The use of Virtual Beach empirical model for Mar del Plata beaches as a management tool

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Abstract
The Quality Management Division of Mar del Plata Sanitary Works, OSSE, has been working in an Integrated Coastal Management Strategy for almost 20 years. One of the main objectives of this programme is to preserve the recreational water quality of Mar del Plata beaches. In 2007 OSSE's Waters laboratory, had worked in collaboration with "Virtual Beach Empirical Model software" authors from the U.S. EPA in developing site-specific predictive models for Mar del Plata beaches using a data base of ten years. In summer 2009, OSSE decided on using the validated regression models to predict bacterial levels in order to decide when chlorination of wastewater becomes necessary to assure beach water quality as a mitigation action. To implement this methodology, it was established that the effluent chlorination resulting by adding liquid sodium hypochlorite (NaOCl) was effective in achieve bacterial abatement in the pretreated effluent. Additionally, the real-time surficial currents and the real-time decay rates (T90 times) studies, were necessary for the implementation of effective chlorination. The calculated *enterococci* geometric mean from empirical values showed a decrease compared to historical levels, achieving the local compliance criteria for Buenos Aires province for the most popular beaches, so Virtual Beach site-specific predictive models have been a successful management tool for the last three summers.

Keywords
Wastewater discharge, recreational water quality, bacterial levels, submarine outfall, Virtual Beach, chlorination

INTRODUCTION

The city of Mar del Plata located on the coast of the Atlantic Ocean (38º S, 57º W) is the principal seaside resort of Argentina, which receives the main tourist influx of the country during the summer months, December to March. The beaches, about 39 Km length, are used extensively by the local (more than 500.000 inhabitants), and tourist population for recreational activities. The wastewater of the city, at the present time, is filtrate through milli-screens with apertures of 0.5 mm and then is discharged at a point directly on the shoreline in a cliff zone of the coast. The submarine outfall for the city is currently under construction. The recreational sectors begin 2.5 km south of the discharge and the most popular beaches, situated near the centre of the city, are about 8-10 km south of the discharge.

The Quality Management Division of Mar del Plata Sanitary Works, OSSE, has been working in an Integrated Coastal Management Strategy for almost 20 years[1]. In 2007 The Waters laboratory of Quality Management Division, worked in collaboration with "Virtual Beach Empirical Model software"[2] authors from U.S. EPA Office of Research and Development in developing site-specific predictive models for Mar del Plata beaches using multiple linear regression techniques and a data base of ten years. The obtained regression equations were validated during the summer of 2008[3]. Since the summers of 2009, the Water laboratory used the validated regression models as a management tool, to predict (through forecasted variables) bacterial levels in order to decide when chlorination of wastewater becomes necessary to assure beach water quality and to estimate the efficiency of disinfection by comparing prediction, from real time (nowcasted) variables, versus measurements. This paper presents the successful use of Virtual Beach site-specific predictive models as a management tool for the last summers.

OBJECTIVES

The objective of this work is implement a programme of chlorination of pretreatment effluent based on the use of predictive tool called "Virtual Beach predictive model for Mar del Plata city" and evaluate the effectiveness of effluent chlorination resulting from the use of the "Virtual Beach predictive model" during the summer of 2010.

METHODS

Prediction

Calibrated and validated equations for Violeta and Bristol Beaches[3] situated at 2.3 and 8.9 Km from pretreatment plant were used to determine the need for chlorination. The equations that comprise the Virtual Beach predictive models for Mar del Plata city are presented in Table1. Bacterial levels were forecasted daily based on nowcased and forecasted explanatory variables obtained from various sources[4], and needed by the Virtual Beach predictive models.

Table 1: Regression equations obtained with 10 years data base

Model 1	VIOLETA BEACH REGRESSION EQUATION (DATA BASE 1996-2008) WIND DIRECTION >= 0 AND <=180º E[Log(FECAL COL)]= 11.716 - 0.1994 * WATER TEMP. + 0.1212 * WIND SPEED + 0.276 * DEWPOINT TEMP(At sample time) - 11.564 * TIME + 0.1358 * WCmpLg1_101	R^2= 72.5 %
	BRISTOL BEACH REGRESSION EQUATION (DATA BASE 1996-2008) WIND DIRECTION >= 0 AND <=180º E[Log(FECAL COL)]= 2.5244 + 0.03423 * WIND DIRECT + 0.1559 * WIND SPEED + 0.2415 * AIR TEMP(At sample time) - 10.392 * TIME + 0.206 * WCmpLg1_101 + 0.1565 * WCmpOn2_101	R^2= 64.9 %
Model 2	VIOLETA BEACH REGRESSION EQUATION (DATA BASE 1996-2008) WIND DIRECTION > 0 AND <180º WIND SPEED >= 10 km/h E[Log(FECAL COL)]= 3.5495 + 0.2476 * DEWPOINT TEMP(At sample time) + 0.1539 * WCmpLg1_101 - 0.0754 * WCmpOn2_101	R2 =84.5%
	BRISTOL BEACH REGRESSION EQUATION (DATA BASE 1996-2008) WIND DIRECTION >0 AND <180º WIND SPEED >= 10 km/h E[Log(FECAL COL)]= 8.9245 + 0.2188 * WATER TEMP. - 14.196 * TIME + 0.1447 * WCmpLg1_101	R2 =75.6%

Chlorination

Liquid sodium hypochlorite effective dose, was defined after several empirical tests where oxide reduction potential (ORP) and *faecal coliforms* and *enterococci* concentrations (NMP/100 ml of bacteria) were measured in raw and chlorinated effluent.[5 6 7] Finally, the chlorination was conducted at the pretreatment plant, by adding liquid sodium hypochlorite solution (conc.100gl$^{-1)}$ to pretreatment effluent in the entry to the contact tank remaining approximately 15 min. The Mitigation effective concentration was 7 - 9 ppm of sodium hypochlorite in the pretreated effluent and the addition frequency was on request, depending on the prediction with Virtual Beach model for Mar del Plata.

Mitigation in beaches

To define the dose, it was necessary to consider previous studies of surface currents[8] and bacterial T90 decay time,[9] in the presence and absence of UV radiation, to achieve effective chlorination objectives in beaches, Operational considerations require that, he effective dose of liquid hypochlorite should be added during 10 hours, based on T90, in the presence and absence of UV radiation, as specified by the study of Mar del Plata effluent[9] and the liquid hypochlorite should be added between 2 am to 2 pm considering Mar del Plata surface currents study, to calculate the time that disinfected effluent takes to reach most populated beaches[8]

Sampling and analysis

A total of 56 samples collection campaigns were carried out during summers 2009 and 2010, 26 of the total campaigns were done during the first summer and 30 during last one.

Analysis

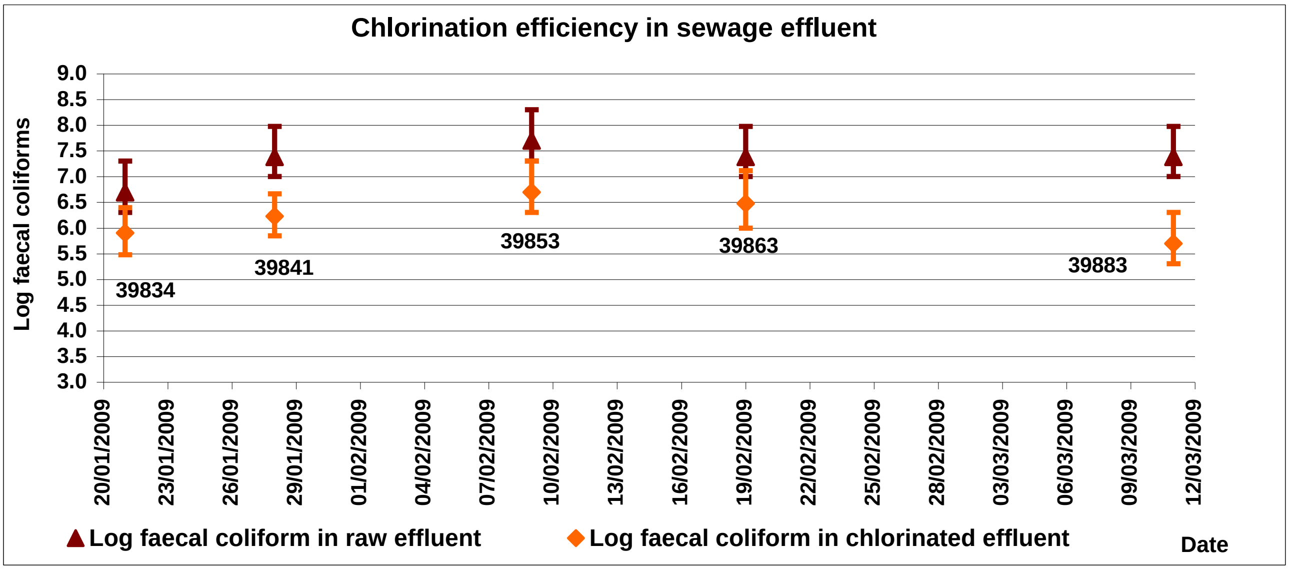
All samples were collected at 1 pm ± 1 hour, walking from the shore to a depth of 1 m and submerging and closing the sample collector approximately 30 cm below the surface. The volume of sample collected was always 1 liter. The analytical technique was Standard Methods of Water and Wastewater, technique: Part 9000: Microbiological Examination. Section 9221 Multiple tube fermentation technique for members of the *Coliform* group and Section 9230 (A y B) f*aecal streptococci* and e*nterococci* groups[10]. All the procedure was checked [11]with ATCC: American Type Culture Collection- Rockville, USA, bacteria. The organoclhoride compounds analyses in two samples of raw and chlorinated effluent were performed by gas chromatography using methods described in EPA SW 846 methods. The analytical methodology was chosen considering that the limits of quantification were below the regulated limits. For the statistical processing of data U.S EPA Virtual Beach Empirical Model software and SPSS statistical software were used.

RESULTS

Chlorination efficiency

The comparison of *faecal coliform,* measured during summer 2009, in raw and chlorinated effluent (about 8ppm) is presented in Figure 1

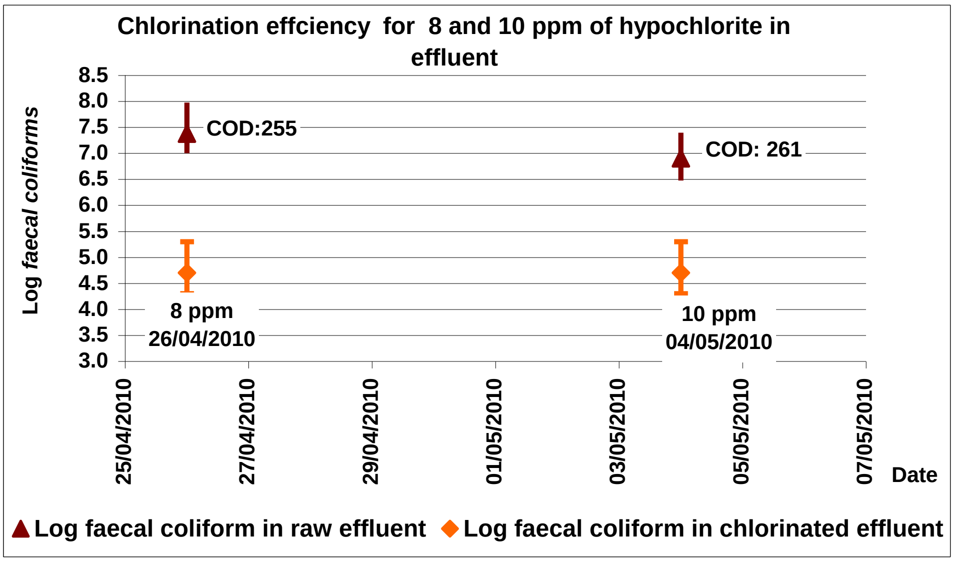
Figure 1: Chlorination efficiency in wastewater raw effluent, summer 2009



As is clear from the figure, *faecal coliform* levels measured in chlorinated sewage effluent were at least one order of magnitude smaller than the values observed in raw effluent. This difference would be equivalent to replacing a city of 500,000 inhabitants with another of 50,000 inhabitants. The results of Student t test for statistical comparison of log *faecal coliform* means in raw and chlorinated effluent, respectively, performed with SPSS Statistical software, showed that both means were statistically different. The addition of hypochlorite was also evidenced in an increase of oxide reduction potential (ORP) measured in the chlorinated effluent with respect to raw effluent.

During summer 2010 it was observed, that the efficiency of disinfection increased when chemical oxygen demand (COD) values in raw wastewater effluent were low (see Figure 3). On the other hand, for high COD values, disinfection efficiency decreases considerably. This aspect was considered in the Integrated Coastal Management Strategy where OSSE Monitoring and Control at the Source (industrial effluent) Program, were improved. Specifically, Municipal Ordinance No.19062, established an increase in the cost of cubic meter (m^3) drained to the sewage collecting system, for industrial effluents with excess in the Chemical Oxygen Demand (COD).[12 13 14]

Figure 3: Chlorination efficiency in wastewater raw effluent, summer 2010



Mitigation in beaches

The results of implementing effluent chlorination based on the use of "Virtual Beach predictive model" for summer 2010 are summarized in a 25 days of chlorination from 10 December to 10 March. January is the principal month of summer. Figure 4 (in page 7) illustrates implementation of this methodology showing predictions (nowcasts) (blue squares) vs. summer 2010 *faecal coliform*s measurements after chlorination, with their uncertainty (vertical line segment), for Violeta beach, the closest to the wastewater discharge, for days of winds from quadrant 0º to 180º (with east wind components) considered critical to make the decision of chlorinating the effluent because wind is one of the main variables in regression model and west winds (between 180 to 360º) do not produce incidences of bacterial levels at beaches, because the plume moves away from the coast[8]. The hours of chlorination and doses achieved are also shown in this figure (yellow squares).

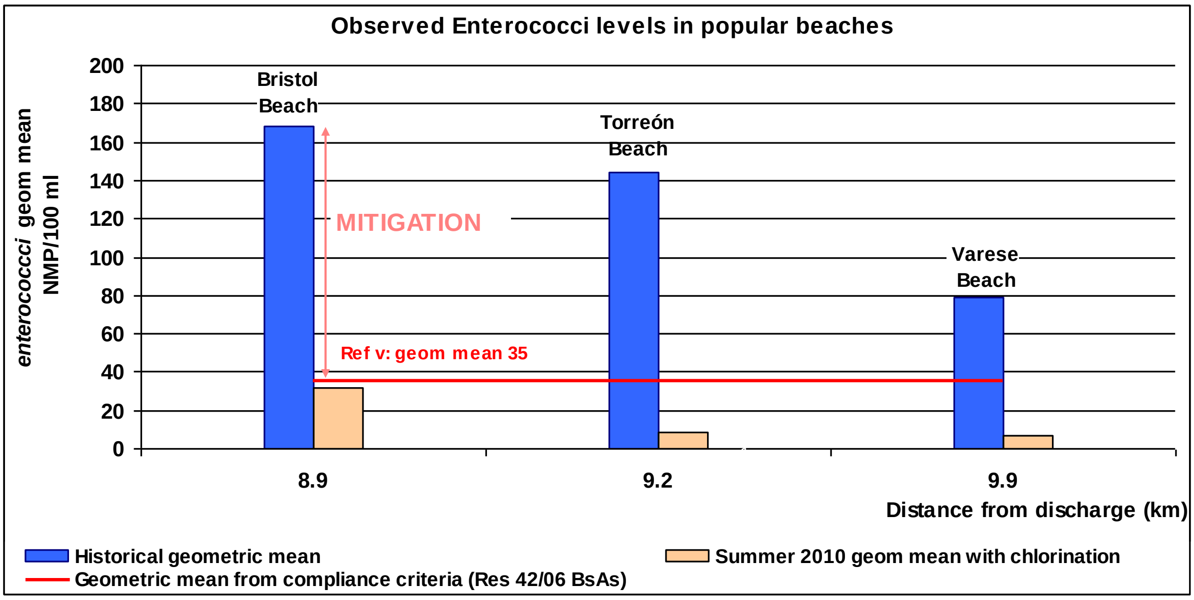
It should be noted that recreational water quality compliance criteria for Buenos Aires province [15] refers to a statistical value (geometric mean of *enterococci*), however the implementation of chlorination associated with Virtual Beach predictions were based on daily bacterial predictions, so, in figure 4, the EPA's recommended water quality criteria for a designated bathing beach for single sample (horizontal red line: *E. coli* EPA's maximum 235 col/100ml[16] and horizontal violet line: *E. coli* EPA's infrequent use, maximum 575 col/100ml[17 18]) and Brazil's water quality criteria from Conama nº 274/00 Resolution, for improper ("impropia") category (horizontal green line maximum 2500 per 100 ml *thermotolerant coliforms* (*faecal coliforms*) in the last measurement.[19]) thresholds values were considered as references. Although EPA's threshold concentration standards are for *E coli*, both have been adopted as reference values for *faecal coliforms* in the present work.

The effectiveness of chlorination can be deduced from Figure 4 as the vertical difference between observed (chlorinated effluent) vs. predicted values (unchlorinated effluent).

Geometric mean of enterococci vs. reference compliance criteria: Buenos Aires Province Resolution Nº 42/06 Water authority (Autoridad del Agua, ADA)

The comparison between calculated *enterococci* geometric means from summer 2010 empirical values and historical geometric means (from 1995 to 2007 measurement)[3] vs. local compliance criteria (red line) for Buenos Aires province (35 NMP/100ml of *enterococci* stated as geometric mean)[15] are presented in Figure 5

Figure 5: Geometric mean of *enterococci* vs. compliance criteria



From Figure 5 it can be seen that the calculated summer 2010 geometric means of measured values were lower than the historical geometric mean at all beaches; consequently, the city wastewater discharge incidence did not affect provincial compliance criteria for the most populated beaches. The *enterococci* levels north of the discharge are always the lowest due to predominance of winds from the north east (0-90º), that move the sewage plume southward and onshore, during summers[8].

Evaluation of organochlorine compounds present as side effects of wastewater effluent chlorination

For the purposes of assessing possible formation of organ chlorine compounds, as by-products of effluent chlorination, analysis were performed in effluent before and after chlorination, at doses of 8 and 10 ppm and different COD values. There weren't detected any compound levels higher than regulated values in any of the samples analyzed.

CONCLUSIONS

- OSSE has implemented mitigation actions with the aim of preserving recreational water quality of Mar del Plata coast until the submarine outfall, actually in construction, is operational.
- Mitigation by chlorination with sodium hypochlorite associated with the use of Virtual Beach predictive tool, in the time slot between 2 am to 2 pm, has proved effective in preserving recreational water quality.
- A dosage of 7-9 ppm liquid sodium hypochlorite was found to decrease bacterial levels in pretreated wastewater effluent at least one order of magnitude.
- The efficiency of disinfection seems to increase when chemical oxygen demand (COD) values in raw wastewater effluent are lower. In response, the management of industrial effluent was enhanced by Integrated Coastal Management Strategy in order to improve the efficiency of disinfection by chlorination.
- Municipal Ordinance that establishes an increase in the cost of cubic meter (m^3) drained to the sewage collecting system for industrial effluents with excess in the Chemical Oxygen Demand (COD) respect Buenos Aires province normative was enacted.[12 13 14]
- The geometric mean values calculated from empirical data were significantly lower than the historical geometric means, achieving the compliance with the criteria reference value for Buenos Aires province of 35 enterococci/100 ml as geometric mean, for most popular beaches situated near the center of the city.
- There were not detected any organochloride compounds at levels higher than regulated values in any of the analyzed samples.

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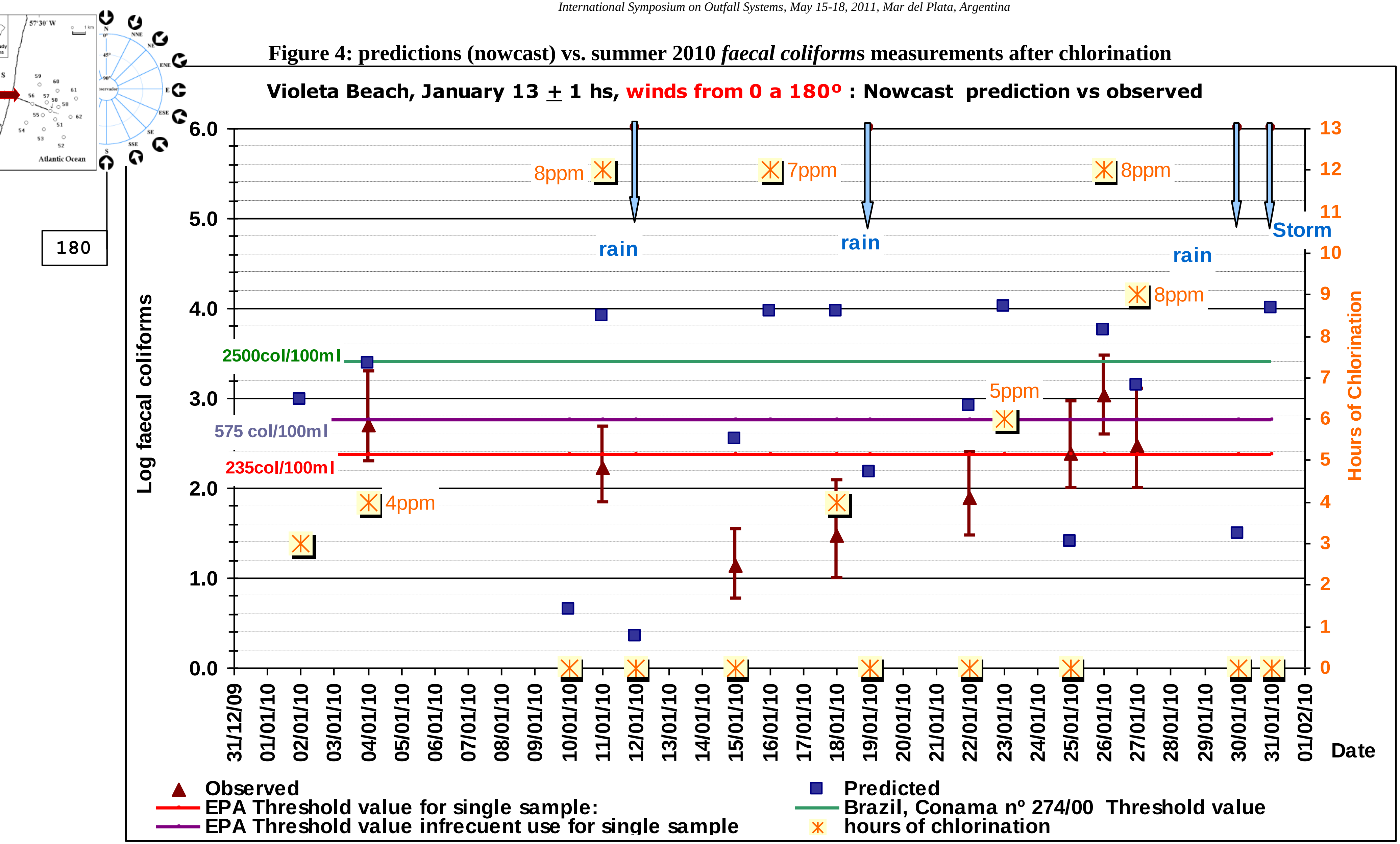
RECOMMENDATIONS

- To continue working by Integrated Coastal Management Strategy.
- To continue working to improve the industrial control at the source to preserve ability of the marine environment cleanses itself.
- To implement a storm discharge water quality preservation strategy.
- To recalibrate Virtual Beach model equations including new explicative variables such as doses and hours of chlorination, effluent COD values in order to improve and update the model in response to the new methodology.

Figure 4: predictions (nowcast) vs. summer 2010 *faecal coliforms* measurements after chlorination



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