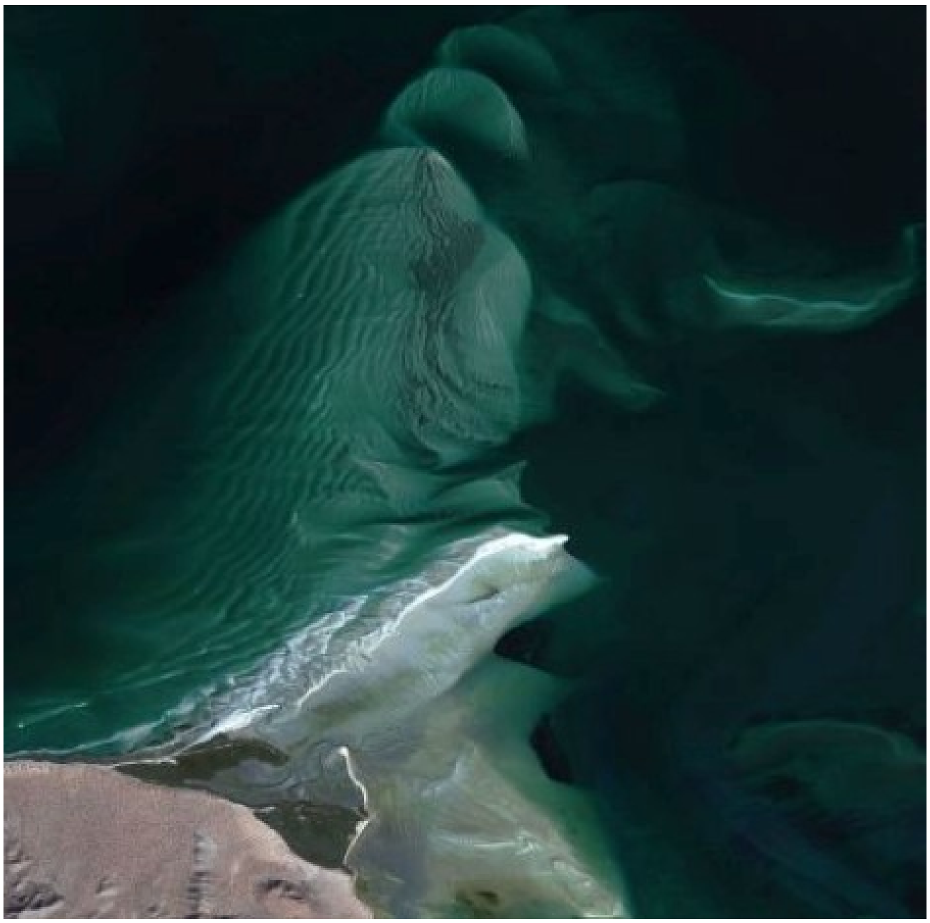
Infiernillo Strait,
Sonora, MEXICO
March 2015

Oceanographic Field Study *Infiernillo* Strait (IS), Sonora, Mexico

March 2015



Prepared by: Eccosolution, LLC

www.eccosolution.com
info.eccosolution@gmail.com

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The focus of this study is the Canal del *Infiernillo*, or *Infiernillo* Strait, as referenced in this report and abbreviated to "IS." The **Gulf of California** (also known as the **Sea of Cortés** ["SOC"], as referenced throughout this report) is a body of water that separates the Baja California Peninsula from the Mexican mainland. It is bordered by the states of Baja California, Baja California Sur, Sonora, and Sinaloa—with a coastline of approximately 4,000 km (2,500 mi). Rivers flowing into the Gulf of California include the Colorado, Fuerte, Mayo, Sinaloa, Sonora, and Yaqui. The gulf's surface area is about 160,000 km^2 (62,000 square miles)[1].

The Gulf is thought to be one of the most diverse seas on the planet, and provides habitat to more than 5,000 species of microinvertebrates.[2] With over a million people, Baja California is one of the longest peninsulas in the world, second only to the Malay Peninsula in Southeast Asia.[3] The Gulf of California is a UNESCO World Heritage Site. For the purposes of this report, the following nomenclature is used: SOC stands for Gulf of California (Sea of Cortés), and PO for Pacific Ocean.



Sección-1: Resumen Ejecutivo, Determinaciones, y Recomendaciones

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At the request of *Tiburón Agua y Electricidad*, SA de CV and partners Kenneth Lampner, Martín Jeffers and José Heliodoro Enríquez, Eccosolution, LLC planned and completed an Oceanographic Field Survey to establish baseline data for tidal currents and discharge in the *Infiernillo* Strait (IS). The field survey and logistical preparation was completed from March 2 to March 23, 2015. The Draft Final Report was presented on April 6, 2015.

The field survey team (consisting of Roger Bason - Coordinator, Julio Aguirre - Electrical Engineer, and Robert Leitner - Field Technician), was ably assisted with field and logistical support by *Tiburón Agua y Electricidad* (*Tiburón* SA). Both Martín Jeffers, Sr. and Jr. participated in onboard data collection. *Tiburón* S.A. provided two (2) vessels for the completion of field data gathering and research: a 50-ft *Toropez* (Captained by Marco-) and the 20-ft *Sparky* (Captained by Ernesto-). Carlos-, assisted by his two sons Carlos and Alejandro, provided onshore logistical support. Dr. Thomas Goreau carried out onshore interviews of the Seri Indians and professional Mexican Marine biologists, as well as visual, video and photo reconnaissance of the southern zones of the *Infiernillo* Strait. These observations are to be interpreted with respect to the potential for bio-remediation of the stressed and endangered Sea of Cortés ecosystem and fisheries using BIOROCK® technology. Dr. Goreau is the co-inventor of BIOROCK®, and serves as President of the Global Coral Reef Alliance.

The purpose of this oceanographic survey is to provide measurements of the physical oceanographic parameters supporting technical, engineering and, ultimately, financial analyses for the generation of energy from discharge, tidal current, and wave activity within the project area. The survey provides baseline numbers for future comparisons with data collected over the seasonal spectrum in order to facilitate an understanding of the daily, monthly, seasonal and annual cycles of tidal flow and discharge in the IS.

The report is presented in seven (7) sections, as follows:

Section-1. Executive Summary, Findings, and Recommendations

Section-2. Oceanographic Context: Sea of Cortés (SOC)

Section-3. Aerial Survey

Section-4. Discharge Summary (Q)

Section-5: Hotspots - Tidal Current Speed (velocity m/s)

Section-6. All Transects - USGS and Data Summary

Section-7. Appendix

Findings

The field survey, conducted during March 2015, provides baseline data necessary for further study of the waterway. A total of 17 transects was completed during the field survey. This information is presented (a) as selected overview graphic and tabular summaries in **Section-4: Discharge (Q)**; and (b) in **Section-6**: **All Transects - USGS and Data Summary,** as detailed pages presented in USGS and screen capture formats**;** and (c) in **Section-7: Appendix**, as the actual raw data collected from each field transect. The raw data files provide over 400 values or data types for each data point in each X-section or transect. This report presents an overview of the critical data in a way that condenses and summarizes the most relevant critical values. It also selects and simplifies the information so that it may be best understood and applied to the stated needs and purposes of current phase of *Tiburón* project development.

In addition to the summaries of transect and X-section information, a total of fourteen (14) hotspots or areas of high tidal flow speeds were identified and presented as mapped locations, and in tabular form, in **Section-5: Hotspots - Tidal Current Speed (velocity m/s)**. These hotspots were identified in the north and south ends of the IS, where channel constrictions serve to focus and accelerate the water currents and flow speed. These higher velocity locations are generally considered to have the highest velocity readings, in each of several key transects. As such, the intent is to provide a summary of information and not an inclusive list of all high speed areas (see **Appendix**). The two locations evaluated include (a) an area approximately 10 km long by 2.5 km wide at the south end of the IS and, (b) at the north end of the IS, an area approximately 7.5 km long and 10 km wide. High-speed values taken from key transects range from a low record of 0.6 m/s to 4.017 m/s (the highest value of water speed recorded). The north and south ends of the IS would seem to be the most likely areas for tidal energy development, as they have registered the highest water speeds as well as channels deep enough to support the deployment of mechanisms as either floating or submerged tidal energy structures.

Channel depths evaluated from the 17 transects vary from the most shallow channel depth of 2.5m (Transect 7) in the Zone 2 part of the IS, which is slightly north of *Puerto Chueca* to the deepest channel locations both of which were measured at 23m. Included among the deep channels are Transect 11, between *Isla Patos* and *Punta Tepopa* in the North IS, and Transect 6—also located slightly North of Puerto Chueca. The highly variable depths of the IS can be observed by reviewing **Section-3: Aerial Survey** photos that reveal the complex forms of shifting sand bars. These features are caused by wind and wave action on geological shoreline structures at both the North and South ends of the IS, resulting in sand particles of varying size, composition and density being deposited within the channel itself. The underlying bedrock is primarily ancient Paleozoic metamorphic "hard rock that has been subjected to intermittent volcanism and the shearing of the San Andreas Fault. The strong currents and ongoing erosion results in several fine-grained beaches along the IS shoreline, and shifting sand bar structures of complex design, shape and depth within the IS itself.

Recommendations

1. Additional field survey work could provide an “annual picture” and more precise data on seasonal variations in the IS.

2. Such field operations would proceed from an informed position regarding a) the navigational opportunities in the IS as indicated by the Seri Indian guide, (b) the channel depth data acquired during the March 2015 Field Survey, and (c) the aerial photos that reveal sandbar shapes and channel passages. Analysis and use of these sources is highly recommended during future research and data gathering.

3. While ongoing data gathering is highly recommended on a monthly basis during the course of a full year, a critical time for data collection would be during annual high tidal flow times—particularly during July, August, September and October.

4. Additional recommended types of data acquisition include the use of (a) bathymetric profiling equipment; (b) underwater video of the seabed; (c) investigation of the seabed composition though selective grab sampling; (d) more detailed wind data collection; (e) long term monitoring of tidal current speeds using "up-looking" ADCP equipment mounted on the seabed for 1 to 3 months; (f) additional discharge measurements and channel transects during the summer months of greater tidal flow; and (g) wave measurements during several months of the year—if not year round—to provide for potential power generation values and related financial feasibility analysis.

5. Should pursuit of ocean energy systems be made in the future, an effort to establish an ocean research station, along with infrastructure to support this research and power off-take, would be indicated.

Section-2: Oceanographic Context: Sea of Cortez (SOC)

The information presented in this report cannot be fully comprehended without an understanding of the several complex contributing factors that affect the tidal currents and water flows in the *Infiernillo* Strait (IS) within a broader regional context. The SOC is a unique waterway in comparison with similarly situated enclosed seas around the world (Figure-2-1). Nine (9) factors influence water flows throughout the SOC, and consequently affect IS flow patterns to a greater or lesser extent.[4] These include:

1. Tidal mixing, which has a greater impact on flow patterns than temperature and salinity.

2. A pattern of overall tidal mixing in the Sea of Cortés, resulting in an outflow from the top 200m of the water column and an inflow from deeper levels.

3. Seasonally reversing surface layer patterns (Figure-2-2). Flowing moderately clockwise in winter, spring and fall, surface layers reverse in summer into a strong, counterclockwise flow. This factor contributes to the occasional violence and turbulence of IS tidal patterns.

4. Seasonal changes and reversing flow patterns are due to impacts imposed by major changes in PO regional currents at the southern end of the SOC. As the PO influences the flow of SOC tides, it is the source that generates unusual sub-inertial and trapped waves that resonate along the entire SOC. The PO also imposes annual variations due to the irregular impacts of *El Niño*. PO influences are stronger than seasonal wind direction, or water density issues related to temperature or salinity.

5. Local processes that include (a) variable wind direction; (b) complex, shifting and irregular channel geomorphology or bathymetric shape, as well as (c) the interaction of tidal flows within the channel—all produce short-lived impacts.

6. Solitary waves (also called "solitons") are a unique phenomenon that can also manifest as wave packets and are known to resonate at various depths and intensities in the SOC.

7. During the Summer months of July, August, September and October, currents flow along the mainland coast of Mexico (eastern shore of the SOC) and generate stronger coastal waves.

8. SOC currents and waves are impacted by recurring winter patterns of winds from the north. During the March 2015 field study, significant wind came from the SE, S, SW, W and North at various times during the seven-day period from March 16 to March 22—which may be considered atypical for the month of March.

9. *El Niño* also impacts tidal flow patterns by causing inter-annual anomalies.

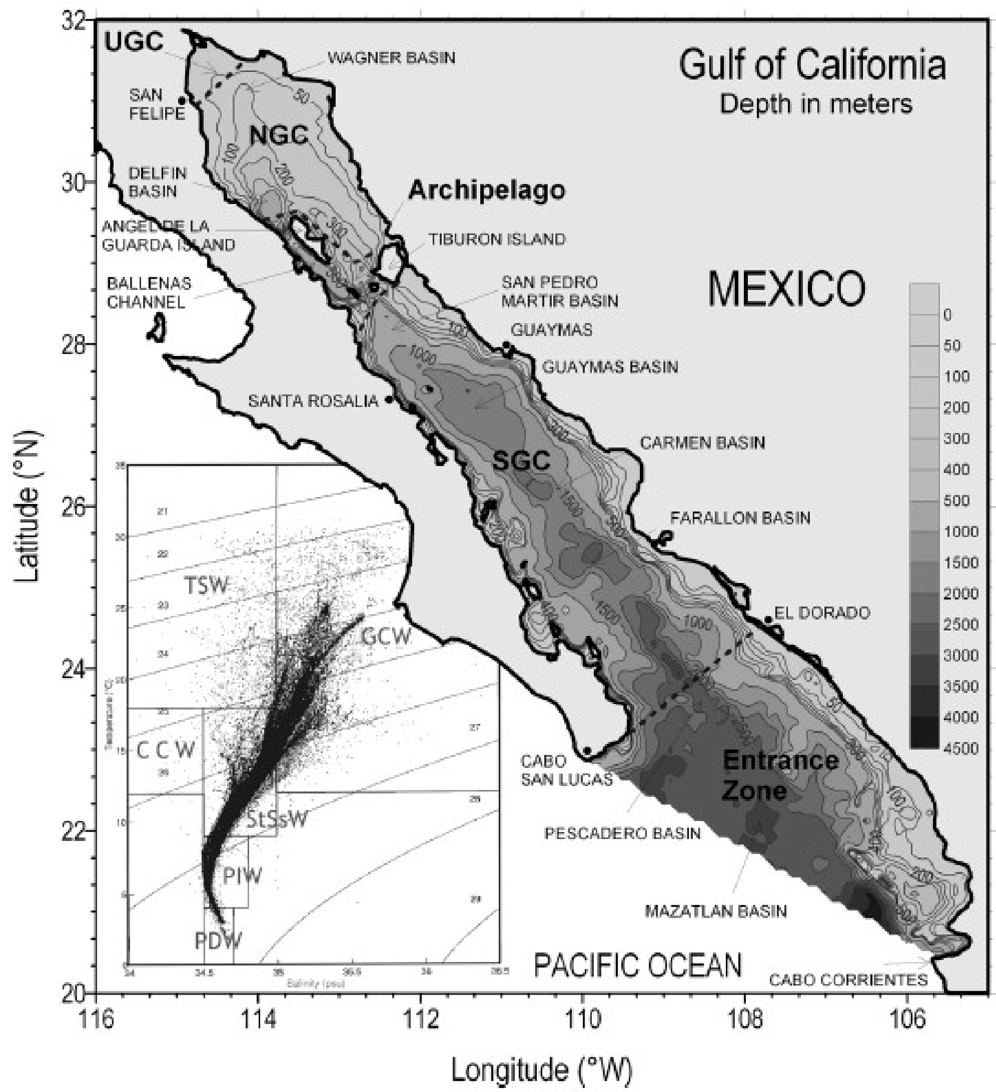

Figure-2-1. Overall depth and bathymetry of the SOC. Water depths of 4,500m at the south entrance of the SOC are funneled into the Archipelago, *Tiburón* Island and the *Infiernillo* Strait (IS). Depths in the IS range from <1m to 17m and greater. (Figure conforme con Lavin and Marinone)

This funneling effect—based on the geomorphology and bathymetry (shape and contour of the seabed), along with the circulation patterns as described in Figures 2-2, 2-3 and 2-4—significantly impacts the speed, discharge, volume, and prevailing direction, of the flow of tidal and water currents in the IS.

The graph in **Figure-2-3** indicates that the lowest annual current flow speeds in the IS occur in the month of March.

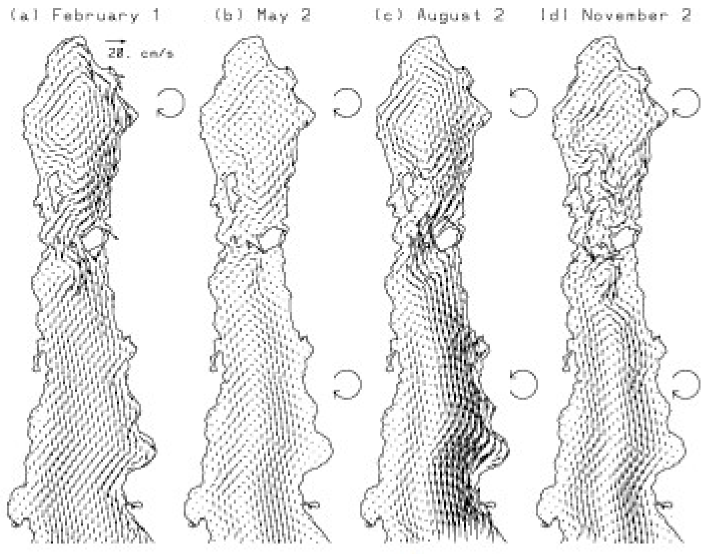

Figure 2-2. Seasonal Flow patterns are clockwise or counterclockwise.
(Figure after Lavin and Marinone)

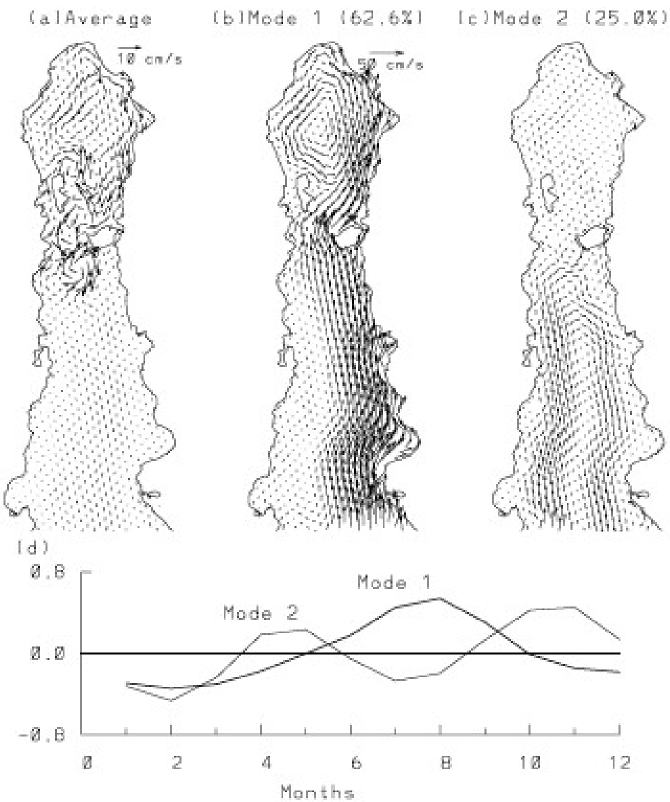

Figure-2-3. Strong counterclockwise flows are more frequent (62.6%). However, during March, these flow speeds approach an annual minimum (see graph at bottom).

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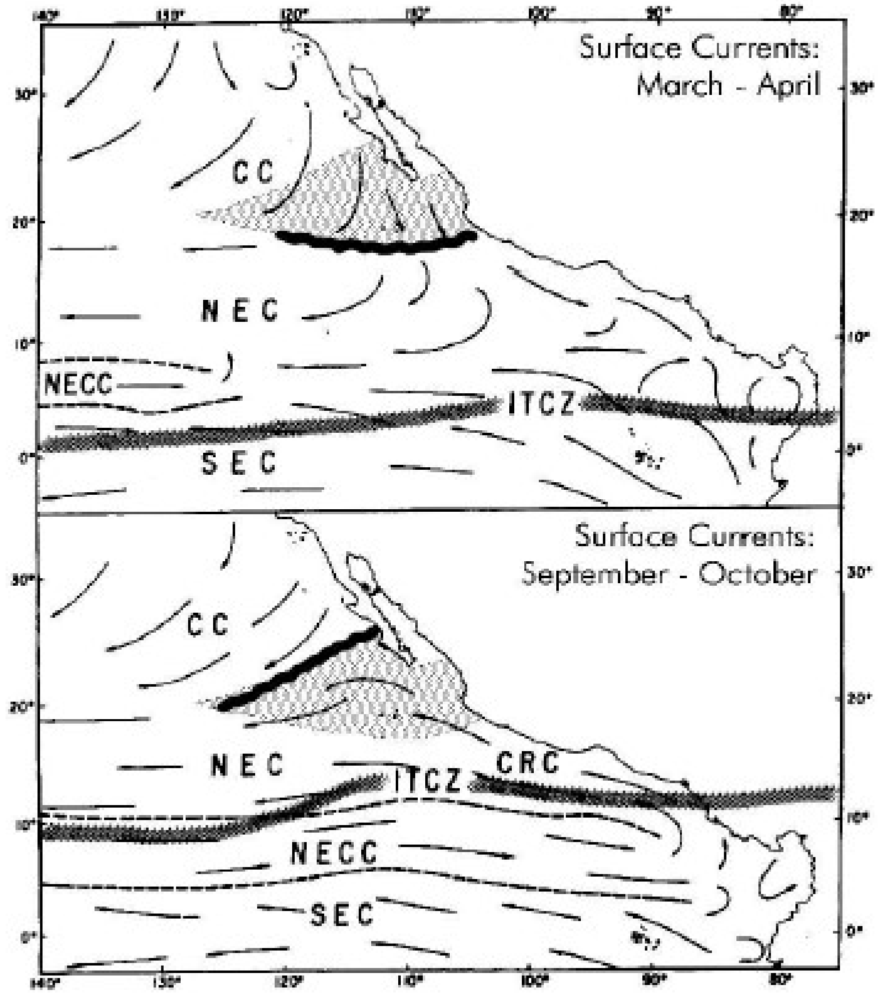

Figure-2-4. The Surface currents in the Eastern Tropical Pacific are presented in (a) March-April and (b) September-October. The limits of the California Current in (a) and (b) are indicated with a wavy band. (Based on the work of Wyrtki [1965], and Baumgartner and Christensen [1985].) Arrows indicate the main surface currents:

SEC = South Equatorial Current
NECC = North Equatorial Counter Current
NEC = North Equatorial
Current
CRC = Costa Rica Current
CC = California Current
ITCZ = Inter-Tropical Convergence Zone

Note that the impact of the southerly trend of the CC in March-April (*a* - above) fosters the clockwise circulation pattern of tidal currents in the SOC, as per Figure-2-2. The retreat of the CC during September-October (*b* - above) indicates the prevailing influence of the CRC during these months, and moves SOC tidal currents into a counterclockwise movement, as per Figure-2-2 (c).

Endnotes:

[1]Wikipedia. "Gulf of California." www.en.wikipedia.org/wiki/Gulf_of_California.

[2]Campos, Ernesto, Alma Rosa de Campos, & Jesús Angel de León-González (2009). *Diversity and ecological remarks of ectocommensals and ectoparasites (Annelida, Crustacea, Mollusca) of echinoids (Echinoidea: Mellitidae) in the Sea of Cortez, Mexico*. Parasitology Research. **105** (2): 479–487.

[3]Richard C. Brusca (1973). *A Handbook to the Common Intertidal Invertebrates of the Gulf of California*. Tucson, Arizona: University of Arizona Press. pp. 10–15.

[4]Lavin, M.F. & S.G. Marinone. *An Overview of the Physical Oceanography of the Gulf of California: Nonlinear Processes in Geophysical Fluid Dynamics*, 173-204. Kluwer Academic Publishers. 2003.

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