

MODELAÇÃO DE CENÁRIOS DE EXPLORAÇÃO EM AQUÍFEROS  
DE ZONAS COSTEIRAS: EFEITOS NA BIODIVERSIDADE DE  
LAGOAS E RESPECTIVAS  
RIBEIRAS COMO ECOSSISTEMAS DEPENDENTES DE ÁGUA  
SUBTERRÂNEA - GROUNDSCENE

PTDC/AAC-AMB/104639/2008

**RELATÓRIO FINAL DE EXECUÇÃO CIENTÍFICA DO PROJECTO**

**Novembro 2013**



Faculdade  
Ciências  
Universidade  
Lisboa



CENTRO DE OCEANOGRÁFIA



TÉCNICO  
LISBOA



ICNF  
Instituto da Conservação  
da Natureza e das Florestas



Administração da  
Região Hidrográfica  
do Alentejo I.P.

**MODELAÇÃO DE CENÁRIOS DE EXPLORAÇÃO EM AQUÍFEROS DE ZONAS  
COSTEIRAS: EFEITOS NA BIODIVERSIDADE DE LAGOAS E RESPECTIVAS  
RIBEIRAS COMO ECOSISTEMAS DEPENDENTES DE ÁGUA SUBTERRÂNEA**

**GROUNDSCENE**

**PTDC/AAC-AMB/104639/2008**

**EQUIPA**

**Luís Cancela da Fonseca<sup>7,8</sup> (Coordenador)**

**FFCUL – Centro de Oceanografia – CIEMAR**

**Paula Chainho<sup>1</sup>, Pedro M. Félix<sup>1</sup>, Maria João Correia<sup>1</sup>, José Lino Costa<sup>1,2</sup>**

**Maria Luísa Chaves<sup>1</sup>, Isabel Domingos<sup>1,11</sup>, Vera Lopes<sup>1</sup>, Carla Mirra<sup>1</sup>**

**João Castro<sup>1,4</sup>, Teresa Cruz<sup>1,4</sup>, André Costa<sup>4</sup>, Maria José Costa<sup>1</sup>, Henrique N. Cabral<sup>1,11</sup>**

**CVRM – IST – UALG**

**Luís Tavares Ribeiro<sup>3</sup>, Tibor Stigter<sup>3,12</sup>, Núria Salvador<sup>3,7</sup>, Luís Costa<sup>7</sup>, Rui Hugman<sup>3,7</sup>**

**Luís Nunes<sup>3,7</sup>, José Paulo Monteiro<sup>3,7</sup>, António Chambel<sup>3,5</sup>, Ana Silva<sup>3</sup>, José Rosa Pinto<sup>6</sup>**

**APA – ARH Alentejo**

**Isabel Pinheiro<sup>9</sup>**

**ICNF - RNLSAS**

**Ana M. Vidal<sup>10</sup>**

<sup>1</sup> Centro de Oceanografia, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

<sup>2</sup> Universidade Lusófona de Humanidades e Tecnologias, Campo Grande 376, 1749-024 Lisboa, Portugal

<sup>3</sup> Centro de Geo-Sistemas/CVRM, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

<sup>4</sup> CIEMAR e Laboratório de Ciências do Mar, Universidade de Évora, apartado 190, 7520-903 Sines, Portugal

<sup>5</sup> Universidade de Évora, R. Romão Ramalho 59, 7000-672 Évora, Portugal

<sup>6</sup> Departamento de Ciências Biológicas e Bioengenharia, Faculdade de Ciências e Tecnologia, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

<sup>7</sup> Centro de Ciências e Tecnologias da Água, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

<sup>8</sup> Laboratório Marítimo da Guia/Centro de Oceanografia (FCUL), Av. Na. Sra. do Cabo, 939, 2750-374 Cascais, Portugal

<sup>9</sup> Agência Portuguesa do Ambiente/Administração da Região Hidrográfica – Alentejo, Rua da Alcárçova de Baixo, 6, 7001-901 Évora, Portugal

<sup>10</sup> Reserva Natural das Lagoas de Santo André e da Sancha, Pavilhão A- Galiza, 7500-022 Vila Nova de Santo André, Portugal

<sup>11</sup> Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

<sup>12</sup> Water Science and Engineering Department, Hydrology and Water Resources Chair Group, UNESCO-IHE, Westvest 7, 2611 AX Delft, The Netherlands

## INTRODUÇÃO

O projecto “Modelação de cenários de exploração em aquíferos de zonas costeiras: efeitos na biodiversidade de lagoas e respectivas ribeiras como ecossistemas dependentes de água subterrânea - GroundScene” (PTDC/AAC-AMB/104639/2008), teve como instituições participantes o Centro de Oceanografia, Faculdade de Ciências da Universidade de Lisboa (CO-FCUL), o Centro de Geo-Sistemas do Instituto Superior Técnico (CVRM-IST), o Instituto de Conservação da Natureza e das Florestas (ICNF) e a Administração da Região Hidrográfica do Alentejo (ARH-Alentejo).

O Projecto GROUNDSCENE aborda um problema que afecta as zonas costeiras a nível global e teve como principal objectivo avaliar as respostas ecológicas face a uma redução da recarga dos aquíferos e a um aumento da extracção de água, num cenário de alterações climáticas em ecossistemas dependentes de águas subterrâneas (EDAS). Com o resultado desta avaliação pretende-se ainda quantificar o caudal ecológico mínimo nos sistemas ribeirinhos, de forma a garantir, quer a sua sustentabilidade ecológica, quer a dos sistemas lagunares associados. Neste âmbito foram abordadas as seguintes questões: O balanço de água do aquífero (recarga/usos) afecta o balanço de água nas lagoas? A biodiversidade de tais sistemas ribeirinhos e das suas zonas de descarga nas lagoas será afectada pelos diferentes níveis de dependência das ribeiras relativamente às AS? Ocorrerão as alterações à biodiversidade nas interfaces AS – ribeiras - lagunas à mesma escala temporal e espacial que nas ribeiras e nas lagunas?

Neste enquadramento prosseguiram-se os seguintes objectivos específicos: (i) determinar o balanço hídrico aquífero-águas superficiais das bacias hidrográficas de Melides e Santo André, (ii) determinar a composição e estrutura das comunidades de macroinvertebrados e peixes das ribeiras e lagoas de Melides e Santo André, (iii) identificar as variáveis ambientais com maior influência na estrutura dessas comunidades, (iv) identificar os constrangimentos mais significativos para essas comunidades nas zonas de interface águas subterrâneas-ribeiras-lagoas.

No âmbito do presente projecto estava prevista a realização de um conjunto de cinco tarefas distintas:

1. Sistematização de dados e revisão bibliográfica
2. Balanço hídrico
3. Interface águas subterrâneas/ribeiras
4. Zonas de descarga (ribeiras-lagoas)
5. Cenários de modelação

No final do período de vigência do GROUNDSCENE, reportamos que foram completados os trabalhos referentes a todas as tarefas, tal como é descrito em detalhe nas secções seguintes.

## 1. TAREFAS

### 1.1. Sistematização de dados e revisão bibliográfica

No decorrer do primeiro ano do projecto efectuou-se uma compilação bibliográfica sobre a temática em estudo, que foi sendo actualizada no decorrer do projecto. A informação contida nos Planos de Região Hidrográfica, entretanto aprovados, e todos os guias metodológicos de apoio à realização dos mesmos foram igualmente integrados na base de dados bibliográficos, para utilização nas fases subsequentes do projecto. Uma base dos dados históricos existentes para os sistemas aquíferos e de águas superficiais foi igualmente compilada e integrados os dados obtidos no âmbito das campanhas GROUNDSCENE, incluindo os seguintes itens:

- i) usos da água;
- ii) número de furos e poços licenciados no aquífero superficial de Sines e respectiva capacidade de captação;
- iii) dados meteorológicos regionais;
- iv) dados hidrológicos, parâmetros físico-químicos da água e sedimentos nos compartimentos águas subterrâneas, ribeiras e lagoas;
- v) macroinvertebrados e peixes nos compartimentos ribeiras e lagoas;
- vi) vegetação ripícola e aquática do compartimento ribeiras.

Os dados compilados foram sendo actualizados ao longo do projecto e foram inseridos numa base de dados em ambiente SIG, posteriormente utilizada para construção do modelo eco-hidrológico.

Foi desenvolvido um site do projecto: <http://sitesforprojects.wix.com/groundscene> (Anexo 1).

### 1.2. Balanço Hídrico

#### 1.2.1. Monitoring stream flow and base flow discharges into the Santo André Lagoon

To estimate stream flow (Q) contributions to the water balance of the Santo André Coastal Lagoon (SAL), four automatic water level data-loggers (CTD) have been installed (see Figure 1 for location), since November 2011, close to the mouths of the two main streams (SR3 – Cascalheira stream; SR2 – Ponte stream) and two smaller streams (SR1 and SR2), which were found to maintain flow all year. The CTD were installed in the stream bed inside a drilled PVC pipe secured to an iron bar. In Figure 2 an installation schema and some photos are presented.



**Figure 1.** Streams automatic data-loggers (CTD) location (□).



**Figure 2.** Streams CTD installation schema (right down corner) and SR1 (left) and SR3 (right) CTD installation photos.

To construct the rating curves (i.e. discharge vs. water level curves) needed to convert streams water levels into discharge, several field campaigns were made at various times during almost two years. In discharge measurements flow is often estimated by determining the velocity at which water flows through a given cross-sectional area (equation 1):

$$Q=VA \quad (1)$$

where, Q is the volumetric flow rate passing the channel reach ( $m^3/s$ ), V is discharge velocity ( $m/s$ ) and A is the cross-sectional area ( $m^2$ ) of flow normal to the flow direction. In a first approach, discharge measurements were made by gauging several vertical velocity profiles at the location of each installed CTD (see photos in Figure 3).



**Figure 3.** Velocity measurements photos at SR3 location, before stream bed changes.

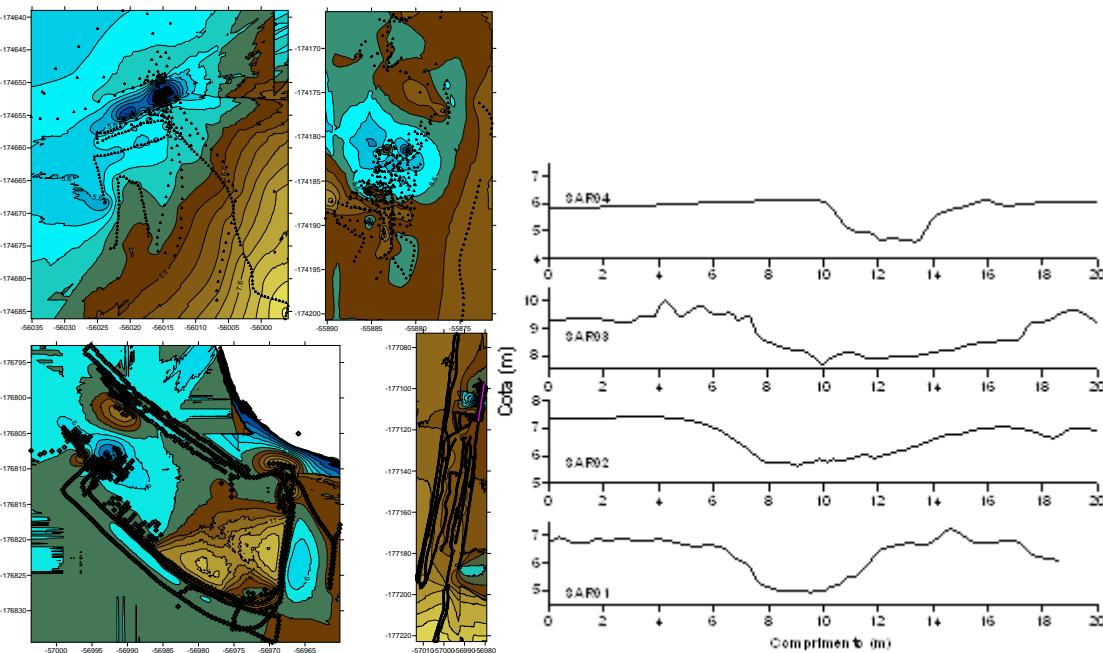
Average vertical velocity ( $V_i$ ) at CTD location was obtained after vertical velocities were integrated. Discharge velocity (V) of these shallow streams was obtained rewriting Manning's equation (equation 2) (Costa and Lança, 2001) into equation 3, considering (i) channel slope (S) and Manning's roughness coefficient (n) as constants and (ii) wetted perimeter of the channel (P) approximately equal to the width of the channel (w), as river channels are commonly much wider than they are deep. As hydraulic radius ( $R_h$ ) is the cross-sectional wetted area ( $A=h.w$ ) divided by the wetted perimeter (P), when considering P approximately equal to w, the  $R_h$  will be approximately equal to h.

$$V = \frac{Rh^{2/3} S^{1/2}}{n} \quad (2)$$

where, V is discharge velocity (m/s), n is Manning's roughness coefficient, Rh is the hydraulic radius (m) and S is channel slope (m/m).

$$\frac{V}{Vi} = \left( \frac{Rh}{h} \right)^{2/3} \quad (3)$$

where, V is discharge velocity (m/s), Vi is average vertical velocity (m/s), Rh is the hydraulic radius (m) and h water height (m) at CTD location. To estimate A and P, a detailed map of the streams' cross-section and flooding areas, at each CTD location, was obtained using a high resolution Differential GPS (DGPS). Recorded DGPS data was processed in Surfer software and streams' cross-section at CTD location was obtained after kriging analysis. In Figure 4 it is showed Surfer kriging results and each stream cross-section.



**Figure 4.** Surfer software kriging process results and streams' cross sections.

Both A and P for each stream were estimated intersecting streams' cross-section with water level elevation values in Grapher software. Two scenarios were considered to obtain water level elevation, one (a) where water level was added to the CTD elevation value (as water level was measured at the CTD location) and a second scenario (b) where water level was added to the lower elevation value of the cross-section. To validate A estimates, the width of the wetted surface (w) was also recorded obtaining a maximum wetted area. Comparing both scenarios with maximum wetted area it was possible to understand that scenario (a) was overestimating and scenario (b) was underestimating A values. An intermediate scenario (c) for each stream was developed where an average elevation value was determined from interpolated elevation values for maximum wetted areas. To validate discharge scenarios, discharge measurements were made by gauging several vertical flow velocity profiles along the stream cross-section at the location of each installed CTD (see Figure 5).

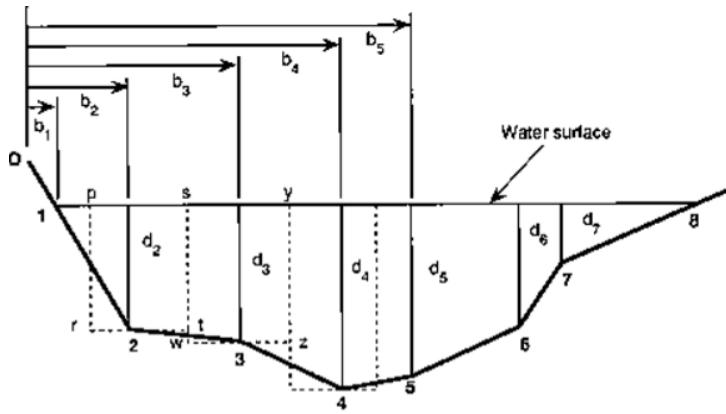


Figure 5. Cross-section of a stream divided into vertical sections for discharge measurements (Kuusisto, 1996).

This second approach to estimate discharge is based on the assumption that the average velocity measured at a vertical line is valid for a rectangle that extends half of the distance to the verticals on each side of it, as well as throughout the depth at the vertical. The area of each rectangle ( $A_i$ ) is determined through equation 4.

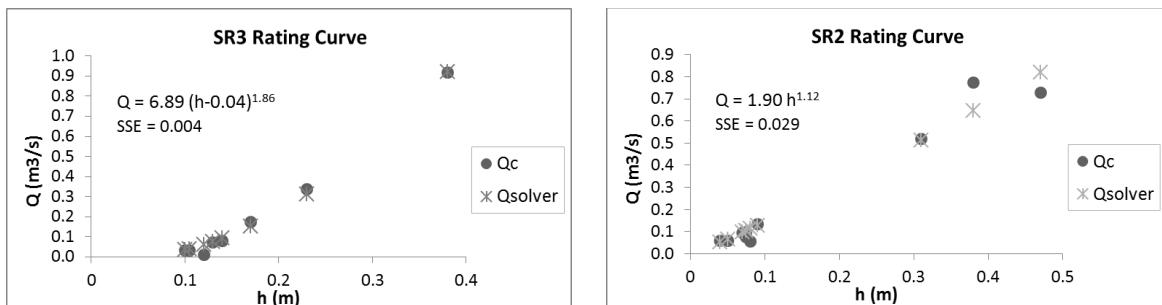
$$A_i = \left[ \frac{(b_i + b_{i+1})}{2} - \frac{(b_{i-1} + b_i)}{2} \right] \times d_i \quad (4)$$

where,  $A_i$  is the area of each rectangle ( $m^2$ ) (dotted lines in Figure 5),  $b_i$  is the horizontal distance (m) from a reference point on one side of the shore to the point where the corresponding vertical velocity profile is being measured and  $d_i$  is the water depth (m) for the same vertical profile. Comparing A, V and Q estimates from both approaches, it seems that first approach scenario (c) is underestimating discharge flow, though more data from second approach is needed for a more detail analysis and to quantify miscalculations of streams' cross-section. For the first approach, adding to the fact that it was sometimes difficult to obtain DGPS signal due to vegetation interference, the DGPS has already an associated vertical error that can be of great significance when water levels are smaller, that can accumulate with miscalculations of streams' cross-section through the kriging processes. The greater the number of sets of discharge and water height measurements, the greater the accuracy of the rating curve, and thus more accurate the estimates of stream water discharges into the lagoon. Unfortunately, as it was only possible to acquire a flow meter near to the end of this project, during its development it was necessary to borrow equipment to measure discharge velocities, what sometimes was difficult to arrange. Moreover, 2012 was an atypical dry year and it was difficult to coordinate field campaigns to coincide with rainfall (scarce and during short periods). Furthermore, it has not been possible to determine the rating curves for the two smaller streams (SR1 and SR4) as flow velocities were most of the times lower than the detection limits of the used equipment. For future reference, both SR1 and SR4 location should be readjusted. For SR1, future efforts should be focused on working together with Instituto da Água (INAG) for the maintenance of the Badoca gauging station (25E/02H) and data collecting to construct the respective rating curve. On the other hand, the heavy rains that occurred earlier in 2013 have completely changed the two main stream beds at the CTD location, which implies the construction of new rating curves. These changes in the SR3 stream bed are evident when comparing photos in Figure 3 and Figure 6. However, this has not yet been possible as stream water levels during the summer season have not allowed velocity measurements.



**Figure 6.** Photos of the SR3 CTD location after changes stream bed changes.

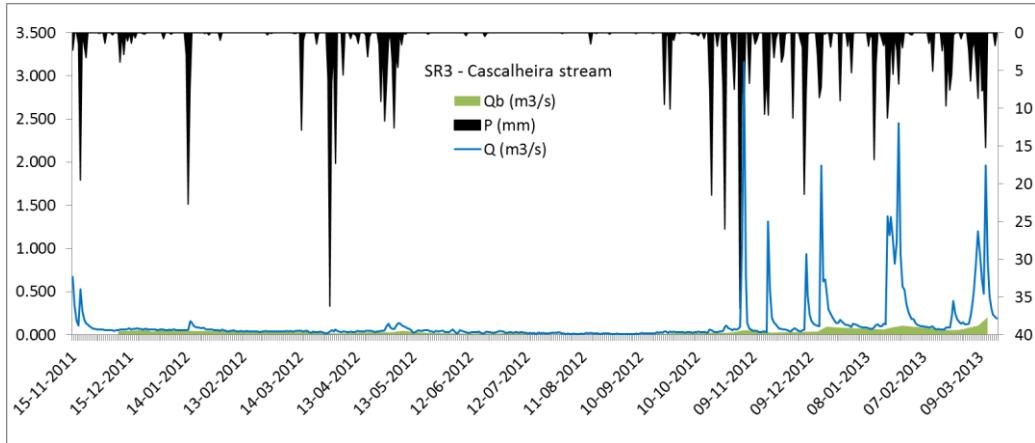
Several methods have been proposed for determining rating curves and improve data fitting (Braca, 2008). In this study three methods were used to build the rating curves by fitting discharge and stage data, the Excel power curve trend line (Qpower), the Excel solver tool (Qsolver) and the fit rating curve obtained with the HYDATA software (Qhydata). Comparing the sum of the squared errors (SSE) of these three approaches, Qsolver had the best-fitting curve. Figure 7 presents the rating curve results for SR3 and SR2.



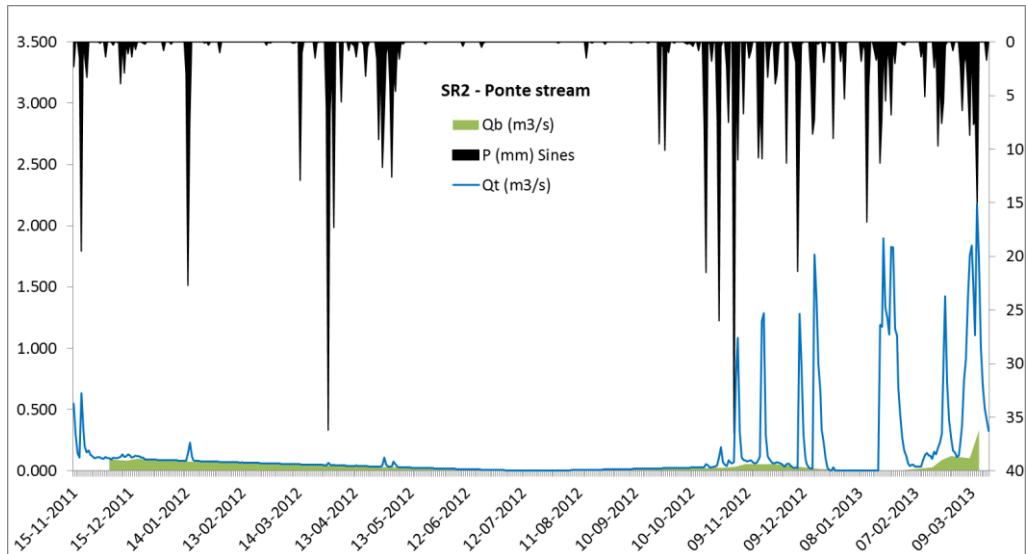
**Figure 7.** Rating curve for the Cascalheira (SR3) and Ponte (SR2) streams.

Analysing and comparing CTD recorded water levels ( $h_{CTD}$ ) data and water height ( $h$ ) of manual measurements it was possible to verify that for SR2 sometime during January 2013 the CTD started to record water levels higher than manual measurements. While SR3 maximum error ( $h - h_{CTD}$ ) found was of 7.5cm, for SR2 until November/December 2012 the CTD was recording  $h_{CTD}$  with a maximum error of 6.7cm and after January 2013 the error started to rise and reached a maximum of 74.2cm. These higher differences were associated with siltation inside the PVC pipe due to sediment dragged in the heavy rains that occurred in January 2013. For SR3,  $h_{CTD}$  values were lower than  $h$  manual measurements, thus to adjust automatic data to manual data the error found between two measurements was interpolated and added to the CTD  $h_{CTD}$  data. For SR2 some attempts to reduce the errors were applied. On one hand the same approach as for SR3 was applied, adding the interpolated error to  $h_{CTD}$  for the period where the errors were smaller and  $h_{CTD}$  lower than  $h$ , and subtracting for the period where the errors were greater and  $h_{CTD}$  higher than  $h$ . On the other hand efforts were applied to reduce the errors by drawing relationships between  $h_{CTD}$  or Qsolver values from SR3 and SR2, for periods where both CTD were recording smaller errors. Both correlations were found

to be poor for higher hCTD and Qsolver values, respectively. Therefore, first approach was also applied to adjust SR2 hCTD. To prevent future sediment siltation the PVC pipes were replaced with longer and larger diameter PVC pipes. SR3 CTD was moved into a new location as the stream bed was silted up by sediments dragged by heavy rains. With all this, it is only possible to present stream flow estimates ( $Q$ ) for SR2 and SR3 for the period from 15-11-2011 to 18-03-2013. Stream flow ( $Q$ ) consist of the sum of direct surface runoff ( $Q_d$ ), the water flow generated within the drainage area of the measuring point after the initial demands of interception, infiltration, and surface storage have been satisfied, and base flow ( $Q_b$ ), the groundwater contributions occurring in effluent reaches and points.  $Q_b$  was determined by hydrograph ( $Q$  graphical representation vs. time) separation techniques. Initially, the HYDATA software (Hydrological Database and Analysis System Version 4.1) developed by the UK Institute of Hydrology was used for automatic base flow separation. The software calculates base flow index (BFI) i.e the ratio of base flow to total flow, but one cannot actually extract the base flow time series. Therefore, the same smoothed minima approach (Gustard et al., 1992) for base flow separation ( $Q_b$ ) was applied manually. This technique uses the minima of five-day non-overlapping consecutive periods from daily flow time series, subsequently connecting turning points from this minima series. Figure 8 and Figure 9 present the obtained hydrograph for Cascalheira (SR3) and Ponte (SR2) streams.



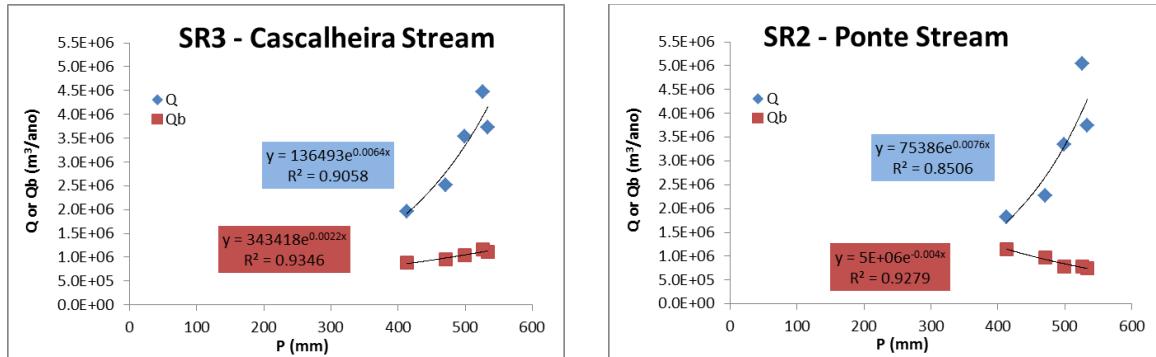
**Figure 8.** Cascalheira (SR3) stream hydrograph for the period from 15-11-2011 to 18 03-2013.



**Figure 9.** Ponte (SR2) stream hydrograph for the period from 15-11-2011 to 18 03 2013.

Although it was not possible to present estimates for one complete hydrological year, Table 1 presents Q, Q<sub>b</sub> and BFI moving annual estimates for the period from 15-11-2011 to 18-03-2013 and precipitation (P) data from Sines weather station managed by the Portuguese Institute of Ocean and Atmosphere (IPMA). Afterwards, exponential relations for moving annual estimates were established for Q vs. P and Q<sub>b</sub> vs. P, while poor relations were found for monthly estimates. No relation was obtained for Q vs. Q<sub>b</sub>.

Figure 10 presents these relations, from where estimates of Q and Q<sub>b</sub> for a 29 hydrological years (October 1983/September 2013) average P (530 mm) were obtained, which are also presented in Table 1.



**Figure 10.** Relations between precipitation (P) and stream flow (Q) and base flow (Q<sub>b</sub>) for Cascalheira and Ponte streams.

For an average year total Q (sum of the two streams) contributing to the SAL water balance is about 8.3 hm<sup>3</sup>/yr, of which about 21% (1.7 hm<sup>3</sup>/yr) are aquifer contributions to the streams having base flow. The BFI index provides indication of the groundwater dependency degree of the streams and thus of the SAL. Streams with BFI values above 0.5 (50% base flow) are generally considered to be significantly groundwater dependent (Environmental Agency, 2013).

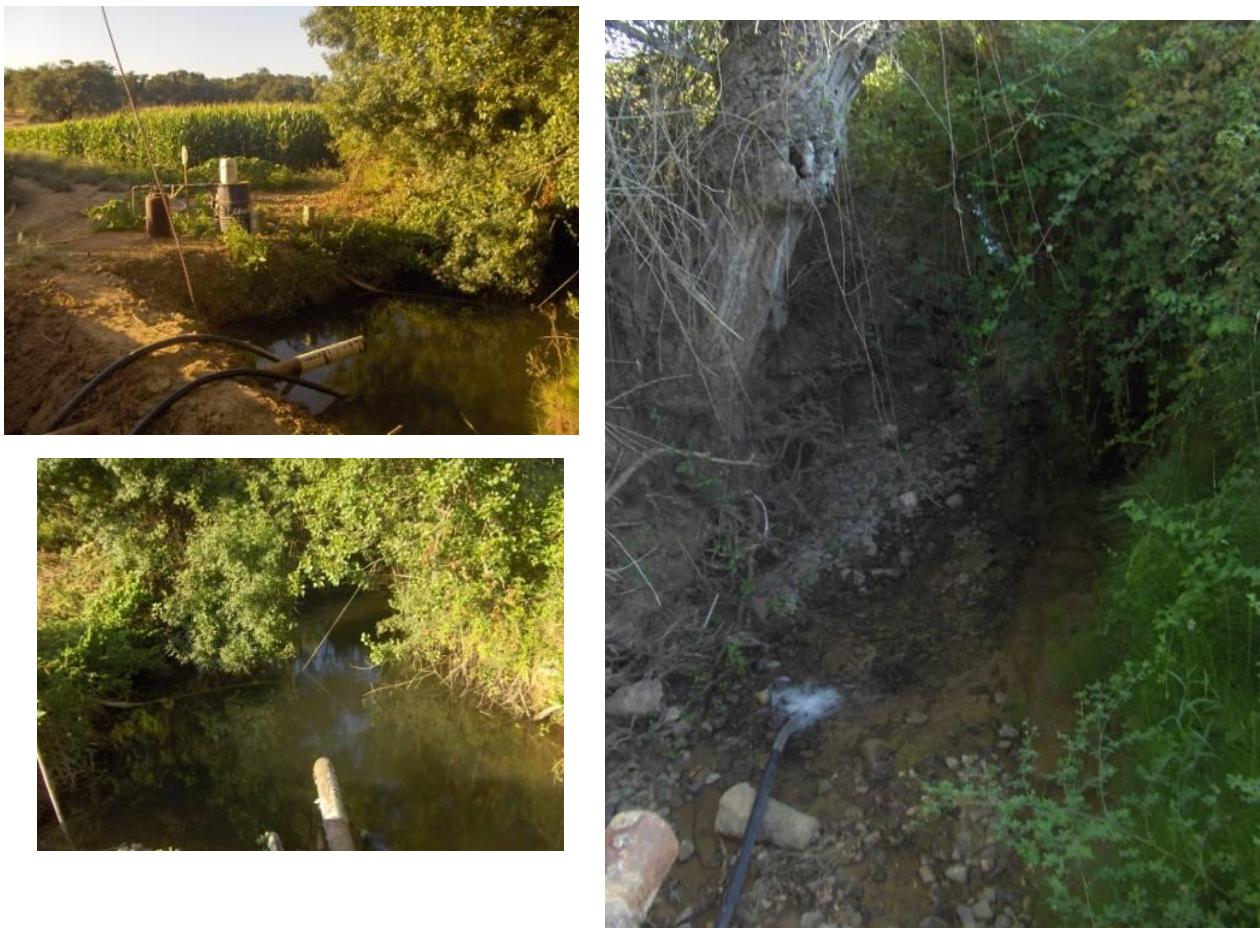
**Table 1.** Surface runoff (Q), base flow (Q<sub>b</sub>) and BFI estimates for Cascalheira and Ponte streams.

Date	Cascalheira Stream (SR3)			Ponte Stream (SR2)			Santo André Coastal Lagoon (SAL)			P (mm)
	Q (m <sup>3</sup> /yr)	Q <sub>b</sub> (m <sup>3</sup> /yr)	BFI	Q (m <sup>3</sup> /yr)	Q <sub>b</sub> (m <sup>3</sup> /yr)	BFI	Q (m <sup>3</sup> /yr)	Q <sub>b</sub> (m <sup>3</sup> /yr)	BFI	
Dec2011-										
Nov2012	1.96E+06	8.78E+05	0.45	1.83E+06	1.15E+06	0.63	3.79E+06	2.03E+06	0.53	412.6
Jan2012-										
Dec2012	2.51E+06	9.50E+05	0.38	2.26E+06	9.77E+05	0.43	4.78E+06	1.93E+06	0.40	470.3
Feb2012-										
Jan2013	3.53E+06	1.04E+06	0.29	3.34E+06	7.77E+05	0.23	6.87E+06	1.81E+06	0.26	498.5
Mar2012-										
Feb2013	3.73E+06	1.11E+06	0.30	3.74E+06	7.46E+05	0.20	7.47E+06	1.86E+06	0.25	534.0
Apr2012-										
Mar2013	4.47E+06	1.16E+06	0.26	5.04E+06	7.88E+05	0.16	9.51E+06	1.95E+06	0.20	526.0
Oct1983-										
Sep2012	4.06E+06	1.10E+06	0.27	4.23E+06	6.00E+05	0.14	8.29E+06	1.70E+06	0.21	530.0

Even though stream monitoring data allowed estimating surface runoff ( $Q$ ) and base flow ( $Q_b$ ) average annual contributions to the SAL water balance, these values are still only indicative of orders of magnitude, given the low density of stream flow monitoring data. One must have in mind that the relations that allowed these estimates were not built on annual values of several complete hydrological years, thus still needing to be improved with more monitoring data. On the other hand, as previously mentioned, during January 2013 the CTD installed in Ponte stream (SR2) suffered siltation by sediments dragged in the heavy rains that occurred and data had to be readjusted. Apparently for this period some  $Q_b$  data may have not been accounted, analysing Figure 9 and Table 1 it is possible to realize that for similar  $Q$  for both streams,  $Q_b$  decreases considerably in SR2 from the moment that January 2013 data is accounted. Also during a field campaign two small farmers' dams built along the Cascalheira stream (Figure 11 and Figure 12) were preventing water flow to arrive at the CTD location, meanwhile they were destroyed, nevertheless situations like this may have great influence in the CTD estimates. Although more monitoring data is needed for more accurate results these estimates were used for the calibration of the numerical flow model.



**Figure 11.** Small dam located upstream the CTD location in the Cascalheira stream, upstream view (left down corner) and downstream view (right).



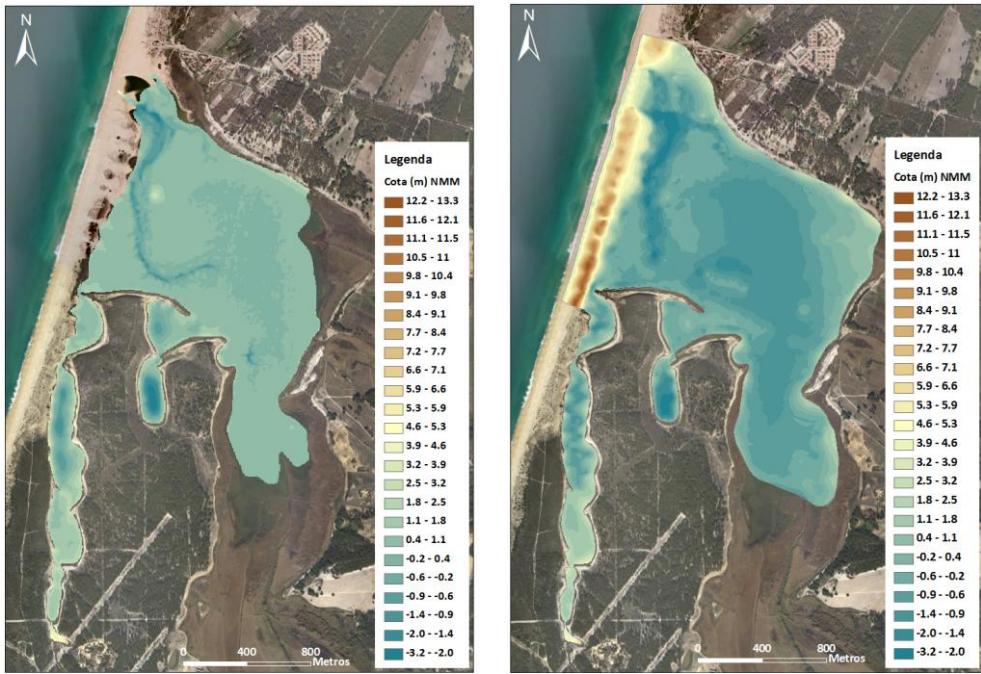
**Figure 12.** Small dam located upstream the CTD location in the Cascalheira stream, upstream view (left) and downstream view (right).

### 1.2.2. Water and salt mass balances for the Santo André Lagoon

Considering the bottom of these coastal lagoons, mainly composed of detritic sediments and organic matter layers, is limiting the hydraulic connection between these lagoons and the top detritic layer of the multi-layer Sines aquifer system, and considering no water gains or losses occurring between the lagoon and the sea throughout the sand barriers, when these lagoons are closed to the sea its water balance may be described as equation 1.

$$\Delta A = Pd - Ev + Q \quad (1)$$

where,  $\Delta A$  is the storage changes ( $m^3$ ),  $Pd$  the direct precipitation ( $m^3$ ) occurring in the lagoon surface area,  $Ev$  water loss due to evaporation ( $m^3$ ) and  $Q$  the surface water runoff ( $m^3$ ) generated within the lagoons' drainage area. When changes in storage are known the water balance may be used to determine  $Q$  estimates. So far three bathymetric surveys were performed for the Santo André Coastal Lagoon (SAL), one in February 1989 (Cancela da Fonseca, 1989), other between May and July 2002 (Mariano, 2004) and other one in February (Pires, 2011). Importing the two more recent bathymetric models (Figure 13) into the ArcGIS Desktop software it was possible to calculate the surface area and volume below a given water level value using the Surface Volume tool.



**Figure 13.** SAL Digital Elevation Model (DEM) obtained from bathymetric survey data for 2002 (left side) and 2009 (right side) (Pires, 2011).

Since the beginning of April 2013, when the lagoon was still opened to the sea and water levels were lower, a water level data-logger (CTD) was installed in the SAL (see Figure 14 for location and Figure 15 for photo) registering continuously the lagoon water levels. At the same time manual measurements were taken using a high resolution Differential GPS (DGPS) (Figure 15).

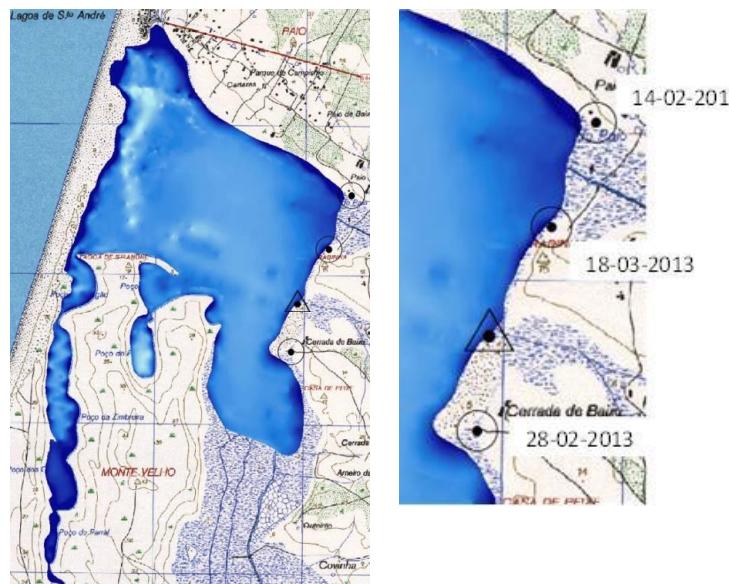


Figure 14. CTD location in Santo André Lagoon.

Table 2 presents a compilation of measured water levels (wl) and wl recorded over the years, obtained through several sources: literature (Mariano, 2004 and Pires, 2011), colleagues of the Faculty of Sciences of

the University of Lisbon (FCUL) and through the Natural Reserve of the Lagoons of Santo André and Sancha (RNLSAS).



**Figure 15.** Installed CTD in the SAL (left) and lagoon water level measurements using a DGPS.

**Table 2.** Santo André Lagoon water level (wl) compilation.

Date	wl (m)	Source	Date	wl (m)	Source	Date	wl (m)	Method
22-03-1998	2.88	RNLSAS	26-02-2009	2.85	Pires (2011)	28-02-2013	4.07	DGPS
19-03-1999	2.5	RNLSAS	09-03-2009	2.73	RNLSAS	18-03-2013	4.41	DGPS
01-03-2000	2.25	RNLSAS	09-04-2009	0.98	Pires (2011)	30-04-2013	2.04	CTD
09-02-2001	4.99	RNLSAS	08-05-2009	1.13	Pires (2011)	06-05-2013	1.81	DGPS
26-04-2001	1.07	FCUL	05-06-2009	1.19	Pires (2011)	31-05-2013	1.90	CTD
28-03-2002	2.45	RNLSAS	10-07-2009	1.06	Pires (2011)	28-06-2013	2.13	CTD
18-04-2002	1.667	FCUL	14-08-2009	0.98	Pires (2011)	23-07-2013	2.11	DGPS
17-05-2002	1.67	Mariano (2004)	09-09-2009	1.17	Pires (2011)	31-07-2013	2.03	CTD
28-05-2002	1.64	Mariano (2004)	14-10-2009	1.04	Pires (2011)	25-09-2013	2.17	DGPS
29-05-2002	1.65	Mariano (2004)	09-11-2009	1.36	Pires (2011)	31-08-2013	2.03	CTD
17-06-2002	1.53	Mariano (2004)	14-12-2009	1.63	Pires (2011)	25-09-2013	2.05	CTD
18-06-2002	1.56	Mariano (2004)	19-01-2010	3.69	Pires (2011)			
19-06-2002	1.57	Mariano (2004)	18-02-2010	3.78	Pires (2011)			
02-07-2002	1.47	Mariano (2004)	17-03-2010	4.69	Pires (2011)			
03-07-2002	1.44	Mariano (2004)	17-03-2010	4.69	RNLSAS			
11-07-2002	1.38	Mariano (2004)	16-03-2011	3.89	RNLSAS			
12-07-2002	1.39	(INAG, 2004)	06-03-2012	1.95	RNLSAS			
08-02-2003	3.56	RNLSAS						
20-02-2004	2.61	RNLSAS						
04-04-2005	1.69	RNLSAS						
27-03-2006	2.78	RNLSAS						
16-03-2007	3.52	RNLSAS						
20-03-2008	2.19	RNLSAS						

On the other hand, as water in these groundwater-dependent lagoons is a mixture of saltwater that enters during the periodical connection with the sea, and freshwater discharged by streams in hydraulic connection with the shallow detritic aquifer. After the closure of the annual connection with the sea, salinity changes in the lagoons depend only on the amount of water that evaporates, and the stream discharge. Salt is a conservative tracer, i.e., it is not created or consumed by chemical or biological processes. Therefore, when salinity values are available, a salt mass balance may also provide an important way to assess the quality of the calculated water balance.

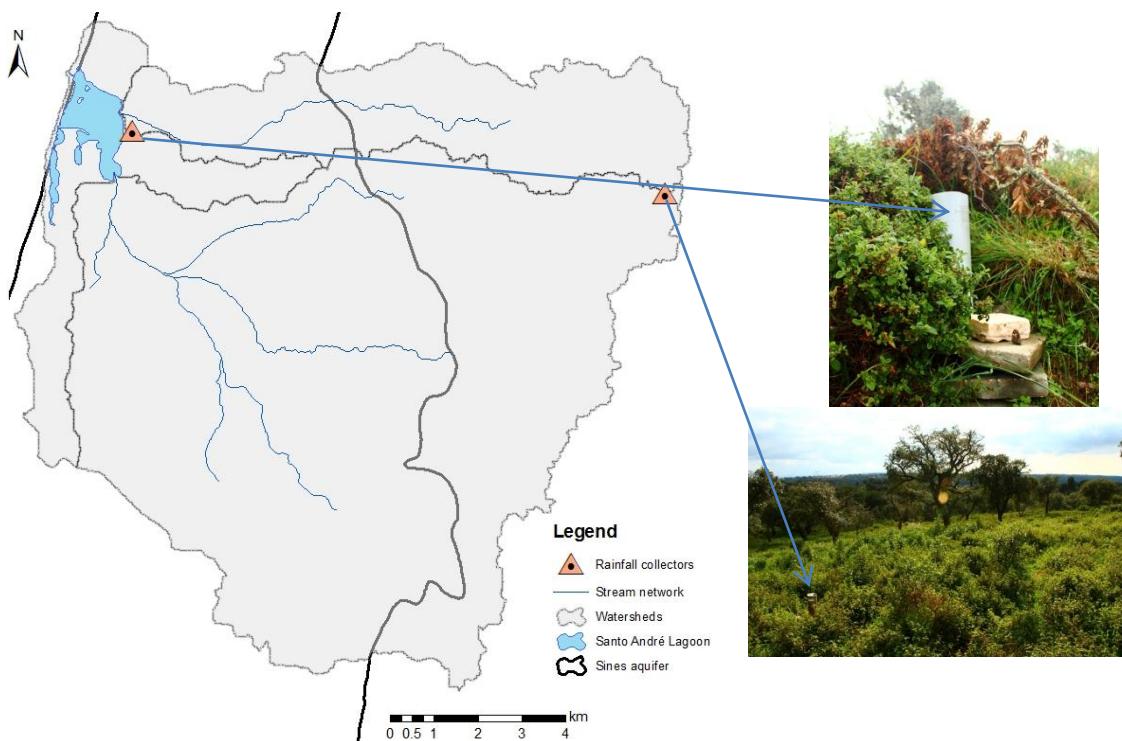
In this sense, it was possible to estimate the water and salt mass balances for 2002, 2009 and 2013. Unfortunately, it was not possible to complete the salt mass balance for 2013, since salinity values were not

available. For 2002 and 2009 salinity values were available in literature Mariano (2004) and Pires (2011), respectively. Table 3 presents the obtained results for the water and salt mass balances. Where  $\Delta V_{bat}$  is the change in volumes obtained in the ArcGIS software crossing the bathymetric model with the available water levels and  $Q_{bat}$  the corresponding surface runoff estimated through equation 1. For 2002 balances the 2002 bathymetry model was used, and for 2009 and 2013 balances the 2009 bathymetry model was used.  $\Delta V_{(1)}$  is the change in the lagoon water volumes obtained by applying the  $Q_b$  estimates from the numerical model (Appendix 2) into equation 1.  $\Delta V^*(1)$  is the change in the lagoon water volumes were obtained by applying the  $Q^*$  estimates from the salt mass balance.  $Q$  is to the surface runoff estimates corresponding to the sum of the individual contributions of two main streams, obtained from the installed monitoring network (Appendix 1), thus not accounting all the surface runoff reaching the lagoon. The precipitation ( $P$ ) was obtained from the Sines weather station managed by the Portuguese Institute of Ocean and Atmosphere (IPMA) and evaporation ( $Ev$ ) data from the Grândola (24F/01C) weather station managed by the Portuguese Water Institute (INAG). For 2013  $Ev$  data was not available so evapotranspiration ( $ET_0$ ) data from the Serominheiro weather station managed by the Regional Directorate for Agriculture and Fisheries (DRAPALG) was used just to get a sense of the magnitude of the surface runoff. Although, it is important to keep in mind that there are no whatsoever certainties related to the evaporation losses in 2013. Even though, the differences between  $Q$  and  $Q_{bat}$  may also be related to the fact that the 2009 bathymetry does not includes the entire flooded area of the SAL, as this bathymetry was obtained for a water level of 2.85 m and in 2013 water level was higher than 4m (see Table 2). Furthermore,  $Ev$  for 2002 and 2009 presented some data gaps, missing data for 3 and 11 days respectively. Unfortunately, due to non-overlapping data and to the fact that no monthly relation was found for  $Q$  vs.  $P$  it was not possible to compare  $Q$  and  $Q^*$ . Comparing  $Q_{bat}$  and  $Q^*$ , for 2002  $Q_{bat}$  seems to be underestimated, while for 2009  $Q_{bat}$  seems to be overestimated. These  $Q_{bat}$  discrepancies may be related to the  $Ev$  data gaps, or to the fact that different methods were used in the bathymetry surveys, 2009 bathymetry provides depths higher than the 2002 bathymetry. These differences between  $Q_{bat}$  and  $Q^*$  may also be related to the fact that the used salinity data is not representative of the lagoon area and depth, or to exchanges occurring between the lagoon and the sea throughout the sand barriers or between the lagoon bottom and the aquifer. Knowing that  $Q$  consist of the sum of direct surface runoff ( $Q_d$ ), and groundwater contributions ( $Q_b$ ), the  $Q_b$  estimates from de numerical flow model are seem to be in accordance.

**Table 3.** Water and salt mass balances results and components.

	from 17-05-2002 to 11-07-2002	from 09-04-2009 to 10-07-2009	from 28-02-2013 to 18-03-2013
$\Delta V_{bat}$ (m <sup>3</sup> )	-5.89E+05	1.91E+05	9.21E+05
$Q_{bat}$ (m <sup>3</sup> )	3.73E+05	1.11E+06	8.89E+05
$\Delta V_{(1)}$ (m <sup>3</sup> )	-3.81E+05	-1.82E+05	2.29E+05
$Q_b$ (m <sup>3</sup> )	5.81E+05	7.37E+05	1.97E+05
$\Delta V^*_{(1)}$ (m <sup>3</sup> )	-2.92E+05	4.86E+04	-
$Q^*$ (m <sup>3</sup> )	6.70E+05	9.68E+05	-
$Q$ (m <sup>3</sup> )	-	-	2.32E+06
$P$ (mm)	20.7	49.4	56.8
$Ev$ (mm)	493.3	429.9	-
$ET_0$ (mm)	-	498.5	45.1
$A_{bat}$ (m <sup>2</sup> )	2.04E+06	2.42E+06	2.71E+06

On the other hand, with the objective of calculating a chloride mass balance, in order to help assessing the estimates of the aquifer recharge, in the end of February 2013, two rainfall collectors were installed, one near the SAL lagoon and other on the upstream watershed limits (see Figure 16 for its location). At the same time, groundwater, stream flow and lagoon water samples were also collected. Unfortunately, it was not possible, during the time of this project, to complete this assessment due to the sampling low density and to the fact that sample need to be analysed in a proper laboratory.



**Figure 16.** Location of the rainfall collectors.

## Referências

Braca G. (2008) Stage–discharge relationships in open channels: Practices and problems. FORALPS Technical Report, 11. Università degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale, Trento, Italy, 24 pp.

Cancela da Fonseca L.M.Q. (1989) Estudo da influência da “abertura ao mar” sobre um sistema lagunar costeiro: a Lagoa de Santo André. Ph.D. Thesis. Universidade de Lisboa: Portugal.

Costa T., Lança R. (2001) Capítulo IX Condutos Livres. Disciplina de Hidráulica Aplicada - Núcleo de Hidráulica e Ambiente, Escola Superior de Tecnologia, Universidade do Algarve.

ENVIRONMENT AGENCY. Summary Assessment Method – Identification of Groundwater Dependent Surface Water Bodies and Ecosystems. APPENDIX A - Regional WFD Contact Duties. Available at:

Gustard A., Bullock A., Dixon J.M. (1992) Low flow estimation in the United Kingdom, IH Report no 108, Institute of Hydrology, Wallingford, Oxfordshire, United Kingdom.

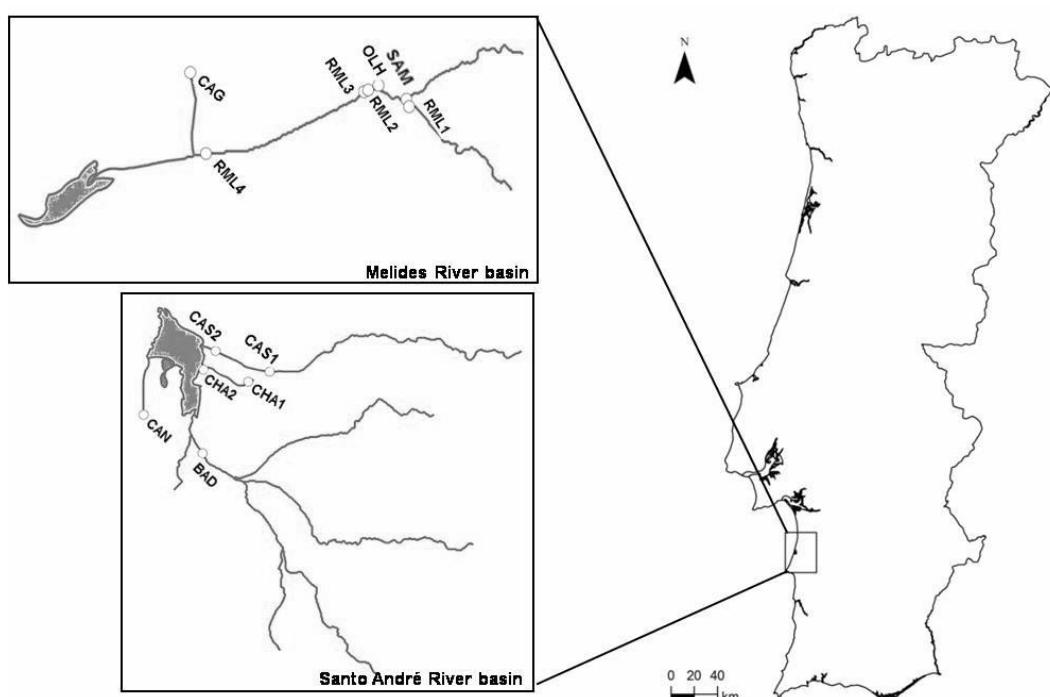
Kuusisto E. (1996) "Chapter 12 - Hydrological Measurements" in Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, London, Edited by J. Bartram and R. Balance.

Mariano, A. C. Álvares, M.T. & Pimenta, M.T (2004) Monitorização batimétrica de lagoas costeiras – Albufeira de Santo André. INAG/DSRH. Lisboa, 43 p.

Pires A.R.M. (2011) Morfodinâmica da barra de maré efémera da Lagoa de Santo André. Ph.D. Thesis. Universidade de Lisboa: Portugal.

### 1.3. Interface águas subterrâneas-ribeirias

As colheitas das comunidades de invertebrados bentónicos e peixes foram realizadas em Maio e Setembro de 2011, por forma a caracterizar a variabilidade faunística em diferentes períodos hidrológicos.



**Figura 17.** Localização das estações de amostragem seleccionadas nas bacias hidrográficas de Melides e Santo André: ribeiras da Badoca (BAD), Cabo d'Água (CAG), Cascalheira (CAS 1 e CAS 2), Serradinha (CHA 1 e CHA 2) Melides (RML 1, RML 2, RML 3 e RML 4), Fonte dos Olhos (OLH) e Samoucal (SAM).

As amostragens foram efectuadas em 14 locais diferentes, distribuídos equitativamente entre as bacias hidrográficas de Melides e Santo André (Figura 17). Os locais estudados são ecossistemas dependentes do aquífero superior de Sines, com excepção da Fonte dos Olhos, que drena directamente do aquífero carbonatado (SALVADOR et al., 2013).

### 1.3.1. Metodologia

As colheitas de macroinvertebrados foram realizadas com uma rede kick de 30x30 cm, com uma malha de 500 µm, com a qual foram realizados arrastos de jusante para montante, durante 60s. As amostras foram fixadas em álcool 70º e, posteriormente, lavadas e triadas em laboratório, para separação dos organismos. Os espécimes foram identificados ao nível taxonómico mais baixo possível e contados. Não foi realizada a amostragem de invertebrados na estação BAD 1. As capturas de ictiofauna foram efectuadas com recurso a um aparelho de pesca eléctrica, operado numa secção de 40 m. Os espécimes foram identificados e contados e medido o seu comprimento total, sendo posteriormente devolvidos à água. As estações de amostragem RML 1 e SAM encontravam-se secas em Setembro de 2011 e nunca foram efectuadas amostragens de peixes na estação CAN, por motivos logísticos.

Foram medidas as seguintes variáveis ambientais, recorrendo a uma sonda multiparamétrica (YSI 600XLM): temperatura da água ( $T$  - °C), condutividade (C - mS/cm), oxigénio dissolvido (OD - mg/L) e sólidos dissolvidos totais (SDT - g/L). Foram ainda determinadas a velocidade da corrente (VC - m/s) e a profundidade (Prof - m) e foram recolhidas amostras de água para determinação das concentrações de nitratos ( $NO_3$  - mg/L), nitritos ( $NO_2$  - mg/L), fósforo total (P - mg/L), amónia ( $NH_4$  - mg/L) e clorofila a (Chl a - µg/L). Foram recolhidas amostras de sedimento para determinação do conteúdo em matéria orgânica (MOT - %), através da diferença entre o peso seco (48h a 60 °C) e o peso livre de cinzas (12h a 480 °C). Foi ainda determinada a granulometria do sedimento por determinação do peso das diferentes fracções granulométricas, separadas através de uma bateria de crivos (2.00 mm, 0.50 mm, 0.25 mm e 0.063 mm). A granulometria (GS) foi representada em unidades phi ( $\Phi$ ) (BLOTT & PYE, 2001).

Para determinação do estado ecológico foi calculado o Índice Português de Invertebrados do Sul (IPtIs), utilizando o software AMIIB®, atendendo ao facto deste índice ter sido proposto para a tipologia em que se integra as bacias deste estudo (INAG, 2009). Foram ainda determinados o índice de qualidade ribeirinha (QBR) (PRAT et al., 2012) e o índice de diversidade de habitat (IHF) (JÁIMEZ-CUÉLLAR et al., 2004), tendo sido elencada a composição florística de um troço de 100m, envolvente às estações prospectadas nestas ribeiras (Anexo 23: Apêndice 3 do 2º Relatório de Progresso). Estes indicadores e uma avaliação qualitativa hierarquizada (classificação de 1 a 4) das pressões humanas (uso urbano, agrícola, industrial e florestal) (PH) foram usados para ver a sua influência na estrutura das comunidades bentónicas.

Foi efectuada uma Análise de Coordenadas Principais (PCO) da comunidade de invertebrados bentónicos das bacias hidrográficas de Melides e Santo André, com recurso ao software Primer® v6, (CLARKE & GORLEY, 2006) utilizando as rotinas PERMANOVA (ANDERSON, GORLEY & CLARKE, 2008). A ordenação foi efectuada com base numa matriz de semelhanças determinada através coeficiente de Bray-Curtis, em dados transformados ( $\log X+1$ ). A esta ordenação foram sobrepostos vectores que representam correlações de Spearman entre as variáveis ambientais, índices de qualidade ripícola e habitat e pressões humanas (A) e

taxa (B) com os eixos da PCO. O mesmo tipo de análise foi efectuado para a comunidade ictiofaunística, com base numa matriz de semelhanças determinada através coeficiente de Bray-Curtis, em dados transformados (raiz quadrada). A esta ordenação foram sobrepostos vectores que representam correlações de Spearman entre as variáveis ambientais (A) e taxa (B) com os eixos da PCO.

### 1.3.2. Resultados

#### *Macrozoobentos*

Foram recolhidos um total de 29959 espécimes de invertebrados e identificados 94 taxa, 52 na bacia de Santo André e 86 na bacia de Melides (21 taxa comuns – Tabela 4).

**Tabela 4** - Lista de taxa de macroinvertebrados identificados nas ribeiras e lagunas de Melides e Santo André.

TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
Annelida				
Oligochaeta ni	x	x	x	x
Clitellata				
Branchiobdellidae ni	x			
Erpobdellidae ni	x			
Branchiobdellidae ni	x			
<i>Glossiphonia</i> sp.	x			
<i>Helobdella</i> sp.	x			
Polychaeta				
Dorvilleidae				
<i>Protodorvillea keferstein</i>				x
Nephtyidae				
<i>Nephtys</i> sp				x
Nereididae				
<i>Alitta succinea</i>				x
<i>Hediste diversicolor</i>		x		x
<i>Perinereis cultrifera</i>				x
Syllidae				
<i>Exogone</i> sp.		x		
<i>Syllis gracilis</i>				x
<i>Syllis hyalina</i>		x		
Oweniidae				
<i>Owenia fusiformis</i>		x		x
Sabellidae				
<i>Desdemona ornata</i>				x
Spionidae				
<i>?Dipolydora caeca</i>				x
<i>Aonides oxycephala</i>		x		x
<i>Dipolydora flava</i>				x
<i>Polydora ciliata</i>		x		x

TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
<i>Polydora cornuta</i>		x		x
<i>Polydora</i> spI				x
<i>Polydora</i> spII				x
<i>Prionospio cirrifera</i>				x
<i>Scolelepis bonnieri</i>				x
<i>Streblospio shrubsolii</i>		x		x
Cirratulidae				
<i>Caulleriella bioculata</i>				x
<i>Tharyx</i> sp.		x		
Capitellidae				
<i>Capitella capitata</i>				x
<i>Capitella</i> sp				x
Capitellidae ni				x
<i>Mediomastus fragilis</i>		x		x
Saccocirridae				
<i>Saccocirrus</i> sp				x
Arthropoda				
Arachnida				
Acarina ni		x		
Hydracarina ni	x		x	
Branchiopoda				
Chydoridae				
<i>Dunhevedia crassa</i>				x
Daphniidae				
<i>Simocephalus vetulus</i>	x	x		x
<i>Ilyocryptus sordidus</i>	x		x	
Insecta				
Chrysomelidae ni	x		x	
Curculionidae ni	x		x	
Dryopidae ni	x		x	
Dytiscidae ni	x		x	x
Elmidae ni	x		x	
<i>Gerris</i> sp				
Gyrinidae ni	x		x	
<i>Gyrinus</i> sp	x			
Haliplidae ni	x		x	
<i>Haliplus</i> sp	x			
Helophoridae ni	x		x	
<i>Hydraena</i> sp	x			
Hydraenidae ni	x		x	
Hydrochidae ni	x		x	
Hydrophilidae ni	x	x	x	x
Hydroscaphidae ni			x	

TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
Hygrobiidae ni				x
Noteridae ni	x			
Anthomyiidae ni	x			x
Athericidae ni	x			
<i>Atricops crassipes</i>	x			
Ceratopogonidae ni	x	x	x	x
<i>Atrichopogon</i> sp			x	
Chaoboridae ni	x			
Chironomidae ni	x	x	x	x
Culicidae ni	x			
Dixidae ni	x			x
Dolichopodidae ni	x			
Empididae ni	x			x
Ephydriidae ni	x		x	x
Limoniidae ni	x	x	x	x
Psychodidae ni				
Ptychopteridae ni	x			x
Rhagionidae ni				x
Simuliidae ni	x			x
Stratiomyidae ni	x			
Tabanidae ni				x
Thaumeleida ni	x			
Tipulidae ni	x			x
Baetidae ni	x	x	x	x
Caenidae ni	x			x
Leptophlebiidae ni	x			
Heptageniidae ni				x
Gerridae ni	x			
Hydrometridae ni	x			x
Corixidae ni	x			x
Mesoveliidae ni	x			x
Naucoridae ni	x			
<i>Nepa</i> sp.	x			
Notonectidae ni	x			x
Veliidae ni	x			x
Heteroptera ni				
Lepidoptera ni				x
<i>Sialis</i> sp.	x			x
Aeshnidae ni	x			x
Coenagrionidae ni	x	x	x	x
Cordulegasteridae ni	x			
Gomphidae ni	x			
Lestidae ni	x			

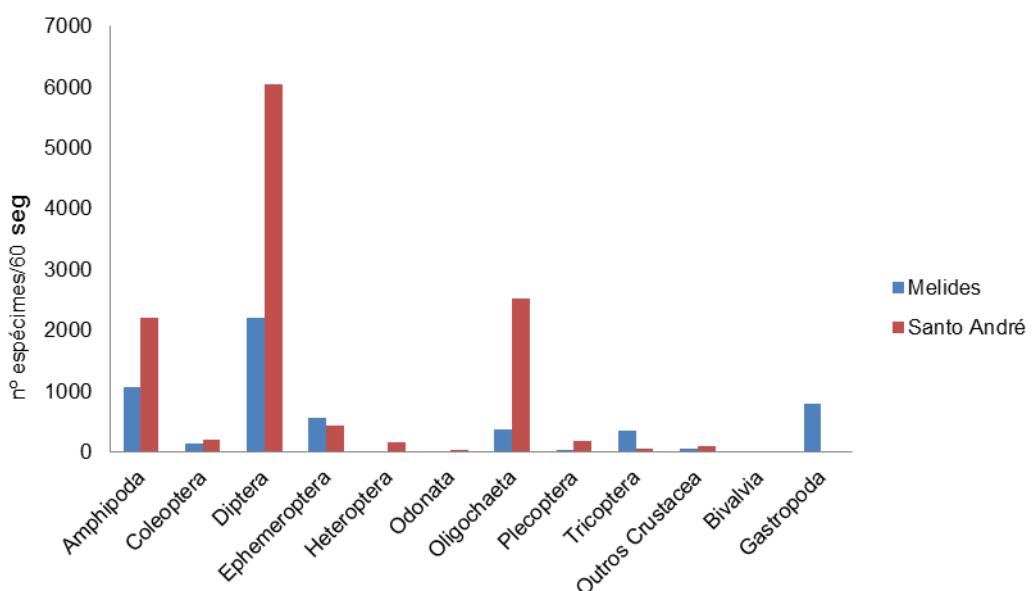
TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
Libellulidae ni	x	x	x	
Odonata ni				
Nevorthidae ni		x		
Capniidae ni	x			x
Leuctridae ni	x			
Perlodidae ni				x
Plecoptera ni				
Brachycentridae ni	x			
Ecnomidae ni	x			x
Glossosomatidae ni	x			
Hydropsychidae ni	x			x
Hydroptilidae ni	x			
Leptoceridae ni	x			x
Phryganeidae ni ni	x			
Polycentropodidae	x			x
Psychodidae ni	x			x
Rhyacophilidae ni	x			
Sericostomatidae ni	x			
Malacostraca				
Gammaridae				
<i>Gammarus chevreuxi</i>				x
Gammaridae ni	x		x	
Microprotopidae				
<i>Microprotopus maculatus</i>				x
Atyidae				
<i>Atyaephyra desmaresti</i>	x		x	
Cambaridae				
<i>Procambarus clarkii</i>	x		x	
Polybiidae				
<i>Liocarcinus marmoreus</i>				x
Portunidae				
<i>Carcinus maenas</i>				x
Asellidae				
<i>Proasellus</i> sp.	x			
Janiridae				
Janiridae ni	x		x	
Sphaeromatidae				
<i>Lekanesphaera hookeri</i>		x		x
Maxillopoda				
Calanoida ni	x	x	x	x
Cyclopoida ni		x		x
Harpacticoida ni		x	x	x
<i>Laophonte</i> sp.			x	

TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
Balanidae				
<i>Balanus crenatos</i>				X
Ostracoda				
Ostracoda ni	X	X	X	X
Bryozoa				
? <i>Hyalinella</i> sp.		X		
Bryozoa ni		X		
Cnidaria				
Anthomedusae ni		X		
<i>Cordylophora caspia</i>		X		X
<i>Hydra</i> sp.	X		X	
Entoprocta				
cf. <i>Barentsia benedeni</i>				X
Foraminifera ni				X
Mollusca				
Bivalvia				
Corbulidae				
<i>Corbula gibba</i>		X		
Mytilidae				
<i>Modiolus modiolus</i>				X
Corbiculiidae				
<i>Corbicula fluminea</i>	X			
Cardiidae				
<i>Cerastoderma edule</i>				X
<i>Cerastoderma glaucum</i>				X
<i>Cerastoderma</i> sp.				X
<i>Laevicardium crassum</i>				X
Kelliidae				
<i>Kellia suborbicularis</i>				X
Mactridae				
<i>Spisula elliptica</i>				X
<i>Spisula subtruncata</i>				X
Semelidae				
? <i>Ervilia castanea</i>				X
<i>Abra alba</i>				X
<i>Abra segmentum</i>				X
<i>Abra</i> sp				X
Sphaeriidae				
<i>Pisidium milium</i>	X			
Sphaeriidae ni	X			
Tellinidae				
<i>Tellina tenuis</i>				X
Veneridae				

TAXA	Melides		Santo André	
	Ribeiras	Lagoa	Ribeiras	Lagoa
<i>Tapes rhomboides</i>				X
<i>Venerupis saxatilis</i>				X
<i>Venerupis senegalensis</i>				X
Bivalvia ni				X
Gastropoda				
Retusidae				
<i>Retusa obtusa</i>				X
Acroloxidae				
<i>Acroloxus</i> sp	X			
Ancylidae				
<i>Ancylus</i> sp	X		X	
Lymnaeidae				
<i>Lymnaea truncatula</i>	X		X	
Lymnaeidae ni	X		X	
<i>Myxas glutinosa</i>				X
Physidae				
<i>Physa</i> sp	X			
<i>Physa fontinalis</i>	X			
Physidae ni	X		X	
Planorbidae				
<i>Ferrissia</i> sp	X			X
Planorbidae ni	X			
<i>Planorbis</i> sp	X			
Assimineidae				
<i>Assiminea</i> sp	X			
Hydrobiidae				
<i>Hydrobia ulvae</i>		X		X
<i>Hydrobia ventrosa</i>		X		X
<i>Potamopyrgus</i>				
<i>antipodarum</i>	X			
Rissoidae				
<i>Obtusella intersecta</i>		X		
Pulmonata ni	X			X
Vertiginidae				
<i>Vertigo</i> sp	X			
Valvatidae	X			
<i>Valvata piscinalis</i>				
Nematoda	X	X	X	X
Nemertea				
Amphiporidae ni				X
Platyhelminthes				
Turbellaria ni	X	X		

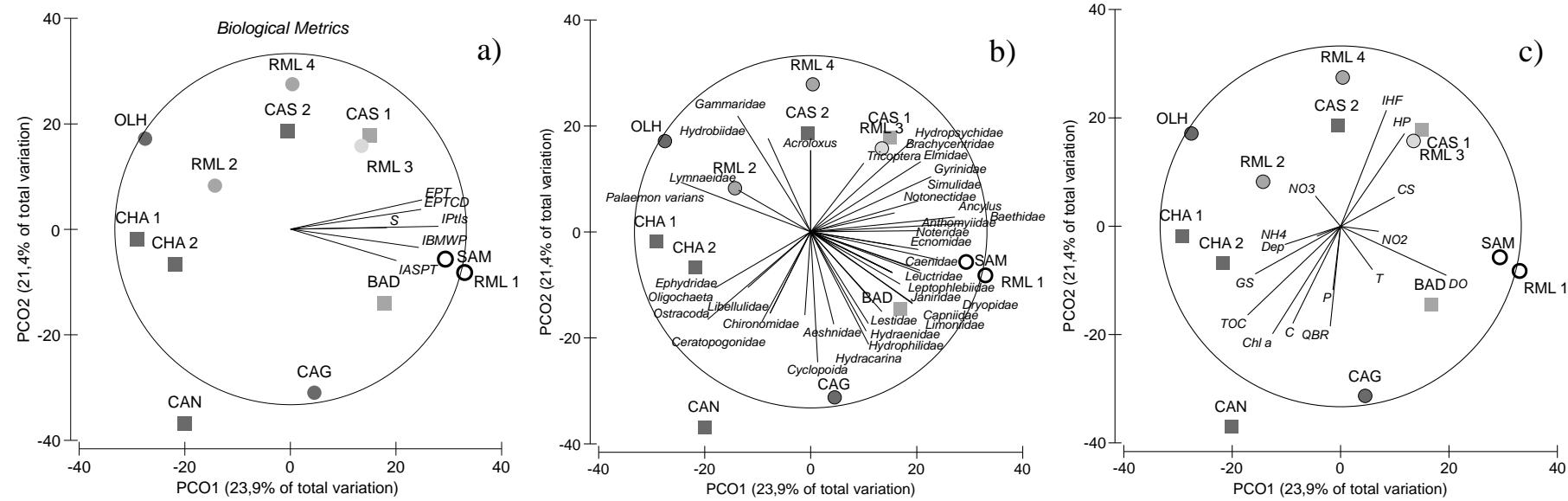
Foram encontradas abundâncias mais elevadas em Santo André (11948,33 ind/60') do que em Melides (5634,33 ind/60'). Os Insecta foram o grupo taxonómico dominante em ambos os sistemas ribeirinhos, devido às elevadas densidades de Chironomidae, seguindo-se os Amphipoda, Oligochaeta e Gastropoda, que foram os taxa dominantes nos locais RML 4, CAS 2, OLH e CHA 2 (Figura 18).

A PCO indica que as comunidades parecem estar estruturadas em função da qualidade ao longo do primeiro eixo, uma vez que os locais que obtiveram um IPTIs mais elevado se encontram no primeiro quadrante positivo, associadas a maiores concentrações de oxigénio dissolvido, enquanto as piores classificações se encontram maioritariamente no primeiro quadrante negativo, correlacionadas com maiores concentrações de nitratos, amónia, clorofila a e conteúdo em matéria orgânica do sedimento (Figura 19a). Os taxa associados aos locais com melhor qualidade ecológica são as famílias Gyrinidae, Baethidae, Noteridae e Leptophlebiidae e o gastrópode do género *Ancylus*. O segundo eixo da PCO, que explica uma % de variância muito similar ao primeiro, parece estabelecer uma separação entre os regimes de caudal dos locais amostrados, com os locais lóticos situados no quadrante positivo e os lênticos no quadrante negativo (Figura 19a).



**Figura 18.** Densidades dos grupos taxonómicos mais representativos nas bacias hidrográficas de Santo André e Melides.

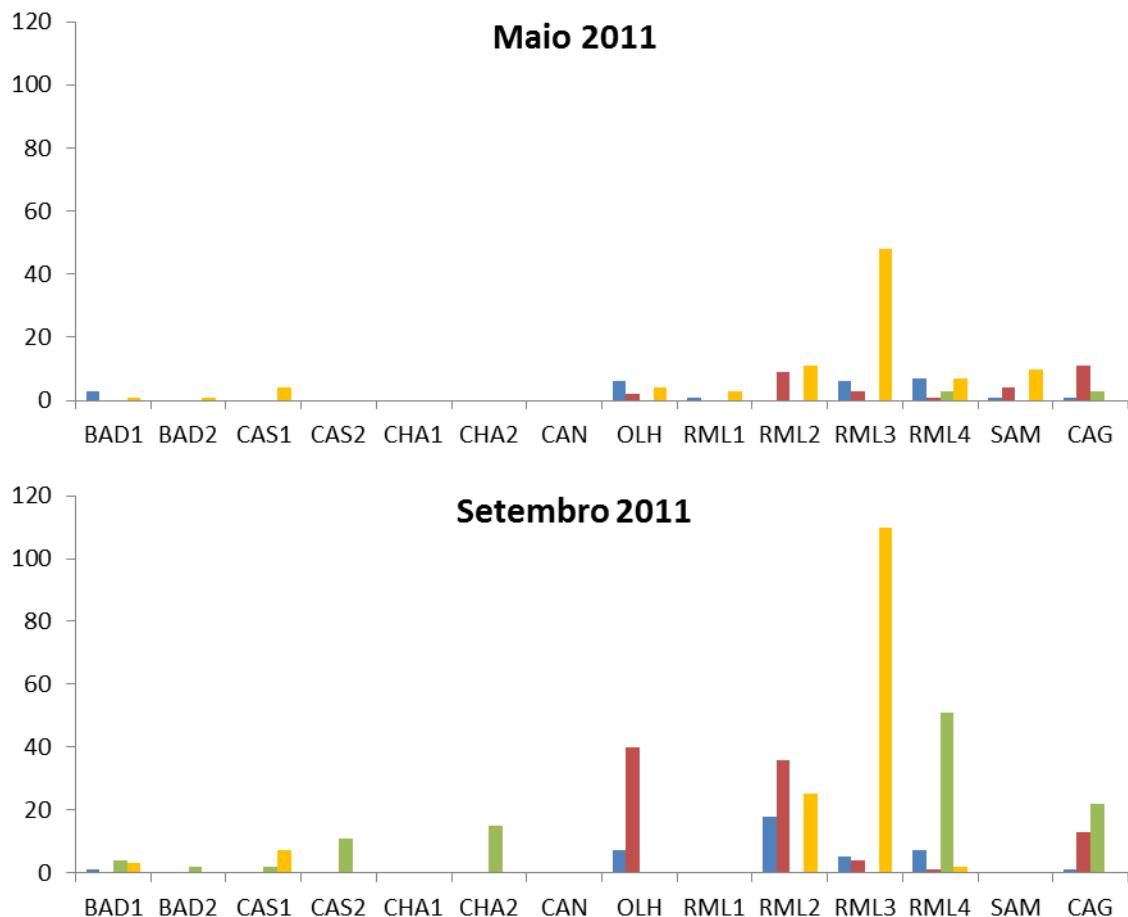
Maiores concentrações de MOT, clorofila a e fósforo estão correlacionadas com o quadrante dos locais com menor velocidade de corrente. Por sua vez, a família Hydrobiidae é a que apresenta maior correlação com o eixo correspondente aos locais lóticos, enquanto um conjunto alargado de taxa se encontram associados aos locais lênticos (Figura 19b). O posicionamento dos vectores dos índices IHF, QBR e PH indicam que os locais com maiores pressões humanas não obtiveram menores valores de IPTIs e que, concomitantemente, os locais com uma galeria ripícola bem estruturada não apresentaram melhor qualidade ecológica (Figura 19a). Salienta-se que no total se inventariaram 123 espécies de plantas nos troços prospectados (cf. Anexo 23), registando-se o número mais elevado (37) em OLH (Melides), um local sob forte influência antrópica e com valores de IHF e QBR intermédios, e o menor (8) em CHA2 (Santo André), um local com um dos valores mais elevados para IHF e um QBR baixo.



**Figura 19.** Principal coordinates analysis (PCO) of the benthic invertebrate communities of the Melides (□) and Santo André (●) river basins, based on log ( $x+1$ ) transformed abundances, using Bray-Curtis similarity as a resemblance measure. Spearman correlations of metrics included in the IPtIs calculation (a), benthic taxa (b) and environmental variables and human pressure ranking (c) with the PCO axes are represented as vectors. Ecological status classifications using IPtIs are indicated by the colors of symbols.

### Ictiofauna

Foram recolhidos um total de 535 indivíduos e identificados 4 espécies de peixes, *Anguilla anguilla*, *Cobitis paludica*, *Gambusia holbrooki* e *Iberochondrostoma lusitanicum*, todas presentes em ambas as bacias hidrográficas. Foram registadas abundâncias mais elevadas em Setembro (72.3%) do que em Maio (27.7%) e a maioria dos exemplares (90%) foi capturado na bacia de Melides (Figura 20).



**Figura 20.** Abundância das espécies ictiofaunísticas (ind/40m) capturadas nas bacias hidrográficas de Santo André e Melides, em Maio e Setembro de 2011.

A PCO indica uma separação entre os locais com características lênticas e lóticas, ao longo do primeiro eixo, com predominância da boga-portuguesa (*I. lusitanicum*) nos locais com caudais mais elevados e *G. holbrooki* nos habitats predominantemente lênticos (Figura 21A).

Os locais com características lênticas localizam-se maioritariamente na bacia de Santo André e estão associados a concentrações mais elevadas em matéria orgânica, amónia e clorofila a, enquanto os locais com características lóticas se encontram maioritariamente na bacia de Melides. Os locais situados a montante do afloramento do aquífero profundo, RML1 e SAM, têm um carácter intermitente, tendo secado em Setembro de 2011. As estações de amostragens situadas a jusante das ribeiras da Cascalheira e da Serradinha (CAS1 e CHA1) não registaram quaisquer espécies ictiofaunísticas em Maio de 2011 (Figura 19).

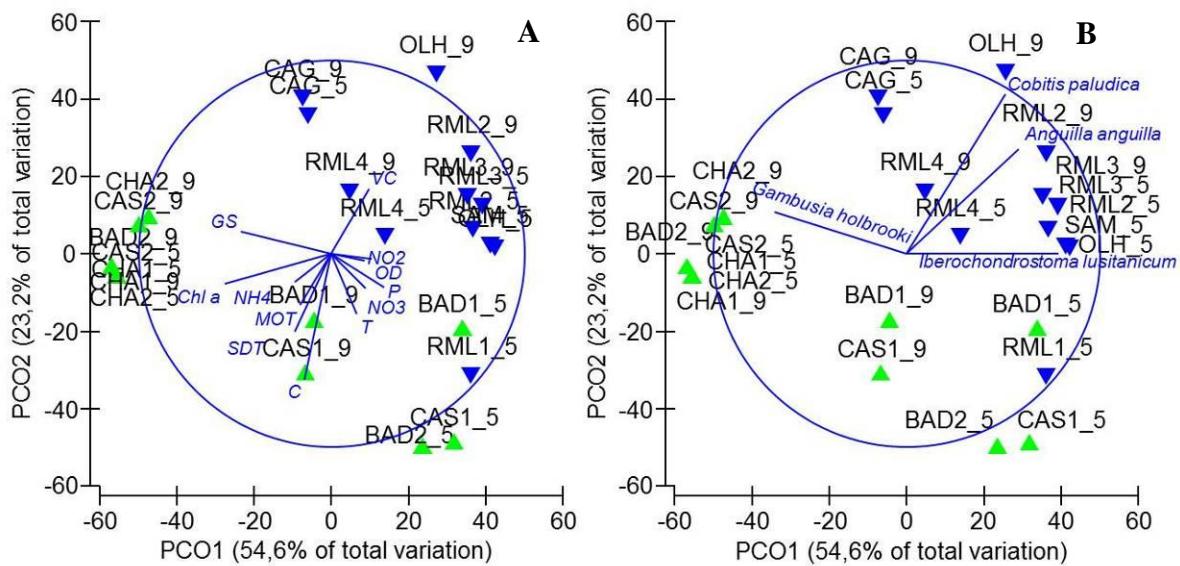


Figura 21. Análise de Coordenadas Principais da comunidade de peixes das bacias hidrográficas de Melides (▼) e Santo André (▲). A ordenação foi efectuada com base numa matriz de semelhanças determinada através coeficiente de Bray-Curtis, em dados transformados (raiz quadrada). Os vectores representam as correlações entre as variáveis ambientais (A) e taxa (B) com os eixos.

### 1.3.3. Discussão

À semelhança do que é indicado para outras bacias mediterrânicas, os Diptera são o grupo taxonómico mais importante das bacias de Melides e Santo André, com dominância da família Chironomidae (e.g. Coimbra et al., 1996; Bonada et al., 2000; Acuña et al., 2005; Chaves et al., 2008). No entanto, ao contrário da maioria das bacias mediterrânicas, onde os Ephemeroptera são outro grupo relevante, nestas bacias os Gammaridae são o segundo grupo dominante, por serem sistemas próximos da zona costeira, sendo estes crustáceos mais abundantes nas localizações mais a jusante (RML4, CAS2 e CHA2), já próximas dos sistemas salobros, tal como é observado em outros sistemas semelhantes (Subida et al., 2009). As maiores diferenças nas comunidades bentónicas entre locais amostrados parecem estar associadas ao carácter lêntico ou lótico desses locais e ao tipo de sedimento. Tal como indicado por outros autores (e.g. Voelz and McArthur, 2000; Duan et al., 2009; Pinto & Feio, 2009), os sistemas lóticos e com maior heterogeneidade de habitats (IHF) suportam uma maior diversidade de organismos e com menor tolerância a variações das condições ambientais. A composição da comunidade ictiofaunística é extremamente pobre, consistindo unicamente em 4 espécies diferentes, que integram um endemismo ibérico, *I. lusitanicum* e uma espécie comercialmente ameaçada, *A. anguilla*. Estas pequenas bacias têm uma riqueza específica inferior a outros sistemas ibéricos, como as ribeiras do Guadiana (Matono et al., 2012), provavelmente pela sua dimensão e por se encontrarem limitadas à zona costeira, tendo por isso menor diversidade de habitats disponíveis.

Os resultados obtidos com o índice proposto para avaliar a qualidade ecológica nos rios portugueses do Sul espelham estas necessidades, tendo-se obtido um bom estado em apenas três locais (SAM, RML1 e RML3), todos eles lóticos e com uma elevada variabilidade de sedimentos. Esta influência do tipo de habitat nos resultados obtidos com as ferramentas de avaliação do estado é evidente nas diferenças obtidas nas estações RML2 e RML3, espaçadas de 20m, localizadas respectivamente a montante e a jusante de um pequeno açude, tendo por isso regimes lêntico e lótico. Enquanto RML2 foi classificada como em estado moderado, RML3 obteve a classificação de bom estado, estando por isso em situações diferentes quanto ao

cumprimento dos objectivos da DQA, apesar de estarem sujeitas ao mesmo tipo de pressão humana. Estes resultados são indicativos de que o IPtIs parece ser uma ferramenta adequada para os sectores lóticos destas pequenas bacias mediterrânicas, mas não está adaptado para avaliar a qualidade ecológica dos troços lênticos destas ribeiras. Já a comunidade ictiofaunística parece indicar também a presença de habitats com alguma perturbação uma vez que, apesar de integrar espécies com uma tolerância intermédia às pressões humanas (*I. lusitanicum* e *C. paludica*), integra também um conjunto de espécies tolerantes (*A. anguilla* e *G. holbrooki*) (Segurado et al., 2011).

## Referências

- Acuña, V., Muñoz, I., Omella, M., Sabater, F., Giorgi, A., Sabater, S. 2005. Drought and postdrought recovery cycles in an intermittent Mediterranean stream: structural and functional aspects. Journal of the North American Benthological Society, 24, 919-933.
- Bonada, N., Rieradevall, M., Prat, N. 2000. Temporalidad y contaminación como claves para interpretar la biodiversidad de macroinvertebrados en un arroyo mediterráneo (Riera de Sant Cugat, Barcelona). Limnetica, 18, 81-90.
- Chaves, M. L., Rieradevall, M., Costa, J. L., Chainho, P., Costa, M. J., Prat, N. 2008. Macroinvertebrate communities of non-glacial high altitude intermittent streams. Freshwater Biology, 53, 55-76.
- Coimbra, C. N., Graça, M. A. S., Cortes, R. M. 1996. The effects of a basic effluent on macroinvertebrate community structure in a temporary mediterranean river. Environmental Pollution, 94, 301-307.
- Duan, X. H., Wang, Z. Y., Xu, M. Z., Zhang, K. 2009. Effect of streambed sediment on benthic ecology. International Journal of Sediment Research, 24, 325–338.
- INAG, 2008. Manual para a avaliação biológica da qualidade da água em sistemas fluviais segundo a Directiva Quadro da Água Protocolo de amostragem e análise para a fauna piscícola. Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional. Instituto da Água, I.P.
- INAG, 2009. Critérios para a classificação do estado das massas de água superficiais- Rios e Albufeiras. Ministério do Ambiente, Ordenamento do Território e do Desenvolvimento Regional. Instituto da Água, I.P.
- Jáimez-Cuéllar, P., Vivas, S., Bonada N., Robles, S., Mellado, A., Álvarez, M., Avilés, J., Casa, J., Ortega, M., Pardo, I., Prat, N., Rieradevall, M., Sáinz-Cantero, C. E., Sánchez-Ortega, A., Suárez, M. L., Toro, M., Vidal-Abarca, M. R., Zamora-Muñoz, C., Alba-Tercedor, J. 2002. Protocolo GUADALMED (PRECE). Limnetica, 21, 187–204.
- Matono, P., J.M. Bernardo, T. Oberdorff & M. Illhéu. 2012. Effects of natural hydrological variability on fish assemblages in small Mediterranean streams: Implications for ecological assessment. Ecological Indicators 23: 467–481.

Pinto, P., Feio, M. J. 2009. Eficiência dos índices de macroinvertebrados desenvolvidos no exercício de intercalibração na avaliação do estado ecológico dos rios de Portugal continental. Revista APRH, 30, 65-76.

Prat, N., Rieradevall, M., Fortuño, P. (2012). Metodología F.E.M. para la evaluación del estado ecológico de los ríos Mediterráneos. Departament d'Ecologia Universitat de Barcelona.

Salvador, N., R. Hugman, T. Stigter, J.P. Monteiro, L. Nunes & D. Duarte. 2013. Quantificação e modelação das relações rio-aquífero no sistema aquífero de Sines. Uma contribuição para a avaliação do estado da lagoa de Santo André. 9º Seminário Sobre Águas Subterrâneas, 7-8 Março de 2013, Campus de Caparica, Portugal.

Segurado, P., J.M. Santos, D. Pont, A.H. Melcher, D.G. Jalon, R.M. Hughes, M.T. Ferreira. Estimating species tolerance to human perturbation: Expert judgment versus empirical approaches. Ecological Indicators 11: 1623–1635.

Subida, M. D., Cunha, M. R., Moreira, M. H. 2009. Life history, reproduction, and production of *Gammarus chevreuxi* (Amphipoda: Gammaridae) in the Ria de Aveiro, northwestern Portugal. Journal of the North American Benthological Society, 24, 82-100.

Voelz, N. J, McArthur, J. V. 2000. An exploration of factors influencing lotic insect species richness. Biodiversity and Conservation, 9, 1543–1570.

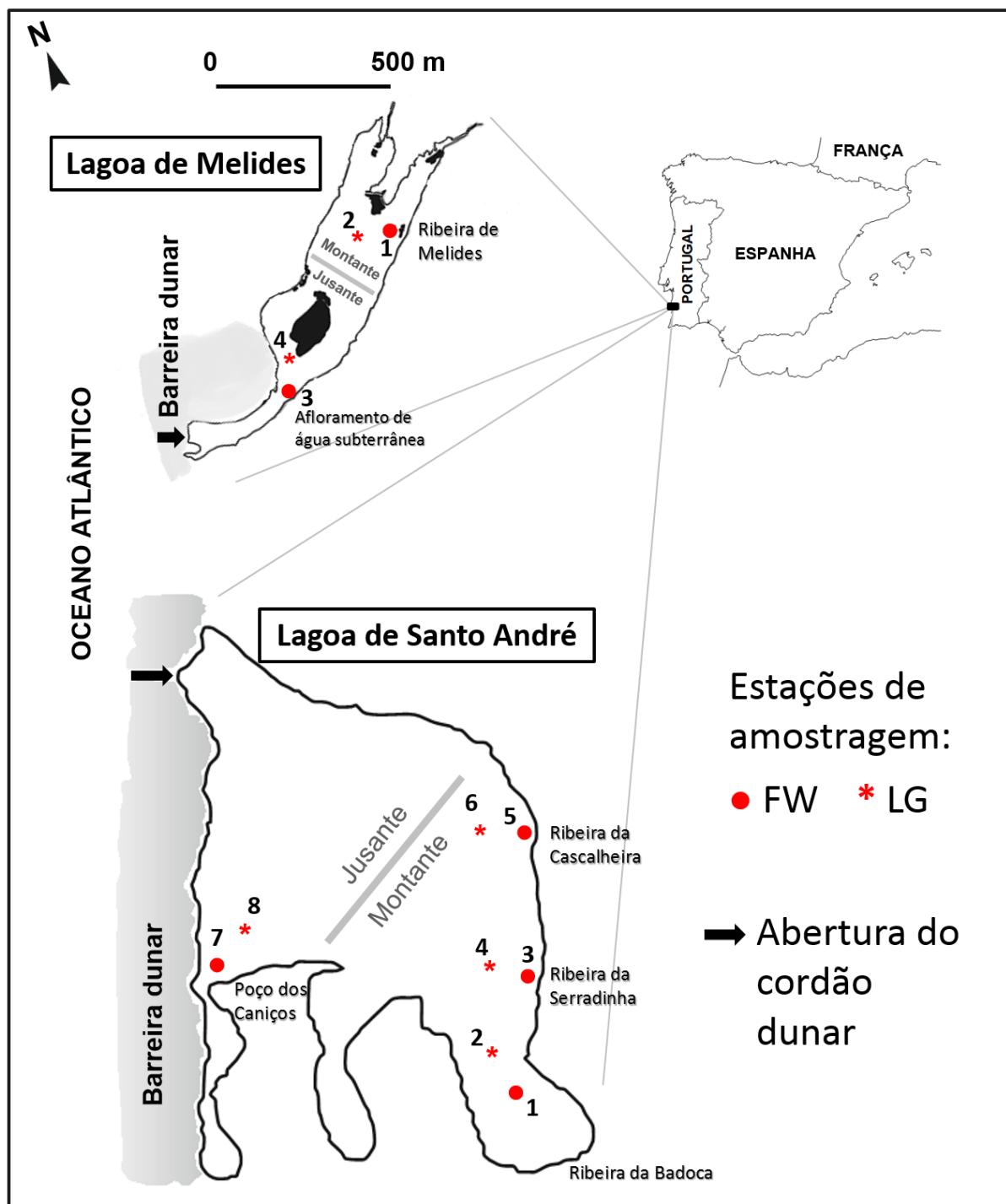
## **1.4. Zonas de descarga (ribeiras-lagoas)**

### **1.4.1. Metodologia**

#### *Macrozoobentos*

Nos ambientes lagunares ocorrem um grande número de diferentes taxa com origens diversas (marinha, aquática continental), que aí subsistem pouco tempo. Poucas espécies, conseguindo tolerar as elevadas variações ambientais que ocorrem, aí se mantêm durante todo o ano. São as consideradas "especialistas lagunares", que por se desenvolverem em habitats actualmente muito ameaçados, devem ser consideradas como particularmente importantes em termos de conservação (Bamber et al., 1992; Barnes, 1999). A amostragem de invertebrados bentónicos foi efectuada em 2011 durante o período de isolamento ao mar, em Maio e Setembro, o período de maior predominância de tais espécies, a distâncias crescentes a partir da zona de confluência de água doce (FW – a 50m da confluência) em direcção ao interior da laguna (zona sem influência directa de água doce – LG – a 200m da confluência) e ao longo das lagunas (montante/jusante), conforme apresentado na Figura 22. Foram ainda realizadas amostragens na zona de abertura de ambas as lagoas a fim de tornar a respectiva listagem de espécies mais completa, embora não tenha sido exequível a sua análise estatística. As colheitas de sedimento foram realizadas utilizando uma draga van Veen (0,05 m<sup>2</sup>), tendo-se efectuado três dragagens para análise da macrofauna bentónica (3 replicados) e uma para sedimentologia. As amostras foram processadas com uma rede de malha 500 µm, fixadas com formol 4% (neutralizado com borato de sódio), corado (Rosa de Bengala) e conservadas em álcool a 70º. Foram

posteriormente triadas com auxílio de uma lupa binocular, e os organismos identificados, sempre que possível, até ao nível da espécie e contados.



**Figura 22.** Área de estudo, com a localização das estações de amostragem e indicação de tributários de água-doce. FW – zona de influência directa de água-doce (50 m da confluência); LG – sem influência directa de água-doce (200 m da confluência). Cada número impar é uma zona FW e o seu número par subsequente é a respectiva zona LG.

A composição granulométrica do sedimento e a matéria orgânica total (MOT) foram determinadas segundo os protocolos atrás descritos. A análise estatística dos dados, foi efectuada com recurso ao software Primer® v6

(Clarke & Gorley, 2006; Anderson, Gorley & Clarke, 2008), utilizando as rotinas PERMANOVA, Simper e MDS para investigar a existência de padrões na comunidade bentónica e respectiva relação com os factores abióticos/ambientais.

#### *Ictiofauna*

Nestes sistemas, os peixes são um dos grupos menos estudados, principalmente no que diz respeito à composição específica e padrões de distribuição espacial. O presente trabalho visou o estudo da estrutura das comunidades de peixes e sua distribuição nas Lagoas de Melides e Santo André, localizadas na região sudoeste Portuguesa (Figura 22). A amostragem foi efectuada duas vezes durante o período de isolamento ao mar em 2011 (Julho e Setembro), colocando nassas (malha de 18 mm), por um período de 24h, a distâncias crescentes (cf. Figura 22) a partir da zona de confluência de água doce (FW – a 50m da confluência) em direcção ao interior da laguna (zona sem influência directa de água doce – LG – a 200m da confluência) e ao longo das lagunas (montante/jusante). Foram ainda utilizadas outras artes de pesca (arrasto-de-vara e redes-de-emalhar) a fim de completar a listagem de espécies, embora estas não tenham sido consideradas na análise estatística. Os exemplares capturados foram identificados à espécie, contados, medidos e atribuído um grupo ecológico de acordo com Elliott & Dewailly (1995) e Gordo & Cabral (2001). Foram ainda determinados vários parâmetros ambientais de interesse em cada campanha de amostragem, representados nos resultados da análise. Para a análise espacial das comunidades piscícolas e sua relação com os parâmetros ambientais recorreu-se a análises de variância com permutação – PERMANOVA (Anderson, Gorley & Clarke, 2008) – e análises canónicas de correspondências – CCA (ter Braak, 1986).

#### **1.4.2.Resultados**

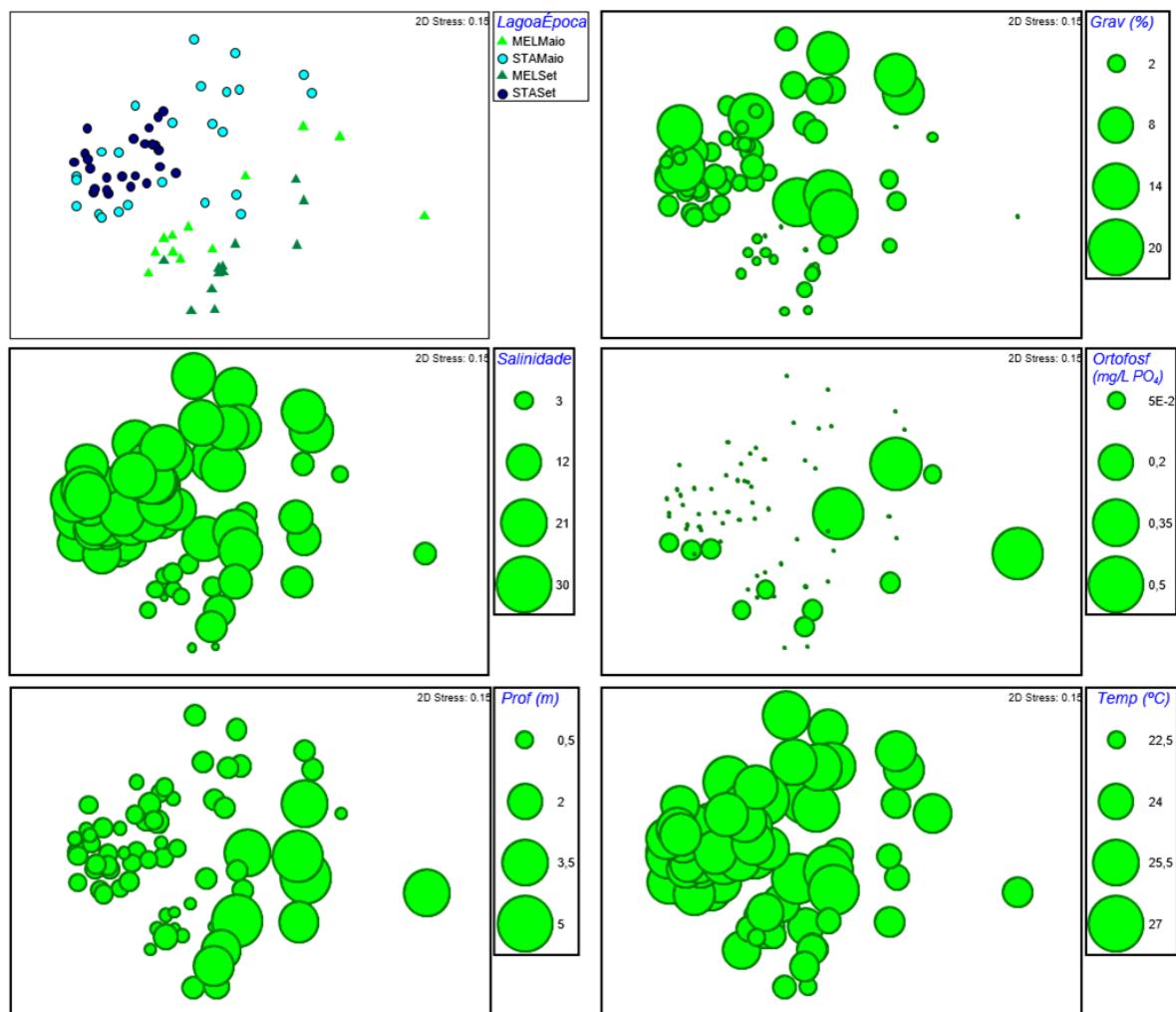
##### *Macrozoobentos*

Foram recolhidos um total de 78799 espécimes de invertebrados e identificados 83 taxa, 71 na Lagoa de Santo André e 34 na Lagoa de Melides (21 taxa comuns) (Tabela 4). A maioria das espécies identificadas são típicas de sistemas lagunares, sendo os Chironomidae, Ostracoda, *Hydrobia ulvae*, Oligochaeta, *Lekanesphaera hookeri* e *Abra segmentum* os taxa que apresentam maior percentagem de ocorrência e representam cerca de 90% da abundância média nas duas lagoas.

**Tabela 5** – Contribuição dos diferentes taxa para a dissemelhança média (61,21%) entre as Lagoas de Santo André e Melides, Taxa classificados por ordem de importância, com um corte a cerca de 75%.

<b>Espécies</b>	<b>Group MEL</b>	<b>Group STA</b>		
	<b>Av. Abund</b>	<b>Av. Abund</b>	<b>Contrib. %</b>	<b>Cumul. %</b>
Ostracoda	5,01	2,91	14,78	14,78
<i>Abra segmentum</i>	0,00	3,45	14,25	29,03
Oligochaeta	1,24	3,28	11,79	40,82
<i>Hydrobia ulvae</i>	0,66	3,04	10,44	51,26
Chironomidae	4,85	4,54	8,01	59,27
<i>Desdemona ornata</i>	0,00	1,63	5,63	64,90
<i>Lekanesphaera hookeri</i>	1,42	0,18	5,61	70,51
<i>Hediste diversicolor</i>	0,72	0,41	3,29	74,10

Embora se observe que os taxa mais frequentes e mais abundantes sejam comuns nas duas lagoas (excepto *Abra segmentum* que é exclusiva da Lagoa de Santo André), a estrutura das duas comunidades é diferente (Figura 23), observando-se maior abundância de *Abra segmentum*, Oligochaeta, *Hydrobia ulvae* e *Desdemona ornata* em LSA e de Ostracoda, Chironomidae, *Lekanaspheira hookeri* e *Hediste diversicolor* em LM (Tabela 5). A diferença entre as lagunas observa-se também nas respectivas condições ambientais, com valores mais elevados de salinidade e temperatura, e sedimentos mais grosseiros na primeira, enquanto em LM se registam profundidades mais elevadas e maior concentração de ortofosfatos (Figura 23).



**Figura 23.** Análise MDS (Multi-dimensional scaling ordination) realizada com os valores de densidade dos taxa identificados nas lagoas Santo André e Melides em cada época de amostragem (A). Representação da variação dos valores de salinidade (B), profundidade (C), % Cascalho (D), concentração de ortofosfatos (E) e temperatura (F) nas estações amostradas.

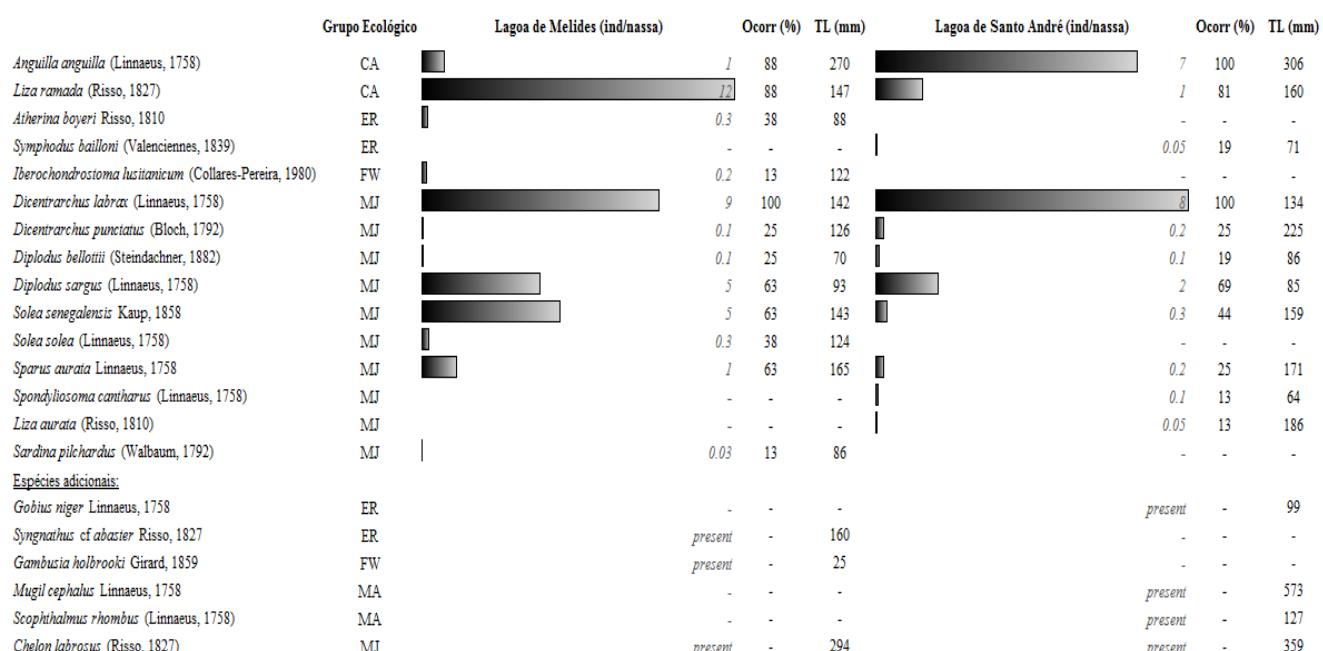
A estrutura da comunidade de invertebrados em cada laguna não apresenta diferenças significativas entre as zonas de confluência de água doce (FW) e as zonas lagunares (LG), com exceção das zonas da Serradinha (apenas em Maio) e Caniços na Lagoa de Santo André (Tabela 6).

**Tabela 6** – Resultados da análise permutacional não métrica (PERMANOVA) de quatro fatores (Fixos: lagoa (La), época (Se), distância à confluência (Di); Aleatório: zona de confluência (Co)), para os padrões de abundância dos macroinvertebrados.

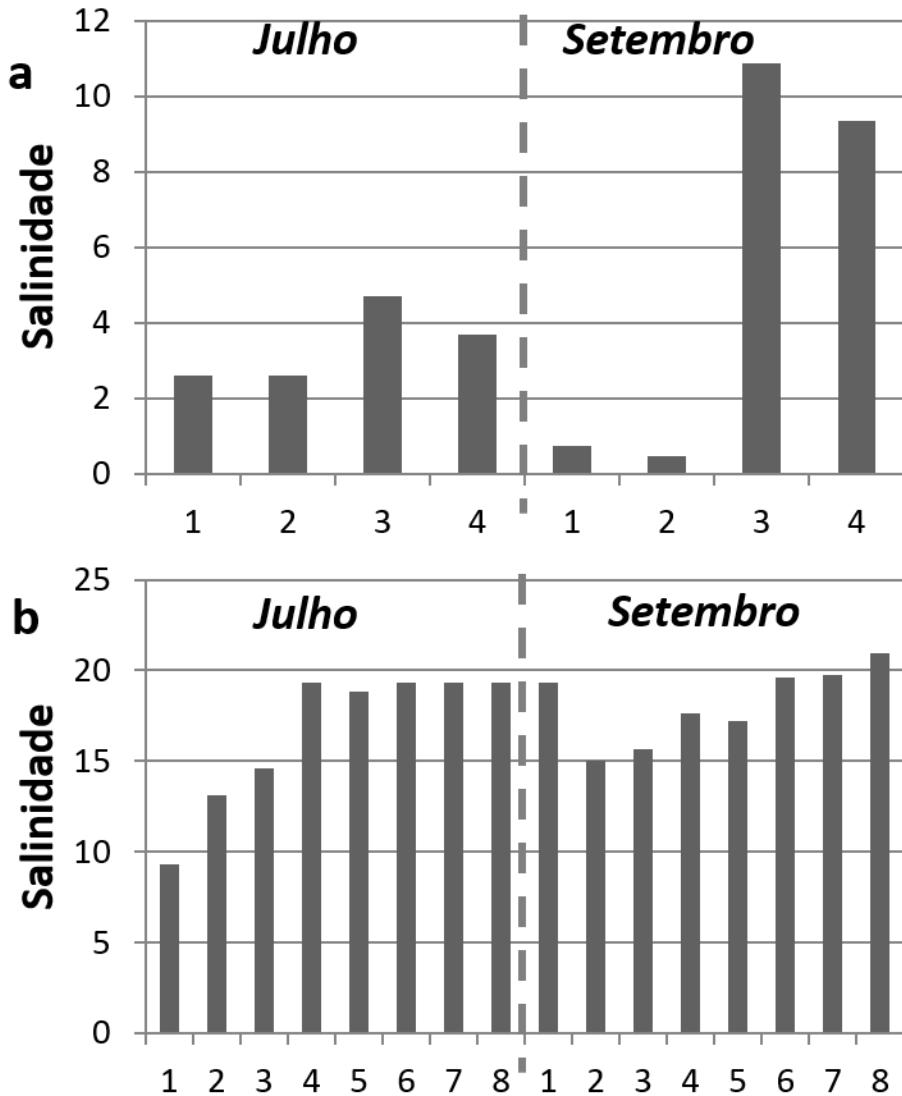
	df	SS	MS	Pseudo-F	P(perm)	U Perms	P (MC)
La	1	24206	24206	4.9795	0.0646	15	0.007
Se	1	5593.5	5593.5	2.9733	0.0688	9929	0.0339
Di	1	1721.8	1721.8	0.89357	0.482	9911	0.5151
Co (La)	4	19445	4861.2	9.0396	0.0001	9918	0.0001
LaxSe	1	4591.8	4591.8	2.4408	0.0986	9930	0.0641
LsxDi	1	3886	3886	2.0167	0.1566	9912	0.1117
SexDi	1	719.96	719.96	0.50096	0.7269	9950	0.7917
SexCo (La)	4	7225	1881.3	3.4983	0.0001	9907	0.0001
DixCo (La)	4	7707.7	1926.9	3.5832	0.0001	9908	0.0001
LaxSexDi	1	1779.3	1779.3	1.2381	0.3234	9954	0.3356
SexDixCo (La)	4	5748.6	1437.1	2.6725	0.0001	9907	0.0006
Res	48	25812	537.76				

### Ictiofauna

**Tabela 7.** Lista das espécies e suas abundâncias médias (número de indivíduos por nassa, em 24h de amostragem), para cada lagoa (barras exprimem abundância relativa). Espécies agrupadas por grupo ecológico, segundo Elliott & Dewailly (1995) e Gordo & Cabral (2001): Residente estuarino (ER), Ocorrência marinha ocasional (MA), Migradores diadromos (CA), Migradores sazonais marinhos (MS), Migradores juvenis marinhos (MJ) e Espécie dulçaquídola ocasional (FW). Ocorr (%) – Percentagem de ocorrência, relativa às estações de cada lagoa; TL (mm) – Comprimento total médio de cada espécie. Espécies adicionais – espécies capturadas com outras artes de pesca, inviáveis para análise estatística, mas descritas para fornecer uma lista de ocorrências mais completa.



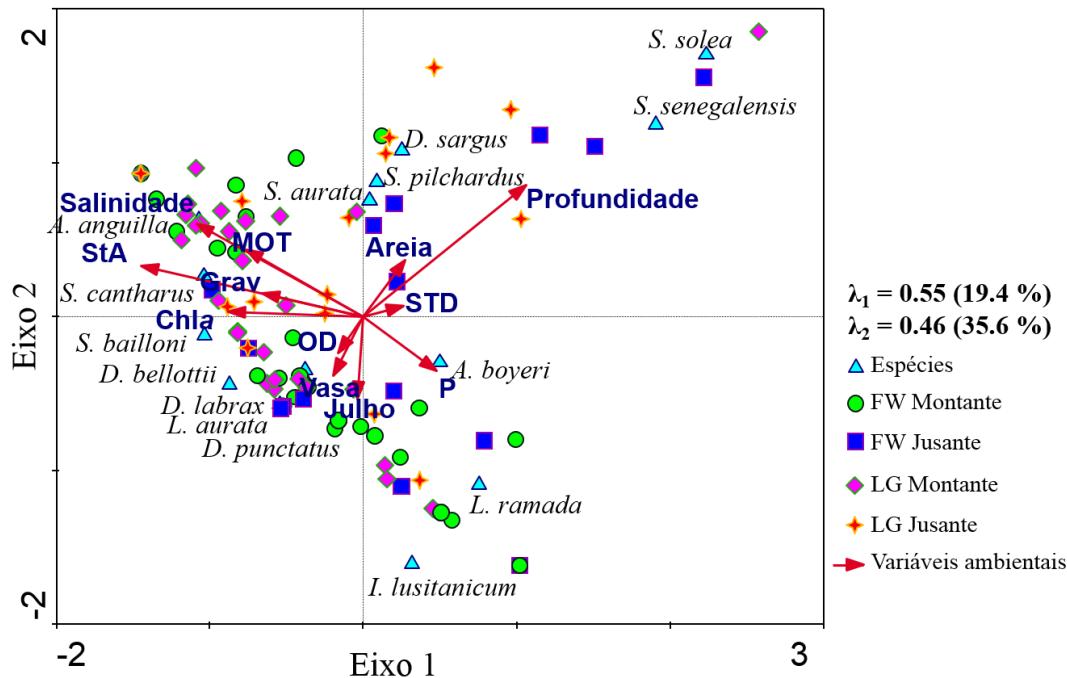
Através da metodologia descrita foram capturadas 12 espécies na lagoa de Melides e 11 em Santo André, sendo 8 delas comuns (i.e. 15 espécies diferentes, no total), conforme listado na Tabela 7. A maioria são migradores marinhos juvenis, embora as espécies com maior percentagem de ocorrência tenham sido *A. anguilla*, *Dicentrarchus labrax*, *Diplodus sargus* e *Liza ramada*. Relativamente à estrutura da comunidade, as diferenças significativas ocorreram entre montante e jusante ( $p<0.05$ ). Isto é, entre as áreas onde se encontram a maior diferença de salinidades (Figura 24).



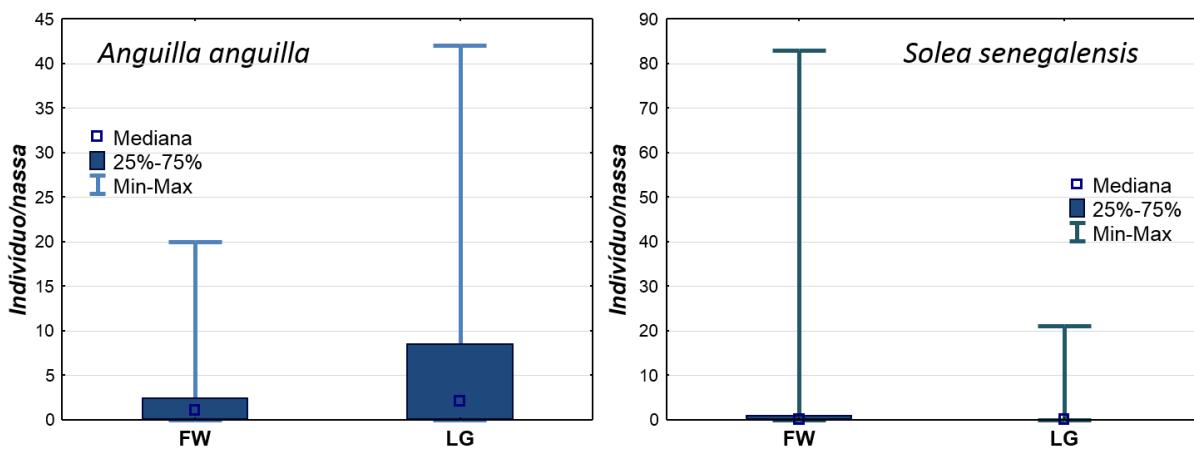
**Figure 24.** Valores de salinidade para as estações de amostragem de Melides (a) e Santo André (b), para ambos os períodos (Julho e Setembro). Estações ímpares estão sob influência directa de água-doce – 50 m da confluência (FW) – e estações pares estão a 200 m da confluência (LG).

No entanto, estrutura da comunidade demonstra que, de entre as espécies que a compõem, as mais tolerantes e oportunistas têm uma distribuição espacial mais alargada (Figura 25). Ou seja, espécies como *Atherina boyeri*, *L. ramada* e *Iberochodrostoma lusitanicum* restringem-se às áreas menos salinas (a última é exclusivamente dulçaquícola); *Solea solea*, *S. senegalensis*, *D. sargus* e *Sardina pilchardus* nas zonas de maior profundidade e mais salinas; e a abundância de *L. aurata*, *Dicentrarchus punctatus*, *D. labrax* e *Diplodus bellottii* coincide com zonas de maior produtividade primária. Apesar da estrutura da comunidade de

peixes não apresentar diferenças entre as zonas FW e LG, o mesmo não é verdadeiro para algumas espécies, analisadas individualmente. Verificou-se que a enguia é mais abundante no ambiente lagunar (LG) do que perto das confluências de água-doce (FW) e o linguado, *S. senegalensis*, segue o padrão oposto, sendo mais abundante em zonas FW (Figura 26).



**Figure 25.** Análise de Correspondências, com sobreposição de matriz de variáveis ambientais. Eigenvalues ( $\lambda_i$ ) e percentagem de variância explicada para os primeiros dois eixos. Variáveis ambientais: Salinidade; Matéria orgânica total (MOT); Profundidade; Santo André (var dummy - StA); Areia; Cascalho grosso (Grav); Sólidos totais dissolvidos (STD); Clorofila a (Chla); Oxigénio dissolvido (OD); Vasa; Mês de amostragem (var dummy - Julho); Fósforo (P).



**Figure 26.** Gráfico de barras, representando diferenças de abundância de espécies entre zonas de influência directa de água-doce (FW) e sem influência directa de água-doce (LG). Teste de Wilcoxon com significância para *Anguilla anguilla* e *Solea senegalensis* ( $p<0.01$  and  $p<0.05$ , respectivamente).

A análise das comunidades planctónicas consistiu em várias abordagens, nomeadamente (i) a amostragem de águas e sedimentos de tanques de lastro de navios de várias proveniências, que acostaram a portos

nacionais, (ii) a realização de uma campanha de amostragem a bordo de um navio que efectuou a rota Lisboa-Açores-Lisboa, (iii) a monitorização do fitoplâncton de portos e marinas e (iv) o estudo do registo histórico do fitoplâncton da costa continental Portuguesa.

#### **1.4.3.Discussão**

##### *Macrozoobentos*

A estrutura da comunidade de macroinvertebrados bentónicos das Lagoas de Santo André e Melides é caracterizada pela predominância de poucas espécies e baixa diversidade, típico de sistemas com elevado stress ambiental (Elliott & Quintino, 2007). A variabilidade espacial e temporal encontrada reflecte não só a variabilidade das características abióticas dos sistemas estudados, mas também a adaptabilidade e a diversidade dos ciclos de vida das espécies identificadas (Lardicci & Rossi, 1998; Basset et al., 2008). Muitos dos taxa são oportunistas e de pequenas dimensões e podem aumentar ou diminuir de densidade rapidamente em resposta a perturbações bióticas e abióticas localizadas no tempo e no espaço (Pearson & Rosenberg, 1978; Basset et al., 2008), cuja relação poderá ser directa (e.g. impacte da salinidade ou temperatura no metabolismo) ou indirecta (e.g. influência da profundidade ou disponibilidade de compostos fosfatados na natureza dos micro-habitats criados ou disponibilidade alimentar) (e.g. Gürel et al., 2005).

O factor tamanho da lagoa parece ser também um factor com impacte na estrutura das comunidades (Bamber et al., 1992; Sabetta et al., 2007), embora de forma indirecta, oferecendo tanto mais potencial para a zonação quanto maior for. Em lagoas pequenas, facilmente um determinado fenómeno se dissipa por toda a lagoa, fazendo variar as condições espaciais e, com elas, a estrutura das comunidades biológicas. Estes resultados vêm corroborar o que tem vindo já a ser sugerido em estudos anteriores (Correia et al., 2012; Félix et al., 2013a, 2013b). Isto justifica, em parte, que as maiores diferenças das comunidades bentónicas sejam entre lagoas e não dentro de cada lagoa, coincidindo com as diferenças entre factores abióticos/ambientais, que, por sua vez, são mais acentuadas entre Melides e Santo André. Em todo o caso, verifica-se que mesmo as características de cada zona de confluência não são estáticas e variam dentro do mesmo período de isolamento ao mar (e mesmo ano hidrológico). No entanto, a análise da interacção entre o input de água doce dos tributários e a estrutura biológica dos sistemas estudados não identificou este como sendo um factor específico responsável pelo padrão faunístico observado. Efectivamente a estrutura destas comunidades não pode ser explicada por um único factor, nem pelos vários factores independentes, mas deverá ter em linha de conta a sinergia entre factores abióticos e a potencial influência de interacções bióticas (Barbone & Basset, 2010).

##### *Ictiofauna*

As diferentes ocupações de micro-habitats pelos peixes estarão relacionadas com um equilíbrio entre balanço osmótico, protecção contra predação e melhores condições tróficas, conforme já observado noutros sistemas (Costa et al., 2008; Vinagre et al., 2009). A presença das espécies de origem sub-tropical, *D. bellottii* e *D. punctatus* demonstra que, apesar de estas ocorrerem já há cerca de duas décadas na costa Portuguesa, estão já a colonizar estes habitats, locais onde anteriormente não se registavam ocorrências (Pombo & Rebelo, 2002; Ribeiro et al., 2008).

De uma forma geral, verifica-se que as lagoas fechadas são potenciais locais de viveiro e de alimentação para muitas espécies, especialmente oportunistas e que a composição das suas comunidades de peixes é

semelhante a sistemas abertos, embora com uma menor diversidade (e.g. Elliott & Dewailly, 1995; Gordo & Cabral, 2001; França et al., 2009). Esta grande diferença é facilmente explicada pelas variações abruptas deste ambiente confinado em relação à salinidade, temperatura, disponibilidade de oxigénio, pH, produtos decorrentes de fenómenos de lixiviação e de actividades antrópicas. Após a colonização das espécies, durante o período de abertura do cordão dunar (o ambiente marinho é a origem da maioria das espécies), a diversidade tende a diminuir e passa a ser regulada por taxas de mortalidade (que depende da plasticidade/tolerância das espécies colonizadoras), do número de espécies residentes e ocasionais espécies dulçaquícolas com algum nível de tolerância à salinidade (ambiente oligohalino). Além disso, a ausência de uma verdadeira zonação nas lagunas estudadas poderá estar relacionado com a sua dimensão, associada ao seu confinamento. Nestas lagunas, um determinado fenómeno, como a entrada água doce, facilmente se dissemina por todo o plano de água, pelo que a laguna tenderá para a homogeneidade ao longo do período em que está isolada do mar. Ao contrário do que ocorre em sistemas abertos, isto justificará a ausência de padrões de distribuição segundo o design experimental considerado (FW/LG), e apenas a existência de diferenças montante/jusante de acordo com a salinidade, que será o factor que mais influencia a distribuição das comunidades nestes sistemas.

## Referências

- Anderson, M.J., Gorley, R.N. & Clarke, K.R., 2008. *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods*. PRIMER-E, Plymouth, UK, 214pp
- Bamber, R.N.; Batten, S.D.; Sheader, M. & Bridgwater, N.D., 1992. On the ecology of brackish water lagoons in Great Britain. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 2: 65 -94.
- Barbone, E. & Basset, A. 2010. Hydrological constraints to macrobenthic fauna biodiversity in transitional waters ecosystems. *Rend. Fis. Acc. Lincei*, 21: 301–314.
- Barnes, R.S.K. 1999. The conservation of brackish water systems: priorities for the 21st century. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 9: 523–527.
- Basset A., Sabetta L., Sangiorgio F., Pinna M., Migoni D., Fanizzi F., Barbone E., Galuppo N., Fonda Umani S., Reizopoulou S., Nicolaïdou A., Arvanitidis C., Moncheva S., Trajanova A., Georgescu L. & Beqira S. 2008. Biodiversity conservation in Mediterranean and Black Sea lagoons: a trait-oriented approach to benthic invertebrate guilds. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 18: S4–S15.
- Clarke, K.R. & Gorley R.N. 2006. *PRIMER v6: User manual/tutorial*. PRIMER-E, Plymouth UK, 192pp.
- Correia MJ, Costa JL, Chainho P, Félix PM, Chaves, ML, Medeiros, JP, Silva G, Azeda C, Tavares P, Costa A, Costa AM, Bernardo J, Cabral HN, Costa MJ, Cancela da Fonseca L. 2012. Inter-annual variations of macrobenthic communities over three decades in a land-locked coastal lagoon (Santo André, SW Portugal). *Estuar Coast Shelf Sci* 110: 168-175.

Costa, J.L.; Domingos, I.; Assis, C.A.; Almeida, P.R.; Moreira, F.; Feunteun, E. & Costa, M.J. 2008. Comparative ecology of the European eel, *Anguilla anguilla* (L., 1758), in a large Iberian river. *Environmental Biology of Fishes*, 81: 421-434.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Netherlands Journal of Aquatic Ecology*, 29: 397-417.

Elliott, M., Quintino, V., 2007. The estuarine quality paradox. Environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. *Marine Pollution Bulletin* 54, 640e645.

Félix, P.M.; Correia, M.J.; Chainho, P.; Costa, M.J.; Cabral, H.N.; Domingos, I.M.; Costa, J.L. & Cancela da Fonseca, L. 2013a. Influence of streams discharges on the structure of fish communities of Portuguese land-locked coastal lagoons. *Cahiers de Biologie Marine* , 54: 429-437.

Félix P.M., Chainho P., Costa J.L., Correia M.J., Chaves M.L., Medeiros J.P., Cabral H.N., Wouters N., Bernardo J., Costa A.M., Cristo M., Silva G., Azeda C., Tavares P., Costa M.J. & Cancela da Fonseca L. 2013b. Short-term versus long-term changes in the benthic communities of a small coastal lagoon: implications for ecological status assessment. *Vie et Milieu*, 63(1): 11-22.

França, S.; Costa, M.J. & Cabral, H.N. 2009. Assessing habitat specific fish assemblages in estuaries along the Portuguese coast. *Estuarine Coastal and Shelf Science*, 83: 1-12.

Gordo, L.S. & Cabral, H.N. 2001. The fish assemblage structure of a hydrologically altered coastal lagoon: the Óbidos lagoon (Portugal). *Hydrobiologia*, 459: 125-133.

Gürel M., Tanik A., Russo R.C. & Gönenç I.E. 2005. Biogeochemical cycles. In Gönenç I.E. & Wolflin J.P. (Eds) *Coastal Lagoons: Ecosystem Processes and Modeling for Sustainable Use and Development*. 79–192. CRC Press, Boca Ratón, Florida.

Lardicci C. & Rossi F., 1998. Detection of stress on macrozoobenthos: evaluation of some methods in a coastal Mediterranean lagoon. *Mar. Environ. Res.* 45:367–386.

Pearson, T.H., Rosenberg, R., 1978. Macrofaunal succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* 16, 229–311.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organization of a coastal lagoon fish community - Ria de Aveiro, Portugal. *Cybium*, 26: 185-196.

Ribeiro, J.; Monteiro, C.C.; Monteiro, P.; Bentes, L.; Coelho, R.; Gonçalves, J.M.S.; Lino, P.G. & Erzini, K. 2008. Long-term changes in fish communities of the Ria Formosa coastal lagoon (southern Portugal) based on two studies made 20 years apart. *Estuarine Coastal and Shelf Science*, 76: 57-68.

Sabetta L., Barbone E., Giardino A., Galuppo N. & Bassett A., 2007. Species-area patterns of benthic macro-invertebrates in Italian lagoons. *Hydrobiologia* 577:127–139.

ter Braak C.J.F. 1986. Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis. *Ecology*, 67: 1167-1179.

Vinagre, C.; Maia, A.; Reis-Santos, P.; Costa, M.J. & Cabral, H.N. 2009. Small-scale distribution of Solea solea and Solea senegalensis juveniles in the Tagus estuary (Portugal). *Estuarine Coastal and Shelf Science*, 81: 296-300.

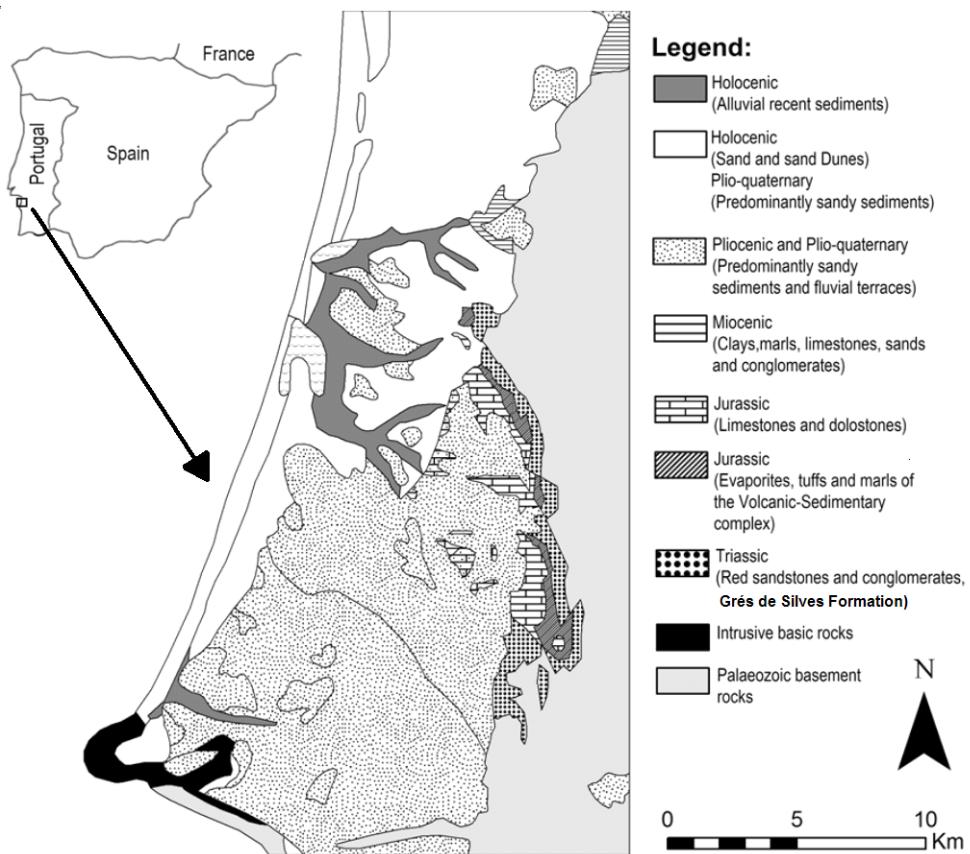
## 1.5. Cenários de modelação

### 1.5.1. Groundwater flow model for the detritic Sines aquifer

Several efforts to simulate the Sines multi-layer aquifer system using numerical models were undertaken for various purposes (Chambel and Monteiro 2007; Fernandes et al. 2006; Monteiro et al. 2008; Monteiro et al. 2010, Monteiro et al. accepted), though, any of these focused particularly on the groundwater-surface water interaction on the streams leading to the Santo André Lagoon (SAL). In order to estimate the groundwater contributions from the top detritic Sines aquifer to the surface water streams leading to the SAL, a finite element numerical flow model was developed.

Monteiro et al. (accepted) synthetizes a hydrogeological characterization to the Sines Multi-Aquifer System as follows. The Sines Multi-Aquifer System (SMAS), is located on the southwest coast of Portugal, extends over an area of 250 km<sup>2</sup>, and encompasses the municipalities of Grândola, Santiago do Cacém and Sines. The system is limited to the East by the Palaeozoic formations and the volcano-sedimentary complex which are overlapped by the Grés de Silves (Triassic), to the South and to the North by the Junqueira and the Fontainha streams respectively, and to the West by the Atlantic Ocean (Almeida et al. 2000). The two main components of this multi-aquifer system are a lower artesian karst aquifer which develops in Jurassic limestone and dolomites, and a top porous free aquifer which is found in the marine Miocene and Plio-Pleistocene formations. The last one is sometimes described as subdivided in at least two aquifers, being one of them semi-confined, which is due to the fact that some clay intercalations may, in some places, create two or more aquifer layers. Anyway, these clay layers are not continuous and the aquifer can broadly be considered phreatic. A detailed description of the hydrostratigraphic unities is presented in Monteiro et al. (2008).

Figure 27 presents a geological map of the region. The Holocene deposits, associated with lowlands at the Melides (0.4 km<sup>2</sup>), Santo André (2.5 km<sup>2</sup>) and Sancha (0.2 km<sup>2</sup>) lagoons were deposited along the terminal reaches of the Melides, Ponte, Badoca and Sancha creeks. These deposits consist essentially of detritic, minerogenic and organic sediments arranged in several units with a maximum thickness of about 40 m (Freitas et al. 2002).

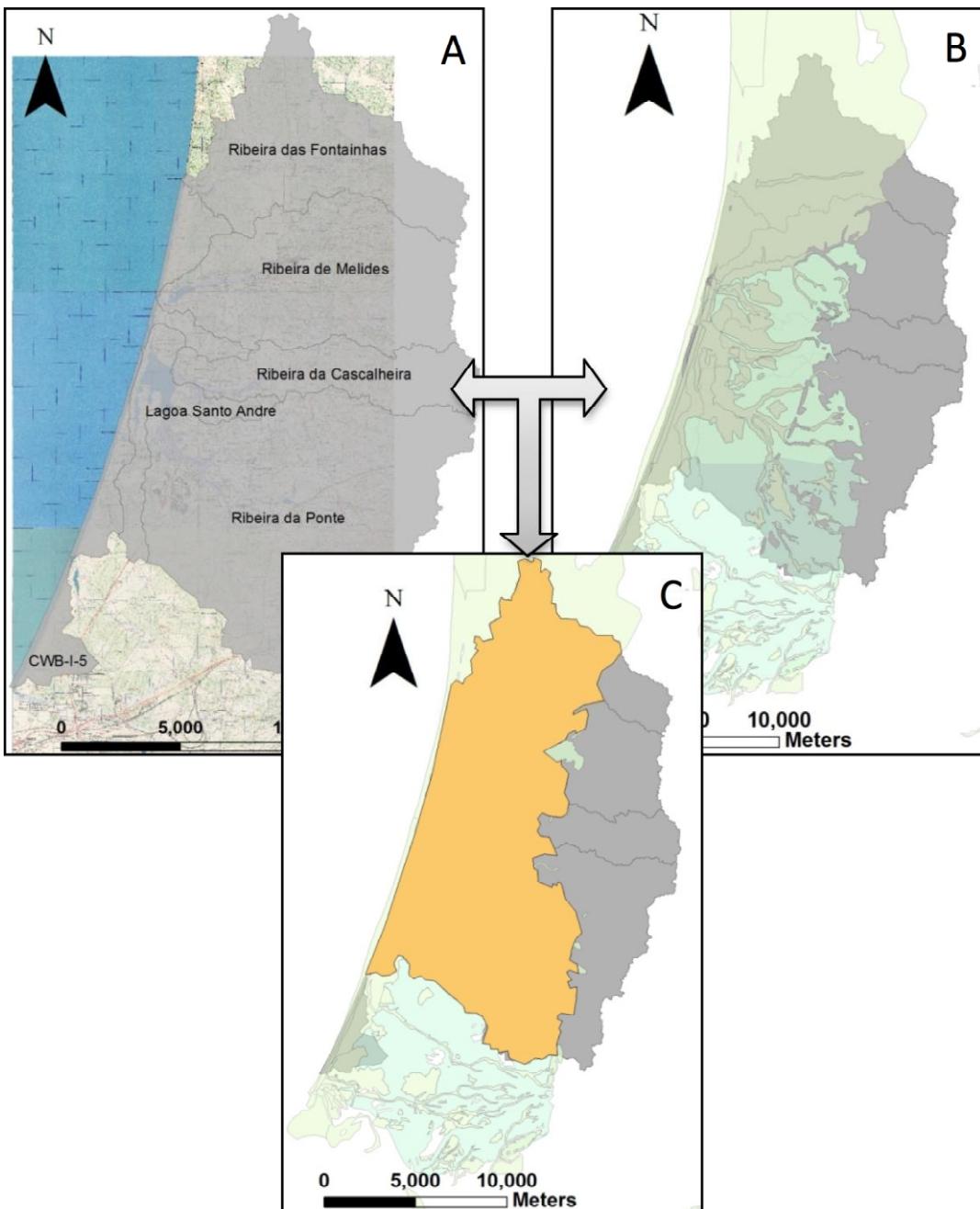


**Figure 27.** Geologic map of the Sines Multi-Aquifer System. Source: Monteiro et al. accepted, adapted from Oliveira et al. (1984) and Inverno et al. (1993).

These deposits limit the hydraulic connection between the lagoons and the shallow detritic aquifer, due to the fine fraction of the sediments in the lagoons. However, as the streams associated with the shallow lagoons (less than 2 m of water column) are effluent in the terminal reaches, where sediments are coarser than in the bottom of the lagoons, the water balance of the lagoons is controlled by the hydraulic connection of the stream network with the shallow aquifer.

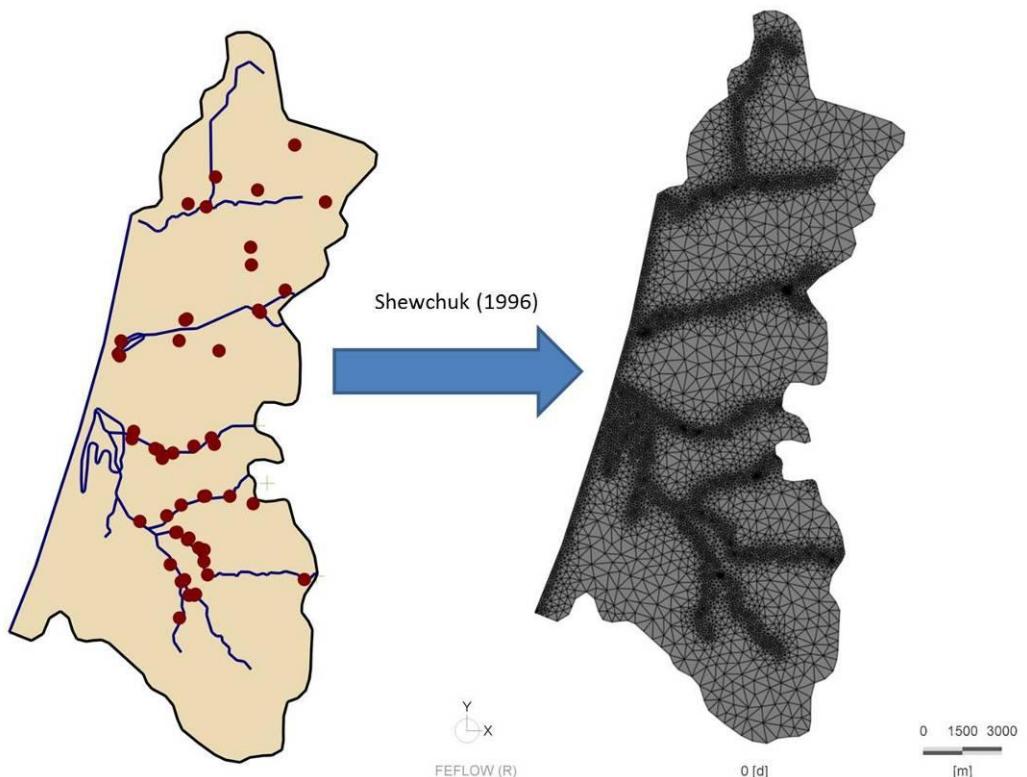
#### 1.5.1.1. Model flow limits

The developed model only considers the top detritic aquifer of Sines, once this is the only sector which contributes directly with water discharge to the streams. Hence, the numerical flow model limits were defined as the sea to the west and as the interception of the Sub-River Basins of interest (Ribeira das Fontainhas, Ribeira da Cascalheira, Lagoa de Santo André, Ribeira de Melides and Ribeirada Ponte) and the Plio-Quaternary layer of Sines, corresponding to the top detritic aquifer, as can be seen in Figure 28. These limits were defined using SIG tools.



**Figure 28.** SIG Analysis to determine the numerical model flow limits. A - Identification and location of Sub-River Basin (in grey) and SAL, with the 1:25000 scale military maps numbers 495, 505 and 516 behind. B – Location of the Plio-Quaternary layer of Sines on top of the sub-river basins of interest. C – Outcome limits of the groundwater flow model (orange).

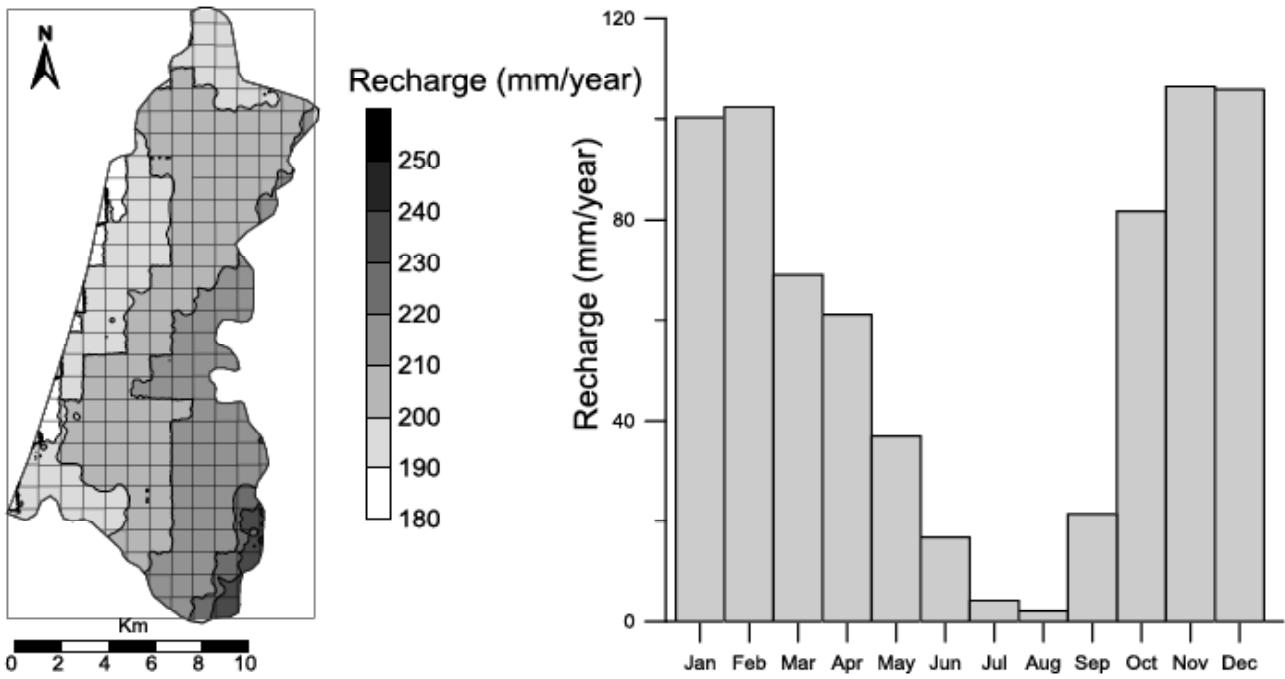
The finite-element mesh was created with Feflow 6.0 (DHI-WASY HmbH) with support of Shewchuk (1996) tool for Mesh Generation and Delaunay Triangulation, taking into account the refining of model nodes at a) the 47 observation points, of which 4 hydraulic head data loggers installed on purpose for this project; b) the streams of interest to the project; c) the Santo André and Melides Lagoons; and d) the coastline. The resulting model 2-D mesh consisted of a total area of  $192.880 \text{ km}^2$ , 13160 elements and 6785 nodes (Figure 29).



**Figure 29.** Mesh generation process, with the location of the observation points (red dots), the streams, Lagoon limits and the coastline (blue lines).

#### 1.5.1.2. Water Balance

Recharge rates applied in the model, 29%, are the same as estimated by Lobo-Ferreira et al. (1999) which are based on the method Vermeulen et al. (1994) with a DRASTIC model for aquifer recharge. Two precipitation data series were considered. Until late in the project, daily precipitation data was not available for the region, so, an average pluriannual monthly series with a  $1 \text{ km}^2$  distribution calculated by Nicolau (2002) was used to estimate precipitation and recharge distribution in the model region. Assuming the recharge rate estimated by Lobo-Ferreira et al. (1999) and considering an average rainfall distribution of 708 mm/year calculated by Nicolau (2002) for the period of 1959/60 – 1990-91, total annual recharge accounts to  $39.5 \text{ hm}^3/\text{year}$  with spatial and temporal distribution as stated in Figure 30.



**Figure 30.** Recharge spatial (left) and temporal (right) distribution according to the average monthly precipitation spatial and temporal distribution calculated by Nicolau (2002) and Lobo-Ferreira (1999) estimated recharge rate.

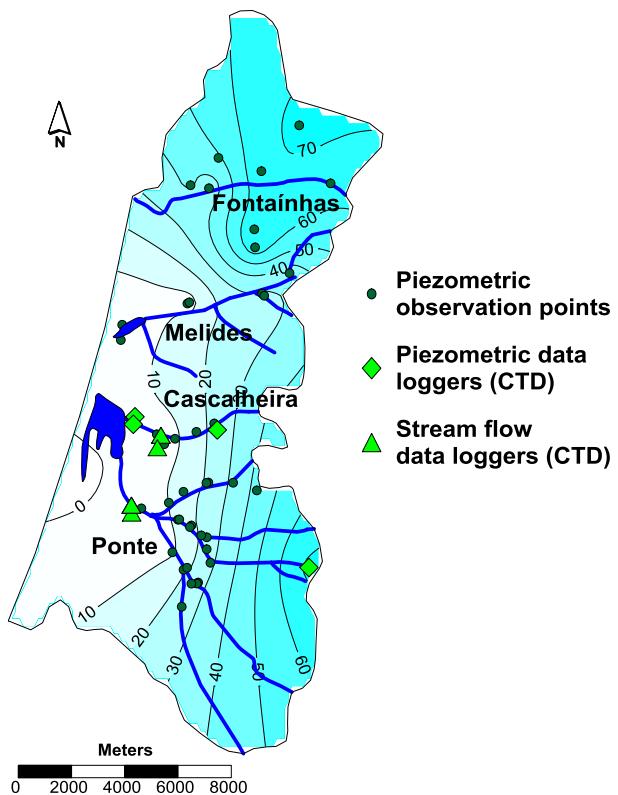
This method was used for early calibration of the permanent-state model. Later, daily precipitation data from Sines weather station managed by the Portuguese Institute of Ocean and Atmosphere (IPMA) was provided for a 30 year period, from 1st July 1983 to 30th June 2013, with an annual mean precipitation of 530 mm/year for 29 hydrological years (1983/84 – 2012/13). The same recharge rate, estimated by Lobo-Ferreira et al. (1999) was applied to the precipitation series, resulting in an annual recharge of 29.5 hm<sup>3</sup>/year. The last approach was used for latter calibration of permanent model, before running the transient model and to estimate the prospective climatic change scenarios precipitation.

Water abstractions volumes from Public supply, Industry, private supply and irrigation, with locations provided by the local River Basin Administration (ARH Alentejo) are estimated by Monteiro et al. (accepted), and account a total of 13.96 hm<sup>3</sup>/year for the Multi-Aquifer System of Sines. Yet, the same author considers only private supply and irrigation abstractions extract water from the top detritic aquifer, which sums 7.56 hm<sup>3</sup>/year. The latter value was the reference volume considered in the model which was spatially distributed into the 133 abstractions locations provided by ARH Alentejo.

#### 1.5.1.3. Monitoring strategy

A monitoring campaign was planned to estimate streams baseflow and hydraulic head levels and variation in order to collect data and calibrate the model. To estimate the baseflow, four automatic water level data- loggers (CTD) were installed, in November 2011, close to the mouths of the two main streams (Cascalheira and Ponte) and two smaller streams (which were found to maintain flow all year). Simultaneously, 53 observation points were considered for the piezometric monitoring network, of which four CTD were installed in wells in the upper aquifer, continuously recording aquifer levels which were later used for model calibration.

Figure 31 presents a distribution of the monitoring plan associated with the hydraulic head distribution calculated from the field data.



**Figure 31.** Identification and location of the main streams; hydraulic head distribution for the modeled region based on field data and; location of the hydraulic head and stream flow data loggers and observation points.

Resulting baseflow estimated from field data for the Cascalheira and Ponte streams ranged from 0.878 to 1.16  $\text{hm}^3/\text{year}$  and 0.746 to 1.15  $\text{hm}^3/\text{year}$  respectively.

#### 1.5.1.4. Numerical model

Three versions of the model were developed, a permanent-state, a transient-state based on known precipitation data and a prospective transient-state model, based on future climatic changes and groundwater extraction scenarios. The following formula expresses the physical principles at the basis of the simulation of the hydraulic behavior of the aquifer system:

$$S \frac{\partial h}{\partial t} + \operatorname{div}(-T \nabla h) = Q \quad (1)$$

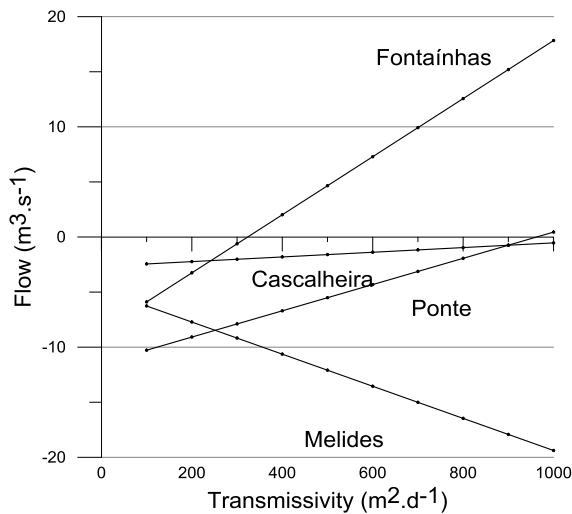
where  $T$  is transmissivity [ $\text{L}^2\text{T}^{-1}$ ];  $h$  is the hydraulic head [ $\text{L}$ ];  $Q$  is the volumetric flux per unit volume [ $\text{L}^3\text{T}^{-1}\text{L}^{-3}$ ], representing sources and/or sinks; and  $S$  is the storage coefficient [-].

##### 1.5.1.4.1. Steady-state model

The first stage of the model, the permanent-state model, was developed in order to define the best suited boundary conditions (BC) and Transmissivity ( $T$ ) estimated through a sensitivity analysis varying  $T$  from 100 to 1000  $\text{m}^2/\text{day}$  considering 100  $\text{m}^2/\text{day}$  increment and assuming that the streams of Cascalheira and Ponte have effluent behavior (negative flow) and that Fontainhas stream has an influent behavior (positive flow). Two

variants were developed (both accounting the abstractions) considering two precipitation series and BC's: i) using Nicolau (2002) precipitation series; ii) using the IPMA precipitation station data series and with redefined BC's.

For the variant i) constant head BC equal to mean sea level along the coastline and constant head BC equal to terrain elevation along the stream nodes were imposed. The sensitivity analysis performed to estimate the best suited T values suggested values between 300 and 800 m<sup>2</sup>/day (Figure 32).



**Figure 32.** Sensitivity analysis for permanent-state model variant i) with the representation of water balance of the rivers in hydraulic connection with the top detritic aquifer. Negative values represent transfers from the aquifer to the river and vice-versa for positive values.

Errors from observed hydraulic head and simulated values decrease with higher values of T, and coefficient of determination ( $R^2$ ) increases with higher values of T (Table 8). Though the model presents statistically good results regarding the hydraulic head distribution, the baseflow estimations were overrated, in particular in Ponte stream, when compared with field data, so, a different approach was necessary in order to calibrate the model discharge to the streams, which was defined in variant ii).

**Table 8.** Average error and coefficient of determination between observed hydraulic head and simulated hydraulic head for the sensitivity analysis performed for the permanent-state model variant i) at the observation points.

T (m <sup>2</sup> /day)	100	200	300	400	500	600	700	800	900	1000
Average error	3.43	3.28	3.24	3.21	3.20	3.19	3.19	3.18	3.18	3.18
R <sup>2</sup>	0.916	0.922	0.924	0.925	0.925	0.926	0.926	0.926	0.926	0.927

The variant ii) of the permanent model considers the IPMA precipitation stations data series (average annual precipitation of 530 mm/year), constant head BC equal to mean sea level along the coastline and fluid-transfer BC with reference head equal to terrain elevation imposed along the streams and a varying transfer rate.

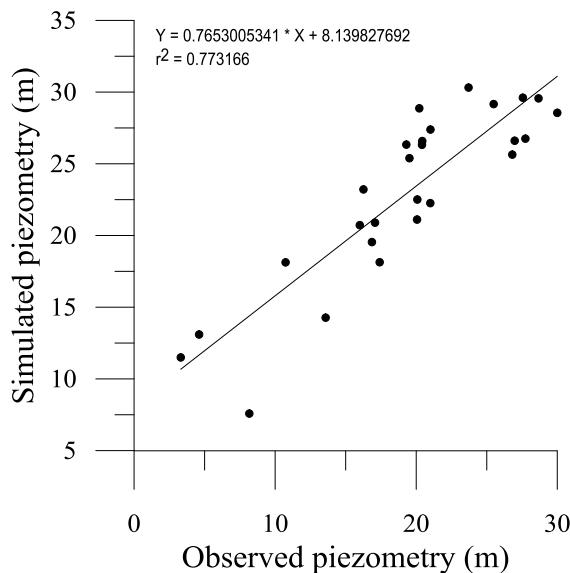
A transfer boundary condition, also known by 3rd type or Cauchy BC (Franke et al. 1987 and Reilly 2001) applies a pre-defined reference head combined with a conductance parameter (transfer rate). Fluid-transfer boundary conditions are applied in cases where a reference potential is linked to the aquifer via a separating medium. This can be the case for example for rivers or lakes with a limited connection to groundwater (surface water level equals groundwater level) as it happens with the streams of Cascalheira and Ponte or for partly clogged drains. The transfer rate is a conductance term describing the properties of a clogging layer. It is defined as:

$$\phi = \frac{K}{d} \quad (2)$$

where  $\Phi$  is transfer rate (in or out of the aquifer) [LT-1]; K is hydraulic conductivity of the clogging layer [L2T-1]; d is thickness of the clogging layer [L].

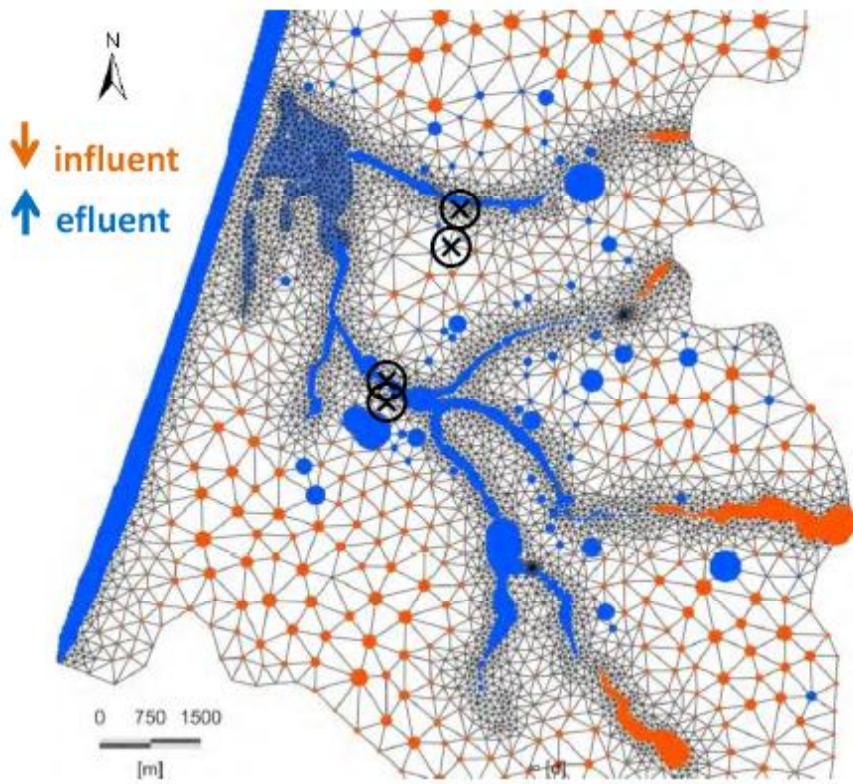
When setting the boundary condition, the reference water level is defined as the value for the boundary condition. The transfer rate is set separately as a material property.

The varying transfer rate was a necessary step in order to calibrate the model discharge to the streams, once these values were overrated according to the baseflow estimated with the field data. Inflow and outflow Transfer rates were imposed on the model, with values of 0.025 m/day to the Ponte stream river basin area and 0.25 m/day to the remaining area of the model, for a transmissivity of 600 m<sup>2</sup>/day. The transfer rates flow values were achieved by a sensitivity analysis varying these values from 0.001 and 0.1 m/day and the presented solution was the one which best suited the field calculated discharge distribution to the streams and the hydraulic head, achieving discharge rates in the same order of magnitude as the field data and hydraulic head average error of 3.19 m with a R<sup>2</sup> of 0.773 (Figure 33).



**Figure 33.** Correlation between observed and calculated hydraulic head for permanent-state model variant ii).

The model representation of the influent and effluent sections of the streams follows a progressive distribution, with higher influent flows in the upstream reaches and higher effluent flows in the downstream reaches of the streams as can be seen in Figure 34.



**Figure 34.** Effluent and influent section distributions of the model with the location of the stream data loggers (X). The blue spots outside the stream represent the wells as the orange spots outside the stream represent the recharge from precipitation.

This fact allows identifying a point from which the aquifer has an effluent behavior down the stream. This point is variable according to the hydraulic head of the aquifer, moving downstream with lower hydraulic head levels and upstream with higher hydraulic heads.

#### 1.5.1.4.2. Transient-State model

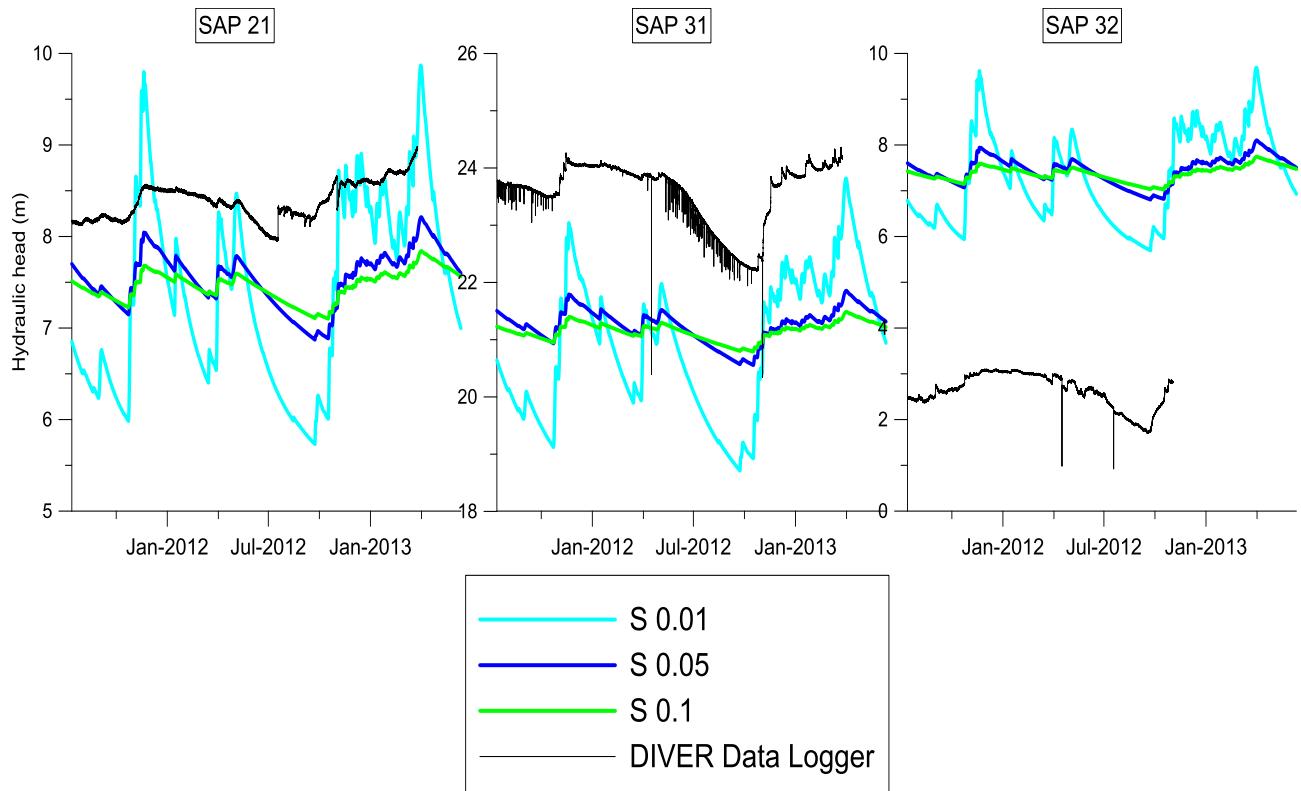
The high seasonal variability of rainfall in semi-arid climates such as occurs in the Sines can lead to significant fluctuations in groundwater levels and flow rates. It is necessary to take into account the temporal variability of these systems when discussing available groundwater and its discharge, as single average annual values can give misleading results (Hugman et al. 2013). In order to analyze the seasonal variation of the groundwater discharge a transient analysis was developed based on the IPMA precipitation stations for a 30 year daily distribution for different gammas of storage coefficient ( $S$ ) ranging from 0.001 to 0.1. The simulation results were then compared with hydraulic head variation and baseflow estimated in the field. From the 4 hydraulic head data loggers installed, one was excluded due to its values suggested it was recording hydraulic potential values from the lower aquifer.

For the 3 data loggers considered (SAP 21, SAP 31, SAP 32) the root mean square error (RMSE) and  $R^2$  were calculated for the period recorded by the data loggers and are shown in Table 9.

**Table 9.** Coefficient of determination ( $R^2$ ) and Root Mean Square Error (RMSE) for the field data hydraulic head levels recorded with the 3 data logger and the simulated hydraulic head for the same period of time.

S	SAP 21		SAP 31		SAP 32	
	$R^2$	RMSE ( $m^2$ )	$R^2$	RMSE ( $m^2$ )	$R^2$	RMSE ( $m^2$ )
<b>0.001</b>	0.531	2.89	0.331	4.71	0.464	4.21
<b>0.01</b>	0.749	1.39	0.745	2.94	0.717	3.78
<b>0.05</b>	0.581	0.92	0.919	2.39	0.777	4.14
<b>0.1</b>	0.581	0.97	0.916	2.49	0.759	4.11

Taking into account the statistical data for the simulations and the analysis to the hydraulic head variation for the data logger and the model simulations (Figure 35) the best suited S levels are of 0.01 and 0.05.



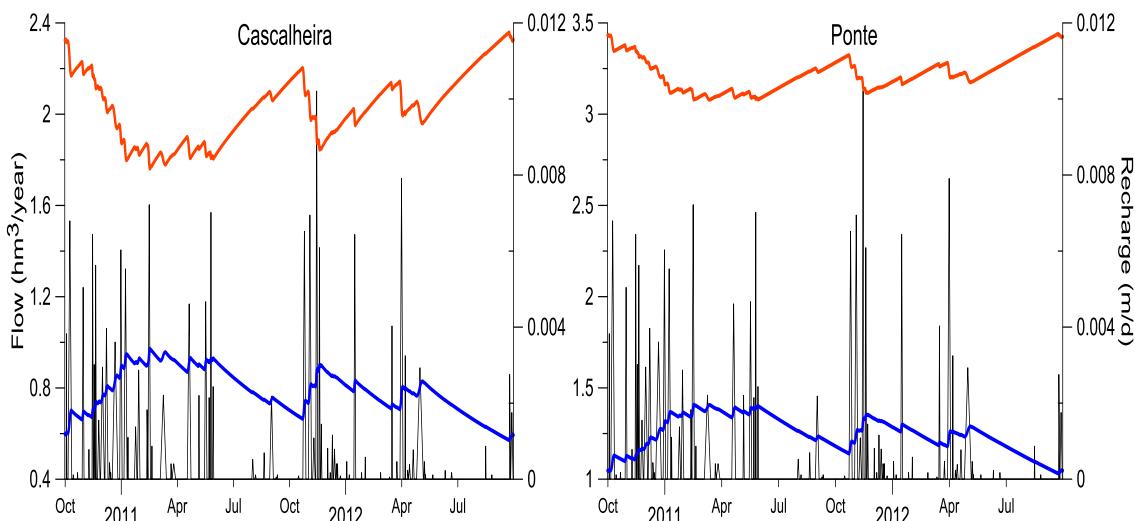
**Figure 35.** Hydraulic head recorded at data loggers compared with hydraulic head simulated by the model for S levels of 0.01, 0.05 and 0.1.

The comparison between simulated and measured baseflows for values of S 0.01 and 0.05 (Table 10), suggests an S value of 0.05 as the most indicated choice, once the baseflow error is, for any of the period of time analyzed, lower for S 0.05 rather than 0.01. Therefore, an S value of 0.05 is assumed for the transient model simulations.

**Table 10.** Cascalheira and Ponte stream baseflow errors between measured baseflow (Qb field) and model simulations baseflow for S = 0,05 (Qb S05) and for S = 0,01 (QB S01).

Cascalheira	Qb field (m <sup>3</sup> /year)	Qb S05 (m <sup>3</sup> /y)	Qb S01 (m <sup>3</sup> /y)	S05 error (m <sup>3</sup> /y)	S01 error (m <sup>3</sup> /y)
Time Period					
Dec 2011 - Nov 2012	8.78E+05	7.23E+05	5.91E+05	1.55E+05	2.87E+05
Jan 2012 - Dec 2012	9.50E+05	7.19E+05	5.98E+05	2.31E+05	3.52E+05
Feb 2012 - Jan 2013	1.04E+06	7.17E+05	6.18E+05	3.19E+05	4.18E+05
Mar 2012 - Feb 2013	1.11E+06	7.17E+05	6.42E+05	3.97E+05	4.72E+05
Apr 2012 - Mar 2013	1.16E+06	7.27E+05	6.99E+05	4.31E+05	4.59E+05
Ponte	Qb field (m <sup>3</sup> /year)	Qb S05 (m <sup>3</sup> /y)	Qb S01 (m <sup>3</sup> /y)	S05 error (m <sup>3</sup> /y)	S01 error (m <sup>3</sup> /y)
Time period					
Dec 2011 - Nov 2012	1.15E+06	1.19E+06	1.29E+06	3.96E+04	1.40E+05
Jan 2012 - Dec 2012	9.77E+05	1.18E+06	1.29E+06	2.02E+05	3.13E+05
Feb 2012 - Jan 2013	7.77E+05	1.17E+06	1.31E+06	3.98E+05	5.37E+05
Mar 2012 - Feb 2013	7.46E+05	1.17E+06	1.35E+06	4.25E+05	5.99E+05
Apr 2012 - Mar 2013	7.88E+05	1.18E+06	1.43E+06	3.90E+05	6.38E+05

A more detailed transient analysis was performed for 2 hydrological years, 2010/2011 – 2011/2012 once these include the period with field data, which suggests a significant seasonality regarding the aquifer discharge to the streams, as can be seen on Figure 36, whereas discharge decreases substantially in dry periods, but with quick recoveries after recharge episodes.



**Figure 36.** Aquifer discharge (blue) and recharge (orange) to and from streams and recharge episodes (episodes).

For the given period, the estimated baseflow reaching the SAL was 2.19 hm<sup>3</sup>/year and 1.72 hm<sup>3</sup>/year for the Cascalheira and Ponte respectively, accounting a total of 3.92 hm<sup>3</sup>/year of groundwater contribution to the SAL.

### **1.5.1.5. Future Scenarios Analysis**

As one of the projects objectives a prospective analysis was developed to estimate groundwater discharge to the streams taking into account climatic changes and the increase of groundwater abstraction, in order to calculate total groundwater contribution to the SAL. Two climatic scenarios were developed: I) annual mean precipitation based on actual precipitation data (530 mm/year); II) assuming a 30% precipitation dropdown until 2080, as prospected by SIAM (SIAM II) based on HadRM2 and HadRM3 scenarios (by the Hadley Centre for Climate Prediction and Research) which suggest a reduction in precipitation of 20 – 30% until the 2080 – 2100 period for the HadRM2 and 30 – 40% until the 2070 – 2010 for the HadRM3 model in the case study region.

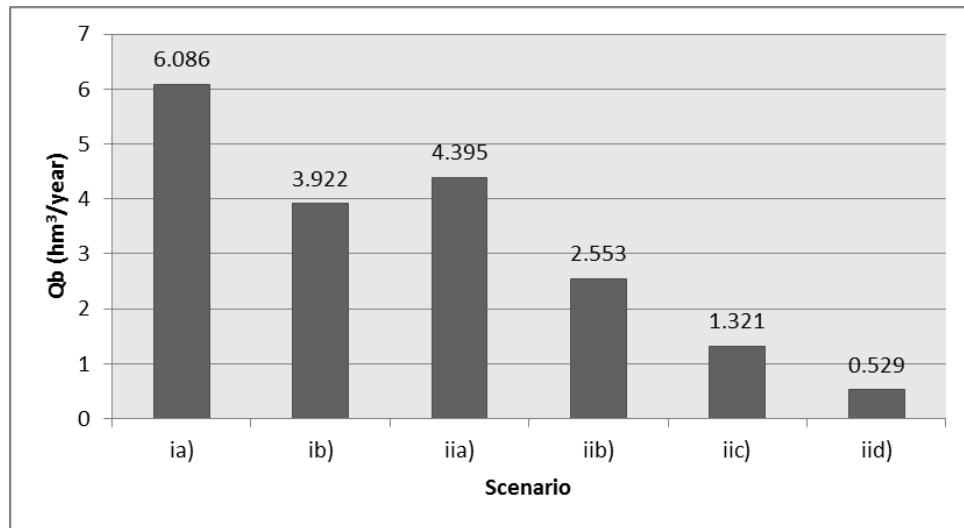
Groundwater extraction is likely to suffer increase not only due to the expected trend of increasing “dry days” in the region (days with precipitation lower than 0.1 mm), possible increase in farm land and lower values of precipitation. No scenarios for possible future groundwater extraction changes were found, so, 4 empiric extraction scenarios were tested: a) interruption of all groundwater extractions; b) actual extraction rates ( $7.96 \text{ hm}^3/\text{year}$ ); c) twice of the actual extraction ( $15.92 \text{ hm}^3/\text{year}$ ) and; d) thrice the actual extraction ( $23.88 \text{ hm}^3/\text{year}$ ). Extraction scenario d) is the only for which extraction exceeds recharge levels considering the climatic scenario II) which accounts for a 30% decrease of precipitation, so being, scenario iid is considered the worst-case scenario in the present analysis. Scenario ib is considered the actual scenario and therefore, the control scenario. Table 11 synthetizes the scenarios considered for the prospective transient analysis.

**Table 11.** Summary of climatic scenarios and water use scenarios.

Climatic scenarios		Water use scenarios	
i	Actual annual precipitation (530 mm/year)	a	Natural state/no abstraction
		b	Actual abstraction (Control Scenario)
ii	Progressive decrease of 30% precipitation until the year 2070 (371.9 mm/year)	a	Natural state/no abstraction
		b	Actual abstraction
		c	twice the actual abstraction
		d	thrice the actual abstraction (Worst-case scenario)

#### **1.5.1.5.1. Future Scenarios Results**

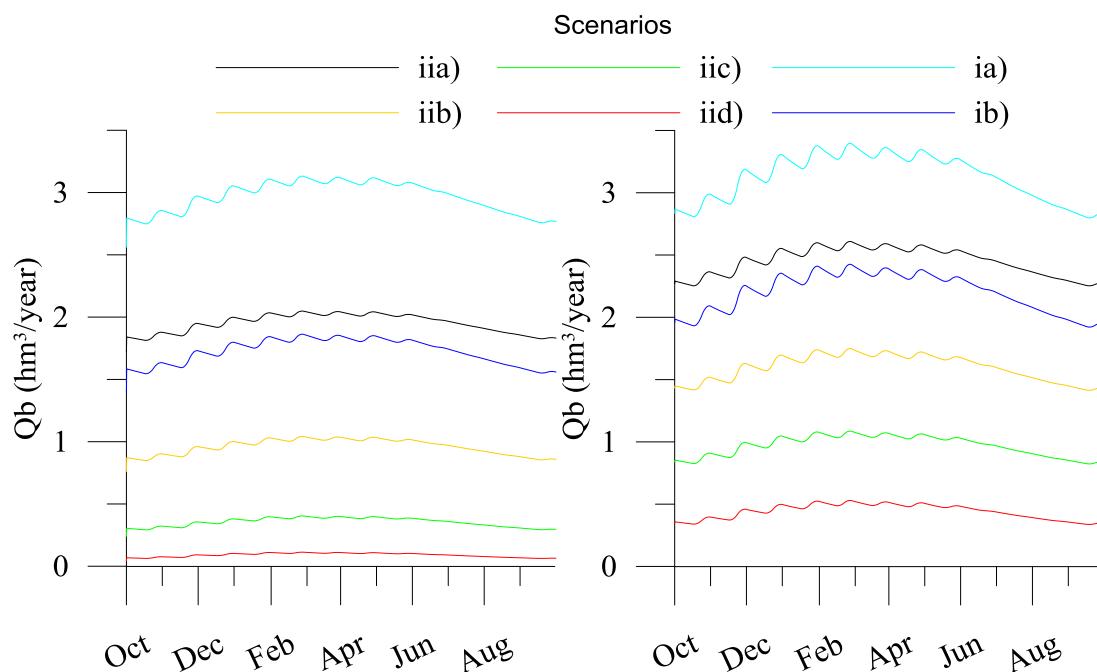
Total baseflow reaching the SAL was estimated for the 6 scenarios considered (Figure 37). The results indicate that, as expected, considering scenario ia - no climatic changes and the cessation of all abstractions - would increase substantially the baseflow contributing to the SAL, when comparing with the control scenario (ib).



**Figure 37.** Total baseflow reaching the Santo André Lagoon for an average year for the simulated scenarios.

More important though is that considering climatic changes, but with cession of abstractions (scenario iia), the total baseflow reaching the lagoon is actually higher than the control scenario. Increasing abstraction values will naturally decrease the total yearly contribution of groundwater to the streams and consequently to the SAL. The contributions of the prospective scenarios iib, iic and iid are of 34.9%, 66.3% and 86.5% respectively lower than the control scenario. Scenario iid, which assumes thrice the actual abstraction, would in fact result in a quarter of the total control scenario groundwater contribution to the SAL, being this considered the worst-case scenario.

It is also possible to identify a seasonality effect in the baseflow reaching the SAL, as presented in Figure 38, with higher values of baseflow in the wet (rainy) season and lower values in the dry season.



**Figure 38.** Average transference values from the aquifer to the Ponte stream (on the left) and Cascalheira stream (on the right) for the simulated scenarios. Scenario ib) is the control scenario.

In the worst-case scenario, for the Ponte stream, baseflow values are so low that it turns hard to identify a seasonality effect, suggesting a residual baseflow for this scenario in this stream.

### 1.5.2. Eco-hydrological model

#### 1.5.2.1. Conceptual model

Streams are perennial (PENN) when they gain water from the aquifer (effluent) throughout the year, which occurs at the downstream sections and intermittent (INT) when they lose water to the aquifer (influent). The geographic location where the stream changes from influent to effluent, from upstream to downstream, changes throughout the year as the water table rises with the winter rains, and lowers as the aquifer loses water through its natural discharges or through pumping, attaining a minimum at the end of the dry season (end of September). This section is here identified as INT-PENN.

Some species are better adapted to withstand water deficit than others. The best adapted ones should be found in sections where flow is intermittent, whereas temporary (TEMP) (opportunistic) species may be found when flow is the highest. Hence, the exclusive presence of permanent (PERM) species may be indicative of a stream section where flow is low or intermittence is too high for temporary species (INT section). The presence of both permanent and temporary in the wet season and only (or at least highly predominant) permanent species during the dry season is indicative of a INT-PENN section. When both permanent and temporary species are present throughout the year the section is PENN (in fact the temporary species may be permanent here).

If measured, or estimated, stream flow is coupled with ecological data then the previous assumptions may be validated. Despite of its simplicity, the conceptual model has, nevertheless, some interesting applications, namely: i) one can use biological indicators to estimate groundwater levels in locations where direct measurements are not available; ii) given the possibility to model the impact of future water use and recharge rates on groundwater levels, the extent of stream length affected by these changes can be quantitatively estimated.

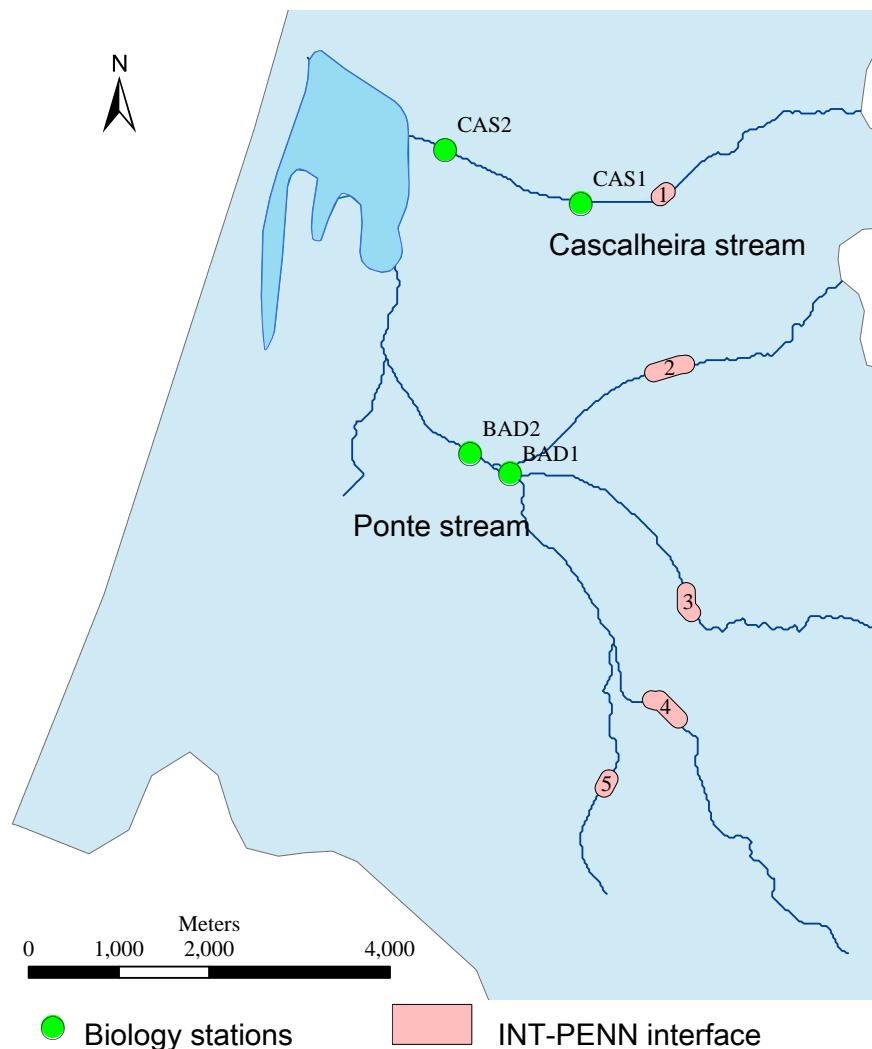
A relative abundance index (RAI) is used in complement to the presence/absence of species:

$$RAI_i = \frac{\sum A_i}{A_T}, \text{with } i = \text{temporary, permanent species}$$

Where  $A_i$  is the count of individuals of all temporary or permanent species, and  $A_T$  is the total count of individuals of both temporary and permanent species.

#### 1.5.2.2. Implementation

A groundwater flow model was developed for the region to allow estimates of base flow in the sampled streams, calibrated with field measurements, as described in 2.5.1.



**Figure 39.** Sampling locations. The INT-PENN interface buffer (in red) considers the lower and higher hydraulic heads location of the interface. Buffer labelled 1 stands for Cascalheira stream. Buffers labelled from 2 to 5 stands for several reaches of Ponte stream.

Ecological data was collected in two locations in both wet and dry seasons along two streams which flow into the Santo André lagoon: Cascalheira (CAS1 and CAS2) and Ponte (BAD1 and BAD2) streams, whose location can be seen on Figure . PERM species and TEMP species for the current study case were identified using a Similarity percentages analysis (SIMPER), available at PRIMER 6 software package. Species providing the discrimination between sites classified as permanent and temporary were identified based on a matrix of abundance data log ( $x+1$ ) transformed. A dissimilarity of 62% was found between these groups. PERM and TEMP species were selected based on the individual % contribution to the total dissimilarity, but also on the exclusive occurrence on permanent or temporary streams. Based on these criteria, the following species were selected:

PERM: Gammaridae;

TEMP: Simuliidae; Baethidae; Ecnomidae; Dytiscidae; Dixidae; Leptophlebiidae

The analysis is made considering both the presence/absence of indicator species as well as the abundance of individuals. Abundance is understood here as the total of individuals of temporary or permanent species, i.e.,  $A_i$ . Results are presented in Table .

**Table 12.** Abundance of temporary and permanent species,  $A_i$  (in %).

Location	Temporary species				Permanent species			
	$A_{\text{temporary}}$		$RAI_{\text{temporary}}$		$A_{\text{permanent}}$		$RAI_{\text{permanent}}$	
	Wet season	Dry Season	Wet season	Dry Season	Wet season	Dry Season	Wet season	Dry Season
<b>CAS1</b> (Upstream)	8833.0	5.5	90.4	11.6	935.5	42.0	9.6	88.4
<b>CAS2</b> (Downstream)	258.3	12.0	39.1	8.4	403.0	131.5	60.9	91.6
<b>BAD1</b> (Upstream)	N/A	14.0	N/A	2.5	N/A	537.5	N/A	97.5
<b>BAD2</b> (Upstream)	558.0	10.0	99.9	0.8	0.5	1209.5	0.1	99.2

In upstream stations, during the dry season, permanent species are dominant, while during the wet season individuals of temporary species are more abundant. Although a decrease in the abundance for all species is found from wet to dry season, this decrease is much larger for temporary species in upstream sections, corresponding to the INT section of the conceptual model. The downstream locations are categorized for an equivalent dominance of permanent and temporary species in wet season and, in wet season, permanent species are the dominant ones, corresponding to observations more similar to section INT-PENN. BAD1 station has no data for the wet season, but the data collected in the dry season, and the station's location suggests it is located in section INT.

The baseflow for each sampling location was calculated using the groundwater flow model, considering the 7 days prior to the time of sampling (Table 13). As expected, baseflow is higher for the wet season than for the dry season. Also, the baseflow for the downstream locations is higher than that for the upstream ones. One important fact is that, according to the model results, all of the locations are downstream of the estimated INT-PENN section, which can be seen in Figure 39, which is in accordance with the ecological indicators.

**Table 13.** Model estimated baseflow for the 7 days previous to the date of sampling.

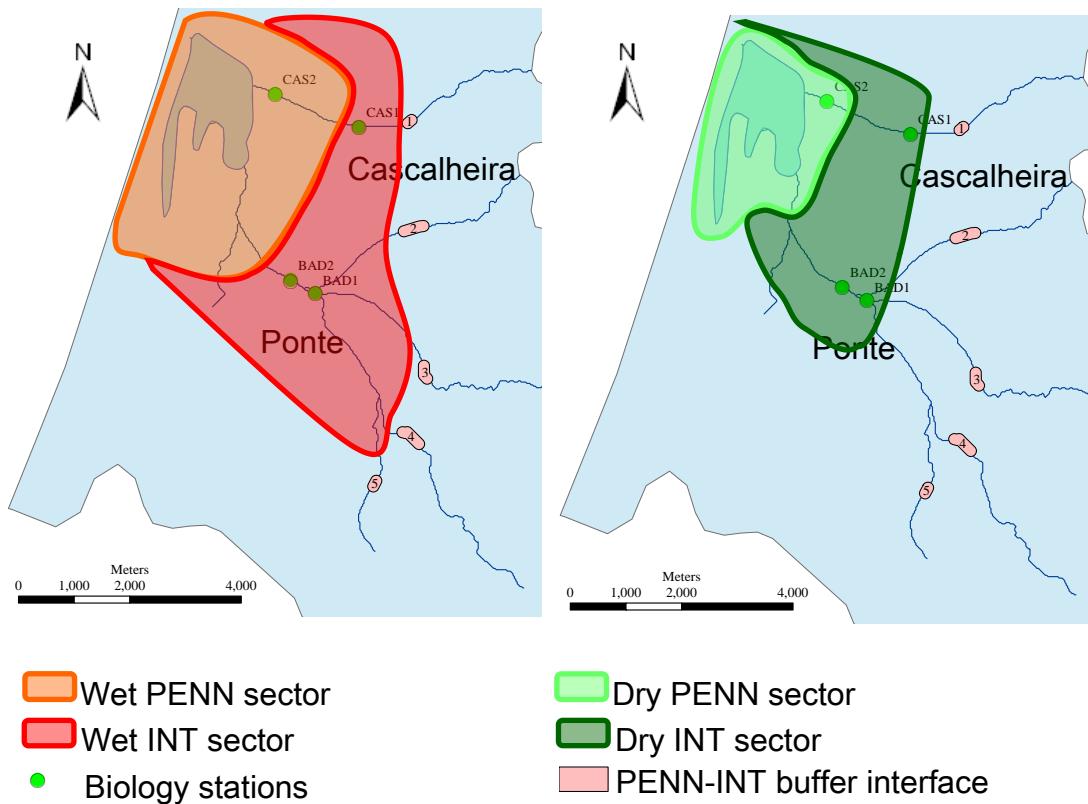
Station	Baseflow ( $\text{m}^3/\text{day}$ )	
	Wet season	Dry Season
CAS1 (Upstream)	1.28E+03	9.57E+02
CAS2 (Downstream)	5.62E+03	4.74E+03
BAD1 (Upstream)	2.45E+03	2.35E+03
BAD2 (Upstream)	3.56E+03	3.12E+03

The previous analysis was based on data with much associated uncertainty. Still, it was possible to define a conceptual model, which follows the rules presented in Table 14: for wet season and upstream locations, temporary species are dominant, and for downstream locations, temporary and permanent share its dominance; during dry season permanent species are dominant at both up and downstream locations.

**Table 14.** Conceptual model indicating the dominant species for the dry and wet season according to the location of the stream.

Location	wet season	dry season
Upstream (lower baseflow)	Temporary	Permanent
Downstream (Higher baseflow)	Temporary and Permanent	Permanent

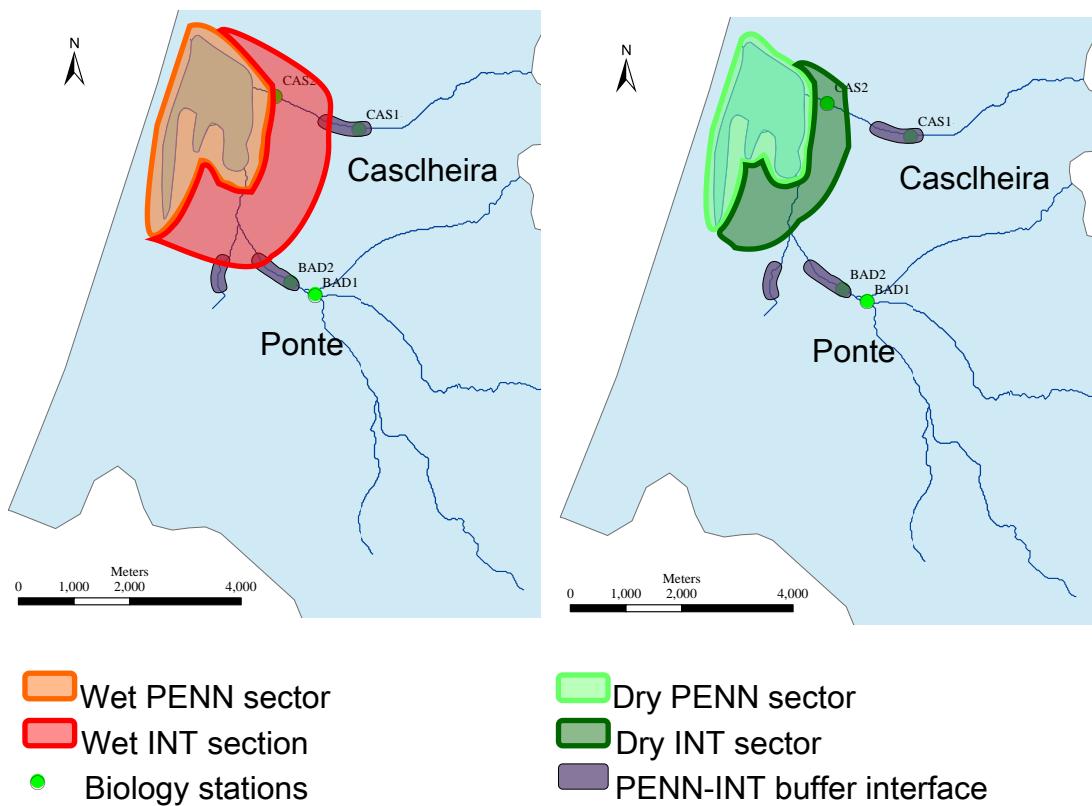
A variation of the conceptual model sector's location is expected, which is suggested in Figure 40, indicating wider up and downstream sectors in wet period, with downstream limits closer to the upstream stations (CAS1, BAD1 and BAD2) and upstream limits closer to the INT-PENN interface. During dry periods the extent stream sections which are PENN and INT-PENN are expected to shrink towards the limit of the lagoon.



**Figure 40.** Wet (on the left) and dry (on the right) seasons buffer for the PENN and INT sectors of the conceptual model.

### 1.5.2.3. Prospective Analysis

The same scenarios, described in 2.5.1., were used for the future scenarios analysis. The Eco-hydrological model was interpreted for the worst-case scenario (iid) which considers a decrease of 30% precipitation until the year 2080 and thrice the actual estimated extraction. The suggested results indicate a migration of the PENN-INT interface towards downstream as indicated in Figure 41. The extremely low baseflows for this scenario allow for a higher variation of the PENN-INT buffer, when compared with the control scenario (ib – Figure 39 or Figure 40). Regarding the Ponte stream, the affluent on the southeast, which had a total PENN behaviour for control scenario, has now a sector with INT behaviour. The remaining streams become PENN at more downstream locations when compared with the control scenario. The authors suggest a possible buffer for the eco-hydrological conceptual model sectors for the worst case-scenario, in which it is expected for these sectors to become smaller when compared with the control scenario, as can be seen in Figure 41.



**Figure 41.** Location of the PENN-INT buffer interfaces for worst-case scenario (iid) based on the model. Suggested wet (on the left) and dry (right) seasons buffer for the PENN and INT sectors of the conceptual model for worst-case scenario.

### 1.5.2.4. Sustainable Baseflow

TEMP species abundance found in the dry season (Table 12) tends to decrease with baseflow (Table 13). The lowest TEMP abundance identified in the dry season coincides with the lowest baseflow,  $9.57 \times 10^{-2} \text{ m}^3/\text{day}$ , equivalent to  $0.35 \text{ hm}^3/\text{year}$  for the Cascalheira stream. Such analysis suggests that for baseflows lower than

0.35 hm<sup>3</sup>/year during the dry season, the chance of not finding TEMP is higher. This baseflow value can guarantee the occurrence of TEMP species in the Cascalheira stream, hence this being suggested as a sustainable baseflow. Despite the obtained results, it is important to refer the low representativeness and abundance of biologic data, hence, more biological field data campaign along the streams and in different periods are still necessary .This raises the question whether the suggested baseflow value can be assumed as a reference value of sustainable baseflow for the TEMP species representative for all the streams. Presuming that it is representative, for the scenarios with increased abstraction and reduced rainfall (iic and iid), sustainable baseflow for the Ponte stream is not reached. As for the Cascalheira stream, only for the worst-case scenario.

## References

- Almeida C., J.L. Mendonça, M.R. Jesus & A.J. Gomes. 2000. Actualização do Inventário dos Sistemas Aquíferos de Portugal Continental [Actualization of the Inventory of the Aquifer Systems of Continental Portugal]. Centro de Geologia e Instituto da Água, Report doc. Elect., CD-Rom.
- Chambel, A. & J.P. Monteiro, J.P. 2007. Sistema Aquífero de Sines – Estudo Hidrogeológico do Sistema Aquífero e Definição dos Perímetros de Protecção das Captações de Água Subterrânea das Águas de Santo André SA, com recurso a Modelação Matemática. Universidade de Évora/Universidade do Algarve. Relatório Técnico.
- Climate Change in Portugal: Scenarios, Impacts, and Adaptation Measures - Phase II, SIAM Project (Scenarios, Impacts and Adaptation Measures). F. D. Santos e P. Miranda (Editors). Gradiva, Lisboa, 2006. Available online at <http://siam.fc.ul.pt/>
- Fernandes, P.G., P. Carreira & M.O. Silva. 2006. Identification of Anthropogenic Features Through Application of Principal Component Analysis to Hydrochemical Data from the Sines Coastal Aquifer, SW Portugal. Mathematical Geology. 38: 765-780.
- Franke, O.L., Reilly, T.E., Bennett, G.D. (1987) Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems – An introduction: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B5, 15 p.
- Freitas, M. C., Andrade, C., Cruces, A., Amorim, A., Cearreta, A., Ramalho, M. J. (2002) Coastal Environmental Changes at Different Time-scales: the Case of the Melides Barrier-Lagoon System (SW Portugal). In: Littoral 2002, The Changing Coast. EUROCOAST / EUCC, Porto, 397-402.
- Hadley Centre, 2002. Available online at <http://www.metoffice.gov.uk/climate-change/resources/hadleycentre>
- Hugman R., T.Y. Stigter & J.P. Monteiro. 2013. The importance of temporal scale when optimising abstraction volumes for sustainable aquifer exploitation: A case study in semi-arid South Portugal. J Hydrol 490:1–10. doi: 10.1016/j.jhydrol.2013.02.053

Lobo-Ferreira, J.P.C., M.J. Moinante, M.M. Oliveira, M.E. Novo, T.E. Leitão, P.E. Moreira & M.J. Henriques. 1999. Plano de Bacia Hidrográfica do Rio Sado. 1ª Fase. Caracterização dos Recursos Hídricos Subterrâneos da Área Abrangida pelo Plano de Bacia Hidrográfica do Rio Sado. Anexo Temático 4 - Recursos Hídricos Subterrâneos. Estudo realizado para a Hidroprojecto, Engenharia e Gestão, S.A., Outubro de 1999, 258 pp.

Monteiro, J.P., A. Chambel & J. Martins. 2008. Conceptual and Numerical Flow Model of the Sines Aquifer System (Alentejo, South Portugal). International Groundwater Symposium. International Association of Hydraulic Engineering and Research (IAHR). Istanbul-Turkey. p.38 (abstract) and doc. elect. CD-Rom 9pp. Disponível em <http://sites.google.com/site/jppmonteiro/home2>.

Monteiro, J.P., A. Chambel, L.M. Nunes, J. Duque, R. Martins, D. Silva & R. Coelho. 2010. Avaliação Técnica dos Níveis de Contaminação Existentes e Acções Correctivas a Implementar (Contaminação de Águas Subterrâneas por Hidrocarbonetos no Sistema Aquífero de Sines). Volume 1. Enquadramento Geral – Modelo Hidrogeológico Local e Regional, Suporte Documental. Relatório Técnico. International Centre for Coastal Ecohydrology/Universidade do Algarve/Universidade de Évora.

Monteiro, J.P., R. Hugman, T. Stigter, N. Salvador, L. Nunes, A. Chambel (accepted). Numerical flow modelling of the Sines Multi-Aquifer System in Portugal for protection of deep supply wells and surface water ecotones. Journal of Hydrogeology.

Nicolau, R. 2002. Modelação e mapeamento da distribuição espacial de precipitação - Uma aplicação a Portugal continental. Dissertação apresentada para obtenção do grau de Doutor em Engenharia do Ambiente pela Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia.

Reilly, T.E. 2001. System and boundary conceptualization in ground-water flow simulation: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter B8, 26 p. (available on the Internet at [http://pubs.usgs.gov/twri/twri-3\\_B8/](http://pubs.usgs.gov/twri/twri-3_B8/)).

Shewchuk, J. R. 1996. Triangle: Engineering a 2D Quality Mesh Generator and Delaunay Triangulator, in "Applied Computational Geometry: Towards Geometric Engineering" (Ming C. Lin and Dinesh Manocha, editors), volume 1148 of Lecture Notes in Computer Science, pages 203-222, Springer-Verlag, Berlin, May 1996.

Vermeulen, H., J.P. Lobo-Ferreira, M.M. Oliveira. 1994. A Method for Estimating Aquifer Recharge in DRASTIC Vulnerability Mapping. Comunicação apresentada ao "Seminário Águas Subterrâneas e Ambiente", realizado pela Associação Portuguesa dos Recursos Hídricos em Lisboa, em Maio de 1993 e à "Second European Conference on Advances in Water Resources Technology and Management", realizada pela European Water Resources Association, em Lisboa, em Junho de 1994; Rotterdam, A.A. Balkema.

## **2. PRODUÇÃO CIENTÍFICA**

Os descritores de realização previstos na proposta do projecto foram globalmente cumpridos e mesmo superados em alguns itens. Estão a ser ultimadas mais algumas publicações científicas em revistas de âmbito internacional.

### **2.1. Publicações**

#### **Artigos científicos em revistas internacionais**

- Correia, M.J., Costa, J.L., Chainho, P., Félix, P.M., Chaves, M.L., Medeiros, J.P., Silva, G., Azeda, C., Tavares, P., Costa, A., Costa, A.M., Bernardo, J., Cabral, H.N., Costa, M.J. & Cancela da Fonseca, L. 2012. Inter-annual variations of macrobenthic communities over three decades in a land-locked coastal lagoon (Santo André, SW Portugal). *Estuarine, Coastal & Shelf Science* 110: 168-175. (Anexo 2)
- Félix, P.M., Correia, M.J., Chainho, P., Costa, M.J., Cabral, H.N., Domingos, I., Costa, J.L. & Cancela da Fonseca, L. 2013. Influence of streams discharges on the structure of fish communities of Portuguese land-locked coastal lagoons. *Cahiers de Biologie Marine* 54: 429-437. (Anexo 3)
- Félix, P.M., P. Chainho, J.L. Costa, M.J. Correia, M.L. Chaves, J.P. Medeiros, H. Cabral, N. Wouters, J. Bernardo, A.M. Costa, M. Cristo, G. Silva, C. Azeda, P. Tavares, M.J. Costa, & L. Cancela da Fonseca. 2013. Short-term versus long-term changes in the benthic communities of a small coastal lagoon: implications for ecological status assessment. *Vie et Milieu* 63: 11-22. (Anexo 4)
- Monteiro, J.P., R. Hugman, T. Stigter, N. Salvador, L. Nunes & A. Chambel (aceite). Numerical flow modelling of the Sines Multi-Aquifer System in Portugal for protection of deep supply wells and surface water ecotones. *Journal of Hydrogeology*. (Anexo 5)
- Mirra, C., M.L. Chaves, P.M. Félix, M.J. Correia, J.L. Costa, P. Chainho & L. Cancela da Fonseca (submetido). Adequacy of benthic indices to assess the ecological status of small Mediterranean river basins. *Ecological Indicators*. (Anexo 6)
- Félix P.M., M.J. Correia, P. Chainho, J.L. Costa, M.L. Chaves, T. Cruz, J. Castro, C. Mirra, I. Domingos, A.C.F. Silva & L. Cancela da Fonseca (submetido). Impact of freshwater inputs on the spatial structure of benthic macroinvertebrate communities of two land-locked coastal lagoons. *Estuarine, Coastal & Shelf Science*. (Anexo 7)

#### **Artigos científicos em Actas de Congressos internacionais**

- Mirra, C., M.L. Chaves, P.M. Félix, M.J. Correia, J.L. Costa, P. Chainho & L. Cancela da Fonseca (submetido). Adequabilidade de índices bentónicos para aferir a qualidade ecológica da água em pequenas bacias hidrográficas mediterrânicas. *Actas do VIII Congresso Ibérico de Gestão da Água*. (Anexo 8)
- Salvador, N., L. Costa, R. Hugman, J.P. Monteiro, T. Stigter & D. Duarte (submetido). Monitoring and modelling groundwater contributions to dependent ecosystems. The case study of the Santo André Coastal Lagoon. *Actas do VIII Congresso Ibérico de Gestão da Água*. (Anexo 9)
- Chainho, P., P.M. Félix, M.J. Correia, J.L. Costa, M.L. Chaves, T. Stigter, R. Hugman, N. Salvador, L. Costa, I. Domingos, V. Lopes, J. Castro, T. Cruz, A. Costa, J.P. Monteiro, A. Chambel, L. Nunes, A.C.F. Silva, J.R. Pinto, A.M. Vidal, I. Pinheiro, M.J. Costa, H.N. Cabral, L.T. Ribeiro & L. Cancela da Fonseca (submetido). Projecto GROUNDSCENE: biodiversidade de lagoas costeiras e respectivas bacias

hidrográficas como ecossistemas dependentes de águas subterrâneas. Actas do III Encontro da Rede BRASPOR. (Anexo 10)

#### **Artigos científicos em Actas de Congressos nacionais**

- Hugman R., Stigter T., Monteiro J.P. & Nunes L. 2012. Importância das propriedades do aquífero e da distribuição espaço-temporal da recarga e extração na determinação de caudais sustentáveis. Actas do 11º Congresso da Água, Porto, Portugal, 15pp. (Anexo 11)
- Costa, L., N. Salvador, R. Hugman, J.P. Monteiro, T. Stigter. 2013. Modelling of the groundwater contribution to the Santo André Lagoon (Sines, Portugal). Actas do III Congresso de Jovens Investigadores em Geociências, LEG 2013 & 6º PGUE, 4pp. (Anexo 12)

## **2.2. Comunicações (internacionais e nacionais)**

#### **Comunicações orais em encontros internacionais**

2011. P. Tavares, P. Chainho, A. Costa, J. Castro, T. Cruz, M.L. Chaves, A.M. Costa, J. Bernardo, J.P. Medeiros, G. Silva, C. Azeda, M.J. Costa, J.L. Costa, H. Cabral & L. Cancela da Fonseca. Inter-annual variations of macrobenthic communities during three decades in a land-locked coastal lagoon (Santo André, SW Portugal). 5th European Coastal Lagoon Symposium (EUROLAG), Aveiro, Portugal, Julho 2011. (Anexo 13)
2013. Chainho, P., P.M. Félix, M.J. Correia, J.L. Costa, M.L. Chaves, T. Stigter, R. Hugman, N. Salvador, L. Costa, I. Domingos, V. Costa, J. Castro, T. Cruz, A. Costa, J.P. Monteiro, A. Chambel, L. Nunes, A.C.F. Silva, J.R. Pinto, A.M. Vidal, I. Pinheiro, M.J. Costa, H.N. Cabral, L.T. Ribeiro & L. Cancela da Fonseca. Projecto GROUNDSCENE: biodiversidade de lagoas costeiras e respectivas bacias hidrográficas como ecossistemas dependentes de águas subterrâneas. III Encontro da Rede BRASPOR, Ponte de Lima, Portugal, July 2013. (Anexo 14)

#### **Painéis em encontros internacionais**

2011. P. Chainho, M.L. Chaves, H. Cabral, N. Wouters, J. Bernardo, A.M. Costa, M. Cristo, G. Silva, C. Azeda, J.P. Medeiros, P. Tavares, M.J. Costa; J.L. Costa & L. Cancela da Fonseca. Do long-term changes occur in the benthic communities of a small coastal lagoon? 5th European Coastal Lagoon Symposium (EUROLAG), Aveiro, Portugal, Julho, 2011. (Anexo 15)
2012. P.M. Félix, M.J. Correia, P. Chainho, H.N. Cabral, M.J. Costa, J.L. Costa & L. Cancela da Fonseca. Influence of permanent and intermittent streams discharges on the structure of fish communities of Melides and Sto André lagoons, Southwest Portugal. XVII Simposio Ibérico de Estudios de Biología Marina (SIEBM), San Sebastián, Spain, Setembro 2012. (Anexo 16)
2013. C. Mirra, M.L. Chaves, P. Chainho, M. J. Correia, P.M. Félix, A.S. Alves, J.L. Costa, L. Cancela da Fonseca. The performance of benthic invertebrate indices to assess ecological status in Mediterranean streams. 8th Symposium for European Freshwater Sciences, Münster, Alemanha, Jul 2013. (Anexo 17)

#### **Comunicações orais em encontros nacionais**

2012. R. Hugman, T. Stigter, J.P. Monteiro, L. Nunes. Importância das Propriedades do Aquífero e da Distribuição Espacio-Temporal da Recarga e Extracção na Determinação de Caudais Sustentáveis, 11º

- Congresso da Água, Associação Portuguesa de Recursos Hídricos (APRH), Porto, Portugal, Fevereiro 2012. (Anexo 18)
2013. Costa, L., N. Salvador, R. Hugman, J.P. Monteiro, T. Stigter. Modelling of the groundwater contribution to the Santo André Lagoon (Sines, Portugal). III Congresso de Jovens Investigadores em Geociências, LEG 2013 & 6º PGUE, Estremoz, Portugal, October 2013. (Anexo 19)
2013. N. Salvador, T. Stigter, J.P. Monteiro, R. Hugman, D. Duarte. Quantificação e modelação das relações rio-aquífero no sistema aquífero de Sines, uma contribuição para avaliação do estado da Lagoa de Santo André. 9º Seminário sobre Águas Subterrâneas, Associação Portuguesa de Recursos Hídricos (APRH), Monte da Caparica, Portugal, Março 2013. (ver Anexo 9)
2013. C. Mirra, M.J. Correia, P. Félix, M.L. Chaves, P. Chainho, J.L. Costa, L. Cancela da Fonseca. A diversidade dos macroinvertebrados das pequenas ribeiras mediterrânicas do Sul de Portugal. Encontro sobre Biodiversidade e Conservação de Invertebrados em Portugal, Lisboa, Portugal, Julho 2013. (Anexo 20)

### **2.3. Relatórios**

- Relatório de progresso do 1º ano do projecto  
 Relatório de progresso do 2º ano do projecto  
 Presente relatório

### **2.4. Organização de seminários e conferências**

- Workshop de lançamento do projecto, RNLSAS, Monte do Paio, Santo André, 20 de Abril de 2010.  
 Workshop de discussão e estruturação do trabalho. Sede da RNLSAS, Brescos, 5 de Outubro de 2010.  
 Workshop de apresentação de resultados e organização do trabalho futuro. RNLSAS, Monte do Paio, Santo André, 23 de Novembro de 2010.  
 Seminario, Projecto Groundscene realizado no Instituto Superior Técnico, Lisboa, 27 de Março de 2012.

### **2.5. Formação Avançada (teses de doutoramento, teses de mestrado, outras)**

#### **Teses de Mestrado**

- Carla Alexandra Mirra Fernandes. 2013. Environmental conditions that constrain invertebrate communities and the performance of benthic indices to assess ecological status in Mediterranean streams. Tese de Mestrado da Universidade dos Açores, 68p. (Anexo 21)
- Vera Cristina Pereira Lopes. 2013. A enguia na lagoa de Santo André - Contributo para a gestão da sua pesca. Tese de Mestrado da Universidade de Lisboa, 105p. (Anexo 22)

### **2.6. Modelos**

Finite element numerical flow model to study the groundwater-surface water interactions between the top detritic Sines aquifer and the associated stream network

Ecohydrological model

## **2.7. Outros**

2012. Chainho, P., Correia, M.J., Félix, P., Mirra, C. & Chaves, M.L.. Sensibilização das comunidades locais – uma acção de educação e sensibilização ambiental foi realizada em Março de 2012 junto da comunidade de Melides, com a participação da Escola Básica de Melides, o Instituto de Conservação da Natureza e Florestas, técnicos e gestores locais. O principal objective desta acção foi a disseminação de informação sobre a biodiversidade dos ecossistemas aquáticos da região e a sensibilização para a importância da sua preservação. Esta acção incluiu uma palestra ilustrativa sobre o tema na escola EB1 de Melides e uma actividade de campo realizada na Fonte dos Olhos, localizada num local de afloramento do aquífero profundo de Sines. Foram adoptadas as metodologias desenvolvidas no âmbito do Projecto Rios (<http://www.projectorios.org>) para monitorização de sistemas dulciaquícolas.
2012. Cancela da Fonseca L. Análise dos efeitos na biodiversidade de lagoas e respectivas ribeiras como ecossistemas dependentes de água subterrânea - Projecto GroundScene (PTDC/AAC-AMB/104639/2008). Palestra apresentada no CICLO DE DEBATES SOBRE AMBIENTE NO ALENTEJO LITORAL, que teve lugar no Campus Universitário de Santo André do Instituto Piaget (25 de Maio de 2012), para divulgação e discussão do estado do ambiente no Alentejo Litoral. Diversos investigadores apresentaram os seus estudos relativos à evolução costeira e alterações resultantes do estabelecimento das populações e da indústria, quer a nível ecológico quer a nível do impacto na saúde humana. Este ciclo de debates destinou-se a estudantes, a profissionais de gestão ambiental e a todos os interessados na temática.
- 2012/2013. I. Domingos, V. Lopes & J.L. Costa. Reuniões com ICNF e a Associação de Armadores da Pesca Artesanal e do Cerco do Sudoeste Alentejano e da Costa Vicentina, com vista a promover a regulamentação e gestão participativa da pesca na Lagoa de Santo André.