STATE COASTAL CONSERVANCY FINAL REPORT
Southern California Kelp Forest Hydrodynamics Study
Grant No. 15-013

Title of Project: Southern California Kelp Forest Hydrodynamics Study

Grant Start Date: October 16, 2015
Grant End Date: June 30, 2018

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Congressional Districts and Representatives: 33rd Congressional District, Ted Lieu
Site Location: Palos Verdes Peninsula, California
Land Owner: State of California

Budget Summary:		
	Conservancy funding:	$68,747.45
	Dolby Funding:	$2,000.00
	EPA 320 Funding:	$ 7,363.45
	Total Project Budget:	$78,106.93
	Total Project Expenses:	$78,113.0

Background

California's coastal communities are already experiencing the early impacts of a rising sea level, including more extensive flooding during storms, periodic tidal inundation, and increased coastal erosion (Griggs et al. 2017). The latter consequence is of particular concern for coastal communities in Southern California, where dense coastal development embodies much of the shoreline. Recession of cliff edges is driven in substantial part by wave erosion and consequent sloughing of soil, rock, and sediment into the sea below. Beyond the loss of cliff structure, the input of sediment into the adjacent waters can result in negative consequences for nearshore ecological communities, including abrasion and suffocation of organisms (Watanabe et al. 2016).

Coastal protection is often cited as an ecosystem service provided by aquatic vegetation, as it has been shown to impede water movement, especially steady currents, and by extension it is often thought to attenuate surface gravity waves as well. However, currents and surface gravity waves are distinct phenomena; the former consist of flows that are largely unidirectional over many minutes to hours or more, while waves are wind-driven disturbances that propagate across the ocean's surface, and produce oscillatory water movements that change direction over seconds. Certain types of aquatic vegetation have been shown to damp current speeds considerably (e.g. seagrass meadows- Fonseca et al. 1982; Harlin et al. 1982; Worcester 1995; Koch and Gust 1999;

turf seaweeds- Carpenter and Williams 1993; large canopy-forming macroalgae- Jackson and Winant 1983; Gaylord et al. 2007; Rosman et al. 2007). Such reduction in current flow speeds have implications for sediment transport and water clarity, which are of particular concern to biological communities residing adjacent to stretches of land that are susceptible to coastal erosion. In particular, reduced flow speeds often lead to lower intensities of vertical mixing, allowing particles to sink out of the water column, simultaneously limiting sediment transport and improving water clarity, the latter of which is critically important for early growth of canopy-forming species when they have not yet reached the surface, and for other photosynthesizing species that also rely on sunlight and reside within kelp forests (Watanabe et al. 2016). Sediments can also inhibit sporophyte adhesion of *Macrocystis pyrifera* ("giant kelp") which is one of the most important canopy-forming macrophytes found along California's coastal rocky reefs (Devinny and Volse 1978).

Although currents play a crucial role in transporting sediments, waves are the primary driver of their entry into the ocean through erosion. Thus considerable attention has been directed at trying to quantify the ability of aquatic vegetation to influence waves. A rich body of empirical support suggests some types of aquatic vegetation have the capacity to reduce wave energy substantially, with estimates of up to 40% in seagrasses, 72% in mangroves, and 82% in salt marshes (Wayne 1975; Horstman et al. 2012; Möller et al. 2014). Given these trends and *Macrocystis pyrifera*'s documented capacity to damp currents (Jackson and Winant 1982; Gaylord et al. 2007; Rosman et al. 2007), a common expectation has been that canopy-forming kelp forests might serve a comparable role in coastal protection along California's shores. However, although some research has suggested that giant kelp forests may dissipate energy from waves, other studies are equivocal, and few empirical efforts have been positioned well to directly test this possibility (Jackson 1984, 1998; Elwany et al. 1995; Mork 1996; Gaylord et al. 2003, 2007). Perhaps the most rigorous prior study that has been conducted suggests little capacity for wave damping by the giant kelp, *Macrocystis pyrifera* (Elwany et al. 1995). Modeling work by Gaylord et al. (2003) provides some clues as to why this might be the case, by showing that the flexible body plans of large canopy-forming kelps reduce their tendency to be drawn out in a fully extended orientation before the bidirectional flows under waves reverse. This trait of swaying with the waves (or "going with the flow," sensu Koehl 1984) encourages the kelp and water to move in concert, minimizing the resistance applied by former on the latter, and thereby limiting the tendency for canopy-forming kelps to impose appreciable drag on wave-driven flows. This process could thus prevent strong dissipation of wave energy. Such a scenario contrasts with how large macrophytes interact with currents, since with currents, a canopy-forming kelp becomes readily drawn out along the dominant flow axis such that its resistive effects on water motion can fully manifest.

As alluded to above, a small number of studies have attempted to investigate the potential for kelp forests to attenuate waves. The most rigorous ones used comparisons of paired sites in close proximity to one another that either had kelp or not. However, even such careful evaluations have traditionally been unable to entirely confront certain challenges of inference. In particular differences in bathymetry and incident wave exposure between such paired locations can never be completely eliminated. Topographic variability presents a particular challenge given its ability to create flow microhabitats that can ameliorate or exacerbate differences in wave amplitudes or wave energy. In this regard, the opportunity to record wave attributes at the same site, both in the absence and presence of kelp, and holding shoreline orientation, topography, and substratum rugosity constant, provides perhaps an ideal situation to definitively answer this open question.

The Bay Foundation has led efforts to restore kelp forests along the Palos Verdes Peninsula since 2013, which provided just an opportunity to examine wave conditions at an identical location either in the presence or absence of kelp. Areas that were once overpopulated with purple urchins and devoid of kelp have returned to thriving kelp forests after culling the urchin population down to a healthy density. The resulting transition between urchin barren and healthy kelp forest presented a unique opportunity to observe the physical dynamics of water flow in and around a kelp forest during a period of regeneration.

Project Deliverables and Findings

Completed Task 1: Identification and monitoring of study sites

Local bathymetry, substrate, exposure, total area, historical kelp presence/absence, and other factors were carefully considered in the selection of rocky reef habitat for this study. Once the site was selected, divers conducted monitoring to classify substrate type and size, kelp cover, and other physical factors of the site. Marguerite (33.75712, -118.41842), the focal site for this study, had bathymetric contour lines fairly parallel to shore, which simplifies trajectories of wave propagation and removes many complexities that can arise through wave refraction. Bedrock and large boulders were the dominant substrate type, with a few sand patches interspersed throughout the site, particularly along the sensor transect (Fig. 1). Long period swells (T_p>15 sec) arrive mostly from the south-southwest (Xu and Noble 2009), although because Marguerite is located on the northern portion of the peninsula, this site also experienced currents and wind waves coming from the north and northwest. This exposure allowed for a range of wave and current conditions to interact with the site.

Figure 1. UPC, substrate, and kelp survey locations within instrument array. Kelp forest edge is represented by green dashed line.

Following the culling of urchins by the restoration team, kelp forest regrowth was characterized monthly within 8 evenly spaced transects (30 m x 4 m, 30 m apart) along a 300 m baseline transect perpendicular to shore (Fig. 1). Along each transect *M. pyrifera* individuals and stipes were counted to estimate the density of giant kelp (Fig. 2). Within each transect, kelp health and heights were tracked by descriptive notes (e.g. individuals without blades and subsurface, surface, or canopy forming, respectively). The kelp forest density time series was then partitioned into categories describing the

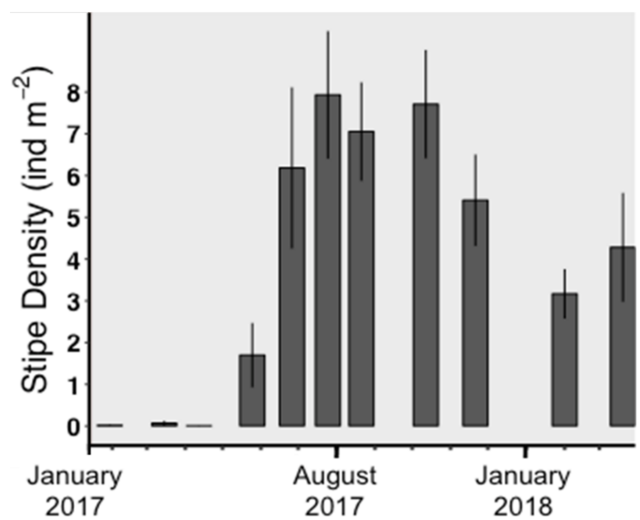


Figure 2. Temporal variation of kelp stipe density (per meter squared). Bars represent the number of stipes per meter squared, averaged across the eight transects. Error bars represent standard error of the mean.

overall kelp conditions (i.e. No Kelp, Growing Kelp, and Kelp), following a BACI design (Smith 2002).

Hydrographic and flow sensing instruments that measure currents and waves were installed in an array, spanning inside and outside of the kelp forest habitat. Measurements from outside of the kelp forest (e.g. offshore) allowed for a localized control of the incident wave and current conditions to which the inshore conditions can be compared across times when kelp is absent or present. Such comparisons are particularly critical for interpretation of kelp effects on waves. For example, it would be inappropriate to make inferences about effects of kelp on wave energy by recording wave conditions within the kelp forest when incident wave conditions are calm (i.e. significant wave height < 0.5 meters) and highlighting differences from wave heights offshore recorded when incident wave conditions are "big" (i.e. significant wave height > 2 meters). Instead, offshore measurements were catalogued to identify incident wave conditions (i.e., conditions at the offshore site) that were identical between 1) periods when kelp were absent inshore and 2) periods when kelp were present inshore. Then wave parameters were calculated at the inshore station in the absence or presence of kelp, for these consistent sets of incident wave conditions recorded at the offshore station. The offshore wave measurements were matched across comparable periods using a series of filters (r-squared values, slopes, and differences between incident wave conditions).

<u>Completed Task 2: Installation and monitoring of changes in current flow</u>

Acoustic Doppler Current Profilers (ADCPs) were deployed inside and outside of the kelp forest habitat throughout the duration of the study in order to quantify the effect of kelp on current speeds throughout the water column. ADCPs measure and record water current velocities using sound waves that are scattered back from particles in the water column. The notion that kelp forests can damp unidirectional currents, as established in the literature (discussed above), is reinforced by our direct measurements of flow speeds inside and outside of the kelp forest habitat, in the absence and presence of kelp (Fig. 3).

In particular, we found that alongshore currents were dramatically reduced within the interior of the kelp forest habitat, once the kelp had established at Marguerite. On average, peak alongshore current velocities at the focal site were approximately equal to those just offshore when kelp were absent, but were only 14% as fast as those offshore when a full forest was present. Positioned adjacent to cliffs vulnerable to coastal erosion and subsequent sediment sloughing, the reduced current flows may serve to decrease sediment transport. As discussed above, reduction in current speeds allow for suspended sediments to drop out of the water column, resulting in reduced sediment transport along and across shore.

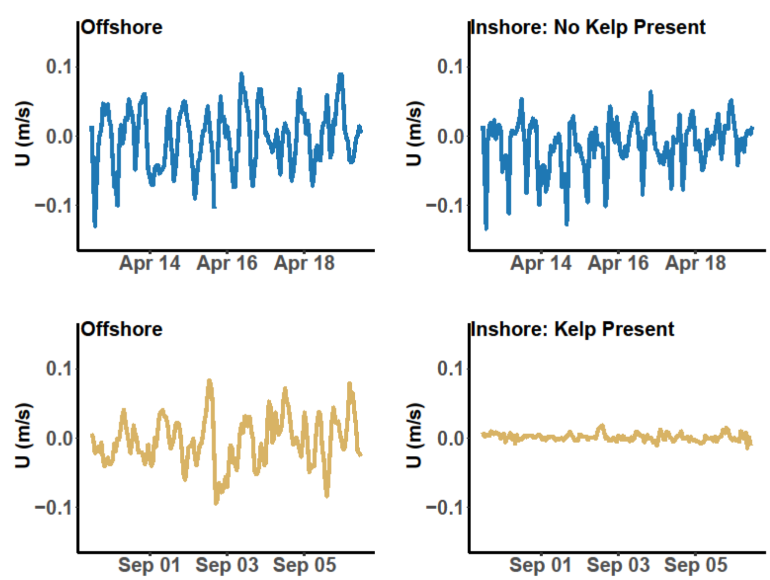


Figure 3. Depth-averaged alongshore velocities (U) recorded at Marguerite. Patterns of alongshore flow within the kelp forest habitat ("Inshore: Kelp Present") decrease in magnitude in the presence of kelp.

Completed Task 3: Measurement of potential changes in wave energy due to kelp

Bottom-mounted pressure sensors, Seabird 26 Seagauge Wave and Tide Recorders (SBE26), were deployed inside and outside of the kelp forest habitat throughout the duration of the study in order to quantify the effect of kelp on surface gravity waves. For a given deployment, the SBE26s recorded pressure at-depth at 4 Hz, for a burst duration of 17 minutes, 4 times a day. Instrument deployments were repeated over the course of two years, ultimately spanning the entire transition from urchin barren to kelp forest, during which a suite of incident wave and sea state conditions were captured.

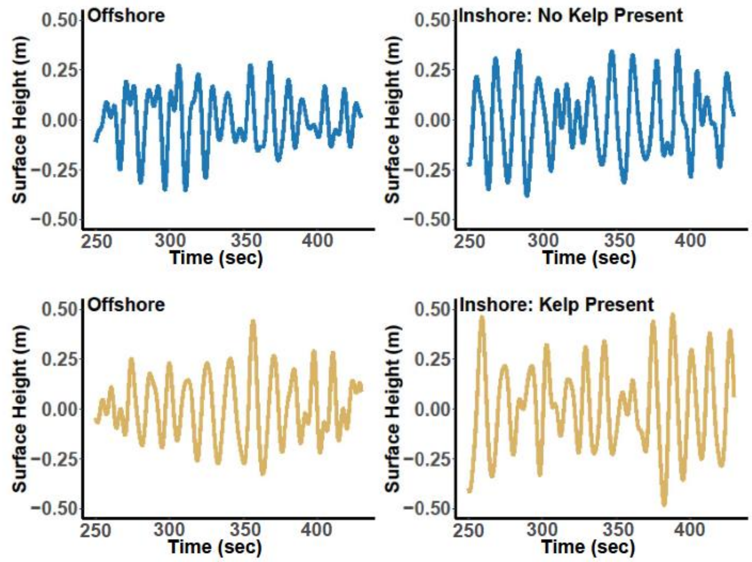


Figure 4. Two-minute long depth-corrected surface height fluctuations in the absence (blue) and presence (gold) of kelp, inside and outside of the kelp forest habitat. Incident wave conditions were matched as much as possible in this first order examination to ensure comparable conditions. Patterns of surface heights within the kelp forest do not display dramatic decrease in magnitude in the presence of kelp.

As is well known from basic wave theory (Kinsman 1965, Dean and Dalrymple 1984), wave-induced pressure fluctuations are attenuated with depth, with the amount of attenuation depending on the wavelength: the shorter the wavelength, the greater the attenuation (see also Denny 1988; Gaylord and Denny 1997). Surface wave time series were reconstructed from the subsurface pressure measurements for each deployment to correct for the effect of depth-attenuation. Offshore wave measurements were then compared between time periods in the absence of kelp to those in the presence of kelp, to ensure the incident wave conditions were analogous to one another. Wave measurements within the forest, in the presence of kelp, were only compared to those, in the absence of kelp, of comparable offshore incident wave conditions. In stark contrast to the example seen above with current damping (Fig. 3), there was not a profound difference in the surface wave fluctuations in the presence of kelp (Fig. 4).

Power spectral analysis is a traditional numerical tool used by oceanographers to partition overall wave energy into component frequencies (or wave periods) at which the energy is delivered to shore. Plots of power spectral density (Fig. 5a-c) provide a summary visualization of results, where, for example, a peak in the curve at a frequency of 0.1 (= a wave period of 10 sec) means that a large fraction of the total wave energy is arriving via waves of 10 second period. If a second peak is present at a frequency of 0.12, then an additional subset of the total energy is associated with waves of 8 second period, and so on. For the purposes of this report, a representative subset of power spectral density plots is shown. They highlight a common pattern among measurement intervals where sea state conditions were characterized by longer period swell, which are the focus here given that such longer-period waves are the ones that typically induce the most severe episodes of coastal erosion (see, e.g., Dayton et al. 1989; Seymour et al. 1992).

In marked contrast to the results for currents, where the presence of kelp has an order of magnitude effect on velocity attenuation (Fig. 3), differences in wave spectra with or without kelp are far more minor. Figure 5 shows three sets of data pairings (i.e., in absence and presence of kelp), which represent incident wave conditions of peak wave periods ranging from 14 to 16 seconds (i.e., longer period swells). Wave conditions offshore of the kelp habitat, as seen in the left panels of each data pair (Fig. 5 a-c), are similar in the absence and presence of kelp. It is within the bottom right panel that an effect of kelp would manifest, however, unlike what was seen in the case of currents, the inshore wave conditions do not differ obviously between those in the absence and presence of kelp. Based on data like those of Fig. 5, which reveal power spectral density plots in the presence or absence of kelp that are visually indistinguishable, forests of *Macrocystis pyrifera* appear to have a limited capacity to damp waves and are unlikely to be a panacea for protection against coastal erosion. That said, a low to modest benefit of giant kelp forests for wave energy attenuation does not negate the many other ecosystem services provided by this iconic foundation species, including provision of habitat, food, and refuge for numerous other taxa of commercial and recreational value. It should also be noted that other species of kelp, and other types of aquatic vegetation, may interact with waves in a very different fashion compared to giant kelp.

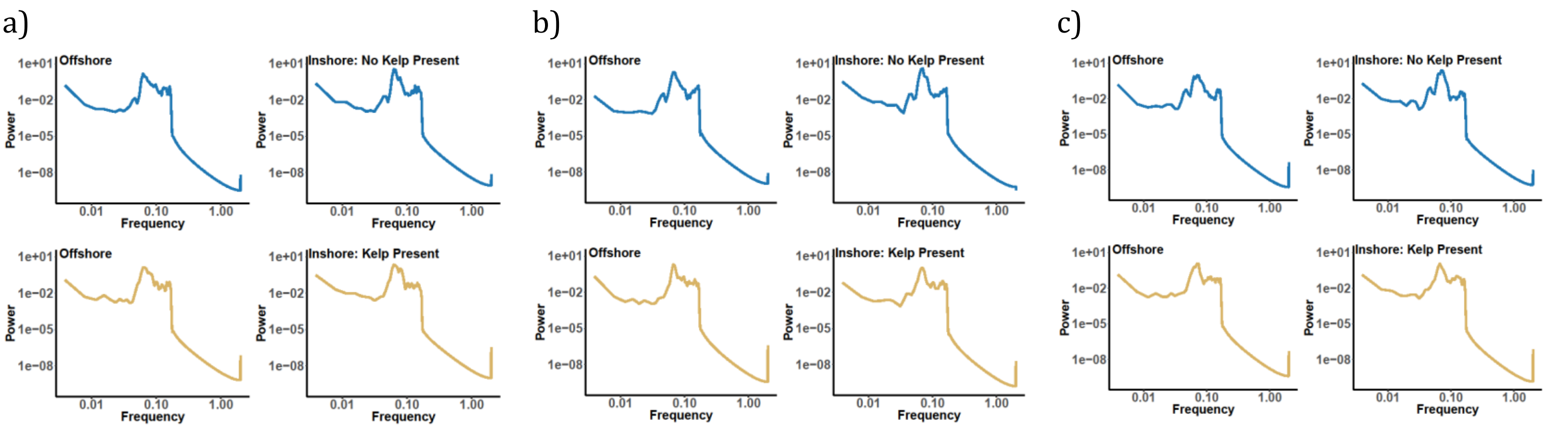


Figure 5. Three occasions of power spectra fluctuations in sea surface elevations quantified in the absence (blue) and presence of kelp (gold), inside and outside of the kelp forest habitat. Incident wave conditions were matched as much as possible in this first order examination to ensure comparable conditions. The similarity of the curves highlights that kelp forest habitat ("Inshore: Kelp Present") does not display a dramatic capacity to attenuate wave energy.

<u>Completed Task 4: Outreach</u>

Outreach related to this program and more generally regarding coastal management was made in conjunction with this project scope. Several presentations were made by The Bay Foundation to the United States Environmental Protection Agency and Association of National Estuary Programs, (ANEP). These included presentations at the Fall 2016 and Fall 2017 ANEP tech transfer conference, and at the Spring 2017 annual meeting of the National Estuary Program. These meetings involve the administrative and technical personnel from 28 programs operating on the Atlantic, Gulf, West Coast and Puerto Rico. These presentations emphasized and drew comparisons to other living shoreline approaches, focusing on the value of hydrodynamic research in conjunction with ecological restoration, blue carbon, and climate change adaptation. In spring 2018 The Bay Foundation presented the methods and some early results from this project via webinar, sponsored by the USEPA, focused on coastal ocean acidification and hypoxia. A similar presentation was made at the Joint Strategic Advisory Council meeting of the Southern California and Central California Coastal Ocean Observing System in the fall of 2017, with the intent of coordination amongst federal, state and academic researchers involved in coastal management and oceanographic observing, modeling and research. In February of 2017 a presentation was made at the Beach Ecology coalition at Pepperdine University engaging that network of beach managers, academic researchers and lifeguards regarding the potential benefits to coastal resilience resulting from the presence of kelp forests and their potential to reduce erosion, alter sediment transport and the damping of wave energy. In April 2018, The Bay Foundation presented to the Gulf of Farallones National Marine Sanctuary Kelp Recovery Management Group to assist them in their approaches to kelp forest systems and the sustainability of ecosystem services. Presentations to academic audiences regarding this project were made at Loyola Marymount University, in the spring of 2017, to four undergraduate classes in; environmental science, climate change, marine biology, and senior capstone. Two presentations were made at UCLA first at the Institute of Environment and Sustainability in the fall of 2017; a subsequent UCLA presentation was provided to Dr. Alison Lippman's restoration ecology course in the spring quarter 2018. In spring 2018, The University of Southern California invited The Bay Foundation to an environmental seminar series advertised to the entire campus, roughly 80 students and faculty were present. Furthermore the method and experimental design as well as early results of this project's efforts were presented at the Southern California Academy of Sciences Annual Meeting at California State Polytechnic University, Pomona. In May 2018 Kristen Elsmore and Tom Ford jointly presented this project to the Southern California Society of Environmental Toxicology and Chemistry at Loyola Marymount University. In July 2018, Kristen Elsmore presented findings from this project at the Phycological Society of America at University of British Columbia. And most recently, Kristen Elsmore presented findings from this project at the Western Society of Naturalists annual meeting in Tacoma Washington.

Less substantive updates and progress reporting regarding this project have been provided to the Santa Monica Bay National Estuary Program Management Conference, via quarterly newsletters, as a part of the director's report at committee meetings and in semi-annual progress reports to the USEPA. Lastly, a group of students from UCLA IoES chose this project as a "client" for their senior practicum in spring 2017. The intention of this project and the need for greater spatial understanding for the heterogeneity of dissolved carbon dioxide at the surface and at depth within kelp forests resulted in a few surveys off the coast of Palos Verdes indicating that giant kelp may elevate pH levels in the ocean water adjacent to the kelp. It was a great effort by these students and a line of research that is still in development between the investigators involved in this project and others at UCLA.

Project Budget

Proposed Budget

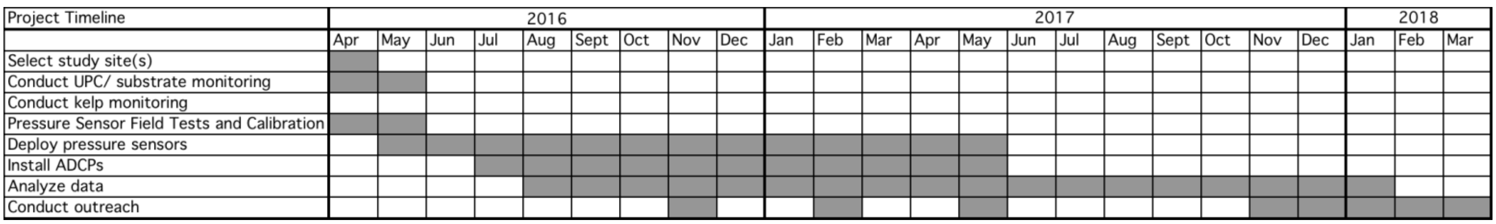
Personnel	SCC Funding	Dolby Funding	EPA 320 Funds
Task 1 Project Management	$ 7,999.92		
Task 2 Identify and Monitor Study Sites	$ 29,750.75		$ 3,174.00
Task 3 Reporting and Outreach	$ 3,601.60		
Supplies	$ 2,700.00		
Contractual	$ 11,946.76	$ 2,000.00	
Services	$ 6,500.00		$ 3,500.00
Travel			$ 684.00
Indirect	$ 6,249.90		
Total	$ 68,748.93	$ 2,000.00	$ 7,358.00
Project total	$ 78,106.93		

Final Budget

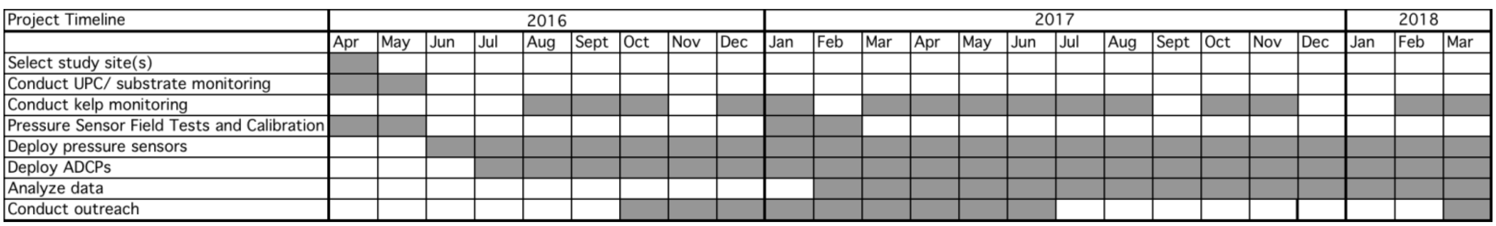
Personnel	SCC Funding	Dolby Funding	EPA 320 Funds
Task 1 Project Management	$ 7,375.94		
Task 2 Identify and Monitor Study Sites	$ 29,913.73		$ 3,338.88
Task 3 Reporting and Outreach	$ 3,601.60		
Supplies	$ 2,187.94	$ 9.29	
Contractual	$ 12,718.34	$ 1,992.82	
Services	$ 6,700.00		$ 3,700.00
Travel			$ 324.57
Indirect	$ 6,249.90		
Total	$ 68,747.45	$ 2,002.11	$ 7,363.45
Project total	$ 78,113.01		

Schedule of Completion

<u>Proposed Schedule of Completion</u>



<u>Final Schedule of Completion</u>



Acknowledgements

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