The proposed Buenos Aires outfalls: Hydrodynamic Modelling

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Abstract
The Matanza-Riachuelo watershed is the most contaminated river basin in Argentina. An extensive sewerage project is underway to address this, key components of which are two treatment plants and outfalls that will discharge into the *Río de La Plata*. In support of this project, extensive measurements of the physical characteristics of the River and modelling of the proposed outfalls have been performed. Data was gathered from acoustic Doppler current profilers (ADCPs), meteorological stations, vertical CTD profiling, and Lagrangian water trajectories from GPS-equipped drifters. The River is essentially fresh with very low salinity and the water column is well-mixed vertically. The river currents are dominated by the tide and flow predominantly along their first principal axes which are essentially parallel to the main River axis and the local shoreline.

The data were used to calibrate and verify a two-dimensional model for the *Río de La Plata* that was constructed using Delft3D. The model consists of a global domain to simulate most of the river with a relatively coarse grid and a nested domain with a high resolution grid to simulate smaller-scale flows around the proposed diffusers. The model closely simulated the major hydrodynamic features of the River.

Two different Lagrangian particle tracking modelling approaches were used to predict the fate and transport of effluent from 12 outfall and diffuser alternatives. Based on this modelling, the final diffuser designs and locations were chosen, and water quality modelling was then conducted and the results compared with water quality regulations. Bacterial impacts decreased rapidly with distance from the diffuser and no impacts on the shoreline or water intakes were predicted. Other non-conservative water quality constituents, including biochemical oxygen demand, dissolved oxygen, ammonium, nitrates, phosphates, and diatoms (algae) were modelled with a water quality module. All of the standards are met, often by large margins.

The effects of sudestadas on water quality were also addressed. Analysis of the currents during these events showed somewhat longer excursions of the plume both into and out of the estuary. The Berazátegui plume can extend upstream of the Bernal water intake. It did not impact it, however, and otherwise the spatial variations of the plume and bacterial impacts were not significantly different from other periods. It was concluded that sudestadas do not significantly affect water quality for the proposed outfalls.

Keywords
Outfall, modelling, hydrodynamic, Buenos Aires, Río de La Plata.

1. Introduction

Two major outfalls are proposed to discharge treated wastewater from the City of Buenos Aires into the *Río de La Plata* at Berazátegui and Riachuelo (Figure 1). In support of the design of these outfalls, and to predict their environmental impacts, extensive studies have been under way since June 2009. They consist of field measurements of various physical properties in the River and mathematical modelling. Measurements include Acoustic Doppler Current Profilers (ADCPs) and meteorological stations. Experiments using GPS-equipped drifters and monthly water column profiling of CTD (conductivity, temperature, and depth) have also been undertaken. A mathematical hydrodynamic and water quality model of the entire River has been constructed and calibrated by comparison to the field measurements. The model is being used to determine the outfall and diffuser designs and their environmental impacts. In this paper, we summarize and analyze a total duration of approximately twelve months of data, from June 2009 to June 2010. Using the outfall and diffuser designs recommended, we report hydrodynamic and bacterial simulations for the entire period and simulations of other water quality parameters for representative months. In addition, the impact of *sudestadas* on water quality and wastefield fate and transport are addressed.

Figure 1. La Plata River and proposed outfalls

Figure 2. Meteorological and water level stations

2. Hydrodynamic Modelling

Introduction

The models were set up, calibrated and validated using the available data. The hydrodynamic and water quality modelling is being performed using Delft3D. Delft3D is a modelling system to investigate hydrodynamics, sediment transport, morphology, and water quality in lakes, rivers, coastal waters, and estuaries. For the hydrodynamic modelling, we use Delft3D-FLOW. This module calculates unsteady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary-fitted grid. The fate and transport of the discharged wastewaters is modelled using Delft3D-PART and Delft3D-WAQ. PART is a particle tracking model and WAQ is a water quality model based on gradient diffusion. The models were run in two-dimensional (depth-averaged) modes.

Data

Bathymetry and hydrometeorology: bathymetry and hydrometeorology data was provided by AySA. Meteorological and water level stations are shown in Figure 2. Three of the stations were set up by AySA specifically for this project: Bernal, San Martin, and Berazátegui. These stations record wind speed and direction, air temperature, humidity, solar radiation, atmospheric pressure, and precipitation. The stations at Bernal and San Martin are attached to the water intake towers and also record water levels. The data for three meteorological stations located on the water (Bernal, San Martin, and Norden) are compared in Figure 3. They are generally similar. Significant variations are evident as was also reported by Fossati et al. (2007). The winds are predominantly from the north and northeast with speeds ranging mostly from 4 to 8 m/s. The second most important wind direction is from the east and southeast, commonly associated with *sudestada* events. Data for some of the stations on land were also compared. They show significant differences with the stations over the water. They are more variable and slower due to local topographic effects. The water level data measured at the Oyarvide Tower are used to drive the mathematical model at its outer boundary. Water levels vary significantly with the tide, up to 2 m. Temporal variations of discharge for the main tributaries, the Uruguay and Paraná Rivers, for the field data period are shown in Figure 4. The total river discharge into the *Río de La Plata* shown in Figure 4 varies considerably, mainly due to variations of the Uruguay River. Compared to the average flows previously estimated by Jaime and Menendez (2002), the flows in June and July 2009 are below the long-term average, in August close to the average, and for September 2009 to February 2010 above average.

CTD Profiling**:** Fourteen CTD profiling campaigns were done near the proposed Riachuelo and Berazátegui outfalls. Profiling was conducted every hour over 24 hour periods. Typical profiles, at Berazátegui on February 11 2009 at 11:45 are shown in Figure 5. All of the profiles show the water column to be homogeneous or very weakly and briefly stratified.

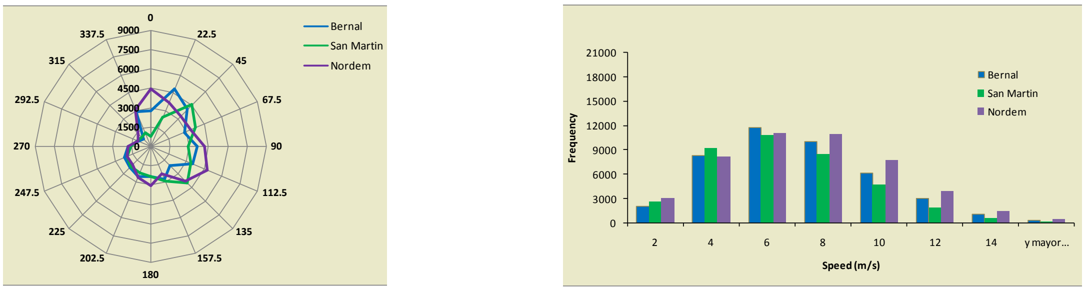

Figure 3. Direction and magnitude histograms for winds measured at the over-water stations.

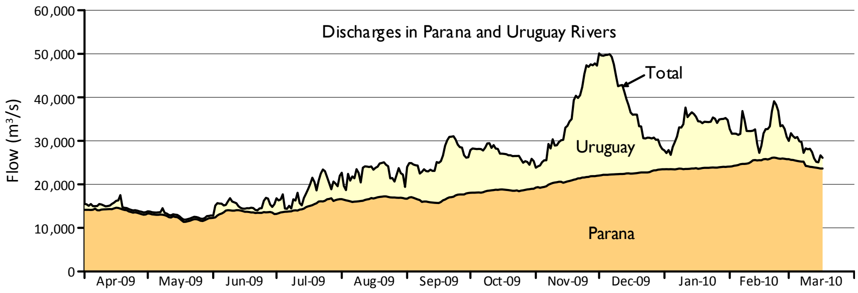

Figure 4. Discharges from the Uruguay and Paraná rivers

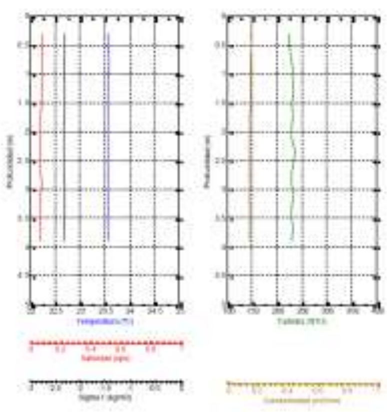

Figure 5. CTD profiles at Berazátegui (Eih, 2009).

Figure 6. ADCP moorings

ADCP Measurements**:** Six ADCPs were installed in June 2009 at the locations shown in Figure 6. The moorings recorded several parameters at 15 minute intervals. In addition to current speed and direction, all record pressure and temperature. ADCPs 5 and 6, which are close to the proposed diffuser locations, also measure conductivity. The ADP (number 2) measures wave characteristics, and also turbidity. Currents for the period 16 June to 16 September 2009 are shown as polar scatter diagrams in Figure 7 for the bottom, mid-depth, and surface bins. Also shown are the first and second principal current axes. The first principal axis maximizes the kinetic energy (variance) of the currents when projected onto it; the second principal axis minimizes it and is orthogonal to the first. Their directions are the directions of the eigenvectors of the covariance matrix of the easterly and northerly current speeds. The currents are quite uniform over depth and generally flow along the well-defined first principal axes. These are essentially parallel to the axis of the river and to the local shoreline. The onshore/offshore components at the nearshore meters (3, 4, and 6) are weak, but near the middle of the river (for example ADCP 1) they are stronger and the current direction is more scattered, especially at the surface presumably due to wind influences. Scalar speeds range up to about 1 m/s with average values around 0.25 m/s. Time series of the first principal components for the ADCPs 5 and 6 for the month of August 2009 are shown in Figures 8. The time series plots show the first principal components to be strongly tidal and coherent over depth. The first principal components explain up to 98% of the total variance of the currents at each station. Peak tidal speeds are typically around 40 cm/s. The second principal components are much slower, and more random in speed and direction.

Surface **Mid-depth** **Bottom**

Figure 7. Polar scatter diagrams and principal axes of currents, 16 June – 16 Sept, 2009

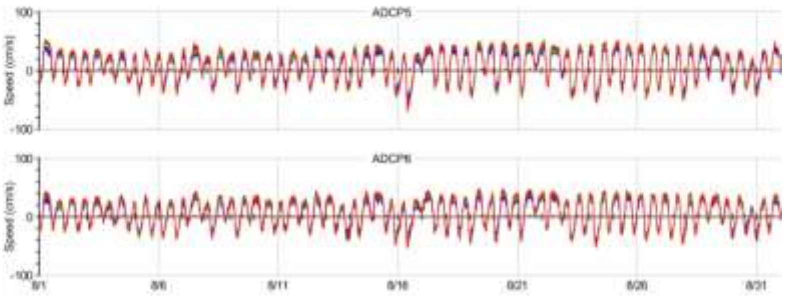

Figure 8. First principal current components, August 2009

***Drifters**:* Ten field experiments with Lagrangian drifters were conducted. The drifters were released at four locations along the proposed diffusers. The releases involved 10 drifters, six near the surface and four near the bottom. Each drifter has a GPS that records position and time and transmits it to a central location. The drifters were tracked for at least 12 hours before being retrieved. In general the drifters follow the tide and move together covering distances up to 10 km in 12 hours with velocities ranging between 0.05 and 0.4 m/s. The bottom drifters move slightly more slowly but the wind does not appear to be a major driving force.

Model Parameters and Inputs

Domain and grids: The modelled domain is the *La Plata River* and corresponds approximately to the inner (upper and intermediate) region shown in Figure 9. The model is bounded by the coastlines of Argentina and Uruguay with a 90 km long open ocean boundary to the east located along the curve line extending from Punta Indio in Argentina and Kiyú in Uruguay. The model consists of two domains (Figure 9). The global model has a low-resolution grid that comprises the River study area and the nested model has a high-resolution grid that encompasses the area around the proposed outfalls. The global and nested grids are shown in Figures 10 and 11. The total number of active cells is 24,895 and 105,104 for the global and nested domains respectively. The grid sizes for the global model vary from 500 m near the proposed outfalls to 1,500 m at the farthest model boundary and for the nested model from 100 m near the outfalls to 300 m near the model boundary.

Time frame and initial conditions: Simulation ran from April 1, 2009 to June 30, 2010. The time step was 5 minutes according to accuracy arguments and sensitivity analyses. The initial hydrodynamic condition for the entire domain corresponds to a stationary condition. Uniform values for all dependent variables were assumed at the start of the simulation time. The initial water level condition was set according to measured values.

Figure 9. Model domain

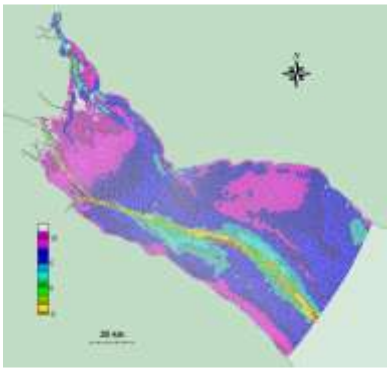

Figure 10. Global grid

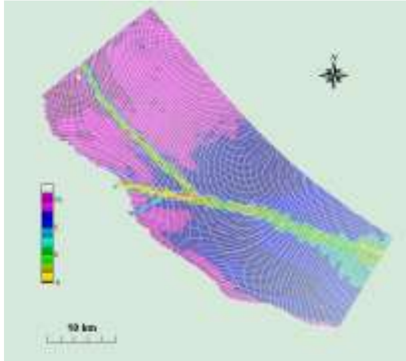

Figure 11. Nested grid

Open boundary conditions: The global model was forced at the open boundary by the water levels that were measured at the Oyarvide tower. The boundary conditions for the nested model are the time series of water levels and currents simulated by the global model. Meteorological data from the Bernal meteorological station was used; the wind field was assumed to be time varying but uniform over the model domain. The main river tributaries were considered to be local water discharges and imposed as boundary conditions for respective model cells as time series according to the available data.

Model Calibration and Validation

The main calibration parameters are horizontal viscosity, wind drag coefficient, and bottom roughness (Manning). They were varied to obtain optimum results according to a calibration process. Their optimum values were found as follows: Manning roughness coefficient n = 0.015, horizontal viscosity = 100 m/s^2 and wind drag coefficient = 0.001. The model was validated using entire set of recorded data, from June 2009 to June 2010.

Results

Currents in the *Río de La Plata* are dominated by the tide. The currents flow predominantly along the first principal axes. Time series of the measured and modelled first and second principal components at ADCP 5 for the period August 1 to 31, 2009 are shown in Figure 12. It is apparent that the model captures the main hydrodynamics features very well. The currents are strongly tidal, with the semidiurnal tide dominant. The tidal current (the first principal component) is simulated very closely in phase and magnitude. The mean scalar speeds are also closely simulated. The modelled mean (vector) speeds are somewhat slower than measured, possibly due to uncertainty in the river tributary inputs, which are the main drivers of the mean velocity in the river. The principal axes of the simulated currents are rotated clockwise relative to the measured values, by 12° (ADCP 5) and 7° (ADCP 6). The current directions were generally consistent with measurements except during periods of strong winds. The standard deviations (or variances) of the first principal components are closely modelled, but the standard deviations of the second principal components are smaller than measured.

3. Water Quality Modelling

Introduction

Detailed water quality simulations to address issues related to microbiological contaminants and environmental degradation were run for the final outfall locations shown in Figure 1 and the final diffuser designs (Roberts 2011). The appropriate water quality standards were assumed to be those for water use Type III, “allowed for recreational activities without direct contact”, SAyDS (2009).

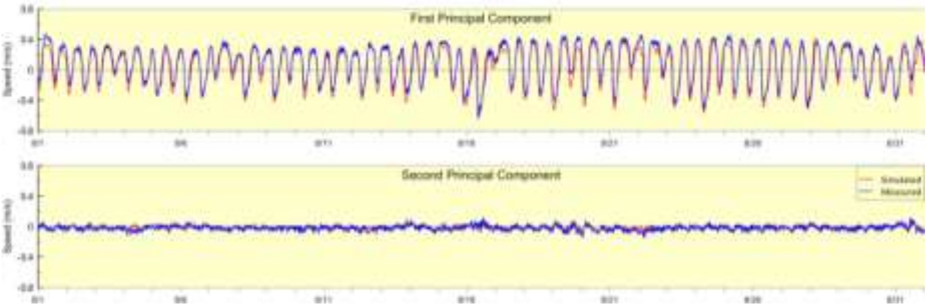

Figure 12. Time series of principal components of measured and simulated currents at ADCP 5

The effluent concentrations, river background levels, and required dilutions to achieve the main water quality requirements are summarized in Table 2. For the Riachuelo outfall the minimum flow is 16.0 m^3/s, average is 18.5 m^3/s, and peak is 25.0 m^3/s. For Berazátegui the minimum flow is 21.0 m^3/s, average is 25.0 m^3/s, and peak is 33.5 m^3/s. Water quality issues were divided into two main groups: conservative and non-conservative. Non-conservative constituents are further divided into two groups: bacteria, and those relating to environmental degradation.

Table 2. Assumed effluent and background concentrations and water quality standards for Type III water use

Parameter	Effluent concentration		River back-ground	Standard Type III	Frequency	Required dilution	Delft3D module and domain
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Conservative:							PART Global
Phenols (µg/l)	40(1)	40(1)	10(2)	<100	90%	None	
Detergents (mg/l)	2(1)	2(1)	0.2(2)	<5	90%	None	
Lead (µg/l)	29(1)	29(1)	5(2)	NR			
Chromium (µg/l)	95(1)	95(1)	5(2)	NR			
Non-conservative – Bacteria:							PART Nested
E. coli (MPN/100ml)	$2.4x10^7$(2)	$2.4x10^7$(2)	300(2)	<20,000	0%		
Non-conservative - Environmental degradation:							WAQ Nested
BOD (gO2/m^3)	87(1)	107(1)	2 (2)	< 10	90%	10:1	
DO (g/m^3)	0.3(1)	0.3(1)	8 (2)	> 4	90%		
NH4 (gN/m^3)	16(1)	16(1)	0.05 (2)	NR			
NO3 (gN/m^3)	0(3)	0(3)	2 (2)	< 10	90%		
PO4 (gP/m^3)	2.4(2)	2.4(2)	0.17(2)	-			
Total P (gP/m^3)	-	-	-	< 1	90%		

NR = No regulation
(1) SAyDS May 2009
(2) AySA historical data
(3) SAyDS April 2008

Conservative Constituents

According to Table 12, the phenols effluent concentration is 40 µg/l and the background level in the river is 10 µg/l. Therefore, the water quality standard of 100 µg/l will never be exceeded, even disregarding the outfall dilution. Similarly, the detergents concentration in the effluent is 2 mg/l and the river background is 0.2 mg/l. Therefore the water quality standard of 5 mg/l will never be exceeded. There are no established regulations for lead and chromium. The river background levels for each are 5 µg/l. Therefore, for dilutions of 20:1 the river concentrations will be 6.2 µg/l for lead and 9.5 µg/l for chromium. The elevations over background levels are 1.2 and 4.5 µg/l for lead and chromium respectively.

Non-Conservative, Bacteria

Model Parameters: the bacterial decay rate is usually expressed in terms of the time for 90%

bacterial mortality, T_{90}, or the first-order decay rate, *k*. These constants are mainly a function of UV radiation intensity although they are also affected by temperature, salinity and nutrient concentrations. Experiments were conducted by AySA to estimate T_{90} for the proposed discharges (AySA, 2008). The results indicated that T_{90} may range from 5 to 24 hrs. Other authors have found good agreement with shoreline bacterial observations by using T_{90} = 24 hrs (SAyDS, 2008). For the present study we assume that T_{90} varies diurnally from 5 to 24 hours. Bacteria concentrations were estimated based on data provided by AySA, the E. Coli concentration in the effluent was assumed to be 2.4×10^7 per 100 ml. Delft3D-PART was then run monthly from July 2009 to June 2010 considering diffuser lengths equal to 1400 m, and 2300 m for the Riachuelo and Berazátegui outfalls respectively and variable bacteria decay rates. The diffusion coefficient was assumed to be 0.32 m^2/s based on the FRFIELD simulations (Roberts 2011).

Results: Animations were generated for the modelling results and some selected frames are shown at Figure 13. Results show the plumes being advected back and forth with the tide with very variable dilution. Average upstream excursions of the plume are about 4.5 km, although maximum excursions can be as far as 10 km. No impacts on the water intakes were predicted. At low current speeds, patches of more concentrated bacteria form, but these patches mix due to diffusion and dispersion as they travel and the bacteria decay due to mortality.

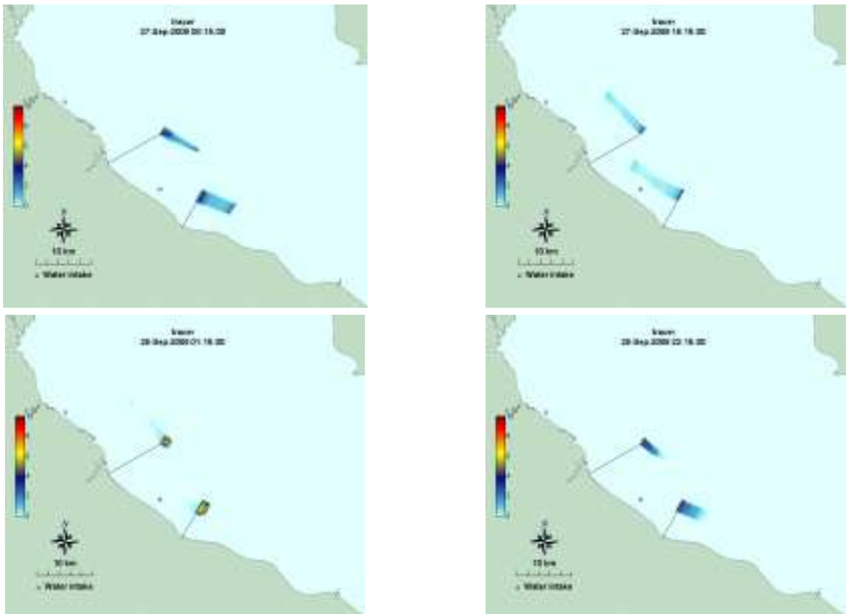

Figure 13. Outfalls plumes during the sudestada on September 27-29, 2009

In order to summarize and present the predictions and compare them on a monthly basis, the frequencies with which E. coli levels exceeded 20,000 per 100 ml were computed from the time series at each observation point and the results were contoured. This is the SaYDS bacterial standard for Class III Waters, “allowed for recreational use without direct contact”, which should not be exceeded more than 10% of the time. The results for some typical months are shown in Figure 14.

Other Non-Conservative Constituents

Other non-conservative constituents were simulated with the module Delft3D-WAQ which accounts for the interactions of nutrients, BOD and DO to assess eutrophication processes in the water body and the possible growth of algae (diatoms) due to the wastewater discharges.

Model parameters: The most important parameters, biodegradation and nitrification constants, were assumed to be 0.25 and 0.10 day-1 respectively according to previous studies on the River (SAyDS, 2008). Initial conditions in the river were set up according to the AySA historical data and the effluent concentrations in Table 12. Delft3D-WAQ allows different substance groups. For the La

Plata River we use two of them: Oxygen-BOD and Eutrophication.

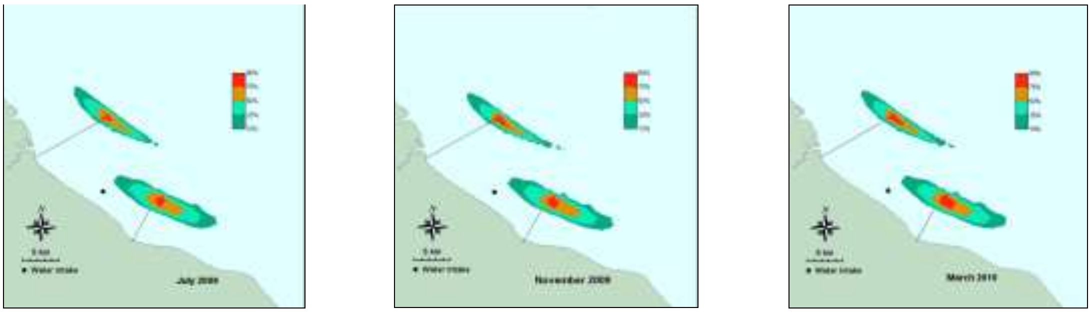

Figure 14. Freq. of exceeding E.Coli levels of 20,000 per 100 ml by some typical months.

Results: Simulated time series of selected water quality parameters: dissolved oxygen and carbonaceous BOD, for July 2009 at observation points located about 200 m from the centers of the Berazátegui and Riachuelo diffusers are shown in Figure 15. Parameter levels always meet the standards for water use Type III. Total phosphorous was always less than 0.4 gP/m^3 and there was no algae growth indicating no eutrophication problems due to the outfall discharges. The level of NO_3 is never higher than 2.2 gN/m^3, DO values never fell below the limit value with average concentrations around 6.5 g/m^3. BOD concentrations were always less than 10 $gO2/m^3$. No impacts on the intakes or the shoreline were predicted.

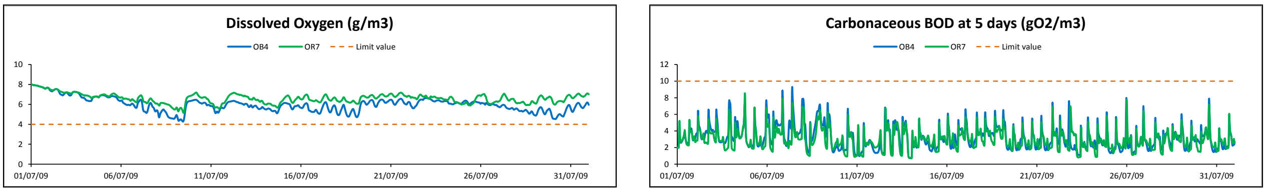

Figure 15. Simulated water quality parameters at observation points OB4 and OR7: July 2009. Type III water quality standards are shown as orange lines

Effect of *Sudestadas* on Water Quality

A *sudestada* is a local phenomenon associated with strong southeasterly winds over the *Río de La Plata* estuary. Escobar (2004) typifies *sudestadas* by their effects on the River level. The implication of these phenomena on water quality is directly related to what happens with the river currents. From the water quality point of view the more critical time is when currents are into the estuary, because this could lead to wastewater reaching the water intakes. We have checked this and although it can generate longer upstream plume excursions, there is no effect on the water intakes.

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