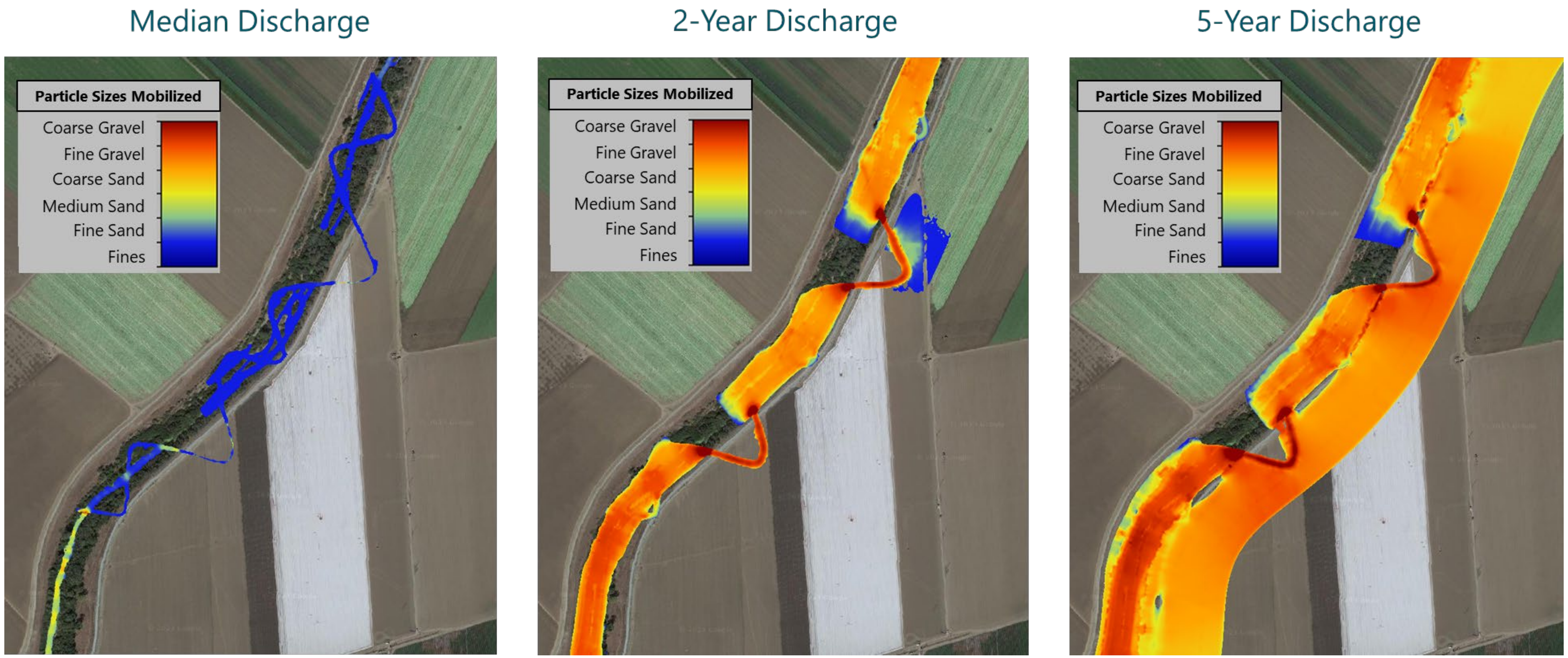


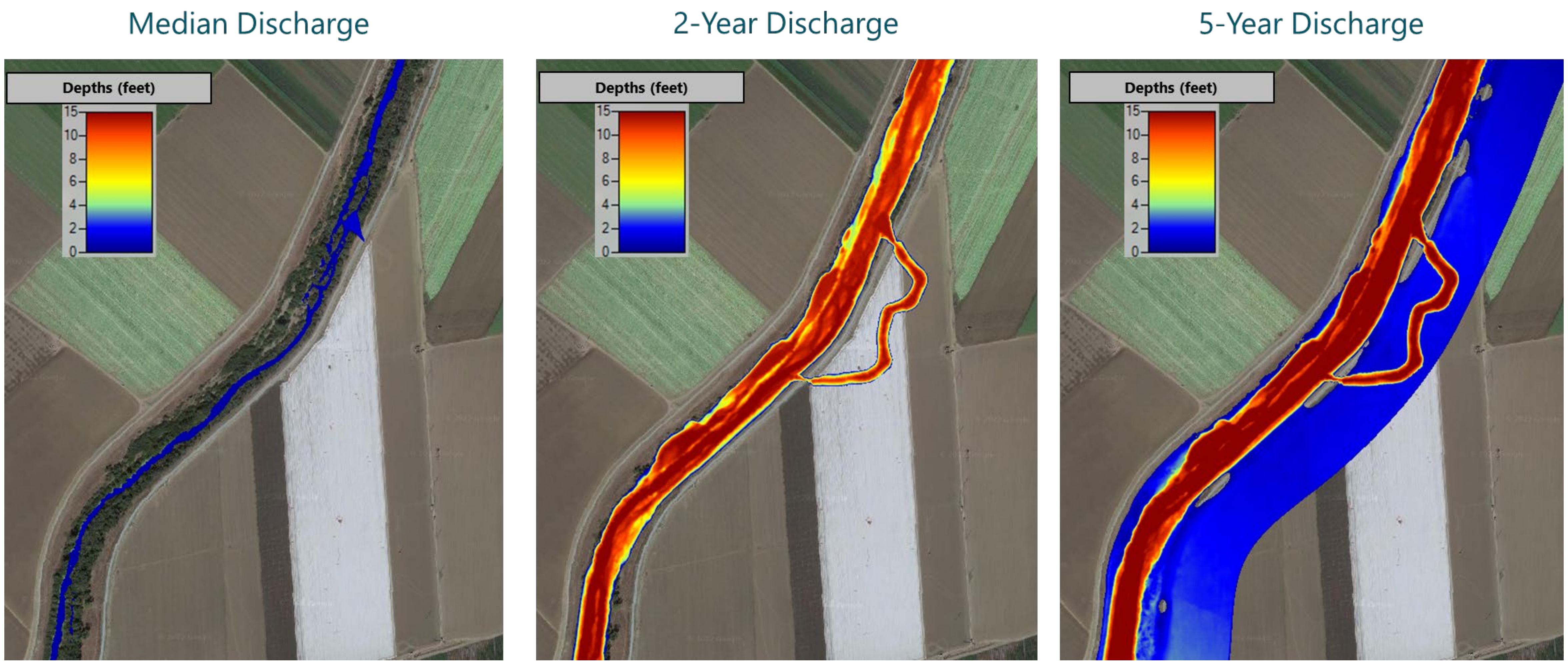
Figure 41
Ribbon C Velocity Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 42
Ribbon C Stable Particle Size Results

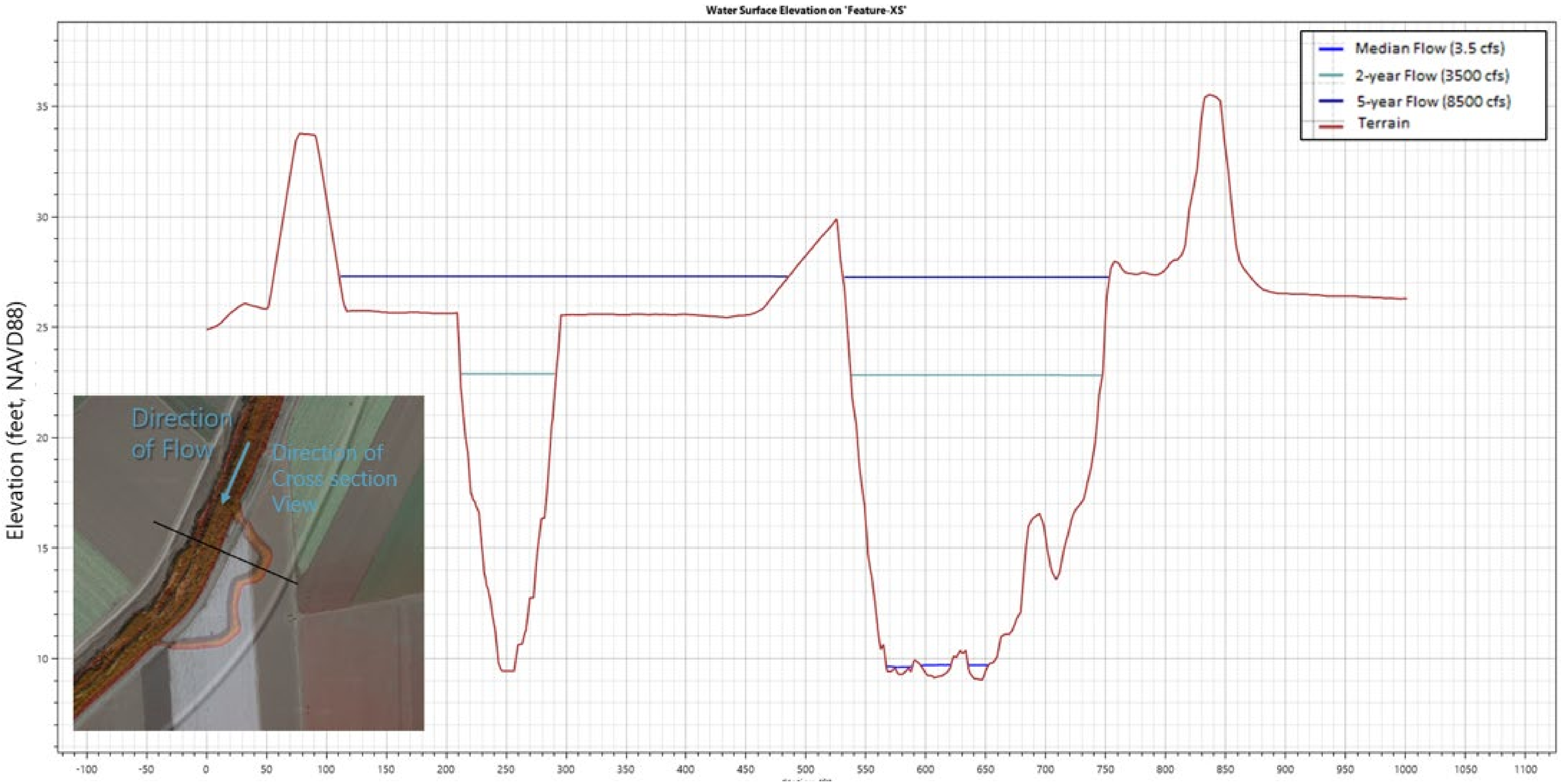


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 43
Floodplain Channel A Depth Results



Note: Cross section shown is looking in downstream direction.

Figure 44
Floodplain Channel A Depth Results Cross Section

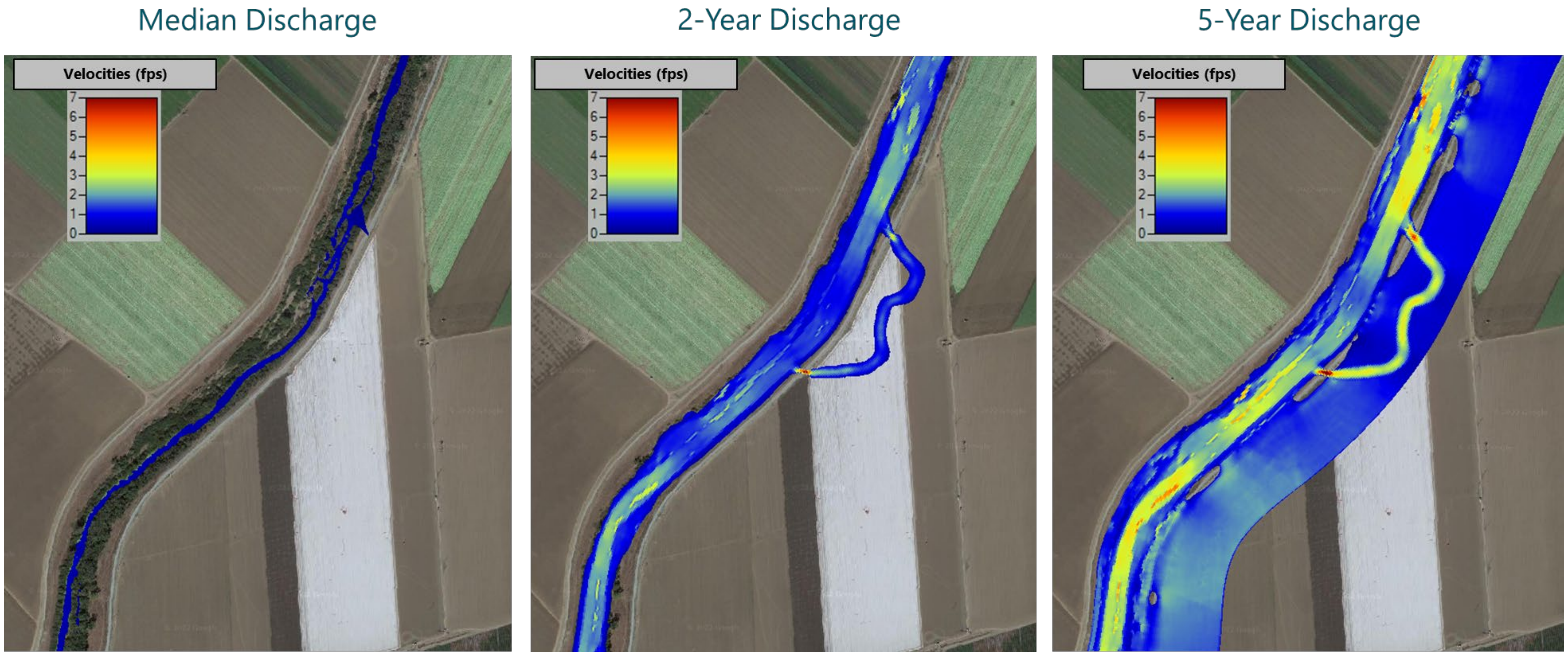


Figure 45
Floodplain Channel A Velocity Results

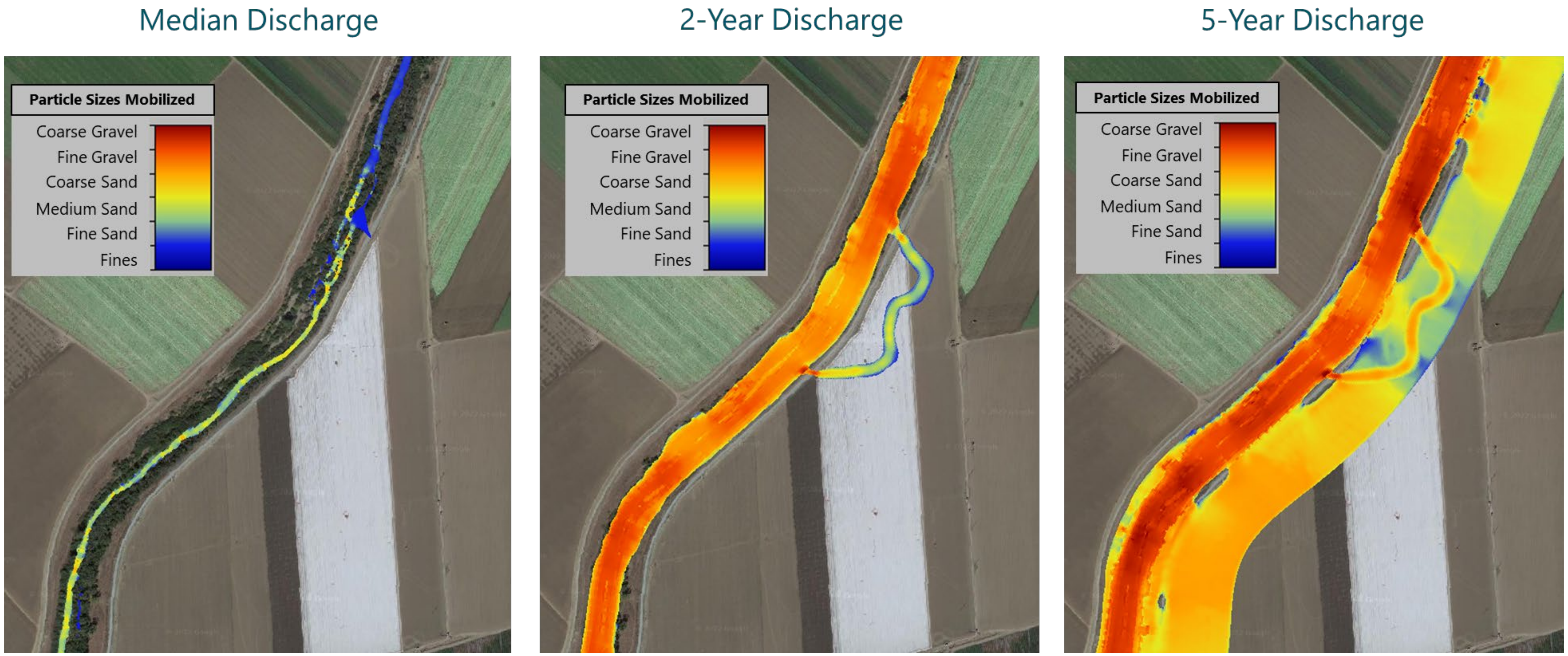
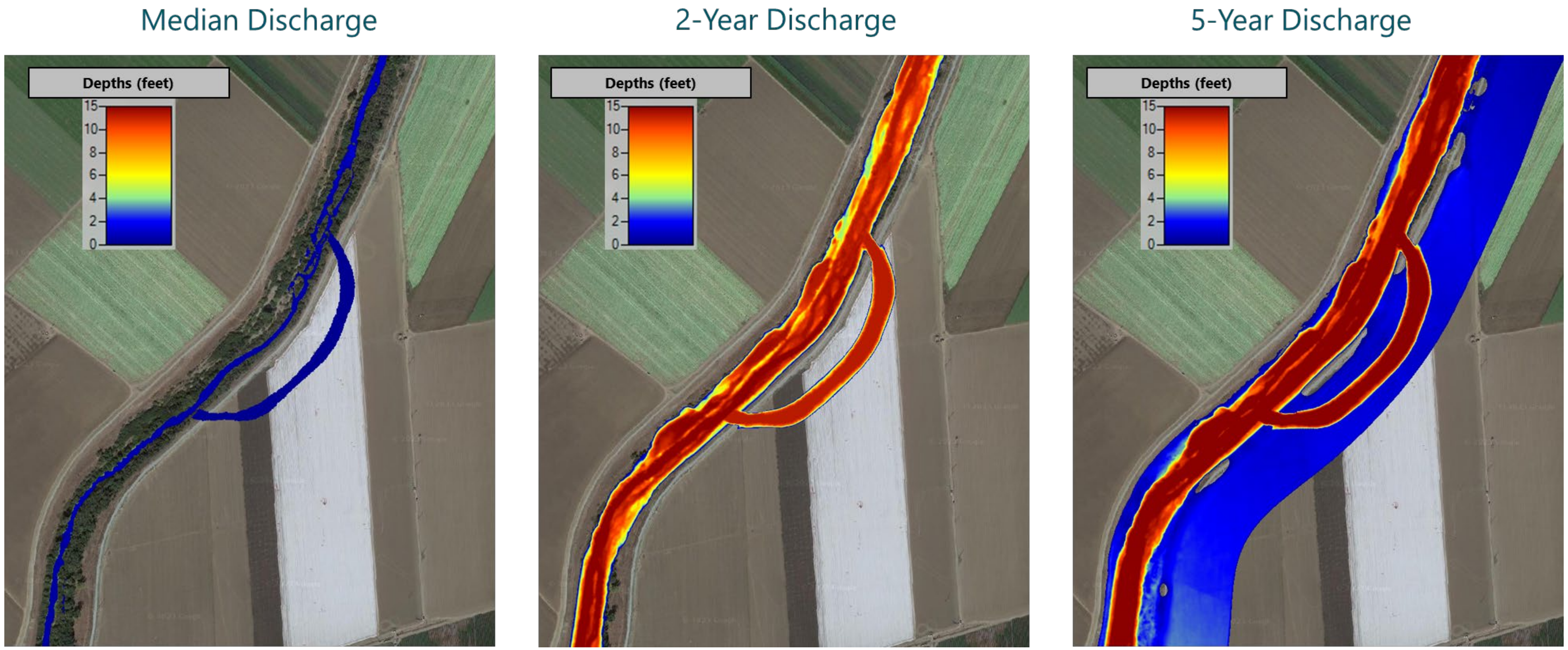


Figure 46
Floodplain Channel A Stable Particle Size Results

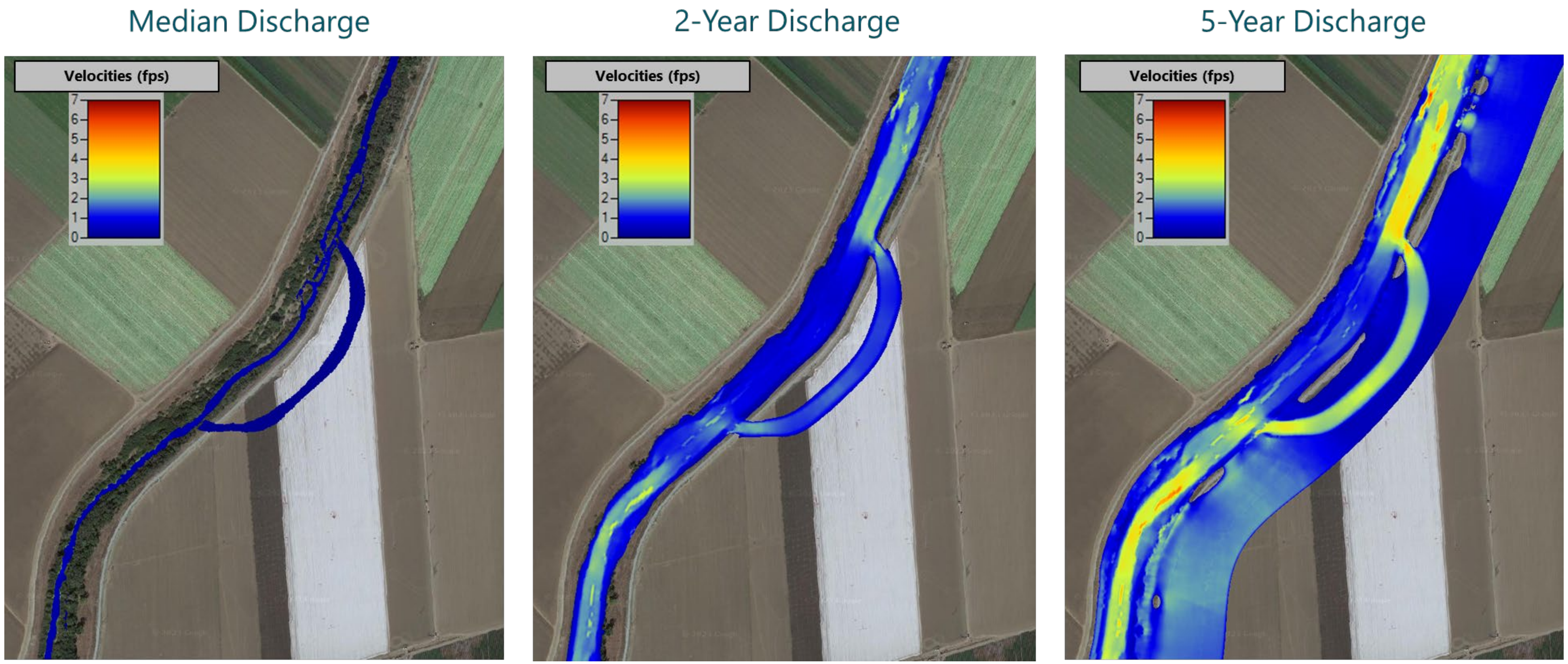


Median Discharge

2-Year Discharge

5-Year Discharge

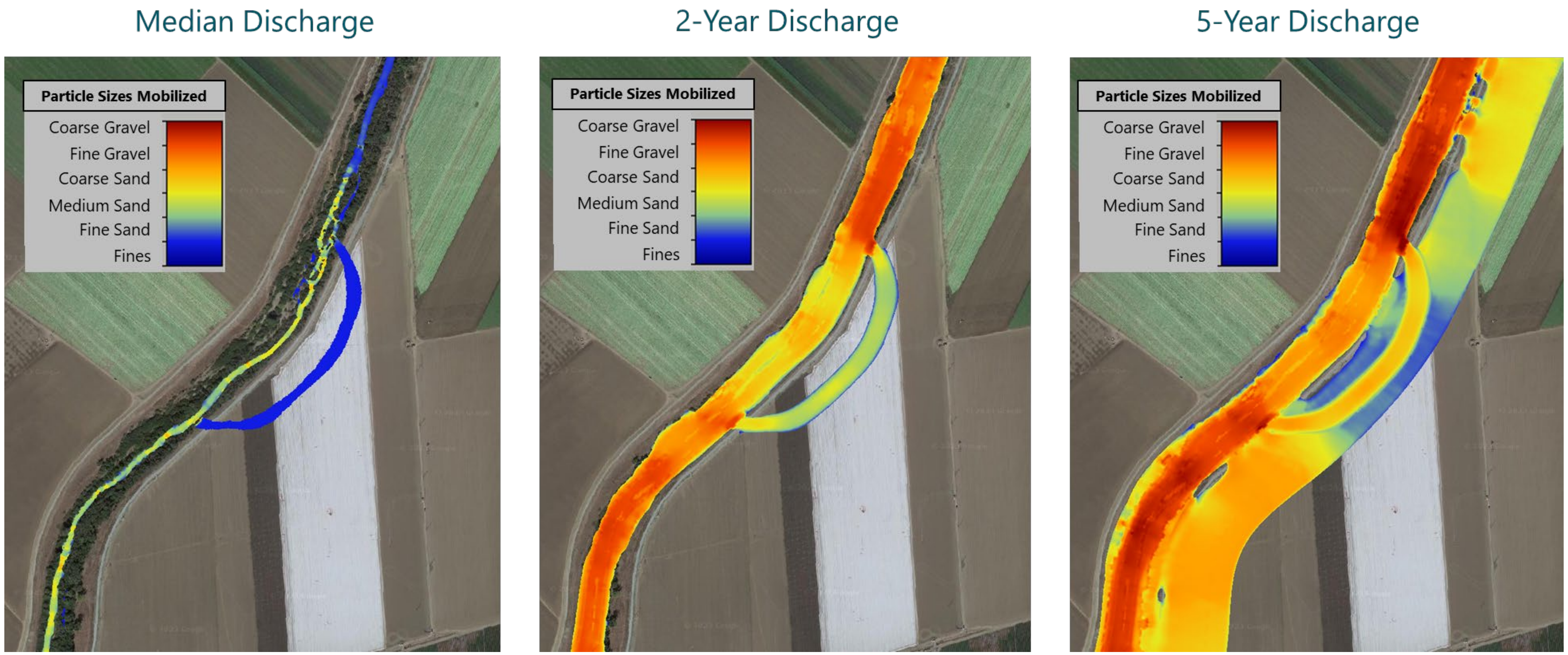
Figure 47
Floodplain Channel B Depth Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 48
Floodplain Channel B Velocity Results

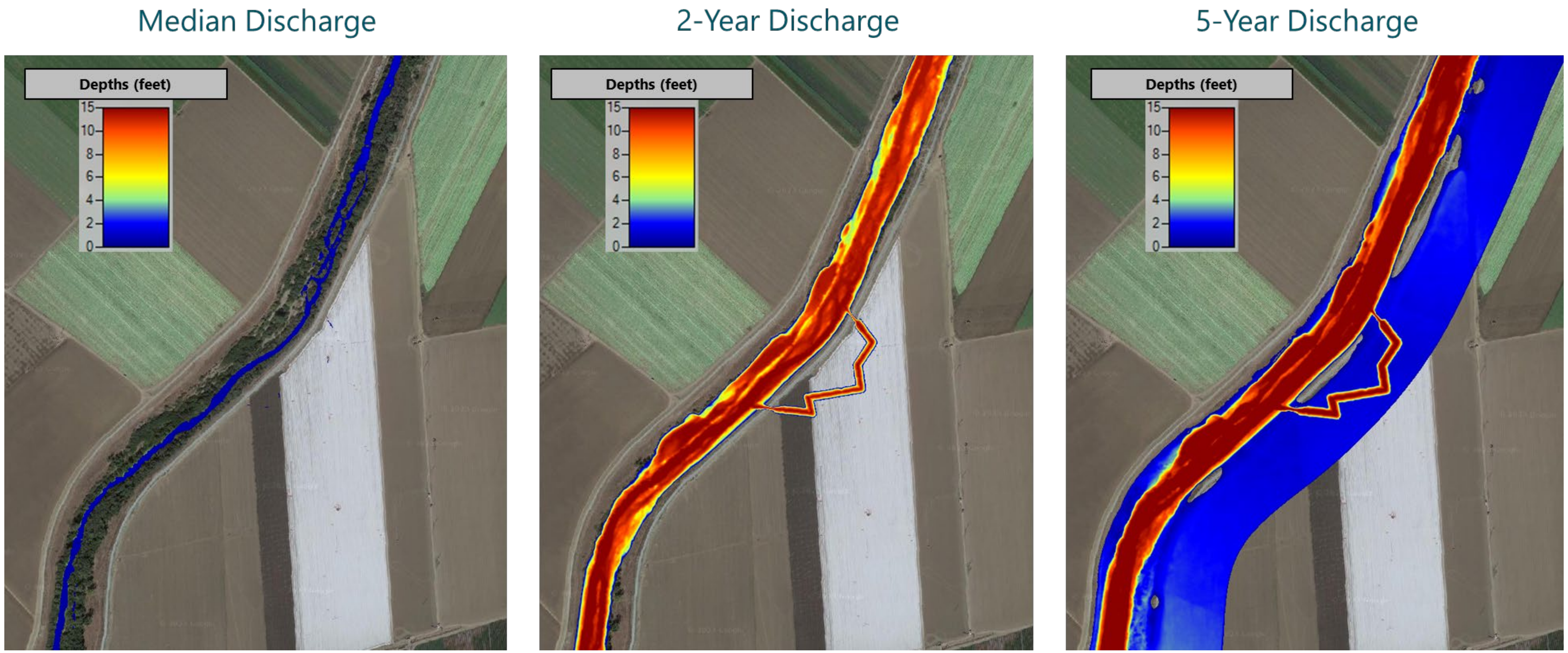


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 49
Floodplain Channel B Stable Particle Size Results

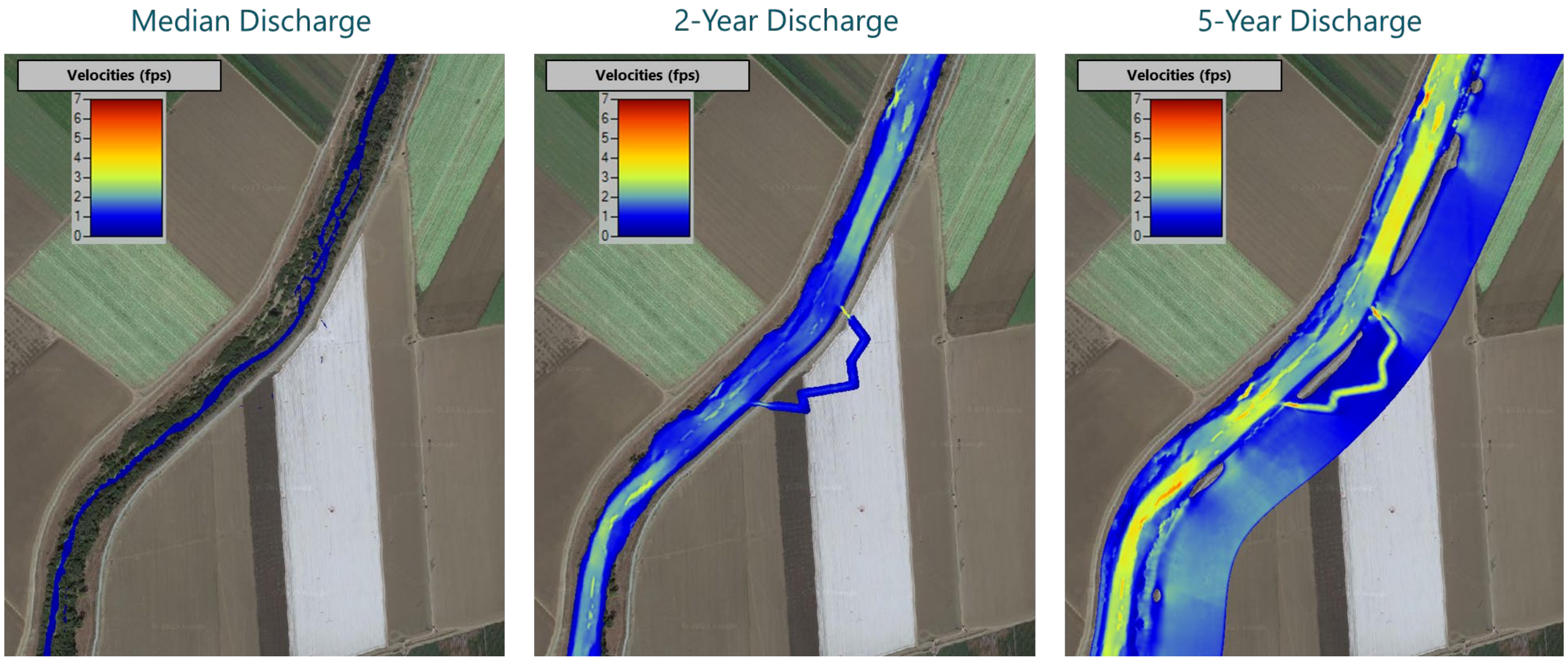


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 50
Floodplain Channel C Depth Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 51
Floodplain Channel C Velocity Results

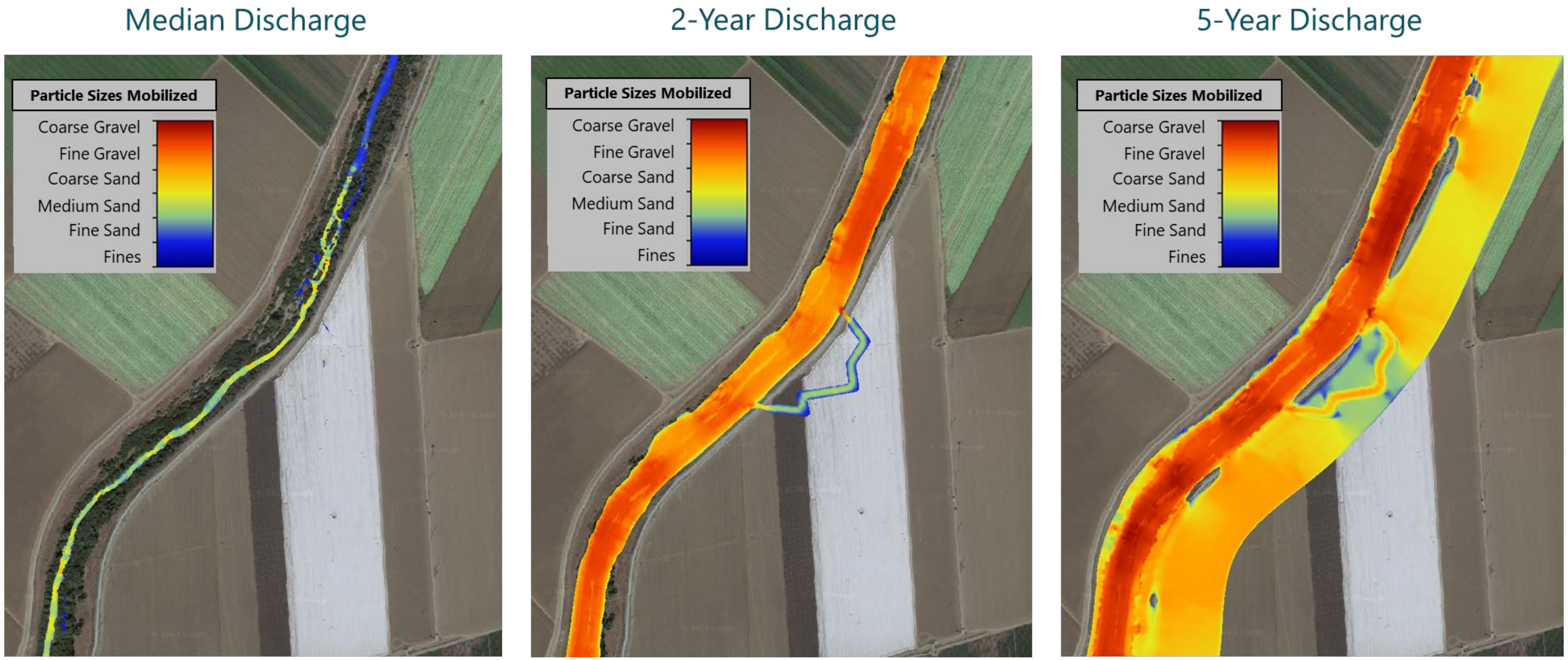
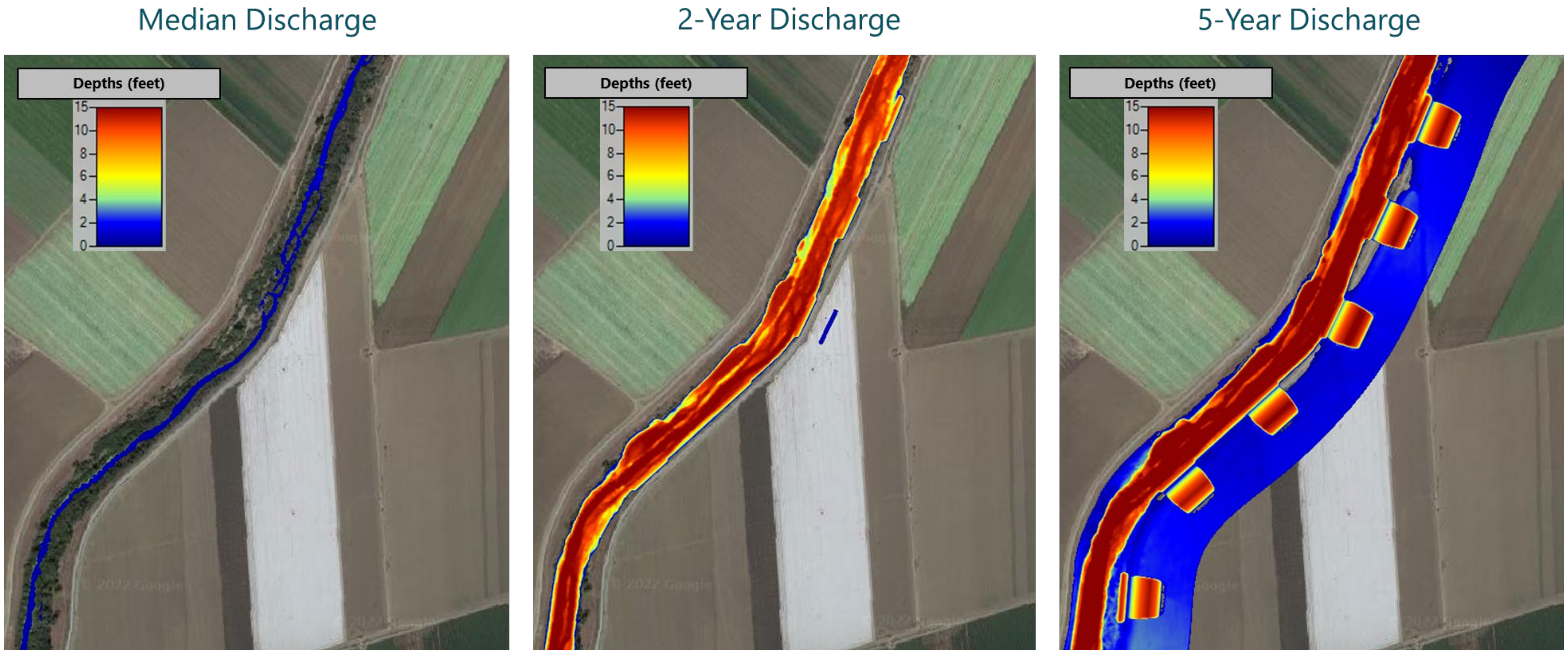


Figure 52
Floodplain Channel C Stable Particle Size Results

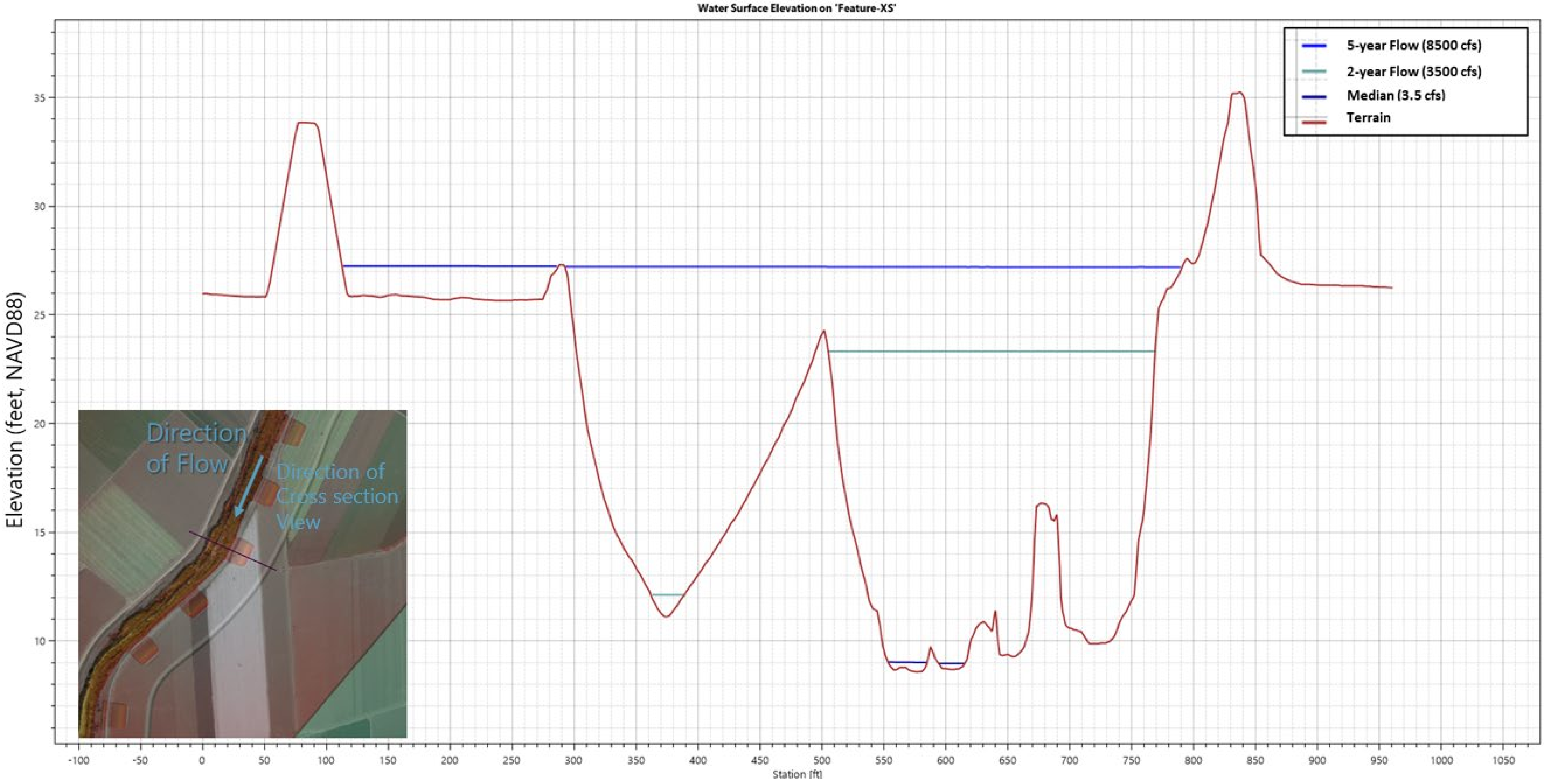


Median Discharge

2-Year Discharge

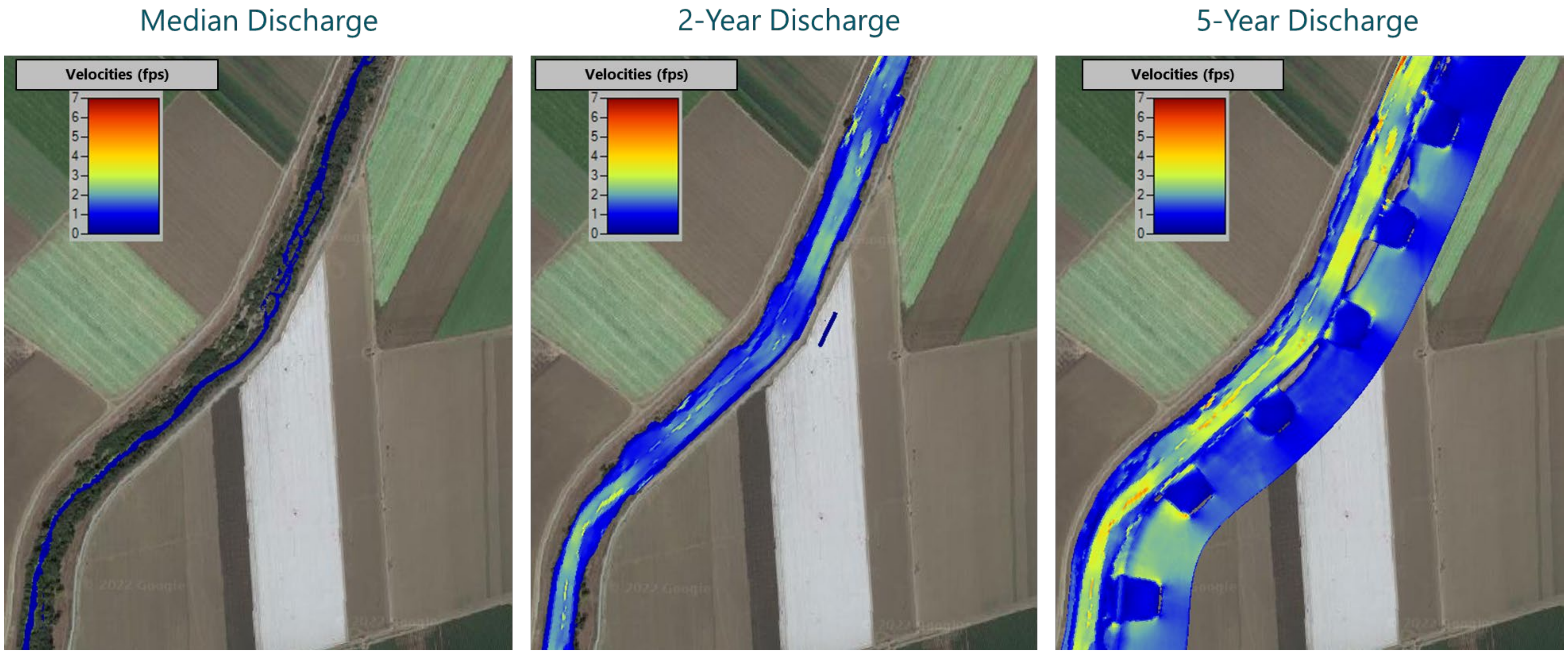
5-Year Discharge

Figure 53
Floodplain Cuts A Depth Results



Note: Cross section shown is looking in downstream direction.

Figure 54
Floodplain Cuts A Depth Results Cross Section



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 55
Floodplain Cuts A Velocity Results

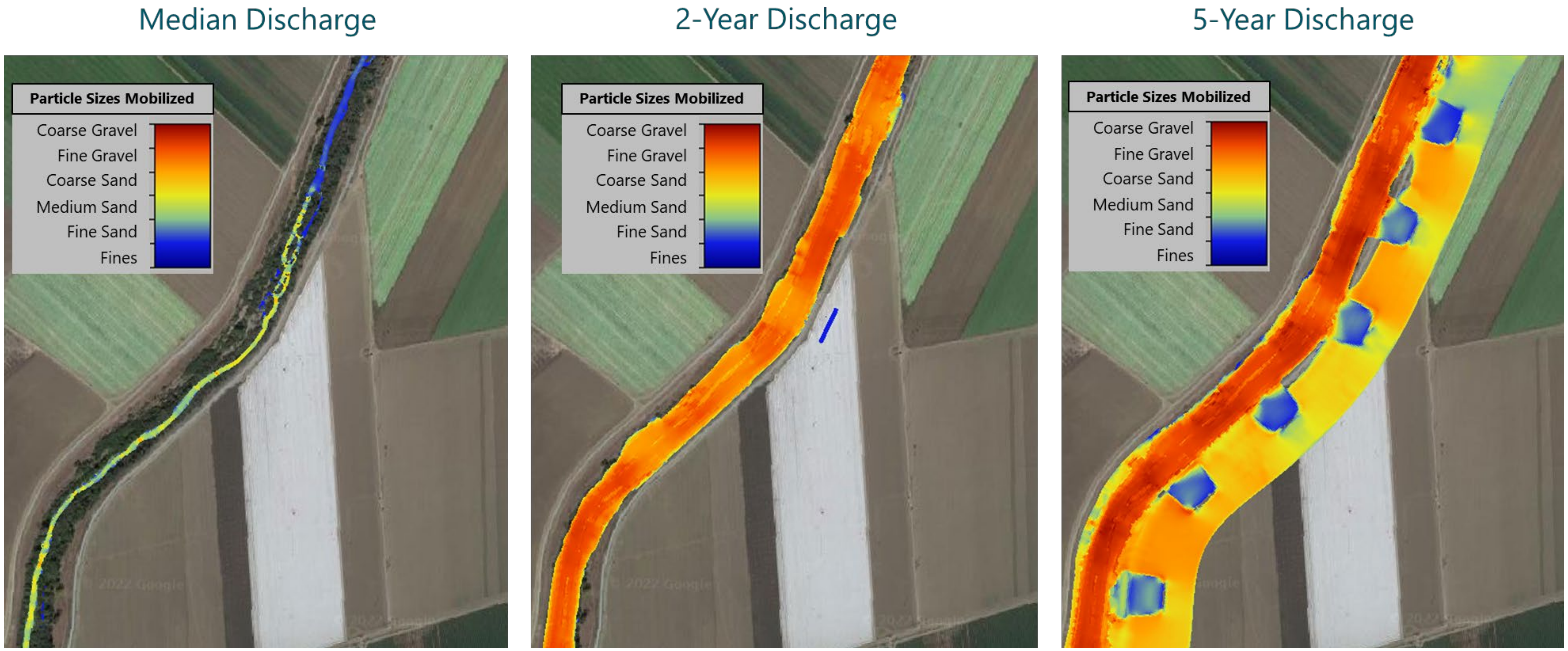
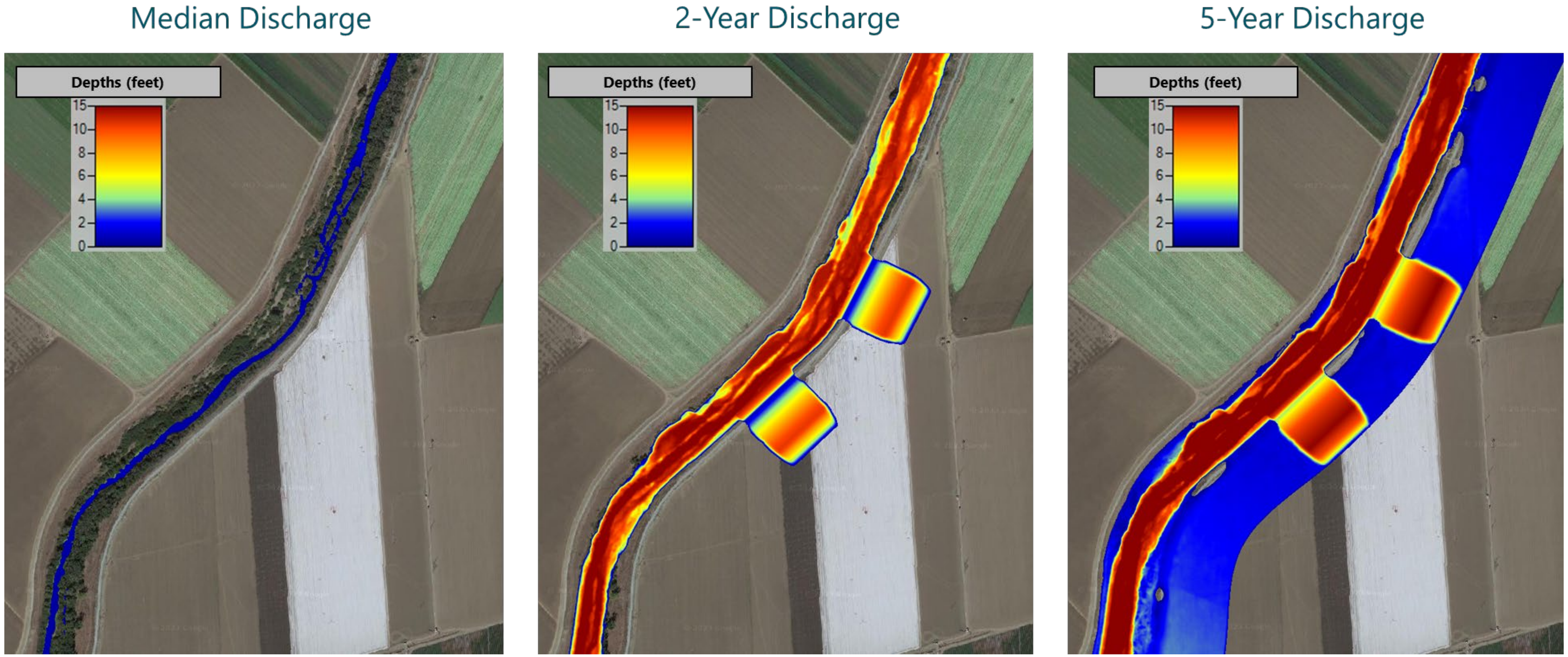


Figure 56
Floodplain Cuts A Stable Particle Size Results

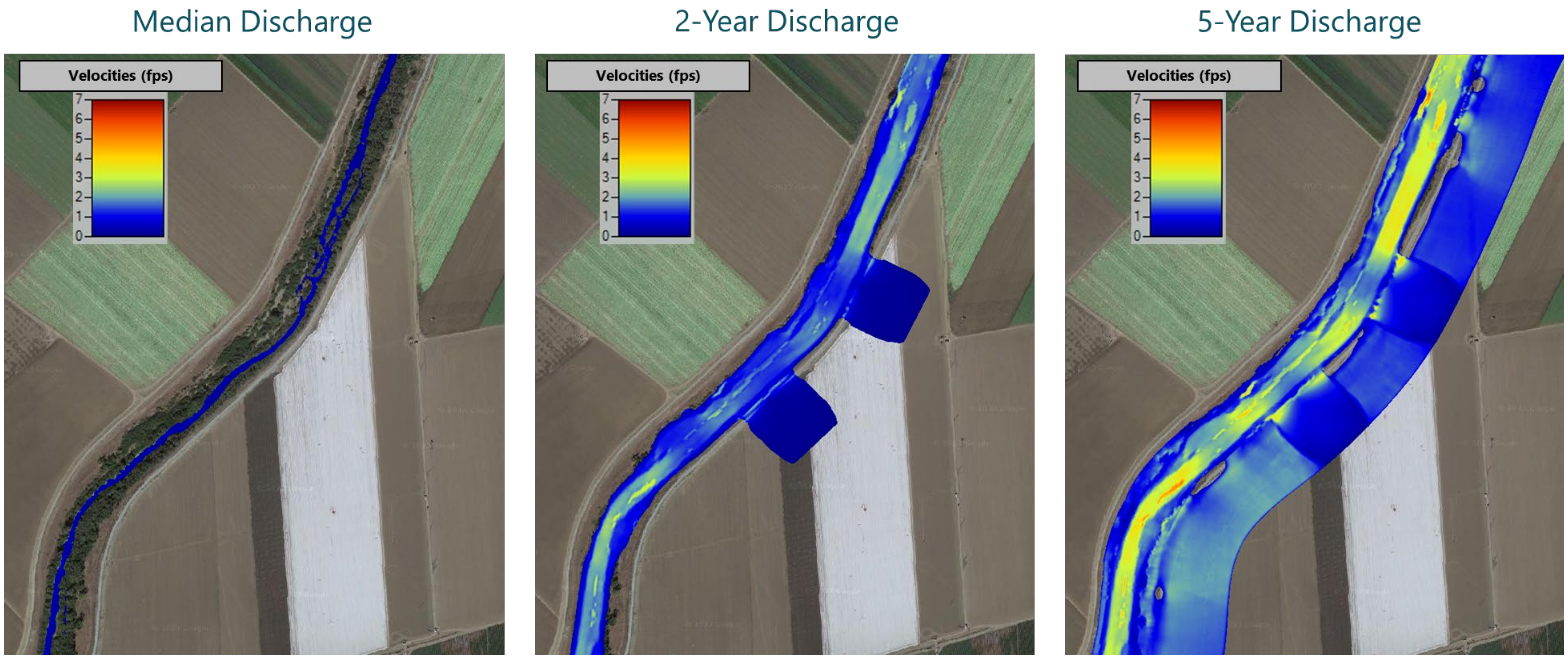


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 57
Floodplain Cuts B Depth Results


Median Discharge

2-Year Discharge

5-Year Discharge

Figure 58
Floodplain Cuts B Velocity Results

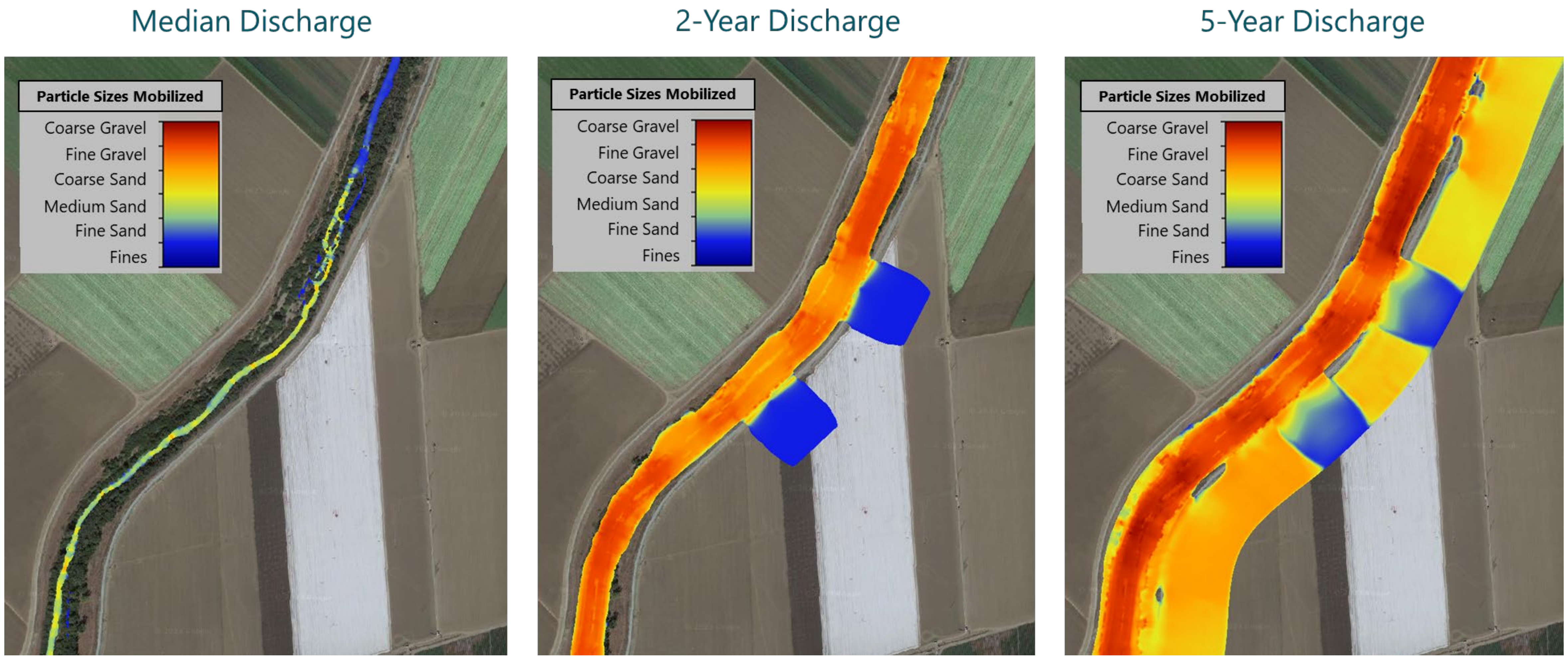
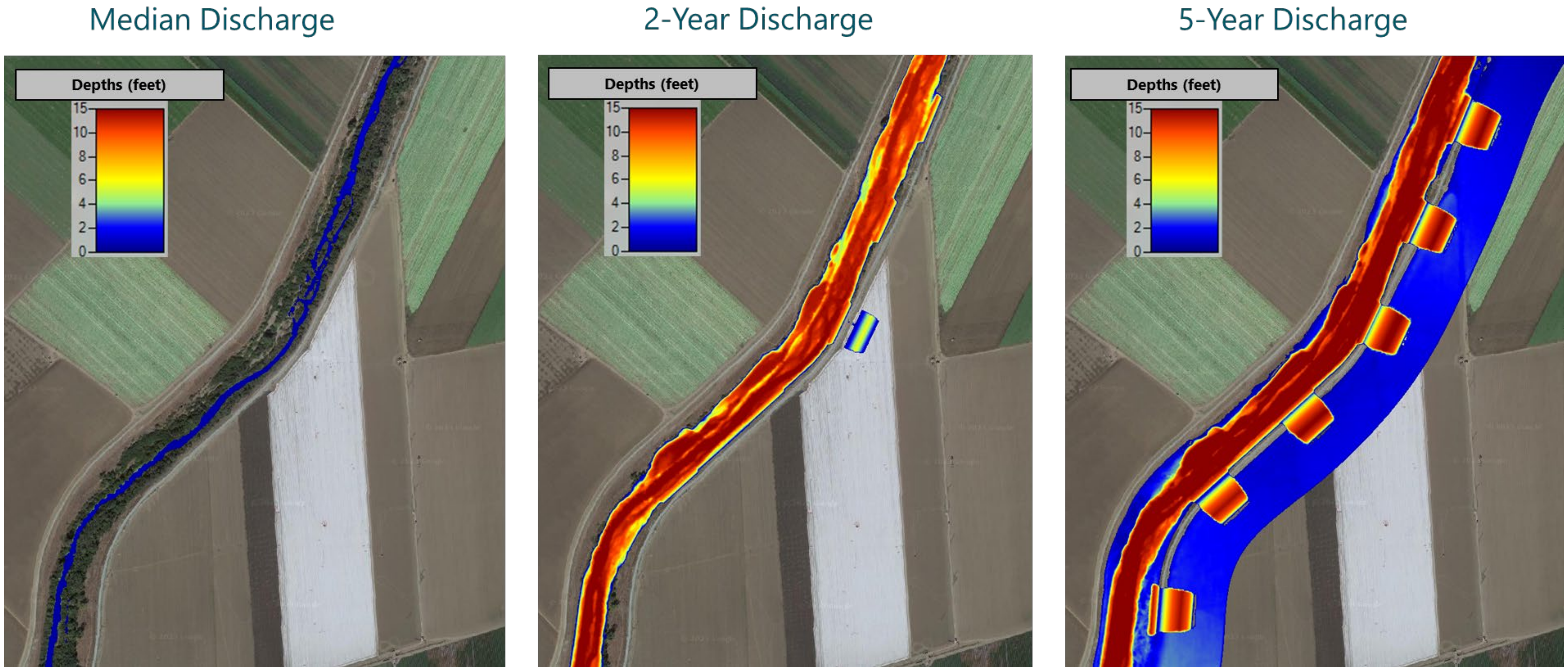


Figure 59
Floodplain Cuts B Stable Particle Size Results



Median Discharge

2-Year Discharge

5-Year Discharge

Figure 60
Floodplain Cuts C Depth Results

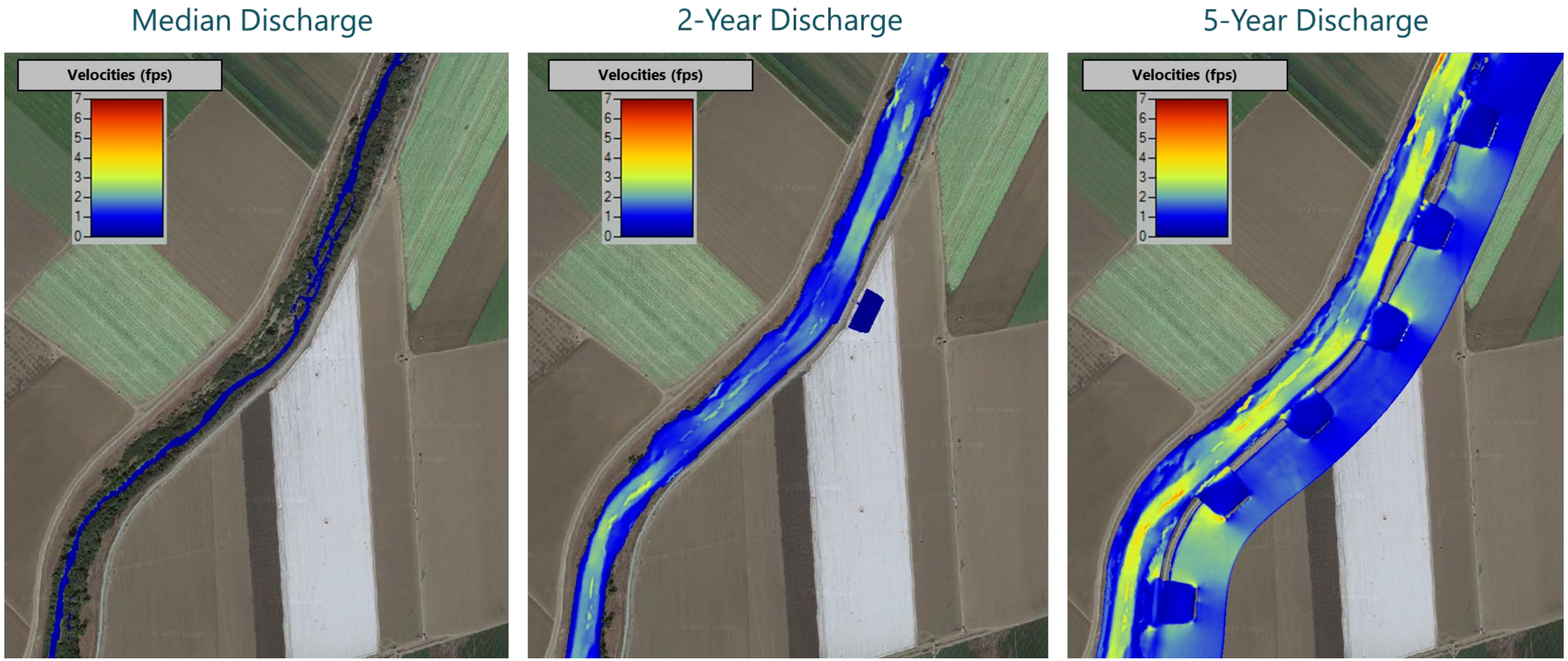


Figure 61
Floodplain Cuts C Velocity Results

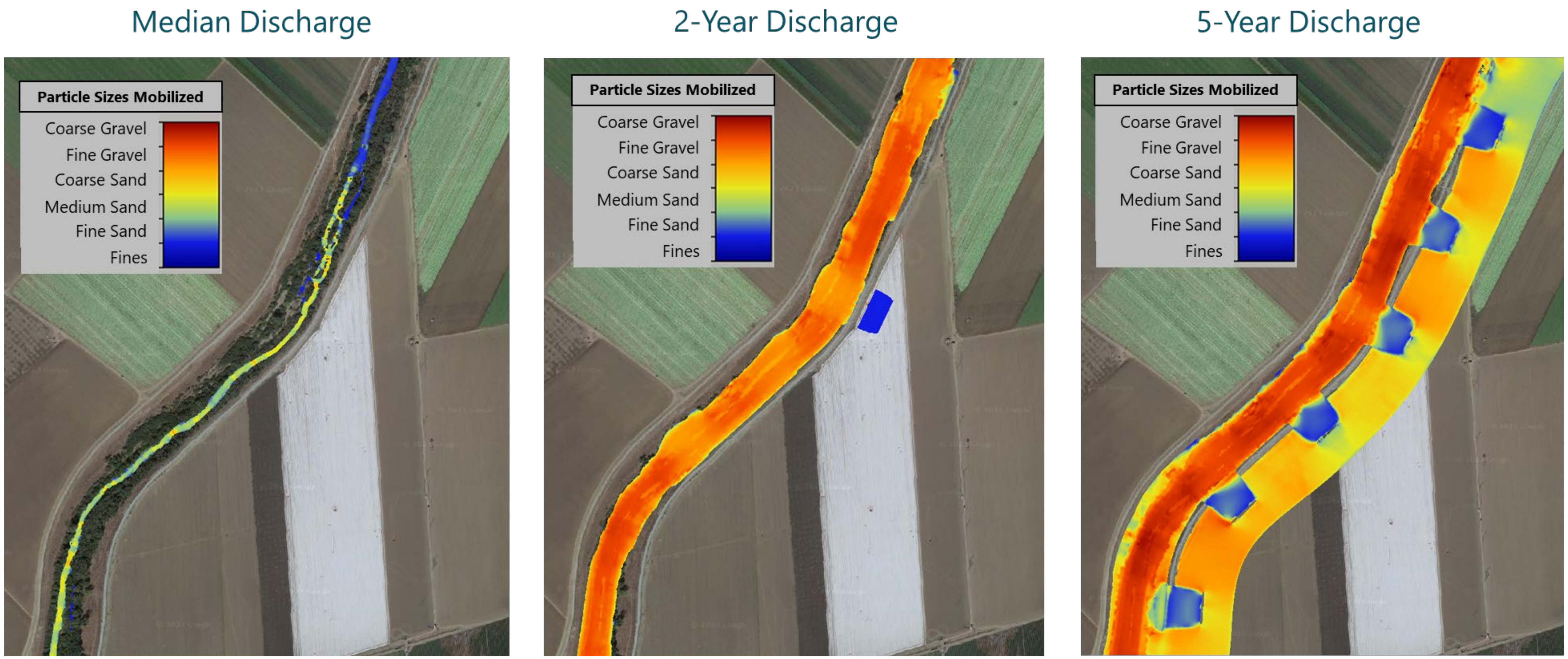


Figure 62
Floodplain Cuts C Stable Particle Size Results

This report covers findings from research cooperative agreement W912HZ-20-2-0049 **Incorporating Engineering With Nature® (EWN®) and Landscape Architecture (LA) Designs into Existing Infrastructure Projects**, an agreement between the **U.S. Army Engineering Research Development Center** (ERDC) and **Auburn University** (AU).

This report has been prepared by the investigators at **Auburn University**, the **University of Virginia**, and the **University of Pennsylvania** in collaboration with **AnchorQEA** and consultants from the **Dredge Research Collaborative**; it also incorporates research and insights from ERDC's **Engineering With Nature®** project team.

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