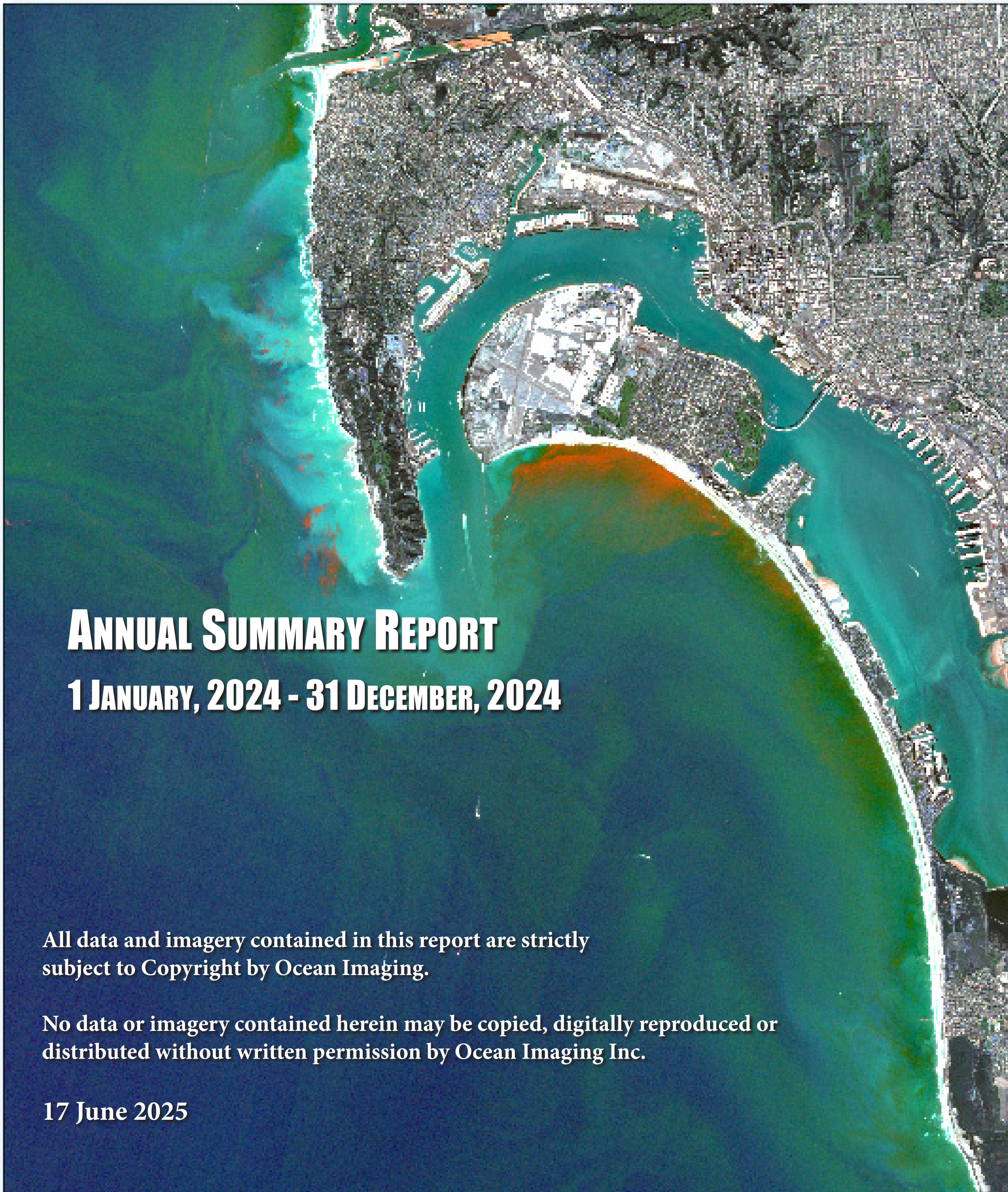
Satellite Coastal Water Quality Monitoring in the San Diego / Tijuana Region

By Mark Hess



Annual Summary Report

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Ocean Imaging

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Table of Contents

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 (USIBWC).

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 near-shore 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 reached 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 1/1/2024 – 12/31/2024.

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, as elsewhere, UV and near-IR wavelengths 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 frequent and 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. Table 1 lists 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-2 satellites. Sentinel-2A and 2B are satellites operated by the European Space Agency (ESA) and are the spaceborne platforms 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. The second satellite carrying the MSI sensor, 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. The revisit time of the Sentinel-2B satellite is also approximately ten days. 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 2024 the Sentinel-2A and 2B satellites provided the most temporally comprehensive set of high-resolution satellite imagery. In total, 105 high resolution, multispectral satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2024. This equates to a 27% increase in satellite data used to document the area when compared to 2023 – most probably due to fewer instances of total cloud cover over the San Diego region. Of the 105 total image sets, 65 were from Sentinel-2A or 2B data making up 62% of the high-resolution satellite data processed and posted as part of the project, roughly the same as in 2023.

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

Table 1. 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 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
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
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

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 similar resolution MODIS products. Sentinel-3-derived chlorophyll and possibly total suspended matter (TSM) products, offering a 300-meter spatial resolution, will be incorporated into the data mix in late 2025.

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 Table 1). 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 three clear images per month from this sensor. Figure 1 shows a set of images from 10/19/24 and 10/21/24 from Landsat 9, SPOT and Sentinel-2 highlighting the ability to obtain high-resolution imagery from multiple satellites on the same and successive days. The three images from 10/19/24 were captured within thirteen minutes of each other. Note the heavy coastal turbidity and discharge from both the TJR as well as shoreline areas south of the border moving north toward the South Bay beaches and offshore waters. Six-kilometer-spaced 25-hour averaged High Frequency Radar-derived (HF Radar) ocean currents from these days computed for the period one to two hours of the satellite data acquisitions are overlaid on the imagery to illustrate the surface flow patterns of the turbid water. Note that the turbid water appears to be clearing up by 10/21/24, however the currents continue to push the water from the TJR and border region northward.

More discussion on river discharge moving into the South Bay region is in the following sections.

As detailed in Table 1, 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-3A and 3B color and thermal imagery (available daily), 30 m & 60 m 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-2A and 2B multispectral imagery (available 2-4 times per week), and 6m resolution Satellite Pour l'Observation de la Terre (SPOT) 6 (available approximately every 5-7 days). In early 2025, Sentinel-2A started to be phased out and acquisition frequency reduced to 1-2 times per month, shortly after the Sentinel-2C system was launched and data became available.

In addition, 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 river and coastal runoff often contain natural and anthropogenic surfactants that dampen the SAR signal and therefore make it detectable in the data. Phytoplankton blooms also release biological surfactants that result in low backscatter observed

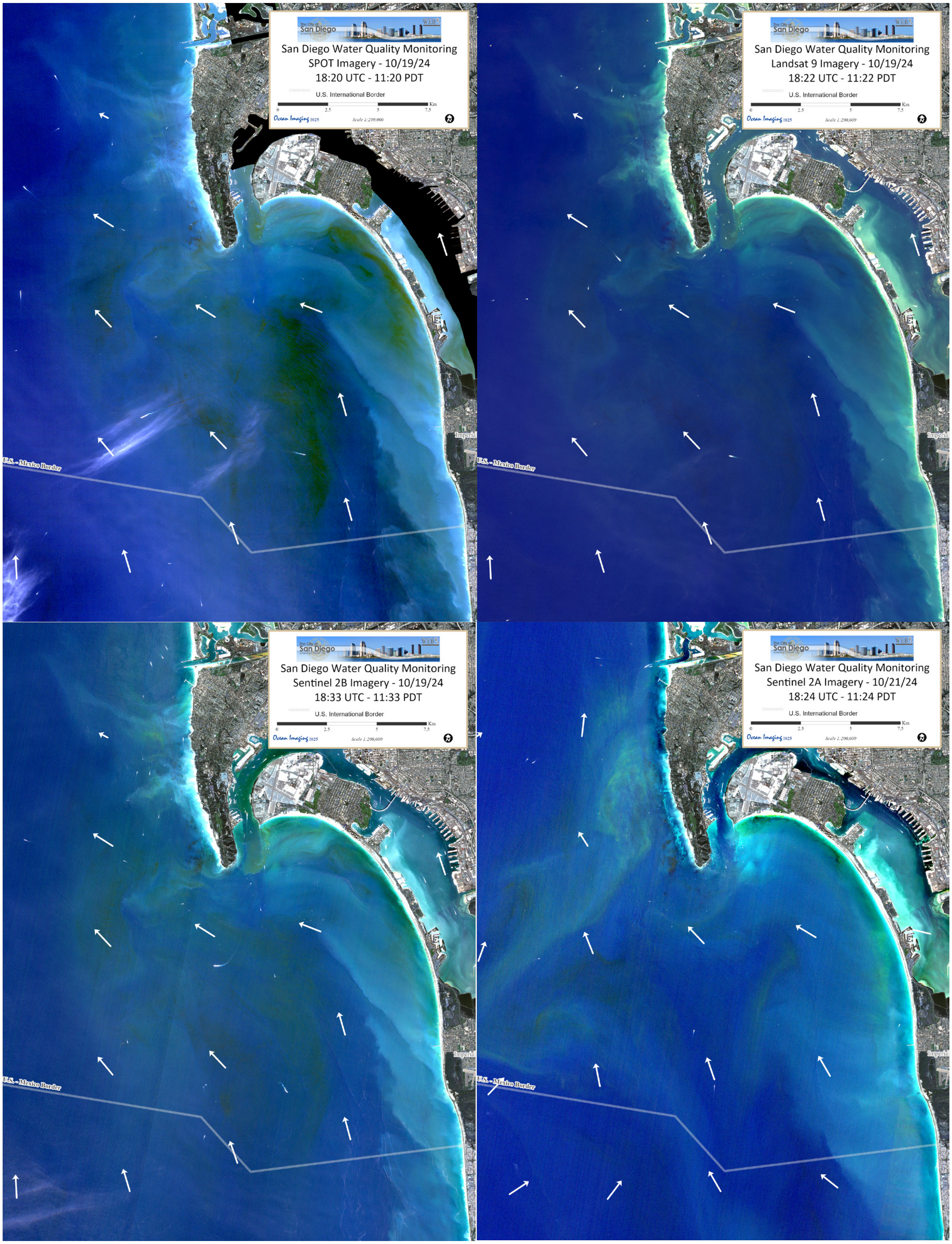


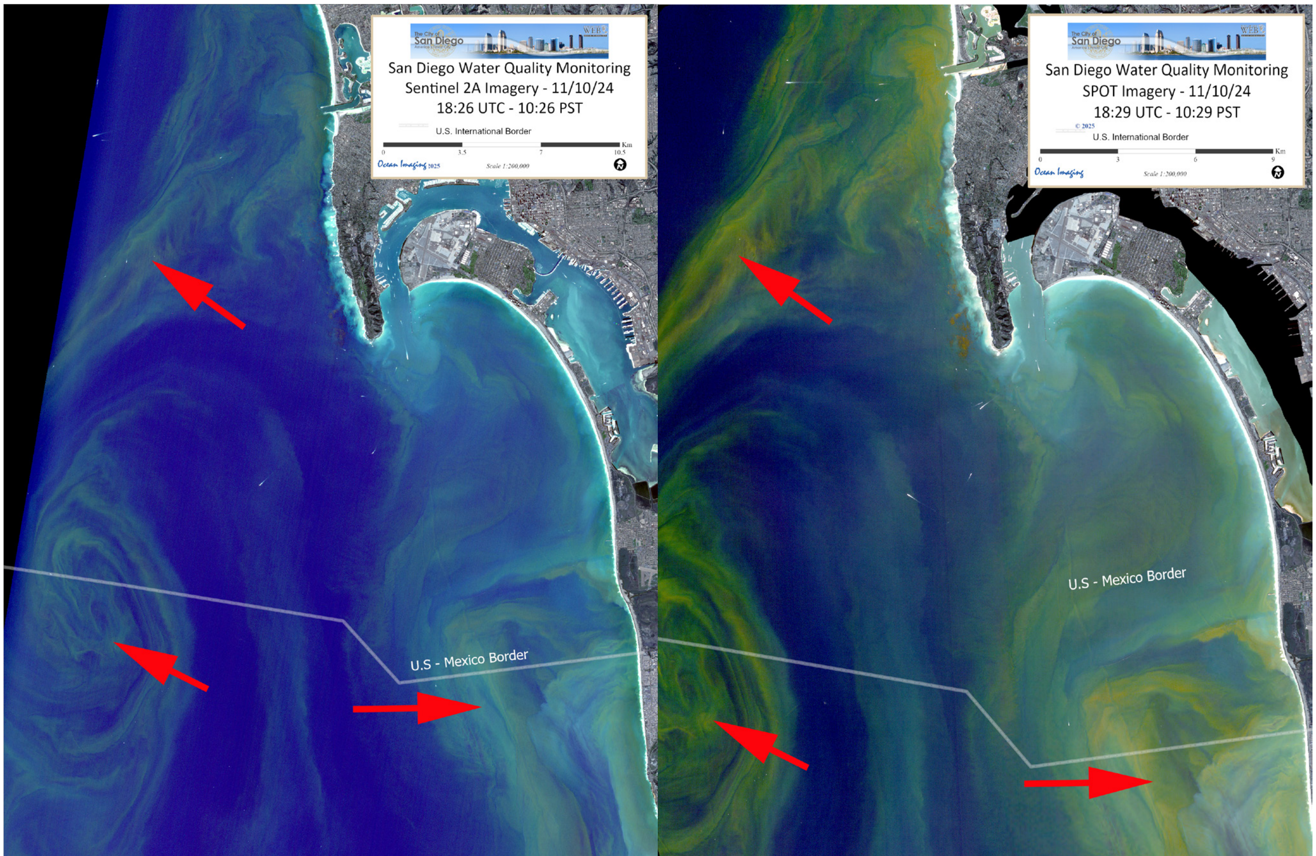
Figure 1. SPOT 6, Landsat 9 and Sentinel-2 high resolution satellite imagery from 01/19/24 and 10/21/24 with HF Radar-derived ocean currents overlaid. The three scenes from 10/19/24 were acquired thirteen minutes apart. Note that the observed movement of the coastal turbidity patterns in the South Bay area agree with the direction of the currents shown in the HF Radar-derived flow field

in the SAR data (Svejkovsky and Shandley, 2001). In 2024, 87 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 Sentinel-1 SAR image from 11/10/24 along with SPOT 6 and Sentinel-2A scenes from the same day highlighting surfactant signatures in the SAR data created by strong phytoplankton blooms in the region. The satellite data acquisitions were approximately 5.5 hours apart. The plankton blooms clearly identifiable in both the SPOT and Sentinel-2 visible imagery (top) corroborate the supposition that the dampened SAR signal (dark areas identified by the red arrows) can help identify plankton blooms and river discharge with a high composition of surfactants. Recent attention on the severity of the TJR polluted discharge (Little, 2024) and Harmful Algal Blooms (HAB) makes monitoring and documenting the coastal and offshore waters with multiple sensor types 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 (http://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 which will become operational in 2025. Details of this project are discussed below. The existing high resolution (6-30 m) observation region extends from approximately La Jolla southward to Rosarita Beach, Mexico and out approximately 50 miles. The coarser-scale products (250-1000 m) such as chlorophyll, SST, ocean 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 ocean dynamics surrounding the outfalls or other sudden/anomalous event. The website was updated in 2022 to improve its ease of use and presentation of available imagery.



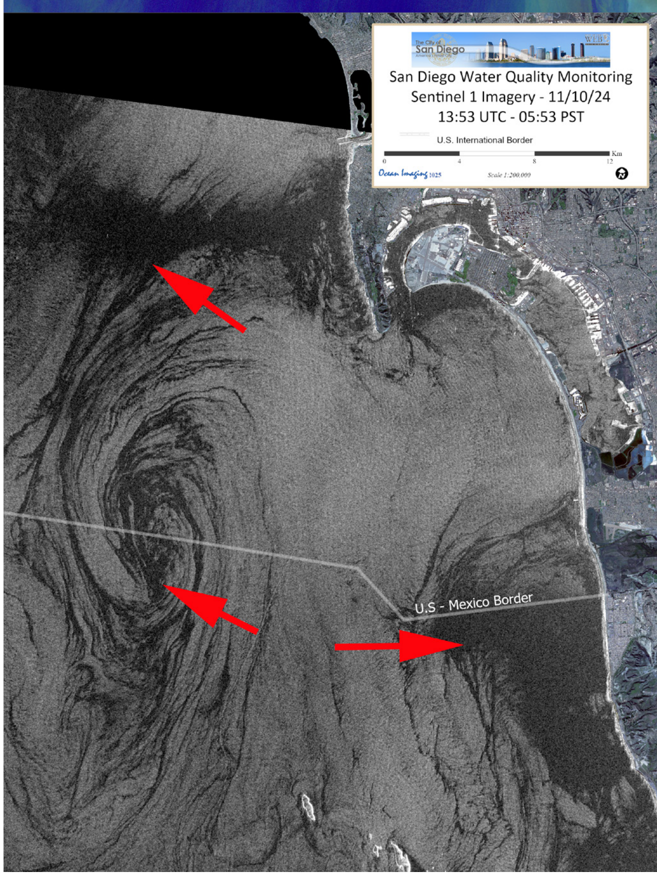


Figure 2. Sentinel-2 (top left), SPOT 6 (top right) and Sentinel-1 SAR (bottom left) imagery illustrating the ability of SAR data to help detect and identify areas biological and anthropogenic surfactants using SAR. The red arrows point to areas of high plankton levels which release surfactants on the sea surface making the blooms visible in the radar image data.

3. HIGHLIGHTS OF 2024 MONITORING

3.1 Atmospheric and Ocean Conditions

Coastal and oceanic water quality can often be correlated to rainfall events. In 2024, the San Diego International Airport station (SDIA) measured 11.37 inches of total annual rainfall and the TJR Estuary 8.67 inches, both higher than 2013-2023 averages of 8.47 and 7.85 inches respectively (see Table 2). The annual recorded precipitation recorded at the SDIA during 2024 was almost three inches above the previous 12-year average for the region. While the monthly rainfall followed normal seasonal patterns for the first four months of the year with the winter and spring months for the most part

Table 2. San Diego and Tijuana Estuary precipitation totals 2012-2024

San Diego International Airport Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
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	3.67
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	4.61
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	2.58
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	0.19
May	0.02	0.26	--	2.39	0.44	0.87	0.09	0.86	0.02	0.07	0.02	0.09	0.08
June	--	--	--	0.04	--	0.02	--	0.01	0.14	0.01	--	0.03	0.01
July	--	0.05	--	1.71	--	--	--	--	--	--	--	--	0.01
August	--	--	0.08	0.01	--	--	0.02	--	--	0.23	--	1.84	0.02
September	--	--	--	1.24	0.32	0.06	--	0.11	--	0.50	0.65	0.05	0.02
October	0.70	0.25	--	0.43	0.07	--	0.57	--	0.12	1.01	0.09	--	0.01
November	0.28	1.48	0.37	1.54	0.61	0.02	0.69	2.72	0.14	--	1.07	0.61	0.14
December	2.19	0.46	4.50	0.88	4.22	--	0.83	4.03	0.60	2.58	1.55	0.79	0.03
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**	**11.37**

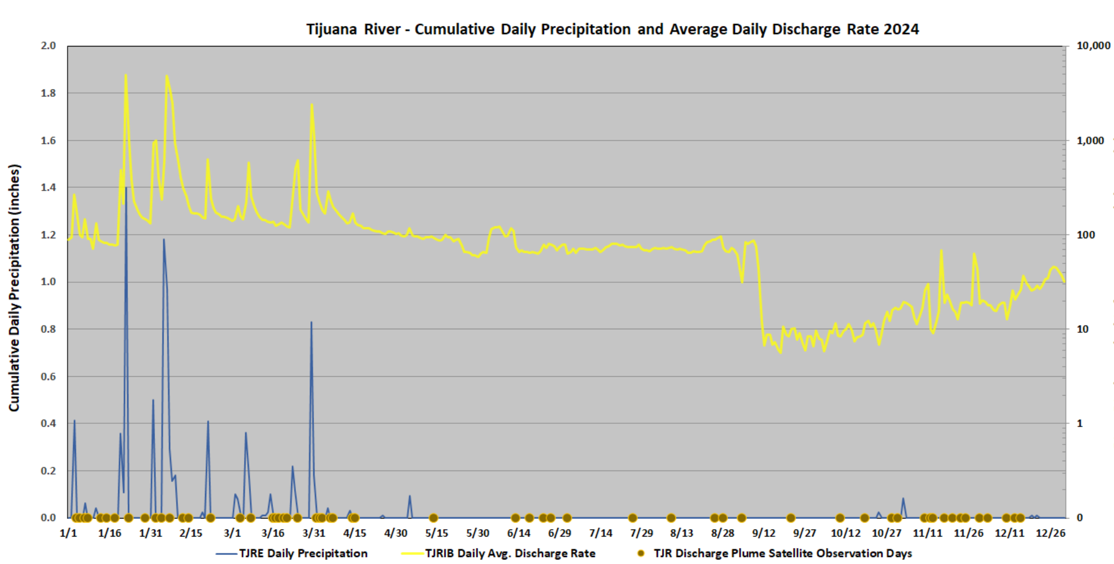
Tijuana Estuary Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
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	2.38
February	0.86	--	1.35	0.13	0.02	4.06	0.47	3.62	0.51	0.06	0.58	2.06	3.73
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	2.22
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	0.09
May	--	0.36	--	1.13	0.97	1.07	0.08	0.50	0.02	0.01	--	0.12	0.09
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	0.02
November	--	0.25	0.29	0.61	0.34	0.06	0.82	2.99	0.08	0.02	0.95	1.08	0.11
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	0.02
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**	**8.67**

matching the expected rainy season and the summer months being mostly dry, the months of September through December exhibited zero to relatively low rainfall compared to the previous twelve years. The influence of an extreme early-February rain event and the occurrence of more than double the average March precipitation had an impact on coastal water quality, which is evident in the satellite imagery showing turbid waters and elevated chlorophyll levels during and subsequent to this time frame.

Figure 3 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 to the side of the plot gives the dates for which there was measurable precipitation at that station. As noted in 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 period of consistent and/or heavy precipitation occurred during the months of January, February and March with relatively little to no rainfall recorded for the remainder of the year.

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. There were 64 days during which the TJR discharge plume was identified as significant in the satellite imagery. Only 24 of these days were during the three rainy months at the beginning of the year and only 36 (56%) of the discharge observations can be confidently attributed to rainfall occurring one to three days prior to the observation. Figures 1 and 4 provide example imagery that show higher than normal coastal turbidity, plankton blooms and visible TJR discharge plumes even though there was no measurable rainfall prior to the imaging dates. This is likely because the TJR flow rate remained above 50 cubic feet per second (cfs) up to the month of September with an average discharge rate for 2024 of 152.8 cfs and 53.5 cfs during the months of June through October. Other possible explanations could be that the coastal turbidity was caused by significant ocean swell/wave action and ocean conditions conducive to phytoplankton blooms.



Date	CumPrcp (in)
01/03/24	0.41
01/07/24	0.06
01/11/24	0.04
01/20/24	0.36
01/21/24	0.11
01/22/24	1.40
02/01/24	0.50
02/02/24	0.01
02/05/24	1.18
02/06/24	0.97
02/07/24	0.29
02/08/24	0.16
02/09/24	0.18
02/19/24	0.02
02/21/24	0.41
03/02/24	0.10
03/03/24	0.08
03/04/24	0.01
03/06/24	0.36
03/07/24	0.17
03/12/24	0.01
03/13/24	0.01
03/14/24	0.02
03/15/24	0.10
03/23/24	0.22
03/24/24	0.11
03/30/24	0.83
03/31/24	0.18
04/05/24	0.04
04/13/24	0.03
04/25/24	0.01
05/05/24	0.09
10/24/24	0.02
11/02/24	0.08
11/23/24	0.01
11/24/24	0.01
12/19/24	0.01
12/21/24	0.01

Figure 3. Daily accumulated rainfall in the Tijuana Estuary, average daily river discharge rate 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.

When the higher coastal turbidity and river discharge levels did follow the rainfall events and water quality noticeably decreased one to two days following measurable precipitation, the coastal and offshore conditions typically improved only two to three days after the rainfall ceased. Figure 5 provides examples of heavy coastal turbidity and extensive

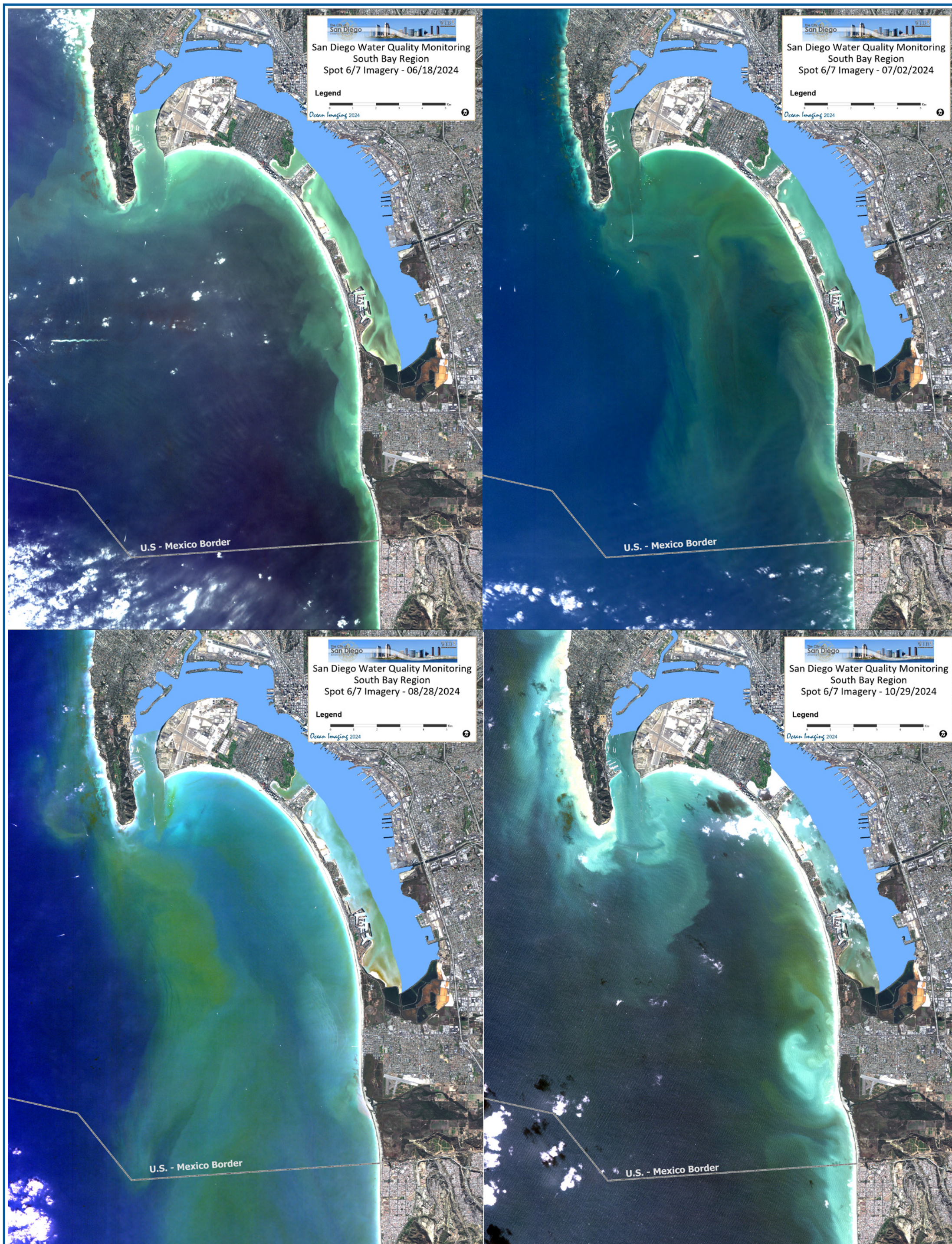


Figure 4. Sample high-resolution imagery from SPOT 6 highlighting turbid water, plankton blooms and TJR runoff plumes during periods when there was no measurable rainfall prior to the satellite imaging dates. Interestingly, on 10/29/24 when the TJR discharge appears to be the most prominent, the TJR flow rate for that day was only 15.8 cfs. It was 64.4, 62.7 and 72.9 cfs on 06/18/24, 07/02/24 and 08/28/24 respectively.

river runoff observed in the satellite imagery resulting from significant precipitation events.

As discussed above, there was negligible 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 (Figure 6). The average flow rate in 2024 (43.0 cfs) was lower than the rate experienced during 2023 (63.6 cfs), most likely due to overall higher rainfall in 2023 (Table 2). Figures

Figure 5. Landsat, Sentinel-2 and SPOT data provide examples of days when the imagery displayed heavy TJR discharge along with coastal and offshore turbidity that can be directly correlated to rainfall events prior to the imaging dates.

5 and 7 provide examples of when the satellite data exhibited notable coastal and offshore turbid conditions as well as strong plankton blooms in the Point Loma and region and area west of Mission Bay that correlate with increased SDR flow and precipitation measurements shown in Figure 6.

In 2024 the County of San Diego issued 276 posted shoreline and/or rain advisories and 102 beach/shoreline closures. This is an 11.5% decrease in the number of advisories and a 104% increase in closures compared to 2023 (312 advisories and 50 closures respectively). The two longest contiguous 2024 closures lasted until 06/30/24 at Border Field State Park along the south end of the Tijuana Slough Shoreline and Imperial Beach. In fact, Border Field State Park had been closed for over two years prior to 2024. The majority of the closures extended from the Tijuana River mouth all the way past Avenida Del Sol to include nearly all of the Coronado City beaches. Most 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 Figures 4 and 5. However, 25 closures were triggered by sewage spills in San Diego Bay, and several other locations. Six of the closures were attributed to an exceedance of bacterial standards with no known source. Also, 44 of the 102 closures happened between the months of May through the beginning of November when no rainfall was recorded at the Tijuana Estuary or SDIA stations within three days prior to the closure. 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. 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. Figures 5 and 8 provide examples of the TJR plume extending north and ocean currents pushing the TJR discharge up past Border Field State Park towards the Coronado beaches, corresponding with shoreline closures during the same period.

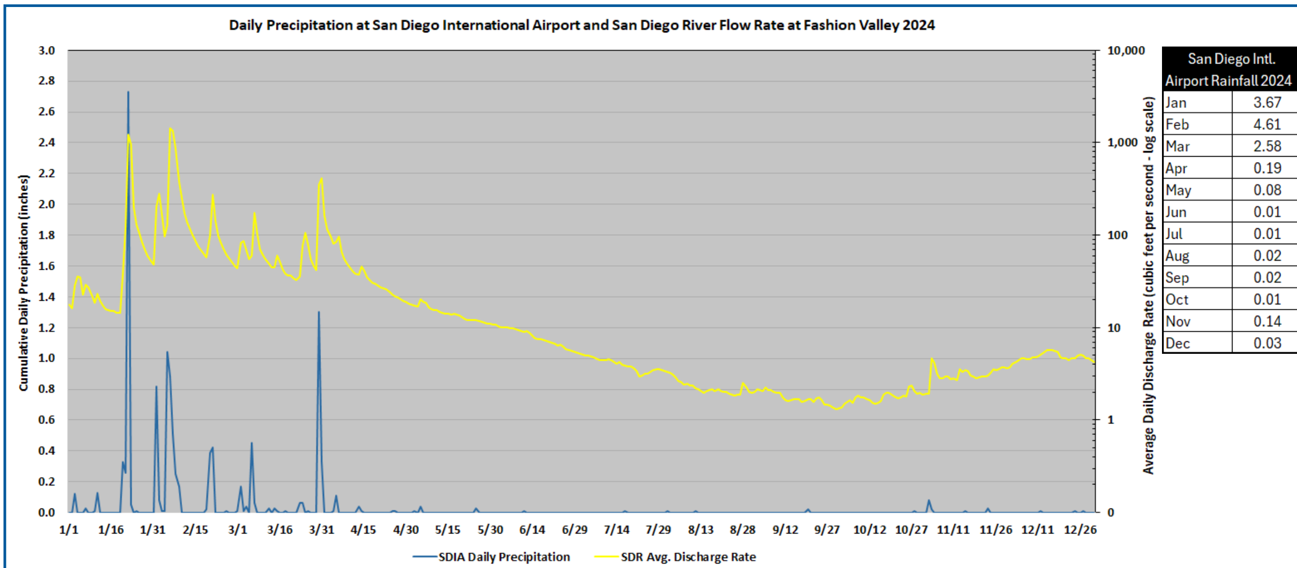


Figure 6. Average daily San Diego River flow rate as measured by the USGS Fashion Valley gauge plotted with daily precipitation amounts as recorded at the San Diego International Airport. Monthly precipitation totals at the SDIA station are displayed to the right of the plot.

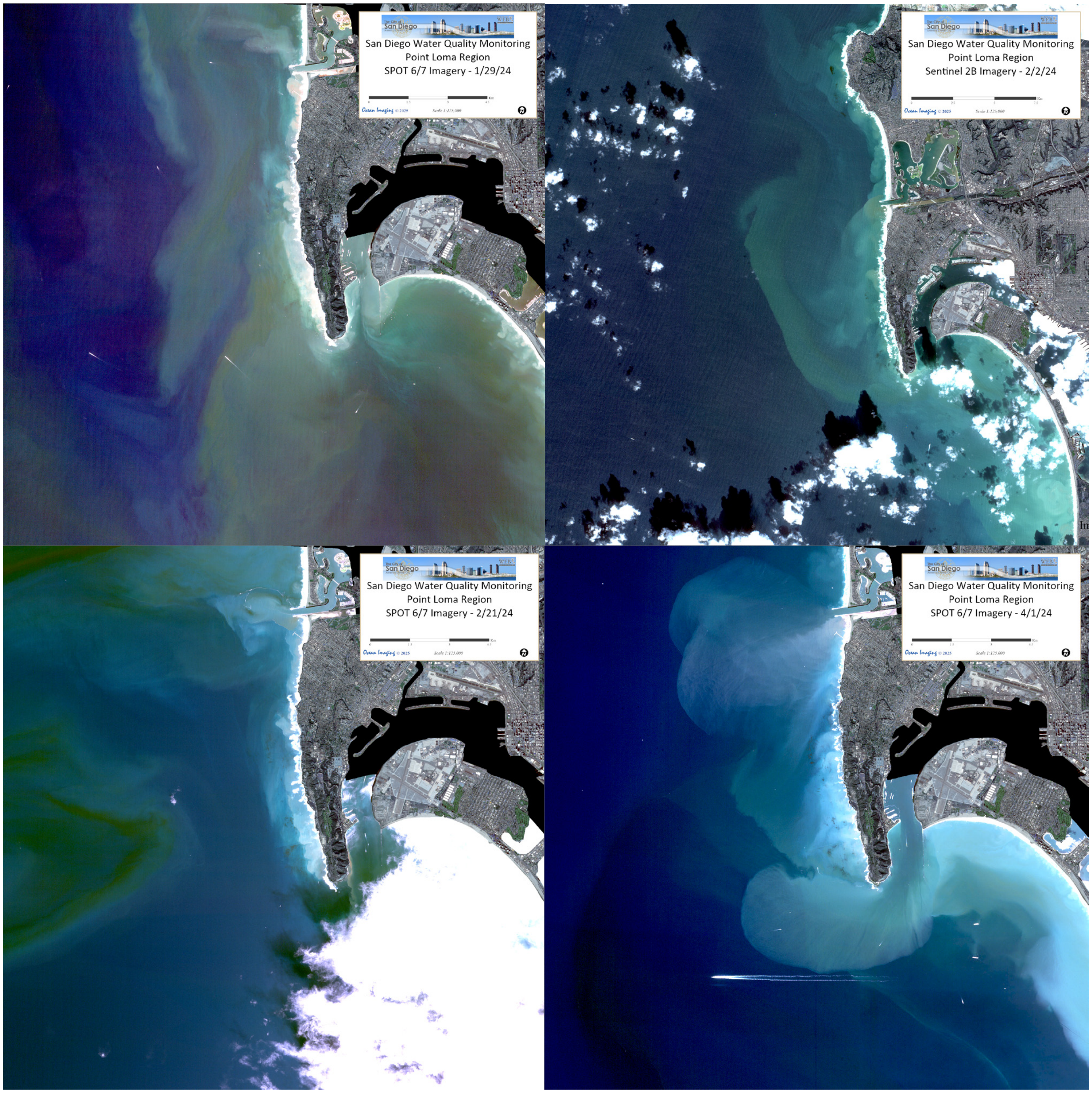


Figure 7. High-resolution SPOT data providing examples of days when the imagery displayed heavier than usual river discharge, coastal and offshore turbidity and plankton blooms that can be directly linked to a prior rainfall event. River gauge data also show higher than average flow rates on or near these dates.

Figure 8. Sentinel-2 and SPOT 6 imagery with time-coincident 6km 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 up past Border Field State Park towards the Coronado beaches, corresponding with shoreline closures during the same time period.

Table 3. 2024 County of San Diego shoreline closures, rain advisories and associated project satellite data (Source: California State Water Resources Control Board). [blue] general rain [light orange] advisory beach closure associated with the Tijuana River [yellow] bay or beach closure due to a sewage spill [salmon] bay or beach closure due to elevated bacteria levels

Station Description	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_SanDiego County Beaches	Rain			1/1/2024	1/6/2024	6	12/31/2023	0	1/2, 1/3, 1/4. 1/5, 1/7
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	1/8/2024	8	12/31/2023	0	1/2, 1/3, 1/4. 1/5, 1/7, 1/8
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	1/8/2024	8	12/31/2023	0	1/2, 1/3, 1/4. 1/5, 1/7, 1/8
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	1/8/2024	8	12/31/2023	0	1/2, 1/3, 1/4. 1/5, 1/7, 1/8
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	1/13/2024	13	12/31/2023	0	10 dates
End of Seacoast Dr	Imperial Beach munici-pal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	6/30/2024	182	12/31/2023	0	86 dates
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/ Grease	1/1/2024	6/30/2024	182	12/31/2023	0	86 dates
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	1/9/2024	1/13/2024	5	1/7/2024	2	1/10, 1/13, 1/14
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	1/10/2024	1/13/2024	4	1/10/2024	0	1/10, 1/13, 1/14
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	1/11/2024	1/13/2024	3	1/10/2024	1	1/13, 1/14
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	1/17/2024	5/6/2024	111	1/11/2024	7	1/18
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			1/20/2024	1/26/2024	7	1/20/2024	0	1/22, 1/23, 1/26, 1/27
Bayside Park (J Street)	San Diego Bay	EH-120	Closure	Sewage Spill	Sewage/ Grease	1/22/2024	1/28/2024	7	1/22/2024	0	1/22,1/23,1/26,1/27,1/29
Sweetwater River (NR)	San Diego Bay	EH-130	Closure	Sewage Spill	Sewage/ Grease	1/22/2024	2/11/2024	21	1/22/2024	0	13 dates
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	1/22/2024	3/19/2024	58	1/22/2024	0	33 dates
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	1/22/2024	4/10/2024	80	1/22/2024	0	53 dates
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	1/22/2024	4/24/2024	94	1/22/2024	0	46 dates
Shelter Is shoreline park	San Diego Bay	EH-200	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/26/2024	4	1/23/2024	0	1/23, 1/26, 1/27
Spanish Landing	Spanish Landing Park	EH-160	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/26/2024	4	1/23/2024	0	1/23, 1/26, 1/27
Tidelands Park	San Diego Bay	EH-070	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/28/2024	6	1/23/2024	0	1/23, 1/26, 1/27, 1/29
Glorietta Bay	San Diego Bay	EH-080	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/28/2024	6	1/23/2024	0	1/23, 1/26, 1/27, 1/29
Centennial Park, Beach To The West	Coronado north beach	EH-063	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/28/2024	6	1/23/2024	0	1/23, 1/26, 1/27, 1/29
Cesar Chavez Park	San Diego Bay	EH-530	Closure	Sewage Spill	Sewage/ Grease	1/23/2024	1/28/2024	6	1/23/2024	0	1/23, 1/26, 1/27, 1/29
Silver Strand (bayside)	San Diego Bay	EH-090	Closure	Sewage Spill	Sewage/ Grease	1/24/2024	1/26/2024	3	1/23/2024	1	1/26, 1/27, 1/29
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			2/1/2024	2/12/2024	12	2/1/2024	0	8 dates
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			2/1/2024	2/12/2024	12	2/1/2024	0	8 dates
Cesar Chavez Park	San Diego Bay	EH-530	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/10/2024	5	2/6/2024	0	2/7, 2/8, 2/9, 2/12
Ruocco Park	San Diego Bay	EH-545	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/10/2024	5	2/6/2024	0	2/7, 2/8, 2/9, 2/12
Outfall at B St Pier, Downstream (420 L)	San Diego Bay	EH-565	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/10/2024	5	2/6/2024	0	2/7, 2/8, 2/9, 2/12
San Diego River outlet	Dog Beach, O.B.	FM-010	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/12/2024	7	2/6/2024	0	2/7, 2/8, 2/9, 2/12, 2/14
Centennial Park, Beach To The West	Coronado north beach	EH-063	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/12/2024	7	2/6/2024	0	2/7, 2/8, 2/9, 2/12, 2/14
Seaport Village	San Diego Bay	EH-540	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/12/2024	7	2/6/2024	0	2/7, 2/8, 2/9, 2/12, 2/14
Tidelands Park	San Diego Bay	EH-070	Closure	Sewage Spill	Sewage/ Grease	2/6/2024	2/17/2024	12	2/6/2024	0	7 dates
Point Loma Treat-ment Plant	Pt. Loma shoreline	PL-050	Closure	Sewage Spill	Sewage/ Grease	2/20/2024	2/22/2024	3	2/20/2024	0	2/21, 2/22
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			2/20/2024	2/24/2024	5	2/20/2024	0	2/21, 2/22
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			3/2/2024	3/5/2024	4	3/2/2024	0	3/3, 3/4
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			3/7/2024	3/10/2024	4	3/4/2024	3	3/8, 3/10

Table 3 Cont'd. 2024 County of San Diego shoreline closures, rain advisories and associated project satellite data (Source: California State Water Resources Control Board). [blue] general rain [light orange] advisory beach closure associated with the Tijuana River [yellow] bay or beach closure due to a sewage spill [pink] bay or beach closure due to elevated bacteria levels

Station Description	Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image data
Missouri St.	Pacific Beach	EH-253	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Crystal Pier	Pacific Beach	FM-020	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Missouri St. (150 ft North)	Pacific Beach	EH-253A	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Missouri St. (150 ft South)	Pacific Beach	EH-253B	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Diamond	Pacific Beach	EH-570	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Law Street	Pacific Beach	EH-571	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Hornblend	Pacific Beach	EH-572	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Loring	Pacific Beach	EH-573	Closure	Sewage Spill	Sewage/ Grease	3/8/2024	3/9/2024	2	3/7/2024	1	3/8, 3/10
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	3/25/2024	4/10/2024	17	3/24/2024	1	11 dates
All_SanDiego County Beaches	All_SanDiego_County	All_SanDiego County Beaches	Rain			3/30/2024	4/3/2024	5	3/20/2024	0	4/1, 4/2, 4/3, 4/4
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	4/14/2024	4/23/2024	10	4/14/2024	0	6 dates
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	4/14/2024	4/23/2024	10	4/14/2024	0	6 dates
Oceanside pier	Oceanside municipal beach, other	OC-080	Closure	Bacterial Standards	Unknown	4/25/2024	4/27/2024	3	4/25/2024	0	4/27
Tyson Street	Oceanside municipal beach, other	OC-050	Closure	Bacterial Standards	Unknown	4/25/2024	4/27/2024	3	4/25/24	0	4/27
Surfrider Way	Oceanside municipal beach, other	OC-090	Closure	Bacterial Standards	Unknown	4/25/2024	4/27/2024	3	4/25/24	0	4/27
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	4/25/2024	4/28/2024	4	4/25/24	0	4/27
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	5/2/2024	5/6/2024	5	4/26/25	4	5/5, 5/7
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	5/7/2024	6/30/2024	55	5/5/24	2	19 dates
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	5/8/2024	5/13/2024	6	5/5/24	3	5/9, 5/12, 5/13, 5/14
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	5/10/2024	5/13/2024	4	5/5/24	5	5/12, 5/13, 5/14
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	5/10/2024	5/13/2024	4	5/5/24	5	5/12, 5/13, 5/14
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	5/20/2024	6/16/2024	28	5/5/24	15	7 dates
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	5/21/2024	5/26/2024	6	5/5/24	16	5/21, 5/25, 5/26
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	5/21/2024	5/30/2024	10	5/5/24	16	5/21, 5/25, 5/26, 6/2
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	5/28/2024	5/30/2024	3	5/25/24	3	6/2
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	6/4/2024	6/14/2024	11	5/25/24	9	6/11
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	6/4/2024	6/14/2024	11	5/25/24	9	6/11
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	6/25/2024	6/30/2024	6	6/11/24	14	6/26, 6/30, 7/1
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	6/26/2024	6/30/2024	5	6/11/24	15	6/26, 6/30, 7/1
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	6/26/2024	6/30/2024	5	6/11/24	15	6/26, 6/30, 7/1
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	7/1/2024	1	6/11/24	20	7/1, 7/2
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	7/1/2024	1	6/11/24	20	7/1, 7/2
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	7/1/2024	1	6/11/24	20	7/1, 7/2
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	8/5/2024	36	6/11/24	20	15 dates
End of Seacoast Dr	Imperial Beach munici-pal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	9/18/2024	80	6/11/24	20	35 dates
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/ Grease	7/1/2024	12/31/2024	184	6/11/24	20	77 dates

Table 3 Cont'd. 2024 County of San Diego shoreline closures, rain advisories and associated project satellite data (Source: California State Water Resources Control Board). [blue] general rain [light orange] advisory beach closure associated with the Tijuana River [yellow] bay or beach closure due to a sewage spill [pink] bay or beach closure due to elevated bacteria levels

Station Description	Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image data
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	7/8/2024	7/21/2024	14	6/11/24	28	7/8, 7/12, 7/13, 7/20
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	7/8/2024	7/21/2024	14	6/11/24	28	7/8, 7/12, 7/13, 7/20
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	7/8/2024	7/28/2024	21	6/11/24	28	8 dates
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	7/23/2024	7/25/2024	3	7/17/24	6	7/24, 7/25, 7/26
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	7/23/2024	7/25/2024	3	7/17/24	6	7/24, 7/25, 7/26
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	8/8/2024	8/21/2024	14	8/1/24	7	9 dates
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	8/17/2024	8/19/2024	3	8/11/24	6	8/17, 8/18, 8/20
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	8/17/2024	8/19/2024	3	8/11/24	6	8/17, 8/18, 8/20
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	8/17/2024	8/19/2024	3	8/11/24	6	8/17, 8/18, 8/20
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	8/22/2024	8/26/2024	5	8/11/24	11	8/22, 8/25, 8/27
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	8/29/2024	9/11/2024	14	8/11/24	18	9/4, 9/6, 9/9, 9/11
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	9/7/2024	9/9/2024	3	8/11/24	27	9/6, 9/9
Cortez Ave	Imperial Beach municipal beach, other	EH-010	Closure	Bacterial Standards	Unknown	9/18/2024	9/19/2024	2	8/11/2024	38	9/18, 9/19
Imperial Beach Pier	Imperial Beach pier area	EH-030	Closure	Bacterial Standards	Unknown	9/18/2024	9/19/2024	2	8/11/2024	38	9/18, 9/19
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Bacterial Standards	Unknown	9/18/2024	9/19/2024	2	8/11/2024	38	9/18, 9/19
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	9/19/2024	9/21/2024	3	8/11/2024	39	9/19, 09/22
Cortez Ave	Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/ Grease	9/21/2024	9/22/2024	2	9/20/24	1	09/22, 09/23
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	10/4/2024	10/11/2024	8	9/20/24	14	10/4, 10/5, 10/10, 10/12
Imperial Beach Pier	Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/ Grease	10/11/2024	10/12/2024	2	9/20/24	21	10/12
Cortez Ave	Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/ Grease	10/11/2024	11/6/2024	27	9/20/24	21	12 dates
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	10/11/2024	11/6/2024	27	9/20/24	21	12 dates
Imperial Beach Pier	Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/ Grease	10/14/2024	11/7/2024	25	9/20/24	24	13 dates
Carnation Ave.	north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/ Grease	10/14/2024	11/7/2024	25	9/20/24	24	13 dates
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	10/17/2024	10/31/2024	15	9/20/24	27	7 dates
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	11/12/2024	12/18/2024	37	11/3/24	9	18 dates
Carnation Ave.	north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/ Grease	11/12/2024	12/18/2024	37	11/3/24	9	18 dates
Cortez Ave	Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/ Grease	11/12/2024	12/18/2024	37	11/3/24	9	18 dates
Imperial Beach Pier	Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/ Grease	11/12/2024	12/28/2024	47	11/3/24	9	21 dates
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/ Grease	12/19/2024	12/31/2024	13	12/19/24	0	12/23, 12/27, 12/28
Cortez Ave	Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/ Grease	12/19/2024	12/31/2024	13	12/19/24	0	12/23, 12/27, 12/28
Carnation Ave.	north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/ Grease	12/20/2024	12/31/2024	12	12/19/24	1	12/23, 12/27, 12/28
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	12/21/2024	12/22/2024	2	12/21/24	0	12/23
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/ Grease	12/21/2024	12/28/2024	8	12/21/24	0	12/23, 12/27, 12/28
Avenida Lunar	Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/ Grease	12/25/2024	12/28/2024	4	12/24/24	1	12/27, 12/28
Loma Ave (frmrly Isabella	Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/ Grease	12/25/2024	12/28/2024	4	12/24/24	1	12/27, 12/28
Navy Fence (A)	Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/ Grease	12/25/2024	12/28/2024	4	12/24/24	1	12/27, 12/28
Imperial Beach Pier	Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/ Grease	12/29/2024	12/31/2024	3	12/27/24	2	12/27, 12/28

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 2024, 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 frequency 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 81 days in the medium-resolution (MODIS and Sentinel-3) and high-resolution satellite imagery 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 9 provides examples from a 300-meter Sentinel-3 image time series of days on which the data revealed heavy coastal turbidity and a developing phytoplankton bloom in this northern section of the project's study area. The bloom moves offshore and is entrained on a large offshore eddy and then begins to deform.

As discussed above there were significant phytoplankton and possible HABs during the spring and late summer to fall of 2024 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 *Lingulodinium polyedra* which absorbs light in the ultraviolet 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 10 provides examples of high-resolution Landsat and 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.

The SCB experienced lower overall chlorophyll levels throughout 2024 when compared to the previous three years, especially 2021. Chlorophyll levels and thus phytoplankton abundance in the SCB were relatively low during the first three months of the year, particularly in the southern part of the region. An increase in coastal upwelling combined with rainfall events during the end of March and beginning of April likely introduced nutrients into the ocean system from river discharge and coastal runoff contributing to the increase the chlorophyll levels during April, May and June. A noticeable decrease in offshore chlorophyll levels from July through September is evident in the representative satellite imagery, as is the increase in levels from October through December. Figure 11 provides representative SCB VIIRS and MODIS-derived chlorophyll images for each month of 2024. As observed in the satellite data, the California Current relaxed during July and August and was not moving greener/nutrient-rich water into the lower part of the SCB region. The California Current appears to build strength again in September, however the chlorophyll levels in the San Diego offshore region remained relatively low. The Current appears to gain strength from October into December as does coastal upwelling. Figure 12 shows 300 and 1000-meter fused 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 2024. 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. This is especially apparent from July through the end of the year when the offshore waters were comparatively devoid of chlorophyll during July, August and September and then coastal upwelling and hence chlorophyll levels dramatically increased during the months of

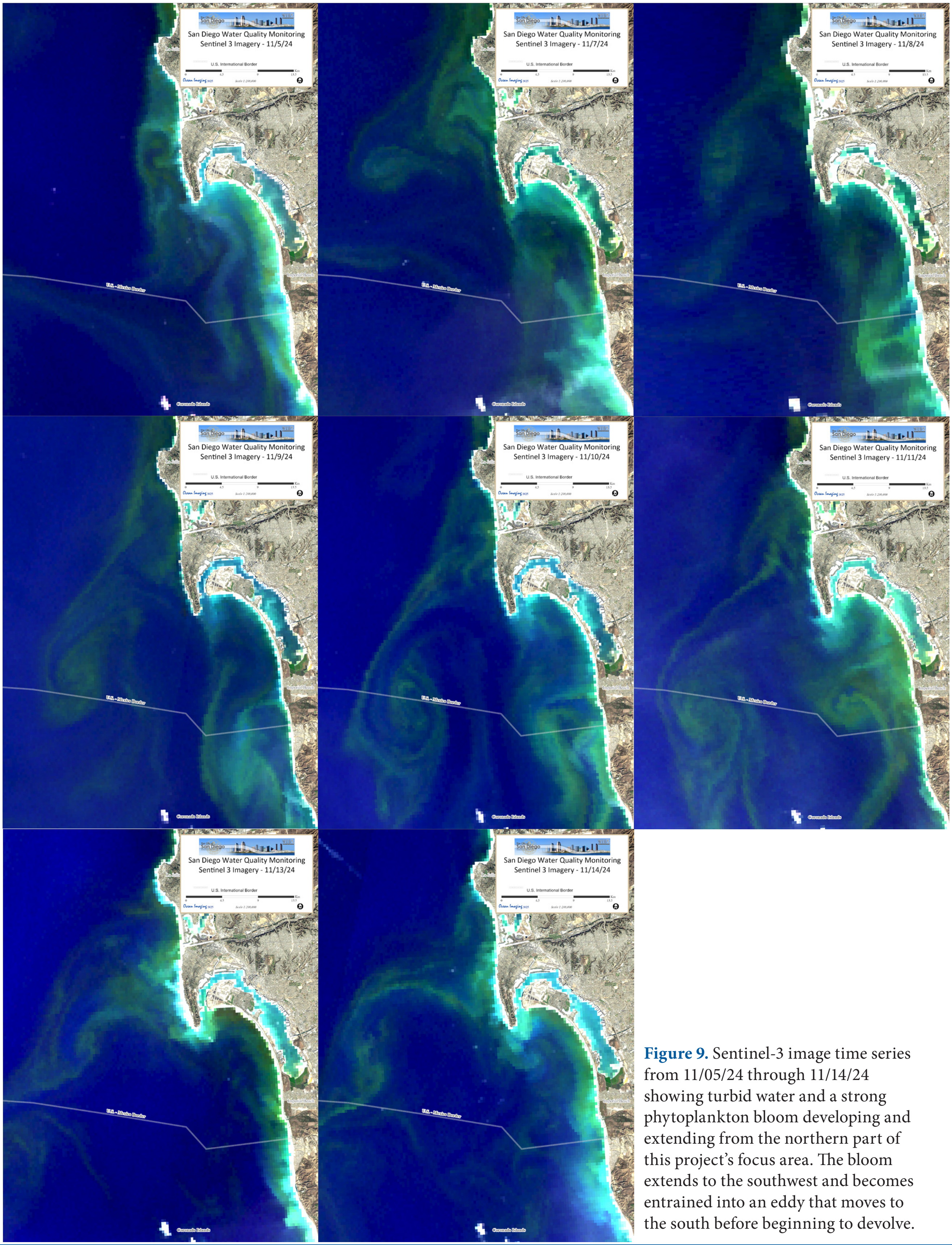


Figure 9. Sentinel-3 image time series from 11/05/24 through 11/14/24 showing turbid water and a strong phytoplankton bloom developing and extending from the northern part of this project's focus area. The bloom extends to the southwest and becomes entrained into an eddy that moves to the south before beginning to devolve.

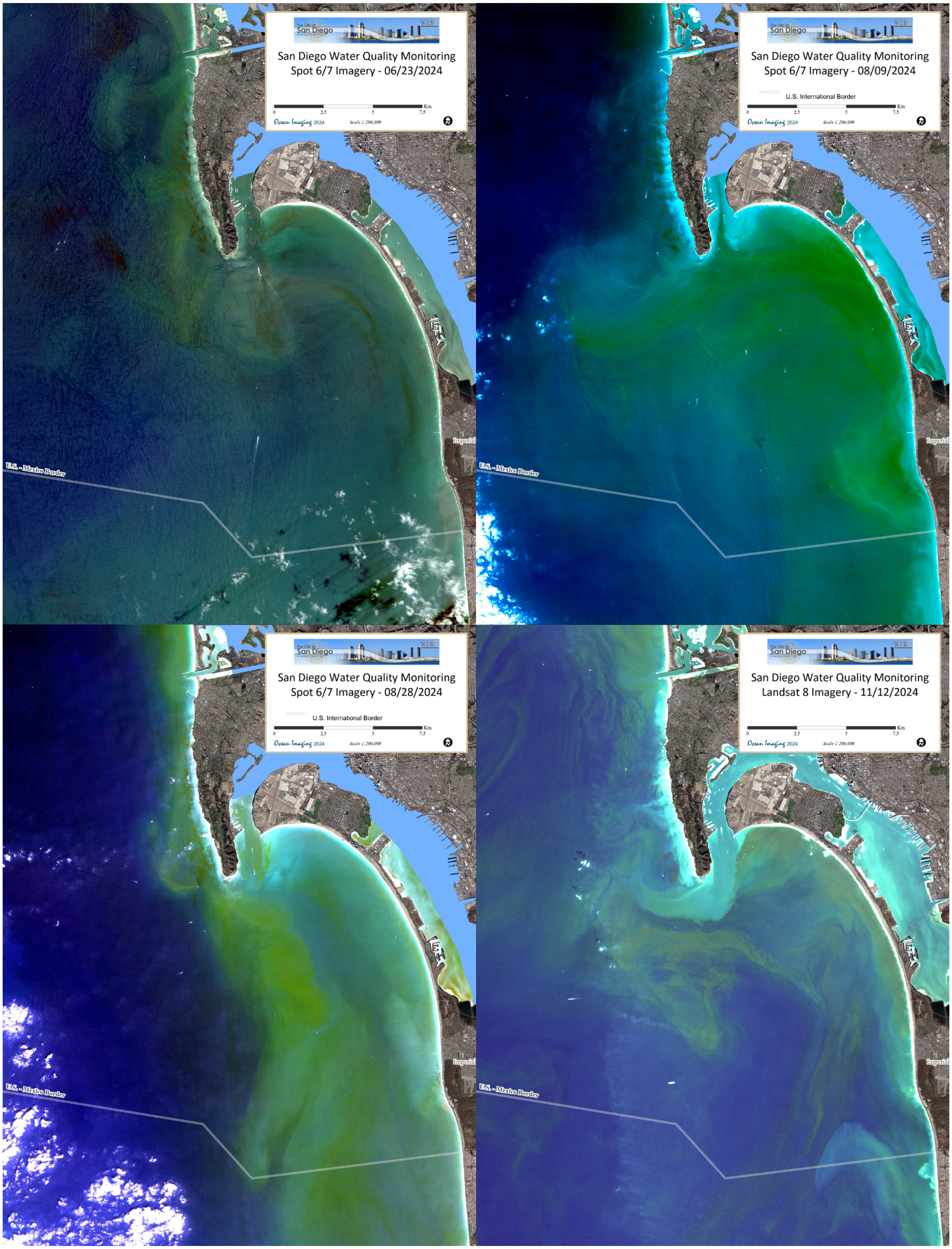


Figure 10. Sample high-resolution Landsat and SPOT data providing examples of days when the imagery revealed strong coastal and offshore phytoplankton blooms and possible HABs that cannot be directly linked to a significant (over 0.01 inches) prior rainfall event.

October through December along the entire San Diego County coastline extending well offshore and far south below the U.S.-Mexico border. Higher chlorophyll levels in the San Diego region were confined to within approximately 15 kilometers of the coast for July through September and then extended farther offshore as the year progressed.

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 63.87 mg/m^3 at station I32, 1-meter depth on 06/04/24) occurred during the month of June. More than 75% of fluorometry readings exceeding 10.0 mg/m^3 occurred from May to July, slightly later than the typical spring bloom season. The higher chlorophyll readings in the month of July were mostly confined to the shoreline stations as the phytoplankton levels in the offshore areas began to recede by the end of June. The imagery in Figures 11 and 12 corroborates these measurements, clearly documenting May and June as months exhibiting high intensities and spatial extent of phytoplankton

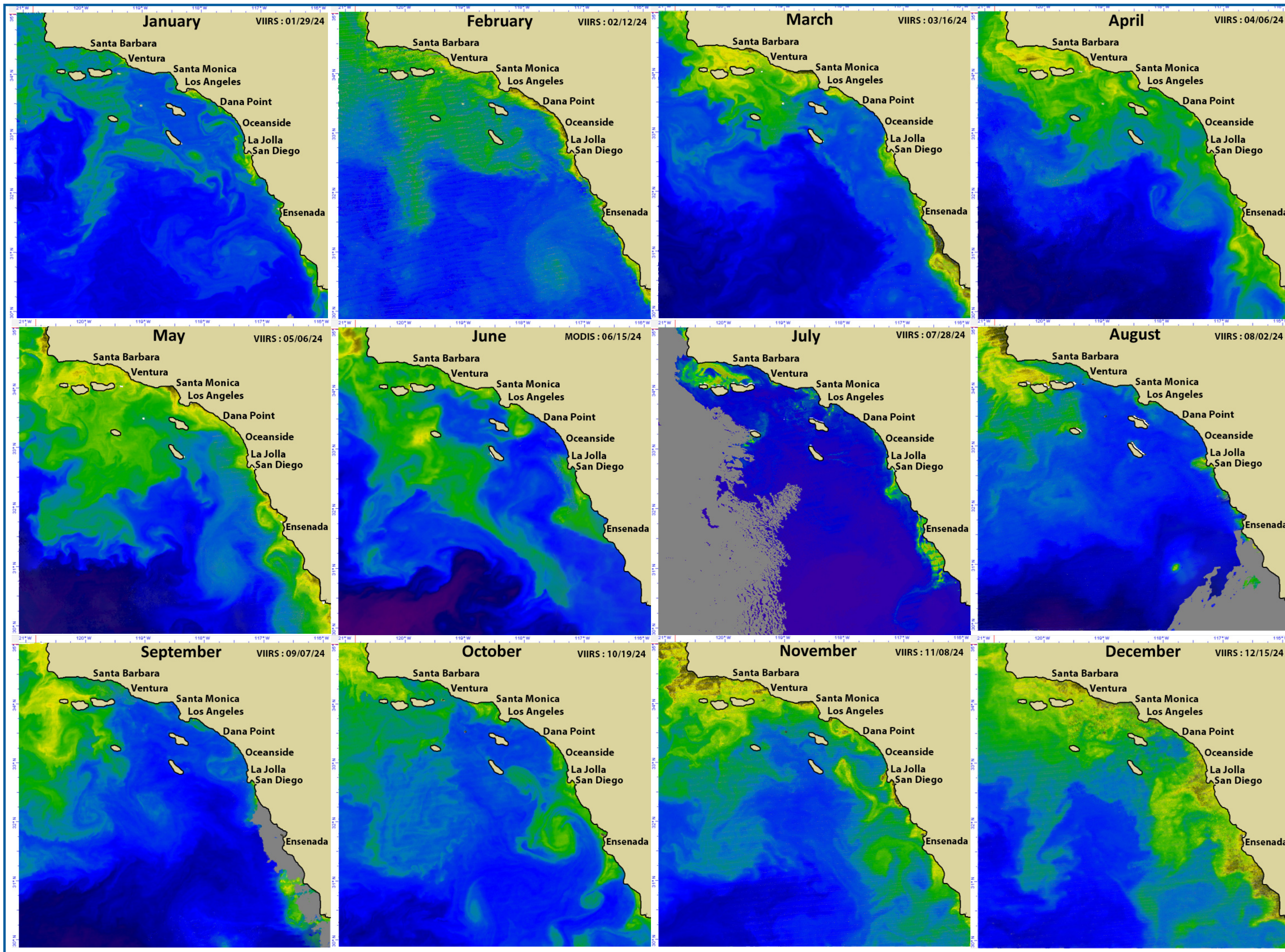


Figure 11. Representative VIIRS and MODIS-derived chlorophyll images for each month of 2024 showing relatively low levels of chlorophyll-rich water in the SCB during the months of January through March and then an increase during the months of April, May and June - likely due to the heavy rainfall and resulting eutrophication combined with coastal upwelling. SCB-wide levels decreased during the summer months and increased again in October through December, likely caused by the California Current bringing nutrient-rich water down into the region.

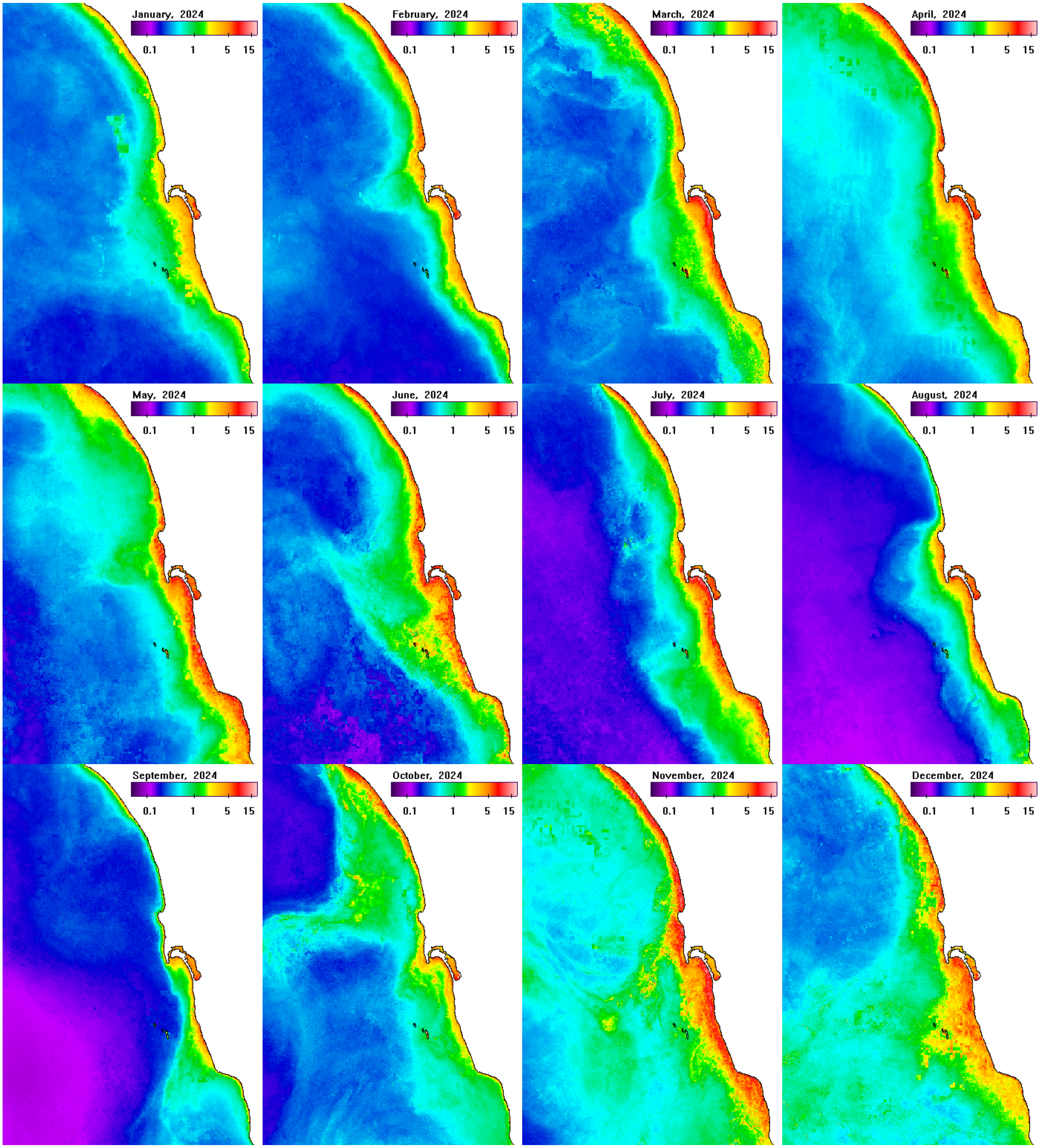


Figure 12. Monthly chlorophyll (mg/m^3) composites of the San Diego County coastal and offshore area derived from 300m and 1km MODIS, VIIRS and OCLI imagery generated by Mati Kahru of Scripps Institution of Oceanography in cooperation with OI as part of a SDPUD-funded project to study a long-term time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

blooms in the San Diego County coastal region. 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 yellow to green plankton blooms are self-evident in the imagery and correlate well with the CTD data.

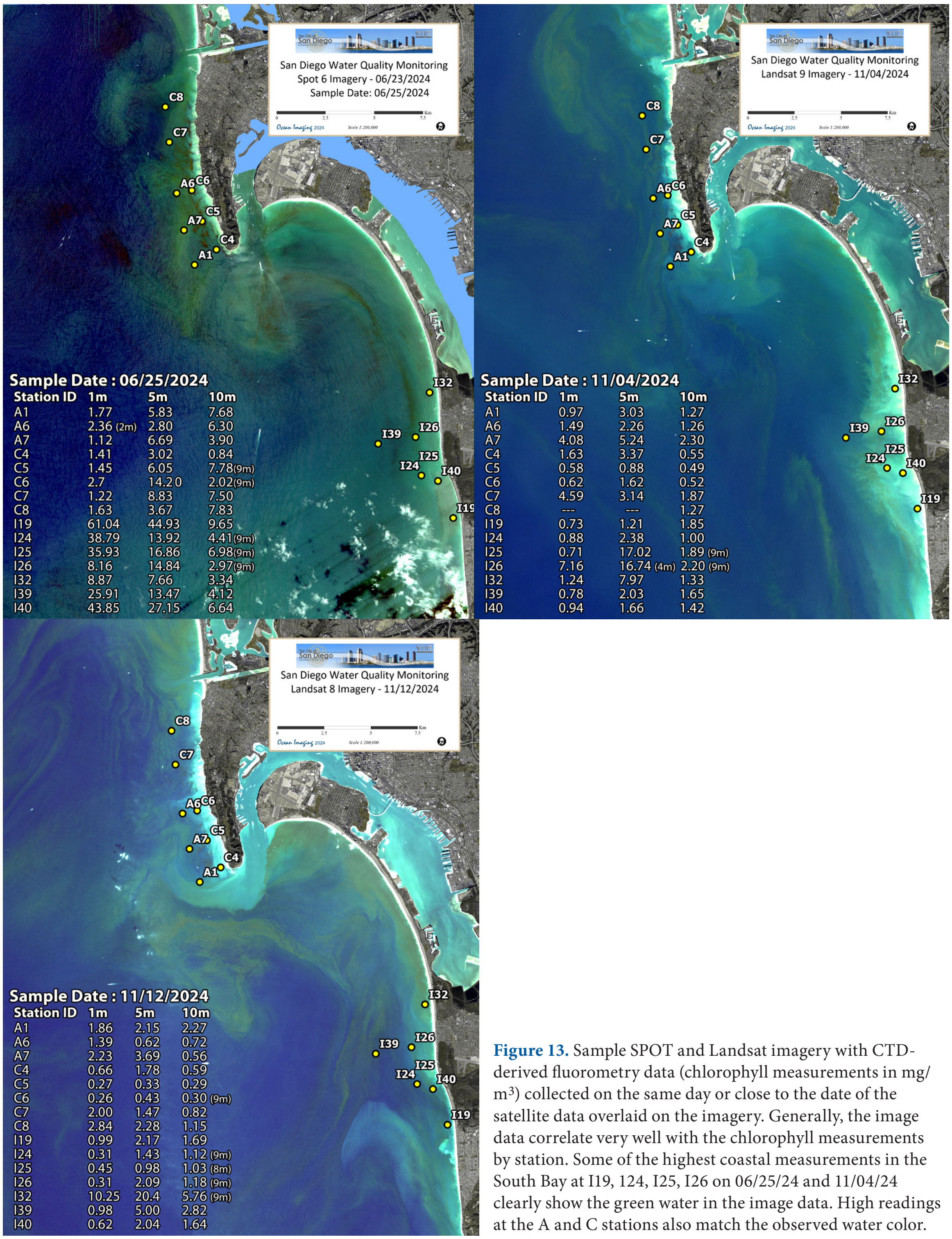


Figure 13. Sample SPOT and Landsat imagery with CTD-derived fluorometry data (chlorophyll measurements in mg/m^3) collected on the same day or close to the date of the satellite data overlaid on the imagery. Generally, the image data correlate very well with the chlorophyll measurements by station. Some of the highest coastal measurements in the South Bay at I19, 124, I25, I26 on 06/25/24 and 11/04/24 clearly show the green water in the image data. High readings at the A and C stations also match the observed water color.

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 until late 2020. Beginning at the end of 2020, the TSS concentrations became much more variable with daily measurements peaking over 900 mg/L in early 2024. 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 mid-April 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 reach the surface between November and April when it can often be detected with satellite imaging. This concept held true in 2024, as the last observation of a SBOO surface plume during the beginning of the year was on 04/02/24 and then was not seen again in the image data until 11/08/24. In total, there were 26 instances during which the SBOO effluent plume was observed in 2024 out of the 105 high resolution satellite scenes acquired and processed. Of the 26, there were four instances of the plume observed by different satellites on the same day. This equates to 22 days when the plume was visible in the high-resolution imagery – four more than observed in 2023. There were 89 days on which one or more of the high resolution, multispectral satellites imaged the study area and so the SBOO plume was detected on 24.7% of satellite observations days. This is more than the average for the previous 12 years (20.3% of the observations). The effluent surface plumes are most often seen moving to the south or as a stagnant body. There was only one day on which the plume was observed moving east or northeast (01/13/24) and two days (04/02/24 and 11/30/24) during which the plume was oriented directly northward. On 01/13/24 when the plume showed an eastward direction, it was effectively blocked from reaching anywhere close to the shore by the offshore movement of the TJR discharge. On 04/02/24 and 11/30/24 when the plume was observed pushing northward, the turbidity signature dissipated only a few kilometers from the SBOO wye. Therefore, from the entire set of 2024 imagery, it can be inferred that the SBOO surface plume never came anywhere near the San Diego shoreline.

Appendix A includes the 2024 SPOT, Sentinel-2 and Landsat multispectral imagery on days which the SBOO plume was detected. There were four occurrences when either Sentinel-2A or 2B data were acquired within minutes of Landsat or SPOT 6 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. This situation is exemplified in Figure 14. On 04/02/24, a mere day after the SBOO plume was visible as a turbid signature against relatively clear water, the more turbid TJR discharge water engulfed the outfall area within the 24-hour interval between satellite data captures. The SBOO effluent is then observed as clearer than the surrounding water.

The months of January, February, November, and December exhibited the highest frequency of 2024 SBOO effluent plume observations in the satellite data. As previously discussed and documented in previous reports, it is typical to see the highest number of SBOO effluent surfacing's during these months. As is characteristically the case, the effluent surface manifestations that occurred during these periods 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 September 2024 California Regional Quality Control Board's Executive Officer Report, transboundary flows were still discharging continuously through the main channel of the Tijuana River up through September of 2024. Transboundary flows are defined as 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 into the international treatment plant, Tijuana Estuary and U.S. coastal waters. Most of these transboundary flows occurred in the TJR main channel resulting in over 36 billion gallons coming into the U.S. system and waters from October of 2023 through June of 2024 (SDRWCB, 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 the TJR transboundary flow occurrences during the summer months were not detected 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 (SDRWCB, 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 always observed as expansive, discolored TJR plumes.

Figure 15 shows the SBIWTP effluent flow rate and TSS over the 2003 to 2024 period (top) and during 2024 plotted with the dates on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery (bottom). As seen in the top plot, the variability in both the SBIWTP

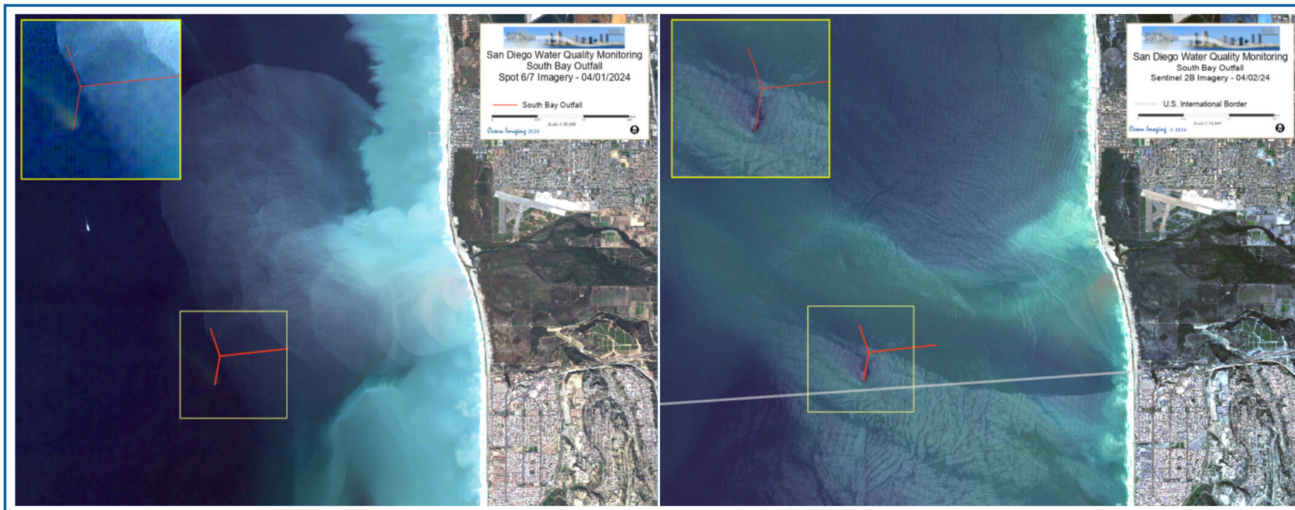


Figure 14. SPOT and Sentinel imagery showing a SBOO surface signature being clearer than the surrounding, extremely turbid water (04/02/24 - right). On 04/01/24, just one day earlier, the TJR discharge had not yet reached the SBOO effluent surfacing area.

effluent flow rate and TSS increased significantly after the beginning of 2019. On the lower graph there are a few notable spikes in flow and the TSS occurred during the first quarter of 2024, however both parameters stabilized as the year progressed with the TSS levels dropping close to zero after November. Despite fluctuations in 2024, the trend line shows the average effluent flow rate of 22.70 million gallons per day (MGD) remained below the permit limit of 25 MGD. The TSS levels were highly variable over the past three years, however there is no direct correlation of the SBOO effluent surface observations to TSS measurements. Of the 22 days on which the SBOO effluent was observed breaking

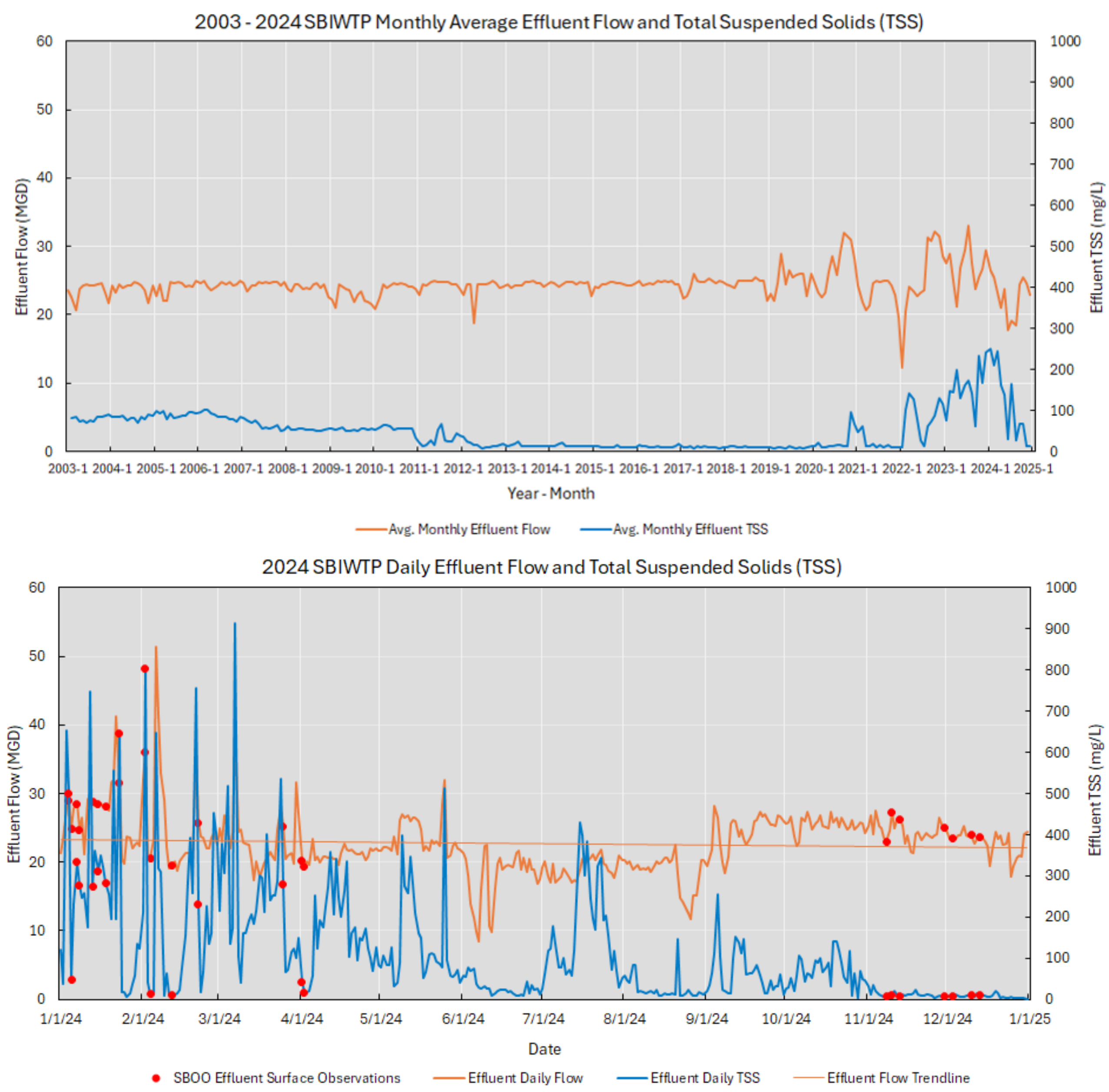


Figure 15. SBIWTP effluent flow rate and TSS from 2003 through 2024 (top) and over the 2024 period (top) plotted with the dates (red dots – bottom graph) on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery. Red dots are shown on the dates corresponding with both the effluent flow and TSS data. The effluent flow trend line is shown as an orange line. Data courtesy of the USIBWC.

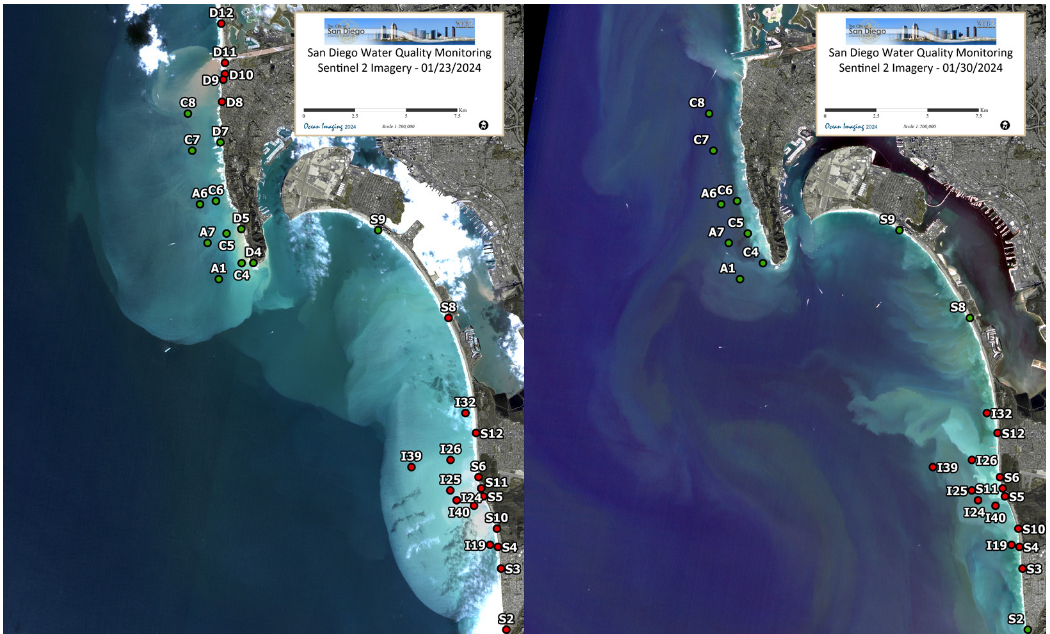
the surface, only ten occurred when the flow rate exceeded 25 MGD, and so it cannot be concluded that the additional flow diverted through SBIWTP resulted in the effluent reaching the ocean's surface more often. These data continue to corroborate the belief that the instances of effluent reaching the surface almost always occur because of seasonal changes in ocean conditions when the water column stratification breaks down and are rarely, if ever, related to a higher flow rate through the system or water with higher TSS levels exiting the outfall.

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, 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 2024, the sampling area of the SBOO/Tijuana River outflow region experienced 68 days, on which the field sampling showed FIB measurements exceeding the single sample maximum (SSM) for fecal coliform density for one or more sampling stations as defined by the 2019 California Ocean Plan (the SSM for 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 35 days on which the bacteria levels were deemed elevated. There were 55 sampling days when at least one shore station showed elevated levels. The number of sampling days for all three SBOO areas totaled 88 in 2024 and 96 in 2023. Therefore, in 2024 for the three sampling regions combined, 77.3% of the sampling days resulted in elevated bacteria levels at one station or more, which is slightly more than the 74.0% recorded in 2023 (using the same 2019 California Ocean Plan standards). As it has been in recent years, the vast majority of the samples showing elevated levels were recorded at the shore stations. Elevated levels offshore near the SBOO wye are rare. Of the three samples collected on two days when elevated bacteria levels were recorded at offshore stations, none (I3, I10 and I18) were close to the SBOO wye.

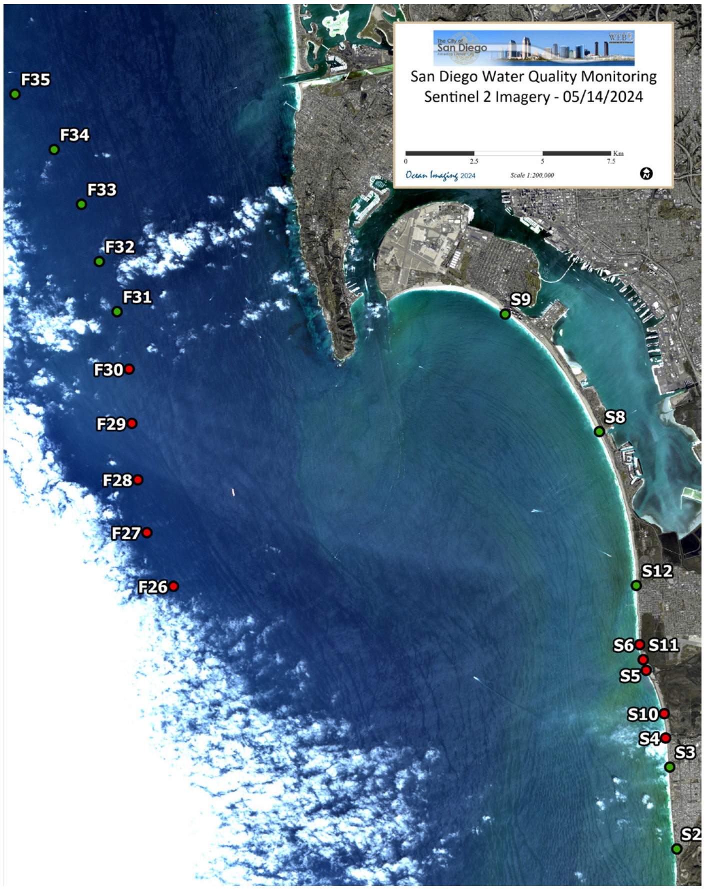
The satellite imagery showing substantial discharge from the TJR region often correlates well with times when the shoreline and kelp area sampling showed elevated bacteria levels. In past years, heavy and/or persistent rainfall was often the most plausible cause for most of the elevated bacteria samples and the turbid and/or discolored 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 (SDRWCB, 2024 and Little, 2024), that premise is no longer valid in many cases. Normally, 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 2024, 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 (SDRWCB, 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 or day prior to the water quality sampling. Note the very turbid water emanating from the TJR river and trending north in both images and that samples with FIB exceeding the SSM were taken as far north as Silver Strand beach. The satellite data examples in this figure were acquired on 01/23/24 and 01/30/24 following heavy, multi-day rain events and TJR daily average flow rates of 4,956 cfs, 1,003 cfs and 140 cfs on 01/22/24, 01/23/24 and 01/30/24 respectively. Also note the elevated FIB levels around the mouth of the San Diego River on 01/24/24. SDR average daily flow rates were 1,233 cfs, 951 cfs and 200 cfs on 01/22/24, 01/23/24 and 01/24/24 respectively. 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, yet some measurements showed FIB exceeding the SSM both on the shore and offshore. In the South Bay, only the shoreline stations were sampled on the day shown in the figure. The FIB measurements exceeding the SSM were likely related to the transboundary flow problems discussed above.



01/23/24				
Station	Depth (M)	Entero	Fecal	Total
S0	0	8000	3400	16000
S2	0	12000	4200	8800
S3	0	11000	6600	16000
S4	0	6800	8600	16000
S5	0	12000	12000	16000
S6	0	12000	12000	11000
S8	0	8200	10000	16000
S10	0	6600	6600	16000
S11	0	12000	12000	16000
S12	0	12000	9200	14000
1/24/24				
I19	2	2200	3600	16000
	6	800	1100	8000
	11	380	200	4400
I24	2	2400	5000	16000
	6	1800	1000	14000
	11	2600	2600	16000
I25	2	1600	2600	16000
	6	1400	2000	16000
	9	2600	2600	16000
I26	2	2400	3000	14000
	6	3000	2200	16000
	9	5800	2600	16000
I32	2	2800	2400	9800
	6	2000	1400	11000
	9	3800	2800	16000
I39	2	600	940	13000
	12	160	120	860
	18	300	140	1000
I40	2	5000	5600	16000
	6	5200	4200	16000
	9	3800	3000	16000
D8	0	420	140	1200
D9	0	280	400	600
D10	0	500	380	1000
D11	0	4000	1200	3400
D12	0	240	110	440

1/30/24				
Station	Depth (M)	Entero	Fecal	Total
I19	2	26	80	600
	6	120	380	4600
	11	220	880	8000
I24	2	260	3800	15000
	6	40	160	760
	11	78	220	1200
I25	2	500	5400	16000
	6	72	110	840
	9	70	120	1500
I26	2	36	2200	7200
	6	460	4000	15000
	9	820	4800	16000
I32	2	96	400	4400
	6	340	520	4000
	9	520	480	5200
I39	2	2	6	180
	12	90	620	4400
	18	100	580	4600
I40	2	600	6800	16000
	6	74	110	1000
	9	180	80	3000
S3	0	320	340	2600
S4	0	200	860	12000
S5	0	720	1600	16000
S6	0	740	1800	16000
S10	0	5800	12000	16000
S11	0	900	1800	16000
S12	0	360	300	4800

Figure 16. Sentinel-2 data with near-surface bacterial sampling data overlaid from the same day and day prior to the image acquisition date. Red dots at PLOO stations (A, C, D) indicate fecal coliform densities in exceedance of the fecal coliform SSM (2019 Ocean Plan). Red dots at SBOO (I, S) stations indicate exceedances of the total coliform, 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 elevated bacteria levels in red text. The left image and table show the satellite data acquired on 01/23/24 with sample data overlaid from 01/23/24 and 01/24/24. The right image and table show satellite and bacteria sample data from 01/30/24.



Station	Depth (M)	Entero	Fecal	Total
F26	1	2	NA	NA
	25	2	NA	NA
	60	160	NA	NA
	80	110	NA	NA
	98	16	NA	NA
F27	1	2	NA	NA
	25	2	NA	NA
	60	440	NA	NA
	80	38	NA	NA
	98	76	NA	NA
F28	1	6	NA	NA
	25	2	NA	NA
	60	620	NA	NA
	80	16	NA	NA
	98	110	NA	NA
F29	1	2	NA	NA
	25	2	NA	NA
	60	880	NA	NA
	80	100	NA	NA
	98	20	NA	NA
F30	1	6	NA	NA
	25	2	NA	NA
	60	1100	NA	NA
	80	1000	NA	NA
	98	24	NA	NA
S0	0	700	3000	16000
S4	0	800	2200	16000
S5	0	12000	12000	16000
S6	0	12000	8200	16000
S10	0	3000	10000	16000
S11	0	12000	12000	16000

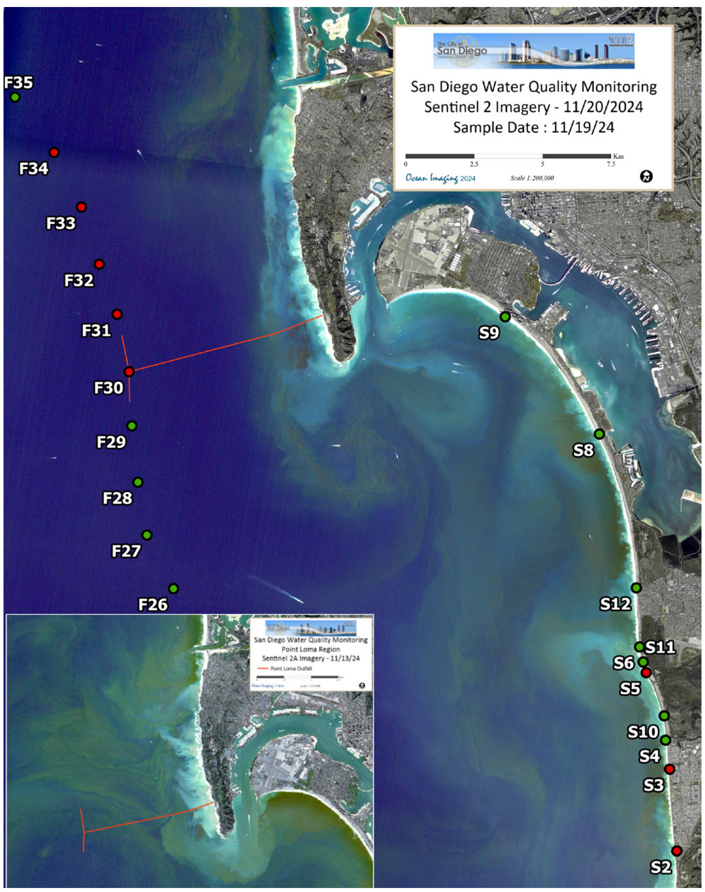
Figure 17. A Sentinel-2 image from 05/14/24 with bacterial sampling data overlaid from the same day. Phytoplankton blooms are evident, however low turbidity, the lack of a significant TJR discharge plume and a lower-than-average river flow rate on 05/14 (99 cfs vs. the 2024 annual daily average of 152 cfs) point to other reasons for the high FIB readings not apparent as fouled water in the image data. Red dots at PLOO stations (F) indicate fecal coliform densities in exceedance of the fecal coliform SSM (2019 Ocean Plan). Red dots at SBOO stations (S) indicate exceedances of the total coliform, 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 right of the image shows the measurement values by depth for each station with elevated bacteria levels in red text.

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 a 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 a few 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 2024 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 very little rainfall for the rest of the year, including November and December which experienced a total of only 0.17 inches for the two months combined. 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 in section 3.1 above.

The 2024 Point Loma shoreline, kelp and offshore bacterial sampling resulted in a comparable number of elevated bacteria measurements when contrasted to previous years 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). Out of 111 total sample days, there were 16 days on which elevated bacteria levels were measured at one or more stations in this region. In 2023 the PLOO stations were sampled on 115 days during the year. In 2024 for the three PLOO sampling areas combined, 14.4% of the sampling days resulted in elevated bacteria levels at one station or more, which is lower than recorded in 2023 (17.4%). The shoreline sampling yielded 8 days on which one or more stations experienced high bacteria counts. The offshore sampling resulted in 8 days when FIB were over the SSM. No kelp stations recorded out of compliance SSMs for FIB in 2024. Figures 17 (above) and 18 provide examples of when multiple stations in the Point Loma sampling region resulted in non-compliant SSM numbers on 05/14/24 and 11/19/24.



Station	Depth (M)	Entero	Fecal	Total
F30	1	2	NA	NA
	25	2	NA	NA
	60	100	NA	NA
	80	440	NA	NA
	98	12		NA
F31	1	2	NA	NA
	25	2	NA	NA
	60	160	NA	NA
	80	6	NA	NA
	98	1000	NA	NA
F32	1	2	NA	NA
	25	2	NA	NA
	60	12	NA	NA
	80	700	NA	NA
	98	70	NA	NA
F33	1	4	NA	NA
	25	2	NA	NA
	60	24	NA	NA
	80	280	NA	NA
	98	60	NA	NA
F34	1	2	NA	NA
	25	2	NA	NA
	60	10	NA	NA
	80	120	NA	NA
	98	74	NA	NA
S0	0	12000	12000	16000
S2	0	140	700	1600
S3	0	110	1200	4000
S5	0	100	380	1800
S10	0	3000	10000	16000
S11	0	12000	12000	16000

Figure 18. Sentinel-2 acquired on 11/20/24 with bacterial sampling data from 11/19/24 overlaid on the image. Red dots at PLOO stations (F) indicate fecal coliform densities in exceedance of the fecal coliform SSM (2015 Ocean Plan). Red dots at SBOO stations (S) indicate exceedances of the total coliform, fecal coliform and/or enterococcus SSMs (2019 Ocean Plan). Green dots identify stations at which the FIB levels were in compliance. The table to the right of the image shows the measurement values by depth for each station with elevated bacteria levels in red text. The inset image is a Sentinel-2 scene, captured one week prior to the sampling, shows SDR discharge, active coastal turbidity and offshore phytoplankton blooms, however, these prior coastal disturbances did not play a part in the increased FIB readings in the area. There is no evidence of the wastewater plume at the surface in the imagery from November 20. Instead, all bacterial exceedances were found at depths of 60 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.

The imagery both dates do not show visible evidence of any direct correlation to the offshore bacteria samples. The inset image from one week earlier 11/13/24 does display significant turbidity along the coast, visible SDR discharge and high levels of offshore chlorophyll. However, the reason for the high FIB levels at the "F" stations is in all probability linked to the PLOO effluent. The stations exhibiting elevated FIB levels are all either right over or north of the wye and at depths of 60 meters or below. This indicates that the high-bacteria effluent originating from the outfall may have been trapped by a pycnocline barrier at depth so any surface presence would not be visible in the satellite imagery.

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 17 years. The September and October dates were chosen to represent the kelp bed canopy coverage for each year since spring and fall are the time periods when the canopy size is considered to be at or near its peak - with fall being the preferred season to map kelp using remote sensing techniques. The estimated size of the Point Loma bed canopy in the fall of 2024 (0.88 km^2) was significantly smaller than the average canopy coverage for the prior 16-year period from 2008-2023 (3.95 km^2). 2024 exhibited the second smallest canopy coverage over the 17-year period only second to 2016. As reported previously, 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 appeared 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 and 2024 computed areal coverages show a considerable decrease in size (Figure 20). Contrary to previous years such as 2018, 2020 and 2021 when the canopy area exhibited significant intra-annual variability, during 2023 and 2024 the bed size remained consistently depleted throughout the year (Figure 21). Very little kelp canopy was visible in the high-resolution SPOT, Sentinel-2 and Landsat imagery from January through September. In fact, no exposed kelp canopy was visible in the satellite data during the entire month of September. During October through December the canopy gradually increased in size through the end of the year. Satellite data acquired throughout January of 2025 showed the kelp canopy continuing to expand, but not to the levels observed in 2017 through 2022. 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 and Figure 20 was computed by first running a Normalized Difference Vegetation Index (NDVI) classification followed by an iso cluster unsupervised classification to generate a single exposed kelp class (ESRI, 2024). It is important to point out that the canopy coverage shown in Table 4 may differ slightly from those provided in the Region Nine Kelp Survey Consortium Aerial Kelp Survey Reports. 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 and Schroeder, 2019).

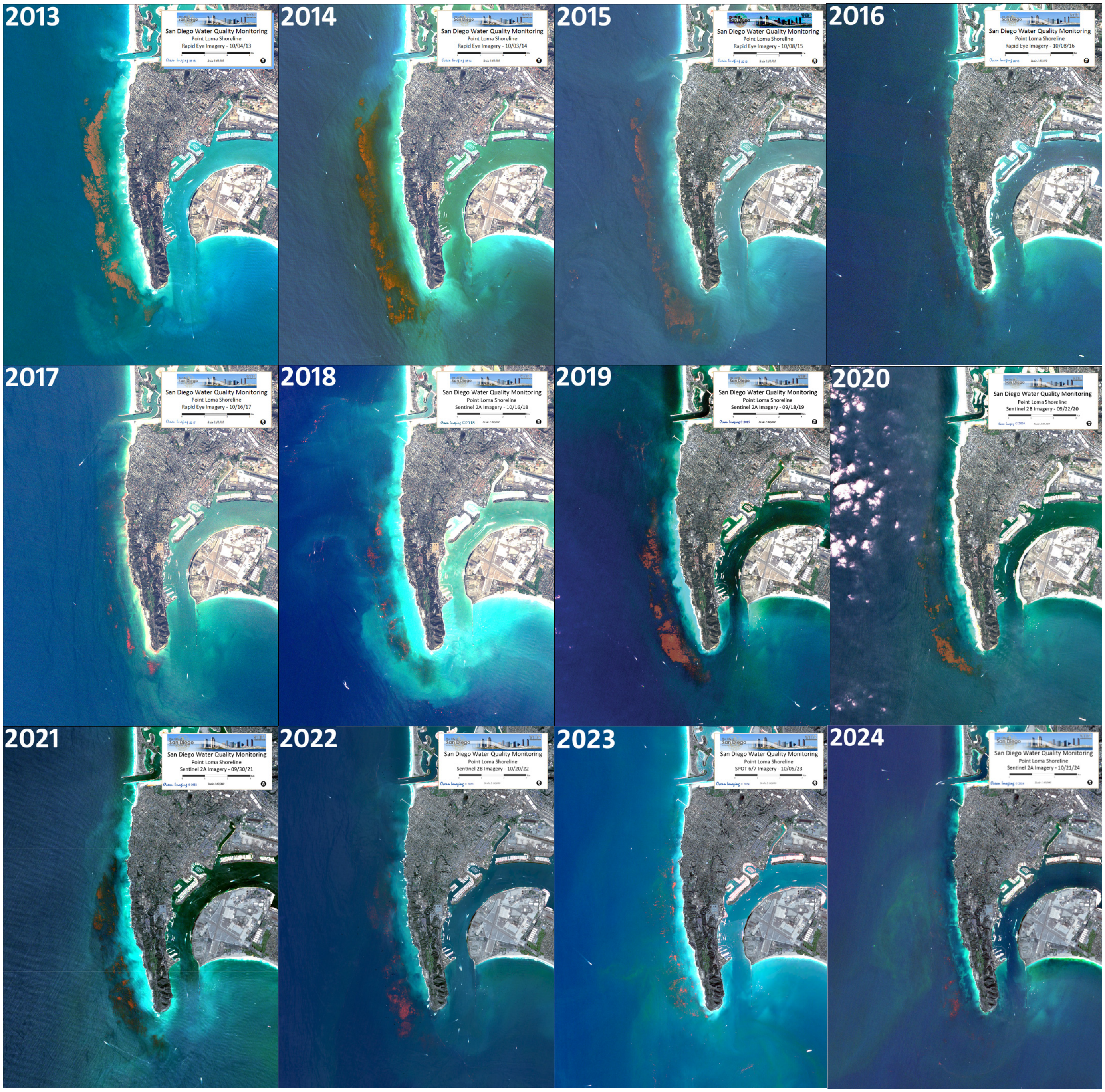


Figure 19. The Point Loma kelp bed as observed in high-resolution satellite imagery for the years 2013-2024. September and October dates were chosen to represent the kelp bed canopy coverage for each year since that period is when the canopy size is thought to be at or near its peak.

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

			Kelp (km²)		
Year	**Date**	**Satellite**	**Point Loma**	**Imperial Beach**	**Tijuana**
2024	10/21/24	Sentinel-2A	0.88	0.00	0.00
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 2008-2023 = 3.95 km²

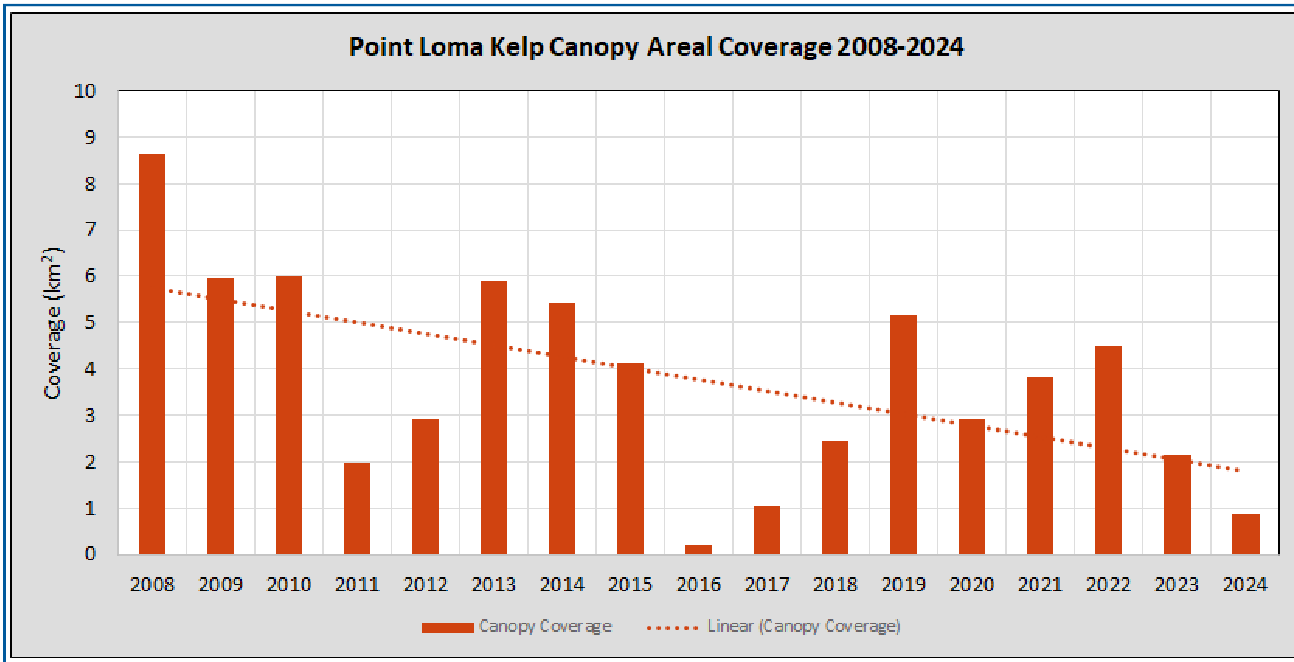


Figure 20. Point Loma kelp canopy coverage 2008-2024. Calculations were from imagery acquired on the September and October dates shown in Table 4 above. The dates were chosen to represent the kelp bed canopy coverage for each year since the September to October time period is when the canopy size is thought to be at or near its peak. The dotted line shows a linear trend line over the period.

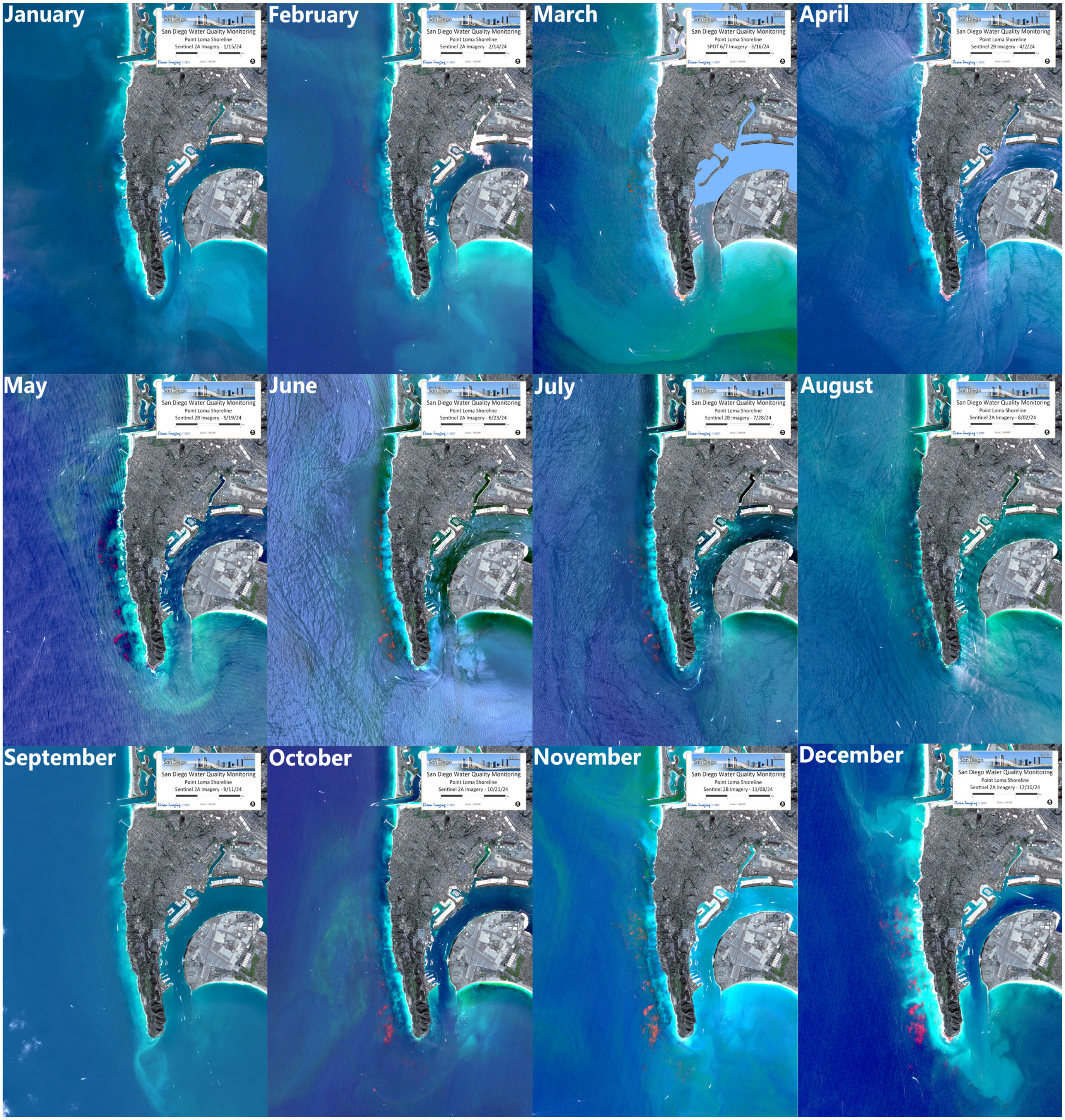


Figure 21. High-resolution satellite imagery documenting the month-to-month variability in the Point Loma kelp bed canopy coverage. The dates were chosen to best represent the maximum-observed canopy coverage for each month.

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 has developed 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 convenient, 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 additional data products. Figure 22 shows the dashboard interface which will be operational by the time of this report's release.

In mid-to-late 2025, 300m resolution chlorophyll and TSM data products derived from the Sentinel-3 satellites will be added to the project's near-daily image mix. These data should help to further identify and track turbid water resulting from offshore runoff and river discharge. The products will initially be experimental in nature to determine the ability of the ESA TSM algorithms to differentiate TSM from offshore chlorophyll blooms. Figure 23 provides an example of the upcoming TSM imagery.

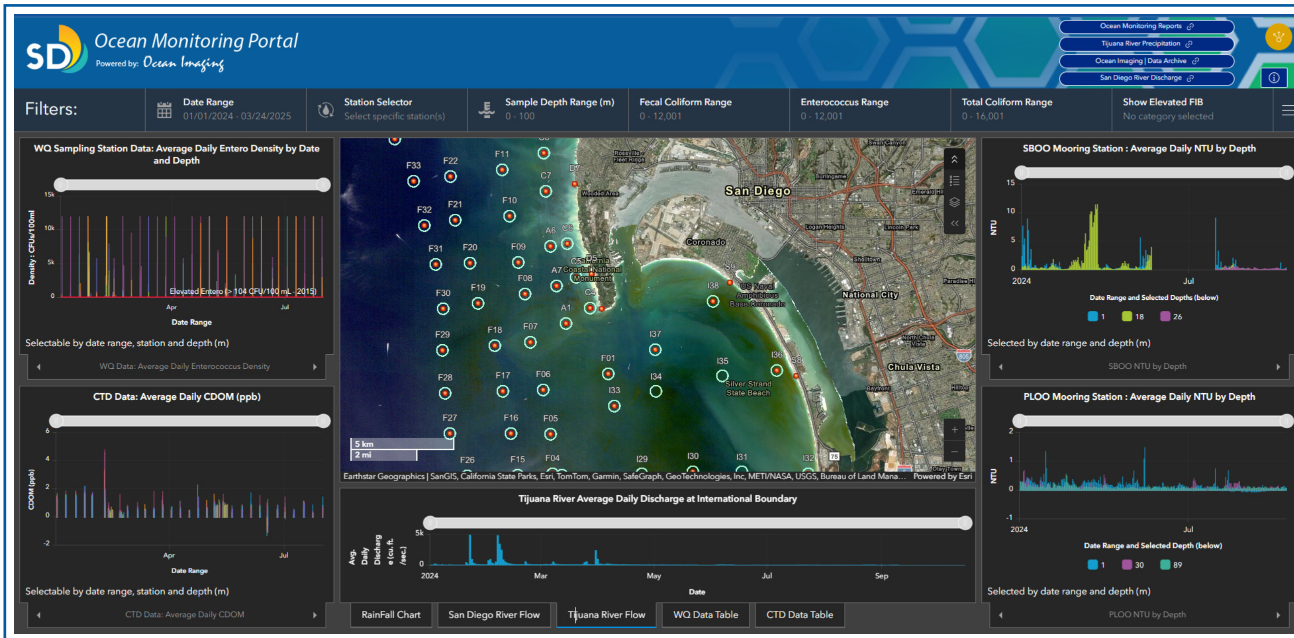


Figure 22. Dashboard-style data portal hosting access to satellite imagery along with several other oceanographic and biological datasets that can be filtered for display by date, sample depth, value range and other definable parameters.

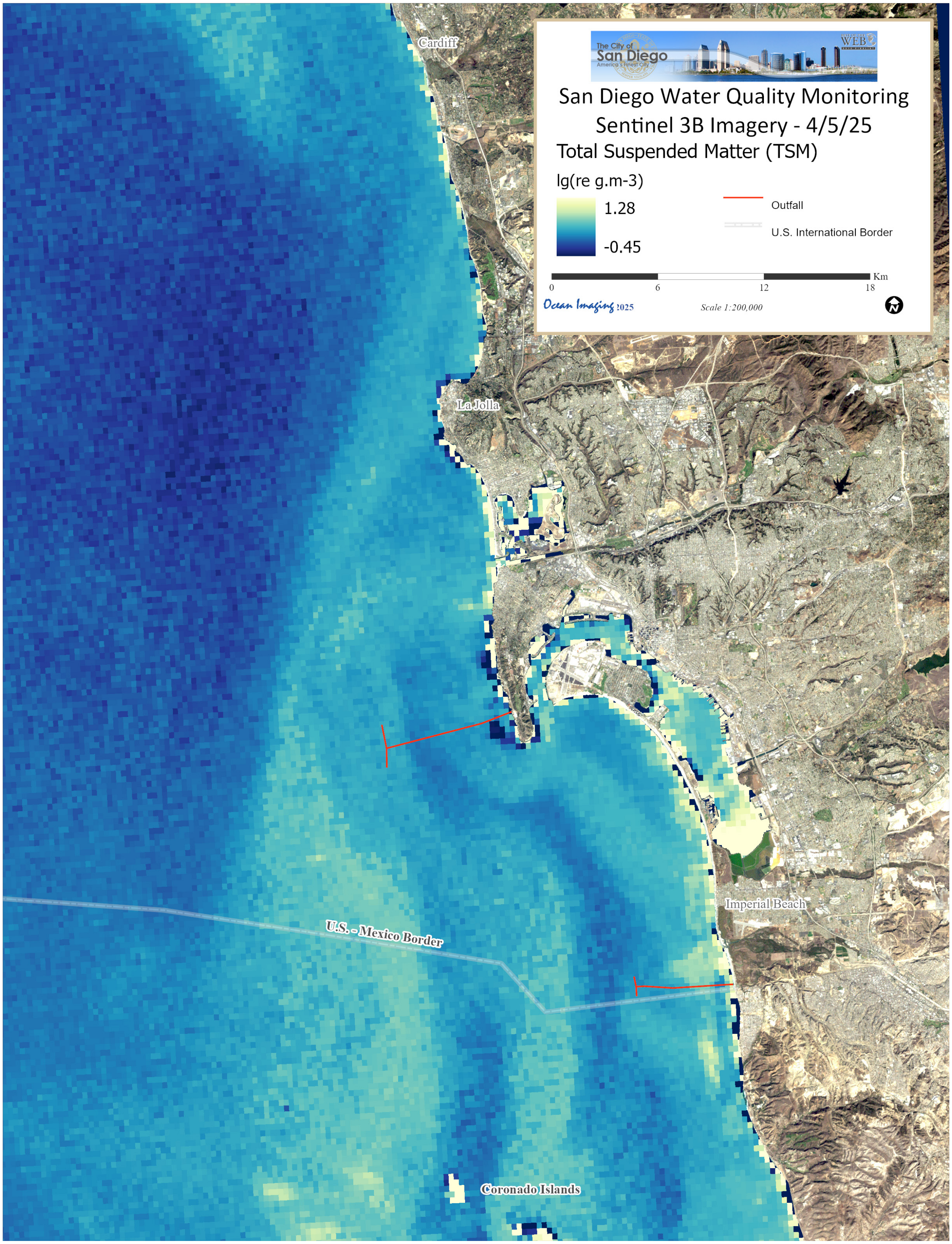


Figure 23. Sample TSM imagery from 04/05/25. This imagery will be posted near-daily beginning in mid-to-late 2025.

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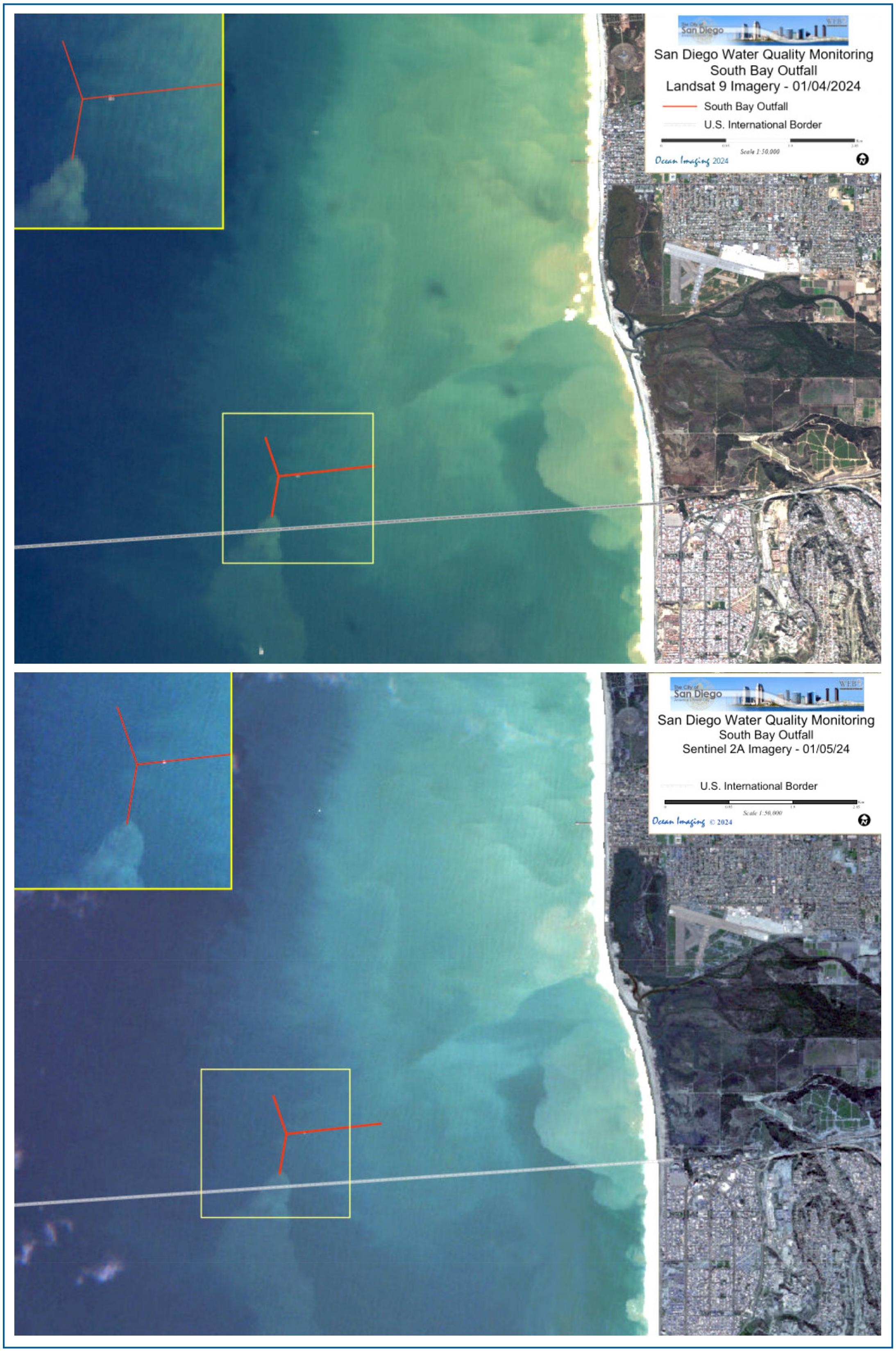
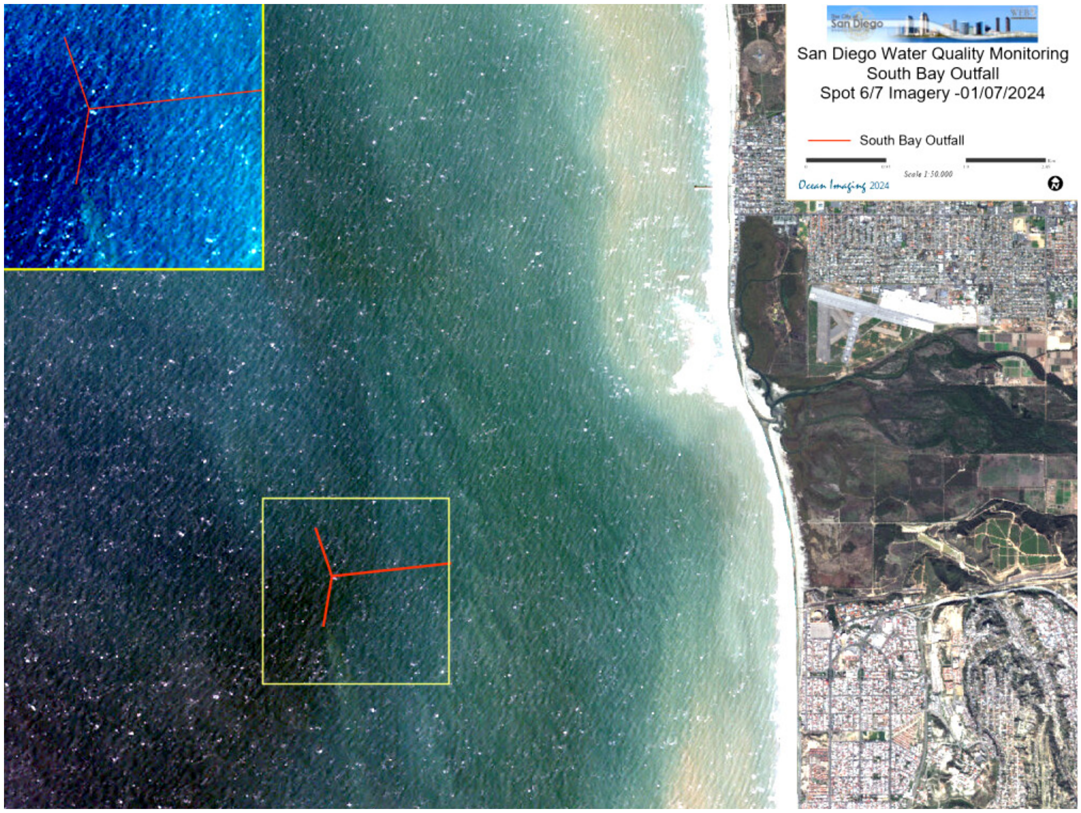
APPENDIX A – HIGH RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED WASTEWATER PLUME





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Spot 6/7 Imagery -01/07/2024
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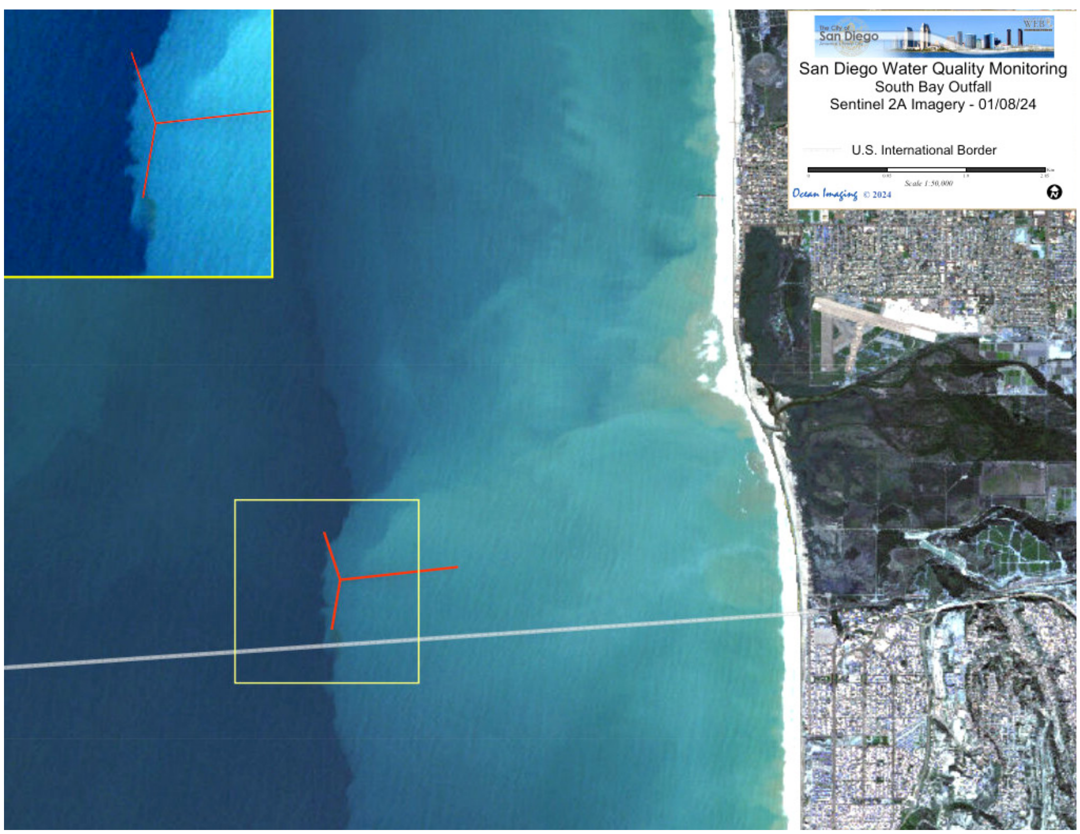
Ocean Imaging 2024



San Diego Water Quality Monitoring
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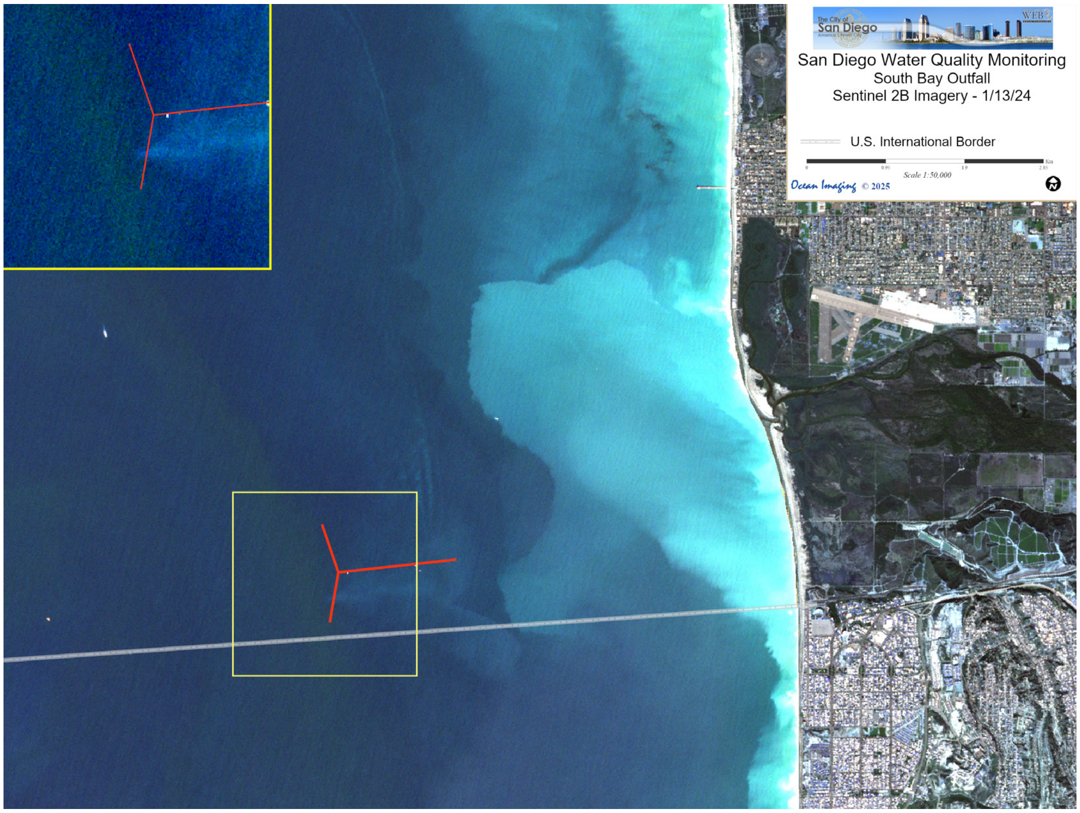
Ocean Imaging © 2024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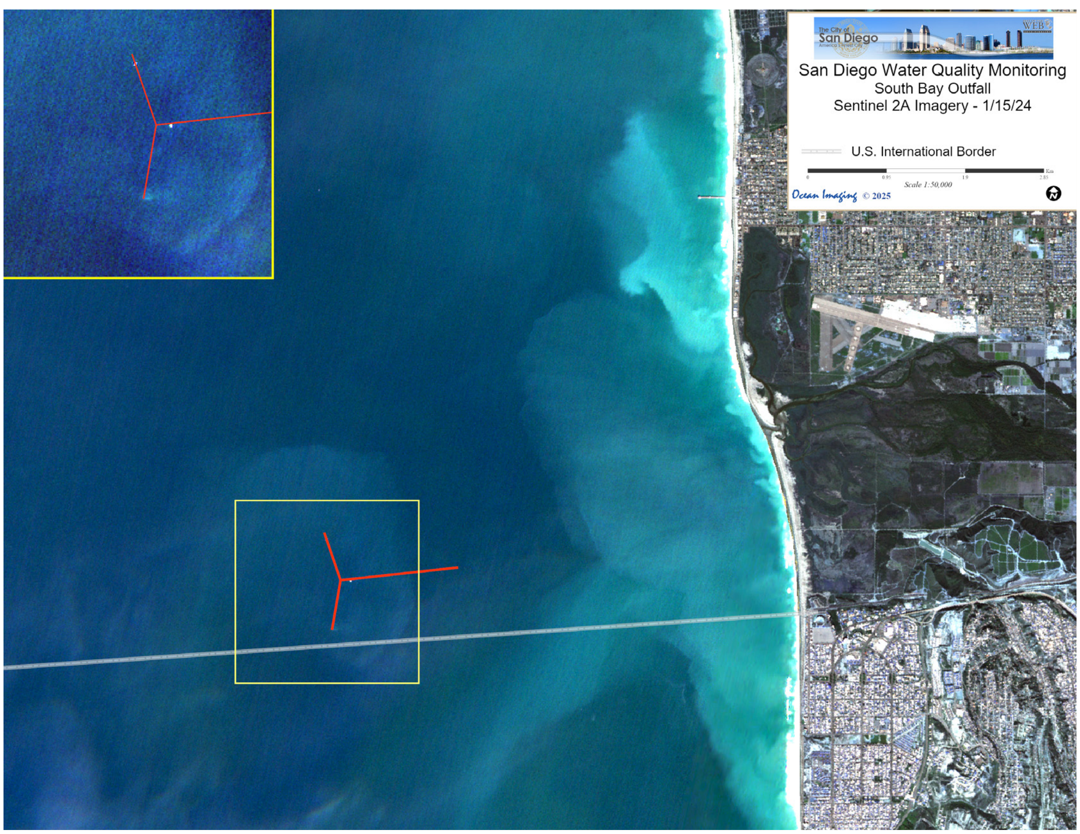
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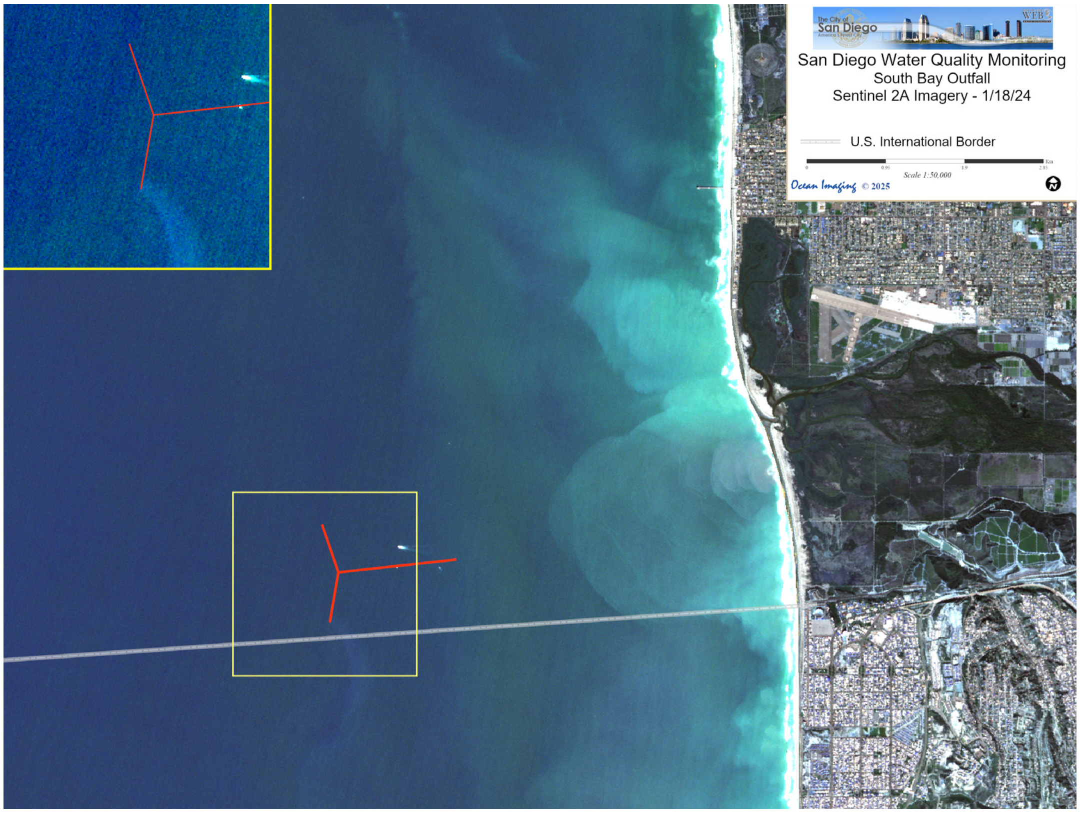
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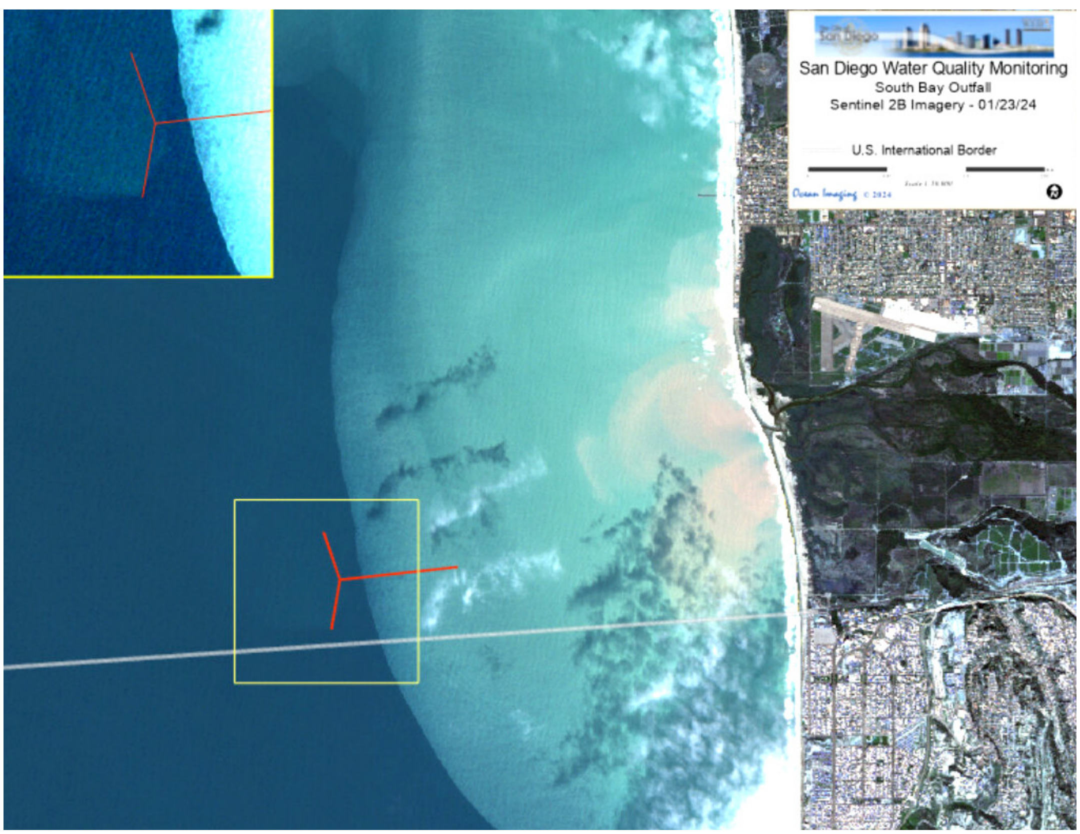
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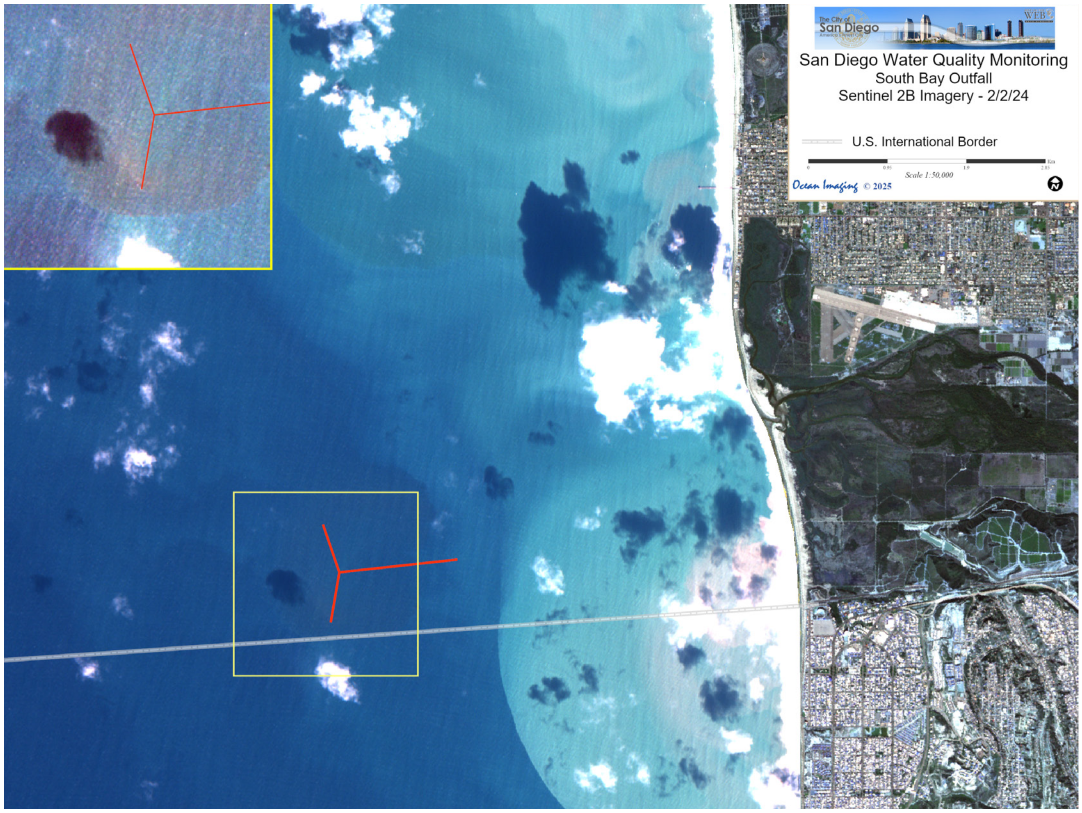
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Ocean Imaging © 2025


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South Bay Outfall
Sentinel 2A Imagery - 02/04/24
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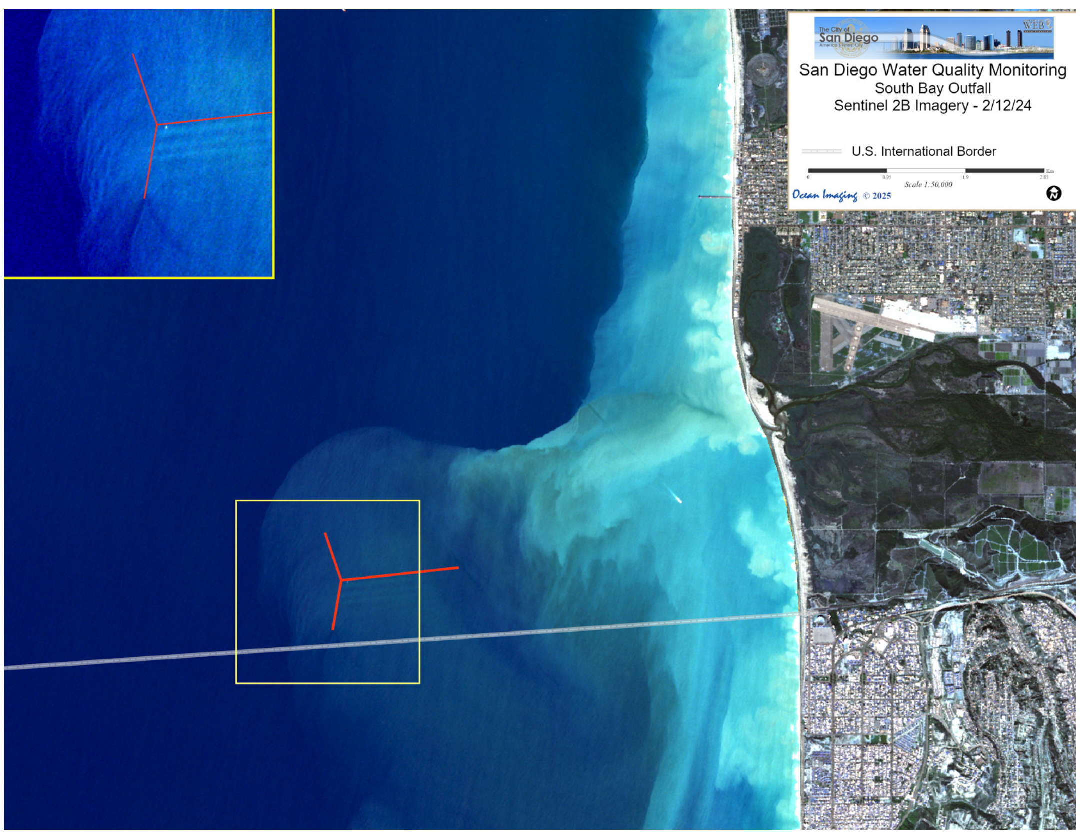
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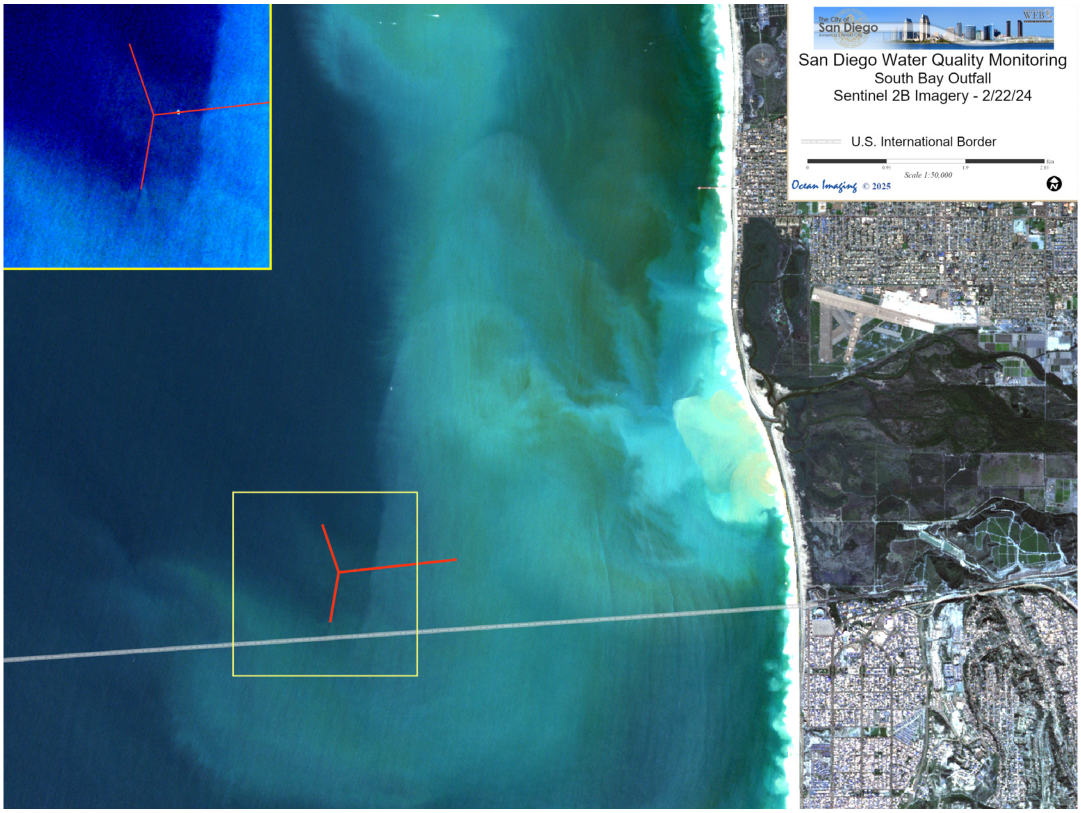
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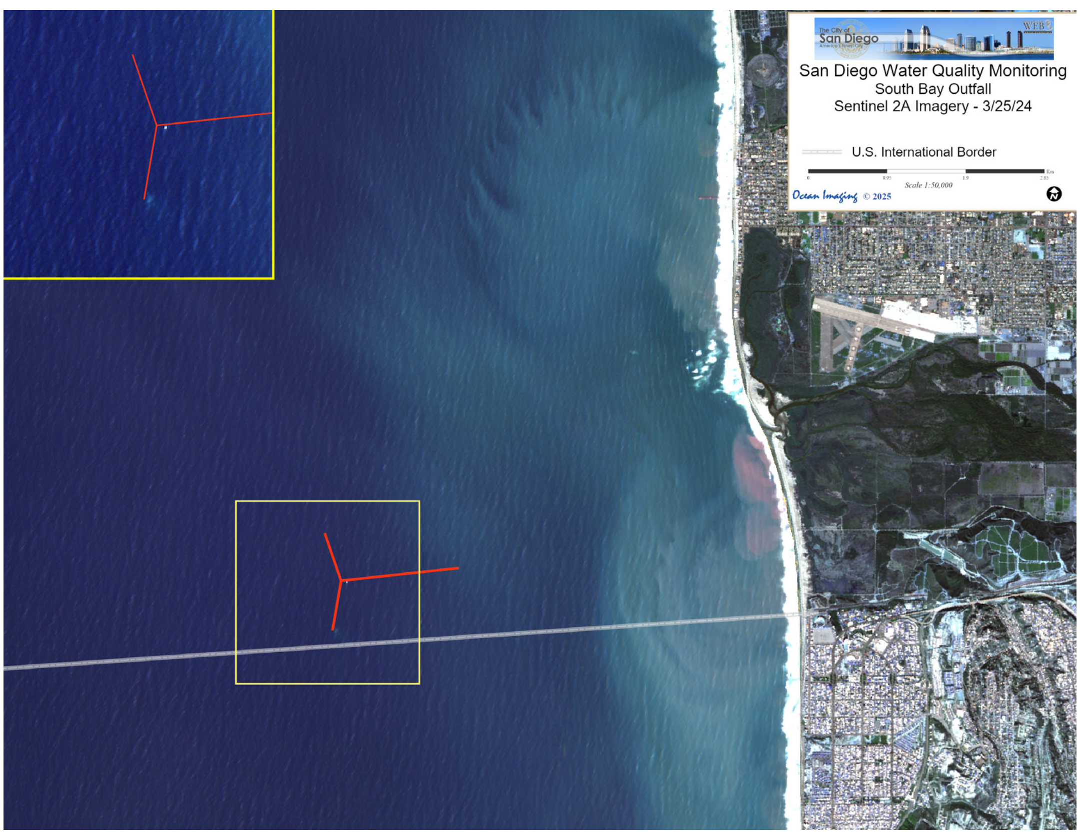
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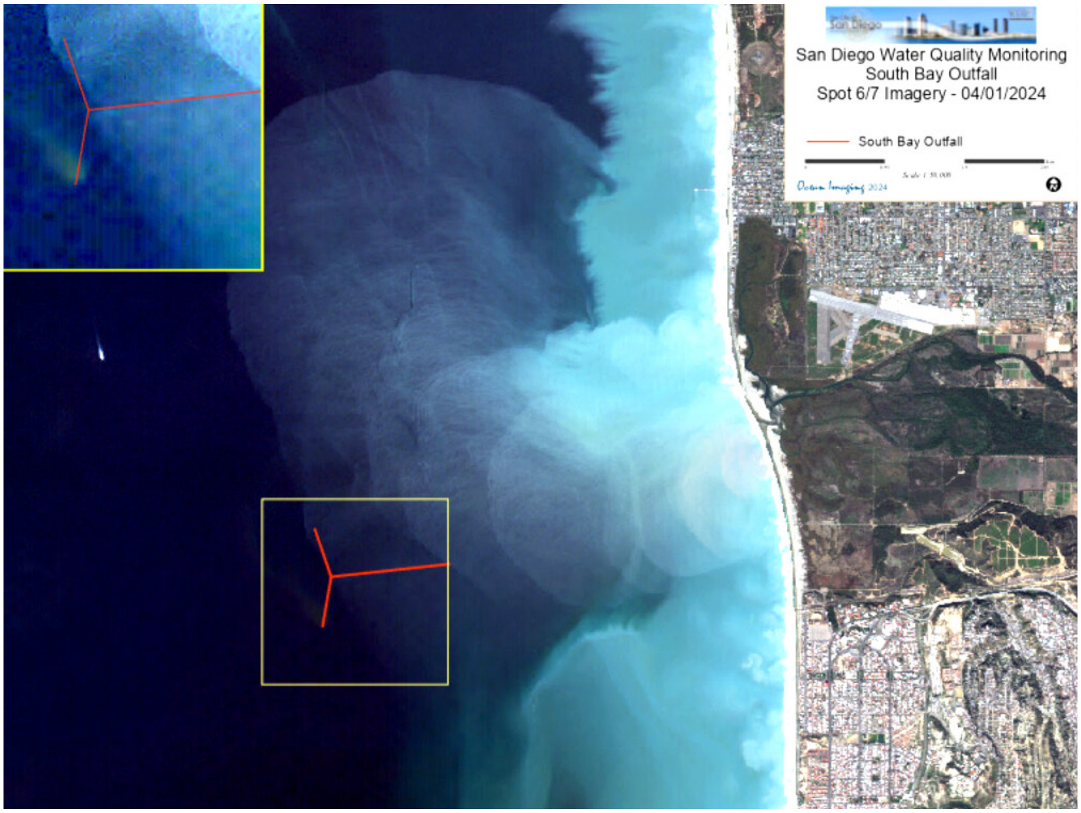
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Spot 6/7 Imagery - 04/01/2024
South Bay Outfall
Ocean Imaging 2024


San Diego Water Quality Monitoring
South Bay Outfall
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South Bay Outfall
U.S. International Border
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San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 04/02/24
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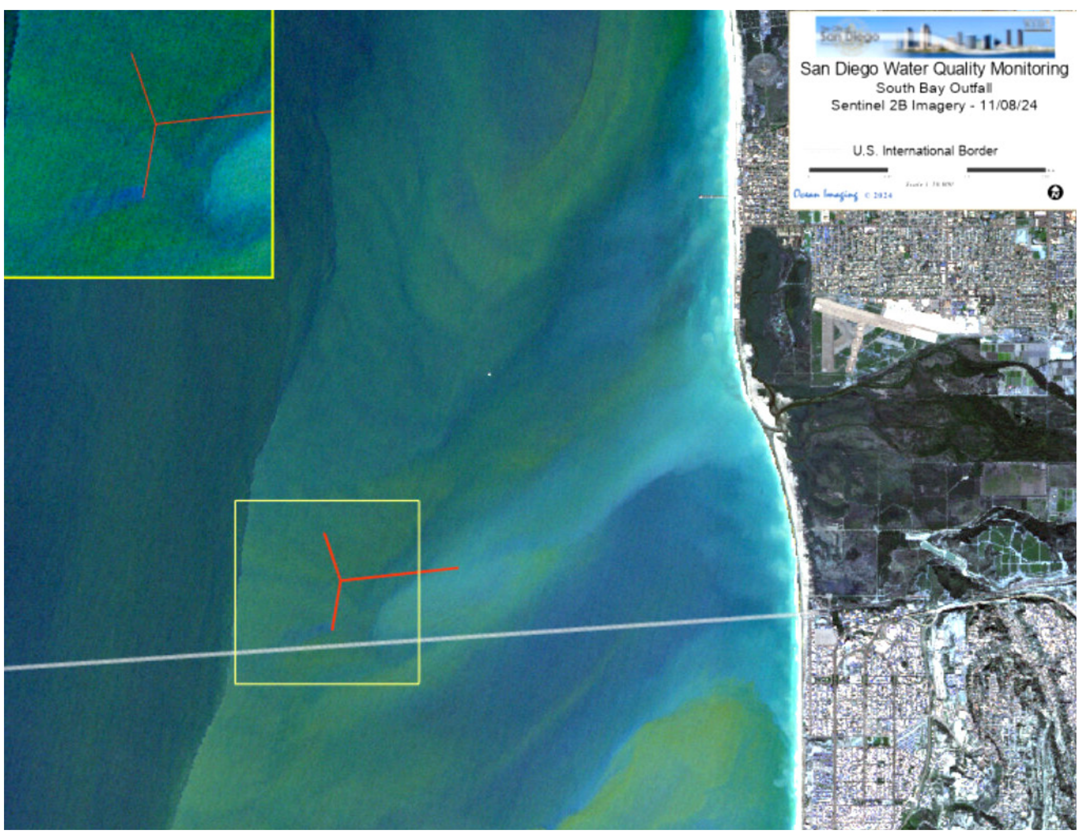
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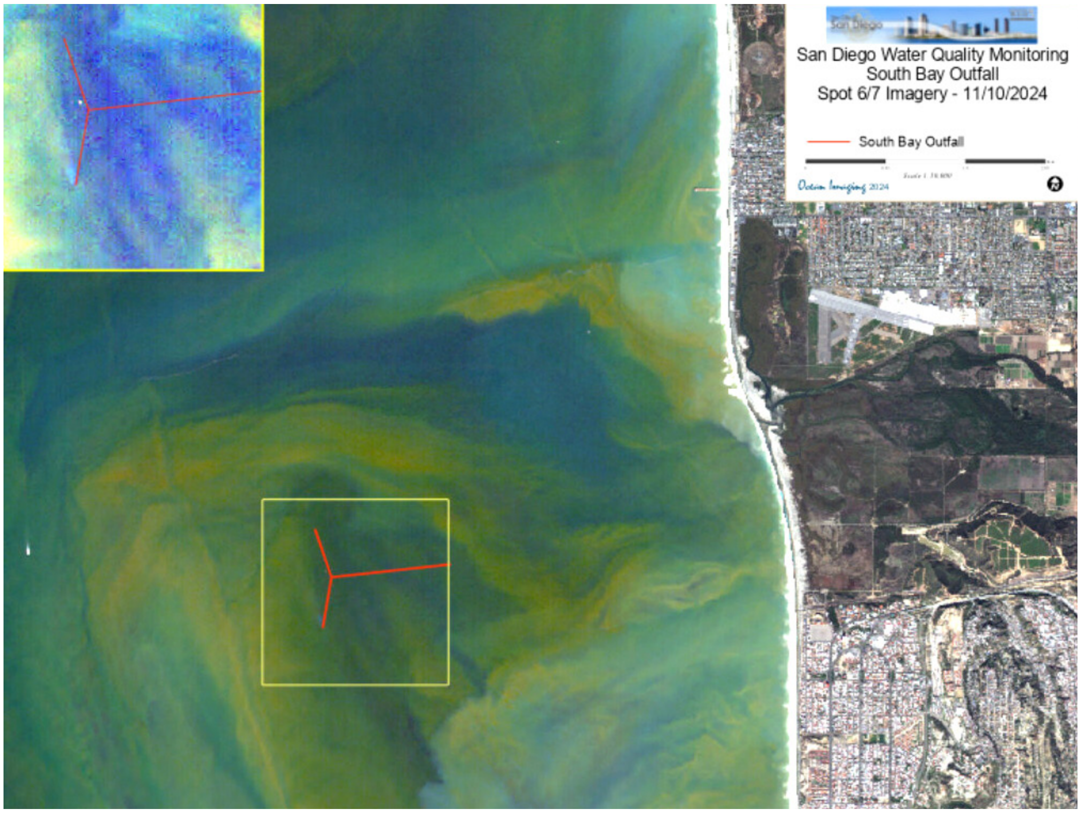
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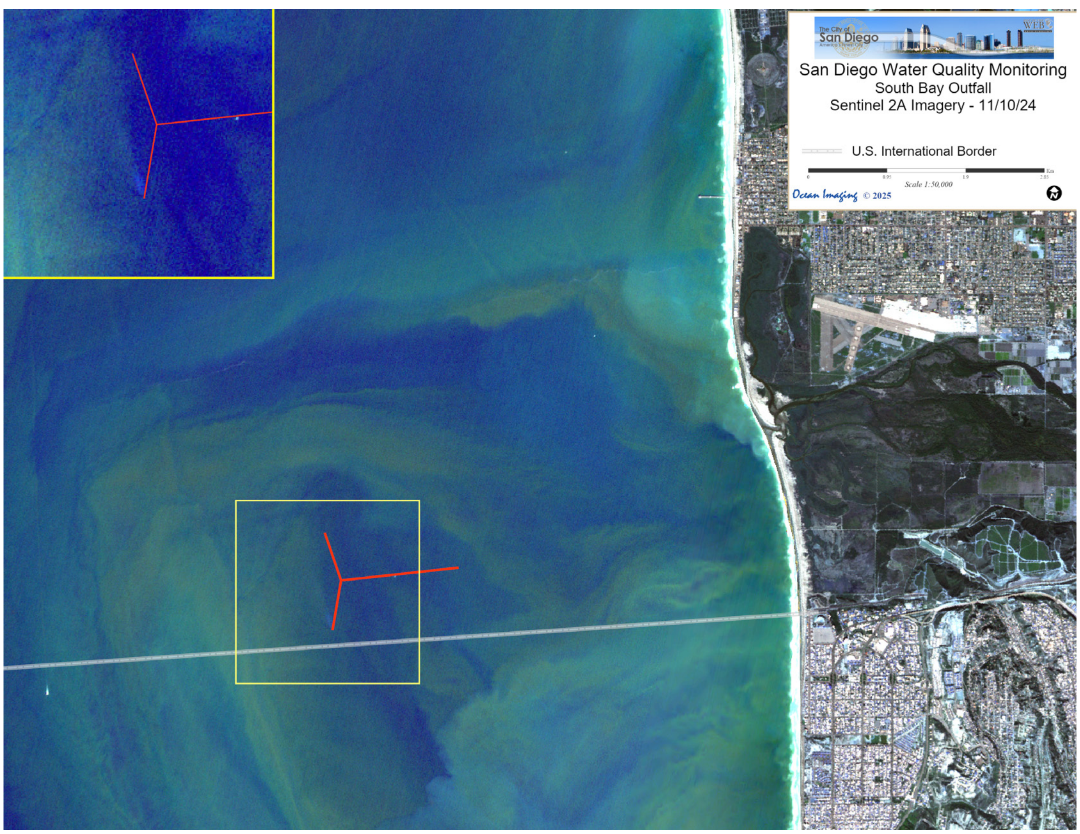
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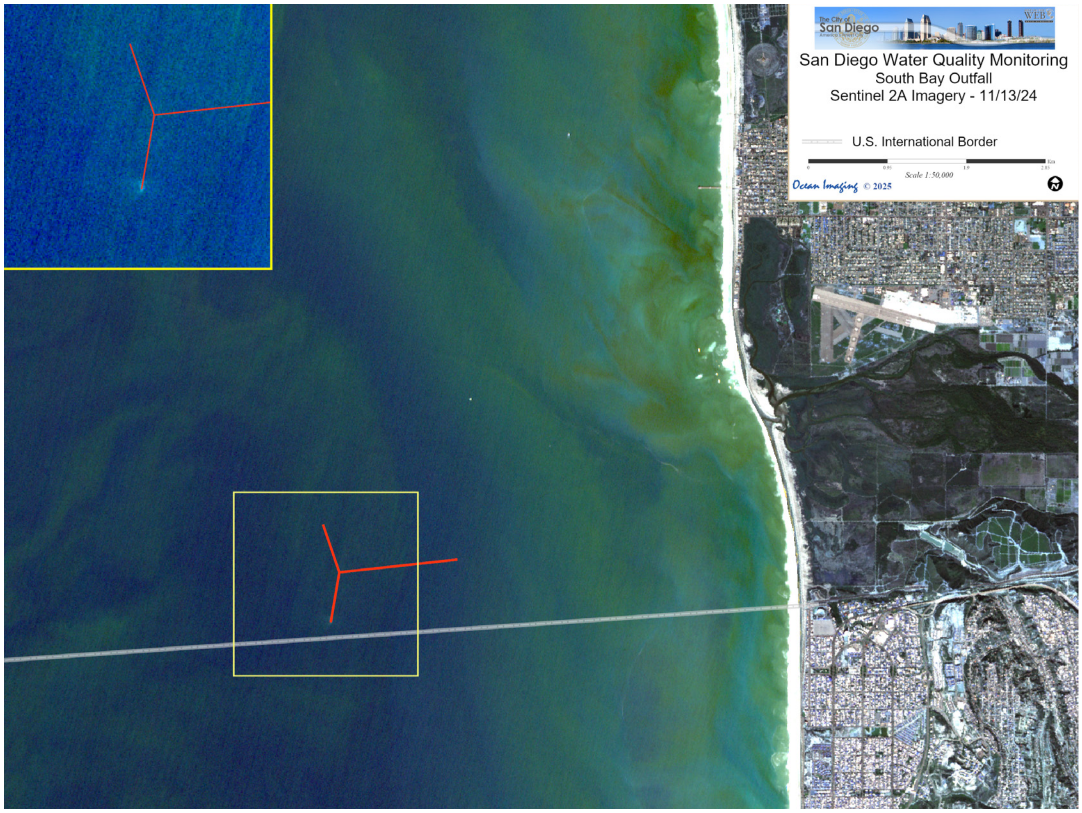
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 11/10/24
U.S. International Border
Scale 1:50,000
Ocean Imaging © 2025


San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 11/13/24
U.S. International Border
Scale 1:50,000
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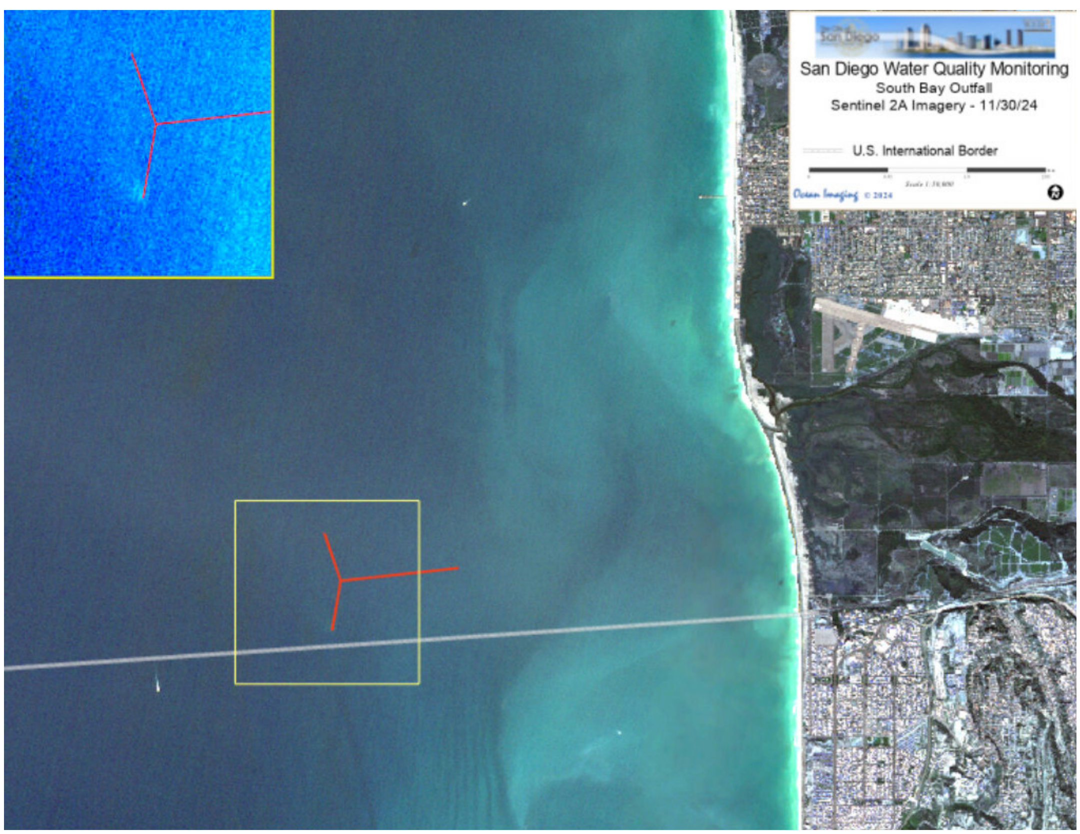
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 11/30/24
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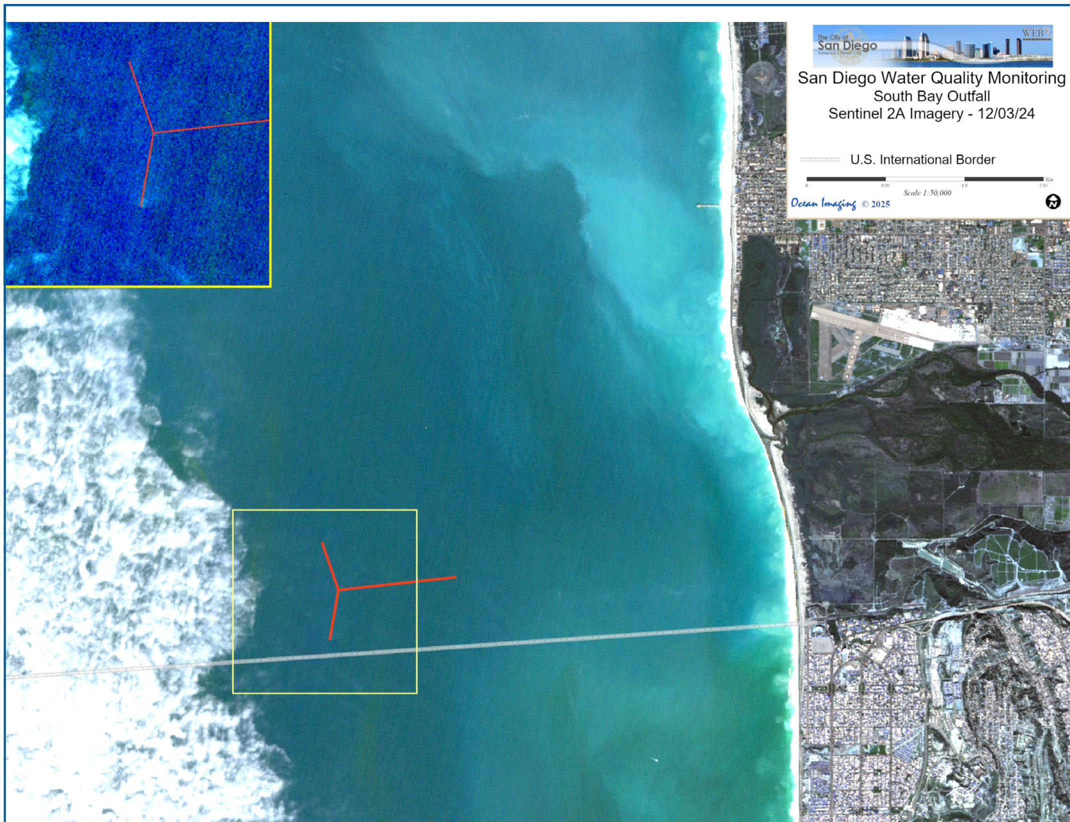
The City of San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 12/03/24
U.S. International Border
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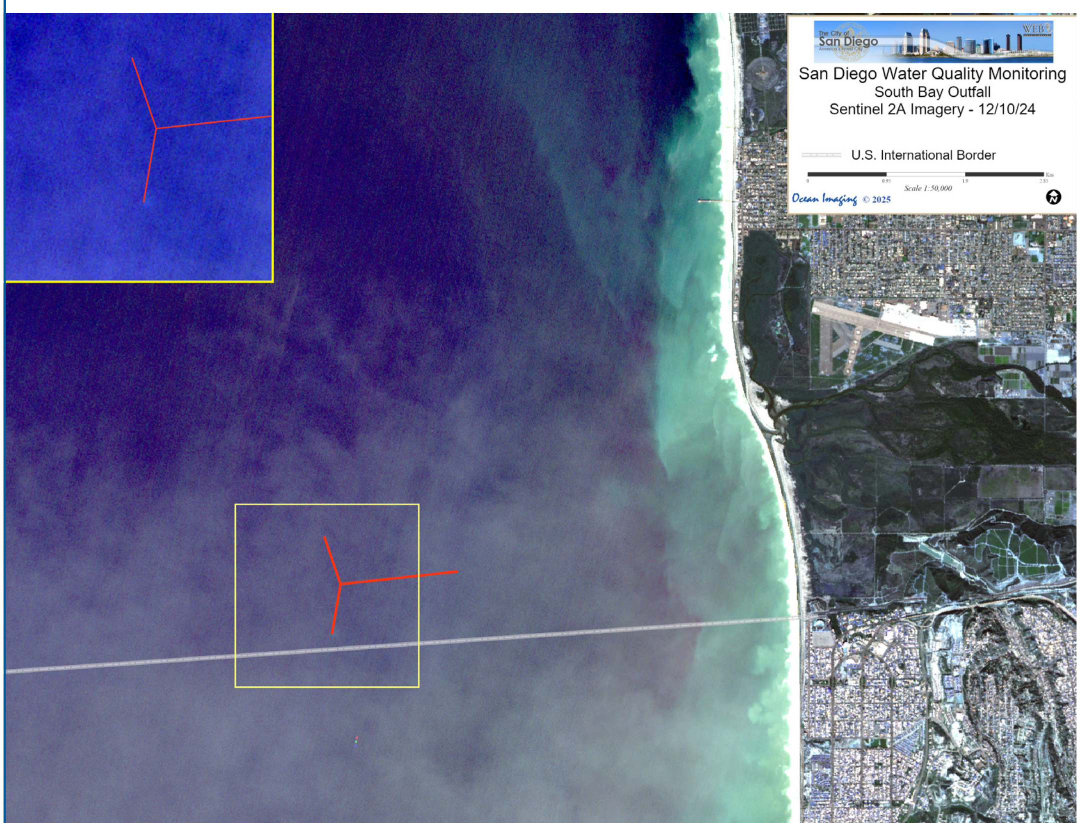
The City of San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 12/10/24
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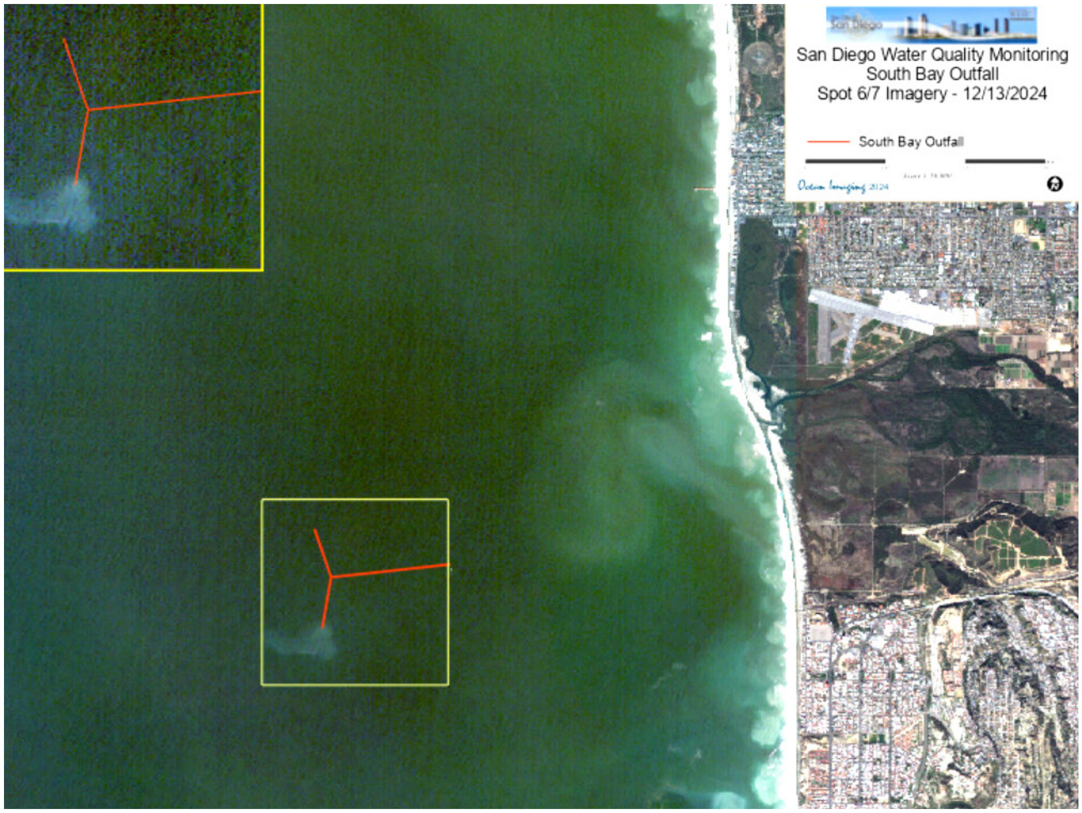
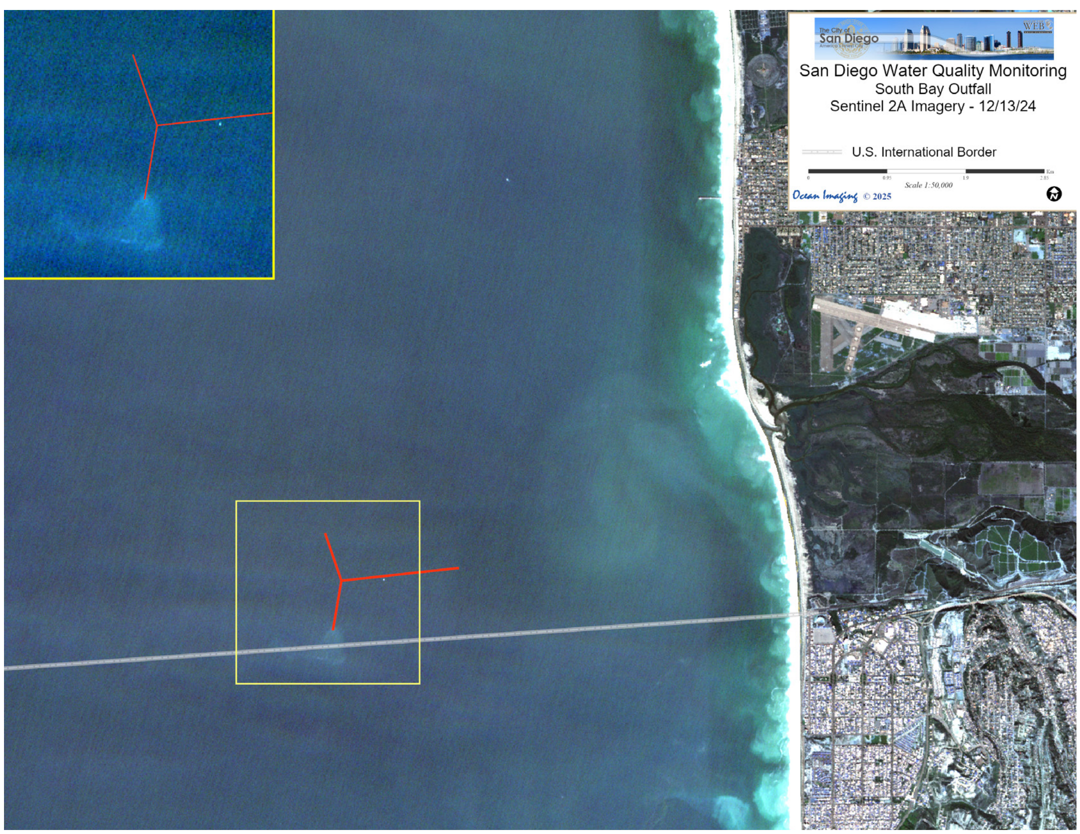

San Diego Water Quality Monitoring
South Bay Outfall
Spot 6/7 Imagery - 12/13/2024
South Bay Outfall


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 12/13/24
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