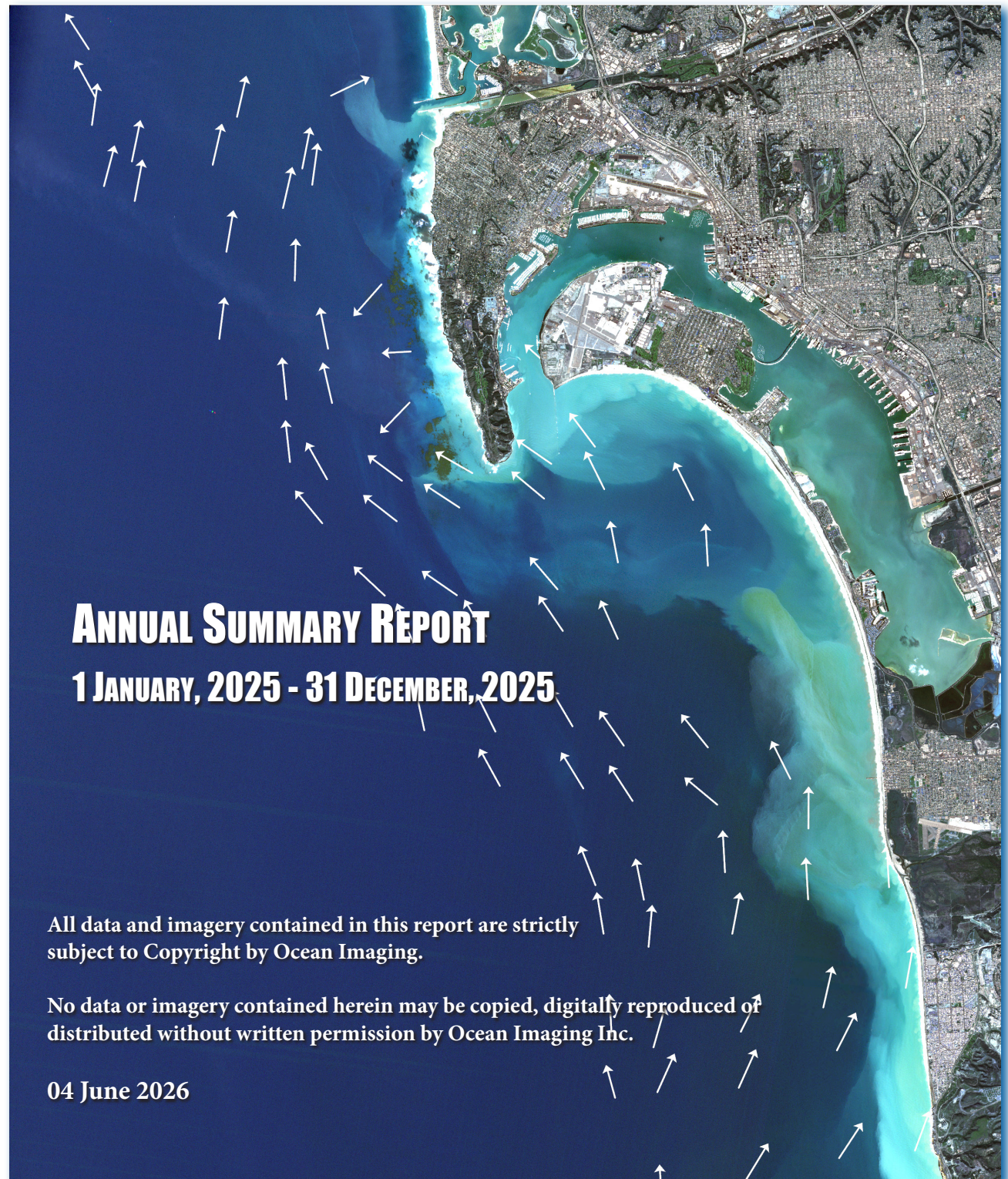


SATELLITE COASTAL WATER QUALITY MONITORING IN THE SAN DIEGO / TIJUANA REGION

By Mark Hess



Ocean Imaging

13976 West Bowles Avenue, Suite 100, Littleton CO 80127

Phone: 303-948-5272

www.oceani.com

TABLE OF CONTENTS

1. INTRODUCTION AND PROJECT HISTORY 1

2. METHODS AND TECHNOLOGY OVERVIEW2

2.1 Imaging in the UV-Visible-Near-Infrared Spectrum 2

2.2 Imaging in the Thermal Infrared Spectrum..... 2

2.3 Satellites and Sensors Utilized 2

2.4 Data Dissemination and Analysis 8

3. HIGHLIGHTS OF 2025 MONITORING8

3.1 Atmospheric and Ocean Conditions 8

3.2 The South Bay Ocean Outfall Region 24

3.3 The Point Loma Outfall Region 30

3.4 Kelp Variability 32

4. PRESENT AND FUTURE ENHANCEMENTS OF THE PROJECT 36

5. REFERENCES37

**APPENDIX A – HIGH-RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED
WASTEWATER PLUME..... 39**

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 several types of remotely sensed data for the detection and monitoring of stormwater runoff and wastewater discharges from offshore outfalls. The methodology was initially demonstrated in collaboration with 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, sizes, 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 since its inception. Initially, emphasis was on utilizing the image data to discern and monitor surface and near-surface signatures from the South Bay Ocean Outfall (SBOO) and Point Loma Ocean Outfall (PLOO), separate them from other nearshore point and non-point runoff features, and monitor their locations, extents, and potential impact on the shoreline. Prior to this project, the spatial extents of the plumes could only be estimated from a relatively sparse spatial grid of field samples, which made it difficult to separate, for example, the SBOO near-surface plume from the Tijuana River runoff plume. This ambiguity made it difficult, in turn, to objectively evaluate the potential contribution, if any, of the SBOO plume to beach contamination along the nearby shoreline. The satellite and aerial imagery helped directly establish the dispersal trajectories of the SBOO effluent during months when it reached the near-surface layer and support the conclusion that it is unlikely to reach the surf zone under observed conditions.

In October 2002, the operational monitoring phase of the project was initiated using a variety of satellite- and model-derived datasets described below. Over the past five to ten years, the project's objectives have broadened from focusing primarily on the outfalls to also providing 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 January, 2025 through 31 December, 2025.

2. METHODS AND TECHNOLOGY OVERVIEW

OI uses several remote sensing technologies to monitor San Diego's offshore outfalls and shoreline water quality. Their primary function is to reveal light reflectance, heat emission, and radar backscatter 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. In general, the satellite sensor data used for this program 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 freshwater, it is less dense than the surrounding salt water and tends to rise toward 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 data 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 aerial data were 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 scenes covering the same geographical area beginning in 2020. Table 1 lists the properties of the remote sensing image sources routinely used during the project during 2025.

Beginning in 2017, OI began processing and posting imagery from the Sentinel-2 satellites. Sentinel-2A, 2B, and 2C are satellites operated by the European Space Agency (ESA) and are the spaceborne platforms for the Multispectral Instrument (MSI). The Sentinel-2A, 2B and 2C MSIs sample 13 spectral bands: four bands at 10 m, six bands at 20 m 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 m depending on ocean conditions. The revisit time of each Sentinel-2 satellite is approximately ten days. Sentinel-2C was launched into orbit by the ESA in late 2024 and provided the first set of data from the MSI sensor in early 2025. Presently with the three Sentinel satellites in orbit the revisit time over the San Diego region is approximately one to two days. This represents a significant improvement in observational frequency relative to previous years. On average the Sentinel-2A, 2B, and 2C data 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 2025 the Sentinel-2 suite of satellites provided the most temporally comprehensive set of high-resolution satellite data. In total, 114 high-resolution, multispectral satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2025. This equates to an 8.6% increase in satellite data used to document the area when compared to 2024 – likely due to the addition of Sentinel-2C data and fewer instances of total cloud cover over the San Diego region. Of the 114 total image sets, 87 were from Sentinel-2A/2B/2C data making up 76% of the high-resolution satellite data processed and posted as part of the project.

In October 2018, OI began using data 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. The 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-IR, 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

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

Sensor	Utilization Period	Resolution (m)	Utilized Wavelength Range
MODIS	2003 - Present	250/500/1000	Band 1 (250 m): .620 – .670 μm Band 2 (250 m): .841 – .876 μm Band 3 (500 m): .459 – .479 μm Band 4 (500 m): .545 – .565 μm
Landsat 8 OLI, TIRS	2013 - Present	30 (visible - Near-IR) 100 (Thermal-IR)	Band 2: .452 - .512 μm Band 3: .533 - .590 μm Band 4: .636 - .673 μm Band 5: .851 - .879 μm Band 10: 10.60 - 11.19 μm Band 11: 11.50 - 12.51 μm
Sentinel-2A/2B/2C	2017 - Present	10 (visible - Near-IR) 60 (Vegetation Red Edge) 60 (UV, SWIR)	Band 1: .443 μm Band 2: .490 μm Band 3: .560 μm Band 4: .665 μm Band 5: .705 μm Band 6: .740 μm Band 7: .783 μm Band 8: .842 μm Band 8A: .865 μm
Sentinel-3A/3B	2018 - Present	300 (all utilized bands)	Band Oa2: .412.5 μm Band Oa3: .442.5 μm Band Oa4: .490 μm Band Oa5: .510 μm Band Oa6: .560 μm Band Oa7: .620 μm Band Oa8: .665 μm Band Oa10: .68125 μm Band Oa11: .7875 μm Band Oa17: .865 μm
VIIRS	2019 - Present	750 (all utilized bands)	Band M1: 0.402 - 0.422 μm Band M2: 0.436 - 0.454 μm Band M3: 0.478 - 0.488 μm Band M4: 0.545 - 0.565 μm Band M5: 0.662 - 0.682 μm Band M6: 0.739 - 0.754 μm Band M7: 0.846 - 0.885 μm Band M8: 1.23 - 1.25 μm Band M9: 1.371 - 1.386 μm Band M10: 1.58 - 1.64 μm Band M11: 2.23 - 2.28 μm Band M12: 3.61 - 3.79 μm Band M13: 3.97 - 4.13 μm Band M14: 8.4 - 8.7 μm Band M15: 10.26 - 11.26 μm Band M16: 11.54 - 12.49 μm
SPOT 6	2019 - Present	6	Band 1: .450 - .745 μm Band 2: .450 - .525 μm Band 3: .530 - .590 μm Band 4: .625 - .695 μm Band 5: .760 - .890 μm
Sentinel-1A/1C 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 μm Band 3: .533 - .590 μm Band 4: .636 - .673 μm Band 5: .851 - .879 μm Band 10: 10.60 - 11.19 μm Band 11: 11.50 - 12.51 μm

daily products dependent on cloud cover for the entire San Diego/Tijuana region using the OLCI instrument. Between the 3A and 3B satellites this results in better than daily coverage with 3A and 3B data occasionally both being available on the same day. True color and near-IR products are posted every two months. Sentinel-3-derived chlorophyll products offering a 300-meter spatial resolution, were 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 six 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-IR 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 runoff plumes. In March of 2023, the SPOT 7 satellite stopped functioning; however, we continue to receive data from SPOT 6 and acquire two to three clear images per month from this sensor during the fall to spring period. Figure 1 shows a set of images acquired on 03/15/25 from SPOT 6 and Sentinel-2A highlighting the ability to obtain high-resolution imagery from multiple satellites on the same day. The two images from 03/15/25 were captured within twenty minutes of each other. Note the turbid effluent from the SBOO seen at the surface of the ocean in both scenes as well as heavy turbidity along the shoreline. Two-kilometer-spaced High Frequency Radar-derived (HF Radar) ocean current vectors from the same day acquired within minutes of the satellite overpasses are overlaid on the imagery to illustrate the surface flow patterns in the region. Note that the turbid water north of the U.S.-Mexico border appears to be moving north and northwest, yet the water near and south of the border (around the SBOO underwater wye) is moving south and west, pushing

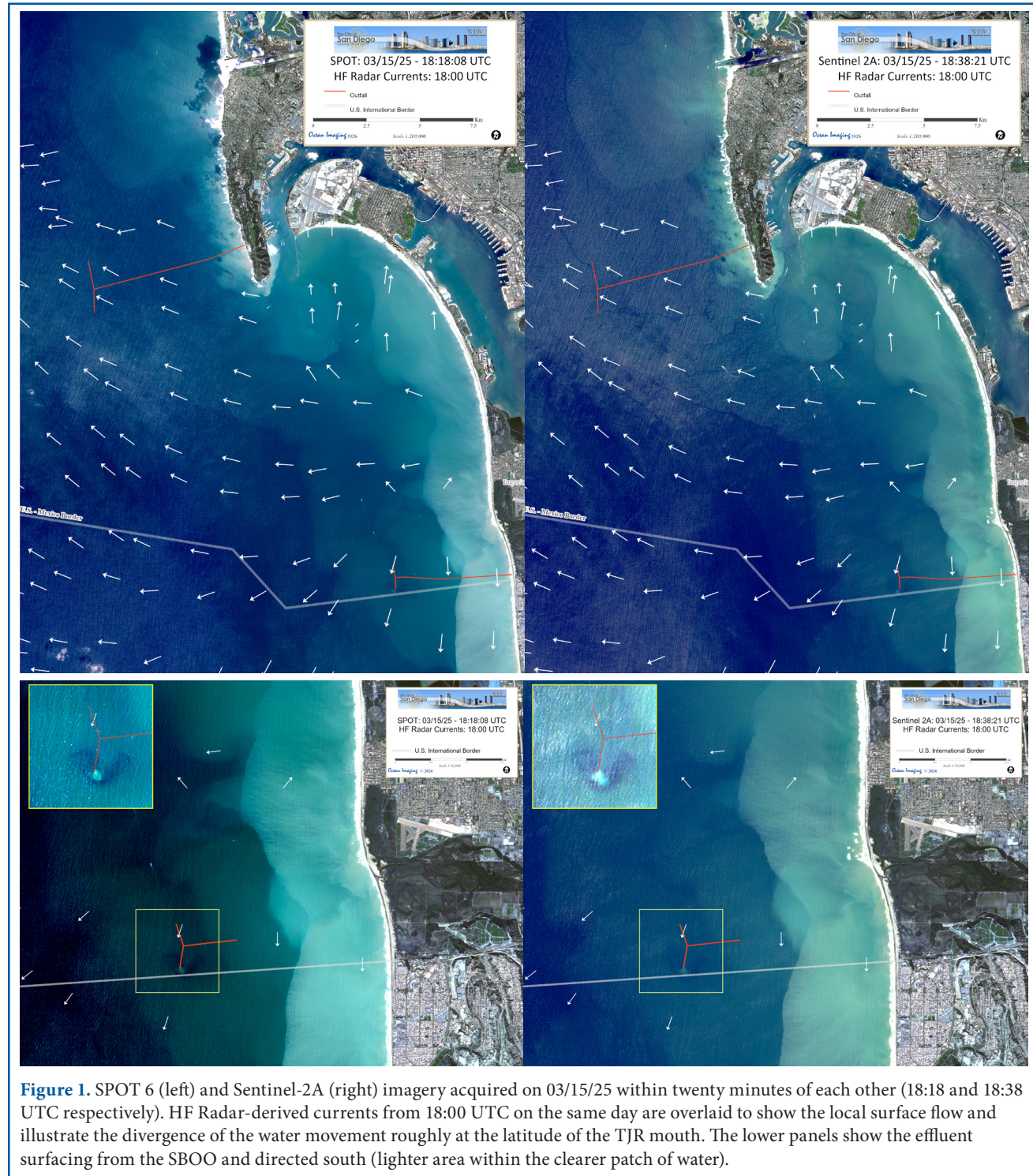
the SBOO effluent with it. It is also evident that the SBOO effluent plume at the ocean's surface enlarged slightly over the twenty-minute period between the two datasets. More discussion on the SBOO and visible effluent follows in subsequent sections.

The use of Advanced Very High Resolution Radiometer (AVHRR) satellite data described in prior reports was discontinued in 2025 due to phasing out of this sensor suite by NOAA in lieu of the newer Visible Infrared Imaging Radiometer Suite (VIIRS) satellites now in orbit. As detailed in Table 1, to date, this work utilizes 1000 m resolution chlorophyll and sea surface temperature (SST) Moderate Resolution Imaging Spectroradiometer (MODIS)-derived image data (available multiple times per day), 750 m VIIRS chlorophyll and SST data (available multiple times per day), 300 m resolution Sentinel-3A and 3B color and thermal image data (available daily), 30 m & 60 m Landsat 8 OLI/TIRS and Landsat 9 OLI-2/TIRS-2 color and thermal image data (each available approximately every 16 days), 10 m resolution Sentinel-2A, 2B, and 2C multispectral imagery (available 2–4 times per week), and 6 m resolution Satellite Pour l'Observation de la Terre (SPOT) 6 (available approximately every 5–7 days). Sentinel-2A was slated to be phased out of the Copernicus program in early 2025, however we continue to receive 2A data into early 2026 and so there has not been a decrease in Sentinel-2 information.

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. Sentinel-1C data became available in late 2025 and was added to the suite of imagery delivered as part of this project. 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 an additional

observational perspective 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

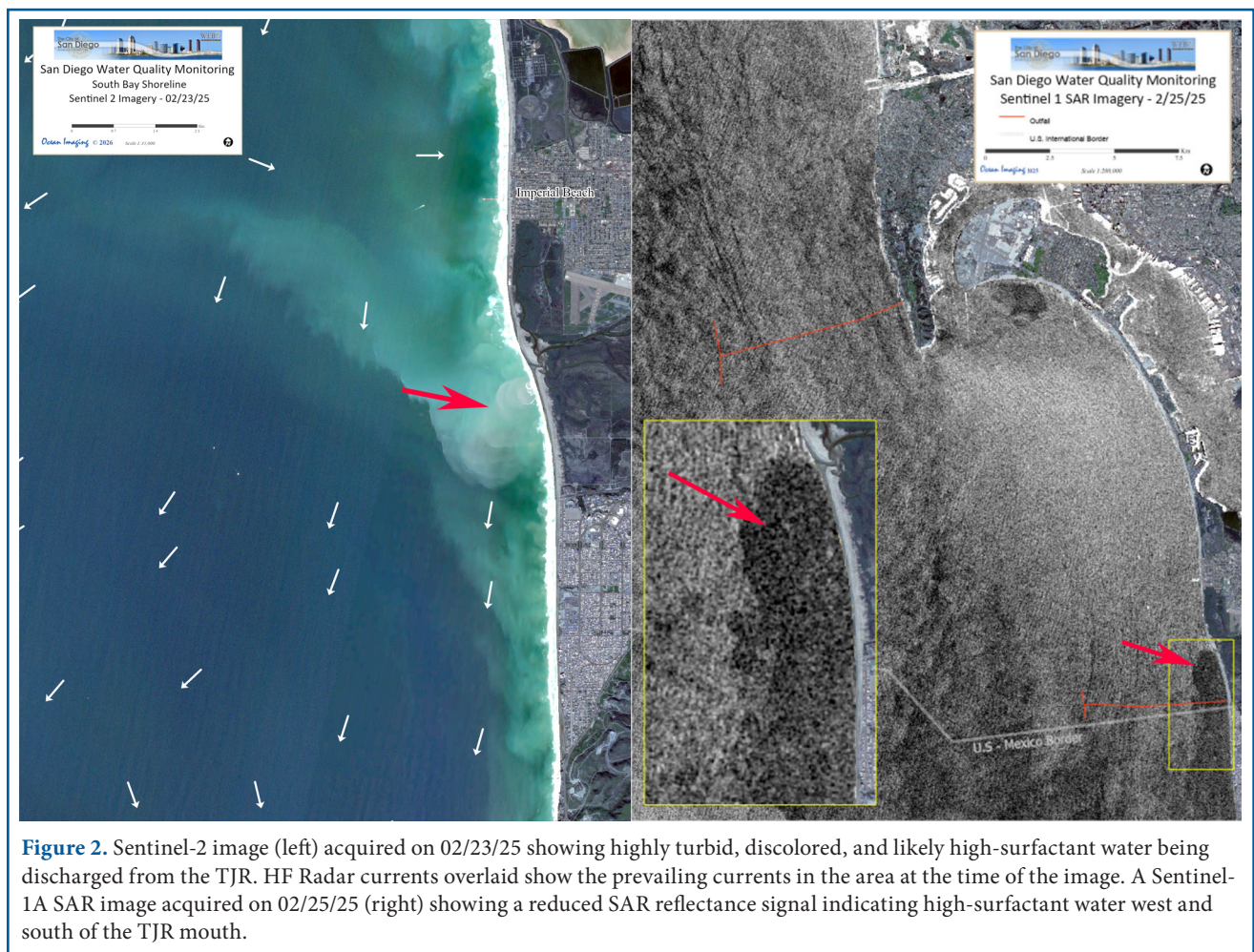
data. Phytoplankton blooms also release biological surfactants that result in low backscatter observed in the SAR data (Svejkovsky and Shandley 2001). In 2025, 124 SAR images were acquired and processed for the San Diego region providing an additional



source of information even during cloudy conditions. Figure 2 shows a Sentinel-2 image captured on 02/23/25 (left) along with a Sentinel-1A SAR image captured two days later when coastal cloud cover prohibited the acquisition of optical satellite data. On 02/23/25 the ocean currents were moving the discolored, potentially impactful TJR water south along the coast. The dampened SAR signal (dark area) in the Sentinel-1A image from 02/25/25 shows that the TJR water likely containing anthropogenic surfactants (often indicative of polluted water) was constrained to the south of the river mouth and did not move north into the San Diego region. This was identifiable even during the cloudy conditions when the optical satellites could not show the core of the TJR plume and its direction. Recent attention on the severity of the TJR polluted discharge (Little 2024) and Harmful Algal Blooms (HAB) make 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 now retrieved from the NOAA National Data Buoy Center HF Radar National Server (<https://hfradar.ndbc.noaa.gov/>) daily and reformatted into ESRI-compatible shapefiles. The products are generated at 1 km and 6 km spatial resolutions. 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 prepped for incorporation into a next-generation WMS dashboard-style data portal which became operational in 2025. The ocean currents will soon be added to the dashboard as the platform is refined and improved. The existing high-resolution (6–30 m) observation region extends from La Jolla southward to Rosarito Beach, Mexico and out approximately 50 miles. The coarser-scale products (250–1000 m) such as chlorophyll, SST and ocean currents 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 website. 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 turnaround 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. Future improvements are planned for the site to increase interactivity and ease of data access and visualization.

3. HIGHLIGHTS OF 2025 MONITORING

3.1 Atmospheric and Ocean Conditions

Coastal and oceanic water quality can often be correlated to rainfall events. In 2025, the San Diego International Airport station (SDIA) measured 9.84 inches of total annual rainfall and 9.03 inches at the Tijuana River International Boundary station (TJRIB), both higher than 2012–2024 averages of 8.69 and 7.91 inches respectively (see Table 2). 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 matching the expected rainy season and the summer months being mostly dry, the months of January and February exhibited relatively low rainfall compared to the previous twelve years – especially when contrasted to 2024. March and November were the rainiest months (2.93 and 3.11 inches measured at the SDIA station respectively). The well above average precipitation in November (2.3 and 2.0 inches above the 2012–2024 averages for the SDIA and TJRIB stations) was evident in the satellite data which exhibited periods of highly turbid water along the coast and 16 observations of significant TJR discharge between mid-November and the end of the year.

Figure 3 shows cumulative daily precipitation in the Tijuana Estuary along with the average daily river discharge at the TJRIB station. The tables below the plot give the date 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 February, March, November, and December with relatively little rainfall recorded between May and August.

We have defined a significant TJR discharge event as when the spectrally distinct “fresh core” of the river discharge plume as defined by Svejksky 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. Thirty-four of these days were during the four rainy months identified above. Hydrologic response in the Tijuana River watershed is strongly event-driven, with the majority of runoff and sediment transport occurring during a relatively small number of larger storm events (Biggs et al. 2022). Watershed-scale modeling of the binational Tijuana River basin indicates that

runoff generation increases nonlinearly with event precipitation, with analyzed storm totals ranging from 7 to 83 millimeters (mm) (0.28 to 3.27 inches), and substantially higher runoff coefficients associated with larger precipitation events (Gudino-Elizondo et al. 2019). It is also evident in Figure 3 that the TJR discharge spikes as a result of rainfall as low as 0.1 inches on a single day. We used ≥ 0.25 inches per day as a loose cutoff to identify a significant rainfall

Table 2. San Diego and Tijuana Estuary precipitation totals 2012-2025

San Diego International Airport Cumulative Monthly Precipitation in Inches

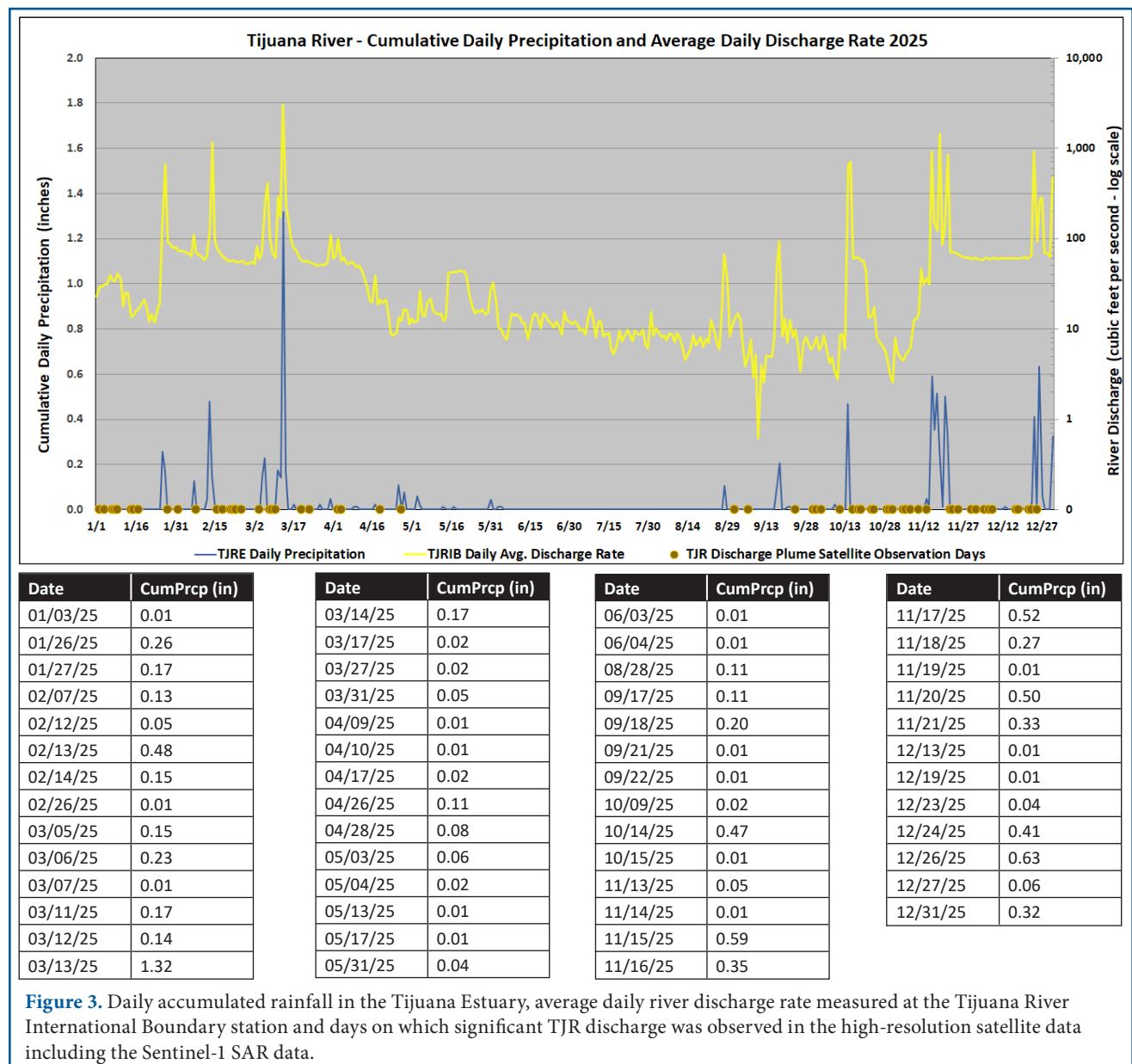
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
January	0.40	0.70	0.01	0.42	3.21	2.99	1.77	2.42	0.48	1.80	0.16	5.14	3.67	0.24
February	1.19	0.63	1.00	0.28	0.05	1.58	0.35	4.04	0.38	0.10	0.70	1.78	4.61	0.95
March	0.97	1.22	1.28	0.93	0.76	0.08	0.65	1.23	2.15	1.48	1.61	3.97	2.58	2.93
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	0.23
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	0.17
June	--	--	--	0.04	--	0.02	--	0.01	0.14	0.01	--	0.03	0.01	0.04
July	--	0.05	--	1.71	--	--	--	--	--	--	--	--	0.01	--
August	--	--	0.08	0.01	--	--	0.02	--	--	0.23	--	1.84	0.02	0.05
September	--	--	--	1.24	0.32	0.06	--	0.11	--	0.50	0.65	0.05	0.02	0.47
October	0.70	0.25	--	0.43	0.07	--	0.57	--	0.12	1.01	0.09	--	0.01	0.42
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	3.11
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	1.23
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	9.84

Tijuana Estuary Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
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	0.44
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	0.82
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	2.29
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	0.24
May	--	0.36	--	1.13	0.97	1.07	0.08	0.50	0.02	0.01	--	0.12	0.09	0.15
June	--	--	0.12	--	--	--	--	0.02	0.21	0.06	--	0.05	--	0.02
July	--	0.01	0.33	0.39	--	0.01	0.01	--	--	--	--	0.01	--	--
August	--	--	0.04	--	--	0.02	--	--	--	0.02	--	1.89	--	0.11
September	0.02	0.01	--	0.48	0.49	0.03	--	--	--	--	0.48	0.04	--	0.34
October	0.50	0.41	--	0.21	--	--	0.13	--	0.04	0.91	0.29	0.01	0.02	0.50
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	2.64
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	1.49
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	9.03

event as recorded at the TJRIB station. As has been the case in past years, analysis of 2025 satellite observations indicates that only six observed TJR plume events occurred within 0–3 days of rainfall exceeding 0.25 inches. Precipitation events of this magnitude can be sufficient to generate runoff-driven plume formation. However, the majority (~90%) of plume observations occurred during periods of low or no measurable rainfall. Figures 2 and 4 provide imagery examples showing higher than normal coastal turbidity, plankton blooms

and visible TJR discharge plumes even though there was no measurable rainfall prior to the imaging dates. The TJR average discharge rate in 2025 was 65.7 cfs which was markedly below the average rate in 2024 of 152.8 cfs (IWBC 2026). However, there were the same number of plumes deemed significant (64) observed in the image data in 2025 as were observed in 2025 indicating that the discharge rate does not necessarily correspond directly with how turbid the river plume appears via satellite.



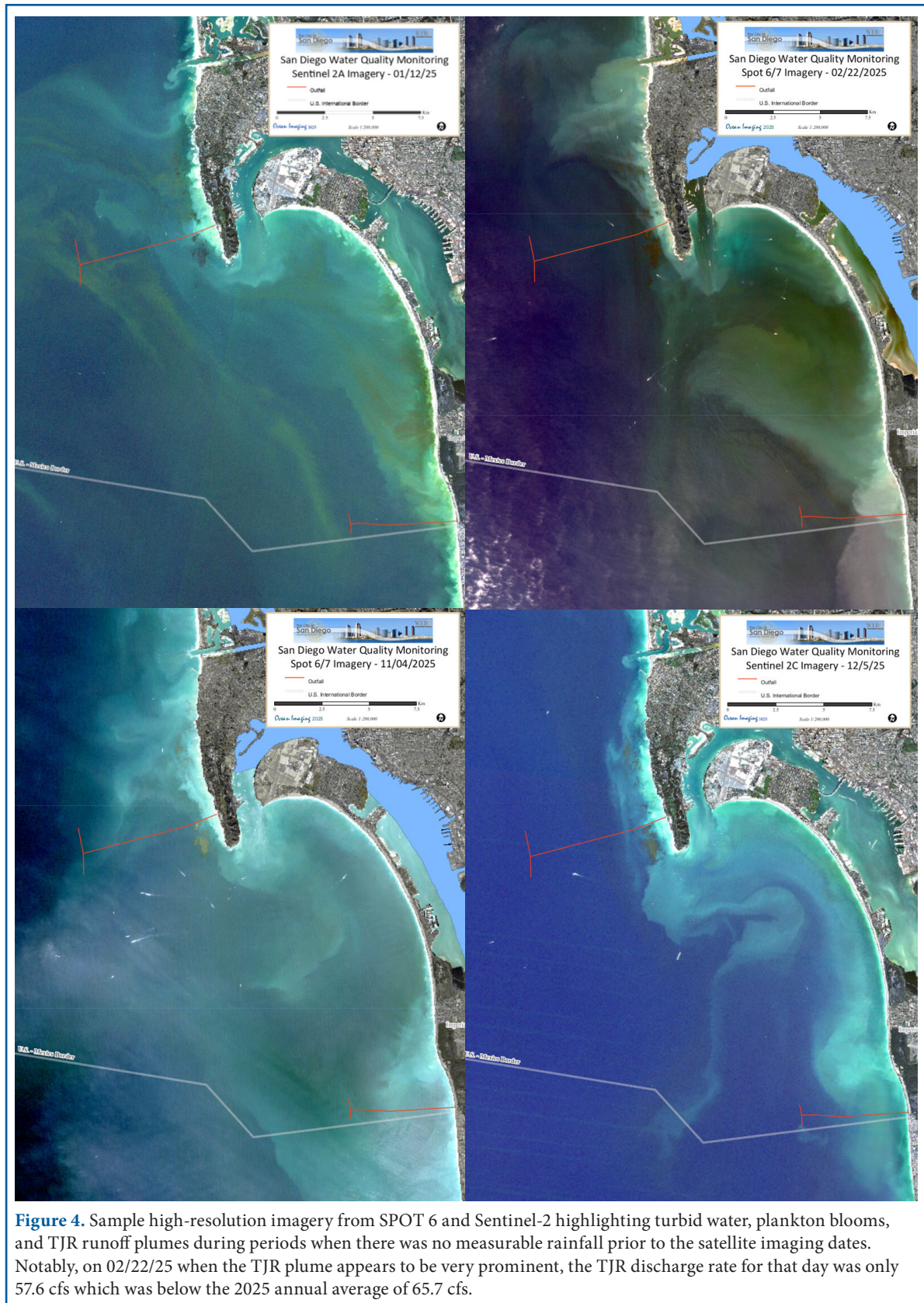


Figure 4. Sample high-resolution imagery from SPOT 6 and Sentinel-2 highlighting turbid water, plankton blooms, and TJR runoff plumes during periods when there was no measurable rainfall prior to the satellite imaging dates. Notably, on 02/22/25 when the TJR plume appears to be very prominent, the TJR discharge rate for that day was only 57.6 cfs which was below the 2025 annual average of 65.7 cfs.

Possible explanations for the observed TJR discharge plumes and reduced coastal water quality include precipitation events inland of San Diego and Tijuana creating runoff into the San Diego and Tijuana regions, coastal turbidity caused by significant ocean swell/wave action and other oceanographic conditions conducive to phytoplankton blooms. It is also possible that plume presence in the TJR coastal zone was partially driven by persistent transboundary flows and infrastructure-related discharges, with rainfall acting as an episodic amplifying factor rather than the primary control. Additional discussion of this topic is provided below.

Figure 5 provides examples of heavy coastal turbidity and extensive river runoff observed in the satellite imagery that may be linked to prior precipitation events. Contrary to previous years, in many cases when strong TJR runoff and coastal turbidity was observed in the image data following a rain event, the coastal waters did not clear up within two to three days and remained turbid for several days after the initial post-storm observation. In some situations, this was because another rain event soon followed, yet in others the exact reason is unknown. SDR river discharge in cfs measured by the United States Geological Survey (USGS) Fashion Valley gauge also tracked closely with the rainfall data recorded at the SDIA station (Figure 6). The mean discharge rate in 2025 (20.9 cfs) was lower than the rate experienced during 2024 (43.0 cfs), most likely due to overall higher rainfall in 2024 (Table 2). Figures 5 and 7 provide examples of when the satellite data exhibited notable coastal and offshore turbid conditions as well as plankton blooms in the Point Loma region and area west of Mission Bay that correlate with increased SDR flow and precipitation measurements shown in Figure 6.

In 2025 the County of San Diego issued 350 posted shoreline and/or rain advisories and 95 beach/shoreline closures. This is a 26.8% increase in the number of advisories and an 8.6% decrease in closures compared to 2024 (276 advisories and 104 closures respectively). As has been typical for the past several years, the two longest contiguous 2025

closures lasted well into October at Border Field State Park along the south end of the Tijuana Slough Shoreline and Imperial Beach which was closed from January through most of July. Most of the closures extended from the Tijuana River mouth all the way past Avenida Del Sol to include nearly all the Coronado City beaches and were attributed to contamination from the TJR runoff. Generally, the closures were associated with a rain event prior to and/or during the closure period leading to heavy TJR discharge and coastal turbidity as shown in Figure 6. However, nine closures were triggered by sewage spills, pump station failures, and/or sewer line problems. Unlike previous years, none of the closures were directly attributed to an exceedance of bacterial standards with no known source. 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 4, 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.

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 in 2025, directly as a source of suspended sediment and indirectly as a source of high nutrient input, potentially encouraging coastal and offshore phytoplankton blooms. While not at the same 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 33 days in the medium-resolution (Sentinel-3) and high-resolution satellite data throughout the year. The area surrounding the Point Loma

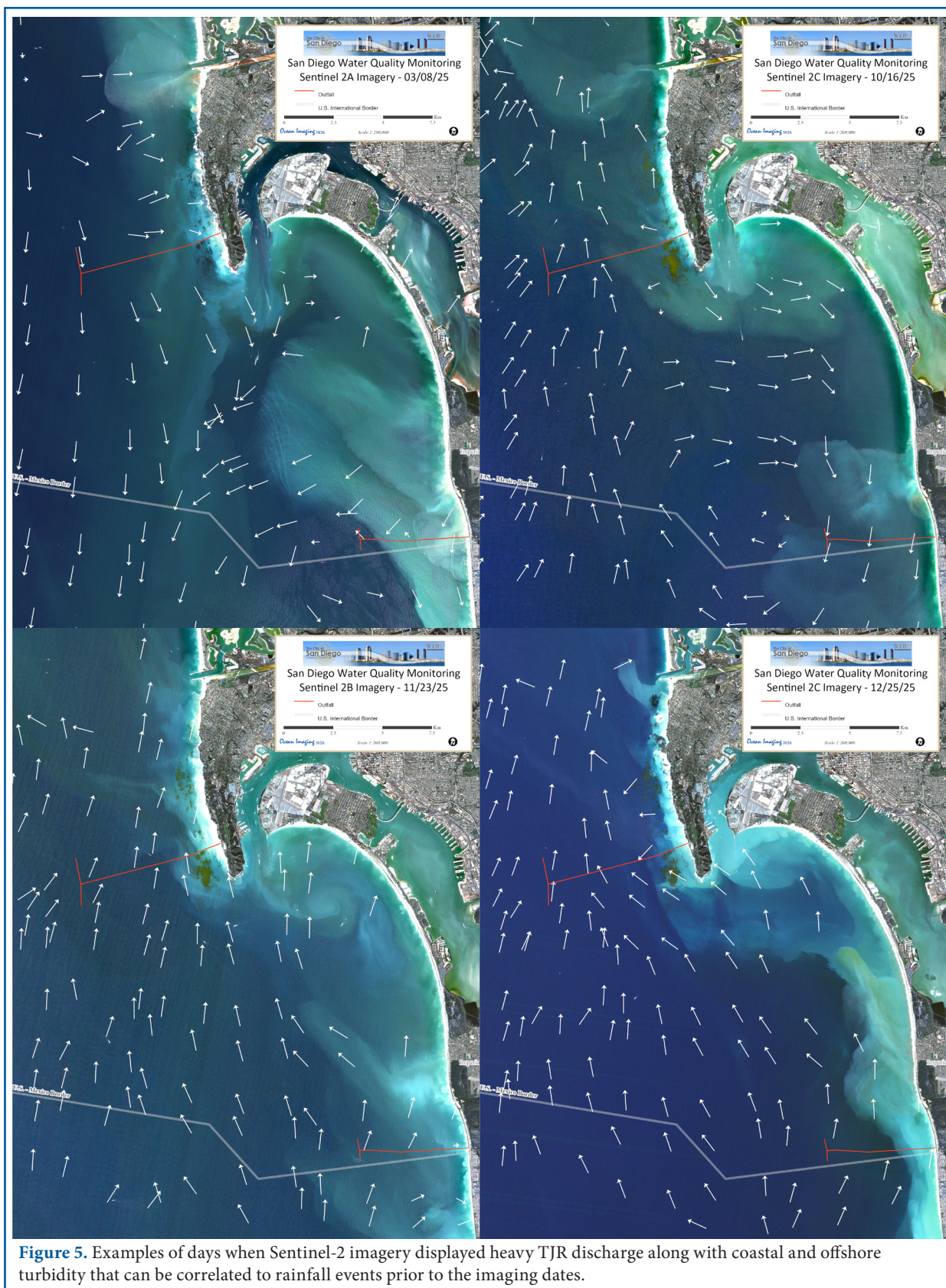


Figure 5. Examples of days when Sentinel-2 imagery displayed heavy TJR discharge along with coastal and offshore turbidity that can be correlated to rainfall events prior to the imaging dates.

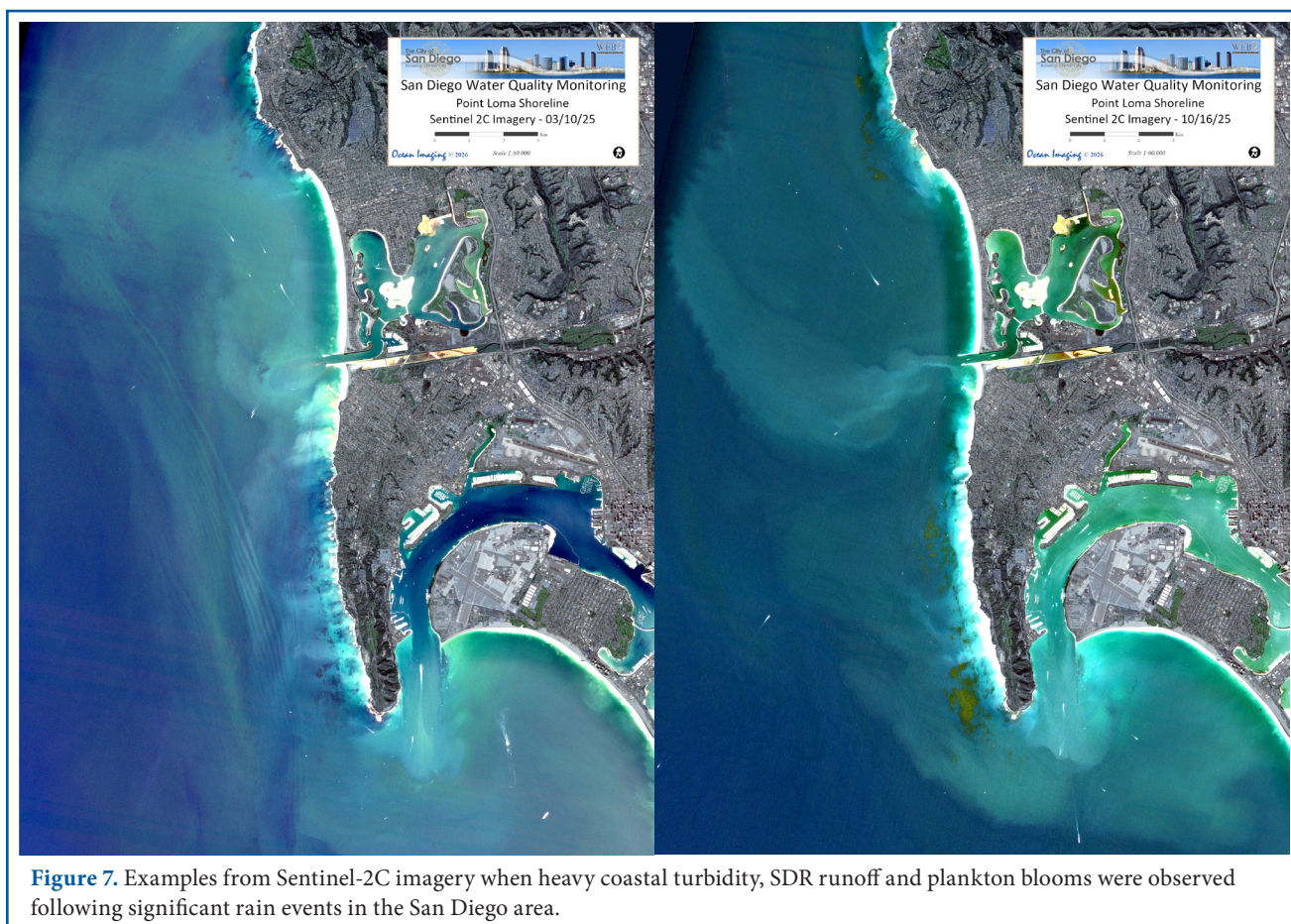
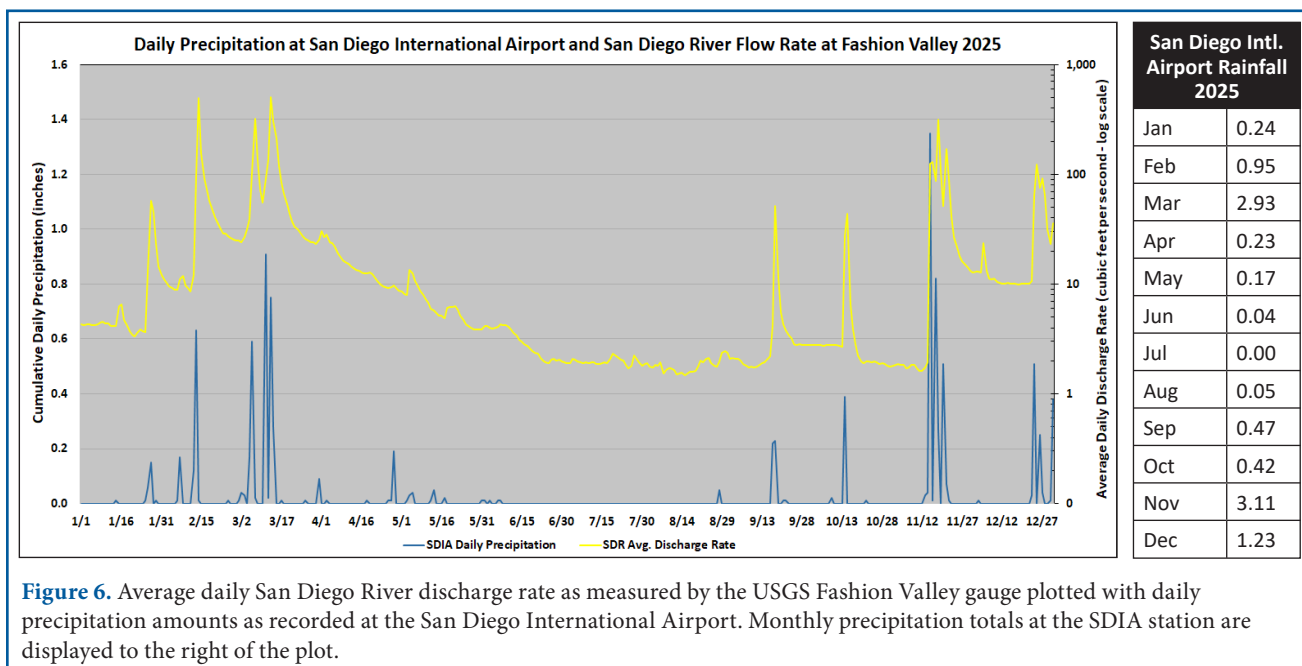


Table 3. 2025 County of San Diego shoreline closures, rain advisories, and associated project satellite data (Source: California State Water Resources Control Board).  general rain advisory  beach closure associated with the Tijuana River bay or  beach closure due to a sewage spill bay or  beach closure due to elevated bacteria level

Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image Data
Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	1/1/2025	10/12/2025	284	12/28/2024	4	74 dates
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/1/2025	1/15/2025	14	12/28/2024	4	9 dates
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	1/1/2025	1/14/2025	13	12/28/2024	4	8 dates
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	1/1/2025	1/2/2025	1	12/28/2024	4	1/2
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	1/1/2025	1/2/2025	1	12/28/2024	4	1/2
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	1/3/2025	1/14/2025	11	1/3/2025	0	1/4, 1/7, 1/8, 1/9, 1/12
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	1/3/2025	1/13/2025	10	1/3/2025	0	1/4, 1/7, 1/8, 1/9, 1/12
La Jolla Shores Beach	EH-340	Closure	Blockage	Sewer Line / Stormdrain	1/15/2025	1/16/2025	1	1/14/2025	1	1/14
La Jolla Shores Beach	SI-010	Closure	Blockage	Sewer Line / Stormdrain	1/15/2025	1/16/2025	1	1/14/2025	1	1/14
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/16/2025	7/28/2025	193	1/14/2025	2	40 dates
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	1/16/2025	7/29/2025	194	1/14/2025	2	40 dates
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	1/16/2025	7/27/2025	192	1/14/2025	2	39 dates
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Unknown	1/18/2025	7/27/2025	190	1/14/2025	4	39 dates
All San Diego County	All San Diego County beaches	Rain			1/27/2025	1/30/2025	3	1/27/2025	0	1/29
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	1/31/2025	4/4/2025	63	1/29/2025	2	19 dates
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	1/31/2025	2/5/2025	5	1/29/2025	2	2/1
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	1/31/2025	2/3/2025	3	1/29/2025	2	2/1
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	1/31/2025	2/3/2025	3	1/29/2025	2	2/1
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	2/7/2025	2/8/2025	1	2/7/2025	0	2/8
North County Beaches	Northern San Diego County beaches	Rain			2/7/2025	2/10/2025	3	2/7/2025	0	2/8
San Diego Bay	EH-211	Closure	Other	Unknown	2/12/2025	2/14/2025	2	2/12/2025	0	
All San Diego County	All San Diego County beaches	Rain			2/12/2025	2/17/2025	5	2/12/2025	0	2/16
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	2/13/2025	2/23/2025	10	2/13/2025	0	2/16, 2/18, 2/21, 2/22, 2/23
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	2/13/2025	2/23/2025	10	2/13/2025	0	2/16, 2/18, 2/21, 2/22, 2/23
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	2/13/2025	2/21/2025	8	2/13/2025	0	2/16, 2/18, 2/21
All San Diego County	All San Diego County beaches	Rain			3/6/2025	3/10/2025	4	3/6/2025	0	3/8, 3/10
All San Diego County	All San Diego County beaches	Rain			3/11/2025	3/18/2025	7	3/11/2025	0	3/15, 3/18
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	3/14/2025	3/23/2025	9	3/14/2025	0	3/15, 3/18, 3/20, 3/23
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	3/14/2025	3/21/2025	7	3/14/2025	0	3/15, 3/18, 3/20
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	3/14/2025	3/23/2025	9	3/14/2025	0	3/15, 3/18, 3/20, 3/23
Marine Street Beach	EH-290	Closure	Sewage Spill	Sewage/Grease	3/15/2025	3/17/2025	2	3/14/2025	1	3/15
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	3/22/2025	3/23/2025	1	3/17/2025	5	3/20, 3/23
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	4/12/2025	5/16/2025	34	4/10/2025	2	7 dates
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	4/12/2025	4/21/2025	9	4/10/2025	2	4/19
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	4/13/2025	4/21/2025	8	4/10/2025	3	4/19

Table 3, Cont'd. 2025 County of San Diego shoreline closures, rain advisories, and associated project satellite data (Source: California State Water Resources Control Board). general rain advisory beach closure associated with the Tijuana River bay or beach closure due to a sewage spill bay or beach closure due to elevated bacteria level

Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image Data
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	4/13/2025	4/21/2025	8	4/10/2025	3	4/19
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	5/3/2025	5/4/2025	1	5/3/2025	0	
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	5/6/2025	5/7/2025	1	5/5/2025	1	5/7
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	5/6/2025	5/12/2025	6	5/5/2025	1	5/7
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	5/6/2025	5/7/2025	1	5/5/2025	1	5/7
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	5/18/2025	6/24/2025	37	5/17/2025	1	5/19, 5/27, 6/20
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	5/23/2025	5/28/2025	5	5/17/2025	6	5/27
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	5/24/2025	5/27/2025	3	5/17/2025	7	5/27
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	5/24/2025	5/27/2025	3	5/17/2025	7	5/27
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	6/2/2025	6/22/2025	20	6/1/2025	1	6/20
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	6/4/2025	6/9/2025	5	6/4/2025	0	
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	6/4/2025	6/9/2025	5	6/4/2025	0	
La Jolla Shores Beach	EH-574	Closure	Sewage Spill	Sewage/Grease	6/16/2025	6/17/2025	1	6/7/2025	9	
Coronado Cays (NR)	EH-575	Closure	Pump Station Failure	Combined Sewer Discharge	7/1/2025	7/2/2025	1	6/7/2025	24	
Coronado Cays (NR)	EH-576	Closure	Pump Station Failure	Combined Sewer Discharge	7/1/2025	7/2/2025	1	6/7/2025	24	
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	7/16/2025	7/28/2025	12	6/7/2025	39	7/16, 7/23, 7/26, 7/28
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	7/16/2025	7/21/2025	11	6/7/2025	39	7/16, 7/23, 7/26
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	7/16/2025	7/21/2025	5	6/7/2025	39	7/16
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	7/16/2025	7/25/2025	9	6/7/2025	39	7/16, 7/23
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	8/2/2025	9/9/2025	38	6/7/2025	56	12 days
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	8/2/2025	9/9/2025	38	6/7/2025	56	12 days
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	8/2/2025	9/9/2025	38	6/7/2025	56	12 days
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	8/2/2025	9/9/2025	38	6/7/2025	56	12 days
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	8/31/2025	9/4/2025	4	8/28/2025	3	9/1, 9/3, 9/4
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	8/31/2025	9/6/2025	6	8/28/2025	3	9/1, 9/3, 9/4, 9/6
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	9/1/2025	9/4/2025	3	8/28/2025	4	9/1, 9/3, 9/4
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	9/1/2025	9/4/2025	3	8/28/2025	4	9/1, 9/3, 9/4
All San Diego County	All San Diego County beaches	Rain			9/18/2025	9/21/2025	3	9/18/2025	0	9/19
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	9/21/2025	9/25/2025	4	9/21/2025	0	9/19, 9/24
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	9/21/2025	9/25/2025	4	9/21/2025	0	9/19, 9/24
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	9/21/2025	9/25/2025	4	9/21/2025	0	9/19, 9/24
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	9/21/2025	9/25/2025	4	9/21/2025	0	9/19, 9/24
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	9/29/2025	10/11/2025	12	9/22/2025	7	10/1, 10/2, 10/4, 10/11
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	9/29/2025	10/9/2025	10	9/22/2025	7	10/1, 10/2, 10/4
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	9/29/2025	10/6/2025	7	9/22/2025	7	10/1, 10/2, 10/4

Table 3, Cont'd. 2025 County of San Diego shoreline closures, rain advisories, and associated project satellite data (Source: California State Water Resources Control Board).  general rain advisory  beach closure associated with the Tijuana River bay or  beach closure due to a sewage spill bay or  beach closure due to elevated bacteria level

Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration (days)	Nearest Rain Date	Time From Rain Event	Satellite Image Data
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	9/29/2025	10/9/2025	10	9/22/2025	7	10/1, 10/2, 10/4
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	10/7/2025	10/9/2025	2	9/22/2025	15	
Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	10/13/2025	12/31/2025	79	10/9/2025	4	24 dates
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	10/13/2025	10/29/2025	16	10/9/2025	4	6 dates
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	10/13/2025	10/29/2025	16	10/9/2025	4	6 dates
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	10/13/2025	10/29/2025	16	10/9/2025	4	6 dates
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	10/13/2025	10/30/2025	17	10/9/2025	4	7 dates
All San Diego County	All San Diego County beaches	Rain			10/14/2025	10/17/2025	3	10/14/2025	0	10/16
Coronado north beach	EH-060	Closure	Line Break	Sewer Line	10/21/2025	10/22/2025	1	10/15/2025	6	
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	10/31/2025	11/9/2025	9	10/22/2025	9	10/31, 11/4, 11/5, 11/7
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	10/31/2025	11/9/2025	9	10/22/2025	9	10/31, 11/4, 11/5, 11/7
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	10/31/2025	11/9/2025	9	10/22/2025	9	10/31, 11/4, 11/5, 11/7
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	10/31/2025	11/9/2025	9	10/22/2025	9	10/31, 11/4, 11/5, 11/7
Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	11/13/2025	12/31/2025	48	11/13/2025	0	12 dates
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	11/13/2025	12/23/2025	40	11/13/2025	0	11 dates
Imperial Beach pier area	EH-030	Closure	Tijuana River Associated	Sewage/Grease	11/13/2025	12/31/2025	48	11/13/2025	0	12 dates
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	11/13/2025	12/23/2025	40	11/13/2025	0	11 dates
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	11/13/2025	11/27/2025	14	11/13/2025	0	12 dates
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	11/14/2025	11/27/2025	13	11/14/2025	0	11 dates
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	11/14/2025	11/27/2025	13	11/14/2025	0	11 dates
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	11/14/2025	11/27/2025	13	11/14/2025	0	11 dates
All San Diego County	All San Diego County beaches	Rain			11/15/2025	11/24/2025	9	11/15/2025	0	11/23
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	12/7/2025	12/11/2025	4	12/3/2025	4	12/7, 12/8
Mission Bay	MB-031	Closure	Sewage Spill	Sewer Line	12/16/2025	12/19/2025	3	12/13/2025	3	12/17, 12/18
Tecolote Shores	MB-041	Closure	Sewage Spill	Sewer Line	12/16/2025	12/19/2025	3	12/13/2025	3	12/17, 12/18
Mission Bay	MB-043	Closure	Sewage Spill	Sewer Line	12/16/2025	12/19/2025	3	12/13/2025	3	12/17, 12/18
Mission Bay	MB-227	Closure	Sewage Spill	Sewer Line	12/22/2025	12/31/2025	9	12/19/2025	3	
Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	12/24/2025	12/31/2025	7	12/24/2025	0	12/25
Imperial Beach municipal beach, other	EH-010	Closure	Tijuana River Associated	Sewage/Grease	12/24/2025	12/31/2025	7	12/24/2025	0	12/25
north Imperial Beach	IB-060	Closure	Tijuana River Associated	Sewage/Grease	12/24/2025	12/31/2025	7	12/24/2025	0	12/25
All San Diego County	All San Diego County beaches	Rain			12/24/2025	12/29/2025	5	12/24/2025	0	12/25
Coronado City beaches	EH-050	Closure	Tijuana River Associated	Sewage/Grease	12/30/2025	12/31/2025	1	12/30/2025	0	12/25
Coronado north beach	EH-060	Closure	Tijuana River Associated	Sewage/Grease	12/30/2025	12/31/2025	1	12/30/2025	0	12/25
Coronado City beaches	IB-079	Closure	Tijuana River Associated	Sewage/Grease	12/30/2025	12/31/2025	1	12/30/2025	0	12/25
All San Diego County	All San Diego County beaches	Rain			12/31/2025	12/31/2025	1	12/31/2025	0	12/25

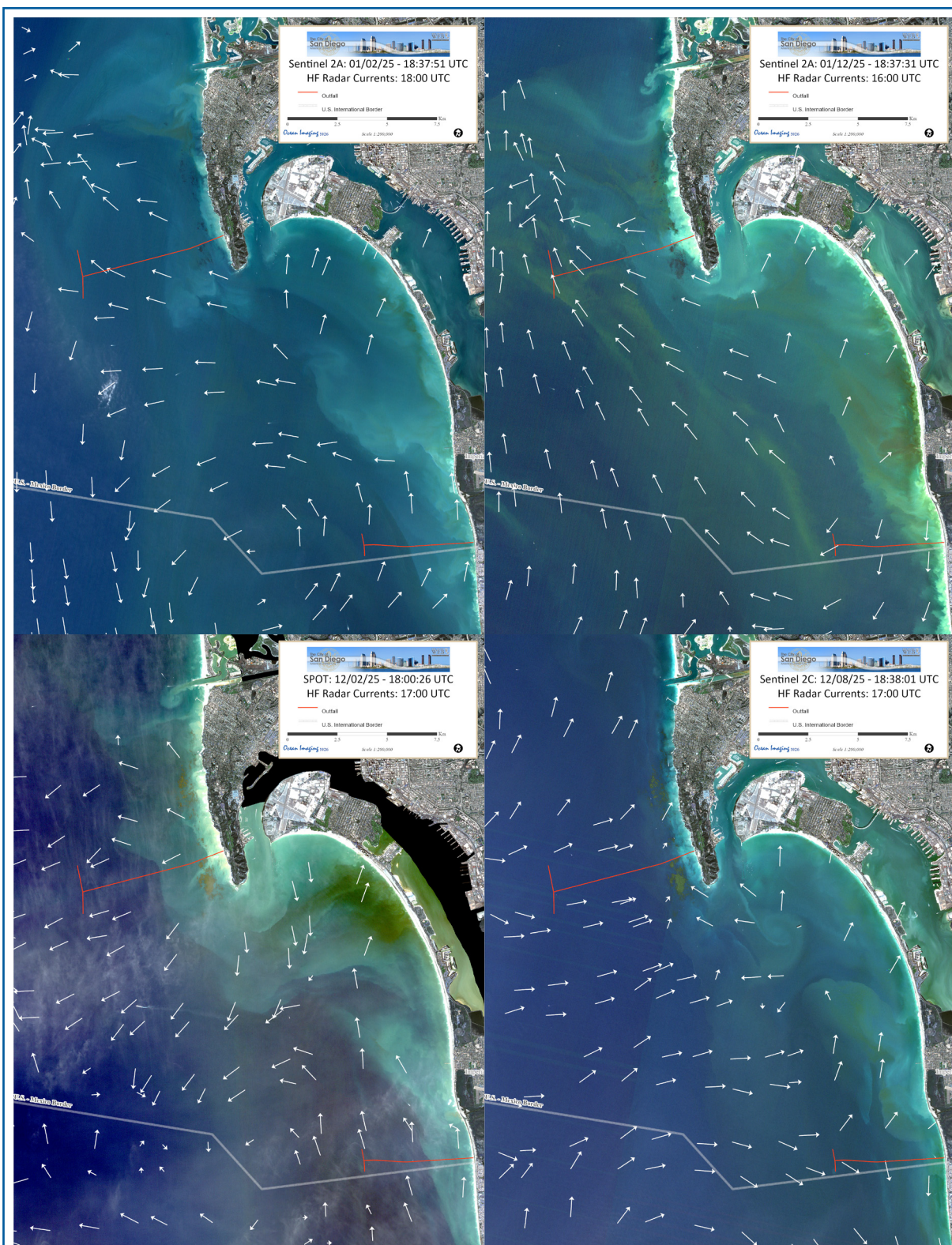


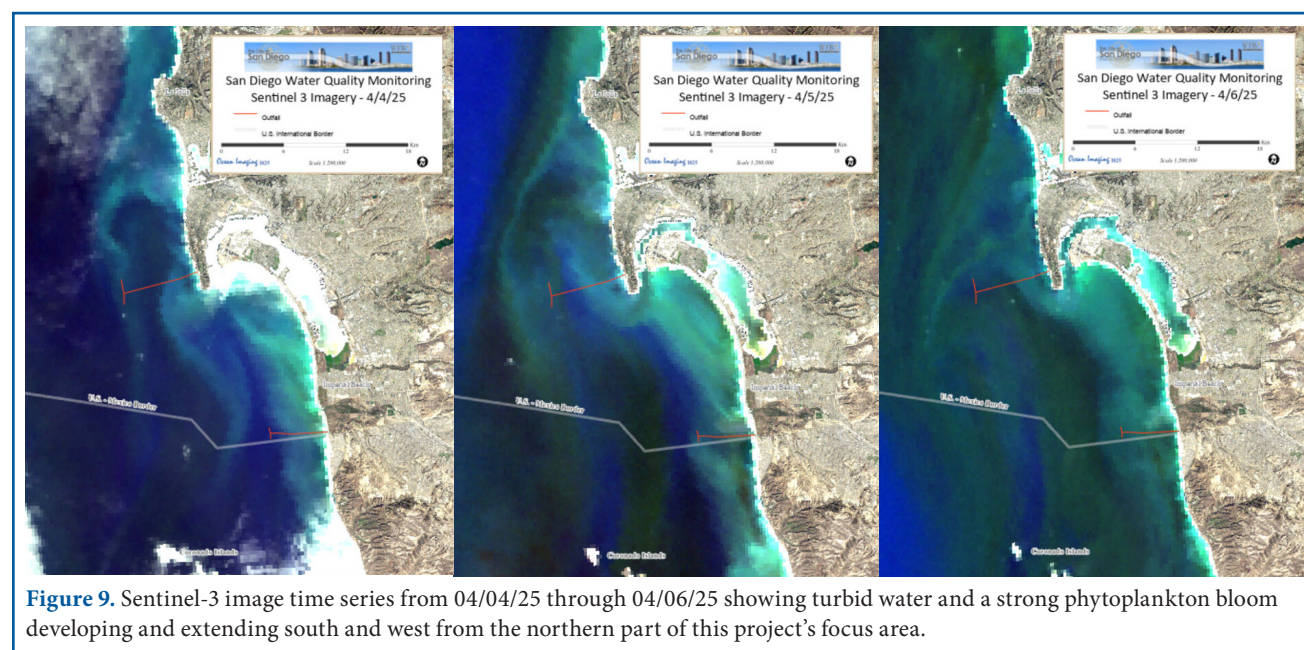
Figure 8. Sentinel-2 and SPOT 6 imagery with time-coincident 2km HF Radar currents overlaid to provide examples of when the TJR plume extended to the north and/or when ocean currents pushed TJR discharge up past Border Field State Park towards the Coronado beaches, corresponding with shoreline closures during the same period.

kelp bed was 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 then grows larger as it extends south during the three-day period.

There were fewer phytoplankton and possible HAB observed in the satellite imagery in 2025 compared to 2024. While not measured quantitatively, HAB are recognized 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 a few examples of high-resolution Landsat and SPOT

data highlighting days when the imagery revealed strong coastal and offshore phytoplankton blooms.

The SCB experienced slightly higher overall chlorophyll levels throughout 2025 when compared to the previous four years, especially when compared to 2023 which showed relatively low chlorophyll levels and thus phytoplankton abundance in the SCB through much of the year (Ocean Imaging 2023). Of the years 2021–2025, 2021 exhibited the highest levels in the SCB over that time frame (Ocean Imaging 2021). Figure 11 provides representative SCB VIIRS and MODIS-derived chlorophyll images for each month of 2025. Increased coastal upwelling during February, March, and early April likely enhanced the supply of nutrient-rich subsurface water to the coastal ocean. Concurrent rainfall events likely contributed additional nutrients through river discharge and coastal runoff. Together, these processes likely contributed to the elevated chlorophyll concentrations observed during this period. Chlorophyll levels were high in the northern bight compared to previous years. The California Current appeared to maintain its strength through the summer, likely facilitating the transport of nutrient-rich waters into the Southern California Bight and contributing to the elevated chlorophyll concentrations observed during that period. The



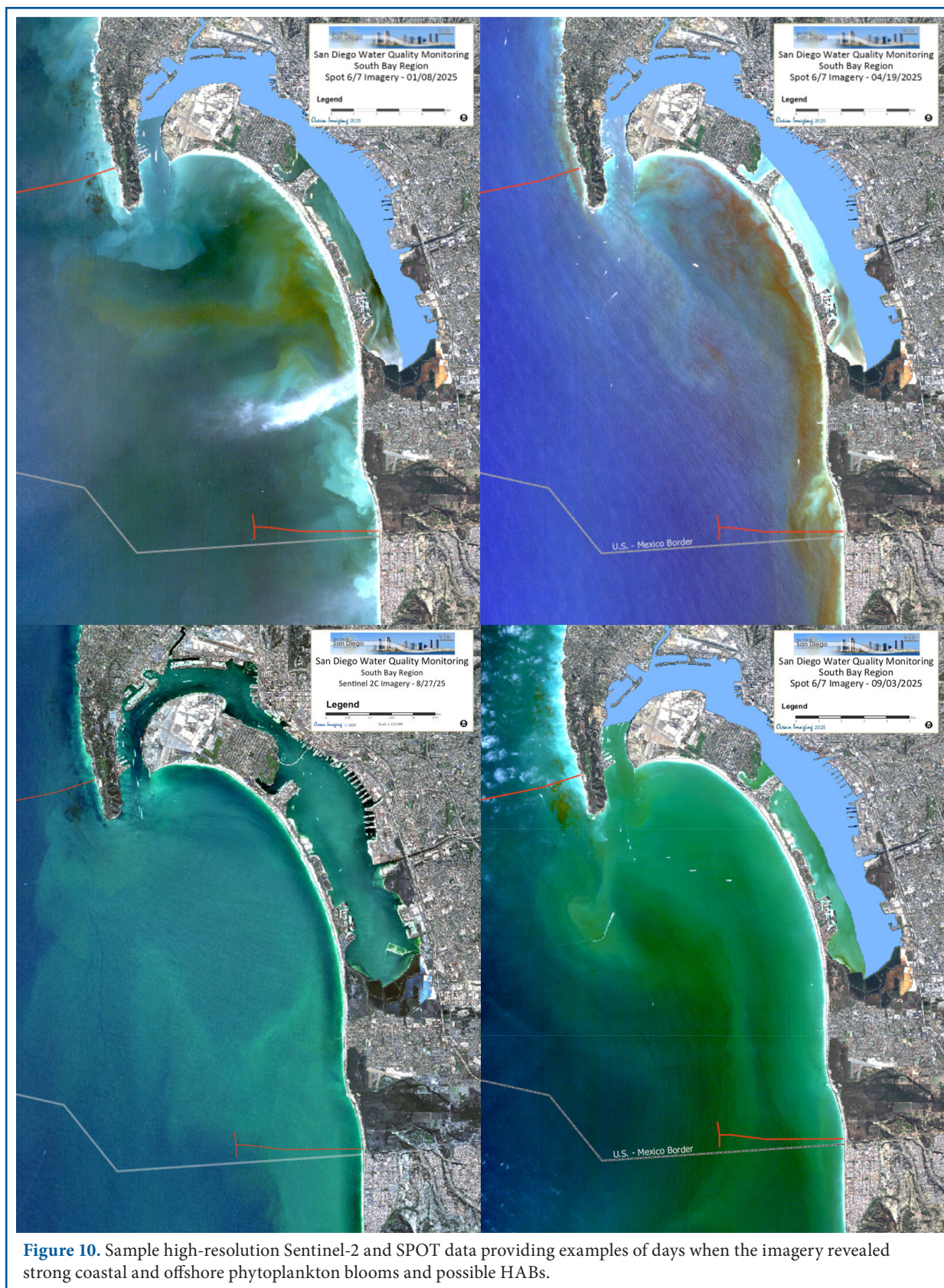


Figure 10. Sample high-resolution Sentinel-2 and SPOT data providing examples of days when the imagery revealed strong coastal and offshore phytoplankton blooms and possible HABs.

current then appeared to weaken in November and December. 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, however, 2025 data were obtained for this report. 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, however, the San Diego region exhibited higher

chlorophyll abundance in April and lower levels in August and September – unlike the entire SCB.

The City of San Diego conductivity-temperature-depth (CTD) sampling results generally correlated well with the satellite data observations, the main difference being that the average chlorophyll readings from the CTD sampling stations was higher than the average measurements derived from the satellite data (Figure 13). The best explanation for this is that the satellite image data (see Figure 12) encompasses a much larger area than that of the sampling stations with the image data averages reflecting lower offshore chlorophyll

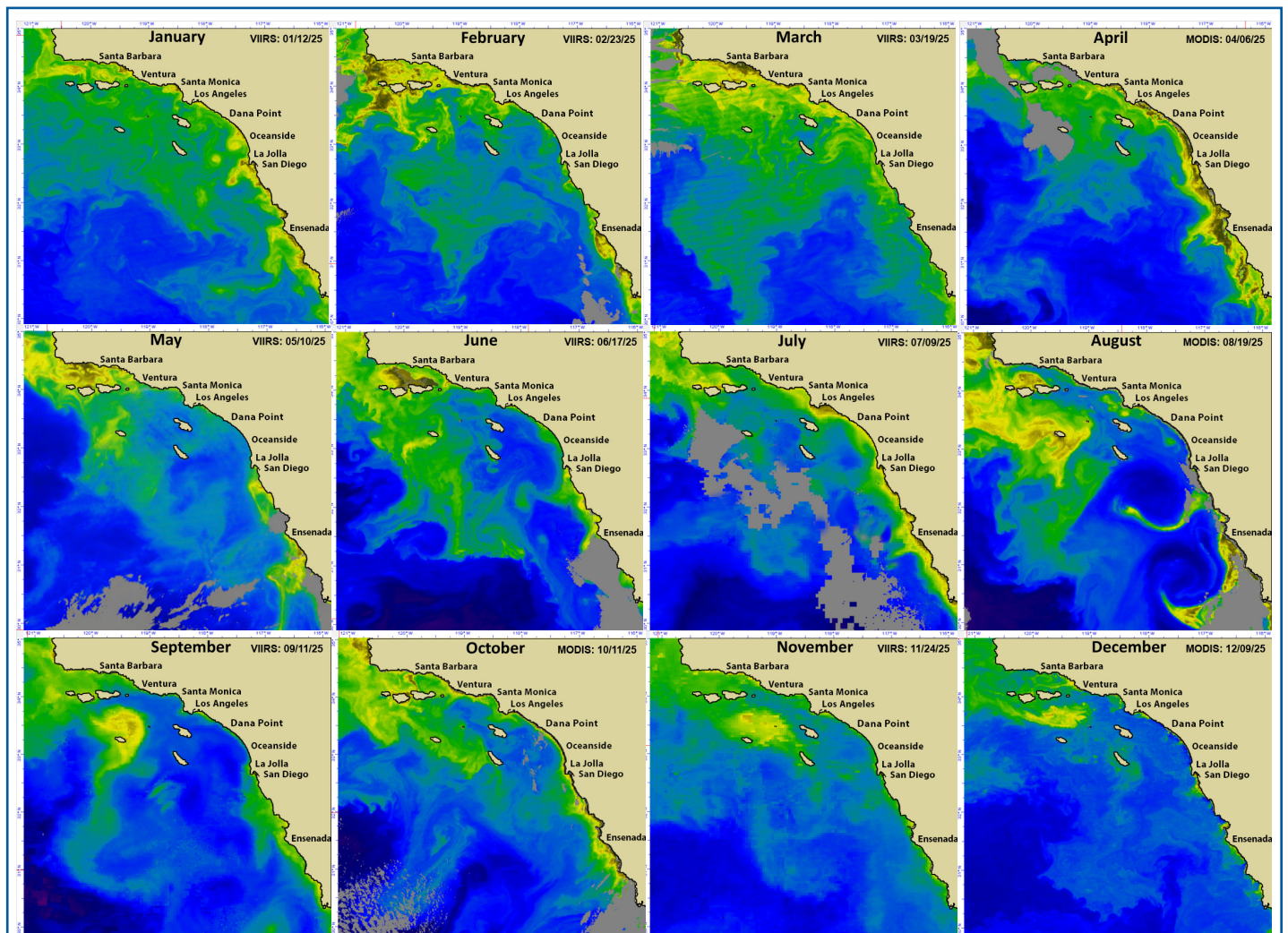


Figure 11. Representative VIIRS and MODIS-derived chlorophyll images for each month of 2025 showing relatively high levels of chlorophyll-rich water in the SCB through much of the year until December when levels decreased. Grey areas in imagery are masked cloud cover.

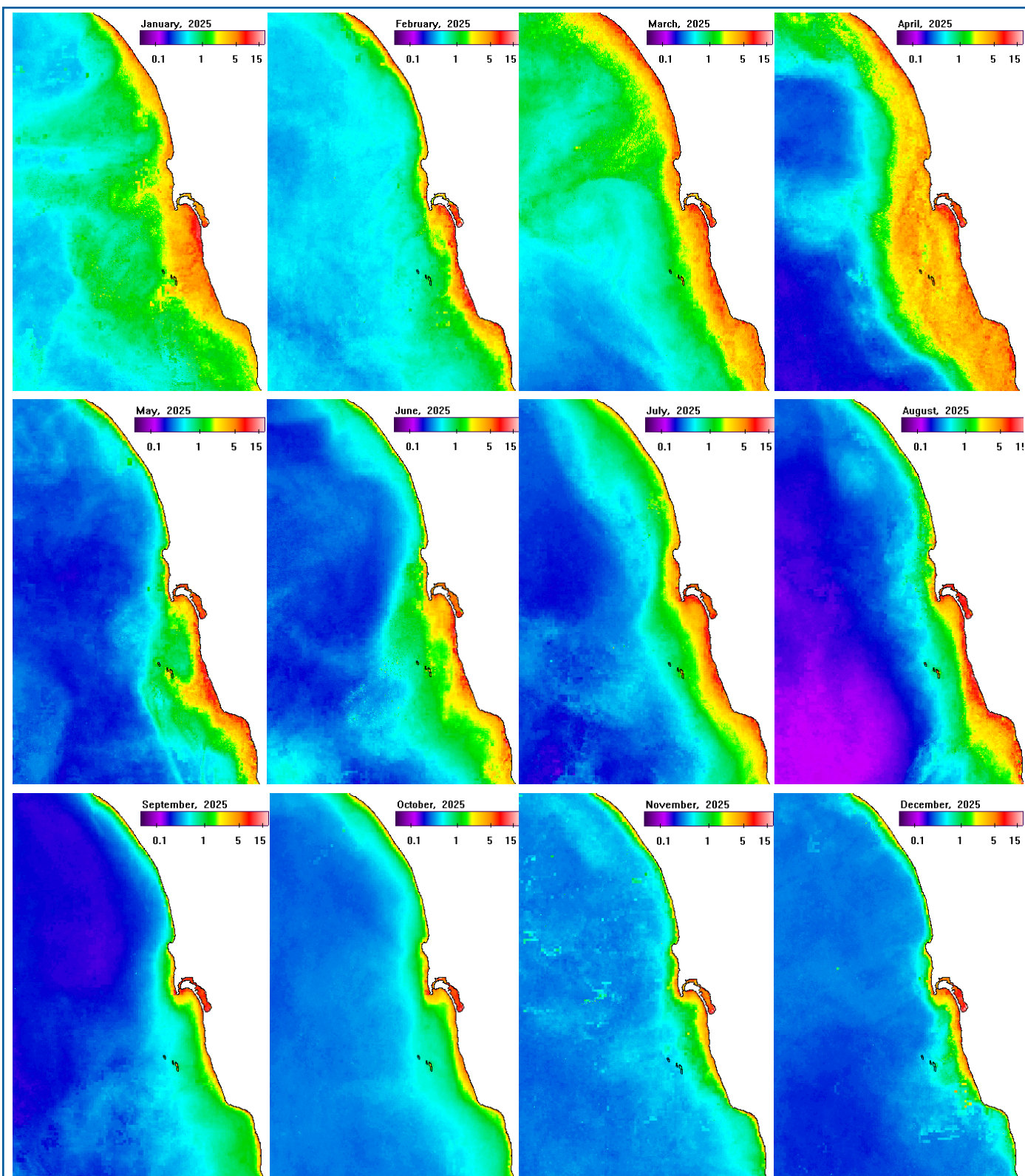
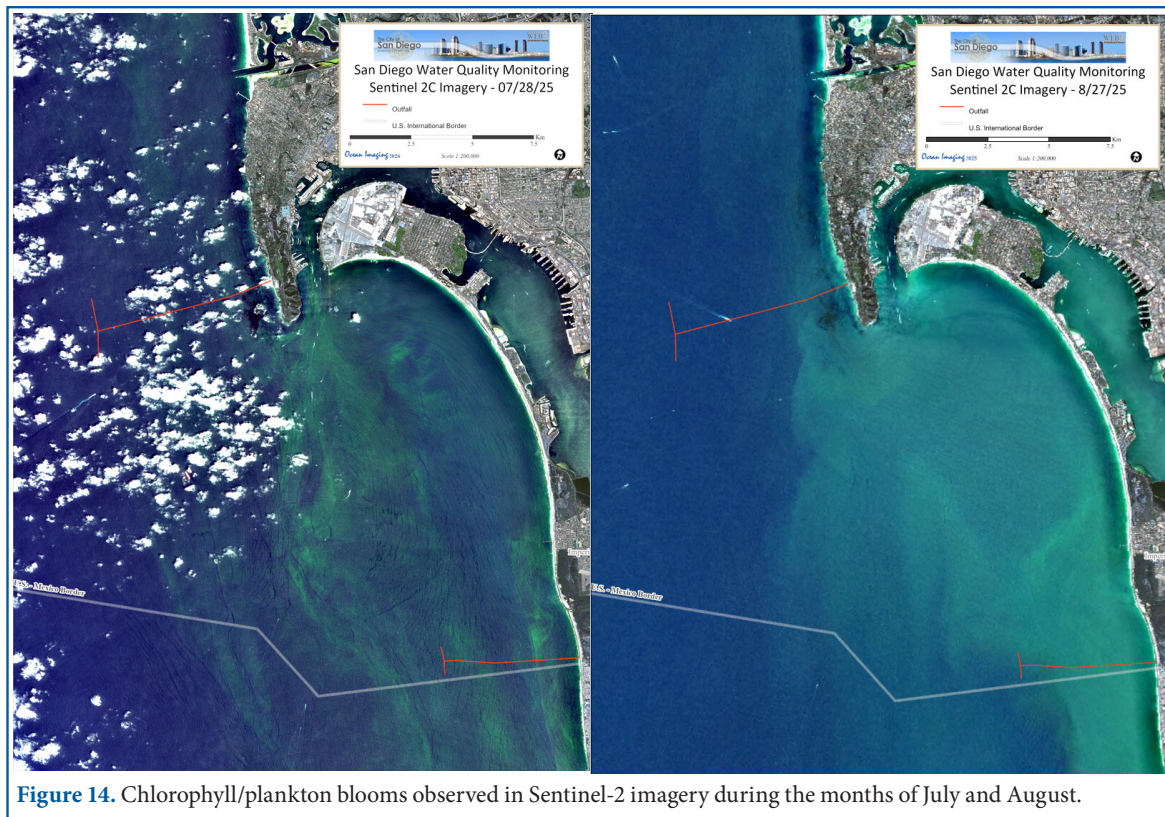
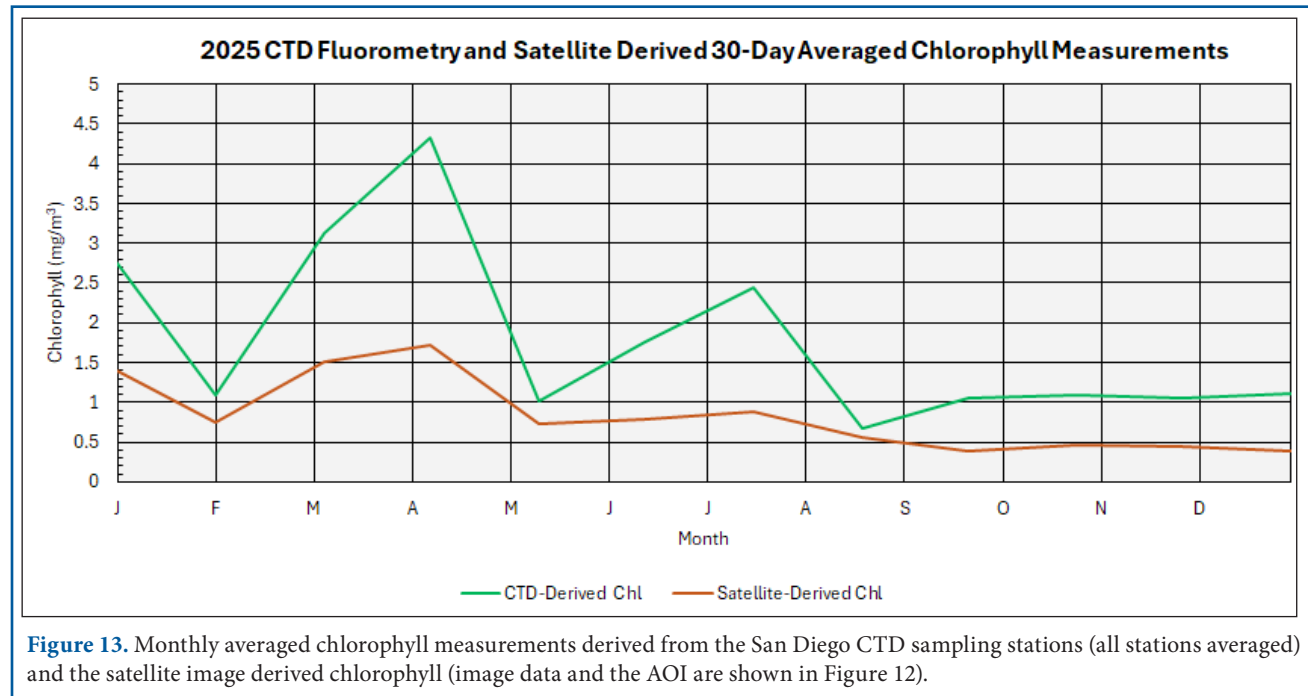
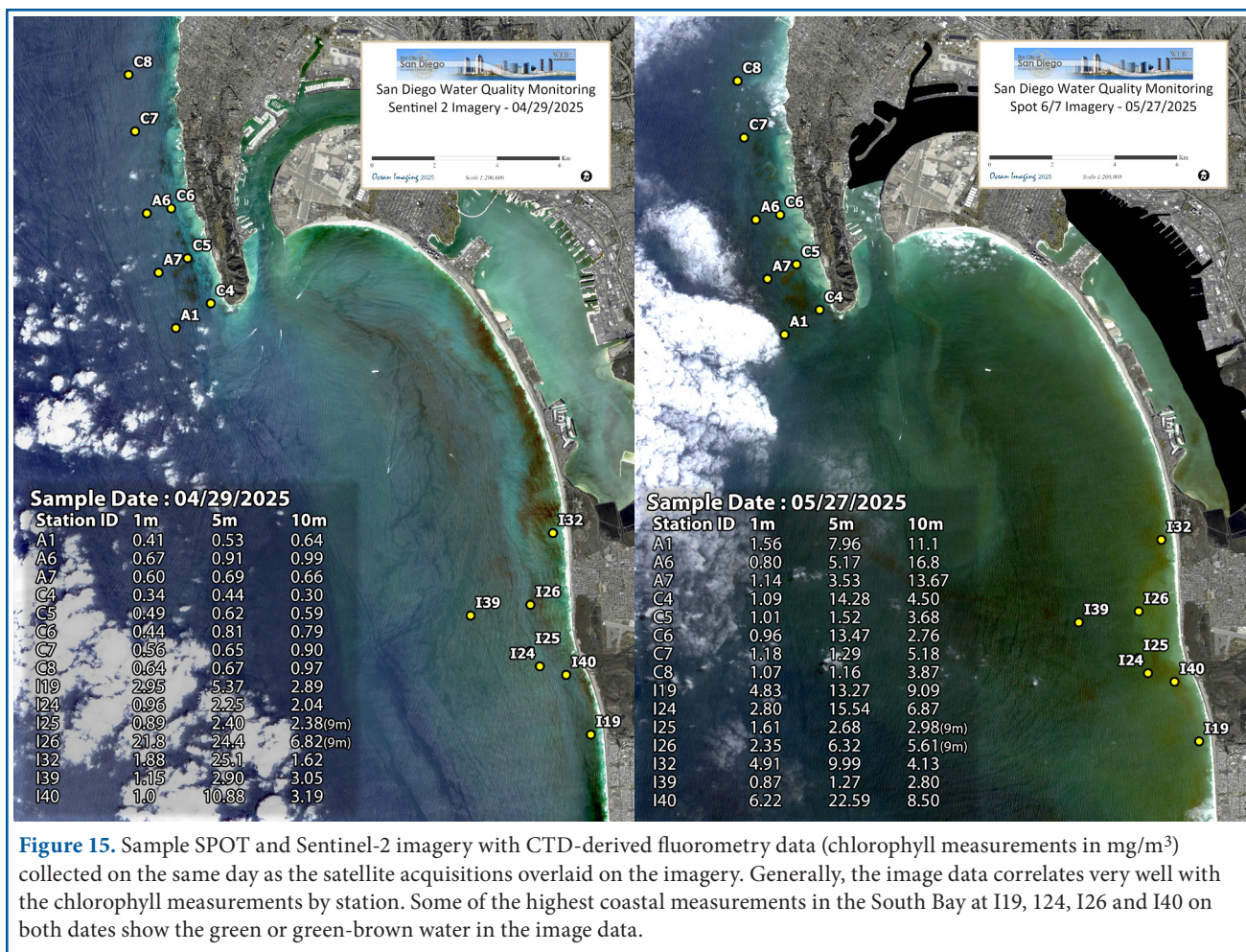


Figure 12. Monthly chlorophyll (mg/m^3) composites of the San Diego County coastal and offshore area derived from 300 m and 1 km MODIS, VIIRS and OCLI imagery generated by Mati Kahru of Scripps Institution of Oceanography in cooperation with OI as part of a SDPUD-funded project to study a long-term time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

levels and the CTD data reflecting higher levels indicative of stronger blooms closer to the coast.

Excluding a few anomalous outliers, some of the highest chlorophyll levels recorded via CTD (as high as 48.96 mg/m³ at station I25, 7-meter depth on 05/12) occurred during the months of April and





May. Approximately 75% of fluorometry readings exceeding $10.0 \text{ mg}/\text{m}^3$ occurred during March, April, and May, which is earlier than what was observed in 2024 and more closely follows typical spring upwelling and bloom season. The higher chlorophyll readings in the months of July and August were mostly confined to the SBOO Offshore stations south of Coronado Island which is exemplified in the satellite imagery provided in Figure 14. Figure 15 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 green-reflecting plankton blooms are self-evident in the imagery and correlate well with the CTD data.

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 $60 \text{ mg}/\text{L}$ for several years prior to the change to the TSS loads reading consistently below $20 \text{ mg}/\text{L}$ until late 2020. Beginning at the end of 2020, the TSS concentrations became much more variable with daily measurements peaking over $900 \text{ mg}/\text{L}$ 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 visible in the 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. Work began in 2024 to rehabilitate the SBIWTP as well as a few pump stations in Mexico. As part of a Cease-and-Desist Order in August of 2025, interim effluent limits were established for the SBIWTP and so the USBWC increased flow through the system up to 30 MGD. In October, the flow was increased to 35 MGD but then decreased back down to 25 MGD to allow for repair of one of the pump stations (San Diego Regional Water Quality Control Board 2025).

Transboundary flows were still discharging continuously through the main channel of the Tijuana River up through early 2026. Transboundary flows are defined as instances of groundwater, urban runoff, 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 international treatment plant, Tijuana Estuary and U.S. coastal waters via the TJR. Most of these transboundary flows occurred in the TJR main channel resulting in over 138 billion gallons coming into the U.S. system and waters from 2020 through 2025. In 2025 18,079 million gallons of this untreated water entered the U.S. (San Diego Regional Water Quality Control Board 2025). While many of these flow events were documented as increased TJR discharge visible in the 64 satellite scenes discussed above, 20 of those observations were during the dry season (May through October) and only six could be correlated to prior precipitation of 0.25 inches or more. Transboundary flows of 2,594 million gallons were recorded during the dry season (San Diego Regional Water Quality Control Board 2025). The addition of Sentinel-2C and the Sentinel-1C and 1D (data becoming available in May of 2026) will increase the amount of remote sensing data available to help in the visual documentation of this situation as the improvements to the SBIWTP and related pump stations unfold over the next few years.

From mid-April through November, the SBOO wastewater plume is predominantly confined well below the surface due to water-column stratification. During that period, it usually cannot be detected with multispectral aerial and satellite imagery, which penetrate the upper 7 m to 15 m (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 typically between November and April when it can often be detected with satellite imaging. This concept held true in 2025, as the last observation of a SBOO surface plume during the beginning of the year was on 04/04/25 and then was not seen again in the image data until 10/29/25. In total, there were 24 instances during which the SBOO effluent plume was observed in 2025 out of the 114 high-resolution satellite scenes acquired and processed. Of the 24, there were five instances of the plume observed by different satellites on the same day. The plume was visible via three different satellites on 03/15/25. This equates to 19 days when the plume was visible in the high-resolution data – three less than observed in 2024. There were 96 days on which one or more high-resolution, multispectral satellites imaged the study area and so the SBOO plume was detected on 19.8% of satellite observations days. This is less than the average for years 2012–2024 (20.6% of the observations). The effluent surface plumes are most often seen moving to the northwest, south or as a stagnant body. There were no days when the plume was moving northeast or east toward the shoreline. Therefore, from the full set of 2025 imagery, there is no evidence in the observation data that the SBOO surface plume never came anywhere near the San Diego coast.

The months of January, November, and December exhibited the highest frequency of 2025 SBOO effluent plume observations in the satellite data. As discussed, and documented in [previous reports](#), it is typical to see the highest number of SBOO effluent surface manifestations 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. As has been the case in previous years, there was an occurrence on 02/01/25 when the SBOO effluent plume appeared in the image data as a faint patch of clearer water breaking the more turbid water on the surface (see Appendix A). As discussed in prior reports, the clear effluent signal visible in the satellite data is most likely caused by the contrast between higher-turbidity coastal surface waters and the more typical turbidity level of effluent water as it reaches the surface. It is also possible that the effluent plume became partially diluted on its way to the surface if weak vertical stratification did exist, thus slowing down its rise in the water column. Appendix A highlights the 2025 SPOT, Sentinel-2, and Landsat multispectral imagery on days which the SBOO plume was detected. There were five occurrences when either Sentinel-2A, 2B or 2C data were acquired within minutes of Landsat or SPOT 6 data providing a near time-coincident validation of features observed in then data.

Figure 16 shows the SBIWTP effluent flow rate and TSS over the 2003 through 2025 period (top) and during 2025 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 effluent flow rate and TSS increased significantly after the beginning of 2019 and continued through 2025. On the lower graph there are a few notable spikes in flow and the TSS occurred during the year, however the TSS levels stabilized somewhat after October. Despite fluctuations in 2025, the trend line shows the average effluent flow rate of 24.6 million gallons per day (MGD) remained below the existing permit limit of 25 MGD. The TSS levels were variable between 2021–2024 with a few significant spikes in 2025, however there is no direct correlation of the SBOO effluent surface observations to TSS measurements. Of the 19 days on which the SBOO effluent was observed breaking

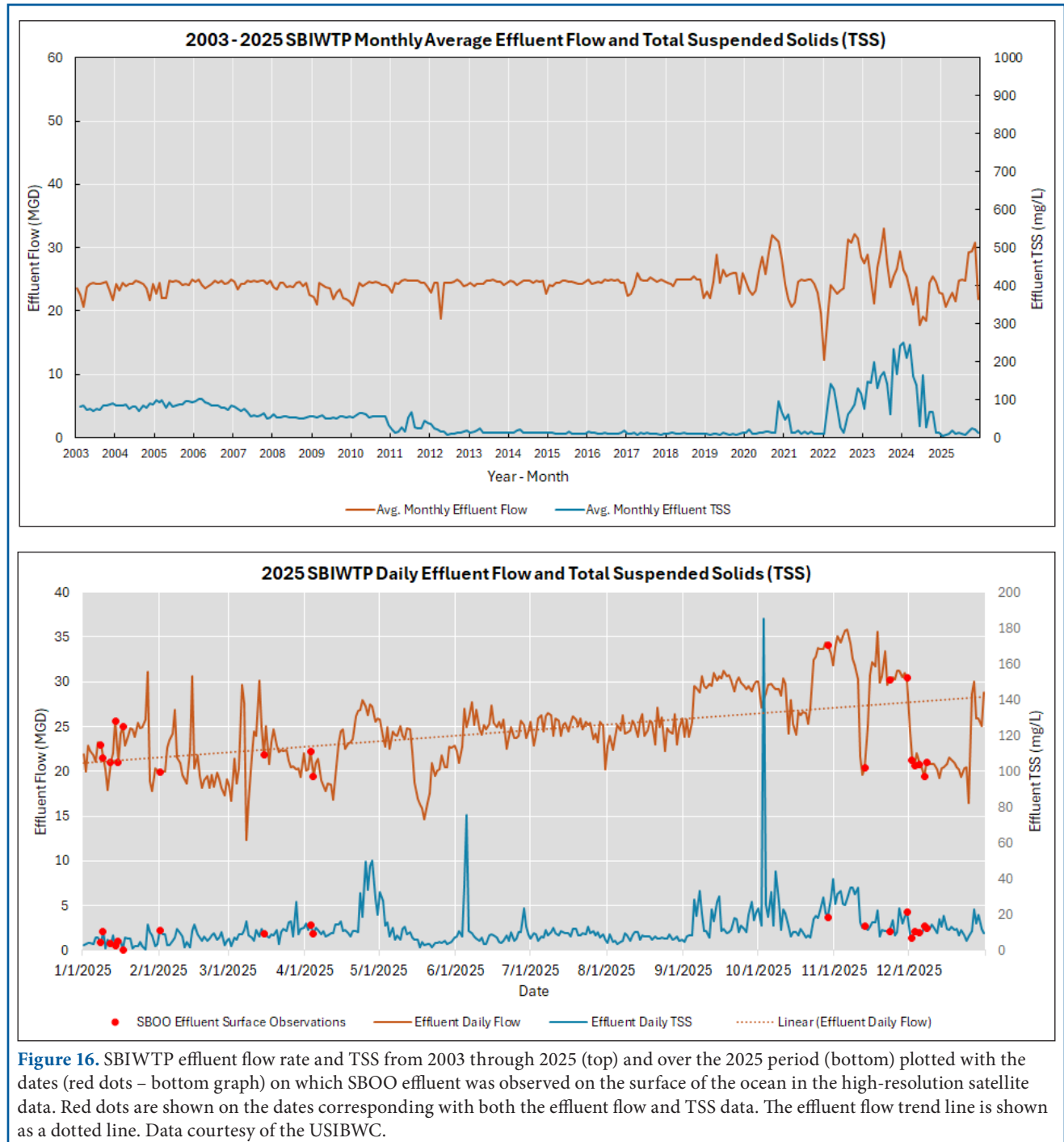
the surface, only four occurred when the flow rate exceeded 25 MGD, and so it cannot be concluded that the additional flow diverted through SBIWTP resulted in the effluent reaching the ocean's surface more often. These data continue to support the proposed explanation that the instances of effluent reaching 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. Shore stations south of the Mexican border are sampled by the Comisión Internacional de Límites y Aguas (CILA) and analyzed by City of San Diego staff. 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, Chlorophyll-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).

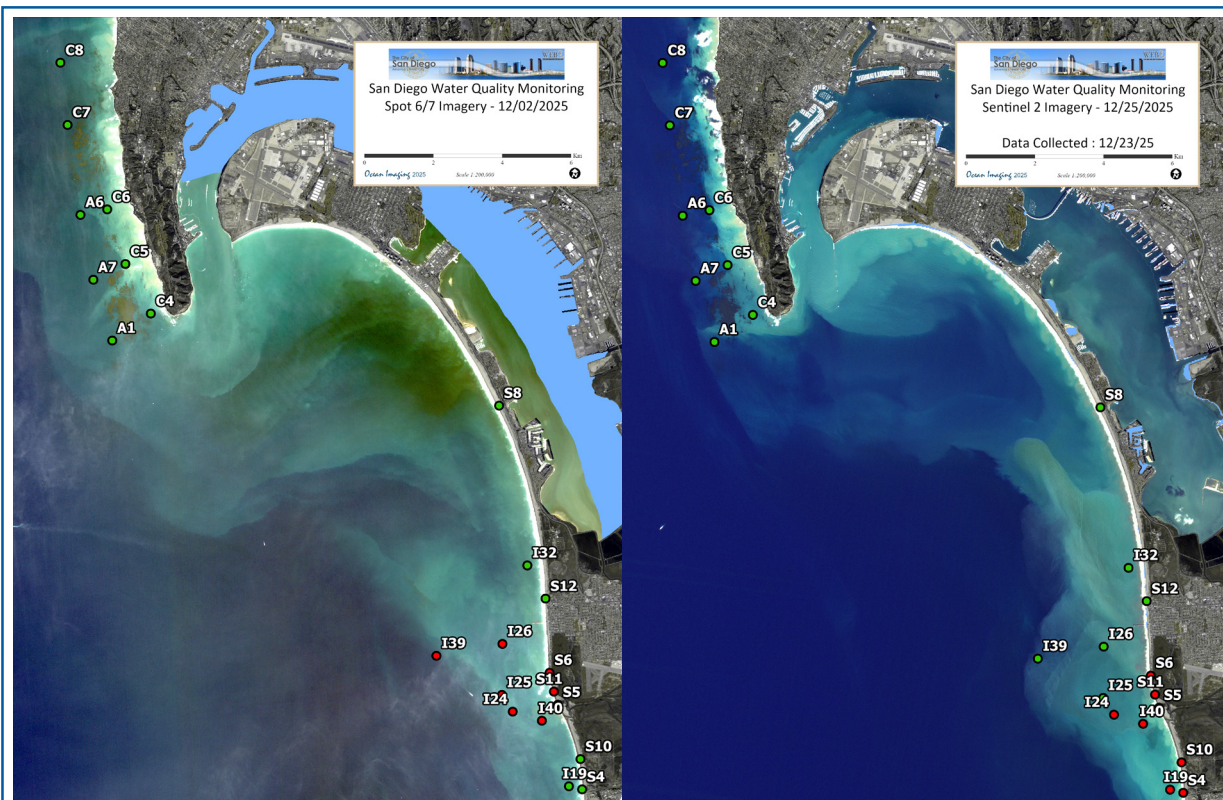
In 2025, the sampling area of the SBOO/Tijuana River outflow region experienced 60 days of the 88 days sampled, on which the field sampling showed FIB measurements exceeding the single sample maximum (SSM) for fecal coliform density for one or more sampling stations as defined by the 2019 California 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 one day 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 23 days on which the bacteria levels were deemed elevated. There were 48 sampling days when at least one shore station showed elevated levels. The number of sampling days for all three SBOO areas totaled 96 in 2025 and 88 in 2024. Therefore, in 2025 for the three sampling regions combined, 62.5% of the sampling days resulted in elevated bacteria levels at one station or more, which is less than the 77.3% recorded in 2024 (using the same 2019 California Ocean Plan standards). As it has been in recent years, most of the samples showing elevated levels were recorded at the shore stations. Elevated levels offshore near the SBOO wye are rare. The one sample collected when elevated bacteria levels were recorded at offshore stations (at depths of six meters or shallower), was at station I11 which is not 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 (San Diego Regional Water Quality Control Board 2025, 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 months of May through August. This was generally true in terms of water clarity observed in the image data during the summer of 2025. However as noted above, there were transboundary flow incidents due to dry season flows from sources in Mexico prior to and after the September SBIWTP capacity ramp up (San Diego Regional Water Quality Control Board 2025). These breeches to the system undoubtedly contributed to many of the elevated FIB measurements. Figures 17 and 18 offer a few examples of the bacteria sample data overlaid on top of image data acquired on the same day (Figure 17) or a few days after the water quality sampling (Figure 18). The satellite data examples in Figure 17 were acquired on 12/02/25 and 12/23/25 neither following heavy, rain events and TJR daily mean discharge rates were 60.6 cfs, and 65.73 cfs on 12/02/25 and 12/23/25 respectively – both close to the 2025 average of 65.7 cfs. Figure 18 offers an example of a situation when the bacteria sampling (11/17/25) took place during the 11/13/25–11/18/25 rain event with the Sentinel-3 image acquired the day after on 11/19/25. The TJR discharge rate was 1,443.9 cfs on the day of image data acquisition. Note the very turbid water emanating from the TJR river and trending north in all three image examples and

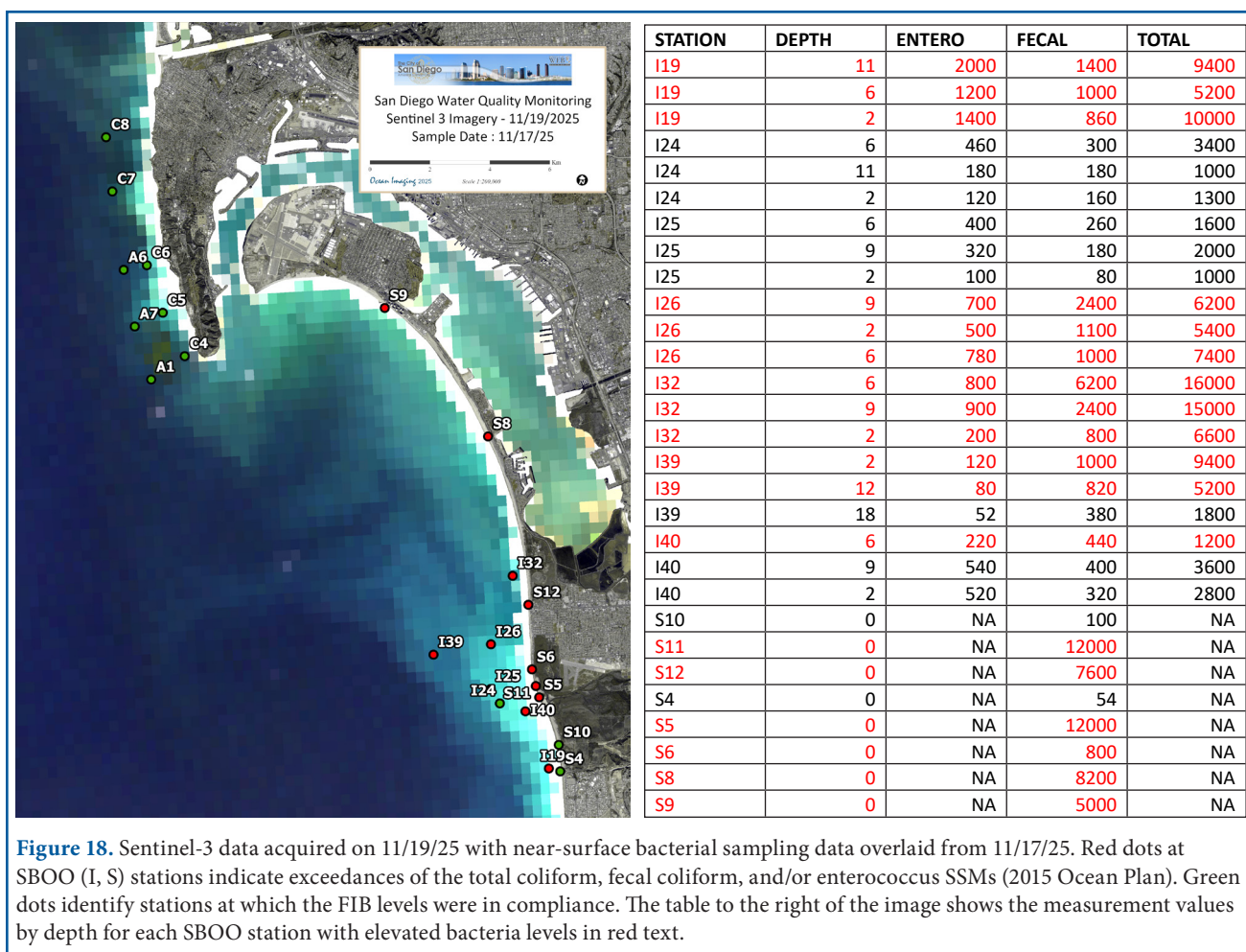


12/2/2025

12/23/2025

STATION	DEPTH	ENTERO	FECAL	TOTAL	STATION	DEPTH	ENTERO	FECAL	TOTAL
I19	11	110	86	280	I19	2	1400	600	2600
I19	2	10	6	20	I19	6	620	400	2200
I19	6	10	6	34	I19	11	4	8	6
I24	11	480	900	5400	I24	2	1200	2000	6400
I24	6	260	720	3600	I24	6	460	600	2600
I24	2	120	180	1200	I24	11	58	80	320
I25	9	300	660	2800	I25	2	22	30	160
I25	2	80	240	1200	I25	6	26	26	80
I25	6	100	220	1100	I25	9	2	2	4
I26	9	200	620	3600	I26	2	280	380	2200
I26	6	70	58	540	I26	6	34	38	100
I26	2	90	40	800	I26	9	2	2	2
I32	6	12	4	20	I32	2	2	2	2
I32	2	8	2	60	I32	6	2	2	2
I32	9	8	2	60	I32	9	2	2	2
I39	2	340	440	3600	I39	2	2	2	2
I39	18	98	380	940	I39	12	2	2	2
I39	12	64	100	480	I39	18	2	2	2
I40	2	4400	8400	16000	I40	6	860	3400	8600
I40	9	3600	7400	16000	I40	9	800	2400	7800
I40	6	2800	7200	16000	I40	2	1400	1200	9600
S0	0	6200	6000	16000	S0	0	4400	6000	16000
S10	0	200	40	800	S10	0	3800	4000	15000
S11	0	280	820	4600	S11	0	12000	12000	16000
S12	0	94	60	240	S12	0	2	2	2
S2	0	100	110	340	S2	0	32	4	16
S3	0	84	92	180	S3	0	600	52	720
S4	0	100	78	100	S4	0	720	960	4000
S5	0	12000	12000	16000	S5	0	8000	4200	16000
S6	0	380	1800	4200	S6	0	6800	12000	16000
S8	0	2	2	20	S8	0	2	2	2
S9	0	24	18	20	S9	0	2	4	18

Figure 17. SPOT and Sentinel-2 data with near-surface bacterial sampling data overlaid from the same day of the image acquisition date. 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 SBOO station with elevated bacteria levels in red text. The left image and table show the satellite data acquired on 12/02/25 with sample data overlaid from the same day. The right image and table show satellite and bacteria sample data from 12/23/25.



that on 11/17/25 the samples with FIB exceeding the SSM were taken as far north as Coronado.

3.3 The Point Loma Outfall Region

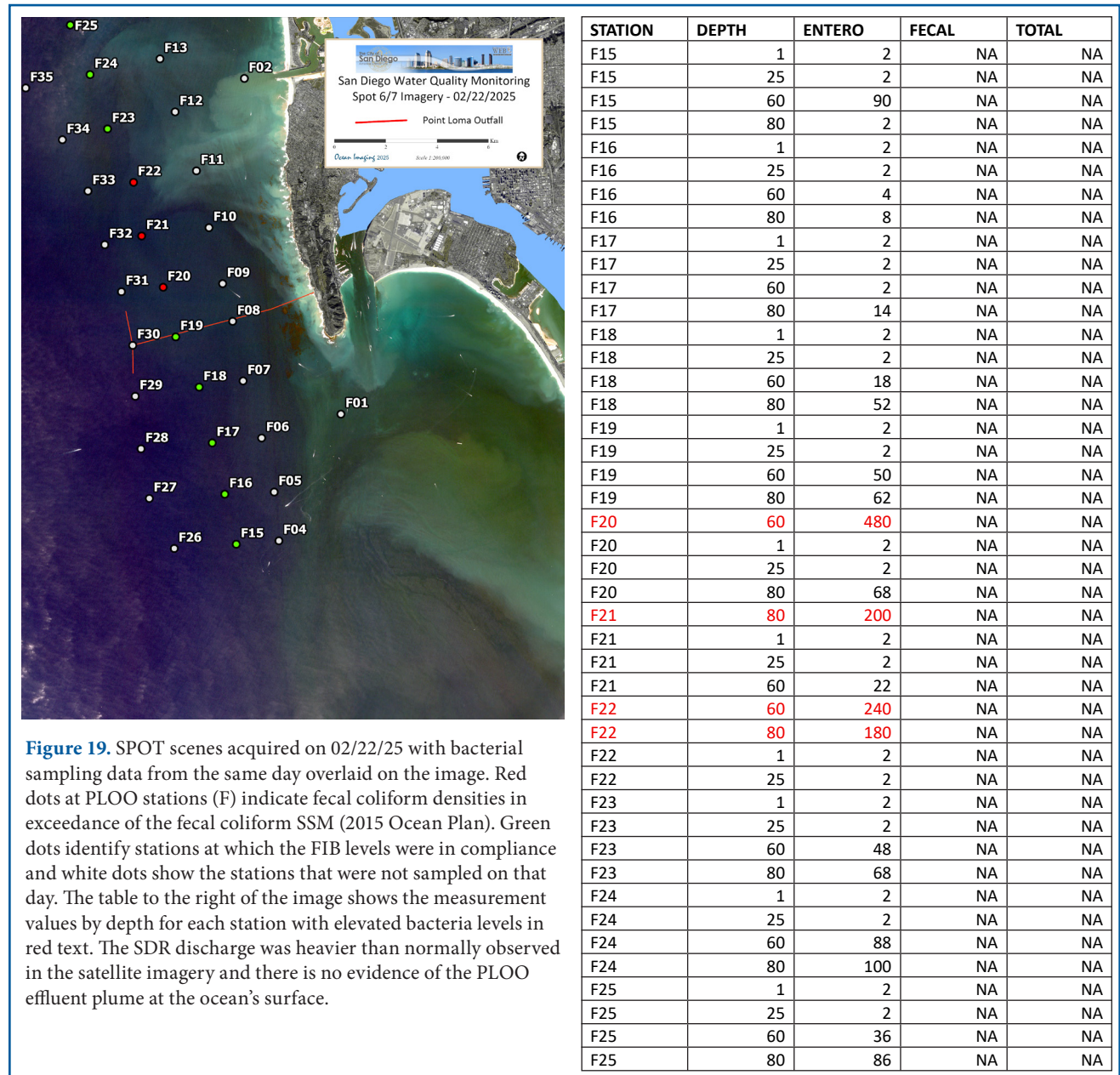
After its seaward extension in 1993, the Point Loma Ocean Outfall (PLOO) is one of the deepest and longest wastewater outfalls in the world, discharging at a depth of 320 feet (~97.5 m), 4.5 miles (7.25 kilometers) offshore. The outfall's plume is very rarely observed directly with multispectral color 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 over the past twenty years 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, however this situation is highly unusual.

In 2025 the Point Loma region was affected by conditions already described for general San Diego County: significant seasonal rainfall during the months of March and November with average or below average precipitation for all other months. 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 2025 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 12 days

on which elevated bacteria levels were measured at one or more stations in this region. In 2025 for the three PLOO sampling areas combined, 10.8% of the sampling days resulted in elevated bacteria levels at one station or more, which is lower than recorded in 2023 and 2024 (17.4% and 14.4% respectively). The shoreline sampling yielded two days on which one or more stations experienced high bacteria counts. The offshore sampling resulted in eight days when FIB were over the SSM and the kelp stations recorded two days on which station A7 was out of compliance for



the FIB SSM. Figure 19 (above) provides one example of when three of the eleven stations sampled on 02/22/25 in the Point Loma sampling region resulted in non-compliant SSM numbers. Stations F1 – F14 and F26 – F35 were not sampled on this day. The SPOT imagery reveals a possible explanation for the elevated FIB numbers as the SDR discharge is more visible than normal and is heading in the direction of the stations with elevated samples. However, the elevated levels were all found at depths between 60 and 80 meters. The stations exhibiting elevated levels were all northeast of the PLOO diffusers and so it is also inconclusive that the high SSM readings were directly related to the effluent exiting the PLOO at a depth of ~97.5 m. The HF Radar currents from that day (not depicted in the figure) show the ocean surface currents moving the water south, yet the HYCOM-derived surface currents (also not shown) contradict this with the water movement heading north. If the HYCOM currents are correct and are translated to the depth of the samples, this could indicate that high-bacteria effluent originating from the outfall may have been trapped by a pycnocline barrier below the surface and was being pushed northward to stations F20 – F22. Currents at the depths of the elevated samples were not available for analysis. Otherwise, the source of the high FIB levels could be attributed to the SDR river discharge. While the direct cause is not known, the imagery in Figure 19 is provided to show the significant discharge from the river as well as the lack of surface manifestation from the PLOO effluent which is rarely, if ever seen, due to the depth of the outfall.

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 20). Table 4 shows the area in km² of three notable kelp beds in the San Diego region over the past 18 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 2025 (3.22 km²) was significantly larger than measured in 2024, but still smaller than the average canopy coverage for the prior 17-year period from 2008–2024 (3.77 km²). 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, with another decline in 2023 and 2024 yet we see a possible resurgence in 2025 (Figure 21). The intra-annual variability, during 2025 exhibited the same lower canopy coverage for the first half of the year, but beginning in July showed canopy growth through the end of the year. (Figure 22). An interesting observation is that the Imperial Beach kelp bed, albeit exceedingly small, was visible in the satellite data during 2025 – the first time since 2015. The first readily identifiable appearance of the canopy was in October with observations extending into December. 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 any 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 21 was computed by first running a Normalized Difference Vegetation Index (NDVI) classification followed by either a Support Vector Machine or iso cluster unsupervised classification to generate a single exposed kelp class (ESRI 2024, ESRI 2025). It is important to point out that the canopy

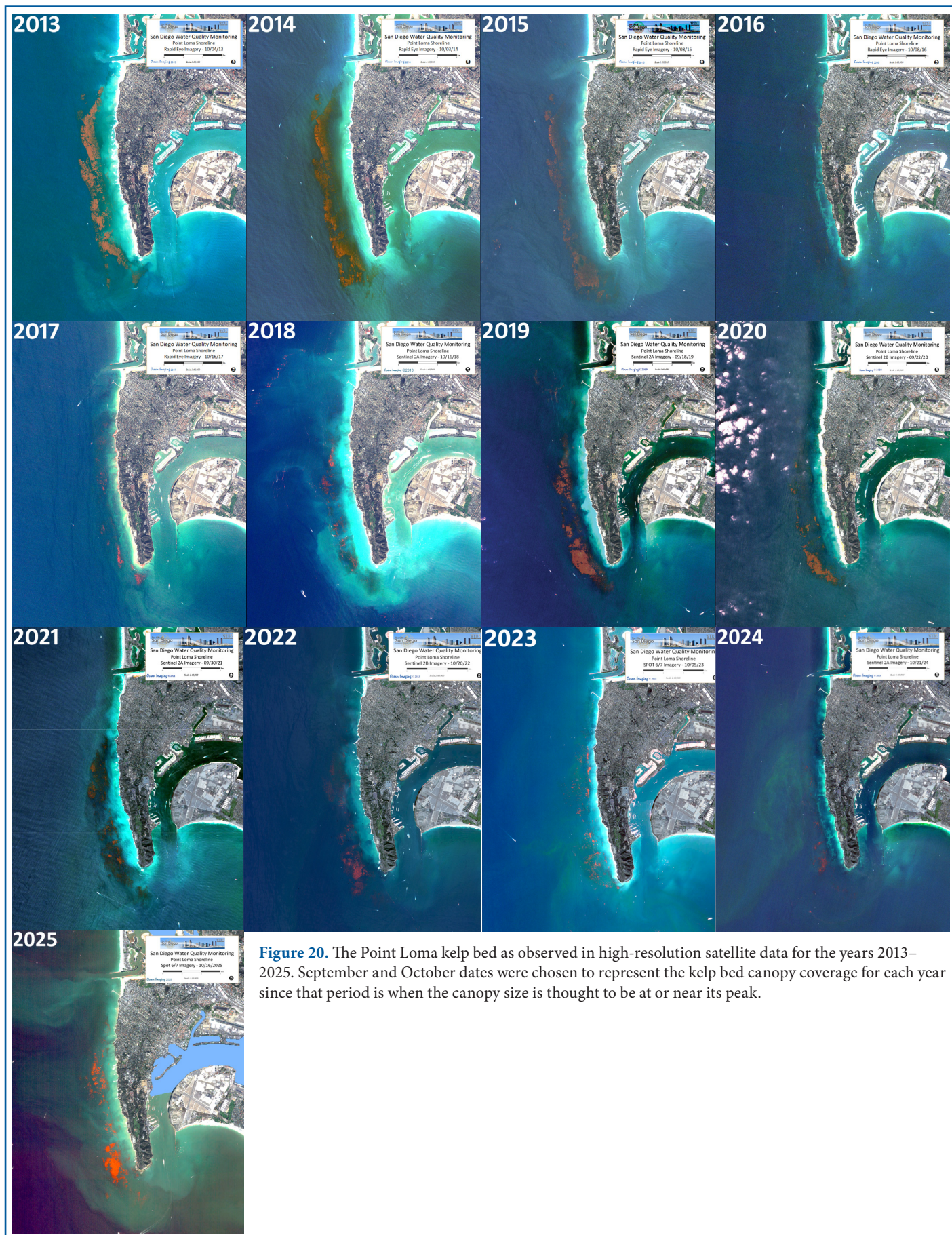


Figure 20. The Point Loma kelp bed as observed in high-resolution satellite data for the years 2013–2025. September and October dates were chosen to represent the kelp bed canopy coverage for each year since that period is when the canopy size is thought to be at or near its peak.

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 in these reports for each year of surveys, photographs from quarterly surveys during which the greatest aerial coverage was observed for

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

Year	Date	Satellite	Kelp (km ²)		
			Point Loma	Imperial Beach	Tijuana
2025	10/16/25	SPOT 6/7	3.22	0.02	0.00
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 2008–2024 = 3.77 km²

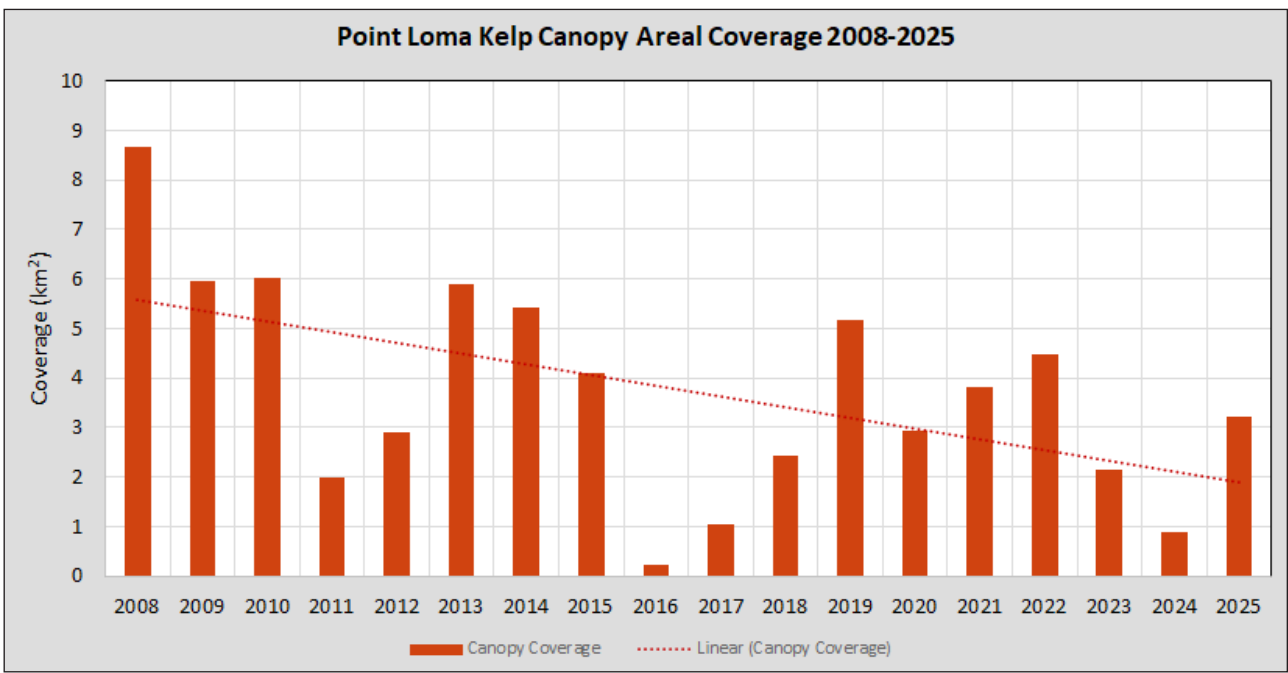


Figure 21. Point Loma kelp canopy coverage 2008–2025. Calculations were from imagery acquired on the September and October dates shown in Table 4 above. The dates were chosen to represent the kelp bed canopy coverage for each year since the September to October time period is when the canopy size is most likely at its peak. The dotted line shows a linear trend line over the period.

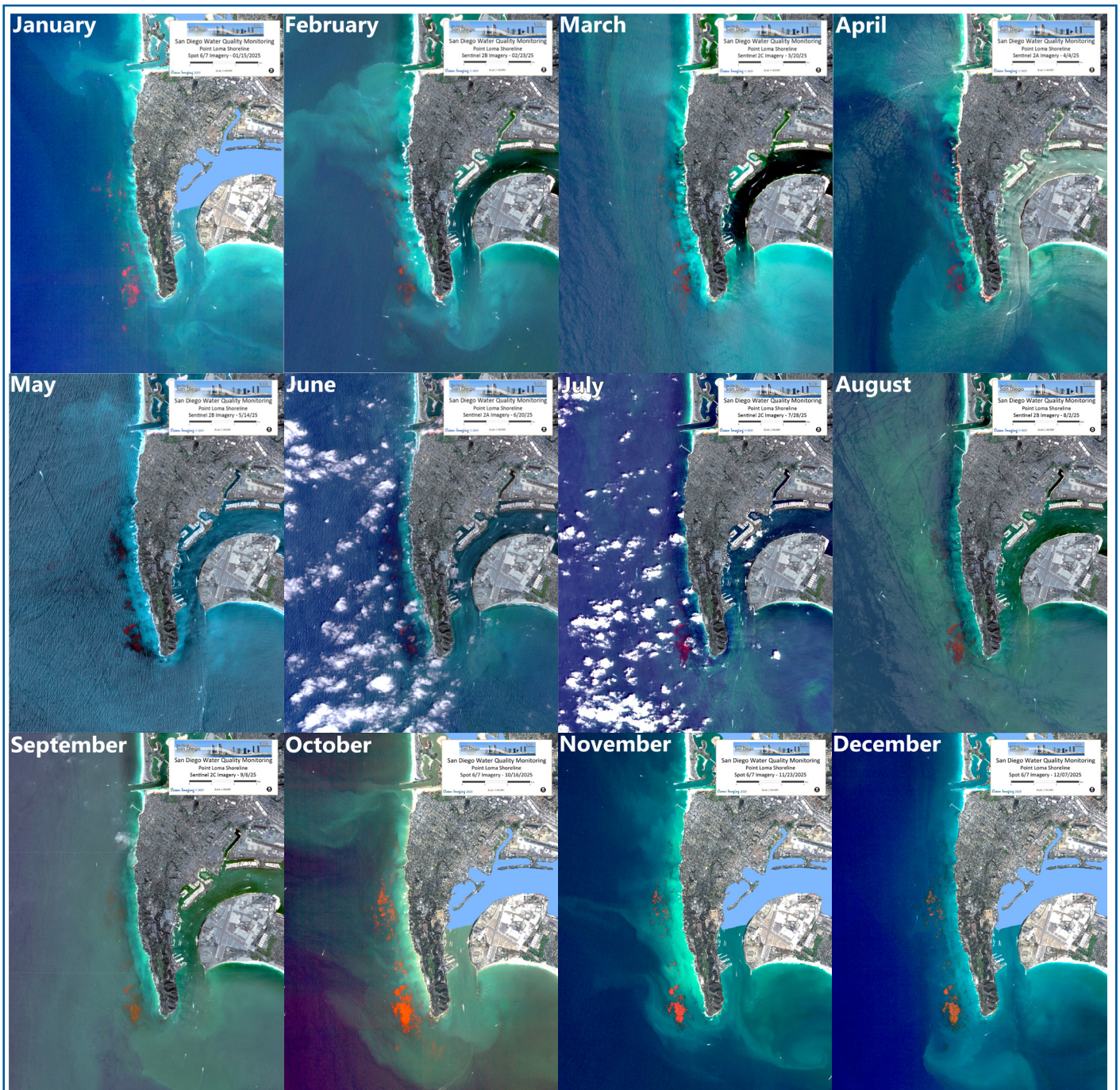


Figure 22. High-resolution satellite data documenting the month-to-month variability in the PointLoma kelp bed canopy coverage. The dates were chosen to best represent the maximum-observed canopy coverage for each month.

each kelp bed were assembled into a composite photo-mosaic representing an annual overview of the region's kelp beds canopy coverage; 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).

4. PRESENT AND FUTURE ENHANCEMENTS OF THE PROJECT

As discussed in the 2024 report, in 2025 OI launched an interactive dashboard-style web portal to provide quicker access to select high-resolution imagery as well as many other tabular data such as water quality, CTD and river discharge data. The site incorporates 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. At present the site is password-protected and for internal use only by SDPUD employees and their partners. The server hosts present, near real-time imagery and tabular data as well as data from the previous 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, tabular 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.

5. REFERENCES

- [APHA] American Public Health Association. (2012). “Standard Methods for the Examination of Water and Wastewater, 22nd edition.” *American Public Health Association, American Water Works Association, and Water Environment Federation*.
- Bell, Tom W., et al. “Three Decades of Variability in California’s Giant Kelp Forests from the Landsat Satellites.” *Remote Sensing of Environment*, vol. 238, 2020, p. 110811., doi:10.1016/j.rse.2018.06.039.
- Biggs, T. W., et al. (2022). Runoff and sediment loads in the Tijuana River: Dam impacts and climate variability. *Journal of Hydrology: Regional Studies*, 41, 101064. <https://doi.org/10.1016/j.ejrh.2022.101064>
- Bordner, R., Winter, J., Scarpino, P., eds., 1978. “Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development,” EPA-600/8-78-017.
- [CDPH] California State Department of Public Health website. (2019). “Regulations for Public Beaches and Ocean Water-Contact Sports Areas.” *Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765*. <https://www.cdph.ca.gov/Programs/CEH/DRSEM/Pages/EMB/RecreationalHealth/Beaches-and-Recreational-Waters.aspx>
- Di Lorenzo, E., Mantua, N. “Multi-year persistence of the 2014/15 North Pacific marine heatwave.” *Nature Climate Change* 6, 1042–1047 (2016). <https://doi.org/10.1038/nclimate3082>
- [ESRI 2024] “ISO Cluster Unsupervised Classification (Spatial Analyst).” *Iso Cluster Unsupervised Classification (Spatial Analyst)-ArcGIS Pro | Documentation*, <https://pro.arcgis.com/en/pro-app/3.4/tool-reference/spatial-analyst/iso-cluster-unsupervised-classification.htm>. Accessed 15 May 2024.
- [ESRI 2025] “Train support vector machine classifier (Spatial Analyst).” *ArcGIS Pro Documentation*. Retrieved March, 2025, from ArcGIS Pro tool reference
- Gierach, M. M., Holt, B., Trinh, R., Pan, B.J., Rains, C., 2017. “Satellite detection of wastewater diversion plumes in Southern California.” *Estuarine, Coastal and Shelf Science*, 186, 171 – 182.
- Gudino-Elizondo, N., Biggs, T., Bingner, R., & Langendoen, E. (2019). Modelling runoff and sediment loads in a developing coastal watershed of the US–Mexico border. *Water*, 11(5), 1024. <https://doi.org/10.3390/w11051024>
- International Boundary and Water Commission, United States and Mexico (IBWC). 2026. Tijuana River at International Boundary (Station 11-0133.00) discharge data, 2024–2025. IBWC Water Data Portal. Available at: <https://waterdata.ibwc.gov/> (accessed , 2026).
- Kahru, Mati, and B. Greg Mitchell. “Spectral reflectance and absorption of a massive red tide off Southern California.” *Journal of Geophysical Research: Oceans*, vol. 103, no. C10, 15 Sept. 1998, pp. 21601–21609, <https://doi.org/10.1029/98jc01945>.
- Little, Joe. “Toxic Tide: The Sewage Crisis at the Border.” *NBC 7 San Diego, NBC 7 San Diego*, 12 Jan. 2024, www.nbcsandiego.com/news/local/toxic-tide-the-sewage-crisis-at-the-border/3391666/.
- Ocean Imaging, Inc. 2021. Satellite Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January 2021–31 December 2021. Prepared for the City of San Diego Public Utilities Department and the International Boundary and Water Commission.
- Ocean Imaging, Inc. 2023. Satellite Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January 2023–31 December 2023. Prepared for the City of San Diego Public Utilities Department and the International Boundary and Water Commission.

- San Diego Regional Water Quality Control Board. (2025, April). San Diego Regional Water Quality Control Board April 2025 meeting [Video]. YouTube. <https://www.youtube.com/live/9SpqCJsl9O4>
- Schroeder, Sarah B., et al. "Passive Remote Sensing Technology for Mapping Bull Kelp (NEREOCYSTIS Luetkeana): A Review of Techniques and Regional Case Study." *Global Ecology and Conservation*, vol. 19, 2019, doi:10.1016/j.gecco.2019.e00683.
- [SDRWCB] San Diego Regional Water Quality Control Board. "San Diego Region - Executive Officer's Reports." *Executive Officer's Report | San Diego Regional Water Quality Control Board*, www.waterboards.ca.gov/sandiego/publications_forms/publications/eoreports.html. Accessed 25 Mar. 2025.
- Southern California Coastal Water Research Project, 10 May 2019, "Harmful Algal Blooms." <https://www.sccwrp.org/about/research-areas/eutrophication/harmful-algal-blooms/>.
- [SWRCB] California State Water Resources Control Board. (2015). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.
- [SWRCB] California State Water Resources Control Board. (2019). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.
- Svejkovsky, J., Haydock, I., 1998. "Satellite remote sensing as part of an ocean outfall environmental monitoring program." *Taking a Look at California's Ocean Resources: An Agenda for the Future*, ASCE, Reston, VA (USA), 2, 1306.
- Svejkovsky, J., Jones, B., 2001. "Satellite Imagery Detects Coastal Stormwater and Sewage Runoff." *EOS-Trans. American Geophys. Union*, 82(50).
- Svejkovsky, J., Shandley, J., 2001. "Detection of offshore plankton blooms with AVHRR and SAR imagery." *Int. J. of Remote Sensing*, 22 (2&3), 471-485.
- Svejkovsky, J., Nezlin, N. P., Mustain, N.M. Kum, J. B., 2010. "Tracking storm water discharge plumes and water quality of the Tijuana River with multispectral aerial imagery." *Estuarine, Coastal and Shelf Science*. 87(3), 387-398.
- [USEPA] United States Environmental Protection Agency. (2014). Method 1600: "Enterococci in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl- β -D-Glucoside Agar (mEI)." *EPA Document EPA-821-R-14-011*. Office of Water (4303T), Washington, DC.
- Zheng, Q., Klemas, V.V., Coastal Ocean Environment. Comprehensive Remote Sensing." *Elsevier*, Amsterdam (2018), pp. 89-120.

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

