Climate Understanding & Resilience in the River Valley

Through the Climate Understanding & Resilience in the River Valley (CURRV) project, the Tijuana River National Estuarine Research Reserve (TRNERR) is leading a collaborative process to assess the vulnerability of the **Tijuana River Valley** to climate change, specifically sea level rise (SLR) and riverine flooding. The CURRV project will result in the development of adaptation strategies to help local communities adapt to climate change, and increase resiliency by providing jointly-developed recommendations to coastal decision-makers on how to consider climate change in managing our natural resources and built infrastructure (Figure 1).

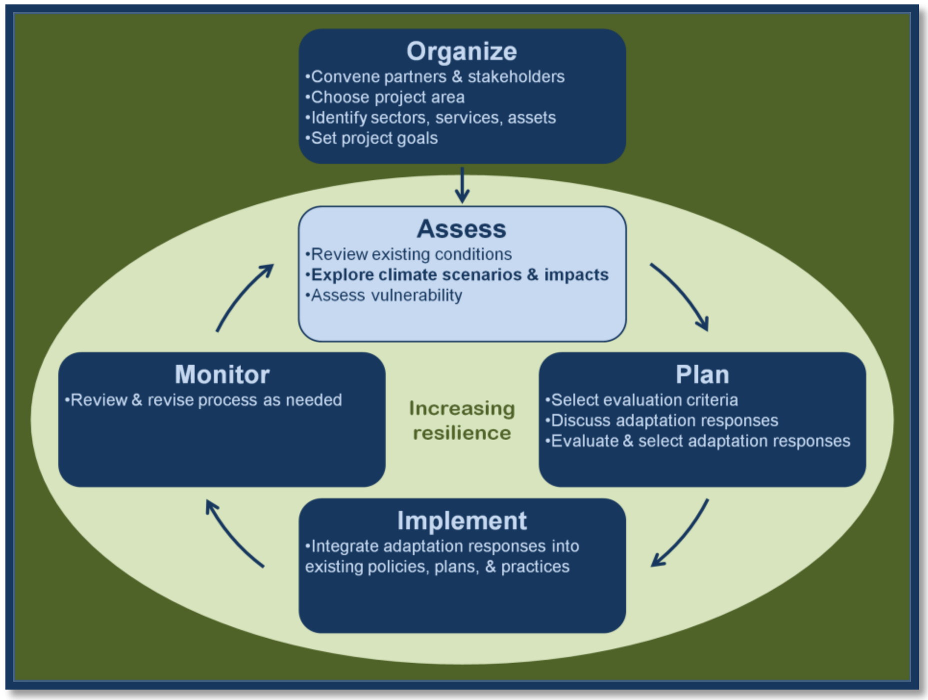

Figure 1: Planning Process
Scenario planning is part of the second phase, "assess", during which climate scenarios and impacts are explored [7, 8].

Climate Adaptation Scenario Planning

In preparation for conducting a climate change vulnerability assessment that will focus on flooding and inundation associated with sea level rise and riverine water inputs, TRNERR hosted a scenario-planning workshop where coastal geomorphologists, engineers, oceanographers, land use managers, and ecologists delved into how climate change might alter the physical landscape of the Tijuana River Valley.

What are scenarios?

A scenario is a plausible, internally consistent description of a possible future state of the world [1]. Scenarios are not forecasts or predictions; rather, each scenario is one alternative representation of how the future may unfold [2].

Why scenario planning?

- ❖ Scenario planning embraces **uncertainty**, helping decision-makers generate creative approaches by envisioning a range of possible futures [1].
- ❖ Allows planners to consider how **multiple variables** interact, instead of considering climate change impacts in isolation [2].
- ❖ Increases the **applicability** of long-term management plans by taking into account highly uncertain drivers of change and other factors of which managers have no control [1].
- ❖ By exploring the most current information on climate change and uncertainties, managers and planners will be prepared to react to **future challenges** with increased speed and confidence [2].

Scenario Framework

A scenario framework, targeting the relationship between two primary variables- (1) the river's connection and interaction with the Pacific Ocean, and (2) riverine water input **-** was provided to workshop participants (Figure 2). Tidal prism and extreme river flow events were chosen as the primary uncertainties because of their strong role in shaping the physical landscape and their centrality to effective management of the river valley.

Primary Uncertainties

Tidal prism

Tidal prism is defined as the volume of water that tides bring in and out of the estuary, and is a primary influence on the nature of the connection between the river and the ocean (i.e., open vs. closed river mouth). Increases or decreases in tidal prism will depend in large part on the relationship between local elevations and sea level. For example, over long time scales, tidal prism may decrease if sediment accretion outpaces the rate of sea level rise (i.e., land rises faster than the sea); conversely, tidal prism may increase if sea level rise outpaces this aggradation (i.e., seas rise faster than the land). On a shorter time scale, episodic events can open or close the river mouth and tidal channels, affecting tidal prism. In general, systems with a large tidal prism tend to have a more consistent connection with the ocean (i.e., open river mouth) and estuaries with smaller tidal prisms tend to have a less consistent connection (i.e., closed river mouth). The tidal prism can also be impacted by land management practices, including restoration activities, interventions to keep the river mouth open, or land uses that affect sediment supply.

Extreme river flow events

Extreme river events can increase or decrease based on changes in precipitation patterns (e.g., frequency and intensity), water management practices (e.g., dams, channelization of river channels), and / or land use patterns (e.g., increased impervious or denuded surfaces) altering the amount and velocity at which freshwater and sediment enters the system. Climate change is projected to affect weather patterns and storms, so considering changes in extreme river flow events is important. From both natural and human perspectives, extreme river flows can change the landscape and produce hazardous flooding. For example, historically, the most dangerous storms in California have been extreme events, particularly wet storms that occur during the winter, producing intense rains over large areas [3].

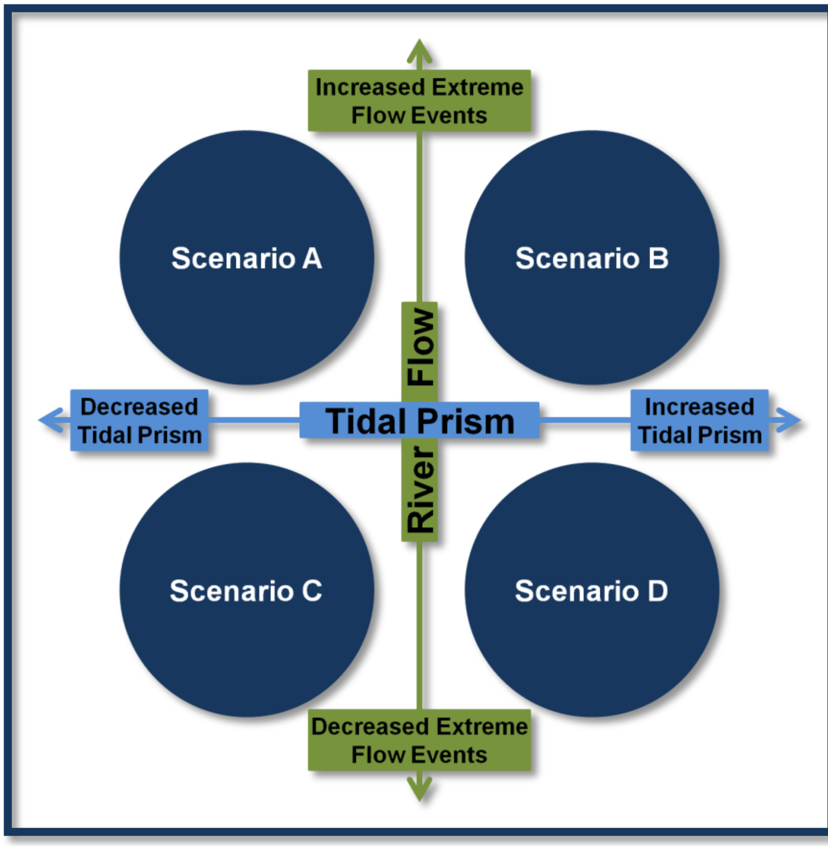

Figure 2: Scenario Framework [1, 2]

Assumptions

Throughout the development of the scenarios several assumptions were made.

- **Sea level rise** (SLR) is occurring.
- A decrease in extreme events means a decrease in the amount of freshwater coming into the system, whereas an increase in extreme events means an increase in the amount of freshwater coming into the system, meaning **typical flows** will remain approximately the same as current conditions. This assumption was made because the river valley is in a Mediterranean climate where most of the freshwater enters the system during extreme events.
- A **Mediterranean climate** will persist with wet winters and dry summers.

Characteristics

The scenarios were developed by describing how changes in tidal prism and extreme river flow events would impact key characteristics. Important physical characteristics that shape the landscape, and thus influence management decisions, were identified (Table 1).

Table 1: Physical Characteristics

Characteristics	Why are they important?
River-Ocean Connection	• The status of the river mouth is central to how the valley functions, and will determine how other characteristics manifest themselves. • Mouth status does not just impact the estuarine environment, as changes in whether the mouth is open or closed alters how and where the river valley floods.
Sediment Dynamics	• Sediment has the capacity to alter topography, which will determine how sea level rise and flooding events impact the valley. • Too much sediment can close the river mouth, bury salt marshes, and fill-in the river channels leading to increased flooding extents. • Too little sediment can lead to channel reconfiguration and decreased elevations, which are important to maintaining resilient salt marshes in the face of sea level rise.
Flooding & Inundation	• Understanding how a system floods, where to expect flooding based on elevations, and what is causing the flooding (e.g., saltwater or freshwater) is crucial to effective management of a system. • Flooding is not only an important factor for natural systems, but also for managing built infrastructure (e.g., saltwater corrosion, where evacuation routes are placed, etc.).
Water Residence Time	• Long residence times can have widespread consequences, including eutrophication and hypoxia, and can even lead to environmental health concerns with disease vectors and contaminants (e.g., mosquitoes, sewage, trash, chemical runoff, etc.). • Residence time may determine the cost of damage experienced by built infrastructure during a flood (e.g., corrosion, how long the facility is out of service, extent of water damage, etc.).
Surface- and Ground-Water Salinity	• Determines the distribution of specific habitat types on a landscape. • Alters what materials are used in built infrastructure (e.g., corrosion). • Impacts availability of irrigation and potable water supplies. • Determines the preservation of cultural resources (e.g., through corrosion).

Scenario Narratives

For each scenario, the identified characteristics were explored and storylines were developed **to accentuate the differences** between the future systems (Table 2) - an emphasis was placed on being descriptive rather than predictive. Related to this, it is important to recognize that anything mentioned in one scenario description could potentially occur within other scenarios, but the narratives are trying to capture what is the most common state of a particular future scenario. The scenarios were developed based on the expertise of scientists and resource / land-use managers.

Table 2: Scenario Narratives

Scenario A Increased extreme river flow events & Decreased tidal prism	Scenario B Increased extreme river flow events & Increased tidal prism
River-Ocean Connection	
Mostly Closed	**Open**
• Marine processes and a decreased tidal prism keep the river mouth closed for prolonged periods of time. • Because riverine flood events that tend to reinforce an open mouth are relatively frequent, the system will periodically open.	• Riverine and marine processes keep the river mouth primarily open. • Relatively brief durations of closure are possible.
Sediment Dynamics	
Moderate Sediment Export & Riverine Sedimentation	**Increased Sediment Export & Beach Sedimentation**
• Aggradation outpaces SLR in the lower valley, due largely to riverine sedimentation. • Estuary / ocean exchange of sediment and other materials is decreased. • Frequent riverine sediment inputs increase sedimentation, but localized scour and deposition have the potential to dramatically restructure the system (e.g., changing channel configurations). • Increased inputs of riverine sediment get trapped in a largely closed system, but export to the beaches occurs during the large river flow events that open the river mouth.	• SLR outpaces aggradation in the lower valley, as the increased tidal prism and open river mouth will increase marine influences. • Estuary / ocean exchange of sediment and other materials is increased. • Increased extreme river flow events, and increased marine influence due to open river mouth, have the potential to both deliver sediment and restructure the upper and lower valley. • Increased inputs of riverine sediment will interact with ocean processes and provide sediment to the beaches.
Flooding & Inundation	
Severe Riverine Flooding	**Riverine Flooding & Coastal Flooding / Inundation**
• Increased riverine flooding, due to increased extreme events and a mostly closed river mouth, could lead to ponding, which decreases the system's ability to store extra water during flow events (i.e., if the bathtub is full, any extra water will cause a flood). • Transient mouth opening associated with extreme riverine flows may mitigate some flooding, but it also increases the chance that riverine flooding will interact with coastal flooding (e.g., high tides or storm surge). • Flooding of beachfront areas will occur with SLR, and may be exacerbated by more frequent riverine flooding of the estuary.	• Increased riverine and coastal flooding, due to increased extreme events, SLR, and an open river mouth. • The highest likelihood of riverine and coastal flooding reinforcing one another. • Although increased export of sediment from the estuary will enhance beach-building, flooding of beachfront areas still occurs with SLR and may be exacerbated by more frequent riverine flooding.
Water Residence Time	
Long Residence Time	**Shortest Residence Time**
• Residence times are relatively long due to poor estuary / ocean exchange. • The system occasionally has decreased residence times when the river mouth is breached during an extreme river event.	• Residence times are short due to the open river mouth and increased river events.
Surface- and Ground-Water Salinity	
Increased Freshwater Influence with Variability	**Saltwater Influence with Freshwater Pulses**
• Increased freshwater influence due to frequent riverine flooding, coupled with decreased tidal exchange. • Periodic mouth openings allow some marine influence, but openings are counter-balanced with inputs of freshwater from riverine flooding. • Variable conditions due to the largely closed river mouth, ranging from hypersalinity (e.g., evaporation of trapped seawater) to low salinities (e.g., freshwater inputs) in the lower valley are experienced. • Saltwater intrusion into groundwater is reduced.	• Tidal influence reaches further inland due to daily tidal exchange and SLR. • Freshwater zones will tend to be compressed, since more frequent exposure to freshwater only occurs transiently during extreme riverine events. • Less salinity extremes due to an open river mouth and increased tidal mixing are experienced. • Saltwater intrusion into groundwater is increased.

Table 2: Scenario Narratives

Scenario C Decreased extreme river flow events & Decreased tidal prism	Scenario D Decreased extreme river flow events & Increased tidal prism
River-Ocean Connection	
Closed	**Mostly Open**
• Riverine and marine processes keep the river mouth primarily closed. • Rare riverine flood events transiently open the mouth, but not enough to keep it persistently open.	• Marine processes and an increased tidal prism keep the river mouth open for prolonged periods of time. • Because riverine flood events that tend to reinforce an open mouth are relatively rare, the system will periodically close.
Sediment Dynamics	
Decreased Sediment Export & Riverine Sedimentation	**Moderate Sediment Export & Beach Sedimentation**
• Aggradation outpaces SLR in the lower valley despite decreased riverine sediment inputs, as the closed river mouth will trap sediment and increase sedimentation rates throughout the valley. • Estuary / ocean exchange of sediment and other materials is dramatically decreased. • Decreased amount of riverine sediment reaching the beaches, due to the closed river mouth and decreased riverine inputs.	• SLR outpaces aggradation in the lower valley, due largely to a decrease in riverine sediment inputs. • Estuary / ocean exchange of sediment and other materials is increased. • Marine processes have the potential to restructure the lower valley. • Less riverine sediment enters the system, but increased tidal exchange allows some material to be exported to the beach.
Flooding & Inundation	
Riverine Flooding	**Coastal Flooding / Inundation**
• Even relatively low river event flows may lead to flooding because a closed river mouth will lead to ponding, which decreases the system's ability to store extra water in the event of flows (i.e., if the bathtub is full, any extra water will cause a flood). • The areal extent of flooding will increase due to filling of the channels and river mouth with sediment, leading to greater flooding and inundation of areas in the upper valley. • Flooding of beachfront areas will occur with SLR, and could be exacerbated by decreased export of sediment from the estuary onto the beach.	• Increased coastal flooding, due to SLR and a mostly open river mouth. • Flooding will be mostly dependent on coastal processes, including tides, wave run-up, and storm surge. • Flooding of beachfront areas will occur with SLR.
Water Residence Time	
Longest Residence Time	**Short Residence Time**
• Residence times are long due to the closed river mouth and decreased extreme river events.	• Residence times are short due to the mostly open mouth. • The system occasionally has increased residence times when the river mouth is closed.
Surface- and Ground- Water Salinity	
Variability with Increased Freshwater Influence	**Greatest Saltwater Influence**
• Increased freshwater influence due to very limited tidal exchange and prolonged mouth closures. • Variable conditions due to the closed river mouth, ranging from hypersalinity (e.g., evaporation of trapped seawater) to freshwater conditions (e.g., freshwater ponding) to in the lower valley are experienced. • Saltwater intrusion into groundwater is reduced.	• Increased tidal influence farther inland due to decreased extreme riverine events and SLR. • Salinity gradients are relatively consistent, with lower valley areas dominated by marine conditions. • Less salinity extremes due to an open river mouth and reduced extreme river flow events are experienced. • Saltwater intrusion into groundwater is markedly increased.

Understanding the CURRV Scenario Planning Process

Why are models and maps not used more extensively to explore future scenarios?

Various maps and models are being viewed as tools in a larger toolbox, and they will be used to supplement the scenarios described in this report during the vulnerability assessment. Although general climate and SLR models help visualize how climate change may affect larger areas, they can be difficult to downscale. Localized flooding models and maps are also useful, but estuarine areas exist at the interface of land, sea, and rivers, and are very complex and difficult to model. In particular, the river-ocean connection will be a primary driver of the behavior of the entire river valley, and the complexity associated with this extremely dynamic area is not currently incorporated into available models. It should be noted that substantial progress is being made, and new models will undoubtedly inform future planning and management.

Why are extreme riverine event flows important? Why not focus on average flows?

Initially the vertical axis represented average annual river flow, but following group discussions about the physical characteristics and processes that shape estuarine systems in Southern California, the expert workshop participants decided to change the riverine axis from average river flow to extreme river flow events (Figure 2). It was determined that extreme events have historically and could in the future profoundly shape the river valley (e.g., by affecting river mouth status, changing geomorphology, and delivering large volumes of water and sediment). Thus the group decided that having an axis of uncertainty related to extreme events would allow for a fuller exploration of the future physical landscape.

Why are climate drivers of change not listed on the axes?

Climate drivers, such as precipitation and temperature, are not listed on the axes because the framework was designed to capture uncertainties related to broader socio-ecological drivers of change, as well as emphasize proximate factors important in understanding and managing this system. For instance, extreme river flow events can be influenced by not only climate drivers (e.g., shifts in precipitation patterns altering watershed inputs) but by management decisions (e.g., channelizing the river channel, dams). By labeling the axes in broader terms, it captures potential interconnections between the climate, environment, and social aspects of the whole system.

Why is sea level rise not listed on the axes?

The axes represent variables with high uncertainty, and not all aspects of climate change carry the same level of uncertainty. For instance, it is virtually certain that sea level rise is occurring and will continue to occur into the future, even if there is uncertainty about how much the seas will rise (i.e., magnitude) and how fast (i.e., rate). This is in contrast to other aspects of climate change, such as weather patterns, that alter river flows, and sediment delivery and accretion, which carry an extremely high level of uncertainty. Sea level rise is therefore treated as an assumption and taken into account in the development of all scenarios.

Why was the magnitude or rate of sea level rise not specified?

Defining meaningful thresholds can be difficult in a multi-agency context, considering “severe” sea level rise would be different for someone working on coastal road infrastructure than someone protecting coastal native plant species [1]. This is why facilitators caution against defining scenarios using drivers whose uncertainty concerns magnitude rather than direction of change [1]. During the vulnerability assessment, maps representing different sea level rise magnitudes will be provided to experts to supplement the scenarios provided in this report.

Why are only physical characteristics discussed? What about biological responses?

Physical characteristics (i.e., river-ocean connection, salinity, sediment dynamics, etc.) define the landscape of the river valley, determining what portions of the system will experience the most severe climate impacts in the future. Following this scenario planning process, managers will come together to explore the system’s vulnerabilities, focusing more directly on how the identified physical landscape will impact the natural (i.e., biological resources) and built infrastructure of the system.

Why were only four scenarios developed?

There are numerous possible scenarios that land use managers may encounter in the future; however, when trying to adequately prepare for climate change it is important to not let uncertainty paralyze the planning process. If presented with one hundred different scenarios, it becomes impossible to address each unique situation, making the scenario planning process more of a thinking exercise than an actionable planning process. This framework focuses on the uncertainties that are central to land use management in the river valley (i.e., tidal prism and extreme river flow events), and organizes a wide variety of potential future conditions and processes into four logically-coherent bins. By limiting the total number of scenarios to four, it allows planners to effectively determine appropriate planning objectives without becoming overwhelmed.

Why were management actions not discussed when developing the scenarios?

The goal of this scenario exercise was to describe the physical setting of potential futures in order to inform a climate vulnerability assessment. Explicit consideration of the management actions that might affect these states will be discussed in later phases of the adaptation planning process, as stakeholders begin to develop climate adaptation strategies that identify management practices which will lower vulnerabilities and increase resilience to climate change. Moreover, although the focus is currently on physical processes, management was implicitly considered, as management actions can modify the degree to which the drivers on the axes of uncertainty manifest themselves (e.g., restoration activities increasing tidal prism).

Why is a planning time horizon not identified?

It is impossible to predict exactly when significant changes in our climate and environment will occur, as there are too many variables interacting on different time scales. In the end, the most important aspect of a planning process is to begin the discussion, exploring potential outcomes and impacts without getting hung-up on exactly when the change may occur. In other words, the primary concern is to be prepared in the event of a change in the system. As this process moves forward, there may be the need to delve more deeply into specific timeframes by land use managers, but by not identifying a time horizon early on in the process there is more room for flexibility down the road.

Next Steps

The scenarios developed in this packet will be used to inform the vulnerability assessment, during which the three key components of vulnerability will be explored: (1) exposure, (2) sensitivity, and (3) adaptive capacity (Figure 3).

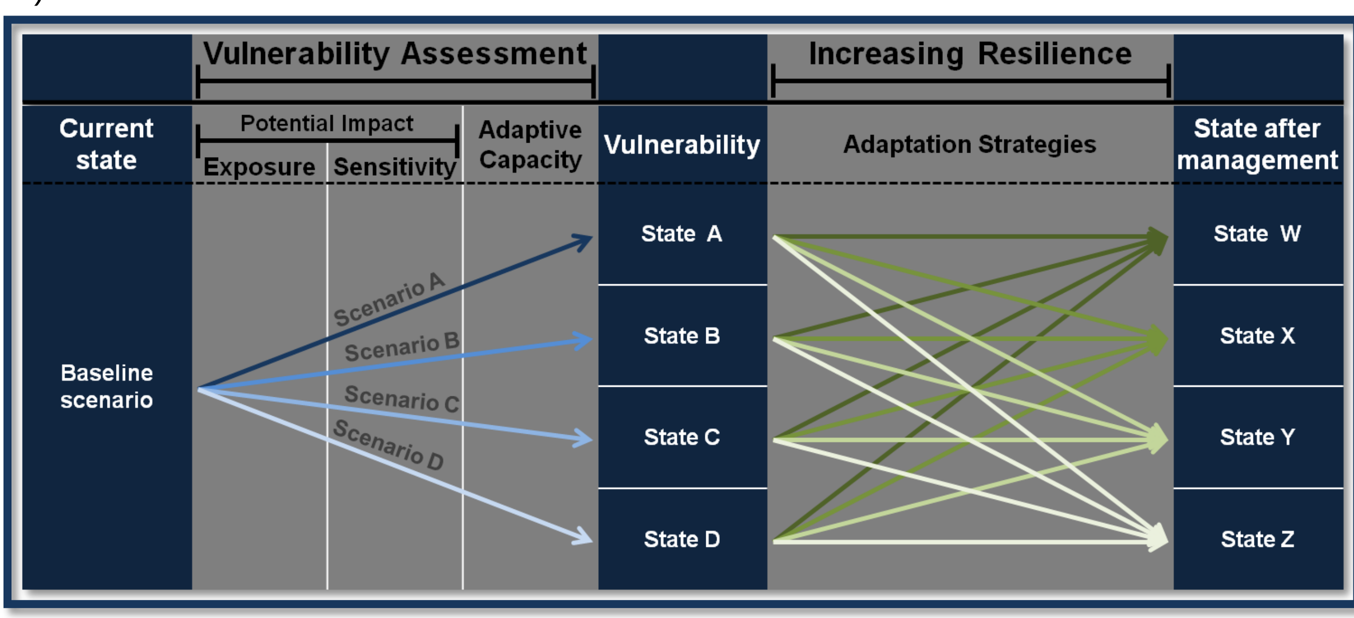

Figure 3: Integrating scenarios into vulnerability assessment and adaptation planning [9].

Glossary

Aggradation: The raising of the bed of a watercourse (e.g., river channels, salt marshes) caused by the accumulation/ deposition of sediment [4]. (Synonym: sedimentation)

Alluvial fan: A landscape feature whose surface is shaped like an open fan or a segment of a cone, and is formed by the accumulation of sediment and organic material deposited by flowing water [4].

Eutrophication: An increase of nutrient inputs into a system that increases the growth of algae, produces declines in the health of fish and shellfish, and depletes dissolved oxygen in the water (i.e., hypoxia) [4].

Flood: Temporary submergence of land from river water flows (i.e., riverine flooding) or the ocean (i.e., coastal flooding).

Geomorphology: The study of physical landscapes (i.e., landforms), and the processes that create and mold them [4].

Hypoxia: A condition where there is not enough oxygen in the water, suffocating plant and animal life, typically a result of excess nutrients (i.e., eutrophication) [4].

Inundation: Permanent submergence of land. If a section of land is regularly submerged (i.e., during a tidal cycle), it is considered inundated.

Resilience: "Amount of change a system can undergo (i.e., its capacity to absorb disturbance) and retain essentially the same functions, structures, and feedbacks [5]."

Lower valley: The portion of the Tijuana River Valley that is currently tidally-influenced (i.e., downstream estuarine portion of the valley).

Ponding: The creation of a lake/ lagoon around the river mouth, typically caused by a closed mouth.

Scour: The weathering of river banks, caused by the clearing and digging action of flowing water, especially the downward erosion by stream water during flood events [4].

Sediment export: Sediment delivered from the upper river valley out to the sea.

Sedimentation: The raising of the bed of a watercourse (e.g., river channels, salt marshes) caused by the accumulation/ deposition of sediment [4]. (Synonym: aggradation)

Storm surge: Water that is pushed toward the shore by the force of wind associated with a storm, as well as elevated due to low atmospheric pressure. [6].

Upper valley: The portion of the Tijuana River Valley that is not currently tidally-influenced (i.e. the upstream riparian & upland portions of the valley).

Water residence time: The average amount of time that water remains in system (e.g., how long freshwater remains in the estuary before heading out to sea, how long flooding waters remain before dissipating)

Wave run-up: The upper levels reached by a wave on a beach or coastal structure [4].

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Workshop Participants

Experts from the following organizations/ agencies: California Coastal Commission; California Department of Water Resources; California Native Plant Society; California State Coastal Conservancy; California State Parks; City of Imperial Beach; Coastal Restoration Consultants; ESA PWA; Goleta Slough Management; Los Peñasquitos Lagoon Foundation; Naval Base Coronado; Oceanographic and Coastal Engineering Service; San Elijo Lagoon Conservancy; San Francisco Estuary Institute (SFEI); Southern California Coastal Water Research Project (SCCWRP); Southwest Wetlands Interpretive Association (SWIA); Thalassa Research and Consulting; University of California, Irvine (UCI); University of California, Los Angeles (UCLA); URS; US Fish & Wildlife Service (USFWS); US Geological Survey (USGS).

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