

FINAL REPORT:

MODELING IMPACTS OF VARIOUS WASTEWATER AND STORMWATER FLOW SCENARIOS ON SAN DIEGO SOUTH BAY AND TIJUANA BEACHES

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EXECUTIVE SUMMARY

The San Diego South Bay and Tijuana MX border region has significant water quality issues due to inflows of untreated sewage from two sources the Tijuana River Estuary (TJRE) and the San Antonio de los Buenos outfall at Pt. Bandera MX (SAB/PTB) located 10 km or 6 miles south of the border. We have performed estuary and ocean modeling simulations for the San Diego South Bay and Mexico border region to evaluate the impacts of potential infrastructure solutions to improve shoreline water quality and reductions on regional beach closures. This model leveraged previous National Science Foundation and NADB/EPA investments in model development. We examined the shoreline water quality impacts of untreated sewage under 4 different inflow scenarios denoted NADB 00, 35, 100, 163 for the 2017 year. The NADB 00 scenario represents normal baseline conditions where TJRE inflow scales with gauged river inflow and is capped at 10 millions of gallons per day (MGD) and SAB/PTB untreated sewage inflow is at 35 MGD. The NADB 35, 100, and 163 scenarios eliminate TJRE inflows below 35, 100, or 163 MGD, respectively. The NADB 35 scenario also reduces SAB/PTB to 10 MGD of treated sewage (5% of pathogen load of untreated sewage). Untreated sewage decays with a 7 day half life representative of noroviruses. Analysis was split into wet season (prior to 1 April and after 1 Oct), tourist (dry) season (22 May to 8 Sept), and full year. A representative untreated sewage concentration (a dilution of 1:2000) value is used to gauge beach closure limits.

Overall, the SAB/PTB source is the dominant source that leads to regional beach closures. At the Imperial Beach Pier during the tourist (dry) season, the baseline (NADB 00) scenario has the beach closed 24% of the time. NADB 35 scenario reduces this to 0%, whereas the NADB 100 & 163 scenarios do not reduce tourist season beach closures. At the Imperial Beach Pier during wet season, the baseline (NADB 00) scenario has the beach closed 9% of the time, $\frac{2}{3}$ of which comes from the TJRE source and $\frac{1}{3}$ from the SAB/PTB source. The NADB 35, 100, & 163 scenarios reduce wet season beach closures to 4% to 6%, and are largely similar in efficacy. **Thus, the NADB 35 scenario has by far the largest benefits in terms of reduced beach closures at IB Pier, because of the strong reduction of SAB/PTB inflows. Similar conclusions are drawn at Playas Tijuana, Silver Strand State Beach, and Hotel del Coronado. This work suggests that eliminating or dramatically reducing SAB/PTB inflows has the strongest benefit to the City of Imperial Beach, Silver Strand State Beach, and City of Coronado.**

1. Background

Various infrastructure projects have been proposed to help address the contamination of beaches that result when untreated wastewater from Tijuana reaches the ocean, either via the Tijuana River Estuary, located in the U.S. just south of Imperial Beach or via coastal discharge at Punta Bandera, located 10 km (6 miles) south of the border. The purpose of this effort is to model what the benefit would be to San Diego South Bay and Tijuana MX beaches from each of the alternatives being considered. To do so, we expanded the scope of the study recently completed by us at Scripps Institution of Oceanography. In the previous study, we developed a sophisticated, realistic, 3-D model to evaluate the impacts from a major 2017 wastewater spill in Tijuana that released about 7 million gallons per day of sewage into the Tijuana River for over 30 days. Because this spill occurred during the winter during a major rainfall event, these flows mixed with stormwater runoff and flowed into the Tijuana River Estuary and out into the Pacific Ocean. In addition, we also examined the impacts from the San Antonio de Los Buenos (SAB) Wastewater Treatment Plant that releases at Pt. Bandera during the same time period.

Beachgoers and lifeguards at Imperial Beach have long complained of foul odors and poor water quality during strong south swells (when currents within the surfzone, where waves are breaking, drive northward transport). These polluted beaches impact many stakeholders in the San Diego South Bay region including the Cities of Imperial Beach and Coronado, the Port of San Diego, CA State Parks, the Tijuana River National Estuarine Research Reserve, and the US Navy Seals.

2. Objectives

Infrastructure solutions for the border water quality issues are being proposed and considered to be implemented via Federal funding. However, it is uncertain what the benefits of a particular project to beach Stakeholders will be. Here we evaluate the benefits of a range of infrastructure scenarios by simulating the reduction in shoreline pollution. Our model is used to determine the net reduction in beach contamination due to each proposed infrastructure project allowing for both benefits and costs to be considered, and allowing projects to be optimized. This analysis elucidates which projects would be the most effective, and thus greatly aid coastal management, improve human health, and limit economic impacts.

3. Model Development

The model covers the San Diego / Tijuana Border region including the Tijuana River Estuary, San Diego Bay, and the San Antonio de los Buenos outfall 10 km south of the border in Mexico on a new model grid (see Figure 1). The model has been used previously for Fall 2015 and winter 2017 spill events. Here we simulate the Year 2017 (spanning 14 Dec 2016 to 20 Dec 2020). As nearshore dye plumes are advected alongcoast up to 10~km and largely remain close to shore over ~12 hrs (Grimes et al., 2020), surfzone processes are required to effectively model untreated sewage transport in the TJRE and coastal ocean. Model details are found in Wu et al. (2020) and summarized briefly here.

The following inputs are used to measure the coastal impacts from the 2017 sewer break:

- offshore oceanic conditions (salinity, temp, currents) provided by NOAA funded CASE simulations.
- surface atmospheric forcing (winds, air temp, heat fluxes imposed at the surface) from NOAA

- tides from NOAA
- waves (imposed at offshore boundaries) from the Coastal Data Information Program (U.S. Army Corp of Engineers funded)

Model untreated sewage has a 7 day half life (10 day e-folding decay time-scale) representing the decay of Norovirus in seawater (Boehm and Soller, 2020). We use norovirus as representative pathogen because norovirus is a leading cause of recreational waterborne illness (e.g., Viau et al., 2011) and has elevated concentrations in untreated sewage (Eftim et al., 2017).

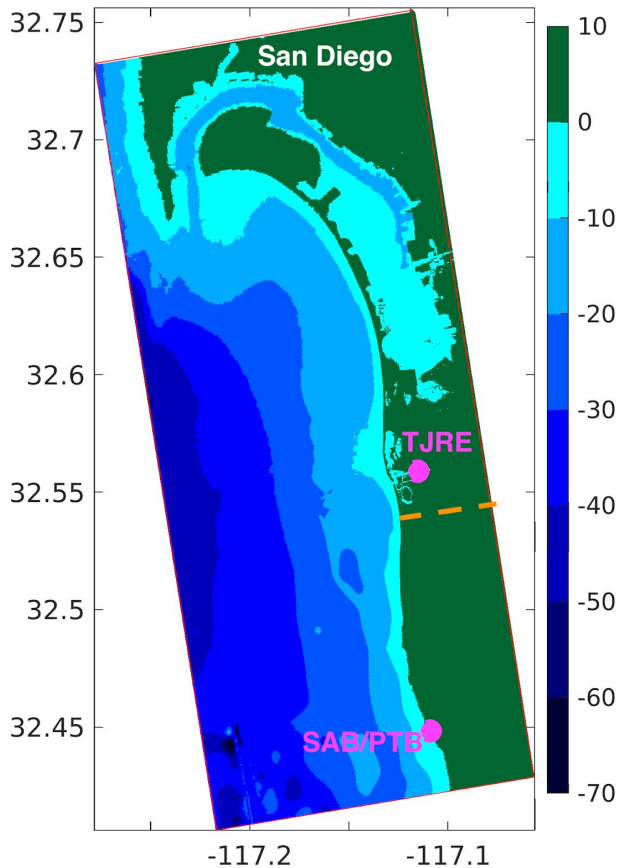


Figure 1. Model grid of the San Diego South Bay and Mexico border region as a function of latitude and longitude spanning Pt. Loma to Pt. Bandera. The US/Mexico border is indicated in orange. Bathymetry is shown in color, and Tijuana River Estuary (TJRE), the and Pt. Bandera where the San Antonio de los Buenos outfall is located (SAB/PTB) are indicated.

4. Year 2017 NADB Simulation Inputs and Scenarios: NADB 00, 35, 100, 163

The work plan included running the model for the year 2017 (Dec 13th 2016 to Dec 12th 2017) that includes both Tijuana River and SAB inflo under 4 scenarios for NADB simulations. These scenarios were developed in consultation with and approved by the EPA. As baseline for freshwater and untreated sewage inputs, we assume that

- Freshwater inputs (imposed at TJ River, Sweetwater River, Jamul River) - matching USGS and IBWC gauged river flows.
- Transboundary flows into the TJ River Estuary river consist of 25% raw sewage for gauged flows up to 23 mgd. Flows greater than 23 mgd contain a fixed 10 mgd of untreated sewage. All flows into estuary of less than 2 mgd are removed. This assumption for

transboundary flows assumes “normal” conditions and does not consider wastewater infrastructure failure events such as occurred during Winter 2017

- Freshwater input at Punta Bandera (Figure 1, 10 km or 6 miles south of the border) is at a constant 50 mgd, of which 35 mgd are untreated sewage.

Model runs include the following scenarios:

- (scenario NADB 00) Base simulation for 2017 with inflows as described above. This scenario assumes no infrastructure solution.
- (scenario NADB 35) All transboundary river flows up to 35 mgd entering the TJRE are eliminated and flows at SAB are reduced to 10 mgd of treated wastewater (raw wastewater flows at SAB are eliminated). Note 1 mgd of treated wastewater is equivalent to 0.05 mgd of untreated wastewater
- (scenario NADB 100) All transboundary flows up to 100 mgd entering the TJRE are eliminated, SAB remains the same as the base simulation (NADB 00)
- (scenario NADB 163) All transboundary river flows up to 163 mgd entering the TJRE are eliminated, SAB remains the same as the base simulation (NADB 00).

The freshwater flux, the untreated wastewater flux, and its concentration entering the TRJE under the 4 scenarios are shown in Figure 2.

We perform analysis over the entire year of model simulation, and over tourist (dry) season, and wet season. The tourist (dry) season is defined as 22 May to 8 Sept, spanning 109 days from the earliest Memorial Day and latest Labor Day Holidays, consistent with County of San Diego definitions. During tourist (dry) season there is minimal freshwater input to the TJRE. The wet season is defined as prior to 1 April and after 1 Oct (spanning 189 days), consistent with State of California definitions. During wet season the TJRE freshwater flux can be large, regularly exceeding 100 MGD (or 5 m³/s), particularly in the early part of 2017. In the later part of 2017 wet season (Nov, Dec 2017), freshwater input is minimal. As the untreated sewage is capped at 10 mgd, for these strong freshwater inputs, the untreated wastewater concentration during these strong events can be relatively weak (Figure 2c).

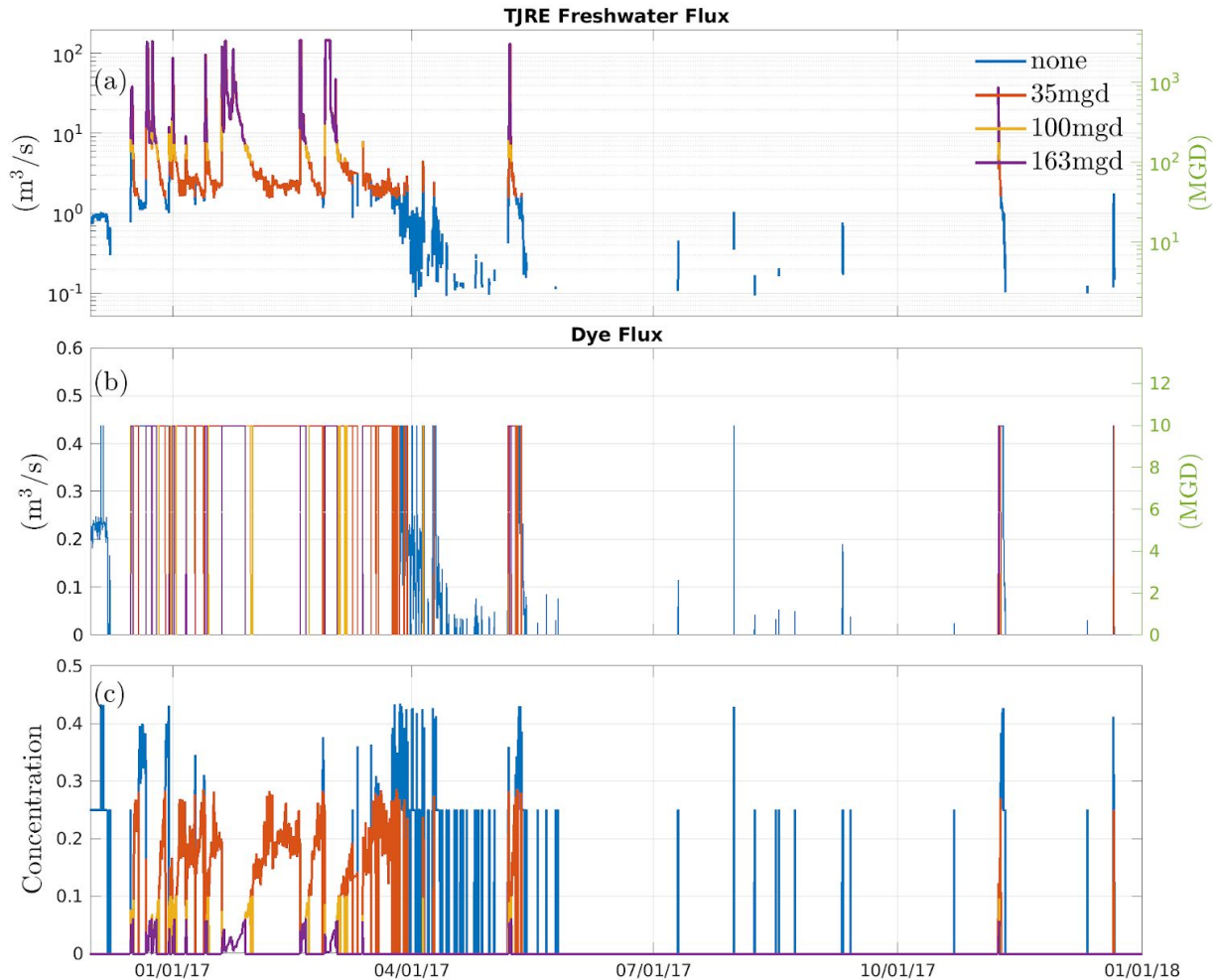


Figure 2. TJRE inputs over the 2017 year for the four scenarios: (a) TJRE input freshwater flux as m^3/s and (right) MGD (b) untreated wastewater flux entering the TJRE, and (c) TJRE input concentration of untreated wastewater. Colors indicate the 00, 35, 100, and 163 scenarios as indicated in the legend.

It is worth examining, the total untreated sewage input to the TJRE under the 4 scenarios. During wet season the NADB 00, 35, 100, 163 scenarios input on average 5.1, 4.4, 1.4, 1.05 MGD to the TJRE, respectively. This compares to wet season SAB/PTB inputting 35 MGD untreated sewage for NADB 00, 100, 163, and equivalently 0.5 MGD for NADB 35. Thus, SAB/PTB under NADB 00, 100, 163 input far more (7x or greater) untreated sewage than entering the TJRE. During tourist (dry) season, the NADB 00, 35, 100, 163 scenarios input on average 0.01, 0, 0, 0 MGD untreated sewage to the TJRE. In contrast SAB/PTB inputs either 35 MGD (for NADB 00, 100, 163) or 0.5 MGD (NADB 35) each day.

5. Example Tourist (Dry) Season Snapshot from the NADB 00 Scenario

Here, we show an example snapshot from the NADB 00 scenario from 11-July-2020 14:00UTC (Figure 3) during tourist (dry) season (22 May to 8 Sept) . The left-most panel shows the regional

salinity and a plume of low-salinity water can be seen propagating north from SAB/PTB. The middle panel shows strong SAB/PTB source (10 km or 6 miles south of the border) dye concentrations along the shoreline between Punta Bandera and Coronado consistent with the low-salinity. This northward propagating plume is during a time of strong south swell (waves incident from the south) that drive currents to the north. During this dry-weather time, the input to the TJRE is negligible (right panel Figure 3).

Dye concentrations are reported in exponential notation such as 10^{-3} (or 0.001) which means that the untreated sewage is diluted by a factor 1:1000, or that you have 1 mL of untreated sewage in a 1 L bottle of clean water. Thus 10^{-2} represents a 1:100 dilution and 10^{-4} represents a 1:10,000 dilution. As is clear from Figure 3, there are times when the entire San Diego South Bight shoreline from PTB to Coronado has dye levels $> 5 \times 10^{-4}$ (or a 1:2000) dilution.

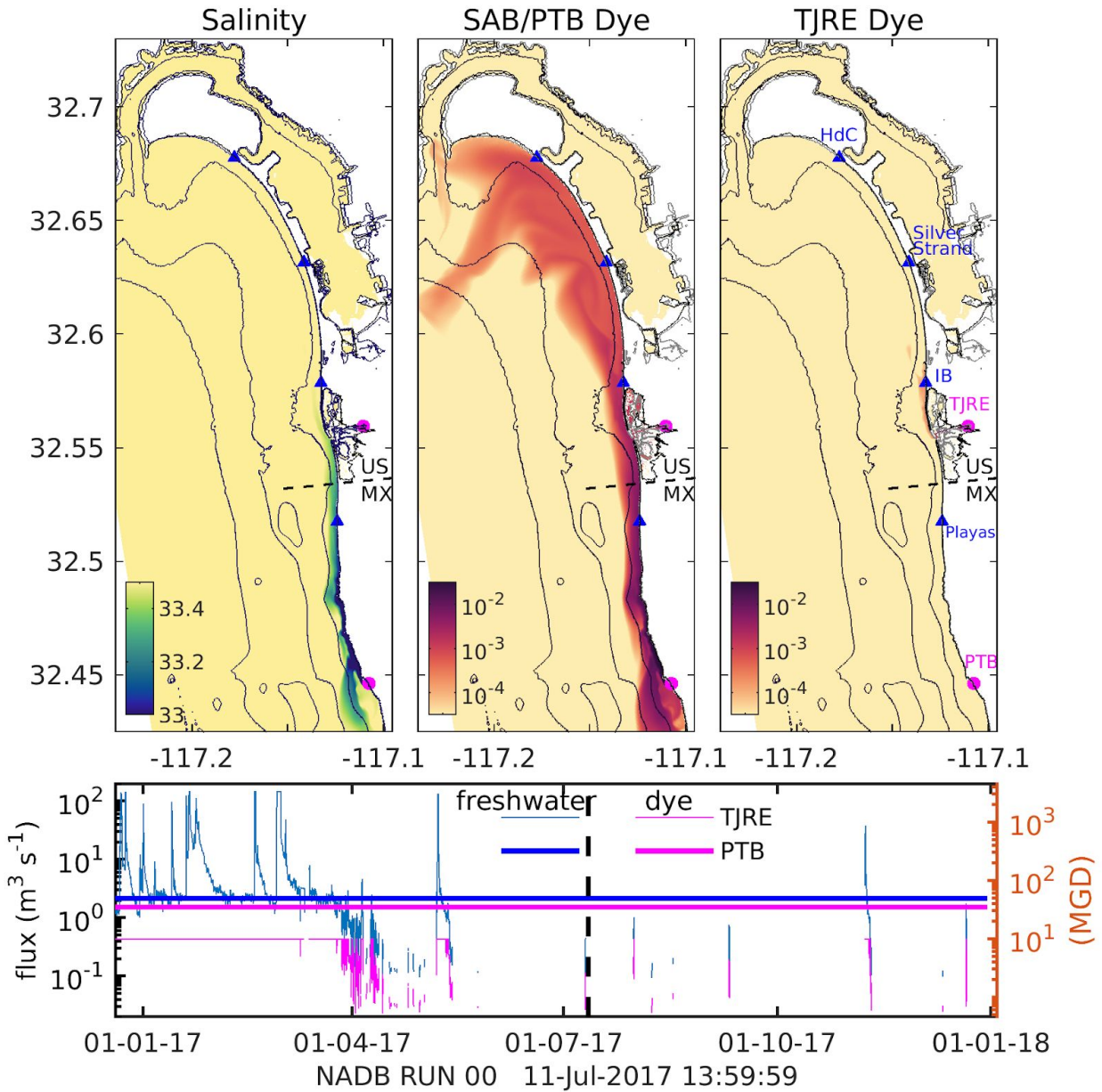


Figure 3. NADB 00 scenario simulation surface snapshot from 11-July-2017 14:00 UTC: (left) Salinity where blues indicate TJRE or SAB/PTB freshwater, (middle) SAB/PTB untreated wastewater concentration, and (right) TJRE untreated wastewater concentration, where reds indicate stronger concentrations. (bottom) Time series of freshwater (blue) and tracer (magenta) discharge from TJRE and PTB are indicated with a vertical black dashed line marking the snapshot time. Magenta dots indicate locations of TJRE and SAB/PTB sources. Blue triangles mark specific regions for analysis including Playas Tijuana (Playas), Imperial Beach Pier (IB), Silver Strand State Beach (SS), and the Hotel del Coronado (HdC). The dashed line marks the US Mexico border. Movies for the NADB 00 scenario are available at <https://youtu.be/ZRhUEWXbLT0>.

There are many different patterns of TJRE and SAB/PTB dye that depend on winds, waves, TJRE freshwater input, tides, and seasons. To make all of this available, we have generated movies of the individual panels in Figure 3 of each of the four scenarios. These movies have been posted to youtube.com at the following links

- NADB 00 scenario movie: <https://youtu.be/ZRhUEWXbLT0>
- NADB 35 scenario movie: <https://youtu.be/fSvXcftNMUc>
- NADB 100 scenario movie: https://youtu.be/_av1IOUPYwE
- NADB 163 scenario movie: <https://youtu.be/eegWf8O6-9Q>

6. Relating Model Dye Concentrations to Beach Closures

Next, we relate the dye concentration (representing the dilution of untreated sewage) to EPA Beach Act closure standards. Beach water quality is often represented by Enterococcus (ENT) and marine beaches are closed¹ if ENT levels exceed 35 MPN/100 mL. In untreated sewage, ENT varies between 10^5 to 5×10^5 MPN/100 mL with an average of 3×10^5 MPN/100 mL (Ahmed et al., 2008). Thus a dye concentration of 10^{-3} represents a value of 300 MPN/100 mL, well exceeding EPA beach water quality standards. As the dye half-life of 10 days is representative of Norovirus, and ENT half-life for the turbid waters of the surfzone is around 3.5 days (Sinton et al. 2002), we use a conservative limit dye concentration of 5×10^{-4} (or for ENT 150 MPN/100 mL) as a representative limit for when ENT standards indicate that a beaches would be closed. An analysis for Total Coliform gives similar cutoff values.

7. Regional Untreated Sewage Impacts Alongcoast and in Time Under Four Scenarios

Next, shoreline untreated sewage concentrations are extracted for the TJRE source, the SAB/PTB source, and for their combined values at each hour of the year 2017 time period. There is a data point every 20-60 m (70 to 200 feet) alongcoast, and the entire alongcoast distance spans 31 km (19.4 miles). Distance alongcoast is given relative to the mouth of the TJRE (located at 32.553N). The SAB/Punta Bandera source is located 32.446N, 12.4 km south of the TJRE mouth. For reference the US/Mexico border is located at 32.534N (2.1 km south of the TJRE). We focus particular attention on untreated sewage concentrations at 4 locations: *Playas Tijuana* (32.518N, 4 km south of TJRE), *Imperial Beach Pier* (32.579N, 3 km north of TJRE), *Silver Strand State Beach* (32.632N, 9 km north of TJRE) and *the Hotel Del Coronado* (32.678N, 15.1 km north of TJRE), located within the City of Coronado. These locations are marked in Figures 4-7. All four locations have significant beach attendances concentrated in summertime during tourist (dry season). For reference, the City of Imperial Beach had on average 2.4 million annual beach visitors between 2015-2019.

We present the untreated sewage concentration as a heat map as a function of time and alongcoast distance for the four scenarios NADB 00 (Figure 4), 35 (Figure 5), 100 (Figure 6), and 163 (Figure 7) for the total untreated sewage (top panel), TJRE-only (middle panel), and SAB/PTB (bottom panel). The color scheme is set so that yellow represents acceptable beach

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<https://www.epa.gov/beach-tech/frequent-questions-final-water-quality-standards-coastal-and-great-lakes-recreation#criteria>

water quality conditions, red/maroon represent concentrations where beaches should be closed, and the lightest red are questionable values.

NADB 00 (baseline) Scenario Untreated Sewage Heat Map

First, we examine the NADB 00 scenario (Figure 4), which is the baseline scenario of no infrastructure improvements. The first highlight is that there is a strong seasonal difference in the untreated sewage source (TJRE vs. SAB/PTB). During wet season (prior to 1 April), the TJRE is the principal source contaminating the region from Playas Tijuana to farther northward. The wet season TJRE outflow is somewhat more likely to go south (due to more prevalent waves from the north during wet season) affecting Playas Tijuana than it is to affect Imperial Beach. There are occasional wet season times when weak TJRE plumes propagate all the way up to Hotel Del Coronado. During wet season, SAB/PTB has weak impacts on Playas Tijuana and northward and most of its untreated sewage flows to the south contaminating the region of Baja Malibu and likely Rosarito MX. This is consistent with the pattern of incident waves out of the northwest during wet season, that drive nearshore (within a 100-300 m of the shoreline) currents to the south.

However, the pattern changes in the tourist (dry) season (22 May to 8 Sept), during which there is little TJRE source (middle panel, Figure 4). Thus TJRE impacts are overall minimal during tourist season. Recall that this is for a “normal” scenario and does not consider infrastructure failures within the City of Tijuana. However, the SAB/PTB source (bottom panel, Figure 4) has many tourist-season events where high concentrations propagate northward alongcoast from Punta Bandera. These events propagate generally 8-14 km/day and are associated with “south swell” events, i.e., dominant waves incident from the south in approximately 10-15 events during the tourist season. Figure 3 shows an example of these northward propagating events. These events regularly have concentrations in excess of 5×10^{-4} (or 1:2000 dilution) the threshold used for when a beach closure should occur. These high concentration events can dilute slowly alongcoast and can lead to significant untreated sewage concentrations from Playas Tijuana all the way to the Hotel del Coronado.

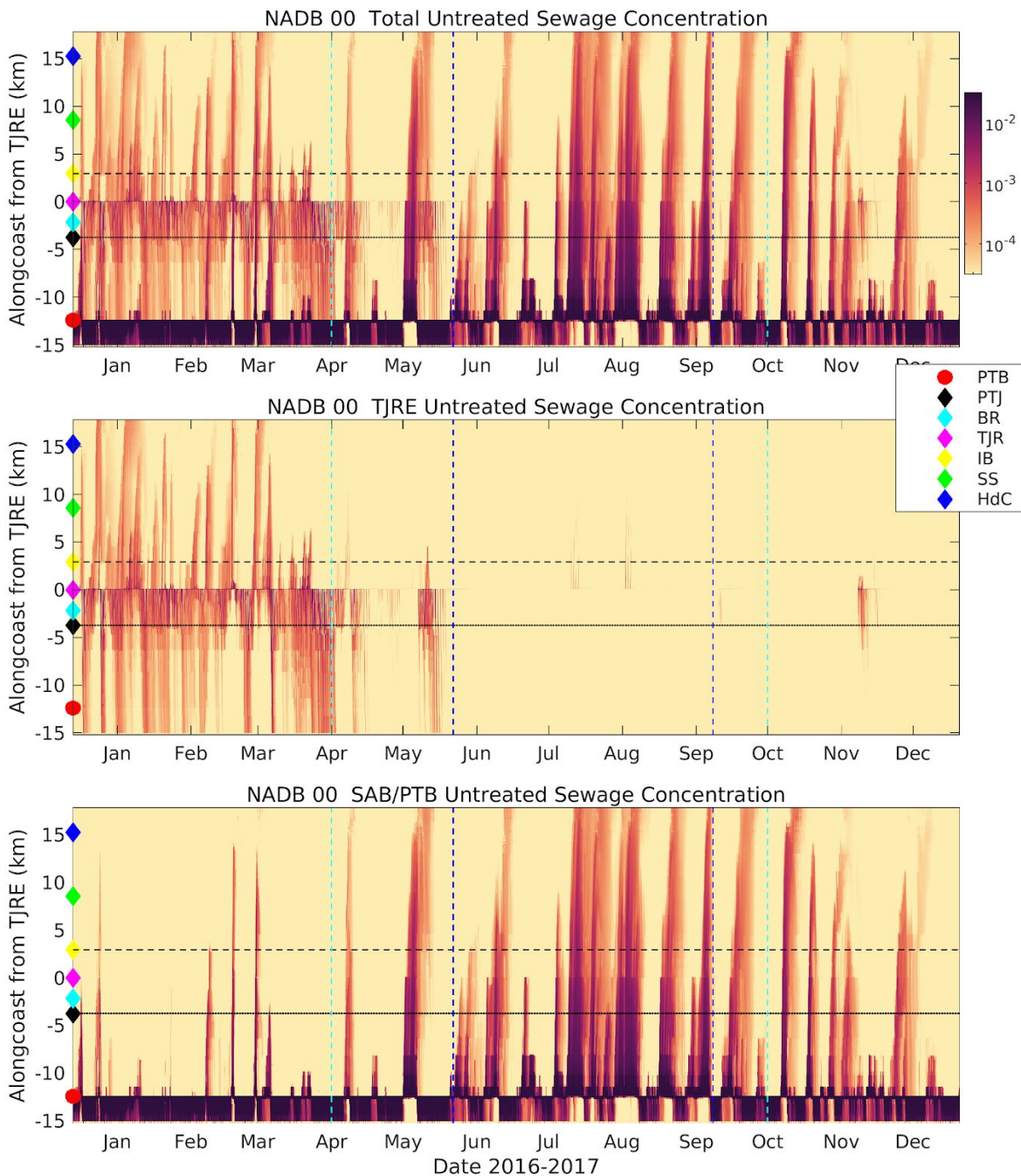


Figure 4. NADB 00 shoreline untreated sewage concentration (colors) versus time and alongcoast distance in km from TJRE mouth for (top) total (TJRE+SAB/PTB) (middle) TJRE only source, and (bottom) SAB/PTB only source. Vertical dashed blue and cyan lines indicate tourist (dry) season and wet seasons. Points of alongcoast interest are marked with symbols including Punta Bandera (PTB red), Playas Tijuana (PTJ, black, solid line), the Border (BR, cyan), The Tijuana River mouth (TJR, magenta), Imperial Beach pier (IB, yellow, dashed line), Silver Strand state beach (SS, green), Hotel del Coronado (HdC, blue).

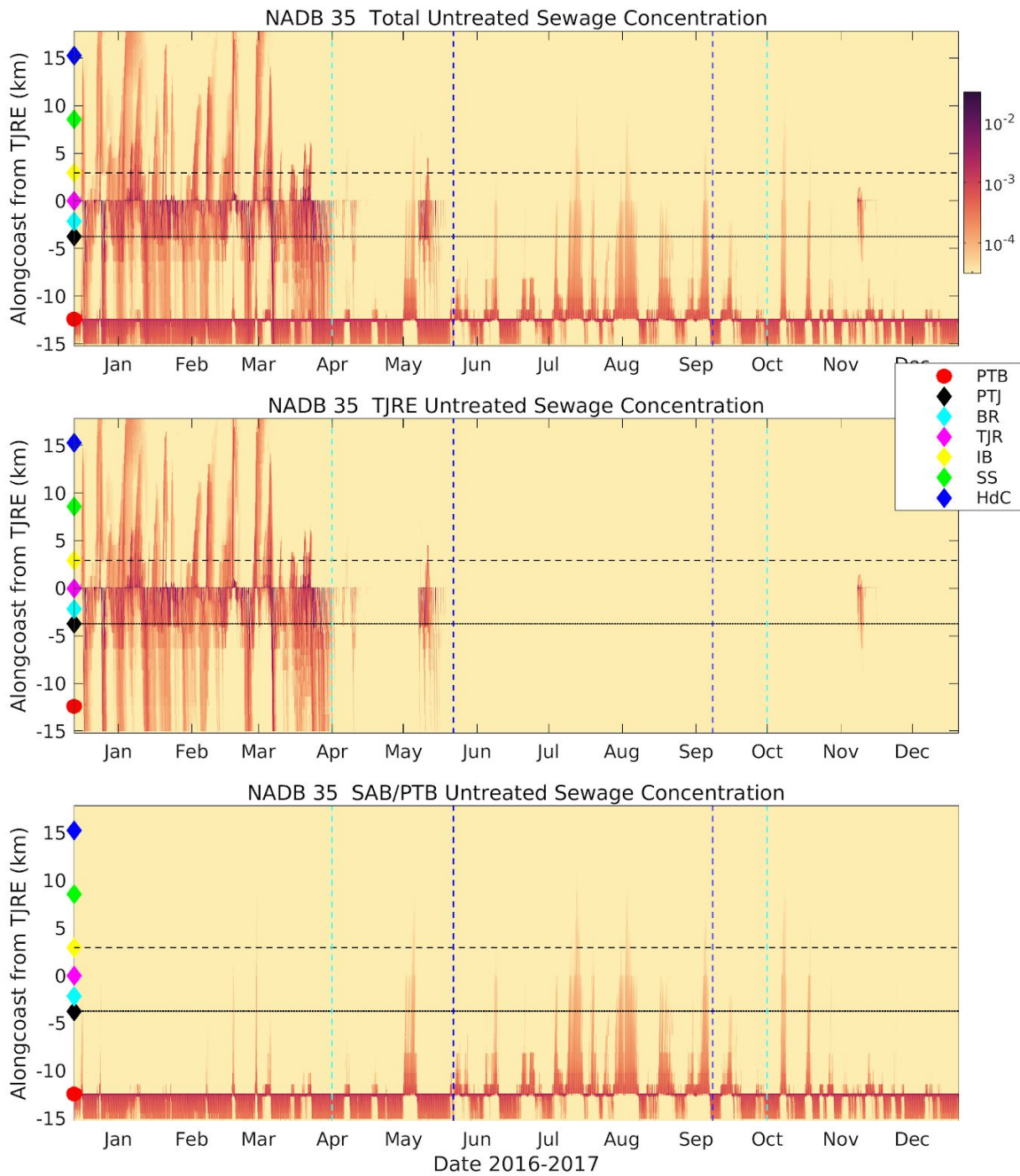


Figure 5. NADB 35 shoreline untreated sewage concentration (colors) versus time and alongcoast distance in km from TJRE mouth for (top) total (TJRE+SAB/PTB) (middle) TJRE only source, and (bottom) SAB/PTB only source. Vertical dashed blue and cyan lines indicate tourist (dry) season and wet seasons. Points of alongcoast interest are marked with symbols including Punta Bandera (PTB red), Playas Tijuana (PTJ, black, solid line), the Border (BR, cyan), The Tijuana River mouth (TJR, magenta), Imperial Beach pier (IB, yellow, dashed line), Silver Strand state beach (SS, green), Hotel del Coronado (HdC, blue).

NADB 35 Scenario Untreated Sewage Heat Map

Next, we examine the shoreline concentrations for the NADB 35 scenario (Figure 5), which eliminates flows entering the TJRE below 35 MGD and also reduces SAB/PTB flows to 10 MGD of treated sewage (recall: here treated sewage is assumed to have pathogen content 5% that of untreated sewage). During wet season, the NADB 35 untreated sewage concentration (Figure 5) is similar to that for the base NADB 00 scenario (Figure 4), although a small reduction in TJRE sourced untreated sewage can be seen during wet season. This is because the average TJRE untreated sewage flow rate of 4.4 MGD is only a slight reduction from the baseline NADB 00 scenario average flow rate of 5.1 MGD.

However, during tourist (dry) season, the NADB 35 (Figure 5) is dramatically different from NADB 00 (Figure 4), as the NADB 35 has dramatically reduced total untreated sewage concentration from Playas Tijuana up to Hotel del Coronado due to the strong reduction in the SAB/PTB source. Essentially, at no time during tourist season does the SAB/PTB sourced concentration exceed the 5×10^{-4} (1:2000 dilution) threshold for beach closures for the NADB 35 scenario. Thus, the NADB 35 scenario reduces beach closures dramatically during tourist season but has minimal impact on wet season untreated sewage concentrations.

NADB 100 & 163 Scenarios Untreated Sewage Heat Map

The NADB 100 (Figure 6) and NADB 163 (Figure 7) scenarios are examined jointly. Recall that these scenarios eliminate TJRE flows below 100 MGD and 163 MGD, respectively (see Figure 2), but leave SAB/PTB flows unchanged. During wet season, these two scenarios clearly reduce the untreated sewage significantly relative to the base NADB 00 scenario (Figures 6,7) as the average sewage entering the TJRE is 1.4 MGD and 1.1 MGD, respectively, significantly reduced to the 5.1 MGD from the baseline scenario. However, during wet season, there are still “events” of SAB/PTB water that advect northward to Imperial Beach and farther northward that also have impacts.

However, during the tourist (dry) season, the NADB 100 & 163 scenarios are nearly identical to the baseline NADB 00 scenario (compare top panel of Figures 6,7 to Figure 4). This is because there is negligible TJRE input during this time and thus the infrastructure flow diversion is not being utilized. In contrast, the 35 MGD continuously input at SAB/PTB has several events of northward advection that can significantly contaminate the region from Imperial Beach all the way to Coronado as in the NADB 00 scenario. Thus, during tourist (dry) season, the NADB 100 & 163 scenarios do not offer benefits to beach goers.

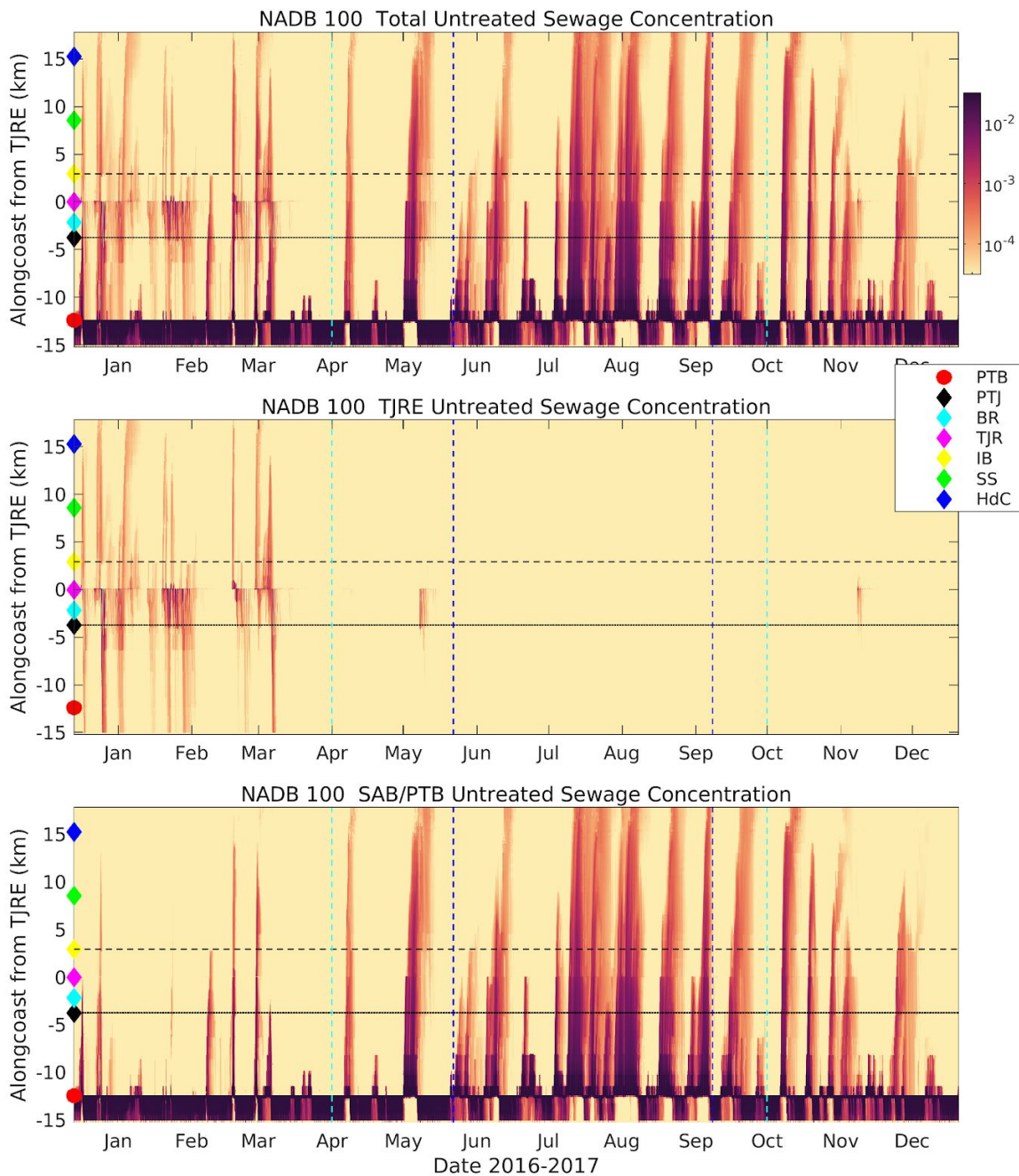


Figure 6. NADB 100 shoreline untreated sewage concentration (colors) versus time and alongcoast distance in km from TJRE mouth for (top) total (TJRE+SAB/PTB) (middle) TJRE only source, and (bottom) SAB/PTB only source. Vertical dashed blue and cyan lines indicate tourist (dry) season and wet seasons. Points of alongcoast interest are marked with symbols including Punta Bandera (PTB red), Playas Tijuana (PTJ, black, solid line), the Border (BR, cyan), The Tijuana River mouth (TJR, magenta), Imperial Beach pier (IB, yellow, dashed line), Silver Strand state beach (SS, green), Hotel del Coronado (HdC, blue).

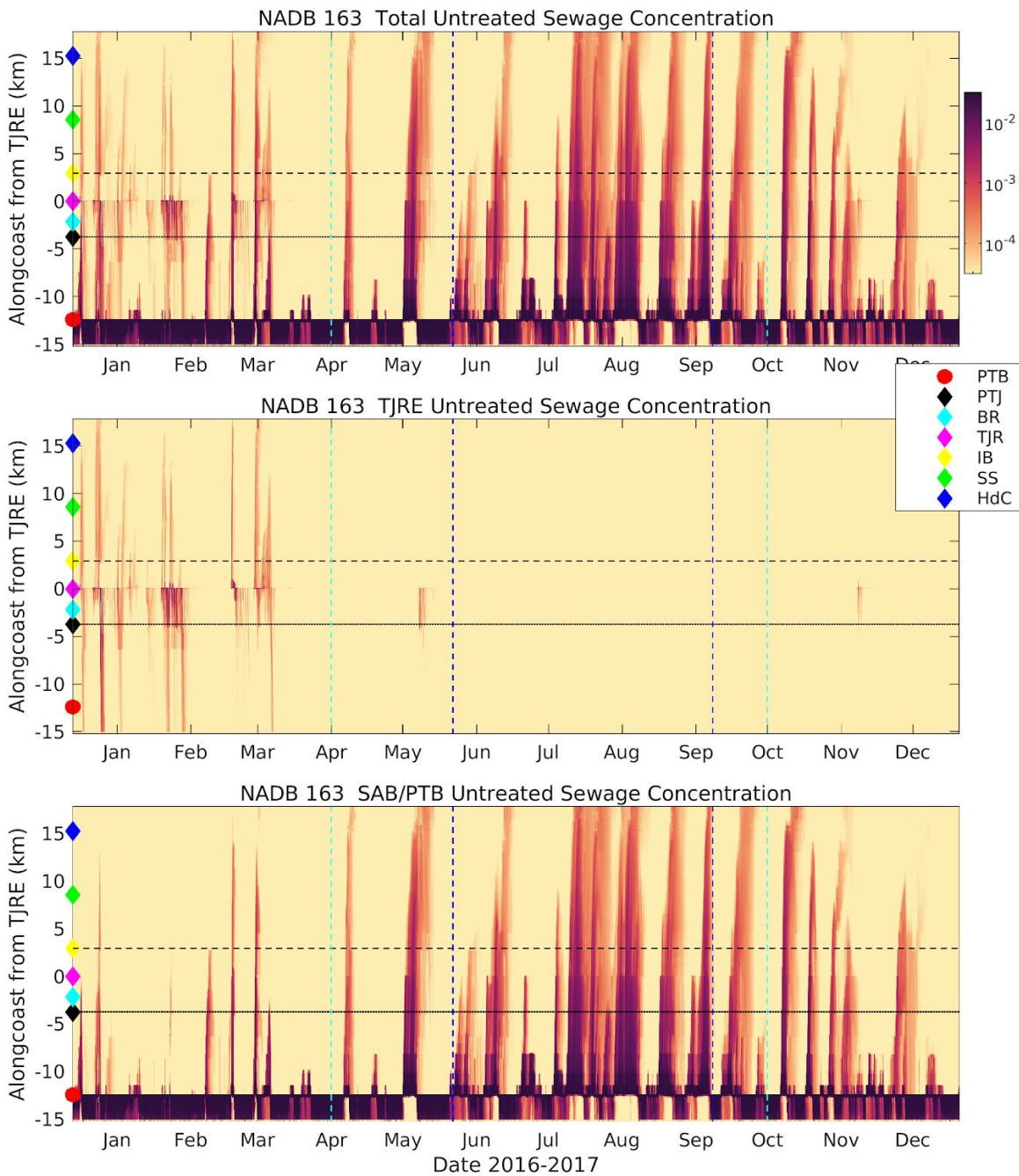


Figure 7. NADB 100 shoreline untreated sewage concentration (colors) versus time and alongcoast distance in km from TJRE mouth for (top) total (TJRE+SAB/PTB) (middle) TJRE only source, and (bottom) SAB/PTB only source. Vertical dashed blue and cyan lines indicate tourist (dry) season and wet seasons. Points of alongcoast interest are marked with symbols including Punta Bandera (PTB red), Playas Tijuana (PTJ, black, solid line), the Border (BR, cyan), The Tijuana River mouth (TJR, magenta), Imperial Beach pier (IB, yellow, dashed line), Silver Strand state beach (SS, green), Hotel del Coronado (HdC, blue).

8. Impact of the Four Scenarios to Regional Beach Closures

Now that the spatiotemporal patterns of untreated sewage concentration have been examined for the four scenarios (Figures 4-7), we now turn to the impact that these scenarios have on beach closures. Recall that a concentration of 5×10^{-4} (or a 1:2000 dilution) is a representative concentration for when Enterococcus (ENT) levels exceed EPA Beach Act standards for beach closure. Below we analyze, the fractional time of beach closures during wet season and tourist (dry) season at the four analysis locations starting with Imperial Beach (IB) Pier, and then Playas Tijuana, Silver Strand State Beach, and lastly Hotel del Coronado.

Imperial Beach Pier

During wet season at the IB Pier, the NADB 00 scenario has the region closed 9% of the time (blue in Figure 8, top). This is mostly (6%) due to the TJRE source and 3% due to SAB/PTB source. The NADB 35, 100, 163 scenario reduce wet season beach closures between 6% to 4% which is due to SAB/PTB flow reductions for NADB 35 scenario and the TJRE flow reductions for the NADB 100 & 163 scenarios. Thus, at the IB pier, the NADB 35, 100, and 163 scenarios are largely equivalent in terms of reduced beach closure benefits (reducing from 9% to ~5%).

During tourist (dry) season (22 May to 8 Sept), the NADB 35 scenario has the most obvious and clear benefits (Figure 8, middle). The baseline NADB 00 scenario has IB Pier closed almost 25% of the time, all of which is due to SAB/PTB. The NADB 100 & 163 scenarios are identical to the NADB 00 scenario because the TJRE inflow is negligible. In contrast, the NADB 35 scenario results in zero tourist (dry) season beach closures as the SAB/PTB inflow is dramatically reduced. Thus, the NADB 35 scenario has by far the largest benefits (reduced beach closures at IB pier) during tourist season when the majority of beach recreation occurs.

We next consider the effect of the 4 scenarios over the entire year (Figure 8, bottom). Again, because the SAB/PTB inflows are so much stronger on average, the NADB 35 scenario results in the largest reduction in beach closures throughout the entire year. **Thus, the NADB 35 scenario has by far the largest benefits in terms of reduced beach closures at IB Pier over either tourist (dry season) only when most beach recreation occurs or over the entire year.**

Playas Tijuana

The pattern seen at the IB pier, is also evident at the other locations. At Playas Tijuana, baseline NADB 00 scenario impacts on beach closures is stronger than at IB Pier. During wet season, Playas Tijuana should be closed 27% of the time, which is a combination of TJRE (18%) and SAB/PTB (10%) sources (Figure 9, top panel). During winter, alongcoast flow is variable but is preferentially to the south, thus Playas Tijuana is more impacted by TJRE outflow than IB Pier even though they are roughly the same distance from TJRE. Episodic northward advecting SAB/PTB water also has stronger impacts at Playas Tijuana as it is only 8 km from PTB as opposed to 15 km for the IB pier. During tourist (dry) season, the Playas Tijuana should be closed 43% of the time (Figure 9, bottom), which is entirely due to SAB/PTB sourced untreated sewage. During tourist (dry) season, the TJRE source has no impact on Playas Tijuana. Thus, the NADB 100 & 163 scenarios are essentially equivalent to the baseline NADB 00 scenario. In

contrast, the NADB 35 scenario results in zero beach closures at Playas Tijuana. For space considerations, we do not consider the entire year fractional beach closures, but the patterns are the same as with the IB Pier. **As with the IB Pier, the NADB 35 scenario has by far the largest benefits in terms of reduced beach closures at Playas Tijuana, particularly during tourist (dry) season.**

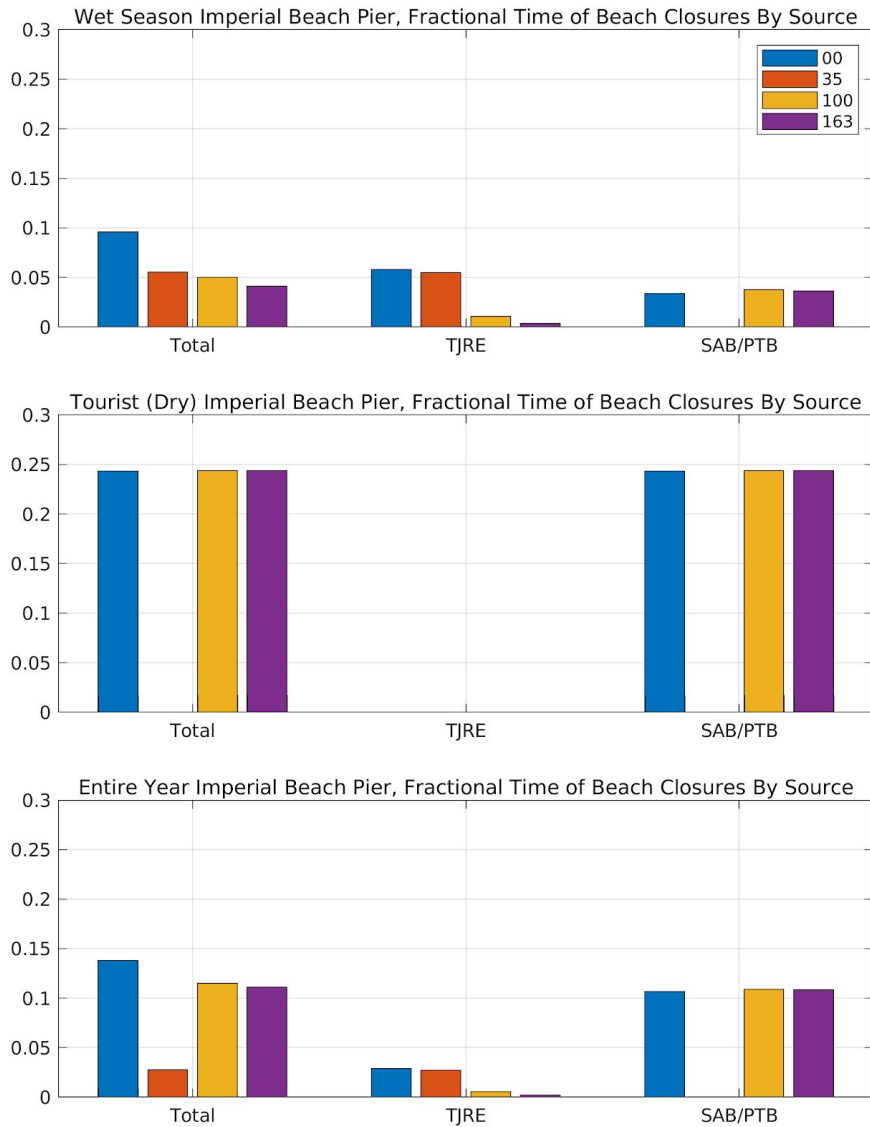


Figure 8: Fraction of time beaches should be closed at Imperial Beach Pier per total untreated sewage, TJRE source, and SAB/PTB source for the 4 scenarios (colors). The top panel shows wet season (1 Oct to 1 April), the middle panel shows tourist (dry) season (22 May to 8 Sept), and the bottom panel shows the entire year (13 Dec 2016 to 12 Dec 2017). Note a value of 0.1 indicates that 10% of the time the beach should be closed. No bar present means the value is zero.

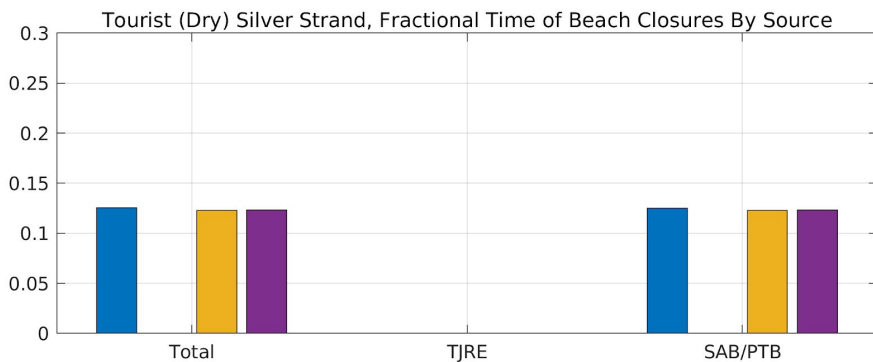
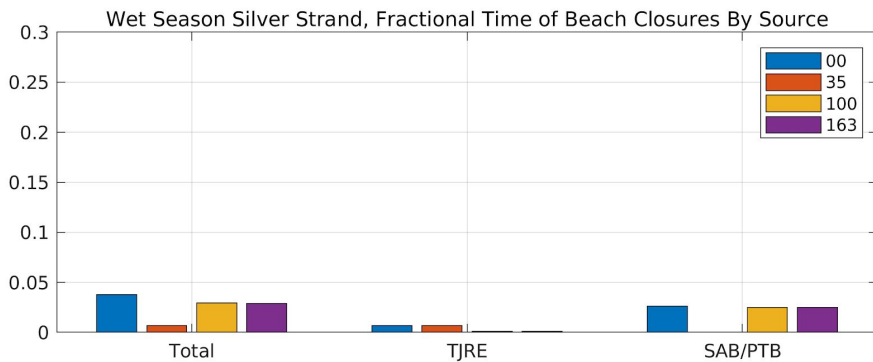
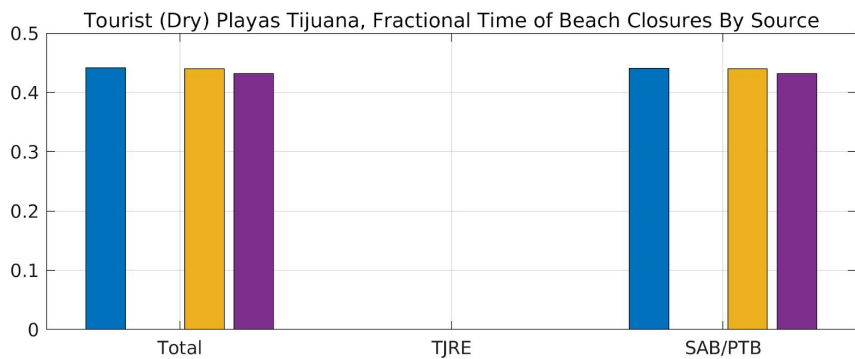
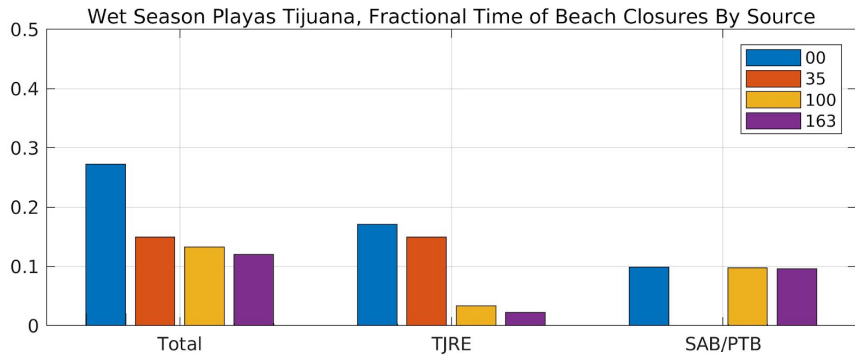


Figure 9: Fraction of time beaches should be closed at Playas Tijuana per total untreated sewage, TJRE source, and SAB/PTB source for the 4 scenarios (colors). The top panel shows wet season (1 Oct to 1 April) and the bottom panel shows tourist (dry) season (22 May to 8 Sept). Note a value of 0.1 indicates that 10% of the time the beach should be closed. No bar present means the value is zero.

Figure 10: Fraction of time beaches should be closed at Silver Strand State Beach per total untreated sewage, TJRE source, and SAB/PTB source for the 4 scenarios (colors). The top panel shows wet season (1 Oct to 1 April) and the bottom panel shows tourist (dry) season (22 May to 8 Sept). Note a value of 0.1 indicates that 10% of the time the beach should be closed. No bar present means the value is zero.

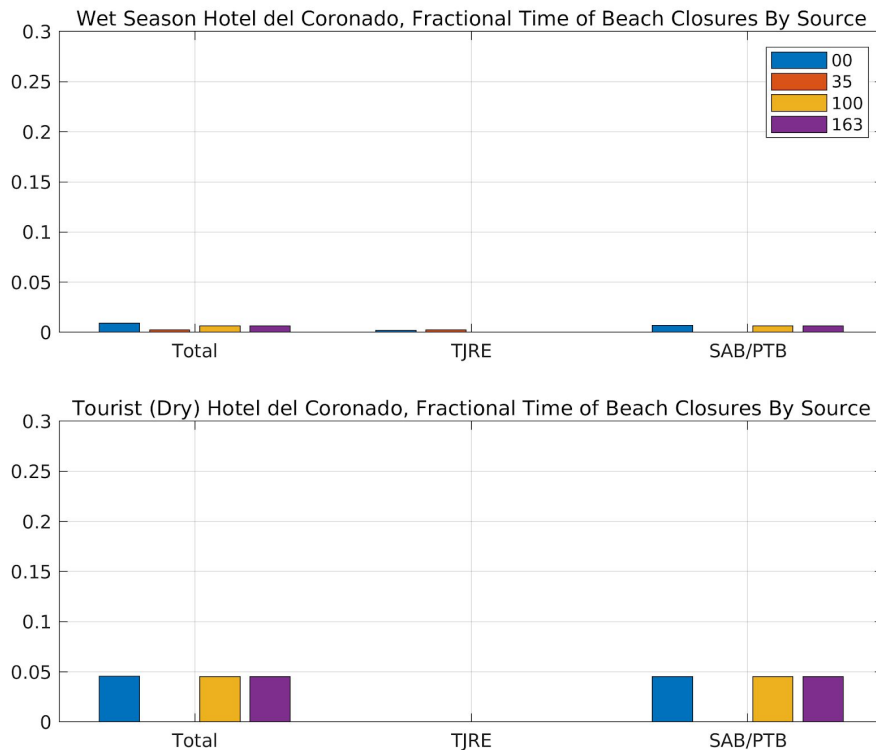


Figure 11: Fraction of time beaches should be closed at Hotel del Coronado per total untreated sewage, TJRE source, and SAB/PTB source for the 4 scenarios (colors). The top panel shows wet season (1 Oct to 1 April) and the bottom panel shows tourist (dry) season (22 May to 8 Sept). Note a value of 0.1 indicates that 10% of the time the beach should be closed. No bar present means the value is zero.

Silver Strand State Beach & Hotel del Coronado

The fractional beach closure patterns at Silver Strand State Beach (SS, Figure 10) and Hotel del Coronado (HdC, Figure 11) have reduced levels relative to the IB pier and HdC having lower levels than SS as it is farther from the two sources. During wet season (Figures 10 & 11, top panels), closures are at 4% and 1.5% at SS and HdC, interestingly largely due to episodic SAB/PTB events and only weakly due to the TJRE source. The NADB 35, 100, & 163 scenarios reduce wet season impacts to 1% and 0.5% at SS and HdC, respectively. But overall, wet season impacts are minimal under all scenarios. During dry season, the SS and HdC pattern is similar to Playas Tijuana and IB Pier, but with reduced levels (Figures 10 & 11, bottom panels). The baseline NADB 00 scenario is at 12.5% and 4.5% beach closure levels at SS and HdC, respectively. As with other locations, these closures are all due to SAB/PTB sourced flows. **As with IB Pier and Playas Tijuana, the NADB 35 scenario has the largest benefits in terms of reduced beach closures at Silver Strand State Beach and Hotel del Coronado.**

9. Conclusions

Herein, we have examined the shoreline water quality impacts of untreated sewage under 4 difference flow scenarios (NADB 00, 35, 100, 163) for the 2017 year split into wet season (prior to 1 April and after 1 Oct) and tourist (dry) season (22 May to 8 Sept). The untreated sewage inflow is based on “normal” scenario and does not represent catastrophic City of Tijuana wastewater infrastructure failure. A representative untreated sewage concentration value is used to gauge beach closure limits. Overall, the SAB/PTB source is the dominant source that leads to regional beach closures. At the Imperial Beach Pier during the tourist (dry) season, the baseline (NADB 00) scenario has the beach closed 24% of the time. NADB 35 scenario reduces this to 0%, whereas the NADB 100 & 163 scenarios do not reduce tourist season beach closures. At the Imperial Beach Pier during wet season, the baseline (NADB 00) scenario has the beach closed 9% of the time, $\frac{2}{3}$ of which comes from the TJRE source and $\frac{1}{3}$ from the SAB/PTB source. The NADB 35, 100, & 163 scenarios reduce wet season beach closures to 4% to 6%, and are largely similar in efficacy. **Thus, the NADB 35 scenario has by far the largest benefits in terms of reduced beach closures at IB Pier, because of the strong reduction of SAB/PTB inflows. Similar conclusions are drawn at Playas Tijuana, Silver Strand State Beach, and Hotel del Coronado.**

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Appendices:

Herein are technical appendices with additional analysis to support the conclusions drawn in the report at the 4 representative sites of beach recreation: Playas Tijuana MX, Imperial Beach Pier, Silver Strand State Beach, and the Hotel del Coronado within the City of Coronado.

- Appendix A provides time information of untreated sewage dilution for the entire year to better appreciate the 3-10 day time-scale of the untreated sewage “events”. Recall that a representative dilution for beach closure is estimated at 5×10^{-4} .
- Appendix B provides untreated sewage dilution statistics over the wet season (1 Oct to 1 April) as a function of the alongcoast. The statistics are the time-mean and the maximum value
- Appendix C is similar to Appendix B but untreated sewage dilution statistics over the tourist (dry) season (22 May to 8 Sept) as a function of the alongcoast. The statistics are the time-mean and the maximum value.
- Appendix D examines the sensitivity of beach closure fraction based on the chosen untreated sewage dilution threshold.

Appendix A: Untreated Sewage Time Series at Playas Tijuana, Imperial Beach Pier, Silver Strand State Park and Hotel Del Coronado

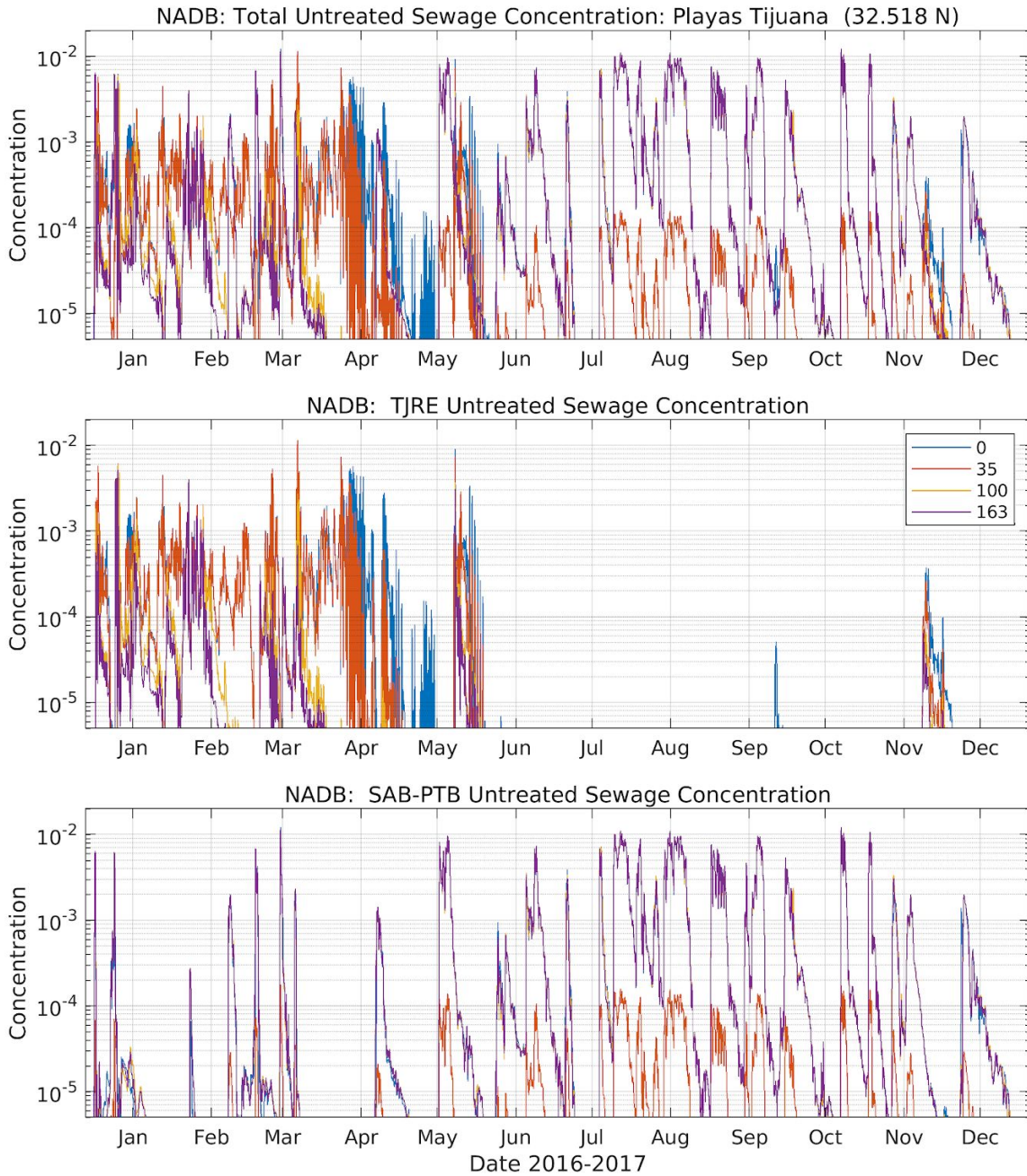


Figure A1: Shoreline untreated sewage concentration at Playas Tijuana (32.518N) over the 2017 Year for (top) the combined TJRE and SAB/PTB source (middle) TJRE only source, and (bottom) SAB/PTB only source. The colors represent the 00, 35, 100, 163 scenarios as indicated in the legend of the middle panel.

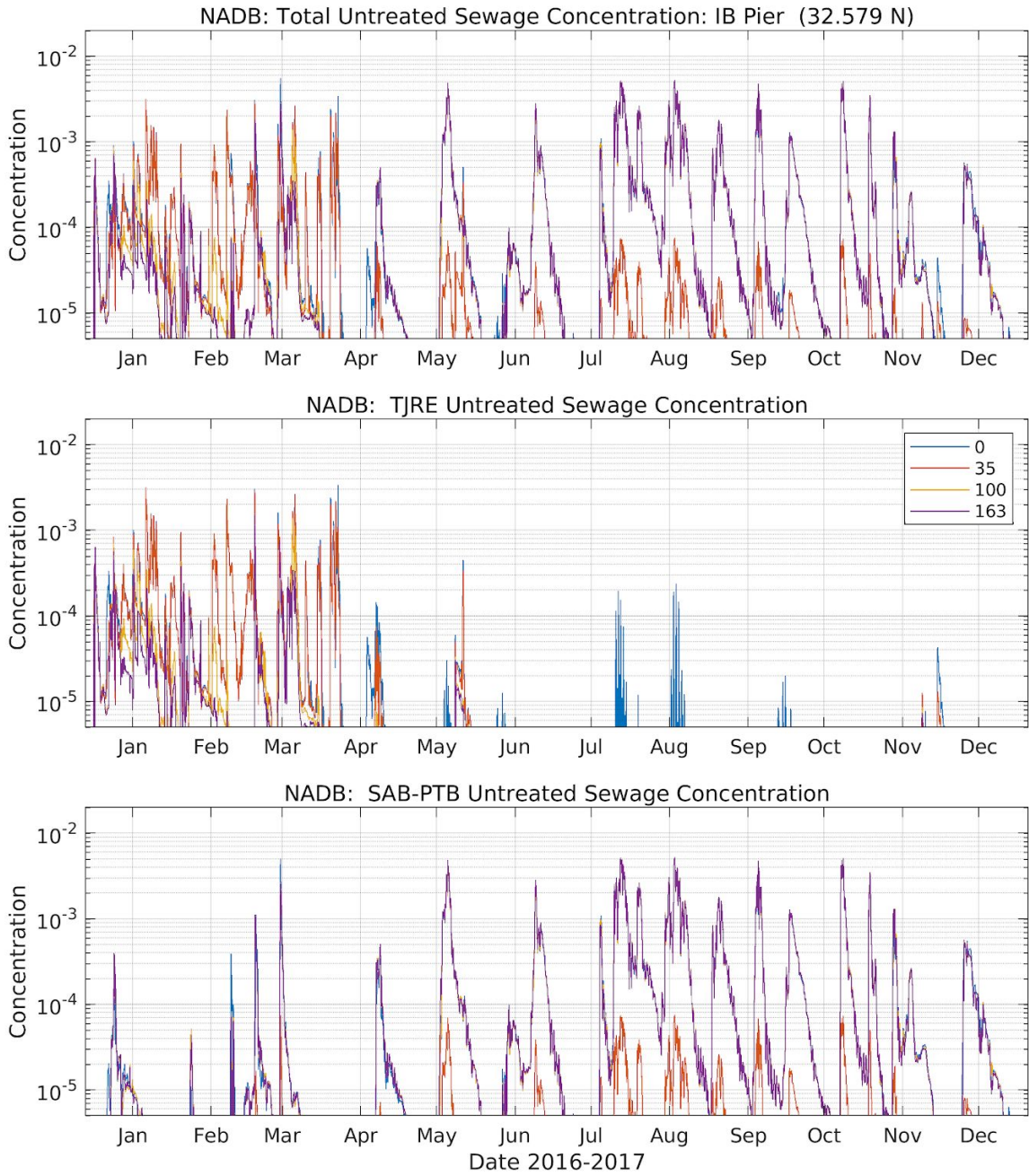


Figure A2: Shoreline untreated sewage concentration at the City of Imperial Beach Pier (32.579N) over the 2017 Year for (top) the combined TJRE and SAB/PTB source (middle) TJRE only source, and (bottom) SAB/PTB only source. The colors represent the 00, 35, 100, 163 scenarios as indicated in the legend of the middle panel.

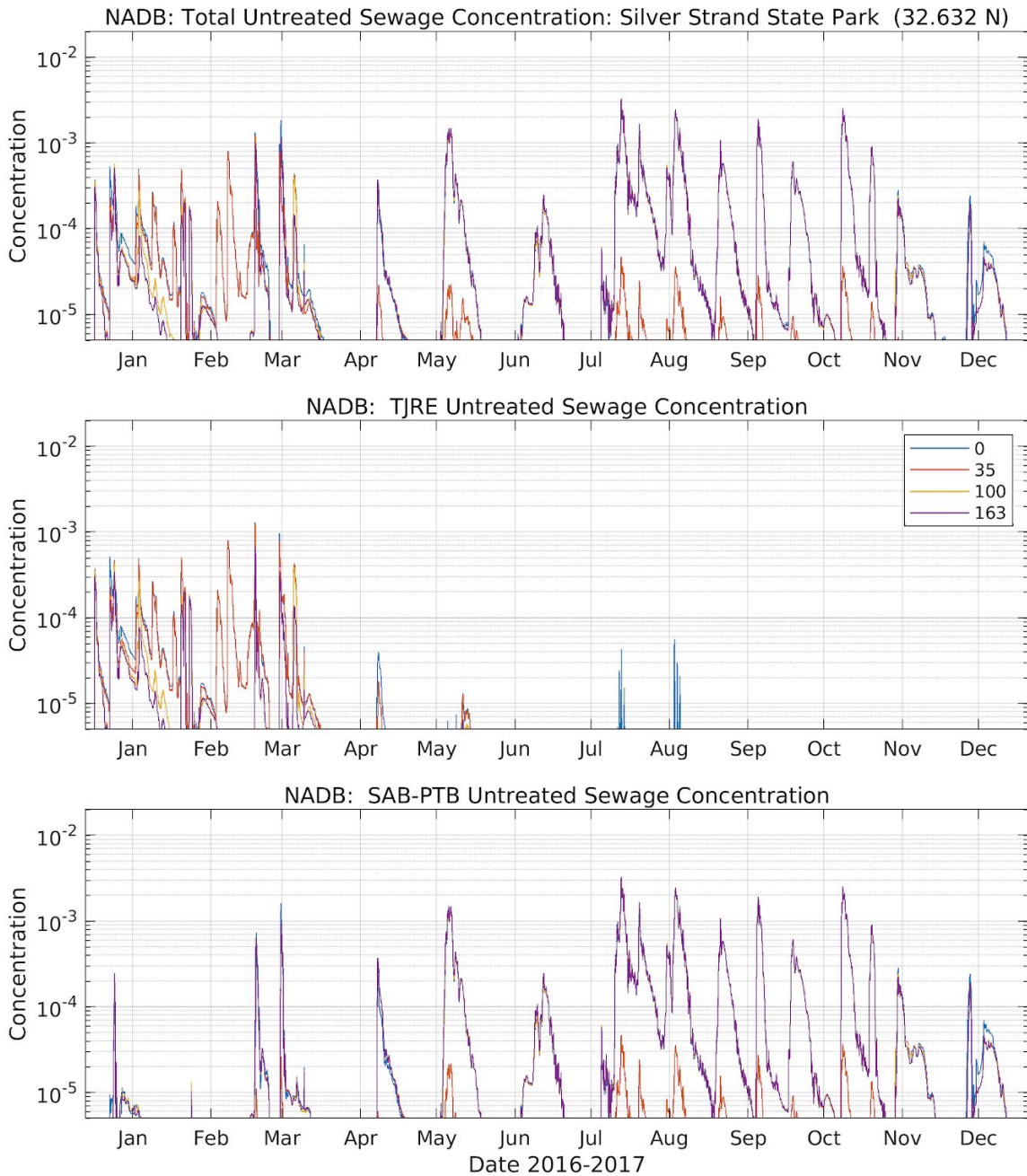


Figure A3: Shoreline untreated sewage concentration at Silver Strand State Park (32.632N) over the 2017 Year for (top) the combined TJRE and SAB/PTB source (middle) TJRE only source, and (bottom) SAB/PTB only source. The colors represent the 00, 35, 100, 163 scenarios as indicated in the legend of the middle panel.

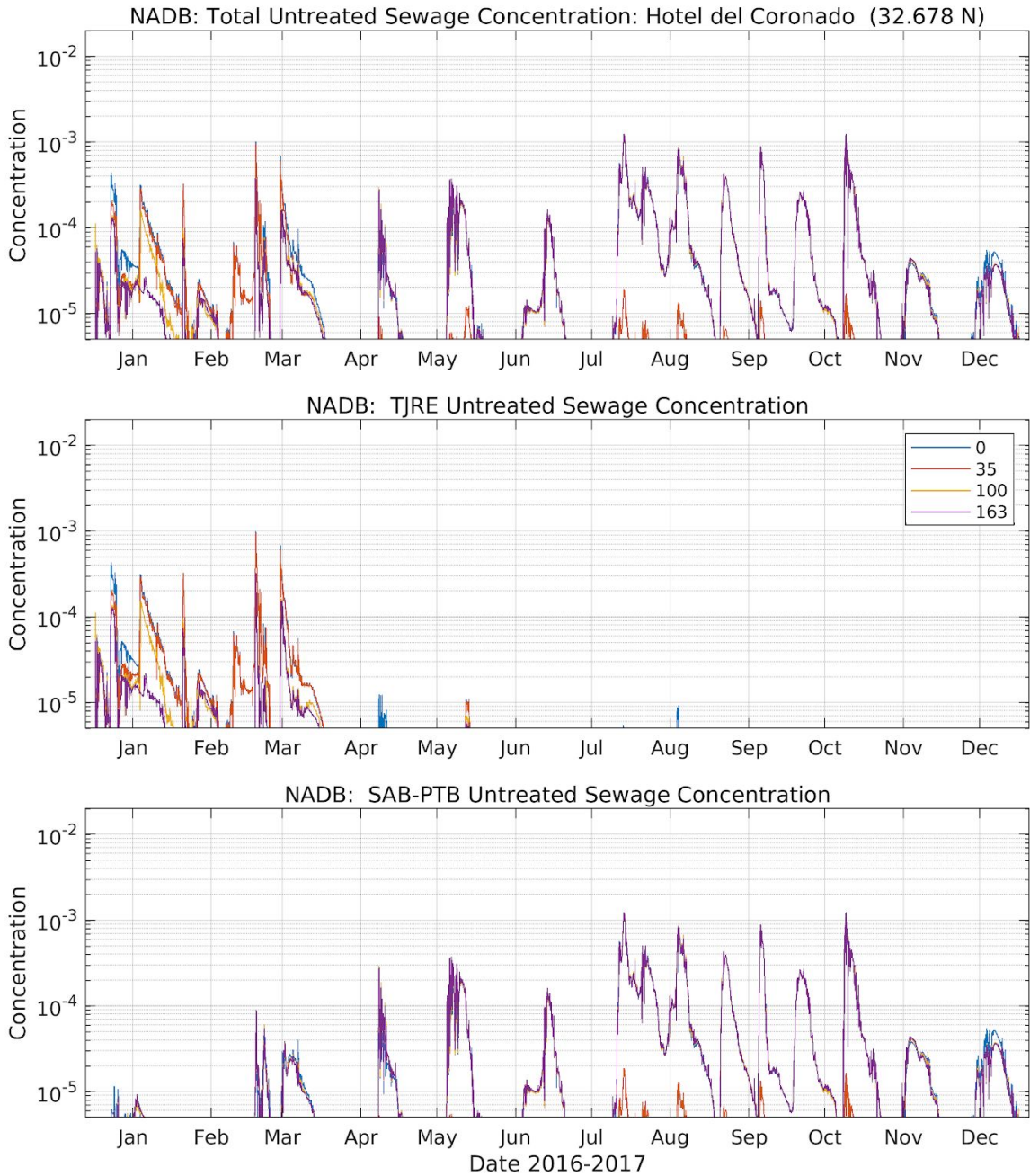


Figure A4: Shoreline untreated sewage concentration at the Hotel Del Coronado (32.678N) over the 2017 Year for (top) the combined TJRE and SAB/PTB source (middle) TJRE only source, and (bottom) SAB/PTB only source. The colors represent the 00, 35, 100, 163 scenarios as indicated in the legend of the middle panel.

Appendix B: Tourist (Dry) Season (22 May to 8 Sept) Untreated Sewage Alongcoast Statistics

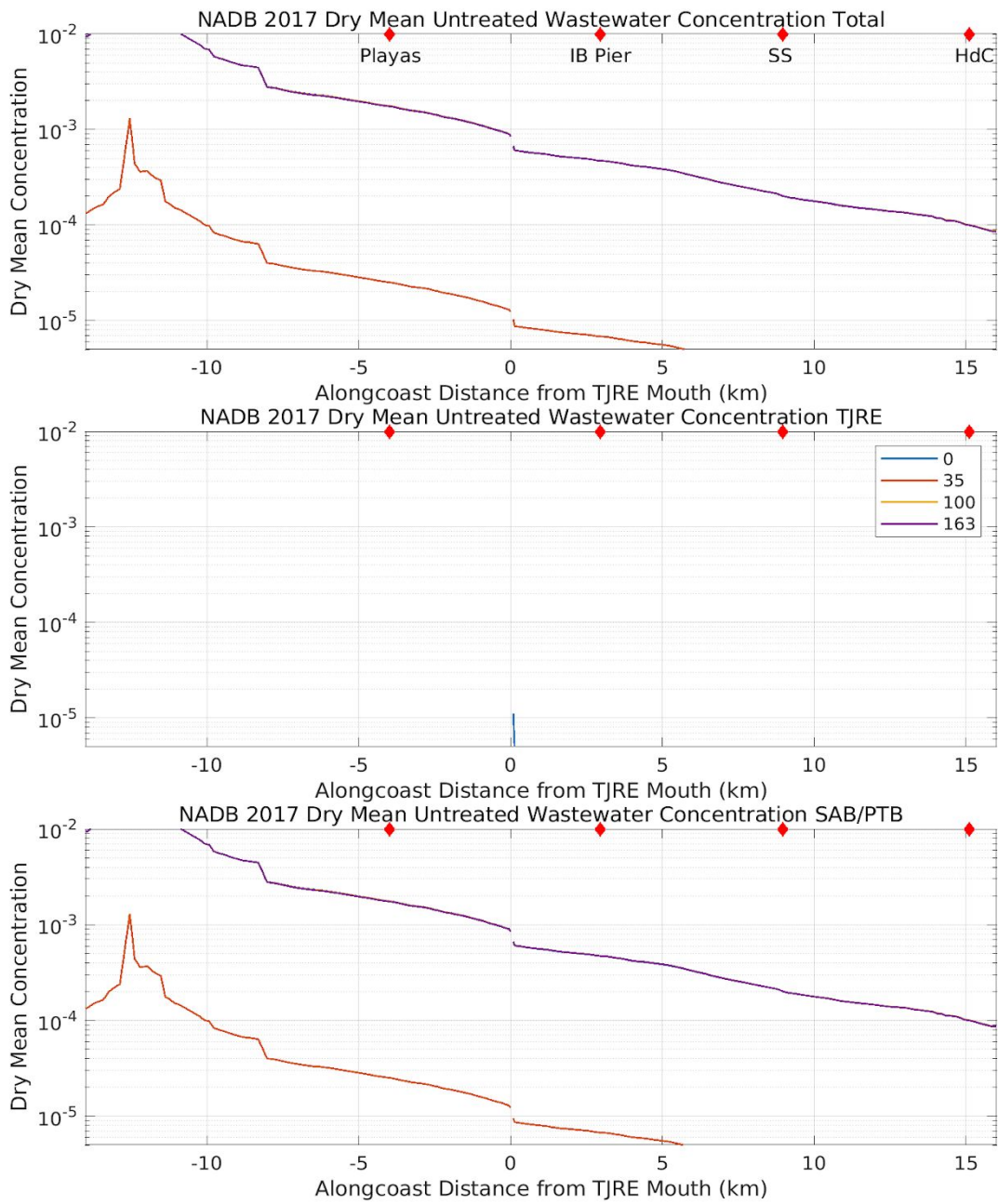


Figure B1: Tourist (dry) seasons mean untreated sewage concentration versus alongcoast distance form TJRE mouth the four NADB scenarios (see legend): (top) total untreated sewage, (middle) TJRE source, and (bottom) SAB/PTB source. The locations of Playas Tijuana, Imperial Beach Pier, Silver Strand State Beach (SS), and Hotel del Coronado (HdC) are indicated.

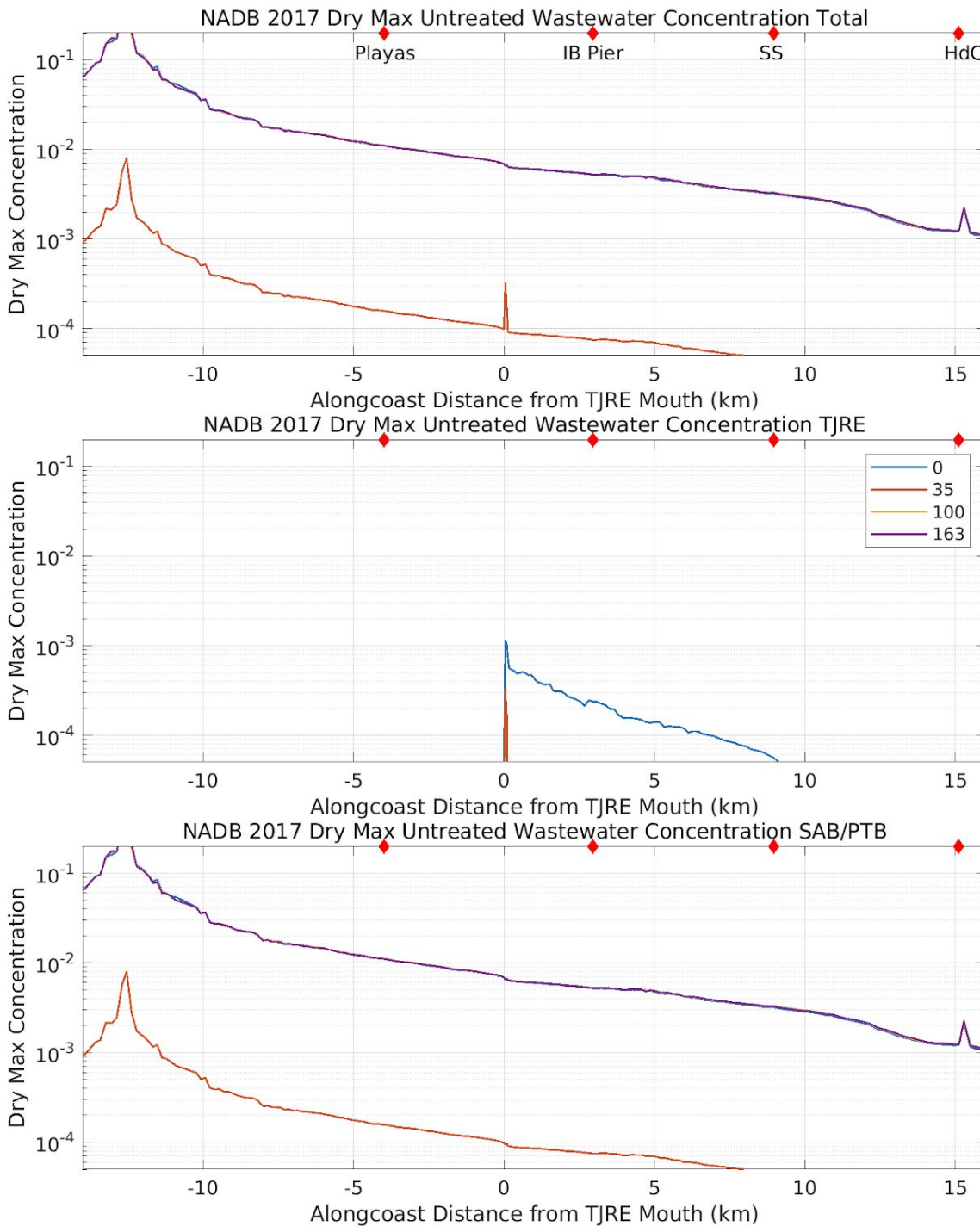


Figure B2: Tourist (dry) season maximum untreated sewage concentration versus alongcoast distance form TJRE mouth the four NADB scenarios (see legend): (top) total untreated sewage, (middle) TJRE source, and (bottom) SAB/PTB source. The locations of Playas Tijuana, Imperial Beach Pier, Silver Strand State Beach (SS), and Hotel del Coronado (HdC) are indicated.

Appendix C: Wet Season (1 Oct to 1 April) Untreated Sewage Alongcoast Statistics

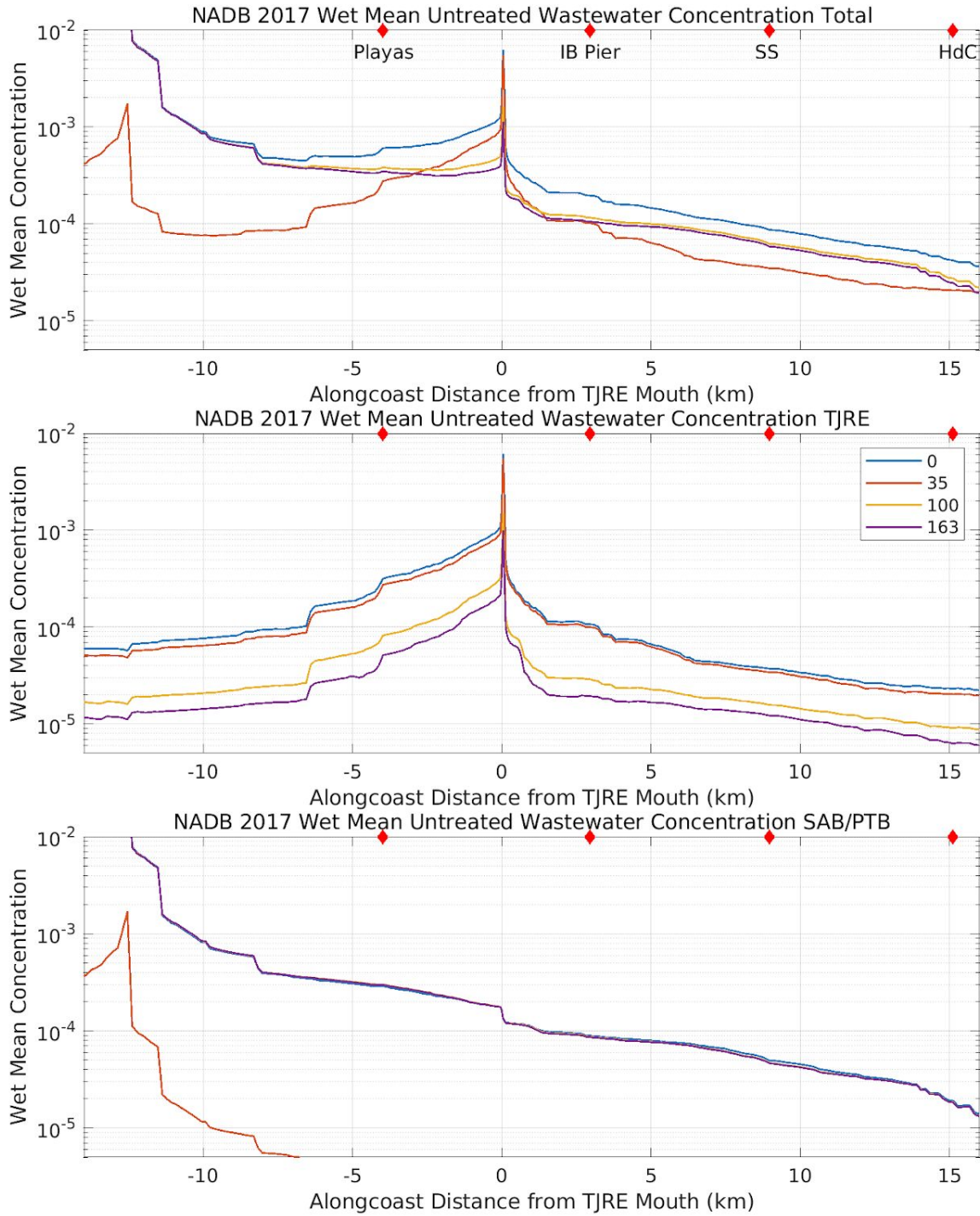


Figure C1: Wet season mean untreated sewage concentration versus alongcoast distance from TJRE mouth the four NADB scenarios (see legend): (top) total untreated sewage, (middle) TJRE source, and (bottom) SAB/PTB source. The locations of Playas Tijuana, Imperial Beach Pier, Silver Strand State Beach (SS), and Hotel del Coronado (HdC) are indicated.

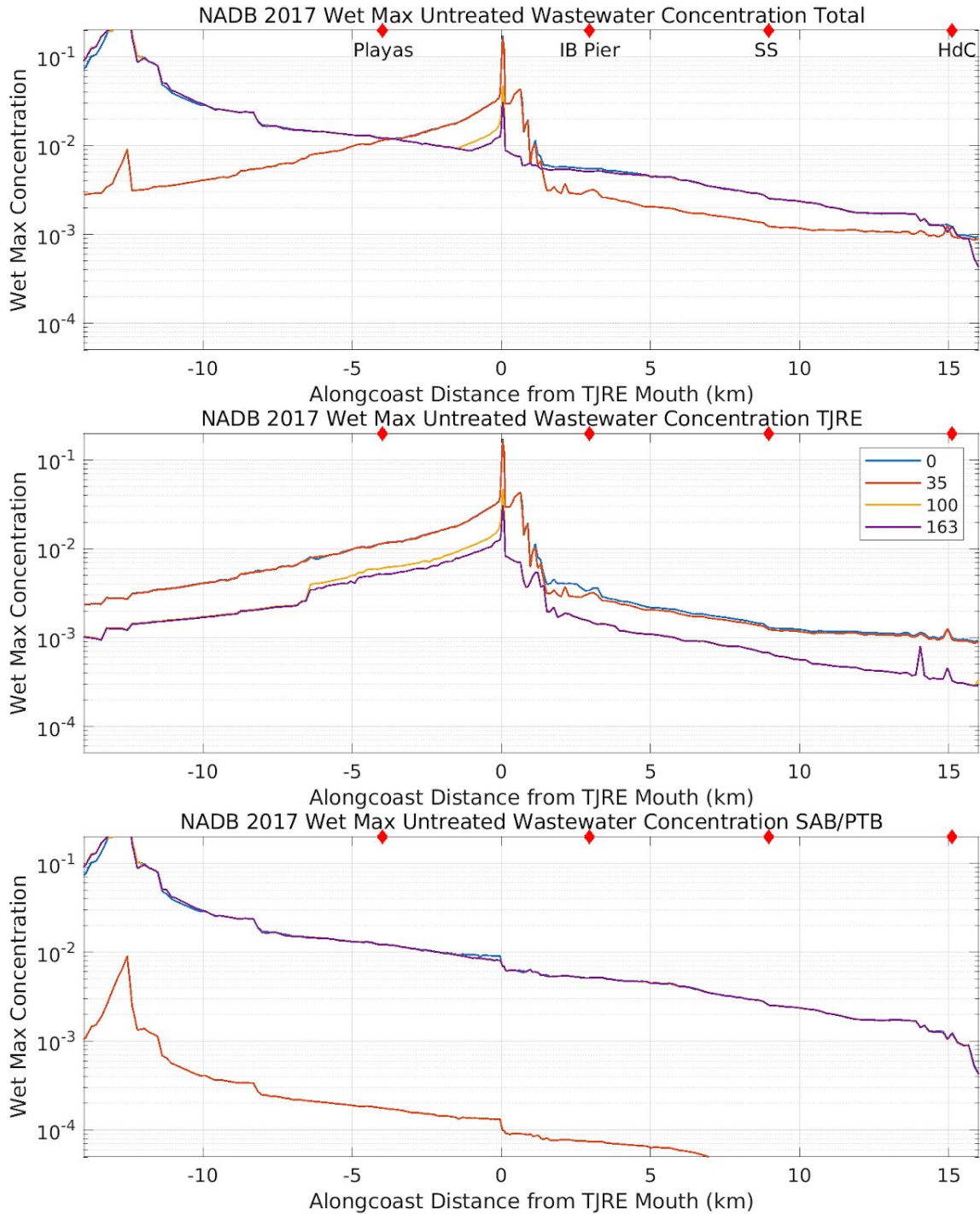


Figure C2: Wet season maximum untreated sewage concentration versus alongcoast distance from TJRE mouth the four NADB scenarios (see legend): (top) total untreated sewage, (middle) TJRE source, and (bottom) SAB/PTB source. The locations of Playas Tijuana, Imperial Beach Pier, Silver Strand State Beach (SS), and Hotel del Coronado (HdC) are indicated.

Appendix D: Sensitivity of beach closure fraction based on the untreated sewage dilution threshold.

The untreated sewage decay half life was set to 7-day representing norovirus (Boehm and Soller, 2020) which are a principal cause of recreational waterborne illness (e.g., Eftim et al., 2017). However, no EPA-developed norovirus levels for beach closure have been identified. Thus, a critical dilution level of 1:2000 (5×10^{-4}) for beach closure represents Enterococcus (ENT) levels 5x larger than EPA Beach Act limits. This 5x larger level was chosen as ENT half life is 2-3 days (e.g., Sinton et al., 2002) for the dark turbid waters of the surfzone. With the relative uncertainty as to the exact untreated sewage concentration threshold for beach closure, we examine the fractional time of Imperial Beach Pier closure as a function of critical dilution level for wet season and tourist season (Figure D1). At lower critical dilution levels (e.g., 1:10,000), the fractional beach closure time increases during both wet and dry seasons, although the wet season relative increase is larger than tourist season due to TJRE-source more often exceeding the lower threshold. However, the overall pattern of tourist (dry) season dominating and benefit of the NADB 35 scenario with the SAB/PTB inflow reduced, remains evident at all critical dilution levels (Figure D1).

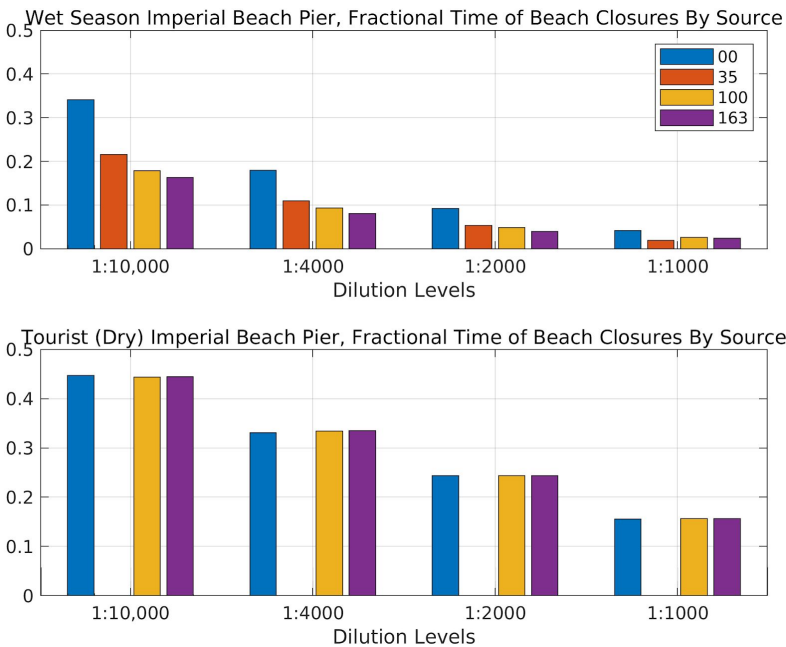


Figure D1: Fraction of time beaches should be closed at Imperial Beach Pier per total (TJRE + SAB/PTB) untreated sewage versus critical dilution levels for the 4 scenarios (colors). The top panel shows wet season (1 Oct to 1 April), the bottom panel shows tourist (dry) season (22 May to 8 Sept). Note a value of 0.1 indicates that 10% of the time the beach should be closed. No bar present means the value is zero. Critical dilution levels chosen are 1:10,000, 1:4000, 1:2000, and 1:1000 dilution which represent untreated sewage concentrations of 10^{-4} , 2.5×10^{-4} , 5×10^{-4} , and 10^{-3} , respectively. Note the dilution level of 1:2000 (concentration 5×10^{-4}) was used in the analysis.

