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

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## Annual Summary Report
### 1 January, 2014 - 31 December, 2014

This draft to become final in sixty days.



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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 stormwater 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 a baseline database 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 Thematic Mapper TM5 & TM7 color and thermal imagery (available 4 times per month). 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. 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 on a daily basis through the City's EMTS web-based GIS "BioMap" Server, and continued expanding the product selection and delivery through 2014. These products range from atmospherically corrected satellite images of sea surface temperature and chlorophyll to radar and model-derived surface current fields.

This report summarizes observations made during the period 1/1/2014 – 12/31/2014.

## 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. 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-NearInfraRed 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.

The color channels on satellite sensors cannot be changed, so they tend to be relatively broad, separating red, green, near-IR, and sometimes blue parts of the spectrum. OI's DMSC aerial 4-channel sensor has the added advantage of allowing each channel wavelength to be precisely customized. Through experimentation, OI has determined the exact wavelength relationships that maximize the detection of the offshore sewage outfall plumes and nearshore discharges such as the Tijuana River. With this channel configuration it is possible to monitor the plumes even when they are not visible to the naked eye.

### 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 salt water 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 is thus processed and posted within 1-2 days after acquisition and the aerial sensor imagery (which requires the most labor-intensive processing), within 2-5 days. OI has, however, in a number of cases, made some imagery available to the CDH and others in near-real time when observations were made that appeared to be highly significant for the management of beach closures or other sudden events. The BioMap Server-directed products are produced daily by OI and are automatically linked with the server when available.

## 3. Highlights of 2014 Monitoring

### 3.1 Atmospheric and Ocean Conditions

2014 was the third consecutive drought year for the San Diego region. Only one significant rain event occurred in its early months February 28th, with almost the entire annual rainfall occurring near the end of the year in December (**Figure 1**). As is shown in **Figure 2**, flow of the San Diego River at the Fashion Valley gauging station actually dropped below 1 cubic foot per second for much of June through mid-September, which has not occurred in previous years. Multiple prolonged rain events in December helped ease the extensive rain deficit for the year, also causing massive quantities of runoff to affect the San Diego coastal waters.

2014 also stands out as having the most persistent high water clarity in the San Diego area in recent years. Throughout the spring, summer and fall no intense plankton blooms or red tides developed along both north and south coasts of San Diego, resulting in persistently high water clarity.

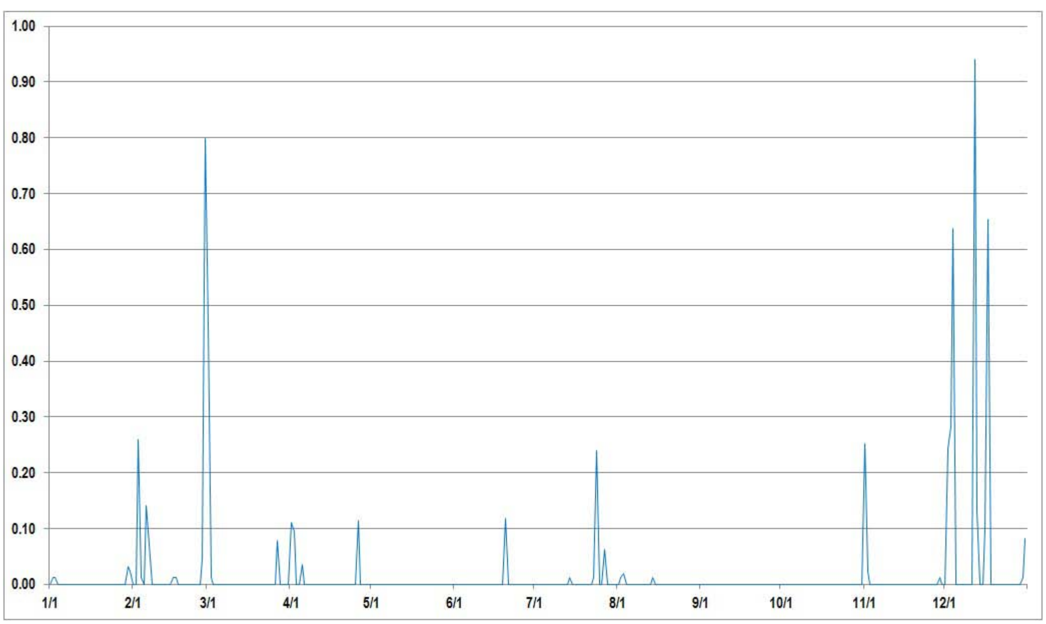
### 3.2 The South Bay Ocean Outfall Region

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.

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 the 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. However, in the past 2 years numerous instances occurred when the plume was detectable on the surface with the multi-

**Tijuana River - Cumulative Daily Precipitation 2014**




| Date | CumPrcp (in) |
|---|---|
| 1/2 | 0.01 |
| 1/3 | 0.01 |
| 1/30 | 0.03 |
| 1/31 | 0.02 |
| 2/3 | 0.26 |
| 2/4 | 0.01 |
| 2/6 | 0.14 |
| 2/7 | 0.07 |
| 2/16 | 0.01 |
| 2/17 | 0.01 |
| 2/27 | 0.05 |
| 2/28 | 0.80 |
| 3/1 | 0.46 |
| 3/2 | 0.01 |
| 3/27 | 0.08 |
| 4/1 | 0.11 |
| 4/2 | 0.09 |
| 4/5 | 0.04 |
| 4/26 | 0.11 |
| 6/20 | 0.12 |
| 7/14 | 0.01 |
| 7/23 | 0.01 |
| 7/24 | 0.24 |
| 7/27 | 0.06 |
| 8/2 | 0.01 |
| 8/3 | 0.02 |
| 8/14 | 0.01 |
| 11/1 | 0.25 |
| 11/2 | 0.02 |
| 11/29 | 0.01 |
| 12/2 | 0.24 |
| 12/3 | 0.28 |
| 12/4 | 0.64 |
| 12/12 | 0.94 |
| 12/13 | 0.13 |
| 12/16 | 0.10 |
| 12/17 | 0.65 |
| 12/30 | 0.01 |
| 12/31 | 0.08 |

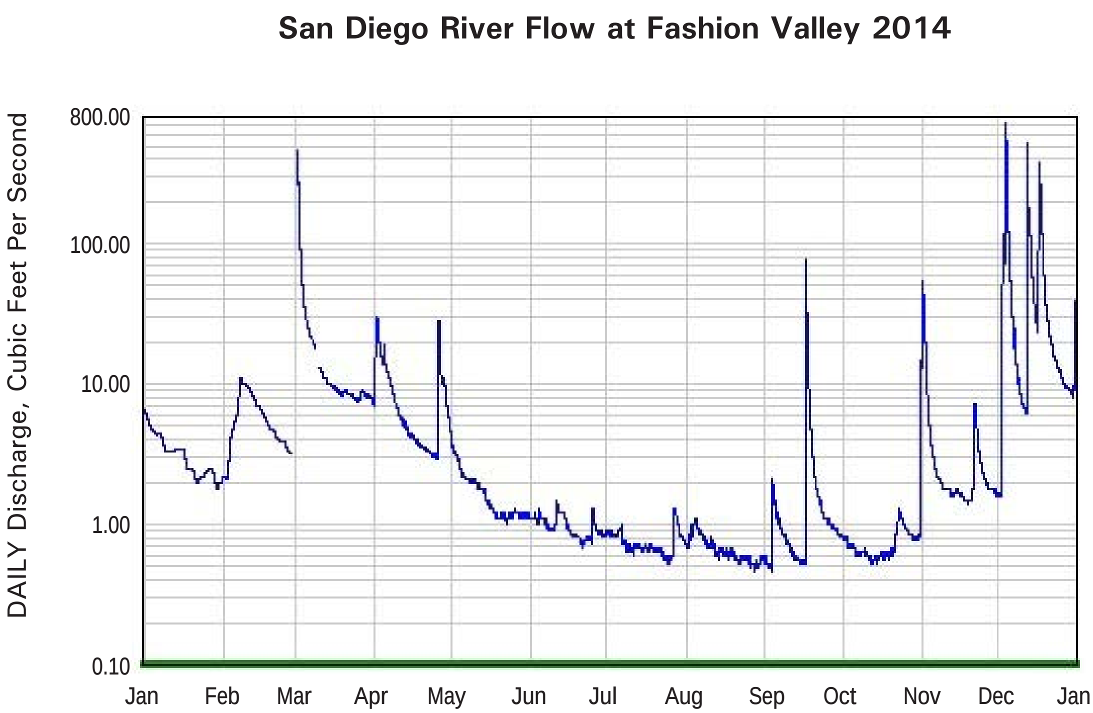
**Figure 1.**

Graph of daily cumulative rainfall in the Tijuana Estuary during 2014.

spectral sensors but only became detectable with thermal imaging a day or two later, only to reappear again in the next acquired color image data set. The existence of a thermal plume signature shows the effluent reached the ocean surface, but its simultaneous lack of a color signature implies it reached the surface in a significantly diluted state. We posit that on days with significant subsurface currents and/or vertical mixing the SBOO effluent plume with its present approximately 16 mg/L TSS load becomes sufficiently diluted as it travels up through the water column to not sufficiently alter the turbidity reflectance of the surface layer.

In 2014 the SBOO plume was detectable in remote sensing imagery during the year's early months until early March. Examples are shown in **Figure 3**. This corresponds to observations in previous years and also corresponds to the seasonal rebuilding of vertical stratification. **Figure 4** shows the SBOO region on 3/5/2014, 5 days after the only major rain event during the early-year rain season. Despite significant turbid runoff along the coast, shoreline bacterial sampling done by the CDH on 3/4/2014 showed only slightly elevated indicator bacteria concentrations outside the immediate Tijuana River mouth.

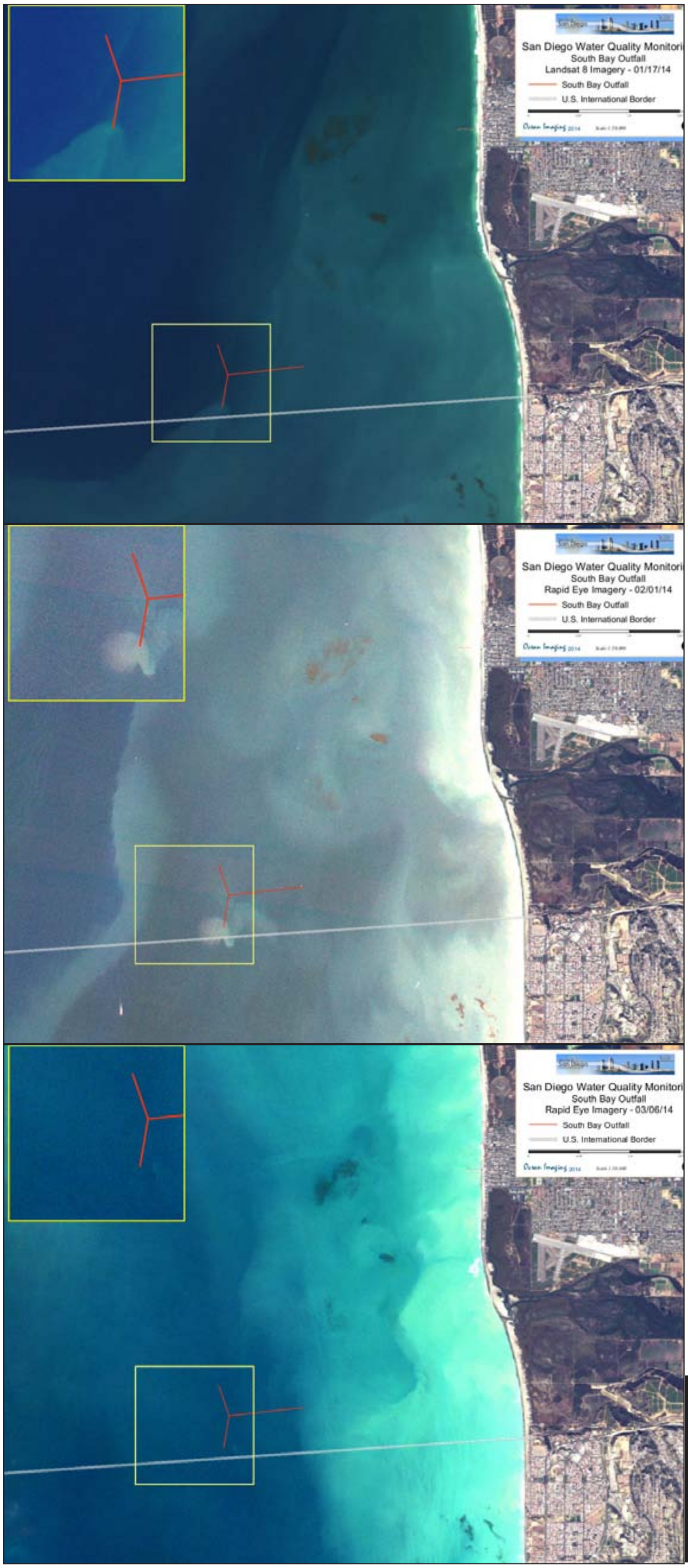
There were a few episodes of significantly elevated bacteria concentrations along the shores of Imperial Beach and Silver Strand during the summer and fall of 2014 in the absence of rain runoff, notably on 7/17, 10/7 and 10/21. Near time-coincident satellite imagery did not reveal any anomalous patterns to account for the elevated readings. As was noted




| Lindbergh Field Rainfall 2014 | |
|---|---|
| January | 0.01" |
| February | 1.00" |
| March | 1.28" |
| April | 0.54" |
| May | 0.00" |
| June | 0.00" |
| July | 0.00" |
| August | 0.08" |
| September | 0.00" |
| October | 0.00" |
| November | 0.37" |
| December | 4.50" |

**Figure 2.**

Graph of mean daily discharge of the San Diego River during 2014 (measured at Fashion Valley). The table on the right shows monthly rainfall totals at Lindbergh Field.




above, no major red tide events occurred in the South Bay region (or elsewhere along the San Diego coast) during 2014, and water clarity generally remained high through much of the year.

The SBOO plume was again detected in an image acquired on 11/17/2014, shown in **Figure 5** along with offshore bacteria field sampling results collected the following day.

December experienced several significant, prolonged rain events (see **Figures 1 and 2**). **Figure 6** shows the SBOO region on 12/19/2014 after one such storm, with a surface signature of the SBOO plume as well as older and fresh discharge plumes from the Tijuana River. Correspondingly, shoreline bacteria sampling showed highly elevated levels along the Tijuana Estuary and northward through Imperial Beach. Such contamination events tended to be relatively short-lived, however, since samples taken on 12/23/2014 at Imperial Beach and Silver Strand showed bacterial levels to have dropped to near-background. The field sampling results are reflected in high resolution satellite imagery acquired on the previous day (12/22/2014) which shows no fresh runoff from the Tijuana River and greatly improved nearshore water clarity (**Figure 7**).

### 3.3. The Point Loma Outfall Region

After its seaward extension in 1993, the Point Loma Outfall (PLO) is one of the

**Figure 3.**

High resolution satellite imagery of the SBOO region showing representative outfall plume signatures on 1/17, 2/1 and 3/6/2014.

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 stratification is 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.

In 2014 the PLO region experienced conditions very similar to those already described for the SBOO further to the south: below average rainfall and thus sub-normal point and non-point terrestrial runoff, and mostly clear-water conditions. Unlike in most previous years, the region did not experience any significant red-tide events or major plankton blooms, with

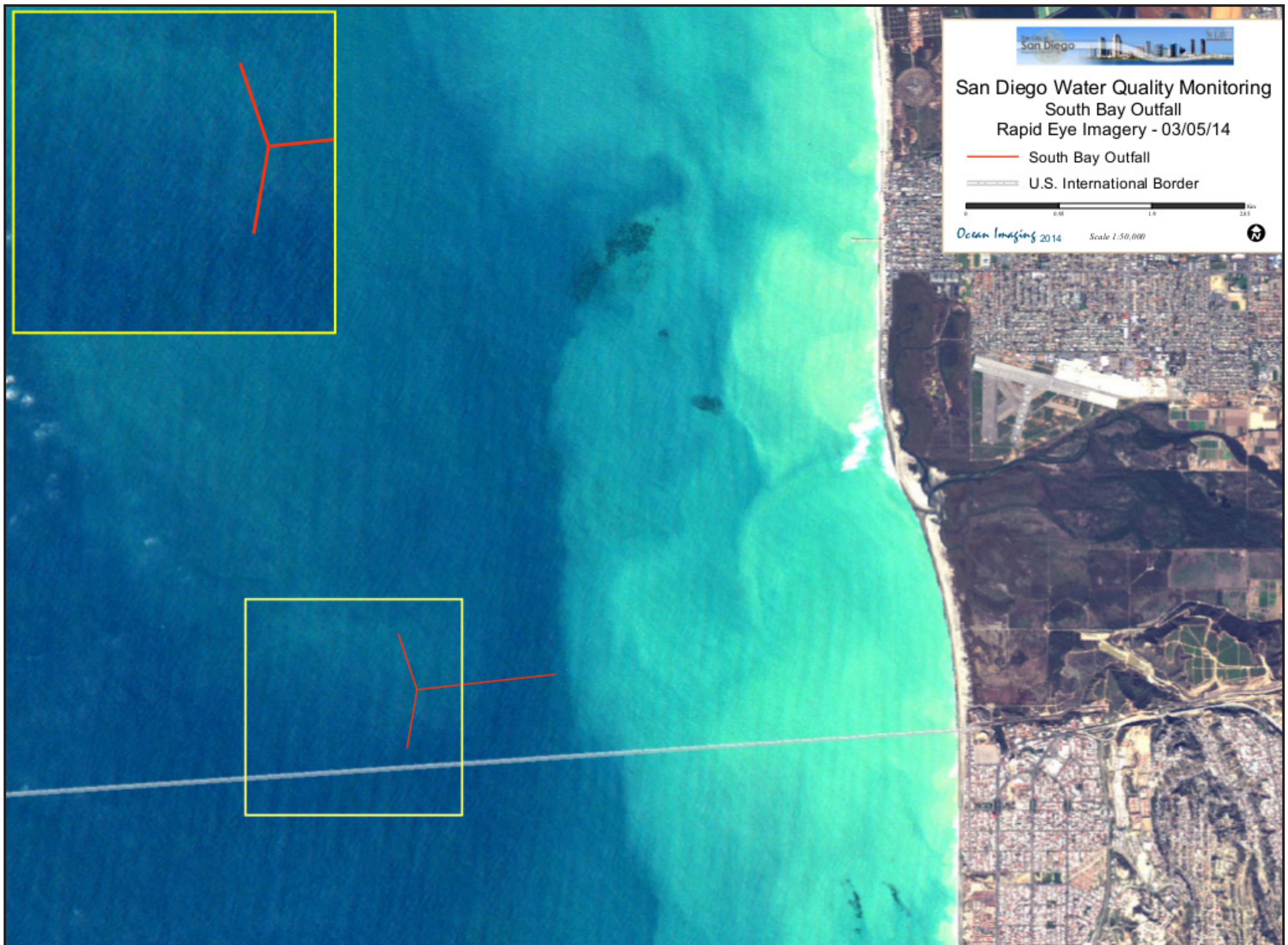



**Figure 4.**

High resolution satellite image of the SBOO region acquired on 3/5/2014, five days after a major rain event. Despite significant turbid runoff along the coast, shoreline bacteria sampling done the previous day showed only slightly elevated concentrations outside the immediate Tijuana River mouth.

one localized exception observed in imagery acquired on 2/14/2014 shown in **Figure 8**.

The 2/28/2014 rain event caused relatively large amounts of turbidity which extended offshore well past the PLO wye (**Figure 9**). It was also associated with elevated shoreline bacteria sampling values at Ocean Beach and Sunset Blvd. Isolated short-lived periods of elevated values at Ocean Beach also occurred in April, and particularly on 7/28/2014. A Landsat-8 image was acquired that day but the nearshore Pt. Loma region data were too contaminated with cloud cover to allow useful analysis.

As was already noted, 2014 persistently exhibited high water clarity, exemplified by a high resolution satellite image acquired on 11/12/2014 (**Figure 10**), which clearly displays bottom features along Pt. Loma between the shoreline and the kelp bed. This trend was broken by the December rains, which resulted in highly turbid runoff from the San Diego River, San Diego Bay and other point and non-point

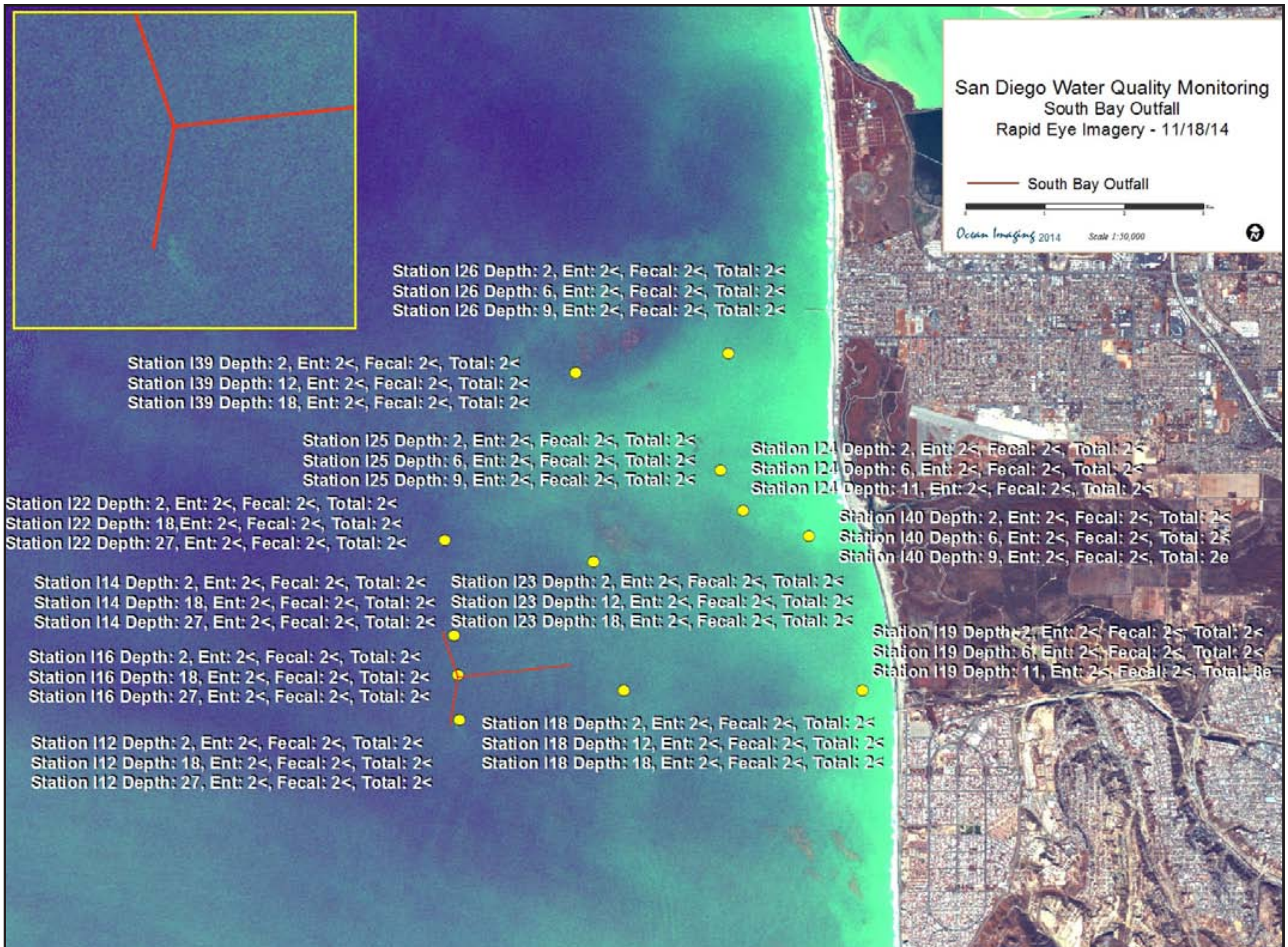



**Figure 5.**

High resolution satellite image acquired on 11/17/2014 and offshore bacteria sampling results from 11/18/2014. A faint plume outfall signature is also detectable.

sources to fill the nearshore areas. As could be expected, shoreline bacteria samples also showed elevated values, particularly at Ocean Beach's Dog Beach through much of the second half of December. The high bacteria levels were likely limited to the very nearshore, however, as is evidenced in **Figure 11** showing an image of the runoff and turbidity patterns on 12/22/2014 along with background-only offshore bacteria sampling results collected the previous day.

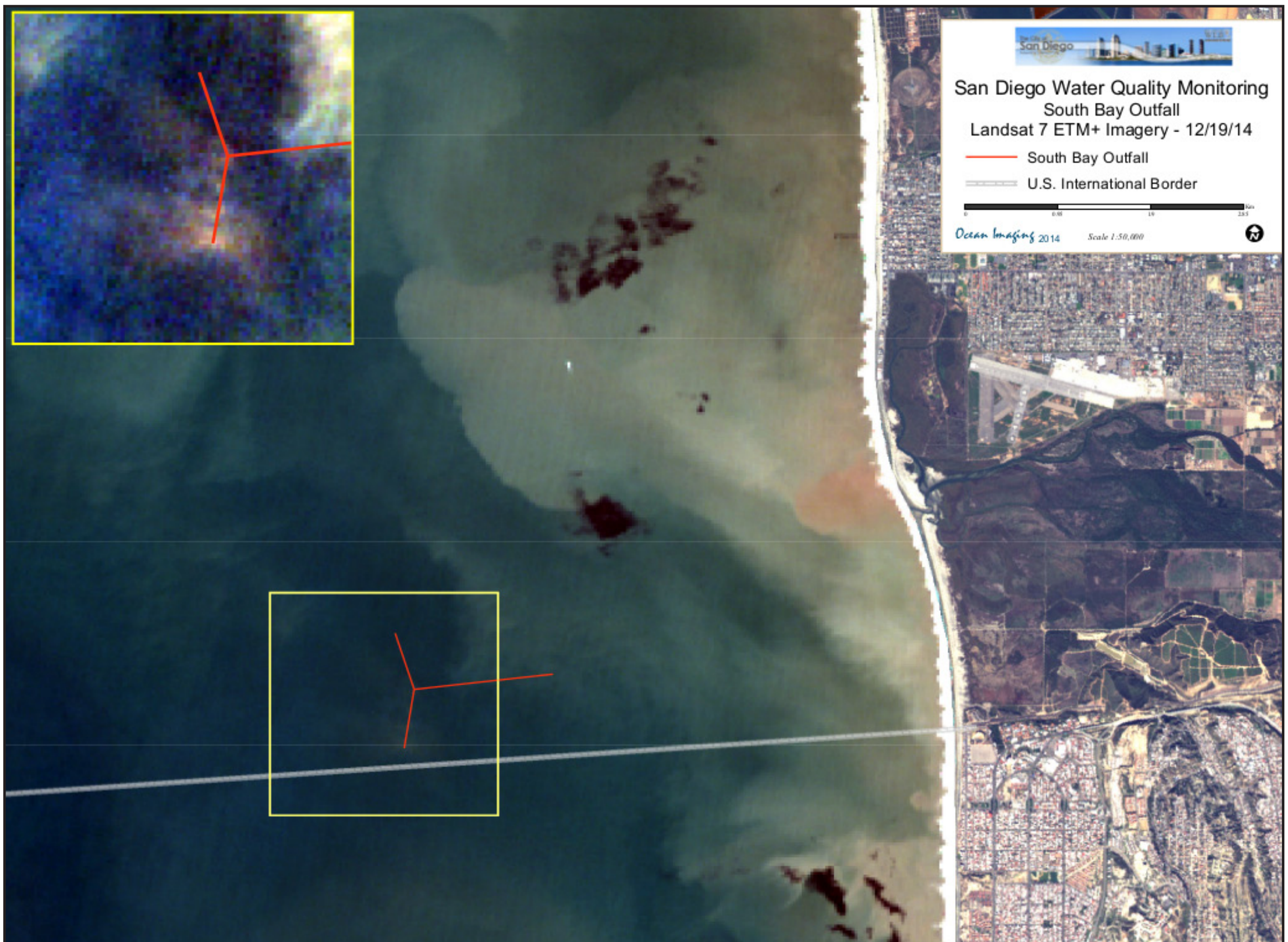



**Figure 6.**

SBOO region on 12/19/2014 after one of several rain events that affected the area in December 2014. An outfall plume signature is evident. Also visible is fresh (reddish) and older (grey) discharge from the Tijuana River. (The dark brown features are kelp.)

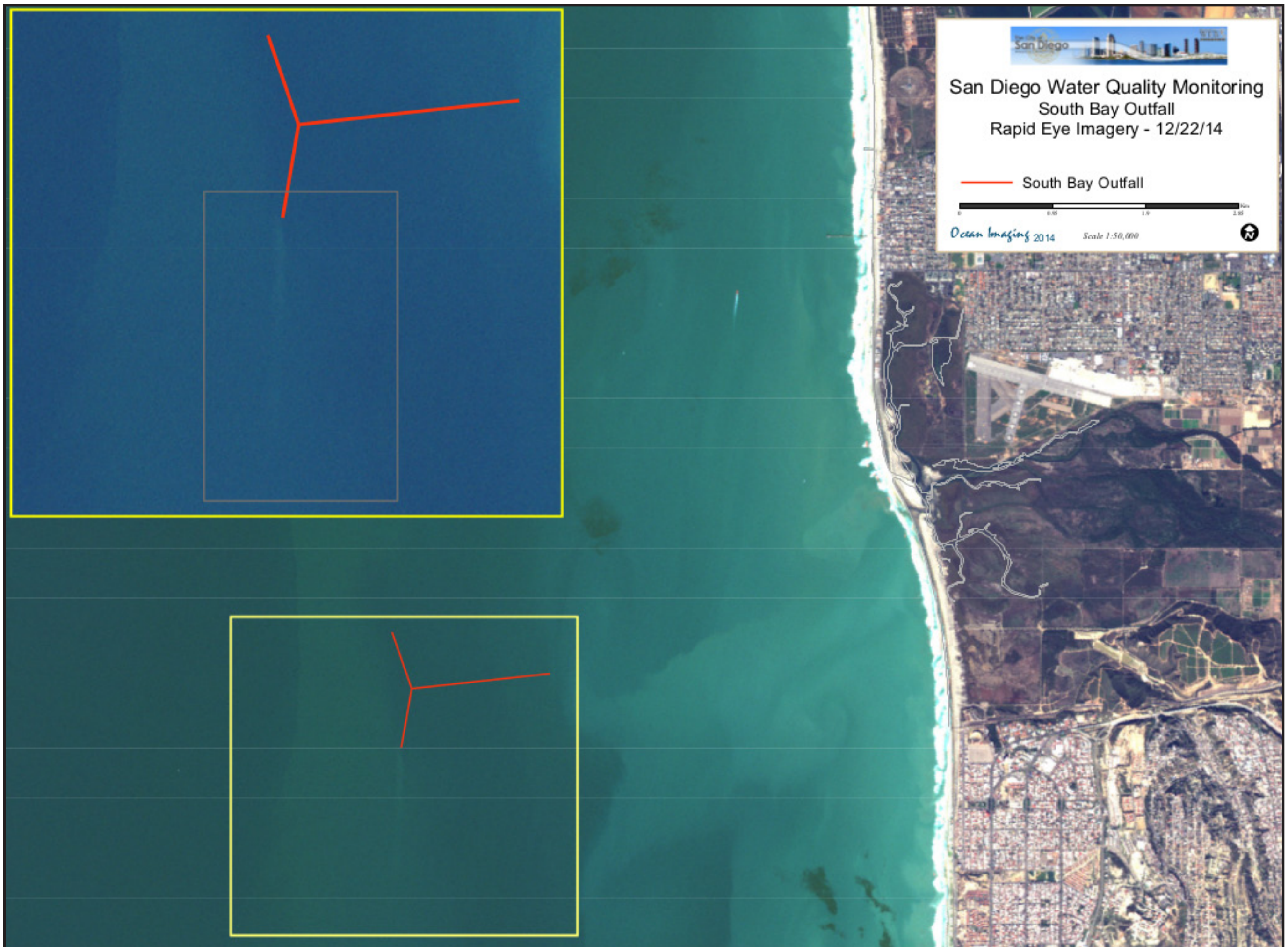



**Figure 7.**

SBOO region on 12/22/2014 showing a southward directed outfall plume, no Tijuana River discharge, and much increased water clarity from 3 days prior (shown in Figure 6).

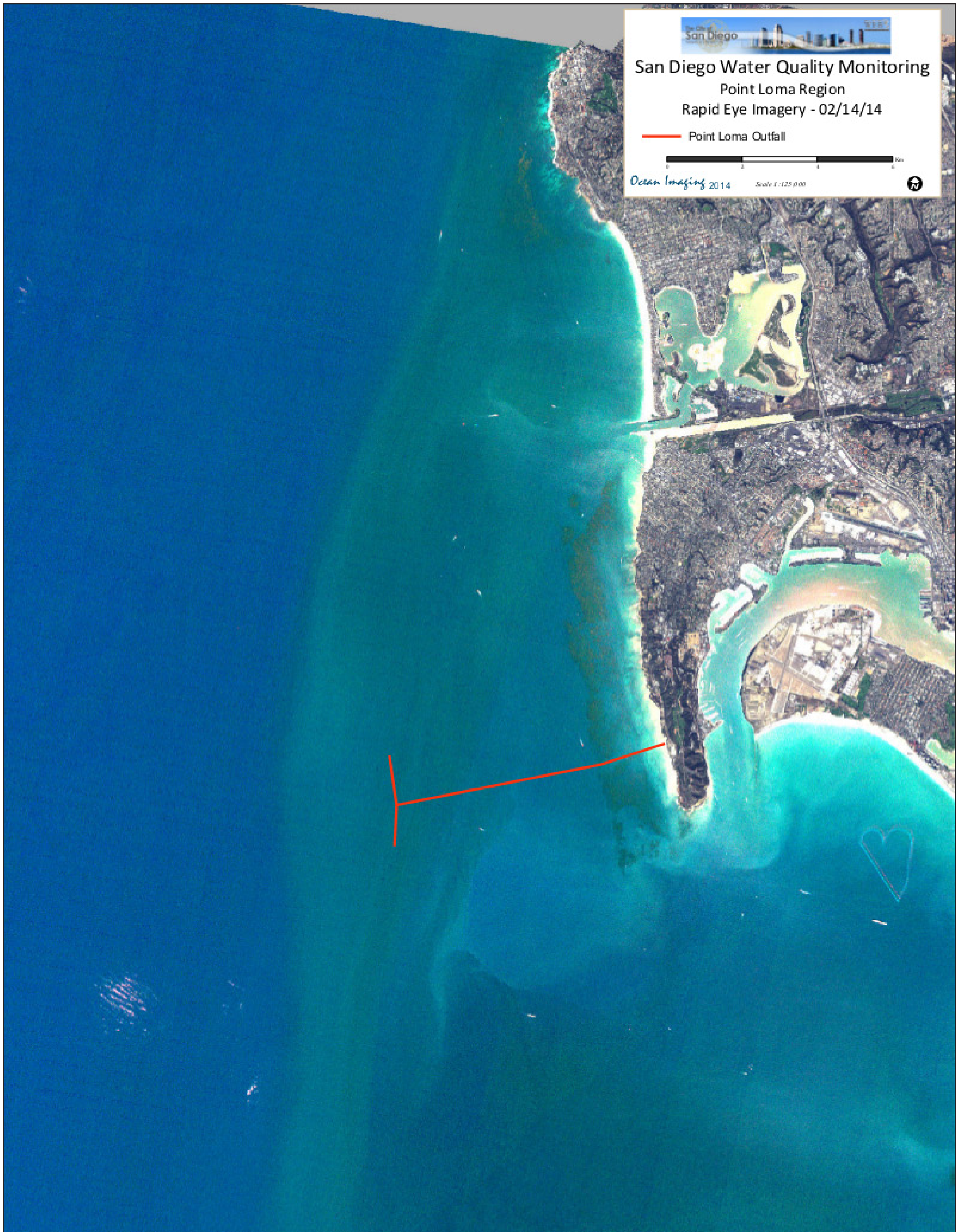



**Figure 8.**

PLO region on 2/14/2014 showing a localized plankton bloom that spread over the PLO wye. Such events were relatively rare in 2014.


**Figure 9.**

PLO region on 3/3/2014 after the only major rain event in the year's early months.

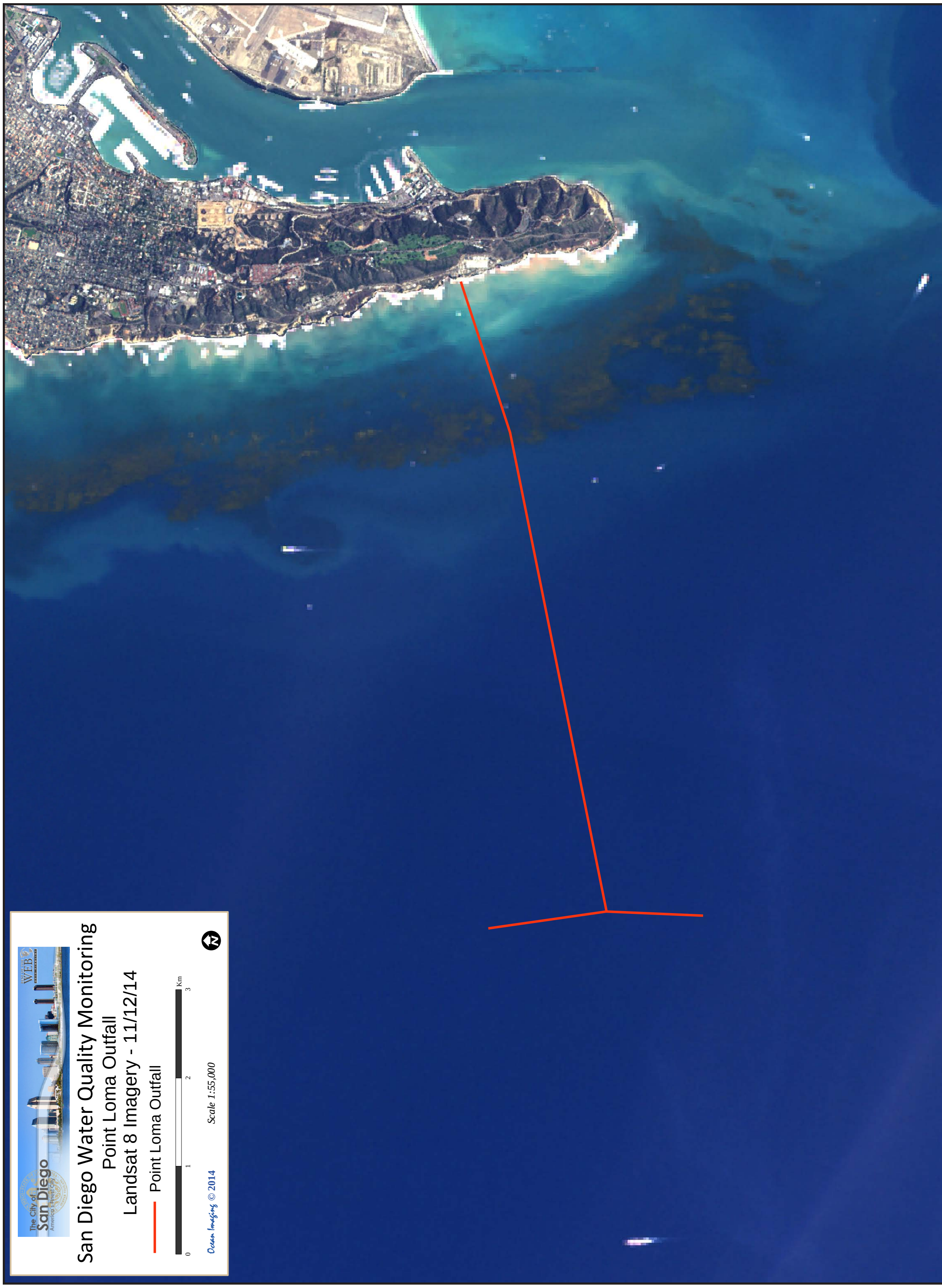



**Figure 10.**

High resolution satellite image of the Pt. Loma region acquired on 11/12/2014 showing relatively high water clarity. The brown features are kelp and bottom features can be clearly seen between the kelp bed and the shoreline.


**Figure 11.**

The Pt. Loma region on 12/22/2014 after one of multiple rain events during December. Offshore bacteria sampling done the previous day show only background values.