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

By Mark Hess

Annual Summary Report

1 January, 2018- 31 December, 2018

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Ocean Imaging

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1. INTRODUCTION AND PROJECT HISTORY

Ocean Imaging Corp. (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 the coastal zone. As part of these projects, OI developed methods to utilize various types of remotely sensed data for the detection and monitoring of storm water runoff and wastewater discharges from offshore outfalls. The methodology was initially demonstrated with collaboration of 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. Those results led, in turn, 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 Pt. 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.

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 established, among other findings, 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, size and dispersion trajectories of various land and offshore discharge sources (e.g. the offshore outfalls, Tijuana River, Punta Bandera Treatment Plant discharge in Mexico, etc.).

In October 2002 the operational monitoring phase of the project was initiated. This work utilizes 500m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) color imagery (available near-daily), and 27m & 60m Landsat Thematic Mapper TM5, TM7 and Landsat 8 OLI/TIRS color and thermal imagery (each available approximately every 16 days). In addition, 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 once or more per week during the rainy season. The flights were also coordinated with the City of San Diego's regular offshore field sampling schedule so that the imagery was collected on the same day (usually within 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. RapidEye maintains a unique constellation of 5 satellites which deliver 6.5 m resolution multispectral imagery. In 2014 Black Bridge Inc. took over the management and resale of RapidEye data and in 2016 Planet Labs, Inc. acquired Black Bridge and the RapidEye fleet of 5 satellites. Subsequently, OI renegotiated with Planet Labs to preserve the original structure and pricing for the continued purchase and use of RapidEye imagery. Unlike other single high-resolution satellites, the multi-satellite constellation enables revisits of the San Diego region on a near-daily basis. Another advantage of using this imagery is the much larger spatial coverage available with each data set that was not possible using the aerial sensor. This enables a more regionally contiguous monitoring of events affecting the target areas. In 2012 OI also began operationally providing the City with a suite of additional oceanographic products daily through the City's EMTS web-based GIS "BioMap" Server and continued expanding the product selection and delivery through 2014 and into 2015. In 2016 Ocean Imaging continued the development of imagery and data services so that the data are compatible with the City's new ESRI ArcGIS online map server. The intent was to deliver all the remote-sensing and model-derived products to the City's end users by fall of 2017. This effort is discussed in more detail in latter sections of this report. The original add-on products ranged from atmospherically corrected satellite images of sea surface temperature (SST) and chlorophyll to radar and model-derived surface current fields and since have been expanded to include ocean currents and mixed layer depth data products derived from the U.S. Navy's Hybrid Coordinate Ocean Model (HYCOM – www.hycom.org). Also added as a full-time operational data set in 2017 was satellite imagery from the Sentinel 2A and 2B satellites. In fall of 2018 data from the Sentinel 3A and 3B satellites were added to the suite of data products. Therefore, as of late 2018, data from all the Sentinel satellites/sensors are provided as regular image products as part of the coastal and outfall monitoring effort.

This report summarizes observations made during the period 1/1/2018 – 12/31/2018.

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 surrounding water.

2.1 Imaging in the UV-Visible-Near Infrared Spectrum

This is the most common technique used with satellite images and the DMSC aerial sensor. 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 (e.g. 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, 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 relationships between the different color signals.

The depth to which the color sensors can penetrate depends on which wavelengths they see, their sensitivity and the general water clarity. In the San Diego region, green wavelengths tend to reach the deepest and, as elsewhere, UV and near-IR wavelengths penetrate the least. Generally, OI's satellite and aerial sensor data reveal patterns in the upper 15-40 feet.

2.2 Imaging in the 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 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. Plumes from offshore outfalls can sometime 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 sometimes tends to displace some of the water above it in a doming effect. This displacement pattern is revealed in the thermal surface imagery.

2.3 Data Dissemination and Analysis

The satellite and aerial imaging data are made available to the funding agencies, the San Diego County Dept. of Health, and the EPA through a dedicated, password-protected web site. Although it is possible to process most of the used data in near-real-time, earlier in the project the funding agencies 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 are 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. OI has, however, in several cases, made some imagery available to the CDH and others in near-real time via email when observations were made that appeared to be highly significant for the management of beach closures or other sudden events. OI has developed an ArcGIS Server Web Map Service (WMS) with the intent of hosting oceanographic products produced daily by OI and automatically linked with the server as soon as available. Discussion follows on the use of the WMS to deliver data.

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 Web Map Service (WMS) Representational State Transfer (REST) service format which is directly compatible with the ESRI WMS the City is working to implement. It was planned 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 online WMS by fall of 2017. To date, the City's WMS is not fully functional and ready to ingest data from OI's server, however 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. While the historical imagery, data and reports will remain accessible via the existing web portal, OI will migrate all 2016-2019 data products to OI's ArcGIS once the City is ready to ingest the data feed from OI's server. Following the completion of the migration of the 2016-2019 data to this system, OI will progressively work backwards in time to make all historical data available to the City's ArcGIS online WMS. As of early 2019, word from the City is that their WMS and ability to ingest data from OI's ArcGIS server is not yet ready and so we have elected to process and archive some of the data products which were intended for delivery via this mechanism. If and when the City is ready to ingest data via this means of delivery, OI will populate the OI ArcGIS server with all the archived data.

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 Multispectral Instrument (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. In total, 82 high resolution satellite images showing the offshore San Diego County region were acquired, processed, and delivered in 2018. This equates to a 43% increase in satellite data used to document the area compared to 2017. Of the 82 total image sets, 55 were from Sentinel 2A or 2B data making up 67% of the high-resolution satellite data processed and posted as part of the project. On average, this effectively added four additional detailed observations of the offshore areas per week when compared to years when Sentinel data were not available.

Appendix A includes the RapidEye, Sentinel and Landsat imagery in which the SBOO plume was detected. There were also nine occurrences when

Figure 1: RapidEye imagery of the SBOO region acquired 02/03/18 at 18:49 GMT (10:49 AM PST) (left) and Sentinel-2B imagery acquired 02/03/18 at 18:41 GMT (10:41 AM PST) (right). The very faint SBOO plume is visible in both images, but slightly more apparent in the Sentinel imagery. Also note the relatively large Tijuana River discharge plume moving offshore and to the south.

Figure 2: RapidEye imagery of the SBOO region acquired 12/07/18 at 18:20 GMT (10:20 AM PST) (left) and Sentinel-2B imagery acquired 12/07/18 at 18:32 GMT (10:32 AM PST) (right). The TJR runoff plume's three components, the Fresh Core" (FC) and "Old Core" (OC) and "Old Plume" (OP) water are distinctly visible in both datasets as is the northward movement of both the SBOO plume and TJR discharge.

either Sentinel 2A or 2B data were acquired within only a few minutes of either RapidEye, Landsat TM7 or Landsat 8 OLI/TIRS data providing a near time-coincident validation of features (or lack thereof) observed in the imagery. Figures 1 through 3 show examples of the SBOO plume near-simultaneously observed by high resolution satellite sensors. On 02/03/18 a very faint plume signature is seen in the RapidEye data over the southern-most wye riser. Without validation of this feature seen in the Sentinel 2B data, there could be some question as to whether this was a true surface manifestation of a turbidity plume over the outfall. RapidEye and Sentinel 2B imagery from 12/07/18 shown in Figure 2 not only show a significant plume over the SBOO, but also provide clear detail of what have been identified as the three distinct components of the Tijuana River (TJR) runoff plume: the Fresh Core" (FC) and "Old Core" (OC) and "Old Plume" (OP) water (as defined in the 2015 Five Year Summary Report). The TJR plume is clearly seen moving northward as is discussed in more detail later in this report. Figure 3 highlights Landsat 8 OLI/TIRS and Sentinel 2B imagery from 12/30/18, exhibiting a strong plume signature not only emanating from the southern-most riser, but also from the two risers to the north signaling the strength of the flow coming out of the wye. The thermal channel from the Landsat 8 sensor shows the SBOO plume to be significantly cooler than the surface water through which the plume is rising and displacing the warmer water. Note, however, that the effluent from the outfall is not moving in any particular direction, but rather expanding from the point at which the effluent water reaches the surface. This indicates a lack of strong currents both at the surface and at depth outside of the TJR coastal area. The TJR runoff plume, however, is also to be extending unusually far offshore and pushing northward.

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 European Space Agency for the Copernicus Program. Sentinel-3A was launched on February 16, 2016 and Sentinel-3B followed on April 25, 2018. These satellites are identical and deliver products in near-real time. The satellites

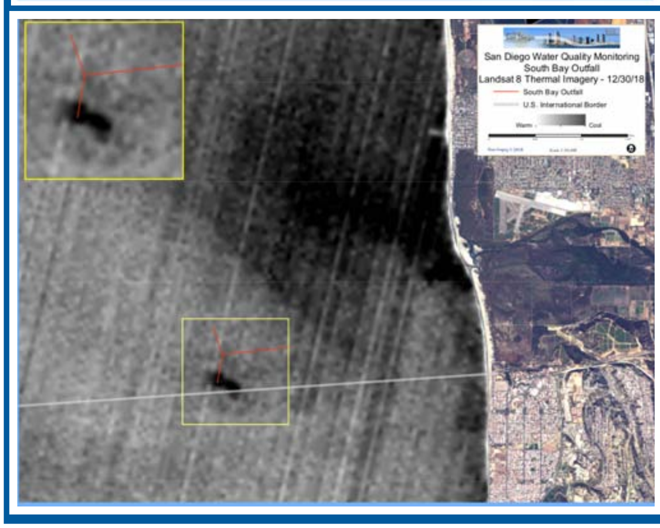


Figure 3: Landsat 8 imagery of the SBOO region acquired 12/30/18 at 18:22 GMT (10:22 AM PST) (top left), the thermal infrared image from the same Landsat 8 data (bottom left) and Sentinel-2B imagery acquired 12/30/18 at 18:41 GMT (10:41 AM PST) (right). Note SBOO turbidity plumes emanating from three of the wye risers. The cooler than ambient temperature of both the TJR runoff plume and the larger, south SBOO plume are also apparent in the thermal infrared channel of the Landsat 8 data.

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. One of the satellites' main secondary missions is to monitor sea-water quality and marine pollution. The instrument on these satellites designed for these purposes is the OLCI. Ocean Imaging creates daily products dependent on cloud cover for the entire San Diego/Tijuana region using the OLCI instrument. Between the 3A and 3B satellites this results in better than daily coverage with 3A and 3B data occasionally both being available on the same day. As of late 2018, true color, near infrared, and Total Suspended Matter (TSM) products are posted bi-monthly along with the similar resolution MODIS products. The TSM product indicates the quantity in grams per cubic meter of suspended particles in water. 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. Possible future products derived from the Sentinel 3 sensors include chlorophyll and sea surface temperature as well as cyanobacteria monitoring. Sentinel 3 holds the only satellite sensor 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 4 shows a sample TSM analysis from 02/07/18 and Figure 5 shows a Sentinel/OLCI-derived chlorophyll concentration analysis from the same day. Testing of and refinement to the TSM and chlorophyll algorithms could then lead to quantitative comparisons to assess how much of the reflectance signal seen in the satellite imagery is from phytoplankton blooms verses suspended sediment from river discharge and/or turbulent conditions along the coast.

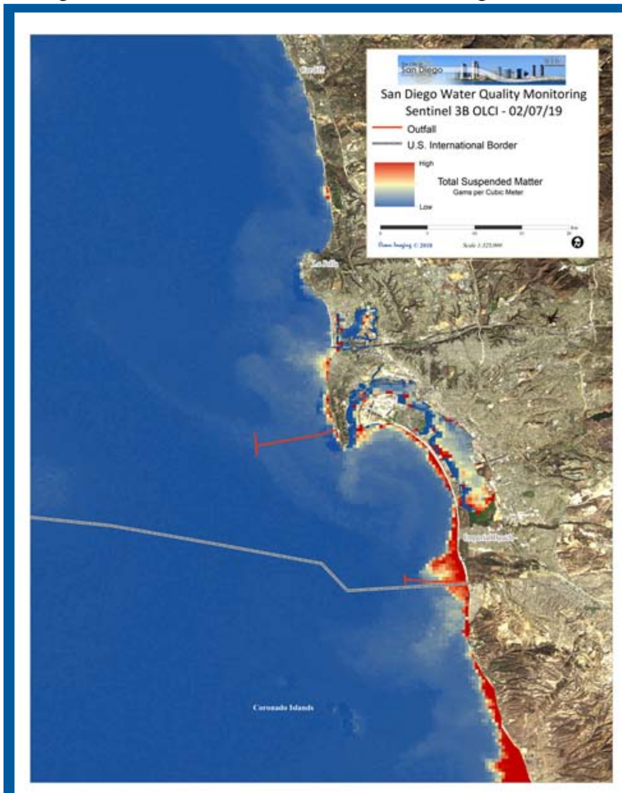


Figure 4. Sentinel 3B-derived Total Suspended Matter analysis at 300-meter spatial resolution from 02/07/18. This product has been added to the SDWQM web portal product offering as of December 2018.

3. HIGHLIGHTS OF 2018 MONITORING

3.1 Atmospheric and Ocean Conditions

According to the Lindberg Field station, in 2018 San Diego showed the lowest cumulative annual precipitation total from the past seven years (4.99 inches). The Tijuana Estuary station reported a higher cumulative precipitation total in 2018 of 6.76 inches, which was about average when compared to the prior six years (Table 1). As was also noted in the 2017 annual report, the monthly and annual precipitation amounts can differ at times between the two reporting stations. As seen Table 1 the Tijuana Estuary station recorded lower precipitation totals than the Lindberg Field station for the years 2012-2015 and higher amounts for years 2016-2018. In 2018, however, both stations recorded

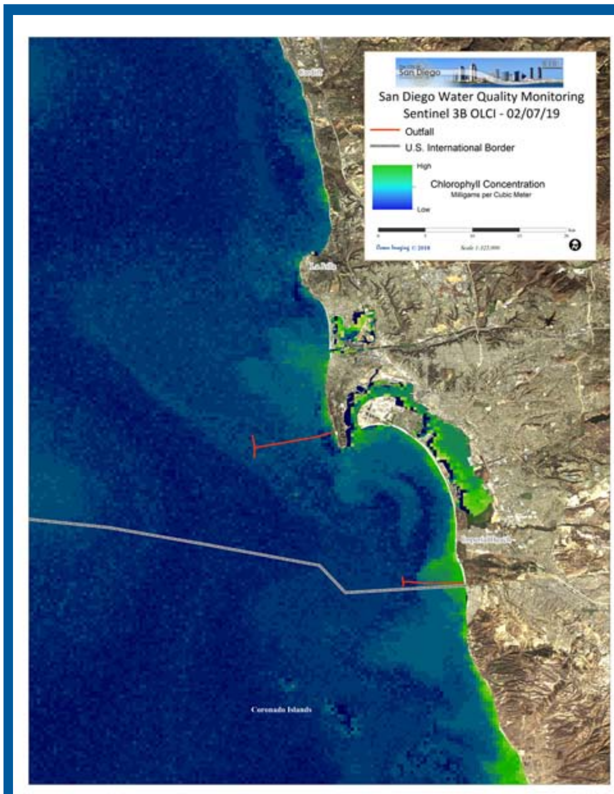


Figure 5. Sentinel 3B-derived chlorophyll concentration analysis at 300-meter spatial resolution from 02/07/18. This product has been added to the SDWQM web portal product offering as of December 2018.

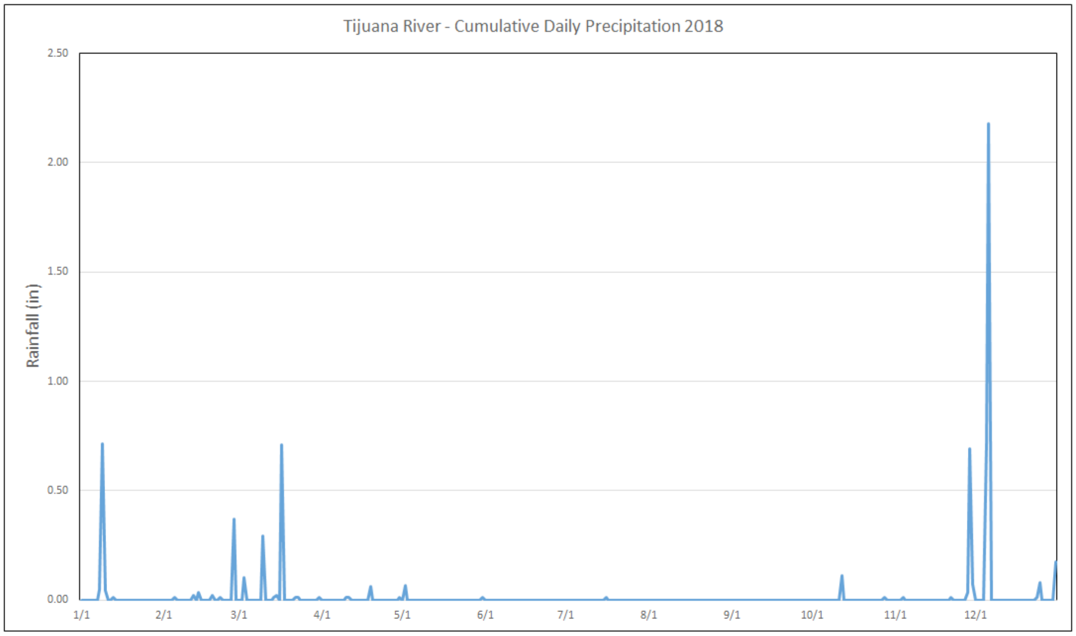
Table 1: 2018 Monthly and annual rainfall totals as recorded by the Lindberg Field and Tijuana Estuary stations.

Lindberg Field Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018
January	0.40	0.70	0.01	0.42	3.21	2.99	1.77
February	1.19	0.63	1.00	0.28	0.05	1.58	0.35
March	0.97	1.22	1.28	0.93	0.76	0.08	0.65
April	0.88	0.01	0.54	0.02	0.55	0.01	0.02
May	0.02	0.26	--	2.39	0.44	0.87	0.09
June	--	--	--	0.04	--	0.02	--
July	--	0.05	--	1.71	--	--	--
August	--	--	0.08	0.01	--	--	0.02
September	--	--	--	1.24	0.32	0.06	--
October	0.70	0.25	--	0.43	0.07	--	0.57
November	0.28	1.48	0.37	1.54	0.61	0.02	0.69
December	2.19	0.46	4.50	0.88	4.22	--	0.83
Annual Total	**6.63**	**5.06**	**7.78**	**9.89**	**10.23**	**5.63**	**4.99**

Tijuana Estuary Cumulative Monthly Precipitation in Inches

	2012	2013	2014	2015	2016	2017	2018
January	0.70	0.05	0.08	0.32	2.40	3.61	0.82
February	0.86	--	1.35	0.13	0.02	4.06	0.47
March	1.21	1.43	0.55	1.01	1.28	0.04	1.17
April	0.82	0.11	0.35	0.07	1.91	0.01	0.10
May	--	0.36	--	1.13	0.97	1.07	0.08
June	--	--	0.12	--	--	--	--
July	--	0.01	0.33	0.39	--	0.01	0.01
August	--	--	0.04	--	--	0.02	--
September	0.02	0.01	--	0.48	0.49	0.03	--
October	0.50	0.41	--	0.21	--	--	0.13
November	--	0.25	0.29	0.61	0.34	0.06	0.82
December	0.04	0.50	3.09	0.61	4.32	0.09	3.16
Annual Total	**4.15**	**3.13**	**6.20**	**4.94**	**11.73**	**8.99**	**6.76**



Date	CumPrcp (in)
1/8	0.05
1/9	0.72
1/10	0.04
1/13	0.01
2/5	0.01
2/12	0.02
2/14	0.04
2/19	0.02
2/22	0.01
2/27	0.37
3/3	0.10
3/10	0.29
3/14	0.01
3/15	0.02
3/17	0.71
3/22	0.01
3/23	0.01
3/31	0.01
4/10	0.01
4/11	0.01
4/19	0.06
4/30	0.01
5/2	0.07
5/31	0.01
7/16	0.01
10/12	0.11
10/28	0.01
11/4	0.01
11/22	0.01
11/28	0.04
11/29	0.69
11/30	0.07
12/5	0.72
12/6	2.18
12/24	0.01
12/25	0.08
12/31	0.18

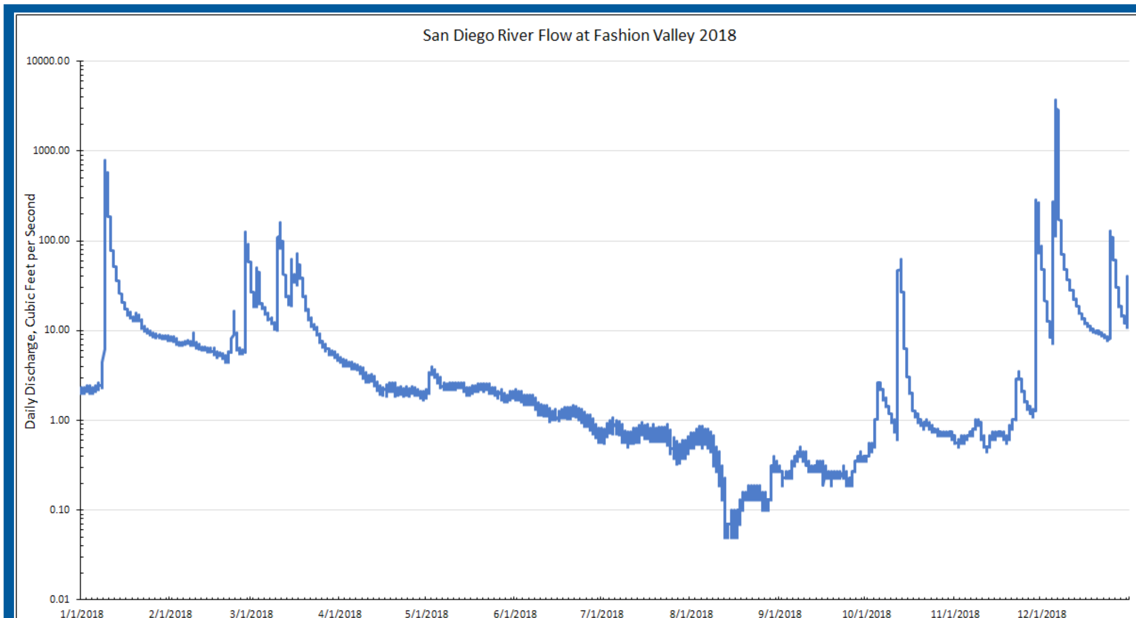
Figure 6. Daily cumulative rainfall in the Tijuana Estuary. The shaded dates in the accompanying table show those days on which SBOO effluent plumes were visible in the available visible and/or thermal infrared satellite imagery.

lower annual precipitation totals than 2016 and 2017.

The monthly precipitation totals recorded for 2018 were more typical in that rainfall numbers in the beginning of the year from January through March and at the end of the year from October through December were more representative of what would be considered the region's rainy season. Somewhat atypical was the near zero amount of precipitation during the months of April through September with the Lindberg Field station recording a total of only 0.13" during that time period (0.19 inches recorded at the Tijuana Estuary station). Usually April and May provide at least some added rainfall to end the rainy season.

Figure 6 shows daily precipitation in the Tijuana River Estuary. The table to the side of the plot shows the dates for which there was measurable precipitation for that station. Except for as observed in the RapidEye image from 01/11/18 (Figure 11), the days following the rain event at the end of February and the month of December the rains as indicated from the Tijuana recording station do not appear to have had a direct effect on the coastal and offshore water quality in the area – especially when using the Tijuana River runoff as an indicator of the rain flush effect. As a general rule of thumb, precipitation resulting in 0.1" or less tends to be blocked by the SBOO-linked diverter above the estuary and does not cause significant runoff to reach the ocean. As can be seen from Figures 12, 18 and 19 and in the imagery shown in Appendix A, rain events resulting in considerably higher daily precipitation totals occurred during the period of 11/29/18 through 12/06/18 and caused significant Tijuana River runoff to be discharged into the ocean. This rain event generated conditions which cannot be directly related to wastewater plumes over the SBOO being visible in the satellite imagery, however the SBOO surface plume was visible in an unusual number of satellite scenes beginning on 12/07/18 through 12/30/18. The heavily turbid river discharge is most likely also in part related to the Tijuana River sewage spill reported to have started on 12/10/18. Additional discussion follows on these events and the corresponding plume detections in the imagery.

Similar patterns can be seen in Figure 7 which shows monthly precipitation totals at Lindbergh Field and the San Diego River discharge rate at the Fashion Valley gauging station. Below that in Figure 8 the mean daily flow of the San Diego River during 2018 (measured at Fashion Valley) is plotted with the daily cumulative precipitation as recorded at the Tijuana River station. This plot merely illustrates the mostly direct relationship between region-wide precipitation amounts and river lfow, however one notable difference is that the precipitation in mid-October does not match the magnitude of the river dicharge of the same time period. Figure 9 shows the 11/02/18 Sentinel 2A image exhibiting heavy TJR discharge with the turbidity plume extending well offshore. This correlates with the monthly rainfall numbers for October and November recorded at the Lindberg Field station, but for some reason are not seen in the Tijuana station data. The 2018 Fashion Valley river flow rates matched what would be expected following seasonal rainfall patterns, however the very dry summer brought the river flow down to near-zero (0.05 cubic feet per second) around mid-August. Aside from 2016 when the flow rate dropped to 0.29 cubic feet per second on 08/30/16, this was a rare occurrence when compared to the previous ten years, thus highlighting the notable lack of summer precipitation in 2018. The Sentinel 2A imagery from 08/14/18 which exhibits very little coastal turbidity,



Lindbergh Field Rainfall 2018	
Jan	1.77"
Feb	0.35"
Mar	0.65"
Apr	0.02"
May	0.09"
Jun	0.00"
Jul	0.00"
Aug	0.02"
Sep	0.00"
Oct	0.57"
Nov	0.69"
Dec	0.83"

Figure 7. Daily flow in fifteen-minute intervals of the San Diego River during 2018 (measured at Fashion Valley). Table on the right shows monthly rainfall totals at Lindbergh Field.

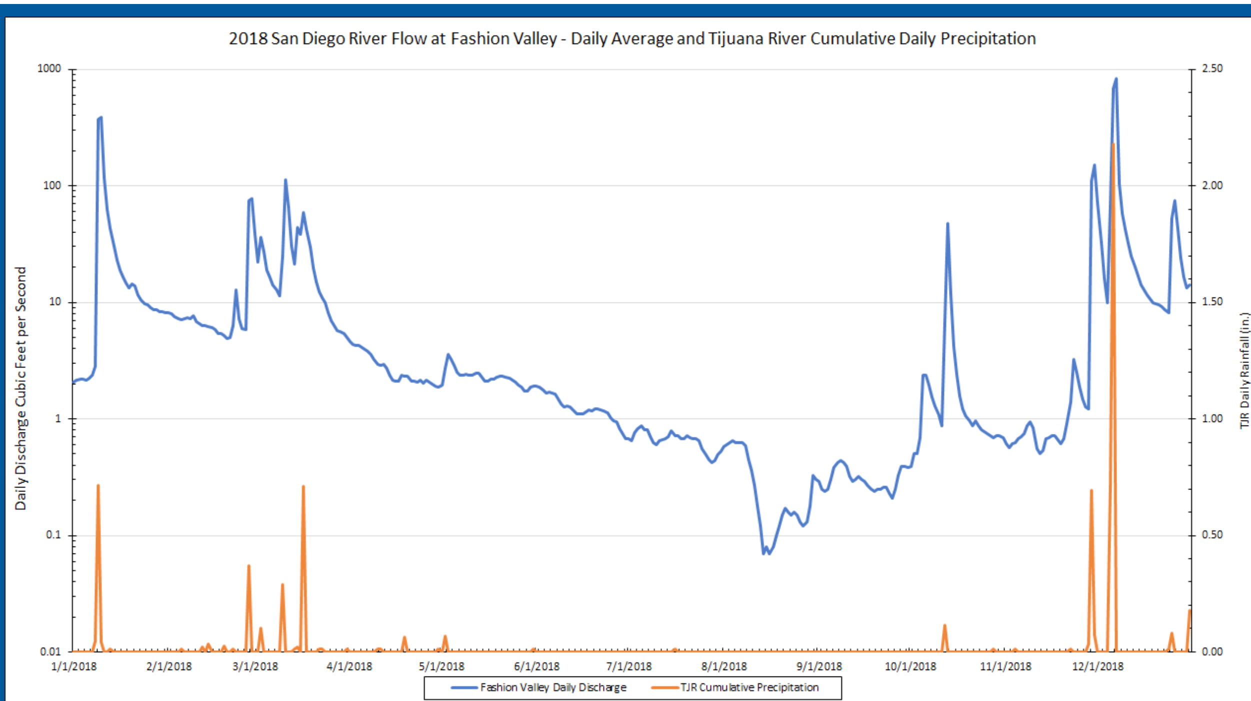


Figure 8. Mean daily flow of the San Diego River during 2018 (measured at Fashion Valley) plotted with the daily cumulative precipitation as recorded that the Tijuana River station.

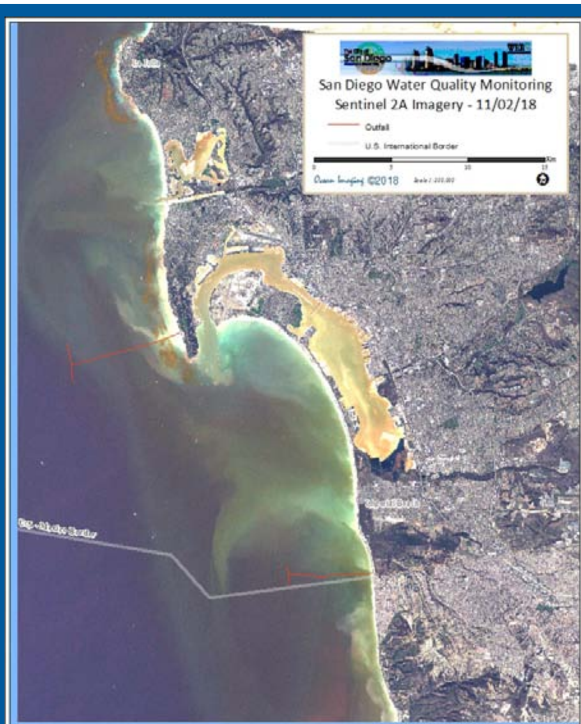


Figure 9: Sentinel 2A imagery of the San Diego region acquired on 11/02/18. A significant TJR runoff plume as well as outflow from Mission Bay and overall turbid conditions along the coast were indicative of the increased rainfall amounts in October and November as recorded by the Lindberg Field station.

Figure 10: Sentinel 2A imagery of the San Diego region acquired on 08/14/18 showing clear water conditions throughout most of the monitoring area punctuating the lack of rainfall and very low river flow rates during that time period

Table 2: 2018 County of San Diego beach/shoreline closures (courtesy of the County of San Diego Department of Environmental Health).

	2018 Closures / Advisories for County of San Diego Beaches.	DATE FORMAT M/D/YYYY	DATE FORMAT M/D/YYYY					
DEH Station	Description of Area	Date of Advisory	Date Opened	Advisory Type	Event Length	Posting Distance	Issuance Time	Indicator
ALL	General Rain Advisory	Jan-9-2018	Jan-13-2018	Rain Advisory	4		8:00	Rain - Extended 1/10/2018
IB-010 to IB-050	Tijuana Slough Shoreline	Jan-9-2018	Feb-1-2018	Closure (TJ River)	23	2.27 miles	8:00	
IB-050, EH-010, EH-030, IB-060	Imperial Beach Shoreline	Jan-9-2018	Jan-13-2018	Closure (TJ River)	4	1.39 miles	12:15	
IB-070	Silver Strand State Beach - north end ocean side	Jan-9-2018	Jan-13-2018	Closure (TJ River)	4	6.66 miles	14:00	
IB-050, EH-010, EH-030, IB-060	Imperial Beach Shoreline	Feb-11-2018	Feb-13-2018	Precautionary Advisory	2	1.39 miles	12:00	Odors (IB)/Telemetry
IB-010 to IB-050	Tijuana Slough Shoreline	Feb-11-2018	Feb-23-2018	Closure (TJ River)	12	2.27 miles	12:00	
ALL	General Rain Advisory	Feb-27-2018	Mar-2-2018	Rain Advisory	3		8:30	Rain
IB-010 to IB-050	Tijuana Slough Shoreline	Feb-27-2018	Mar-28-2018	Closure (TJ River)	29	2.27 miles	8:30	
ALL	General Rain Advisory	Mar-10-2018	Mar-14-2018	Rain Advisory	4		22:30	Rain (late PM)
IB-050, EH-010, EH-030, IB-060	Imperial Beach Shoreline	Mar-11-2018	Mar-15-2018	Closure (TJ River)	4	1.39 miles	11:30	
IB-070	Silver Strand State Beach - north end ocean side	Mar-11-2018	Mar-14-2018	Closure (TJ River)	3	6.66 miles	17:00	
IB-080	Avenida Del Sol - Coronado	Mar-12-2018	Mar-14-2018	Closure (TJ River)	2	2.7 miles	11:00	
ALL	General Rain Advisory	Mar-15-2018	Mar-20-2018	Rain Advisory	5		9:15	Rain - Extended 3/17/2018
IB-050, EH-010, EH-030, IB-060	Imperial Beach Shoreline	Mar-18-2018	Mar-20-2018	Closure (TJ River)	2	1.39 miles	16:30	
IB-070	Silver Strand State Beach - north end ocean side	Jun-21-2018	Jun-22-2018	Closure	1	6.66 miles	20:45	Diesel spill
ALL	General Rain Advisory	Oct-13-2018	Oct-16-2018	Rain Advisory	3		8:30	Rain
EH-060	8th St - Del Mar	Oct-14-2018	Oct-17-2018	Closure	3	300	11:30	Sewage Spill
IB-010 to IB-050	Tijuana Slough Shoreline	Oct-15-2018	Oct-19-2018	Closure (TJ River)	4	2.27 miles	11:30	
ALL	General Rain Advisory	Nov-29-2018	Dec-3-2018	Rain Advisory	4		8:30	Rain (through late PM)
IB-010 to IB-050	Tijuana Slough Shoreline	Nov-29-2018	Dec-31-2018	Closure (TJ River)	33	2.27 miles	14:30	
ALL	General Rain Advisory	Dec-5-2018	Dec-10-2018	Rain Advisory	5		14:30	extended 12/6/2018 (late PM)
IB-050, EH-010, EH-030, IB-060	Imperial Beach Shoreline	Dec-6-2018	Dec-17-2018	Closure (TJ River)	11	1.39 miles	11:00	
IB-070	Silver Strand State Beach - north end ocean side	Dec-7-2018	Dec-11-2018	Closure (TJ River)	4	6.66 miles	13:00	
IB-080	Avenida Del Sol - Coronado	Dec-7-2018	Dec-11-2018	Closure (TJ River)	4	2.7 miles	13:00	

river or outfall effluent over the entire study region provides a good visual example of these conditions (Figure 10). The flow rates did peak in late November and early December as would be expected given the heavy rainfall event during that time.

In 2018 the county of San Diego issued 114 posted shoreline advisories and 16 beach/shoreline closures. The longest closure lasting 33 days between November 29 and December 31 was along the Tijuana Slough Shoreline. Almost all the closures were in the area between the Tijuana River mouth and Avenida Del Sol on the south end of Coronado. With the exception of the 02/11/18 closure of the Tijuana Slough Shoreline and the closure of Silver Strand State Beach in Oceanside on 06/21/18, all the closures can be attributed to a rain event prior to and/or during the closure period (Table 2). These two closures were in response to a diesel spill and sewage spill near each of the DEH stations respectively.

The satellite imagery available on the web portal on or around the closure dates visually correlate with the closure data as imagery during those time periods show high turbidity and suspended solids levels along the coastline in the closed region as well as persistent, higher than normal TJR runoff, sometimes being carried north by the ocean currents. Figure 11 is a RapidEye image from 01/11/18 showing most of the area of interest following the rainfall events on 01/09/18 and 01/10/18 with turbid water all along the coast from Mission Bay down past the TJR mouth. While much of the water movement was to the west and south, there is indication that

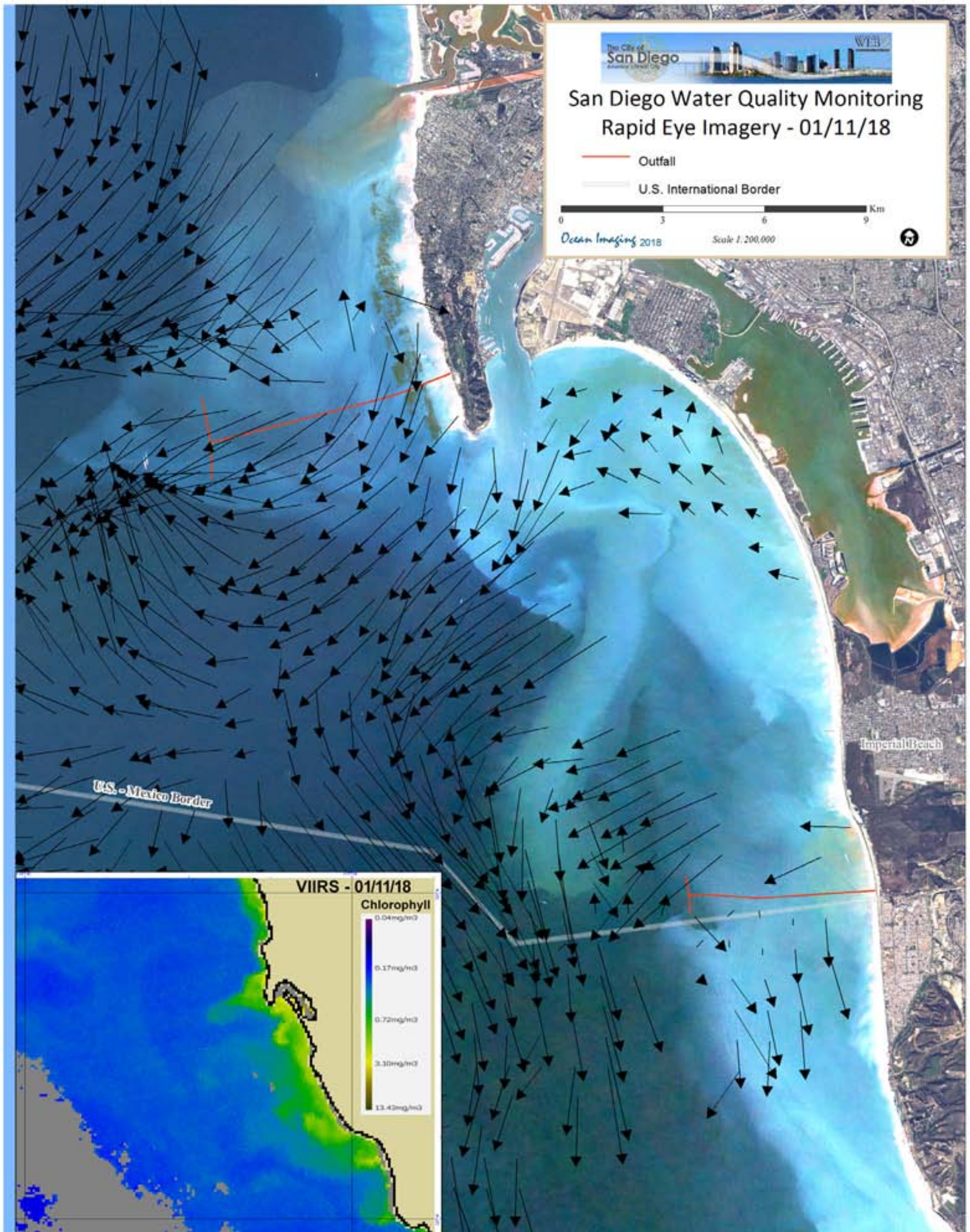


Figure 11: RapidEye image from 01/11/18 showing heavy coastal turbidity and river runoff following the rain events on 01/09/18 and 01/10/18 totaling 0.75 inches of precipitation over the two days. These conditions resulted in three main shoreline closures (Table 2) in the San Diego County region on 01/09/18, the Tijuana Slough closure lasting all the way through 02/01/18. Note the 25-hour averaged HF Radar-derived currents from 1800 UTC of the same day shown over the satellite image confirming that the water exiting Mission Bay was moving to the southwest, water discharging from the TJR was moving west and south, however there was some surface flow to the north of the TJR up around the Silver Strand and Southern Coronado area. The VIIRS-derived Chlorophyll image inset into the bottom left of the figure shows the coastal phytoplankton blooms which developed along the coast of San Diego County from Mission Bay south. The Chlorophyll scale ranges from ~0.04 mg/m3 to ~13.4 mg/m3.

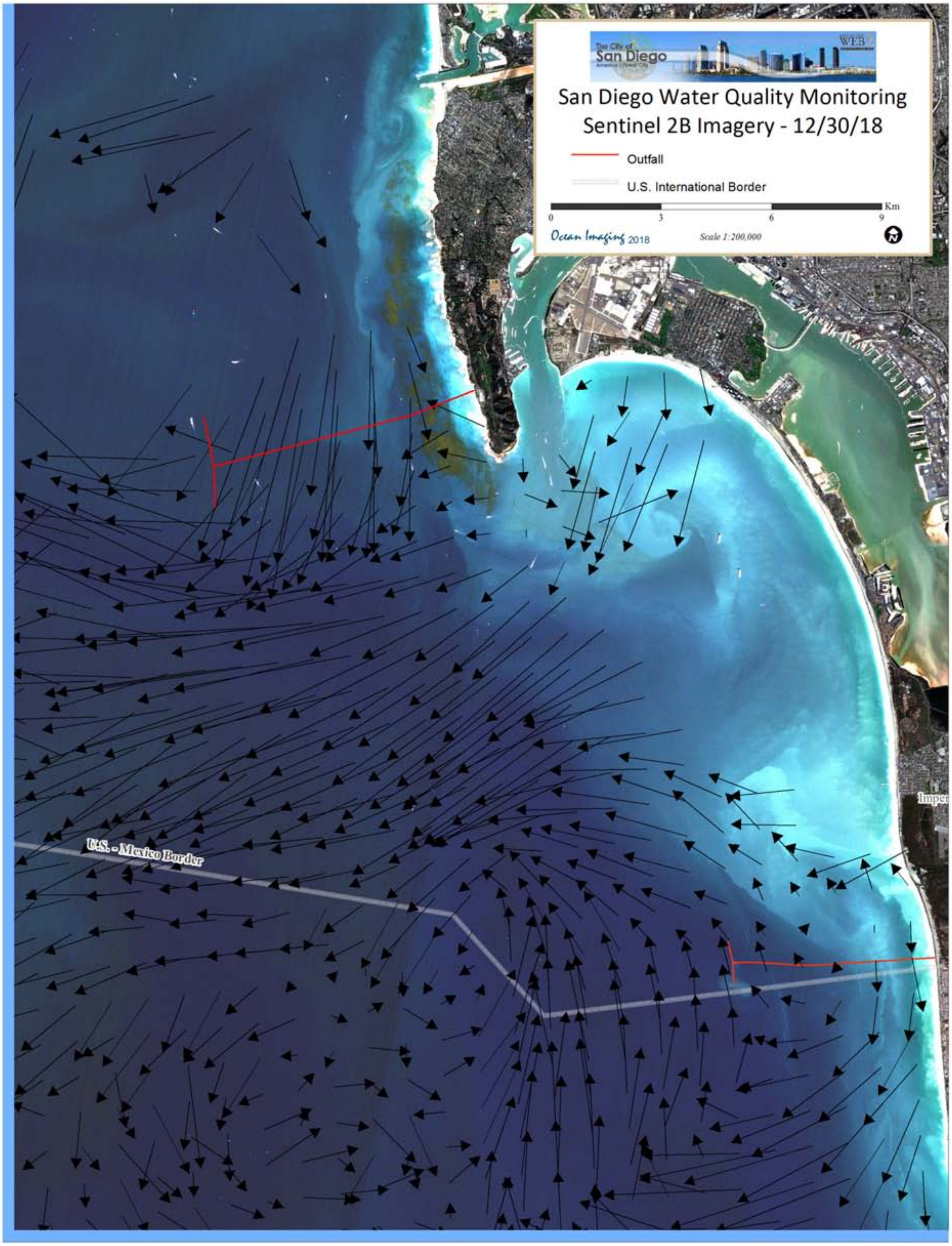


Figure 12: RapidEye image from 12/30/18 showing a strong TJR runoff plume moving northwest.

currents along the coast north of the TJR pushed shoreline discharge up from the north part of Imperial beach and the Silver Strand area towards the southern part of Coronado. Figure 12 highlights a Sentinel 2B image from 12/30/18 exhibiting significant TJR runoff several weeks after the 12/05/18 and 12/06/18 rainfall events. Some of the runoff plume visible in the imagery could also have been due to the TJR sewage spill which began earlier that month. Note the northwest movement of the TJR plume.

Although discharge from the San Diego River does not cause the same level of beach contamination issues of the Tijuana River discharge, the runoff from the two rivers, Mission Bay and coastal lagoons affected nearshore water clarity on several occasions in January, November and December of 2018, directly as a source of suspended sediment and indirectly as a source of nutrients feeding localized plankton blooms. Figure 11 from 01/11/18 offers a good visual example of this situation.

The majority of 2018 showed consistent chlorophyll levels indictive of phytoplankton blooms off the coast of San Diego as well as covering a large percentage of the California bight. Only one period in late February exhibited high chlorophyll levels off the coast which could be, at least, partially attributed to a rainfall event on 02/27/18 contributing to nutrient influx from river discharge into the coastal and offshore system. All the other phytoplankton bloom events were most likely the result of localized and/or regional coastal upwelling. The area of interest for this project showed either high levels of chlorophyll, coastal turbidity, or both in the MODIS and VIIRS satellite imagery for much of the year. Only during the time periods of 01/01/18–01/15/18, 02/16/18-02/21/18, 08/13/18-08/30/18, 10/25/18-10/31/18, 11/12/18-12/11/30/18, 12/8/18-12/11/18 and 12/17/18 did the San Diego coastal region show relatively low levels of chlorophyll/phytoplankton or turbidity as measured by these two satellite sensors. Therefore, the San Diego coastal region experienced few days of clear, plankton-free water during the entire year. Figure 13 shows a time series of VIIRS-derived chlorophyll imagery from 03/26/18 to 05/16/18. The area between Oceanside, Santa Catalina Island and San Clemente Island did see periods of clear water, but the rest of the California Bight experienced mostly chlorophyll-rich and/or turbid conditions. The City of San Diego CTD data corroborated the chlorophyll a levels seen in the satellite data. Some of the highest chlorophyll a levels recorded via CTD (10.0-59.0 ug/L) occurred between 05/15/18-05/18/18 and on 06/11/18. Likewise, some of the lowest chlorophyll a levels (0.01–1.2 ug/L) documented in the CTD data occurred during the latter parts of August and November which is also observed in the MODIS and VIIRS imagery. Two examples of strong phytoplankton blooms as seen in the satellite imagery are shown in Figures14 and 15. Figure 16 highlights one example of particularly active phytoplankton growth in the California Bight and one example of a time period when chlorophyll levels were notably low.

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). The plume also cannot 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

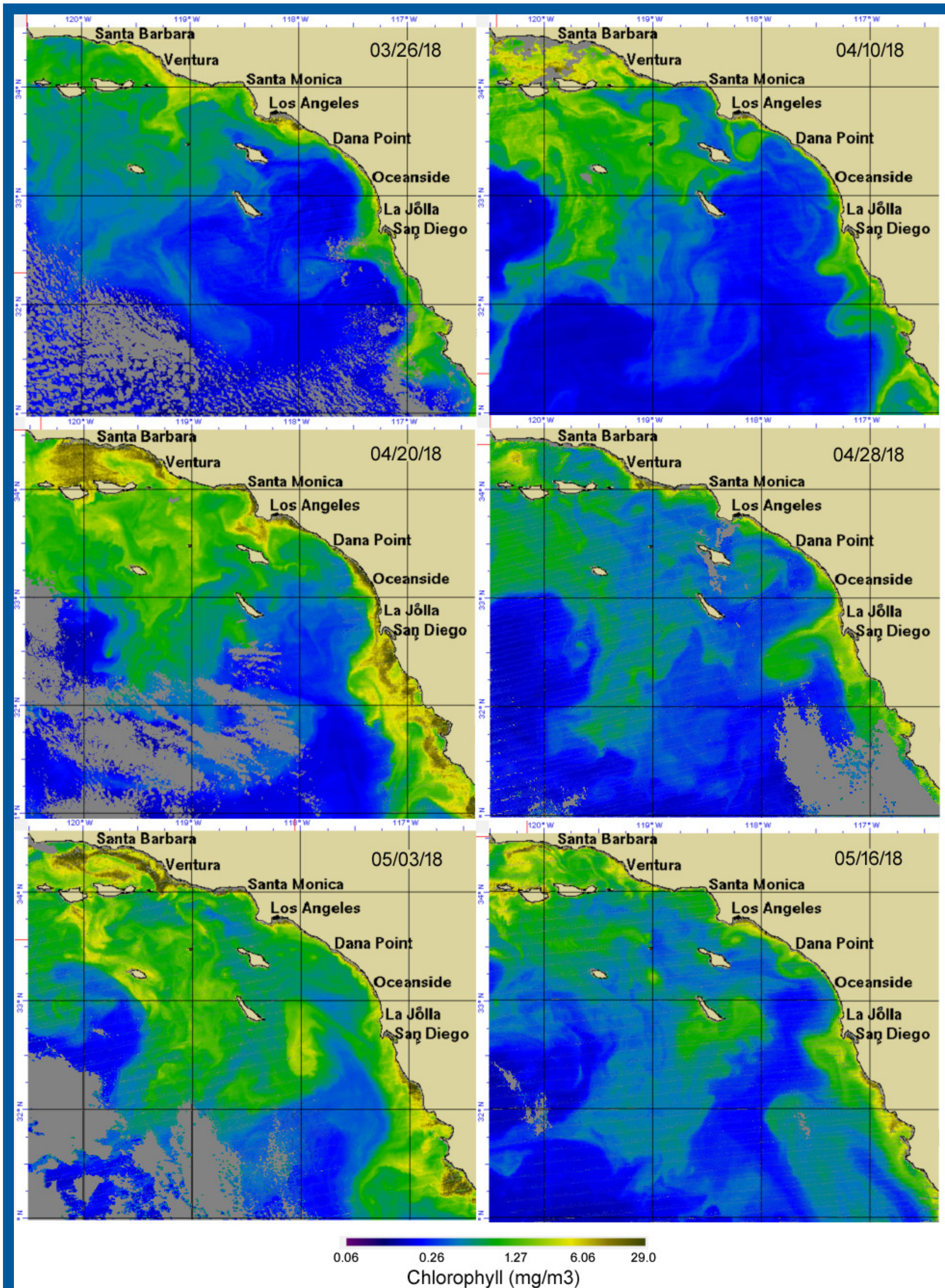


Figure 13: Chlorophyll imagery derived from the VIIRS sensor showing strong phytoplankton blooms off the coast of San Diego County as well as the entire Southern California Bight during the period of 03/26/18 through 05/16/18. The actual period of high chlorophyll levels off San Diego and the Bight lasted roughly from late February through the middle of June.

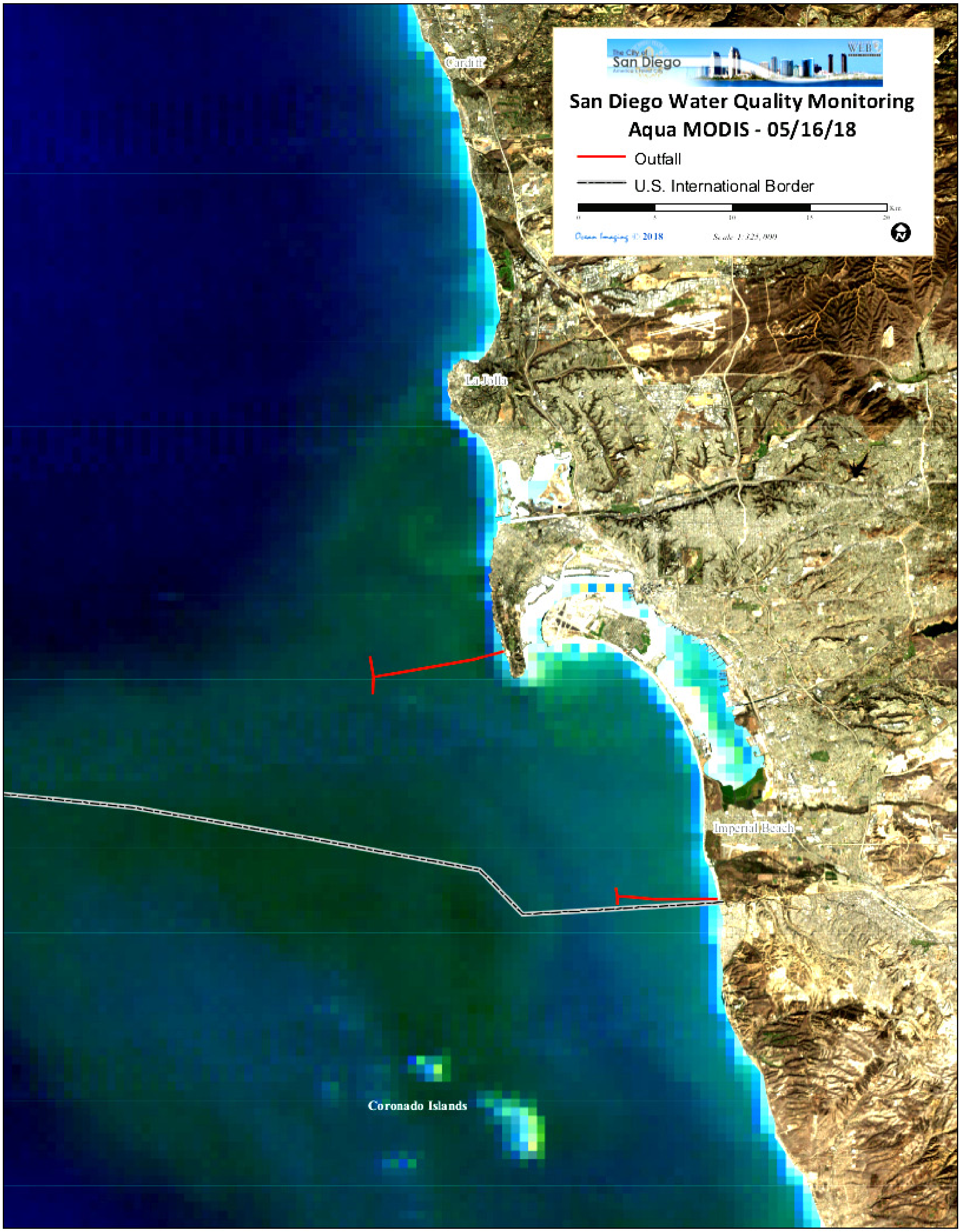


Figure 14: MODIS visible image from 05/16/18 showing a plankton bloom moving west from San Diego region.

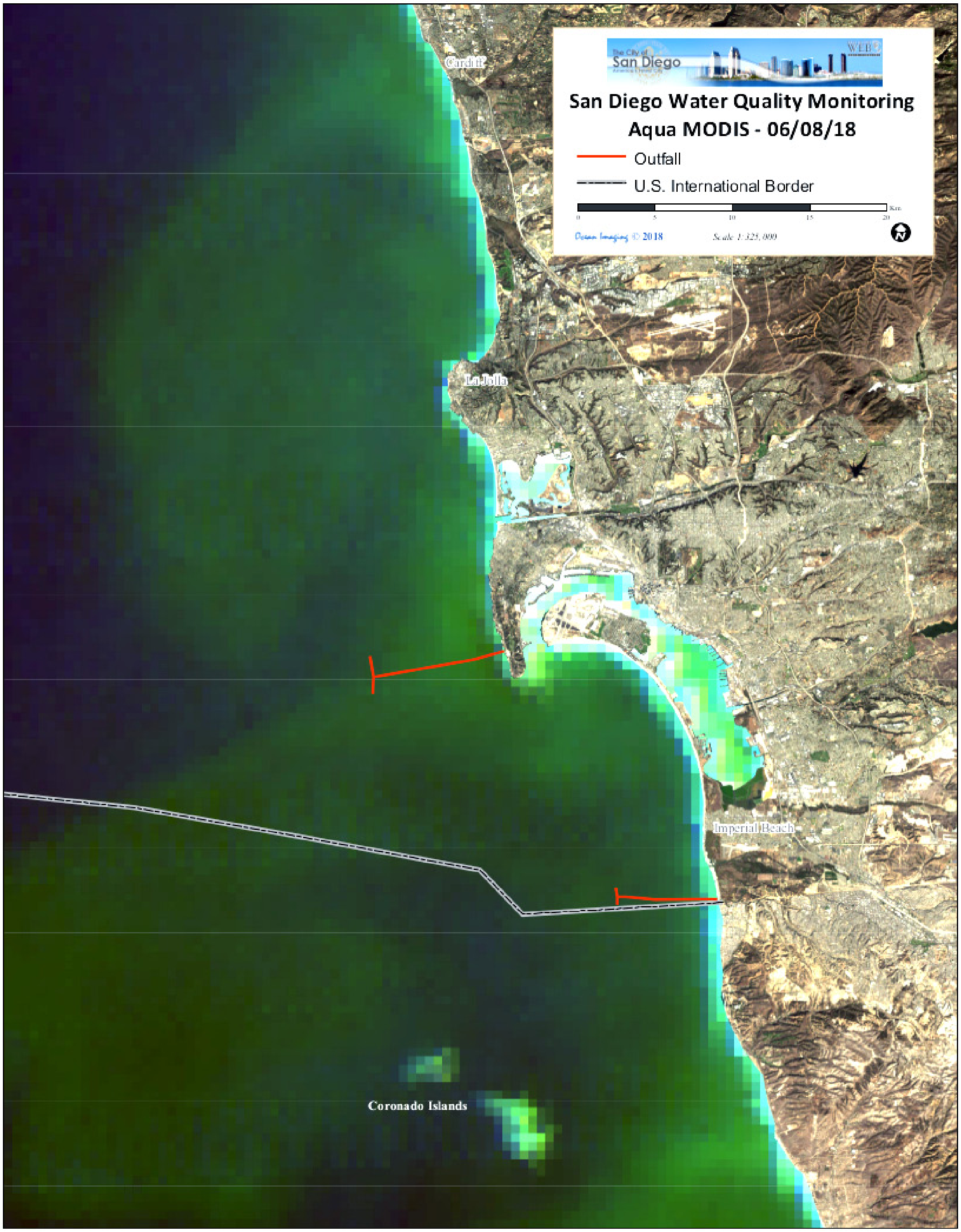


Figure 15: MODIS visible image from 06/08/18 showing a large chlorophyll-rich plankton bloom extending off the coast of the San Diego region.

concept held true in 2018 as the SBOO plume was observed reaching the surface only once between mid-February and early December on 03/27/18.

The SBOO treatment plant switched from advanced primary to secondary treatment in January 2011. This change resulted, among other factors, 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 plume signature was regularly detected in multispectral imagery as per the seasonal fluctuation described above. Since then, the plume signature continues to be observed with multispectral color and thermal imagery during months with weak vertical stratification, however, more intermittently. On occasion the plume signature is distinctly discernable in thermal images (indicating it has fully reached the ocean surface), but undetectable in the color imagery. We believe this is due to the reduction in TSS concentrations.

The plume's 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 plume 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 plume signature was identifiable up to more than 4km away from SBOO wye. Other plume signatures imaged during 2013 and 2014 when TSS loads were approximately 16 mg/L show that these are sufficient for adequate separation of the effluent from surrounding waters if the plume remains concentrated.

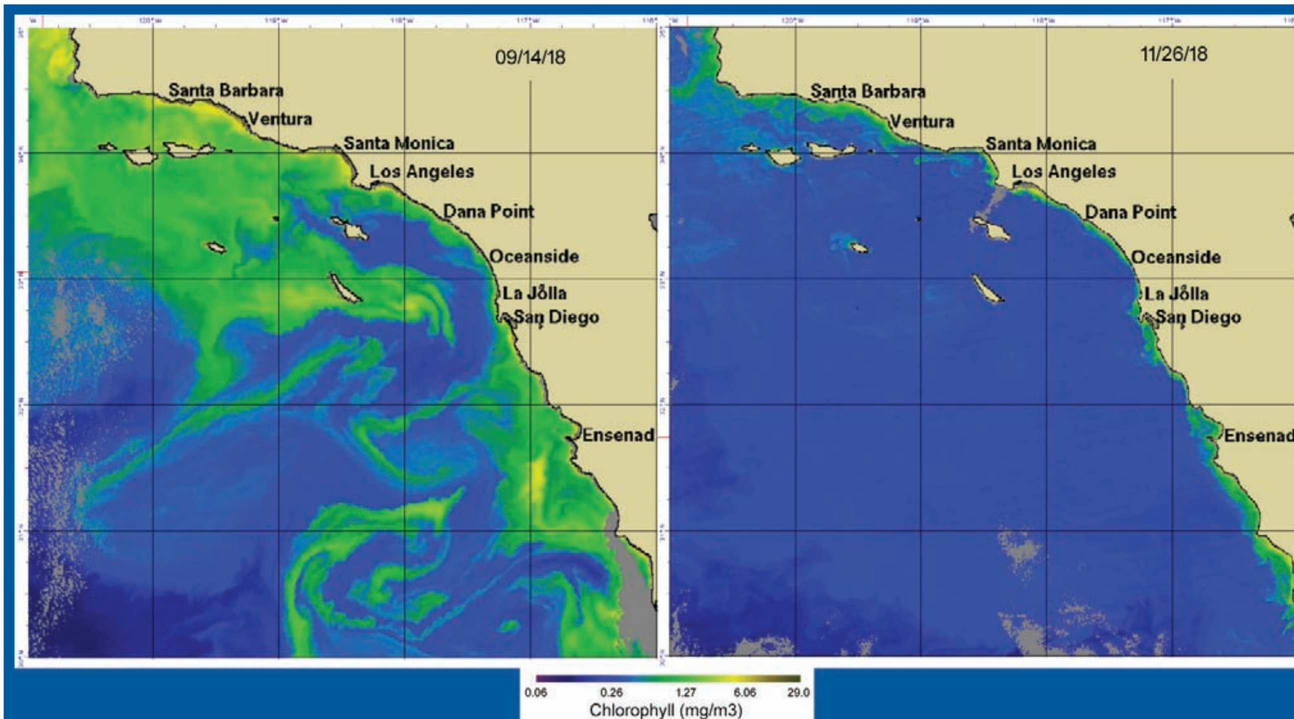


Figure 16: Chlorophyll imagery derived from the MODIS and VIIRS sensors showing strong, dynamic phytoplankton blooms off the coast of San Diego in in the Southern California Bight on 09/14/18 (left) and a dramatic lack of chlorophyll in the region on 11/26/18 (right).

There were 15 instances for which the SBOO effluent plume was observed in 2018 out of the 82 high resolution satellite scenes acquired and processed. Of these 15, four were instances of the plume observed by different satellites on the same day. This equates to 11 days on which the plume was visible in the imagery. This is roughly the same as 2016 when the SBOO plume was observed a total 13 times out of 40 high resolution satellite scenes and more than in 2017, when the plume was recorded in the satellite data on only six days of that year.

As have been the case in previous years, in one occurrence on 03/27/18 the SBOO "plume" appears in the imagery as a patch of clearer water breaking the more turbid water on the surface. In this case, the clear effluent signal in the imagery was mostly like 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 water became somewhat diluted on its way to the surface if weak vertical stratification did exist, thus slowing down its rise in the water column. CTD readings were

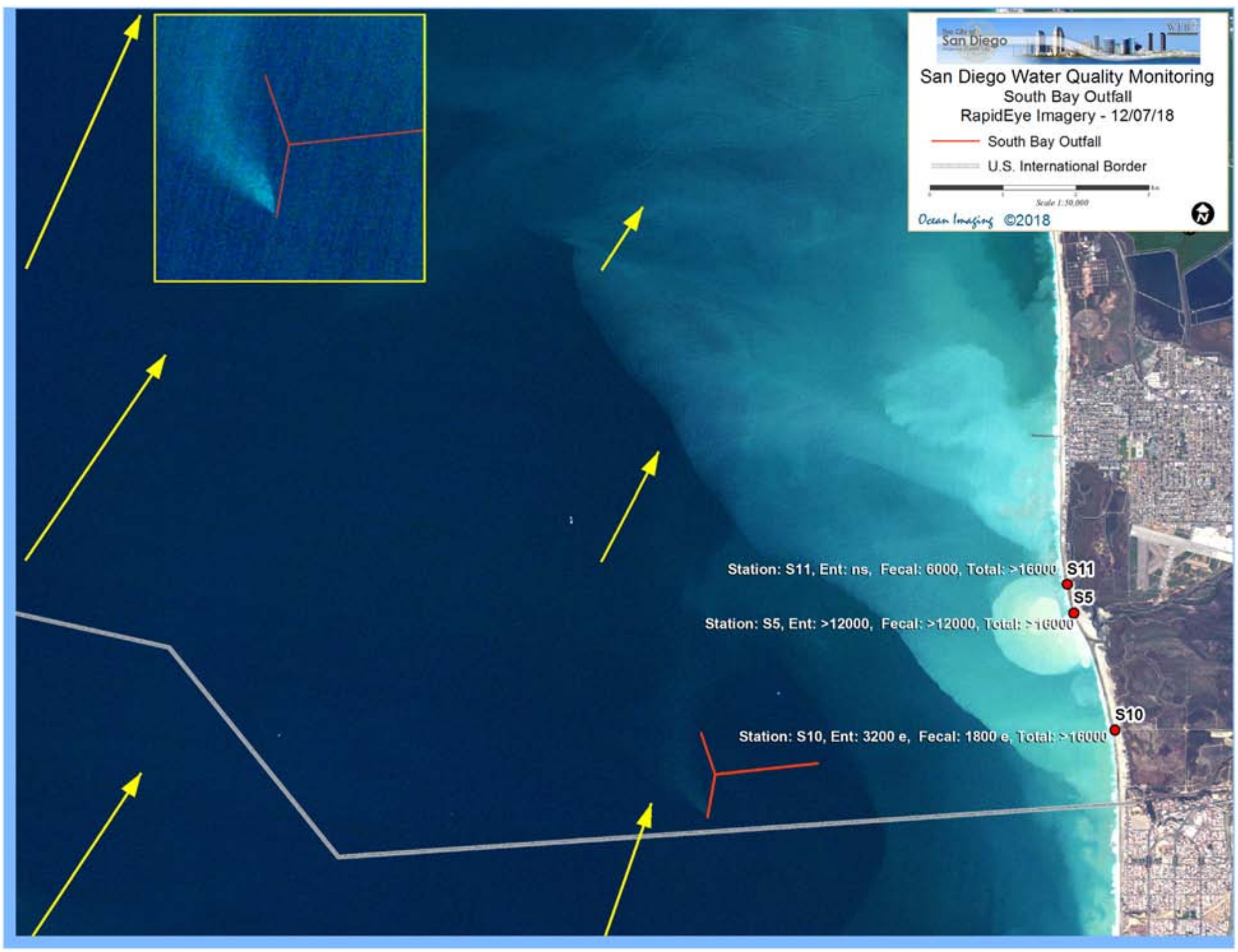


Figure 17: RapidEye image of the Tijuana River shoreline region acquired on 12/07/18 and coastal bacteria sampling results collected on the same day. Elevated bacteria values are evident within the TJR discharge plume and at the stations both north and south of the river mouth. HYCOM-derived current vectors show the northward movement of the plume water up into the San Diego region. The SBOO effluent plume is also observed moving to the north on the ocean's surface.

not taken near this date to validate what was seen in the satellite date. This occurrence can be seen in the Sentinel imagery found in Appendix A.

The period between 12/07/18 and 12/30/18 exhibited the highest number of 2018 SBOO effluent plume observations in the satellite imagery. These relatively frequent effluent surfacings were most probably the result of two primary factors: the lack of strong vertical stratification during the winter months and perhaps relatively weak subsurface currents over the SBOO which allowed the undispersed effluent to reach the surface. The strong TJR runoff seen in the satellite imagery acquired during this time period

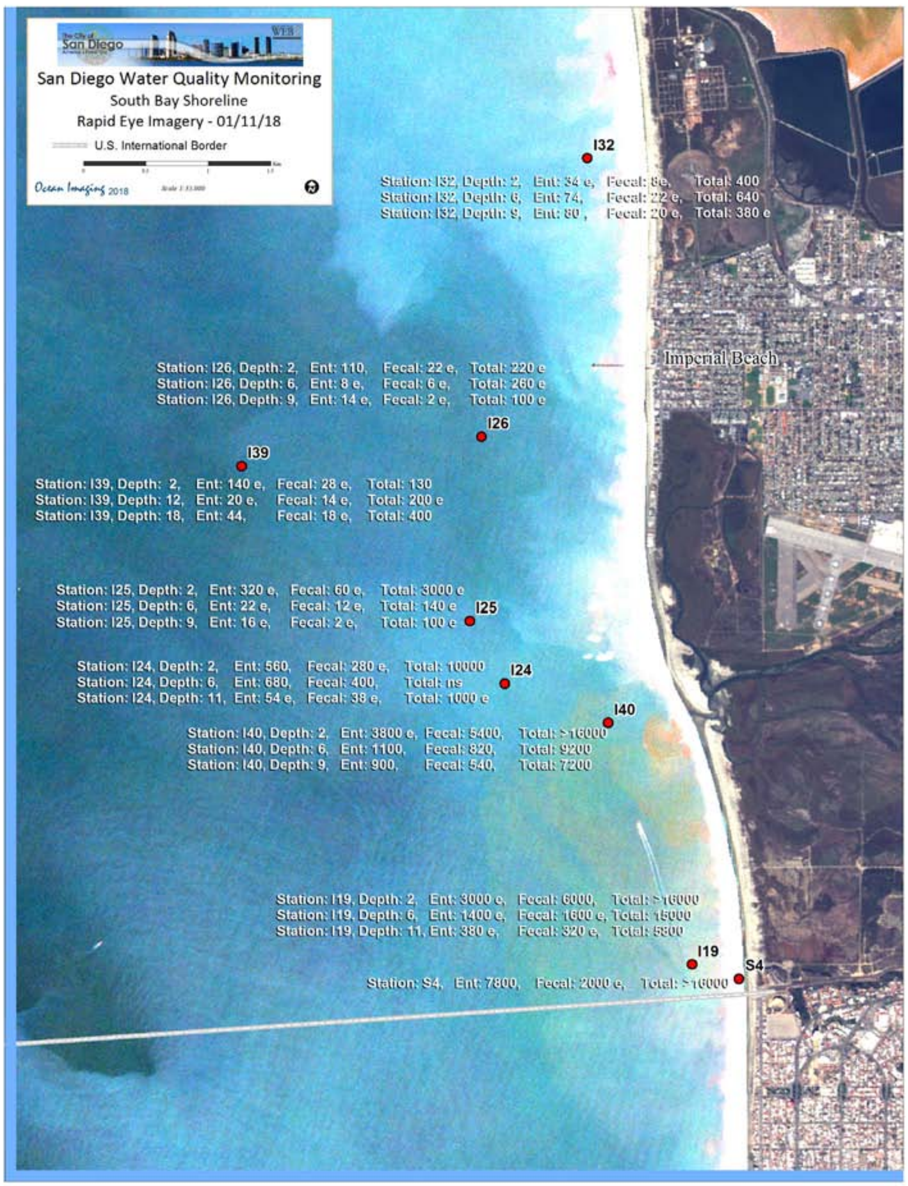


Figure 18. RapidEye image of the Tijuana River shoreline region acquired on 01/11/18 and near-surface bacterial sampling results collected on the same day. Elevated bacteria values are evident within the discharge plume with the highest levels to the south of the river mouth.

was mostly probably a result of the heavy rainfall as well as a sewage spill into the Tijuana River which reportedly started on 12/10/18. Figure 17 shows the RapidEye scene from 12/07/18 with HYCOM currents overlaid. Unfortunately, the HF Radar currents for that day did not cover the inshore region, however the HYCOM currents provide data that validate the northward movement of the Tijuana River plume as is depicted in the satellite image. This strong, contaminated river effluent seen moving up the coast was very likely the primary driver in the numerous shoreline closures during that time.

In 2018 the shoreline area of the Tijuana River outflow region ("SBOOshore" in the City's Water Quality database) experienced 17 days on which the field sampling down to and including the depth of six meters showed elevated bacteria levels as defined by the California Ocean Plan (>10,000 CFU/100mL; fecal coliforms >400 CFU/100 mL; Enterococcus >104 CFU/100 mL – instances when all three of these criteria were met). The offshore SBOO region ("SBOOOffshore") and the kelp bed region ("SBOOKelp") combined, which includes the stations over the SBOO wye, experienced a total of 2 days in 2018 for which the sampling showed elevated bacteria

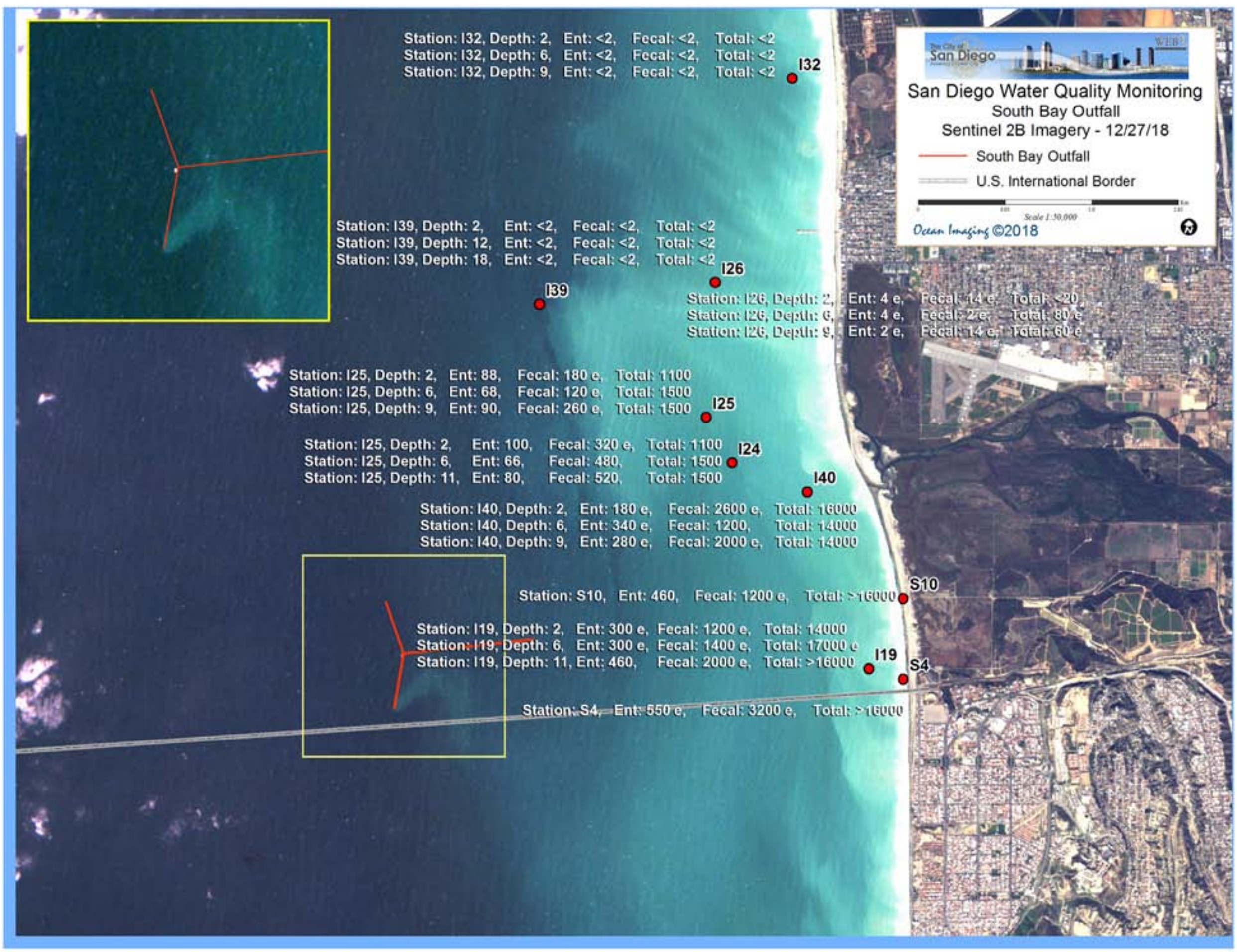


Figure 19: Sentinel 2B image from 12/27/18. Bacteria sampling data from several stations are overlaid on top of the satellite data. Strong SBOO effluent plume signals as well as high bacteria levels near and along the coast south of the TJR continued through the end of the year well after the heavy rains earlier in the month of December.

levels at depths of six meters or shallower. In 2017 the number of elevated bacteria days were 27 and 6 for the sampling regions respectively. The total number of sample days for all the three sampling areas (at six meters or shallower) in 2017 was 157 and 144 in 2018. Adjusting for the number of samples taken each year, this represents roughly a 37% decrease in high bacteria days for the SBOO/TJR region from 2017 to 2018.

Figure 18 shows an example of the contaminated TJR runoff plume along the Tijuana shoreline. Very high bacteria counts are apparent within the TJR outflow plume which is a result of the heavy rainfall which took place on 01/09/18 and 01/10/18. The TJR effluent is seen to be flowing to the southward along the coast which matches the direction HF Radar currents shown in Figure 11. The higher bacteria counts at the southern stations corroborate the surface flow observed in the image and HF Radar data.

Only a few field samples were available in the southern region on 12/07/18, however measurements correlate well with the heavy, distinct inshore “Fresh Core” (FC) component of the TJR runoff plume (as defined in the 2015 Five Year Summary Report). Figure 17 shows the RapidEye satellite image for the TJR shoreline with the three available field readings overlaid.

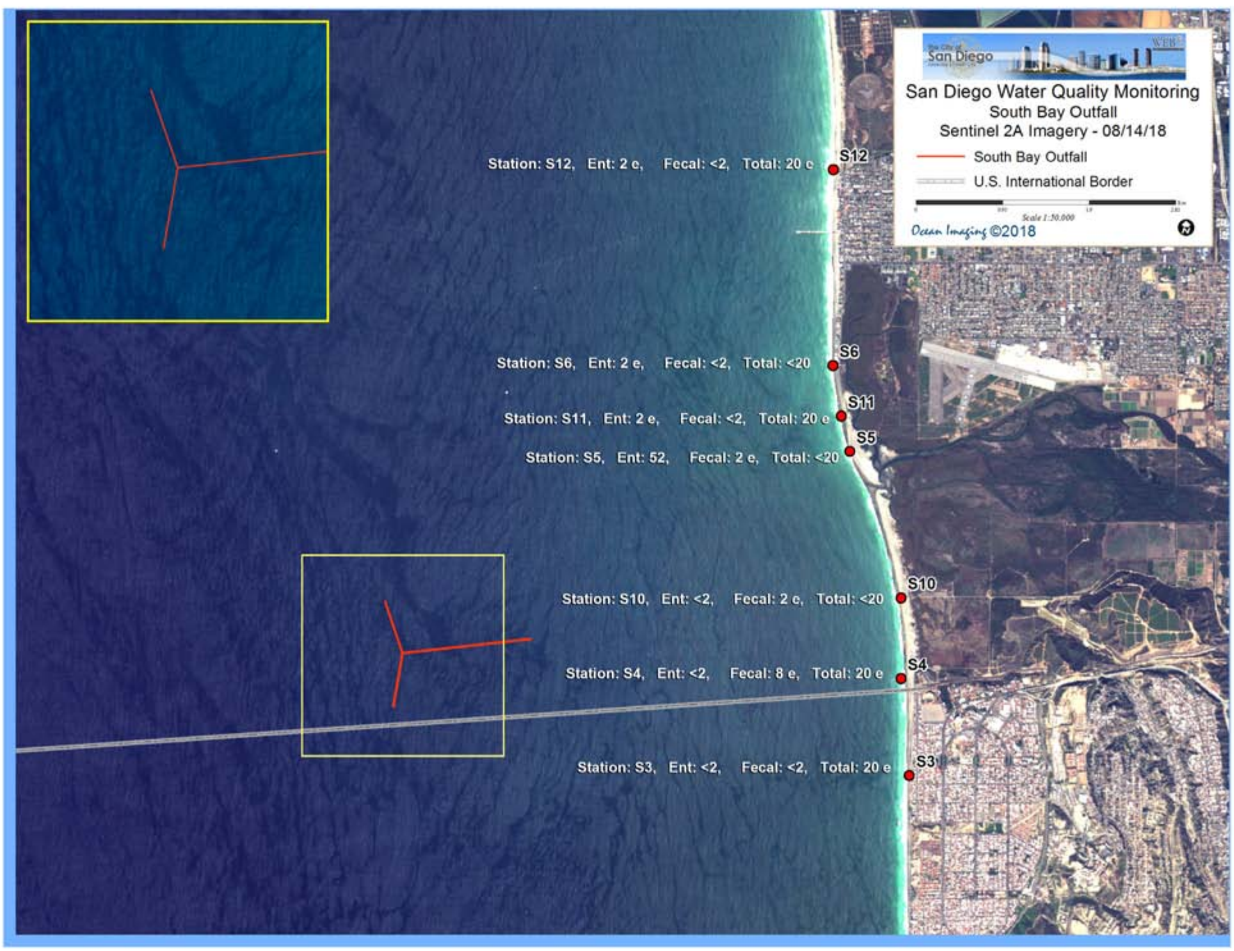


Figure 20: Sentinel 2A image of the SBOO region acquired on 08/14/18 and near-surface coastal bacterial sampling results collected on the same day. Note the clear water along with the low bacteria levels.

Following the Tijuana River sewage spill and heavy rains in the beginning of December 2018, high bacteria counts as well as a SBOO turbidity plume (not necessarily related to the sewage spill or rain events) were evident all the way through the end of the year. Figure 19 shows a Sentinel 2B image acquired on 12/27/18 with field sample data from the same day overlaid. Bacteria levels were notably high – especially to the south. The last SBOO effluent surface manifestation of 2018 was observed on 12/30/18 with a relatively large turbidity reflectance signal (compared to other SBOO effluent plumes observed in the 2018 satellite imagery) (Appendix A).

The best water quality and clarity in the South Bay region in 2018 was observed from May through September. There was only one day when elevated bacteria levels at depths of six meters or shallower were recorded at the SBOOshore stations, zero days recorded at the SBOOKelp stations and zero recorded at the SBOOOffshore sampling stations during this five-month period. The one day of high bacteria measurements were recorded at the far south "S0" station. The summer was unusually dry as there were no significant rain events during this time period. No SBOO plume signatures were seen in the satellite imagery during this time. The bacteria sampling data from 08/14/18 overlaid on top of the Sentinel

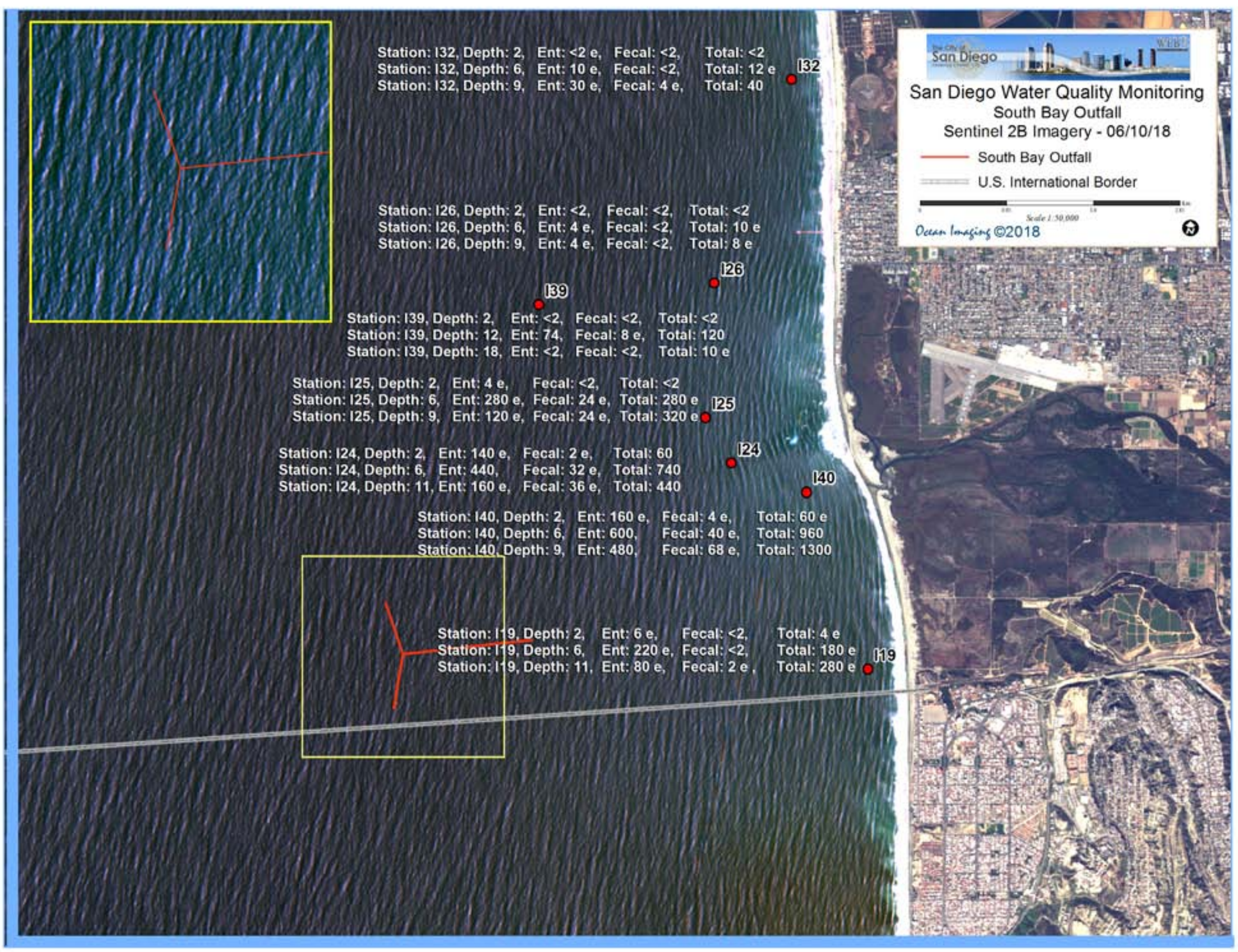


Figure 21: Sentinel 2B image of the SBOO region acquired on 06/10/18 and near-surface coastal bacterial sampling results collected on 06/11/18.

2A satellite data illustrate the good water quality conditions during this time period (Figure 20). On 06/11/18 the inshore region did exhibit a few relatively high bacteria levels. Figure 21 shows the sampling data from 06/11/18 overlaid on the Sentinel 2B image from 06/10/18. CTD data also revealed that there was very little chlorophyll in the area on that day.

3.3. The Point Loma Outfall Region

After its seaward extension in 1993, the Point Loma Outfall (PLOO) is one of the deepest and longest wastewater outfalls in the world, discharging 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, however, 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.

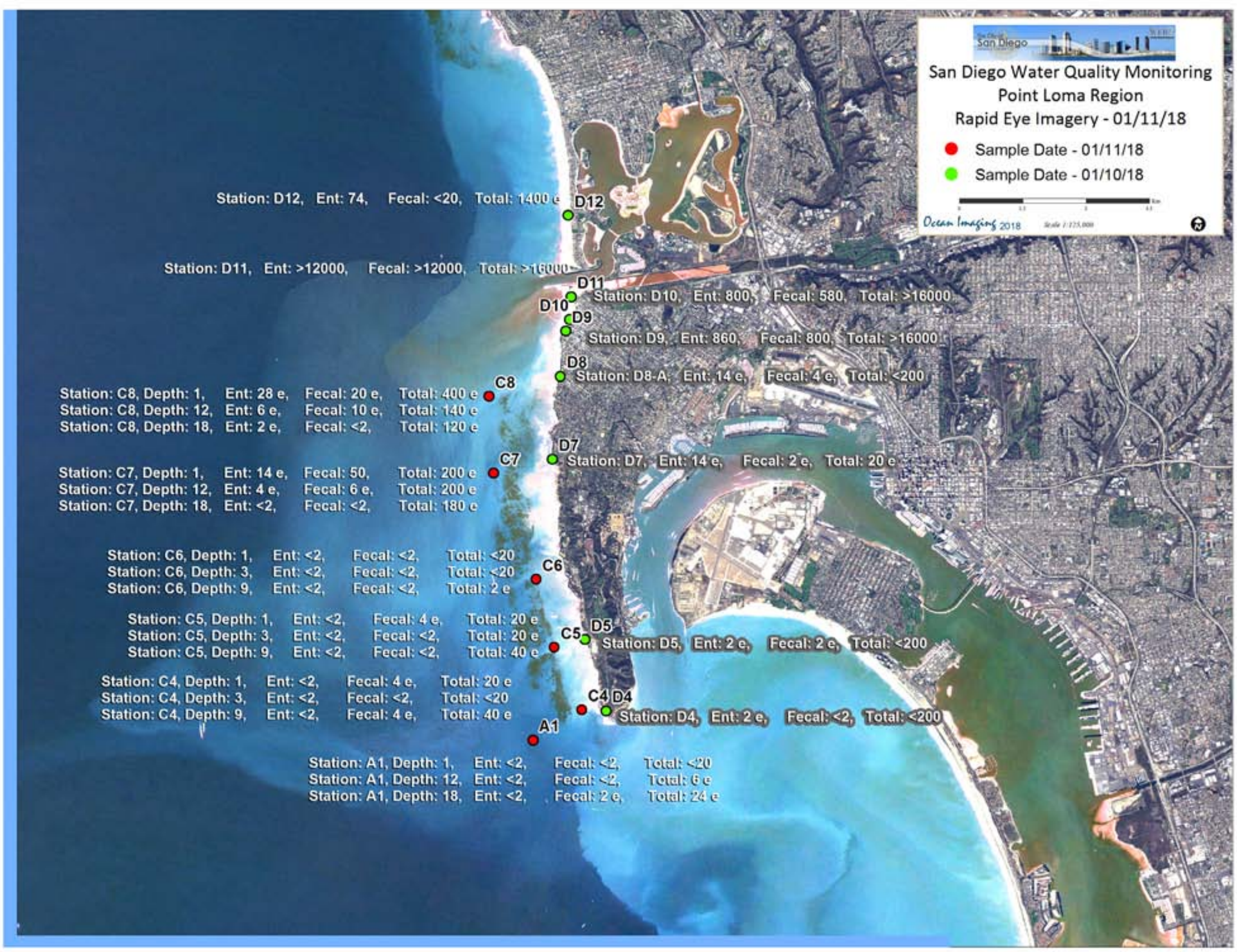


Figure 22: RapidEye image of the Pont Loma region acquired on 01/11/18 and near-surface coastal bacterial sampling results collected on 01/10/18 and 01/11/18. Note the higher bacteria near the outflow of Mission Bay, however no obvious turbidity plume emanating from the outfall.

Figure 23a: High resolution RapidEye satellite images showing the Pt. Loma kelp bed on 10/11/11, (top left), 10/14/12 (top right), 10/04/13 (bottom left) and 10/03/14 (bottom right). Years 2015-2018 are in Figure 23b.

Figure 23ba. High resolution RapidEye and Sentinel satellite images showing the Pt. Loma kelp bed on 10/08/15 (top left), 10/08/16 (top right), 10/16/17 (bottom left) and 10/16/18 (bottom right). Note the significant decrease in canopy area coverage in 2016, 2017 and 2018 compared to the previous five years, even during potentially peak growth months.

In 2018 the Point Loma region was affected by conditions already described for the South Bay region: significant seasonal rainfall during the months of January, February, and December with near zero rainfall during the months of May through September. Similar to 2017, this compromised water clarity in the nearshore areas in January, late February to early March as runoff from the San Diego River and Mission Bay brought sediment-laden water inside and outside the Point Loma kelp bed after the major rain events described above. Both shoreline and periodic kelp bed bacterial sampling generally showed only occasional and marginally increased concentrations. Shoreline field sampling showed only eight measurements of elevated bacteria levels (> 500 CFU/100mL) occurring on 01/10/18, 01/12/18 and 01/31/18. Offshore and kelp bed sampling only showed elevated levels on two occasion during the year. The high bacteria measurements in January can be attributed to heavy rain events either prior

Figure 24a: High resolution RapidEye and Sentinel satellite images showing the Pt. Loma kelp bed (from top left to bottom right: 01/29/18, 02/24/18, 03/27/18, 04/28/18, 05/16/18, 06/10/18. Note an increase in the kelp bed canopy during April through July and then from November to the end of December.

to or during the site sampling. Figure 22 shows the 01/10/18 and 01/11/18 shoreline and offshore bacteria data plotted over RapidEye data acquired on 01/11/18. While no plume associated with the outfall was visible, heavy coastal turbidity was apparent fueled by heavy sediment/turbidity plumes emanating from Mission Bay and San Diego Bay.

As has been reported in previous years, strong, multi-day northward current episodes after rains can bring contaminated waters from sources in Mexico (e.g. Los Buenos Creek and the Tijuana River) northwestward and occasionally affect the southern Pt. Loma area. Despite the multiple rain events, this was not directly observed in 2018.

One observation provided by the satellite image archive was the continuing small size of the Point Loma kelp bed seen in the fall of 2018 (Figures 23a and 23b). As has been reported in previous years, the satellite data show the bed to begin to decrease in size during February of 2016, perhaps due to the

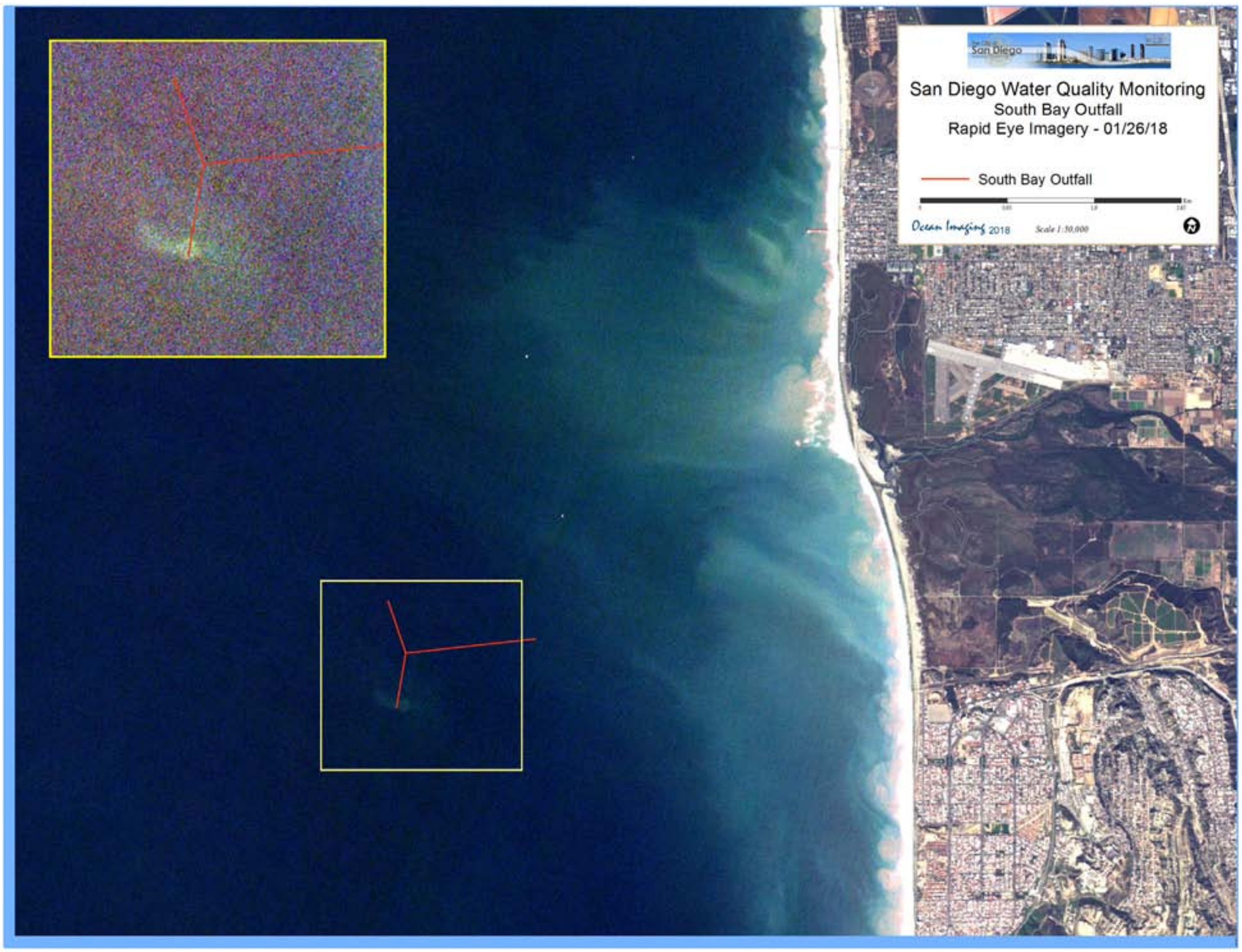
Figure 24b: High resolution RapidEye and Sentinel satellite images showing the Pt. Loma kelp bed (from top left to bottom right: 07/05/18, 08/09/18, 09/18/18, 10/16/18, 11/02/18 and 12/30/18.

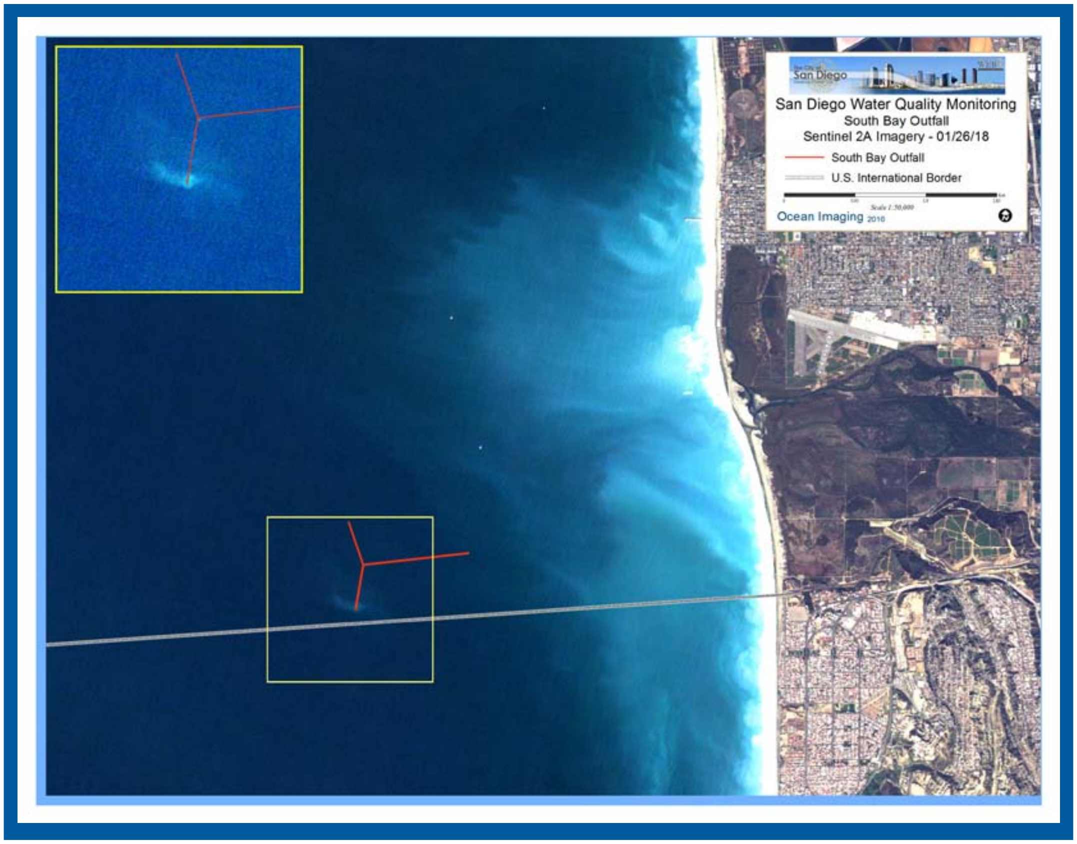
storm events taking place during early to mid-January. Noted in the 2017 annual report, the kelp bed appeared to be coming back in January of 2017, but then decreased in size as the year progressed resulting in much smaller than average canopy coverage by the end of that year. In 2018, the kelp bed followed a similar annual pattern. Table 3 shows the area in km2 of three notable kelp beds in the San Diego region. The September and October dates chosen to represent the kelp bed canopy coverage are normally when the canopy size is near its peak. Evident in the table is, not only the continued low canopy areal coverage of the Point Loma bed since 2015, but also the total absence of the Imperial Beach and Tijuana beds for the third year in a row. At 2.44 km2 the size of the Point Loma bed has increased over the past two years but is still well below the average size of the past eleven years which is 4.06 km2. Tide levels were not a factor in the inter-year comparison as there was little variability in tide level between the years. In fact, the tide levels were all relatively high (+2.8 - +5.8 feet) at the time of satellite overpass for all the years. What is not shown in Figures 23a and 23b nor Table 3 is highlighted in Figure 24. This figure provides imagery of the Point Loma kelp bed on a monthly basis. It should be noted that the kelp canopy does appear to grow back to a near-normal size during the months of April through July and then drop off in areal coverage beginning in September. Then again, despite significant rainfall events taking place in late November and early November however, the bed experiences considerable regrowth by the end of the year. Therefore, it cannot be said that 2018 was a poor year for the health of the Point Loma kelp as we see decent growth during the summer and winter months. Regardless, the commonly held belief that kelp forests are in peril along West Coast warrants keeping a close watch on the health of the kelp beds in the San Diego region.

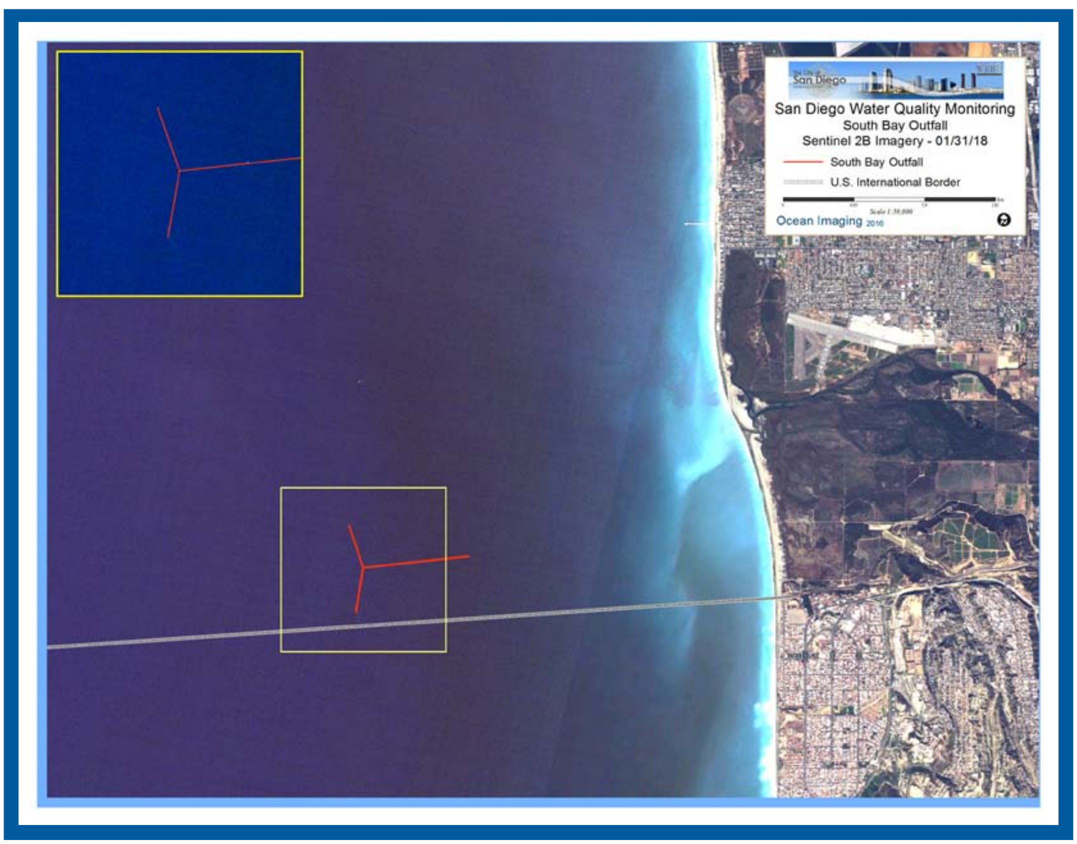
Table 3. Kelp canopy areas of three San Diego kelp beds measured from satellite imagery collected for this project.

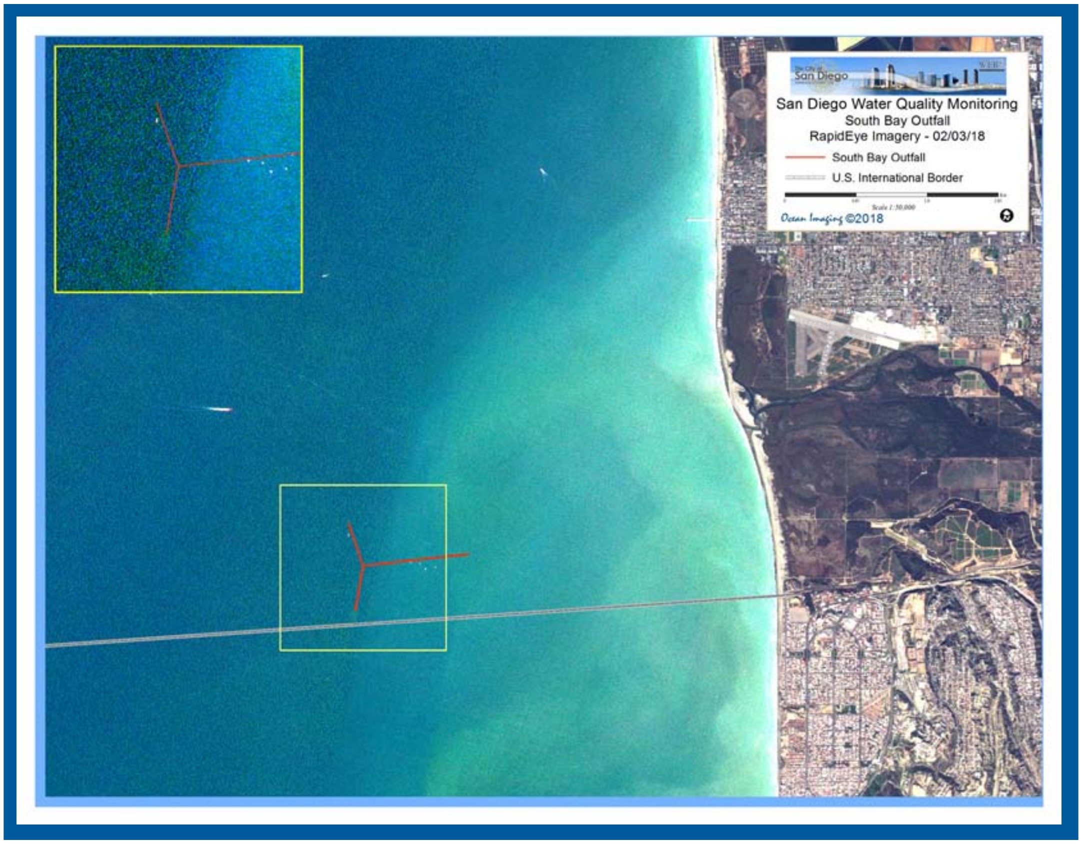
			Kelp (km²)		
Year	Date	Satellite	Point Loma	Imperial Beach	Tijuana
2018	10/16/2018	Sentinel 2A	2.44	0.00	0.00
2017	10/04/2017	RapidEye	1.05	0.00	0.00
2016	09/08/2016	RapidEye	0.22	0.00	0.00
2015	09/17/2015	Landsat 7	4.11	0.39	0.29
2014	09/14/2014	Landsat 8	5.42	0.59	0.30
2013	09/23/2013	RapidEye	5.89	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

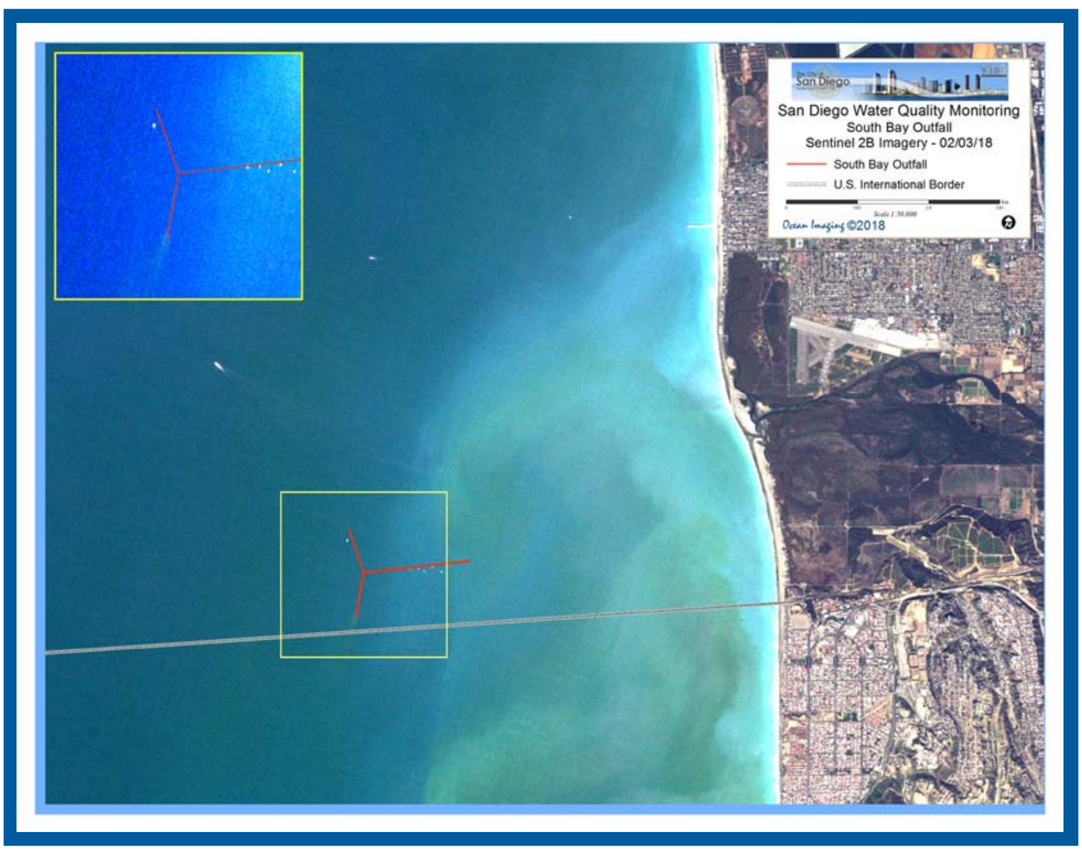
APPENDIX A – HIGH RESOLUTION SATELLITE IMAGERY SHOWING SBOO-RELATED WASTEWATER PLUME

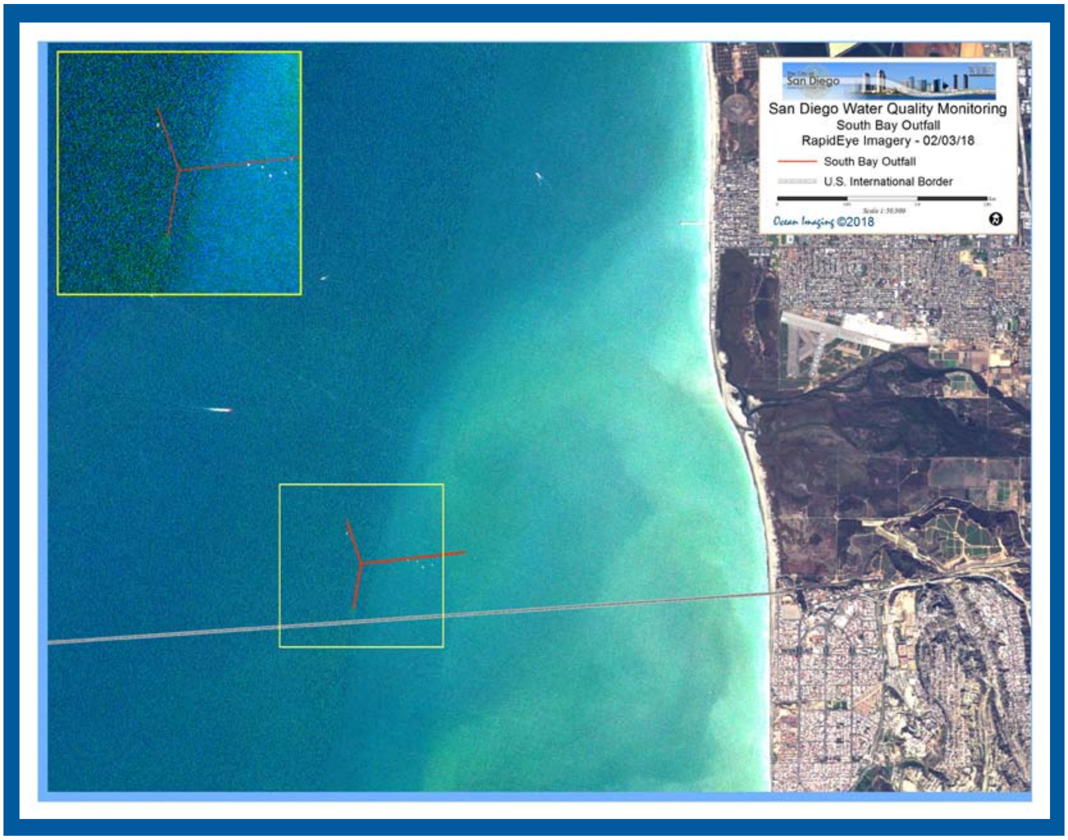


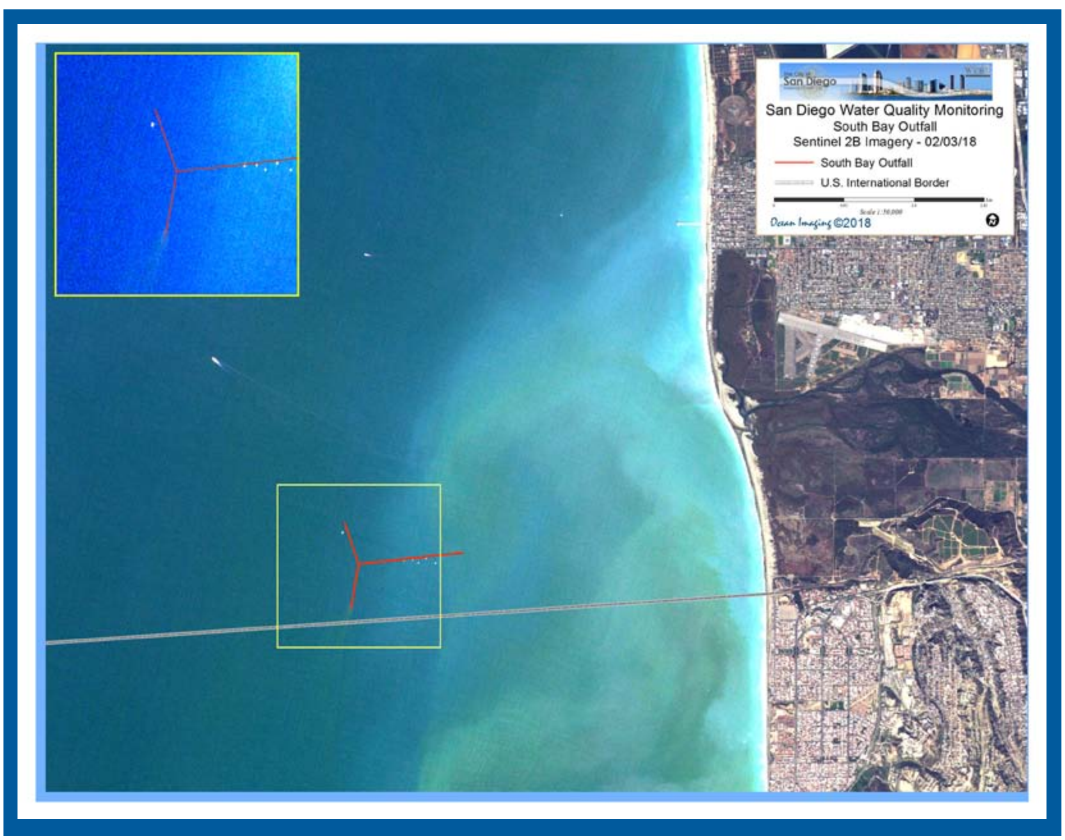

San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 01/26/18
South Bay Outfall
U.S. International Border
Ocean Imaging 2016


San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 01/31/18
South Bay Outfall
U.S. International Border
Ocean Imaging 2016


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
RapidEye Imagery - 02/03/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 02/03/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
RapidEye Imagery - 02/03/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 02/03/18
South Bay Outfall
U.S. International Border
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San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 02/08//18
South Bay Outfall
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San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 03/27/18
South Bay Outfall
U.S. International Border
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South Bay Outfall
RapidEye Imagery - 12/07/18
South Bay Outfall
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San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 12/07/18
South Bay Outfall
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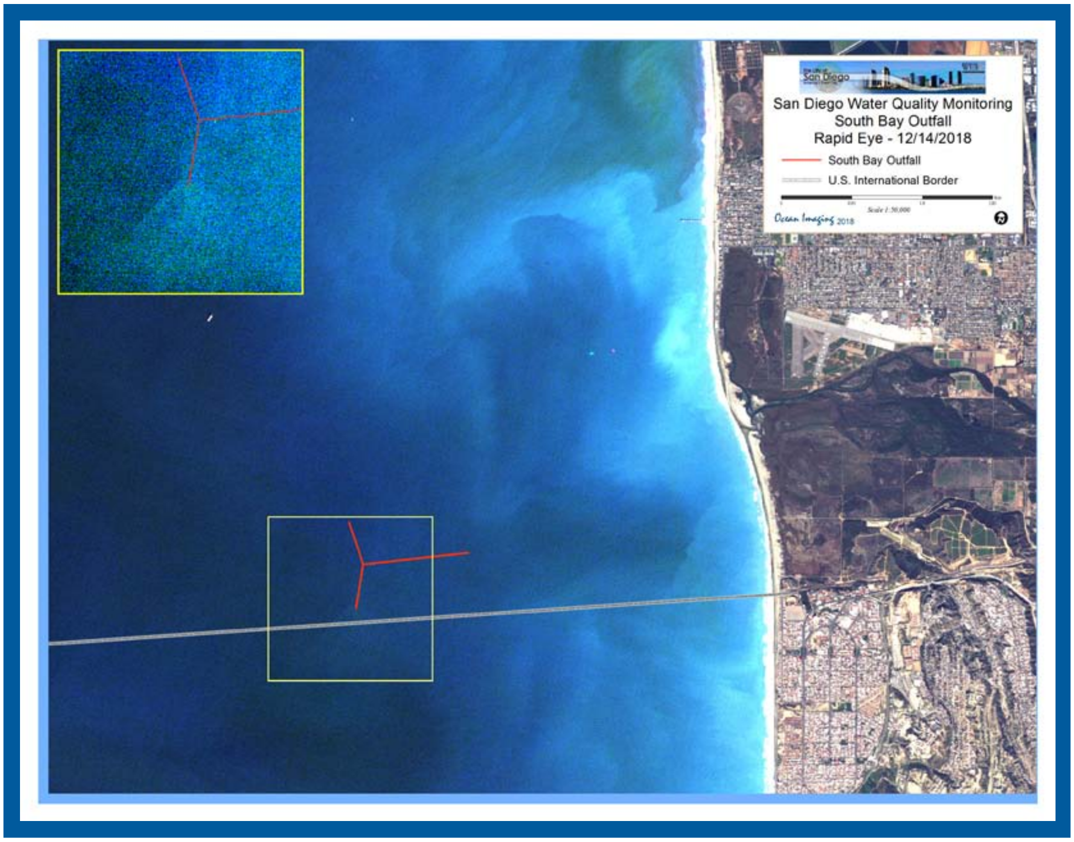
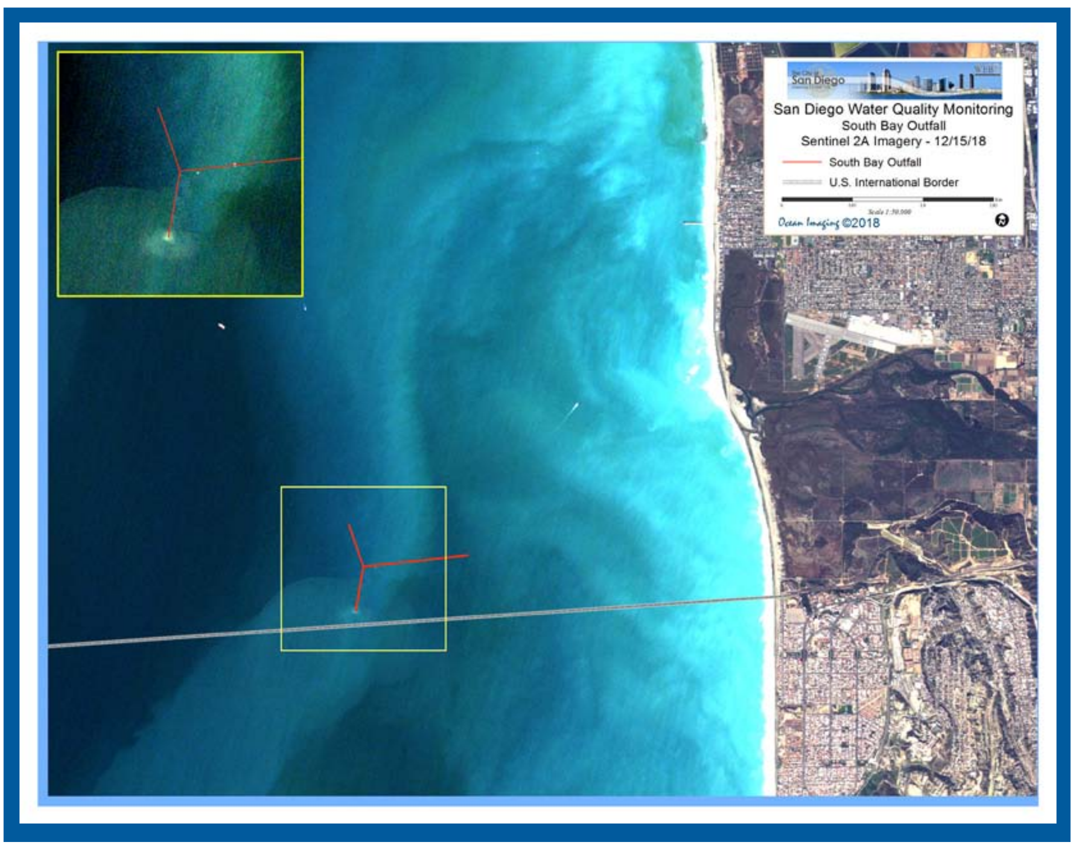
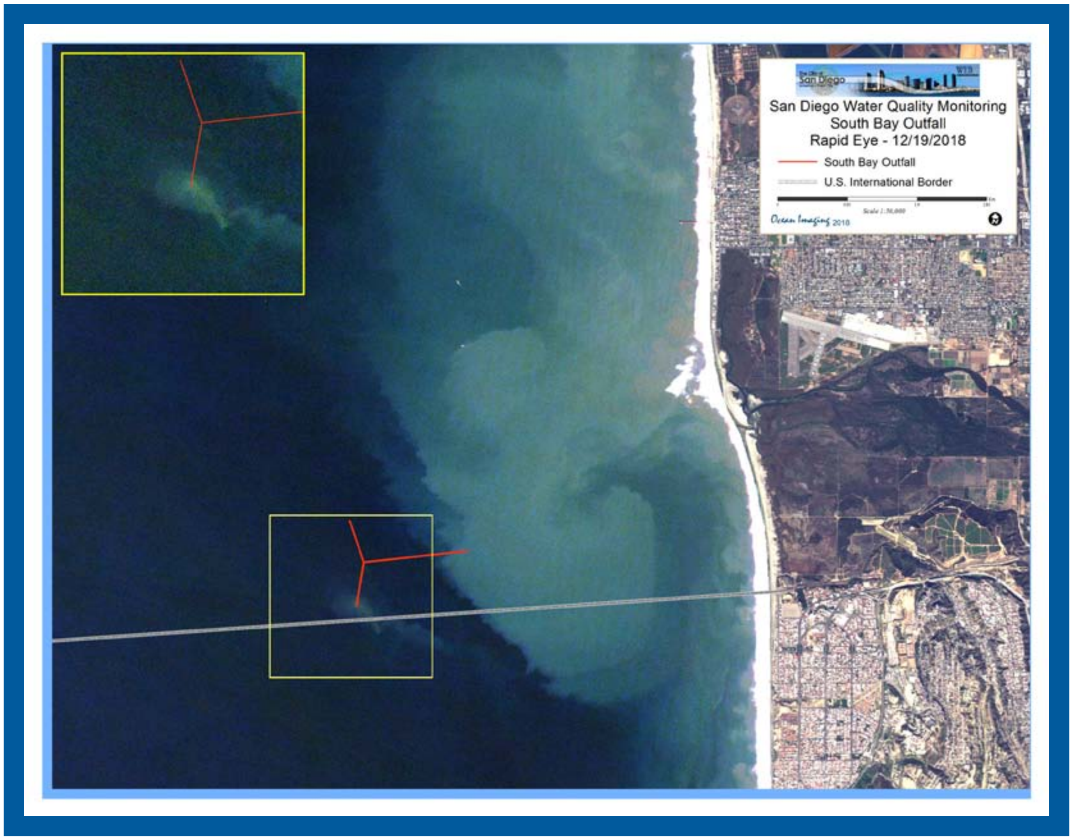
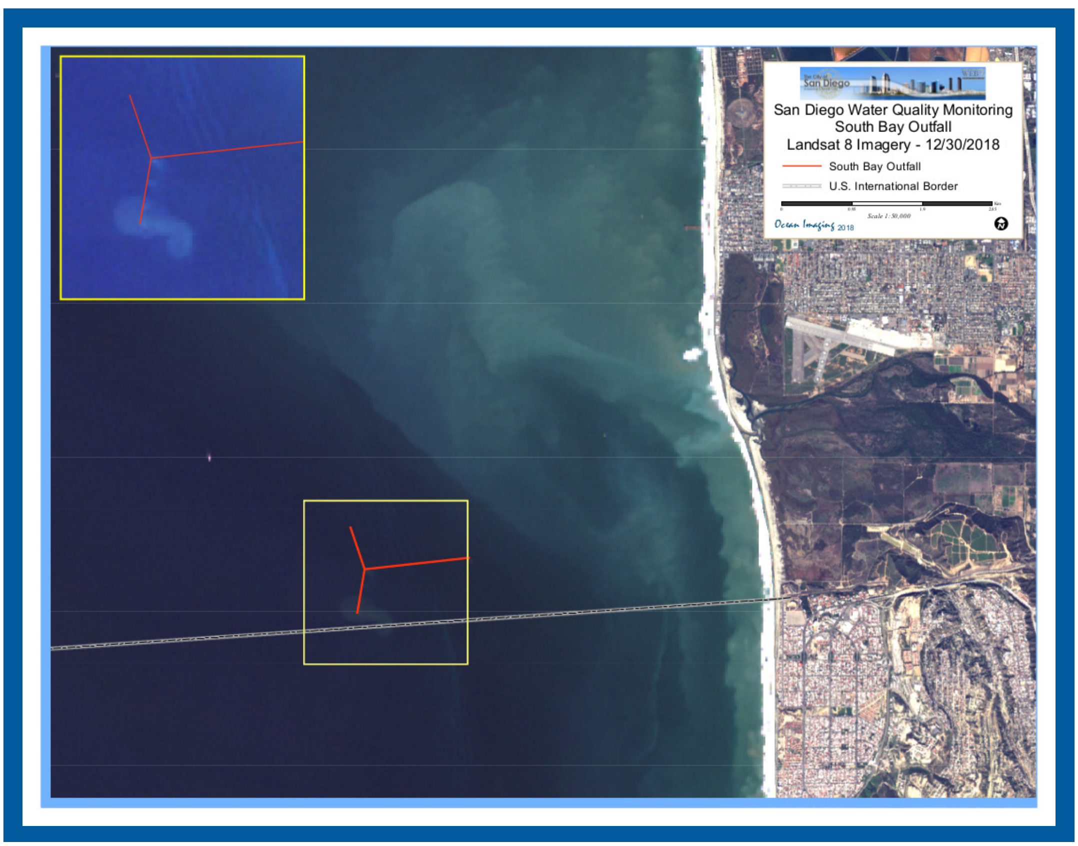

San Diego Water Quality Monitoring
South Bay Outfall
Rapid Eye - 12/14/2018
South Bay Outfall
U.S. International Border
Ocean Imaging 2018


San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2A Imagery - 12/15/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego Water Quality Monitoring
South Bay Outfall
Rapid Eye - 12/19/2018
South Bay Outfall
U.S. International Border
Ocean Imaging 2018


San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 12/27/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Sentinel 2B Imagery - 12/30/18
South Bay Outfall
U.S. International Border
Ocean Imaging ©2018


San Diego
San Diego Water Quality Monitoring
South Bay Outfall
Landsat 8 Imagery - 12/30/2018
South Bay Outfall
U.S. International Border
Ocean Imaging 2018