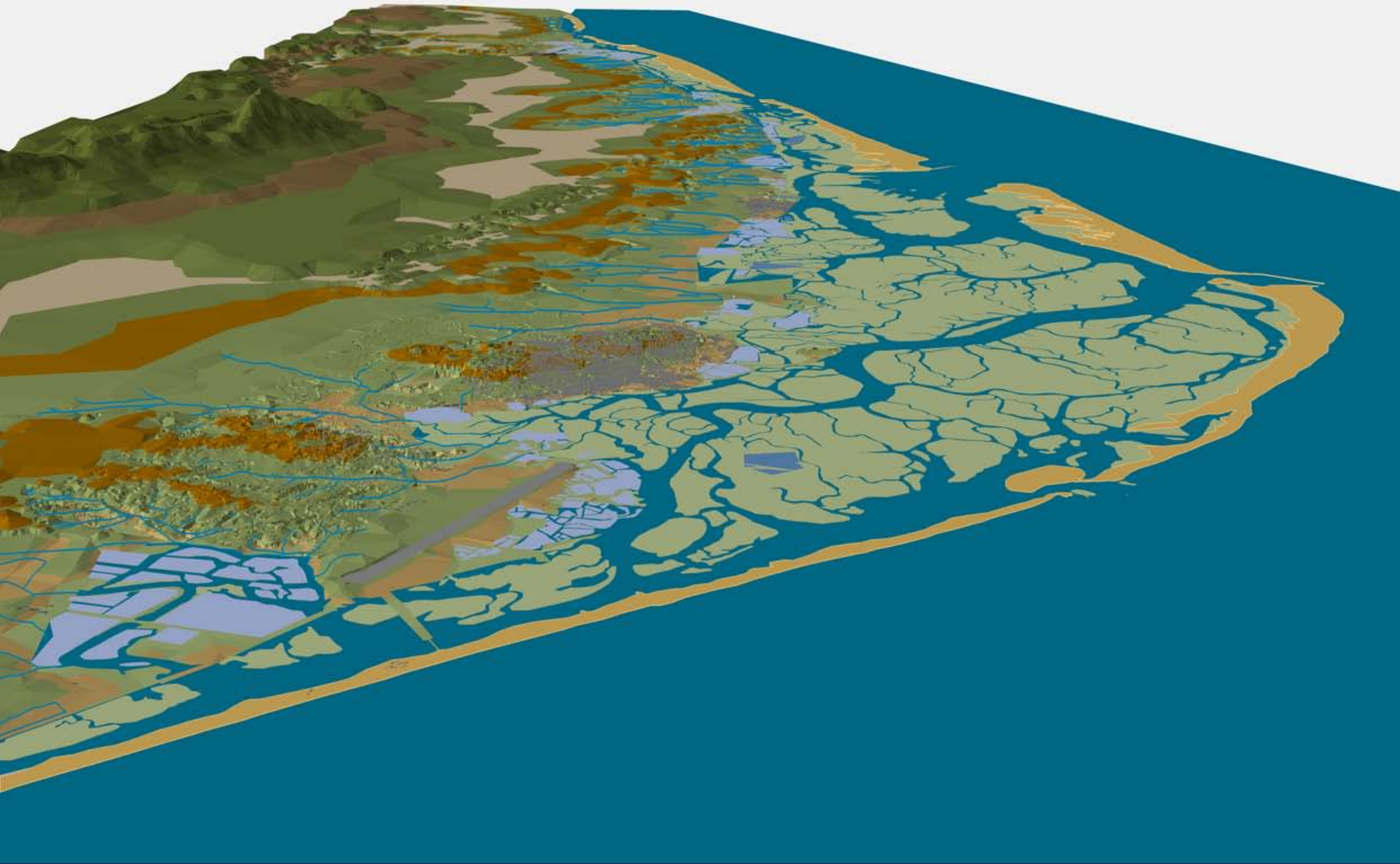

RIA FORMOSA

Challenges of a coastal lagoon in a changing environment

Edited by

Jaime Aníbal, Ana Gomes, Isabel Mendes & Delminda Moura

UAlg CIMA
UNIVERSIDADE DO ALGARVE
CENTRO DE INVESTIGAÇÃO MARINHA E AMBIENTAL

4. The role of Ria Formosa as a waste water receiver

Filipe Veríssimo[1], Flávio Martins[2] & João Janeiro[2]

[1] Águas do Algarve, S.A. | f.verissimo@adp.pt

[2] Centre for Marine and Environmental Research (CIMA), University of Algarve, Campus de Gambelas, 8005-139 Faro | fmartins@ualg.pt; janeiro.jm@gmail.com

Ria Formosa is a system of barrier islands that communicates with the sea through six inlets, situated in the Algarve, the most southern region of Portugal which encompasses the municipalities of Loulé, Faro, Olhão, Tavira and Vila Real de Santo António, covering an area of about 18,400 hectares along a 60 km stretch from the Ancão beach to Manta Rota beach (Figure 4.1). It is an area protected by the status of Natural Park, granted by Law n.º 373/87 of December 9th and its classified as a sensible area according to the law n.º 152/97 of June 19th concerning urban waste water discharges, in order to assure water quality standards for shellfish aquaculture. This ecosystem is very important from the socio-economic point of view, being responsible for 41% of the Portuguese national production of bivalve shellfish, with a small finfish production (IMAR, 2012).

Figure 4.1.
Algarve's Sanitation Multi-Municipal System.

The Ria Formosa is the receiving environment of six Waste Water Treatment Plants (WWTP) (see Box 4.1)

Box 4.1. What are Waste Water Treatment Plants?

WWTP are infrastructures composed by a set of processes, with the main objective to remove the contaminant loads in the waste water. There are different types of biological treatment, the treatment process chosen must be fitted to the required quality of treated waste water disposed in the receiving environment. Also, the size and design of the WWTP depends on the waste water flowrate and contaminant loads. (Davis, 2010). A typical municipal WWTP may include primary treatment to remove solid material, secondary treatment to digest dissolved and suspended organic material as well as the nutrients nitrogen and phosphorus, and – sometimes but not always – disinfection to kill pathogenic bacteria. The sewage sludge that is produced in sewage treatment plants undergoes sludge treatment.

in the region: Quinta do Lago, Faro Noroeste, Faro Nascente, Olhão Poente, Olhão Nascente and Almargem (Figure 4.1). These WWTP are managed by Águas do Algarve that is the concessionaire of the Algarve's Sanitation Multi-Municipal System, managing the infrastructures for interception, treatment and final disposal of waste water collected from the Algarve's sixteen Municipalities. The system has 447.3 kilometres of drainage systems, 175 waste water pumping stations and 66 WWTP.

This chapter details the impact of the faecal coliform plumes from the discharges of treated waste water from three WWTP (Almargem, Faro Noroeste and Faro/Olhão) by the use of mathematical modelling for the simulation of hydrodynamic variables, water quality and bacteriological tracers.

Box 4.2. What is Mathematical modelling?

Modeling is an experimental tool for testing theories and assessing quantitive conjectures. A mathematical model usually describes a system by a set of variables and a set of equations that establish relationships between the variables. The variables represent some properties of the system, for example, measured system outputs often in the form of signals, timing data, counters, etc. Mathematical modeling has many applications in sciences and can be used to simulate tide, weather, Planning of production units, wind channel simulations, car crash simulations, etc.

4.1. Modelling the dispersion of waste water

The mathematical modelling (see Box 4.2) of waste water plumes is a tool that enables the prediction of water quality, enables the adjusting of the discharge point of new WWTP and supports decision making in case of discharges due to malfunctions in the WWTP. The MOHID Water Modelling System (MARETEC, 2018) was used as an integrated modelling tool, capable of simulating physical and biogeochemical processes in coastal systems. MOHID Water is responsible for the modelling of hydrodynamic processes, simulation of dispersion phenomena (lagrangian and eulerian methodologies, see Box 4.3), wave propagation, sediment transport, water quality / biogeochemical processes in the water column and exchanges with the bottom (Neves et al., 2000). The model allows to simulate the main physical mechanisms such as density gradients (baroclinic flows), tide, wind and fresh water inflows (Martins et al., 2001).

The main forces in the Ria Formosa are tidal and freshwater flow. Forcing due to wind is negligible since the fetch distance in this system is small. Calibration and validation of the hydrodynamic component was

Box 4.3. What is the difference between Eulerian and Lagrangian aproach?

Essentially all the relevant models for the simulation of coastal and ocean processes deal with the same basic principle of transport by advection and diffusion of a property in a moving medium (water). There are two different approaches to describe that process: the Lagrangian approach and the Eulerian approach. In the Lagrangian approach the focus is on a specified volume of water, called the system, and its evolution is followed through space and time. In the Eulerian approach the focus is on a specified portion of space, the control volume, and the evolution of the properties associated to the water inside the control volume is monitored while fluxes of water are allowed to flow in and out from it (Zhao et al., 2011).

performed by comparing the results of the model, in the form of time series, with measurements made during continuous field campaigns.
The calculation of water quality properties evolution is done using a specific module: the Water Quality module. This module is responsible for calculating the terms related to the sources and sinks, specific for each fundamental property, in each of the cells of the mesh and at each instant (Martins et al., 2003).
Simulation of the WWTP plumes was done using a Lagrangian type transport model. In this model the discharge water mass is associated with individual water masses that are released at short intervals from a fixed location in space and are carried by the model. These masses of water (particles) thus undergo advective transport by the field of velocities and diffusive transport due to the volume variation of the particle. Additionally, a random variation in the trajectory is included to account for large size turbulence (Allen, 1982). The microbiological properties of the discharge varies due to both dilution and mortality. The mortality law for faecal coliforms used considers the effects of radiation, temperature, and salinity.

4.2. Almargem WWTP

The Almargem WWTP is located on the left bank of the Almargem stream in Tavira. The treated effluent is discharged into the Almargem water stream, in the vicinity of Ria Formosa. This installation was designed to serve an equivalent population of 48,200 equivalent inhabitants during summer time, 12,200 m^3/day in the year of 2025. The treatment system implemented is of secondary level by activated sludge, and UV disinfection. The Almargem WWTP began its service in May 2007 and due to its construction the served area was increased, leading to the decommissioning of the Tavira and 5 other smaller low technology WWTP. The discharge limits for the treated effluent issued by the Environmental Portuguese Agency (APA) are 25 mg/L O_2 of BOD, 125 mg/L O_2 of COD, 35 mg/L of TSS and 2000 CFU/100mL of faecal coliforms (see Box 4.4).

Box 4.4. Did you know that…

Coliform bacteria generally originate in the intestines of warm-blooded animals. Faecal coliforms are capable of growth in the presence of bile salts or similar surface agents, are oxidase negative, and produce acid and gas from lactose. Large quantities of fecal coliform bacteria in water indicate a higher risk of pathogens being present in the water. Some waterborne pathogenic diseases that may coincide with fecal coliform contamination include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. Untreated organic matter that contains fecal coliform can be harmful to the environment. Aerobic decomposition of this material can reduce dissolved oxygen levels if discharged into rivers or waterways. This may reduce the oxygen level enough to kill fish and other aquatic life.
Most Probable Number (MPN) a method used to estimate the concentration of viable microorganisms in a sample by means of replicate liquid broth growth in ten-fold dilutions. It is commonly used in estimating microbial populations in soils, waters, agricultural products.

4.2.1. System hydrodynamics

Ria Formosa hydrodynamics can be subdivided into two independent regions: The Western Region, spanning from the beginning of the Ancão Peninsula to the Marim Channel and the Eastern Region that stretches from the Marim channel to the end of the Cacela Peninsula, covering the Almargem riverbank. The Eastern region is characterized by less extensive wetland zones and a single main channel, responsible for transport, in the direction parallel to the barrier islands. From the hydrodynamic point of view this means that the residence time is inferior to the one of the Western region. The hydrodynamics of the two regions are virtually independent since they are only connected by the *Marim* channel which has a reduced transport capacity.

Velocities are higher in the Spring Tide in the periods of flood and ebb tide, with maximum velocities of the order of 0.5m/s while in Neap Tide in the periods of flood and ebb tide the maximum velocities are of the order of 0.3 m/s. The maximum speeds occur mainly in the deepest channels such as the Barra de Tavira and the Cabanas Channel. The velocities in the Gilão River are smaller during the ebb tide than in the flood tide in both Spring and Neap tide (Figure 4.2).

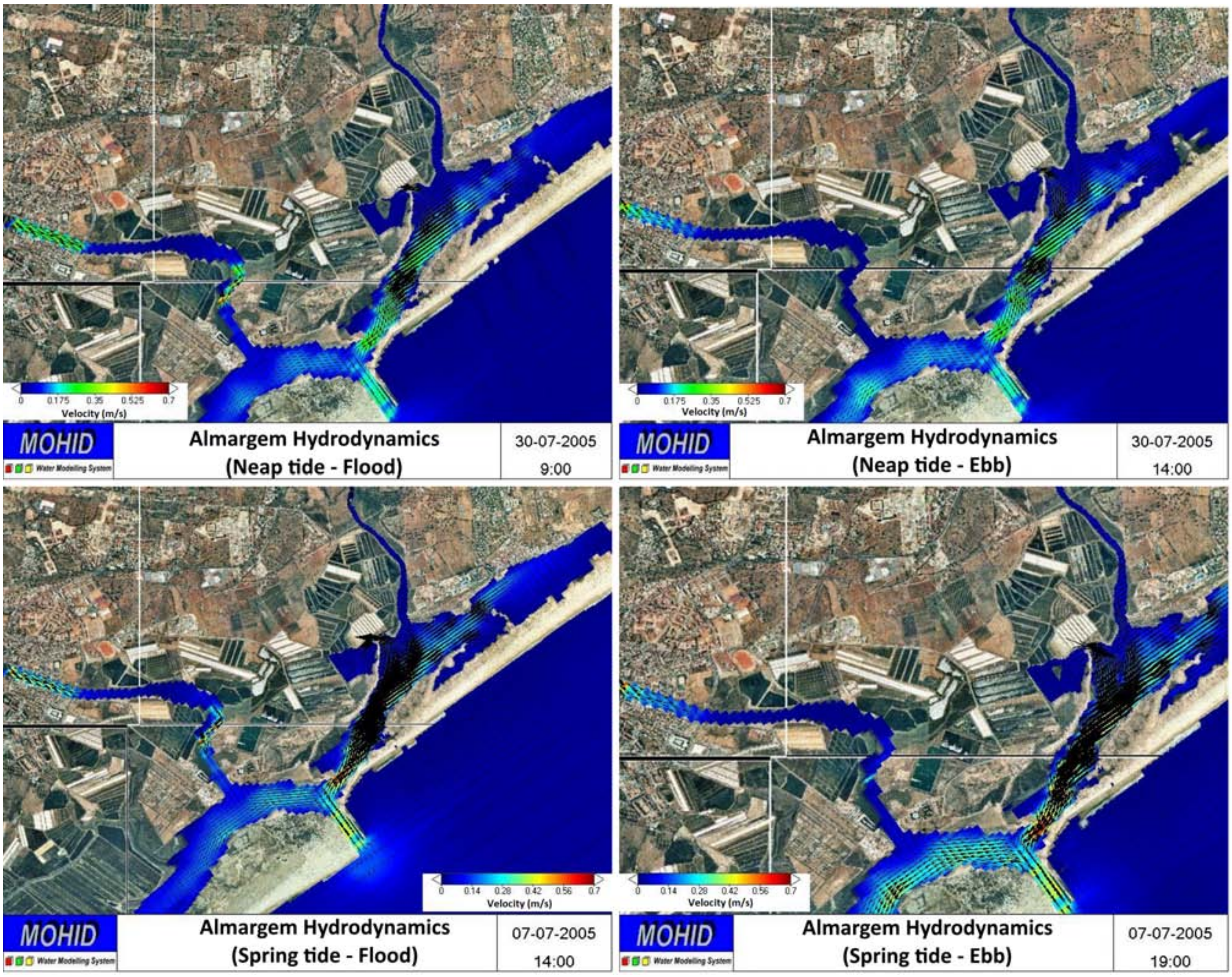

Figure 4.2.
Hydrodynamics model results for Spring and Neap tide in the Almargem system

The Almargem water stream presents low velocities in the flood and ebb tide in both Spring and Neap Tide.

4.2.2. Waste water plumes

The simulation of faecal coliform plumes associated with the discharge of the Tavira WWTP were performed by forcing the Lagrangian transport model with the previously calibrated velocity fields. For this a continuous discharge was considered with a 10,000 MPN/100 ml concentration of faecal coliforms and a variable T_{90} in time as a function of temperature, solar radiation and salinity. Figure 4.3 shows the results obtained for the simulation of the discharge plume of the Tavira WWTP. The same figure also shows the discharge of Almargem WWTP, with a discharge of 2000 MPN/100 ml, used in the study of different scenarios before the construction.

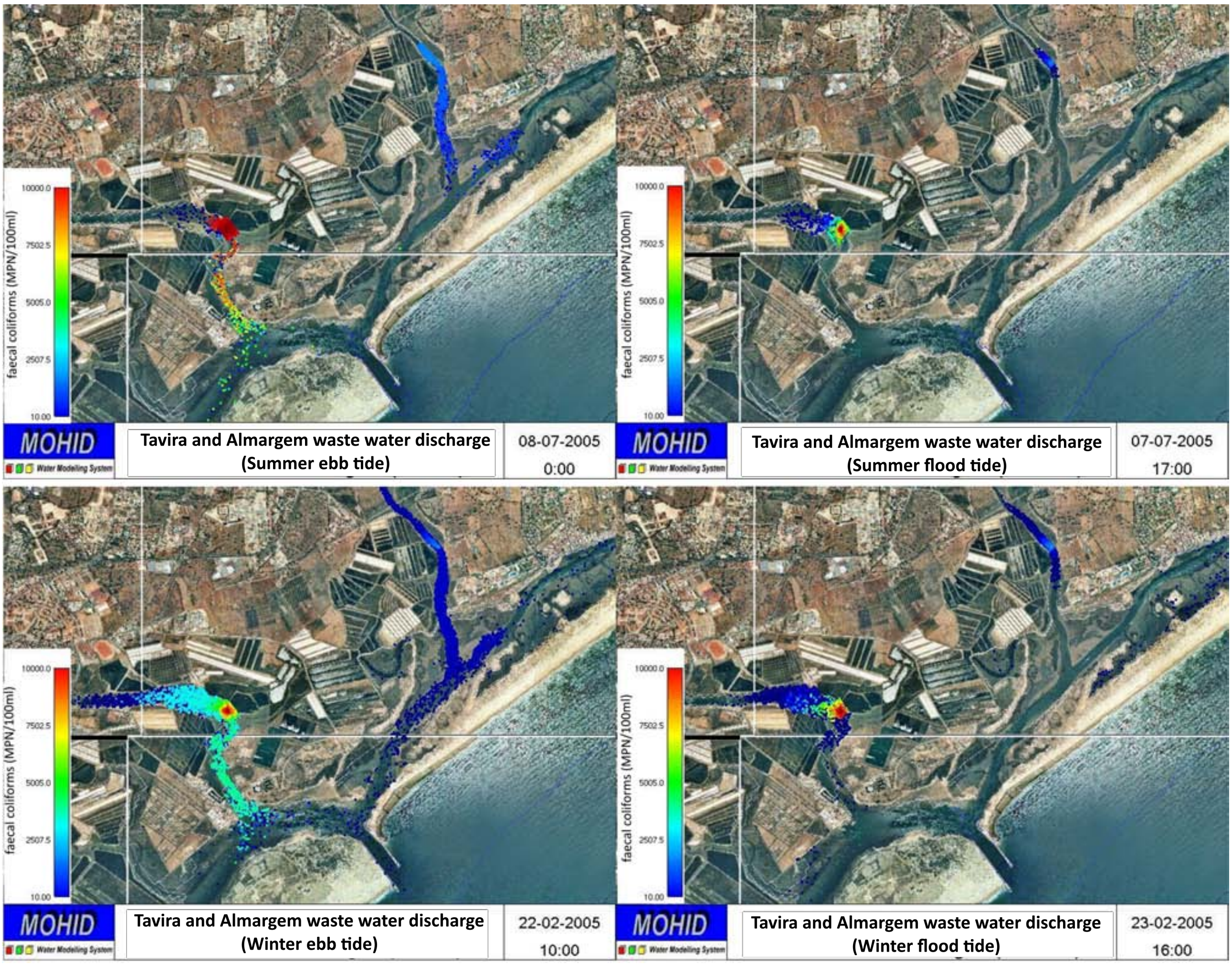

Figure 4.3.
Waste water plume dispersion associated to the discharges of Tavira and Almargem WWTP for different season and tide conditions.

The concentrations in the plume along the estuary depend mainly on the tide situation and the season and time of day due to the solar radiation factor. In an ebb tide situation, the transport of the plumes are carried out downstream of the discharge, following the deeper channel, where the dispersion produces lower concentrations due to the dilution effect. In flood tide conditions, the plumes are transported upstream of the discharge. Concentrations of faecal coliforms in winter are higher than in summer due to lower solar radiation, inducing a decrease in faecal coliform mortality.

For the Almargem WWTP, three different scenarios of a continuous discharge with a concentration of 2,000 NMP/100 ml of faecal coliforms were simulated and a T_{90} to be varied in time as a function of temperature, solar radiation and salinity at different locations in the domain in study. In scenario I the discharge is carried out in the middle of the Almargem channel, in scenario II the discharge is carried out in the downstream region of the Almargem channel and in scenario III the discharge is carried out in the Cabanas channel. The objective was to simulate various locations for the actual discharge of the Almargem WWTP, to try to minimize its negative effects on the surrounding environment. Figure 4.4 show the expected results for each scenario in one of the various tide situations considered.

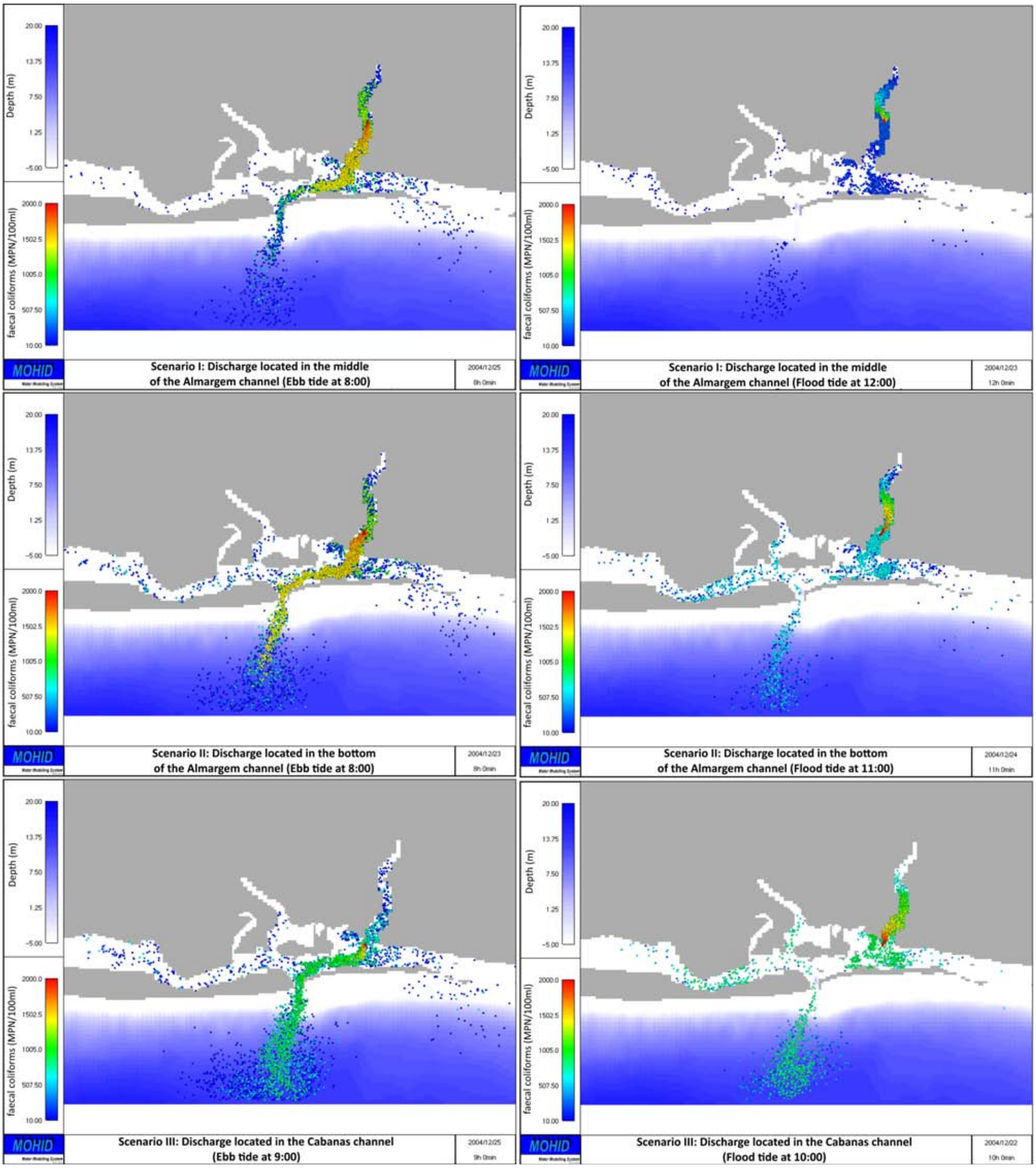

Figure 4.4.
Expected results for three different discharge locations of the Almargem WWTP.

In the region associated to the Almargem, Rio Gilão and Cabanas channels, the microbiological campaigns showed that the situation in the Gilão River is significantly different from that found in the rest of the domain. Microbiological concentrations in the Gilão River are close to or even above the limit value for bathing waters. For the remaining domain the values are always below the limit value. These results show that the discharges of the Tavira WWTP cause some impact on the Gilão River, but that dilution and inactivation are sufficient to prevent this impact from reaching the bathing areas. On the other side, it also shows that the situation in the Almargem channel, even without any point discharge in its interior, already presents concentrations similar to those of the Cabanas channel. This may be due to upstream discharges from the stream. The mathematical modelling results confirmed these observations, the concentrations of the plumes discharged by Tavira WWTP are higher in the interior of the Gilão River, having a strong dispersion in the region between the *quatro Águas* dock and the *Barra de Tavira*. The concentrations that spread to the beaches outside the sandbanks are therefore low. In the model results the effects of solar radiation on inactivation can be observed, producing plumes with higher microbiological concentration at night. Even in this case the impact on bathing waters is reduced. In the three different scenarios simulated it was verified that the upstream discharges produce a greater contamination within the Almargem channel but the concentrations in the Cabanas channel and especially in the outer coastal region are low. With the discharges located in the Cabanas Channel the concentration in the Almargem River is substantially lower, but the concentrations in the interior of the Ria Formosa extend to a much higher area and there is also some impact on the outer coastal region.

4.3. Faro Noroeste WWTP

The Intermunicipal WWTP of Faro Noroeste went into operation in August 2009, and the old lagoon system was abandoned. The new WWTP was built based on the treatment needs of the project horizon, which represents a 400% increase over the nominal capacity of the old plant and the new quality objectives defined for the final effluent of the WWTP. The new WWTP has a treatment capacity of 44,530 habitants, in summer season, 13,221 m^3/day in the year of 2033.

Figure 4.5.
Faro Noroeste WWTP. 1 - Preliminary treatment/Sludge dewatering building; 2 - Biological reactors (Oxidation ditch) 1 & 2; 3 - Secondary clarifiers 1 & 2; 4: UV Desinfection. Credits: Águas do Algarve, S.A.

The treatment scheme is developed along two lines, based on a biological treatment system by activated sludge, in a prolonged aeration regime, in two biological reactors with the oxidation ditch configuration and with surface aerators. The final effluent of the Faro Noroeste WWTP is the *Esteiro do Ramalhete*, in Ria

Formosa. The discharge limits for the treated effluent issued by APA are 25 mg/L O_2 of BOD, 125 mg/L O_2 of COD, 35 mg/L of TSS and 300 CFU/100mL of faecal coliforms.

4.3.1. System hydrodynamics

The region of Faro Noroeste is included in the Western Region of Ria Formosa, which stretches from the beginning of the Ancão Peninsula to the Marim Channel. This region is shallow, and hydrodynamics essentially depends on the tide. The tidal prism in this zone (difference between the volume of water in high tide and in the low tide) is higher than the volume of water in low tide. For this reason, the average residence time is small, of the order of one day (Neves et al, 1996; Dias et al, 2009). This explains the good dispersion capacity of this region.

In this system the highest speeds are found in the Ria Formosa bars and Faro main channel. In these places the transport is more efficient, giving short residence times. Globally there is also a generalized velocity difference between Spring and Neap tide conditions, with the flow pattern being the same (Figure 4.6).

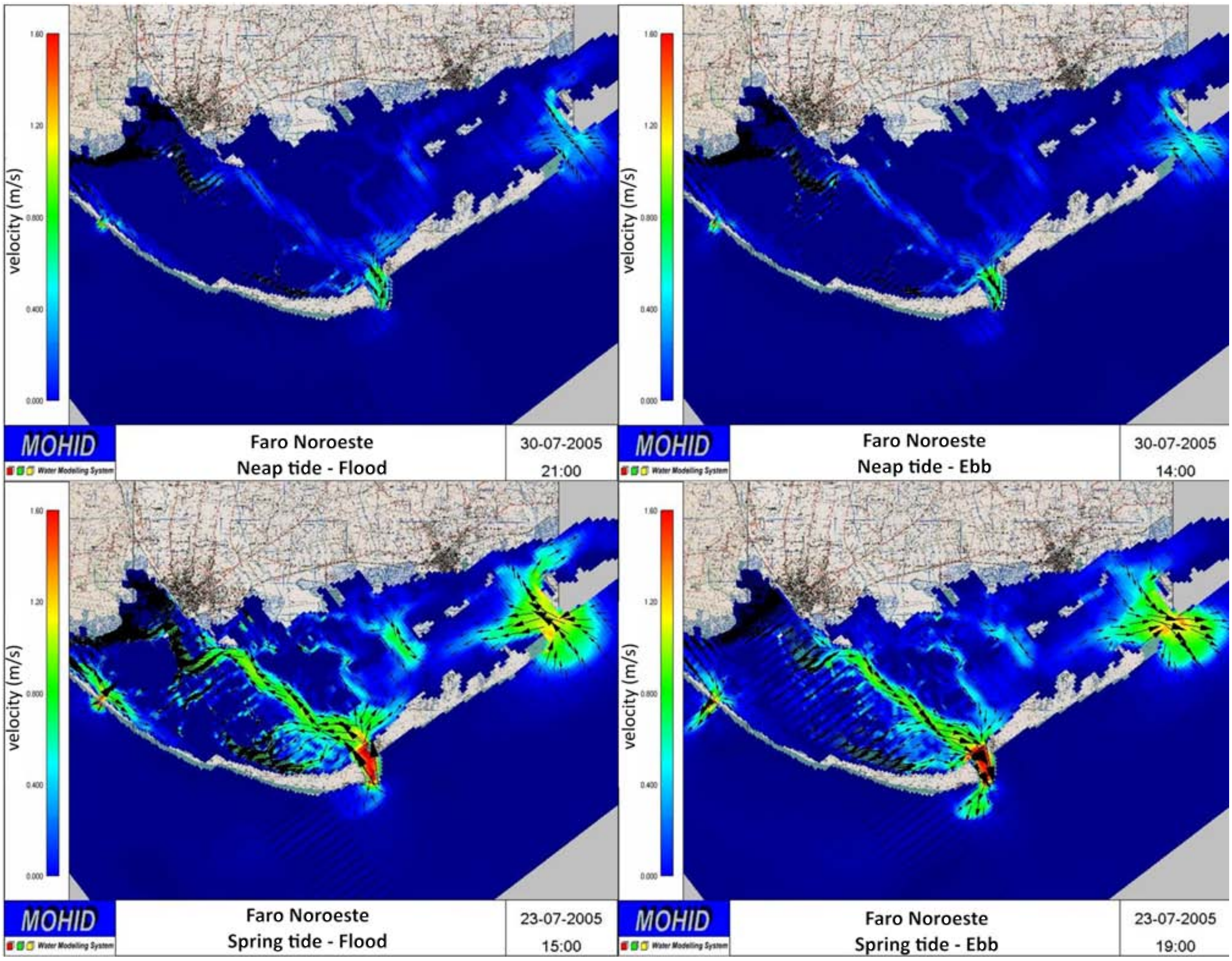

Figure 4.6.
Hydrodynamics model results for Spring and Neap tide in the Faro Noroeste system.

The transient velocity fields show that the highest velocities occur in the Ria Formosa opening, whereas the smaller ones occur in the confined zones of the lagoon. For example, in the Faro bar the speed is higher than 1 m/s, while in the Ramalhete channel the maximum speed is of the order of 0.5 m/s.

4.3.2. Waste water plumes

The simulation of coliform plumes at the Faro Noroeste WWTP was performed for a discharge of 1×10^4 MPN/100 ml of faecal coliforms, which corresponds to average value discharged for the old WWTP. This value corresponds to the limit value imposed by the discharge license. The value was changed to 300 MPN/100 ml in order to meet the minimum quality objectives of shellfish waters.

The dispersion of the faecal coliform plumes for the winter season and different tide conditions is represented in Figure 4.7.

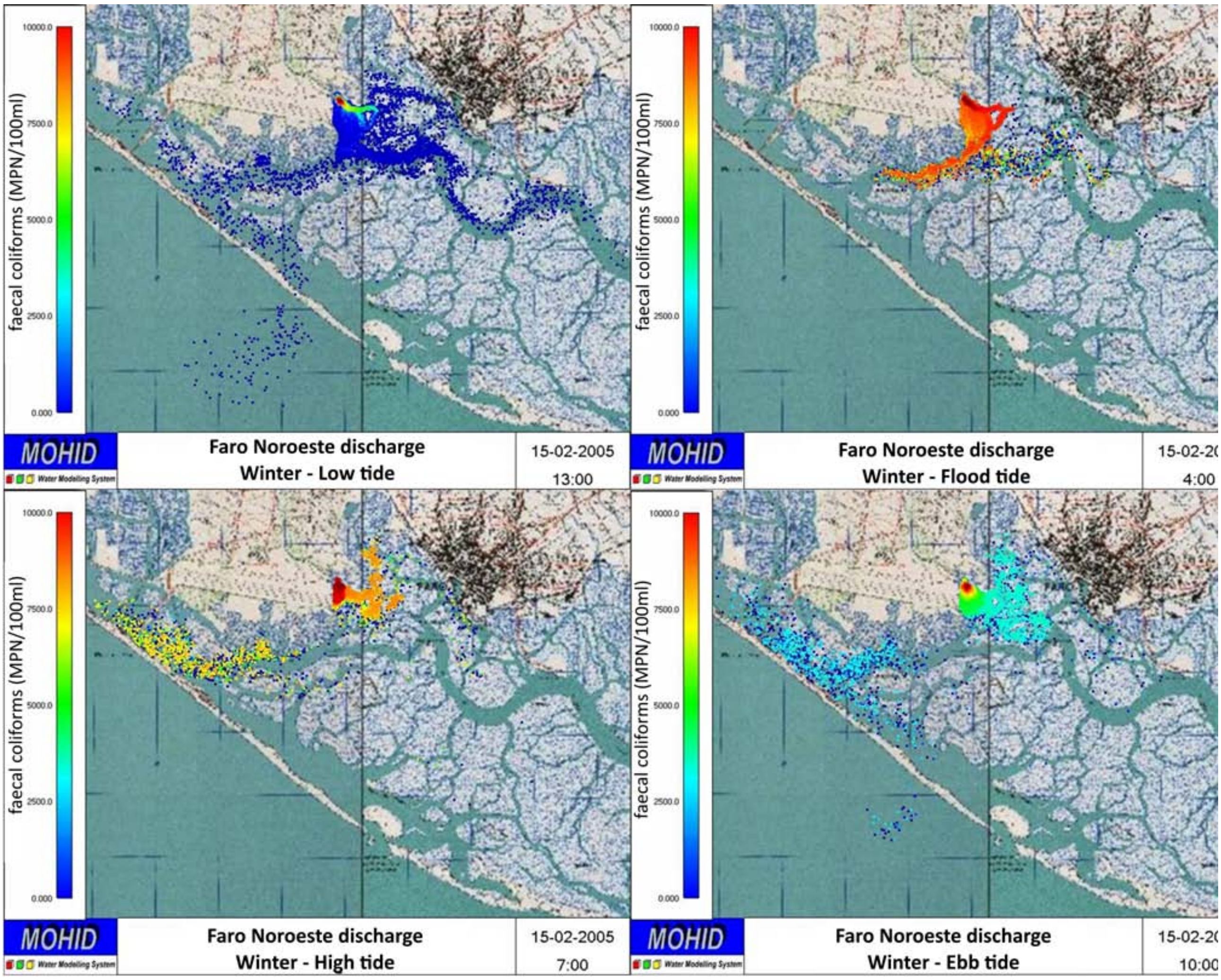

Figure 4.7.
Waste water plume dispersion associated to the discharge of Faro Noroeste WWTP for winter season and different tide conditions.

The dispersion of the faecal coliform plumes for the summer season and different tide conditions, is represented in Figure 4.8.

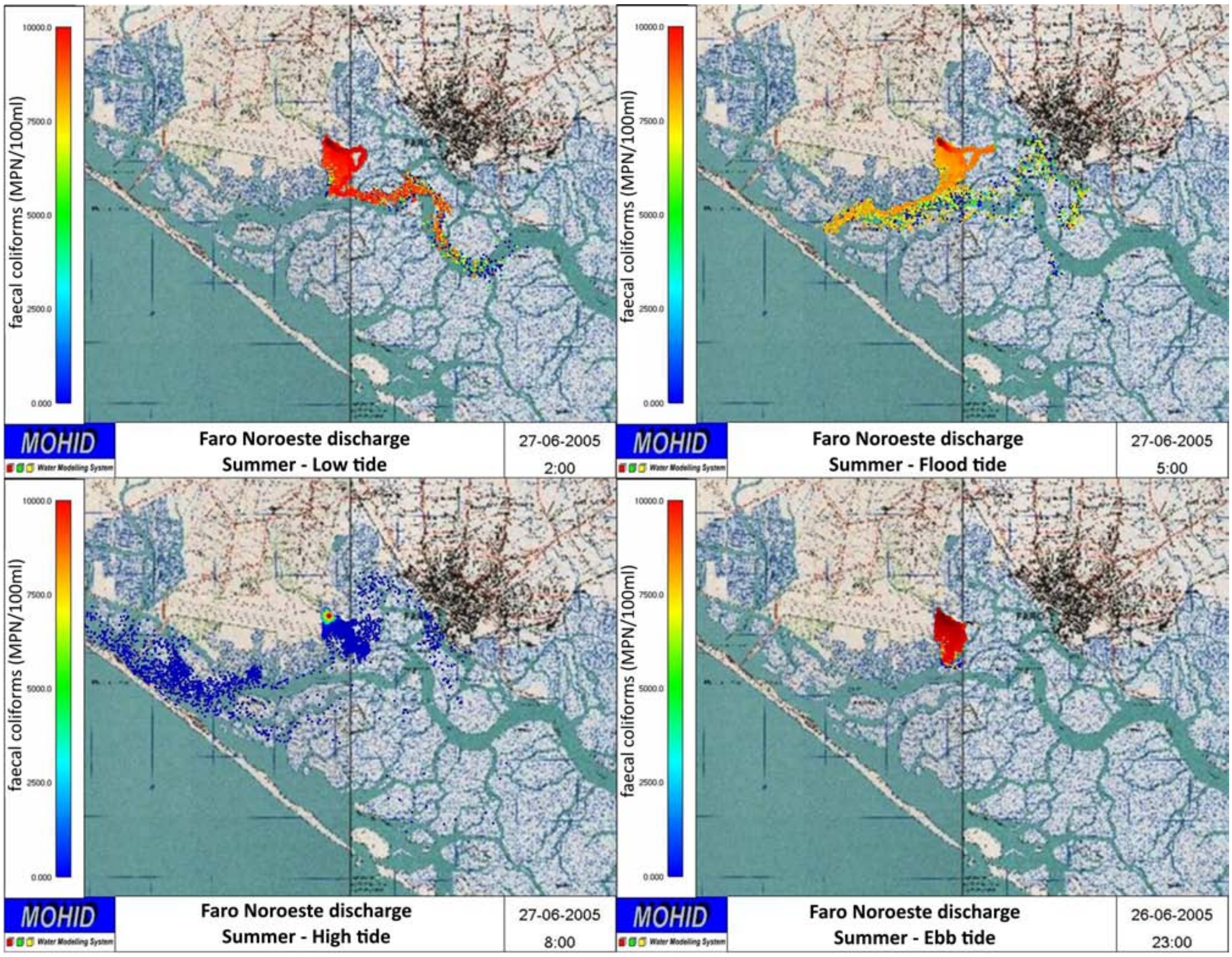

Figure 4.8.
Waste water plume dispersion associated to the discharge of Faro Noroeste WWTP for summer season and different tide conditions.

The faecal coliform plumes are transported during the ebb tide along the Ramalhete channel and the Faro main channel towards the Faro-Olhão bar. During the day the concentration of the faecal coliforms plume in the water column is only significant for a relatively small area. At night, the plume length is larger and more concentrated, extending to a significant part of the Faro channel. This situation is explained by less inactivation during this period.

During flood and high tide the plumes are transported towards the Ancão bar and to the region of Montenegro to the North. Comparing the winter situation with the summer it is worth noting the decrease in the faecal coliform plume in the summer, due to the greater inactivation of these by an increase in solar radiation.

For this WWTP, only one discharge scenario was performed, with a coliform concentration in the order of 1×10^4 MPN/100 ml, 400 m downstream of the current discharge. For this scenario two transport situations of the faecal coliform plumes are presented, one for flood tide and another for ebb tide Figure 4.9.

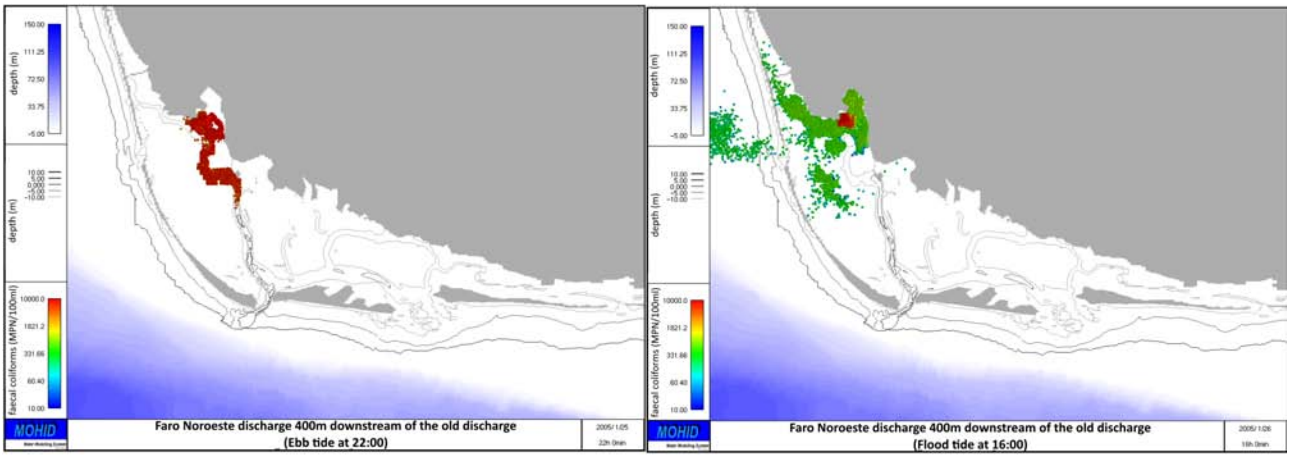

Figure 4.9.
Faecal coliform plumes simulated for a discharge with a concentration of $1{\times}10^4$ MPN/100 ml, 400 m downstream of the old discharge.

For this scenario the contamination situation is not very different from the old discharge situation, since in both scenarios there is a large amount of plume that is confined to the WWTP region. However, under conditions of high solar radiation (during the day) the concentration of the coliform plumes drops significantly due to increased inactivation. In the flood tide, although the concentration is lowered by the action of the dilution, the contamination is transported to a larger area. There is also a higher transport of the coliform plume towards the Ancão, with the discharge at 400 m, compared to the current situation, especially in flood tide.
In the Faro Noroeste region the microbiological field campaigns show that the concentrations are between the maximum recommended and limit values or even below the maximum recommended for all points outside the discharge channel. This shows that the dilution and inactivation in this region is sufficient to ensure good water quality by the bathing criteria. Also, coliform accumulation in molluscan shellfish is function of the distance from the discharge and the number of hours of contact with the discharged plume in each tidal cycle (Martins et al., 2006). In the discharge channel the concentrations are high, which is not surprising because in low-water conditions the collected samples have only effluent, without any dilution. The results of the modelling allow to identify the circulation pattern in this region. It was shown that during the ebb tide drainage is mainly through the Faro channel and during the flood tide the water of the Faro channel flows to the region of Montenegro through Esteiro Largo and to the West region through the Ramalhete. This circulation causes the WWTP plume to have a greater influence in the Faro channel during the ebb, while Ramalhete and esteiro Largo are more influenced during flood tide.

4.4. Faro/Olhão Intermunicipal WWTP

The new Faro/Olhão WWTP was built at the site of the old Faro Nascente WWTP, about 2 km east of Faro, included in the ria Formosa area. It has a treatment capacity of 113,200 habitants, 28,149 m^3/day in the year of 2033. This WWTP treats a large part of the wastewater generated in the city of Faro, treated in the old Faro Nascente WWTP, and the wastewater generated in the city of Olhão, treated at the old Olhão Poente WWTP.
The construction of the new WWTP allowed the deactivation of the existing lagoon systems in both facilities, which are inadequate regarding the quality levels required for the treated effluent to be discharged, and which are also undersized by current (qualitative and quantitative) inflow conditions.

The treatment line of the liquid phase consists of complete pre-treatment, homogenization and flow equalization, intermediate pumping, biological treatment according to the Nereda® process, filtration and disinfection. The sludge line comprises gravimetric thickening, and centrifugal dewatering with storage of dehydrated sludge in storage towers.

4.4.1. System hydrodynamics

The results from the simulations obtained for the hydrodynamics of the system are presented in Figure 4.10. The tide situations presented correspond to the extreme conditions of flow in the study area.

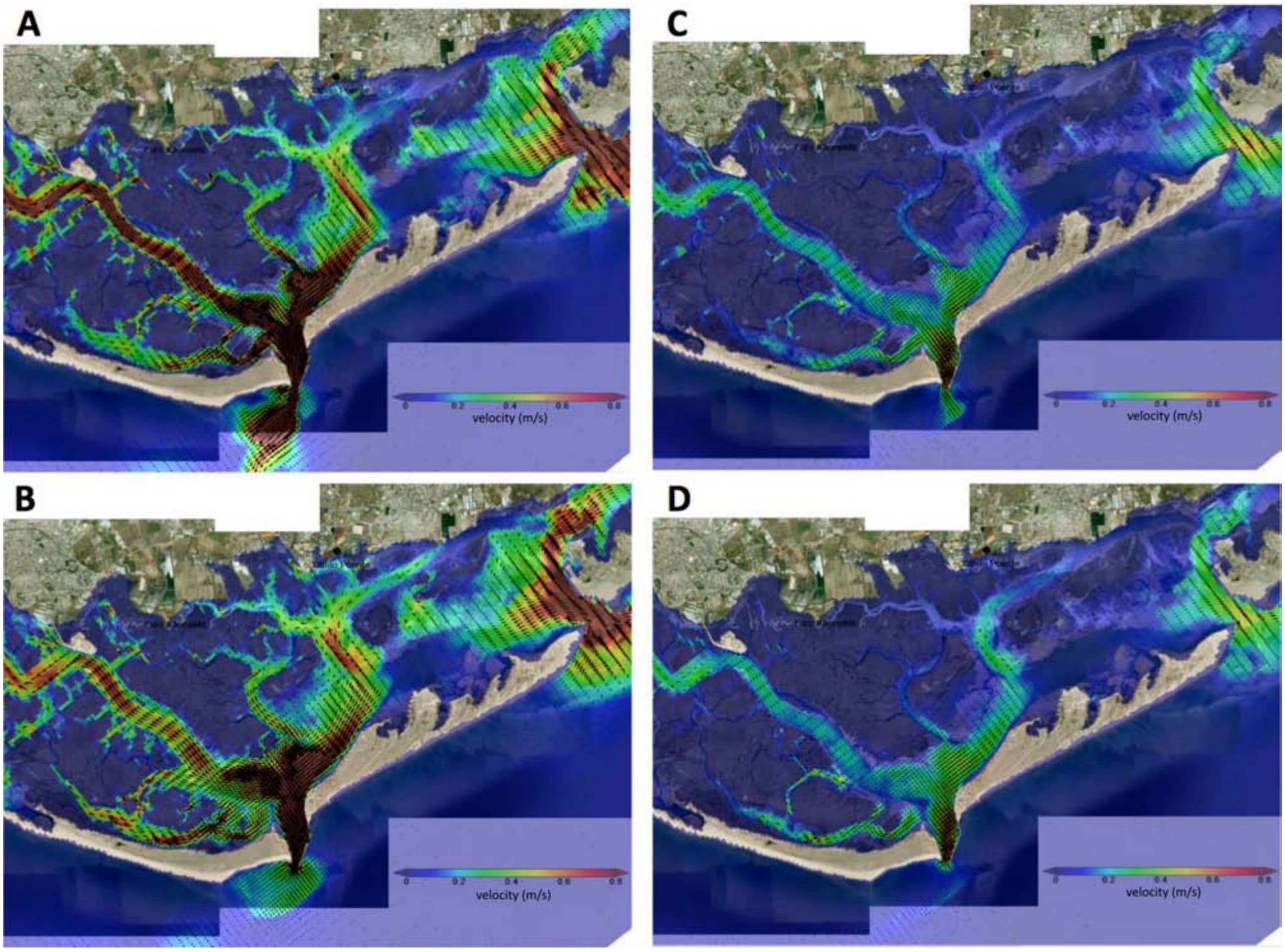

Figure 4.10.
Transient velocity fields for the study area. A – Spring tide, Ebb; B – Spring tide, Flood; C – Neap tide, Ebb; D – Neap tide, Flood.

The highest speeds are found in the bars, Faro channel and the Olhão channel. This situation is similar to the one encountered in the Faro Noroeste results. In these locations the transport is more efficient, giving short residence times. In the channel where the Faro Nascente WWTP discharge is located, the flow in Spring tide presents velocities close to 0.2 m/s both in flood and in ebb. In Neap tide conditions the velocities in the channel are very low, suggesting high residence times in this zone during this tide situation. On the other hand, Olhão Poente WWTP is located in a more hydrodynamically active zone, where speeds between 0.2 and 0.3 m/s are observed in Spring tide and close to 0.1 m/s in Neap tide. Overall, there is a generalized difference in velocities between Spring and Neap tide conditions, as expected, while maintaining the same flow pattern.

4.4.2. Waste water plumes

The simulation of faecal coliform plumes was performed for the various discharge scenarios considering three concentrations of coliforms in the discharge, 1×10^4, 2×10^3 and 300 MPN/100ml for the new Faro/Olhão WWTP. The following results were obtained for Spring and Neap tide scenarios, and for a low tide at night and high tide during the day. These periods are, respectively, where the highest and lowest concentrations in the simulated scenarios were observed due to the hydrodynamic conditions and variation of the inactivation rate of the coliforms with the solar radiation.

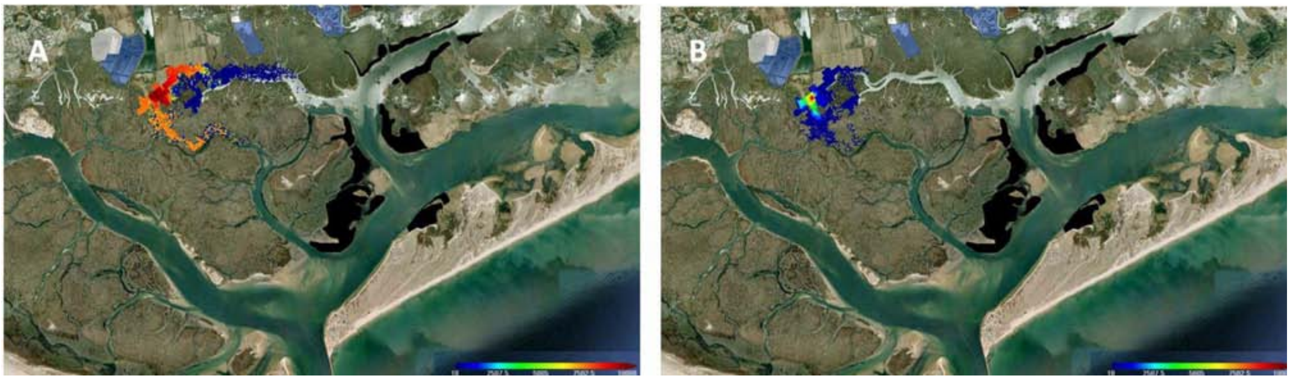

Figure 4.11.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro/Olhão. Concentration of the discharge equal to 1×10^4 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

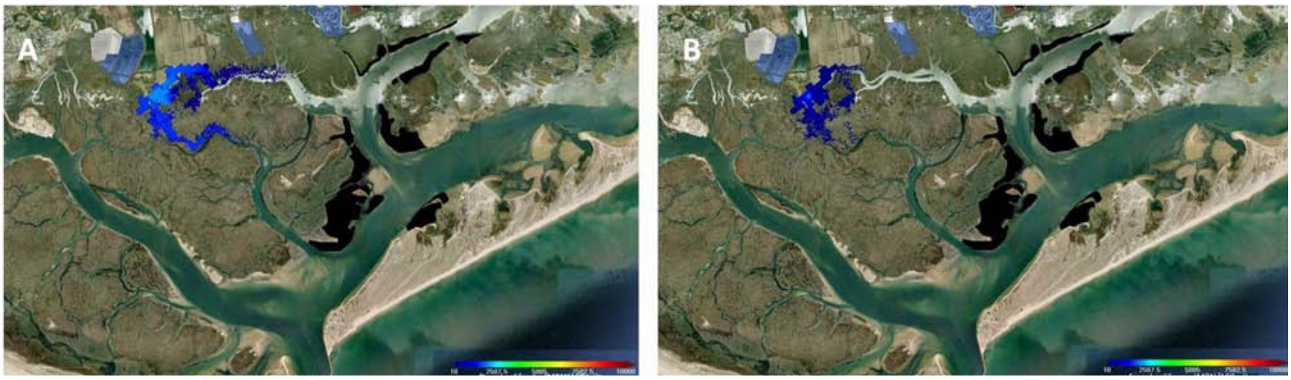

Figure 4.12.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro/Olhão. Discharge concentration equal to 2×10^3 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

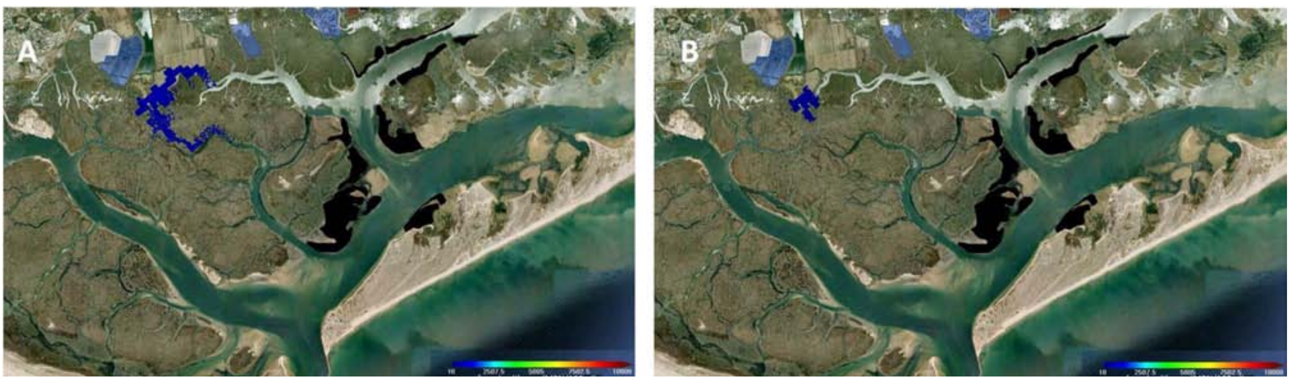

Figure 4.13.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro/Olhão. Discharge concentration equal to 300 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

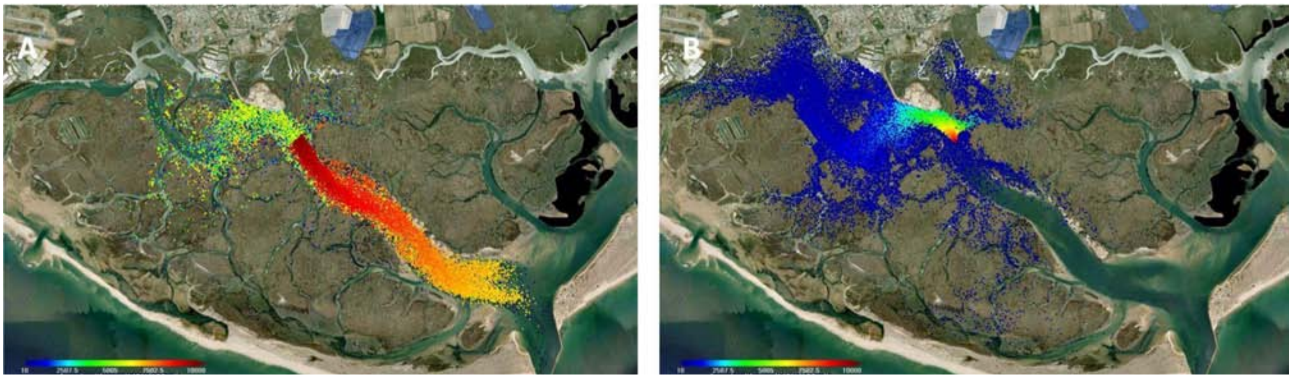

Figure 4.14.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro Channel. Concentration of the discharge equal to 1×10^4 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

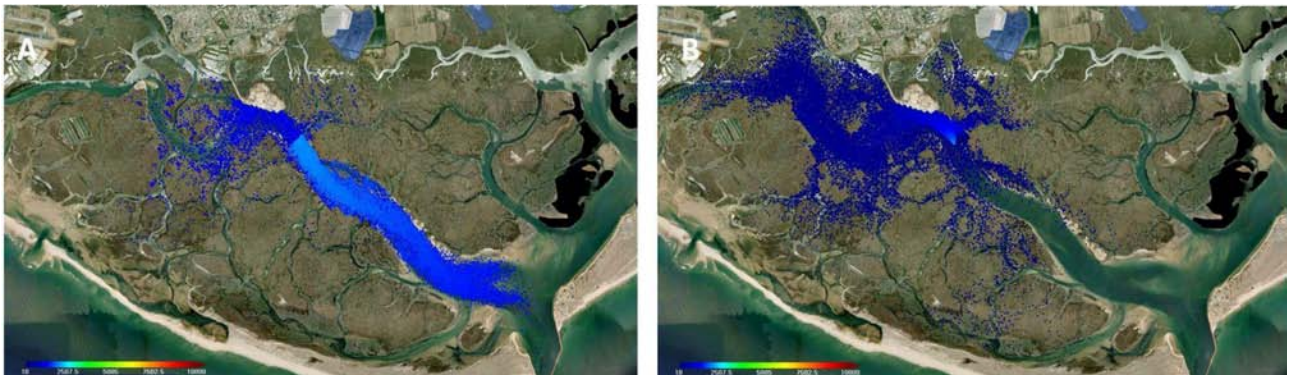

Figure 4.15.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro Channel. Discharge concentration equal to 2×10^3 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

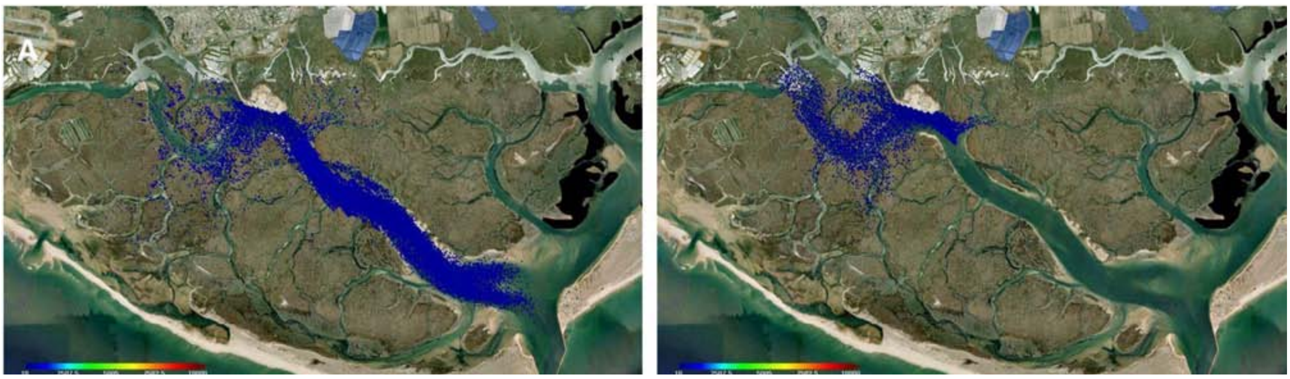

Figure 4.16.
Microbiological plume obtained in the period of Neap tide for the discharge in Faro Channel. Discharge concentration equal to 300 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

For the Neap tide scenario, the microbiological plume associated to the discharge in Faro/Olhão is maintained confined to the channel where the discharge is carried out and to the channel immediately to the south, for both tide conditions. In terms of concentrations there is a clear difference between the day and night situation due to the inactivation of faecal coliforms associated with solar radiation. As the concentration of coliforms in the discharge is reduced the area of influence of the plume also decreases, especially at high tide during the day. For the location of the discharge in the Faro Channel, it could be thought, in the first analysis, that the microbiological impact was lower due to the greater dynamics and mixing capacity of the discharge point. Unlike salinity, the concentration of faecal coliforms is not a conservative property due to its inactivation, that is, a conservative property here is understood as that of a property that in its transport is subject to advection and diffusion but has no processes of destruction or creation (sinks and sources). This fact puts two antagonistic processes in presence when the microbiological load is discharged in a region of high dynamics: on one hand, the greater dynamics produces a greater diffusion, lowering the concentration, but on the other hand, this same dynamic does not give time to the inactivation occurs before the plume spreads over a larger area of Ria Formosa. On the contrary, a discharge in a confined area such as that of the current Faro Nascente WWTP, produces higher local concentrations due to less diffusion but restricts the affected region, giving time for the plume to inactivate before being dispersed to other regions.

For discharges into the Faro Channel at low water, the plumes spread in the area adjacent to the discharge zone, as well as throughout the channel downstream near the Faro Ria Formosa exit. At high water, the plume is transported upstream of the discharge, and spreads over a larger area due to rising water levels during this tide situation. During the flood some particles are retained downstream of the discharge into small existing channels and are then transported again during the ebb. In concentrations terms, as in the case of Faro/Olhão, there is a clear difference between the day and night situation, due to the faecal coliform mortality associated with solar radiation. As the concentration of coliforms in the discharge is reduced this area also decreases, especially at high tide during the day, in which the area of the plume is substantially reduced.

For Spring tide, the main difference compared to the Neap tide is the extension of the coliforms plume, which, as expected, extends over a larger area due to the increase of the submerged zones and the greater dynamics of the system.

Figure 4.17.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro/Olhão. Concentration of the discharge equal to 1×10^4 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

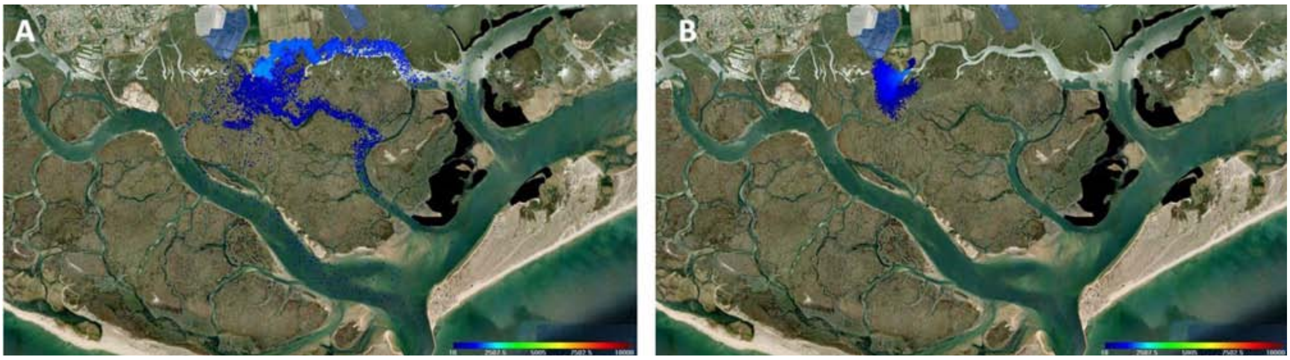

Figure 4.18.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro/Olhão. Concentration of the discharge equal to $2\text{x}10^3$ MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

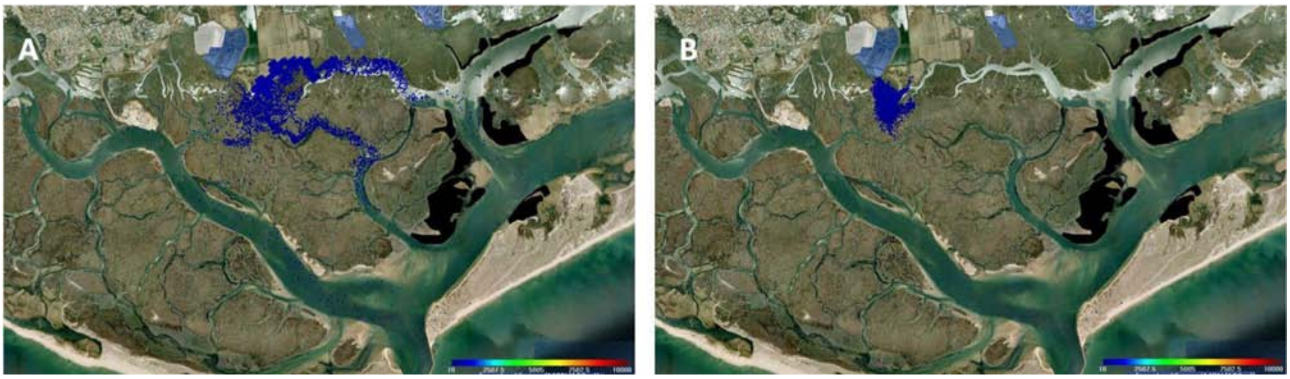

Figure 4.19.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro/Olhão. Concentration of the discharge equal to 300 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

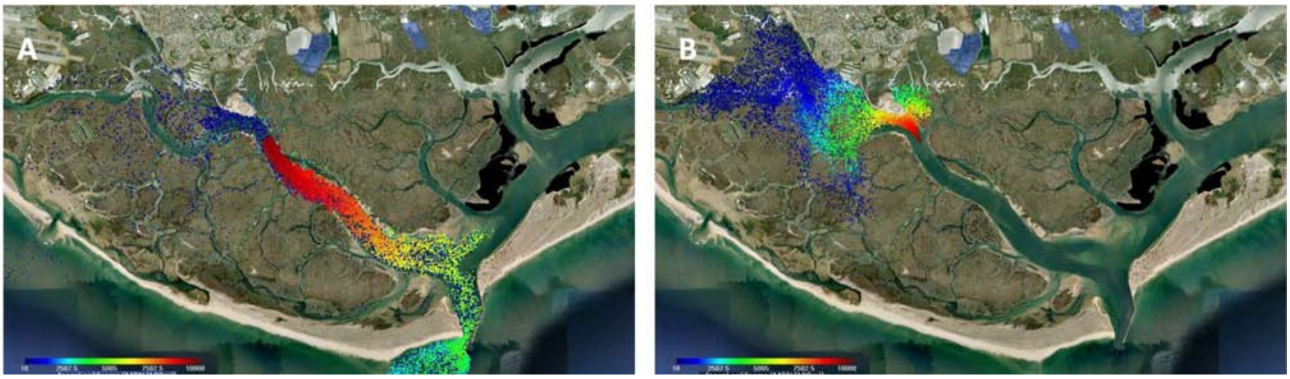

Figure 4.20.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro Channel. Concentration of the discharge equal to 1×10^4 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

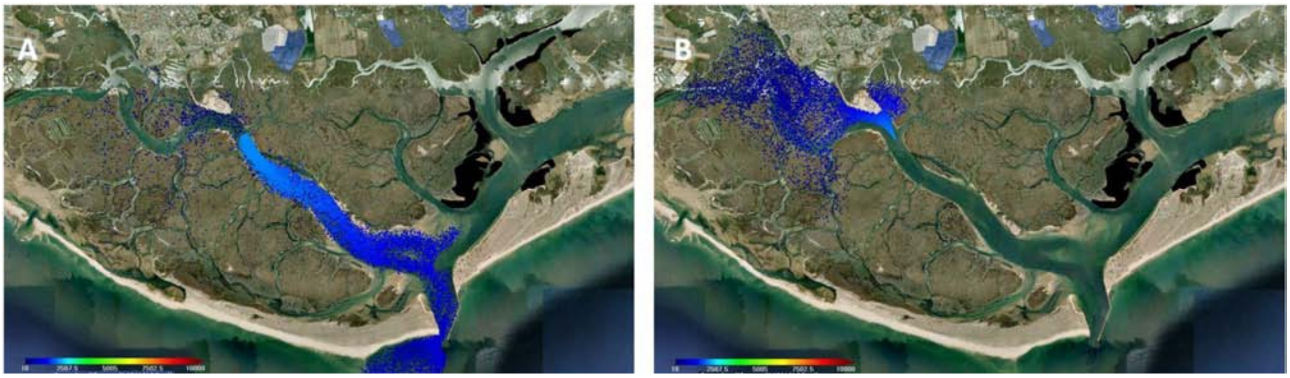

Figure 4.21.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro Channel. Concentration of the discharge equal to 2×10^3 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

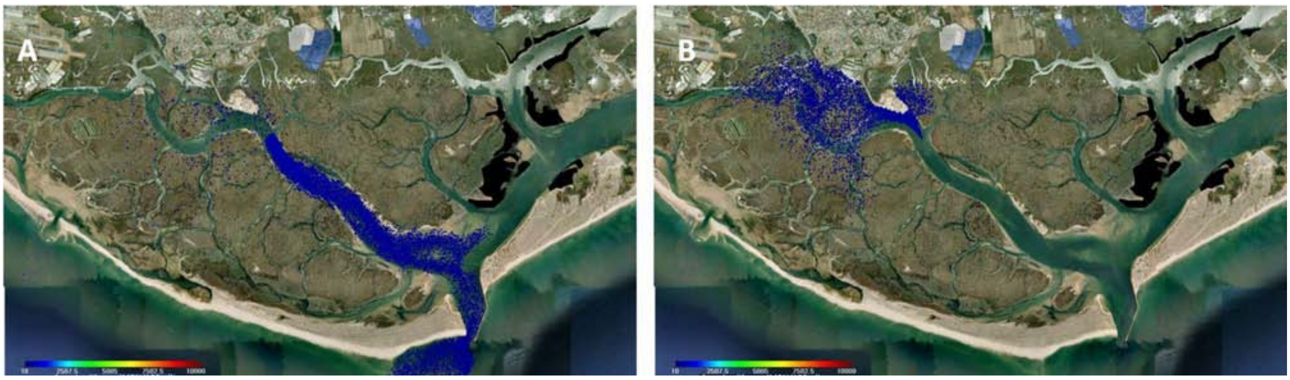

Figure 4.22.
Microbiological plume obtained in the period of Spring tide for the discharge in Faro Channel. Concentration of the discharge equal to 300 MPN/100 ml. A) Night with low tide conditions; B) Day with High tide conditions.

In Spring tide scenario, at low tide the plume associated with the discharge in Faro/Olhão is less confined, leaving either the channel where the discharge is located, or the channel to the south, entering through the Olhão channel and the Faro channel. At high tide, the plume is again confined to the area surrounding the discharge and is even more confined than in the same situation but in Neap tide scenario. This is because, in a Neap tide scenario, the flow of flood water cannot counter the direction of the discharged water flow, thus creating a larger zone regarding the dispersion of the particles, since they can enter the channels adjacent to the discharge, being more easily transported away from the discharge. During the Spring tide scenario, the flood flow is strong enough to change the direction of the upstream discharge flow, creating a physical containment barrier for the plume and preventing the particles from entering the channels south of the discharge. In concentrations terms, there is a clear difference between the day and night situation due to solar radiation. As the concentration of coliforms in the discharge is reduced the area of influence of the plume also decreases.
Considering the location of the discharge in the Faro Channel at low tide, the plume associated with the discharge is transported out of the Barra de Faro / Olhão, due to the increase of the current in the Faro Channel during ebb in Spring tide. This increase in current velocity also reduces the scattering of the particles in the area adjacent to the discharge, channeling all particles through the Faro Channel. During the flood, many of the particles that are in the vicinity of Barra de Faro / Olhão are transported not only along the Faro Channel, but also along the Olhão Channel, spreading in the vicinity of this. Dependent on the time on which the ebb/flood tide inversion occurs (night or day), the particles carried by the Olhão Channel tend to remain (more or less) time in that zone before being inactivated by solar radiation. At high tide, the area of influence of the plume associated with the discharge is similar to that described for the Neap tide scenario.

Final remarks

In the region associated to the Almargem WWTP, the mathematical model allowed to predict that with entry in service of the Almargem WWTP and the decommissioning of the old Tavira WWTP the fecal coliform concentrations in the Gilão River will decrease substantially. The Impact in the Almargem water stream was only moderate, however, since the discharge regulations limits for the new WWTP are 2,000 MPN/100ml of faecal coliforms and therefore, overall, the microbiological contamination inside the Ria Formosa would decrease. The simulations with several alternative locations for the discharge in the Almargem River and the Cabanas Channel showed that the discharge in the middle of the Almargem Channel is more advantageous, being the plume confined to the interior region of the Almargem Channel

and does not affect in any way the bar or the bathing waters regions. The downstream discharge locations progressively aggravate the bacterial concentration in the areas closest to the bathing waters.
In the Faro/Olhão region, in relation to hydrodynamics of the system there are significant differences of speeds when considering a neap tide situation or a spring tide situation, however the flow pattern is the same. The highest speeds are found in the bars, in the main channel of Faro and in the main channel of Olhão, resulting in shorter residence times in these zones, however, in the channel where the discharge of Faro/Olhão WWTP is located, the flow in neap tide situation presents very low channel velocities, which suggests high residence times in this area during this tide situation. This fact conditions the impact in terms of salinity produced by the discharge of fresh water. Salinity is a conservative property, which is why its concentration depends only on the dilution capacity of the system. Thus the discharge of fresh water into the main channel does not have any significant impact on the region surrounding the discharge due to the high dilution capacity produced by the flow in that area.
Unlike salinity, microbiological contamination is not a conservative property. The faecal coliforms concentration used as an indicator for this contamination depends not only on the dilution of the system but also on the inactivation, which is mainly due to the effect of solar radiation, as well as to saline shock and the effect of temperature. This shows that the regions with the greatest dilution capacity dont always match to those in which the impact of the microbiological discharge is better. This fact is notorious in this study, where more confined regions of microbiological plumes where obtained, although with higher maximum concentration values, in the case of discharge in Faro\Olhão compared to what happens for the discharge in the Faro Channel. This is due to the greater dynamics in the Faro channel that transports the contaminated water through the system very quickly, before it has time to be inactivated.
Studies conducted at the Ria Formosa over the last years concerning WWTP discharges allowed the global characterization of the ecosystem in terms of anthropogenic influence and trophic activity of the study areas and in the development of models that describe the processes that impact the water quality in these places. The studies were able to respond to short-term issues - support for the remodelling / construction of WWTP and the assessment of their environmental impact in the receiving environment - and issues expected in the medium term, namely those arising from the Portuguese authorities' obligations to the European Union due to the application of directives related to waste water (Water Directive, Bathing Water Directive and Urban Waste Water Treatment Directive and Water Directives for Shellfish Use).

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