1. TITLE: DRIVERS OF MORPHODYNAMIC CHANGE AND HYPOXIC EVENTS IN SOUTHERN CALIFORNIA LAGOONS

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4. FUNDING REQUESTED
2016-2017 $48,354 Federal/State $24,178 Match
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5. STATEMENT OF THE PROBLEM
Estuaries and wetlands provide extensive biological and ecological functions and are heavily utilized by humans. They are among the most productive ecosystems in the world, serving as key links in the food web. In addition, they provide many human services including freshwater, food, waste disposal, runoff filtration, and recreation, amongst many other economically valuable uses. However, these systems are highly sensitive to environmental changes. In California they have already been significantly impacted by human uses and continue to experience enhanced pressures from increasing development and a changing climate. More than 50 marsh estuaries and bays (all low-inflow estuaries, LIEs) line the highly urbanized Southern California coastline. These systems persist as critical regions for coastal resiliency to extreme events and ecosystem health. While it has been suggested that estuaries and coastal marshes may mitigate negative impacts of a changing climate, their response to climatic variations is not well understood [e.g., Shepard et al., 2011].

One problem of particular interest in Southern California LIEs is sediment transport and the associated morphologic changes that alter hydrodynamic and ecosystem dynamics. For example, many LIEs periodically fill in with sediment such that they are closed to tidal action. This can lead to stagnation and hypoxic conditions with significant ecosystem consequences. Thus many Southern California LIEs undergo costly mouth maintenance including dredging and jetty construction to maintain open inlets and protect infrastructure such as roads and railroads. For example, dredging costs alone in individual Southern California LIEs range from ~$100K to over $1M annually [Jenkins and Wasyl, 2006 and M. Hastings personal communication, 2014]. An improved understanding of these dynamics as well as predicting their response to future climate conditions is of great concern to LIE managers and surrounding communities and is a current area of focus for LIE managers (e.g., Board of Governors of the Southern California Wetlands Recovery Project, M. Hastings, J. Crooks, personal communication and attached letters of support). Thus we propose to address the resiliency of Southern California estuaries to both rising sea level and increased frequency of extreme water level events by investigating the detailed physical drivers of hydrodynamic-morphodynamic feedbacks and resulting ecosystem consequences.

6. INVESTIGATORY QUESTION
It is not well understood how estuaries in general, and LIEs in particular, will respond to sea level rise and climate change including potential changes in morphology and consequences of those changes [e.g., Reeve and Karunarathna, 2009]. The proposed work will expand upon an ongoing 1-year USC Sea Grant project to examine questions to address coastal resiliency and sustainability in LIEs. The ongoing work is
examining larger temporal and spatial scale processes including the relative importance of waves versus river flow, the long-term (~monthly) impact of storms on estuarine circulation, and the adaptability of natural versus engineered systems. So far, our results suggest the dominance of wave impacts on morphodynamic-hydrodynamic interactions, thus here we propose to investigate the shorter time-scale links between waves, mean currents, water level, and morphodynamic processes in more detail. The strong connections between entrance morphodynamics and hypoxia have led us to simultaneously investigate hypoxia and re-oxygenation processes associated with closures and breaching. We therefore have designed a set of experiments, informed by our ongoing work, to address the following questions:

1. **What is the relative importance of waves, wave-current interactions, and mean currents in driving sediment transport in estuarine mouths?** Our preliminary results suggest that larger wave events during high tides enhance up-estuary beach sand transport increasing mouth closure risk (see Figure 3 and §7.D). Our measurements also suggest that the wave frequency and direction are important to the total sediment flux. Thus we plan to investigate the interaction of waves of varying frequencies and mean currents and their impact on sediment transport and ultimately mouth morphology.

2. **How does hydraulic control at an estuarine mouth regulate wave-current interactions and thus sediment transport and hypoxia on tidal and event time scales?** We hypothesize that hydraulic control at the mouth/sill regulates lagoon water levels that, in turn, determine wave dissipation with strong feedback to tidal timescale sediment transport. Specifically, we hypothesize that upstream wave energy propagation increases with water level modulated by depth-limited wave breaking, similar to that observed on coral reefs. We anticipate that tidally modulated, wave-driven bed stress causes net landward sediment transport resembling beach sandbar migration.

   We further hypothesize that oxygen conditions respond to this hydraulic control. Our previous measurements show that re-oxygenation can occur during a closure (e.g., Figure 3) which we hypothesize is due to vertical mixing from incoming tidal flow when the tide is high enough to spill over but not breach the sill. We anticipate both hydraulic control and stratification influence this process.

3. **How will an embayment respond relative to an intertidal marsh-like system?** In our ongoing project, we hypothesized that constrained LIE entrances in engineered systems will be more susceptible to closure. Here we expand further upon this hypothesis by investigating the sediment transport response of embayments versus marsh-like systems to elevated water events.

While some of these questions have been addressed qualitatively [e.g., Jacobs et al., 2010], quantitative physical process dynamics, particularly in response to extreme events have not been examined. Weaknesses in our dynamical understanding result in poor predictive capabilities and make it difficult for managers to plan for climate change, sea level rise, and extreme event impacts in coastal LIEs. This proposed work will enhance predictability for mouth processes including mouth closures, morphological changes, and the potential impacts on infrastructure and system function. These are critical areas in need of enhanced understanding as outlined by the Board of Governors of the Southern California Wetlands Recovery Project in November 2014 and emphasized in our letters of support from local managers.

7. **MOTIVATION**

Estuaries and wetlands provide extensive biological and ecological functions and are heavily utilized by humans yet they have experienced significant degradation. Historical salt-marsh habitat loss is greater than 65% and continues at 1-2% per year [Lotze et al., 2006; Murray et al., 2011]. Due to their contributions to habitat and biodiversity, as protective barriers, and to coastal economies amongst others, numerous restoration efforts have been undertaken. Restoration goals are difficult due to lack of undisturbed reference sites [Grayson et al., 1999], and unfortunately many attempted restorations have
been slow and incomplete [Moreno-Mateos et al., 2012]. Thus, an improved understanding of estuarine and wetland dynamics and resiliency is required to predict future changes and inform sustainable coastal development and restoration. Here we describe the project motivation first broadly by describing Southern California estuaries and then by focusing in on the morphodynamics of these systems.

A. Southern California Estuaries

We focus on Southern California low inflow estuaries (LIEs), prevalent along Mediterranean climate coasts (e.g., California, Spain, South Africa, Australia). LIEs (including lagoons, marshes, wetlands and low-inflow embayments) stretch throughout much of California. Our proposed work will concentrate on Southern California given its unique regional physical forcing conditions and extent of human interaction. Figure 1 shows the location of the larger LIEs including 36 estuaries that are marsh/wetland types and 13 that are more open water bay/harbors. There are a multitude of smaller inlets not marked.

![Figure 1. Overview of Southern California estuaries and conditions](image)

California-wide map shows annual average precipitation (green, cm) and offshore water temperature on 10 Sept 2010 showing the typical summer upwelling pattern (color, degrees C). The inset of Southern California marks larger LIEs including marsh/wetland type estuaries (blue star) and harbor/bay type estuaries (red square). 36 marsh estuaries and 13 bays are marked, however, many other smaller inlets are not included.

Due to a strong north/south gradient in both upstream (river flow) and downstream (oceanic) estuarine forcing conditions, Southern California LIEs represent a subclass of LIEs. Southern California LIEs receive minimal river flow correlated with intermittent precipitation events [Nezlin and DiGiacomo, 2005; Warrick et al., 2007] (as seen by the strong north/south gradient in precipitation in Figure 1). Reduced upwelling south of Point Conception (e.g., Hickey [1998] and Figure 1) leads to warmer, fresher, reduced nutrient oceanic water offshore of Southern California LIEs.

Southern California LIEs also share similar anthropogenic pressures due to significant urbanization and coastal development, with over 17 million people in coastal Southern California counties and over 20 million including inland counties [US Census Bureau 2010]. The coast is a significant revenue stream for the region including tourism, shipping, and fishing [e.g., The Port of Los Angeles 2014; Port of Long Beach 2014]. For example, tourism in San Diego and Los Angeles Counties totaled over $18 billion each.
in 2013 [Los Angeles Department of Tourism 2014; San Diego Tourism Authority 2014]. In addition Southern California LIEs are utilized for aquaculture and sites for critical infrastructure including desalination and energy generation facilities. Agua Hedionda, one of the sites for this proposed work, is home to significant infrastructure of this type.

LIEs provide multiple ecosystem services. Southern California LIEs are important rearing grounds for juvenile fish (particularly for local fisheries such as California halibut), host a variety of endangered species, and act as stopovers on the pacific flyway [Larson, 2001]. Additionally, LIEs act as buffer zones between urbanized regions and the coast. LIE marshes and wetlands act to filter contaminants from urban runoff prior to coastal discharge. They also provide coastal protection and resiliency where sea level rise can potentially be mitigated [Shepard et al., 2011]. Marshes and wetlands within LIEs play an important role in coastal ecosystem carbon storage [Murray et al., 2011]. Southern California estimates for marsh habitat destruction range from 70-90% of historical extent [Larson, 2001; Southern California Wetlands Recovery Project, 2013] thus all of these positive benefits have been reduced significantly. For example, the Ocean Health Index points to salt marsh loss as one of the main drivers negatively impacting US west coast carbon storage [Halpern et al., 2014]. Their ability to perform these valuable ecosystem services has been limited and it is unknown how they will respond to additional future changes.

B. Hydrodynamics and morphodynamics of Low Inflow Estuaries

LIE hydrodynamics differ from freshwater dominated estuaries. LIEs can become hypersaline with a salinity minimum inside of the system leading to relatively small exchange and stagnant conditions [Largier et al., 1997; Largier et al., 1996; Largier, 2010]. The morphodynamics of many LIEs are particularly sensitive to wave forcing and intermittent floods making them subject to mouth closures and channel migration [e.g., Moreno et al., 2010; Zedler, 2010]. Morphodynamic changes are due to sediment transport divergence caused by the underlying hydrodynamics. Morphodynamic alterations then impact the system hydrodynamics substantially including transitions to a closed lagoon state with strong stratification, high phytoplankton biomass, and potentially low oxygen [e.g., Ortega-Cisneros et al., 2014]. Thus there is strong feedback between hydrodynamics, morphodynamics, and ecosystem function.

Of the LIEs that remain in Southern California, most have been heavily physically modified including dredging, seawall and jetty building, mouth constrictions, and other development. Southern California inlets historically migrated seasonally (southward in the winter, northward during the summer) and even in response to individual storm events [Engstrom, 2006]. Physical manipulation has negatively impacted the resiliency of these ecosystems [Jacobs et al., 2010; Shepard et al., 2011].

These systems’ response to extreme events is poorly understood [Shepard et al., 2011]. Some work has shown that extreme events have the ability to drastically modify morphology, salinity structure, productivity and vegetation [e.g., Zedler, 2010; Engström, 2006; Riddin and Adams, 2010; Jacobs et al., 2010]. Yet the physics underlying these processes has not been elucidated. Specifically the sediment transport mechanisms in these systems have only recently begun to be investigated (see below).

C. Extreme events in Southern California

We aim to take advantage of elevated water level events (large ocean waves and increased sea level due to tides, storms and/or El Niño) to assess Southern California LIE morphodynamic event response. Extreme events provide a window into potential future conditions. Long-term California climate projections predict not only mean sea level rise, but also an increase in the frequency of extreme sea level events [Cayan et al., 2008]. Similarly, storm events, which bring large waves and setup, are expected to become larger [Das et al., 2013]. The predicted El Niño [NOAA Climate Prediction Center, 2014] provides an enhanced opportunity to carry out this work as El Niño brings anomalously high sea level (10-20 cm) to the Southwest United States [e.g., Cayan et al., 2008; Das et al., 2013].
Extreme water level events in California can have both immediate and long-lasting coastal consequences. Typically storms occur during the winter and spring months of December through March with some during November and April. These storms bring larger waves from offshore (see Figure 2) and wave setup. Additionally, tides experience extreme highs during December-February due to tropic-spring high tides [Flick and Cayan, 1984] increasing the chances for winter extreme water level events. High swell events from the southwest also occur in summer and fall, associated with remote tropical storms.

![Figure 2. Southern California seasonal wave patterns.](image)

Monthly wave climatology compiled from the CDIP, SIO Oceanside buoy. Color indicates mean significant wave height (m) while size indicates the standard deviation of the wave height. Dots are scattered by the mean wave direction where 270° indicates waves coming from due west.

In Southern California and the southwest US, there is a strong correlation between extreme water levels and ENSO (El Niño/Southern Oscillation) events as observed in wave records [e.g., Bromirski et al., 2003], and flooding events. For example, the 1982-83 and 1997-98 El Niños, amongst the strongest on record [Wolter and Timlin, 1998], brought substantial flooding and damage to coastal California, with the 1982-83 winter causing over $100 million worth of damage [Flick and Cayan, 1984]. Large wave events from the west which directly impact the Southern California coastline, are both more frequent and have larger significant wave heights during El Niño. If a moderate to strong El Niño occurs during winter 2015-2016, this will provide an enhanced sampling opportunity. Current NOAA predictions suggest a strong El Niño with a 90% chance of continuation into fall 2015 and an 85% chance of continuation through winter 2015-2016 [NOAA Climate Prediction Center, 2014]. Local Southern California ENSO indices and the Multivariate ENSO index also both point towards continued El Niño conditions [SCCOOS, 2014; Wolter, 2015]. Importantly, even without El Niño, we expect ample elevated water level events due to the combination of winter storms and extreme winter tides. For example, during winter 2014-2015 (ENSO neutral conditions) we captured 3 complete inlet closures in Los Peñasquitos and multiple other extreme water level events that significantly impacted sediment transport and morphology. This is typical for Los Peñasquitos and other local LIEs. Agua Hedionda is dredged deeper and thus complete closures occur less frequently (every 2 years), yet we anticipate significant sediment transport occurs during winter events.

D. Extreme event LIE response in Southern California – preliminary results

An ongoing 1-year USC Sea Grant project is examining the role of extreme events (storms) on estuarine circulation and morphodynamics. Preliminary results indicate that both wave and tidal energy play major roles in driving morphodynamic alterations in small Southern California estuaries, although not always acting in concert. Large wave events occurring at the same time as relatively high tides allow infragravity waves (periods > 30 s) to propagate at least 0.75 km upstream into the estuary. These high wave events appear to transport beach sand into the lagoon in significant quantities and correlate with mouth closure (Figure 3), although the detailed physics linking the waves to the sediment transport are unclear with our current data. Closure is rapidly followed by estuarine eutrophication where stratification along with reduced flow allows for dissolved oxygen in the bottom layer to quickly become hypoxic. However, our observations indicate that extreme high tides can breach the sandbar and naturally re-open the lagoon mouth restoring tidal action and re-oxygenating the system. In addition, we observed re-oxygenation associated with intermittent overtopping at the mouth while the estuary remained closed. Thus our
ongoing project has raised multiple questions about the detailed mechanisms by which sediment transport occurs and extreme water levels lead to either hypoxia or re-oxygenation.

Figure 3. Los Peñasquitos December 2014 closure. This 16 d time series from December 2014 shows the offshore significant wave height (Hs, m) and direction (degrees) in the top panels, turbidity in the middle panel (brown), water level (m, dark blue) and along-estuary velocity (red is into the estuary, i.e., with a flood tide), and near-bottom dissolved oxygen (mg L\(^{-1}\)) in the lagoon in the bottom panel. The lagoon mouth closed around 12 Dec. 2014 in response to large waves (~2 m) coming from due west, i.e., directly into the lagoon. During closure, water levels remain high, flushing becomes weak and oxygen levels quickly drop to hypoxic conditions (red on bottom panel). The lagoon is re-oxygenated while closed on 16 Dec. 2014 and re-opens on 21 Dec. 2014 (not shown in this time series). Significant wave height data from Oceanside, CA from CDIP, SIO. La Jolla water level is from NOAA and lagoon water level and currents are from our instrumentation. Dissolved oxygen is from NOAA NERR SWMP.

E. Wave-current interactions & sediment transport
Infragravity waves are low-frequency surface gravity wave with periods of ~30 to 300 seconds. We hypothesize that the tidally modulated infragravity energy observed during our ongoing LP study (Figure 4) plays an important role in sediment transport near the mouth. On gently sloping beaches infragravity waves are thought to be the result of non-linear wave-wave interactions between shoaling waves [Longuet-Higgins and Stewart, 1962; Herbers et al., 1995]. In the surfzone, sediment suspension has been shown to occur at infragravity timescales with important effects on the cross-shore transport of sediment [Beach and Sternberg, 1988]. Infragravity waves have been found to also be important to barrier breaching and dune erosion [Roelvink et al., 2009]. To date, very few models of wave-dominated inlets have been able to successfully model closures [Ranasinghe et al., 1999; Bertin et al., 2009] and even fewer observational studies have been conducted in inlets to understand the mechanisms of infragravity waves and wave-current interactions on sediment transport. One study conducted in Portugal observed infragravity wave propagation into a wave-dominated inlet and through modeling found that infragravity
waves increased sand transport into the inlet up to 20% during flood tides while wave-current interactions did not allow waves to propagate into the system during the ebb tide which could contribute to inlet closure [Dodet et al., 2013; Bertin and Olabarrieta, 2015]. We propose that infragravity energy is critical in modulating sediment suspension at the swell band, such that infragravity water level variations result in increased shoreward fluxes.

Figure 4. Infragravity waves in Los Peñasquitos. This time series from December 2014 shows tidal amplitude in the lagoon (blue) and at Scripps Pier (gray) in the top panel, the spectra of the energy derived from the ADCP pressure signal in the middle panel (i.e., spectrogram), and the offshore wave height at the Torrey Pines Outer Buoy in the bottom panel. In the spectrogram, the darker blues indicate more energy and wave periods of 30 seconds, 1 minute, and 2 minutes are indicated with red lines in the legend. During high tides and large wave events, energy in the infragravity band is seen over 0.75 km upstream of the mouth. La Jolla water level is from NOAA. Lagoon water level and spectrogram are from our upstream ADCP deployed as part of the ongoing USC Sea Grant project. The ADCP pressure sensor was sampling at 0.5 Hz. Significant wave height data from CDIP, SIO Torrey Pines Outer Buoy.

8. GOALS AND OBJECTIVES

A. Overall Goals

• Assess the impact of wave-current interactions on sediment transport and morphodynamic responses to extreme events in Southern California LIEs using in-situ and remote observations
• Compare results from two different types of LIEs (marsh vs. embayment)
• Use these observations to make predictions about the response of these estuaries to future conditions including sea level rise and elevated water level events in order to assist managers in planning dredging events and in adopting coastal resiliency programs

B. 2016-2018 Objectives

Instruments measuring salinity, temperature, pressure, suspended sediment, currents, turbulence, and basic water quality parameters (i.e. dissolved oxygen, turbidity, pH) are already deployed in Southern California estuaries via the NOAA National Estuarine Research Reserve (NERR) program (salinity, temperature, oxygen, pH, water depth, turbidity) and our ongoing USC Sea Grant project (currents, turbulent stresses, waves, water depth, salinity, temperature, turbidity). We will maintain these instruments prior to and through the February 2016 project start date in order to capture the approaching El Niño and pre-storm season conditions. During the February 2016-February 2018 project period (as outlined as a timeline in the Projected Work Schedule.) we will:

• Maintain and add to our existing observations in our focus estuary while adding observations to the second comparative system
• Conduct monthly enhanced sampling, including higher spatial and temporal resolution hydrographic transects; sediment sampling; and aerial surveys
• Conduct rapid response sampling before and after large storms, including higher spatial and temporal resolution hydrographic transects; sediment sampling; concurrent wave, turbulence, dissipation, and suspended sediment measurements near the channel mouth; and aerial surveys
• Analyze the data to address wave-wave and wave-current interactions on sediment transport and hydraulic control
• Compare observations between the two systems
• Relate observed conditions to predicted future scenarios in these systems and other LIEs, specifically focusing on applications for managers
• Present our results at conferences, through manuscript publication, and via outreach

9. METHODS
We plan a 2-year project to complement and extend the measurements we started in Los Peñasquitos Lagoon during the current USC Sea Grant project. This includes maintaining a long-term mooring that measures currents throughout the water column, water surface level, salinity, temperature, and dissolved oxygen (CT-DO) at multiple depths; and two buried pressure sensors in the lagoon mouth. To test our hypotheses we plan to add short-term higher resolution current and pressure measurements collocated with optical backscatter sensors (to measure suspended sediment) and a near-field camera looking down at the water surface to further investigate sediment re-suspension at multiple locations along the estuary during times when wave propagation into the estuary is expected. Additionally, we plan to fly a drone-mounted camera coupled with high-resolution GPS elevation surveys at the lagoon mouth to quantify larger scale morphodynamic changes. These higher resolution measurements will allow us to address our hypotheses by calculating currents and wave dissipation, which together determine sediment suspension and transport, and comparing these to both in-situ and remote measurements of suspended sediment. Finally, we plan to extend our study to Agua Hedionda Lagoon with more limited observations.

While the study sites are all located in the southern extent of Southern California for logistical regions, these systems well represent the range of LIEs throughout the Southern California region. Agua Hedionda is representative of some of the more open water lagoons/bays in the region (e.g., Los Batiquitos Lagoon, Buena Vista Lagoon, Santa Clara, UCSB Lagoon, etc.) while Los Peñasquitos is representative of the smaller systems with extensive marsh habitat (e.g., San Elijo, Seal Beach Wetlands, Upper Newport Bay, etc. and to some extent the more natural systems such as Mugu Lagoon and Tijuana Estuary).

   A. In-situ long-term instrumentation
We will deploy 2 moorings in our focus estuary (e.g., Figure 5) to be maintained throughout the project. The downstream mooring will be a continuation of instrumentation we have deployed since December 2014 and includes an upward-looking, bottom-mounted acoustic Doppler current profiler (ADCP) sampling currents and pressure at 2 Hz and a bottom and top-mounted conductivity-temperature-depth (CTD) sensor that measures salinity, temperature, density, and water level at 10 min intervals. We will add to this mooring a bottom-mounted dissolved oxygen sensor and an optical backscatter sensor (OBS) to measure suspended sediment. The upstream mooring will include top and bottom CTD sensors. In addition to mean currents, the ADCP high frequency pressure signal will allow for quantification of infragravity waves. Additionally, during key months, we will add a bottom-mounted Acoustic Doppler Velocimeter (ADV) to measure higher frequency waves, turbulence statistics and turbulent dissipation. The ecosystem response to morphodynamic changes in terms of stratification, along channel density gradients, and dissolved oxygen will be tracked with the CT-DO sensors. Additionally, four bottom-mounted temperature sensors will be deployed along the estuary to track the propagation of incoming waves and tidal bores. These are closely spaced in order to capture anomaly propagation as well as to assess the value of future work using a Distributed Temperature Sensor (DTS) cable which is capable of 0.5 m horizontal temperature resolution, in collaboration with Kristen Davis, the associate investigator on this project. In the second estuary, 1 mooring with an ADCP and top/bottom CTDs will be deployed.

In addition, two pressure gauges sampling at 2 Hz will be buried near the Los Peñasquitos river mouth in the beach to measure waves and runup, one around Mean Sea Level, another just within the estuary mouth. A third mooring just offshore will measuring the incoming wave direction and height. These will be deployed from December 2015 through May 2016 by experienced technicians and redeployed for 2 more 6 month cycles to extend these observations over 1.5 years, building on the 5 month dataset collected during the first project.

Giddings, S.N. USC Sea Grant 2015
Finally, these instruments will be complemented by ongoing monitoring efforts and collaborations in each LIE (see Figure 5 and Figure 6). This includes CT-DO and pH sensors and a meteorological station maintained by the NERR in Los Peñasquitos and an elaborate carbon chemistry sampling package being tested in Agua Hedionda by SIO scientists Todd Martz and Kiley Yeakel. In addition to the carbon chemistry (pH, total Alkalinity, pCO2, salinity, temperature), we have agreed to help Martz and Yeakel plan and deploy instrumentation for measuring currents and waves. Thus there will be at least one other mooring in addition to the mooring deployed for this project in Agua Hedionda.

Figure 5. (left) Los Peñasquitos Lagoon and instruments
Existing monitoring sites (Los Peñasquitos Lagoon Foundation, red diamonds, see support letters from Mike Hastings and Jeff Crooks), proposed long-term mooring locations (blue dots), proposed bottom-mounted temperature sensors (purple dots), proposed short-term tripod location (blue star), proposed pressure sensors (open circle), and proposed digital camera view overlain on an image from Google Earth. The white line indicates scale.

Figure 6. (right) Agua Hedionda Lagoon instrumentation
Same as Figure 5 but for the second sampling site, Agua Hedionda Lagoon. Existing monitoring in the estuary is conducted by the NOAA Shellfish Water Quality Monitoring Station. Additionally, instrumentation will be in place by our collaborators Martz and Yeakel (see letter of support) to measure carbon chemistry parameters along with our additional mooring.

Giddings and Pawlak have both designed and deployed moorings of this type in many shallow water systems (including within Los Peñasquitos during the ongoing project) and will be contributing significant matching funds in terms of new and existing instruments and field equipment. These moorings will need to be recovered and re-deployed approximately every two months due to battery and memory limitations. The buried pressure sensors need to be recovered and re-deployed every 6 months. For upstream freshwater flow rates, we will use the closest available gauges (United States Geological Survey) scaled to account for ungauged watershed.

B. Remote instrumentation and imaging
During our ongoing project, we have utilized an existing time-lapse camera focused over the mouth of the estuary (NERR SWMP) along with an in-house camera system deployed periodically to investigate large-scale morphodynamic changes (e.g., channel movements). The camera system, designed by
undergraduate environmental engineering students in collaboration with the project PIs as part of a capstone engineering design course (MAE 126B), integrates orientation and location data with imagery. Using camera orientation data and known GPS points in the field of view, we can geo-rectify large scale images in order to get quantitative measures of morphologic change [Pawlowicz, 2003; Bourgault et al., 2011]. We will continue use of this instrumentation to monitor morphodynamic alterations. Additionally, we will use the camera system to conduct some closer field-of-view measurements of suspended sediment to corroborate the tripod measurements (see below).

To assess the generality of observations at the two selected sites, we will recruit an undergraduate student to carry out analysis of imagery (historical and collected as part of this proposed work) of LIE entrances in the southern California region. A significant historical imagery dataset exists for region via Google Earth (1-5 images per year, extending back to 2003 and further), and via the California Coastal Records Project (http://www.californiacoastline.org/, roughly two-year intervals). These data sets will be complemented by oblique imagery obtained biweekly during the study period at four LIE entrances near the two study sites (Buena Vista, Batiquitos, San Elijo, and San Dieguito Lagoons). The project PIs will co-advise an environmental engineering undergraduate who will carry out the imagery analysis as part of a two-quarter independent research course (MAE 199). The student will continue to participate as a research assistant over two summer months.

C. Regular transects surveys
Regular high-resolution spatial and temporal sampling will be conducted approximately monthly during spring tides from a small vessel in both locations, continuing from our ongoing USC Sea Grant project. This sampling will include vertical profiles with a CTD that is cast over the side of the boat and a boat-mounted acoustic Doppler velocity profiler capturing velocity throughout the water column. When available, the CTD casts will include an OBS, and oxygen sensor. These transects will include along and cross-estuary transects every 2 hours throughout a tidal cycle. In addition we will collect water samples mid-water column to be filtered later in order to measure suspended sediment and calibrate the OBS. Additionally, in our focus estuary, we will conduct these surveys twice monthly during at least one winter month and one summer month in order to assess spring-neap tidal cycle variation. These additional surveys will be timed to occur at peak spring and peak ebb tides.

D. Extreme event surveys
Both before and after storm events we will conduct high-resolution spatial and temporal sampling from a small vessel in our focus estuary. As with the regular surveys, this sampling will include CTD and ADCP surveys including along and cross-estuary transects every 2 hours throughout a tidal cycle.

In addition, in our focus estuary, we will deploy a tripod near the estuary mouth with two Acoustic Doppler Velocimeters (ADVs) programmed to capture waves, turbulence, and mean currents at two heights. These instruments will be aligned to allow for wave-turbulence decomposition. In addition to measuring waves, turbulence and mean currents, the ADVs will directly measure dissipation which we will compare to indirect estimates from two pressure sensors on either side of the ADV. Additionally, they will be connected to OBS units which when combined with in-situ sediment samples can be converted into suspended sediment concentrations. Finally, the camera will be mounted atop the tripod frame looking down at the water surface to provide a cross-reference for periods of high suspended sediment. Due to battery and memory life as well as potential for theft, this instrumentation cannot be deployed continuously. Thus, these tripods will be deployed for ~6 hours during large wave events and during calm conditions spanning the flood tide in order to capture wave-current interactions and hydraulic control effects.

The largest water level events historically occur in January-March. Thus we will deploy the additional in-situ instrumentation in Los Peñasquitos in November 2015 to capture pre-storm conditions. Additional
deployment costs and instruments will be supported by PI startup funds and existing resources. Instruments will remain in the estuary through October 2017, being recovered and re-deployed as necessary based on battery life (approximately every other month). The additional sensors in the second system (the embayment, i.e. Agua Hedionda) will occur at the start of the project period, February 2016, during one of the rainiest expected months with significant differences between El Niño and neutral or La Niña conditions. Transects will be initiated prior to storm events based on weather and buoy reports. Transects will follow storm events by 1-2 days to ensure safe sampling conditions.

E. Data analysis
The observational program described above is designed to address the questions posed in Section 6. Analysis of the observational data will be carried out to examine the associated hypotheses in a quantitative manner. The beach pressure sensors, upstream ADCP, and downstream ADVs will provide measurements of wave height and frequency while an offshore sensor will provide incoming wave direction. Using this instrumentation along with OBSs we will further quantify stresses, sediment flux, and investigate hydraulic control as explained below in more detail.

The ADVs will be synced and deployed at separate heights so that their separation is greater than the turbulent length scales. Using the assumption that variance associated with waves is much larger than that associated with turbulence, wave-turbulence decomposition will be performed to separate the effects of waves and Reynolds stresses on the bed [Shaw and Trowbridge, 2001; Trowbridge, 1998]. The wave, current, and combined bottom shear velocities and stresses and the apparent bottom roughness will be calculated [Grant and Madsen, 1979; Wiberg and Dungan Smith, 1983]. We will investigate effects of wave-current interactions on waves propagating into the lagoon during strong flood and ebb tidal flows [e.g., Olabarrieta et al., 2011; Dodet et al., 2013].

The dominant forcing for sediment transport near the inlet occurs due to a combination of bed load transport and suspended sediment transport. The bed load transport, governed by the Shield’s parameter will be calculated [Ribberink, 1998] based on shear velocities and in-situ sediment grain size distributions. OBS sensors will be deployed along with the ADVs and be calibrated with in-situ bed sediments samples [Green and Boon, 1993]. The measurements from the ADVs and OBS sensors will be used to quantify the sediment flux [Butt et al., 2004; Beach and Sternberg, 1988].

The hydraulic control parameters at the mouth sill will be analyzed [Seabergh, 2006] to understand the hydrodynamics at the constriction and its effects on sediment transport and inlet stability [Pacheco et al., 2008; Escoffier, 1940]. Based on measurements taken during the ongoing USC Sea Grant study, we will assume that when the inlet is open, the water column above the sill is vertically well mixed. We will also investigate the effects of tidal or wave bores identified during the previous study. Bores have been shown to increase turbulent mixing in the bottom layer [Koch and Chanson, 2008]. Bores may impact sediment transport [Butt and Russell, 2000] and re-oxygenation of bottom waters.

To determine larger scale morphodynamic response, we will quantitatively assess channel migration, accretion, and erosion using the digital camera data (using georectified imagery) and aerial surveys, validated by boat-based transects. We will relate these large scale morphodynamic responses to the observed hydrodynamics and use a few approaches to try to relate our observations to previous work and modeling studies [e.g., Friedrichs and Perry, 2001; Lanzoni and Seminara, 2002]. One approach we will use is a simple quantitative paradigm for assessing system responses described as $\frac{dS}{dt} = k (S - S^*)$ where $S$ is a variable describing the temporal evolution of some system characteristic. $S^*$ represents the ‘stable’ condition and $1/k$ is the time scale for the system response. If $k$ is constant, the relation has a solution that decays exponentially with time. This simple model for dynamic evolution is used commonly for beach morphology, for example, where the $S$ may be a measure of the bathymetry, $S^*$ is determined from a Bruun type equilibrium profile and $k$ is determined empirically. For the complex systems we are
examining, this relation provides only a guiding framework, but we intend to explore the use of this paradigm in explaining estuarine response using data from the observational plan described above. We will also use guiding framework such as the Exner equations and other modeling studies as comparisons.

Comparisons with other sites using historical and new imagery (undergraduate researcher) will examine the relative morphological states for neighboring LIEs, (using channel width, for example) to establish the extent to which mouth response is coherent over time throughout the region.

10. RELATED RESEARCH
There have been significant efforts in the Southern California region to investigate marsh habitat and biodiversity, efforts to address the impact of contaminants, and historical-based analysis of hydrodynamic and morphodynamic properties funded by Sea Grant and other organizations. Although some work on the event-time scale provides important qualitative context [e.g., Zedler, 2010], to our knowledge, direct observations of hydrodynamics and morphodynamics at a process level linking it to larger scales has not been done. Thus our proposed work compliments previous and ongoing work in the region. Ongoing regional monitoring (e.g., Figure 5 and Figure 6) will allow us to explore additional collaborations.

D. Jacobs et al. [2010] conducted a classification of California estuaries based on watershed, the degree of coastal exposure, and the type of formation to predict closure frequency and processes. This project was funded by USC Sea Grant and provides an important foundation upon which our work will build. Similarly, prior work by T. Longcore and colleagues focused on using historical ecology to establish baseline conditions for Southern California estuaries and geomorphic changes [Stein et al., 2010].

A currently funded USC Sea Grant project led by J. Largier and D. Gorge is investigating sediment transport using both observations and modeling around a headland, Point Dune, near Malibu. Their work has potential ties to ours, although much of their focus is on transport of particles, larvae, and sediment further offshore, but with some implications for beach transport. Beach transport processes are linked to processes within the estuaries. Similar related offshore work includes two previous USC Sea Grant studies by B. Jones and J. Fuhrman that investigated the downstream impacts of discharge and urban runoff on pathogen and contaminant transport. While they were not looking within the estuaries, but rather on the coast, their work highlights the importance of coastal impacts of these urban watersheds [Reifel et al., 2009; Warrick et al., 2007].

Extensive work has been conducted in the Southern California region investigating marsh habitat, biodiversity, function, restoration, transition, and other biological/ecosystem processes. As just a few examples, J. Zedler, L. Levin, C.R. Whitcraft, J. Crooks, amongst others have investigated processes ranging from species invasion, to marsh accretion, to habitat structure [e.g., Whitcraft and Levin, 2007; Zedler, 1996], with some of this work supported by Sea Grant. This work helps set the historical and current biological ecosystem value and function of these systems. We will continue to include measurements of suspended sediment and dissolved oxygen along with analysis of ongoing monitoring of water quality parameters within the estuary. Collaborations with additional planned projects include carbon chemistry in Agua Hedionda (T. Martz and K. Yeakel, see letter of support) and measurements of bacteria/phytoplankton community composition and gene expression in Los Peñasquitos (A. Allen and R. Diner, personal communication, 2015) amongst others. These collaborations and ongoing monitoring analysis will broaden the suite of water quality parameters and links to biological processes such as those investigated by Jones and Fuhrman.

Additionally, we are aware of complementary work either ongoing or being proposed in the region including beach studies, sea level rise response, proposed El Niño rapid response work, genetic analysis of closed versus open estuarine states, parasitism in estuaries, and others. For example, Scripps colleagues R. Guza and T. Gallien have collected ongoing records of beach accretion and erosion near the mouth of
Los Peñasquitos Lagoon and the Tijuana Estuary which will help us connect beach sediment supply and beach processes to estuarine processes. As already mentioned, preliminary and planned work by Martz and Yeakel in Agua Hedionda will be strongly complimentary. Additionally, we have strong connections with related researchers studying San Dieguito Lagoon (including Steven Schroeter, a UCSB Ecologist, and Scripps graduate student May-Linn Paulsen conducting carbon measurements there), Mission Bay Kendall Front Reserve, and the Tijuana River Estuary.

11. BUDGET RELATED INFORMATION
   A. Budget Explanation/Justification
   Personnel: We are requesting 0.5 months each of a Staff Research Associate and a Senior Marine Mechanician to calibrate, prepare, deploy, and recover the buried pressure sensors and offshore pressure + velocity (i.e., wave height and direction) sensor in Years 1 and 2. These personnel are highly experienced with this type of deployment. We are also requesting 2 months for an undergraduate researcher in year 2 to process and analyze the remote imagery and to help with field work.

   Salary recharge rates are calculated for actual productive time only (except for non-faculty academic sick leave). The rates include components for employee benefits, provisions for applicable merit increases and range adjustments in accordance with University policy, except postdoc rates which do not include components for downtime, so those rates are calculated for all working hours. Staff overtime or remote location allowance may be required in order to meet project objectives, and separate rates are used in those cases.

   Supplies, Materials, and other costs:
   • We plan to purchase 2 OBS 3+ sensors in Yr 1 which will be integrated with the ADVs recently purchased from Giddings’ startup funds.
   • We plan to purchase 4 SBE 56 temperature sensors to deploy along the estuary to capture incoming tidal/wave bores. This will also provide preliminary tests for determining the value of a cable which can take spatially continuous temperature measurements (with collaborator K Davis).
   • Battery packs for instrumentation are requested in both years.
   • An estimate for miscellaneous field supplies is included from a prior project of similar scale and includes line, shackles, weights, and material to build instrument frames for both years.
   • A request for a cargo van vehicle rental is included to transport equipment to and from the field sites for 6 days Yr 1 and for 4 days in Yr 2.
   • An estimate for boat costs including gas and maintenance based on a prior project of similar scale is included for both years.
   • IT support costs are requested for computer software maintenance and consortium costs related to the use of laboratory computers supporting hardware and software development for both years. This applies to computers being used for data analysis and instrument programming.
   • Other project specific costs for both years include telephones, tolls, voice and data charges, photocopying, faxing and postage are requested. Supply and expense items, categorized as project specific, and computer and networking services are for expenses that specifically benefit this project and are reasonable and necessary for the performance of this project.
   • Publication costs are requested for one manuscript in Yr 2.

   Travel: Registration costs to attend the Headwaters 2 Ocean (H2O) conference in 2016 are included. Because this conference is local to San Diego, no additional travel costs are required. This is an excellent venue to disseminate information to interested government agencies, managers, scientists, and citizens. Costs to attend the Physics of Estuaries and Coastal Seas conference in 2016, held in the Netherlands, are included for year 1. This biannual conference focuses on estuarine physics and typically over 50% of the attendees are working on sediment transport. The 2016 location, while distant, is ideal for this project.
because researchers and managers in the Netherlands currently lead the world in understanding coastal resiliency and coastal management and the conference draws experts internationally. Finally, in year 2, 2 trips to a TBD National conference are included. All conference fees include estimates of airfare, per diem, and registration fees.

B. Matching Funds
Giddings and Pawlak both have 9-month faculty appointments. Giddings will apply 0.9 mo. of her salary and Pawlak will apply 1.2 mo. of his salary towards the cost sharing which covers the required 50%.

12. ANTICIPATED BENEFITS
Our proposed research will significantly enhance our understanding of urban Southern California lagoon physical (hydrodynamic and morphodynamic) response to elevated water level events (tides, waves, storms, and El Niño) and the ensuing ecosystem response (dissolved oxygen). While the physical processes we are proposing to investigate are detailed and complex, our approach will yield system-level understanding that will greatly improve our ability to predict morphodynamic changes and oxygen responses in low inflow estuaries. This will provide direct benefits for LIE managers and municipalities, for example, by aiding with planning for scheduled dredging. Over longer timescales, the work will provide managers with a foundation for improved coastal resiliency, water quality, ecosystem health, and adaptation to a changing climate. Specifically, we will continue our strong collaborations with the Los Peñasquitos Foundation (see letter of support from M. Hastings), Los Batiquitos Lagoon Foundation, NOAA's Tijuana NERR (see letter of support from J. Crooks), the San Dieguito wetlands restoration team, and develop ties with stakeholders in Agua Hedionda (see letter of support from Martz and Yeakel) including the Agua Hedionda Lagoon Foundation, Carlsbad aquafarm, and desalination plant.

As Southern California estuaries are heavily developed, these studies will help coastal managers plan for complex interactions between the built and natural environment. Specifically, we have chosen two estuaries that have direct local stakeholder interest and that are representative of the two main types of estuaries found in Southern California: open, embayment lagoons and lagoons with extensive marshland. Los Peñasquitos is bordered by the city of Del Mar and San Diego neighborhoods of La Jolla and Carmel Valley. It is also home of the Los Peñasquitos Lagoon Foundation and further upstream the Los Peñasquitos Canyon Preserve, and bordered to the south by the Torrey Pines State Natural Reserve. The Los Peñasquitos Lagoon Foundation is a non-profit organization managed in partnership with California State Parks. Mike Hastings, Executive Director of the Los Peñasquitos Lagoon Foundation and Dr. Jeff Crooks, Research Coordinator for the Tijuana River NERR, have both been instrumental in supporting our ongoing and proposed work (see attached letters of support). Our work will directly impact Hastings’ and Crooks’ management goals and long-term planning providing them with desired additional information regarding estuary function, flushing, and opening/closure mechanisms.

Agua Hedionda is a highly modified and highly utilized LIE located within the urban city of Carlsbad. It contains the Agua Hedionda Lagoon Foundation and Discovery Center; the Magdalena Ecke Family YMCA Aquatic Park, a summer camp; the Hubbs-Sea World Fish Hatchery, a hatchery for the endangered white-sea bass; Carlsbad Aquaculture, a mussel and oyster aquaculture facility; a power plant; a soon to be on-line desalination plant; and extensive recreational use. Ongoing management efforts are required in the lagoon to maintain this functionality including approximately bi-annual dredging. Additionally, significant research efforts have been focused on trying to plan for the desalination facility and the resulting brine discharge. The Agua Hedionda Lagoon Foundation runs the Agua Hedionda Lagoon Discovery Center (http://lagoon.aguahedionda.org/agua-hedionda-lagoon-discovery-center) and we are working with Yeakel to make connections with this group. Yeakel has also connected with managers at the NOAA fishery as well as the power plant. Finally, we plan to learn from Dr. Scott Jenkins and his extensive work in the lagoon.
Broadly, our scientific results will benefit managers at LIEs throughout Southern California as we will work to connect our results in these individual systems to more general types of LIEs. In addition to the scientific applications to management, all collaborators will be involved in outreach that furthers the project benefits. Both the Tijuana River NERR and Agua Hedionda Lagoon Foundation have visitor centers aimed at outreach to the general public. Project PIs will hold presentations and run mini-workshops at these centers and beyond to reach out to local communities. The PIs success in this has already been established during the first few months of the current USC Sea Grant project collaborating with the Tijuana NERR to host a booth at the Science EXPO day and participating in the Expanding Your Horizons conferences. Giddings is also a new member of the Technical Advisory Committee to the city of Del Mar on a sea level rise planning effort and she regularly attends Tijuana Estuary bi-national planning meetings. In addition, we will host a project website aimed at broad dissemination and free data access. Finally, this project will provide continued training in field methodology and hydrodynamic calculations for a Sea Grant Trainee (Madelein Harvey, currently supported by the existing one year USC Sea Grant) and an undergraduate environmental engineering student.

13. COMMUNICATION OF RESULTS

As mentioned above, we plan to continue our direct communication with managers at the Los Peñasquitos Lagoon Foundation and Tijuana River NERR. This not only includes M. Hastings and J. Crooks, but we are also in regular communication with Darren Smith from California Fish and Wildlife and Rangers Hardenbrook and Winterton from Torrey Pines State Park who have been supportive in providing access and permits for our currently USC Sea Grant funded study. We hope to establish similar relationships with managers at the Agua Hedionda Lagoon Foundation as well as partner stakeholders there (NOAA, the power plant and the desalination plant). This will include quarterly meetings and ongoing conversations as to how we can incorporate our results into management. During our first year of USC Sea Grant funding, we have also maintained significant communication with other local lagoon managers including those at San Dieguito and Los Batequitos lagoons; relationships that we will continue to grow.

As highlighted in the support letters from M. Hastings and J. Crooks, our work will directly impact their ability to assess estuary mouth state, closure risks, and resulting ecosystem consequences for the lagoon.

Also as mentioned above, we plan to work with the local communities surrounding these estuaries. We have previously used the Tijuana River NERR Visitor Center to interact with local communities and students at outreach events aimed to introduce students to estuarine dynamics and environmental stewardship. We plan to expand our outreach activities to include volunteer activities at the Agua Hedionda Lagoon Discovery Center who work with YMCA and Boy and Girl Scout programs. Brochures and signs will be installed to explain to onlookers the ongoing work.

Importantly, these systems are similar to systems prevalent throughout Southern California. Thus to reach the broader Southern California audience, we hope to participate in USC Sea Grant workshops such as the workshops on sea level rise and coastal habitat conservation offered previously. Additionally, we plan to attend the Headwaters 2 Ocean (H2O) annual meeting which is aimed at addressing a wide spectrum of coastal issues drawing a diverse audience including researchers, engineers, managers, scientists, architects, urban planners, and representatives from local, regional, state, federal and non-profit agencies. This meeting provides an excellent venue to communicate results broadly. Using connections from this meeting and other networking, we hope to establish relationships with managers of estuaries throughout Southern California to discuss how our results pertain to their systems with the hopes of facilitating future collaborations and improving comparative studies and categorization.

Finally, we will publish at least one scholarly journal article resulting from this research for dissemination to the scientific community and attend two other conferences that are focused on estuarine dynamics and include sessions on sediment transport, hydrodynamics, and estuarine management.
14. REFERENCES


Ortega-Cisneros, K., U. M. Scharler, and A. K. Whitfield (2014) "Inlet mouth phase influences density, variability and standing stocks of plankton assemblages in temporarily open/closed estuaries." Estuarine, Coastal and Shelf Science, 136(0), 139-148.


Southern California Wetlands Recovery Project (2013), Chapter II: Southern California Wetlands, in *WRP Regional Strategy*.


PROJECTED WORK SCHEDULE

Project Title: Drivers of Morphodynamic Change and Hypoxic Events in Southern California Lagoons

<table>
<thead>
<tr>
<th>Objective</th>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
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<td>in-situ observations *</td>
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<td>in-situ obs, bay-like estuary</td>
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<td></td>
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<tr>
<td>high resolution pressure sensors</td>
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<td></td>
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<tr>
<td>intensive event surveys</td>
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<tr>
<td>data analysis</td>
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<tr>
<td>extension to other estuaries</td>
<td></td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>manuscript preparation &amp; presentation</td>
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<td></td>
<td>C</td>
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</table>

* solid indicates in-situ measurements while hashing indicates instrument deployment/recovery and turnarounds
1 indicates monthly transect sampling, 2 indicates 2 surveys to capture spring/neap variation
C indicates a conference
Q indicates the student’s qualifying exam while hashing indicates preparation for the exam

As described in the methods, in-situ instrumentation will begin prior to the February 2016 start of this grant in order to capture the beginning of the storm season, and as part of the currently funded 1 year USC Sea Grant project ending at the end of January 2016. Instruments, including moorings and beach pressure gauges, will be prepared and deployed early using instruments purchased through Giddings startup and Pawlak’s existing instrument pool with resources from the ongoing USC Sea Grant project.

This proposed grant will begin February 2016, Year 1, and will build substantial capacity upon what we can accomplish with our startup funds and existing instrumentation. Using this grant, we will deploy additional instrumentation as well as enhance our rapid response event sampling. This includes additional measurements during the intensive surveys as well as the ability to carry out the surveys throughout the winter season into the particularly stormy February and March months. The additional measurements will include enhanced in-situ transect surveys, remote imagery surveys, and tripod measurements. Due to battery and memory limitations, in-situ instrumentation will need to be recovered and re-deployed every two months (hashing). Analysis will occur throughout the year as new data will be coming in every two months and transect data every one month at a minimum. We will present at the H2O (Headwaters 2 Ocean) conference in late May 2016, the PECS (Physics of Estuaries and Coastal Seas) conference in August 2016, and likely the CERF (Coastal and Estuarine Research Federation) conference in November 2017. The student trainee will take her qualifying exam to become a PhD candidate in June 2016. We will begin manuscript preparation and extension to other estuaries starting during spring/early summer of 2016.
### A. SALARIES AND WAGES:

<table>
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<tr>
<th>Description</th>
<th>No. of People</th>
<th>Amount of Effort</th>
<th>Sea Grant Funds</th>
<th>Matching Funds</th>
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<tr>
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<td>b. Research Associates:</td>
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### B. FRINGE BENEFITS:

- *see below*

**Total Personnel (A and B):**

9,772 15,598

### C. PERMANENT EQUIPMENT:

17,116

### D. EXPENDABLE SUPPLIES AND EQUIPMENT:

17,116

### E. TRAVEL:

- 1. Domestic: 350
- 2. International: 3,798
- **Total Travel:** 4,148 0

### F. PUBLICATION AND DOCUMENTATION COSTS:

1

### G. OTHER COSTS:

- 1 Project Specific: 160
- 2
- 3
- 4
- 5
- 6
- 7
- **Total Other Costs:** 160 0

**TOTAL DIRECT COST (A through G):**

31,196 15,598

**INDIRECT COST (On campus 55%):**

17,158 8,579

**INDIRECT COST (Off campus % of $):**

17,158 8,579

**Total Indirect Cost:**

17,158 8,579

**TOTAL COSTS:**

48,354 24,178

*UCSD SIO:* Salary recharge rates are calculated for actual productive time only (except for non-faculty academic sick leave). The rates include components for employee benefits, provisions for applicable merit increases and range adjustments in accordance with University policy, except postdoc rates which do not include components for downtime, so those rates are calculated for all working hours. Staff overtime or remote location allowance may be required in order to meet project objectives, and separate rates are used in those cases.
**SEA GRANT BUDGET FORM 90-4**

**GRANTEE:** UCSD Scripps Institution of Oceanography

**GRANT/PROJECT NO.:** UCSD #2016-0029

**BRIEF TITLE:** DRIVERS OF MORPHODYNAMIC CHANGE AND HYPOXIC EVENTS IN SOUTHERN CALIFORNIA LAGOONS

**PRINCIPAL INVESTIGATOR:** Sarah Giddings

**DURATION (months):** February 1, 2017 - January 31, 2018

### A. SALARIES AND WAGES:

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<thead>
<tr>
<th>Senior Personnel</th>
<th>No. of People</th>
<th>Amount of Effort</th>
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<th>Matching Funds</th>
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| Other Personnel |
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| a. Professionals: | | | |
| b. Research Associates: | 2 | 1.0 | 10,114 |
| c. Res. Asst./Grad Students: | | | |
| d. Prof. School Students: | | | |
| e. Pre-Bachelor Student(s): | 1 | 2.0 | 4,846 |
| f. Secretarial-Clerical: | | | |
| g. Technicians: | | | |
| h. Other: | | | |
| Total Salaries and Wages: | 5 | 3.9 | 14,960 | 9,833 |

### B. FRINGE BENEFITS:

*see below*

| Total Personnel (A and B): | 14,960 | 11,962 |

### C. PERMANENT EQUIPMENT:

| 4,504 |

### D. EXPENDABLE SUPPLIES AND EQUIPMENT:

| 4,504 |

### E. TRAVEL:

| Domestic | 3,300 |
| International | 3,300 | 0 |
| Total Travel: | 3,300 |

### F. PUBLICATION AND DOCUMENTATION COSTS:

| 1,000 |

### G. OTHER COSTS:

| 1 Project Specific Supplies | 160 |
| 2 | 160 |
| 3 | 160 |
| 4 | 160 |
| 5 | 160 |
| 6 | 160 |
| 7 | 160 |
| Total Other Costs: | 160 | 0 |

**TOTAL DIRECT COST (A through G):** 23,924 11,962

**INDIRECT COST (On campus 55%):** 13,158 6,579

**INDIRECT COST (Off campus of $):**

| Total Indirect Cost: | 13,158 | 6,579 |

**TOTAL COSTS:** 37,082 18,541

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*UCSD SIO:* Salary recharge rates are calculated for actual productive time only (except for non-faculty academic sick leave). The rates include components for employee benefits, provisions for applicable merit increases and range adjustments in accordance with University policy, except postdoc rates which do not include components for downtime, so those rates are calculated for all working hours. Staff overtime or remote location allowance may be required in order to meet project objectives, and separate rates are used in those cases.
NAME: Sarah N. Giddings, Assistant Professor, UCSD, Scripps Institution of Oceanography

Address: 9500 Gilman Drive #0206, La Jolla, CA 92093-0206

Phone: (work) 858-534-5103 Email: sarahgid@ucsd.edu

EDUCATION
Ph.D. Civil and Environmental Engineering, Stanford University, Dec. 2010
M.S. Civil and Environmental Engineering, Stanford University, June 2005
B.S. Civil and Environmental Engineering, University of California, Berkeley, Dec. 2003

POSITIONS HELD
Assistant Professor, University of California, San Diego, Scripps Institution of Oceanography, (1/14-current)
NSF Ocean Sciences Postdoctoral Research Fellow, University of Washington (1/13 – 12/13)
Postdoctoral Research advisor Dr. Parker MacCready, University of Washington (1/11 - 12/12)
Engineering Intern: Stetson Engineers Inc. water resources consulting engineers (1/04 - 8/04)
Research Assistant for Dr. Mark Stacey, Civil and Environmental Engineering, U.C. Berkeley (6/03-12/03)
Intern: Alameda County Water District Operations Department, (1/02 – 8/02)
Research Assistant for Dr. Robert Harley, Civil and Environmental Engineering, U.C. Berkeley (6/01-6/02)

SELECTED PUBLICATIONS


PROFESSIONAL ACCOMPLISHMENTS
• NSF Ocean Sciences Postdoctoral Research Fellowship, Jan 2013
• Conference Chair Eastern Pacific Ocean Conference (EPOC) Co-chair, 2012
• UW Postdoctoral Association research symposium award for best talk, 2011
• Outstanding contribution to manuscript review, Coastal and Estuarine Research Federation, 2011
• Society of Women Engineers Teaching Excellence Award, 2010
• Physics of Estuaries and Coastal Seas Conference award for best oral presentation, 2008
• Achievement Rewards for College Scientists Foundation Fellowship 2008-2009
• National Science Foundation Graduate Research Fellowship 2004-2007
• Stanford Graduate Fellowship, NSF-Wells Family Fellow, 2004

SYNERGISTIC ACTIVITIES
Teaching: I have taught several graduate level classes and one undergraduate class

Educational Outreach: I am engaged in numerous educational outreach programs throughout the year, three that exemplify outreach to young and underrepresented students include:
Volunteer for Science EXPO (with the Tijuana NERR), March 2015
Volunteer for Avanzamos, UCSD (targeted towards young Latinas), March 2014
Volunteer for Ocean Inquiry Project (lower socioeconomic students), April 2011 – current
Expanding your Horizons Conference (women in science), March 2006 and 2007

Collaborations, Workshop participation, reviews: I have collaborated with a variety of scientists on interdisciplinary research including chemists and biologists. In addition I have participated in a variety of workshops on interdisciplinary topics and reviewed over 15 manuscripts and 6 proposals.

Student Advising: I currently advise 2 PhD students, sit on 2 additional PhD Committees, and have advised 2 undergraduate researchers
NAME: Geno Pawlak, Professor, UCSD, Department of Mechanical and Aerospace Engineering

Address: 9500 Gilman Drive #0411, La Jolla, CA 92039-0411

Phone: (work) 858-534-2343 Email: pawlak@ucsd.edu

EDUCATION
University of Minnesota, Aerospace Engineering and Mechanics, B.S.E., 1991
University of California, San Diego, Mechanical Engineering, M.S.E., 1994
University of California, San Diego, Mechanical Engineering, Ph.D, 1997

POISITIONS HELD
2015-Present Professor, Mech. and Aerosp. Engineering, University of California, San Diego;
2007-2012 Assoc. Professor, Ocean and Resources Engineering, University of Hawaii;
Cooperating Graduate Faculty, Dept. of Oceanography (2002-2012)
Ocean and Resources Engineering Graduate Program Chair (2010-2012)
2001-2007 Assistant Professor, Dept. of Ocean and Resources Engineering, University of Hawaii.
1998-2001 Postdoctoral Research Associate, School of Oceanography, University of Washington.
1997-1998 Postdoctoral Research Associate, Scripps Institution of Oceanography, University of California, San Diego.

SELECTED PUBLICATIONS

SYNERGISTIC ACTIVITIES
- Serve as faculty advisor for UCSD Global Teams in Engineering Service (TIES) program. TIES is a humanitarian engineering program that assembles teams of undergraduates to work with non-profits in San Diego and in developing countries around the world.
- Participated in UH Faculty Ambassadors Program: This program takes UH faculty members to local schools with the purpose of giving high school students a personal view of the university academic. The project aims to increase interest in higher education in general.
- Session Convener/Chair, 2010 AGU Ocean Sciences Meeting; Session Chair AGU Fall Meeting; Organizing Committee, 2012 APS Division of Fluid Dynamics Meeting

ADVISING
Current students: Andre Amador (PhD), Isabel Arzeno (PhD), Ajinkya Desai (MS)
Completed degrees: Vasco Nunes (MS), Abdulla Mohamed (MS), Melinda Swanson (MS), Lauren Tuthill (MS), Miguel Canals (PhD), Marion Bandet-Chavanne (PhD), Kumar Rajagopalan (PhD)
Postdoctoral Researchers (current): Payam Aghsaee
Postdoctoral Researchers (previous): Jeremy Bricker, Jon Fram, Andrew Hebert, Judith Wells, Sergio Jaramillo, Audric Collignon

Total Graduate Students advised: 10
Total Postdoctoral Researchers advised: 7
CURRICULUM VITAE – KRISTEN DAVIS  
July 2015

Address:  Henry Samueli School of Engineering  
Civil and Environmental Engineering  
University of California, Irvine  
Irvine, CA 92697

Phone:  (949) 824-4498 (office)  
E-mail:  davis@uci.edu

Education  
University of Florida, Environmental Engineering Sciences, B.S., 2000  
Stanford University, Civil and Environmental Engineering, M.S., 2004  
Stanford University, Civil and Environmental Engineering, Ph.D., 2009

Professional History  
2012-Present  Asst. Professor, Civil and Environmental Engineering & Earth System Science, University of California, Irvine
2010-2012  Research Associate, Applied Physics Laboratory, University of Washington
2009-2010  Postdoctoral Scholar, Departments of Physical Oceanography and Biology, Woods Hole Oceanographic Institution

Selected Publications  


**Synergistic Activities**
- Acting primary research advisor to three undergraduate students participating in the California Alliance for Minority Participation (CAMP) program at UC, Irvine to support underrepresented students in the science, technology, engineering, and math fields.
- Community Outreach: Organized an interactive science program for elementary and middle school girls through the Sally Ride Program and served as a “Science Superstar” for Project Scientist for a STEM summer camp for girls ages 5-12 years old.

**Graduate Advisor**
S.G. Monismith, Civil and Environmental Engineering, Stanford Univ., Stanford, CA

**Postdoctoral Advisors**
S.J. Lentz, Dept. of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA
Pineda, J., Dept. of Biology, Woods Hole Oceanographic Institution, Woods Hole, MA
Banas, N., Applied Physics Laboratory, University of Washington, Seattle, WA

**Advising**
Current students: Aryan Safaie, Emma Reid, Shukai Cai
Total Graduate Students advised: 5
SUMMARY PROPOSAL FORM

Project No. (For office use)_________

PROJECT TITLE: Drivers of Morphodynamic Change and Hypoxic Events in Southern California Lagoons

OBJECTIVES:
Our project objectives are to:
- Assess the impact of wave-current interactions on sediment transport and the morphodynamic responses to extreme events in Southern California LIEs using in-situ and remote observations
- Compare results from two different types of LIEs (marsh vs. embayment)
- Use these observations to make predictions about the response of these estuaries to future conditions including sea level rise and elevated water level events in order to assist managers in planning dredging events and in adopting coastal resiliency programs

We plan to approach these broad objectives by asking the following research questions:
1. What is the relative importance of waves, wave-current interactions, and mean currents in driving sediment transport in estuarine mouths?
2. How does hydraulic control at an estuarine mouth regulate wave-current interactions and thus sediment transport and hypoxia (through reduced flushing) on tidal and event time scales?
3. How will an embayment respond relative to an intertidal marsh-like system?

METHODOLOGY:
We plan to address our hypotheses by carrying out detailed in-situ observations in two Southern California estuaries (chosen to represent two estuary types) measuring currents, salinity, temperature, oxygen, water depth, suspended sediment, turbulent stresses, turbulent dissipation, and waves. Moorings will be placed in both study sites. Long-term moorings will be supplemented with transect surveys and short-term moorings to gain enhanced temporal and spatial resolution. We will conduct monthly hydrographic surveys (in both systems) and surveys before and after individual storm events (in our main study site), and will deploy high-resolution wave-turbulence-sediment tripods. Remote imagery measurements will complement the in-situ observations and quantify morphodynamic change.

RATIONALE:
Low inflow estuaries, prevalent throughout Southern California, provide extensive ecological and human benefits. The number and total area of these systems have been drastically reduced and those systems that remain are heavily modified by human development. It is unclear if these estuaries can maintain their roles as key contributors to habitat, biodiversity, carbon storage, and coastal protection. The response and resiliency of these systems to elevated water level events are particularly poorly understood. Some work has shown that extreme events have the ability to drastically modify morphology and transition vegetation structure, yet the physics underlying these processes has not been studied in detail. Thus we aim to explore in detail the coupled hydrodynamic-sediment transport mechanisms and their impact on larger scale system morphodynamics and hydrodynamics in urbanized Southern California estuaries in order to inform sustainable development and future adaptation.

DATA SHARING PLAN:
We will make our data available as soon as it is uploaded and preliminary data quality control is completed. It will be made available on a project website and via email request in full accordance with the recently outlined NOAA Data Management Planning Procedural Directive.
Dr. Sarah Giddings
Scripps Institution of Oceanography, University of California, San Diego

Dear Dr. Giddings,

Thank you for contacting us about your proposal to USC Sea Grant, entitled “Drivers of Morphodynamic Change and Hypoxic Events in Southern California Lagoons.” The work you have done to date has already improved our understanding of estuarine hydrodynamics, and we strongly support this proposed project. Southern California lagoons are complex, both in terms of their environments and their management. A primary factor shaping these areas is their connection to the ocean, and there has been growing interest in evaluating our approaches to mouth management. This became formalized in November, 2014, when the Board of Governors of the Southern California Wetlands Recovery Project, a consortium of 14 federal and state resource agencies, identified the need “develop guidance on the management of intermittently open estuaries.” Currently, our ability to effectively manage these lagoon mouths is hampered by an incomplete understanding of the dynamics of these systems. Thus, your project is timely and much-needed, and we will be happy to support your work in whatever way we can.

We are especially pleased that you will be able to leverage our long-term monitoring programs in your proposed project. We have extensive water quality datasets for several local systems, and we will make these data available to you. Given the importance of this topic, we would also like to highlight your project and its results in our outreach and education programs at the Tijuana River National Estuarine Research Reserve. We have opportunities to reach broad audiences through a variety of means, such as incorporating project results into our K-12 curriculum (which includes teacher trainings), presenting in our seminar series for the public, and developing interpretive elements for our Visitor Center. Of course, your work will also substantially inform our Reserve-based research and adaptive management program.

We look forward to the opportunity of working with you on this project, and please let us know how we can be of assistance.

Sincerely,

Dr. Jeff Crooks
Research Coordinator
Subject: USC Sea Grant Proposal – Drivers of Morphodynamic Change and Hypoxic Events in Southern California Lagoons.

To USC Sea Grant review panel,

As the Executive Director of the Los Peñasquitos Lagoon Foundation (LPLF), I am writing in support of Dr. Giddings’ USC Sea Grant proposal entitled: **Drivers of Morphodynamic Change and Hypoxic Events in Southern California Lagoons**. Los Peñasquitos Lagoon is a dedicated Marsh Preserve located within the Torrey Pines State Natural Reserve in San Diego County. A coastal estuary, the Lagoon faces many challenges caused by encroachment of urban areas and transportation corridors that make Los Peñasquitos Lagoon a managed system. Restoring and maintaining tidal circulation using heavy equipment to excavate the inlet area is a management priority listed in the Los Peñasquitos Lagoon Enhancement Plan. Our long-term monitoring program has documented impacts caused by constricted tidal circulation and extended inlet closures that can quickly lead to hypoxia within Lagoon channels that can cause fish kills and devastate populations of aquatic invertebrates that provide the primary food source to both migratory and endemic bird populations that include several listed bird species. Loss of tidal mixing also creates a serious threat to human safety as the entire Lagoon becomes an active breeding habitat for *Culex tarsalis*, a mosquito known as a vector for arboviruses that can be fatal to avian, equine and human populations within a 2-mile radius from the Lagoon. These same dry weather inputs cause water levels within Los Peñasquitos Lagoon to continually rise during extended inlet closures, flooding sensitive nesting habitat for listed bird species and facilitating habitat conversion that results in net-loss of native salt marsh plant species.

Since 1932, the inlet at Los Peñasquitos Lagoon has been constrained under a bridge span that was constructed along with Highway 101 and other hardened structures that impair the Lagoon’s connectivity with the ocean. In 2005 this bridge was replaced with the new design using four support columns instead of seventy-four, effectively altering the hydrodynamics and morphology of the inlet area. Restoring, enhancing and protecting Los Peñasquitos Lagoon through the long-term will require a better understanding of lagoon hydrology and the role that inlet morphology plays. LPLF is working to modify its approach to maintaining the Lagoon inlet to ensure that hypoxic events are avoided and to facilitate the success of large-scale restoration of salt marsh habitat that will occur in the near-term as a compliance
measure under the San Diego Basin Plan and the Los Peñasquitos Lagoon Sediment Total Maximum Daily Load.

LPLF has been working closely with Dr. Giddings and her project team to improve our long-term monitoring program that was initiated in 1987. The proposed study will greatly improve our management of the inlet area and our understanding how morphodynamic change at the inlet affects Los Peñasquitos Lagoon with regard to lagoon processes, water quality and management needs. Results from this study will also compliment our efforts to assess and evaluate large-scale restoration alternatives developed in the updated the Lagoon’s enhancement plan that consider how modified hydrology may or may not support large-scale restoration efforts and vector management needs in lieu of projected sea level rise scenarios.

We look forward to working with Giddings in an ongoing collaboration that will be mutually beneficial and working together on future projects as they arise. This will include conversations regarding connecting science with management not only within Los Peñasquitos Lagoon, but also forming connections with managers in similar systems throughout Southern California that include the Tijuana River National Estuarine Research Reserve. Additionally, we hope to use this opportunity to assist our ongoing efforts to enhance public knowledge of the estuary and its benefits and challenges to improve coastal stewardship efforts.

We wholeheartedly support these research efforts and highly recommend Giddings’ proposal for USC Sea Grant funding as we see estuarine function as a key contributor to understanding coastal resilience in Southern California.

Sincerely,

Mike Hastings
Executive Director, Los Peñasquitos Lagoon Foundation
July 1, 2015

University of Southern California Sea Grant Program
Los Angeles, California 90089-0373

Dear University of Southern California Sea Grant,

It is my pleasure to write a letter in support of the proposal “Drivers of morphodynamic change and hypoxic events in Southern California lagoons” being submitted to the USC Sea Grant Program by Dr. Sarah Giddings and Dr. Geno Pawlak.

My group currently maintains a real-time seawater carbonate chemistry monitoring station at Agua Hedionda Lagoon in Carlsbad, California - one of the sites proposed for PI Giddings and Pawlak’s work. Our shore station measures and streams live temperature, salinity, total dissolved inorganic carbon (TCO$_2$), total alkalinity, and pCO$_2$ data from the Agua Hedionda lagoon as part of NOAA’s Integrated Ocean Observing System and Ocean Acidification Programs, and in collaboration with Carlsbad Aquafarm, a local shellfish and seaweed farm. The aim of our observing systems is to provide shellfish farmers in local estuaries real-time water quality data both to assess the current impacts of ocean acidification on shellfish aquaculture productivity and to mitigate expected future acidification events.

Preliminary data from our shore station has revealed the wide range of seawater carbonate chemistry conditions within the Agua Hedionda Lagoon over the span of hours to weeks. To understand the drivers of inorganic carbon dynamics, we plan to deploy chemical sensors within the lagoon to obtain \textit{in situ} measurements of pH, dissolved oxygen, temperature and salinity, as well as deploy physical oceanographic instrumentation in collaboration with PI Giddings and Pawlak. Our chemical instrumentation will facilitate the proposed work investigating hypoxia within the lagoon, and correspondingly, the proposed physical oceanographic measurements will greatly complement our understanding of estuarine carbon transport processes.

In conclusion, I fully support the research proposed by PI Giddings and Pawlak. The proposed work will not only increase our understanding of storm-induced morphodynamic change and hypoxia in coastal estuaries, but also greatly aid ongoing collaborative efforts to understand the many physical and chemical oceanographic dynamics in these environments.

Sincerely,

Todd R. Martz
Associate Professor
Scripps Institution of Oceanography