Environ Earth Sci
DOI 10.1007/s12665-014-3462-8

THEMATIC ISSUE

Portugal's river basin management plans: groundwater innovative methodologies, diagnosis, and objectives

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Received: 21 November 2013 / Accepted: 17 June 2014

Abstract The European Union Water Framework Directive aims to protect inland surface waters, transitional waters, coastal waters, and groundwater and achieve certain environmental objectives through the implementation of programs of measures specified in river basin management plans (RBMPs). For that purpose, information systems have been identified as a priority tool for managing water resources effectively and efficiently, within the process of characterization and modelling of quantitative and qualitative aspects of groundwater bodies, also considering the projected climate change scenarios. This paper addresses some of the innovative issues developed in Portugal for RBMPs, exemplified for the Tagus and for the West RBMPs, e.g. modelling groundwater recharge assessment under climate change scenarios projected for 2071–2101 for the aquifer system of Torres Vedras (West RBMPs). Regarding groundwater depending ecosystems, a methodology to classify regional surface water bodies in hydraulic connection with the underlying body of groundwater is presented. A synthesis of the diagnosis and the proposed objectives is presented for Tagus and West RBMPs. The full report was published by the Consortium that developed the Groundwater Component (Lot 2), formed by Hidroprojecto, LNEC and ICCE, in Lobo Ferreira et al. (Consórcio Hidroprojecto/LNEC/ICCE. LNEC, Report 289/2011–NAS 1056 2011a, Consórcio Hidroprojecto/LNEC/ICCE. LNEC, Report 290/2011–NAS 597 2011b).

Keywords River basin management plans · Groundwater · Climate change · Methodologies · Diagnosis

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Introduction

Legal framework

The European Parliament and the Council Directive of 23 October 2000 (2000/60/EC), known as the Water Framework Directive (WFD), came into force in Portugal on 22 December 2000, having been transposed in Portugal by the Law No. 58/2005 of December 29—the Water Act. The Portuguese Water Act defines in its art. 1 the overall objectives, and in art. 47 those with relevance to groundwater.

River basin management plans (RBMPs) have set out the objectives to be achieved by 2015 and the program of measures to do so. These should be established considering, among other things, the assessment of chemical and quantitative status of groundwater bodies. The program includes basic measures, projects, and actions needed to achieve the environmental objectives laid down in legislation, as is stated in paragraph 3 of Article 30. of the Portuguese Water Act, and paragraph 1 of Article 5. Decree-Law No. 77/2006 of 30 March (paragraph 34, Part 6, Volume I, Ordinance No. 1284/2009).

The additional measures aimed at ensuring greater protection or improvement of water whenever necessary, particularly for compliance with international agreements and include the measures, projects, and actions set out in paragraph 6 of Article 30 of the Portuguese Water Act, and

Published online: 30 July 2014

paragraph 2 of Article 5. Decree-Law No. 77/2006 of 30 March (see paragraph 35, Part 6, Vol I, Order No. 1284/2009).

Organizational structure

The RBMPs were developed in accordance with the provisions in the EU Technical Guideline no 18 which states that the structure of the RBMPs report comprises Parts 1–7 and the complementary parts A and B, as follows:

- Part 1: background and overview
- Part 2: characterization of the river basin district
- Part 3: summary of the characterization and diagnosis of the river basin district
- Part 4: prospective scenarios
- Part 5: objectives
- Part 6: programme of measures and investment
- Part 7: promotion system, monitoring, and evaluation
- Complementary Part A: strategic environmental assessment
- Complementary Part B: public participation

Part 1 defines the legal and institutional framework of the planning process. This part also identifies and characterizes the objectives of the Plan and the principles of planning and management of water resources.

Part 2 elaborates the characterization of the river basin, which is a dynamic and organized technical content, allowing for a diagnosis of current situation.

Part 3 synthesizes and characterizes the basins according to seven thematic areas:

- Thematic area 1: water quality
- Thematic area 2: water quantity
- Thematic area 3: risk management and enhancement of water domain
- Thematic area 4: institutional and regulatory framework
- Thematic area 5: economic and financial framework
- Thematic area 6: monitoring, research, and knowledge
- Thematic area 7: communication and governance

Part 4 includes scenarios that support identification and analysis of socio-economic trends that influence the pressures and impacts generated by the uses of water.

Part 5 sets out the strategic objectives for the environment and other river basin and water bodies, identifying those at risk of not achieving the goals, and analyses the cases exemptions and extensions of time.

Part 6 presents the program of measures (basic additional and supplementary) to achieve the objectives, establishes priorities for implementation, and defines financial programming.

Finally, Part 7 defines the system monitoring, control and evaluation, involving a coordination and monitoring and an organizational system that ensures the implementation, coherence, and consistency of the implementation of measures as well as their coordinated implementation with other sectorial plans and programs.

Characterization of groundwater bodies in RBMPs

The Tagus and West RBMPs were chosen to describe the used methodologies as their groundwater (gw) bodies exhibit a large diversity of hydrogeological settings. These areas cover three main hydrogeological units, which coincide with mainland Portugal's three basic geological structures: Old Massif, Ceno-Mesozoic Western Rim, and the Tagus-Sado Tertiary Basin.

All together in Tagus RBMPs fifteen groundwater (gw) bodies have been studied by Lobo Ferreira et al. (2011a) (Fig. 1). Twelve gw bodies had been previously classified as independent aquifer systems by Almeida et al. (2000). The three gw bodies which were not previously classified as aquifer systems were "Maciço Antigo Indiferenciado da Bacia do Tejo", "Orla Ocidental Indiferenciado da Bacia do Tejo", and "Bacia do Tejo-Sado Indiferenciado da Bacia do Tejo". These three gw bodies comprise all the geological formations that were not considered as aquifer systems in the hydrogeological units, respectively, in the Old Massif, in the Ceno-Mesozoic Western Rim and the Terciary Tagus-Sado Basin. These geological formations include aquifer, aquitard, and aquiclude formations that in a macro-scale behave as local groundwater flow systems able to support local water supply systems. Table 1 presents a general description of the gw bodies existing in the Tagus RBMPs.

Specific methodologies developed

Conceptual models

For the development of the conceptual model of Tagus and West RBMPs gw bodies, in this item highlighted as the geometry of the gw body, a survey was completed with Hydro GeoAnalyst software, version 2011.1, from Schlumberger Water Services, including over 1500 logs of pumping wells.

According to Almeida et al. (2000), SNIRH (2014), Lobo Ferreira et al. (2011b) Torres Vedras aquifer system is a 79.83 km^2 area confined multilayer system, with intergranular porosity, calcium and sodium bicarbonate to chloride chemical facies, transmissivities ranging from 2.5 to 400 m^2/d (67 wells were considered) and high median

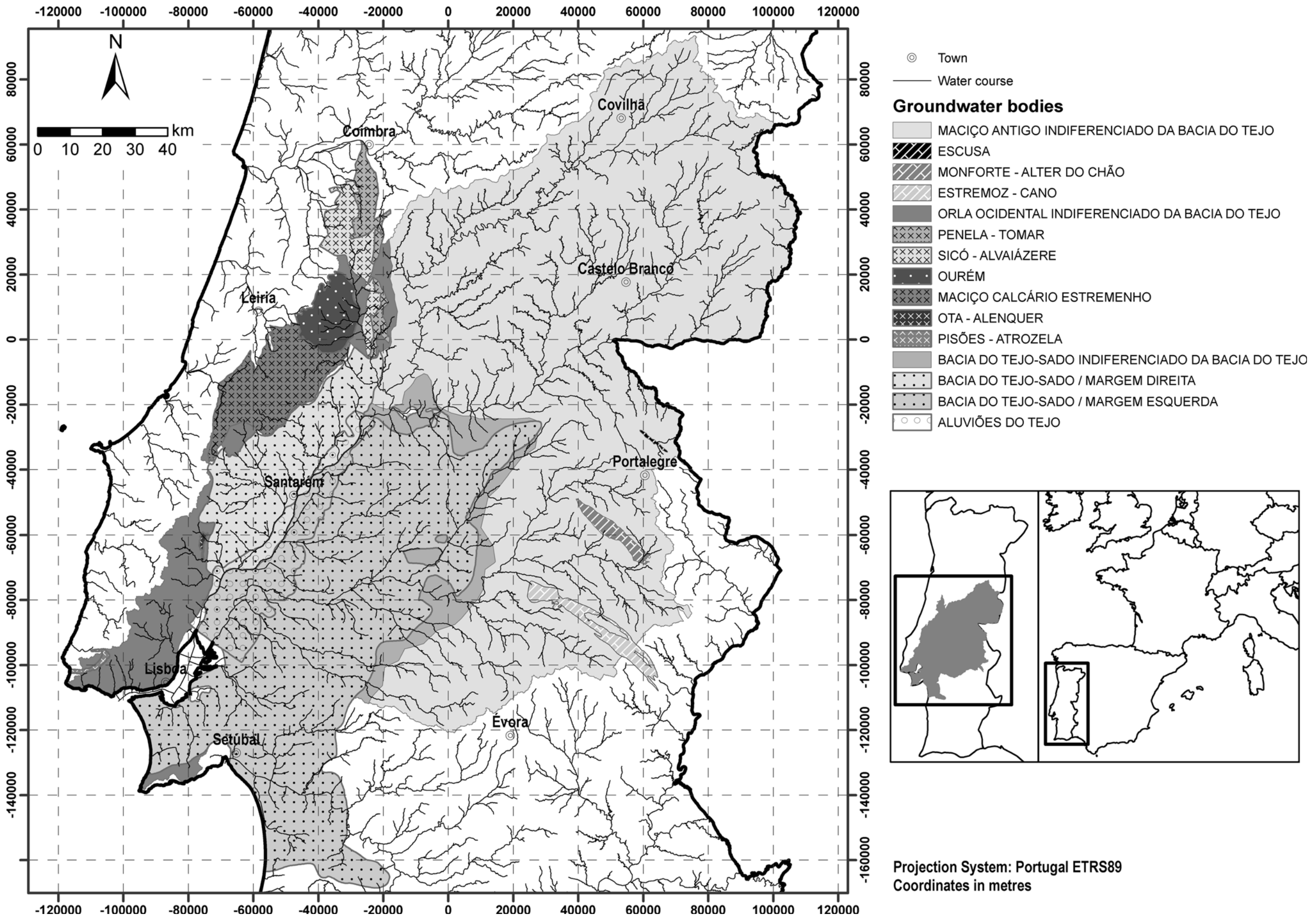

Fig. 1 Groundwater bodies of Tagus RBMPs (Source: adapted from Lobo Ferreira et al. 2011a)

discharge (equal to 6 l/s). The combination of information from the logs allows the formulation of the geometrical model. Logs are classified in main lithological formations that, using personal judgment, are linearly connected between adjacent boreholes. Cross-section interpretation allows the perception of the gw body dimensions and characteristics and the identification of fault areas. In the example of the aquifer system of Torres Vedras (West RBMPs) surveys show an aquifer system consisting of alternation of sand and clay, as shown in W-E section in Fig. 2. In the hydrogeological model of Torres Vedras gw body, three main overlapping aquifers are defined: the upper or shallow is characterized by a coarse sand unit. The second aquifer is composed of a sandstone unit, separated from the upper aquifer by a clay unit. The third (deepest) aquifer is characterized by the unit of alternating clay and sandstone and is separated from the surface by at least two clay units, the second one characterized by significant thickness in the central zone of the aquifer system. In the third unit, the central and eastern sector of the aquifer system has a strong clay component that defines various sandstone subunits. Sector South seems dominated by an absence of significant levels of thick clays (cf. Fig. 2), assuming more predominantly sandy layers.

Groundwater recharge assessment

Groundwater recharge was assessed using the mathematical model BALSEQ_MOD (Oliveira 2004, 2006). The model has as background BALSEQ model developed by Lobo Ferreira (1981) to estimate the recharge of groundwater on the island of Porto Santo, located in the archipelago of Madeira, Portugal. BALSEQ_MOD is a daily sequential soil water balance model that uses as input data daily precipitation and monthly reference evapotranspiration, and computes in a sequence the processes of soil infiltration, increased storage in the soil, direct runoff, evapotranspiration, soil water storage, and deep infiltration (water that infiltrates below the base of the soil when the soil moisture content is higher than the value of its field capacity and the water drains by gravity). In this method, interflow is considered negligible. The deep infiltration of water is used as an estimation of the refilling of the saturated zone closest to the surface.

Table 1 General description of the groundwater bodies existing in the Tagus river basin management plan

Hydrogeological unit	Code—Groundwater body designation	Area (km^2)	Aquifer type	Porosity type	Hydrochemical facies	Transmissivity—m^2/d (No. of determinations)	Median discharge[a] (L/s)
Old Massif	A2—Escusa	7,70	Unconfined	Karstic, double porosity	Calcium and/or magnesium bicarbonate	5,5–4,050 (some)	High
	A3—Monforte-Alter do Chão	97,87	Unconfined	Karstic, fissured	Calcium and/or magnesium bicarbonate	65–540 (some)	Medium
	A4—Estremoz-Cano	202,10	Unconfined, confined	Karstic, intergranular	Calcium and/or magnesium bicarbonate	230–5,500 (some)	Medium
	A0 × 1RH5—Maciço Antigo Indiferenciado da Bacia do Tejo	14268,13	Unconfined, confined	Fissured, double porosity, intergranular	Calcium and/or magnesium bicarbonate, mixed chloride	–	Low to Medium
Tagus-Sado Tertiary Basin	T1—Bacia do Tejo-Sado/Margem Direita	1629,03	Unconfined, confined, multilayer	Intergranular	Calcium-sodium and/or calcium-magnesium bicarbonate, mixed chloride	0,1–4,100 (202)	Medium to High
	T3—Bacia do Tejo-Sado/Margem Esquerda	6875,44	Unconfined, confined, multilayer	Intergranular	Sodium chloride, sodium and mixed bicarbonate	3–4,100 (431)	High
	T7—Aluviões do Tejo	1113,20	Unconfined, confined, multilayer	Intergranular	Calcium bicarbonate, sodium and mixed chloride	6–5,794 (108)	High
	T01RH5—Bacia do Tejo-Sado Indiferenciado da Bacia do Tejo	926,29	Unconfined, confined (?), multilayer	Intergranular	Calcium and/or magnesium bicarbonate, calcium and/or magnesium chloride	–	(Medium)
Ceno-Mesozoic Western Rim	O15—Ourém	315,54	Confined, multilayer	Intergranular	Calcium bicarbonate and sodium chloride	3–527 (>4)	Medium
	O26—Ota—Alenquer	9,38	Unconfined (?)	Karstic	Calcium bicarbonate	1,000–14,700 (some)	(High)
	O28—Pisões—Atrozela	22,09	Confined (?)	Karstic	Calcium bicarbonate	–	(Medium)
	O01RH5—Orla Ocidental Indiferenciado da Bacia do Tejo	1371,20	Unconfined to confined, multilayer	Intergranular, fissured, karstic, double porosity	Sodium chloride, mixed bicarbonate	–	(Low to Medium)
	O9—Penela—Tomar	244,79	Unconfined (?)	Karstic, fissured	Calcium bicarbonate	1–850 (>7)	Medium
	O11—Sicó—Alvaiázere	331,55	Unconfined (?)	Karstic	Calcium and/or magnesium bicarbonate and mixed chloride	4–570 (13)	Medium
	O20—Maciço Calcário Estremenho	767,55	Unconfined (?)	Karstic	Calcium and mixed bicarbonate	1–4,800 (some)	Low

Source of information: Almeida et al. (2000), SNIRH (2014), Lobo Ferreira et al. (2011a)

[a] Median discharge: Low (<1 l/s), Medium (≥1 l/s e < 6 l/s), High (≥ 6 l/s); when the classification is between brackets no. of determinations is low

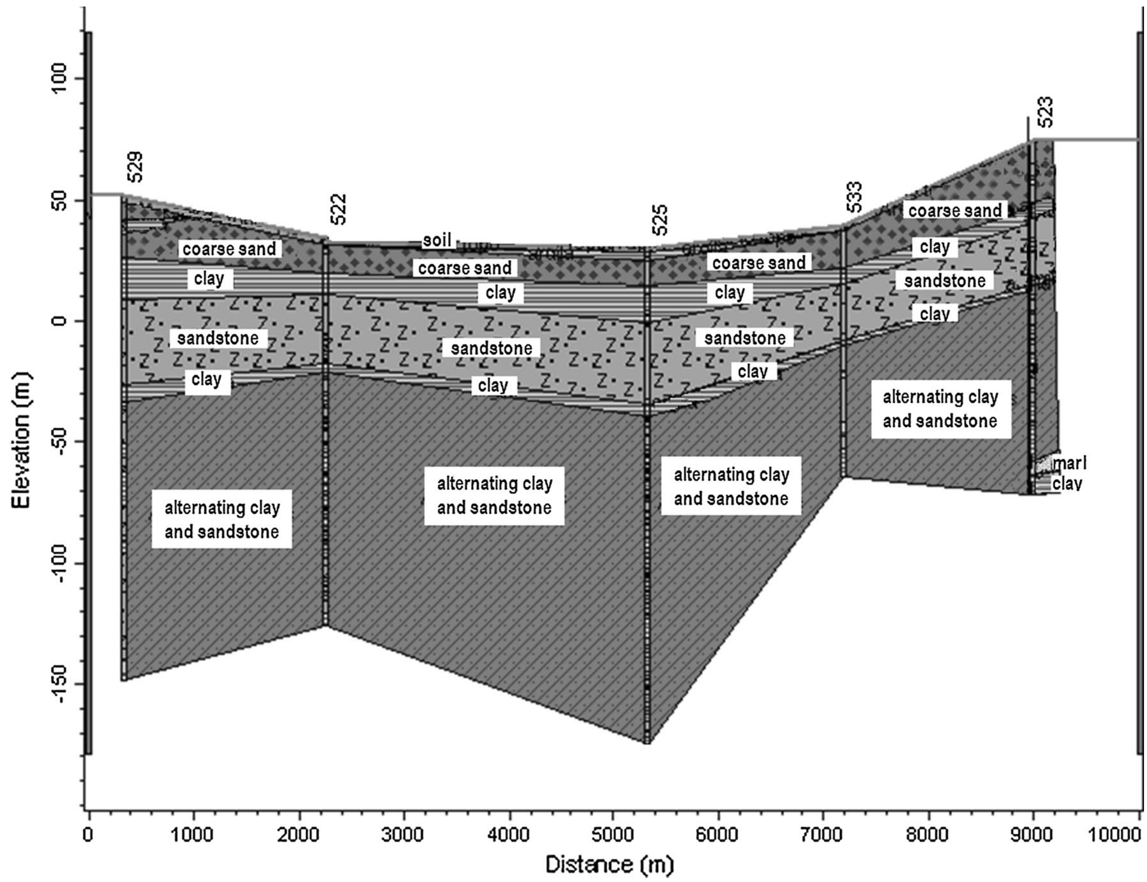

Fig. 2 W-E section in the Torres Vedras aquifer system

Thirty years' time series of daily precipitation for each gw body have been used, bridging data gaps through statistical methods. Evapotranspiration series were calculated using the FAO's Penman–Monteith method (Allen et al. 1998) based on temperature, wind speed, and minimum relative humidity for the same period of time.

The soil types in each aquifer were deduced from the outcropping geological formations, based on geological mapping at various scales. Each soil type was assigned characteristic parameters, such as hydraulic conductivity, field capacity, porosity, etc. This information was superimposed on land use.

Land use, was based on EU CORINE mapping of mainland Portugal, and included the analysis of aerial photography.

The data output resulting from running the model included daily values of all the processes considered in the balance: precipitation, actual evapotranspiration, direct runoff, and groundwater recharge.

This methodology was used for groundwater recharge assessment studies of Tagus RBMPs and also for the RBMPs of West region (Fig. 1). Figure 3 represents the annual average recharge distribution for both RBMPs.

Climate change and groundwater recharge

Based on the analysis of possible climate change for Portugal, BALSEQ_MOD model has been run for the projected variation in precipitation and temperature (rise) for the periods 2021–2050 and 2071–2100 considering the emission scenario A1B for the aquifer systems, which were also numerically modelled, of Monforte-Alter do Chão (Tagus RBMPs) and Torres Vedras (West RBMPs). Oliveira et al. (2012) describe the whole study for the Torres Vedras aquifer system, from which Fig. 4 illustrates some of the results. The average variation of precipitation and temperature projected by the models considered in the ENSEMBLES project (http://www.ensembles-eu.org/) was applied to the 1979–2009 recorded time series as follows. The future precipitation series were estimated using two different precipitation patterns: one obtained using a correction factor given by the average variation on precipitation that applies to all data of the recorded series of 30 years (cf. Fig. 5a—scenario 22), and another one that reduces the same amount of precipitation by disregarding the smallest events of rainfall in the series, according to the methodology described by Oliveira et al. (2007)—cf. Fig. 4b and

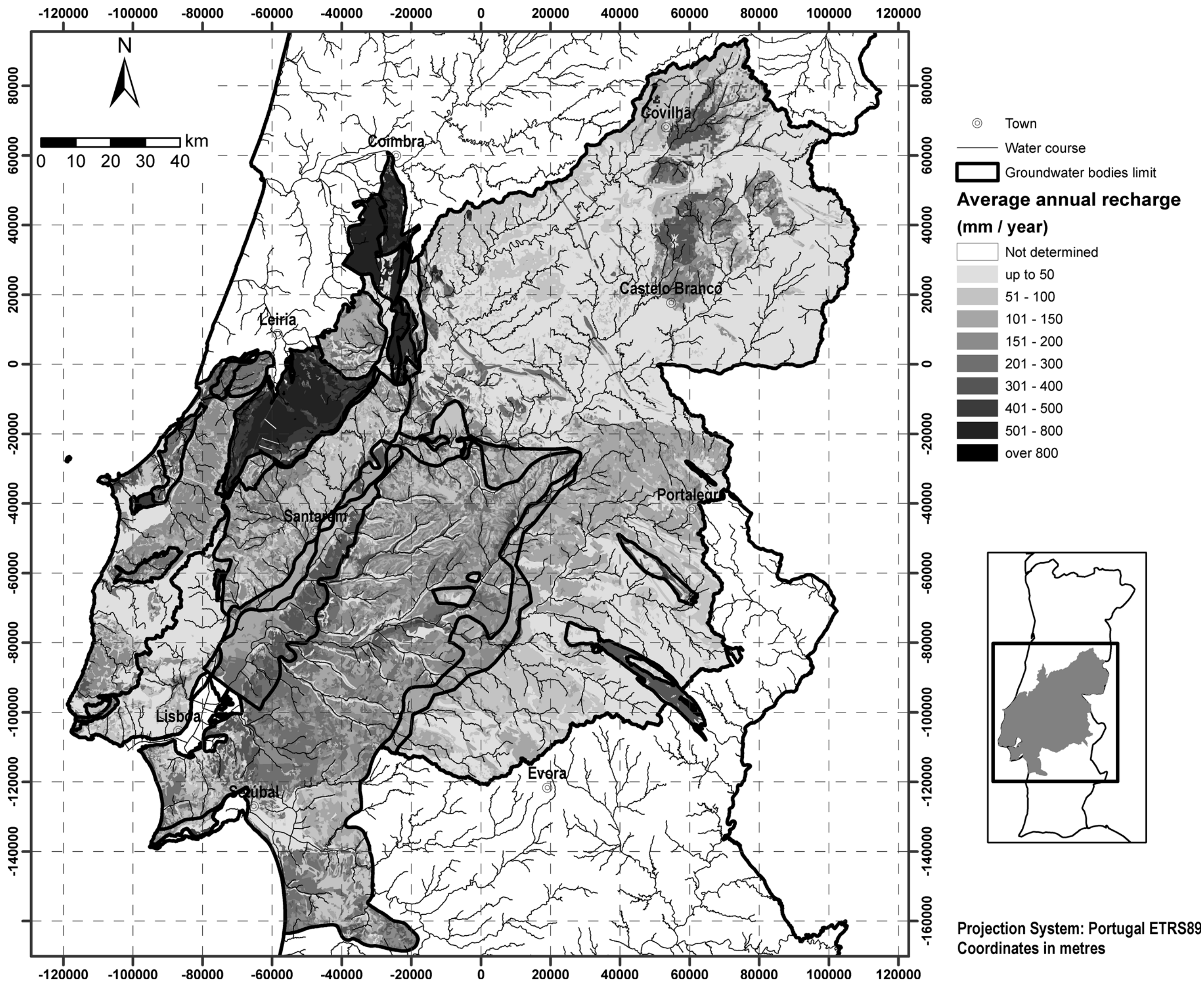

Fig. 3 Annual average recharge distribution for Tagus and West river basin management plans (Source: map created using information from Lobo Ferreira et al. 2011a, b)

Fig. 5b—scenario 24. The future temperature series were assessed applying a corrective factor given by the average variation on temperature. The potential reduction projected for aquifer recharge, as can be seen in Fig. 5, is greater than 50 %, considering the average variations as described.

Infiltration facility index (IFI)

The infiltration facility index (IFI) has been developed by Oliveira and Lobo Ferreira (2002) with the aim of defining areas of maximum infiltration in response to the Portuguese Decree-Law no. 93/90 of March 19 concerning the delimitation of the National Ecological Reserve (NER). NER includes the areas of maximum infiltration, defined as "areas where, due to the nature of the soil, to the geological substratum and also to the morphological conditions of the topographic surface, the infiltration of water presents favorable conditions, hence contributing to the recharge of phreatic surfaces".

The IFI requires the characterization of four factors:

1. Geology. This first factor can take the IFIs to its maximum value (if an area is intensively fractured or a karst area). If this is not the case, then three other factors have to be assessed:
2. Soil type (A, B, C, and D).
3. Topographic slope (<2 %, 2–6 %, 6–12 %, 12–18 %, >18 %).
4. Maximum amount of storable water in the soil which can be used for evapotranspiration—AGUT (ten classes of 50 mm ranging from <50 to >450 mm).

Each class is assigned to an index between 1 and 10, which eventually combines to produce the IFI. The maximum index (IFI = 30) means the most favorable

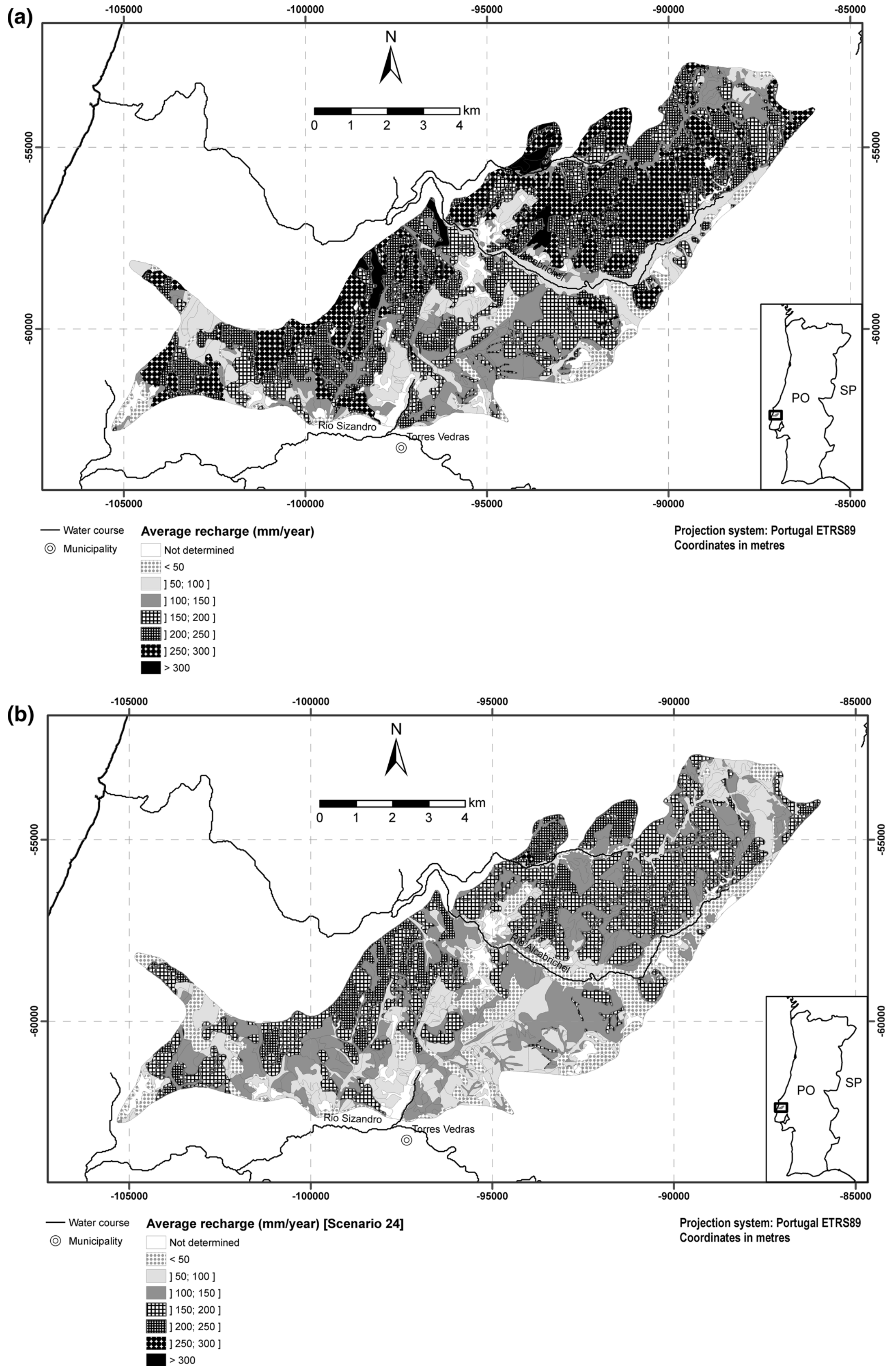

Fig. 4 Projected average annual recharge for Torres Vedras aquifer system. **a** 1979–2009 series. **b** 2071–2100 scenario 24 (Source: adapted from Oliveira et al. 2012)

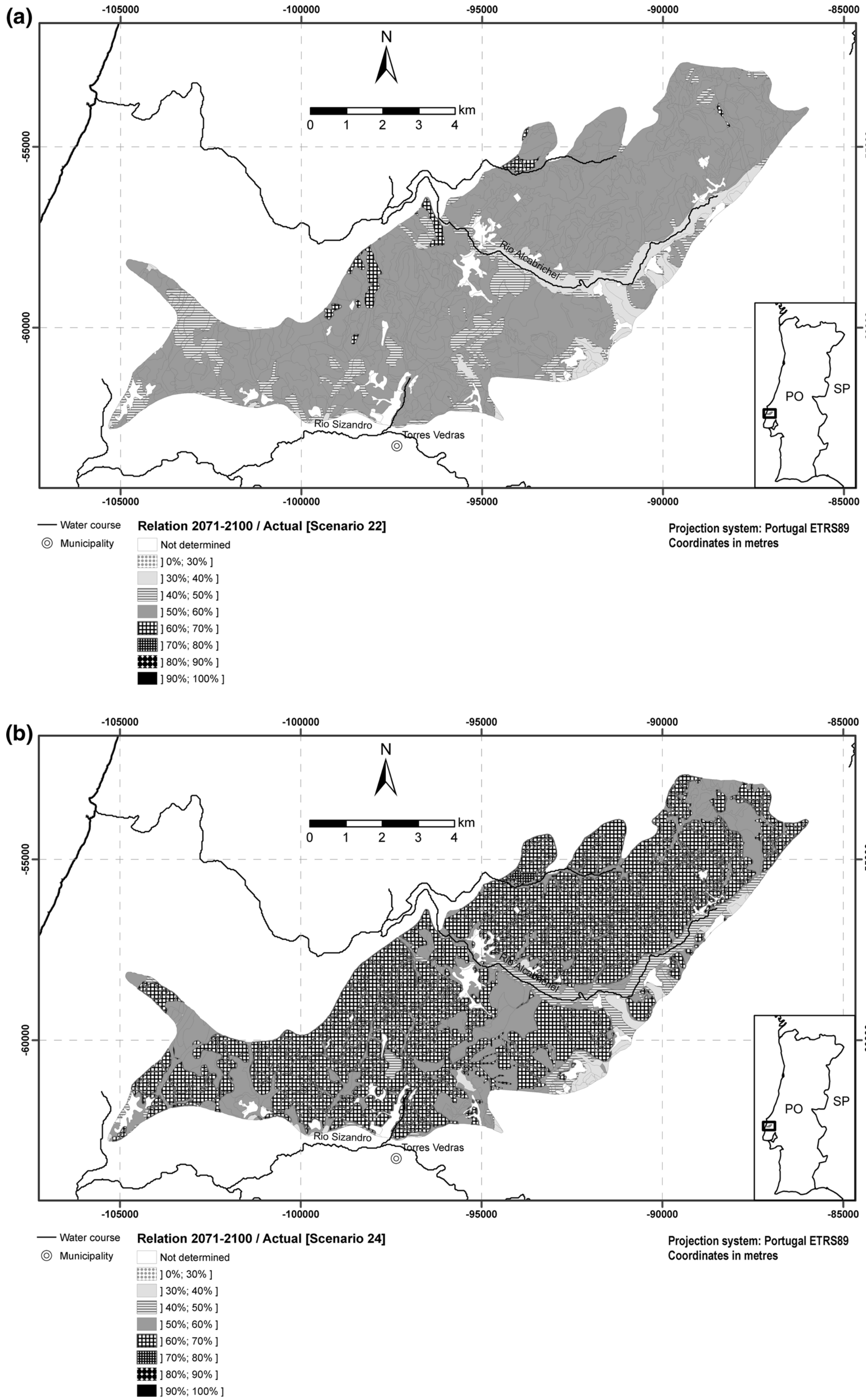

Fig. 5 Relationship between average annual recharge projected for Torres Vedras aquifer system under climate change scenarios and current recharge (1979–2009). **a** Scenario 22, **b** Scenario 24 (Source: adapted from Oliveira et al. 2012)

conditions for the infiltration and is obtained either for an intensively fractured or karst aquifer outcrop, or for a type A soil, terrain slope <2 % and AGUT <50 mm. Identified the areas with high IFI (more conductive to infiltration), these should be validated with field observations and information from residents on the behavior of these areas during the occurrence of rain.

To define special protection areas for groundwater recharge in the RBMPs areas, IFI index was applied to all groundwater bodies that have, or potentially may have, pumping wells for human consumption. Areas that drain into groundwater bodies could possibly be considered as special protection areas, if measures allowing greater infiltration could be implemented, such as land use change to areas that allow greater recharge.

Characterization of maximum infiltration areas include:

- their identification and description;
- the quantitative status of groundwater bodies affected;
- the conditions to be considered for licensing of the use or occupation; and
- measures that are provided and their status:
- programmed;
- under implementation; and
- already implemented.

For conditioning the use of areas which are areas of infiltration, the following was considered:

- delimitation of special protection areas for groundwater recharge;
- definition and implementation of rules and limitations to the use of special protection areas for groundwater recharge, and respective licensing conditions;
- defining land use constraints for special protection areas regarding groundwater recharge; and
- programming interventions in areas of high infiltration.

Figure 6 shows IFI index calculated for the area of the Tagus RBMPs.

Groundwater dependent ecosystems (GDE)

Monteiro et al. (2011) presented three methodologies for the identification of Groundwater Dependent Ecosystems (GDE) of Portugal's river basin districts 6 (Sado and Mira) and 7 (Guadiana): (1) establishment of a mapping criterion to get a picture of the regional surface water bodies in hydraulic connection with the underlying groundwater body, (2) a case-by-case analysis of the conceptual models of groundwater flow systems with upward seepage areas associated with aquatic ecosystems (ponds and streams) or dependent terrestrial ecosystems (riparian areas and areas of diffuse discharge), and (3) temporary ponds whose existence is due to local hydrogeological conditions that support ecosystems with specific characteristics. Monteiro et al. (2011) intended to provide a starting point for the discussion of criteria for identification of GDE, at regional scale.

The EU Habitats Directive (92/43/EEC) classifies Mediterranean temporary ponds as priority habitats. Salvador et al. (2011) identified the importance of Mediterranean temporary ponds in Portugal.

The overlay of geographical distribution of these ponds with the hydrogeological properties of the environments in which they occur shows that these ecosystems are dependent on groundwater as their hydroperiod is generally higher than the simple accumulation of rainwater in depressions of permeable land. Thus, it is considered that temporary ponds are included in the category of protected areas identified in Annex IV of the WFD. About 400 ponds were identified, from which it was possible to conduct a preliminary analysis of hydrogeological context that is presented and discussed using some examples below.

GDE identified in the Tagus RBMPs region are surface water bodies associated with groundwater, associated with terrestrial ecosystems (riparian areas), and terrestrial ecosystems dependent on groundwater.

Terrestrial GDE are the wetlands resulting from diffuse upward percolation of groundwater (Mediterranean temporary ponds). The GDE identified in the Tagus and West RBMPs are represented in Fig. 7 (cf. Lobo Ferreira et al. 2011a, b).

Climate change and groundwater dependent ecosystems

In the framework of both Tagus and West RBMPs, using numerical groundwater flow modelling and groundwater recharge assessment predicted under climate change scenarios, an analysis of climate change impact on dependent ecosystems was made for the Torres Vedras (Lobo Ferreira et al. 2012a) and for the Monforte-Alter do Chão (Lobo Ferreira et al. 2012b, 2013) aquifer systems. The analysis was carried out considering the A1B emission scenario, using the results of the SMHIRCA_ECHAM5 climate model. It was obtained an increasing drawdown in the aquifer system for both analysis periods (2021–2050 and 2071–2100), with an increasing diminution both for the wet zones and for the areas where the groundwater level is closer to the surface (Fig. 8). Results also depended on the method used to estimate precipitation series under climate change: a more pronounced reduction of GDE areas is observed for the method that used the removal of the lower precipitation values in opposition to the method that estimated precipitation applying a constant reduction factor to the reference series (see the section Groundwater Recharge Assessment). It should be stated at this point that this methodological approach is particularly useful to indicate eventual consequences of climate changes in the GDE areas. A thorough analysis of the climate change on the GDE is still to be made, comprising a whole set of emission scenarios, results of general circulation models, and corresponding projected climate time series.

Risk of pollution associated with roads

For the purposes of analyzing one common pollution risk, the risk of pollution associated with roads was defined using a simplified method based on Leitão et al. (2005a). Typically road runoff pollution has a diffuse pattern and may impact water systems in three main types of cases: (1) the rainfall events that washout the pollutant load accumulated at the paved surface; (2) the washout of chemicals and other materials resulting from maintenance activities; and (3) the pollution from road surfaces that may occur after accidental spillages of toxic and dangerous substances. Road runoff quality is characterized by the presence of suspended solids, heavy metals, petroleum derived hydrocarbons, and organic matter, among other pollutants (Folkeson et al. 2008; Leitão et al. 2005b).

The risk index scale was divided into four classes:

- 3–15: low risk
- 16–20: medium risk
- 21–25: high risk
- 26–30: very high risk

Figure 9 shows the IFI analysis overlapping the roads network map, pumping wells protected areas, springs and a 1 km area adjacent to the road axis, allowing classification of the risk of pollution from road to groundwater, according to the four above mentioned, risk classes have ranged from low to very high risk.

Data models

The Tagus and West RBMPs were developed in a GIS environment. The characteristics of the GIS spatial information make this subsystem (groundwater) as a cross-cutting component of the Plan, covering the existing information available at Tagus Region Water Authority (ARH Tejo), and all the new assessed contents that allow

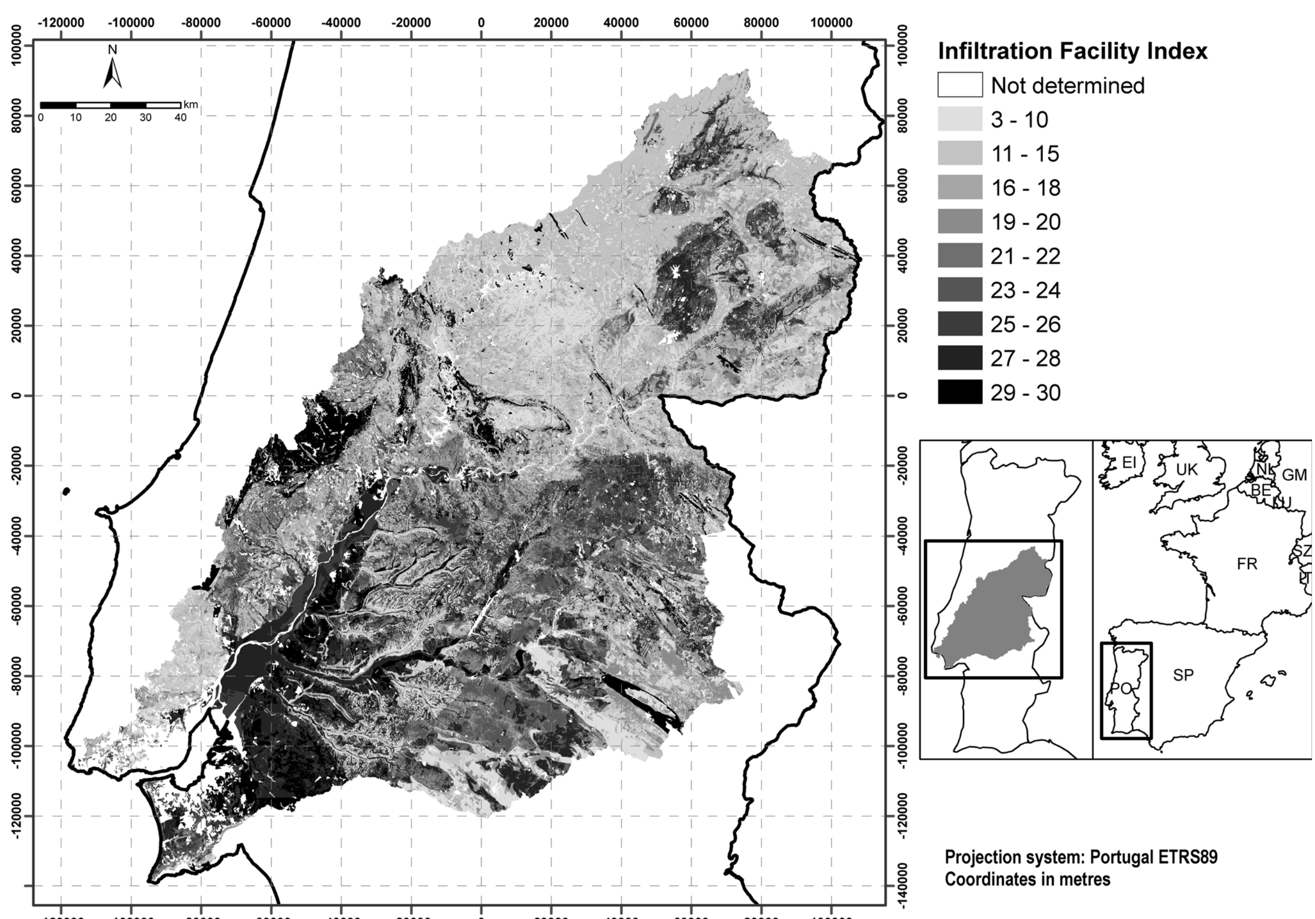

Fig. 6 Tagus RBMPs facility infiltration index mapping (Source: Lobo Ferreira et al. 2011a)

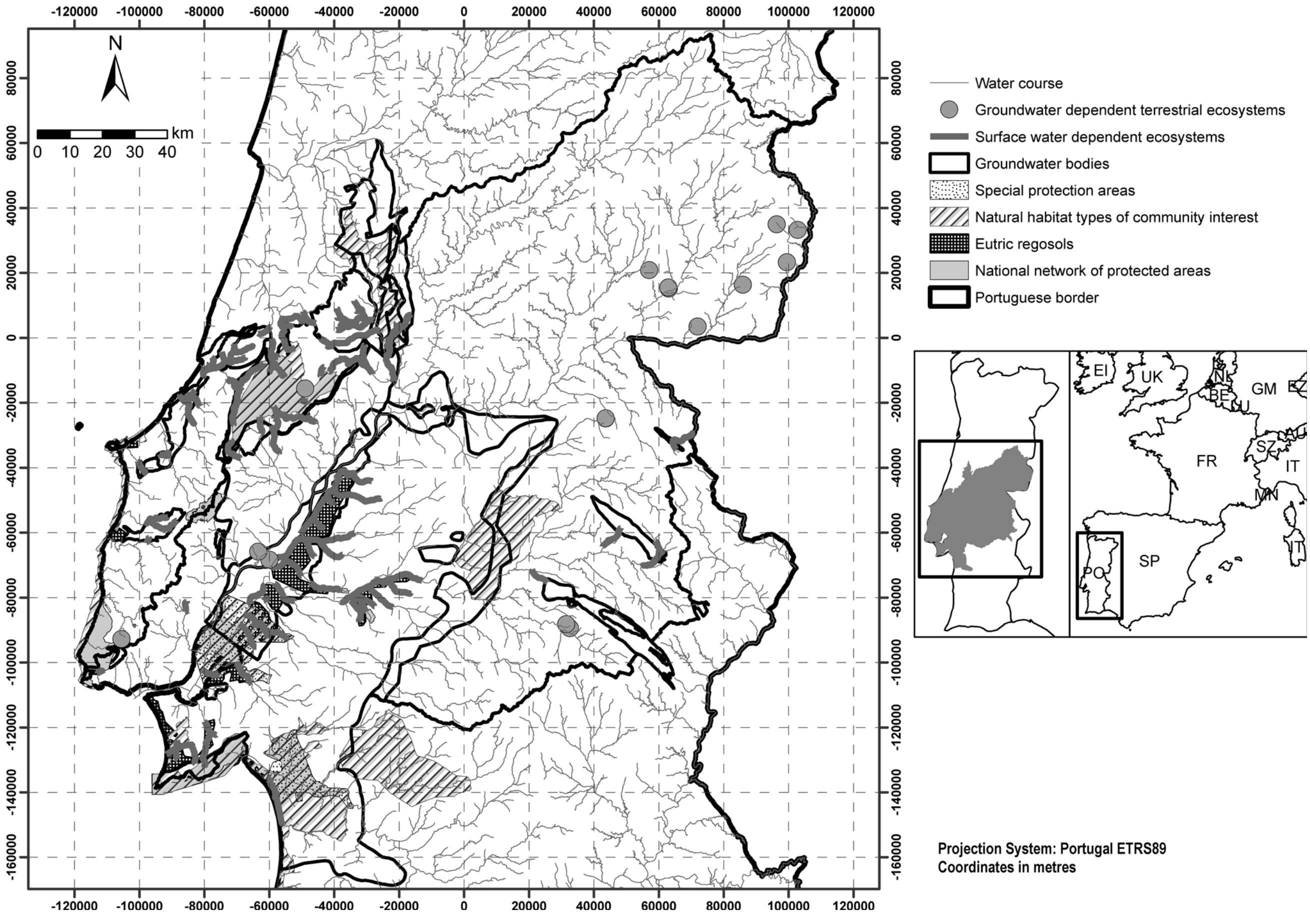

Fig. 7 Groundwater dependent ecosystems represented in the cartographic coverage used for the preparation of Tagus and West RBMPs (Source: adapted from Lobo Ferreira et al. 2011a, b)

georeferencing. The transverse dimension of GIS, which comes from the common representation of the territory (digital cartography), the need for harmonization of forms of representation and coding of mapped entities, was a guarantor of coherence and consistency of information used and produced, and a powerful tool for the analysis and presentation of the Plan.

In parallel, to the Centro Region Water Authority (ARH Centro), an analysis of the aquifer systems covered by the geographical areas of the basins of the rivers Mondego, Vouga, and Lis was developed by Charneca et al. (2011). Information systems have been identified as a tool for managing water resources effectively and efficiently, contributing to the goals established in EU RBMPs. In this context, it was conducted a study for the design of geographic information systems to support: (a) planning and management of water resources, (b) the development of flood hazard maps for rivers and estuaries, and (c) the characterization and modelling of quantitative and qualitative aspects of groundwater bodies, namely changes in recharge and chemical status.

Under the jurisdiction of ARH Centro, the objective of the groundwater component was the quantitative and the qualitative groundwater mathematical modelling of Leirosa-Monte Real aquifer and the Aveiro Quaternary Alluvium aquifer, the hydrogeological characterization of all aquifers, groundwater recharge assessment (Martins et al. 2011a), characterization of the vulnerability to pollution (Martins and Henriques 2011), characterization of the vulnerability to seawater intrusion (Martins et al. 2011b), as well as modelling protection zones for groundwater pumping wells. This included the characterization and modelling of quantitative and qualitative aspects of groundwater bodies applicable to the river basin under study. The aim is the definition and implementation of data models for geographic databases and geographic referenced thematic characterization of the river system of water bodies and groundwater, and their protected areas.

This component was divided into the following tasks:

- Task 1.1.: requirement analysis of models of spatial data;

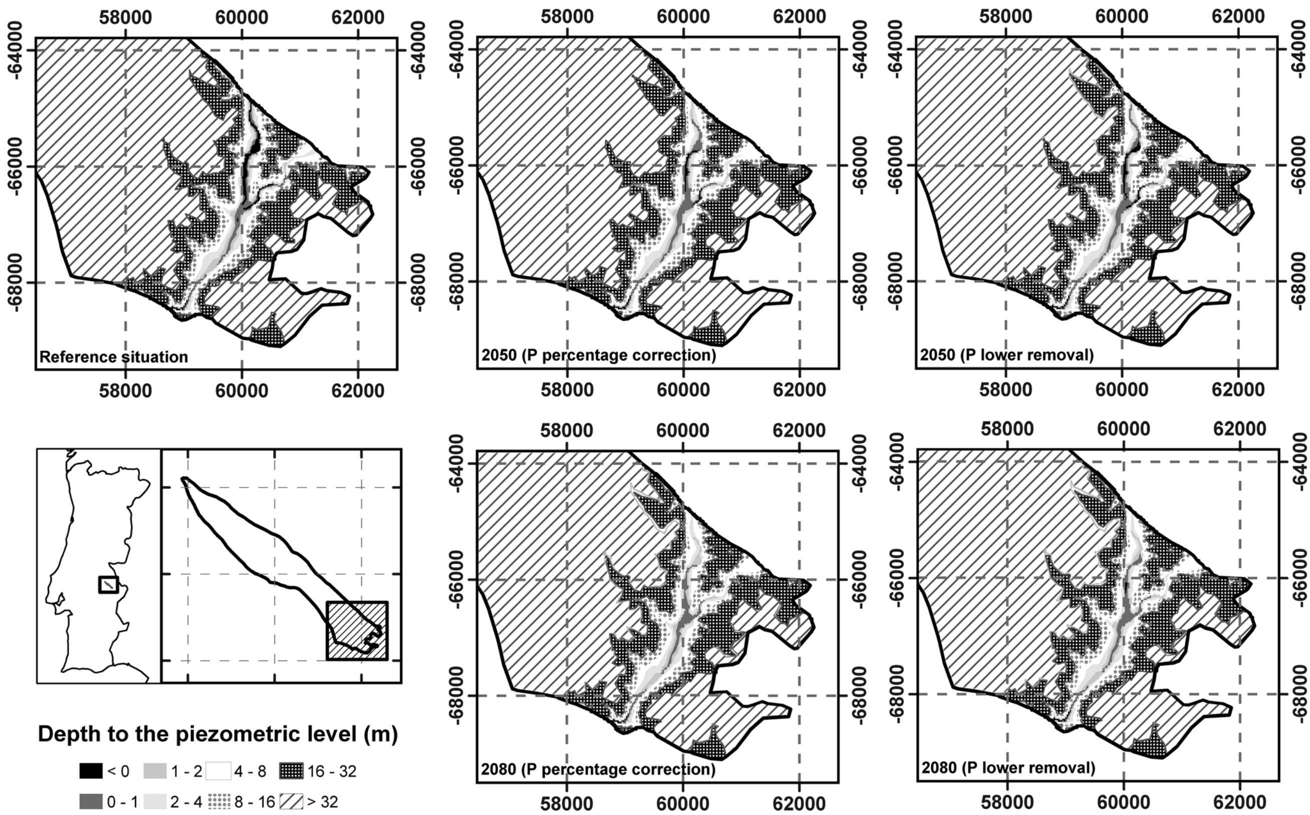

Fig. 8 Wet zones and depth to the piezometric level under climate change scenarios in Monforte-Alter do Chão aquifer system (Source: adapted from Lobo Ferreira et al. 2012b, 2013)

- Task 1.2.: specification of geographic information through data models;
- Task 1.3.: implementation and validation of the data model;
- Task 1.4.: support for the trial of the system and to define strategies for its maintenance.

The geographical data model (GDM) supports the development of products relating to all modelling components in aquifers, which include the hydrogeological characterization of the area of jurisdiction of ARH Centro, the characterization of the vulnerability to pollution and seawater intrusion, as well as groundwater protection and zoning for the abstraction of groundwater.

Figure 10 illustrates one of the class diagrams of the GDM, in this case the "wellhead protection area" (Charneca et al. 2011). This diagram models the associations between the class of pumping wells (name of the class: GroundWaterPoints), containing the general characteristics of the pumping well (designation, depth, screen zone, indication of overlapping gw bodies, etc.), and the wellhead protection area consisting of up to four geographical classes: (a) immediate (name: ImmediateProtection), (b) intermediate (name: IntermediateProtection), (c) extended zones (name: ExtendedProtection), and d) in some cases, mainly related with karstic or intensively fractured areas, the special protection zone (name: SpecialProtection), each one described by a distinct geographical class. The associations relate the identifier of the pumping well (IDHydro) with the identifier of the protection zone (IDHydroProtectionZone).

Diagnosis

Water quality thematic area

The risk analysis of pressures and their impacts on groundwater quality in the region of the Tagus RBMPs as presented by Lobo Ferreira et al. (2011a) shows that five out of 15 groundwater bodies run the risk of not complying the water quality objectives as defined in the WFD.

These are the water bodies that are in one or more of three situations: (1) poor chemical status, (2) with statistically significant upward trend in any parameter with a value exceeding 75 % of regulatory limits, and (3) subject to high pressures with high mass impact on vulnerability.

The chemical status was evaluated by applying all the tests required by the WFD (cf. EU Guideline no 18).

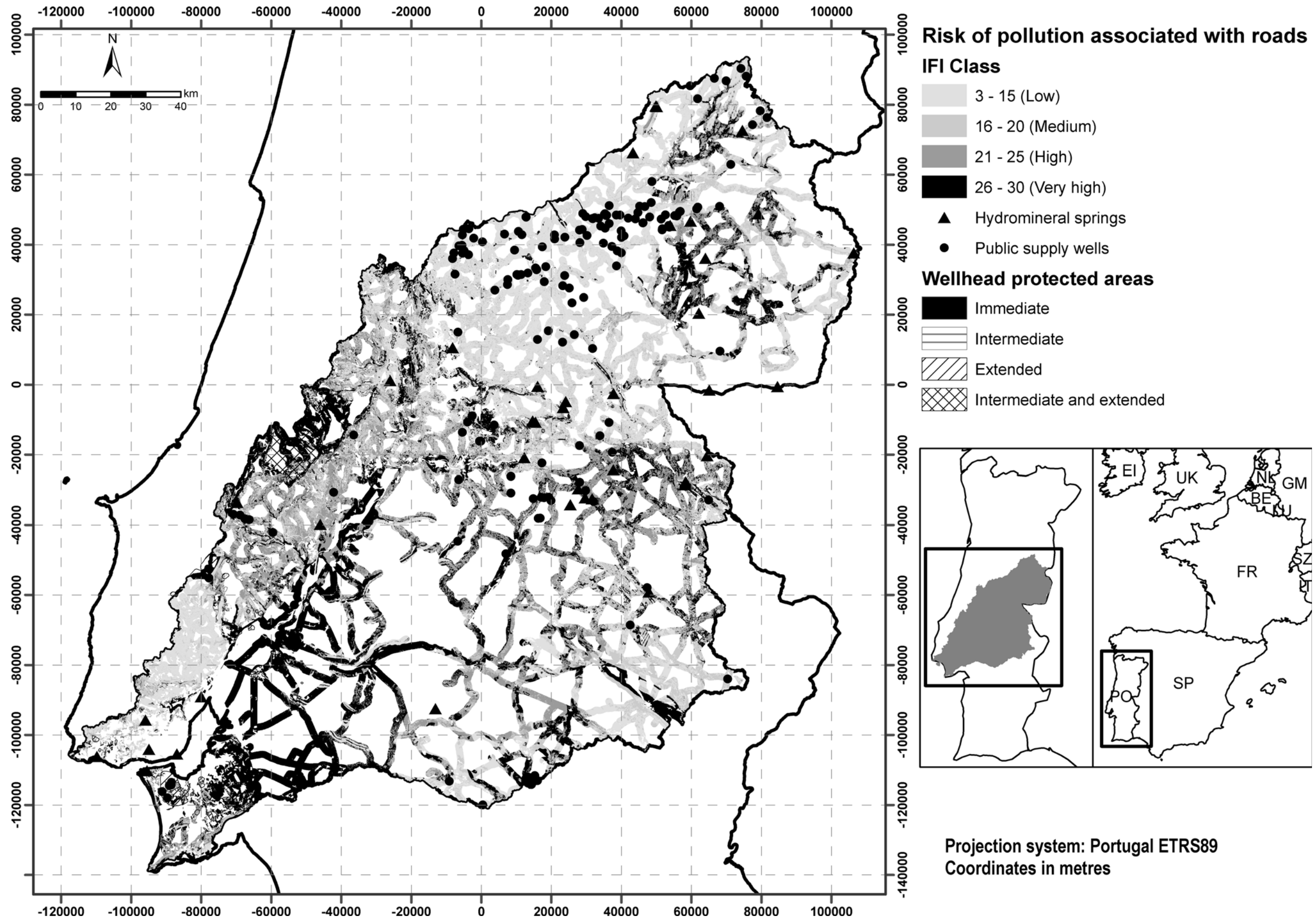

Fig. 9 Map of the risk of pollution associated with roads of Tagus RBMPs area (Source: Lobo Ferreira et al. 2011a)

Figure 11 presents the chemical status and the identification of significant trends in pollutants (upward and reversal trends) detected for the Tagus RBMPs groundwater.

Water quantity thematic area

Exemplifying the trend analysis developed on the evolution of groundwater levels for the quantitative status definition, Fig. 12 presents the time series of observations in piezometer 318/2, located in the Maciço Calcário Estremenho water body. Each hydrological year, maximum, minimum and mean value is represented (the average being calculated using 12 monthly values). It can be seen that the average value is closer to the maximum value than to the minimum. This means that along the year piezometric levels keep closer to the maximum levels. It can be noted that negative trends are obtained if the whole series is considered. However, if only the last 10 years are considered, mean and minimum values' trends are positive. This demonstrates that this analysis depends on the time scale used and if a time trend analysis of the behavior of the piezometric levels of the gw bodies is pursued then a shorter time scale seems more adequate, despite it should be long enough to attenuate the effect of dry or wet years.

In terms of data interpretation, it was considered that the analysis of the maximum yearly values would be better (instead of considering the often incomplete series of monthly values, or the yearly average or minimum values), as it gives the capacity of the gw body to recover its maximum levels and is not so much affected by missing monthly data. According to LNEC criterion of trend analysis that considers critical value the downward trend of 100 mm/year (=0.274 mm/day) for the maximum annual piezometric levels, there are no critical downward trends in this aquifer.

However in other aquifer systems of Tagus RBMPs, the overall assessment of trends in piezometric levels over time showed some situations with piezometric levels lowering in the following groundwater bodies: O15—Ourém, T1—Right Bank of Tagus-Sado, T3—Left Bank of Tagus-Sado, and also in the northern part of the water body T7—Tagus alluvium. Figure 13 represents the assessment of trends in annual maximum piezometric levels, considering the

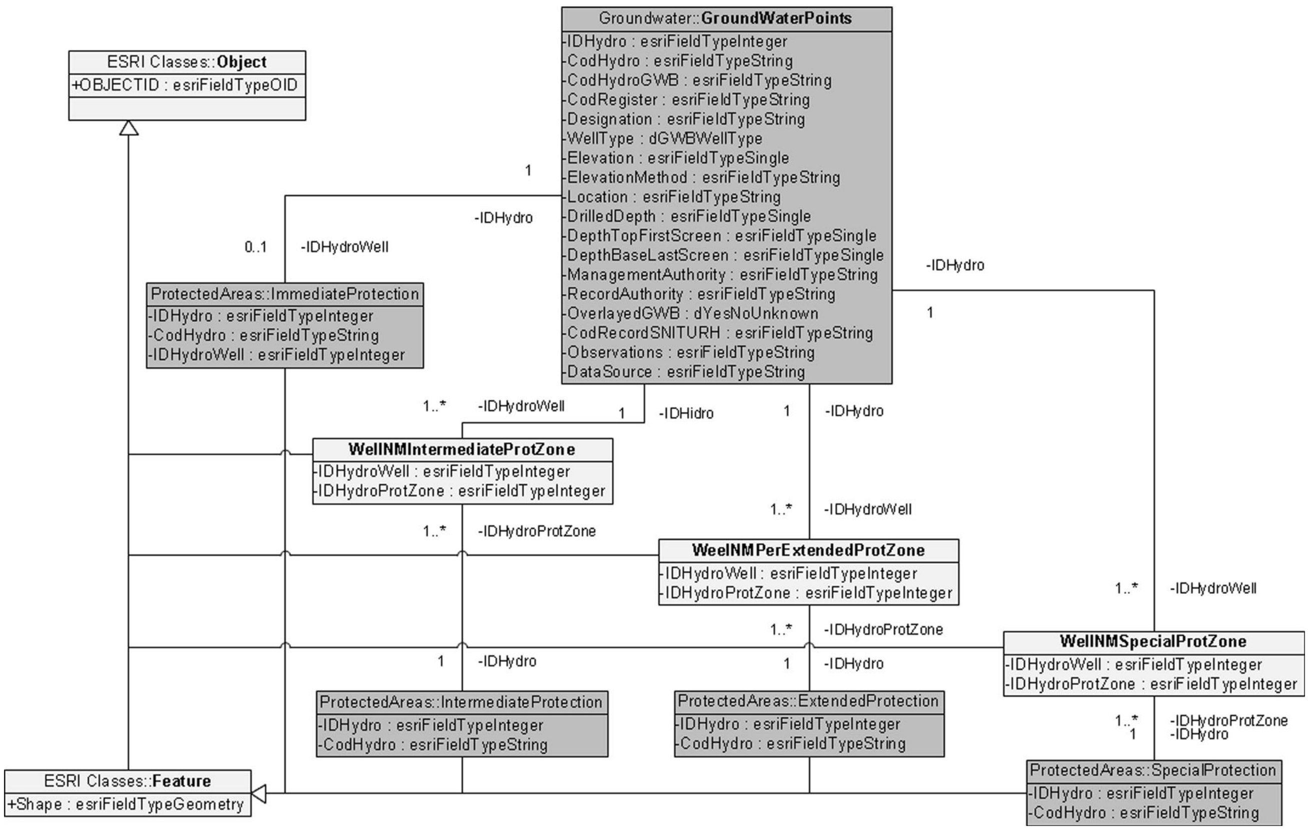

Fig. 10 Class diagram representing the associations between the class of pumping wells (GroundWaterPoints) and the groundwater abstraction protection zoning classes (ImmediateProtection, IntermediateProtection, ExtendedProtection, and SpecialProtection) (Source: adapted from Charneca et al. 2011)

downward trend as cases where the annual fall is greater than 100 mm/year.

According to the results of mass balance of groundwater developed by Lobo Ferreira et al. (2011a), exploitation rates calculated for the groundwater bodies of Tagus RBMPs vary between 1.5 and 77 %.

According to this assessment, the quantitative status of all bodies of groundwater in the Tagus RBMPs was classified as "good".

Objectives

Water quality thematic area

The main objective concerning water quality is to achieve good status of groundwater, through the protection, improvement, and recovery of all groundwater bodies and reversing any significant and sustained trend of increasing concentration of pollutants resulting from human activity, to gradually reduce their pollution levels.

According to Lobo Ferreira et al. (2011a) the groundwater bodies which currently do not meet the desired quality objectives in the area of the Tagus RBMPs are: Monforte-Alter do Chão (due to nitrates from agriculture and landfill origin); Estremoz-Cano (due to nitrates from agriculture and landfill origin); Pisões-Atrozela (due to ammonium, arsenic, lead, and pesticides possibly connected to road and agriculture pollution) and the Tagus alluvium (due to nitrates and ammonium connected to inadequate agriculture practices). The Left Bank of Tagus-Sado also has a statistically significant upward trend of nitrate and ammonium nitrogen. The proposed targets will ensure the progressive reduction of pollution of groundwater and prevent the worsening of pollution. The proposed timeframe for achieving environmental objectives for Estremoz-Cano is 2021, and for the Tagus alluvium is 2027.

For the remaining groundwater bodies (Undifferentiated Old Massif of the Tagus Basin, Escusa, Undifferentiated West Rim of Tagus Basin, Penela-Tomar, Sicó-Alvaiázere, Ourém, Maciço Calcário Estremenho, Ota-Alenquer, Undifferentiated Basin of Tejo-Sado and the Right river bank of Tagus-Sado), the objectives are to avoid further deterioration, protect and improve the status of aquatic and terrestrial ecosystems and wetlands directly

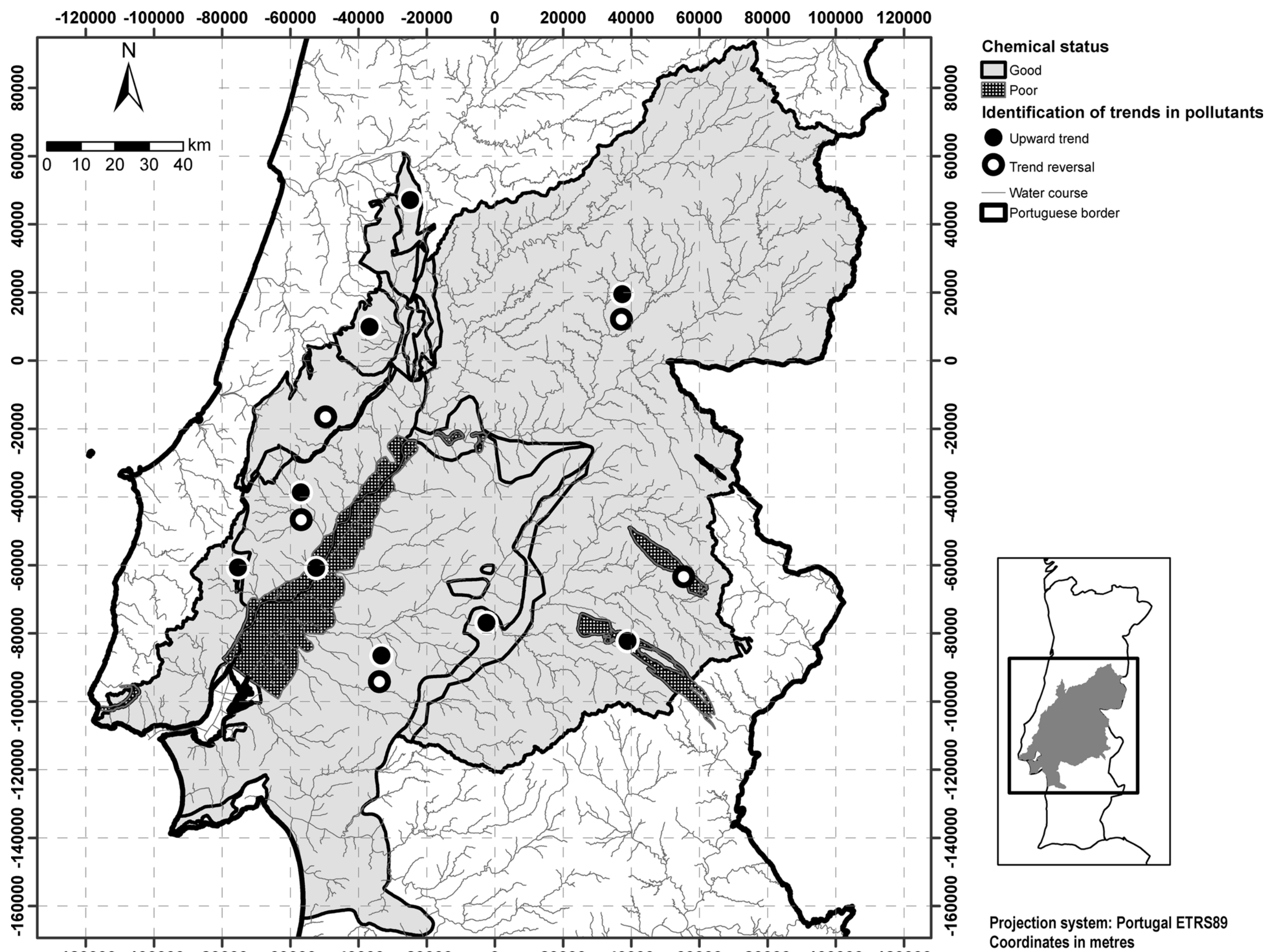

Fig. 11 Summary of the General Chemical Status and the significant and constant groundwater trends in Tagus RBMPs (Source: Lobo Ferreira et al. 2011a)

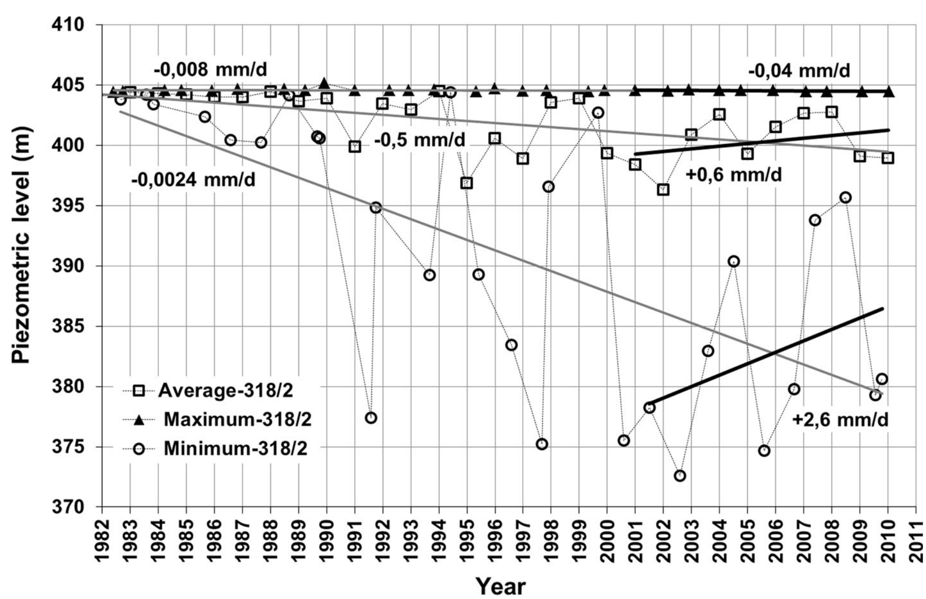

Fig. 12 Piezometric levels: annual maximum, minimum and average in piezometer 318/2 (Maciço Calcário Estremenho) per hydrological year and trends of evolution (Source: Lobo Ferreira et al. 2011a)

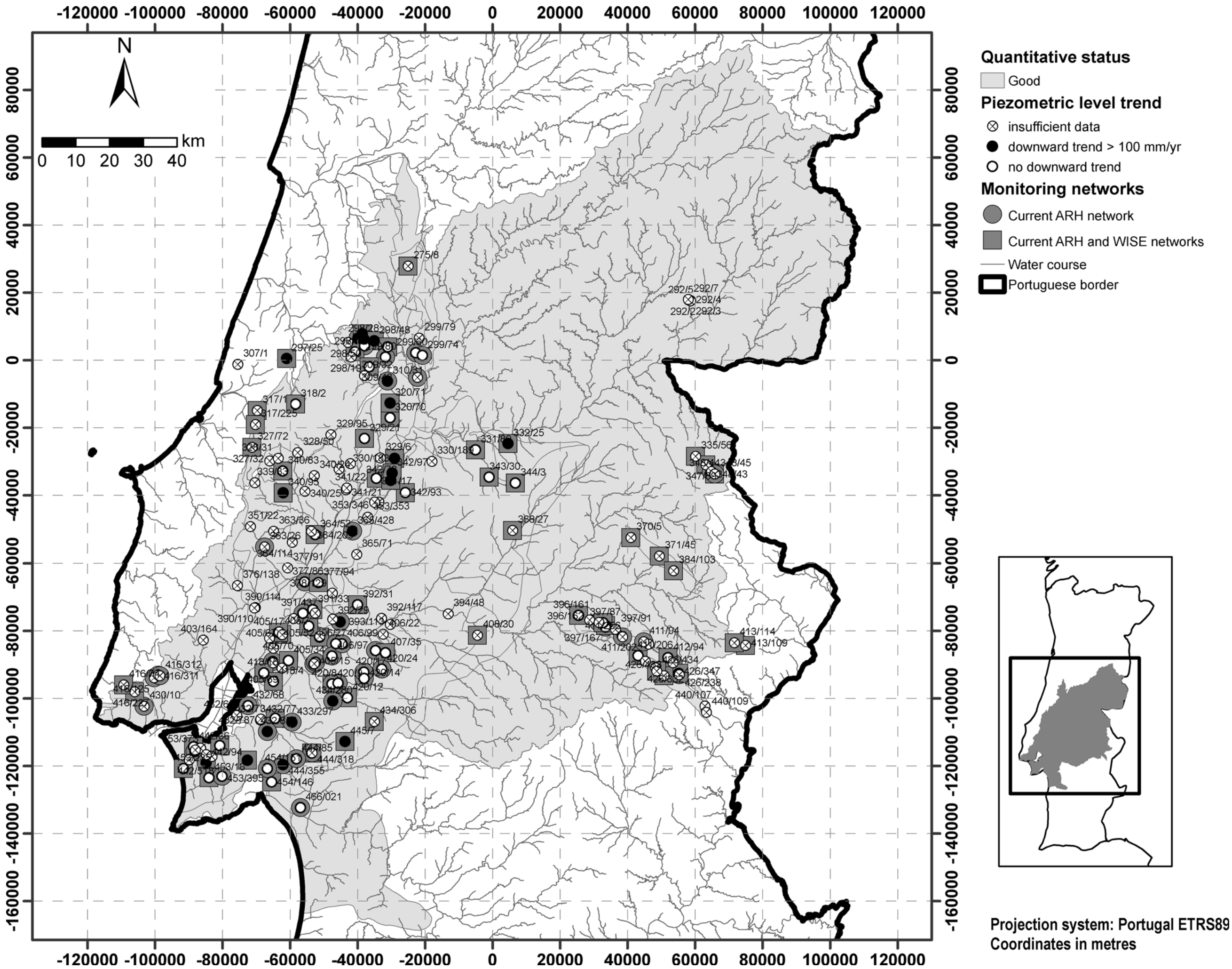

Fig. 13 Evolution of piezometric levels in Tagus RBMPs monitoring wells (Source: Lobo Ferreira et al. 2011a)

depending on aquatic ecosystems in relation to their water needs.

Water quantity thematic area

In Tagus RBMPs, the main objective in this thematic area is to maintain the good status of groundwater, by ensuring a balance between extraction and recharge of water bodies.

Apparent downward trends were recorded in some piezometers, namely those relating to the following groundwater bodies: (1) Ourém, (2) Right Bank of Tagus-Sado, (3) Left Bank of Tagus-Sado, and (4) north area of Tagus alluvium.

Given that there are some uncertainties in the available data series, either because of their limited length or because of discontinuity, and since there are no water bodies where the relationship extraction/recharge approach a value considered critical (90 %) for the maintenance of good quantitative status of bodies of groundwater, none of these groundwater bodies were suggested to be considered in a bad status.

Thus, for these water bodies the objectives are to promote sustainable water use, based on long-term protection of available water resources.

Conclusions

This paper disseminates some of the results achieved in the RBMPs of mainland Portugal, all concluded during 2011, in aspects related to groundwater. The drivers for preparing Portuguese RBMPs, e.g. for Tagus and West RBMPs, are presented, highlighting the new developments, such as recharge assessment under climate change scenarios, IFI, GDE, risk of pollution associated with roads, and GDM.

Regarding the measures proposed for the Tagus RBMPs, approximately 60 basic measures and 30 additional measures were defined aiming, respectively, the achievement of environmental laws and ensuring greater protection and a further improvement of the water quality, where it is necessary.

Basic measures included measures to: prevent or limit the input of pollutants; gradually reduce pollution levels by reversing persistent significant trends; improve the quality of groundwater affected by the presence of hazardous substances, and additional measures included measures for further: environmental impact assessments, identification and protection of GDE and for reducing the concentrations of hazardous substances at the source.

Under the additional measures, a priori considered for sites needing intervention due to the proven presence of contamination, are the following: (1) some areas in Seixal, the former Siderurgia Nacional (National Steel) and others in the area of SPEL old sandpits, (2) old Barreiro's industrial zone, and (3) the industrial area of Alcanena.

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