Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region

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Annual Summary Report

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Ocean Imaging

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1. INTRODUCTION AND PROJECT HISTORY

In the 1990s, Ocean Imaging Corporation (OI) received multiple research grants from NASA's Commercial Remote Sensing Program for the development and commercialization of remote sensing applications in the coastal zone. As part of these projects, OI developed methods to utilize various types of remotely sensed data for the detection and monitoring of stormwater runoff and wastewater discharges from offshore outfalls. The methodology was initially demonstrated with collaboration of the Orange County Sanitation District in California (Svejkovsky and Haydock, 1998). The NASA-supported research led to a proof-of-concept demonstration project in the San Diego, California region co-funded by the EPA in 2000. Those results led, in 2002, to adding an operational remote sensing-based monitoring component to the San Diego region's established water quality monitoring program. The project continues as a joint effort between the Ocean Monitoring Program of the City of San Diego's Public Utilities Department (SDPUD) and the International Boundary and Water Commission (IBWC).

The first phase of the project was a historical study utilizing several types of satellite data acquired between the early 1980s and 2002. The study established the prevailing near-surface current patterns in the region under various oceanic and atmospheric conditions. The current directions were deduced from patterns of turbidity, ocean temperature and surfactant slicks. In some cases, near-surface current velocity could be computed by tracking recognizable color or thermal features in time-sequential images. The historical study thus established baseline data for the region's current patterns, their persistence, their frequency, and the historical locations, size and dispersion trajectories of various land and offshore discharge sources from Publicly Owned Treatment Works (POTW) (e.g., the offshore outfalls, Tijuana River, Punta Bandera Treatment Plant discharge in Mexico, etc.).

The prime objectives of the project have expanded somewhat since its inception. Initially, emphasis was on utilizing the image data to discern and monitor surface and near-surface signatures from the South Bay Ocean Outfall (SBOO) and Point Loma Ocean Outfall (PLOO), separate them from other nearshore point and non-point runoff features, and monitor their locations, extents, and potential impact on the shoreline. Prior to this project, the spatial extents of the plumes could only be estimated from a relatively sparse spatial grid of field samples, which made it difficult to separate, for example, the SBOO near surface plume from the Tijuana River runoff plume. This ambiguity made it difficult, in turn, to objectively evaluate the potential contribution, if any, of the SBOO plume to beach contamination along the nearby shoreline. The satellite and aerial imagery helped directly establish the dispersal trajectories of the SBOO effluent during months when it reaches the near-surface layer and support the claim that it likely never reaches the surf zone.

In October 2002, the operational monitoring phase of the project was initiated using the variety of satellite- and model-derived datasets discussed below. Over the past five to ten years, the project's objectives have broadened from focusing primarily on the outfalls to also provide larger-scale, regional observations of the physical and biological patterns and processes affecting the San Diego County and Tijuana River discharge regions. It is this broader-view perspective that led to the creation of supplementary image products from additional sensors and sources for the SDPUD.

This report summarizes observations made during the period 1/1/2023 – 12/31/2023.

2. METHODS AND TECHNOLOGY OVERVIEW

OI uses several remote sensing technologies to monitor San Diego's offshore outfalls and shoreline water quality. Their main principle is to reveal light reflectance and heat emission patterns that are characteristic of the different discharges, water masses, plankton blooms and suspended sediment loads. Most often this is due to specific substances contained in the effluent but absent in the surrounding water.

2.1 Imaging in the UV-Visible-Near Infrared Spectrum

This is the most common technique used with satellite and aerial images. Wavelengths (colors) within the range of the human eye are most often used but ultraviolet (UV) wavelengths are useful for detecting fluorescence from petroleum compounds (oil, diesel, etc.) and near-infrared (near-IR) wavelengths can be useful for correcting atmospheric interference from aerosols (e.g., smog and smoke). Near-IR wavelengths are also highly reflected from kelp seaweeds, so such data are particularly useful for delineating the region's kelp beds and monitoring their extents through time.

The best detection capabilities are attained when several images in different wavelengths are acquired simultaneously. These "multispectral" data can be digitally processed to enhance features not readily visible in simple color photographs. For example, two such images can be ratioed, thus emphasizing the water features' differences in reflection of the two specific wavelengths. A multi-wavelength image set can also be analyzed with multispectral classification algorithms which separate distinctive features or effluents based on the correlation relationships between the different color signals.

The depth to which the color sensors can penetrate depends on which wavelengths they see, their sensitivity and the general water clarity. In the San Diego region, green wavelengths tend to reach the deepest and UV and near-IR wave-lengths penetrate the least. Generally, OI's satellite and aerial sensor data reveal reflective features in the upper one to fifteen meters of the ocean.

2.2 Imaging in the Thermal Infrared Spectrum

Some satellite and aerial sensors image heat emanating from the ground and the ocean. They thus reveal patterns and features due to their differences in temperature. Since thermal infrared (TIR) wavelengths are strongly absorbed by water, the images reveal temperature patterns only on the water's surface. Such images can help detect runoff plumes when their temperatures differ from the surrounding ocean water. Runoff from shoreline sources tends to be warmer than ocean water, although the reverse can be true during the winter. Plumes from offshore outfalls can sometimes also be detected with thermal imaging. Since the effluent contains mostly fresh water, it is less dense than the surrounding salt water and tends to rise towards the surface. How far it rises depends on outfall depth, ocean currents, and stratification conditions. If it makes it all the way to the surface, it is usually cooler than the surrounding sun-warmed surface water. A plume signature detectable in multispectral color imagery but not detectable in simultaneously collected TIR imagery indicates the rising plume has not reached the actual ocean surface and remains submerged.

2.3 Satellites and Sensors Utilized

Until 2010, the project relied heavily on acquisition of multispectral color imagery with OI's DMSC-MKII aerial sensor and TIR imagery from a Jenoptik thermal imager integrated into the system. These aerial image sets were most often collected at 2m resolution. The flights were done on a semi-regular schedule ranging from one to two times per month during the summer to once or more per week during the rainy season. The flights were also coordinated with the City of San Diego's regular offshore field sampling schedule so that the imagery was collected on the same day (usually within two to three hours) of the field data collection. Additional flights were performed on an on-call basis immediately after major storms or other events such as sewage spills. In late 2010, OI negotiated a special data collection arrangement with Germany's RapidEye Corporation and this project began utilizing their multispectral imagery in lieu of most of the aerial Digital Multispectral Camera (DMSC) image acquisitions. The use of satellite as opposed to aerial data also enables a more regionally contiguous monitoring of events affecting the target areas. In late 2019 the RapidEye satellite constellation was decommissioned by the current operator Planet Labs. Subsequently, OI secured the regular acquisition of SPOT 6 and SPOT 7 satellite imagery covering the same geographical area beginning in 2020. Tables 1a and 1b list the properties of the remote sensing image sources routinely used during the project.

Beginning in 2017, OI also began processing and posting imagery from the Sentinel-2A satellite. Sentinel-2A is a satellite operated by the European Space Agency (ESA) and is the spaceborne platform for the Multispectral Instrument (MSI). The Sentinel-2A and 2B MSIs sample 13 spectral bands: four bands at 10 meters, six bands at 20 meters and three bands at 60-meter spatial resolution. The green band focusing in the 560 nm wavelength is ideal for detecting turbidity plumes from the outfalls both at the surface and at depths down to 15 meters depending on ocean conditions. The revisit time of the Sentinel-2A satellite is approximately ten days. A second satellite carrying the MSI sensor, the Sentinel-2B, was launched into orbit by the ESA and provided the first set of data from the MSI sensor as of March 17, 2017. Beginning in 2018, data from Sentinel 2B became a regular addition to the satellite imagery products posted to the OI web portal. On average the Sentinel 2A and 2B imagery processed to highlight anomalous turbidity signals emanating from the PLOO, SBOO, as well as the discharge from the Tijuana River (TJR) and San Diego River (SDR) are posted to the OI web portal within 24-36 hours of satellite data acquisition. In some cases, if the data are available to OI earlier, the image products are delivered as quickly as 12 hours post-acquisition. During 2023 the Sentinel 2A and 2B satellites provided the most temporally comprehensive set of high-resolution satellite imagery. In total, 77 high resolution satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2023. This equates to a 34% decrease in satellite data used to document the area when compared to 2022 – most probably due to more instances of total cloud cover over the study area. Of the 77 total image sets, 48 were from Sentinel 2A or 2B data making up 62% of the high-resolution satellite data processed and posted as part of the project, a 7% decrease from 2022.

In October 2018, OI began using imagery from Sentinel-3A. Shortly thereafter, in December 2018 imagery from Sentinel-3B was incorporated into the mix of observation platforms. Like Sentinel 2, Sentinel-3A and Sentinel-3B are earth observation satellites developed by the ESA for the Copernicus Program. Sentinel-3A was launched on February 16, 2016, and Sentinel-3B followed on April 25, 2018. The 3A and 3B satellites are identical and deliver products in near-real time. The satellites include four different remote sensing instruments. The Ocean and Land Colour Instrument (OLCI) covers 21 spectral bands (400–1020 nm) with a swath width of 1270 km and a spatial resolution of 300 m. Sea and Land Surface Temperature Instrument covers 9 spectral bands (550–12 000 nm), using a dual-view scan with swath widths of 1420 km (nadir) and 750 km (backwards), at a spatial resolution of 500 m for visible and near-infrared, and 1 km for thermal infrared channels. The Sentinel 3 mission's main objectives are to measure sea surface topography along with the measurement of ocean/land surface temperature and ocean/land surface color. One of the satellites' main secondary missions is to monitor sea-water quality and marine pollution. The instrument on these satellites designed for these purposes is the OLCI. Ocean Imaging creates daily products dependent on cloud cover for the entire San Diego/Tijuana region using the OLCI instrument. Between the 3A and 3B satellites this results in better than daily coverage with 3A and 3B data occasionally both being available on the same day. True color, near infrared, products are posted bi-monthly along with the similar resolution MODIS products. Possible future products derived from the Sentinel 3 sensors include total suspended matter, chlorophyll, and sea surface temperature as well as cyanobacteria monitoring. Sentinel 3 carries the only satellite sensor package with the necessary spectral bands, spatial resolution, and coverage for near real-time detection of cyanobacteria.

As stated above, the RapidEye satellites were decommissioned in late 2019 and replaced by data from the SPOT 6 and SPOT 7 satellites in January of 2020. The two SPOT satellites/sensors are identical in design and function. They both image in spectral bands similar to the RapidEye satellites at a ground sampling distance of 8.8 meters for the multispectral data (see Tables 1a and 1b). The dynamic range of these sensors is 12-bits per pixel. OI uses the blue, green, red, and near-infrared bands from these sensors. Empirically we have found that the SPOT data have a high signal to noise ratio and therefore produce a high-quality product for detecting wastewater surface manifestations and delineating the river run-off plumes. In March of 2023, the SPOT 7 satellite stopped functioning, however we continue to receive data from SPOT 6 and are able to acquire roughly two to four clear images per month from this sensor. Figure 1 shows a set of images from 01/18/23, 01/19/23 and 01/20/23 from Landsat 9, SPOT and Sentinel 2 following significant rain events that impacted the region between 01/15/23 and 01/20/23 - highlighting the ability to obtain high-resolution imagery from multiple satellites on the same and successive days. Note the heavy

Table 1a. Satellite sensors utilized in the project and their characteristics.

Sensor	Utilization Period	Resolution (m)	Utilized Wavelength Range
AVHRR	2003 - Present	1100	Channel 4: 10.30 – 11.39 um Channel 5: 11.50 – 12.50 um
MODIS	2003 - Present	250/500/1000	Band 1 (250 m): .620 – .670 um Band 2 (250 m): .841 – .876 um Band 3 (500 m): .459 – .479 um Band 4 (500 m): .545 – .565 um
Landsat TM/ETM+ 4-7	2003 - Present	30 (visible - Near-IR) 60 (Thermal-IR)	Band 1: .450 - .520 um Band 2: .520 - .600 um Band 3: .630 - .690 um Band 4: .760 - .900 um Band 6: 10.40 - 12.50 um (TM5 Thermal not used due to noise)
Landsat 8 OLI, TIRS	2013 - Present	30 (visible - Near-IR) 100 (Thermal-IR)	Band 2: .452 - .512 um Band 3: .533 - .590 um Band 4: .636 - .673 um Band 5: .851 - .879 um Band 10: 10.60 - 11.19 um Band 11: 11.50 - 12.51 um
Sentinel 2A/2B	2017 - Present	10 (visible - Near-IR) 60 (Vegetation Red Edge) 60 (UV, SWIR)	Band 1: .443 um Band 2: .490 um Band 3: .560 um Band 4: .665 um Band 5: .705 um Band 6: .740 um Band 7: .783 um Band 8: .842 um Band 8A: .865 um
Sentinel 3A/3B	2018 - Present	300 (all utilized bands)	Band Oa2: .412.5 um Band Oa3: .442.5 um Band Oa4: .490 um Band Oa5: .510 um Band Oa6: .560 um Band Oa7: .620 um Band Oa8: .665 um Band Oa10: .68125 um Band Oa11: .07875 um Band Oa17: .865 um

discharge from both the TJR and SDR helping to create the turbid offshore waters on the 18th which gradually decreases over the following three-day period. The 25-hour averaged High Frequency Radar-derived (HF Radar) ocean currents computed for a period within one to two hours of the satellite data acquisition have been overlaid on the imagery to help illustrate the surface flow patterns of the various turbidity features. A quick measurement of the movement of ten identifiable turbidity features in the fourteen minutes between the acquisition of the Landsat 9 and Sentinel 2 satellite imagery on the 18th reveals that the water emanating from the river mouths traveled at between roughly 0.4 and 0.5 meters per second (m/s). The offshore currents moved at speeds roughly 0.1 to 0.3 m/s. It should also be noted that the current directions as computed by the feature-tracking method correlate well with the currents derived from the HF Radar system.

As detailed in Tables 1a and 1b, to date, this work utilizes 1100 m resolution Advanced Very High Resolution Radiometer (AVHRR)-derived imagery (available multiple times per day), 1000 m resolution chlorophyll and sea surface temperature (SST) Moderate Resolution Imaging Spectroradiometer (MODIS)-derived imagery (available multiple times per day), 500 m resolution MODIS true color imagery (available near-daily), 750 m resolution Visible Infrared Imaging Radiometer Suite (VIIRS) chlorophyll and SST imagery (available multiple times per day), 300 m resolution Sentinel 3 color and thermal imagery (available daily), 30 m & 60 m Landsat 7 ETM+ and Landsat 8 OLI/TIRS and Landsat 9 OLI-2/TIRS-2 color and thermal imagery (each available approximately every 16 days), 10 m resolution Sentinel 2 multispectral imagery (available 2-4 times per week), and 6m

Table 1b. Satellite sensors utilized in the project and their characteristics.

Sensor	Utilization Period	Resolution (m)	Utilized Wavelength Range
VIIRS	2019 - Present	750 (all utilized bands)	Band M1: 0.402 - 0.422 um Band M2: 0.436 - 0.454 um Band M3: 0.478 - 0.488 um Band M4: 0.545 - 0.565 um Band M5: 0.662 - 0.682 um Band M6: 0.739 - 0.754 um Band M7: 0.846 - 0.885 um Band M8: 1.23 - 1.25 um Band M9: 1.371 - 1.386 um Band M10: 1.58 - 1.64 um Band M11: 2.23 - 2.28 um Band M12: 3.61 - 3.79 um Band M13: 3.97 - 4.13 um Band M14: 8.4 - 8.7 um Band M15: 10.26 - 11.26 um Band M16: 11.54 - 12.49 um
SPOT 6	2019 - Present	6	Band 1: .450 - .745 um Band 2: .450 - .525 um Band 3: .530 - .590 um Band 4: .625 - .695 um Band 5: .760 - .890 um
SPOT 7	2019 - 2023	6	Band 1: .450 - .745 um Band 2: .450 - .525 um Band 3: .530 - .590 um Band 4: .625 - .695 um Band 5: .760 - .890 um
Sentinel 1A SAR	2021 - Present	5 x 20	C-band operating at a center frequency of 5.405 GHz
Landsat 9 OLI-2, TIRS-2	Late 2021 - Present	30 (visible - Near-IR) 100 (Thermal-IR)	Band 2: .452 - .512 um Band 3: .533 - .590 um Band 4: .636 - .673 um Band 5: .851 - .879 um Band 10: 10.60 - 11.19 um Band 11: 11.50 - 12.51 um

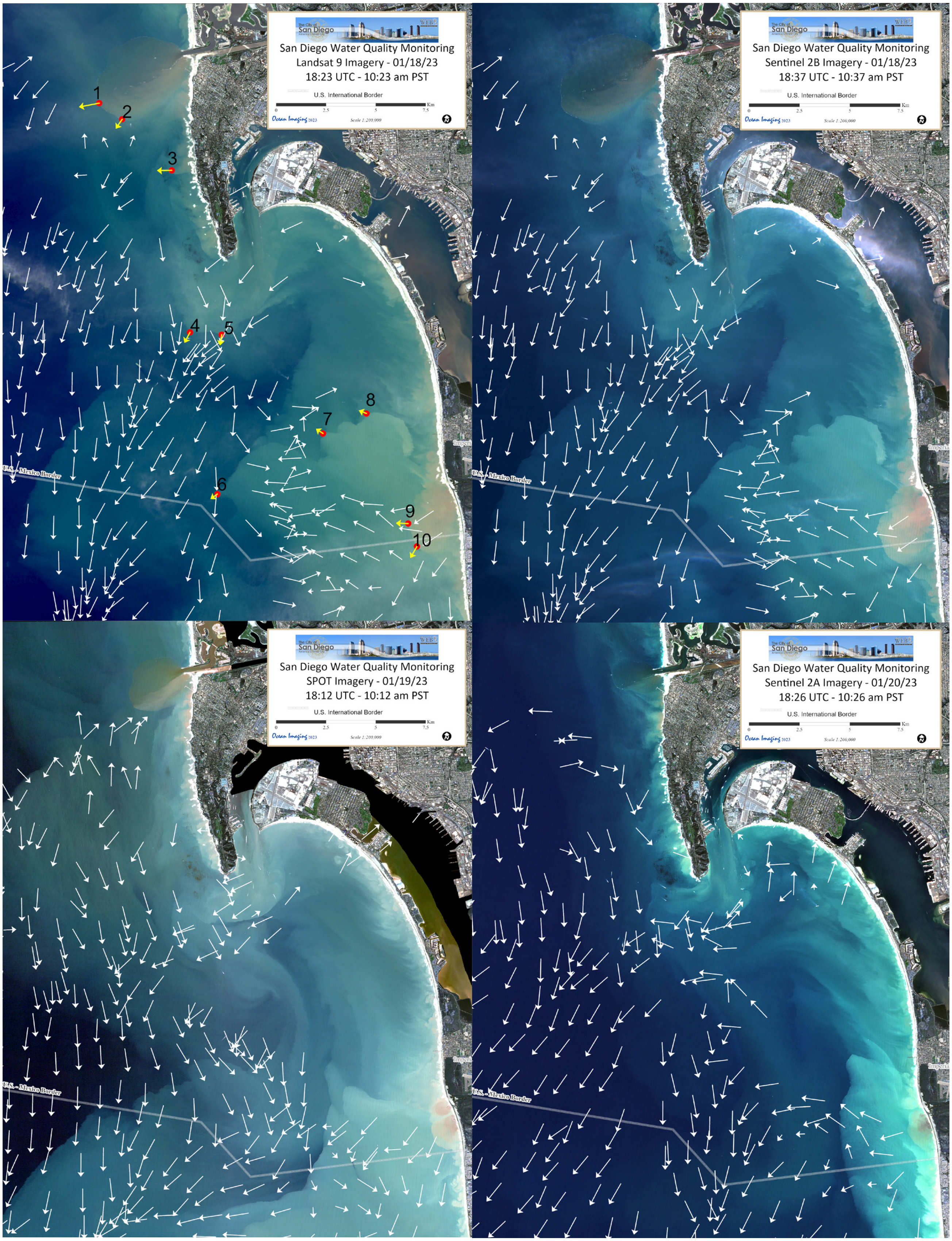


Figure 1. Landsat 9, Sentinel 2, and SPOT 6 high resolution satellite imagery from 01/18/23 to 01/20/23 with HF Radar-derived ocean currents overlaid. The top two scenes were acquired fourteen minutes apart by the Landsat 9 and Sentinel 2 satellite platforms. The top left image shows vectors (yellow) computed by tracking identifiable turbidity features in both 01/18 images and computing the distance between the successive points. By number, the distance each feature moved in the fourteen-minute period between scenes was: 1) 439.1m, 2) 244.6m, 3) 140.7m, 4) 237.9m, 5) 101.2m, 6) 160.0m, 7) 189.6m, 8) 170.5m, 9) 307.1m and 10) 312.1m. Note that most of the vector directions agree with the direction of the currents shown in the HF Radar-derived flow field.

resolution Satellite Pour l'Observation de la Terre (SPOT) 6 (available approximately every 5-7 days).

Synthetic Aperture Radar (SAR) data from the Sentinel 1A satellite (available every 3-6 days at a spatial resolution of 5m x 20 m) were added to the suite of remote sensing products in late 2021. SAR can detect surfactant films associated with natural processes (Svejkovsky and Shandley, 2001) and plumes containing anthropogenic substances (Svejkovsky and Jones, 2001, Gierach et al., 2017) when optical sensors might be limited by cloud cover or heavy atmospheric haze. The primary purpose of these satellites for this project is to provide another look at the TJR discharge plume to assess its offshore extent and direction of flow. The runoff often contains natural and anthropogenic surfactants that dampen the SAR signal and therefore make it detectable in the data. In 2023 88 SAR images were acquired and processed for the San Diego region providing an additional source of information even during cloudy conditions. Figure 2 shows a sample SAR image from 01/31/23 alongside a SPOT 7 scene from the same day highlighting a probable surfactant signature from the TJR discharge. The satellite data acquisitions were approximately 5.5 hours apart. The TJR discharge plume is clearly identifiable in the SPOT image (right) and, although different in shape and extent due to the time difference of the satellite acquisitions, it corroborates the supposition that the dampened SAR signal (seen in the area outlined by a yellow box in right image) identifies river discharge with a high composition of surfactants. Figure 3 illustrates a situation when on 02/13/23 there was no clear visible satellite data to document the TJR discharge plume, yet the SAR image provides data to show the extent of the plume likely containing surfactant-laden water. A SPOT 6 image acquired two days later offers a clear view of the strong discharge and highly turbid water moving up the

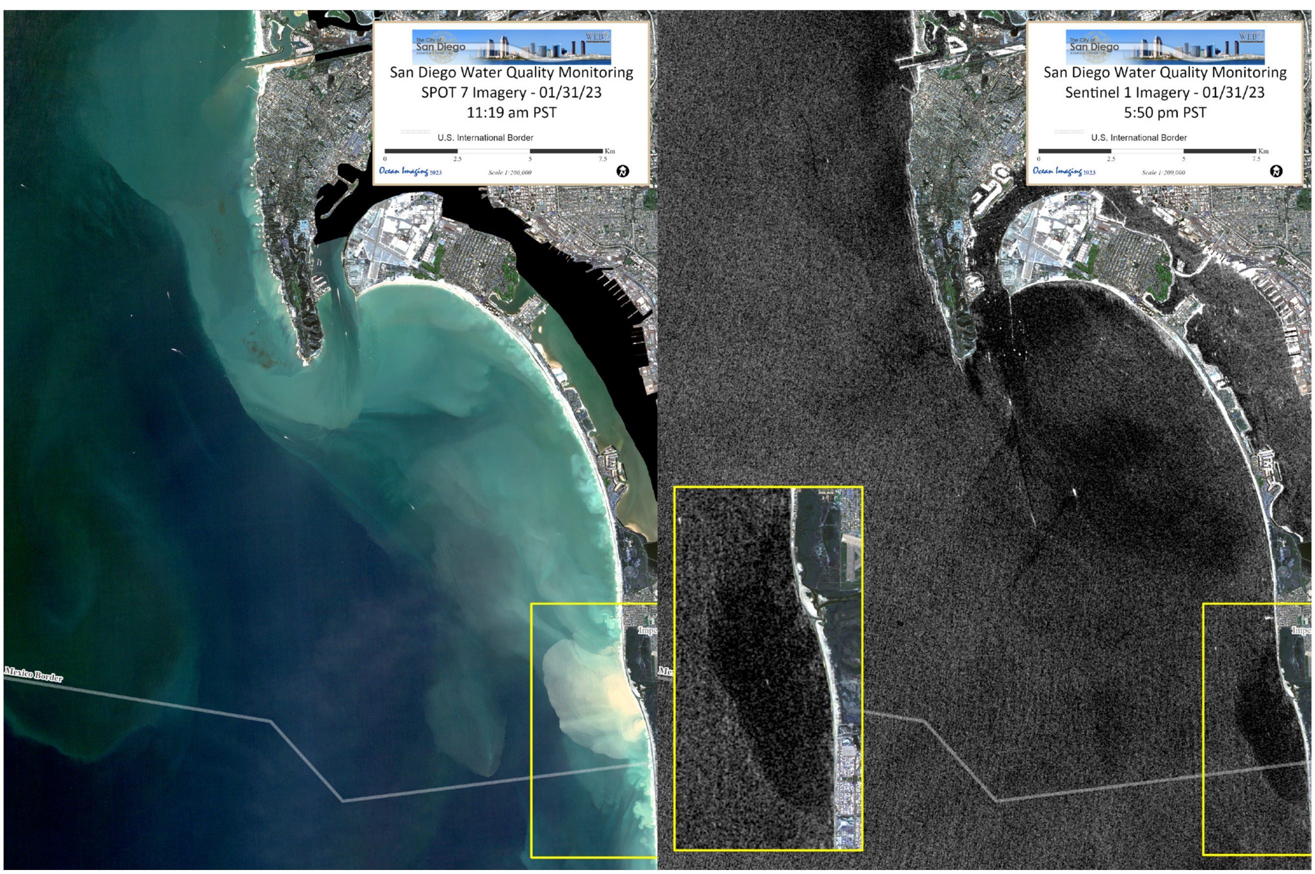


Figure 2. SPOT 7 (left) and Sentinel 1 SAR (right) imagery illustrating the ability of SAR data to help detect and identify areas of TJR discharge containing surface-dampening surfactants.

coastline. The streaky signature in the SAR image north of the river outlet also indicates possible surfactants moving up the coast. Recent attention on the severity of the TJR polluted discharge (Little, 2024) makes monitoring and documenting the TJR discharge plume increasingly important.

In 2012, OI added additional broad-scale products to the datasets available to the SDPUD and project partners. These include two types of ocean current data: High Frequency Radar-derived surface currents (HF Radar) and Hybrid Coordinate Ocean Model (HYCOM) model-derived surface currents (https://hycom.org). The raw data for the HF Radar currents are retrieved from National HF Radar Network via the Scripps Coastal Observing Research and Development Center (CORDC) on an hourly basis and reformatted into ESRI-compatible shapefiles. The hourly products are averages of the previous 25 hours and generated at 1 km and 6 km spatial resolutions. Additional HYCOM model-based products include daily ocean salinity, mixed layer depth, and subsurface temperature at 50, 100, 150 and 200 meters. In 2016 these products were delivered in a Web Map Service (WMS) Representational State Transfer (REST) service format compatible with the City's now retired BioMap server. They are presently being generated and archived in preparation for delivery via a next generation WMS dashboard-style data portal now in development. Details of this project are discussed below. The existing high resolution (6-30 m) observation region extends from approximately La Jolla southward to Rosarito Beach, Mexico and out approximately 50 miles. The coarser-scale products (250-1000 m) such as chlorophyll, SST, ocean

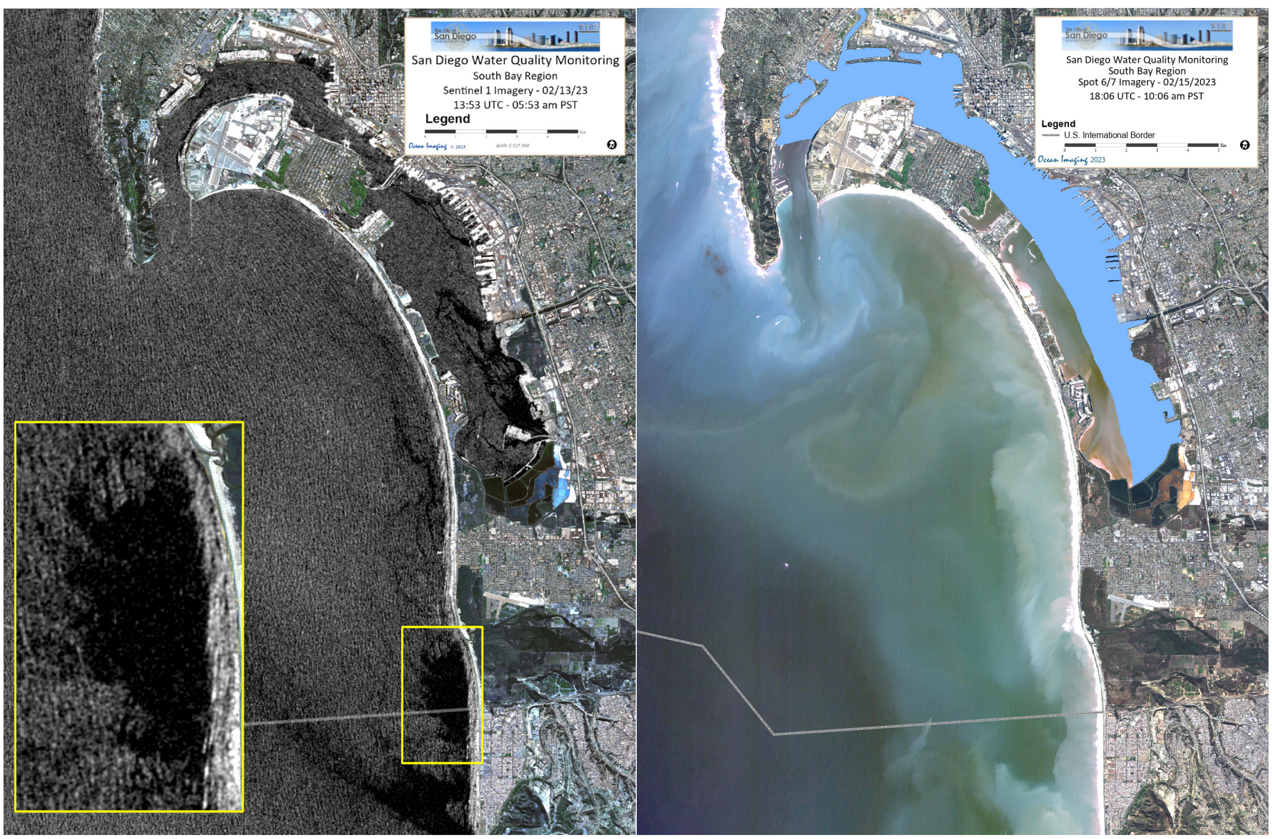


Figure 3. Sentinel 1 SAR (left) data acquired on 02/13/23 and SPOT 6 image acquired on 02/15/23 (right). Both datasets show relatively strong TJR discharge and associated ocean turbidity. The SAR image also indicates that the river plume and possibly the water moving up the shoreline contained surfactant films often associated with anthropogenic substances linked to river water contamination.

currents and HYCOM-derived products encompass the entire Southern California Bight (SCB).

2.4 Data Dissemination and Analysis

The satellite data are made available to the SDPUD and other project constituents through a dedicated, password-protected web site. Although it is possible to process most of the data in near-real-time, earlier in the project it was decided that the emphasis of this program is not on providing real-time monitoring support and the extra costs associated with the rapid data turn-around are not warranted. Most satellite data are therefore processed and posted within 1-2 days after acquisition. As noted above however, OI has in several cases made imagery available to the SDPUD in near-real time (within 12-24 hours) via email when observations appeared to be highly significant to the management of beach closures or other sudden/anomalous events. The website was updated in 2022 to improve its ease of use and presentation of available imagery.

3. HIGHLIGHTS OF 2023 MONITORING

3.1 Atmospheric and Ocean Conditions

Coastal and oceanic water quality can often be correlated to rainfall events. The annual recorded precipitation for 2023 was well above the previous 10-year average for the region. The San Diego International Airport station (SDIA) measured 14.42 inches of total annual rainfall and the TJR Estuary 12.66 inches, both higher than 2013-2022 averages of 8.05 and 7.73 inches respectively (see Table 2). 2016 was the only comparable year over the twelve-year period. While the monthly rainfall followed normal patterns seasonally, with the winter and spring months for the most part matching the expected rainy season and the summer months being mostly dry, an extreme rain event in mid-January and over twice the normal precipitation during the month of March had a significant impact of the coastal water quality. The May through September summer months were mostly dry except for Hurricane Hilary which made landfall on San Diego shores on 08/20/23. The SDIA station recorded 1.84 and the Tijuana Estuary station recorded 1.86 inches of precipitation on that day.

Figure 4 shows cumulative daily precipitation in the Tijuana Estuary along with the average daily river discharge at the Tijuana River International Boundary station (TJRIB). The table below the plot gives the dates for which there was measurable precipitation at that station. As has been noted in the previous reports and is evident in Table 2, the monthly and annual precipitation amounts can differ at times between the SDIA and TJR reporting stations. The primary periods of consistent and/or heavy precipitation occurred during the months of January, February, March, November, and December with anomalous 1.84 and 1.89 inches measured at the SDIA and Tiuana Estuary stations in August. We have defined a significant TJR discharge event as when the spectrally distinct "fresh core" of the river discharge plume as defined by Svejkovsky et al., 2010 is clearly visible in the imagery. The majority (49 out of 50) significant TJR discharge events observed in the remotely sensed data occurred during the months of January through April and October through December, which is during the Southern California rainy season. However, in 2023 only 58% of significant TJR discharge events can be directly correlated to rainfall occurring one to two days prior to the observation. Most of the non-rain related TJR discharge events were observed in October through the first half of December and can in all probability be attributed to the TJR river flow rate largely remaining above 30 cubic feet per second (cfs) during that period. When the increased river discharge levels, higher coastal turbidity and thus lower water quality, did follow the rainfall events, the coastal and offshore conditions typically improved only after one to three days of rainfall totaling less than 0.1 inches. Figures 1, 2, 3 and 5 provide examples of heavy coastal turbidity, extensive SDR and TJR plumes as well as large plankton blooms observed in the satellite imagery resulting from significant precipitation events. On 01/20/23 (Figure 1) the offshore turbidity visibly decreased following only one day of dryer and calm conditions.

As discussed above, aside from the heavy rainfall associated with Hurricane Hilary in August, there was little measured precipitation in the San Diego region from May through October. River flow rates in cfs measured by the United States Geological Survey (USGS) Fashion Valley gauge generally correspond well with the rainfall data, however, the overall flow rate in 2023 was higher when compared to prior years, mostly likely due to heavy rainfall during the first three months of the year (Figure 6). There were also periods in May and October when the discharge rates did not match rainfall recorded at the SDIA. Despite the mostly dry summer conditions, the river flow rates did remain above five cfs for most of the season as documented by both the TJRRIB and USGS gauges. This may explain the days when considerable river discharge

Table 2. San Diego and Tijuana Estuary precipitation totals 2012-2023

San Diego International Airport Cumulative Monthly Precipitation in Inches

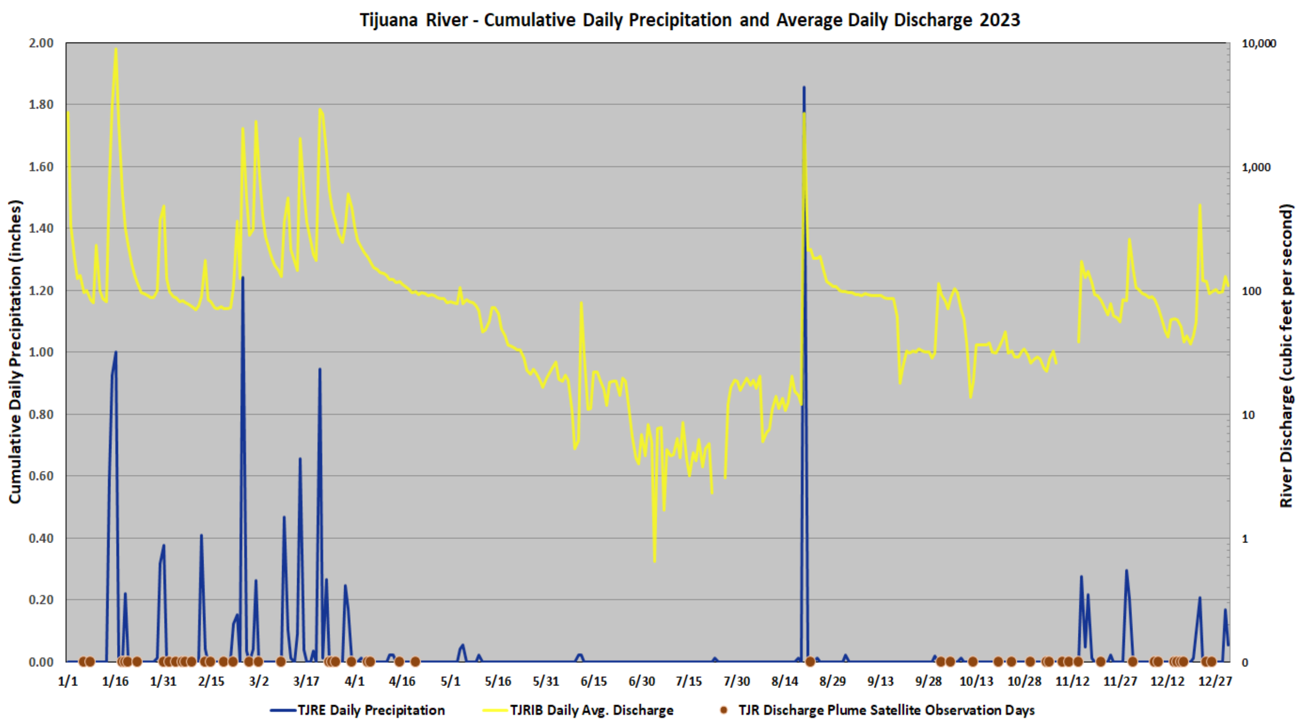
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
January	0.40	0.70	0.01	0.42	3.21	2.99	1.77	2.42	0.48	1.80	0.16	5.14
February	1.19	0.63	1.00	0.28	0.05	1.58	0.35	4.04	0.38	0.10	0.70	1.78
March	0.97	1.22	1.28	0.93	0.76	0.08	0.65	1.23	2.15	1.48	1.61	3.97
April	0.88	0.01	0.54	0.02	0.55	0.01	0.02	0.10	3.68	0.07	0.02	0.12
May	0.02	0.26	--	2.39	0.44	0.87	0.09	0.86	0.02	0.07	0.02	0.09
June	--	--	--	0.04	--	0.02	--	0.01	0.14	0.01	--	0.03
July	--	0.05	--	1.71	--	--	--	--	--	--	--	--
August	--	--	0.08	0.01	--	--	0.02	--	--	0.23	--	1.84
September	--	--	--	1.24	0.32	0.06	--	0.11	--	0.50	0.65	0.05
October	0.70	0.25	--	0.43	0.07	--	0.57	--	0.12	1.01	0.09	--
November	0.28	1.48	0.37	1.54	0.61	0.02	0.69	2.72	0.14	--	1.07	0.61
December	2.19	0.46	4.50	0.88	4.22	--	0.83	4.03	0.60	2.58	1.55	0.79
Annual Total	**6.63**	**5.06**	**7.78**	**9.89**	**10.23**	**5.63**	**4.99**	**15.52**	**7.71**	**7.85**	**5.87**	**14.42**

Tijuana Estuary Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
January	0.70	0.05	0.08	0.32	2.40	3.61	0.82	1.80	0.61	2.21	0.17	3.47
February	0.86	--	1.35	0.13	0.02	4.06	0.47	3.62	0.51	0.06	0.58	2.06
March	1.21	1.43	0.55	1.01	1.28	0.04	1.17	1.33	2.59	1.12	1.64	3.32
April	0.82	0.11	0.35	0.07	1.91	0.01	0.10	0.33	5.52	0.04	0.13	0.06
May	--	0.36	--	1.13	0.97	1.07	0.08	0.50	0.02	0.01	--	0.12
June	--	--	0.12	--	--	--	--	0.02	0.21	0.06	--	0.05
July	--	0.01	0.33	0.39	--	0.01	0.01	--	--	--	--	0.01
August	--	--	0.04	--	--	0.02	--	--	--	0.02	--	1.89
September	0.02	0.01	--	0.48	0.49	0.03	--	--	--	--	0.48	0.04
October	0.50	0.41	--	0.21	--	--	0.13	--	0.04	0.91	0.29	0.01
November	--	0.25	0.29	0.61	0.34	0.06	0.82	2.99	0.08	0.02	0.95	1.08
December	0.04	0.50	3.09	0.61	4.32	0.09	3.16	3.82	0.60	1.18	1.13	0.54
Annual Total	**4.15**	**3.13**	**6.20**	**4.94**	**11.73**	**8.99**	**6.76**	**14.41**	**10.18**	**5.63**	**5.38**	**12.66**

and offshore turbidity were observed in the satellite imagery yet there was little to no measurable rainfall from either station within a few days prior to the observations. Figure 7 provides examples of when the satellite data exhibited notable coastal and offshore turbid conditions as well as strong plankton blooms that were unrelated to rainfall.

In 2023 the county of San Diego issued 312 posted shoreline and/or rain advisories and 50 beach/shoreline closures. This is a 54.5% increase in the number of advisories and an 18% decrease in closures compared to 2022 (202 and 61 closures respectively). The longest contiguous 2023 closure lasting the full year and into 2024 was at Border Field State Park along the south end of the Tijuana Slough Shoreline. In fact, this area has been closed for over



Date	CumPrcp (in)
01/14/23	0.59
01/15/23	0.93
01/16/23	1.00
01/17/23	0.01
01/19/23	0.22
01/20/23	0.01
01/29/23	0.01
01/30/23	0.32
01/31/23	0.38
02/12/23	0.41
02/13/23	0.04
02/21/23	0.01

Date	CumPrcp (in)
02/22/23	0.12
02/23/23	0.15
02/25/23	1.24
02/26/23	0.04
02/28/23	0.04
03/01/23	0.26
03/10/23	0.47
03/11/23	0.10
03/12/23	0.01
03/14/23	0.09
03/15/23	0.66
03/16/23	0.04

Date	CumPrcp (in)
03/19/23	0.04
03/21/23	0.95
03/22/23	0.01
03/23/23	0.27
03/29/23	0.25
03/30/23	0.17
04/03/23	0.01
04/12/23	0.02
04/13/23	0.02
05/04/23	0.04
05/05/23	0.06
05/10/23	0.02

Date	CumPrcp (in)
06/10/23	0.02
06/11/23	0.02
07/23/23	0.01
08/18/23	0.01
08/20/23	1.86
08/21/23	0.01
08/24/23	0.01
09/02/23	0.02
09/30/23	0.02
10/08/23	0.01
11/15/23	0.28
11/16/23	0.05

Date	CumPrcp (in)
11/17/23	0.22
11/18/23	0.01
11/24/23	0.02
11/29/23	0.30
11/30/23	0.20
12/20/23	0.01
12/21/23	0.10
12/22/23	0.21
12/30/23	0.17
12/31/23	0.06

Figure 4. Daily accumulated precipitation (CumPrcp) in the Tijuana Estuary, average daily river discharge measured at the Tijuana River International Boundary station and days on which significant TJR discharge was observed in the high-resolution satellite imagery including the Sentinel 1 SAR data.

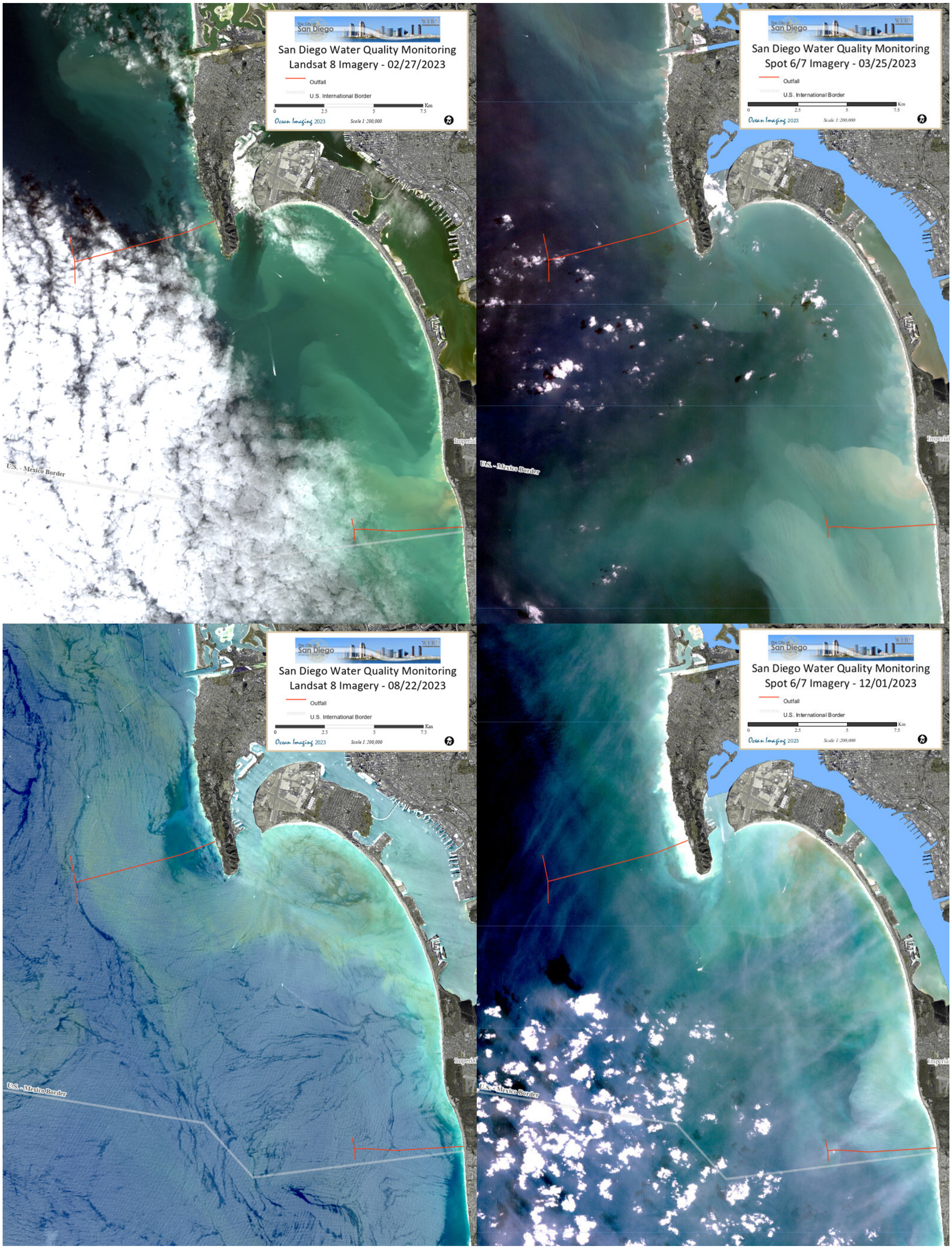
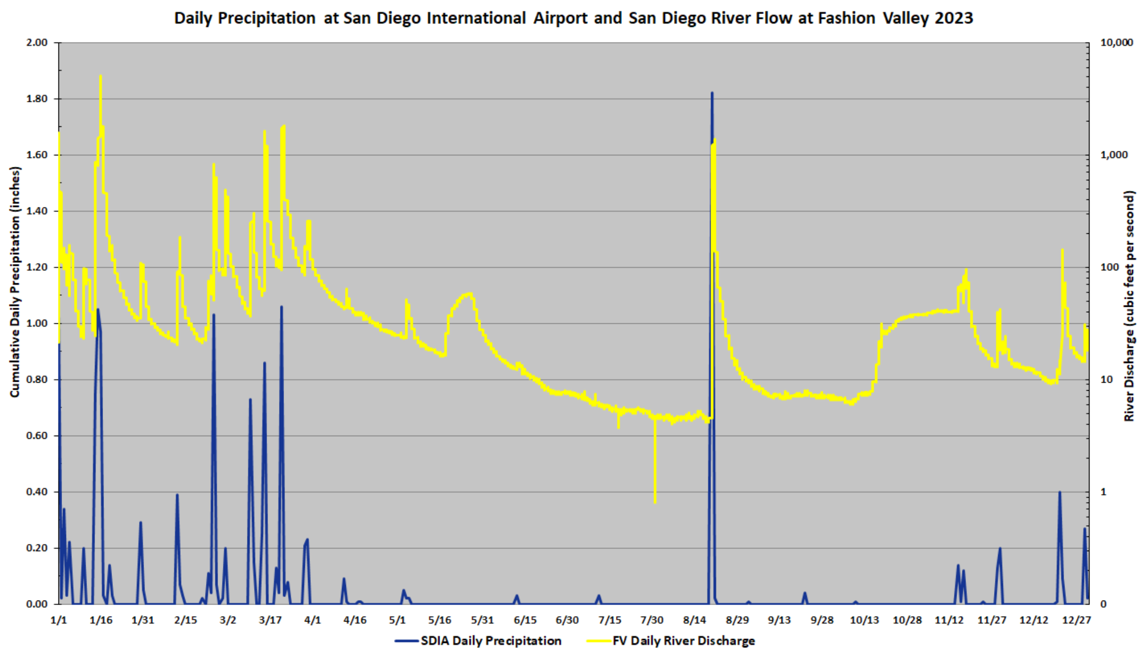


Figure 5. Sample high-resolution imagery from SPOT and Landsat highlighting turbid water, plankton blooms and heavy river runoff immediately following rain events.



San Diego Intl. Airport Rainfall 2023	
Jan	5.14
Feb	1.78
Mar	3.97
Apr	0.12
May	0.09
Jun	0.03
Jul	--
Aug	1.84
Sep	0.05
Oct	--
Nov	0.61
Dec	0.79

Figure 6. Daily San Diego River flow rates measured by the USGS Fashion Valley gauge plotted with daily precipitation amounts as recorded at the San Diego International Airport. Monthly precipitation totals at the SDIA station are displayed to the right of the plot.

two years. The majority of the closures extended from the Tijuana River mouth all the way past Avenida Del Sol to include most all of the Coronado City beaches. This is farther north than was typical for previous years (Table 3). Most beach closures were associated with contamination from the TJR runoff. Generally, the closures can be attributed to a rain event prior to and/or during the closure period leading to heavy TJR discharge and coastal turbidity as shown in the figures above. However, nine closures were triggered by sewage spills in San Diego Bay, south Carlsbad State Beach, Buccaneer Beach Tecolote Shores, and several locations within Mission Bay. As seen in Table 3 below, most bay closures were associated with sewage spills. Also, 12 of the 50 closures happened between the months of May and October when no rainfall prior to the closure was recorded at the Tijuana Estuary or SDIA stations. Table 3 also shows the date(s) of the high-resolution satellite data in the project's archive acquired closest in time to the start date of the closure and/or rain advisory. The high-resolution satellite data during the beach closure periods regularly show high turbidity and suspended solids and/or high plankton levels along the coastline near the closed regions as well as greater than normal TJR runoff, sometimes being carried north by the ocean currents. Figure 5 and Figure 8 provide examples of the Tijuana River plume extending north and/or ocean currents pushing the TJR discharge waters north up past Border Field State Park towards the Coronado beaches, corresponding with shoreline closures usually within zero to two days of the image data.

As noted above there were strong phytoplankton and possible harmful algal blooms (HABs) during the spring and late summer to fall of 2023 which may have contributed to decreased offshore water quality. This is seen by dark green and brown to red reflectance in the satellite data caused by phytoplankton containing photosynthetic pigments that vary in color from brown to red and blooms often dominated by the dinoflagellate L. polyedra which absorbs light in the ultra violet part of the electromagnetic spectrum (Kahru, et al.,1998, Zheng, et al., 2018). Diatoms (primarily Pseudo-nitzschia spp) and dinoflagellates are largely responsible for the local harmful algal blooms (red tides) when they occur (Southern California Coastal Water Research Project, 2019). Figure 9 provides examples of high-

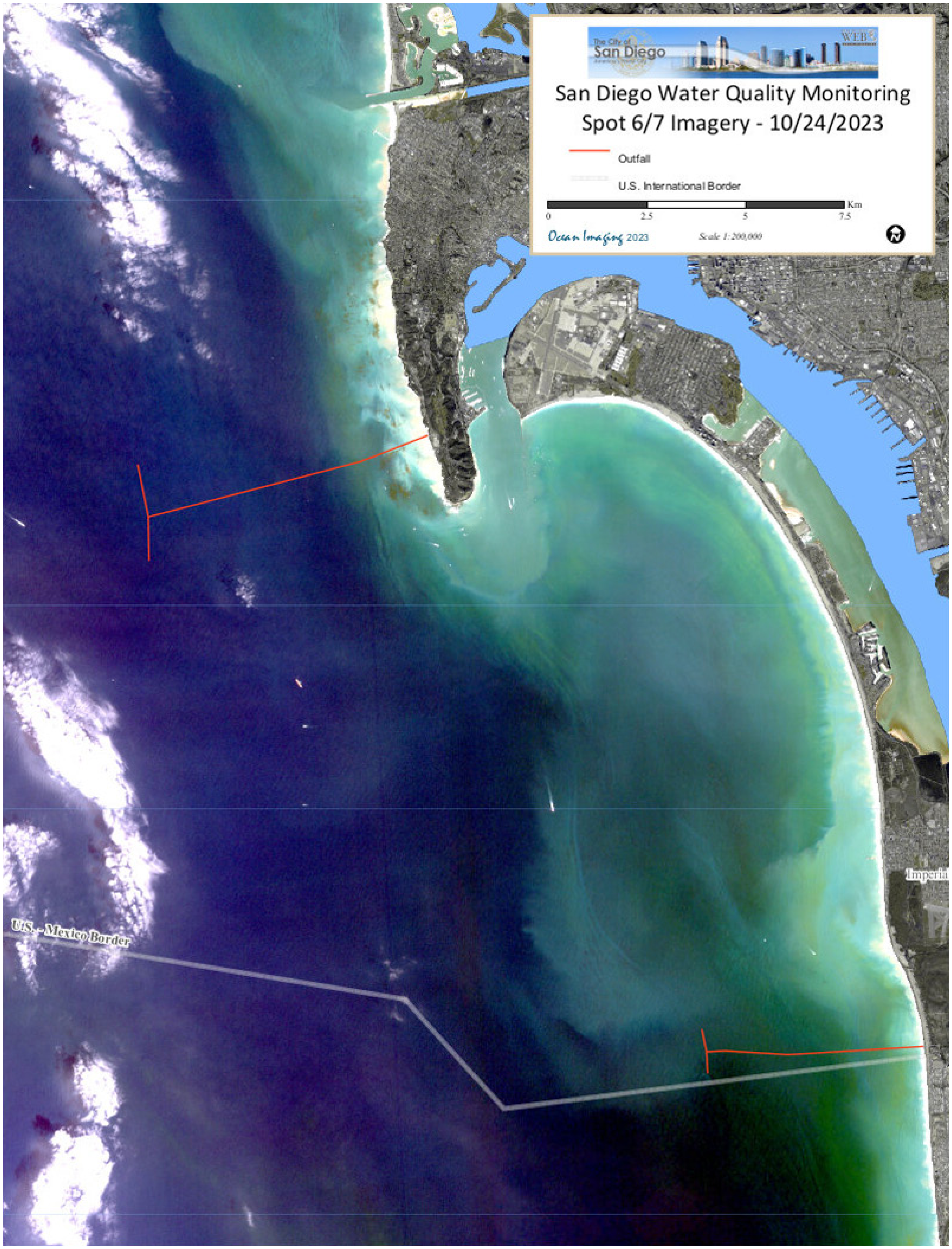


Figure 7. Sample high-resolution SPOT data providing examples of days when the imagery displayed heavier than usual river discharge, coastal and offshore turbidity and plankton blooms that cannot be directly linked to a prior rainfall event. River gauge data do, however, show higher than average flow rates on or near these dates.

Table 3. 2023 County of San Diego shoreline closures, rain advisories and associated project satellite data (Source: California State Water Resources Control Board) general rain advisory; beach closure associated with the Tijuana River; bay or beach closure due to a sewage spill; bay or beach closure due to elevated bacteria levels

StationDescription	Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image Data
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			1/1/2023	1/9/2023	9	1/1/2023	0	1/6, 1/8
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	1/1/2023	2/20/2023	51	1/1/2023	0	16 dates
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/1/2023	7/10/2023	191	1/1/2023	0	34 dates
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	1/1/2023	12/31/2023	365	1/1/2023	0	All
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	1/2/2023	2/8/2023	38	1/2/2023	0	12 dates
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			1/10/2023	1/20/2023	11	1/6/2023	4	1/18, 1/19, 1/20
Batiquitos Lagoon outlet	South Carlsbad State Beach	EH-440	Closure	Sewage Spill	Sewage/Grease	1/16/2023	1/21/2023	6	1/16/2023	0	1/18, 1/19, 1/20
Ruocco Park	San Diego Bay	EH-545	Closure	Sewage Spill	Sewage/Grease	1/16/2023	1/23/2023	8	1/16/2023	0	1/18, 1/19, 1/20
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			1/30/2023	2/2/2023	4	1/30/2023	0	1/31, 2/2
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	2/10/2023	2/12/2023	3	2/12/2023	2	2/12
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			2/13/2023	2/16/2023	4	2/13/2023	0	2/13, 2/15
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	2/22/2023	6/24/2023	123	2/22/2023	0	16 dates
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			2/23/2023	3/4/2023	10	2/23/2023	0	2/22, 2/27, 3/2
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	3/1/2023	4/23/2023	54	3/1/2023	0	11 dates
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			3/10/2023	3/13/2023	4	3/10/2023	0	--
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			3/15/2023	3/19/2023	5	3/15/2023	0	--
Batiquitos Lagoon outlet	South Carlsbad State Beach	EH-440	Closure	Sewage Spill	Sewage/Grease	3/15/2023	3/20/2023	6	3/15/2023	0	--
Loma Alta Creek oultet	Buccaneer Beach	OC-022	Closure	Sewage Spill	Sewage/Grease	3/15/2023	3/20/2023	6	3/15/2023	0	--
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			3/21/2023	3/26/2023	6	3/21/2023	0	3/24, 3/25, 3/26
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			3/29/2023	4/2/2023	5	3/29/2023	0	3/31
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	4/24/2023	5/1/2023	8	4/18/2023	6	--
Enchanted Cove	Mission Bay	MB-015	Closure	Sewage Spill	Sewage/Grease	7/21/2023	7/22/2023	2	6/12/2023	39	--
Fiesta Island East Shore	Mission Bay	MB-045	Closure	Sewage Spill	Sewage/Grease	7/21/2023	7/22/2023	2	6/12/2023	39	--
Leisure Lagoon Point	Mission Bay	MB-046	Closure	Sewage Spill	Sewage/Grease	7/21/2023	7/22/2023	2	6/12/2023	39	--
Tecolote Shores - Pump 58	Mission Bay	MB-047	Closure	Sewage Spill	Sewage/Grease	7/21/2023	7/22/2023	2	6/12/2023	39	--
Tecolote Shores swim area	Tecolote Shores	MB-041	Closure	Sewage Spill	Sewage/Grease	7/21/2023	7/22/2023	2	6/12/2023	39	--
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			8/20/2023	8/24/2023	5	8/20/2023	0	8/22
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	8/20/2023	8/29/2023	10	8/20/2023	0	8/22, 8/28
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	8/20/2023	8/29/2023	10	8/20/2023	0	8/22, 8/28
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	8/20/2023	9/21/2023	33	8/20/2023	0	8/22, 8/28, 9/4, 9/7, 9/9, 9/14, 9/20
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	8/20/2023	10/5/2023	47	8/20/2023	0	10 dates
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	8/20/2023	12/16/2023	119	8/20/2023	0	29 dates
Navy Fence (A)	Coronado north beach	EH-060	Closure	Bacterial Standards	Sewage/Grease	8/31/2023	9/20/2023	21	8/24/2023	7	9/4, 9/7, 9/9, 9/14, 9/20
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	8/31/2023	9/21/2023	22	8/24/2023	7	9/4, 9/7, 9/9, 9/14, 9/20
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	9/22/2023	10/2/2023	11	9/3/2023	19	9/25, 10/2
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	9/27/2023	10/2/2023	6	9/3/2023	24	10/2
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	9/27/2023	10/2/2023	6	9/2/2023	25	10/2
Campland swimming area	Mission Bay, Campland On The Bay	MB-080	Closure	Bacterial Standards	Unknown	10/2/2023	10/4/2023	3	9/30/2023	2	10/2
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	10/3/2023	10/4/2023	2	9/30/2023	3	--
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	10/9/2023	10/13/2023	5	10/8/2023	1	10/10, 10/12
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	10/9/2023	10/24/2023	16	10/8/2023	1	10/10, 10/12, 10/20, 10/24
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	10/14/2023	10/16/2023	3	10/11/2023	3	--
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	10/14/2023	10/17/2023	4	10/11/2023	3	--
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	10/26/2023	10/29/2023	4	10/11/2023	15	10/27
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	10/28/2023	10/29/2023	2	10/11/2023	17	--
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	10/30/2023	11/14/2023	16	10/11/2023	19	10/30, 11/1, 11/4, 11/5, 11/9, 11/11, 11/14
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Unknown	11/2/2023	11/5/2023	4	10/11/2023	22	11/4, 11/5
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	11/9/2023	11/10/2023	2	10/11/2023	29	11/9
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	11/12/2023	11/13/2023	2	10/11/2023	32	--
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			11/16/2023	11/19/2023	4	11/16/2023	0	--
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	11/17/2023	12/16/2023	30	11/17/2023	0	11/21, 12/1, 12/8, 12/9, 12/14, 12/15, 12/16
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	11/19/2023	12/3/2023	15	11/18/2023	1	11/21, 12/1
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	11/19/2023	12/6/2023	18	11/18/2023	1	11/21, 12/1
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	11/19/2023	12/8/2023	20	11/18/2023	1	11/21, 12/1, 12/8
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	12/5/2023	12/6/2023	2	12/1/2023	4	--
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	12/9/2023	12/15/2023	7	12/1/2023	8	12/9, 12/14, 12/15
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	12/18/2023	12/31/2023	14	12/1/2023	17	12/24, 12/26
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	12/21/2023	12/31/2023	11	12/21/2023	0	12/24, 12/26
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	12/21/2023	12/31/2023	11	12/21/2023	0	12/24, 12/26
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	12/21/2023	12/31/2023	11	12/21/2023	0	12/24, 12/26
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	12/21/2023	12/31/2023	11	12/21/2023	0	12/24, 12/26
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			12/22/2023	12/25/2023	4	12/22/2023	0	12/24
All SanDiego County Beaches	All SanDiego County	All San Diego County Beaches	Rain			12/31/2023	12/31/2023	1	12/31/2023	0	--

resolution SPOT data highlighting days when the imagery revealed strong coastal and offshore phytoplankton blooms that cannot be directly linked to a significant (over 0.01 inches) prior rainfall event.

Although discharges from the San Diego River and Mission Bay do not cause the same level of beach contamination issues as the Tijuana River, the runoff from the San Diego River did affect nearshore water clarity and quality on several days throughout the year in 2023, directly as a source of suspended sediment and indirectly as a source of high nutrient input, encouraging coastal and offshore phytoplankton blooms. While not at the scale or as dramatic as observed in previous years, turbidity plumes emanating from the river entrance and/or phytoplankton blooms either along the coast or offshore of the area were documented on 82 days in the medium-resolution (MODIS and Sentinel 3) and high-resolution satellite imagery

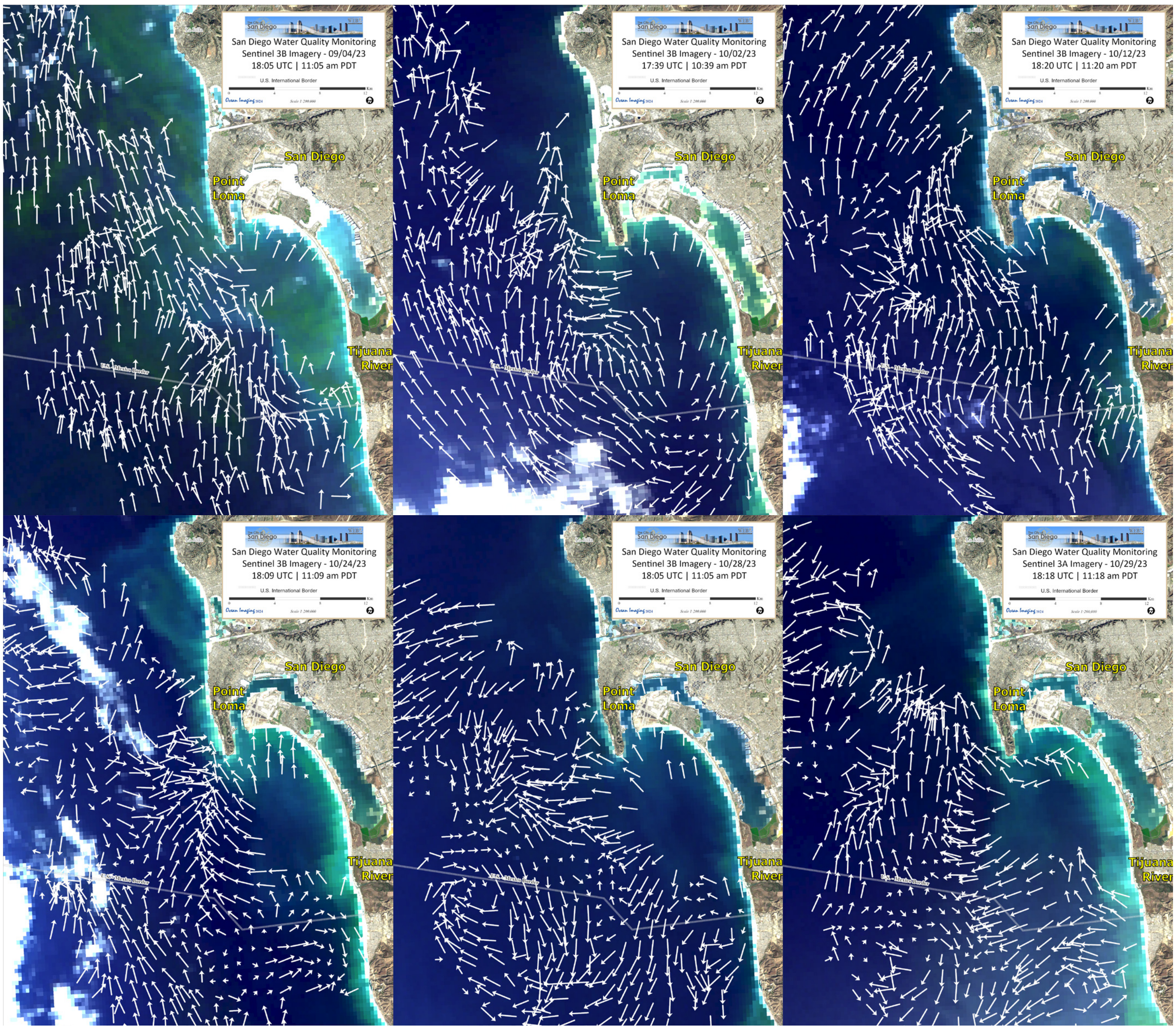


Figure 8. Sentinel 3A & 3B imagery with HF Radar currents overlaid to provide examples of when the Tijuana River plume extended to the north and/or when ocean currents pushed TJR discharge waters north up past Border Field State Park towards the Coronado beaches, corresponding with shoreline closures usually within zero to two days of the image data.

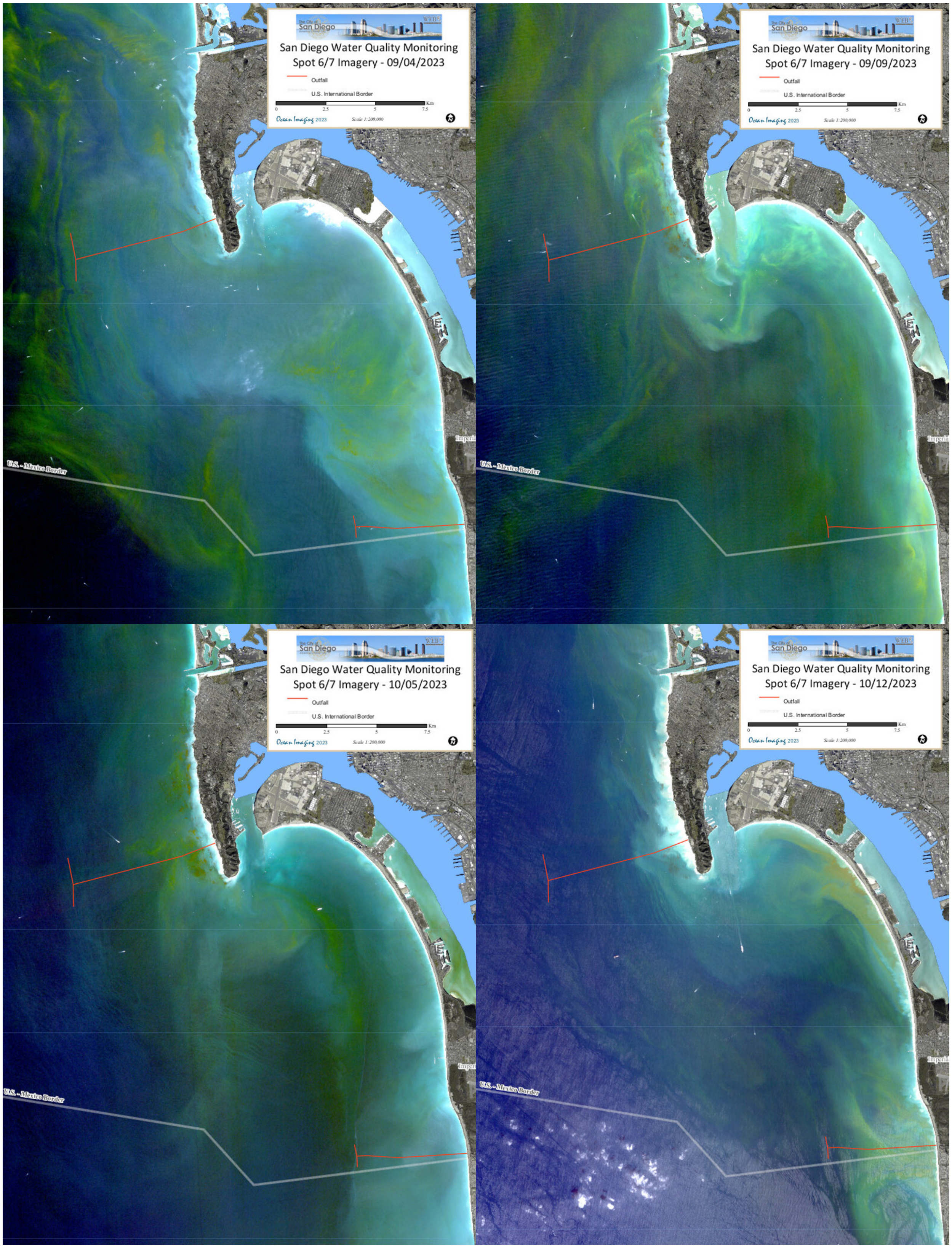


Figure 9. Sample high-resolution SPOT data providing examples of days when the imagery revealed strong coastal and offshore phytoplankton blooms and red tides that cannot be directly linked to a significant (over 0.01 inches) prior rainfall event.

throughout the year. The area surrounding the Point Loma kelp bed tended to be more often affected by direct shore runoff and discharges from the San Diego River and Mission Bay during the prevalent southward current regime. Figure 10 provides examples of days on which the data revealed heavy coastal turbidity and phytoplankton blooms in this northern section of the project's study area.

The SCB experienced lower overall chlorophyll levels throughout 2023 when compared to the previous two years, especially 2021. Chlorophyll levels in the SCB and thus phytoplankton abundance were high during the first four months of the year particularly south of the U.S.-Mexico border during March and April. The heavy rainfall events up through the first part of April introducing nutrients into the ocean system from river discharge and runoff likely contributed to the phytoplankton blooms. A noticeable decrease in offshore chlorophyll levels from June through October is evident in the representative satellite imagery. Figure 11 provides representative MODIS- and VIIRS-derived chlorophyll images for each month of 2023. As is seen in the image data, the California Current relaxed during the summer months and/or was not moving greener/nutrient-rich water into the SCB but appears to gain strength in November and December. Figure 12 shows 300-meter resolution monthly chlorophyll averages for the area offshore of San Diego County and south of the U.S.-Mexico border. These composites were generated from MODIS, VIIRS and OLCI data as part of a SDPUD-funded project to study plankton abundance and extent in the region from 1997 through 2023. The series provides a more coastal, regional perspective of the changes in phytoplankton throughout the year. The data correlate well with the SCB imagery in Figure 11 for the first seven months but show an increase in chlorophyll between August and November along the San Diego coastline down past the Coronado Islands south of the border. This is also evident in the high-resolution images acquired during September and October shown in Figure 9.

The City of San Diego conductivity/temperature/depth (CTD) sampling results correlated well with the satellite data observations. Some of the highest chlorophyll levels recorded via CTD (as high as 61.17 mg/m^3 at station I40, 1-meter depth on 04/18/23) occurred during the month of April. This fits more of the seasonal expectation compared to the post-April blooms in 2022. In fact, 67% of all the fluorometry readings above 10.0 mg/m^3 were recorded in the month of April. The imagery in Figures 11 and 12 corroborate these measurements, clearly documenting April as the month exhibiting the highest intensity and spatial extent of phytoplankton blooms in the project's area of interest. Figure 13 offers examples of the CTD fluorometry data in correlation with the high-resolution satellite imagery on or near the same day as the field samples. While the high-resolution remotely sensed data do not depict quantitative chlorophyll levels, the plankton blooms are self-evident in the imagery and correlate well with the CTD data.

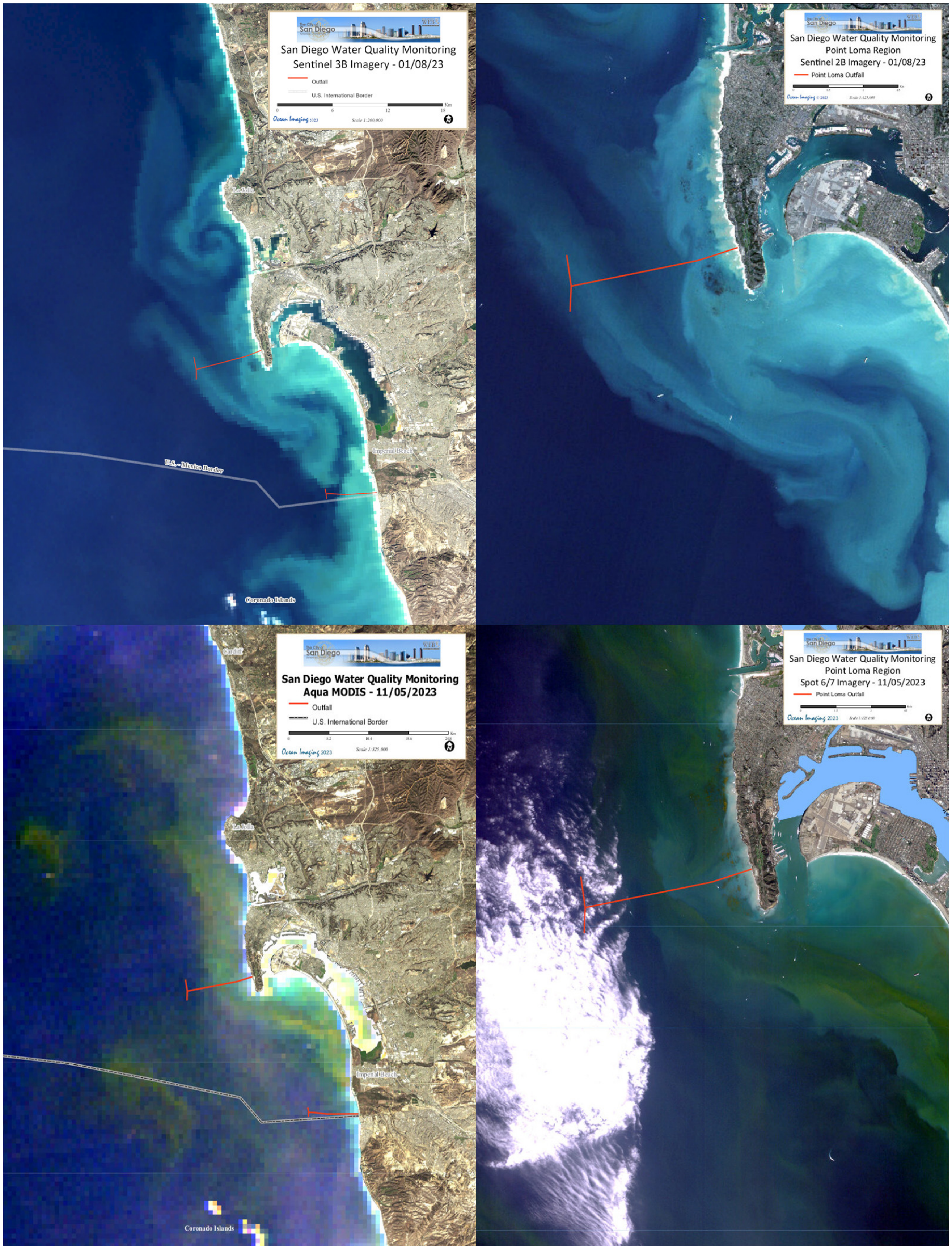


Figure 10. Sentinel 3 images (left side) and the higher resolution SPOT and Sentinel 2A images (right side) showing the turbid water and strong phytoplankton blooms extending from the northern part of this projects focus area all the way down into the South Bay region on 01/08/23 (top) and 11/05/23 (bottom).

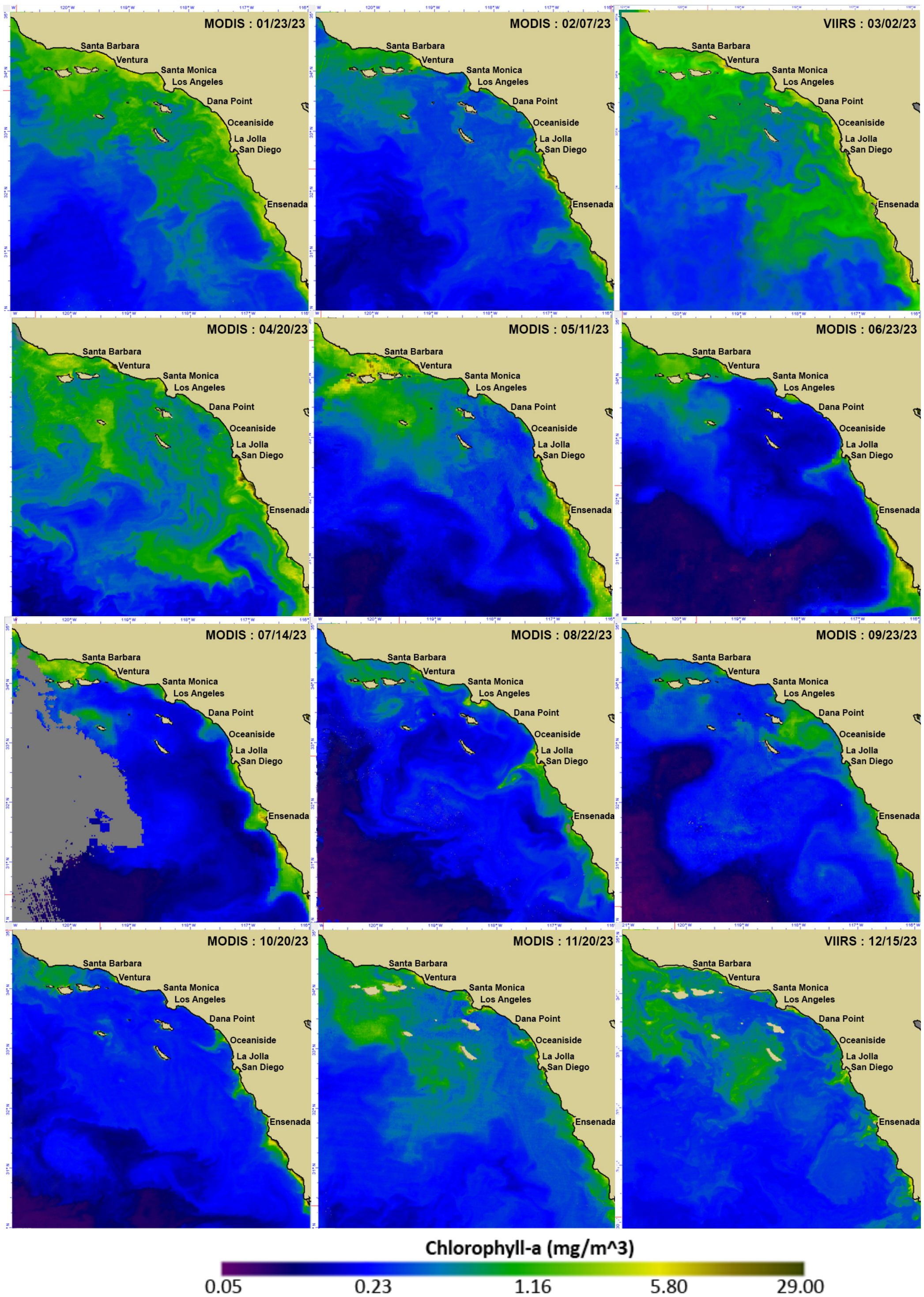


Figure 11. Representative MODS- and VIIRS-derived chlorophyll images for each month of 2023 showing high levels of chlorophyll-rich water in the SCB during the months of January through April likely due to the heavy rainfall and resulting eutrophication combined with coastal upwelling. SCB-wide levels decreased during the summer months and increased again in November and December, caused by the California Current bringing nutrient-rich water down into the region.

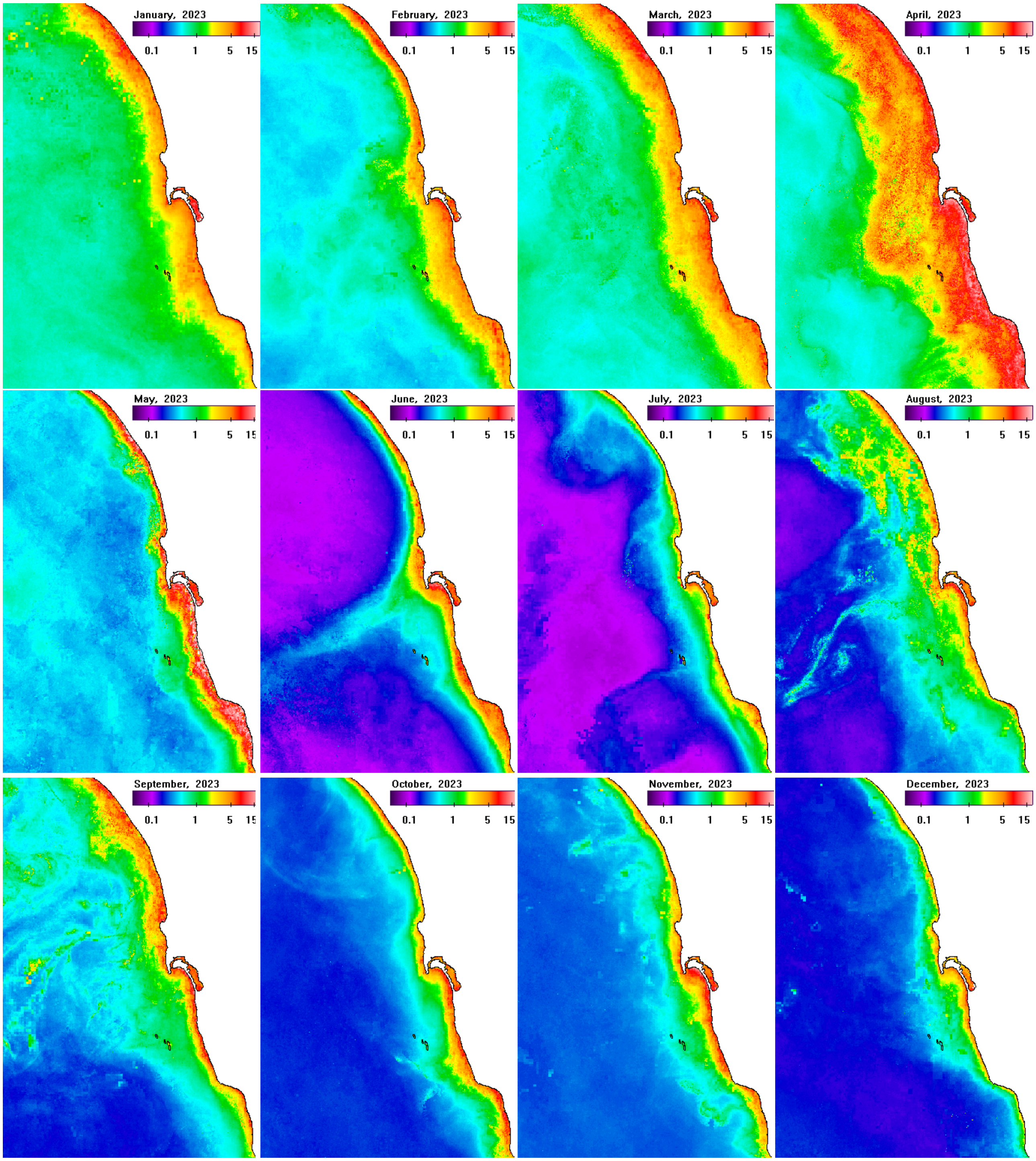
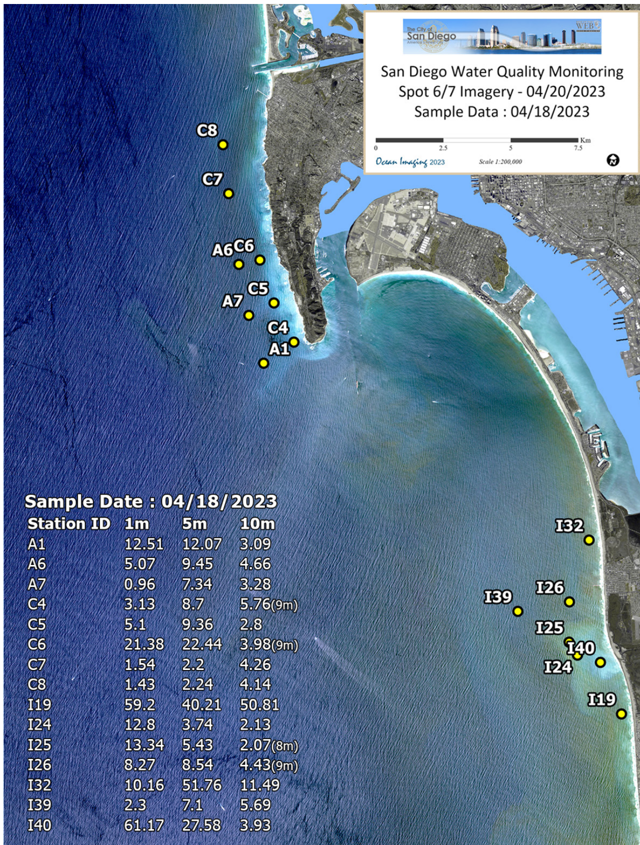
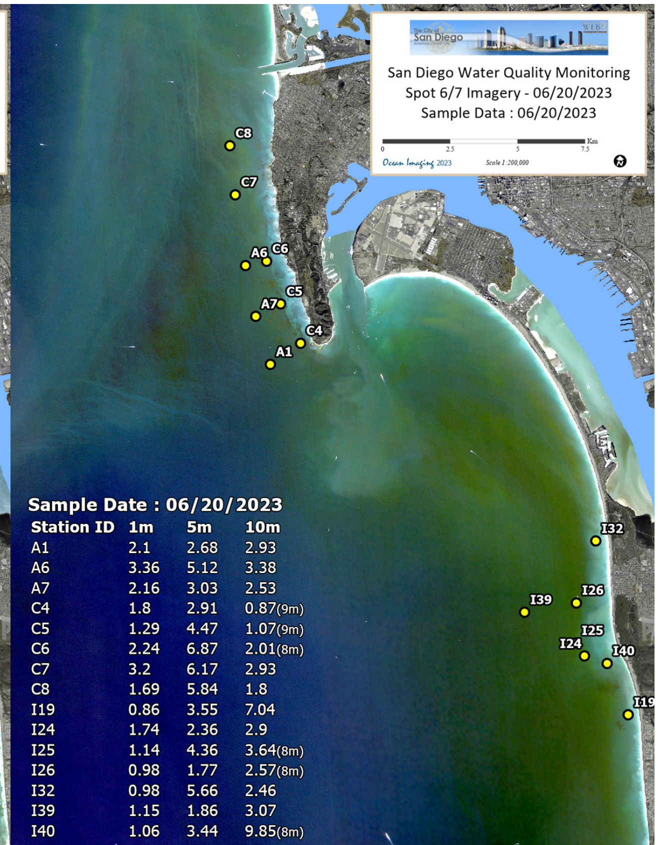


Figure 12. Monthly chlorophyll (mg/m^3) composites of the San Diego County coastal and offshore area derived from 300m and 1km MODIS, VIIRS and OCLI imagery generated by Mati Kahru of Scripps Institution of Oceanography in cooperation with OI as part of a SDPUD-funded project to study a long-term time series of satellite imagery to assess phytoplankton abundance and extent possibly related to increasing eutrophication of the ocean in this region.





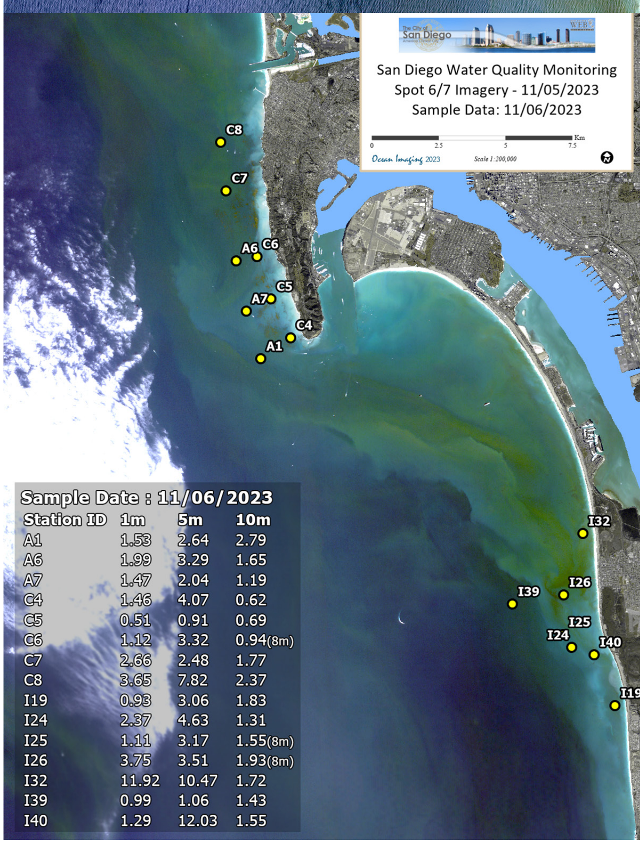


Figure 13. Sample 6-meter SPOT imagery with CTD-derived fluorometry data (chlorophyll measurements in mg/m^3 taken within two days of the satellite data) overlaid on the imagery. Generally, the image data correlate very well with the chlorophyll measurements by station. On 04/20/23 two stations in the Point Loma area (A1 and C6) show notably high readings, yet the water does not appear exceptionally green to the sensor. This could be due to the sun glint effectively masking the water reflectance. However, some of the highest coastal measurements in the South Bay at I19, I32 and I40 do show the green water in the image data. The SPOT image from 11/06/23 provides a dramatic example of chlorophyll-rich water moving to the northwest from the TJR region.

3.2 The South Bay Ocean Outfall Region

The South Bay International Wastewater Treatment Plant (SBIWTP) switched from advanced primary to secondary treatment in January 2011. This change resulted in the reduction of total suspended solids (TSS) concentrations from an average of 60 mg/L for several years prior to the change to the TSS loads reading consistently below 20 mg/L since 2012. Prior to 2011, a distinct effluent signature was regularly detected in multispectral imagery as per the seasonal fluctuation described above. Since then, the effluent signature continues to be observed with multispectral color and thermal imagery during months with weak vertical stratification, however, more intermittently. On occasion the signature is distinctly discernable in thermal images (indicating it has fully reached the ocean surface), but undetectable in the color imagery. We theorize this is due to the reduction in TSS concentrations.

The SBOO wastewater plume generally remains well below the surface between approximately late March and November due to vertical stratification of the water column. During that period, it usually cannot be detected with multispectral aerial and satellite imagery, which penetrate the upper 7 to 15 meters (depending on water clarity), nor can it be detected with thermal IR imaging, which does not penetrate below the surface. Seasonal breakdown of the vertical stratification results in the plume's rise closer to the surface or to actually reach the surface between approximately late November and April when it can often be detected with satellite imaging. This concept held true in 2023, as the last observation of a SBOO surface plume during the beginning of the year was on 03/24/23 and then was not seen again in the image data until 10/24/23. In total, there were 22 instances during which the SBOO effluent plume was observed in 2023 out of the 77 high resolution satellite scenes acquired and processed. Of the 22, two were instances of the plume observed by different satellites on the same day. This equates to 20 days when the plume was visible in the high-resolution imagery – only one more than observed in 2022, but above the average percentage of SBOO plume surface observations per days imaged when compared to the previous 11 years (25.9% vs. 18.6% in 2023). The effluent surface plumes are most often seen moving to the south or as a stagnant body, however there were five days on which the SBOO effluent was observed moving to the north, further into San Diego waters. The 01/31/23 image (Appendix A) provides an example of a large SBOO plume being pushed northward.

Appendix A includes the 2023 SPOT, Sentinel 2 and Landsat imagery on days which the SBOO plume was detected. There were two occurrences when either Sentinel 2A or 2B data were acquired within minutes of Landsat or SPOT 6/7 data providing a near time-coincident validation of features observed in the imagery.

As has been the case in previous years, there was an occurrence when the SBOO effluent plume appeared in the imagery as a patch of clearer water breaking the more turbid water on the surface. As discussed in prior reports, the clear effluent signal in the imagery is most likely due to the contrast between the higher turbidity coastal surface waters and the 'normal' level of turbidity of the effluent water breaking the surface. It is also possible that the effluent plume became somewhat diluted on its way to the surface if weak vertical stratification did exist, thus slowing down its rise in the water column. Figure 14 provides an example of this situation as well as the satellite's view of two large, discolored discharge plumes flowing from the TJR.

The months of January, February, November, and December exhibited the highest frequency of 2023 SBOO effluent plume observations in the satellite data. As has been documented in previous reports, it is typical to see the highest number of SBOO surface plumes during these months. As is typically the case, the relatively frequent effluent surface manifestations that occurred during this time period were most probably the result of two primary factors: the lack of strong vertical stratification during the winter months and relatively weak subsurface currents over the SBOO which allowed the undispersed effluent to reach the surface. According to the 2023 IBWC Transboundary Flow Report, there were 25 monthly documented instances of groundwater, urban run-off, storm water, treated sewage wastewater, and untreated sewage wastewater from infrastructure deficiencies and other sources in Mexico coming across the U.S.-Mexico border and into the SBOO pipeline, Tijuana Estuary and U.S. coastal waters. Most of these transboundary flows occurred in the TJR main channel resulting on billions of gallons coming into the U.S. system and waters throughout 2023 (SDRWQCB, 2024). As is discussed above, while the satellite imagery documented many of the related SBOO effluent surface manifestations and pollution discharge from the TJR, several of these instances during the summer months are not seen in the satellite data. This may be because, while many were documented as caused by rain and weather events, a significant percentage during the months of June through August were considered dry weather flows from numerous sources in Mexico that exceeded the San Diego-Tijuana wastewater system capacity (SDRWQCB, 2024). The relatively lower TJR discharge rate during June and July as seen in Figure 4 above also offers evidence as to why these flows are not observed as expansive, discolored TJR plumes. Figure 15 shows the SBIWTP Effluent Flow rate (EFF Flow) and the Effluent Total Suspended Solids (EFF TSS) over the 2023 period plotted with the dates on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery. There are a few notable spikes in EFF Flow during January and August, likely due to rainfall events. As can be seen in the trend line, the EFF flow averaged

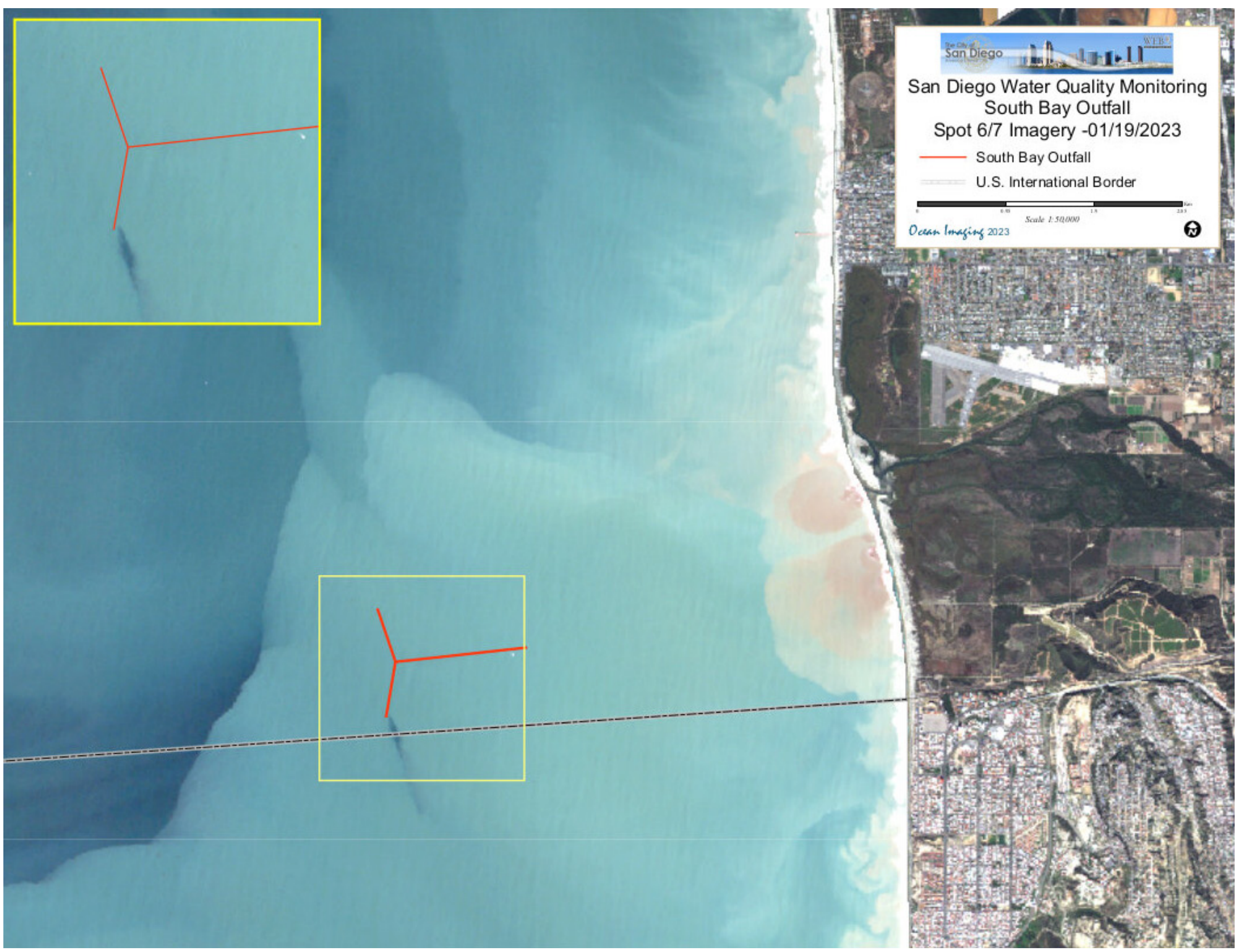


Figure 14. SPOT 6-meter image showing a SBOO surface signature being clearer than the surrounding extremely turbid water. Also note the heavy, discolored TJR discharge as two distinct ‘fresh core’ plumes extending more than 1.5 km from the river mouth.

27.04 million gallon per day (MGD) for the year which is higher than the maximum capacity (25 MGD) of the treatment plant. The EFF TSS were highly variable compared to past years, however there is no correlation of the SBOO effluent surface observations to TSS percentage. Of the 20 SBOO effluent observations, 12 occurred when the EFF flow rate exceeded 25 MGD, but it cannot be concluded that the additional flow diverted through SBIWTP resulted in the effluent reaching the ocean's surface more often. It should also be noted that the higher flow rates seen from May through the middle of August did not result in the effluent breaking through the pycnocline during these months. This corroborates the belief that the instances of effluent reaching the surface almost always occur because of seasonal changes in ocean conditions when the water column stratification breaks down and are not always related to a higher flow rate through the system.

A total of 19 shoreline stations, ranging from Mission Beach to northern Baja (across the US/Mexico border) are sampled weekly by City of San Diego staff to monitor the levels of three types of fecal indicator bacteria (i.e., total coliform, fecal coliform, *Enterococcus* bacteria) in recreational waters. An additional 15 nearshore (kelp) stations are also sampled weekly to monitor Fecal Indicator Bacteria (FIB) and a range of water quality parameters (i.e., temperature, salinity, dissolved oxygen, pH, transmissivity, Chlorophyl-a, colored dissolved organic matter (CDOM)). Furthermore, 69 offshore stations are sampled quarterly to monitor both water quality conditions and one or more types of FIB. PLOO stations are located along, or adjacent to, the 18, 60, 80, and 98-m depth contours, and SBOO stations are located along the 9, 19, 28, 38, and 55-m depth contours.

The City Marine Microbiology Laboratory (CMML) follows guidelines issued by the U.S. Environmental Protection Agency (USEPA) Water Quality Office, State Water Resources Control Board (SWRCB) including the 2019 Ocean Plan, the California Department of Public Health (CDPH), and Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner, et. al., 1978,

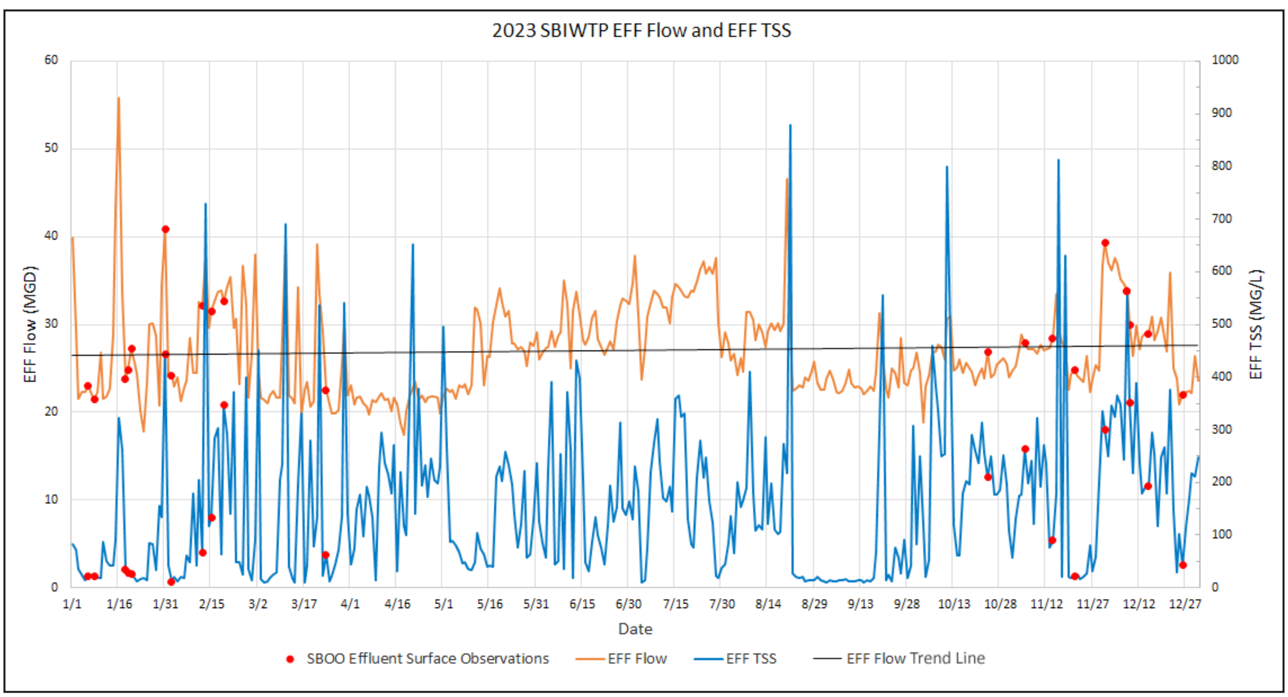


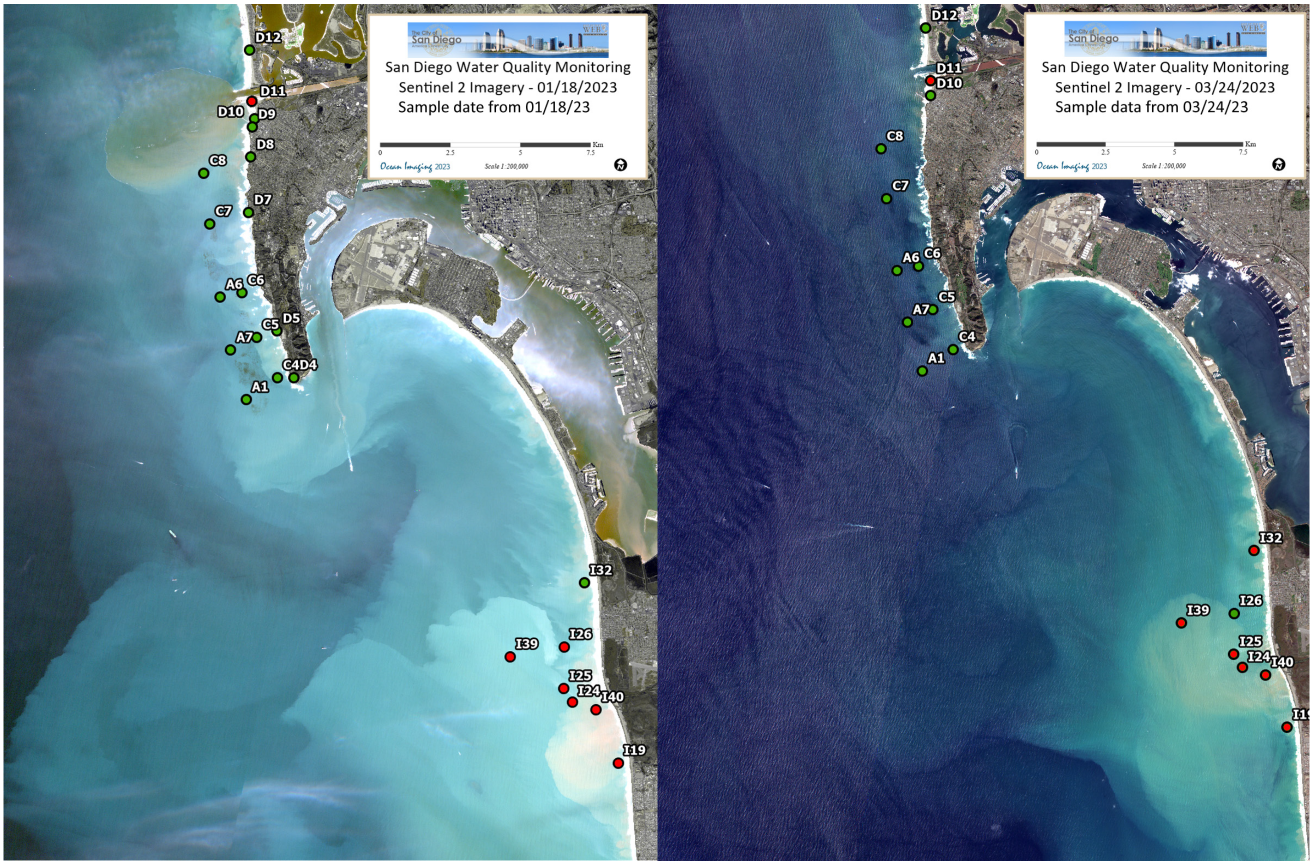
Figure 15. SSBIWTP EFF flow rate and EFF TSS over the 2023 time period plotted with the dates (red dots) on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery. Red dots are shown on the dates corresponding with both the EFF flow and EFF TSS data. Data courtesy of the IBWC. EFF trend is shown as a black line.

American Public Health Association (APHA), 2012, CDPH, 2019, USEPA, 2014). All bacterial analyses were initiated within eight hours of sample collection and conformed to standard membrane filtration techniques, for which the laboratory is certified (ELAP Field of Testing 126). FIB densities were determined and validated in accordance with USEPA and APHA guidelines as follows in APHA, 2012.

In 2023, the sampling area of the SBOO/Tijuana River outflow region experienced 71 days on which the field sampling showed FIB measurements exceeding the single sample maximum for fecal coliform density for one or more sampling stations as defined by the 2019 California Ocean Plan (the single sample maximum fecal coliform density at a site will not exceed 400 per 100 mL) (SWRCB, 2019). The offshore SBOO region, which includes the stations over the SBOO wye experienced only two days of elevated bacteria levels at depths of six meters or shallower and the nearshore region (referred to as the “kelp” region in previous reports) experienced 32 days on which the bacteria levels were deemed elevated. There were 52 sampling days when at least one shore station showed elevated levels. The total number of sampling days for all three SBOO areas totaled 148 in 2023 and 96 in 2022. Therefore, in 2023 for the three sampling regions combined, 48.0% of the sampling days resulted in elevated bacteria levels at one station or more, which is less than the 58.3% recorded in 2022 (using the same 2019 California Ocean Plan standards). As has been typical in recent years, the majority of the samples showing elevated levels were recorded at the shore stations. Elevated levels offshore near the SBOO wye are rare. Of the two days when elevated bacteria levels were recorded at an offshore station, neither (I11 and I18) were in close proximity to the SBOO wye.

The satellite imagery showing substantial discharge from the TJR region often correlated well with times when the shoreline and kelp area sampling showed elevated bacteria levels. In past years, heavy and/or persistent rainfall was often the most plausible cause for most of the elevated bacteria samples and turbid waters seen in the remote sensing data. However, given the increasing problems with untreated sewage and other pollutants flowing out of the TJR for much of the year (SDRWQCB, 2024 and Little, 2024), that premise is no longer valid in many cases. Typically, the best water quality and clarity in the South Bay region is observed during the dry season from May through August. This was generally true in terms of water clarity observed in the image data during the summer of 2023, however as noted above, there were several transboundary flow incidents due to ‘dry weather flows from numerous sources in Mexico’ that exceeded the San Diego-Tijuana wastewater system capacity (SDRWQCB, 2024). These breeches to the system undoubtedly contributed to many of the elevated FIB measurements. Figure 16 offers a few examples of the bacteria sample data overlaid on top of imagery acquired on the same day of sampling. Note the very turbid water emanating from the TJR river and trending north in both images. The satellite data were acquired on 01/18/23 and 03/24/23 following heavy, multi-day rain events and SBIWTP EFF flow rates of 55.77 MGD on 01/16/23, 39.11 MGD on 03/21/23 and 33.44 MGD on 03/22/23.

Figure 17 offers an example of a day when, with the exception of phytoplankton blooms, the turbidity levels were low, and the general water clarity was good. The image was taken eight days after Hurricane Hilary moved through the region allowing the ocean conditions time to stabilize. Nutrients in the runoff possibly increased the magnitude and extent of the plankton blooms. Eight sampling stations (three nearshore and five shoreline), however, had fecal coliform densities exceeding the single sample maximum, in all probability the result of the transboundary flow problems. Red dots at SBOO stations indicate fecal coliform densities in exeedance of the fecal coliform SSM (2019 Ocean Plan). Red dots at PLOO stations indicate exceedances of the total colifom, fecal coliform and/or enterococcus SSMs (2015 Ocean Plan). Green dots identify stations at which the FIB levels were in compliance. The table to the left of the image shows the measurement values by depth for each station with elevated bacteria levels.



Station	Depth (M)	Entero	Fecal	Total	Station	Depth (M)	Entero	Fecal	Total
D11	NA	120	60	800	D11	NA	280	NA	NA
I19	2	3600	4400	16000	I19	2	840	2200	16000
	6	1000	1000	10000		6	860	1200	16000
	11	2600	2200	16000		11	520	1000	11000
I24	2	1600	3400	16000	I24	2	660	3200	16000
	6	2200	1100	8400		6	640	760	6800
	11	2800	1200	8000		11	700	580	7200
I25	2	920	560	7000	I25	2	460	2400	16000
	6	1400	800	6000		6	280	560	8600
	9	3800	880	10000		9	300	900	6200
I25	2	1100	320	5000	I32	2	76	160	2200
	6	760	260	3600		6	62	140	1400
	9	1400	760	9200		9	920	460	8200
I39	2	2400	2200	12000	I39	2	620	3200	16000
	12	560	120	4000		12	2	8	40
	18	1100	220	3000		18	6	2	120
I40	2	7400	10000	16000	I40	2	620	1800	13000
	6	3200	1100	7000		6	740	1200	8000
	9	4400	800	16000		9	1100	1600	16000

Figure 16. Sentinel 2 data with near-surface bacterial sampling data overlaid from the same day of image acquisition. Red dots at SBOO stations indicate fecal coliform densities in exeedance of the fecal coliform SSM (2019 Ocean Plan). Red dots at PLOO stations indicate exceedances of the total colifom, fecal coliform and/or enterococcus SSMs (2015 Ocean Plan). Green dots identify stations at which the FIB levels were in compliance. The tables below each image show the measurement values by depth for each station with stations and elevated bacteria levels in red text.

Station	Depth (M)	Entero	Fecal	Total
I26 (08/28/23)	2	20	80	1000
	6	140	500	16000
	9	80	620	2400
I32 (08/28/23)	2	2	10	60
	6	240	1800	16000
	9	320	2000	16000
I39 (08/28/23)	2	160	520	4000
	12	2	8	20
	18	2	4	38
S0 (08/29/23)	NA	3200	3600	16000
S3 (08/29/23)	NA	24	2000	1600
S5 (08/29/23)	NA	360	800	8400
S11 (08/29/23)	**NA**	**460**	740	**9400**
S12 (08/29/23)	**NA**	**5200**	12000	**16000**

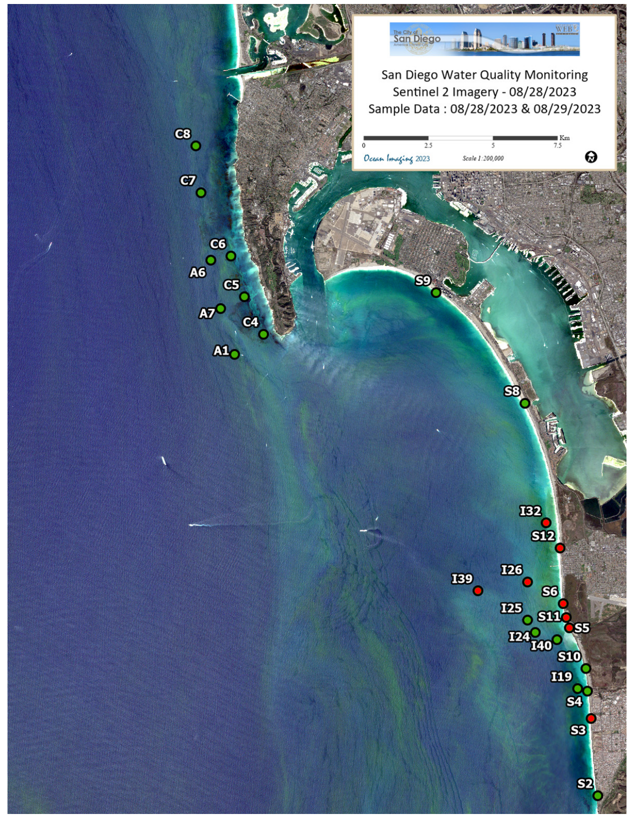


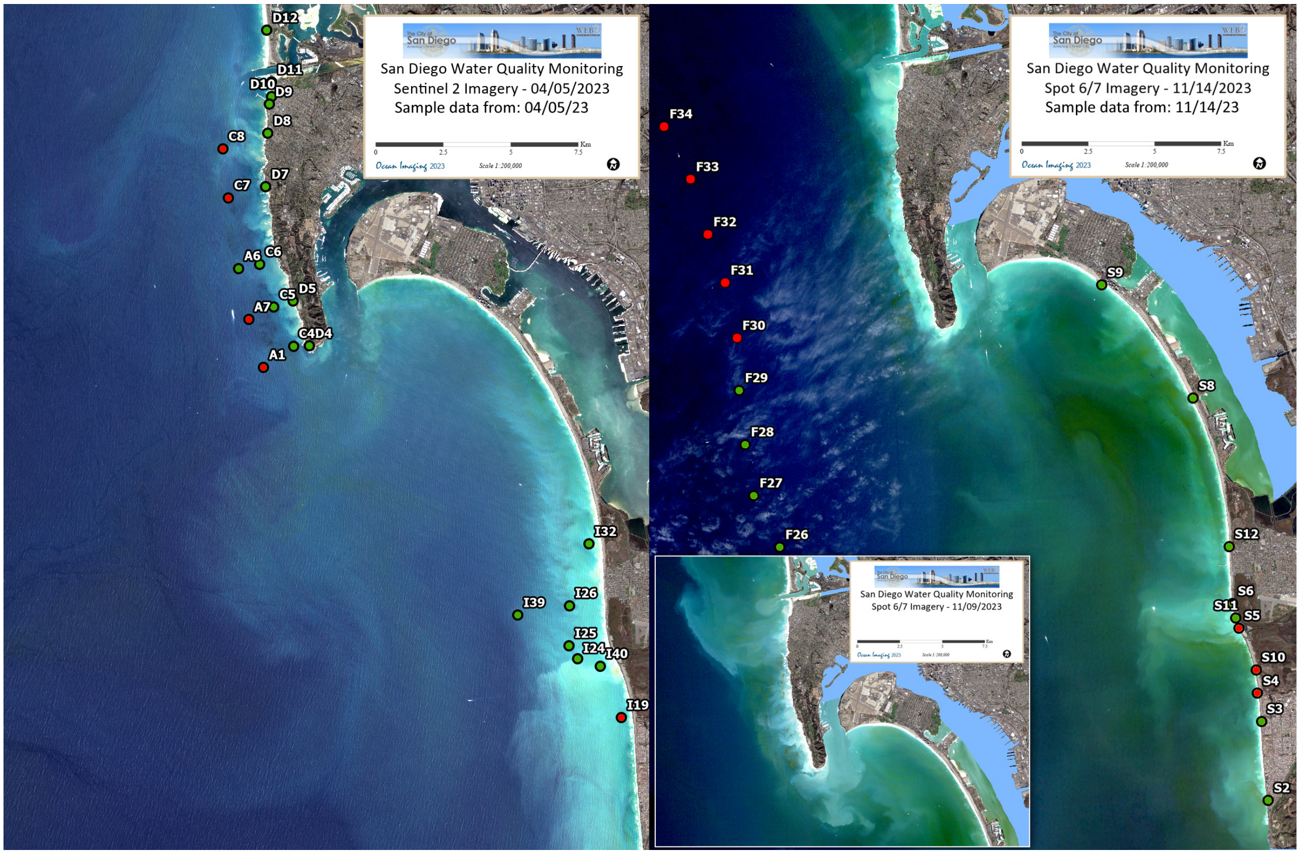
Figure 17. A Sentinel 2 image from 08/28/23 with near-surface bacterial sampling data overlaid from offshore (08/28/23) and shoreline (08/29/23) stations. Phytoplankton blooms are evident, however low turbidity, the lack of a significant TJR discharge plume and lower than average river flow rates on 08/28 and 08/29 (114 and 108 MGD vs. the annual average of 187 MGD) point to other reasons for the high FIB readings that are not readily visible in the imagery.

3.3 The Point Loma Outfall Region

After its seaward extension in 1993, the Point Loma Ocean Outfall (PLOO) is one of the deepest and longest wastewater outfalls in the world, discharging at the depth of 320 feet (~97.5 meters), 4.5 miles (7.25 kilometers) offshore. The outfall's plume is generally not observed directly with multispectral color or thermal imagery. It appears to not reach the surface waters, even during the winter months when the water column's vertical stratifications are weakened. We believe that on some occasions we have observed the plume's extents indirectly through an anomalous lateral displacement of thermal or chlorophyll features around the outfall wye. This effect can be explained by the doming up of the discharged effluent and laterally displacing the near-surface waters above it.

In 2023 the Point Loma region was affected by conditions already described for general San Diego County: significant seasonal rainfall during the months of January through March and then again in November through December and almost no rainfall during the months of April through August – apart from Hurricane Hilary in late August. Similar to past years, compromised water clarity was likely a result of runoff from the San Diego River and Mission Bay bringing sediment-laden water inside and outside the Point Loma kelp bed after the rain events described above.

The 2023 Point Loma shoreline, kelp and offshore bacterial sampling resulted in a similar number of elevated bacteria measurements when compared to the previous year as defined by the 2015 California Ocean Plan (Total coliform density will not exceed 10,000 per 100 mL; or Fecal coliform density will not exceed 400 per 100 mL; or Total coliform density will not exceed 1,000 per 100 mL when the ratio of fecal/total coliform exceeds 0.1; or enterococcus density will not exceed 104 per 100 mL) (SWRCB, 2015). Shoreline field sampling yielded 12 days on which one or more stations experienced high bacteria counts. Offshore and kelp station sampling resulted in 7 days and 1 day respectively when stations recorded excessive FIBs. Figure 18 presents examples when multiple stations in the Point Loma sampling area showed high FIB numbers on 04/05/23 and 11/14/23. The elevated bacteria at PLOO kelp stations on April 5 are possibly related to discharge originating from the San Diego River. There is no evidence of the wastewater plume at the surface in the imagery from November 14. Instead, all bacterial exceedances were found at depths of 80 m or more, indicating that the plume was trapped by the pycnocline barrier and so any surface presence would not be visible in the satellite imagery.



Station	Depth (M)	Entero	Fecal	Total
A1	1	2	10	110
	12	60	600	2200
	18	100	680	5400
A7	1	2	6	38
	12	94	360	2200
	18	110	980	4800
C7	1	2	2	16
	12	18	68	360
	18	64	500	2200
C8	1	2	2	4
	12	66	400	1400
	18	78	480	1000
I19	2	600	3000	16000
	6	100	180	4800
	11	46	50	1200

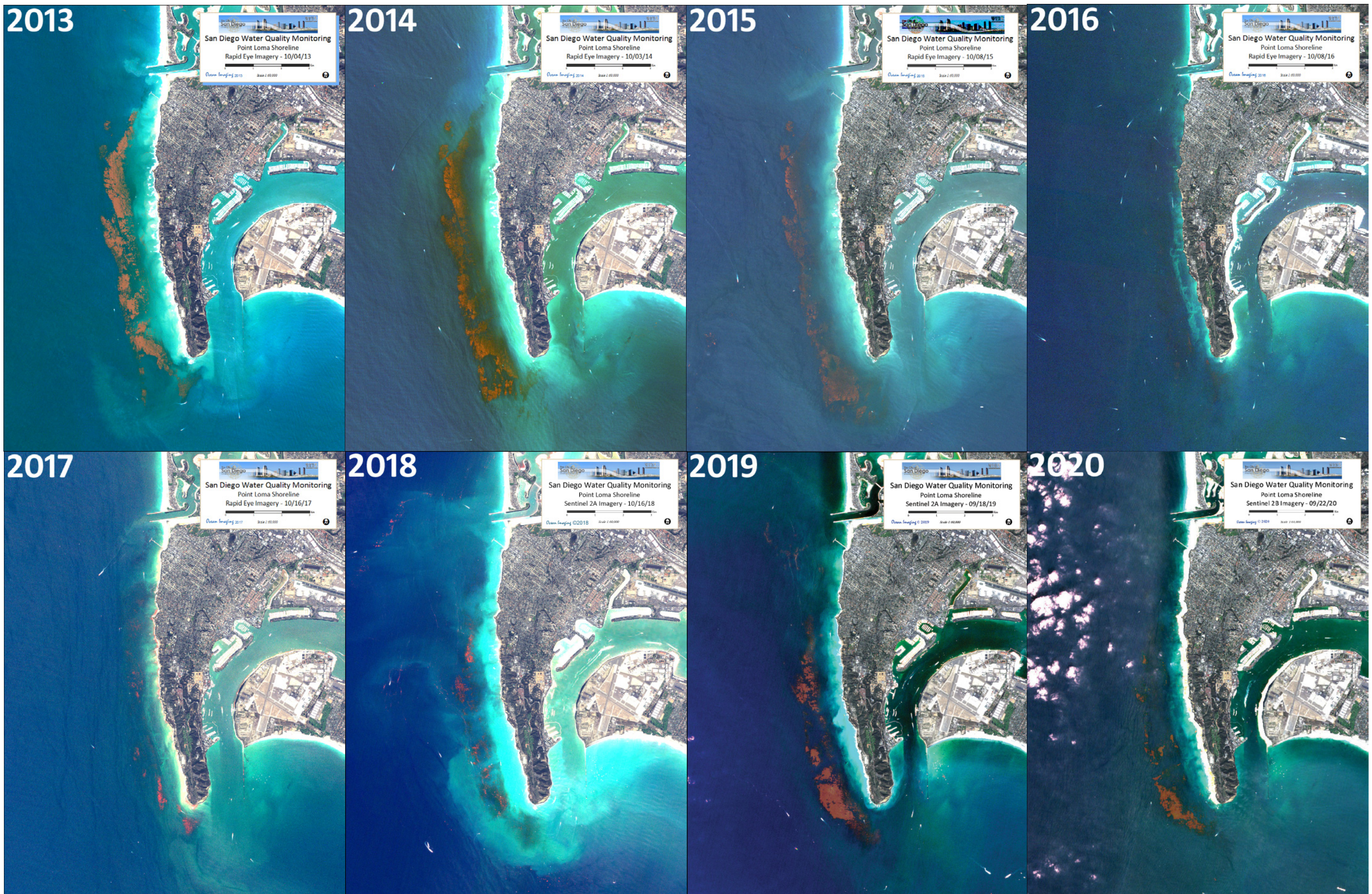
Station	Depth (M)	Entero	Fecal	Total
F30	25	2	NA	NA
	60	2	NA	NA
	80	320	NA	NA
	98	320	NA	NA
F31	1	2	NA	NA
	25	2	NA	NA
	60	2	NA	NA
	80	660	NA	NA
	98	460	NA	NA
F32	1	2	NA	NA
	25	2	NA	NA
	60	2	NA	NA
	80	620	NA	NA
	98	720	NA	NA
F33	1	2	NA	NA
	25	2	NA	NA
	60	2	NA	NA
	80	300	NA	NA
	98	200	NA	NA
F34	1	2	NA	NA
	25	2	NA	NA
	60	2	NA	NA
	80	20	NA	NA
	98	200	NA	NA
S0	NA	5400	6800	16000
S4	NA	300	640	1200
S5	NA	400	660	1600
S10	NA	460	1600	6000

Figure 18. Sentinel 2 and SPOT imagery acquired on 04/05/23 and 11/14/23 respectively with near-surface bacterial sampling data overlaid from the same day. An inset SPOT image from 11/09/23 shows heavy discharge from the San Diego River and Mission Bay along with coastal runoff a few days prior to the 11/14 data. However bacterial exceedances on 11/14 were all at 80 meters or deeper indicating that they were related to the PLOO effluent plume trapped beneath the pycnocline barrier. Stations showing FIB measurements exceeding the single sample maximum as defined by the 2019 California Ocean Plan are shown as red dots for the SBOO region and as defined by the 2015 California Ocean Plan metrics for the PLOO region. The table shows the measurement values by depth for each station that exceeded single sample maximums.

3.4 Kelp Variability

One observation provided by the satellite image archive is the continuing variability in the size of the Point Loma kelp bed over time (Figure 19). Table 4 shows the area in km^2 of three notable kelp beds in the San Diego region over the past 16 years. The September and October dates were chosen to represent the kelp bed canopy coverage for each year since spring and fall are considered to be the time periods when the canopy size is at or near its peak - with fall being the traditionally preferred time period to map kelp using remote sensing techniques. The estimated size of the Point Loma bed canopy in the fall of 2023 (2.14 km^2) was significantly smaller than the average canopy coverage for the prior 15-year period from 2008-2022 (4.07 km^2). As has been reported in previous years, the satellite data show the bed begin to decrease in size during February of 2016, perhaps due to the storm events taking place during early to mid-January, effects from the 2014-2016 strong El Niño event and/or the Northeast Pacific marine heat wave (Di Lorenzo, 2016). Noted in the 2017 and 2018 annual reports, the kelp bed looked to be coming back in January of 2017, but then decreased in size as the year progressed resulting in much smaller than average canopy coverage by the end of that year. Using the fall imagery as an indicator for annual health, the bed size appeared to be stabilizing since the 2016 and 2017 lows, however the 2023 computed area shows a considerable decrease in size. Contrary to previous years such as 2018, 2020 and 2021 when the canopy area exhibited significant intra-annual variability, in 2023 the bed size remained consistently depleted throughout the year (Figure 20). While there were significant differences in tidal heights at the time of each satellite image acquisition, tides cannot be flagged as the primary reason for the difference in canopy coverage observed in the satellite data. There were days when the areal coverage was high, but the tide level was also high and vice versa when the imagery revealed smaller bed size, but the tides were relatively low.

Canopy coverage for each year in Table 4 was computed by first running a Normalized Difference Vegetation Index (NDVI) classification followed by a commonly used unsupervised iso cluster classification algorithm (ESRI, 2024). It is important to point out that the canopy coverages shown in Table 4 may differ slightly from those provided in the Southern California Bight Regional Aerial Kelp Survey reports. (https://www.sandiego.gov/public-utilities/sustainability/ocean-monitoring/reports/kelp-survey-report-archives). This is because the canopy areas for the Point Loma bed computed for those reports are averages of four surveys performed throughout the year; while the coverage estimates shown in this report are taken from single satellite images acquired during the fall time period chosen to represent the maximum coverage experienced during that time of year. Tide levels were not a factor in the inter-year comparison as there was little variability in tide level between the years (often approximately two feet or less). However, due to the overflight times of these satellites, the canopy areas could be underrepresented compared to the kelp survey reports because the tide levels at the time of satellite data acquisition could vary significantly from the tides during the aerial surveys. The Imperial Beach and Tijuana beds have not been visible in the satellite data since 2015. It is being documented that kelp forests along the West Coast have been experiencing noteworthy variability in canopy size for the past several years, and thus warrants keeping a close watch on the health of the kelp beds in the San Diego region (Bell, et al. 2020, Schroeder 2019).



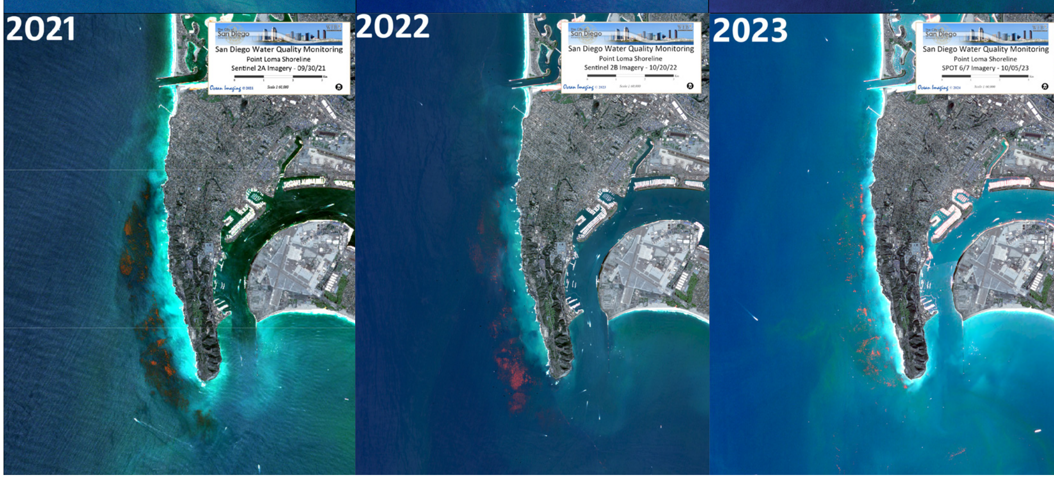


Figure 19. The Point Loma kelp bed as observed in high-resolution satellite imagery for the years 2013-2023. September and October dates were chosen to represent the kelp bed canopy coverage for each year since that period is when the canopy size is thought to be at or near its peak.

Table 4. Kelp canopy areas of three San Diego kelp beds measured from satellite imagery collected for this project.

			Kelp (km^2)		
Year	**Date**	**Satellite**	**Point Loma**	**Imperial Beach**	**Tijuana**
2023	10/05/23	SPOT 6/7	2.14	0.00	0.00
2022	10/20/22	Sentinel-2B	4.48	0.00	0.00
2021	09/30/21	Sentinel-2B	3.82	0.00	0.00
2020	09/22/20	Sentinel-2A	2.93	0.00	0.00
2019	09/18/19	Sentinel-2A	5.17	0.00	0.00
2018	10/16/18	Sentinel-2A	2.44	0.00	0.00
2017	10/04/17	RapidEye	1.05	0.00	0.00
2016	09/08/16	RapidEye	0.22	0.00	0.00
2015	09/17/15	Landsat 7	4.11	0.39	0.29
2014	09/14/14	Landsat 8	5.42	0.59	0.30
2013	09/23/13	RapidEye	5.89	0.19	0.05
2012	09/15/12	RapidEye	2.91	0.00	0.00
2011	09/01/11	RapidEye	1.99	0.00	0.00
2010	09/27/10	Landsat 7	6.01	0.00	0.00
2009	09/16/09	Landsat 5	5.96	1.01	0.21
2008	09/05/08	Landsat 7	8.66	0.82	0.01
* Average surface canopy coverage 2008-2022 = 4.07 km^2					

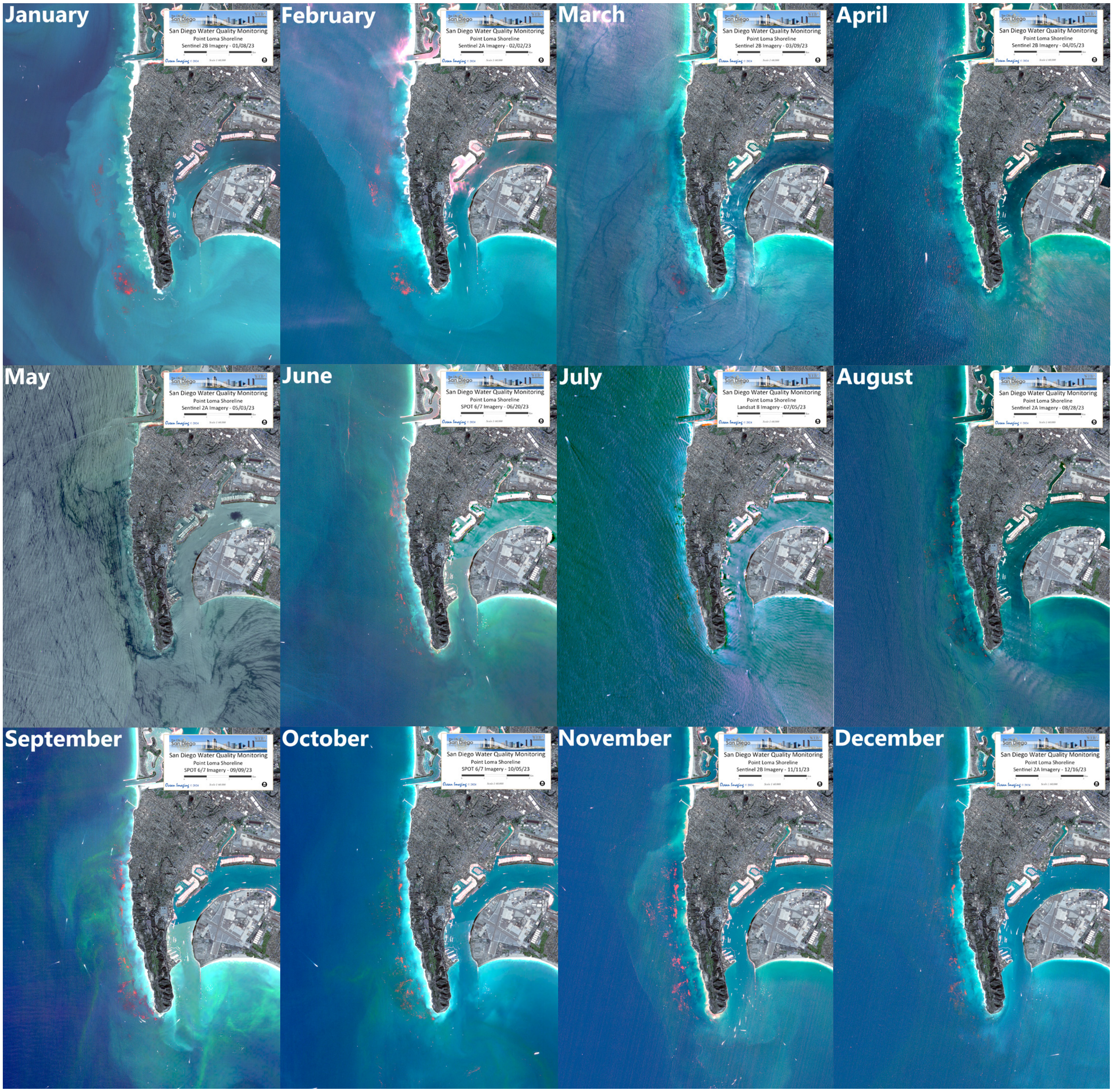


Figure 20. High-resolution satellite imagery documenting the 2023 month-to-month variability in the Point Loma kelp bed canopy coverage. The dates were chosen to best represent the maximum-observed canopy coverage for each month.

4. PRESENT AND FUTURE ENHANCEMENTS OF THE PROJECT

In 2016, OI began to generate ocean currents and other satellite- and model-derived oceanographic data products in a Web Map Service (WMS) Representational State Transfer (REST) format which would have been compatible with a WMS the City was working to implement. It was intended that all the OI-delivered data products, including all the satellite imagery would be delivered via OI's ArcGIS Server for easy ingestion into the City's WMS by fall of 2017. While this system was not implemented, OI is now developing a dashboard-style web portal to fill that purpose. The site will incorporate an interactive WMS to serve as a mechanism to better facilitate the visualization viewing of existing and future satellite image data products as well as any other tabular data sets the City chooses to host on the platform. Not only will the server give the user the capability to overlay different data types on top of each other (i.e., ocean currents on top of satellite imagery) it will significantly enhance the information experience providing fast and easy, near real-time access to the many data products delivered as part of this project. Initially the site will be password-protected and for internal use only by SDPUD employees and their partners. The server will host present, near real-time imagery and tabular data as well as data from the previous one to two years. Discussions have also begun regarding the development of a public-facing data dashboard hosting most of the same datasets that have been vetted through the City's quality control procedures. As part of this process, the historical imagery, data, and reports will remain accessible via the existing web portal. If a public-facing dashboard style data portal is implemented by the City, OI will progressively work backwards in time to make all historical data available via this platform, including the archived imagery and HYCOM data products. Figure 21 shows a protype of the dashboard presently in development.

Figure 21. Prototype dashboard-style data portal hosting access to satellite imagery along with several other oceanographic and biological datasets that can be filtered for display by date, sample depth, value range and other definable parameters.

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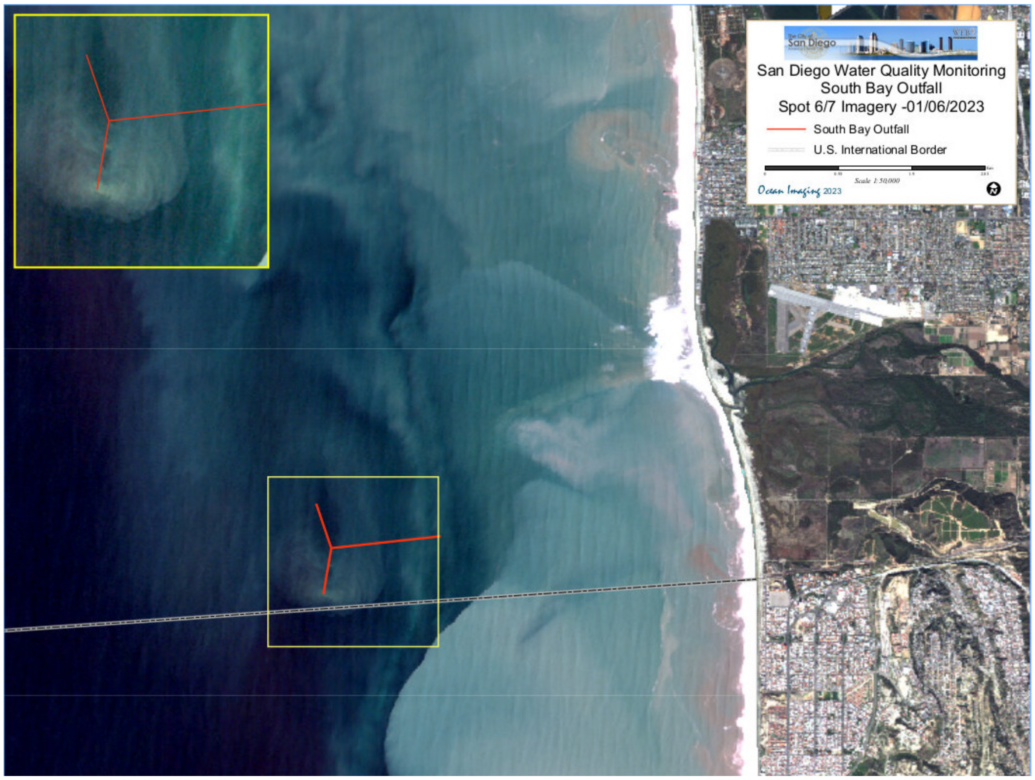
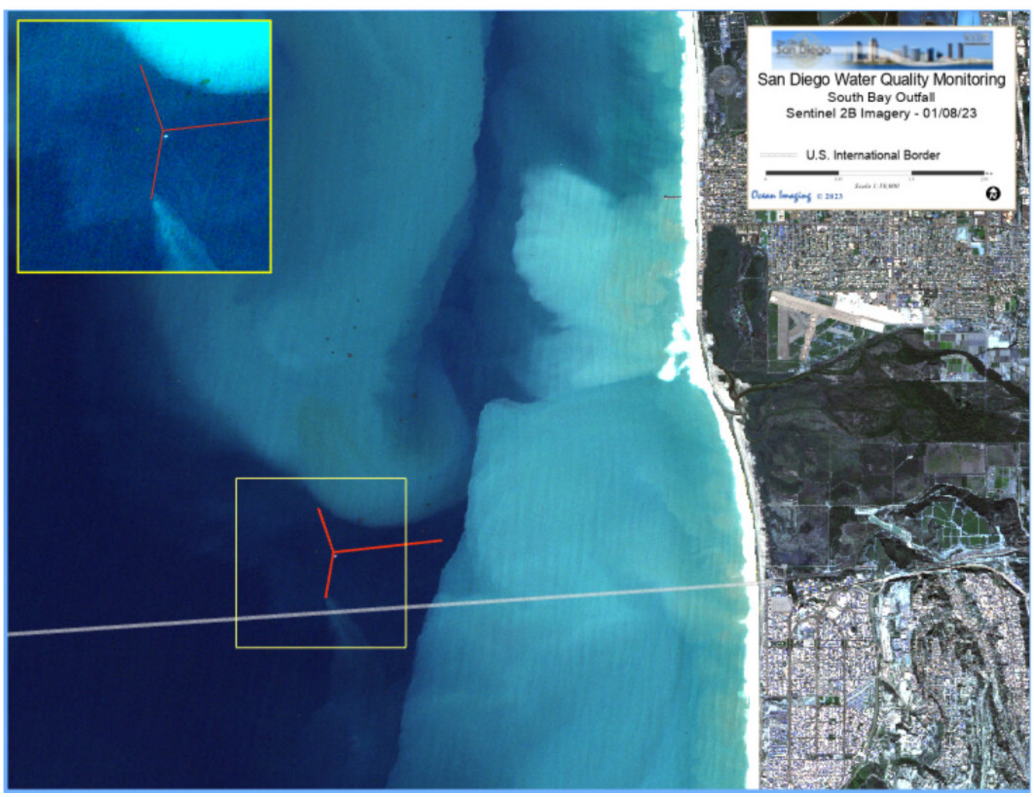
APPENDIX A – HIGH RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED WASTEWATER PLUME



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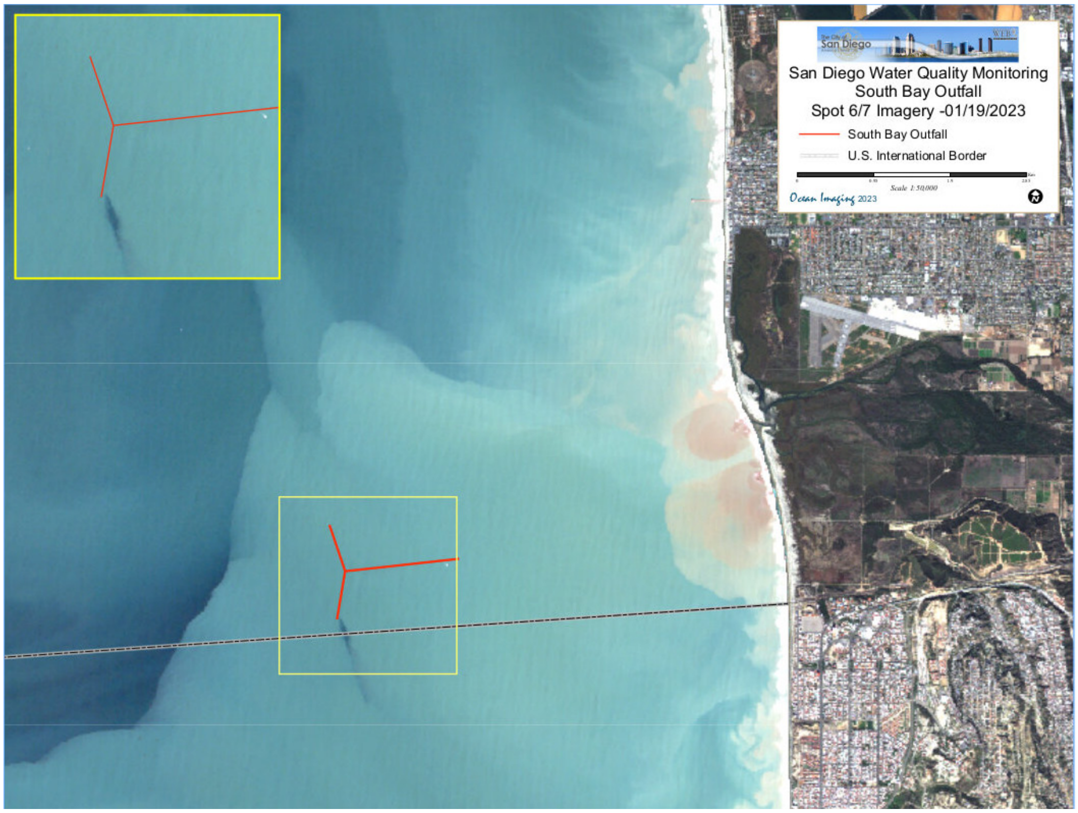
South Bay Outfall
Landsat 9 Imagery - 01/18/2023
South Bay Outfall
U.S. International Border
Scale 1:50,000
Ocean Imaging 2023


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 01/18/23
U.S. International Border
Scale 1:50,000
Ocean Imaging © 2023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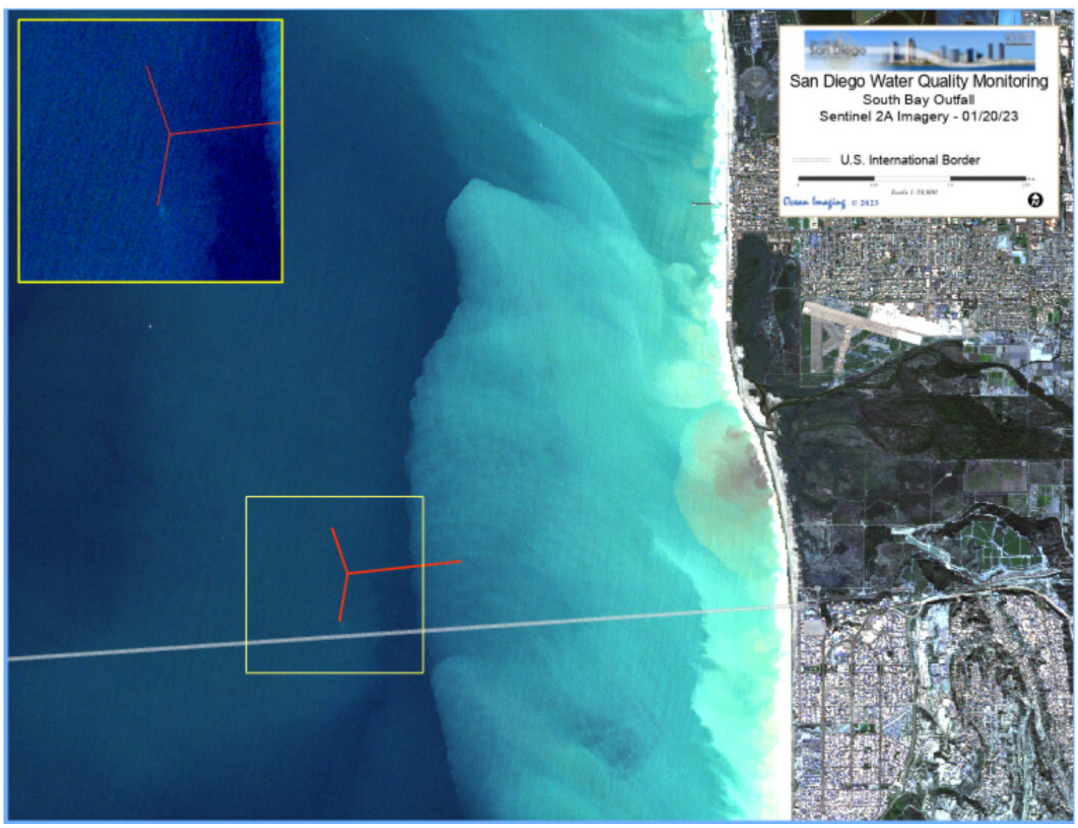
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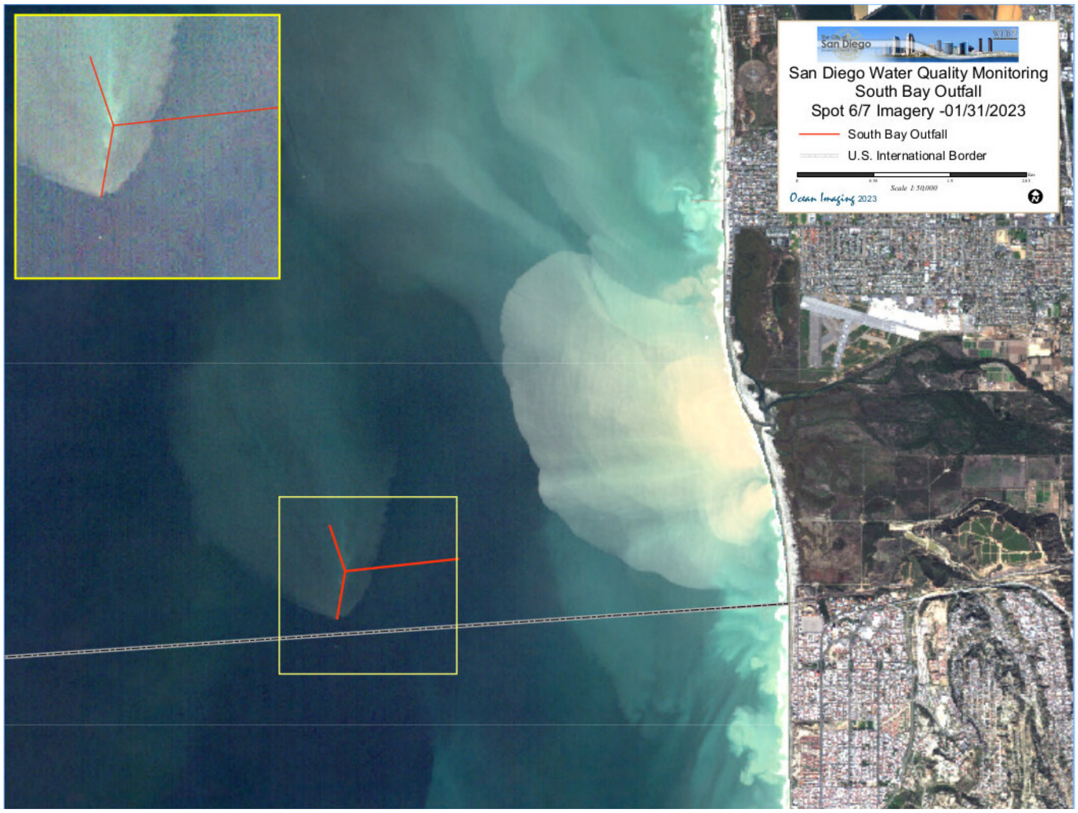
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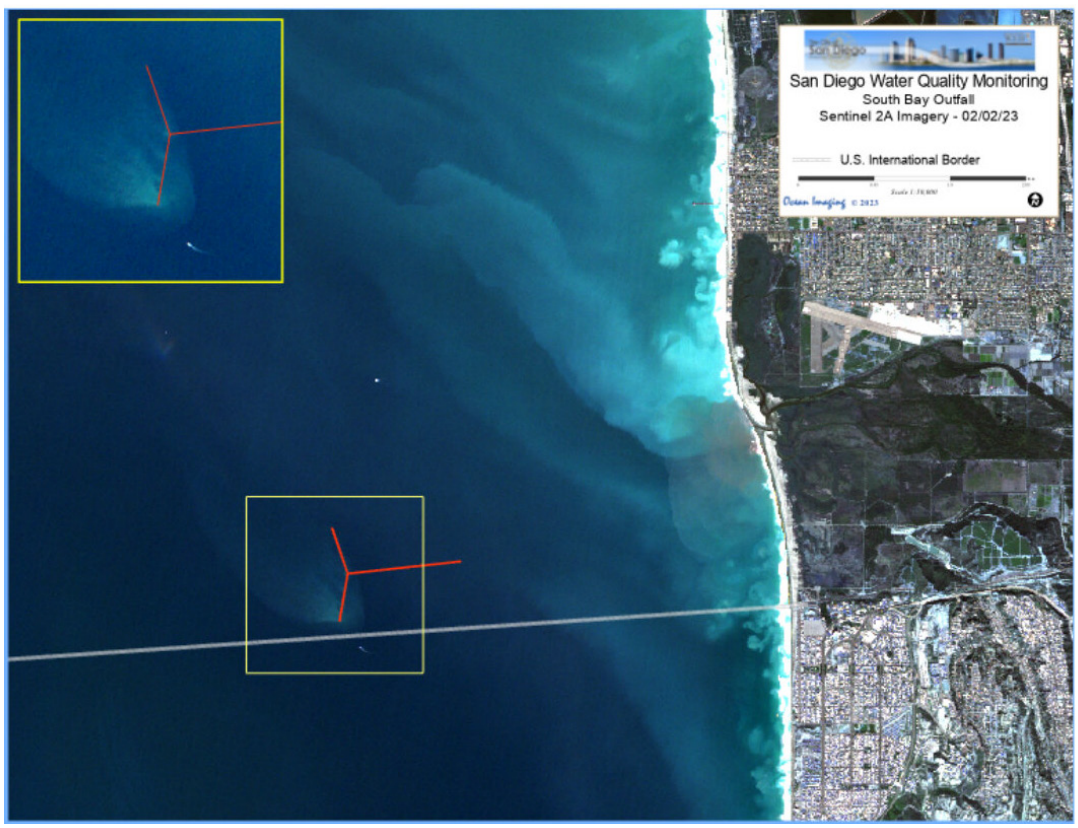
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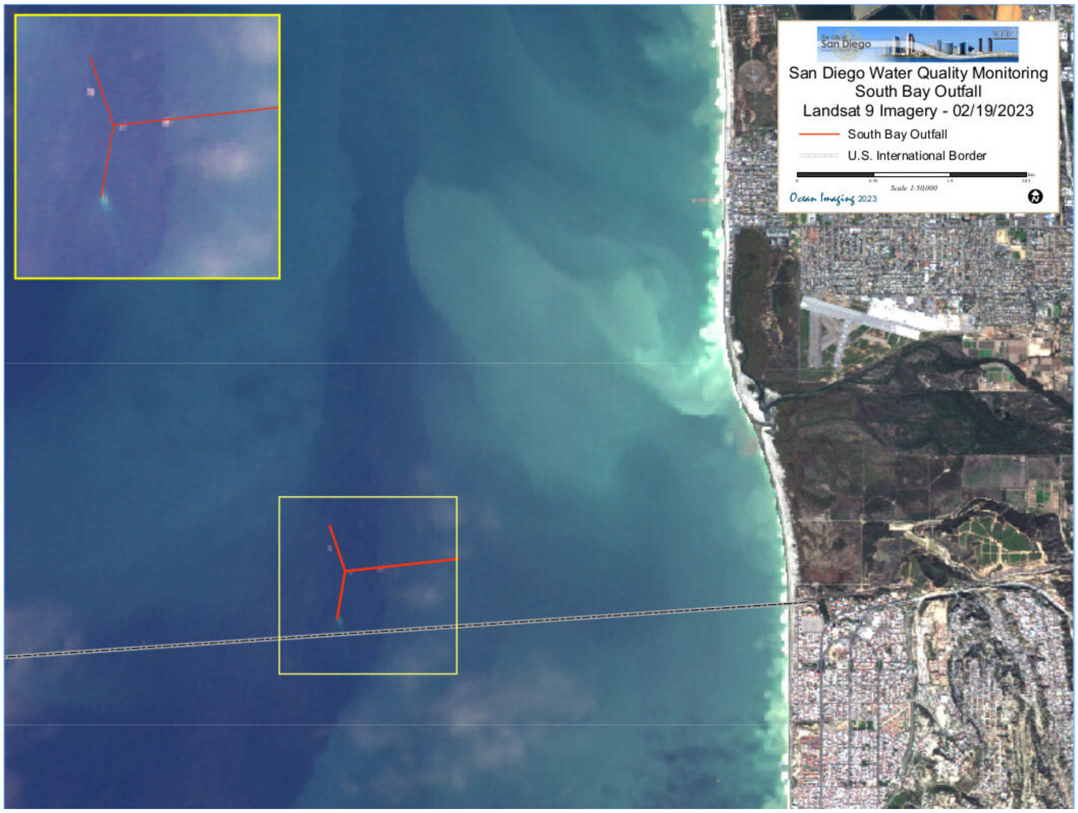
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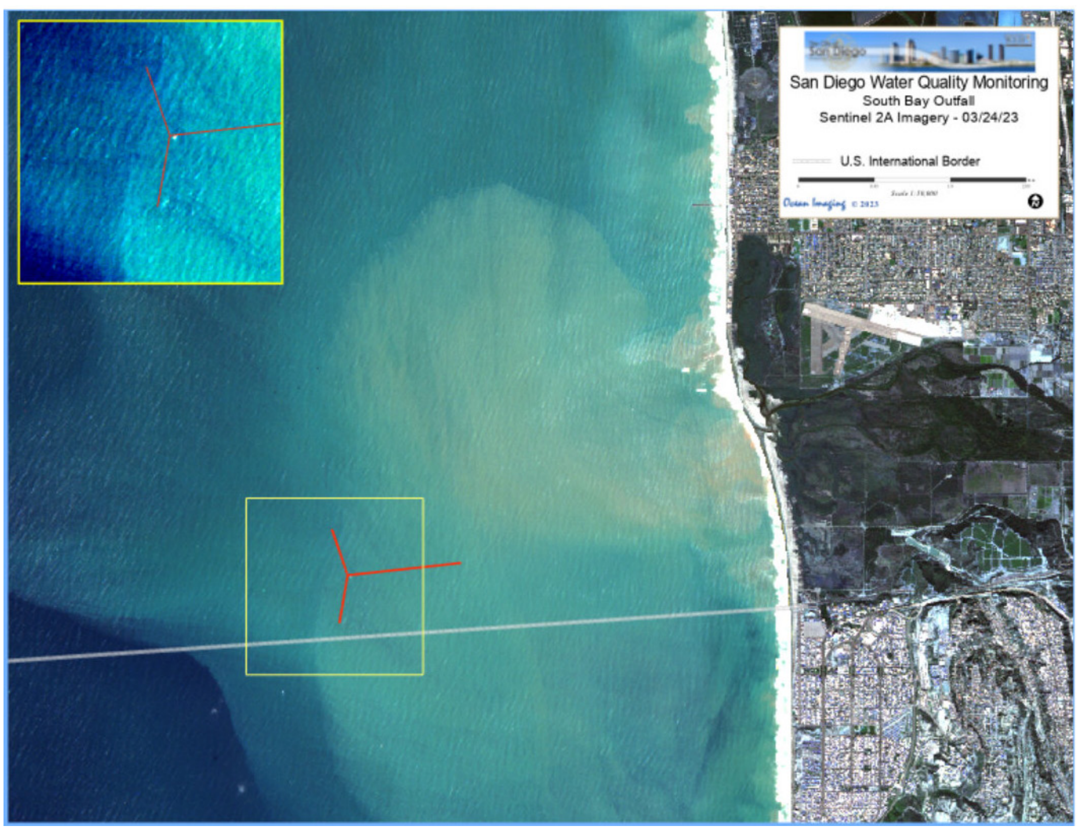
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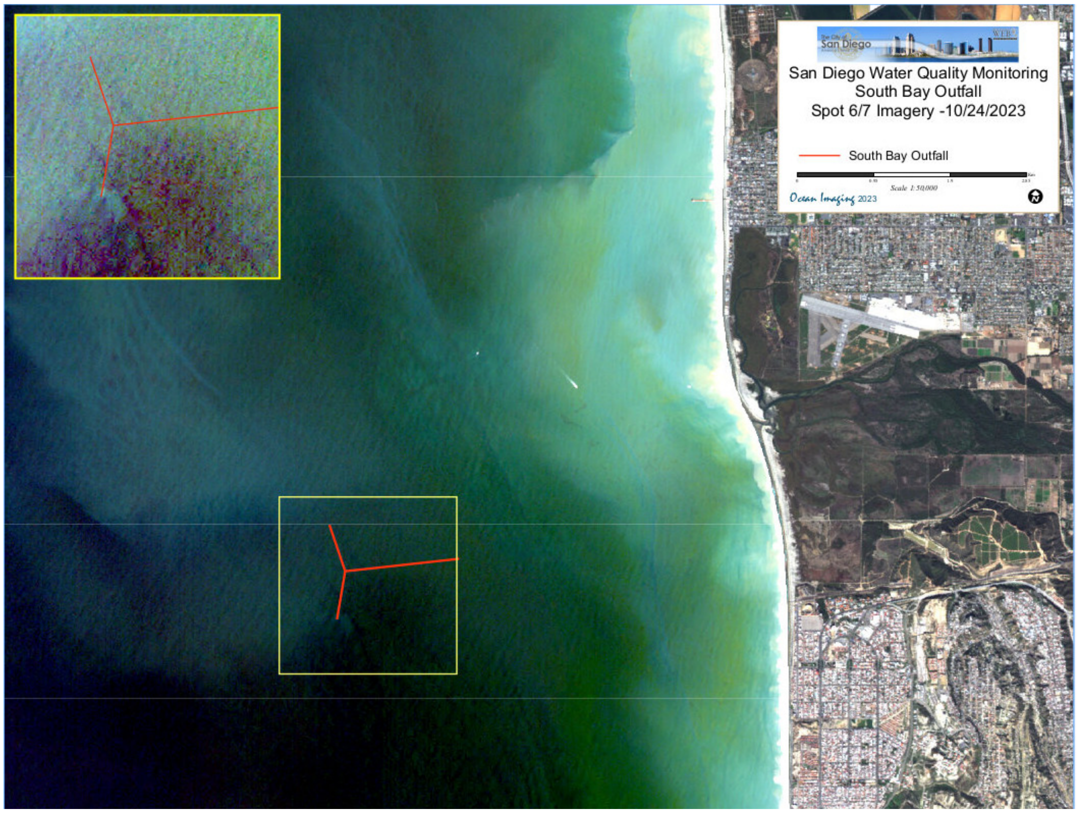
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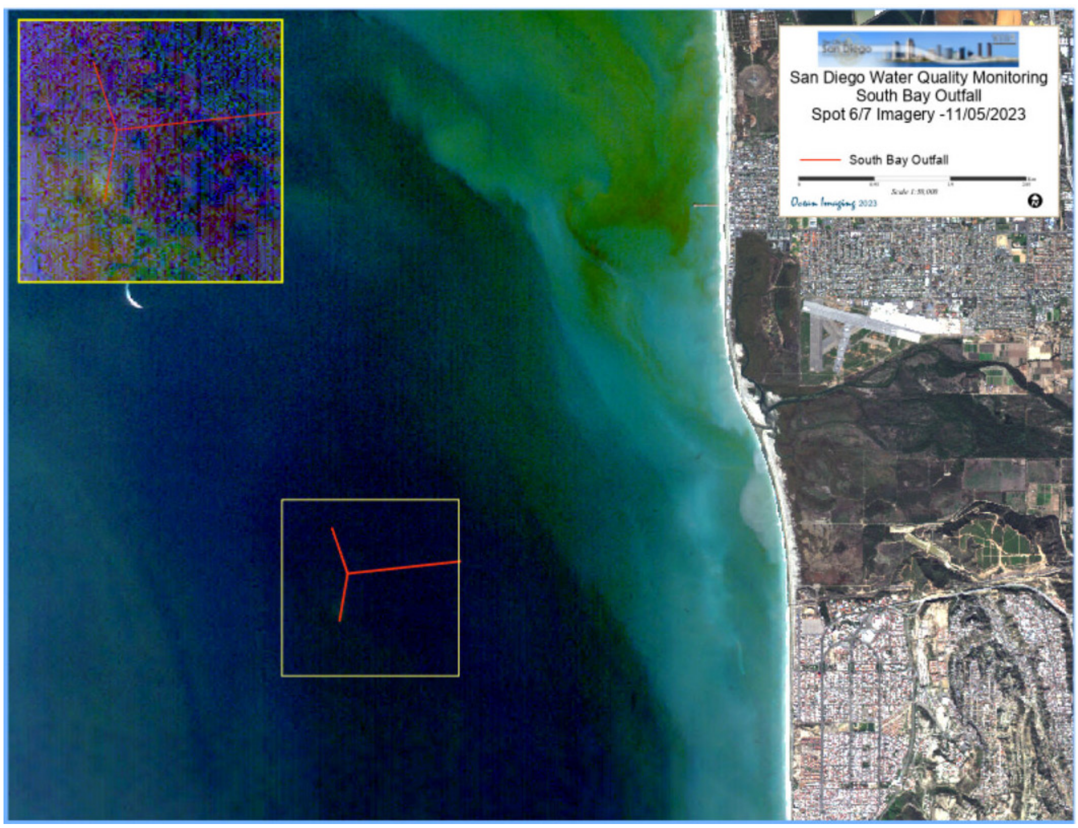
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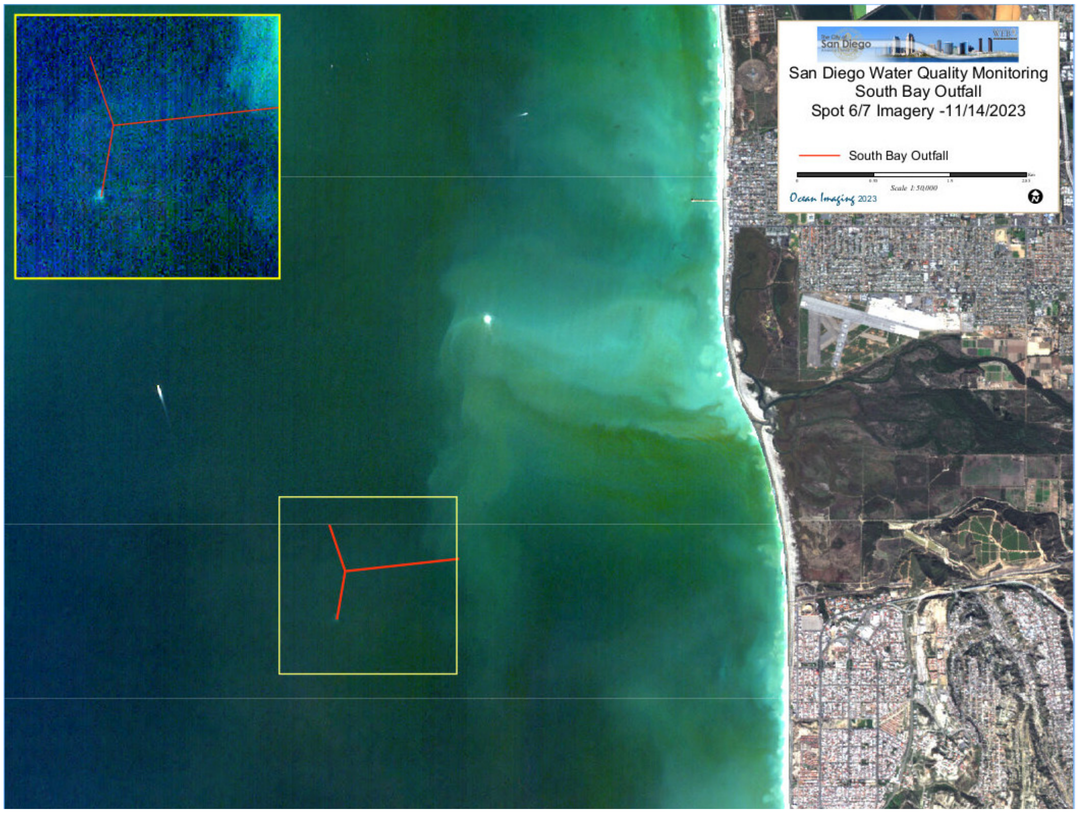
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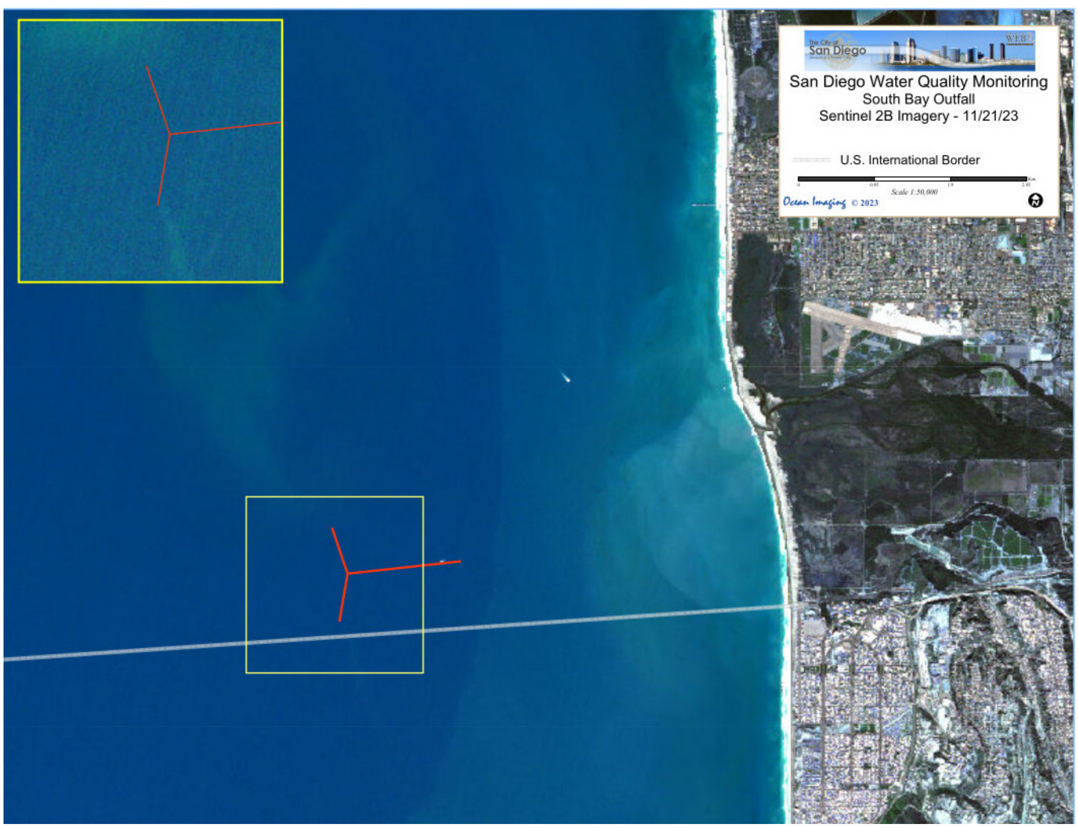
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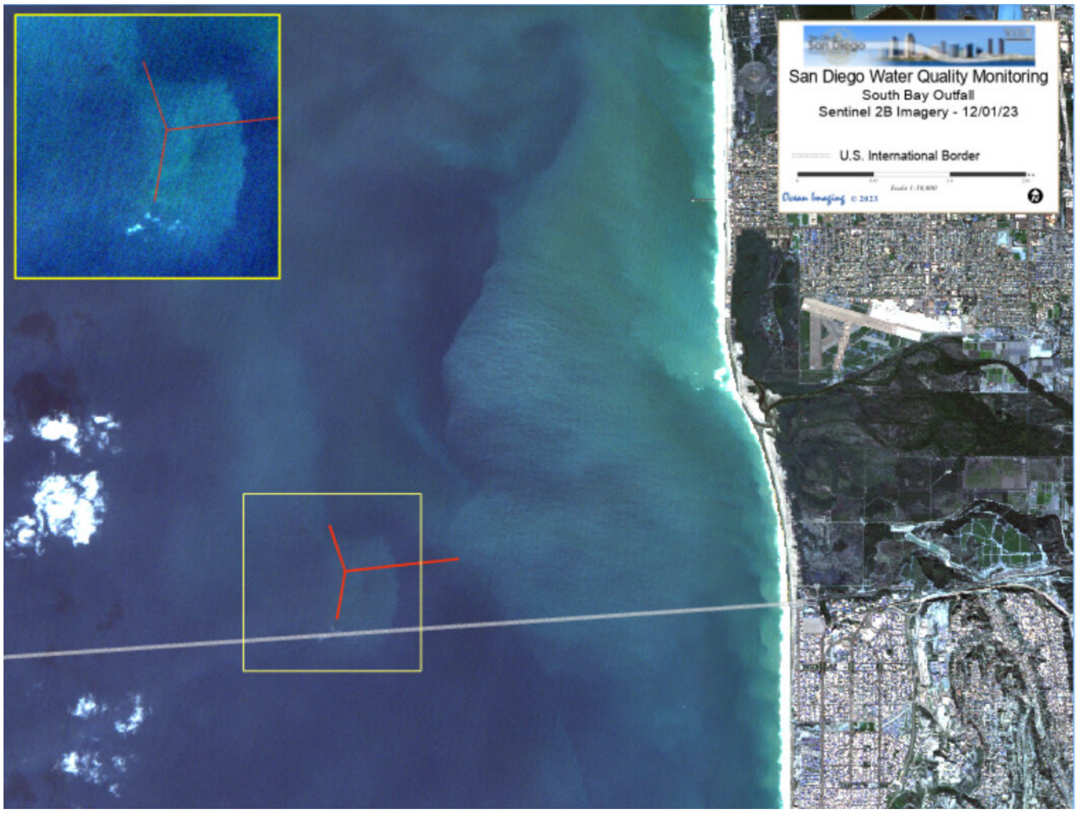
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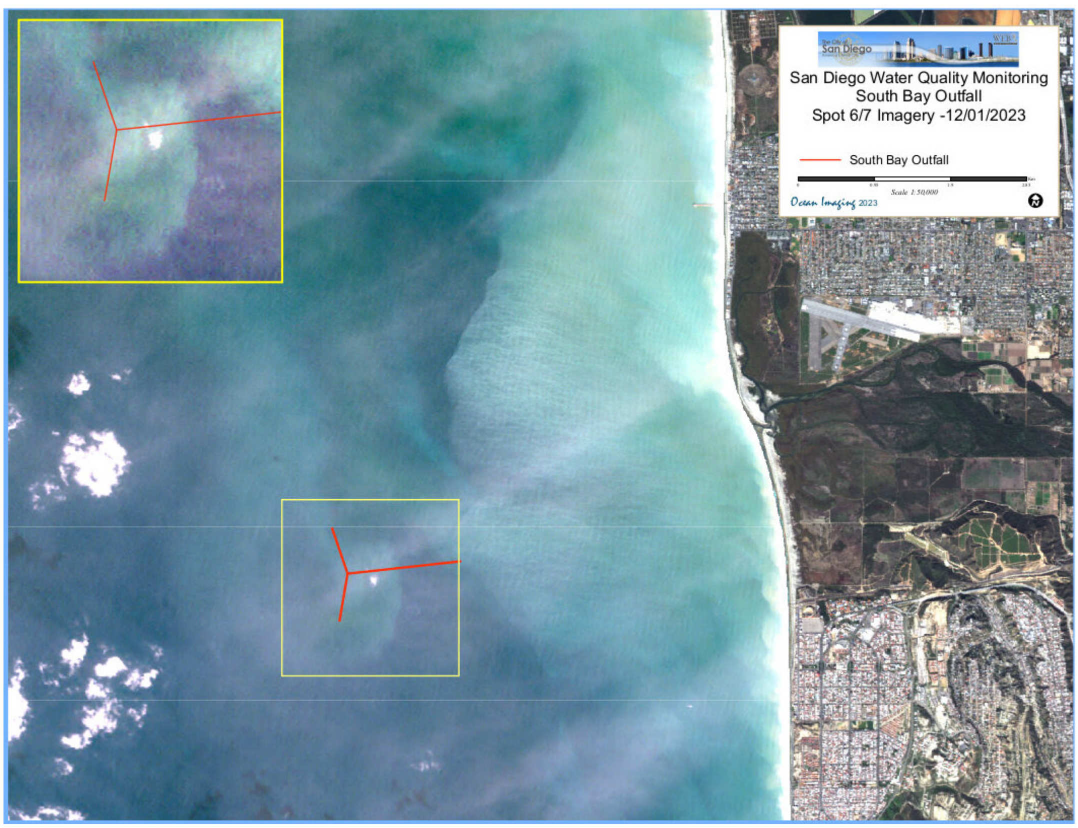
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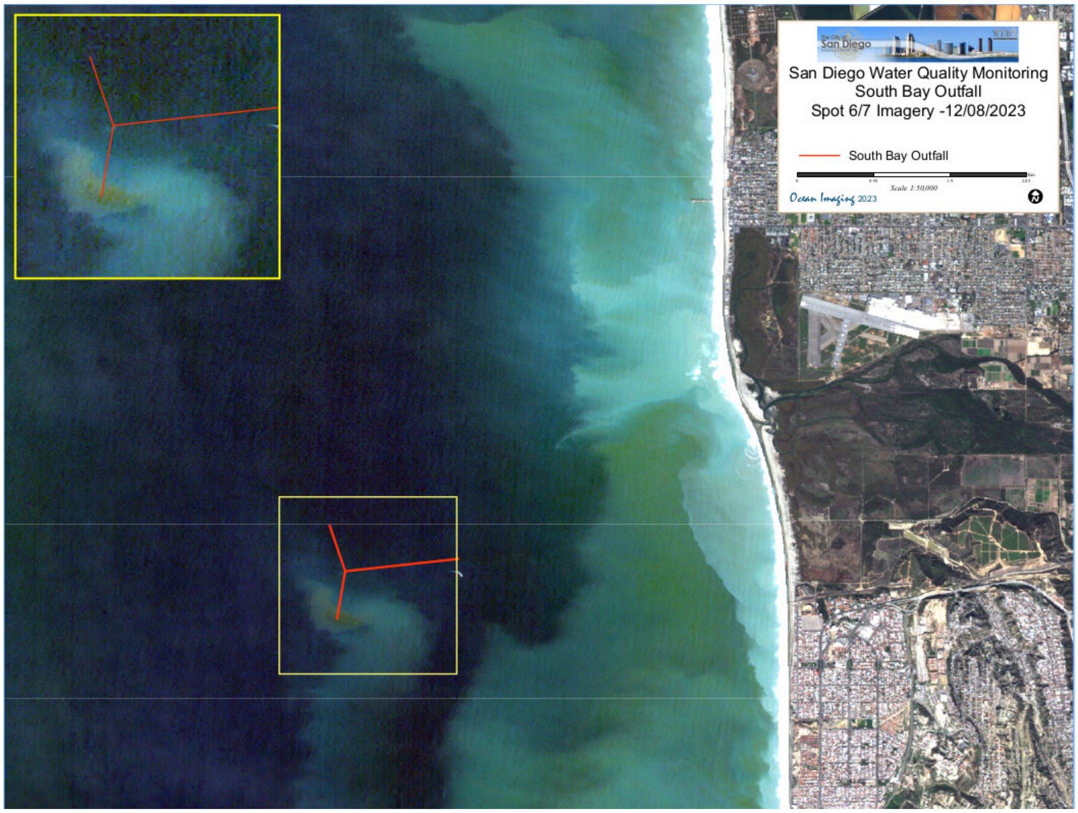
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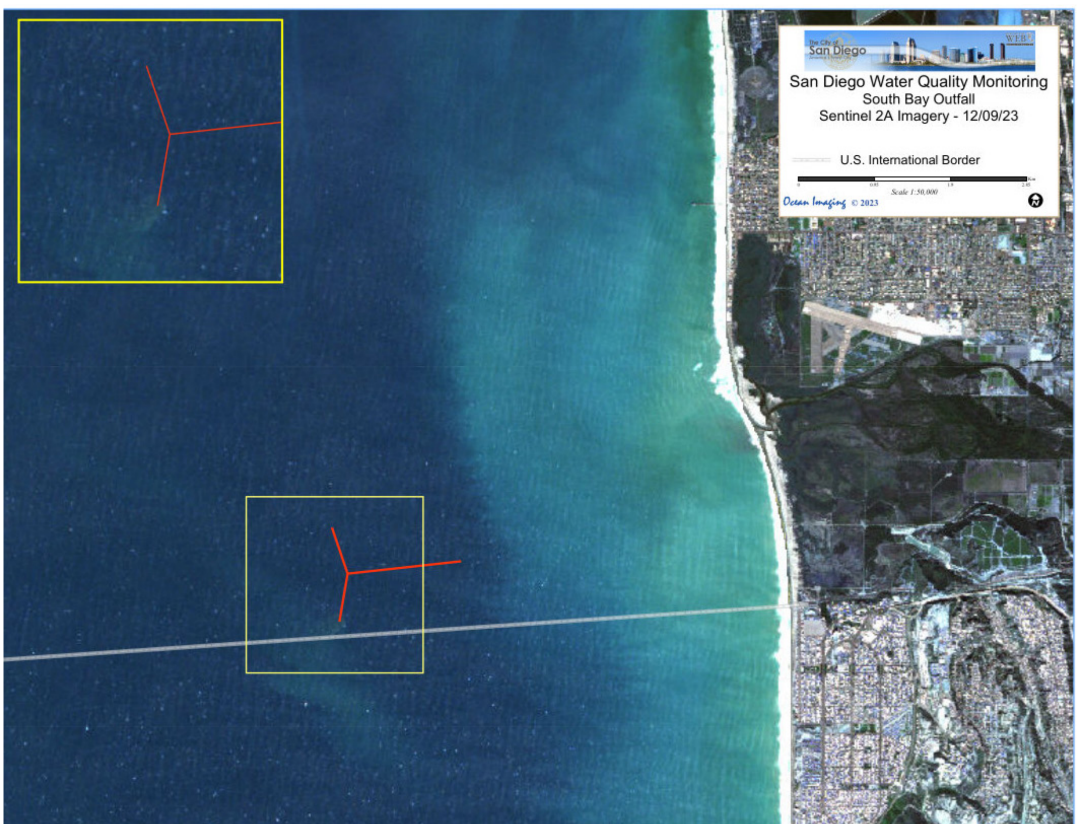
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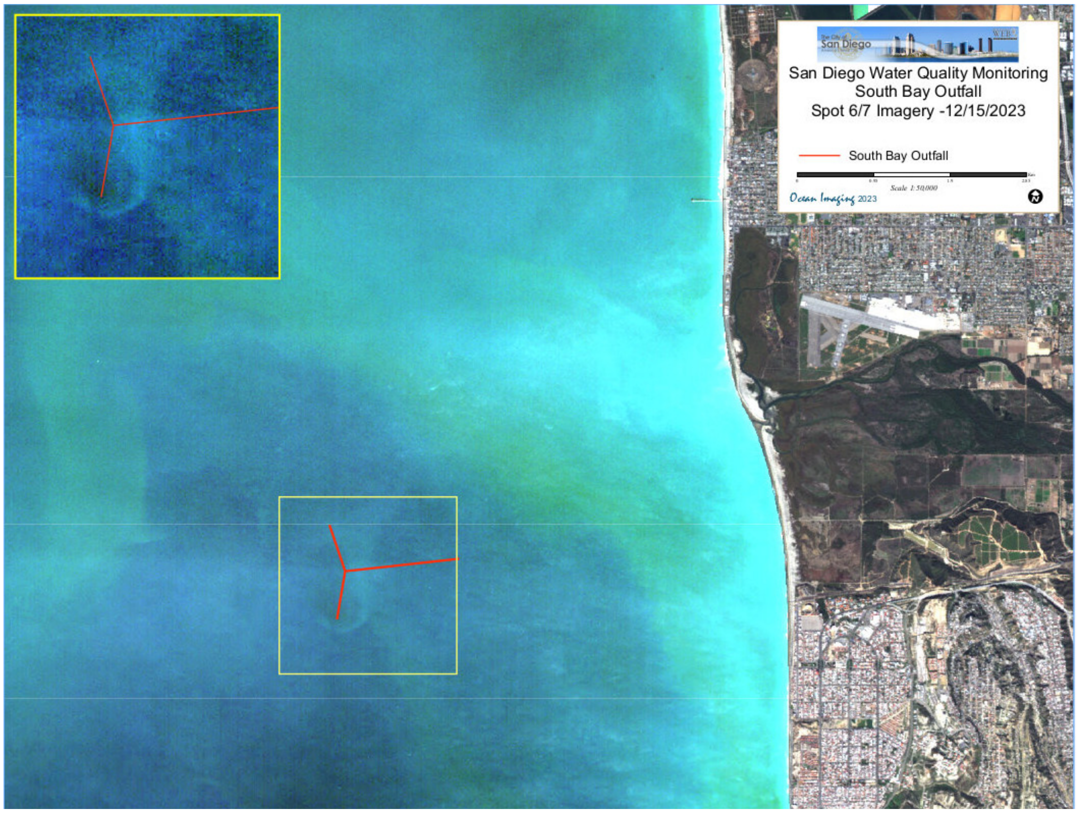
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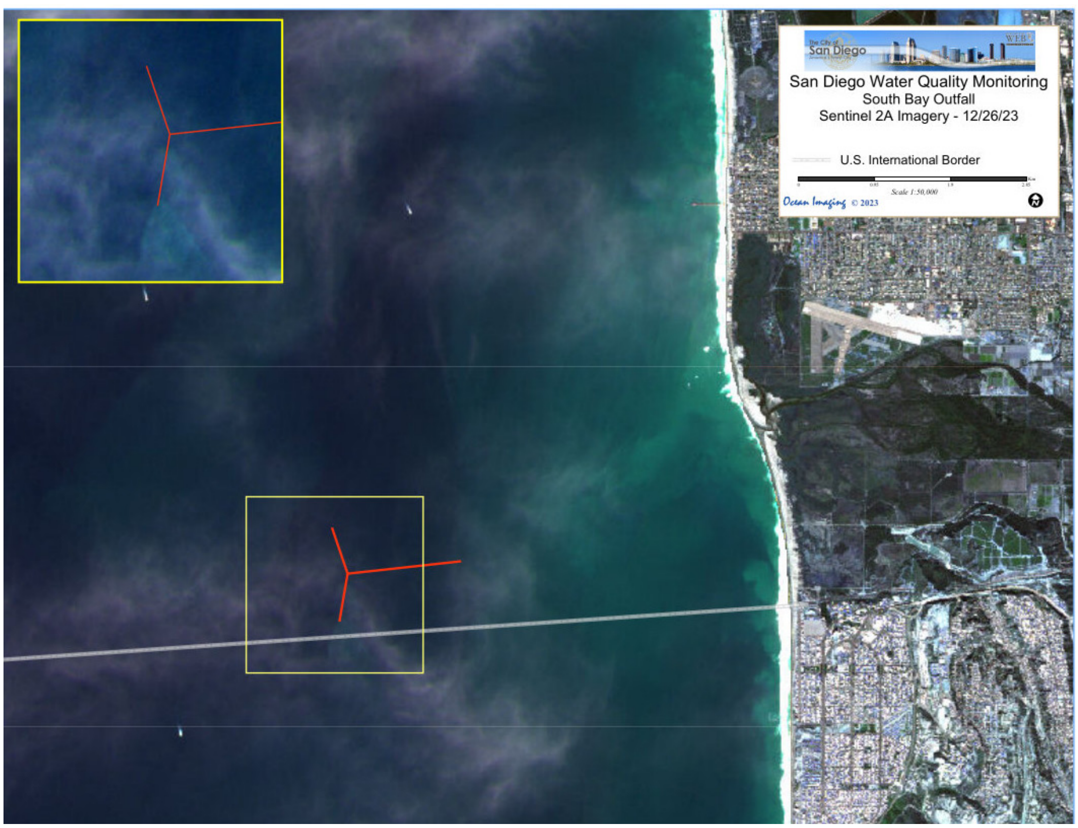
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