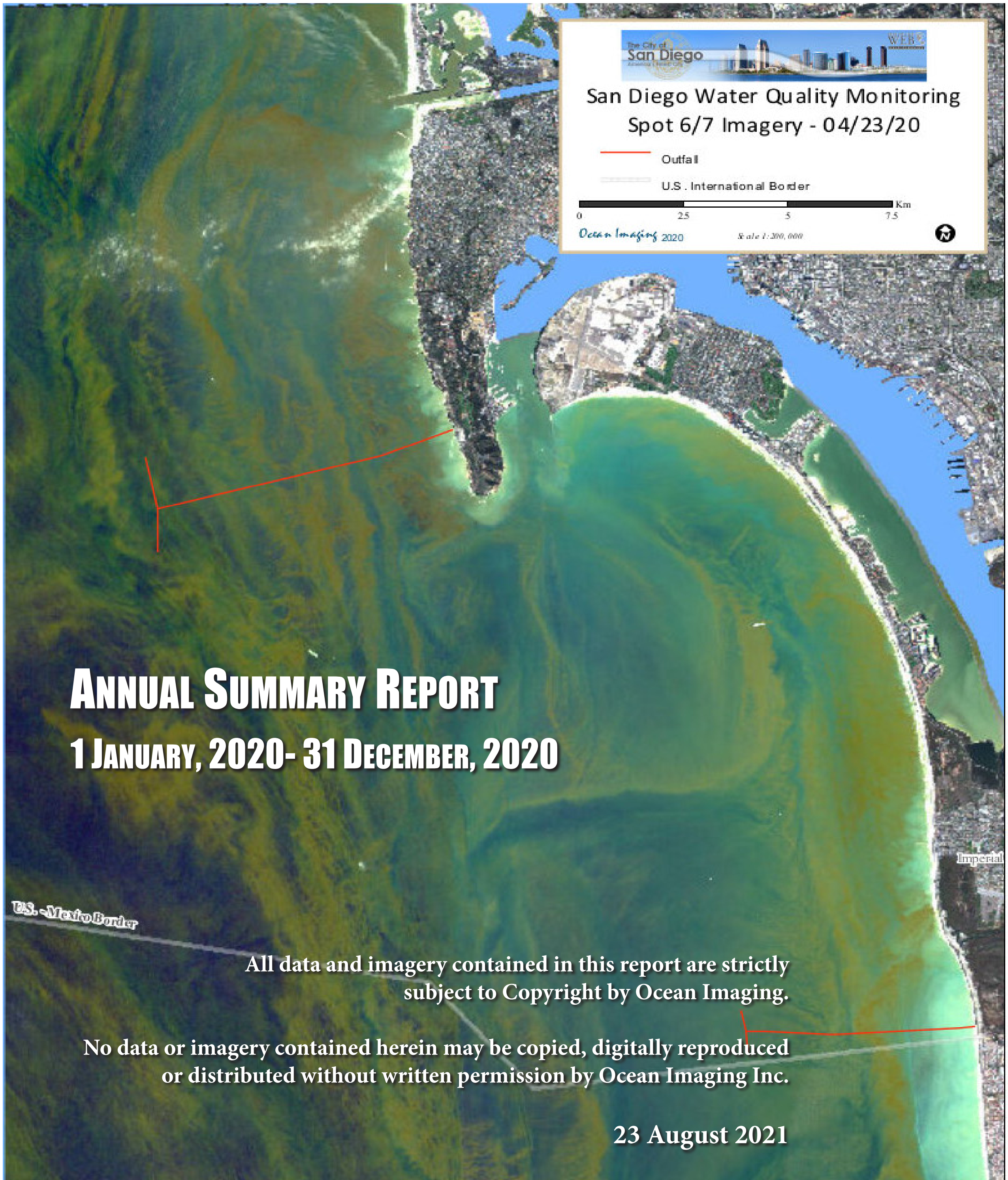
Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region

By Mark Hess



Annual Summary Report

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Ocean Imaging

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Table of Contents

1. INTRODUCTION AND PROJECT HISTORY

Ocean Imaging Corporation (OI) specializes in marine and coastal remote sensing for research and operational applications. In the 1990s, OI received multiple research grants from NASA's Commercial Remote Sensing Program for the development and commercialization of novel remote sensing applications in coastal zones. As part of these projects, OI developed methods to utilize various types of remotely sensed data for the detection and monitoring of storm water runoff and wastewater discharges from offshore outfalls. The methodology was initially demonstrated in collaboration with the Orange County Sanitation District. The NASA-supported research and demonstration led to a proof-of-concept demo project in the San Diego region co-funded by the EPA in 2000. In turn, those results led to adding an operational remote imaging-based monitoring component to the San Diego region's established water quality monitoring program, as stipulated in discharge permits for the International Wastewater Treatment Plant and Point Loma outfalls. The project was spearheaded by the State Water Resources Control Board (SWRCB), EPA Region 9, and continues to be jointly funded by the International Boundary Waters Commission and the City of San Diego (City).

The first phase of the project was a historical study utilizing various types of satellite data acquired between the early 1980s and 2002. The study helped to better understand 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 and occurrence frequency, and the historical locations, and size and dispersion trajectories of various land and offshore discharge sources (e.g. offshore outfalls, Tijuana River, Punta Bandera Treatment Plant discharge in Mexico, etc.).

In October 2002, the operational monitoring phase of the project was initiated. To date, this work utilizes 1100m resolution AVHRR-derived SST imagery (available multiple times per day), 1000m resolution chlorophyll and Sea surface Temperature (SST) MODIS-derived imagery (available multiple times per day), 500m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) color imagery (available near-daily), 750m resolution Visible Infrared Imaging Radiometer Suite (VIIRS) chlorophyll and SST imagery (available multiple times per day), 300m resolution Sentinel 3 color and thermal imagery (available daily), 27m & 60m Landsat Thematic Mapper TM7 and Landsat 8 OLI/TIRS color and thermal imagery (each available approximately every 16 days), 10m resolution Sentinel 2 multispectral imagery (available 2-4 times per week), and 6m resolution SPOT 6 and SPOT 7 (available approximately every 4-5 days). More information on these satellites and sensors is provided below. Until 2010, the project relied heavily on acquisition of multispectral color imagery with OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system (see details in the "Technology Overview" section). These aerial image sets were most often collected at 2m resolution. The flights were done on a semi-regular schedule ranging from 1-2 times per month during the summer to as often as twice 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 2-3 hours) of the field data collection. Additional flights were done 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 DMSC image acquisitions. The use of satellite as opposed to aerial data also enables a more regionally contiguous monitoring of events affecting the target areas. In late 2019, the RapidEye satellite constellation was decommissioned by the current operator Planet Labs. Subsequently, OI secured the regular acquisition of SPOT 6 and SPOT 7 satellite imagery covering the same geographical area beginning in 2020. These data are discussed in more detail below.

In 2012, OI also began operationally providing the City with a suite of additional oceanographic products daily through the City's Environmental Monitoring and Technical Services (EMTS) web-based GIS "BioMap" Server and continued expanding the product selection and delivery through 2014 and into 2015. In 2016 the BioMap project was discontinued, however, OI continues to work with the City to develop a delivery and display Web Map Service (WMS) designed around the ESRI ArcGIS Online platform. The intent is to eventually deliver all the remote-sensing and model-derived products to the City's end users via this system. Additional discussion on this possibility follows below.

This report summarizes observations made during the period 1/1/2020 – 12/31/2021.

2. 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, heat, or microwave signal patterns that are characteristic of the different discharges and water turbidity. Most often this is due to specific substances contained in the effluent but absent in the receiving water.

2.1 Imaging in the UV-Visible-Near Infrared Spectrum

Imaging in the UV-Visible-Near Infrared Spectrum is the most commonly used technique with satellite and aerial sensors. 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-IR wavelengths can be useful for correcting atmospheric interference from aerosols such as smog and smoke.

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, individual bands from two such images can be ratioed, thus emphasizing the water features' differences in reflection of the two wavelengths. A multi-wavelength image set can also be analyzed with multispectral classification algorithms which separate different features or effluents based on the correlation 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, the satellite data used for this effort reveal patterns in the upper 15-40 feet.

2.2 Imaging in the Infrared Spectrum

Some satellite and aerial sensors take radiometric measurements of thermal energy radiated from the Earth's surface which can be used to calculate temperature from the ground and the ocean. The differences in temperature can then be used to reveal important coastal and oceanographic patterns and features. Since infrared 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 the ocean water, although the reverse can be true during the winter. Surface manifestations 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 saltwater and tends to rise to the surface. If it makes it all the way, it is usually cooler than the surrounding sun-warmed surface water. If it is constrained by a strong thermocline and/or pycnocline ("vertical stratification"), it can displace some of the water above it in a doming effect. This displacement pattern is revealed in the thermal surface imagery. The Landsat 8 OLI/TIRS, Sentinel 3 SLSTR (Sea and Land Surface Temperature Radiometer), MODIS, (VIIRS) and AVHRR satellites/sensors all have thermal infrared channels as part of their sensor package.

2.3 Data Dissemination and Analysis

The satellite imaging data are made available to the funding agencies, the San Diego County Department of Health (CDH), and the EPA through a dedicated, password-protected website. Although it is possible to process most of the used data in near-real-time, earlier in the project the funding agency decided that the emphasis of this project is not on providing real-time monitoring support and the extra costs associated with the rapid data turn-around were not warranted. Most satellite data are thus processed and posted within 1-2 days after acquisition and the aerial sensor imagery (which when used prior to 2010 required the most labor-intensive processing), within 2-5 days. However, OI has in several cases, made some imagery available to the CDH and others in near-real time (within 12-24 hours) via email when observations were made that appeared to be highly significant for the management of beach closures or other sudden/anomalous events. OI has developed an ArcGIS Server WMS with the intent of hosting oceanographic products produced daily by OI and automatically linked with the ESRI Online server as soon as available.

2.4 Present and Future Enhancements of the Remote Sensing Monitoring Project

In 2016, OI began to generate the ocean currents and other HYCOM-derived products in a WMS Representational State Transfer (REST) service format which is directly compatible with the ESRI WMS the City is 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 ArcGIS WMS by fall of 2017. To date, the City's WMS is not fully functional and ready to ingest data from OI's server; nevertheless OI has put in place all the delivery infrastructure to transition to this means of data and product delivery as soon as the City is ready. Discussions with the City's GIS personnel in 2020 focused the possibility of utilizing the ERSI ArcGIS Online service (*https://www.esri.com/en-us/arcgis/products/arcgis-online/overview*) and ways to utilize the City's GIS infrastructure to ingest data from OI's WMS. Work to develop this method of disseminating all this project's data products continues in 2021. As part of this process, the historical imagery, data and reports will remain accessible via the existing web portal while OI and the City migrate all 2016-2021 data products to OI's ArcGIS Server. Following the completion of the migration of the 2016-2021 data to this system, OI will progressively work backwards in time to make all historical data available to the City's ArcGIS online WMS.

Beginning in 2017, OI also began processing and posting imagery from the Sentinel 2A satellite. Sentinel-2A is a satellite operated by the European Space Agency (ESA) and is the spaceborne platform for the Multispectral Instrument (MSI). The Sentinel-2 MSI samples 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 40 feet depending on ocean conditions. The revisit time of the Sentinel-2A satellite is approximately ten days. A second satellite carrying the MSI sensor, the Sentinel-2B, was launched into orbit by the ESA and provided the first set of data from the MSI sensor as of March 17, 2017. Beginning in 2018, data from Sentinel 2B became a regular addition to the satellite imagery products posted to the OI web portal. On average the Sentinel 2A and 2B imagery processed to highlight anomalous turbidity signals emanating from the Point Loma Ocean Outfall (PLOO), the South Bay Ocean Outfall (SBOO), as well as the discharge from the Tijuana River were posted to the OI web portal within 24-36 hours of satellite data acquisition. In some cases, if the data were available to OI earlier, the image products were delivered as quickly as 12 hours post acquisition. During 2020 the Sentinel 2A and 2B satellites provided the most temporarally comprehensive set of high-resolution satellite imagery. In total, 133 high resolution satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2020. This equates to a 10% increase in satellite data used to document the area when compared to 2019. Of the 133 total image sets, 87 were from Sentinel 2A or 2B data making up 65% of the high-resolution satellite data processed and posted as part of the project and in increase of 2% over 2019. On average, this effectively increased the number of high-resolution satellite observations of the San Diego region to eleven per month.

There were 19 occurrences when either Sentinel 2A or 2B data were acquired within only a few minutes of either SPOT, Landsat TM7 or Landsat 8 OLI/TIRS data providing a near time-coincident validation of features (or lack thereof) observed in the imagery. There were three days on which all three satellite/sensors acquired data of the San Diego offshore region within minutes to hours of each other. Figure 1 provides an example on 12/11/20 of the SBOO surface turbidity expression near-simultaneously observed by Sentinel 2A SPOT and the Landsat 7 high resolution satellite sensors on 12/11/20. The surface turbidity plume extending to the northwest is one of the largest/strongest observed during 2020 and can be seen emanating from three different risers on the SBOO wye. The Landsat image thermal imagery reveals that the turbid water coming from the wye is cooler than the surrounding water. Appendix A includes the 2020 SPOT, Sentinel and Landsat imagery on days which the SBOO plume was detected.

In October 2018, OI began using imagery from Sentinel-3A. Shortly thereafter, in December 2018 imagery from Sentinel-3B began to be incorporated as well. Just like Sentinel 2, Sentinel 3A and 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 4 different remote sensing instruments. The Ocean and Land Color 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 Radiometer (SLSTR) 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 missions' main objectives are to measure sea surface topography along with the measurement of ocean/land surface temperature and ocean/land surface color.

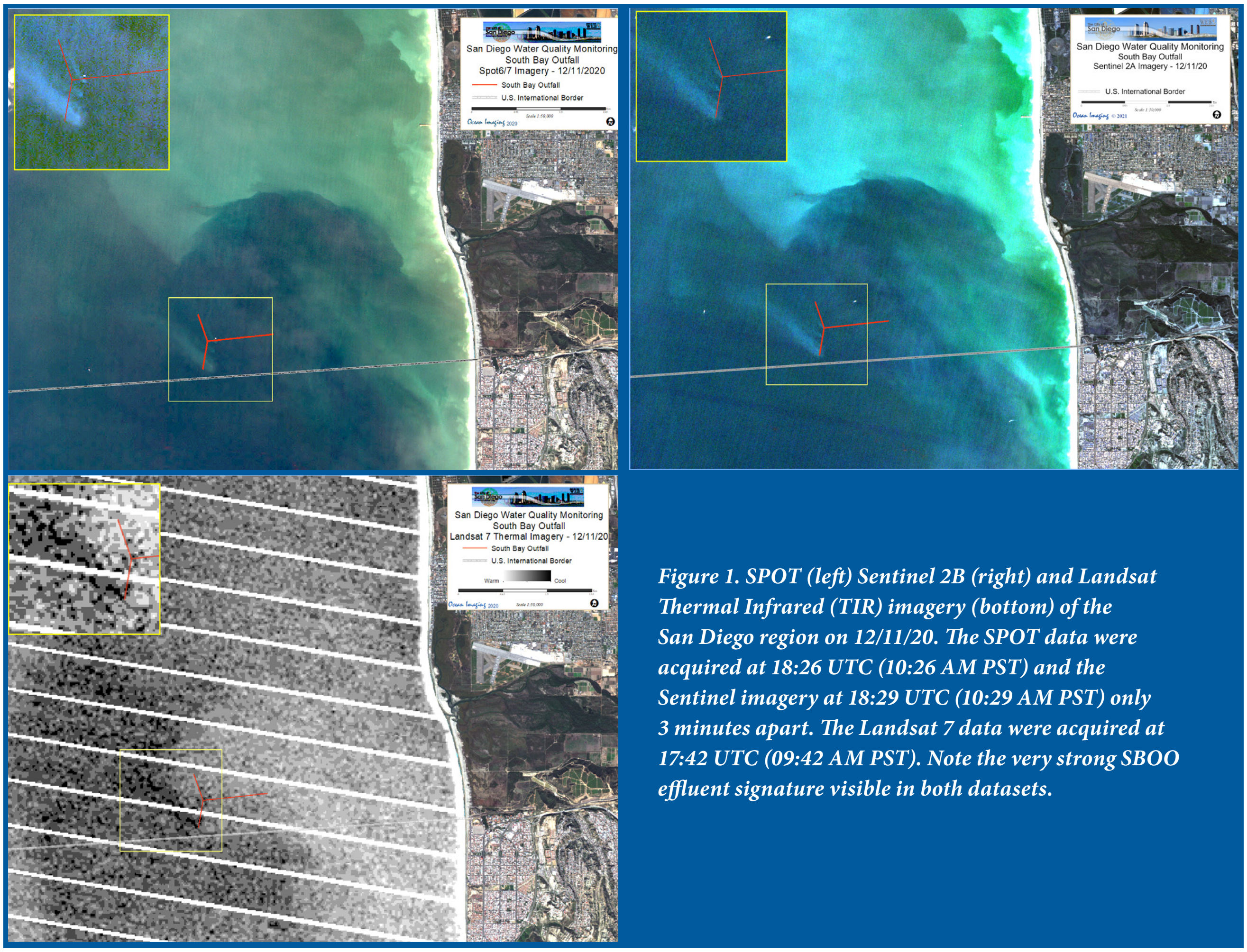


Figure 1. SPOT (left) Sentinel 2B (right) and Landsat Thermal Infrared (TIR) imagery (bottom) of the San Diego region on 12/11/20. The SPOT data were acquired at 18:26 UTC (10:26 AM PST) and the Sentinel imagery at 18:29 UTC (10:29 AM PST) only 3 minutes apart. The Landsat 7 data were acquired at 17:42 UTC (09:42 AM PST). Note the very strong SBOO effluent signature visible in both datasets.

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. OI creates daily products dependent on cloud cover for the entire San Diego/ Tijuana region using the OLCI instrument. Between the 3A and 3B satellites this results in better than daily coverage with 3A and 3B data occasionally both being available on the same day. True color, near infrared products are posted bi-monthly along with the similar resolution MODIS products. For a time, Total Suspended Matter (TSM) products indicating the quantity in grams per cubic meter of suspended particles in water were also made available but proved to be less indicative of SBOO outfall anomalies than originally thought. TSM products are calculated from estimated inherent optical water properties such as pigment absorption and total scattering products at 443 nm. This empirical algorithm was created in order to evaluate the turbidity of water. Therefore, the TSM products are still being evaluated as a means to track and quantify discharge from the Tijuana River (TJR) discharge. Other possible future products derived from the Sentinel 3 sensors include chlorophyll and sea surface temperature as well as cyanobacteria monitoring. Sentinel 3 carries the only satellite sensor package with the necessary spectral bands, spatial resolution, and coverage for near real-time detection of cyanobacteria. The results of these products may also be compared to the field sampling data in order to assess accuracy. Figure 2 shows a relatively long time series of the offshore San

Diego region using Sentinel 3 data between 11/24/20 and 12/04/20. During this period, a plankton bloom developed west of Point Loma and Coronado and formed a cyclonic eddy off the coast. The plankton then dissipated but formed again towards the middle of December. This unique time series highlights the usefulness of how daily Sentinel 3 data at 300-meter resolution can provide informative temporal documentation of the oceanographic and biological conditions in the region. An animated version of this figure, running through 12/30/20, which better illustrates the dynamics of the changing conditions over time, can be found on the Ocean Imaging Web Site here: *https://oceani.com/SDWQ_DigitalImagery.html*.

As stated above, the RapidEye satellite data were discontinued as of late 2019 and replaced by data from the SPOT 6 and SPOT 7 satellites in January of 2020. The two SPOT satellites/sensors (SPOT 6 and SPOT 7) 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. The dynamic range of these sensors is 12-bits per pixel.

SPOT6/7 spectral bands:
Panchromatic: 0.450-0.745µm
Blue: 0.450-0.520µm
Green: 0.530-0.590µm
Red: 0.625-0.695µm
Near-infrared: 0.760-0.890µm

OI uses the blue, green, red, and near-infrared bands for this project. 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. Because of the ability of these sensors to image from off-nadir viewing angles it is also possible to obtain imagery close together in time. Figure 3 shows a set of SPOT images from 11/24/20, 11/29/20 and 11/30/20 as well as Sentinel 2 imagery from 11/26/20 highlighting the ability to obtain high-resolution imagery from multiple satellites on successive days. Note the relatively small TJR discharge moving offshore to the northwest on the 24th which develops into a large, turbid plume, first continuing its push to the northwest and then turning southward on itself by the 30th. There is also a weak manifestation of the SBOO plume seen as a clear-water area just south of the wye seen in the 11/29/20 SPOT data. The 25-hour averaged High Frequency Radar-derived (HF Radar) ocean currents from these days derived within one to two hours of the satellite data acquisition are overlaid on the imagery corroborate this shift in current direction.

3. HIGHLIGHTS OF 2020 MONITORING

3.1 Atmospheric and Ocean Conditions

According to the San Diego International Airport station (formerly referred to as the Lindbergh Field station), in 2020, San Diego experienced less than 50% of the annual precipitation compared to 2019 (7.71"), falling below the 10-year average of 8.25". The Tijuana Estuary station reported a higher cumulative precipitation total in 2020 than the San Diego station of 10.18", yet still several inches less than 2019 (Table 1). As has been noted in the previous reports, the monthly and annual precipitation amounts can differ at times between the two reporting stations.

The monthly precipitation totals recorded for 2020 followed normal patterns seasonally, with the exception of April, which experienced unusually high rainfall totals. The 2020 winter months did experience rainfall totals more in line with seasonal expectations which differed significantly from 2019. In 2019, the months of January, February, November and December experienced totals well above

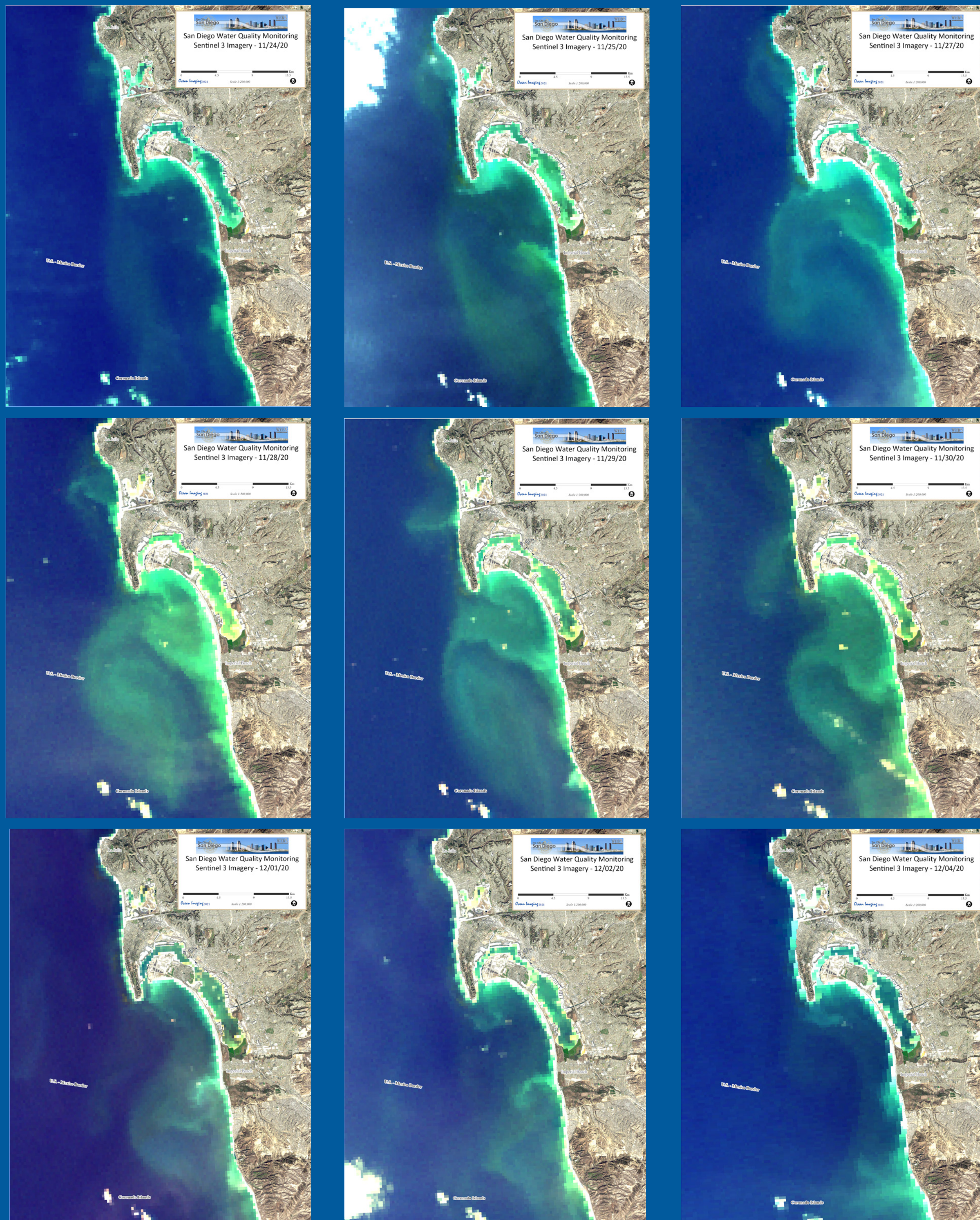


Figure 2. Sentinel 3 RGB Time series showing the development and dissipation of a phytoplankton bloom and large eddy west of San Diego. For a more complete time series presented as an animation visit: https://oceani.com/SDWQ_DigitalImagery.

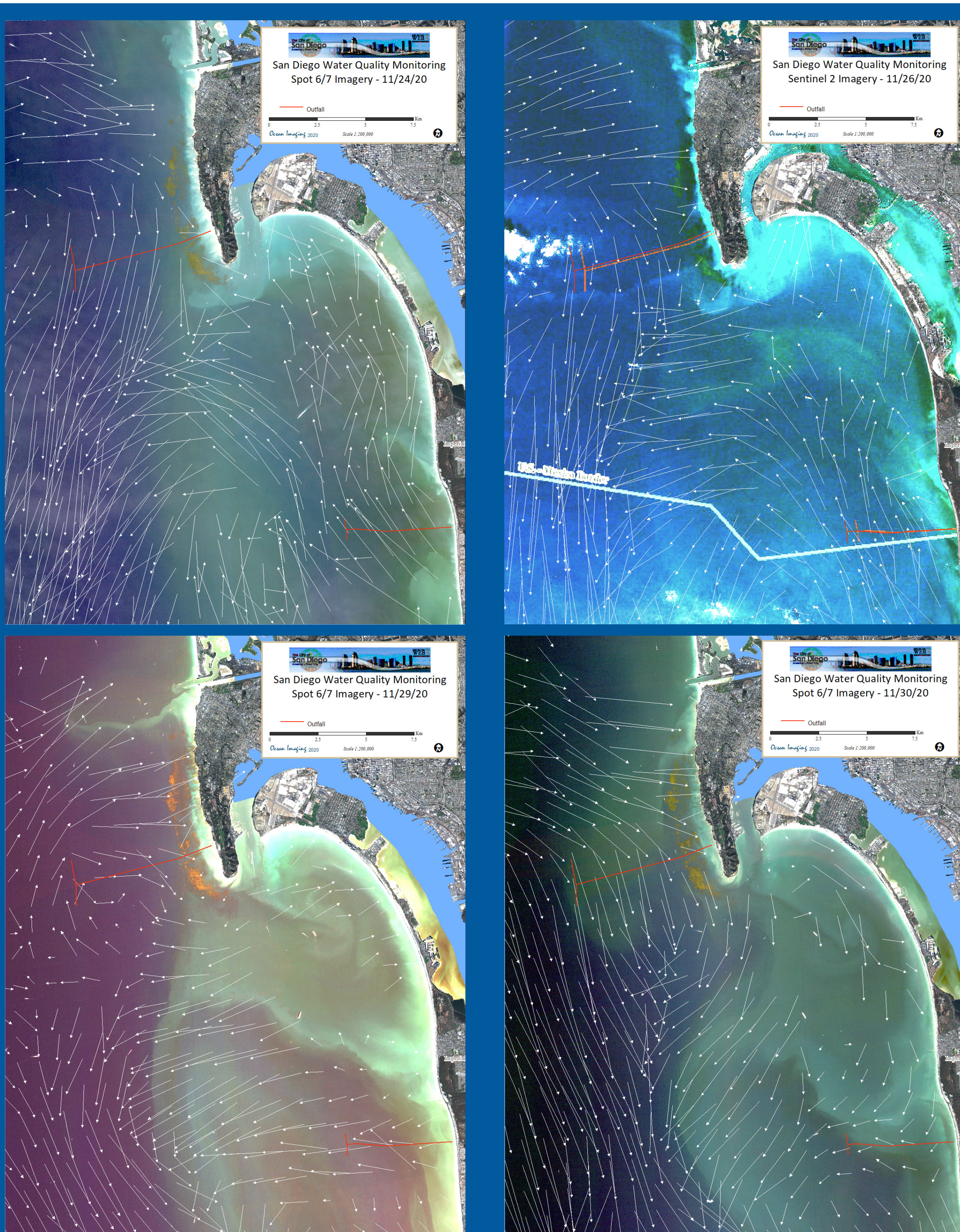


Figure 3. SPOT and Sentinel 2imagery of the SBOO region between 11/24/20 and 11/30/20. Both satellite systems show the development and expansion of a large TJR discharge plume fist moving to the northwest and then to the south during this time period. 25-hour averaged HF Radar currents from the same day and time period are overlaid on the image data.

normal. Also somewhat in contrast to 2019, in 2020, following a wet April, the dry season extended from May all the way through the end of November.

Figure 4 shows cumulative daily precipitation in the Tijuana River Estuary. The table to the side of the plot gives the dates for which there was measurable precipitation at that station. The primary period of consistent and/or heavy precipitation occurred between mid-March and Mid-April. Fewer instances of SBOO effluent surfacing and excessive TJR discharge were observed during this period than the two months prior, however unusually strong plankton blooms were observed over the entire San Diego region during the months of March, April and May. Figure 5 shows a time series of dramatic plankton

Table 1. San Diego and Tijuana Estuary precipitation totals 2011-2020

San Diego International Airport Cumulative Monthly Precipitation in Inches

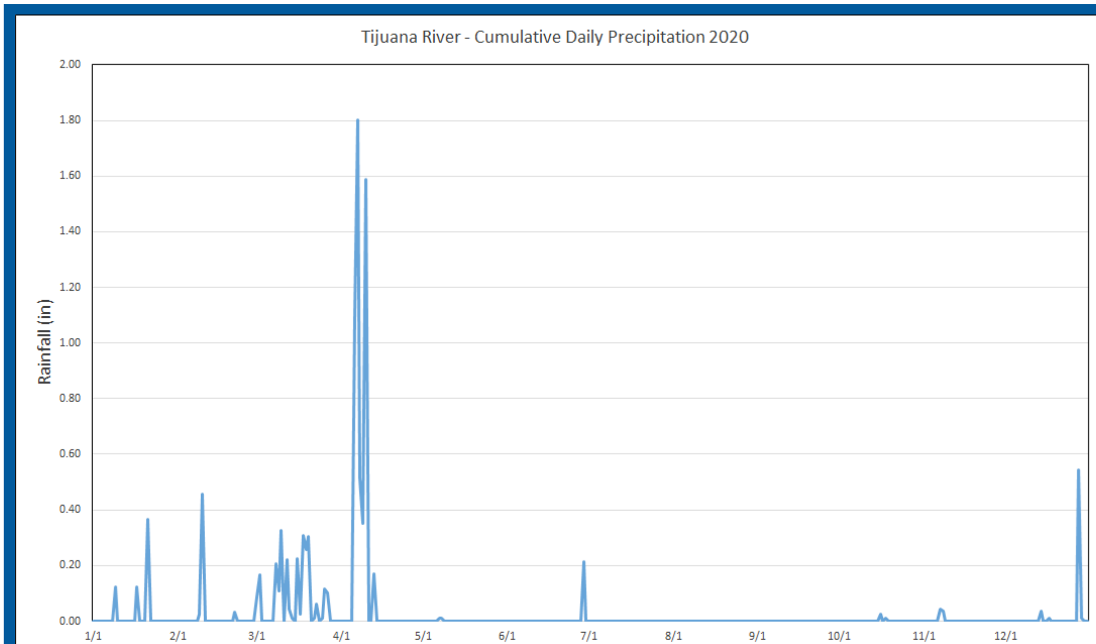
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	0.30	0.40	0.70	0.01	0.42	3.21	2.99	1.77	2.42	0.48
February	2.10	1.19	0.63	1.00	0.28	0.05	1.58	0.35	4.04	0.38
March	1.46	0.97	1.22	1.28	0.93	0.76	0.08	0.65	1.23	2.15
April	0.26	0.88	0.01	0.54	0.02	0.55	0.01	0.02	0.10	3.68
May	0.36	0.02	0.26	--	2.39	0.44	0.87	0.09	0.86	0.02
June	0.03	--	--	--	0.04	--	0.02	--	0.01	0.14
July	--	--	0.05	--	1.71	--	--	--	--	--
August	--	--	--	0.08	0.01	--	--	0.02	--	--
September	0.13	--	--	--	1.24	0.32	0.06	--	0.11	--
October	0.46	0.70	0.25	--	0.43	0.07	--	0.57	--	0.12
November	3.12	0.28	1.48	0.37	1.54	0.61	0.02	0.69	2.72	0.14
December	0.86	2.19	0.46	4.50	0.88	4.22	--	0.83	4.03	0.60
Annual Total	**9.08**	**6.63**	**5.06**	**7.78**	**9.89**	**10.23**	**5.63**	**4.99**	**15.52**	**7.71**

Tijuana Estuary Cumulative Monthly Precipitation in Inches

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	0.27	0.70	0.05	0.08	0.32	2.40	3.61	0.82	1.80	0.61
February	1.95	0.86	--	1.35	0.13	0.02	4.06	0.47	3.62	0.51
March	1.23	1.21	1.43	0.55	1.01	1.28	0.04	1.17	1.33	2.59
April	0.22	0.82	0.11	0.35	0.07	1.91	0.01	0.10	0.33	5.52
May	0.29	--	0.36	--	1.13	0.97	1.07	0.08	0.50	0.02
June	0.02	--	--	0.12	--	--	--	--	0.02	0.21
July	0.01	--	0.01	0.33	0.39	--	0.01	0.01	--	--
August	--	--	--	0.04	--	--	0.02	--	--	--
September	0.13	0.02	0.01	--	0.48	0.49	0.03	--	--	--
October	0.35	0.50	0.41	--	0.21	--	--	0.13	--	0.04
November	2.86	--	0.25	0.29	0.61	0.34	0.06	0.82	2.99	0.08
December	0.52	0.04	0.50	3.09	0.61	4.32	0.09	3.16	3.82	0.60
Annual Total	**7.86**	**4.15**	**3.13**	**6.20**	**4.94**	**11.73**	**8.99**	**6.76**	**14.41**	**10.18**

blooms in the region over this three-month span. As seen in Figure 4, except for four days, the period between 03/08/20 and 03/27/20 experienced some level of precipitation for the entire 20-day span. The coastal turbidity levels, TJR discharge, and a few days when the SBOO effluent was visible on the ocean's surface followed the daily rainfall patterns with water quality levels decreasing one-to-two days following the more significant rain events and water clarity increasing after a few days of low to zero rainfall. Figure 6 illustrates this correlation. The second and only other period of heavy precipitation occurred between 04/06/20 and 04/13/20. A total of 5.53" was recorded during the eight days with intense rain falling every day between the sixth and tenth of April. Heavy cloud cover prohibited the acquisition of usable satellite imagery during much if this time period, however strong turbidity plumes can be seen emanating from both the TJR and Mission Bay on 04/11/20 in the SPOT data from that day. Despite cloud cover obscuring a portion of the region, a distinct SBOO surface effluent signature, phytoplankton blooms and evidence of strong northward currents are also visible in these data.

Aside from these rain events and 0.21" recorded on 06/29/20, the period between May and the first half of December experienced very little measur-



Date	CumPrcp (in)
01/09/20	0.12
01/17/20	0.12
01/21/20	0.37
02/09/20	0.02
02/10/20	0.46
02/22/20	0.03
03/01/20	0.09
03/02/20	0.17
03/08/20	0.20
03/09/20	0.11
03/10/20	0.33
03/12/20	0.22
03/13/20	0.04
03/14/20	0.01
03/16/20	0.22
03/17/20	0.02
03/18/20	0.31
03/19/20	0.26
03/20/20	0.30
03/22/20	0.01
03/23/20	0.06
03/25/20	0.01
03/26/20	0.11
03/27/20	0.10
04/06/20	1.10
04/07/20	1.80
04/08/20	0.52
04/09/20	0.35
04/10/20	1.59
04/13/20	0.17
05/07/20	0.01
05/08/20	0.01
06/29/20	0.21
10/16/20	0.02
10/18/20	0.01
11/07/20	0.04
11/08/20	0.04
12/14/20	0.04
12/17/20	0.01
12/28/20	0.54
12/29/20	0.01

Figure 4. Daily accumulated rainfall in the Tijuana Estuary

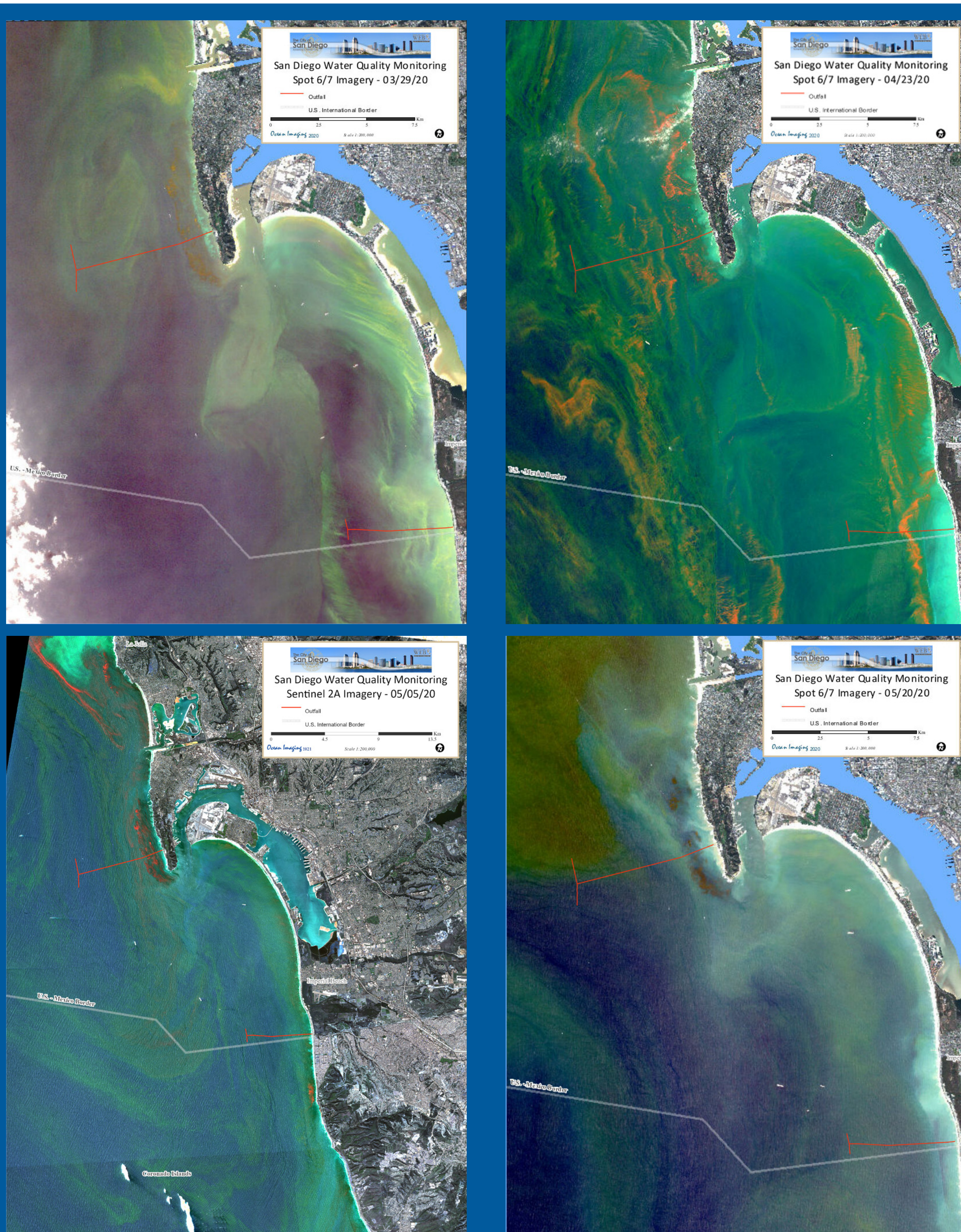


Figure 5. Plankton blooms visible in the SPOT and Sentinel 2 imagery on 03/29/20 (Red-Green-Blue), 04/23/20 (Red-Green-Near Infrared), 05/05/20 (Red-Green-Near Infrared) and 05/20/20 (Red-Green-Blue). Note the strong, probably coccolithophore bloom west of La Jolla in the 05/05/20 image as well as the intense reflectance in the Near-Infrared (NIR) channels (orange-red) in the imagery acquired on 04/23/20 and 05/05/20. The strong NIR signal illustrates the high levels of algae/phytoplankton in the blooms.

able precipitation. Even in December only one day (12/28/20) showed rainfall levels exceeding 0.04". Despite the dry conditions, there were several days during this time period that exhibited either very strong phytoplankton blooms, heavy coastal runoff/turbidity, or both (Figure 7). The month of November had several days during which the TJR discharge extended far offshore and even was seen pushing up past the southern tip of Point Loma (Figures 3 and Figure 8). November only experienced totals of 0.14 and 0.08" of precipitation for the month recorded at the San Diego International Airport and Tijuana River Estuary stations respectively.

River flow rates as shown in Figure 9, which plots the daily San Diego River flow rates in cubic feet per second (cfs) measured by the United States Geological Survey (USGS) Fashion Valley gauge, mostly correspond with the rainfall data. Monthly precipitation totals at the San Diego International Airport station are displayed to the right of the plot. In general, the 2020 the river flow rates matched what would be expected given seasonal rainfall patterns, however the peak of 66.3 cfs on 11/08/20 does not

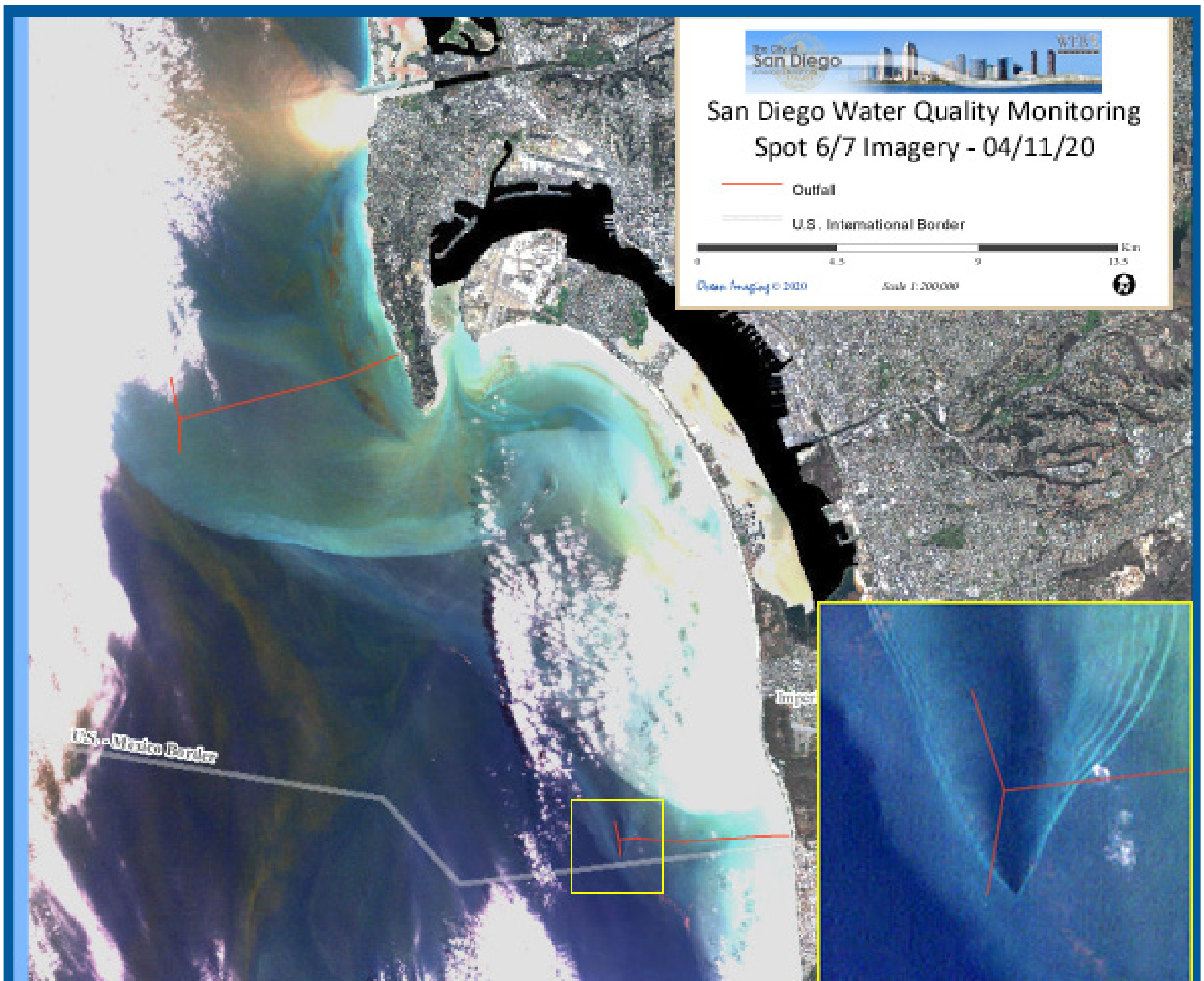


Figure 6: SPOT image from 04/11/20 during a period of heavy rainfall showing very dynamic conditions from Mission Bay down to the border. Between the clouds to the west and off the southern San Diego shoreline large phytoplankton blooms, heavy coastal turbidity and strong discharge emanating from Mission Bay are all clearly visible. A large SBOO effluent surface manifestation is also very apparent.

necessarily proportionally match the total of 0.08" of rainfall, which occurred 11/07/20 and 11/08/20. Yet, this flow rate does help explain the heavy runoff and coastal turbidity seen in the satellite imagery during that time (example imagery in Figure 8 above).

In 2020 the county of San Diego issued 151 posted shoreline and/or rain advisories and 28 beach/shoreline closures. This is close to the number of advisories and closures as in 2019 (166 and 32 respectively). The longest contiguous 2020 closure lasting 263 days between January 1st and September 20th was in Border Field State Park along the south end of the Tijuana Slough Shoreline. This closure was an extension from 2019 and so in reality lasted 303 days. As is typical for the region, all but two of the closures were in the area between the Tijuana River mouth and Avenida Del Sol at the south end of North Island and the result of contamination from the TJR runoff. The two exceptions were Torrey Pines State Beach and Carlsbad Municipal Beach which were closed due to nearby sewage spills. Except for those during the May through October summer months, almost all of the closures can be attributed to a rain event prior to and/or during the closure period (Table 2). Table 2 also shows the date of the high-resolution satellite data acquired closest in time to the start date of the closure and/or rain advisory.

The satellite imagery available on or around the closure dates and rainfall events generally visually correlate with the closure data. Imagery during those time periods show high turbidity and suspended solid levels along the coastline near the closed regions as well as greater than normal TJR runoff, sometimes being carried north by the ocean currents. Figure 10 provides an example of the Tijuana River plume extending north corresponding with shoreline closures beginning on the same day.

Although discharge from the San Diego River does not cause the same level of beach contamination issues as the Tijuana River discharge, the runoff from the river, Mission Bay and coastal lagoons did affect nearshore water clarity and quality on several days throughout the year in 2020, directly as a source of suspended sediment and indirectly as a source of high nutrient level. During the past year the San Diego region, and much of the coastal Southern California region, experienced dramatic phytoplankton blooms covering the area almost to the shoreline to several miles offshore. Figure 6 (page 12) from 04/11/20 is a SPOT image that offers a comprehensive example of these conditions. Despite the cloud cover in the image, the heavy and very turbid discharge coming from Mission Bay, significant coastal turbidity from the US-Mexico border up to and around Point Loma, as well as large, dense phytoplankton blooms are all evident in this scene.

Besides the expected higher levels resulting from the California Current moving down past Point Conception, the Southern California Bight experienced lower overall levels of chlorophyll during the months of January through early March. After mid-March the levels were significantly increased region wide. As seen in Figure 11, a strong push of the California Current to the southeast along with coastal upwelling from May through December kept the chlorophyll in the bight high throughout the summer months and into winter. The coastal San Diego region showed normal coastal upwelling leading to phytoplankton blooms with the exception of months of March through May when large dense plankton blooms and red tide conditions existed for most of that three-month period from the border up past Oceanside. The blooms during this period were unusually intense and were visible in all types of satellite data down to the relatively coarse resolution MODIS imagery. Figure 5 (page 11) provides a times series from the Terra, Aqua and Sentinel 3 satellites during April and May highlighting these anomalous conditions. While red tides reflect strongly in the red wavelengths of the electromagnetic spectrum, they also reflect highly in the bands used to detect and quantify chlorophyll_a. In the

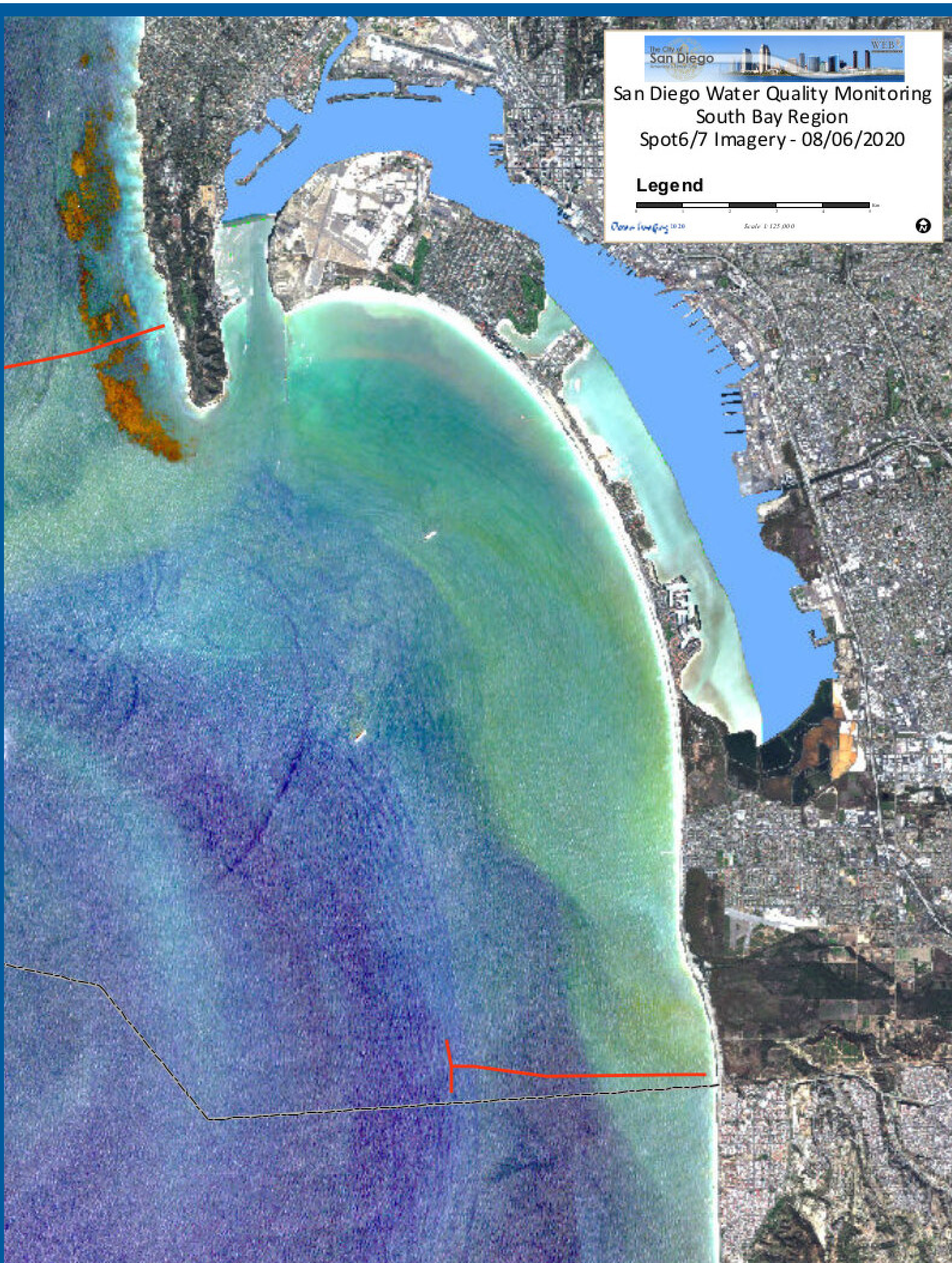


Figure 7. SPOT image from 08/06/20. Despite sun glint somewhat obscuring the data, coastal turbidity and phytoplankton blooms are easily visible in the scene.

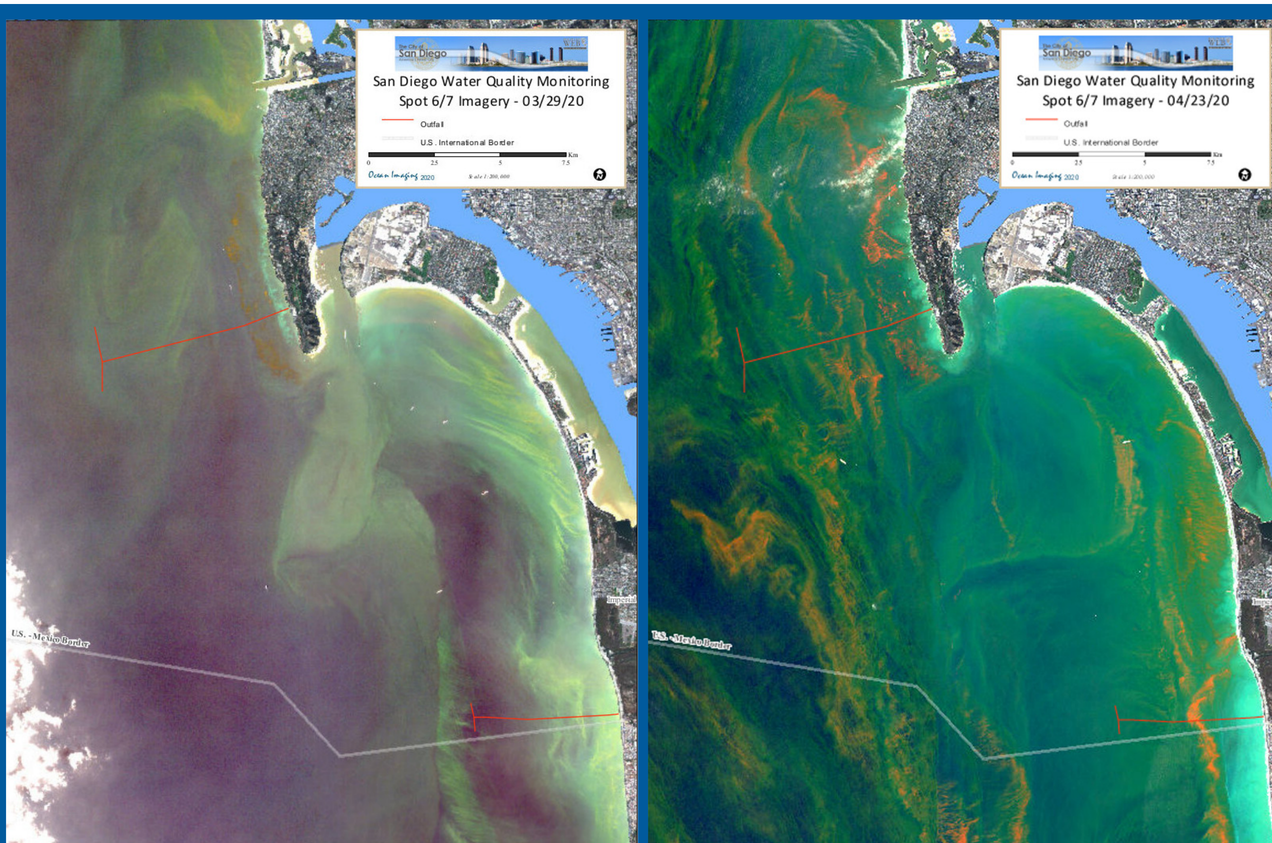
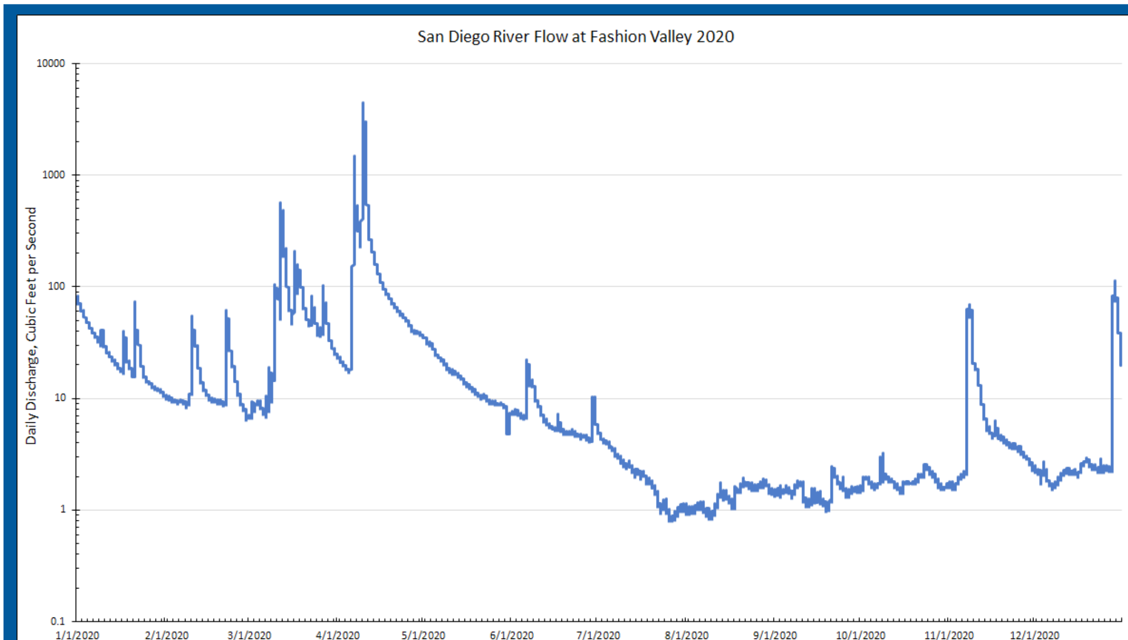


Figure 8. Sentinel 2 imagery from 11/11/20 and 11/14/20 showing heavy coastal turbidity and TJR runoff despite relatively little precipitation prior to that time period.



San Diego Intl. Airport Rainfall 2020	
Jan	0.48
Feb	0.38
Mar	2.15
Apr	3.68
May	0.02
Jun	0.14
Jul	--
Aug	--
Sep	--
Oct	0.12
Nov	0.14
Dec	0.6

Figure 9. Daily San Diego River flow rates in cubic feet per second measured by the USGS Fashion Valley gauge. Monthly precipitation totals at the San Diego International Airport station are displayed to the right of the plot.

Table 2. 2020 County of San Diego shoreline closures and advisories (courtesy of the County of San Diego Department of Environmental Health).

StationDescription	Beach Name	Station Name	Type	Cause	Source	Start Date	End Date	Duration	Nearest Rain Date	Time from Rain Event	Satellite Image data
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	1/1/2020	9/20/2020	263	12/26/2019	6	1/1/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/1/2020	1/7/2020	6	12/26/2019	6	1/1/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/10/2020	1/11/2020	1	1/9/2020	1	1/9/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	1/17/2020	1/23/2020	6	1/17/2020	0	1/14/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			1/17/2020	1/20/2020	3	1/17/2020	0	1/14/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			1/21/2020	1/24/2020	3	1/21/2020	0	1/14/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			2/10/2020	2/13/2020	3	2/10/2020	0	2/11/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	2/22/2020	2/25/2020	3	2/22/2020	0	2/23/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			2/22/2020	2/25/2020	3	2/22/2020	0	2/23/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	2/28/2020	3/4/2020	5	2/22/2020	6	2/25/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	3/10/2020	5/3/2020	54	3/10/2020	0	3/9/2020
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	3/10/2020	3/27/2020	17	3/10/2020	0	3/9/2020
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	3/10/2020	3/29/2020	19	3/10/2020	0	3/9/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			3/10/2020	3/22/2020	12	3/10/2020	0	3/9/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			3/23/2020	3/26/2020	3	3/23/2020	0	3/24/2020
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	4/2/2020	5/2/2020	30	3/27/2020	6	4/3/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			4/6/2020	4/14/2020	8	4/6/2020	0	4/3/2020
Avd. del Sol	Coronado City beaches	IB-080	Closure	Tijuana River Associated	Sewage/Grease	4/8/2020	4/30/2020	22	4/8/2020	0	4/11/2020
Buena Vista Lagoon outlet	Carlsbad municipal beach	EH-480	Closure	Sewage Spill	Rain	4/11/2020	4/17/2020	6	4/10/2020	1	4/11/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	5/8/2020	5/16/2020	8	5/8/2020	0	5/5/2020
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	5/13/2020	5/15/2020	2	5/8/2020	5	5/13/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	5/28/2020	6/9/2020	12	5/8/2020	20	5/20/2020
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	6/5/2020	6/8/2020	3	5/8/2020	28	6/7/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Unknown	6/12/2020	7/17/2020	35	5/8/2020	35	6/10/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	7/22/2020	7/31/2020	9	6/29/2020	23	7/24/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	8/4/2020	8/6/2020	2	6/29/2020	36	8/6/2020
Del Mar - South Camino Del Mar-0	Torrey Pines State Beach	EH-109-0	Closure	Sewage Spill	Sewer Line	8/12/2020	8/14/2020	2	6/29/2020	44	8/11/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	8/14/2020	8/25/2020	11	6/29/2020	46	8/13/2020
Silver Strand N end (ocean)	Silver Strand State Beach	IB-070	Closure	Tijuana River Associated	Sewage/Grease	8/18/2020	8/23/2020	5	6/29/2020	50	8/16/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	9/8/2020	9/11/2020	3	6/29/2020	71	9/5/2020
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	10/4/2020	10/6/2020	2	6/29/2020	97	10/2/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			11/7/2020	11/11/2020	4	11/7/2020	0	11/9/2020
End of Seacoast Dr	Imperial Beach municipal beach, other	IB-050	Closure	Tijuana River Associated	Sewage/Grease	11/9/2020	11/17/2020	8	11/8/2020	1	11/9/2020
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	11/9/2020	11/22/2020	13	11/8/2020	1	11/9/2020
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	11/28/2020	12/7/2020	9	11/8/2020	20	11/29/2020
Border Fence N side	Border Field State Park	IB-010	Closure	Tijuana River Associated	Sewage/Grease	12/25/2020	12/31/2020	6	12/17/2020	8	12/25/2020
All_SanDiego_County_Beaches	All_SanDiego_County	All_SanDiego_County_Beaches	Rain			12/28/2020	12/31/2020	3	12/28/2020	0	12/29/2020

April and May VIIRS imagery, the plankton blooms were so intense that the chlorophyll levels were so high that they surpassed the normal cutoffs in the false color enhancements used to display the data. Therefore, if examined closely the enhanced MODIS and VIIRs imagery for the months of April and May appear to show colors that are typically reserved for highly turbid water (as opposed to high chlorophyll). In these cases, the data are actually showing the unusually large and concentrated blooms.

The City of San Diego CTD sampling data correlated well with what was observed in the satellite data. Some of the highest chlorophyll levels recorded via CTD (as high as 62.3 µg/L) occurred between March and May during the series of pervasive phytoplankton blooms. These months, especially the end of April into May, showed consistently high chlorophyll in the satellite data along the coastal areas of San Diego County. Figures 12 and 13 along with Tables 3 and 4 show examples of the CTD fluorometry data in correlation with the high-resolution satellite imagery. While these data are not depicting quantitative chlorophyll levels, the plankton blooms are self-evident in the imagery and correlate positively with the CTD data – especially those taken on 05/20/20.

3.2 The South Bay Ocean Outfall Region

The South Bay Ocean Outfall (SBOO) wastewater plume generally remains well below the surface between approximately late March and November due to vertical stratification of the water column. During that period, it usually cannot be detected with multispectral aerial and satellite imagery which penetrate the upper 7 to 15 meters (depending on water clarity), nor can it be detected with thermal IR imaging which does not penetrate below the surface. Seasonal breakdown of the vertical stratification results in the plume's rise closer to the surface or to actually reach the surface between approximately late November and late March, when it can often be detected with aerial and satellite imaging. For the most part this concept held true in 2020, however, SBOO effluent surface signatures were observed in the satellite imagery twice in late March (03/19/21 and 03/21/20) and twice in April (04/11/20 and 04/23/20). The 04/23/20 occurrence, while small and faint, was one of the latest signs (seasonally) of the effluent hitting the surface seen in satellite data. The first fall observance of the SBOO surface plume was on 11/11/20. This observations date is earlier than normal (see Appendix A for imagery).

The SBOO treatment plant 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 15 mg/l. 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 that this is due to the reduction in TSS concentrations.

The effluent surface reflectance signature in the multispectral visible and near-IR imagery is dominated by reflectance spectrum characteristics of its suspended sediment; hence a reduction in the sediment concentration can be expected to affect the detectability of the plume. However, analysis of the size and intensity of the plume patterns relative to the TSS reductions does not show a direct correlation. In fact, some of the largest effluent signatures have been imaged after the secondary treatment switch, such as on 4 January 2012, when the TSS load was approximately 50% of concentrations in the early years. In that instance the effluent plume

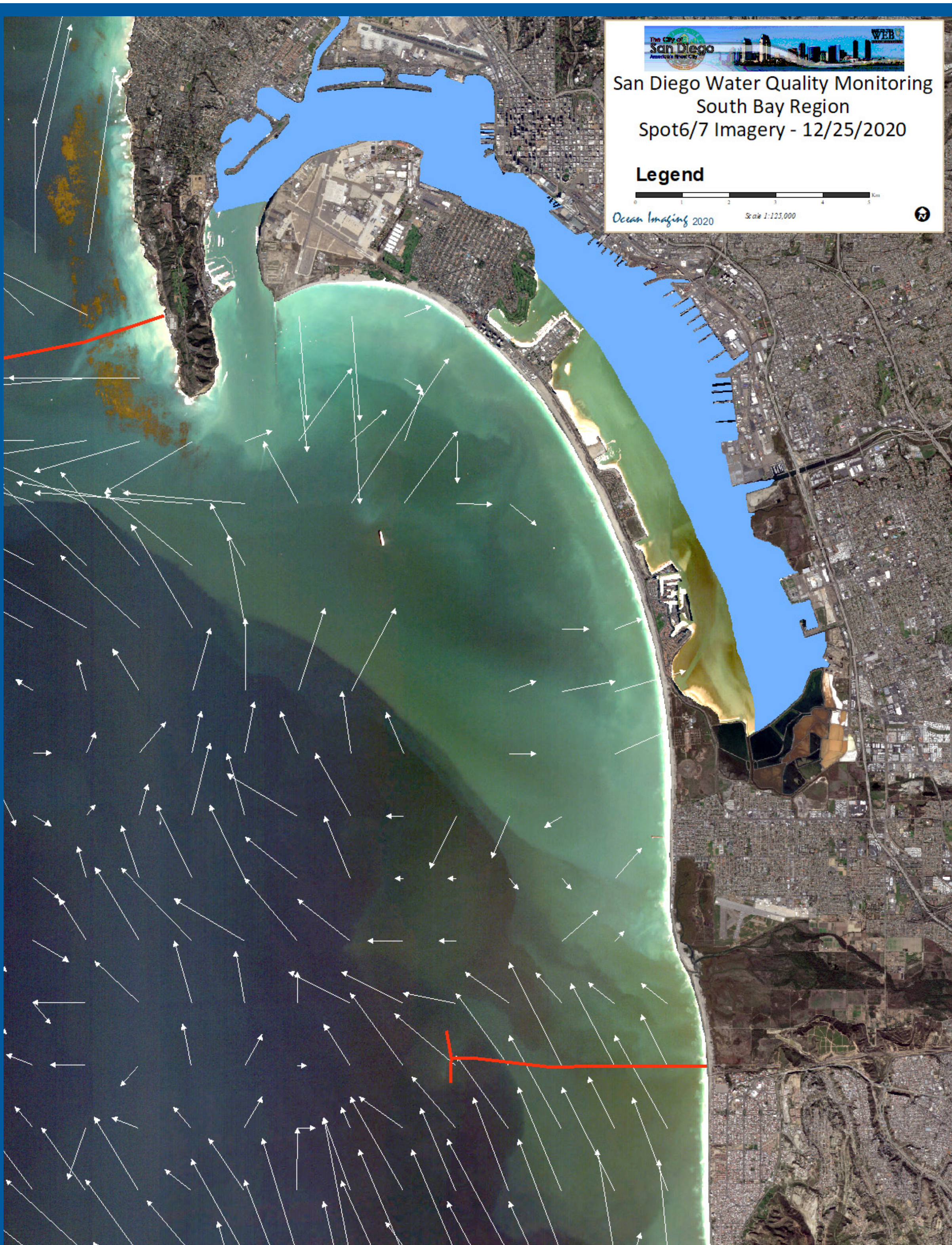


Figure 10. SPOT image showing TJR discharge moving northward into the San Diego region on 12/25/20 corresponding with the closure of the Border Field State Park area. HF Radar currents are overlaid to further illustrate the northwest flow of the TJR runoff and push of turbid water to the coast near Border Field State Park.

signature was identifiable up to more than 4km away from SBOO wye. In 2020 there were two occasions, on 02/03/20 and 04/11/20, when the plume signature extended at least 4km from the wye – one in the southerly direction and the other to the north.

There were 34 instances during which the SBOO effluent plume was observed in 2020 out of the 133 high resolution satellite scenes acquired and processed (Appendix A). Of the 34, seven were instances of the plume observed by different satellites on the same day. This equates to 27 days on which the plume was visible in the high-resolution imagery. This is 10 more than observed in 2019 and more observed in the previous four years, though there were also more high-resolution satellite scenes acquired in 2020 to detect the anomalies. In 2016 the SBOO effluent plume was observed 32.5% of the time (13 detections out of 40 high-resolution satellite images); in 2017 the plume was observed 10.9% of the time (6 detections in 55 images); in 2018 the plume was observed 18.3% of the time (15 detections in 82 images); in 2019 the plume was observed 14.7% of the time (17 detections in 116 satellite images – accounting for the duplicates); in 2020 the effluent was observed on the surface 21.6% of the time (27 detections in 125 satellite images – accounting for observations in multiple data sets on the same day). This is almost a 7% increase over the previous year. It should be noted that in 10 of the 34 detections the plumes were relatively small in size and/or exhibited a faint reflectance signal, only detectable by maximizing the enhancement of the image data around the outfall region.

As has been the case in previous years, there were a few occurrences when the SBOO effluent plume appears in the imagery as a patch of clearer water breaking the more turbid water on the surface. The SBOO effluent on the ocean's surface was evident as an area of clear water in seven out of the 27 plume observations. 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. While most of these clear-water effluent manifestations were small and faint in 2020, Figure 6 (page 12 above) provides a vivid example of this situation.

The period between 11/11/20 and 12/29/20 exhibited the highest number of 2020 SBOO effluent plume observations in the satellite data. In fact, frequent occurrences of the SBOO effluent being visible on the ocean's surface in the satellite imagery were noted well into January of 2021. A PowerPoint presentation documenting the time series of SBOO observations can be found on the San Diego Water Quality pages of the Ocean Imaging web site here:: *https://www.oceani.com/SDWQ_DigitalImagery.html*. As is typically the case, the relatively frequent effluent surface manifestations that occurred during this time period were likely 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. There were several instances during this time period when the South Bay International Wastewater Treatment Plant (SBIWTP) took on excess sewage from Tijuana exceeding the maximum allowed capacity of 25 MGD – the monthly average limit as mandated by the NPDES. The actual fuctional capacity is closer to 30 MGD (Ami Latker and Morgan Rogers, personal communication). Figure 14 shows a plot of the SBIWTP Effluent Flow rate (EFF Flow) and the Effluent Total Suspended Solids (EFF TSS) over the 2020 time period plotted with the dates on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery. As can be seen, beginning around early May the EFF flow averaged higher than the mandated maximum capacity of the treatment plant.

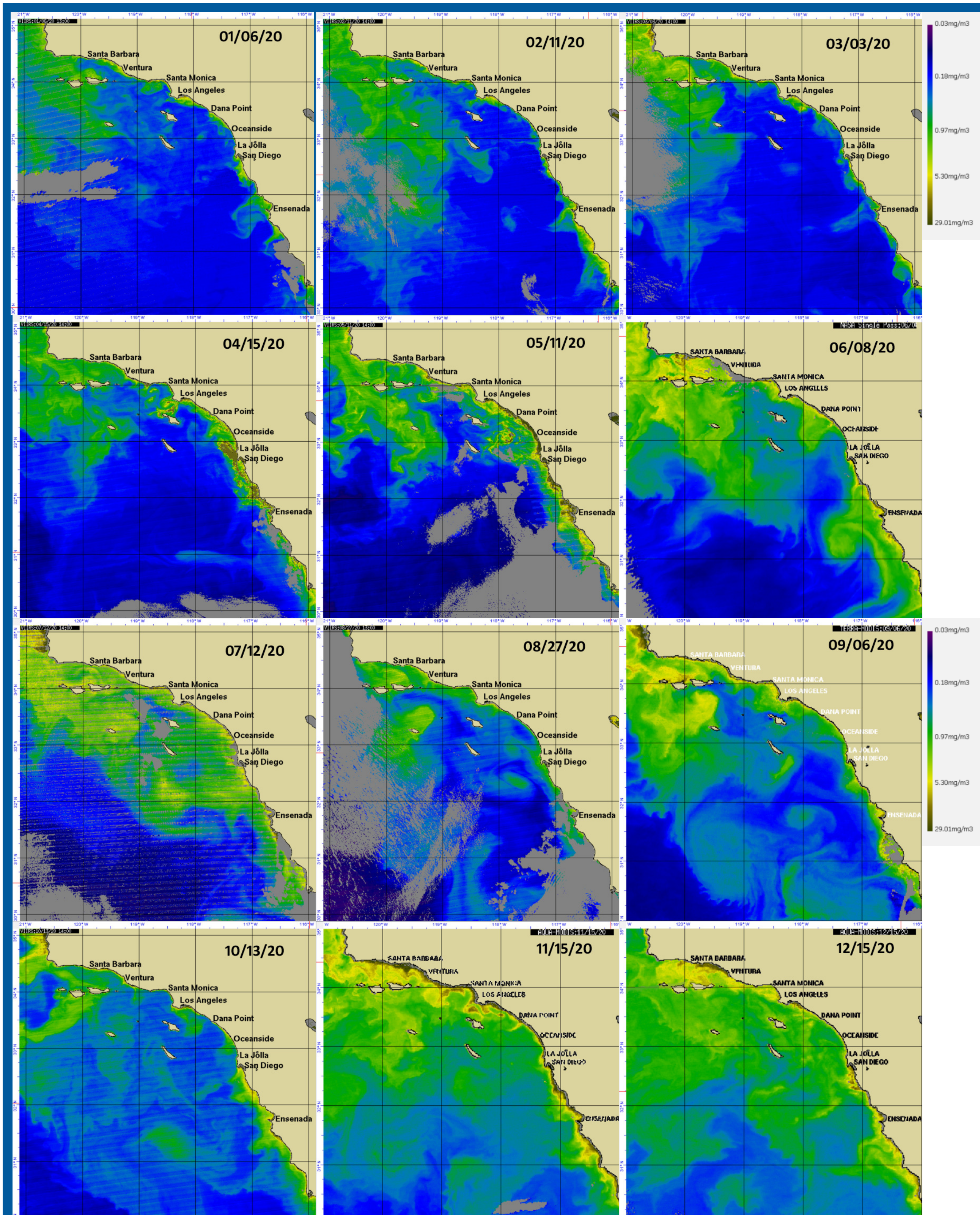


Figure 11. Representative MODS- and VIIRS-derived chlorophyll images for each month of 2020 showing significant phytoplankton blooms and/or turbidity along the coastal region for much of 2020.

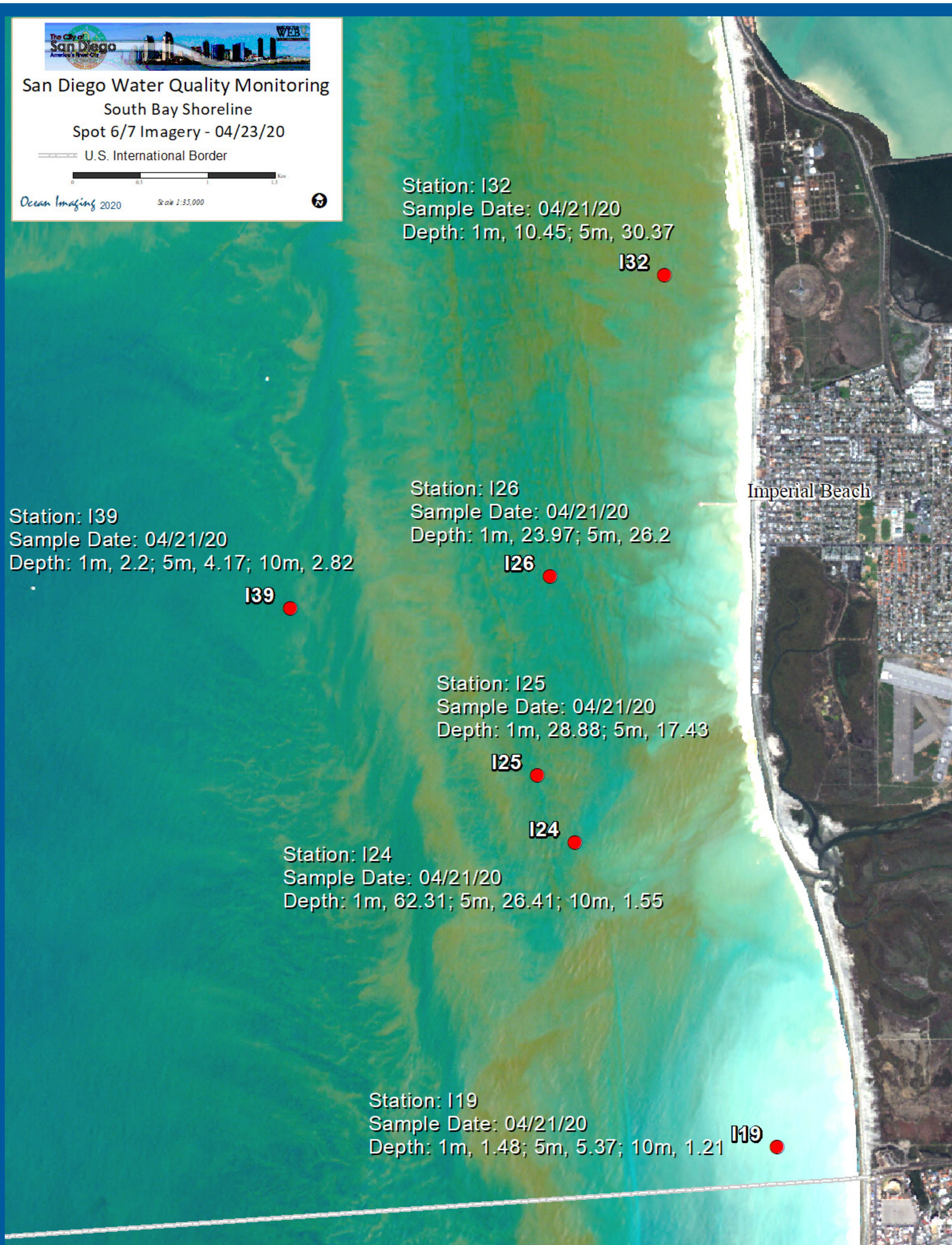


Figure 12. 6-meter SPOT satellite image from 04/23/20 showing the TJR shoreline region. Strong phytoplankton blooms can be seen in the imagery. Sampling stations for the CTD data taken on 04/21/20 are overlaid corresponding to the Chl a data listed in Table 3 below.

After the beginning of August, the average EFF flow was 27.5 MGD compared to 24.5 MGD prior to August. This equates to roughly a 12% increase over the mandated maximum capacity of the plant. However, no SBOO effluent surfacings were observed in the satellite data until November which is the typical time after which seasonal changes in ocean conditions occur and the stratification breaks down allowing the effluent to reach the surface. This is an indication that even though the EFF Flow was above normal levels and at the maximum capacity of the plant for several months, the SBOO effluent was most likely kept from reaching the surface of the ocean by vertical stratification and subsurface currents.

In 2020, the shoreline area of the SBOO/Tijuana River outflow region experienced 126 days on which the field sampling showed elevated bacteria levels as defined by the Cal Ocean Plan 2015 (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). 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 25 days on which the bacteria levels were considered elevated at depths of six meters or shallower. The number of elevated bacteria days sampled at the shore stations was 118. The total number of sampling days for all three SBOO areas (either along the shoreline or offshore, but at six meters or shallower) totaled 162 in 2020, 164 in 2019 and 157 in 2018. In 2020 for the three sampling regions combined, 77.8% of the sampling days resulted in elevated bacteria levels at one station or more. This compares to 71.9% elevated bacteria rate for the three areas in 2019 and 12.1% in 2018. It should be noted, however, that there were far fewer sampling days for the shoreline region in 2018 (36) compared to 2019 (124) and 2020 (137). 2020 continued to experience a higher-than-normal number of sewage spills and transboundary flow of sewage, solid waste and sediment across the U.S.-Mexico border into the canyon collectors such as Stewart's Drain, the TJR man channel and thus into the Tijuana Estuary and U.S. coastal waters (San Diego Regional Water Quality Control Board, 2021). The satellite imagery showing substantial discharge from the TJR region often correlate with

Table 3. CTD-derived chlorophyll measurements recorded at depths of 1, 5 and 10 meters on 04/21/20 at the stations shown in Figure 12.

Clorophyll Sampling 4/21/20 (Chl_a ug/L)			
Station ID	1 Meter Depth	5 Meter Depth	10 Meter Depth
I19	1.48	5.37	1.21
I24	62.31	26.41	1.55
I25	28.88	17.43	NA
I26	23.97	26.2	NA
I32	10.45	30.37	NA
I39	2.2	4.17	2.82

Table 4. CTD-derived chlorophyll measurements recorded at depths of 1, 5 and 10 meters on 05/20/20 at the stations shown in Figure 13.

Clorophyll Sampling 5/20/20 (Chl_a ug/L)			
Station ID	1 Meter Depth	5 Meter Depth	10 Meter Depth
F26	0.83	0.94	1.83
F27	0.71	0.91	1.71
F28	0.65	1	1.57
F29	0.68	0.95	1.24
F30	0.95	1.24	1.51
F31	11.16	16.83	9.62
F32	11.57	17.3	4.63
F33	14.53	27.72	30.47
F34	14.66	28.8	14.61
F35	19.71	24.33	4.28
F36	13.35	24.31	9.99

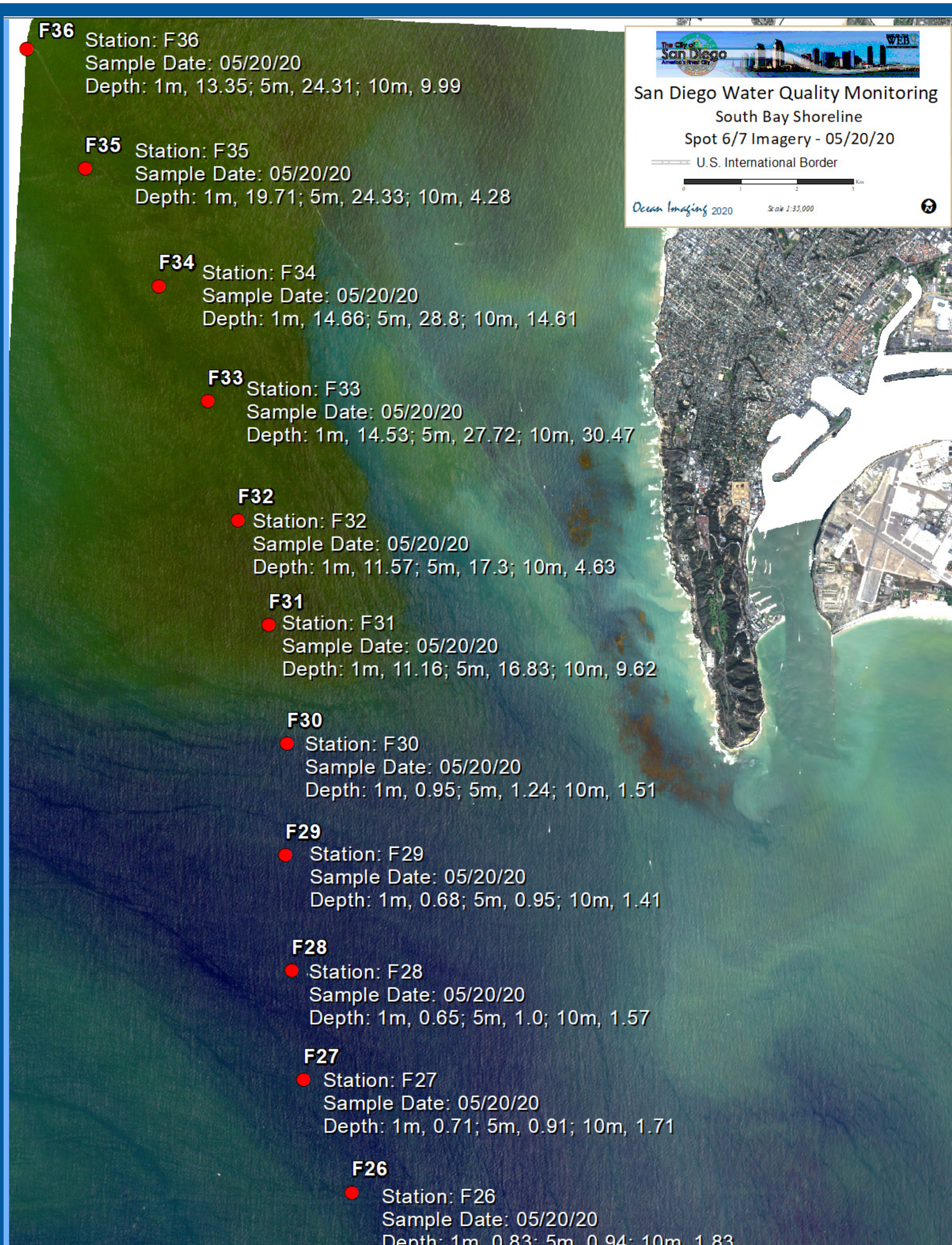


Figure 13. 6-meter SPOT satellite image from 05/20/20 showing the Point Loma Offshore station region. A strong phytoplankton bloom can be seen in the imagery west of Point Loma. Sampling stations for the CTD data taken on 05/20/20 are overlaid corresponding to the Chl a data listed in Table 4 below.

times when the shoreline and kelp area sampling showed elevated bacteria levels (Figure 15). Heavy and/or persistent rainfall is the most plausible cause for the majority of the elevated bacteria samples and turbid waters seen in the remote sensing data. This is apparent in the imagery showing strong turbidity features along the shoreline, but not extending far enough offshore to affect the SBOO offshore stations.

In some cases, the TJR turbidity plume appears to split and move both north and south along the coast as opposed to directly west or southwest into the area of the SBOO wye. In seven cases during the year, multiple small runoff point sources along the beach are visible in the imagery. It is not clear whether this is due to alongshore transport of the runoff before heading out to sea or if there were locations withing the TJR estuary which were breeched due to excess flow of water and sewage emanating from the watershed. Figure 16 provides an example.

As is typical, the best water quality and clarity in the South Bay region in 2020 was observed from June through August. There were zero days when elevated bacteria levels were recorded at the SBOO offshore and only two days of elevated levels at the SBOO nearshore stations. The shoreline stations recorded 20 days showing elevated levels at one station or more. All except for one of those elevated samples, however, were at stations near or south of the U.S.-Mexico border.

3.3. The Point Loma Outfall Region

After its seaward extension in 1993, the Point Loma Outfall (PLOO) is now one of the deepest and longest wastewater outfalls in the world, discharg-

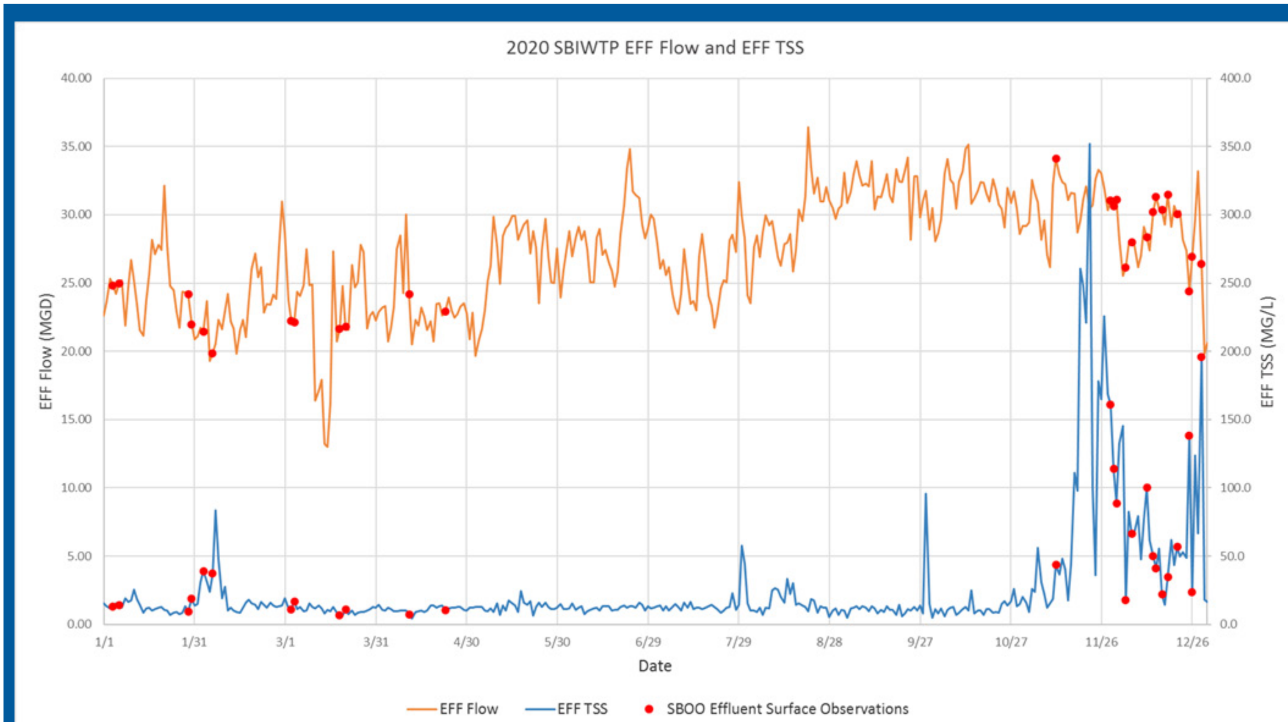


Figure 14: SBIWTP EFF flow rate and EFF TSS over the 2020 time period plotted with the dates on which SBOO effluent was observed on the surface of the ocean in the high-resolution satellite imagery (red dots – dates for the same date are plotted with the corresponding EFF flow and EFF TSS data). Data courtesy of the IBWC San Diego IWWTP office of Municipal & Commercial Business.

ing at the depth of 320 feet, 4.5 miles offshore. The outfall's plume is generally not observed directly with multispectral color or thermal imagery. It appears to not reach the surface waters, even during the winter months when the water column's vertical stratifications are weakened. We believe, that on some occasions we have observed the plume's extents indirectly through an anomalous lateral displacement of thermal or chlorophyll features around the outfall wye. This effect can be explained by the doming up of the discharged effluent and laterally displacing the near-surface waters above it.

In 2020, the Point Loma region was affected by conditions already described for general San Diego County: significant seasonal rainfall during the months of January through April and December with minimal rainfall during the months of May through November. Similar to past years, this compromised water clarity in the shoreline areas in January through mid-May and from later September through the end of December as runoff from the San Diego River and Mission Bay brought sediment-laden water inside and outside the Point Loma kelp bed after the rain events described above.

The shoreline, kelp and offshore bacterial sampling resulted in a lower number of elevated bacteria level occurrences than the previous year. Shoreline field sampling yielded 4 days on which a few of the stations experienced of elevated bacteria levels (as defined by the California Ocean Plan described above). Offshore and kelp station sampling resulted in 7 and 0 days respectively on which some of these

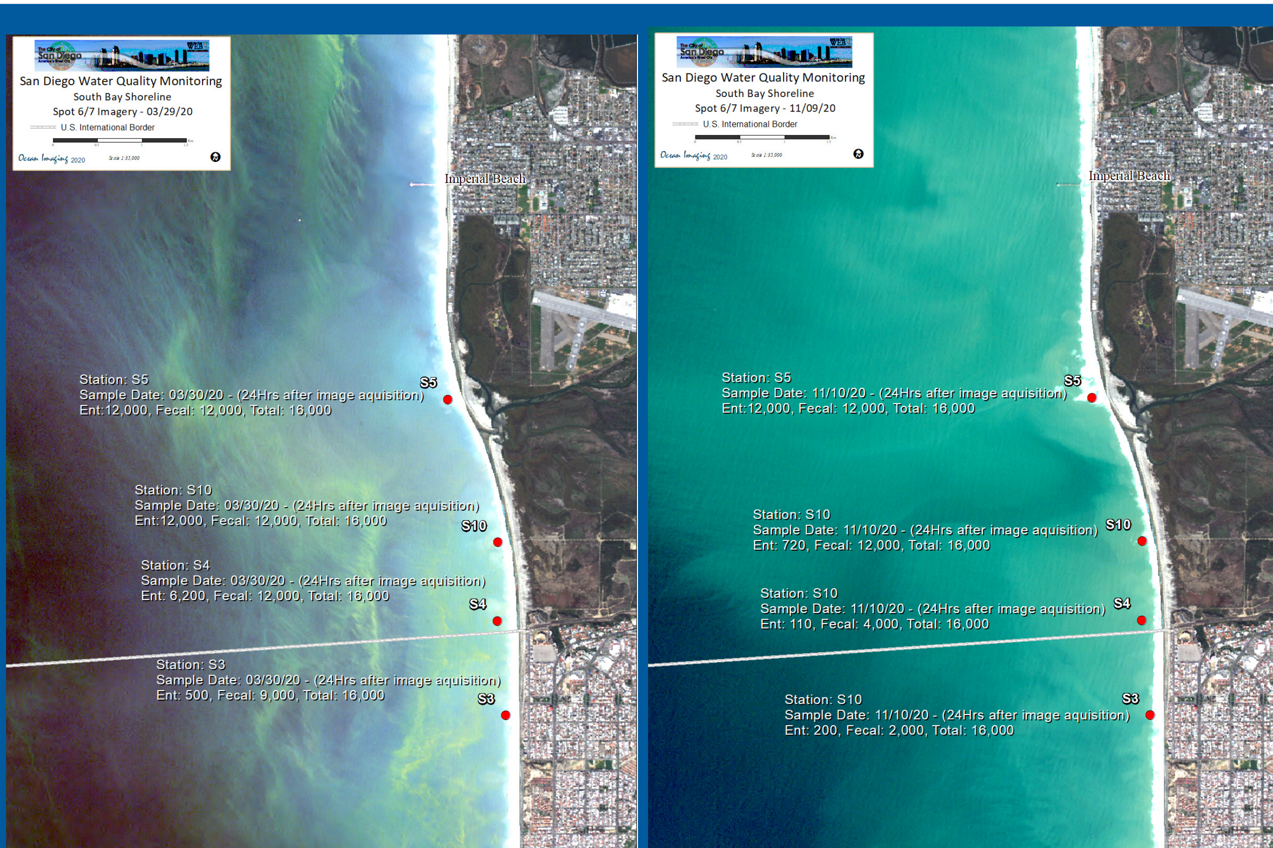


Figure 15. SPOT imagery of the TJR shoreline region with bacteria sample data overlaid. Note elevated bacteria levels along the shore. The offshore stations west of these image areas where the turbidity levels decrease did not show elevated bacteria sample data.

stations recorded high levels. As expected, most of the high bacteria measurements were seen in winter months and attributed to rain events, yet the offshore region did see a few days with elevated levels in August when there was no precipitation. Figure 17 displays samples taken on 11/10/20 and 11/13/20 plotted over a SPOT image from 11/09/20. No obvious visual correlation to the slightly elevated bacteria data exists in the satellite data.

One observation provided by the satellite image archive is the continuing variability in the size of the Point Loma kelp bed (Figure 18). Table 4 shows the area in km^2 of three notable kelp beds in the San Diego region over the past 13 years. The September and October dates were chosen to represent the kelp bed canopy coverage for each year since spring and fall are considered to be the time periods when the canopy size is thought to be at or near its peak. The size of the Point Loma bed in the fall of 2020 (2.93 km^2) increased since its low point in the fall of 2016, however was significantly smaller than measured in the fall of 2019 as well as most of the years prior to 2016. As previously reported in previous years, the satellite data show the bed begin to decrease in size during February of 2016, perhaps due to the storm events taking place during early to mid-January or effects from the 2014-2016 El Niño event or the Northeast Pacific marine heat wave (Di Lorenzo, 2016). Noted in the OI 2017 and 2018 annual reports, the kelp bed appeared to be coming back in January of 2017, but then decreased in size as

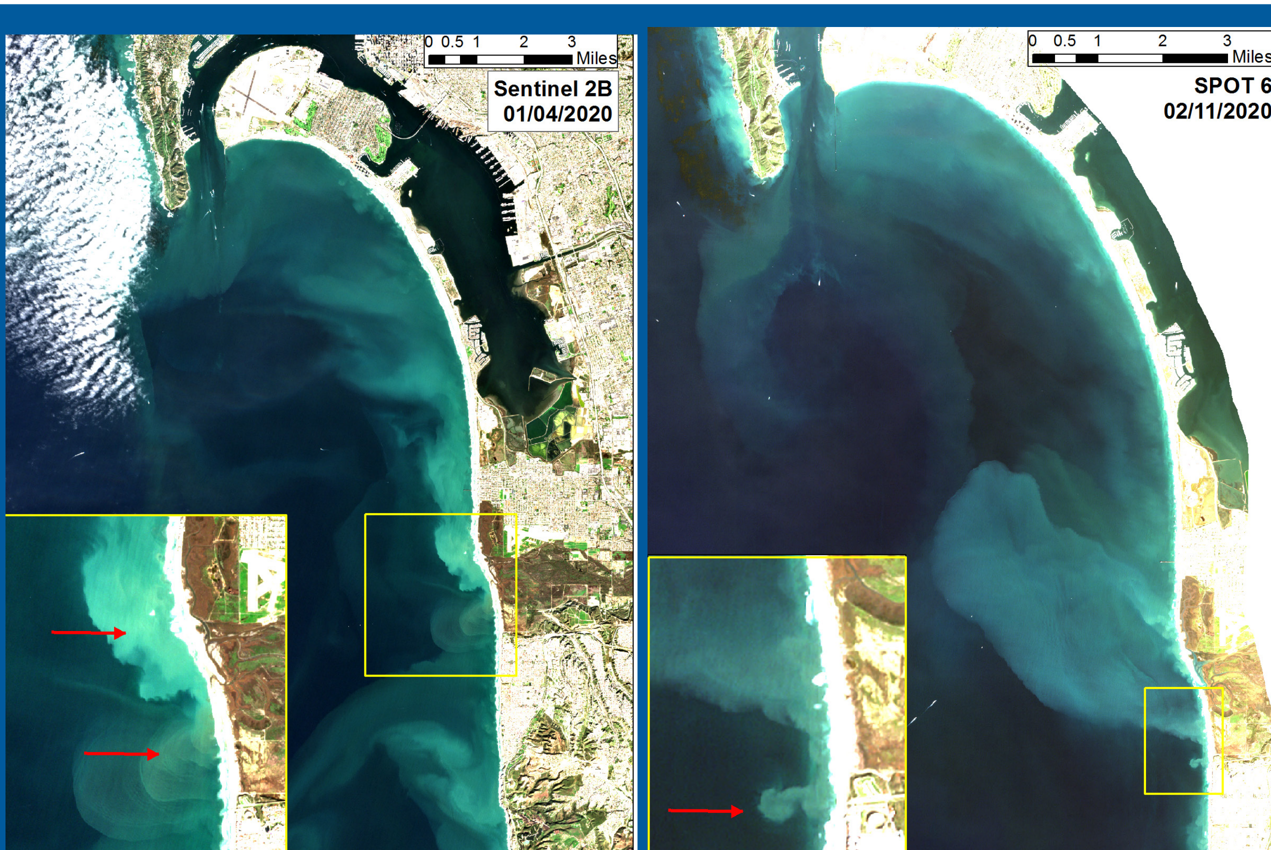


Figure 16. Sentinel 2B (left) and SPOT (right) satellite imagery from January and February of 2020 showing an apparent shoreline split in the TJR runoff plume as well as locations where there looks to be discharge origins outside of the normally expected river mouth area. Heavy rainfall events occurred prior to both of the satellite data acquisition dates.

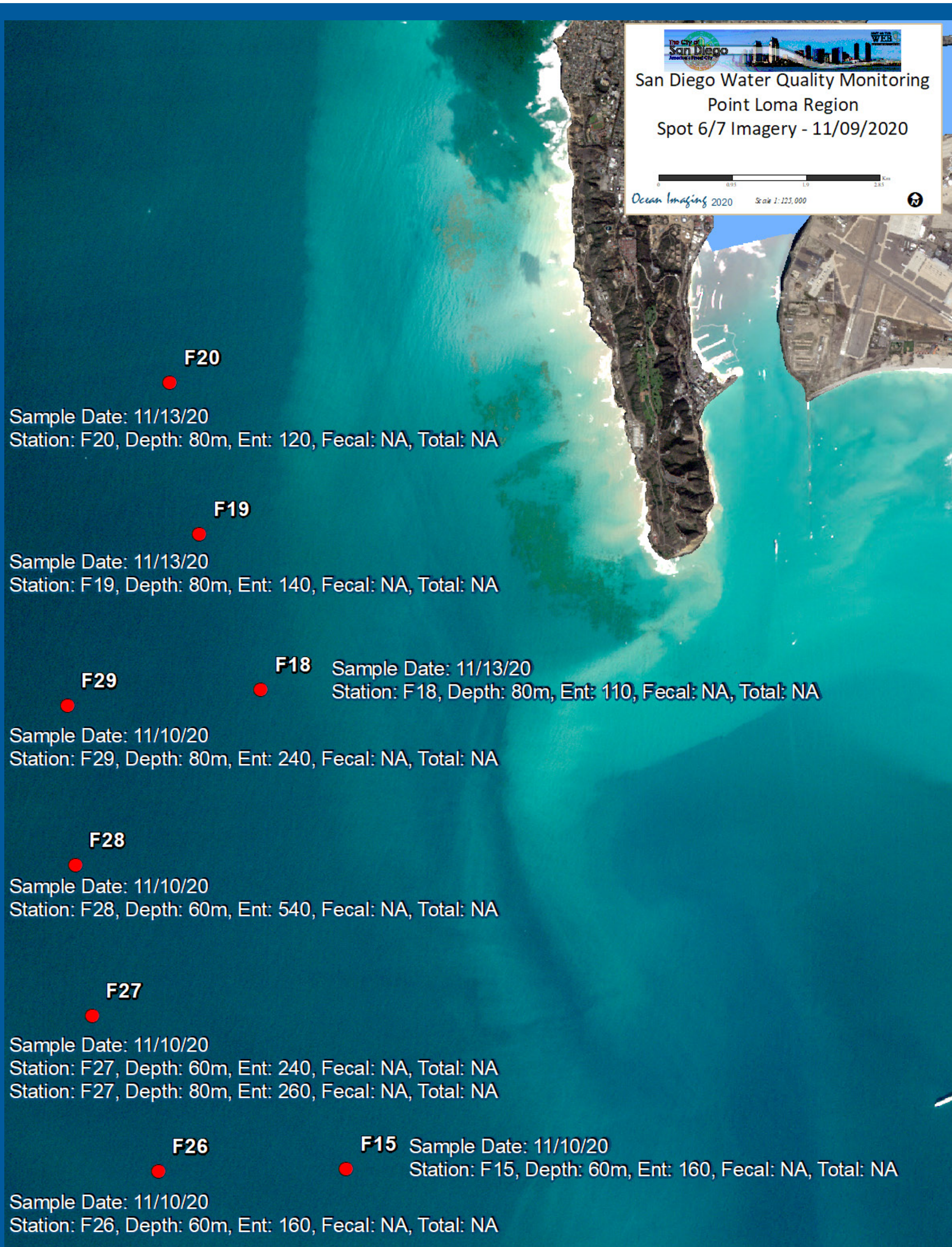


Figure 17. Bacteria on 11/10/20 and 11/13/20 plotted over a SPOT image from 11/09/20.

the year progressed resulting in much smaller than average canopy coverage by the end of that year. During 2020, the Point Loma bed showed quite a bit of month-to-month variability, similar to 2018. In the beginning of the year, the bed roughly held the canopy size documented in the 2019 report, however the areal coverage of the exposed canopy decreased significantly during the months of March through May; stabilizing during the summer months to approximately to the size noted in Table 4; increasing in size through November, and then dropping in coverage again by the end of December (Figure 19).

It is important to point out that the canopy coverages shown in Table 4 may differ slightly from those provided in the Southern California Bight Regional Aerial Kelp Survey reports. This is because the canopy areas for the Point Loma bed computed for those reports are averages of four surveys performed throughout the year and the coverage estimates shown in this report are taken from single satellite images acquired during the fall time period. Tide levels were not a factor in the inter-year comparison as there was little variability in tide level between the years (often approximately one foot or less). However, due to the overflight times of these satellites, the canopy areas could be underrepresented because the tide levels at the time of data acquisition were not optimal for mapping kelp. This may also be another factor if canopy coverage estimates vary between this report and the Southern California Bight Regional Aerial Kelp Survey reports. It is being documented that kelp forests along the West Coast have been in decline in some areas and so this warrants keeping a close watch on the health of the kelp beds in the San Diego region (Bell, et al., 2020; Schroeder, 2019).

References:

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

			Kelp (km^2)		
Year	Date	Satellite	Point Loma	Imperial Beach	Tijuana
2020	09/22/2020	Sentinel 2A	2.93	0.00	0.00
2019	09/18/2019	Sentinel 2A	5.17	0.00	0.00
2018	10/16/2018	Sentinel 2A	2.44	0.00	0.00
2017	10/04/2017	RapidEye	1.05	0.00	0.00
2016	09/08/2016	RapidEye	0.22	0.00	0.00
2015	09/17/2015	Landsat 7	4.11	0.39	0.29
2014	09/14/2014	Landsat 8	5.42	0.59	0.30
2013	09/23/2013	RapidEye	5.89	0.19	0.05
2012	09/15/2012	RapidEye	2.91	0.00	0.00
2011	09/01/2011	RapidEye	1.99	0.00	0.00
2010	09/27/2010	Landsat 7	6.01	0.00	0.00
2009	09/16/2009	Landsat 5	5.96	1.01	0.21
2008	09/05/2008	Landsat 7	8.66	0.82	0.01

Figure 18. The Point Loma kelp bed as observed in high-resolution satellite imagery for the years 2012-2020 (top to bottom). September and October dates were chosen to represent the kelp bed canopy coverage for each year since that time period is when the canopy size is thought to be at or near its peak.

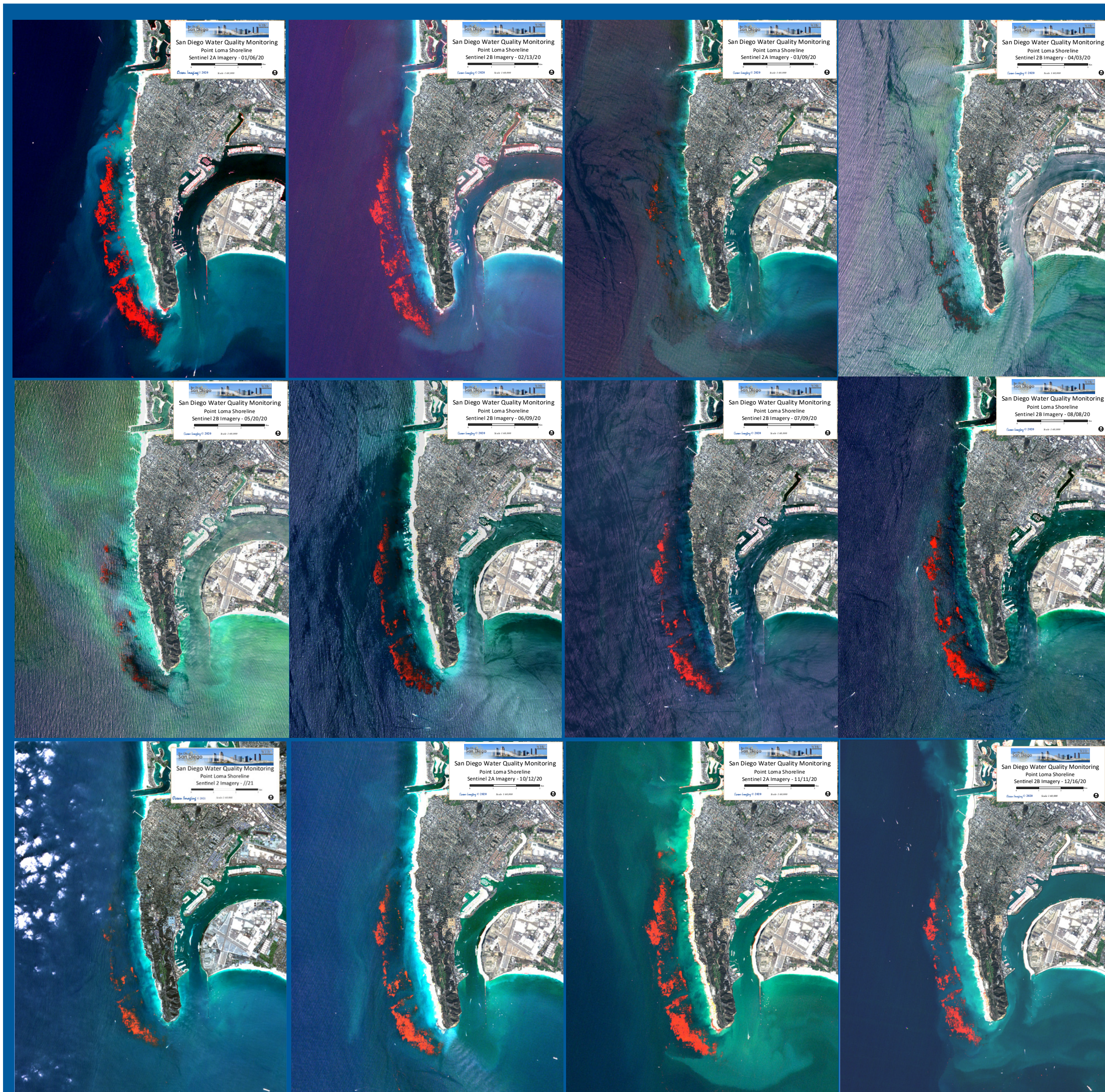


Figure 19. Sentinel 2 satellite imagery documenting the month-to-month variability in the Point Loma kelp bed canopy coverage. The dates were chosen to best represent the maximum-observed canopy coverage for each month.

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.

Di Lorenzo, E., Mantua, N. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Clim Change 6, 1042–1047 (2016). https://doi.org/10.1038/nclimate3082

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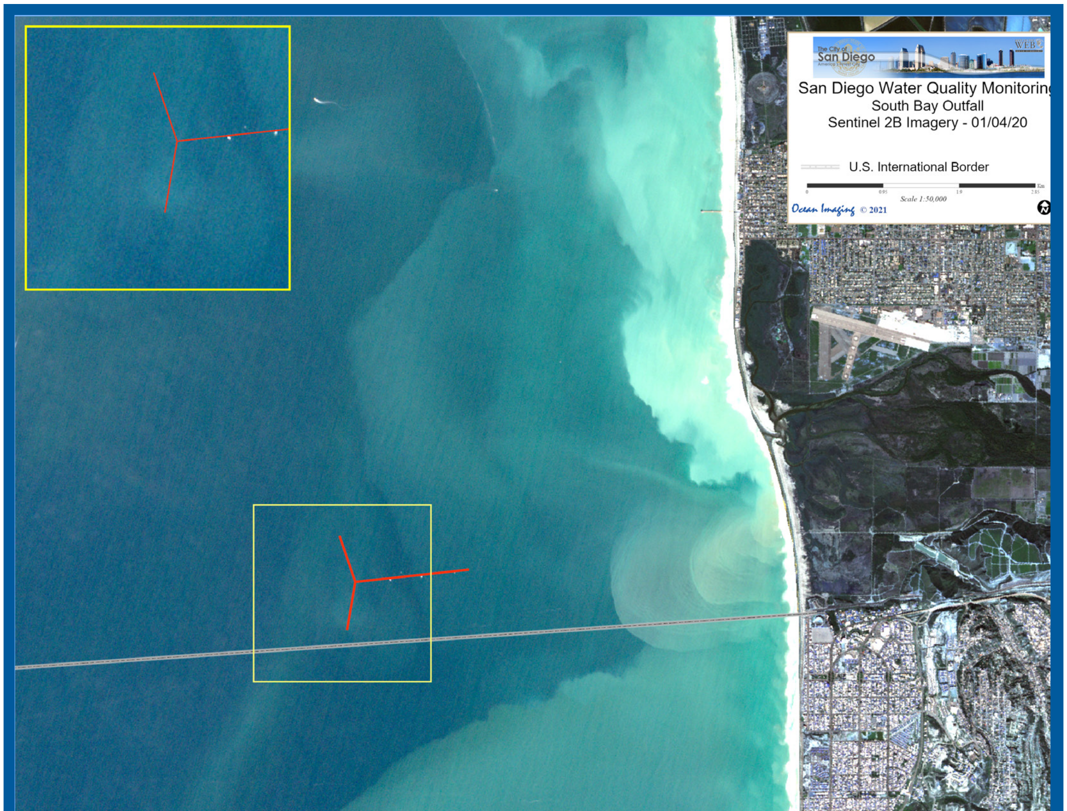
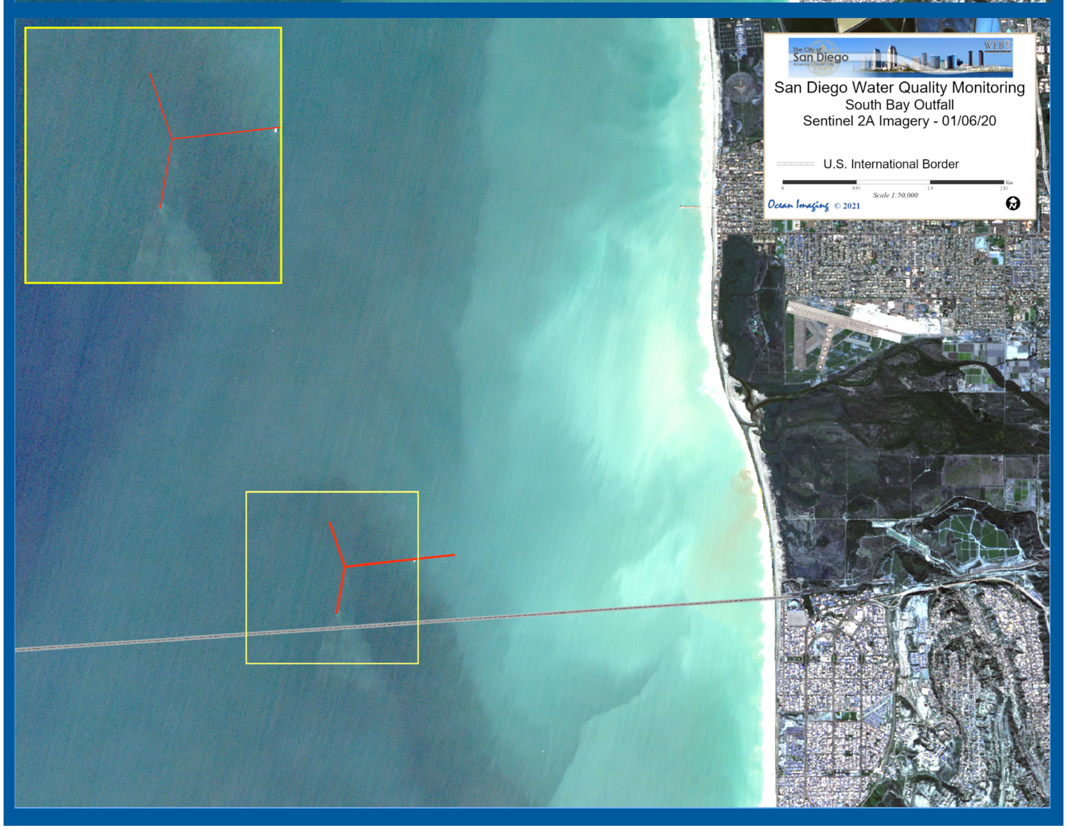
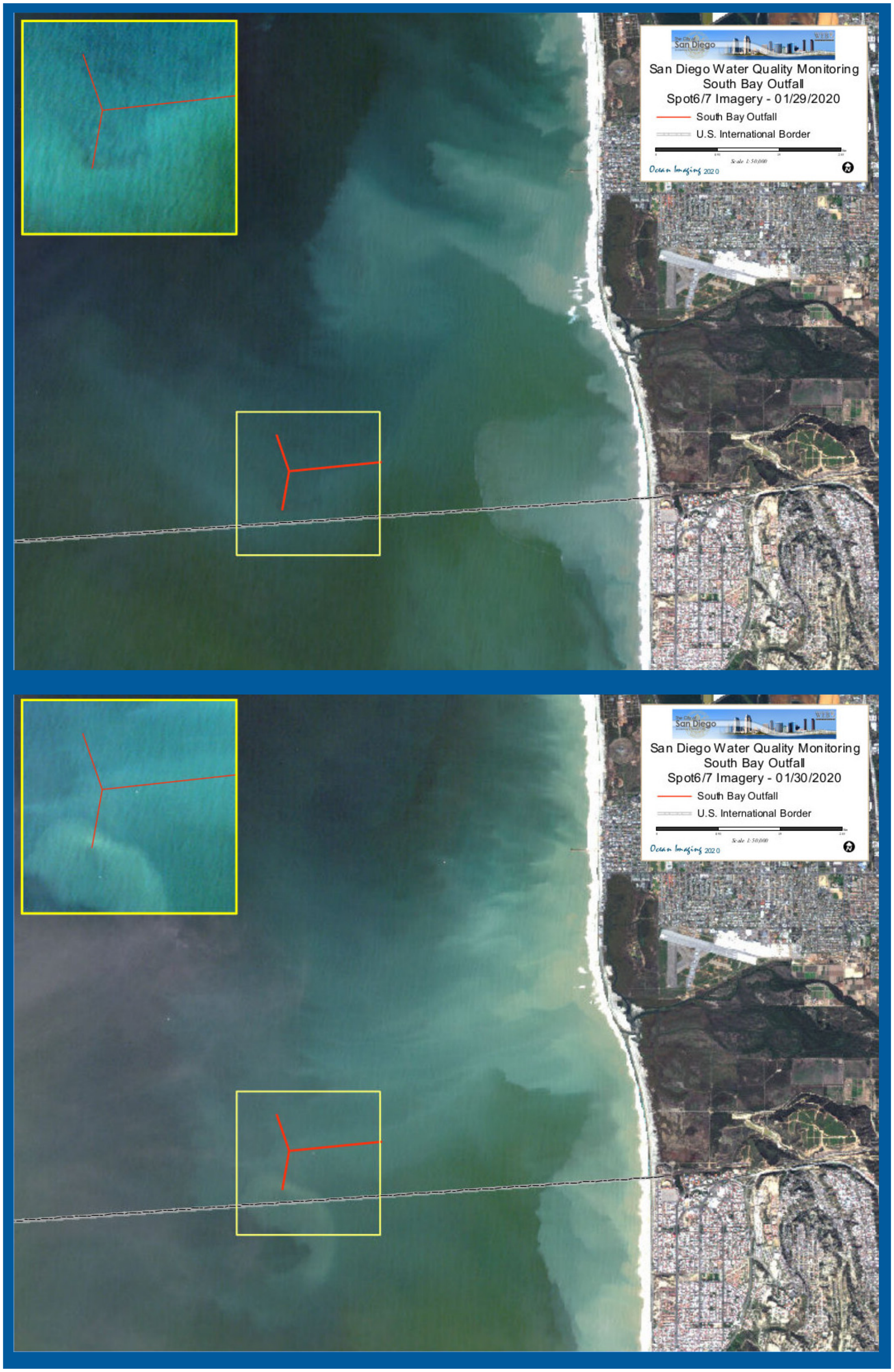
Schroeder, Sarah B., et al. "Passive Remote Sensing Technology for Mapping Bull KELP (NEREOCYSTIS Luetkeana): A Review of Techniques and Regional Case Study." Global Ecology and Conservation, vol. 19, 2019, doi:10.1016/j.gecco.2019.e00683.

"Southern California Bight Regional Aerial Kelp Surveys." MBC Aquatic, 2020, www. mbcaquatic.com/reports/southern-california-bight-regional-aerial-kelp-surveys.

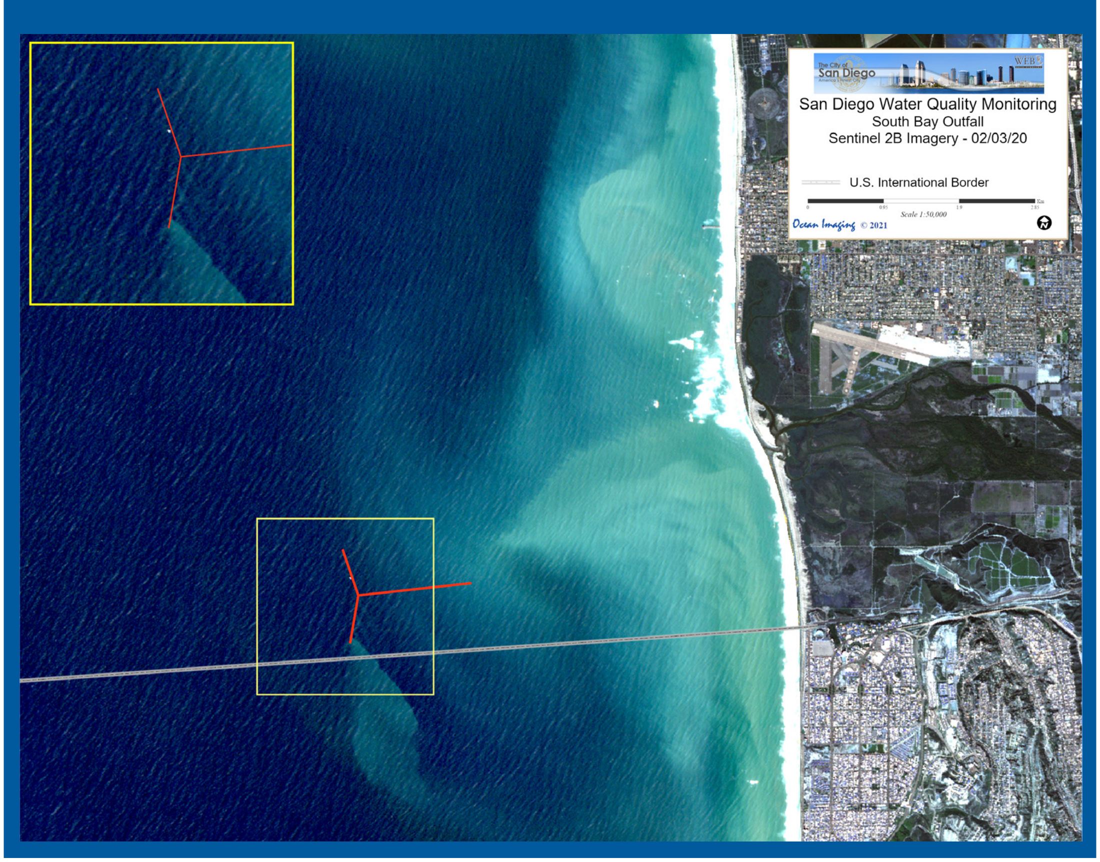
APPENDIX A – HIGH RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED WASTEWATER PLUME FROM JANUARY-DECEMBER 2020

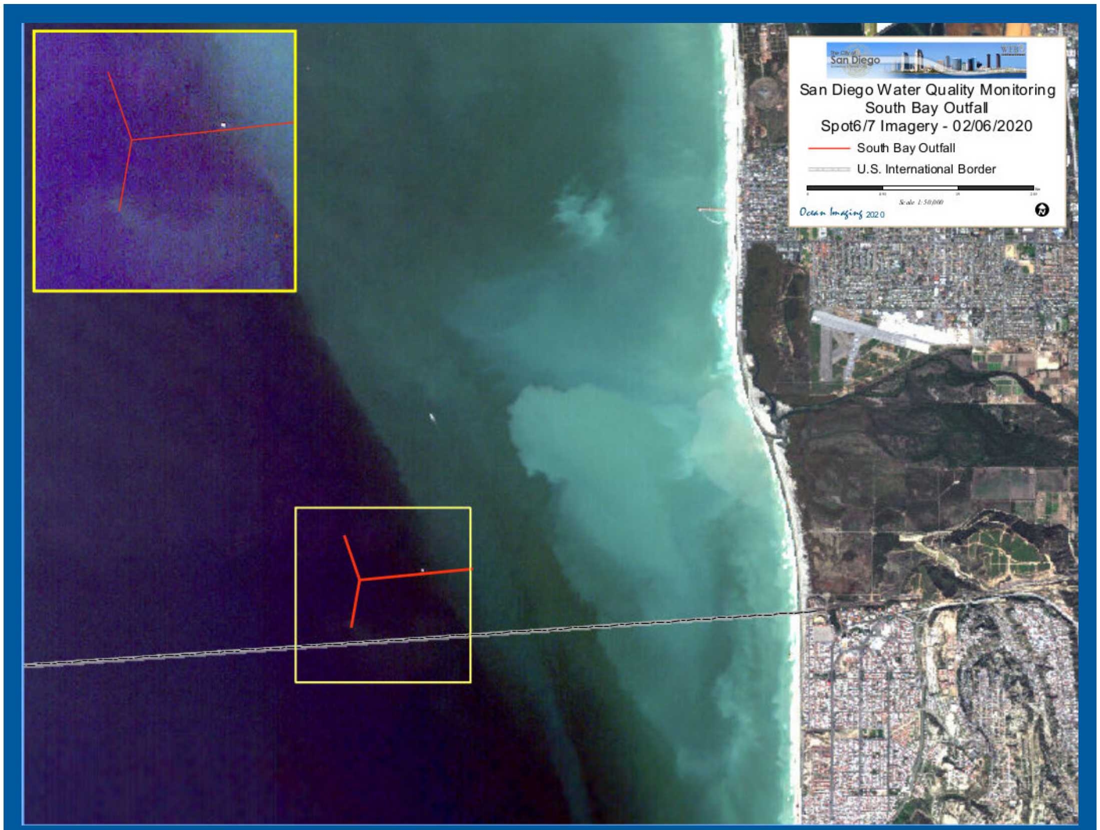





San Diego Water Quality Monitoring
South Bay Outfall
Spot6/7 Imagery - 01/29/2020
South Bay Outfall
U.S. International Border
Ocean Imaging 2020
San Diego Water Quality Monitoring
South Bay Outfall
Spot6/7 Imagery - 01/30/2020
South Bay Outfall
U.S. International Border
Ocean Imaging 2020


San Diego Water Quality Monitoring
South Bay Outfall
Landsat 8 Imagery - 02/03/20
U.S. International Border
Ocean Imaging © 2021


San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 02/03/20
U.S. International Border
Ocean Imaging © 2021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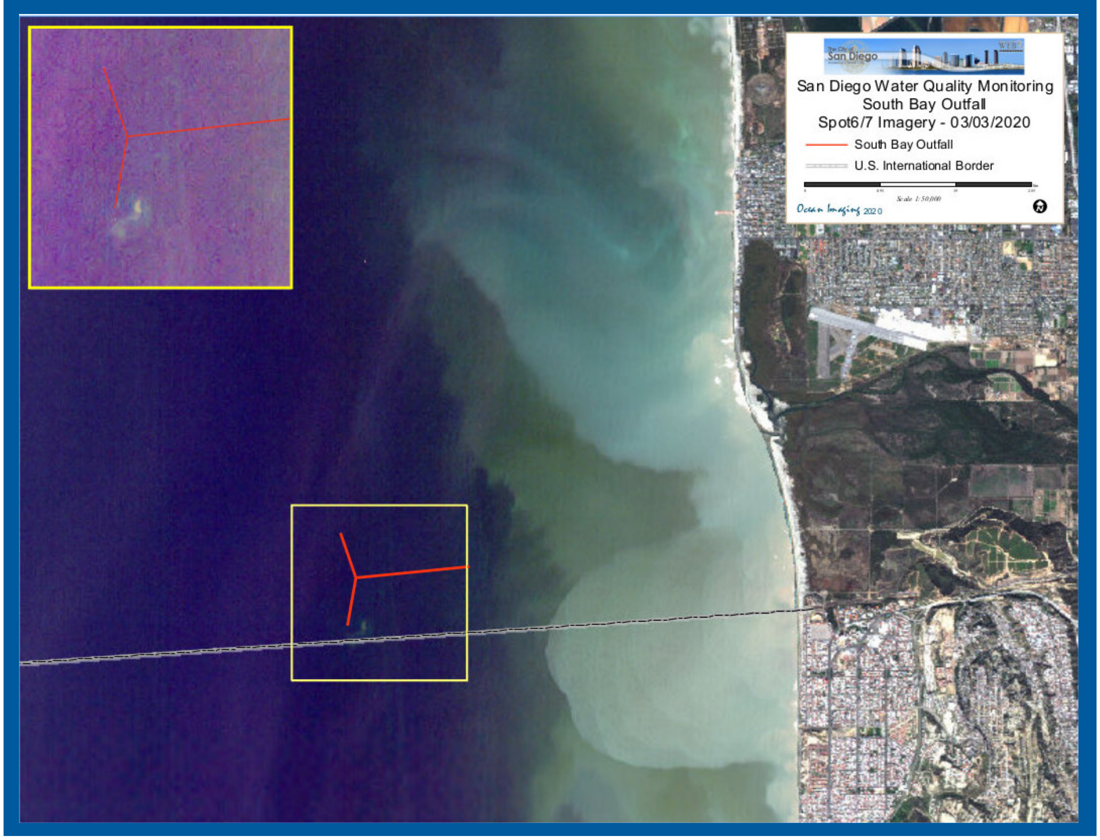
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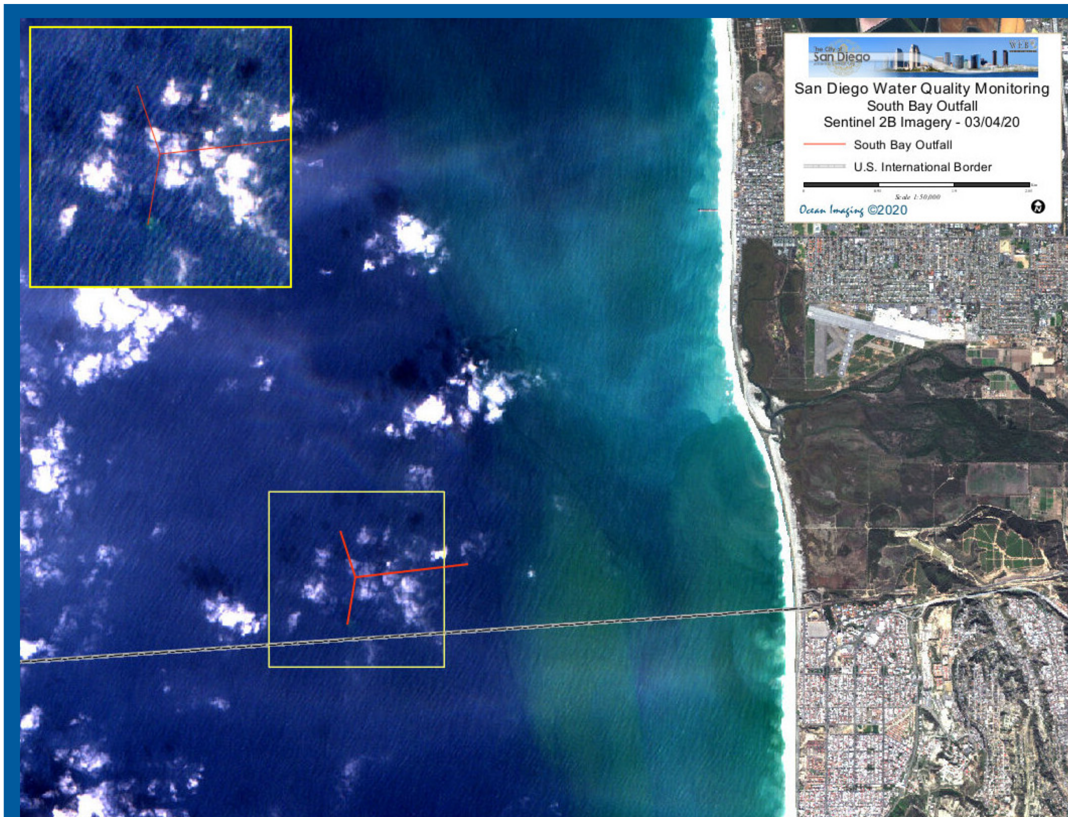
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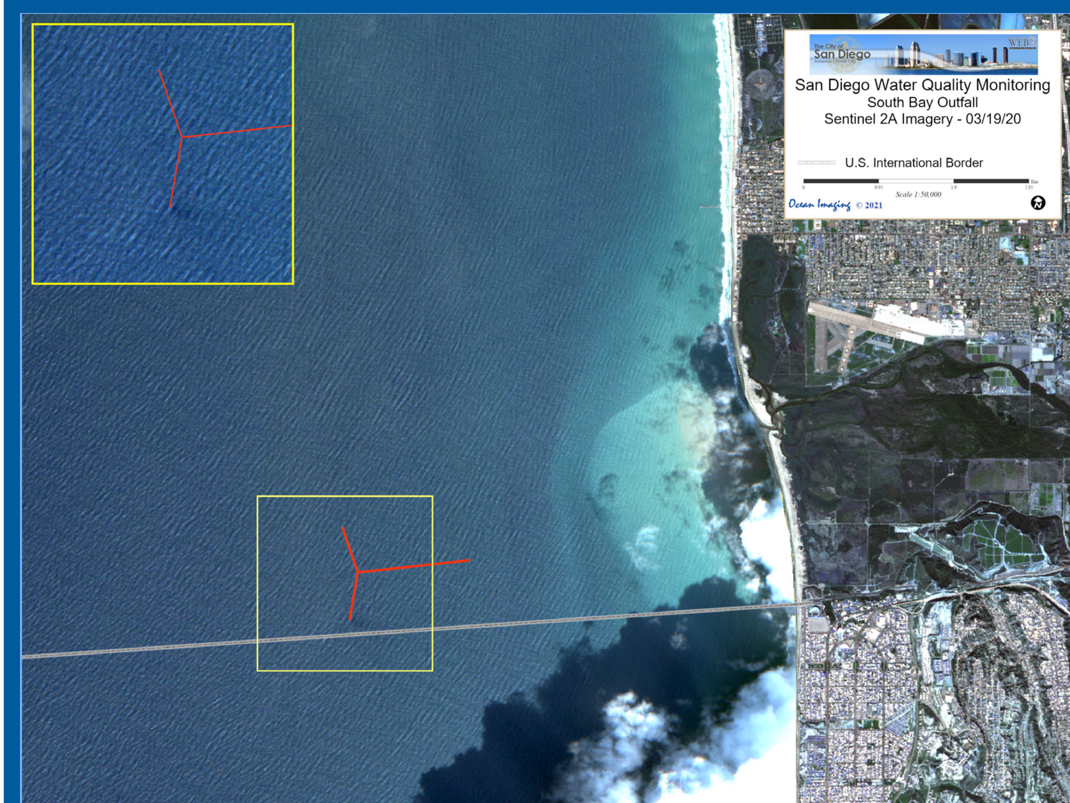
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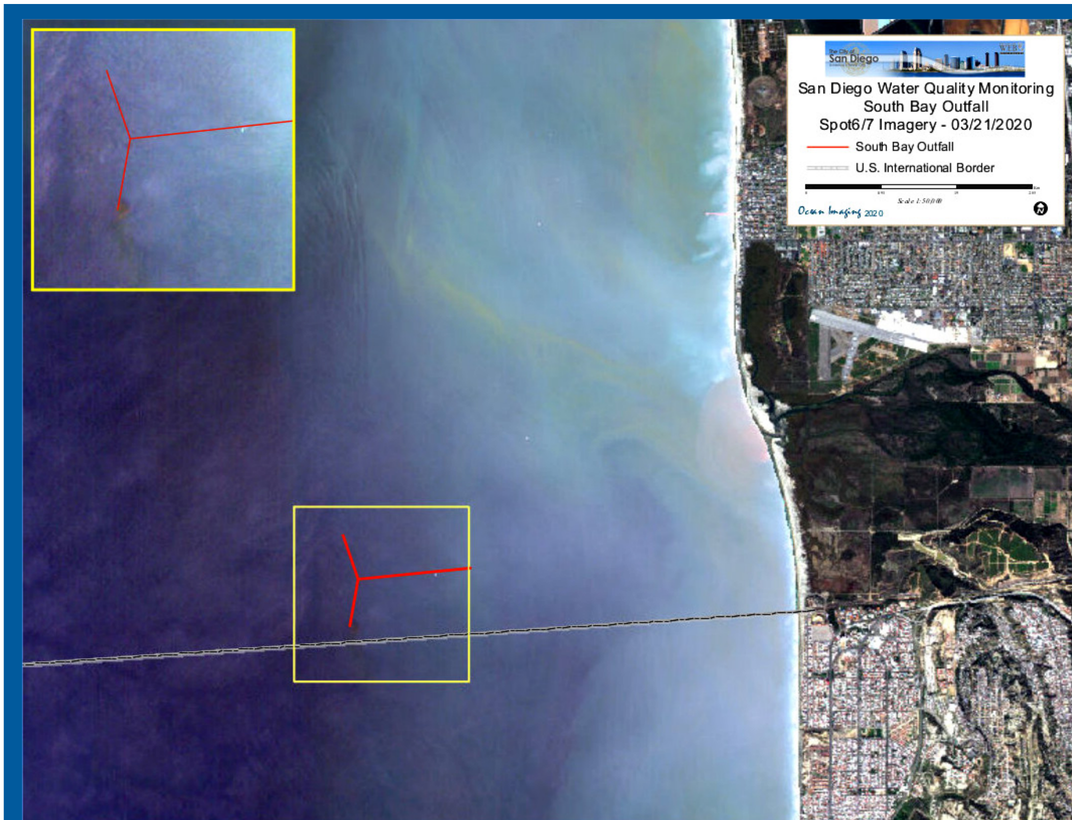
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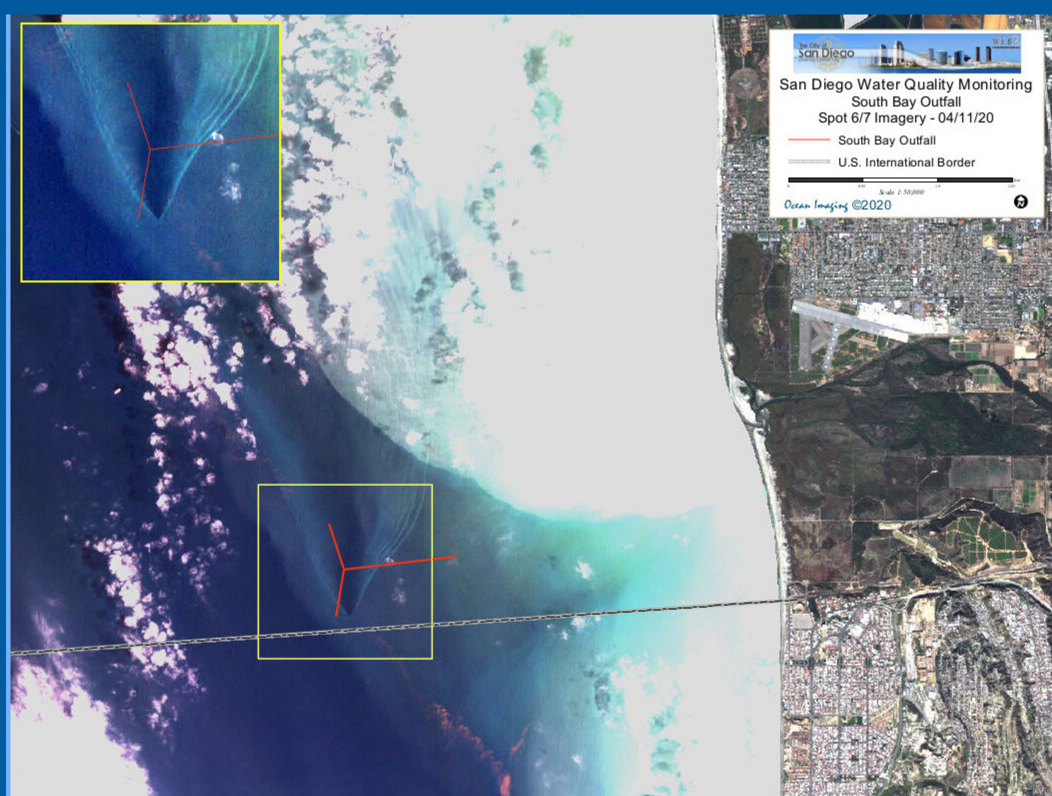
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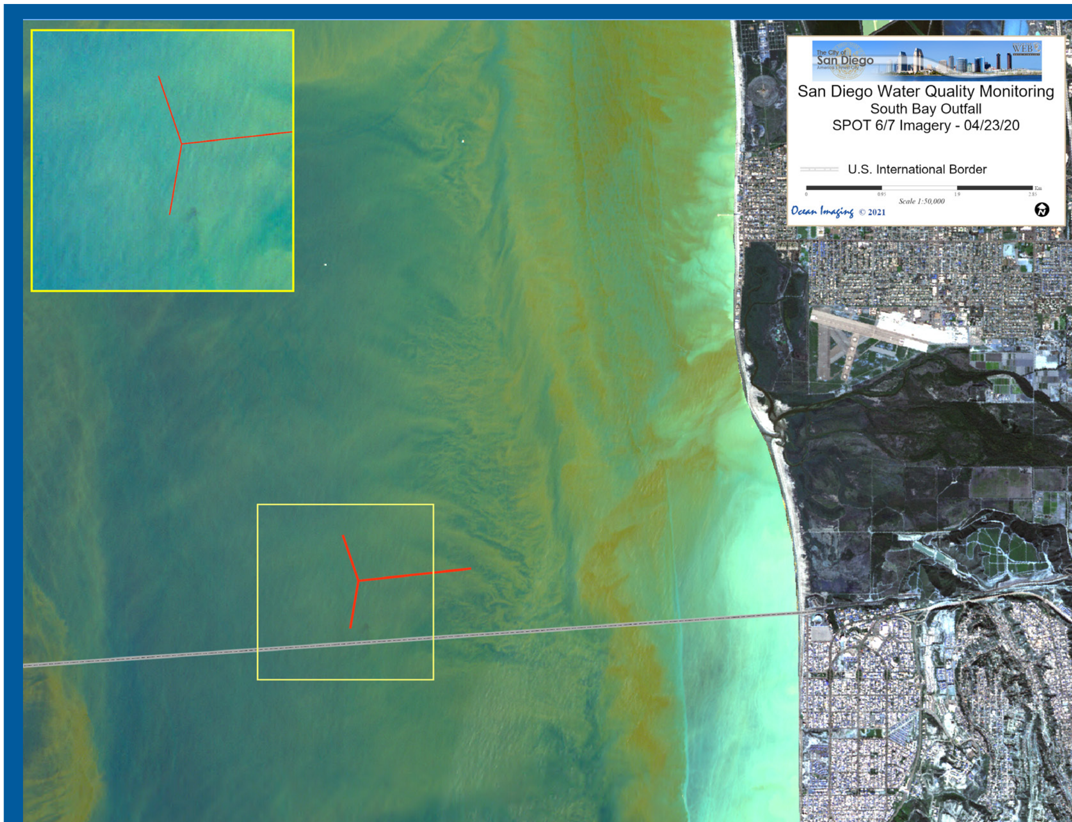
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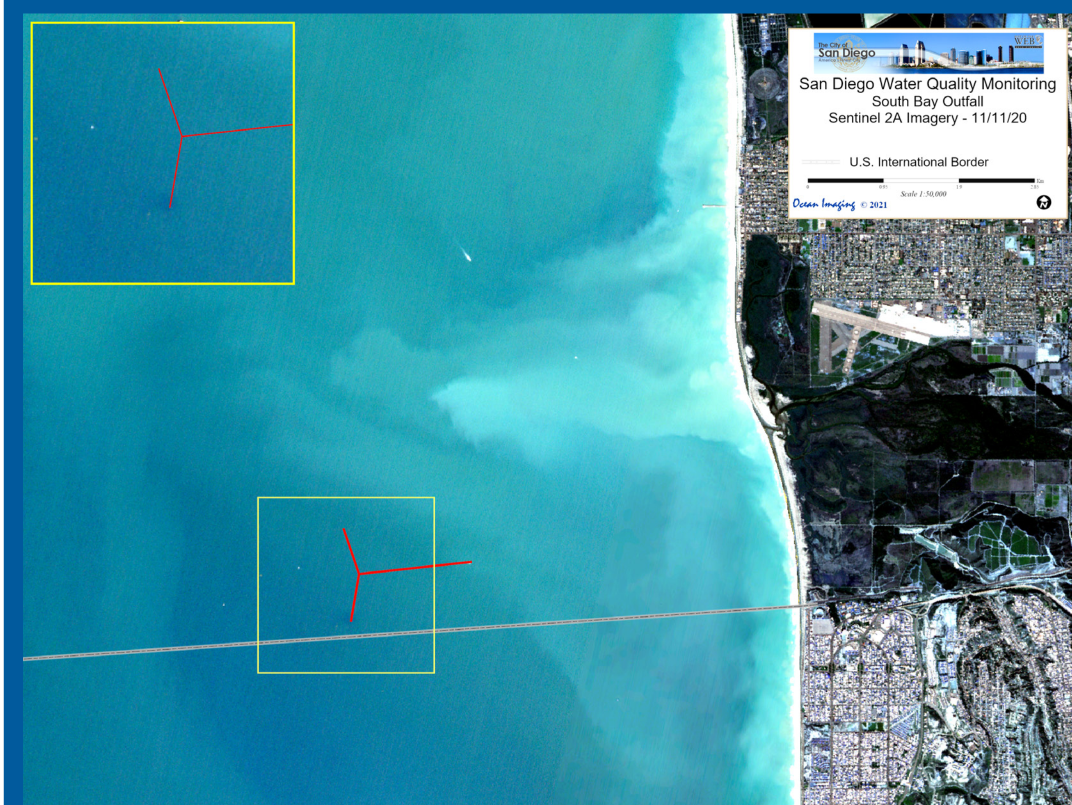
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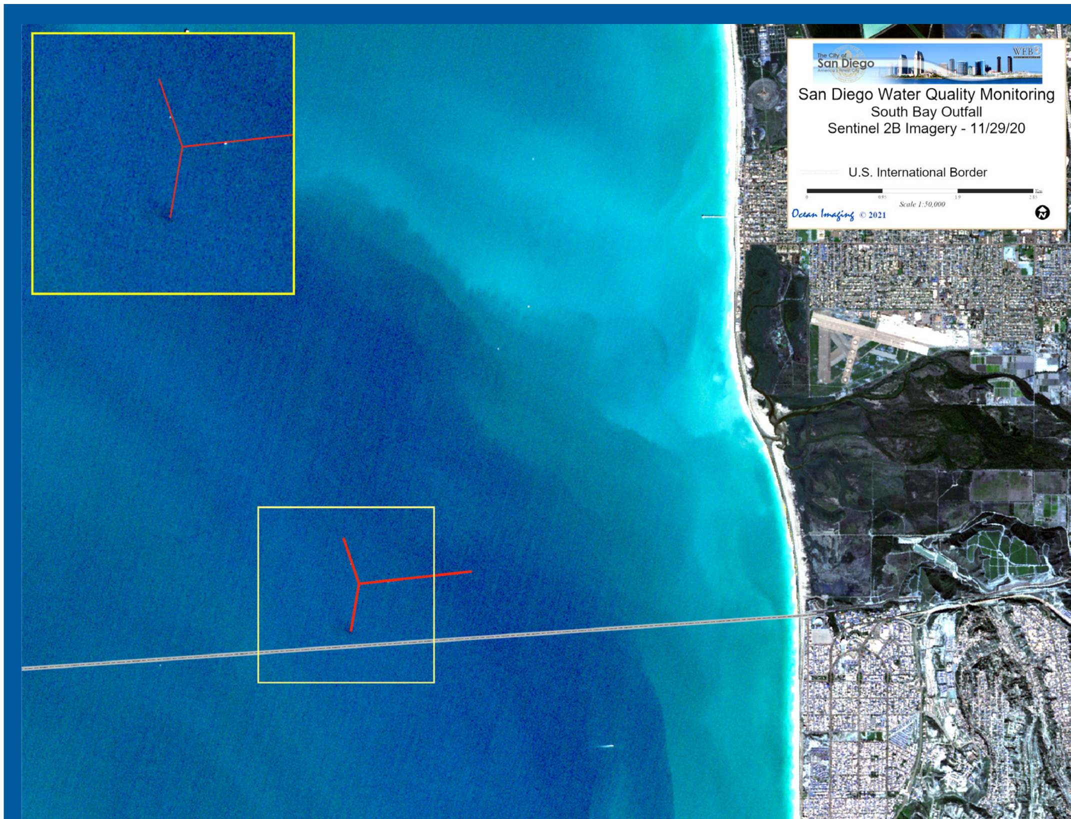
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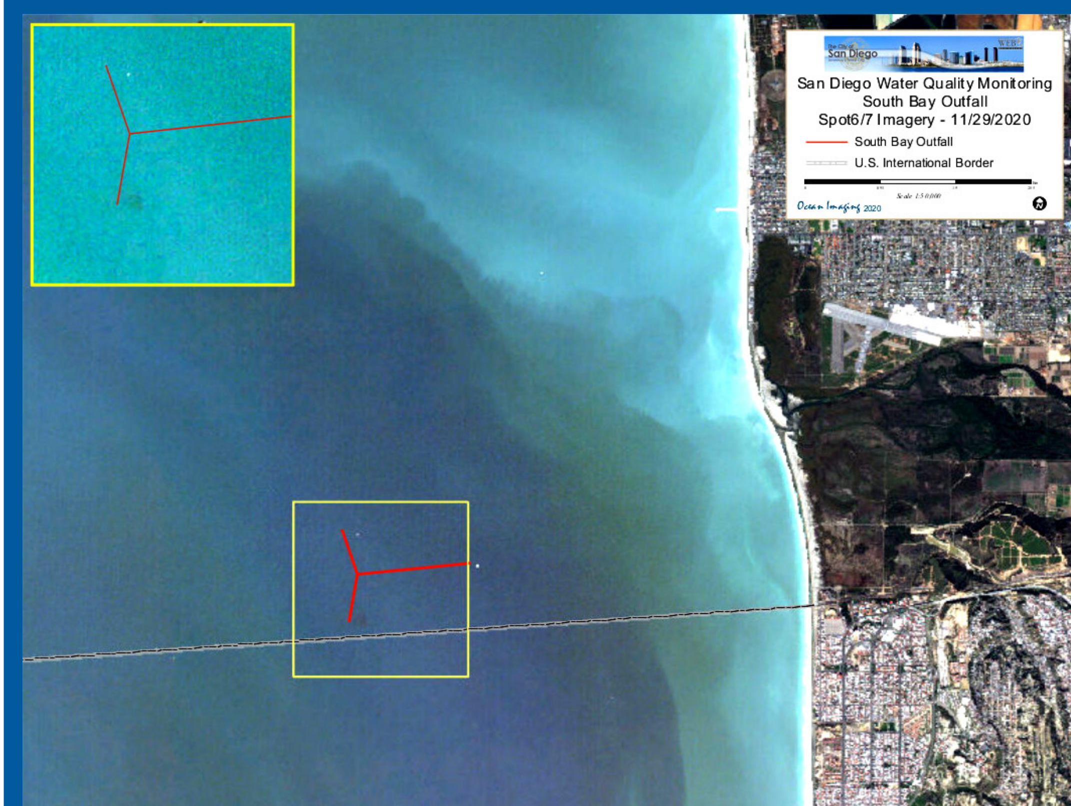
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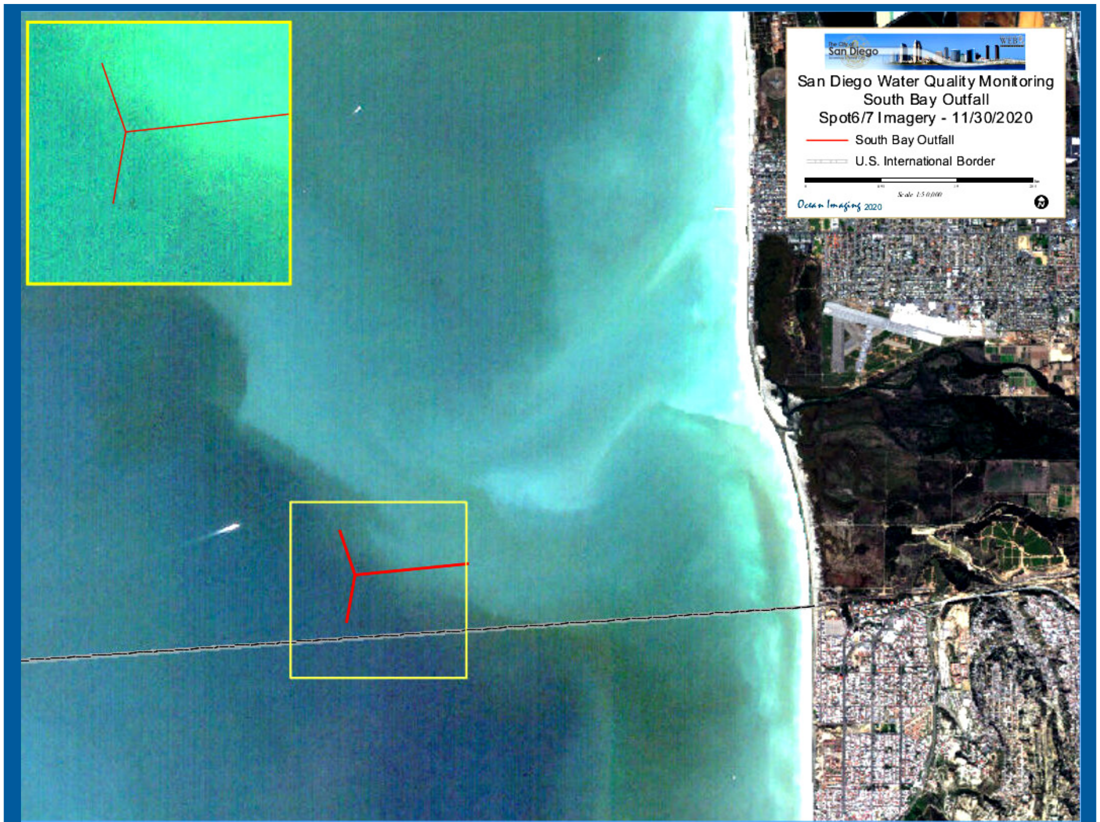
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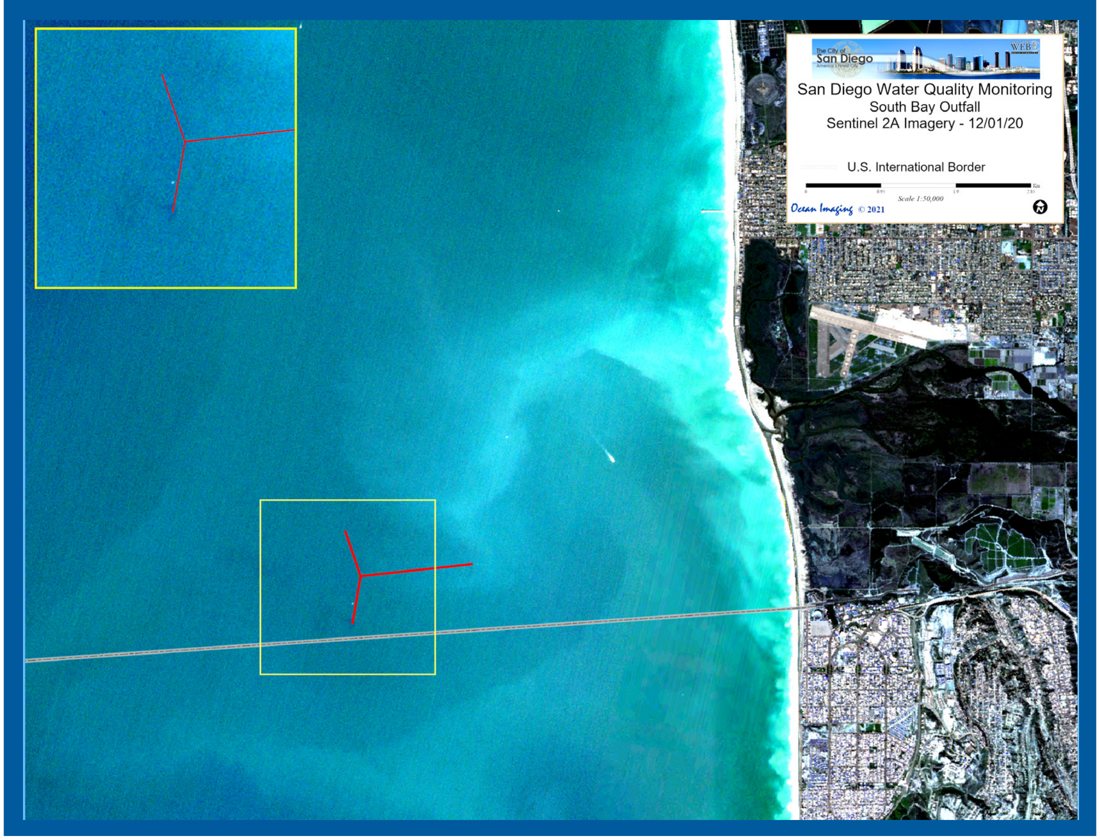
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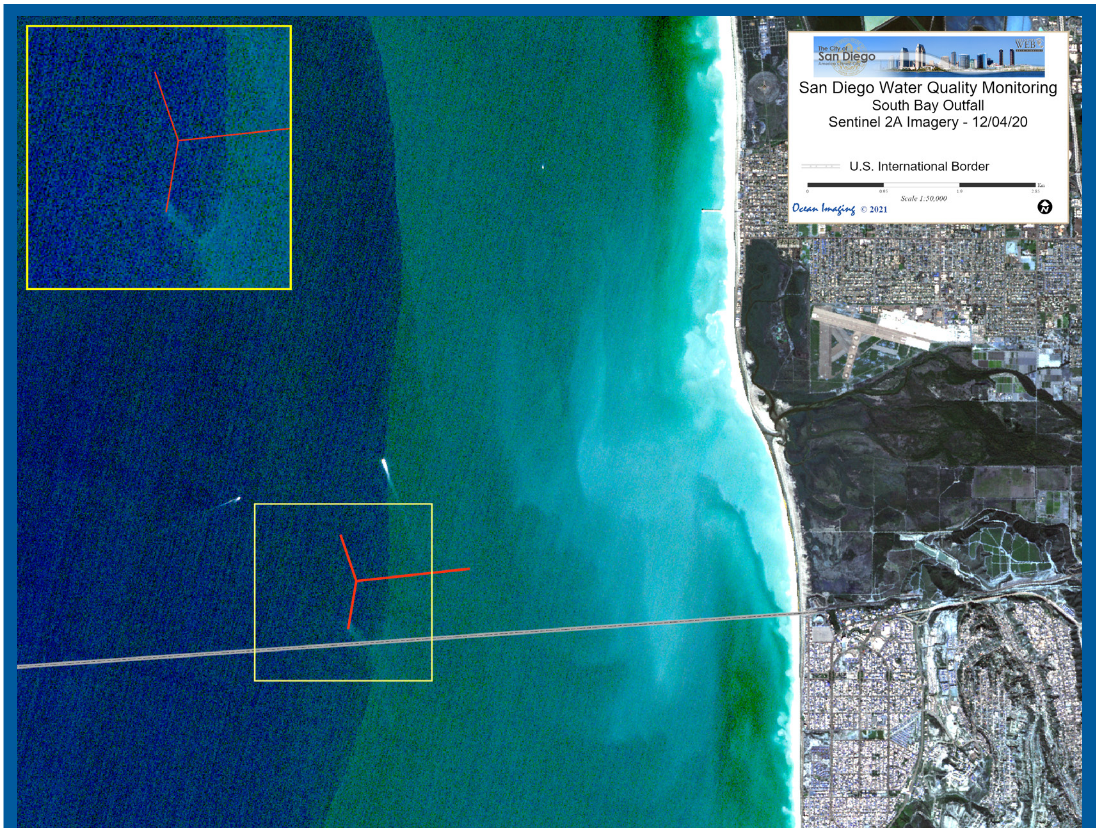
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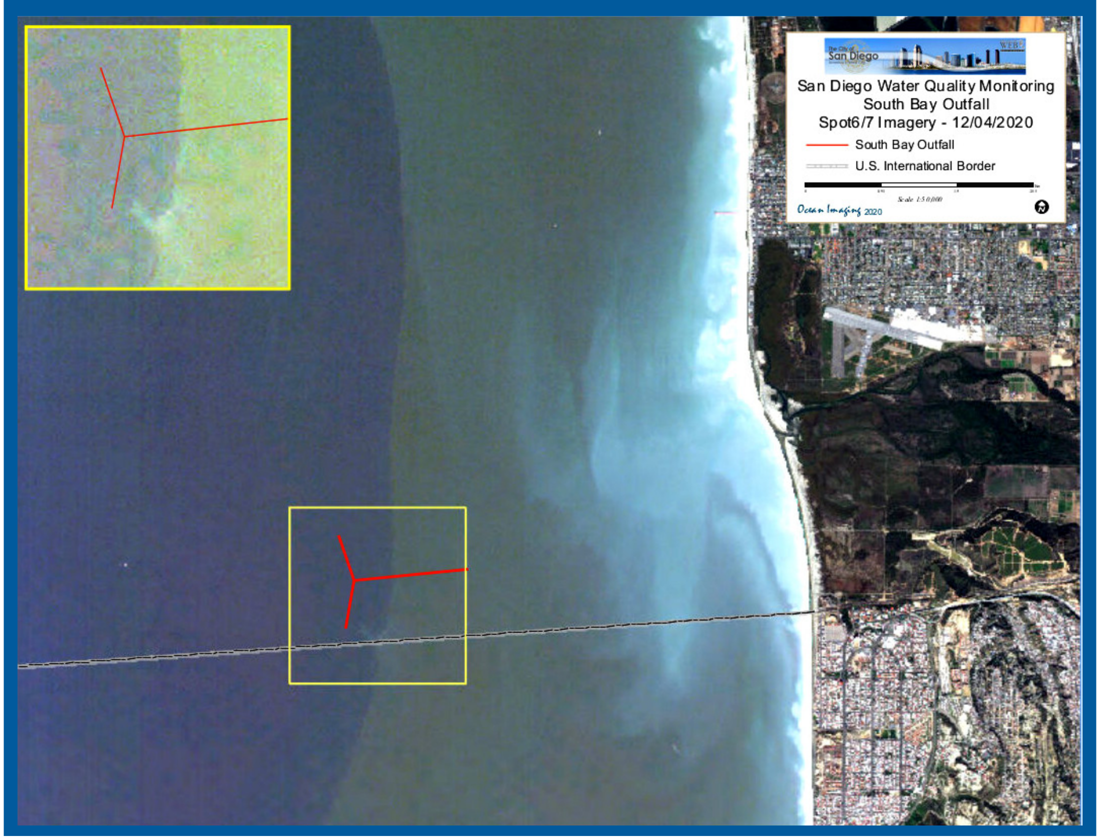
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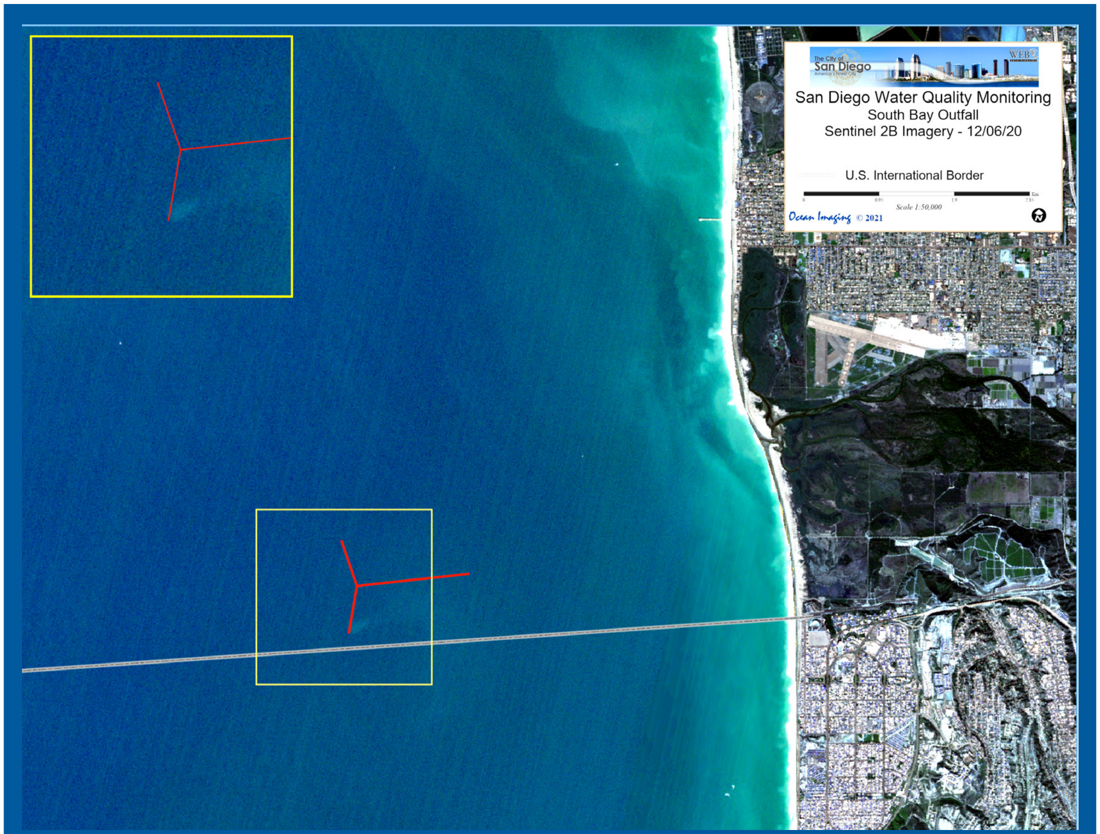
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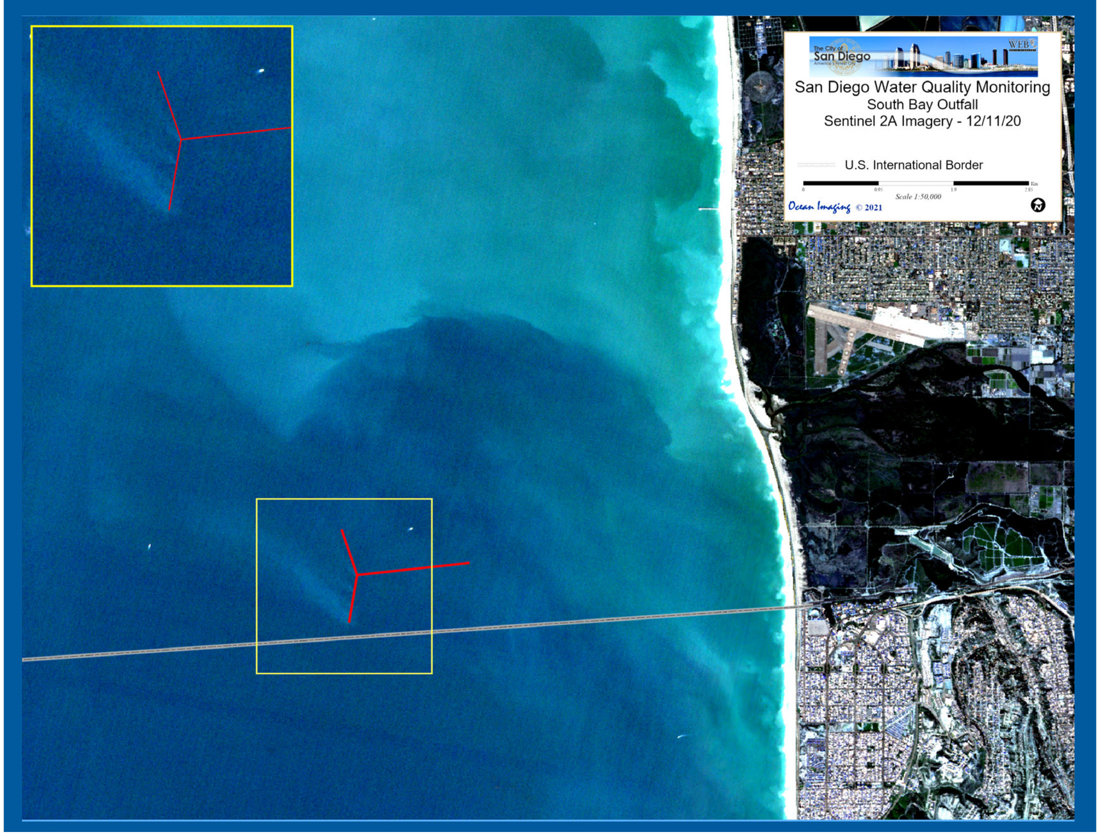
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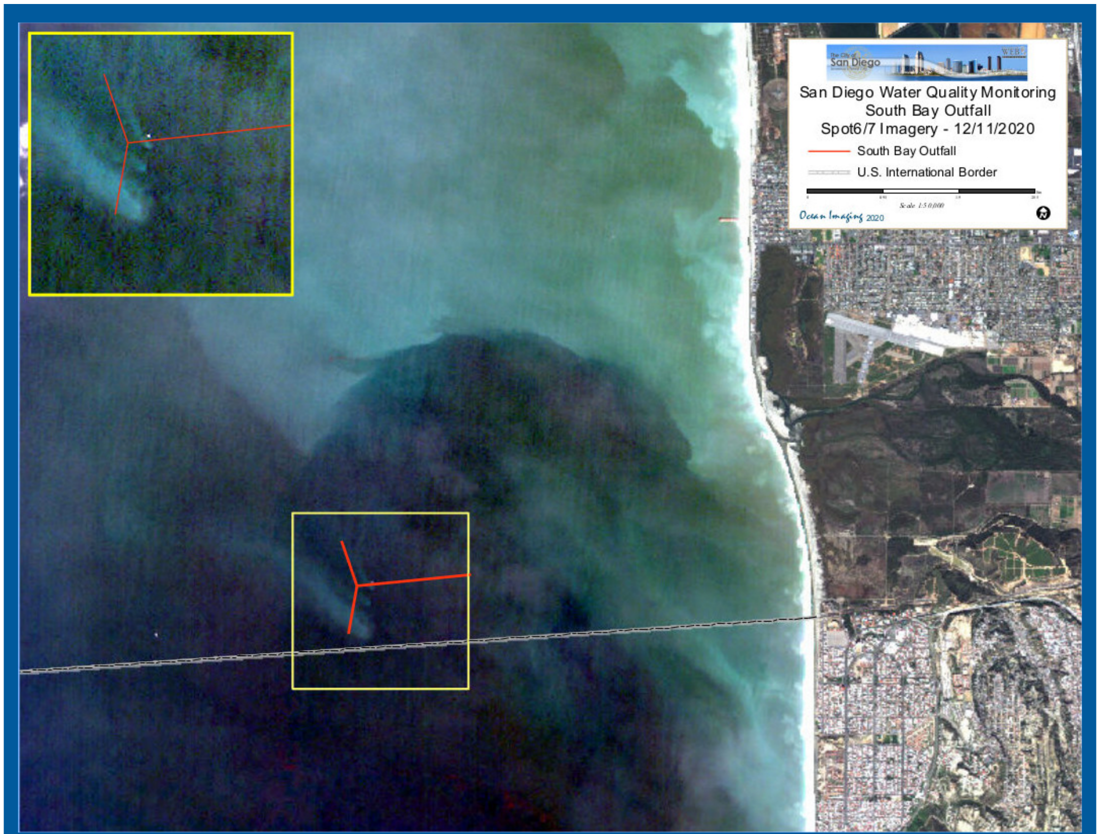
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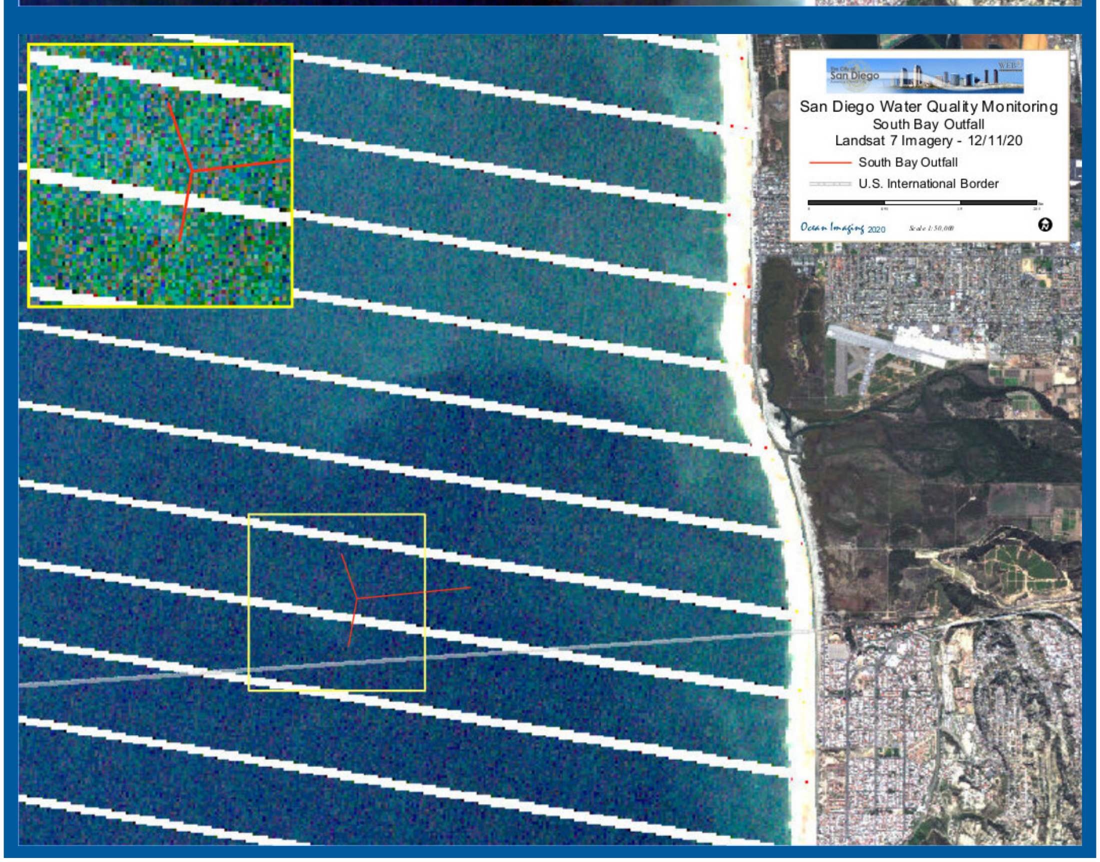
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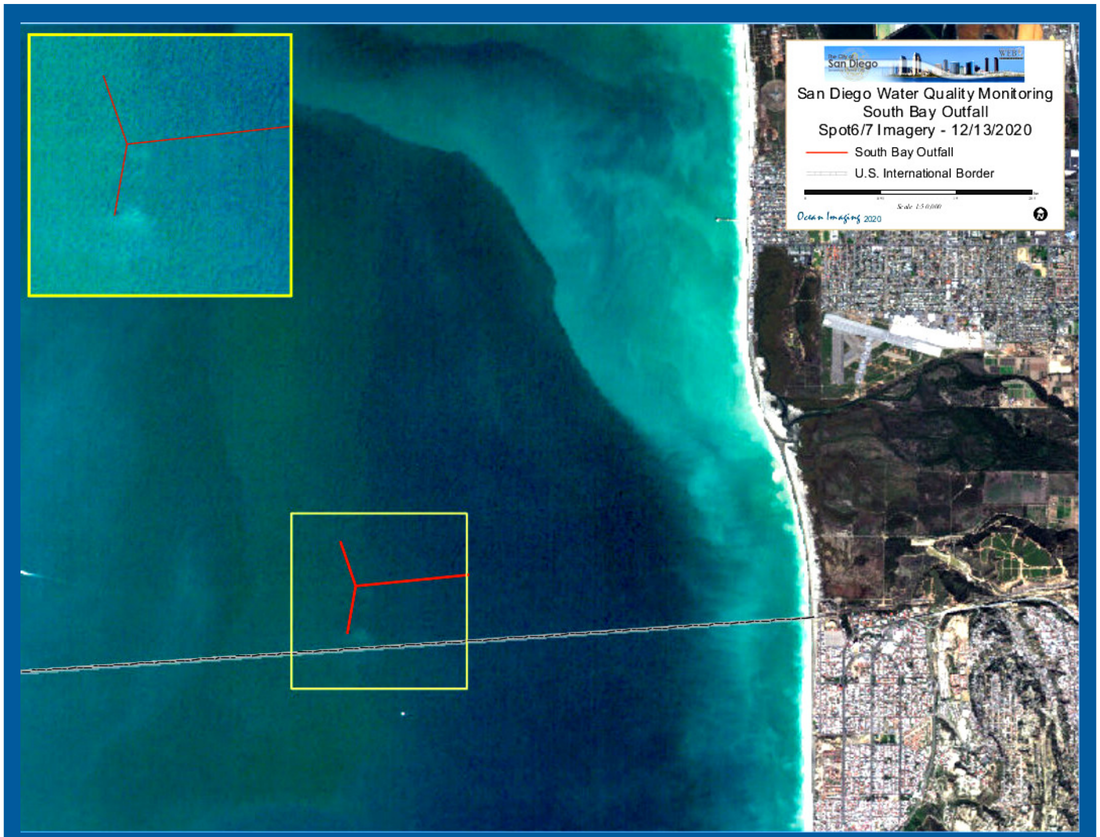
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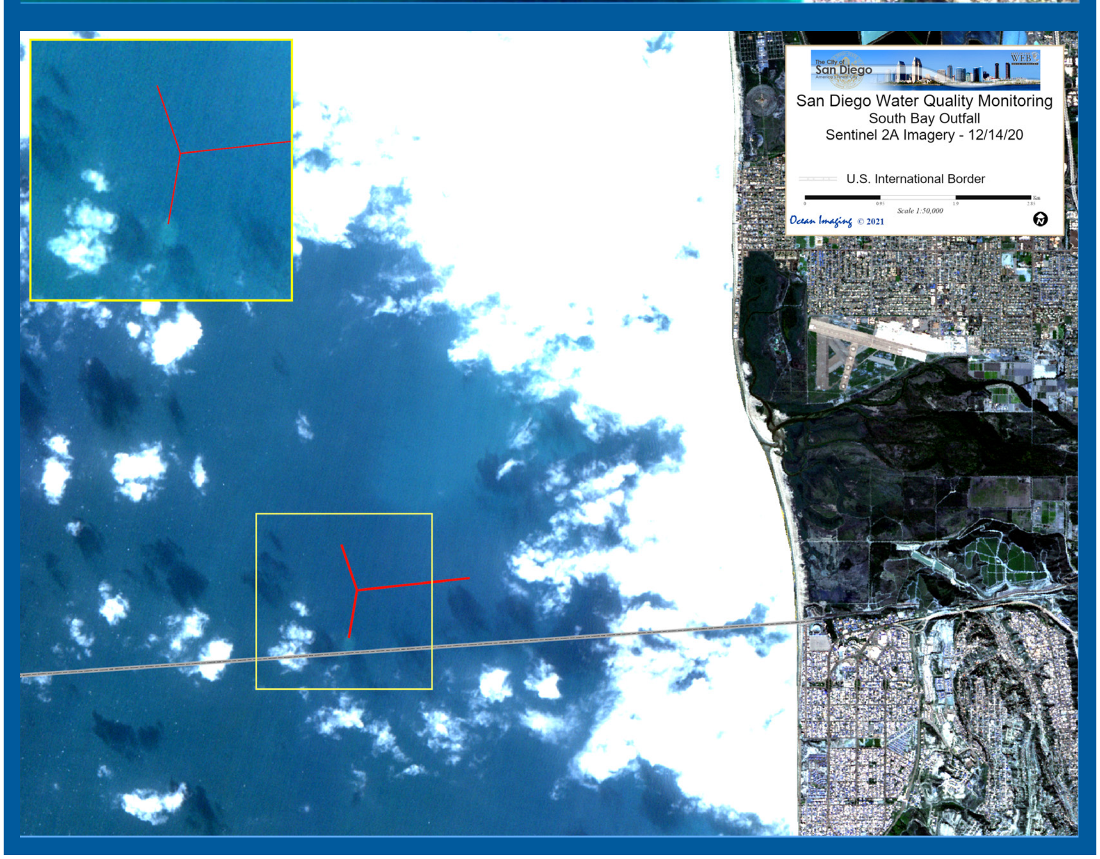
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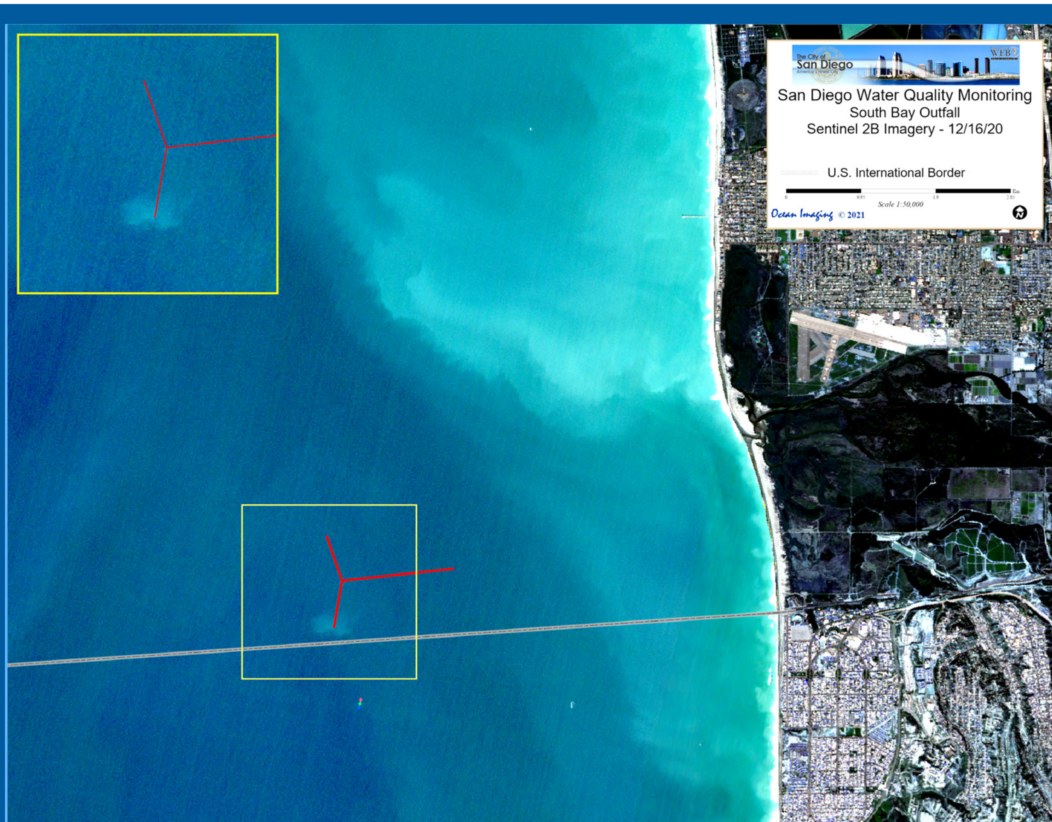
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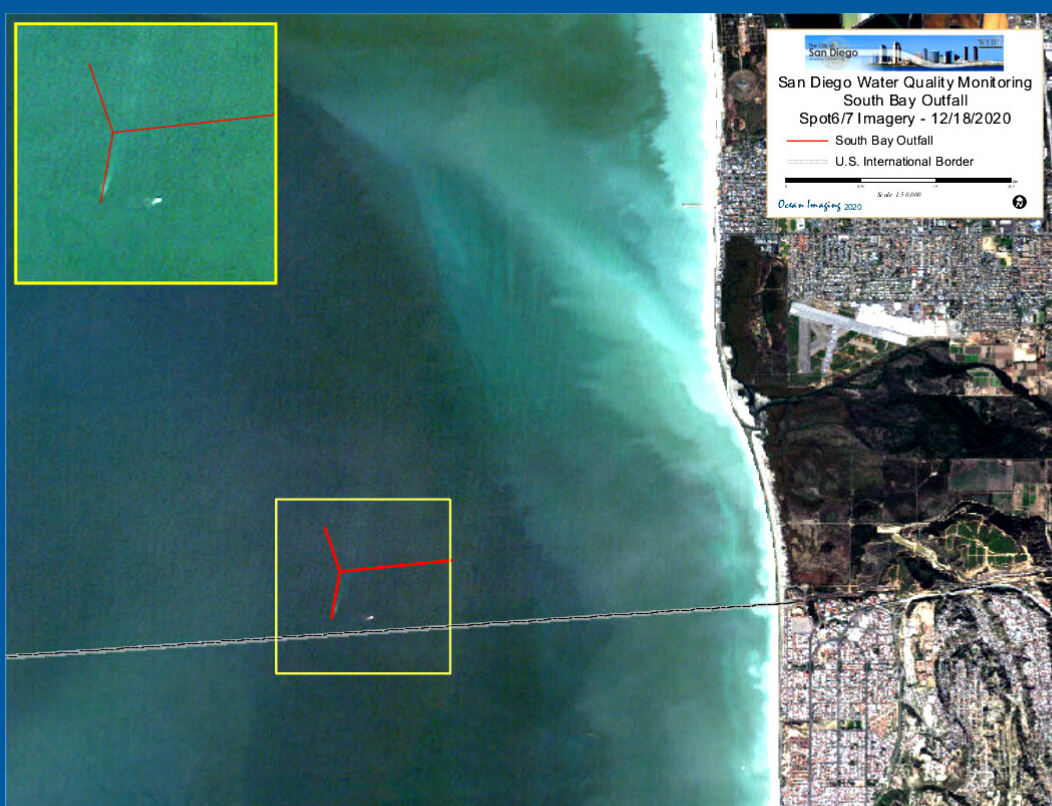
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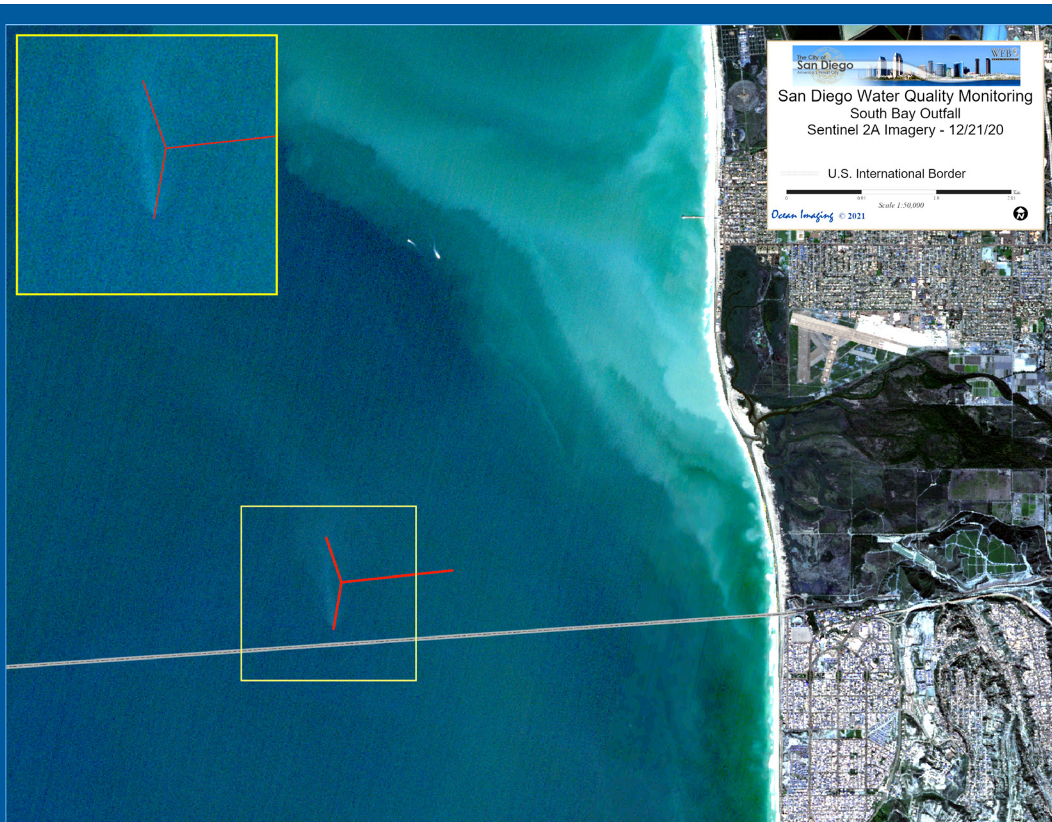
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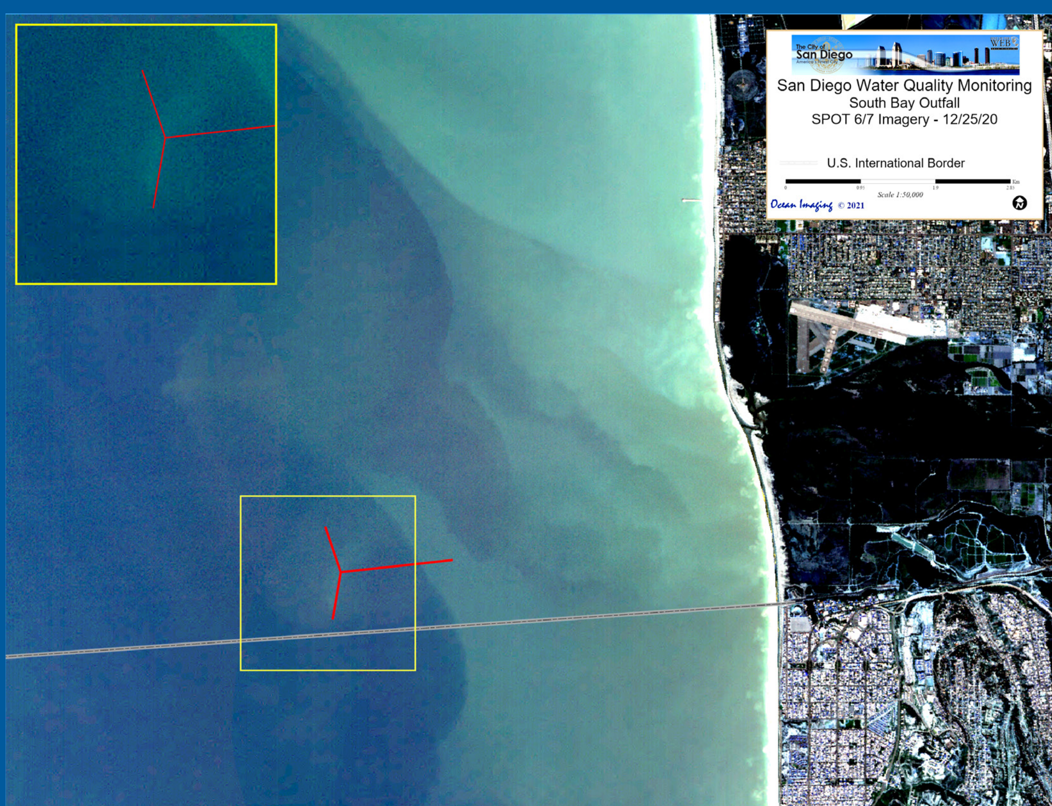
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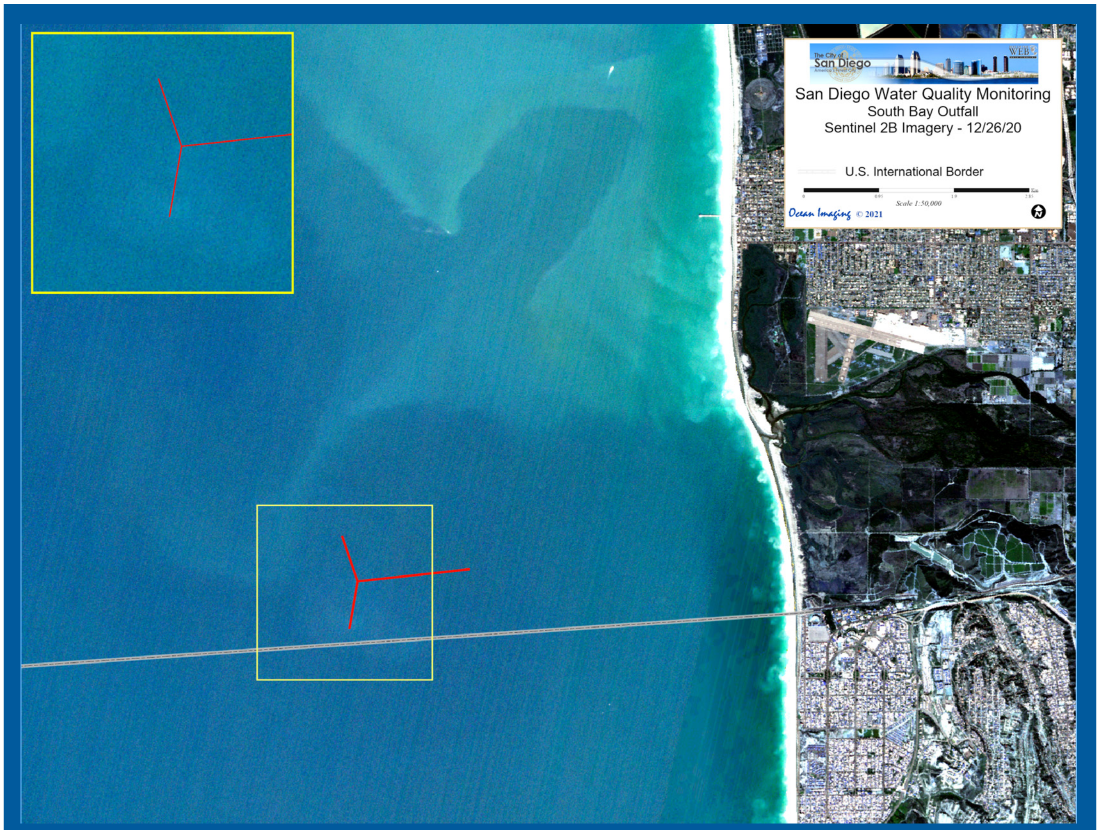
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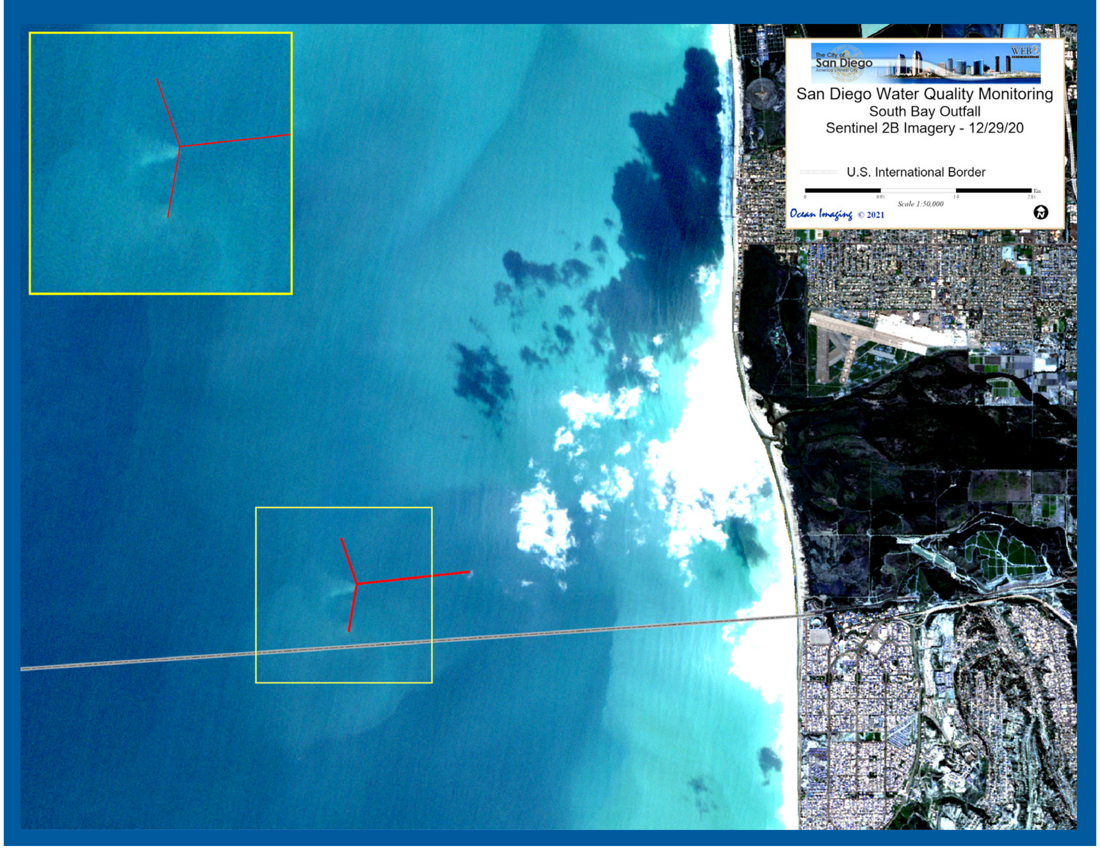
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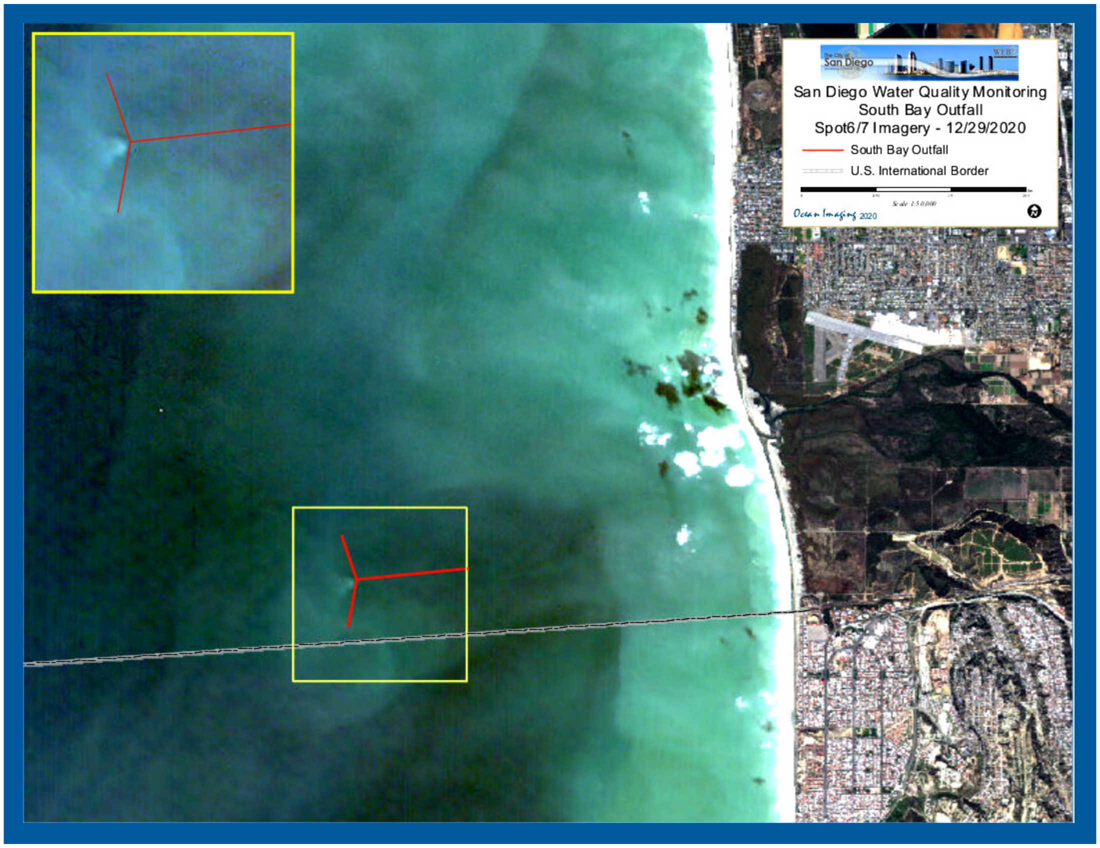
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