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50 Anos de Atividade em Hidráulica e Recursos Hídricos de

João Paulo de Cárcomo Lobo Ferreira

Investigador-Coordenador

no LNEC de 11.01.1973 a 04.05.2023

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J.P. Cárcomo Lobo Ferreira

Doktor-Ingenieur em Engenharia Civil pela *Technische Universität Berlin*. Investigador-Coordenador com Habilitação do Laboratório Nacional de Engenharia Civil (LNEC). Chefe do Núcleo de Águas Subterrâneas do LNEC. Presidente da APRH (1992-1994). Primeiro Prémio de "Trabalhos de Investigação no Domínio do Ambiente" da Secretaria de Estado do Ambiente e Recursos Naturais (1986).
João Paulo C Lobo Ferreira

Investigador-Coordenador Aposentado a 24 de janeiro de 2022

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Direção de Serviços de Recursos Humanos e Logística

Ver Curriculum

Situação Profissional

Coordenador da Assessoria para as Relações Internacionais

Graus Académicos e Científicos

- Licenciatura em Engenharia Civil pelo Instituto Superior Técnico, Universidade Técnica de Lisboa, em julho de 1975.
- Equivalência ao grau de "Diplom-Ingenieur (Dipl.-Ing.)" pela Universidade Técnica de Berlim, Alemanha, em outubro de 1978.
- "Especialista" pelo Laboratório Nacional de Engenharia Civil, Lisboa, em maio de 1986.
- "Doktor-Ingenieur (Dr-Ing.)" pela Technische Universität Berlin, Alemanha, em outubro de 1986.
- Equivalência ao grau de "Doutor em Engenharia Civil" pelo Instituto Superior Técnico, Universidade Técnica de Lisboa, em abril de 1989.
- "Habilitado para o exercício de funções de coordenação científica" pelo LNEC, em fevereiro de 2000.

Funções e Cargos Públicos Relevantes

Áreas de Investigação / Interesse

Domínios de Especialização

- Hidrogeologia e modelação matemática de águas subterrâneas;
- Hidrologia estocástica (avaliação de parâmetros de aquíferos em situação de incerteza, incluindo a avaliação da recarga de aquíferos);
- Avaliação da vulnerabilidade de formações aquíferas à poluição;
- Avaliação de recarga de aquíferos (modelação sequencial do balanço hídrico);
- Desenvolvimento, comparação e aplicação de modelos matemáticos do escoamento e do transporte de massa em meios porosos e fraturados.

Áreas de interesse

- Hidrogeologia e modelação matemática de águas subterrâneas;
- Caracterização de parâmetros de aquíferos;
- Avaliação da vulnerabilidade de formações aquíferas à poluição;
- Avaliação de recarga de aquíferos;
- Desenvolvimento, comparação e aplicação de modelos matemáticos do escoamento e transporte de massa em meios porosos e fraturados.

Línguas

- Domínio oral e escrito da língua inglesa, alemã e francesa. Entendimento escrito e oral das línguas espanhola e italiana.
- Língua mãe: Português.

Publicações Relevantes

- 2 teses ("Doktor-Ingenieur" pela Universidade Técnica de Berlim e para "Especialista" do LNEC);
- 1 Programa de Investigação para obtenção do Título de Habilitado para o exercício de funções de coordenação científica;
- 2 livros (coeditor);
- 8 Memórias do LNEC;
- 2 Informações Técnicas de Hidráulica do LNEC;
- 4 Anais de Simpósios e Seminários;
- Mais de 100 Comunicações a encontros científicos;
- Mais de 100 Relatórios do LNEC;
- 2 Relatórios do TechWare;
- 1 artigo publicado no Journal of Hydrology e 1 artigo publicado no Journal of Contaminant Hydrology.
- Foram atribuídos os seguintes prémios à Tese para Especialista do LNEC "A Dispersão de Poluentes em Águas Subterrâneas"
- "Primeiro Prémio de Trabalhos de Investigação no Domínio do Ambiente", da Secretaria de Estado do Ambiente e Recursos Naturais, em 1986;
- "Prémio Manuel Rocha", do Laboratório Nacional de Engenharia Civil, em 1987 e "Prémio da Associação Portuguesa de Recursos Hídricos", secção "Engenharias", em 1987.

João-Paulo Cárcomo Lobo-Ferreira Edit

PhD · Consultant at National Laboratory for Civil Engineering

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Repositorio DSpace at LNEC 15 de novembro de 2023 Lobo Ferreira, J. P. C.

Repositorio DSpace at LNEC: Percorrer o repositório dos 306 resultados disponíveis em https://repositorio.lnec.pt/ na pesquisa de

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Data	Título	Autor(es)
Mar-2021	Large scale physical model experiments to improve water quality using soil-aquifer-treatment (SAT-MAR)	*Leitão, T. E.*; *Martins, T.*; *Henriques, M. J. A.*; *Lobo Ferreira, J. P. C.*
2-Nov-2020	EXPERIÊNCIA DO LNEC NAS BACIAS DO CUNENE E CUVELAI AVALIAÇÃO E MODELAÇÃO DE ÁGUAS SUPERFICIAIS E SUBTERRÂNEAS	*Lobo Ferreira, J. P. C.*
18-Mai-2020	How to control groundwater quality degradation in coastal zones using MAR optimized by GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models	*Lobo Ferreira, J. P. C.*
Mai-2020	Large Scale Soil-Aquifer-Treatment (SAT-MAR) Physical Model Experiments to Improve Water Quality	*Leitão, T. E.*; *Martins, T.*; *Henriques, M. J. A.*; *Lobo Ferreira, J. P. C.*
Set-2019	Estudos sobre a reutilização de águas residuais tratadas para gestão da recarga de aquíferos	*Leitão, T. E.*; *Martins, T.*; *Mesquita, E.*; *Henriques, M. J. A.*; *Carvalho, T.*; *Rosa, M. J.*; *Lobo Ferreira, J. P. C.*
20-Mai-2019	10th International Symposium on Managed Aquifer Recharge Abstract Book	*Lobo Ferreira, J. P. C.*; *Escalante , E.*
Mai-2019	Large scale soil-aquifer-treatment (SAT-MAR) physical model experiments to remove rice paddy field contaminants	*Leitão, T. E.*; *Martins, T.*; *Henriques, M. J. A.*; *Lobo Ferreira, J. P. C.*; *Rogeiro, J.*; *Ilie, A. M. C.*
17-Dez-2018	Application of the GALDIT method combined with geostatistics at the Bouteldja aquifer (Algeria)	*Lobo Ferreira, J. P. C.*

8-Jun-2018	A risk assessment methodology to evaluate the risk failure of managed aquifer recharge in the Mediterranean Basin	*Sanchez-Vila, X.; Lobo Ferreira, J. P. C.; Rossetto, R.; Escalante , E.; Sapiano, M.; Schüth , C.*
7-Mar-2018	MARSOL White Book on the state of the art in Managed Aquifer Recharge Modelling. A Literature Review.	*Lobo Ferreira, J. P. C.; Martins, T.*
7-Mar-2018	The Strategic Research and Innovation Agenda of the H2020 Piano Project.	*Lobo Ferreira, J. P. C.*
Set-2017	Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da Região Metropolitana do Recife (Brasil)	*Oliveira, M. M.; Leitão, T. E.; Martins, T.; Duarte Costa, W.; Albuquerque, M.; Lobo Ferreira, J. P. C.*
Set-2017	Livro branco da gestão da recarga de aquíferos: Seleção de contribuições portuguesas para o projecto Marsol sobre mitigação da escassez de água e de secas	*Lobo Ferreira, J. P. C.; Leitão, T. E.; Martins, T.; Oliveira, M. M.; Mota, R.; Henriques, M.; Monteiro, J. P.; Hugman, R.; Costa, L.; Carvalho, T.; Agostinho, R.; Sousa, R.*
Jun-2017	Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da Região Metropolitana do Recife. Relatório da atividade 10 – Relatório Final	*Leitão, T. E.; Duarte Costa, W.; Oliveira, M. M.; Novo, M. E.; Martins, T.; Henriques, M. J. A.; Charneca, N.; Lobo Ferreira, J. P. C.; Viseu, T.; Santos, M.A.V.; Cabral, J J.; Freitas, A.*
Mai-2017	Soil-Aquifer Treatment as a passive solution to enhance treated wastewater quality	*Leitão, T. E.; Martins, T.; Mesquita, E.; Henriques, M. J. A.; Rogeiro, J.; Carvalho, T.; Rosa, M. J.; Lobo Ferreira, J. P. C.*
2-Mar-2017	Combinação do método da resistividade elétrica com registos contínuos de condutividade elétrica e de nível piezométrico num ensaio de recarga de aquífero	*Mota, R.; Oliveira, M. M.; Leitão, T. E.; Lobo Ferreira, J. P. C.*
Mar-2017	Tratamento solo-aquífero como solução passiva para melhorar a qualidade de águas residuais tratadas antes da sua utilização para recarga de aquíferos	*Leitão, T. E.; Martins, T.; Mesquita, E.; Henriques, M. J. A.; Rogeiro, J.; Carvalho, T.; Rosa, M. J.; Lobo Ferreira, J. P. C.*

Mar-2017	Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da Região Metropolitana do Recife. Relatório da atividade 9 - Síntese dos resultados da modelagem numérica	*Leitão, T. E.; Duarte Costa, W.; Oliveira, M. M.; Novo, M. E.; Martins, T.; Henriques, M. J. A.; Charneca, N.; Lobo Ferreira, J. P. C.; Viseu, T.; Santos, M.A.V.; Cabral, J J.; Freitas, A.*
Fev-2017	Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da Região Metropolitana do Recife. Relatório da atividade 8 - Operação do modelo numérico	*Leitão, T. E.; Duarte Costa, W.; Oliveira, M. M.; Novo, M. E.; Martins, T.; Henriques, M. J. A.; Charneca, N.; Lobo Ferreira, J. P. C.; Viseu, T.; Santos, M.A.V.; Cabral, J J.; Freitas, A.*
Jan-2017	Deliverable 4.5 - Managed aquifer recharge as a solution to water scarcity and drought. Mar to improve the groundwater status in south Portugal	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Martins, T.; Oliveira, M. M.; Henriques, M. J. A.; Mota, R.; Carvalho, T.; Carvalho, J.M.; Agostinho, R.; Carvalho, R.; Sousa, R.; Monteiro, J. P.; Costa, L. R. D.; Mesquita, E.; Rogeiro, J.; Rosa, M. J.*
Out-2016	Physical (Sandbox) modelling of Melides demo site	*Leitão, T. E.; Martins, T.; Henriques, M. J. A.; Lobo Ferreira, J. P. C.; Rogeiro, J.; Carmen, A. M.*
Ago-2016	Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da Região Metropolitana do Recife. Relatório das actividades 06 e 07: Elaboração do modelo hidrogeológico conceitual e modelo numérico, seu ajuste, calibração e validação.	*Leitão, T. E.; Duarte Costa, W.; Oliveira, M. M.; Novo, M. E.; Martins, T.; Henriques, M. J. A.; Charneca, N.; Lobo Ferreira, J. P. C.; Viseu, T.; Santos, M.A.V.; Cabral, J J.; Freitas, A.*
Ago-2016	Policies, Innovations and Networks for enhancing Opportunities for China Europe Water Cooperation	*Lobo Ferreira, J. P. C.; Lamas, L.; Leitão, T. E.; Melo, J.*
Jul-2016	Hydrogeological modelling at the South Portugal MARSOL demonstration sites	*Lobo Ferreira, J. P. C.; Leitão, T. E.; Oliveira, M. M.; Martins, T.; Mota, R.; Monteiro, J. P.; Costa, L. R. D.; Hugman, R.; Carvalho, T.; Carmen, A. M.; Carvalho, R.; Sousa, R.*

Jul-2016	Monitoring results from the South Portugal - MARSOL demonstration sites	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Oliveira, M. M.; Martins, T.; Henriques, M. J. A.; Mota, R.; Carvalho, T.; Carvalho, J.M.; Agostinho, R.; Carvalho, R.; Sousa, R.; Monteiro, J. P.; Costa, L. R. D.; Hugman, R.*
31-Mai-2016	Perímetros de proteção às captações de água – fundamentais para a qualidade da água	*Lobo Ferreira, J. P. C.*
7-Mar-2016	Políticas, Inovação, e Redes para Melhorar as Oportunidades de Cooperação China-Europa na Água. O Projeto PIANO.	*Lobo Ferreira, J. P. C.*
Mar-2016	Interim report for the Project Period June 2015 - February 2016	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Oliveira, M. M.; Martins, T.; Henriques, M. J. A.; Mota, R.; Barbosa, A. E.; Carvalho, T.; Carvalho, J.M.; Agostinho, R.; Carvalho, R.; Sousa, R.; Monteiro, J. P.; Costa, L. R. D.; Hugman, R.*
Mar-2016	Gestão de recarga induzida de aquíferos. Exemplos do projeto MARSol no Algarve	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Carvalho, T.; Monteiro, J. P.; Oliveira, M. M.; Agostinho, R.; Costa, L. R. D.; Martins, T.; Henriques, M. J. A.*
22-Nov-2015	Estratégias e ações para fomentar o uso da Gestão da Recarga de Aquíferos: o exemplo do Grupo de Ação “EIP AG 128 MARtoMARket”	*Lobo Ferreira, J. P. C.*
12-Abr-2015	Estimating harvested rainwater at greenhouses in south Portugal aquifer Campina de Faro for potential infiltration in Managed Aquifer Recharge	*Costa, L.; Monteiro, J. P.; Leitão, T. E.; Lobo Ferreira, J. P. C.; Oliveira, M. M.; Carvalho, J.M.; Carvalho, T.; Agostinho, R.*
Abr-2015	Demonstrating managed aquifer recharge as a solution to water scarcity and drought: description of Marsol project demo sites in Portugal	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Carvalho, T.; Monteiro, J. P.; Oliveira, M. M.; Agostinho, R.; Costa, L. R. D.; Henriques, M. J. A.; Martins, T.; Carvalho, J.M.*

Abr-2015	New test of the Gabardine infiltration basin for mar in rio Seco (Campina da Faro aquifer system, Algarve)	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Costa, L. R. D.*; *Carvalho, T.*; *Agostinho, R.*; *Monteiro, J. P.*
Abr-2015	Interpretation of an injection test in a large diameter well in south Portugal and contribution to the understanding of the local hydrogeology	*Costa, L. R. D.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Carvalho, T.*; *Carvalho, J.M.*; *Agostinho, R.*
2015	Modelling Contributions of the Local and Regional Groundwater Flow of Managed Aquifer Recharge Activities at Querença-Silves Aquifer System	*Costa, L.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Mota, R.*; *Lobo Ferreira, J. P. C.*; *Carvalho, J.M.*; *Carvalho, T.*; *Agostinho, R.*; *Hugman, R.*
Set-2014	Artificial recharge enhancement to prevent seawater intrusion in the coastal aquifer of Korba-Mida (Tunisia)	*Gaaloul, N.*; *Leitão, T. E.*; *Lobo Ferreira, J. P. C.*
Set-2014	Demonstrating managed aquifer recharge as a solution for climate change adaptation: results from Gabardine project and asemwaterNet coordination action in the Algarve region (Portugal)	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*
Abr-2014	Combined Use of Electrical Resistivity Tomography and Hydrochemical Data to Assess Anthropogenic Impacts on Water Quality of a Karstic Region: A Case Study from Querença-Silves, South Portugal	*Leitão, T. E.*; *Mota, R.*; *Novo, M. E.*; *Lobo Ferreira, J. P. C.*
Fev-2014	Projeto de investigação programada "Alterações climáticas e águas subterrâneas" - Relatório final de apresentação de resultados	*Novo, M. E.*; *Lobo Ferreira, J. P. C.*
2014	Portugal's river basin management plans: groundwater innovative methodologies, diagnosis, and objectives	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*
Jun-2013	Combined use of geophysical methods and water information to assess human activities impacts on karst groundwater quality	*Leitão, T. E.*; *Mota, R.*; *Novo, M. E.*; *Lobo Ferreira, J. P. C.*

Mai-2013	Artificial recharge effects in a coastal aquifer located in the semi-arid environment of Korba-Mida, Cap-Bon Peninsula, Tunisia	*Leitão, T. E.; Gaaloul, N.; Lobo Ferreira, J. P. C.*
Mai-2013	Análise da contribuição das fontes poluentes para a carga total de nitratos e fosfatos que afluem à Lagoa de Melides por transporte subterrâneo	*Lobo Ferreira, J. P. C.; Novo, M. E.; Oliveira, L. G. S.*
Mai-2013	Metodologia para a definição de medidas de intervenção para a recuperação do estado "Bom" do meio hídrico superficial e subterrâneo: o caso de estudo da bacia hidrográfica de Melides	*Novo, M. E.; Oliveira, L. G. S.; Leitão, T. E.; Lobo Ferreira, J. P. C.; Oliveira, M. M.*
Mai-2013	Metodologia para a definição das áreas prioritárias para aplicação de medidas com vista à recuperação do estado "Bom" do meio hídrico superficial e subterrâneo: o caso de estudo da bacia hidrográfica de Melides (litoral Alentejano – Portugal)	*Novo, M. E.; Lobo Ferreira, J. P. C.; Henriques, M. J. A.; Oliveira, L. G. S.*
7-Mar-2013	Variabilidade climática, recursos hídricos subterrâneos e ecossistemas dependentes de águas subterrâneas	*Lobo Ferreira, J. P. C.; Leitão, T. E.; Martins, T.; Oliveira, M. M.; Monteiro, J. P.; Novo, M. E.*
7-Mar-2013	Análise da contribuição das fontes poluentes para a carga total de nitratos e fosfatos que afluem à Lagoa de Melides por transporte subterrâneo	*Lobo Ferreira, J. P. C.; Novo, M. E.; Oliveira, L. G. S.*
7-Mar-2013	Evolução da qualidade das águas subterrâneas na zona envolvente ao complexo químico de estarreja. Perspetivas futuras	*Leitão, T. E.; Lobo Ferreira, J. P. C.; Martins, T.*
7-Mar-2013	Uma experiência de investigação em águas subterrâneas: adaptação a um mundo em mudança	*Lobo Ferreira, J. P. C.*
Mar-2013	Estudo da viabilidade de utilização das águas subterrâneas do campus do LNEC, nomeadamente para abastecimento aos modelos físicos do pavilhão de hidráulica marítima - Relatório final	*Lobo Ferreira, J. P. C.; Henriques, M. J. A.; Martins, T.; Leitão, T. E.; Novo, M. E.; Oliveira, M. M.; Oliveira, L. G. S.; Pope, L.*

Fev-2013	Combined use of geophysical methods and water information to assess human activities impacts on karst groundwater quality	*Leitão, T. E.*; *Mota, R.*; *Novo, M. E.*; *Lobo Ferreira, J. P. C.*
Jul-2012	Componente do Núcleo de Águas Subterrâneas para o enquadramento das medidas de mitigação em Melides – Projecto PROWATERMAN	*Oliveira, L. G. S.*; *Novo, M. E.*; *Lobo Ferreira, J. P. C.*
4-Jun-2012	Environmental Situation in the Surrounding Area of Lajes Field Airport, Azores	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Novo, M. E.*; *Oliveira, L. G. S.*; *Oliveira, M. M.*; *Mota, R.*; *Henriques, M. J. A.*; *Martins, T.*
Jun-2012	Plano de gestão da Bacia Hidrográfica do Tejo - Modelação do sistema aquífero de Monforte-Alter do Chão e análise dos impactos das alterações climáticas nos ecossistemas dependentes das águas subterrâneas (EDAS)	*Lobo Ferreira, J. P. C.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Martins, T.*; *Novo, M. E.*; *Oliveira, L. G. S.*; *Leitão, T. E.*; *Henriques, M. J. A.*
Jun-2012	Água, ecossistemas aquáticos e atividade humana – Projeto PROWATERMAN - Referência do projeto n.º PTDC/AAC-AMB/105061/2008 contributos para o desenvolvimento de medidas para uma gestão sustentável dos recursos hídricos no Sul de Portugal	*Oliveira, L. G. S.*; *Martins, T.*; *Lobo Ferreira, J. P. C.*; *Oliveira, M. M.*; *Novo, M. E.*; *Leitão, T. E.*
Jun-2012	Plano das Bacias Hidrográficas das Ribeiras do Oeste - Modelação do sistema aquífero de Torres Vedras e análise dos impactos das alterações climáticas nos ecossistemas dependentes das águas subterrâneas (EDAS)	*Lobo Ferreira, J. P. C.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Martins, T.*; *Novo, M. E.*; *Oliveira, L. G. S.*; *Leitão, T. E.*; *Henriques, M. J. A.*
Jun-2012	Plano das Bacias Hidrográficas das Ribeiras do Oeste - Medidas para alcançar e manter o estado bom do sistema aquífero de Caldas da Rainha-Nazaré	*Lobo Ferreira, J. P. C.*; *Novo, M. E.*; *Leitão, T. E.*; *Oliveira, M. M.*; *Henriques, M. J. A.*; *Oliveira, L. G. S.*; *Martins, T.*
Jun-2012	Plano de gestão da Bacia Hidrográfica do Tejo - Medidas para alcançar e manter o estado bom do sistema aquífero de Escusa	*Lobo Ferreira, J. P. C.*; *Novo, M. E.*; *Leitão, T. E.*; *Oliveira, M. M.*; *Henriques, M. J. A.*; *Oliveira, L. G. S.*; *Martins, T.*

Mar-2012	A New Spatial Multi-Criteria Decision Support Tool for Site Selection for Implementation of Managed Aquifer Recharge	*Rahman, M.*; *Rusteberg, B.*; *Gogu, R.*; *Lobo Ferreira, J. P. C.*; *Sauter, M.*
6-Fev-2012	Avaliação da recarga dos sistemas aquíferos abrangidos pelas regiões hidrográficas do Vouga, Mondego, Lis, Ribeiras do Oeste e Tejo	*Oliveira, M. M.*; *Martins, T.*; *Lobo Ferreira, J. P. C.*
6-Fev-2012	Estudo do impacto das alterações climáticas na recarga do sistema aquífero de Torres Vedras	*Oliveira, M. M.*; *Novo, M. E.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*
6-Fev-2012	Estado químico das massas de águas subterrâneas nas áreas dos planos de bacia do Tejo e das ribeiras do Oeste	*Leitão, T. E.*; *Nunes, L. M.*; *Silva, D.*; *Lobo Ferreira, J. P. C.*
6-Fev-2012	A água subterrânea nos actuais planos hidrológicos de bacia. Metodologias inovadoras, diagnóstico, objectivos e medidas dos planos de gestão de regiões hidrográficas portuguesas, com especial realce para o PGRH Tejo e o PBH Oeste	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*
6-Fev-2012	Contribuição para a quantificação das relações rio-aquífero no sistema aquífero Querença-Silves	*Salvador, N.*; *Oliveira, M. M.*; *Reis, E.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*; *Monteiro, J. P.*
6-Fev-2012	Avaliação do risco de poluição acidental nas áreas dos planos de bacia do Tejo e das ribeiras do Oeste	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*; *Leal, G.*; *Oliveira, M. M.*; *Henriques, M. J. A.*; *Igreja, A.*
6-Fev-2012	Protecção das origens de águas subterrâneas para consumo humano: definição de áreas de protecção no sistema aquífero de Leirosa - Monte Real	*Martins, T.*; *Henriques, M. J. A.*; *Lobo Ferreira, J. P. C.*
Fev-2012	Projecto de cooperação científica e tecnológica entre o LNEC (Portugal), o INRGREF (Tunísia), com o suporte financeiro da FCT (Portugal) e o Technology and Competency Development da Tunísia. Relatório de Progresso referente ao ano de 2011.	*Lobo Ferreira, J. P. C.*
2012	Estudo da Viabilidade de Utilização das Águas Subterrâneas do Campus do LNEC,	*Lobo Ferreira, J. P. C.*; *Henriques, M. J. A.*; *Martins, T.*; *Leitão, T. E.*; *Novo,*

	nomeadamente para Abastecimento aos Modelos Físicos do Pavilhão da Hidráulica Marítima	*M. E.*; *Oliveira, M. M.*; *Oliveira, L. G. S.*; *Pope, L.*
7-Dez-2011	On groundwater innovative methodologies, diagnosis, objectives and measures for Portugal's new river basin management plans	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*
25-Set-2011	Management of agriculture land use based on groundwater sustainability scenarios. A case-study in Portugal	*Leitão, T. E.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*; *Laranjeira, I.*
25-Set-2011	Avaliação da Vulnerabilidade à Contaminação das Águas Subterrâneas na Bacia Hidrográfica TeTê/Jacaré– UGRHI-13	*Lobo Ferreira, J. P. C.*; *Custódio, J.*
25-Set-2011	Integrated Management of Watersheds and Aquifers Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Oliveira, L. G. S.*; *Diamantino, C.*
25-Set-2011	Avaliação da Vulnerabilidade à Intrusão Marinha da Zona de Influência de Maré da Guiné Bissau	*Lobo Ferreira, J. P. C.*; *Terceiro, A.*; *Oliveira, L. G. S.*
25-Set-2011	Protecção das Origens Superficiais e Subterrâneas nos Sistemas de Abastecimento de Água	*Lobo Ferreira, J. P. C.*; *Rocha, J. S.*; *Leitão, T. E.*; *Barbosa, A. E.*; *Oliveira, M. M.*
25-Set-2011	Impacte dos Fogos Florestais na Qualidade da Água. Alguns Exemplos em Portugal	*Leitão, T. E.*; *Laranjeira, I.*; *Lobo Ferreira, J. P. C.*
14-Set-2011	A água subterrânea nos actuais planos hidrológicos de bacia metodologias inovadoras, diagnóstico, objectivos e medidas dos planos de gestão de regiões hidrográficas portuguesas, com especial realce para o PGRH Tejo e o PBH Oeste	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*
Set-2011	Água, ecossistemas aquáticos e actividade humana - Uma abordagem integrada e participativa na definição de estratégias inovadoras e prospectivas de gestão integrada de recursos hídricos no Sul de Portugal – Prowaterman Referência do projecto n.º PTDC/AAC -AMB/105061/2008 terceiro	*Oliveira, L. G. S.*; *Leitão, T. E.*; *Lobo Ferreira, J. P. C.*; *Oliveira, M. M.*; *Novo, M. E.*

	relatório temático – Saídas de campo do primeiro semestre de 2011, resultados quantitativos e qualitativos das campanhas, balanço hídrico e vulnerabilidade WRASTIC	
Ago-2011	Plano de gestão da Região Hidrográfica do Tejo - Lote 2: Recursos Hídricos Subterrâneos (Versão de Agosto de 2011)	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*; *Novo, M. E.*; *Henriques, M. J. A.*; *Oliveira, L. G. S.*; *Martins, T.*
Ago-2011	Caracterização da vulnerabilidade à intrusão marinha dos sistemas aquíferos da Região Hidrográfica do Centro	*Martins, T.*; *Henriques, M. J. A.*; *Lobo Ferreira, J. P. C.*
Ago-2011	Plano das bacias hidrográficas das Ribeiras do Oeste - Lote 2: Recursos Hídricos Subterrâneos (Versão de Agosto de 2011)	*Lobo Ferreira, J. P. C.*; *Leitão, T. E.*; *Oliveira, M. M.*; *Novo, M. E.*; *Henriques, M. J. A.*; *Oliveira, L. G. S.*; *Martins, T.*
3-Jun-2011	Plano das Bacias Hidrográficas das Ribeiras do Oeste. Lote 2: Recursos Hídricos Subterrâneos - Síntese para Consulta Pública do PBH Oeste	*Lobo Ferreira, J. P. C.*; *Pinto, I. V.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Leitão, T. E.*; *Nunes, L. M.*; *Novo, M. E.*; *Salvador, N.*; *Pombo, S.*; *Silva, M. F.*; *Igreja, A.*; *Nunes, J. F.*; *Henriques, M. J. A.*; *Silva, D.*; *Oliveira, L. G. S.*; *Martins, R.*; *Monte, M.*; *Martins, J.*; *Braceiro, A.*; *Henriques, R. S.*; *Quaresma, M.*
3-Jun-2011	Plano de Gestão da Região Hidrográfica do Tejo. Lote 2: Recursos Hídricos Subterrâneos - Sintese para Consulta Pública do PGRH Tejo	*Lobo Ferreira, J. P. C.*; *Pinto, I. V.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Leitão, T. E.*; *Nunes, L. M.*; *Novo, M. E.*; *Salvador, N.*; *Nunes, J. F.*; *Pombo, S.*; *Silva, M. F.*; *Igreja, A.*; *Henriques, M. J. A.*; *Silva, D.*; *Oliveira, L. G. S.*; *Martins, T.*; *Martins, J.*; *Braceiro, A.*; *Henriques, R. S.*; *Martins, R.*
Jun-2011	Report on Eu Mission to the Yellow River Basin. Doncument	*Lobo Ferreira, J. P. C.*
10-Mai-2011	Estudo do efeito da maré na qualidade das águas subterrâneas. Um caso de estudo em Alcântara	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*; *Henriques, M. J. A.*

10-Mai-2011	Persistent Scatterers Interferometry detects and measures ground subsidence in Lisbon	*Heleno, S.; Oliveira, L. G. S.; Henriques, M. J.; Falcão, A. P.; Lima, J. N.; Cooksley, G.; Ferretti, A.; Fonseca, A. M.; Lobo Ferreira, J. P. C.; Fonseca, J.*
5-Mai-2011	SUBSIn – Utilização do INSAR na Detecção e Caracterização de Subsidência na Região de Lisboa	*Heleno, S.; Henriques, M. J.; Falcão, A. P.; Lima, J. N.; Lobo Ferreira, J. P. C.*
Mai-2011	Persistent Scatterers Interferometry detects and measures ground subsidence in Lisbon	*Heleno, S.; Oliveira, L. G. S.; Henriques, M. J.; Falcão, A. P.; Lima, J. N.; Cooksley, G.; Ferretti, A.; Fonseca, A. M.; Lobo Ferreira, J. P. C.; Fonseca, J.*
10-Mar-2011	Efeitos da maré na piezometria e drenância entre as formações suspensas e o aquífero basal das formações aquíferas do concelho de Praia da Vitória, Açores	*Lobo Ferreira, J. P. C.; Oliveira, L. G. S.*
10-Mar-2011	Avaliação da Vulnerabilidade à Intrusão Marinha da Zona de Influência de Maré da Guiné Bissau	*Lobo Ferreira, J. P. C.; Terceiro, A.; Oliveira, L. G. S.; Baldé, I.*
31-Jan-2011	Plano das Bacias Hidrográficas das Ribeiras do Oeste.Segunda versão dos conteúdos do PBH Oeste.Versão 1	*Lobo Ferreira, J. P. C.; Pinto, I. V.; Monteiro, J. P.; Oliveira, M. M.; Leitão, T. E.; Nunes, L. M.; Novo, M. E.; Salvador, N.; Pombo, S.; Silva, M. F.; Igreja, A.; Nunes, J. F.; Henriques, M. J. A.; Silva, D.; Oliveira, L. G. S.; Martins, R.; Monte, M.; Martins, J.; Braceiro, A.; Henriques, R. S.; Quaresma, M.*
31-Jan-2011	Plano das Bacias Hidrográficas das Ribeiras do Oeste. Segundo Relatório Intercalar do PBH Oeste. Versão 1	*Lobo Ferreira, J. P. C.; Pinto, I. V.; Monteiro, J. P.; Oliveira, M. M.; Leitão, T. E.; Nunes, L. M.; Novo, M. E.; Salvador, N.; Pombo, S.; Silva, M. F.; Igreja, A.; Nunes, J. F.; Henriques, M. J. A.; Silva, D.; Oliveira, L. G. S.; Martins, R.; Monte, M.; Martins, J.; Braceiro, A.; Henriques, R. S.; Quaresma, M.*

31-Jan-2011	Plano de Gestão da Região Hidrográfico do Tejo. Segunda versão dos conteúdos do PGRH Tejo. Versão 1	*Lobo Ferreira, J. P. C.*; *Pinto, I. V.*; *Monteiro, J. P.*; *Oliveira, M. M.*; *Leitão, T. E.*; *Nunes, L. M.*; *Novo, M. E.*; *Salvador, N.*; *Nunes, J. F.*; *Pombo, S.*; *Silva, M. F.*; *Igreja, A.*; *Henriques, M. J. A.*; *Silva, D.*; *Oliveira, L. G. S.*; *Martins, T.*; *Martins, J.*; *Braceiro, A.*; *Henriques, R. S.*; *Martins, R.*
20-Out-2010	Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Henriques, M. J. A.*
Set-2010	Água, ecossistemas aquáticos e actividade humana - Uma abordagem integrada e participativa na definição de estratégias inovadoras e prospectivas de gestão integrada de recursos hídricos no Sul de Portugal – Prowaterman referência do projecto n.º PTDC/AAC-AMB/105061/2008 Segundo relatório temático – Recarga artificial de aquíferos e vulnerabilidade das águas subterrâneas às alterações climáticas	*Oliveira, L. G. S.*; *Novo, M. E.*; *Terceiro, A.*; *Lobo Ferreira, J. P. C.*
Ago-2010	Cooperação Internacional em águas subterrâneas – CIAS - Projecto de Cooperação Científica e Tecnológica entre o LNEC (Portugal), o IPT (Brasil), o Ministério dos Recursos Naturais e Ambiente da Guiné-Bissau e a Universidade Agostinho Neto (Angola) com suporte financeiro da FCT (Portugal) e do Ministério de Ciência e Tecnologia, Fundo Sectorial de Recursos Hídricos – CTHIDRO, do Brasil	*Terceiro, A.*; *Lobo Ferreira, J. P. C.*
Mar-2010	Modelação matemática em aquíferos costeiros. Aplicação a dois casos de estudo em países africanos: Angola e Tunísia	*Terceiro, A.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*; *Miguel, G.*; *Gaaloul, N.*; *Oliveira, E.*
Mar-2010	Protecção das origens superficiais e subterrâneas nos sistemas de abastecimento de água	*Lobo Ferreira, J. P. C.*; *Rocha, J. S.*; *Leitão, T. E.*; *Barbosa, A. E.*; *Oliveira, M. M.*

Jan-2010	9.º Simpósio de Hidráulica e Recursos Hídricos dos Países de Língua Oficial Portuguesa - 9.º Silusba	*Lobo Ferreira, J. P. C.*
Jan-2010	SUBSIn – Utilização do InSAR na detecção e caracterização de subsidência e deslizamentos do solo na região de Lisboa: Componente águas subterrâneas - Referência do projecto n.º PTDC/CTE-GEX/65261/2006 segundo relatório de progresso referente à análise DPSIR (Driving Forces- -Pressures-State-Impact-Responses) e à modelação de subsidência do caso de estudo em Vialonga	*Oliveira, L.*; *Lobo Ferreira, J. P. C.*; *Silva, S. I.*
Out-2009	Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Henriques, M. J. A.*
Out-2009	Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Henriques, M. J. A.*
20-Out-2010	Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Henriques, M. J. A.*
Set-2010	Água, ecossistemas aquáticos e actividade humana - Uma abordagem integrada e participativa na definição de estratégias inovadoras e prospectivas de gestão integrada de recursos hídricos no Sul de Portugal – Prowaterman referência do projecto n.º PTDC/AAC-AMB/105061/2008 Segundo relatório temático – Recarga artificial de aquíferos e vulnerabilidade das águas subterrâneas às alterações climáticas	*Oliveira, L. G. S.*; *Novo, M. E.*; *Terceiro, A.*; *Lobo Ferreira, J. P. C.*
Ago-2010	Cooperação Internacional em águas subterrâneas – CIAS - Projecto de Cooperação Científica e Tecnológica entre o LNEC (Portugal), o IPT (Brasil), o Ministério dos Recursos Naturais e Ambiente da Guiné-Bissau e a Universidade Agostinho Neto (Angola) com suporte financeiro da FCT	*Terceiro, A.*; *Lobo Ferreira, J. P. C.*

	(Portugal) e do Ministério de Ciência e Tecnologia, Fundo Sectorial de Recursos Hídricos – CTHIDRO, do Brasil	
Mar-2010	Modelação matemática em aquíferos costeiros. Aplicação a dois casos de estudo em países africanos: Angola e Tunísia	*Terceiro, A.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*; *Miguel, G.*; *Gaaloul, N.*; *Oliveira, E.*
Mar-2010	Protecção das origens superficiais e subterrâneas nos sistemas de abastecimento de água	*Lobo Ferreira, J. P. C.*; *Rocha, J. S.*; *Leitão, T. E.*; *Barbosa, A. E.*; *Oliveira, M. M.*
Jan-2010	9.º Simpósio de Hidráulica e Recursos Hídricos dos Países de Língua Oficial Portuguesa - 9.º Silusba	*Lobo Ferreira, J. P. C.*
Jan-2010	SUBSIn – Utilização do InSAR na detecção e caracterização de subsidência e deslizamentos do solo na região de Lisboa: Componente águas subterrâneas - Referência do projecto n.º PTDC/CTE-GEX/65261/2006 segundo relatório de progresso referente à análise DPSIR (Driving Forces- -Pressures-State-Impact-Responses) e à modelação de subsidência do caso de estudo em Vialonga	*Oliveira, L.*; *Lobo Ferreira, J. P. C.*; *Silva, S. I.*
Out-2009	Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems under Extreme Drought Scenarios	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Henriques, M. J. A.*
Out-2009	Planeamento e Gestão do Uso do Solo Agrícola para uma Protecção Sustentável das Águas Subterrâneas - Um Caso de Estudo em Portugal	*Leitão, T. E.*; *Oliveira, L. G. S.*; *Lobo Ferreira, J. P. C.*; *Laranjeira, I.*
Out-2009	Efeitos da Infiltração de Água num Canal de Recarga no Controlo da Intrusão Salina e nas Extracções de Aquíferos Costeiros	*Ferreira da Silva, J.*; *Lobo Ferreira, J. P. C.*; *Lima, A. S.*; *Garcez Moreira, J.*
Out-2009	POCI/AGR/59180/2004 – Avaliação do impacte de fogos florestais nos recursos hídricos subterrâneos - Relatório final de execução material	*Lobo Ferreira, J. P. C.*; *Novo, M. E.*; *Oliveira, M. M.*; *Laranjeira, I.*; *Leitão, T. E.*; *Henriques, M. J. A.*; *Martinho, N.*

Set-2009	Metodologias para um melhor planeamento e gestão do uso do solo agrícola atendendo à vulnerabilidade dos aquíferos à poluição difusa - Relatório final - Referência do projecto n.º POCI/AGR/57719/2004	*Leitão, T. E.*; *Laranjeira, I.*; *Oliveira, L.*; *Paralta, E.*; *Lobo Ferreira, J. P. C.*; *Cunha, M. C.*; *Terceiro, P.*
Abr-2009	On Methods for Regional Ground- And Surface Water Protection And Zoning: Application To The Zhangji Case Study Area (China)	*Lobo Ferreira, J. P. C.*; *Yuanyuan, M.*; *Rui, F.*
Set-2008	Modelo matemático do escoamento subterrâneo no vale de Alcântara - Relatório das Tarefas 1, 2 e 3.1	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*; *Mancuso, M. A.*; *Novo, M. E.*; *Henriques, M. J. A.*
Jun-2008	An integrated framework for sustainable agriculture land use and production practices	*Leitão, T. E.*; *Cunha, M.C.*; *Laranjeira, I.*; *Lobo Ferreira, J. P. C.*; *Paralta, E.*
Mai-2008	ECOMANAGE – INTEGRATED ECOLOGICAL COASTAL ZONE MANAGEMENT SYSTEM - Deliverables 2.6 & 2.8 - Argentina: D2.6 - SIG mapping of hydrogeologic parameters, including groundwater recharge asessment and vulnerability to pollution, D2.8 - Groundwater flow and transport components of the global estuary model (2nd Part: Bahía Blanca estuary)	*Oliveira, M. M.*; *Limbozzi, F.*; *Carrica, J.*; *Albouy, E.*; *Lobo Ferreira, J. P. C.*
Abr-2008	Ensaios de recarga artificial e aplicação de métodos geofísicos no leito do Rio Seco (Projecto GABARDINE)	*Diamantino, C.*; *Lobo Ferreira, J. P. C.*; *Mota, R.*
Abr-2008	Alterações climáticas e seus impactos em recursos hídricos subterrâneos de zonas insulares - metodologias de vulnerabilidade às alterações climáticas	*Novo, M. E.*; *Lobo Ferreira, J. P. C.*
Abr-2008	Alterações climáticas e seus impactos em recursos hídricos subterrâneos de zonas insulares - recarga de aquíferos	*Novo, M. E.*; *Lobo Ferreira, J. P. C.*
Jul-2007	ECOMANAGE - Integrated Ecological Coastal Zone Managment System Deliverable 2.8. Groundwater modeling of the sedimentary aquifer on santos estuary basin using GIS mapping of hydrogeologic parameters	*Mancuso, M. A.*; *Lobo Ferreira, J. P. C.*

	(Deliverable 2.8 - 1st Part: Santos Estuary - Quantity)	
Jul-2007	ECOMANAGE Integrated Ecological Coastal Zone Management System Deliverable 2.8 Groundwater modeling of the sedimentary aquifer on Santos Estuary basin using GIS mapping of hydrogeologic parameters	*Mancuso, M. A.*; *Lobo Ferreira, J. P. C.*
Jul-2007	Base de Dados Publicacoes, No Servidor Caliban. As publicações do NAS em Julho de 2007	*Rodrigues, M.*; *Lobo Ferreira, J. P. C.*
Mar-2007	First year achievements of Gabardine project in Portugal	*Lobo Ferreira, J. P. C.*
2007	Artificial aquifer recarge experiments in the Portuguese Campina de Faro Case-study area	*Diamantino, C.*; *Lobo Ferreira, J. P. C.*; *Leitão, T. E.*
2006	Metodologias de Avaliação do risco dos meios hídricos à poluição e sua aplicação a um caso de estudo na China	*Diamantino, C.*; *Henriques, M. J. A.*; *Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2006	Reservas Subterrâneas O recurso alternativo	*Oliveira, M. M.*; *Moinante, M. J.*; *Lobo Ferreira, J. P. C.*
2006	Definição de perímetros de protecção em captações de água subterrânea localizadas na área de estudo de Zhangji (China)	*Moinante, M. J.*; *Lobo Ferreira, J. P. C.*
2005	regional surface water protection and zoning: application to the Zhangji case study	*Lobo Ferreira, J. P. C.*; *Moinante, M. J.*; *Diamantino, C.*; *Henriques, M. J. A.*; *Oliveira, M. M.*
2005	Models to Predict The Impact of The Climate Changes on Aquifer Recharge. Comunicaçãoa apresentada no 4º Intercéltico "Water in Celtic Countries: Quantity, Quality and Climate Variability", Guimarães de 11 a 14 de Julho de 2005	*Oliveira, M. M.*; *Novo, M. E.*; *Lobo Ferreira, J. P. C.*
2005	Assessing Aquifer Vulnerability to Sea-Water Intrusion Using GAIDIT Method: Part 2 - GALDIT Indicators Description. Comunicação	*Chachadi, A. G.*; *Lobo Ferreira, J. P. C.*

	apresentada no 4º Intercéltico "Water in Celtic Countries: Quantity, Quality and Climate Variability",Guimarães, 11 a 14 de Julho de 2005	
2005	On Wellhead Protection Assessment methods and a Case-Study Application in Montemor-O-Novo, Portugal. Comunicação apresentada no 4º Intercéltico "Water in Celtic Countries: Quantity, Quality and Climate Variability", Guimarães, 11 a 14 de Julho de 2005.	*Moinante, M. J.*; *Lobo Ferreira, J. P. C.*
2005	Regional groundwater protection and zoning: application to the Zhangji case study	*Lobo Ferreira, J. P. C.*; *Moinante, M. J.*; *Diamantino, C.*; *Henriques, M. J. A.*; *Oliveira, M. M.*
2005	Methodologies for Pollution Risk Assessment of Water Resources Systems. Comunicação apresentada no 4º Intercéltico "Water in Celtic Countries: Quantity, Quality and Climate Variability", Guimarães, 11 a 14 de Julho de 2005	*Diamantino, C.*; *Henriques, M. J. A.*; *Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2005	Assessing Aquifer Vulnerability to Sea-Water Intrusion Using Galdit Method: Part 1 - Application to the Portuguese Aquifer of Monte Gordo. Comunicação apresentada no 4º Intercéltico "Water in Celtic Countries: Quantity, Quality and Climate Variability",Guimarães, 11 a 14 de Julho de 2005	*Lobo Ferreira, J. P. C.*; *Chachadi, A. G.*; *Diamantino, C.*; *Henriques, M. J. A.*
2005	Critérios para definir a sustentabilidade de exploração de águas subterrâneas	*Oliveira, M. M.*; *Moinante, M. J.*; *Lobo Ferreira, J. P. C.*; *Almeida, M. C.*
2004	Valorização e Protecção da Zona Costeira Portuguesa: Aspectos temáticos relativos à componente Águas Subterrâneas	*Lobo Ferreira, J. P. C.*; *Diamantino, C.*; *Leitão, T. E.*; *Oliveira, M. M.*; *Moinante, M. J.*
2004	Groundwater vulnerability assessment in Portugal	*Lobo Ferreira, J. P. C.*; *Oliveira, M. M.*
2004	Estimation of surface runoff and groundwater recharge in Goa mining area using daily sequential water balance model - BALSEQ	*Chachadi, A. G.*; *Choudri, B. S.*; *Noronha, L.*; *Lobo Ferreira, J. P. C.*

2003	Assessing the Impacts of Sea-Level Rise on Salt Water Intrusion in Coastal Aquifers using GALDIT model	*Chachadi, A. G.*; *Lobo Ferreira, J. P. C.*; *Noronha, L.*; *Choudri, B. S.*
2003	Qualidade das Águas Subterrâneas das Áreas Envolventes do Estuário do Rio Guadiana e Zonas Adjacentes	*Leitão, T. E.*; *Moinante, M. J.*; *Lobo Ferreira, J. P. C.*
2003	Análise de Sensibilidade da Aplicação de Métodos Indexados de Avaliação da Vulnerabilidade à Poluição de Águas Subterrâneas	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2003	Ground Water Availability in Low Precipitation Areas (Highlighting Porto Santo Island Case Study - Portugal)	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2003	Estimativa do Volume e da Qualidade em Nitratos da Água Subterrânea que Escoa para o Estuário do Rio Guadiana, na Zona do Sapal de Castro Marim	*Diamantino, C.*; *Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2003	On the Experience of Groundwater Vulnerability Assessment in Portugal	*Lobo Ferreira, J. P. C.*; *Oliveira, M. M.*
2003	Poluição de Águas Subterrâneas: Principais Problemas, Processos de Prevenção e de Reabilitação	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*; *Oliveira, M. M.*; *Moinante, M. J.*
2002	Modelação da Intrusão Salina com o Modelo Matemático FEFLOW - Fundamentos Teóricos. Formulação para um caso real de estudo.Comunicação apresentada no 6º Congresso da Água: A água é d´ouro, organizado pela Associação Portuguesa dos Recursos Hídricos (APRH), realizado no Centro de Congressos da Alfândega, Porto, 18 a 22 de Março de 2002.	*Diamantino, C.*; *Lobo Ferreira, J. P. C.*
2002	A Qualidade das Águas Subterrâneas em Portugal: O Cumprimento dos Objectivos da Directiva-Quadro da Água será conseguido, em Portugal, a bem ou a mal	*Lobo Ferreira, J. P. C.*

2002	Portuguese working paper on water issues: The water cycle dimension for coastal zone water managment	*Lobo Ferreira, J. P. C.*
2002	Proposta de uma Metodologia para a Definição de Áreas de Infiltração Máxima.Comunicação apresentada no 6º Congresso da Água: A água é d´ouro, organizado pela Associação Portuguesa dos Recursos Hídricos (APRH), realizado no Centro de Congressos da Alfândega, Porto, 18 a 22 de Março de 2002.	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2002	Assessing the Impact of Sea-Level Rise on Salt Water Intrusion in Coastal Aquifers using GALDIT model	*Chachadi, A. G.*; *Lobo Ferreira, J. P. C.*; *Noronha, L.*; *Choudri, B. S.*
2002	Proposta de uma Metodologia para a Definição de Áreas de Infiltração Máxima	*Oliveira, M. M.*; *Lobo Ferreira, J. P. C.*
2001	Gestão integrada de águas superficiais e subterrâneas.	*Lobo Ferreira, J. P. C.*
2001	Sea water intrusion vulnerability mapping of aquifers using the GALDIT method	*Chachadi, A. G.*; *Lobo Ferreira, J. P. C.*
2000	Aquifer Recharge and Evaluation of Groundwater Vulnerability to Pollution.	*Lobo Ferreira, J. P. C.*
2000	Monitorização da Poluição das Águas do Aquífero Superficial de Estarreja (Portugal). Estratégias para a sua Reabilitação	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*
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2000	On legislation and concepts concerning geographical zoning for groundwater protection	*Lobo Ferreira, J. P. C.*
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1999	Resenha de Actividade	*Lobo Ferreira, J. P. C.*
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1990	Modelos de simulação do escoamento e do transporte de massa em meios fracturados. Aplicação da modelação estocástica inversa e do modelo TRAFRAP-WT à região de Bagueixe.	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*
1990	Proposta de aplicação do modelo Gleams à Região de Aveiro para a modelação do transporte de poluentes de origem agrícola em meios não-saturados.	*Novo, M. E.*; *Lobo Ferreira, J. P. C.*
1990	Computação gráfica. Alguns programas disponíveis no LNEC para o VAX8700.	*Moura Cruz, M. P. Q.*; *Lobo Ferreira, J. P. C.*
1989	On groundwater pollution modelling and control	*Lobo Ferreira, J. P. C.*
1989	An effective single well injection/detection technique for the evaluation of the local scale dispersivity of Rio Maior Aquifer, Portugal	*Lobo Ferreira, J. P. C.*

1989	A groundwater pollution case-study: Rio Maior, Portugal	*Lobo Ferreira, J. P. C.*
1989	Modelos de simulação do transporte de massa em meios fracturados. Apreciação crítica de modelos de soluções analíticas.	*Leitão, T. E.*; *Lobo Ferreira, J. P. C.*
1989	Heat and mass transport in fractured rocks.	*Bear, J.*; *Marsily, G.*; *Tsang, C.*; *Lobo Ferreira, J. P. C.*
1989	Avaliação da vulnerabilidade à poluição e qualidade das águas subterrâneas de Portugal. Parte A: Algarve e Alentejo.	*Lobo Ferreira, J. P. C.*; *Calado, F.*
1988	Modelação matemática da qualidade das águas subterrâneas. A experiência do LNEC	*Lobo Ferreira, J. P. C.*
1986	A Dispersão de Poluentes em Águas Subterrâneas. Análise custo-eficácia de modelos matemáticos e ensaios de traçadores para a realização de estudos de impacto ambiental.Volume I e II.	*Lobo Ferreira, J. P. C.*
Jan-1985	Estudo do transporte de poluentes em águas subterrâneas. Programas para a visualização gráfica de resultados numéricos obtidos por modelos de cálculo automático.	*Lobo Ferreira, J. P. C.*; *Moura Cruz, M. P. Q.*
1985	Aplicação da equação universal de perda de solo (Fórmula de Wischmeier) para o cálculo da erosão hídrica da ilha do Porto Santo.	*MAIA, M. B.*; *Lobo Ferreira, J. P. C.*; *Rocha, J. S.*
Ago-1982	Estudo da erosão do solo na ilha do Porto Santo.	*Lobo Ferreira, J. P. C.*
1982	Problemas de recursos hídricos em ilhas e zonas costeiras. Seminário 258.	*Lobo Ferreira, J. P. C.*; *Melo Baptista, J. P.*; *Cunha, L. V.*
1982	Caracterização e gestão de recursos hídricos em ilhas vulcânicas. Seminário 287.	*Lobo Ferreira, J. P. C.*; *Melo Baptista, J. P.*; *Cunha, L. V.*
Jan-1982	Actualização do estudo hidrológico da bacia hidrográfica do rio Maior.	*Lobo Ferreira, J. P. C.*

1982	Técnicas para o controle da erosão do solo.	*Lobo Ferreira, J. P. C.*; *Huertas, C.*
Dez-1981	Estudo global dos recursos hídricos da ilha do Porto Santo.	*Lobo Ferreira, J. P. C.*; *Melo Baptista, J. P.*; *Rodrigues, J. D.*; *Cunha, L. V.*
Dez-1981	INMG - Estudo climo-hidrológico da ilha do Porto Santo. Anexo do estudo global dos recursos hídricos da ilha do Porto Santo.	*Lobo Ferreira, J. P. C.*; *Melo Baptista, J. P.*; *Rodrigues, J. D.*; *Cunha, L. V.*
Set-1980	Participação na 11.ª sessão do curso superior internacional de hidrologia da universidade de Moscovo e missão a Berlim, Holanda e Inglaterra.	*Lobo Ferreira, J. P. C.*
Mai-1976	Estruturas compactas para dissipação de energia por ressalto.	*Lemos, F. O.*; *Lobo Ferreira, J. P. C.*

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Adriano Gaspar Adão; Gabriel Luís Miguel; João Paulo**LoboFerreira**2009

- **Avaliação da vulnerabilidade à intrusão marinha do aquífero costeiro Quelo-Luanda usando o método GALDIT**

  Patrícia Terceiro; João Paulo**LoboFerreira**; Gabriel Luís Miguel; Adriano Adão2009

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  João Paulo**LoboFerreira**; Luís Oliveira; Erika da Justa Teixeira Rocha; Noureddine Gaaloul2009

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- **Avaliação da vulnerabilidade da contaminação da faixa oriental do sistema aquífero Quelo – Luanda a partir do índice D.R.A.S.T.I.C.**

João Paulo**LoboFerreira**, Adriano Gaspar Adão, Gabriel Luís Miguel
O presente trabalho teve como meta traçar a cartografia da vulnerabilidade a contaminação da faixa Oriental do aquífero Quelo – Luanda, sendo a mesma o objecto de estudo e que, que coincidentemente está localizado a oriente da Cidade de Luanda. Isto foi feito por formas a complementar estudos anteriores que não abrangeram a área. Trata-se de um sistema aquífero multicamadas, cujas formações aquíferas são nomeadamente, Luanda e Quelo. Este trabalho iniciou com uma caracterização geológica e hidrogeológica do sistema aquífero. Esta caracterização incluiu e desenvolveu aspectos relacionados com a análise de parâmetros hidrogeológicos e morfológicos, bem associados a outras formas de parametrização das características intrínsecas ao aquífero, permitindo assim a adopção de um determinado valor para o índice D.R.A.S.T.I.C. que levou a definição da vulnerabilidade a contaminação da faixa em estudo. Nesta comunicação apresenta-se os resultados obtidos com a aplicação deste índice ao aquífero para avaliação da sua vulnerabilidade a contaminação.

- **Índice de suporte à escolha de áreas favoráveis à recarga artificial (GABA – IFI): Análise das componentes ambientais, sociais e económicas**

João Paulo**LoboFerreira**, Luís Oliveira, Erika da Justa Teixeira Rocha, Noureddine Gaaloul2007

A recarga artificial de sistemas aquíferos é uma boa resposta para resolver problemas de escassez de água ou de poluição de águas subterrâneas. Para definir as áreas mais adequadas à realização da recarga artificial, desenvolveu-se uma metodologia que resulta na criação de um índice designado de GABA-IFI. Este índice é composto por três subíndices: GABA-IFI_€ para a parte económica; GABA-IFI_Soc relacionado com a parte social; e GABA-IFI_N relacionado com as características naturais do meio. O GABA-IFI foi aplicado a um caso de estudo no sistema aquífero da Costa Oriental de Cap Bon (Tunísia). Cap Bon encontra-se com problemas de sobreexploração de aquíferos, muito devido ao uso agrícola, resultando num rebaixamento significativo do nível piezométrico e na consequente deterioração da água doce devido à intrusão marinha. Estão a ser implementadas medidas para a mitigação do problema, salientando-se a recarga artificial de sistemas aquíferos com água residual tratada. Este artigo, desenvolvido no âmbito do Projecto de Cooperação Portugal – Tunísia (LNEC – I.N.R.G.R.E.F., Institut National de Recherches en Genie Rural, Eaux et Forets), visa analisar a viabilidade quantitativa da actual estação, perto da cidade de Korba, que se encontra em funcionamento desde 2007. Como medida complementar e de resolução do problema actual de intrusão marinha é apresentada uma alternativa que passa pela inserção de duas novas estações de recarga artificial. Verificou-se que a metodologia desenvolvida permitiu identificar os locais preferenciais e quantificar as necessidades hídricas da zona em estudo de forma a colmatar o problema de intrusão marinha na zona de Cap Bon.

- **Relato do Tema 5 – ‘Águas Subterrâneas’**

J. P.**LoboFerreira**1996
Apresenta-se o Relato do Tema 5 ‘Águas Subterrâneas’ do 4 Congresso da Água da APRH. Extraem-se e sintetizam-se os aspectos considerados mais relevantes, inovadores e actuais da mais de meia centena de comunicações apresentadas sobre águas subterrâneas, nos domínios da investigação aplicada, do ensino, do projecto e exploração de captações e de análise de legislação. Foi com muito agrado que se procedeu a esta tarefa. Tal permitiu a análise do vasto trabalho em desenvolvimento em todas as regiões do País, desde o 3 Congresso da Água, realizado em Abril de 1996. Realça-se a profundidade de análise das muitas áreas em que se pode desdobrar a componente científica das Águas Subterrâneas e a enorme

capacidade de trabalho demonstrada pelos nossos especialistas em Águas Subterrâneas. Salienta-se a importância e o número das comunicações (quinze) referentes ao Estudo dos Recursos Hídricos Subterrâneos do Alentejo (ERHSA), que se desenvolve desde o último trimestre de 1996 e se estenderá até ao ano de 1999. A concretização da Sessão Especial (Tema 5) sobre Águas Subterrâneas, vem também coroar o trabalho desenvolvido nos últimos quinze anos pela Comissão Especializada de Águas Subterrâneas da APRH, nomeadamente organizando e fomentando a apresentação de comunicações aos Seminários bienais sobre Águas Subterrâneas, que se têm realizado com antecedência de alguns meses em relação aos Congressos da Água da APRH.

- **Models to predict the impact of the climate changes on aquifer recharge**

J. P.**LoboFerreira**, Manuel Mendes Oliveira, Maria Emília Novo Oliveira

Climate change is a statistically significant alteration of the climate variables in terms of their distribution both on time and in space. These changes will have a direct impact on the hydrologic system and an indirect impact on the quality of the surface and ground water resources. This paper deals with the impact of climate changes on groundwater recharge. Several models to estimate recharge are presented, among which the daily sequential water balance model reveals to be the most appropriate to attain this goal. Climate changes may be predicted using climate models. Average precipitation and temperature values are outputs of these models. For a case study area of north Portugal, theoretical forecasted precipitation and reference evapotranspiration series are used to study the impact of precipitation change in groundwater recharge. For a scenario of 70 % of actual precipitation, recharge would lower to 45% of the estimated actual recharge.

- **Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of Monte Gordo**

J. P.**LoboFerreira**, Catarina Diamantino, A. G. Chachadi, M. J. Henriques2005

This paper is divided in two parts. Part 1 presents the first application in Europe of an index developed in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to sea-water intrusion in coastal aquifers. The most important factors controlling seawater intrusion were found to be the following: Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; Depth to groundwater Level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer, which is being mapped. The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference. These factors, in combination, are determined to include the basic requirements needed to assess the general seawater intrusion potential of each hydrogeologic setting. GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed examination. A numerical ranking system to assess seawater intrusion potential in hydrogeologic settings has been devised using GALDIT factors. The application of the method is exemplified in the paper for the assessment of aquifer vulnerability to seawater intrusion in Portugal (Monte Gordo aquifer in the Portuguese Southern Algarve region). The system contains three significant parts: weights, ranges, and ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. Part 2 of the paper is available in the Proceedings of this 4th Interceltic Colloquium as CHACHADI and **LOBO-FERREIRA** (2005). In the second part of the paper the method for assessing GALDIT index parameters is fully explained and an application to a costal aquifer located in Goa, not only for today's conditions but also considering a 0.5 m sea level rise are presented.

- **Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: Part 2 – GALDIT Indicators Description**

J. P.**LoboFerreira**, A. G. Chachadi2005

This paper is Part 2 of the paper submitted to this 4th Interceltic Colloquium as **LOBO-FERREIRA** et al. (2005). In this second part of the paper the method for assessing GALDIT index parameters is fully explained. The original development of GALDIT index was done in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to sea-water intrusion in coastal aquifers. The most important factors controlling seawater intrusion were found to be the following: Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; Depth to groundwater Level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer, which is being mapped. The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference. These factors, in combination, are determined to include the basic requirements needed to assess the general seawater intrusion potential of each hydrogeologic setting. GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed examination. A numerical ranking system to assess seawater intrusion potential in hydrogeologic settings has been devised using GALDIT factors. The system contains three significant parts: weights, ranges, and ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. In this part we also present the first applications of the method developed for the Bardez aquifer in Goa, India.

- **On wellhead protection assessment methods and a case-study application in Montemor-o-Novo, Portugal**

J. P.**LoboFerreira**, Maria João Moinante

Groundwater is vulnerable to several kinds of pollution usually related to the development of anthropogenic activities. Nowadays, the wellhead protection areas and their corresponding restrictions are the most widely used instruments for protecting aquifers. After the description of the wellhead protection area and the presentation of Portuguese regulations that govern wellhead protection areas, a review of the methods applied to define wellhead protection areas in the case study area is presented. The study area is briefly described, including the wells used for public water supply, and the analytical methods for wellhead protection zones definition are applied, including the one suggested by the Portuguese legislation, as well as the ASMWIN numerical model. Finally, some conclusions were made, based on the achieved results.

- [Methodologies for pollution risk assessment of water resources systems]

J. P.**LoboFerreira**, Catarina Diamantino, Manuel M. Oliveira, Maria José Henriques
Water resources systems (both surface water and groundwater resources) are subject to different anthropogenic pollution impacts. Their intrinsic characteristics to better support pollution impacts or on the other hand their intrinsic vulnerability to pollution may or may not allow them to resist pollution accidents of different types. The

Realçam-se 3 documentos de 1973-1983:

1a) Estruturas compactas para dissipação de energia por ressalto.

Authors: Lemos, F. O.

Lobo Ferreira, J. P. C.

Issue Date: May-1976

1b) Estruturas compactas para dissipação de energia por ressalto

Authors: Lemos, F. O.

Lobo Ferreira, J. P. C.

Issue Date: 1978

Publisher: LNEC

Series/Report no.: Memória Nº 502

Abstract: Os autores efectuaram um estudo comparativo da eficácia de dois tipos de estruturas de dissipação de energia por ressalto ambos providos de blocos dissipadores. Um é o tipo BR III, desenvolvido pelo Bureau of Reclamation e largamente utilizado nos EUA; o outro é o de Kumin, desenvolvido no Instituto Hidrotécnico Vedeneev e utilizado na URSS.

2) Title: Introdução à contaminação de águas subterrâneas.

Authors: Lobo Ferreira, J. P. C.

Issue Date: 1983

Publisher: LNEC

Series/Report no.: ITH 2

Abstract: Apresenta-se uma introdução à problemática da contaminação de águas subterrâneas, relacionada com a evacuação de excreta. Recordam-se conceitos gerais de hidrogeologia necessários ao desenvolvimento posterior de alguns aspectos básicos da poluição de águas subterrâneas . Reflecte-se e responde-se a questões relacionadas com direcções, velocidades e concentrações de poluentes em águas subterrâneas. Termina-se com a apresentação de um método prático para a delimitação de zonas de protecção de captações para o abastecimento de água.

3) Title: The finite element method in water resources engineering.

Authors: Lobo Ferreira, J. P. C.

Issue Date: 1983

Publisher: LNEC

Series/Report no.: ITH 4

Abstract: This paper is divided in two main parts: 1st PART: A simple theoretical introduction to the Finite Element Method (FEM), is presented and is complemented by a comparison of the FEM with other methods that can also be used to solve differential equations. In this part we will present some differential equations which allow the application of the FEM to several problems in water resources engineering. 2nd PART: In this part we will introduce a practical work recently done at the Technical University of Berlin (FRG) on FEM. This work has two parts: a) The first one is the Manual of Operating of a Computer Program; b) The second one is concerned with the theoretical background of the approach used. This part is intended to give an overall idea of the relationship between theory and its applications. The 2nd part ends with some conclusions and a list of bibliographic references. This paper is directed to people not acquainted with the FEM, who intended, however, to be introduced to some new techniques and theoretical methods which may be applied in the Water Resources Engineering field.

Seleção de Documentos no DSPACE com link para pdfs:

4) Título: How to control groundwater quality degradation in coastal zones using MAR optimized by GALDIT Vulnerability Assessment to Saltwater Intrusion and GABA-IFI models

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Salt water intrusion, GABA-IFI; mathematical models; GALDIT; GABA-IFI

Data: 18-Mai-2020

Editora: IAH – International Association of Hydrogeologists (iah.org) e pela IAPG – International Association for Promoting Geoethics (geoethics.org).

Relatório da Série N.º: Congresso Internacional "GEOETHICS & GROUNDWATER MANAGEMENT: THEORY AND PRACTICE FOR A SUSTAINABLE DEVELOPMENT" – GEOETH&GWM'20;

Resumo: To counteract harmful, eventually with catastrophic consequences, today and future groundwater quality degradation due to saltwater intrusion into coastal aquifers, Managed Artificial Recharge (MAR) is considered the best solution, a sound, safe and sustainable solution. MAR, in coastal areas, depends on the availability of water including waste water appropriately treated. How to control saltwater intrusion in coastal zones implementing a MAR facility? The parameters required to answer that question, include the selection of the most appropriate technology and the best location for MAR. The appropriate location must have good infiltration rates; enough space to store underground the recharged water; guarantee that the travel time of the recharged water in the aquifer is long enough, compatible with the expected frequency of drought periods; economic efficiency maximization; availability of areas for MAR; and, positive impacts on the society. GABA-IFI model addresses those parameters allowing the selection of the most appropriate area for the location of MAR. Complementary, mathematical models are available to quantify MAR water injection rates required to recover groundwater depleted levels. Where should the injection be located? GALDIT is probably, today, the most used model worldwide to assess the vulnerability of saltwater intrusion in costal aquifers by a numerical calculation.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012683/1/GEOETH_%20JPLoboFerreira_revised.pdf

5) Título: The Strategic Research and Innovation Agenda of the H2020 Piano Project.

Outros títulos: PIANO Project: Policies, Innovation, And Network for enhancing Opportunities for China - Europe Water Cooperation

Autor: GIUSTA, E.

Lobo Ferreira, J. P. C.

Palavras-chave: Strategic Research and Innovation Agenda;Technological Water Innovations;China-Europe Water Platform;H2020 PIANO project

Data: Mai-2018

Editora: University of Natural Resources and Life Sciences (BOKU) Vienna , Austria

Resumo: Relations between the EU and China have developed rapidly since the first diplomatic ties were established in 1975. Since 1998, EU-China summits have been held almost every year. The creation of the EU-China Comprehensive Strategic partnership in 2003 has deepened and broadened collaboration in a wide range of areas. The EU-China 2020 Strategic Agenda for cooperation, jointly signed and adopted in 2013, provides strategic guidance for the relations between these two regions of the world on many topics, including science, technology and innovation. In fact, both the EU and China need to foster science, technology and innovation (STI) development to address the economic, social and sustainability challenges they encounter. Interactions between the two regions have also been growing across themes such as environment, energy, climate issues and many others. Within the field of environment, water is a priority for the cooperation with China. An EU-China water platform (CEWP) was established in 2012 to promote policy dialogue, joint research and business development in the water sector. The European partners of the PIANO project (Policies, Innovation, And Network for enhancing Opportunities for China-Europe water cooperation) have worked on the development of this Strategic Research and Innovation Agenda (SRIA) in close cooperation with the representatives of the Chinese institutions, who signed a letter of intent to be involved in the project activities at the time the proposal was presented to the European Commission for its funding by the programme Horizon 2020. Then, in 2015, the EU-China Research and Innovation Co-funding mechanism was not yet in place and Chinese researchers could not be proper partners in the PIANO project activities. Nevertheless, they have provided a very relevant and effective contribution to this SRIA. This Strategic Research and Innovation Agenda is conceived to be a forward-looking document that sets out the direction of future collaborative EU-China research and innovation activities in the water sector, with a special attention to the thematic areas identified and focused on by the PIANO project. This document builds on strategic agendas of European and international actors in water management and internal and external consultations among experts and relevant stakeholders of both areas of cooperation. The PIANO SRIA aims to support the activities of the China-Europe Water Platform in its research pillar being the reference document for the implementation of further initiatives of joint international cooperation between Europe and China in water innovation, a sector which offers increasing opportunities to all interested actors, in particular European small and medium enterprises (SMEs) able to produce advanced technological solutions. This SRIA identifies needs and priorities in the EU-China cooperation in water innovation. It also highlights the main opportunities for the development of further collaborative actions engaging public and private partnerships based on the sharing of knowledge and good practices. In this way, strategic long-term agreements involving multi-stakeholders in research and innovation applied to water management will be fostered. Researchers, governmental agencies, innovative enterprises and private stakeholders should combine synergies to strengthen innovation capacity and promote social and economic cooperation in both regions of the world. Moreover, the PIANO SRIA intends to contribute to the achievement of the United Nations' Sustainable Development Goals.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012686/1/The-PIANO-SRIA.pdf

6) Título: Como Controlar A Degradação Da Qualidade De Águas Subterrâneas Em Zonas Costeiras Usando A Gestão Da Recarga De Aquíferos (MAR) Otimizada Pela Avaliação Da Vulnerabilidade À Intrusão Marinha Com Os Modelos GALDIT e Gaba-IFI

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Gestão da Recarga de Aquiferos;Intrusão Marinha;Aquiferos Costeiros;Modelos de otimização

Data: 16-Set-2019

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Relatório da Série N.º: 14.º SILUSBA, Praia, 16-20 de setembro de 2019;

Resumo: Uma das melhores soluções para fazer face à variabilidade climática, que se teme aumente nas próximas décadas também para as zonas costeiras, é a Gestão da Recarga de Aquíferos (MAR). A sua aplicação depende da disponibilidade de água para recarga, e inclui as águas residuais apropriadamente tratadas. Como controlar a intrusão marinha em zonas costeiras com MAR? Sabemos que os locais mais apropriados devem ter boas taxas de infiltração, capacidade de armazenamento no subsolo, o tempo de percurso da água de recarga no aquífero suficientemente longo e compatível com a frequência esperada dos períodos de seca. Deve ainda maximizar-se a eficiência económica, garantir a disponibilidade de áreas para o MAR. Finalmente, devem serem avaliados os impactes positivos, tanto para a sociedade como nos ecossistemas. O índice GABA-IFI, que se apresenta na comunicação, avalia parâmetros para a seleção das áreas mais adequadas para a localização das técnicas MAR. Além disso, temos hoje bons modelos matemáticos para calcular os efeitos benéficos da injeção de água no escoamento subterrâneo, visando a recuperação dos níveis aquíferos esgotados, e na qualidade das águas subterrâneas, por exemplo em zonas agrícolas vulneráveis contaminadas por nitratos. Mas o GABA-IFI por si só não é suficiente para responder às questões relativas ao esperado aumento do nível do mar nas zonas costeiras. Nesses casos, temos que saber avaliar as zonas mais vulneráveis à intrusão marinha para melhor controlar a degradação da qualidade da água via MAR. O índice GALDIT é hoje, provavelmente, o mais utilizado a nível mundial para tal fim. O GALDIT utiliza parâmetros hidrogeológicos, como a condutividade hidráulica, o nível piezométrico de água subterrânea, a distância ao litoral e o historial da intrusão marinha, para mapear índices de vulnerabilidade à intrusão no aquífero. O GALDIT atribui um peso a cada um dos parâmetros referidos e prioriza os parâmetros através de um processo de tomada de decisão. Em seguida, avalia a possibilidade da intrusão marinha por meio de um cálculo numérico. Na comunicação serão apresentados exemplos.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012687/1/JPLF%2014SILUSBA_V4.pdf

7) Título: Trabalhando as variáveis do método GALDIT de vulnerabilidade à intrusão salina no curso inferior do rio Bacanga, Maranhão, Brasil

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Intrusão marinha;método GALDIT;Rio Bacanga, Marnhão, Brasil;aquiferos costeiros

Data: 16-Set-2019

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Resumo: A água é uma fonte imprescindível para o abastecimento humano e através dos tempos a busca por este recurso, tem se intensificado pela elevada procura por água de boa qualidade. A bacia do rio Bacanga, localizada inteiramente dentro dos limites do município de São Luís, mais precisamente na porção noroeste da Ilha do Maranhão, Maranhão, Brasil, demarcada pelos pares de coordenadas geográficas: 2°31’50,85”S a 2°34’34,11”S e

44°18’14,22”W a 44°28’92,00” W, possui papel singular no abastecimento público de água do município de São Luís. Neste sentido, investiga-se a relação entre a perfuração de poços tubulares e a alta explotação das águas subterrâneas no curso inferior da bacia do rio Bacanga, fato este que poderá proporcionar a intrusão da cunha salina nos aquíferos do Grupo Barreiras e Itapecuru. Para isso, se utiliza o método GALDIT proposto Chachadi e Lobo Ferreira (2001), utilizado em diversas partes do mundo, que analisa dados hidrodinâmicos de poços tubulares, para a avaliação do grau da vulnerabilidade à intrusão salina. Nesta pesquisa se descreve as atividades desenvolvidas no período de agosto de 2016 a 2018 para o emprego do Método Galdit onde foram reunidos o levantamento de banco de dados das variáveis empregada no método tais como: G – Ocorrência do aquífero, A – Condutividade Hidráulica; L – Nível piezométrico; D – Distância da Linha de Costa; I – Estado atual da intrusão salina no aquífero (Bicarbonatos/Cloretos); e T – a espessura do aquífero do curso inferior da bacia do rio Bacanga, tabulação, tratamento e análise dos dados.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012685/1/14SILUSBA_67.pdf

8) Título: EXPERIÊNCIA DO LNEC NAS BACIAS DO CUNENE E CUVELAI AVALIAÇÃO E MODELAÇÃO DE ÁGUAS SUPERFICIAIS E SUBTERRÂNEAS

Outros títulos: SOLUÇÕES PARA MITIGAÇÃO DE CHEIAS E SECAS, BALSEQ E GABA-IFI

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Cooperação LNEC - Universidade Agostinho Neto; modelação de águas subterrâneas; gestão da recarga de aquíferos; vulnerabilidade à poluição de aquíferos; mitigação das cheias na bacia do Cuvelai

Data: 2-Nov-2020

Editora: Universidade Agostinho Neto

Resumo: Saúdo calorosamente os participantes desta sessão comemorativa da Universidade Agostinho Neto para apresentar a experiência do LNEC nas bacias do Cunene e Cuvelai nomeadamente sobre a avaliação e modelação de águas superficiais e subterrâneas, soluções para mitigação de cheias e secas e os modelos BALSEQ e GABA-IFI. Saliento a boa cooperação desenvolvida por Portugal e Angola com os nossos Países Irmãos da CPLP nos SILUSBAs, os Simpósios de Hidráulica e Recursos Hídricos dos Países de Língua Oficial Portuguesa. Realço o 9º SILUSBA realizado em Benguela em 2009. Passaram 25 anos desde que, em Abril de 1994, a Comissão Diretiva da Associação Portuguesa dos Recursos Hídricos (APRH), a que tive a honra de presidir, e a Associação Brasileira de Recursos Hídricos (ABRH), lançaram o bem sucedido desafio de incorporar os novos Países da CPLP na organização dos SILUSBAs. Em 2019, como Presidente da Comissão Organizadora Internacional no 14º SILUSBA em Cabo Verde, escolhi o tema "SILUSBA 25 anos construindo a Comunidade da Água da CPLP”. Realço que os SILUSBAs têm como objectivos principais promover o avanço do conhecimento nos domínios da Hidráulica e dos Recursos Hídricos; promover o intercâmbio de ideias e de experiências nos domínios da Hidráulica e dos Recursos Hídricos; e estimular acções de formação, de investigação e de desenvolvimento de interesse comum. É esse o espírito desta minha apresentação de hoje.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1013073/1/Resumo%20Univ%20Agostinho%20Neto%202020%20_%20JPLoboFerreira2.pdf

9) Título: 10th International Symposium on Managed Aquifer Recharge Abstract Book

Outros títulos: Lobo Ferreira, J. P. C. Participation

Autor: Lobo Ferreira, J. P. C.

Escalante , E.

Palavras-chave: Managed Aquifer Recharge; Gestão da Recarga de Aquíferos

Data: 20-Mai-2019

Editora: ISMAR 10 Grupo Tragsa

Resumo: How to control saltwater intrusion in coastal zones implementing an appropriated MAR facility? The parameters required to answer that question, include the selection of the most appropriate MAR technology and the best location for MAR having (1) good infiltration rates; (2) enough space to store underground the recharged water; (3) guarantee that the travel time of the recharged water in the aquifer is long enough, compatible with the expected frequency of drought periods; (4) economic efficiency maximization; (5) availability of areas for MAR; and, (6) positive impacts on the society. GABA-IFI model addresses those parameters allowing the selection of the most appropriate place for the location of MAR. Examples will be presented in the paper. Nevertheless, GABA-IFI is not sufficient regarding coastal zones and the expected increase in sea levels worldwide. We have to assess the most vulnerable zones to control groundwater quality degradation assessing vulnerability to saltwater intrusion. GALDIT method is an appropriate toll to assess vulnerability to saltwater intrusion, and today, probably, the most used model towards that aim worldwide. Examples will be presented in the paper. GALDIT uses the hydrogeological parameters such as aquifer properties, hydraulic conductivity, groundwater level, distance from the coastline, current severity of saltwater intrusion, and aquifer thickness to make saltwater intrusion vulnerability indices. The GALDIT gives a weight to each of the indices, and prioritize the indices through a decision-making process, and then assess the possibility of saltwater intrusion by a numerical calculation. GALDIT spatial mapping is acquired using GIS techniques to show the intrinsic vulnerability to saltwater intrusion quantitatively. Worldwide application of GALDIT allow us to assess today and future expected seawater intrusion vulnerability in many coastal regions of the five continents, by applying different sea water level rise scenarios. To counteract the expect harmful eventually catastrophic consequences of saltwater intrusion into coastal aquifers and their groundwater quality Managed Aquifer Recharge is the best NBS and a precious toll, i.e. a sound, safe and sustainable, scientific based, solution. MAR in coastal areas depends on the availability of water including waste water appropriately treated. The optimization of MAR is the aim of the paper, taking advantage of Vulnerability Assessment of saltwater Intrusion using GALDIT model. This will allow the selection of the most vulnerable areas affected or expected to be affected by seawater intrusion optimizing MAR water needs in scenarios of sea level rise due to climate change.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1013470/1/JP%20Lobo%20Ferrreira%20ISMAR%2010%20Madrid%202019.pdf

10) Título: Application of the GALDIT method combined with geostatistics at the Bouteldja aquifer (Algeria)

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: GALDIT;Sea water intrusion;Vulnerability;Bouteldja ,Algerie

Data: 17-Dez-2018

Editora: Springer-Verlag GmbH , part of Springer Nature 2019

Citação: https://doi.org/10.1007/s12665-018-8005-2

Resumo: This paper aims to spatially characterize the marine intrusion in the case of the Bouteldja main aquifer using the GALDIT method coupled with a geostatistical approach. The latter was used to compensate the weakness of GALDIT method for not considering the spatial variability of the studied variables. Using a field data set of the Bouteldja aquifer, the semi-variograms of four continuous important variables (hydraulic conductivity A, groundwater level L, thickness T and sea water intrusion I) were studied and modeled. The obtained structures were mainly composed of spherical models with a small nugget effect, except the I variable which has shown a perfectly continuous Gaussian model with zero nugget effect, arguing that the marine intrusion is seriously present and continuous. These individual results were also mapped by kriging and the intrusion easily shown on the field. However, the GALDIT computation and mapping did not confirm the found intrusion. It has merely shown a medium to low vulnerability in narrow and parallel bands close to the shore area. This work has shown that the GALDIT method used solely, without a geostatistical approach, would lead to a misinterpretation of the vulnerability of a main aquifer to saline intrusion. Keywords · Shore aquifer · Bouteldja · Vulnerability · · Pollution · Salinity

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012684/1/ApplicationoftheGALDITmethod.pdf

11) Título: A risk assessment methodology to evaluate the risk failure of managed aquifer recharge in the Mediterranean Basin

Autor: Sanchez-Vila, X.

Lobo Ferreira, J. P. C.

Rossetto, R.

Escalante , E.

Sapiano, M.

Schüth , C.

Palavras-chave: Managed aquifer recharge (MAR);risk assessment

Data: 8-Jun-2018

Editora: Published by Copernicus Publications

Citação: Hydrol. Earth Syst. Sci., 22, 3213–3227, 2018

Relatório da Série N.º: Hydrol. Earth Syst.;https://doi.org/10.5194/hess-22-3213-2018

Resumo: Managed aquifer recharge (MAR) can be affected by many risks. Those risks are related to different technical and non-technical aspects of recharge, like water availability, water quality, legislation, social issues, etc. Many other works have acknowledged risks of this nature theoretically; however, their quantification and definition has not been developed. In this study, the risk definition and quantification has been performed by means of “fault trees” and probabilistic risk assessment (PRA). We defined a fault tree with 65 basic events applicable to the operation phase. After that, we have applied this methodology to six different managed aquifer recharge sites located in the Mediterranean Basin (Portugal, Spain, Italy, Malta, and Israel). The probabilities of the basic events were defined by expert criteria, based on the knowledge of the different managers of the facilities. From that, we conclude that in all sites, the perception of the expert criteria of the non-technical aspects were as much or even more important than the technical aspects. Regarding the risk results, we observe that the total risk in three of the six sites was equal to or above 0.90. That would mean that the MAR facilities have a risk of failure equal to or higher than 90% in the period of 2–6 years. The other three sites presented lower risks (75, 29, and 18% for Malta, Menashe, and Serchio, respectively).

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012682/1/hess-22-3213-2018.pdf

12) Título: MARSOL White Book on the state of the art in Managed Aquifer Recharge Modelling. A Literature Review.

Autor: Lobo Ferreira, J. P. C.

Martins, T.

Palavras-chave: Managed Aquifer Recharge, numerical modelling, groundwater, review, MARSOL project.

Data: 7-Mar-2018

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Resumo: In the context of Managed Aquifer Recharge (MAR) numerical modelling, an important process with many applications such as the prediction of rise of groundwater mounds, to determine where groundwater must eventually be pumped, to understand quality changes in infiltration water and aquifer water, to predict the success of treatment induced by MAR methodologies or to calculate the necessary injected volumes to counter a saltwater intrusion problem. It is essential, as a state of the art overview, to compile several applications in different demo-areas and scales, where modelling was essential to refine artificial recharge strategies and to help understanding the main impacts of a MAR project. The main objective of the EU INNO-DEMO FP7 project MARSOL was to demonstrate that MAR is a sound, safe and sustainable strategy that can be applied with great confidence. With this, MARSOL aimed to stimulate the use of reclaimed water and other alternative water sources in MAR and to optimize Water Resources Management through storage of excess water to be recovered in times of shortage. MARSOL operated 8 demonstration sites in 6 countries around the Mediterranean (Portugal, Spain, Italy, Greece, Malta, Israel) applying various technologies i.e. infiltration ponds, river bed infiltration, direct injection wells, river bank filtration, to infiltrate various water sources, i.e. river water, surface runoff, treated waste water, desalinated sea-water. More information can be found in www.marsol.eu and in Costa et al (2015) (https://www.researchgate.net/publication/275716406_Modelling_Contributions_of_the_Local_and_Regional_Groundwater_Flow_of_Managed_Aquifer_Recharge_Activities_at_Querenca-Silves_Aquifer_System), regarding Querença-Silves aquifer system in Portugal. One of the outputs of MARSOL project was the “White book on MAR modelling: Selected results from MARSOL PROJECT”, cf. Lobo-Ferreira et al (2016) available in https://www.researchgate.net/publication/314957907_White_book_on_MAR_modelling_Selected_results_from_MARSOL_PROJECT. This oral presentation will address the state of the art of modelling methodologies and tools in Managed Aquifer Recharge, both in flow and transport model applications. Following MARSOL literature review for MAR modelling, the main conclusion, considering that for every model there is a different set of input data required, so one of the most important factor in selecting the appropriate model to a specific area/study is to verify what data is available/obtainable in order to feed it as much as possible allowing it to produce reliable results. Used models vary, but finite difference MODFLOW base software seems to be by far more frequently used, both due to be easily available and well documented, there are several programs adapted to specific problems. Due to its complexity finite elements are not so abundantly used, although the FEM grid is far more adjustable to complex limits of study areas. On the other hand, FEM HYDRUS was commonly selected for simulations in vadose zone. In hydrogeochemical studies related to MAR, PHREEQC based software was the most used, mostly due to its very wide set of capabilities concerning not only speciation simulation but also transport. Aquifer and local (small area of the aquifer) seems to be the most common scales studied. Small scale models (infiltration basin or aquifer sandbox model recreation) are scarce. MAR modelling, at a large scale, has been used as a decision support tool as basis to decide the suitability of MAR methodologies, most effective measures of environmental problem containment and to explore scarcity scenarios. Local scale modelling efforts have been developed during MARSOL project in order to determine the infiltration capacity of the injection well, the aquifer’s local hydraulic properties and the direction and residence time of the injected water. At a local scale event, local hydraulic parameters are determined with the support of analytical methods, such as conventional pumping test analysis techniques. To support the local scale analysis and modelling of the well injection tests, resistivity profiles using dipole-dipole array were

performed before, during and up to 4 days after an injection test with salty water as a tracer with the goal of gathering more information regarding water pathways in the area with the time lapse evolution of the resistivity, though a low variation of resistivity with time was achieved. Also in de numerical modelling context, MARSOL Deliverable 12.2 “GIS database of the MARSOL DEMO Sites” aimed to prepare GIS layers of information for conceptual modelling for selected MARSOL sites. This activity was developed to produce the structure of a GIS database that is able to accommodate main available information of the Demo sites, concerning background information as the conceptual groundwater flow model, water budgets under actual and climate change projected situations, vulnerability indexes, infiltration indexes, field tests, already existing data concerning geology, soil, land cover, aquifer information, river basins, streams, natural and artificial reservoirs, etc. Besides information for conceptual modelling the GIS database was also structured to contain the MAR facilities, infrastructures and also some related monitoring information. Besides the information available in the MARSOL website and https://www.eip-water.eu/MAR_Solutions further reasoning on Modelling in Water Resources and on MAR is in https://www.southasiawaterinitiative.org/sites/sawi/files/WRS%20SAWI%20reportjune8.pdf#page=57.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012679/1/14CA_White_Book_on_MAR_Modelling_Oral_Presentation_v2.pdf

13) Título: The Strategic Research and Innovation Agenda of the H2020 Piano Project.

Outros títulos: Strengthening the international cooperation between Europe and China in the water sector by identifying thematic priorities for joint actions

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: policies, innovation, networks, technological water innovations;H2020 programme;China –Europe Water Platform;strategic research and innovation agendas

Data: 7-Mar-2018

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Resumo: The Strategic Research and Innovation Agenda of the H2020 PIANO project is conceived to be a forward-looking document that sets out the direction of future collaborative EU-China research and innovation activities in the water sector with a special attention to the thematic areas identified and focused by the PIANO project: agricultural, municipal, industrial water management, river basin management, water for energy. This Strategic Research and Innovation Agenda (SRIA) builds on strategic agendas of European and international actors in water management and internal and external consultations among experts and relevant stakeholders of both areas of cooperation. The SRIA elaborated by the PIANO project partners aims to support the activities of the China-Europe Water Platform in its research pillar being the reference document for the implementation of further initiatives of joint international cooperation between Europe and China in water innovation, a sector which offers increasing opportunities to all interested actors, in particular European small and medium enterprises able to produce advanced technological solutions. Researchers, governmental agencies, innovative enterprises and private stakeholders should combine synergies to strengthen innovation capacity and promote social and economic cooperation in both areas of the world. The PIANO SRIA identifies needs and priorities in the EU-China cooperation in water innovation. It also highlights the main opportunities for the development of further collaborative actions engaging public and private partnerships based on the sharing of knowledge and good practices. In this way strategic long-term agreements involving multi-stakeholders in research and innovation applied to water management will be fostered. Moreover, the PIANO SRIA intends to contribute to the achievement of the United Nations' Sustainable Development Goals

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012680/1/14CA_125.pdf

14) Título: Perímetros de proteção às captações de água – fundamentais para a qualidade da água

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Perímetros de proteção de captações de águas subterrâneas;Modelos matemáticos;Qualidade da água

Data: 31-Mai-2016

Editora: Entidade Reguladora dos Serviços de Águas e Resíduos dos Açores (ERSARA)

Resumo: A delimitação de perímetros de proteção de origens de água tem sido reconhecida como uma das principais ferramentas para garantir a qualidade dessas origens enquanto componentes de sistemas de abastecimento de água para consumo humano. A sua importância veio a materializar-se na legislação comunitária e nacional, que estabelece a obrigação de delimitação de perímetros de proteção previamente à atribuição de títulos de utilização de recursos hídricos para abastecimento público. Esta é, contudo, uma tarefa complexa e exigente, pelo que o Instituto Regulador de Águas e Resíduos (IRAR) e o Laboratório Nacional de Engenharia Civil (LNEC) entenderam, em 2009, publicar em parceria o Guia Técnico Nº 11 sobre Proteção das Origens Superficiais e Subterrâneas nos Sistemas de Abastecimento de Água, de autoria de JP Lobo Ferreira, Teresa E Leitão, Manuel M Oliveira, João Soromenho Rocha e Ana Estela Barbosa (cf. Lobo-Ferreira et al., 2009)1. Esse Guia Técnico tem um carácter essencialmente prático e visa apoiar as entidades gestoras na delimitação adequada dos perímetros de proteção e no cumprimento das respetivas obrigações legais, promovendo simultaneamente uma maior fiabilidade do serviço público de abastecimento de água bem como a salvaguarda da saúde pública. O texto que se apresenta nesta comunicação foi adaptado de Lobo-Ferreira et al. (2009). Apresentam-se os aspetos relacionados com a proteção de origens de águas subterrâneas, descrevem-se os critérios e metodologias para delimitação de perímetros de proteção de captações de águas subterrâneas e as restrições à utilização do solo no interior dos perímetros de proteção. Inclui-se uma descrição da utilização de modelos numéricos de escoamento e transporte de massa em águas subterrâneas. Complementa-se a comunicação com as ações a desenvolver para uma adequada gestão dos perímetros de proteção após a sua delimitação, nomeadamente, inventariação de fontes potenciais de poluição, implementação de redes de monitorização, definição de planos de contingência e informação e participação do público.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012582/1/Lobo%20Ferreira_PROTEC%c3%87%c3%83O%20DE%20ORIGENS%20DE%20%c3%81GUAS%20SUBTERR%c3%82NEASx.pdf

15) Título: Policies, Innovations and Networks for enhancing Opportunities for China Europe Water Cooperation

Outros títulos: LNEC Progress report August 2016 - Sharing of Technological solutions: Key lessons learned from the Portuguese participation in H2020 PIANO project

Autor: Lobo Ferreira, J. P. C.

Lamas, L.

Leitão, T. E.

Melo, J.

Palavras-chave: Technological solutions;China Europe Water Cooperation

Data: Ago-2016

Editora: LNEC

Resumo: This document presents the developments in the first 18 months of activity of LNEC in PIANO project (Policies, Innovation, and Network for Enhancing Opportunities for China-Europe Water Cooperation) financed by the European Union (Horizon 2020) and the Chinese Secretariat of China Water Platform Europe (China-Europe Water Platform, CEWP, http://cewp.org/), as key lessons learned from the Portuguese participation, led by Laboratório Nacional de Engenharia Civil (LNEC). PIANO project aims to strengthen cooperation in the field of water between Europe and China, promoting the creation of networks of enterprises (including SMEs), entrepreneurs, NGOs, policy makers, regulators and funding agencies to create social opportunities and business. The PIANO project objectives are (1) strengthening and expanding the existing network of the China Europe Water Platform (CEWP) to cover all relevant actors for water research and innovation relevant for China Europe water cooperation; (2) identification of European technological water innovations and areas for joint development of technological solutions that have a potential for implementation in China; (3)identification of drivers and barriers and elaborating strategies for overcoming such barriers and taking advantage of drivers for implementation and replication of technological water innovations; (4) promotion of knowledge exchange and policy dialogue to build an enabling environment for the uptake of technological water innovations with a great potential for implementation, further replication and market uptake in China; (5) consolidation of a shared strategic research and innovation agenda between Europe and China in the water domain; and, (6) effective dissemination and mainstreaming of the project results within China, Europe and worldwide to various target audiences. The priority research areas focus on societal challenges related to Agricultural water management (WP2_1.a), to Municipal water management (WP2_1.b), to Industrial water management (WP2_1.c), to river basin management highlighting the problem of floods (WP2_1.d) and to the Water for energy nexus (WP2_1.e). The project consortium is composed of nine partners of which eight are located in eight different EU Member States and one is based in China. The consortium encompasses partners from high level academic institutions and experienced research institutes to non for profit organizations, from European umbrella associations to a commercial SME and a large international company. The PIANO partners are supported in their activities by many Chinese institutes and research centres. LNEC leads the development of tasks (WP2_1d) and (WP2_1.e). In the case of the task "Water for Energy" LNEC has the support of EDP / Labelec. Within the activities led by LNEC an inventory of about 50 technological water innovative solutions (TWI) was developed in the thematic areas WP2_1.d and WP2_1.e. Later, following several prioritization criteria, 20 TWIs of each of both thematic areas were ranked in descending order of suitability and potential deployment opportunities in China. They are presented for discussion.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012581/1/Piano_LNEC%20Progress%20Report%20_August2016x.pdf

16) Título: Estratégias e ações para fomentar o uso da Gestão da Recarga de Aquíferos: o exemplo do Grupo de Ação “EIP AG 128 MARtoMARket”

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Gestão da Recarga de Aquíferos;Tratamento solo-aquífero;European Innovation Partnership on Water;Contaminantes emergentes

Data: 22-Nov-2015

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Resumo: O Laboratório Nacional de Engenharia Civil (LNEC) propôs à Parceria Europeia para a Inovação na Água, EIP Water, a candidatura MARtoMARket que veio a ser selecionada para integrar o restrito grupo das 34 EIP Water Action Groups (cf. http://www.eip-water.eu/actiongroups) a nível de toda a União Europeia, como EIP Water Action Group 128 MARtoMARket http://www.eip-water.eu/MAR_Solutions. A seleção desta temática pela EIP Water deve-se ao facto de que a Gestão da Recarga de Aquíferos (GRA), comummente designada por Recarga Artificial de Aquíferos (RAA),se ter tornado, quando utilizável, numa das melhores soluções técnica para uma moderna gestão integrada dos Recursos Hídricos (GIRH), visando a mitigação dos impactos negativos das Alterações Climáticas. Como a variabilidade e alguns impactos negativos das Alterações Climáticas estão aumentando rapidamente, tanto em escala como em intensidade, torna-se cada vez mais importante fomentar a "inovação na ação água”, incorporando "soluções tecnológicas" permanentes e apropriadas às condições hidrogeológicas e climatéricas regionais. Nesta comunicação, pretende-se tirar partido das potencialidades do desenvolvimento do novo projeto FP7 INNO-DEMO MARSOL, financiado pelo Programa-Quadro de Investigação Científica da União Europeia, em ligação com o Grupo de Ação “EIP AG 128 MARtoMARket”. O projeto MARSOL conta com oito casos de estudo e demonstração, sendo um deles localizado no Sul de Portugal, na região do Algarve. Nesta região desenvolveu-se já um outro projeto comunitário sobre a temática GRA, o projeto GABARDINE (cf. http://www.acquesotterranee.it/sites/default/files/AS10040.pdf). Na conferência da EIP Water realizada em Barcelona, Espanha, em novembro de 2014, o AG MARtoMARKET organizou uma reunião aberta sobre a temática “Demonstrating the feasibility and efficiency of MAR in combating future water scarcity threats in the CircumMediterranean área”. Sendo a temática “escassez de água” uma das mais importantes para os países da CPLP, membros do SILUSBA, propõe-se partilhar as discussões havidas em Barcelona e os resultados alcançados no desenvolvimento da EIP AG 128 MARtoMARket com os participantes do 12º SILUSBA. Tal insere-se no âmbito das atividades que visam fomentar a disseminação de soluções técnicas, por exemplo, para reutilização de águas residuais após tratamento no solo, ou para converter aquíferos cársticos em grandes reservatórios de armazenamento de água e ainda a “Transferência de conhecimento e tecnologia para se passar cientificamente baseados à ação”.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012580/1/12SILUSBA_VF_MartoMarket_JPLF_PTx.pdf

17) Título: Modelling Contributions of the Local and Regional Groundwater Flow of Managed Aquifer Recharge Activities at Querença-Silves Aquifer System

Autor: Costa, L.

Monteiro, J. P.

Oliveira, M. M.

Mota, R.

Lobo Ferreira, J. P. C.

Carvalho, J.M.

Carvalho, T.

Agostinho, R.

Hugman, R.

Palavras-chave: Managed aquifer recharge, water scarcity, drought, mitigation strategies and technologies, MARSOL project;Modelling;Campina de Faro Algarve

Data: 2015

Editora: EGU

Resumo: The Querença-Silves (QS) aquifer system is one of the most important natural groundwater reservoirs in the Algarve region of southern Portugal. With a surface area of 324 km2, this karst aquifer system is the main source of supply for irrigation as well as an important source of water for the urban supply. Due to the importance given to QS aquifer system by both governmental actors and end users, ongoing research during the last two decades at the University of Algarve has attempted to provide a better understanding of the hydrogeology and hydraulic behavior, which has resulted in the development of regional scale numerical models. The most recent hydrogeologicaldatahasbeenacquiredduringtheongoingMARSOLproject(MARSOL-GA-2013-619120)whichaimsto demonstrate that Managed Aquifer Recharge (MAR) is a sound, safe and sustainable strategy that can be applied with great confidence in finding solutions to water scarcity in Southern Europe. Within the scope of the project large diameter well injection tests (with and without tracers) as well as geophysical surveys have been carried out in order to determine the infiltration capacity and aquifer properties. The results of which allowed the use of analytical methods to determine local scale values of hydraulic parameters (e.g. hydraulic conductivity and storage coefficient). These values will be compared with results from pre-existing numerical flow and transport models in order to obtain complementary solutions to the problem at local and regional scales. This analysis will contribute to the selection of the most appropriate methods to interpret, reproduce and model the impacts of MAR activities planned within the scope of the MARSOL project. Subsequent to the planned injection tests and, with the support of modelling efforts, the capacity of infiltration of rejected water from water treatment plants or surface storage dams in the large diameter well will be assessed.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012563/1/EGU2015-11930.pdf

18) Título: Estimating harvested rainwater at greenhouses in south Portugal aquifer Campina de Faro for potential infiltration in Managed Aquifer Recharge

Autor: Costa, L.

Monteiro, J. P.

Leitão, T. E.

Lobo Ferreira, J. P. C.

Oliveira, M. M.

Carvalho, J.M.

Carvalho, T.

Agostinho, R.

Palavras-chave: Managed Aquifer Recharge;potential infiltration;Campina de Faro Algarve

Data: 12-Abr-2015

Editora: EGU

Citação: Bibcode: 2015EGUGA..1710415C

Resumo: The Campina de Faro (CF) aquifer system, located on the south coast of Portugal, is an important source of groundwater, mostly used for agriculture purposes. In some areas, this multi-layered aquifer is contaminated with high concentration of nitrates, possibly arising from excessive usage of fertilizers, reaching to values as high as 300 mg/L. In order to tackle this problem, Managed Aquifer Recharge (MAR) techniques are being applied at demonstration scale to improve groundwater quality through aquifer recharge, in both infiltration basins at the river bed of ephemeral river Rio Seco and existing traditional large diameter wells located in this aquifer. In order to assess the infiltration capacity of the existing infrastructures, in particular infiltration basins and large diameter wells at CF aquifer, infiltration tests were performed, indicating a high infiltration capacity of the existing infrastructures. Concerning the sources of water for recharge, harvested rainwater at greenhouses was identified in CF aquifer area as one of the main potential sources for aquifer recharge, once there is a large surface area occupied by these infrastructures at the demo site. This potential source of water could, in some cases, be redirected to the large diameter wells or to the infiltration basins at the riverbed of Rio Seco. Estimates of rainwater harvested at greenhouses were calculated based on a 32 year average rainfall model and on the location of the greenhouses and their surface areas, the latter based on aerial photograph. Potential estimated annual rainwater intercepted by greenhouses at CF aquifer accounts an average of 1.63 hm3/year. Nonetheless it is unlikely that the totality of this amount can be harvested, collected and redirected to aquifer recharge infrastructures, for several reasons, such as the lack of appropriate greenhouse infrastructures, conduits or a close location between greenhouses and large diameter wells and infiltration basins. Anyway, this value is a good indication of the total amount of the harvested rainfall that could be considered for future MAR solutions. Given the estimates on the greenhouse harvested rainwater and the infiltration capacity of the infiltration basins and large diameter wells, it is intended to develop groundwater flow models in order to assess the nitrate washing rate in the CF aquifer. This work is being developed under the scope of MARSOL Project (MARSOL-GA-2013-619120), in which Campina de Faro aquifer system is one of the several case studies. This project aims to demonstrate that MAR is a sound, safe and sustainable strategy that can be applied with great confidence in finding solutions to water scarcity in Southern Europe.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012558/1/Estimating%20harvested%20rainwater%20at%20greenhouses%20in%20south%20Portugal%20aquifer%20Campina%20de%20Faro%20for%20potential%20infiltration%20in%20Managed%20Aquifer%20Recharge.%20-%20NASA_ADS.pdf

19) Título: Políticas, Inovação, e Redes para Melhorar as Oportunidades de Cooperação China-Europa na Água. O Projeto PIANO.

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: Tecnologias inovadoras da Água;projeto H2020 PIANO;Cooperação Europa-China;Políticas, inovação, redes, gestão de cheias, água para energia.

Data: 7-Mar-2016

Editora: Associação Portuguesa dos Recursos Hídricos APRH

Resumo: Apresentam-se os desenvolvimentos do primeiro ano de atividade do projeto comunitário PIANO (Policies, Innovation, and Network for Enhancing Opportunities for China-Europe Water Cooperation), financiado pela União Europeia (PQ Horizonte 2020) e pelo Secretariado Chinês da Plataforma da Água China-Europa (China-Europe Water Platform, CEWP, http://cewp.org/), na vertente liderada pelo LNEC. O projeto PIANO visa reforçar a cooperação, no domínio da água, entre a Europa e a China, promovendo a criação de redes de empresas (incluindo PMEs), empresários, ONGs, decisores políticos, reguladores e agências de financiamento, para criar oportunidades sociais e de negócios. Os objetivos do projeto PIANO são (1) o fortalecimento e expansão da rede existente da Plataforma da Água China-Europa (CEWP) para cobrir todos os atores relevantes para a cooperação entre a China e a Europa em domínios de investigação e inovação da água, (2) a identificação de inovações tecnológicas europeias no domínio da Água para o desenvolvimento conjunto de soluções tecnológicas inovadoras (Technology Water Innovations, TWI) com potencial de implementação na China, (3) a identificação dos drivers e barreiras relativos a esta cooperação e elaboração de estratégias para as superar, nomeadamente, aproveitando os drivers para a sua implementação e replicação de inovações tecnológicas de água na China, a promoção do intercâmbio de conhecimento e política de diálogo para construir um ambiente propício para a absorção de inovações tecnológicas de água, e também a replicação e penetração no mercado na China, (4) a consolidação de uma agenda estratégica partilhada de investigação e inovação (SRIA) entre a Europa e a China no domínio da Água, e (5) uma eficaz divulgação e generalização dos resultados do projeto. As áreas de investigação prioritárias concentram-se nos desafios societais relacionados com a gestão da água na agricultura (WP2_1.a), em circuito urbano (WP2_1.b), em circuito Industrial (WP2_1.c), por bacias hidrográficas realçando a problemática das cheias (WP2_1.d) e com o nexus Água-Energia (WP2_1.e). O consórcio do projeto é composto por nove parceiros, localizados em oito Estadosmembros da UE e um na China. O consórcio engloba parceiros de instituições académicas e institutos de pesquisa e organizações sem fins lucrativos, associações europeias, uma PME comercial e uma grande empresa internacional. O LNEC lidera o desenvolvimento das tarefas (WP2_1d) e (WP2_1.e). No caso da tarefa "Água para Energia" o LNEC conta com o apoio da EDP/Labelec. No âmbito da atividade liderada pelo LNEC foram analisadas e inventariadas cerca de 50 soluções tecnológicas inovadoras (Technology Water Innovations, TWI) nas áreas temáticas WP2_1.d e WP2_1.e. Posteriormente, em função de vários critérios de priorização, 20 TWIs de cada uma das áreas temáticas referidas foram ordenados por ordem decrescente de adequabilidade e oportunidade potencial de implementação na China. Apresentam-se para discussão e divulgação os ordenamentos referidos, apenas da responsabilidade do LNEC.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012579/1/13CA%20LoboFerreira_PIANO_VF_15ppx.pdf

20) Título: 20 anos da História da Água em Portugal

Outros títulos: Volume I

Autor: Lobo Ferreira, J. P. C.

Palavras-chave: História da Água em Portugal;Recursos Hídricos Subterrâneos

Data: 8-Ago-2015

Editora: Conselho Nacional da Água

Citação: http://conselhonacionaldaagua.weebly.com/uploads/1/3/8/6/13869103/livro_cna_vol1_2015.08.08.pdf

Resumo: É com muito gosto que partilho uma seleção de memórias relacionadas com a minha atividade junto do CNA desde 1994, tanto a associativa (enquanto APRH) como a de Investigação (enquanto LNEC), sobre Recursos Hídricos. Sintetizei a seleção de memórias e a relação com o CNA em três períodos: (1) o da fase de lançamento do CNA (desde 1992, como Presidente da Comissão Diretiva da APRH), (2) o das atividades relacionadas com a Investigação Científica e o desenvolvimento da última geração de Planos de Bacia Hidrográfica (PBHs), anteriores à implementação da Diretiva-Quadro da Água (DQA) em finais da décadas de 90, incluindo a elaboração de pareceres para o CNA (como Chefe do Núcleo de Águas Subterrâneas do LNEC) e, (3) mais recentemente desde fevereiro de 2009, como Vogal do CNA. Inclui reflexões resultantes da atividade de coordenação de equipas que elaboraram algumas das componentes subterrâneas da 1ª Geração de Planos de Gestão de Recursos Hídricos (PGRH) no âmbito da DQA.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012557/1/CNA%2020%20Anos%20da%20Historia%20da%20%c3%81gua%20em%20Portugal%20contributo%20JPLF%20LNEC.pdf

21) Título: Água, ecossistemas aquáticos e actividade humana - PROWATERMAN

Autor: Lourenço, N.

Lobo Ferreira, J. P. C.

Palavras-chave: Água, ecossistemas aquáticos e actividade humana;Projeto PROWATERMAN

Data: 30-Abr-2013

Editora: LNEC

Resumo: O sul de Portugal é uma região onde a escassez de água e as condições climáticas extremas (com uma longa estação quente e seca e um volume limitado e variável de recursos hídricos) produzem uma forte vulnerabilidade ambiental. A procura crescente de recursos hídricos causada pelo crescimento populacional e económico, especialmente do turismo, e as condições climáticas contribuem para uma crescente escassez de água, bem como para a degradação da sua qualidade. Nesta região, a diminuição da disponibilidade de água pode ter efeitos negativos exponenciais no bem-estar da população humana e no funcionamento dos ecossistemas aquáticos, transformando a gestão dos recursos hídricos num desafio significativo para o desenvolvimento das populações locais. O objetivo global do projeto PROWATERMAN foi, nas áreas selecionadas do sul de Portugal (Alentejo Litoral e Algarve), analisar e compreender as dimensões ambientais, socioeconómicas e institucionais da sustentabilidade da água, para garantir a qualidade desse recurso e aumentar a eficiência e equidade no seu uso através de uma abordagem integrada da gestão dos recursos hídricos. Assim, neste projeto foram identificadas estratégias locais inovadoras para a gestão sustentável da água e formular um conjunto de orientações de boas práticas para a conservação da qualidade e quantidade da água. Isto foi feito através de uma abordagem integrada do contexto socioeconómico e ecológico-ambiental da gestão dos recursos hídricos. O projeto contribuiu para a análise das complexas interações dos sistemas sociais ecológicos que sustentaram a identificação participativa de estratégias de gestão sustentável da água no sul de Portugal.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1012541/1/P1.1%20-%20Descri%c3%a7%c3%a3o%20conceptual%20do%20projeto%20e%20sele%c3%a7%c3%a3o%20das%20%c3%a1reas%20de%20estudo.pdf

22) Título: White book on MAR modelling: Selected results from MARSOL PROJECT

Autor: Lobo Ferreira, J. P. C.

Leitão, T. E.

Martins, T.

Monteiro, J. P.

Costa, L.

Hugman, R.

Carvalho, T.

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Sousa, R.

Rossetto, R.

Borsi, I.

Sanchez-Vila, X.

Escalante , E.

Oliveira, M. M.

Palavras-chave: Managed aquifer recharge, water scarcity, drought, mitigation strategies and technologies, MARSOL project

Data: 31-Jan-2017

Editora: Publisher: MARSOL project Editor: LNEC January 2017 (https://www.researchgate.net/publication/314957907_White_book_on_MAR_modelling_Selected_results_from_MARSOL_PROJECT

Citação: (https://www.researchgate.net/publication/314957907_White_book_on_MAR_modelling_Selected_results_from_MARSOL_PROJECT

Resumo: FP7 INNO_DEMO MARSOL project Workpackage 12 Final Summary of Activities by Dr.-Ing. Habil. JP Lobo Ferreira, LNEC, December 31th, 2016 The contribution of Workpackage 12 to MARSOL Final report addresses the work developed in all Tasks, i.e. not only T12.1 (month 1-6), T12.2 (month 1-12), T12.3 (month 6-12), T12.4 (month 6-30), already addressed in the Mid-term report (dated July 14th, 2015) but also in the new addressed tasks T12.5 – Physical models (month 24-33), T1.6 - Guide lines for best practices (month 27-36) and T12.7 – Visualisation (month 27-36): Concerning Task 12.1, the general literature review on modelling approaches for MAR sites task, included several previous MAR projects developed by MARSOL partners. Some of the more relevant MAR modelling applications collected in this review are summarised in D12.7 White book on MAR modelling, besides having being preliminary presented in the Interim Report for the Project Period December 2013 – August 2014, where the scale of application, the model used and the application objective have been described. Concerning Tasks 12.2 and 12.3, Deliverable 12.1 on water budget and climate change impact assessment of selected MARSOL demo site areas (Portugal, Greece, Israel and Spain) was developed during the 2nd reporting period September 2014 – May 2015. During the second report period Deliverable 12.2 has also addressed. This included the development of specifications towards its achievement and also completed the requirements analysis (first round) based on the demo sites visits and the Field Trip Books provided for three MARSol demo sites (Menashe - Israel, Arenales - Spain, and Sant'Alessio - Italy), plus the Portuguese demo sites, in order to identify the elements that could be incorporated in D12.2 GIS database of the MARSOL demo sites. Concerning Task 12.4, aiming data gathering for hydrogeological modelling, infiltration tests with tracer experiments were performed in PT demo sites by partner TARH, UAlg and LNEC. Follow-up groundwater quantity and quality monitoring and specifically designed two geophysical experiments by partner LNEC have been conducted at PT Querença-Silves Demo site during December 2014 and April 2016, aiming data gathering for the conceptual model and the follow-up of the tracer into the aquifer during the 90 hours MAR tracer experiment. For PT Campina de Faro Demo site, and for south Malta new finite element groundwater flow models (with FEFLOW model purchased with MARSOL budget) was developed by partner UALg. On Task 12.1: Methods evaluation (month 1-6): A literature review on potential and currently applied modelling approaches for MAR sites and the evaluation of weaknesses and strengths has been developed. A 40 page report was concluded December 2016, to be included as Chapter 1 of D12.7 (due month 36), with the title STATE OF THE ART AND LITERATURE REVIEW IN MANAGED AQUIFER RECHARGE MODELLING, authored by LNEC (Martins, T. and Lobo-Ferreira, JP., 2016). On Task 12.2: Water budget and conceptual modelling (month 1-12) Deliverable 12.1 “Water budget and climate change impact” assessed for selected

MARSOL case-study areas (Portugal, Greece, Israel and Spain) information on their water budget and on modelling expertise, in connection with the work developed for specific case-studies and thematic deliverables, e.g. for Portugal in Deliverable 4.2 on “South Portugal MARSOL demonstration sites characterisation” and Deliverable 8.1 on “DSS with integrated modelling capabilities”, with modelling examples from Italy, e.g. “first application of the FREEWAT preliminary scripts on the S. Alessio site”. On Task 12.3: Climate change impact (month 6-12) The starting point for this task was the DEMO Site 2 – PT2 Querença-Silves Aquifer. Groundwater recharge assessments models, e.g. BALSEQ_MOD developed by partner LNEC, and groundwater vulnerability assessment methods, e.g. DRASTIC mentioned in the DoW, have been applied to PT demo site. Concerning the climate change impact in the study area DEMO Site 2 – PT2 Querença-Silves Aquifer, the research team of the University of the Algarve (UAlg) presented a description regarding groundwater flow simulation of future scenarios using the ENSEMBLES projections (A1b scenarios) for recharge. These predictions were compared with others made for instance during the Portuguese FCT sponsored ProWaterMan project for the same area, by UAlg and LNEC partners. These PT results are useful to assess the role of MAR in MARSOL aquifer systems, taking into account the future trends of climate change patterns expected for the other MARSOL demo sites. On Task 12.4: Hydrogeological modelling (month 6-30) The reporting of Deliverables 12.3 on “Progress report on numerical models of the MARSOL DEMO sites” was concluded in September 2015, for selected MARSOL case-study areas (Portugal, Italy, Spain, Israel and Greece). A contribution from TUDa on to the hydrological/hydrogeological models for the Lavrio test site (WP 3) and the Menashe test site (WP 9) was included. These contributions are related to regional and local scales. Complementary contributions on laboratorial scales, from LNEC and IWW, on WP 14s “Contaminants modelling at column scale”, and from UPC on “Modelling the potential impact of chaotic advection to enhance degradation of organic matter and emergent compounds” have been included. Partner IWW worked on hydrochemical modelling within WP 14. Partner TUDa implemented a coupled surface water/groundwater model for both the Lavrio (Greece) and Menashe (Israel) demo sites and the saturated flow model of the Coastal aquifer – Menashe region, Israel, was developed by partner Mekorot. On Task 12.5: Physical models at LNEC (month 24-33) Regarding Task 12.5, the construction of MARSOL physical sandbox model (nicknamed at LNEC as the “artificial aquifer“ model) was achieved and research MAR tracer experiments have been developed and concluded by partner LNEC. The aim was to get knowledge on quantity and quality tracer experiment percolation through three different natural and man-made soil types, to be used in two prototype basins for SAT-MAR “artificial recharge” towards gathering data for later SAT-MAR modelling in PT3_7 Melides, included in Deliverable D12.7 White book on MAR modelling. On T1.6 - Guide lines for best practices (month 27-36) The results achieved in the development of this task will be presented in MARSOL D12.7 White book on MAR modelling (due month 36), that includes (1) the STATE OF THE ART AND LITERATURE REVIEW IN MANAGED AQUIFER RECHARGE MODELLING, by LNEC (Martins, T. and Lobo-Ferreira, JP., 2016), (2) MAR THROUGH FORESTED INFILTRATION IN THE RIVER BRENTA CATCHMENT, VICENZA, ITALY, by SGI and AAWA (Elisa Filippi (SGI), Vincenzo Marsala (SGI), Michele Ferri (AAWA), Alberto Cisotto (AAWA), Giovanni Tomei (AAWA) (3) the SANDBOX MODEL EXPERIMENTS RESULTS AND NUMERICAL MODELLING, by LNEC (Leitão, T.E., Martins, T., Henriques, M.J., Ilie, A.M.C. and Lobo-Ferreira, J. P., 2016), and (4) TRAGSA MARSOL MODELING ACTIVITIES by TRAGSA (Enrique F. Escalante et al.). Finally, on Task 12.7: Visualization Deliverable 12.4 on the Final Report on numerical model, for all MARSOL demo sites in Greece, Portugal, Spain, Italy, Israel and Malta, was ready for publishing July 2016. Complementing the work developed in Workpackage WP12 on Modelling, as presented in the above mentioned Deliverable 12.4, several pdfs and videos have been developed to facilitate the visualisation of the hydrogeological assessment, the experiments carried on MARSOL demo sites, as well as their modelling results. The achievements related to modelling addressed in other Workpackages have also been considered, e.g. the latest results, in video format, obtained in WP4 Deliverable 4.4 on the Hydrogeological modelling at the South Portugal MARSOL demonstration sites, the overview presented in Deliverable 9.4 on “A combined un-saturated and aquifer flow model for the Menashe site" co-authored by Yoram Katz (Mekorot), Yonatan Ganot (ARO), Daniel Kurtzman (ARO) and the Demo Site 8, South Malta Coastal Aquifer results achieved by the University of the Algarve (UALG) depicting the development of a numerical groundwater 3D model for the MSLA sector of the aquifer south to the Victoria Fault. Also a video with modelling information for Italy Deliverable 8.1 on "DSS with integrated modelling capabilities" has been included.

http://dspace2.lnec.pt:8080/jspui/handle/123456789/1012531

23) Título: Água, ecossistemas aquáticos e actividade humana.

Outros títulos: Uma Abordagem integrada e participativa na definição de estratégias inovadores e prospectivas de gestão Integrada de recursos hídricos no sul de Portugal – PROWATERMAN

Autor: Lobo Ferreira, J. P. C.

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Pires, A. R.

Monteiro, J. P.

Palavras-chave: Água, qualidade das águas superficiais e subterrâneas, alterações climáticas, medidas mitigadoras;Gestão de recursos hídricos;ecossistemas aquáticos;atividade humana, Algarve, Alentejo

Data: 30-Abr-2013

Editora: LNEC

Relatório da Série N.º: http://www.lnec.pt/hidraulica-ambiente/pt/projectos/detalhe/prowaterman-agua-ecossistemas-aquaticos-e-atividade-humana-uma-abordagem-integrada-e-participativa-na-definicao-de-estrategias-inovadoras-e-prospetivas-de-gestao-integrada-de-recursos-hidricos-no-s/;

Resumo: O objetivo global do projeto PROWATERMAN foi, nas áreas selecionadas do sul de Portugal (Alentejo Litoral e Algarve), analisar e compreender as dimensões ambientais, socioeconómicas e institucionais da sustentabilidade da água, para garantir a qualidade desse recurso e aumentar a eficiência e equidade no seu uso através de uma abordagem integrada da gestão dos recursos hídricos. Assim, neste projeto foram identificadas estratégias locais inovadoras para a gestão sustentável da água e formular um conjunto de orientações de boas práticas para a conservação da qualidade e quantidade da água. Isto foi feito através de uma abordagem integrada do contexto socioeconómico e ecológico-ambiental da gestão dos recursos hídricos. O projeto contribuiu para a análise das complexas interações dos sistemas sociais ecológicos que sustentaram a identificação participativa de estratégias de gestão sustentável da água no sul de Portugal. A utilização sustentável dos recursos naturais não significa desenvolvimento sustentável, mas um passo para realizá-lo. Apoia-se no conceito de sustentabilidade ambiental. Portanto, estratégias locais de desenvolvimento devem lidar com a manutenção do equilíbrio das entradas e saídas de recursos finitos, com a preservação dos processos dos ecossistemas responsáveis pela substituição desses recursos e, por isso, com estratégias de gestão sustentável da água. Os estudos de invertebrados, em especial, das relações de macro-invertebrados, estrutura da comunidade e variáveis ambientais têm-se mostrado muito úteis como ferramenta de monitorização e de avaliação da qualidade dos ambientes aquáticos. Este projeto reforçou a importância desta análise, utilizando macroinvertebrados e outros bioindicadores (perifíton, zooplâncton, crustáceos e anfíbios), enquanto contributo correto para avaliação da qualidade das águas superficiais. A análise da vulnerabilidade de águas subterrâneas à exploração excessiva e à poluição é fundamental em qualquer estratégia sustentável de gestão dos recursos hídricos. De facto, as águas subterrâneas podem funcionar como uma reserva estratégica para as necessidades domésticas e de irrigação. Identificaram-se e analisaram-se portanto os principais fatores que conduzem à sua exploração excessiva e contaminação, e que podem pôr em causa a subsistência das famílias e o funcionamento dos ecossistemas. Além disso, foi investigado o potencial de reutilização de águas residuais enquanto processo de redução da sobre-exploração dos aquíferos locais. A equipa reúne quatro instituições académicas e de investigação e apresenta um elevado grau de complementaridade, tendo já experiência de trabalho conjunto em projetos de investigação anteriores, nacionais e internacionais, que permitiu uma efetiva integração da análise produzida. As instituições envolvidas possuem uma vasta experiência ativa de investigação âmbito da gestão sustentável dos recursos naturais e especificamente nas áreas de Gestão Integrada de Recursos Hídricos. A experiência dos investigadores, fundamental no desenvolvimento do projeto relaciona-se com análise integrada dos recursos naturais, gestão, modelação, simulação e otimização dos recursos hídricos superficiais e subterrâneos, monitorização e avaliação de parâmetros de avaliação de vulnerabilidade das águas subterrâneas à poluição e avaliação da recarga de aquíferos, biomonitorização de ambientes aquáticos de água doce, abordagens participativas aos processos de decisão e governança dos recursos.

file:///D:/lferreira/Downloads/Livro%20PROWATERMAN%20V%20Final%20FCT%2020130612.pdf

24) Título: Análise da qualidade da água e questões de governância na Albufeira de Alqueva

Autor: Terceiro, P.

Lobo Ferreira, J. P. C.

Leitão, T. E.

Palavras-chave: Qualidade da água;Governância;Modelo dpsir;Gestão de recursos hídricos

Data: Abr-2008

Resumo: A Directiva-Quadro da Água (DQA) estabelece um quadro de acção comum a nível comunitário, com vista ao desenvolvimento de políticas integradas de protecção e melhoria do estado das massas de água. Neste contexto, surge a necessidade de avaliar novas metodologias para o desenvolvimento de estratégias orientadas para o desenvolvimento sustentável a nível da bacia hidrográfica, unidade primordial de gestão e planeamento adoptada pela Directiva. O modelo DPSIR (força motriz, pressão, estado, impacte, resposta) foi identificado como um possível método de análise para o desenvolvimento de estratégias de gestão de acordo com a DQA. Este modelo ilustra, de uma forma integrada, a interacção entre as causas dos problemas ambientais, os impactes e as respostas da sociedade. O encerramento das comportas da albufeira de Alqueva, em Fevereiro de 2002, criou uma reserva estratégica de água com vista ao abastecimento de populações, indústria e agricultura, sendo por isso fundamental que a água possua qualidade adequada aos fins a que se destina. O presente trabalho desenvolve um sistema de indicadores de qualidade da água, aplicado à albufeira de Alqueva de acordo com o modelo DPSIR, focando-se especialmente nos indicadores de estado e resposta, e tendo por base a identificação das forças motrizes e pressões influentes sobre a albufeira. É efectuada a caracterização da qualidade da água da albufeira permitindo que, em função do seu estado, sejam propostas respostas em termos de governância da água, contribuindo para uma melhor gestão dos recursos hídricos.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/12291/1/9%c2%ba%20CAgua_ASEM_Terceiro_LoboFerreira_Leitao.pdf

25) Título: An integrated framework for sustainable agriculture land use and production practices

Autor: Leitão, T. E.

Cunha, M.C.

Laranjeira, I.

Lobo Ferreira, J. P. C.

Paralta, E.

Palavras-chave: Framework;Sustainable agriculture

Data: Jun-2008

Resumo: Diffuse pollution is among the major environmental concerns in terms of prevention of further deterioration and restoration of water to a "good status" in terms of ecological and chemical parameters. A step forward should be made for finding better land use, crop irrigation and fertilization practices to avoid damaging water bodies. This paper presents a framework for obtaining the decisions to be implemented in order to define a sustainable agriculture land use and production practices. A multidisciplinary approach is proposed for building a decision model capable of representing all the issues involved in the scope of an integrated management of land and water resources. The framework proposed is the basis of a research project recently financed by the Portuguese research foundation (Fundação para a Ciência e a Tecnologia). The main objectives of the project can be summarized as follows: 1) Improve the scientific knowledge regarding the interrelation between the agriculture land use and the production practices and the groundwater and the surface water quality protection, towards a more sustainable agriculture; 2) Contribute to support future decisions in terms of more adequate policies regarding rural land use planning (type of crops and associated fertilizers and treatment techniques), taking into consideration the protection of the environment based on vulnerability and risk concepts. Keywords: Diffusion pollution, Sustainable agriculture practices, decision models.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/15976/3/17849-1.pdf

26) Título: A acção de coordenação asemwaternet e a aplicação ao Algarve de técnicas aquifer storage and recovery

Autor: Oliveira, L.

Lobo Ferreira, J. P. C.

Palavras-chave: Sistema aquífero;Querença-silves;Gestão integrada;Asr;Secas;Asemwaternet

Data: Abr-2008

Editora: APRH

Resumo: O objectivo global da Acção de Coordenação ASEMWaterNet do 6º Programa-Quadro de Investigação da Comissão Europeia, é promover a cooperação científica e tecnológica entre a Europa e a Ásia na gestão de recursos hídricos. O LNEC, como coordenador do Workpackage Basin, propôs a selecção de três regiões de estudo (na China, no Vietname e na República da Coreia) para uma correcta procura de soluções para o STEP 2 – Solution (2º e 3º anos da Acção). No 2º ano abordou-se o tema "Water resources management under extreme drought", tendo o co-autor Luís Oliveira desenvolvido uma Tese de Mestrado Bolonha (IST) no Núcleo de Águas Subterrâneas do LNEC no âmbito da Acção ASEMWATERNet. O trabalho desenvolveu a aplicação de técnicas aquifer storage and recovery para uma gestão integrada de recursos hídricos do Algarve, com recurso à recarga artificial no sistema aquífero de Querença-Silves. O objectivo é solucionar, parcialmente, os efeitos de futuras secas no Algarve. O trabalho foi estruturado do seguinte modo: (1) apresentação dos conceitos base sobre secas, (2) estudo das técnicas de recarga artificial de aquíferos, (3) caracterização do caso em estudo (sistema aquífero Querença-Silves no Algarve) e (4) avaliação final da aplicabilidade dos métodos de recarga artificial ao aquífero Querença-Silves para mitigação de secas no Algarve. Conclui-se que a recarga artificial é merecedora de consideração num plano de Gestão Integrada de Recursos Hídricos no Algarve.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/15952/1/9CA_ASEM_ASR-QS_LO_LF_98.pdf

27) Título: Análise da contribuição das fontes poluentes para a carga total de nitratos e fosfatos que afluem à Lagoa de Melides por transporte subterrâneo

Autor: Lobo Ferreira, J. P. C.

Novo, M. E.

Oliveira, L. G. S.

Palavras-chave: Edas;Relação aquífero-meio hídrico superficial;Zonas de descarga do aquífero;Poluição por nitratos;Tempos de percurso;Trajetos de partículas poluentes;Associação fonte poluente-zona de descarga

Data: 7-Mar-2013

Editora: APRH

Citação: Livro de Resumos do 9º Seminário sobre Águas Subterrâneas

Resumo: Apresenta-se uma metodologia de análise da influência de fontes poluentes em ecossistemas lagunares costeiros parcialmente dependentes de águas subterrâneas (EDAS), tomando como caso de estudo a lagoa costeira de Melides (litoral alentejano, Portugal). Esta lagoa tem registado problemas de eutrofização e foi classificada em estado Medíocre devido ao elevado número de diatomáceas. Neste ecossistema costeiro os nutrientes chegam pela ribeira que desagua na lagoa e pelas descargas, bastante significativas, do aquífero superficial livre subjacente. A análise desenvolvida considera o transporte subterrâneo de poluentes desde a sua origem – diferentes fontes distribuídas irregularmente ao longo da bacia hidrográfica – até à ribeira e à lagoa de Melides, sendo objeto de análise os nitratos e fosfatos, causadores de eutrofização em massas de água com circulação limitada. Sendo os nitratos um poluente conservativo e com mobilidade semelhante à da água, pôde fazer-se a análise do seu percurso desde a sua entrada no aquífero até às zonas de descarga no meio hídrico superficial por modelos numéricos de fluxo subterrâneo. Além de simular os fluxos no aquífero desde os pontos de injeção dos poluentes até às zonas de descarga na ribeira e na lagoa de Melides, o modelo numérico desenvolvido para a área de estudo permitiu identificar as origens dos poluentes que aí afluem e que são: agrícola, agropecuária e fossas sépticas. Definido o funcionamento do aquífero e suas relações com o meio hídrico superficial através do modelo numérico, fez-se a análise do trajeto das partículas com o programa MODPATH em conjugação com o MODFLOW. Esta análise forneceu o tempo de percurso médio de uma partícula poluente desde cada fonte poluidora até à lagoa de Melides, a localização das zonas de descarga do poluente na ribeira ou na lagoa, consoante a localização de cada fonte poluente em questão e as direções de fluxo no aquífero, a percentagem de poluente entrado em cada fonte que é transferido para a ribeira e/ou lagoa em cada local de descarga, admitindo que não ocorre degradação ao longo do percurso (poluente estritamente conservativo). A determinação dos tempos de percurso permitiu definir o n.º de fontes poluentes, assim como quais são efetivamente estas fontes e onde se localizam, cujos poluentes demoram até 1 ano a atingir os meios hídricos superficiais – ou seja as fontes com impacto imediato nestes ecossistemas -, as fontes associadas a tempos de percurso suficientemente longos (mais de 70 anos) para se considerarem como pouco relevantes para o problema atual e as fontes associadas a tempos de percurso cujas extensões são inferiores a 50 anos mas suficientemente longos para poderem fazer sentir os seus efeitos na qualidade das águas superficiais depois e 2027, mesmo que sejam já aplicadas medidas de mitigação sobre essas fontes. De seguida, e com vista a avaliar o impacte da carga poluente das várias fontes poluidoras, calcularam-se os valores médios de carga poluente (nitratos e fosfatos) por fonte poluidora, considerando (1) todas as fontes de poluição existentes e (2) as associadas a tempos de percurso iguais ou menores de 1 ano. Calculou-se ainda o peso percentual de cada fonte poluente para a carga poluente total – considerando os mesmos dois grupos de fontes poluentes – e o peso percentual para esta mesma carga por tipo de atividade económica. Foi ainda calculada a percentagem da carga poluente total por fonte poluente que atinge cada ponto de descarga no meio hídrico superficial, a percentagem (e peso em kg) da carga poluente por fonte de poluição que passa em cada ponto de monitorização no aquífero. Deste modo foi possível definir não apenas a importância em termos de contribuição poluente potencial por fonte poluente mas também por atividade económica e por parcela agrícola. Foi também possível identificar quais as atividades económicas com maior peso poluente e, na componente agrícola, quais as culturas com maior carga poluente e/ou que mais rapidamente atingem as águas da lagoa. Esta informação é importante para definir quais as fontes poluentes com impacte mais imediato no estado da lagoa e as que têm efeito diferido, e deste modo a que deverão ser objeto de intervenção prioritária. Por seu lado, os locais de entrada dos poluentes no meio superficial são importantes para definir eventuais áreas de contenção da poluição, em particular no caso de zonas de descarga associadas a fontes poluentes cujos tempos de percurso da poluição aí entrada sejam superiores a 1 ano; o conhecimento da carga poluente por atividade económica é necessário para definir tendências de evolução em cenários de mudança (ex.: sócio-económicos). Foi ainda calculado, com base num valor médio do volume da lagoa, a correspondência em termos de concentração na lagoa (valor em mg/l) da carga poluente gerada por atividade económica, e também para os arrozais.

http://dspace2.lnec.pt:8080/jspui/bitstream/123456789/1004541/2/LF_ENovo_OL-9SAS_pp30-31.pdf

A) Base de Publicações da APRH (https://www.aprh.pt/pt/infoteca/artigos/

Resultados “Lobo-Ferreira”

28) Título: Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of Monte Gordo

Autores:

J. P. Lobo Ferreira, Catarina Diamantino, A. G. Chachadi, M. J. Henriques

Resumo:

This paper is divided in two parts. Part 1 presents the first application in Europe of an index developed in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to sea-water intrusion in coastal aquifers. The most important factors controlling seawater intrusion were found to be the following: Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; Depth to groundwater Level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer, which is being mapped. The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference. These factors, in combination, are determined to include the basic requirements needed to assess the general seawater intrusion potential of each hydrogeologic setting. GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed examination. A numerical ranking system to assess seawater intrusion potential in hydrogeologic settings has been devised using GALDIT factors. The application of the method is exemplified in the paper for the assessment of aquifer vulnerability to seawater intrusion in Portugal (Monte Gordo aquifer in the Portuguese Southern Algarve region). The system contains three significant parts: weights, ranges, and ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. Part 2 of the paper is available in the Proceedings of this 4th Interceltic Colloquium as CHACHADI and LOBO-FERREIRA (2005). In the second part of the paper the method for assessing GALDIT index parameters is fully explained and an application to a costal aquifer located in Goa, not only for today’s conditions but also considering a 0.5 m sea level rise are presented.

29) Título: Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: Part 2 – GALDIT Indicators Description

Autores:

J. P. Lobo Ferreira, A. G. Chachadi

Resumo:

This paper is Part 2 of the paper submitted to this 4th Interceltic Colloquium as LOBO-FERREIRA et al. (2005). In this second part of the paper the method for assessing GALDIT index parameters is fully explained. The original development of GALDIT index was done in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to sea-water intrusion in coastal aquifers. The most important factors controlling seawater intrusion were found to be the following: Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; Depth to groundwater Level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer, which is being mapped. The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference. These factors, in combination, are determined to include the basic requirements needed to assess the general seawater intrusion potential of each hydrogeologic setting. GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed examination. A numerical ranking system to assess seawater intrusion potential in hydrogeologic settings has been devised using GALDIT factors. The system contains three significant parts: weights, ranges, and ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. In this part we also present the first applications of the method developed for the Bardez aquifer in Goa, India.

30) **Título: Avaliação de reservas hídricas subterrâneas dos sistemas aquíferos do Kalahari e Quaternário, em Angola**

Autores:

J.P. Lobo Ferreira, M.E. Novo

Resumo:

Quantificar as reservas hídricas de um aquífero constitui uma tatefa de invulgar dificuldade. Nesta comunicação apresenta-se, com base nos estudos desenvolvidos por Moninante *et al.* (1994), uma metodologia de avaliação de reservas hídricas subterrâneas. Esse estudo visou uma primeira quantificação das reservas hídricas armazenadas nos sistemas aquíferos de Portugal Continental. Procurou-se tirar partido da vasta informação já publicada por numerosos autores sobre este tema tendo-se tentado, na medida do possível, uniformizar conceitos de modo a tornar comparáveis e adicionáveis resultados parcelares de estudos anteriores. Procurou-se ainda distinguir conceitos diversos como o de reserva armazenada, reserva extraível, reserva armazenada apenas em curto espaço de tempo (nomeadamente para o caso de maciços graníticos ou xistosos), apontando-se o intervalo esperado para os valores das reservas a partir dos valores mínimos, médios e máximos de porosidades eficazes dos diversos sistemas aquíferos presentes. Exemplifica-se a aplicação do modelo conceptual apresentado por Moinante *et al.* (1994) ao cálculo das reservas hídricas dos sistemas aquíferos do Kalahari e Quaternário, em Angola, com base nos estudos desenvolvidos por Moinante *et al.* (1994)e por Novo e Lobo-Ferreira (1996). Apresentam-se os valores que se pensa serem mais realistas para uma gestão integrada de recursos hídricos, e que poderão vir a ser considerados como reservas estratégicas, extraíveis, em caso de necessidade premente, como por exemplo em situações de seca ou de escassez hídrica temporária. Os valores que se apresentam devem, contudo, ser considerados apenas como ordens de grandeza, devendo ser confirmados e/ou revistos à medida que o conhecimento científico, técnico e factual sobre sistemas aquíferos apresentados e sobre os respectivos modos de exploração forem sendo mais investigados e aperfeiçoados.

31) Título: Recomendações para a protecção e gestão integrada de captações de águas subterrâneas em Portugal

Autores:

J. P. Cárcomo Lobo Ferreira, Piercarlo Ciabatti

Resumo:

A Proposta para um Programa de Acção Comunitário para a Protecção e Gestão Integrada de Águas Subterrâneas, datada de Maio de 1995, em fase final de aprovação pelas delegações dos Estados-membros da União Europeia, sublinha na secção referente às 'Principais Componentes do Programa de Acção para a Protecção e Gestão Integrada de Águas Subterrâneas, que 'os Estados-membros devem rever e onde apropriado ajustar e fortalecer as medidas de protecção em torno de captações subterrâneas, com base nos estudos publicados por CIABATTI e LOBO-FERREIRA (1994). Nesse trabalho foram desenvolvidos, entre outros, os seguintes temas: (1) análise de normas relativas ao zonamento da protecção das águas subterrâneas existentes em diversos Estados-membros da União Europeia, incluindo, e nos estados Unidos da América, 2 (2) aplicação, com base na modelação matemática, de alguns métodos de definição dos perímetros de protecção das captações ao aquífero de Estarreja (utilizando para o abastecimento de água a um pequeno centro urbano situado na região central de Portugal) e ao aquífero de Valada (utilizado para o abastecimento de água à cidade de Lisboa). Esquematiza-se, em dois quadros, a informação analisada sobre os métodos de zonamento de diversos países da União Europeia e dos Estados Unidos, e sobre o tipo de actividades proibidas no interior de cada zona de protecção, com base na legislação alemã, e apresentam-se, em diversas figuras, as delimitações calculadas de acordo com os métodos de zonamento analisado. Da análise dos dados disponíveis e dos resultados obtidos na aplicação prática salientam-se, nesta comunicação, considerações que poderão se úteis para a reformulação da Norma Portuguesa n.º836, sobre protecção de captações de águas subterrâneas.

32) Título: Caracterização e mapeamento das águas subterrâneas de Portugal

Autores:

J. P. Cárcomo Lobo Ferreira, Manuel Mendes de Oliveira

Resumo:

Nesta comunicação apresenta-se um extracto do estudo desenvolvido pelo Laboratório Nacional de Engenharia Civil para a Comissão Europeia, no âmbito de um contrato com a Direcção-Geral do Ambiente, Segurança Nuclear e Protecção Civil – DG XI, intitulado ‘Desenvolvimento de um Inventário das Águas Subterrâneas de Portugal. Caracterização dos Recursos Hídricos Subterrâneos e Mapeamento DRASTIC da Vulnerabilidade dos Aquíferos de Portugal’ (cf. Lobo-Ferreira e Oliveira 1993). Constituiu objectivo principal do Estudo e elaboração de um inventário das Águas Subterrâneas de Portugal, do ponto de vista da caracterização dos recursos, da caracterização das utilizações e da elaboração de mapas de vulnerabilidade dos aquíferos à poluição. Contribuições anteriores para a caracterização dos recursos hídricos subterrâneos do Algarve, Alentejo e da Região Centro, parcialmente englobadas no Estudo para a Comissão Europeia, foram desenvolvidos no âmbito de diversos protocolos estabelecidos entre a Direcção-Geral da Qualidade do Ambiente (DGQA) e o Laboratório Nacional de Engenharia Civil (LNEC). O estudo para a Comissão Europeia foi executado em estreita colaboração com a Direcção-Geral da Qualidade do Ambiente, nomeadamente para a elaboração dos mapas no Sistema de Informação Geográfica ARC/INFO. No âmbito deste trabalho desenvolveu-se, em colaboração com a Direcção-Geral dos Recursos Naturais, a primeira base de dados operacional (em Portugal) para águas subterrâneas, que contém actualmente parâmetros quantitativos e qualitativos de mais de 7 000 pontos de águas subterrâneas do Continente. Salienta-se o carácter original, a nível da União Europeia, dos estudos desenvolvidos sobre a avaliação regional da recarga de aquíferos e sobre mapeamento da vulnerabilidade dos aquíferos à poluição efectuado com o método DRASTIC, desenvolvido nos E.U.A.

33) Título: Aplicação de modelos de transporte de reactivo ao aquífero de Rio Maior

Aplicação de modelos de transporte de reactivo ao aquífero de Rio Maior

Autores:

J. P. Cárcomo Lobo Ferreira, Teresa Eira Leitão

Resumo:

Apresenta-se a aplicação de modelos analíticos de massa em águas subterrâneas, a um caso de estudo no aquífero de Rio Maior. O estudo foi realizado utilizando dois ensaios de traçador efectuados em simultâneo, utilizando dois tipos de traçadores: um conservativo (cloreto de sódio) e outro não conservativo (sulforodamina B). Os ensaios foram realizados sob as mesmas condições hidrogeológicas tendo em vista a análise da influência dos processos químicos, no traçador não conservativo, no transporte de massas em aquíferos. Os ensaios foram efectuados utilizando uma técnica inovadora desenvolvida por Lobo-Ferreira (1988), na qual se utiliza um único piezómetro para a injecção e detecção do traçador. Os resultados foram comparados com os valores obtidos por dois modelos analíticos concebidos para analisar o transporte de massa envolvendo fenómenos de adsorção. O resultado deste estudo ilustra o diferente comportamento observado entre traçadores conservativos e não conservativos. Os dois modelos, CANALX, que traduz a variação da concentração no espaço e CANALT, que traduz a variação da concentração no tempo, constituem importantes instrumentos de análise do comportamento de poluentes sujeitos a fenómenos de adsorção em águas subterrâneas.

34) Título: "Gestão optimizada das águas subterrâneas: aplicação ao caso de estudo do abastecimento de águas subterrâneas do concelho de Palmela (Portugal)"

Autores: JP Lobo-Ferreira; Emanuel Migliari

Jornadas Luso-Espanholas "As águas subterrâneas no sul da Península Ibérica"

23 a 27 de junho de 2003

Universidade do Algarve, Campus de Gambelas, Faro

ARTIGOS SELECIONADOS PARA A COLECTÂNEA

4th IYRF Zhengzhou China

Lobo Ferreira, J., Oliveira, L., Diamantino, C. (2011). Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems Under Extreme Drought Scenarios. In: Jones, J. (eds) Sustaining Groundwater Resources. International Year of Planet Earth. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3426-7_12

Groundwater Artificial Recharge Solutions for Integrated Management of Watersheds and Aquifer Systems Under Extreme Drought Scenarios

- First Online: 01 January 2011

Part of the International Year of Planet Earth book series (IYPE)

Abstract

This chapter addresses groundwater artificial recharge solutions for integrated management of watersheds and aquifer systems under extreme drought scenarios. The conceptual idea of Aquifer Storage and Recovery (ASR) is considered here as one of the science-based mitigation measures for climate variability and climate change in many parts of the world. Towards a sounder selection of the most appropriate method to build ASR facilities, several experiments have been carried out in the southern Portuguese region of the Algarve during the European Union-sponsored 6th Framework Programme for Research, Project GABARDINE on “Groundwater Artificial Recharge Based on Alternative Sources of Water: Advanced Integrated Technologies and Management”. The values obtained for infiltration rates available on the multiple experimental facilities depend not only on the hydraulic heads but also on the type of experiments and on the type of soils available regionally. The results gathered allowed the drawing of several original charts on infiltration rates that will be presented at the end of this chapter. The aim of all these experiments was to improve the knowledge on real case studies that involve application of different AR methodologies to assess the parameters needed to develop optimization models. The model may incorporate restrictions and parameters of the objective function values evaluated in the experiments described above. The results presented in this chapter allow the selection of the most appropriate AR techniques aimed at the maximization of groundwater quality improvement, while minimizing the cost. In parallel a new method, called GABA-IFI, aimed at preliminary identification of candidate areas for the installation of groundwater artificial recharge systems, was developed for the European Union-sponsored 6th Framework Programme for Research Coordinated Action ASEMWATERNet, a “Multi-Stakeholder Platform for ASEM S&T Cooperation on Sustainable Water Use” based on previous studies developed for five Portuguese Watershed Plans. This new method was applied both to Campina de Faro aquifer and to Querença-Silves aquifer in the Algarve. This chapter addresses the achievements of this project.

Groundwater artificial recharge solutions for integrated management of watersheds and aquifer systems under extreme drought scenarios

by

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Abstract:

This paper addresses groundwater artificial recharge solutions for integrated management of watersheds and aquifer systems under extreme drought scenarios. Based on a lecture presented by Dr. JP Lobo Ferreira at UNESCO's International Year of Planet Earth (IYPE) Workshop held in Oslo, Norway, August 2009, the conceptual idea of Aquifer Storage and Recovery (ASR) is considered, in this paper, as one of the scientific based solutions towards scientific based mitigation measures to climate variability and change in many parts of the world.

In Portugal two European Union sponsored 6th Framework Programme for Research Projects have been addressing this topic, namely GABARDINE Project on "Groundwater artificial recharge based on alternative sources of water: Advanced integrated technologies and management" (*cf.* http://www.lnec.pt/organizacao/dha/organization/dha/nas/estudos_id/gabardine) and the Coordinated Action ASEMWATERNet, a "Multi-Stakeholder Platform for ASEM S&T Cooperation on Sustainable Water Use" (*cf.* http://www.lnec.pt/organizacao/dha/nas/estudos_id/asemwaternet and http://www.asemwaternet.org.pt).

This paper addresses selected achievements of those Projects.

1. Introduction

Pyne (1995) defined Artificial Storage and Recovery (ASR) as "the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed".

The Australian ASR and Artificial Storage, Transport and Recovery (ASTR) Guideline (Dillon *et al.*, 2006) advices nine guiding principles necessary to achieved best practices for ASR and ASTR. They are: Adopting a risk management approach, preventing irreparable damage, demonstrations and continuous learning, adopting a precautionary approach, establishing water quality requirements, rights of water bankers and recoverable volume, finite storage capacity of aquifers and interference effects between sites, highest valued use of resources and community and other stakeholder consultation.

Towards a sounder selection of the most appropriate method to build ARS facilities, several experiments have been carried out in the Portuguese Southern region of the Algarve. The values obtained for infiltration rates available on the multiple experimental facilities, depend not only on the hydraulic heads but also on the type of experiments and on the type of soils available regionally. The results gathered allowed the drawing of several original charts on infiltration rates that will be presented at the end of this paper.

In parallel a new method, called GABA-IFI, aiming preliminary identification of candidate areas for the installation of groundwater artificial recharge system was developed for ASEMWATERNet Coordination Action, at LNEC, based on based previous studies developed for five Portuguese Watershed Plans by Oliveira and Lobo-Ferreira (2002). This new method is described in http://www.asemwaternet.org.pt/pdf/events/GAB-IFI_eng.pdf. It was applied both to Campina de Faro aquifer and to Querença-Silves aquifer, in the Algarve.

2. Why do we need to consider droughts and ARS facilities? The example of Portugal

A drought is a natural phenomenon in the Mediterranean region. It is not a fatality rather a recurrent situation requiring solutions and mitigation measures.

In Portugal the characterization of droughts is made since 1942 using precipitation data. Using the SPI-12 index (*cf.* Palmer, 1965) it is possible to say that since the agricultural year (September to August) of 1943/1944 there have been five years considered as drought in most of the country, being two years extreme droughts (*cf.* Domingos, 2006). An example of such characterizations can be seen in Figure 1. In this figure rows correspond to years (1969-2005) and columns correspond to districts from Northern Portuguese districts (on the left side) to Southern districts (in the right side). One may easily see in this SPI-12 index table, computed for all Portuguese mainland districts (*i.e.* not for the Portuguese Azores and Madeira archipelagos) a sequence of blue lines (wet years) flowed by a frightening sequence of red lines (dry years), that seams to become more solid as time proceeds, and also more compact along the districts from North to South. Some thing has to be done on adaptation measures to this reality. It is time now to proceed with scientific based appropriate methodologies to avoid recurrent scarcity.

3. Artificial recharge experiments in the Algarve

Following what was mentioned in the Introduction, the main objectives of Gabardine Project in the Algarve were: (1) to identify alternative water sources and study the economic and environmental feasibility of its use in semi-arid areas, in the context of an integrated water resources management, (2) to study the aquifers as a main water source for both seasonal and long term storage of these alternative water sources and (3) to improve knowledge about possible methods to introduce these water sources in the aquifer, namely through artificial recharge.

Alternative water sources for groundwater artificial recharge may include the superficial runoff surplus produced during flash flood events, treated urban wastewater, desalinate water surplus or water import.

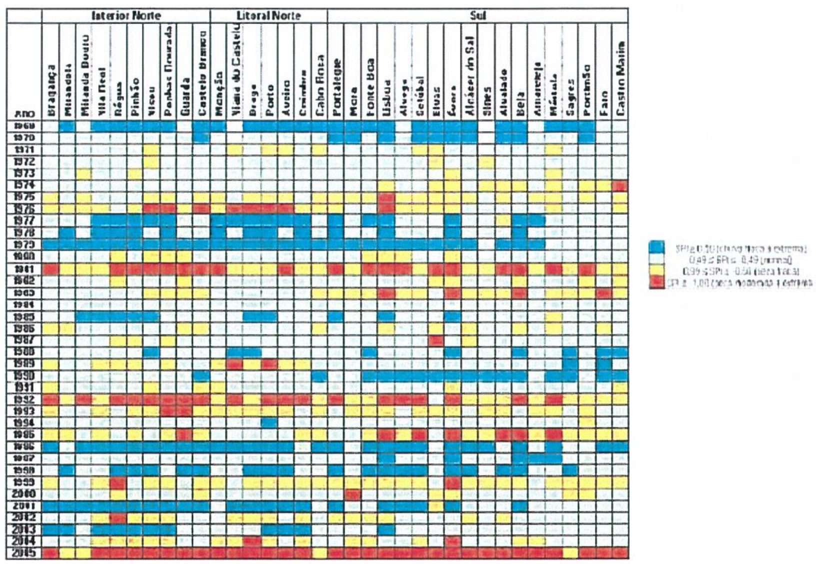

Figure 1 - SPI-12 values computed for selected municipalities (columns) from 1969-2005 for the Northern coastal zone and interior regions of Portugal as well as for the Southern region

The development of this study approached several issues related to the subject like: precipitation rate analysis, both water and recharge balance, identification of the potential alternative water sources intended to recharge the aquifer and assessment of existing technologies for its use, development of tools aimed for managing groundwater recourses considering artificial recharge, assessment of aquifer vulnerability and characterization of the unsaturated zone. Several artificial recharge devices have been developed and implemented in Gabardine Project.

Regarding Campina de Faro aquifer case study in the Algarve, the main goal was to optimize groundwater rehabilitation through implementation of artificial recharge, minimizing the effects of diffuse pollution caused by agricultural practices. This goal aimed the assessment in the Portuguese study area of problems resulting from the application of these practices. Today they are well documented in terms of groundwater quality. The study area was designated as a vulnerable area concerning nitrate concentration by the application in Portugal of the Nitrate Directive (in 2004). Together with the “good quality status” referred by the Water Framework Directive, these are the main reasons for the implementation of infrastructures aiming the improvement of groundwater quality in a section of this aquifer allowing, on the other hand, increasing groundwater availability with good quality in the Algarve region.

The Project improved scientific knowledge of several methodologies aimed not only to improve groundwater quality but also allowing subterranean storage of water with good quality in wet year periods of major availability and during events of heavy rainfall.

Multiple artificial recharge experiments were accomplished in the Portuguese case study area during the second year of the Project by Diamantino *et al.* (2007). Figure 2, presenting a set of selected pictures, show an example. The purpose of the experiments was to assess and quantify the effectiveness and applicability of the different groundwater artificial recharge methodologies, in a way that the achieved results can contribute to the development of the Gabardine Decision Support System (GDSS).

Complementarily, it was included a preliminary development of an optimization model that merges restrictions and parameters for the objective function. Its future application will allow selecting more adequate techniques considering the maximization of the improvement of water quality and total cost minimization.

Artificial recharge tests in infiltration basins

The objective of the AR was the assessment of infiltration rates in the very permeable yellow sands and to assess the unsaturated zone, and saturate zone transport parameters with a tracer test. To accomplish this purpose Areal Gordo AR Basins 1, 2 and 3 (Figure 2 and Figure 3) have been constructed for in situ infiltration and tracer test experiences. Besides, laboratory soil-column tests were performed in soil samples collected at the bottom of the basin. Areal Gordo AR Basin 2 had an area of 61 m^2. The bottom was excavated up to the third layer of yellow sandy soils at approximately 8 meters depth. The source of water for this infiltration test comes from a nearby well opened in the confined aquifer. To fulfil the objective of measuring the infiltration rate capacity, the water level in the basin was maintained constant (with a water column of approximately 90 cm) for a period of 3 days, and the infiltration rate was calculated by dividing the volume of water added by the basin area. At that time, the piezometric level and the groundwater quality parameters have been continuously recorded at the 6 m far LNEC4 well. The arrival to this well was 70 hours. This allowed estimating the permeability of this sandy layer as 0.21 m/d, considering the distance of 8 meters between the bottom of the infiltration pond and the well (*i.e.* up to 1.5 m in the vadose zone + 6.5 m distance in the aquifer).

Artificial recharge using a large diameter well

In the case study area of Campina de Faro a large amount of 5.0 m diameter wells equipped with a waterwheel are common, the so called "noras" (Figure 4). Some of them are still used for agricultural irrigation or even domestic consumption. In Areal Gordo an injection test was performed in one of those wells with the objective of assessing if they could be an effective infrastructures to be used, as already available facilities for AR. Also foreseen was the assessment of the infiltration rate *vs.* the recharging depth of water column, ranging from the surface to water table depth. Besides recording the level inside the large diameter well the effect of the recharge in the regional water level was monitored in the nearby LNEC5 monitoring well. This well allowed assessing a first approach to the groundwater hydraulic conductivity and some transport parameters. The input water discharge from a close deep well was controlled during the injection periods. The main characteristics of this large diameter well are presented hereinafter: area at the bottom of the "nora" with a diameter of 5 m = 19.625 m; depth to water table at the beginning of the first test=19 m; available storage volume at the "nora" for the test=373 m^3; total well depth=24 m. The monitoring equipment used was the following: multiparametric water sensors for continuous monitoring installed in the "nora" and LNEC5 well; from the discharge well a flow meter was installed for continuously record the discharge water volume.

Three injection tests were developed during March, 2007. A maximum value was assessed when the water level at the "nora" stabilized near the surface (at 1.5 m depth) allowing the recharge water input of 20 m^3/h to be incorporated in the aquifer. The values vary with the water level inside the "nora" ranging from 0.25 m/d - 1.18 m/d to a maximum value of 24.5 m/d, respectively for the 1st, 2nd and 3rd test (Figure 5). As expected, it was concluded that increments in the infiltration rate are strongly connected to the increase in the water column inside the well

Artificial recharge using a medium diameter well

A one day injection test was performed in an experimental medium diameter well of 0.5 m, located in Areal Gordo, and called LNEC6. The objective of this test was to determine the infiltration capacity and to compare it to the one assessed for the 5 m large diameter "nora". The injection test was performed during 4 hours and the depth to water table was recorded during the test. The input water discharge from a close deep well was controlled during the injection periods. Two injection discharges were considered, one to fill up the well and the other necessary to stabilize the water level: Qi_ascend=20m^3/h and Qi_descend=2.2 m^3/h. The main characteristics of LNEC6 well, opened in the unconfined sandy aquifer, are the following: section area (diameter 0.5 m)=0.196 m^2; depth to water table=18.9 m; available storage volume=3.7 m^3; total well depth=28 m. The monitoring equipment used was the same as in the previous injection test. The depth to the water table recorded in LNEC6 is plotted in Figure 6 as well as the two injection periods (4 hours total time duration). The infiltration rate was calculated by the change in the water level after the stop of the injection and during the necessary time interval to achieve the initial head, before the injection test (*i.e.* 7.4 m of water level variation during 0.6 days = 11.5 m/day of infiltration rate).

Artificial recharge experiments in river bed infiltration basins

In Rio Seco river bed, two 100 m^2 (20m(H)x5m(W)x5m(D)) infiltration basins were constructed and filled in with clean gravels for AR tests (Figure 7). The main objectives of the experiment were to assess the effectiveness of this type of AR structures for surface water infiltration, including the computation of groundwater recharges rates and evaluating groundwater mass transport parameters in unconfined aquifer via the monitoring of a breakthrough tracer curve. Two concrete sections were constructed and two pneumatic gauges for

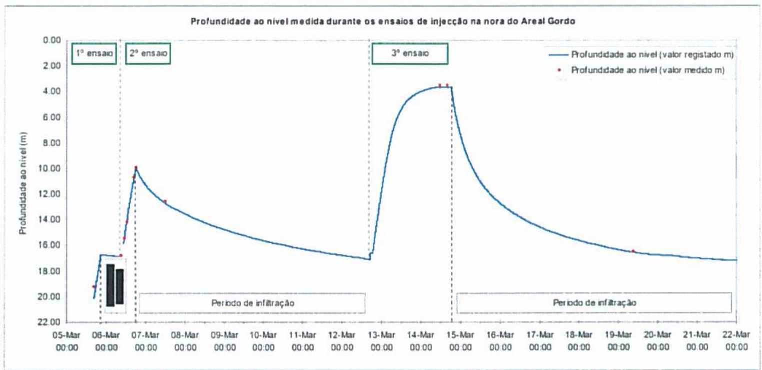

Figure 5 – Depth to the water table automatically recorded and manually measured during the injection tests performed in the "nora"

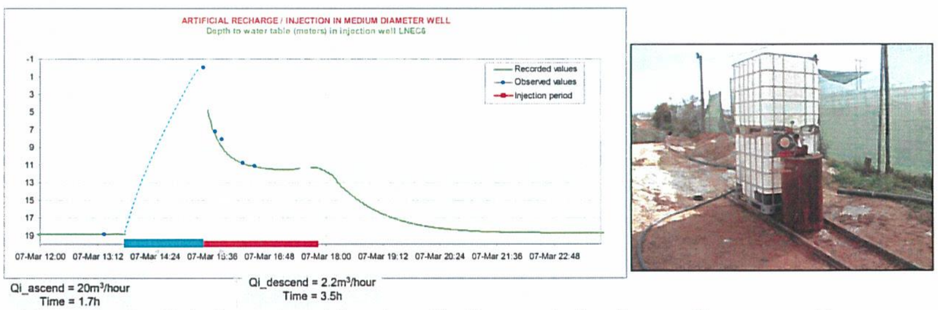

Figure 6 – Depth to the water table automatically recorded and manually measured in LNEC6 (medium diameter well) during the injection test

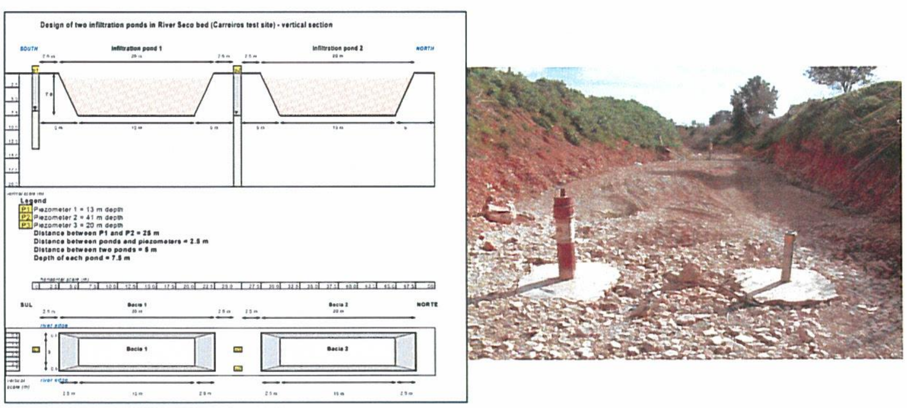

Figure 7 - Design configuration of the two infiltration basins in the river bed of rio Seco (Carreiros)

Results of the groundwater quality and quantity assessment recorded in the monitoring wells during the rainy months of November and December 2006, river water levels control were installed, upstream and downstream of the infiltration basins, during January, 2007, in order to measure the river discharge upstream and downstream the AR infiltration basins. Tracer tests have been performed during May, 2007 (Figure 8 and Figure 9).

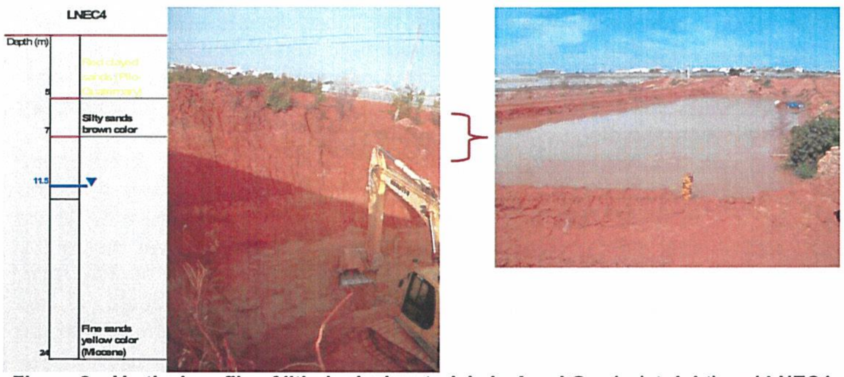

Figure 2 –Vertical profile of lithological materials in Areal Gordo (at right) and LNEC4 well lithological column and, infiltration basin in the first layer (at left)

Figure 3 – Infiltration basin in the second layer and monitoring equipment used for the infiltration test

Figure 4 – Injection test developed in the "nora": water levels at the beginning and at the end of the test

of surplus water in wet years or so that extra supply water may be available later in dries years. As we have clearly shown in this chapter for Campina de Faro, Portugal, other uses can be aimed at artificial recharge facilities, *e.g.* for cleaning polluted aquifer. So, the solutions proposed are worthy to be considered in implementing integrated water resource management plans, being part of a variety of solutions to minimize the water scarcity, for instance in the Algarve during severe drought situation.

Several in situ artificial recharge experiments and laboratory tests were performed in the framework of the Gabardine Project for a selected area of the Campina de Faro aquifer system. The comparison of different lithological materials in situ and in the lab, and the assessment of artificial recharge efficiency allowed data gathering regarding performances (on rates of infiltrations) and the adequacies of the different techniques for different geological layers (Figure 11). The in situ experiences showed very favourable rates of infiltration in yellow sands, especially in the large diameter well ("nora") experiment, when infiltration rates were as high as 24 m/day. In the case of the "nora" a function of the infiltration rate vs. the water column depth in the "nora" was computed.

The aim of all these experiments was to improve the knowledge on real case studies application of different AR methodologies to assess the parameters needed to develop optimization models. The model may incorporate restrictions and parameters of the objective function that values evaluated in the experiments, described above. The results presented in this chapter allow the selection of most appropriate AR techniques aiming the maximization of groundwater quality improvement, while minimizing the cost.

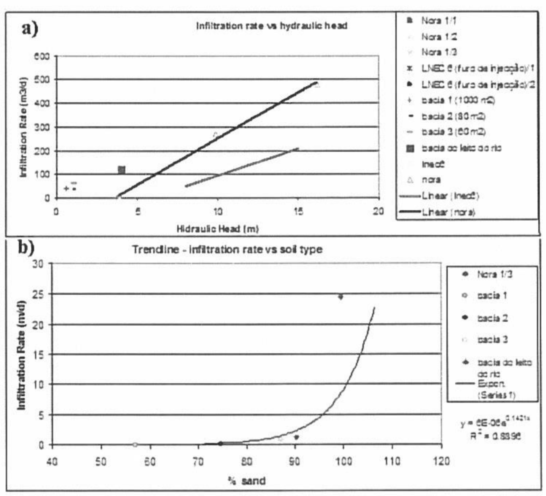

Figure 11 – a) Infiltration rates vs. the type of technology used (infiltration basins in the field or in river bed and, large and medium diameter recharge wells) ; b) Infiltration rates vs. the type of soil available in the Algarve at Campina de Faro and Rio Seco

when surface runoff infiltrates in basins, show NO_3^- concentrations strongly decreasing the same period and tend to get closer to the NO_3^- quality value of the river water (Figure 10).

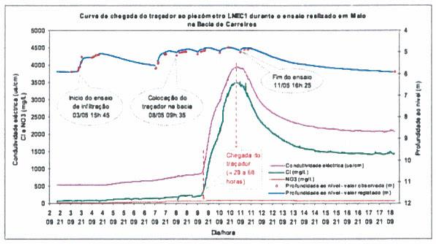

Figure 8 - Breakthrough tracer experiment curves at Rio Seco infiltration basin (Carreiros)

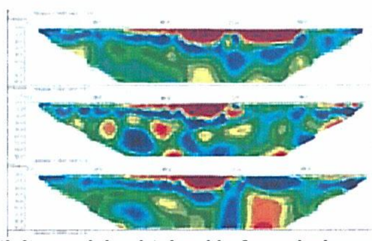

Figure 9 - Electric resistivity models obtained before, during and after the tracer test at the infiltration basin in Rio Seco, Carreiros (Mota *et al.*, 2008)

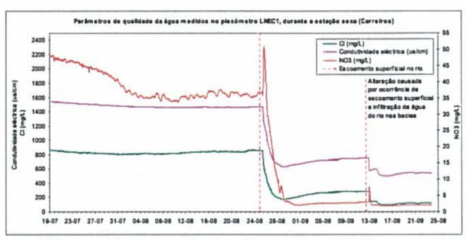

Figure 10 – Variation of the water quality in Campina de Faro unconfined aquifer, after runoff events in Rio Seco, monitored in LNEC 1 piezometer 2.5 m downstream of the infiltration basin

This is a remarkable fact, and of paramount relevance regarding the achievements of artificial recharge experiments towards the rehabilitation of the polluted unconfined aquifer, confirmed by LNEC 1 piezometer 2.5 m downstream of the infiltration basin.

4. Conclusions

As main conclusion, we may state that artificial recharge may be seen as one good solution aiming a scientific based adaptation to climate change or climate variability conditions in the near future. This technology allows the use

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13 SAS APRH Argelia GALDIT

NEW DEVELOPMENTS AND APPLICATIONS OF GALDIT METHOD: BOUTELDJA AQUIFER (ALGERIA) CASE-STUDY ASSESSING GALDIT PARAMETERS WITH GEOSTATISTICS

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ABSTRACT

This paper addresses the application and new developments of GALDIT method worldwide. GALDIT approach has been first developed during the project "EU–India INCO-DEV COASTIN" whose objective was to determine the vulnerability of a North Goa, India, coastal aquifers to sea water intrusion. The approach is based on the hydrogeological characteristics (depth of the water body, thickness of the aquifer), morphological (distance from the coast), hydrodynamic (transmissivity) and chemistry (impact of marine intrusions). The parameters of this method are based on the physical characteristics that can affect the marine intrusion. In Portuguese Speaking Countries, namelly Portugal, Guiné-Bissau, Angola and Brazil, GALDIT method has been applied not only for cooperation sponsored research projects but also for academicals studies and Master Degrees at Universities. Some of the achieved results have been presented in several APRH Congresses and Groundwater Seminars, highlighting the effect of sea level rise in coastal aquifers[1]. Besides, in more than 25 countries coastal aquifers have also been studied using GALDIT model. In Northern Africa, as addressed in this paper, we can mention the groundwater of Guerbes–Annaba in Algeria, the groundwater of Mahdia, in Tunisia, the groundwater of Mnasra-Gharb, in Morocco, and the Quaternary layer of Collo, in Algeria. The original GALDIT method, as developed by Chachadi and Lobo-Ferreira (2001), has been further applied and developments have been made and suggested, as those addressed in this paper by coupling GALDIT method with a geostatistical approach by Djoudar et al. (2019). This was suggested to increase the potentialities of GALDIT method considering the spatial variability of the studied variables. Using a field data set of the Bouteldja aquifer, the semi-variograms of four continuous important variables (hydraulic conductivity A, groundwater level L, thickness T and sea water intrusion I) have been studied and modelled. The GALDIT computation and mapping of the Bouteldja aquifer has shown a medium to low vulnerability in narrow and parallel bands close to the shore area.

Key Words: GALDIT, Vulnerability, Sea water intrusion, Pollution, Salinity

1. INTRODUCTION

Continued human interference with the coastal hydrologic system has led to pollution of coastal groundwater aquifers by salt water. According to Chachadi and Lobo-Ferreira (2001) the incidence of groundwater pollution due to salt water intrusion has increased manifold in the last two decades. Change in groundwater levels with respect to mean sea elevation along the coast largely influences the extent of sea water intrusion in the fresh water aquifers. The smaller the drop in groundwater levels, the lesser the sea water intrusion in the aquifers. In other words, the magnitude of change in sea level would have the identical effect on sea water intrusion if the groundwater levels were held constant. In the geological past, sea levels have changed with changes in natural climatic conditions several times. This happened during the glacial and interglacial periods, which are well recorded by coastal sediments in the form of transgressive and regressive sediment types. However, in the geological present, the climate is largely influenced by human interference in the form of air and water pollution and this has led to an imbalance in atmospheric heat. The effect of this thermal imbalance is seen in the melting of polar ice caps leading to a rise in sea level. The overuse of groundwater along parts of the coastal belts for various

[1] https://drive.google.com/file/d/0B_WArT_Dlk89NjI1M2ZiMTEtNmY4MC00MjQ0LWJlZmUtMTMxMWY2MjdkZTVm/view?resourcekey=0-sN3K5Wwp_UpFK0gpEJkC8g.

purposes has affected groundwater quality and quantity. As an example, in India that led to rapid decline in groundwater levels leading to salt water intrusion and water quality deterioration particularly in parts of Andhra Pradesh, Gujarat, Orissa, Tamil Nadu, and West Bengal.

Researchers further developed different approaches to increase the applicability of GALDIT, e.g. Mojgan Bordbar papers[2] (1) "Modification of GALDIT model by Weights of Evidence (WoE) to assess groundwater vulnerability to seawater intrusion in Gharesoo-Gorgan Rood coastal aquifer", in Iran, a new modified GALDIT approach was applied to assess groundwater vulnerability and, (2) "Meta-heuristic algorithms in optimizing GALDIT framework: A comparative study for coastal aquifer vulnerability assessment[3]. The Weight of Evidence (WoE) statistical method was applied to modify the weights of GALDIT. The model was validated with correlation coefficient between groundwater vulnerability model and TDS concentrations. Using the optimization algorithms in each region increases the accuracy of GALDIT index. Applying Meta-heuristic algorithms, a proper understanding was acquired on the vulnerability of coastal aquifer to seawater intrusion. Moreover, the result of this paper provides a practical reference for hydrologists and decision makers to protect the groundwater resources in coastal aquifers.

2. MATERIALS AND METHODS

2.1 GALDIT method

GALDIT is an indexation vulnerability methodology which uses intervals, classes and weights. It was developed as preliminary tool to predict groundwater subject to marine salt water intrusion. The GALDIT method was developed by Chachadi and Lobo-Ferreira (2001) within the framework of the Euro-Indian COASTIN (INCO DEV program of the 4th EU Framework Research Programme). The first application results of this model have been obtained in the coastal regions of Goa, India (Fig. 1, Chachadi and Lobo-Ferreira, 2005) and, in the Algarve, Portugal, by Lobo-Ferreira et al. (2005). An indexation of the vulnerability and a classification of the potentialities of a sea water intrusion in a given coastal geological context were established from the six GALDIT parameters. The calculation of the GALDIT index is based on six parameters, which are: (G) groundwater occurrence (aquifer type; unconfined, confined and leaky, confined); (A) aquifer hydraulic conductivity; (L) groundwater level above sea level; (D) distance from the shore (distance inland perpendicular from shoreline); (I) impact of existing status of seawater intrusion in the area; and (T) thickness of the aquifer being mapped. This index is a weighted value where each parameter receives a weight corresponding to its relative role. It is defined by the following formula:

$$\text{GALDIT} = \frac{\sum_{i=1}^{6} P_i R_i}{\sum_{i=1}^{6} P_i},$$

where Pi weights attributed to each parameter (i) according to its level of influence on the salted intrusion. The importance goes from 1 (weak influence) to 4 (strong influence). Ri the rank or the value which varies from 1 (weak vulnerability) to 10 (high vulnerability).

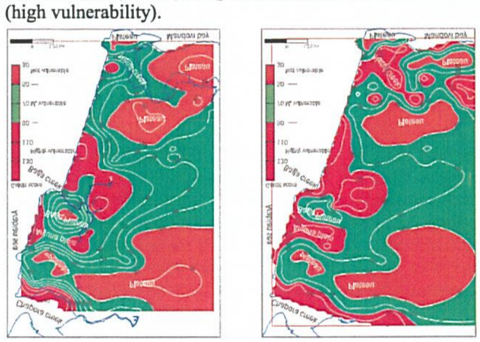

Fig. 1 - North Goa, India, comparison of sea water intrusion maps for today's and for raised sea level 0,5m scenario (according to Chachadi and Lobo-Ferreira, 2005)

[2]https://www.researchgate.net/publication/327222090_Modification_of_GALDIT_model_by_Weights_of_Evidence_to_assess_groundwater_vulnerability_to_seawater_intrusion_in_Gharesoo-Gorgan_Rood_coastal_aquifer
[3] https://www.sciencedirect.com/science/article/pii/S0022169420302286

2.2 Geostatistical computations

Hereinafter we highlight the new research developed by Djoudar et al. (2019) using the GALDIT method coupled with a geostatistical approach. Results are shown in Figs. 2, 3 and 4 and in Table 1.

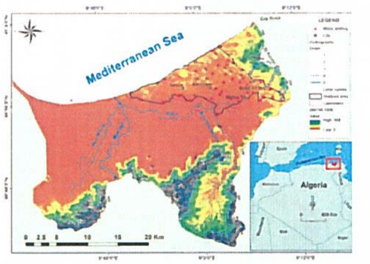

Fig. 2 - Geographic situation of the sand ridge of Bouteldja (according to Djoudar et al., 2019)

Fig. 3 - Map of GALDIT index vulnerability of the Bouteldja aquifer (according to Djoudar et al., 2019)

The principal tool in geostatistical computation, modelling and kriging, is the semi-variogram. A semi-variogram simply consists in calculating the spatial variance (or theoretical semi-variogram) between the observations in u and u plus a distance h further (u+h). This theoretical equation has been simplified to make the experimental calculations easier regarding the piezometric map of the dune massif of Bouteldja, considering former studies of Kherici et al. (2010). The geostatistical analysis was performed following several steps before final kriging maps. The first step was the experimental semi-variograms calculation and modelling of each variable in the sampled area. The omnidirectional experimental semi-variograms (EVS) for variables (hydraulic conductivity) A, (groundwater level above sea level) L, (thickness of the aquifer) T and (impact of existing status of seawater intrusion) I, have been calculated in the isotropic case because of the erratic behaviour of the directional structures. The EVS range distances have varied from 550 to 750 m. The details of these semi-variogram calculations are summarized in Table 1 and Fig. 4. The best experimental omnidirectional semi-variograms (direct ESV) were obtained through values levels of h (lag distance) of 550 m, 750 m, 650 m and 730 m, respectively, for the variables A, L, T and I. All of these variables showed a more or less structured spatial correlation with a generally spherical model of low nugget effect (tends to zero). There is an exception with the marine intrusion I variable which is modelled as Gaussian with a null nugget.

Table 1 Experimental semivariograms and fitted models of studied variables, along with corresponding parameters (range, sill, nugget effect, according to Djoudar et al., 2019)

Variables	Experimental semi-variogram omnidirectional (ESV)		Number and type of structure		Range (m)	Sill
	Lag distance (m)	Number of lag distance				
Conductivity (m/J)	550	6	1	Nugget effect model	–	1.74
			2	Spherical model	1621	27.39
Height of groundwater level above sea level (m)	750	10	1	Nugget effect model	–	13.02
			2	Spherical model	2247	69.55
Thickness of aquifer (m)	650	10	1	Nugget effect model	–	101.2
			2	Spherical model	1947	805.2
Seawater intrusion	730	6	1	Gaussian model	2198	2.27

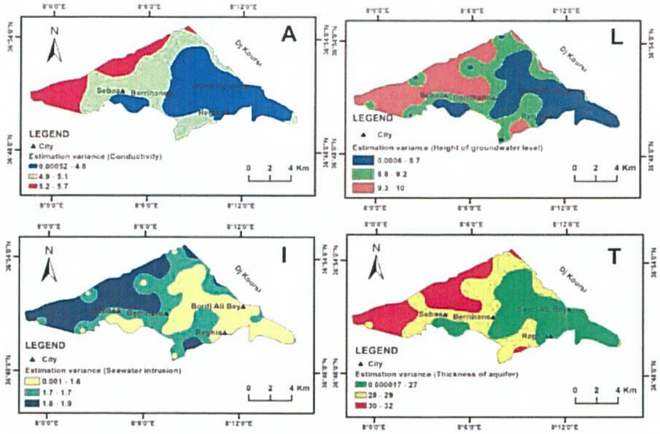

Fig. 4. Maps of estimation variances of variable (A, L, I, T, according to Djoudar et al., 2019)

3. CONCLUSIONS

The incidence of groundwater pollution due to salt water intrusion has increased manifold in the last two decades. Change in groundwater levels with respect to mean sea elevation along the coast largely influences the extent of sea water intrusion in the fresh water aquifers. GALDIT is a well-known framework for evaluating the groundwater vulnerability in coastal zones. In more than 25 countries many coastal aquifers have been studied using GALDIT. In Northern Africa we highlighted the application of GALDIT to the groundwater of Bouteldja littoral aquifer, an important reservoir of groundwater in the extreme east of Algeria. The research developed for Bouteldja aquifer allowed the suggestion of a new approach using the GALDIT method coupled with a geostatistical approach to capture the spatial variability of those continuous variables composing the GALDIT method. The four continuous variables A, L, I and T were geostatistically modelled and kriged all over the study area. The GALDIT vulnerability map revealed mainly two levels of vulnerability: • Average level, along the coast which could be probably strong to very strong; considering the sandy nature of the aquifer reservoir; • Low level, in the rest of the study area. This could be explained by the protective role played by the clay lenses.

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DEMONSTRATING MANAGED AQUIFER RECHARGE (MAR) AS A SOLUTION FOR WATER SCARCITY AND DROUGHT IN PORTUGAL AND SPAIN.

João Paulo LOBO FERREIRA (1); Enrique ESCALANTE (2), Christoph SCHÜTH (3) and Teresa E. LEITÃO (4)

ABSTRACT

In the Algarve, southern Portugal region, Managed Aquifer Recharge (MAR) research activities have been developed aiming not only water surplus storage in aquifers during wet years, focusing in the Querença-Silves aquifer (FP6 ASEMWATERNet coordination Action, *cf.* Lobo-Ferreira and Oliveira, 2008), but also groundwater quality rehabilitation in the Campina de Faro aquifer (FP6 Gabardine Project, *cf.* Lobo-Ferreira *et al.*, 2006). Following MAR research potentialities in southern Portugal, this paper describes the objectives, conceptual demonstration, background and capabilities of the two selected Circum-Mediterranean pilot sites (in Portugal and in Spain) that will be researched in the recently approved FP7-ENV-2013-WATER-INNO-DEMO MARSOL project. In the Algarve pilot site, several case-study areas will be located in the Querença-Silves aquifer and in the Campina de Faro aquifer.

The research addressed in this paper is relevant not only to Portugal and Spain but also to the majority of the Mediterranean coastal region, as a proactive behaviour regarding climate change adaptation. As a matter of fact, according to the latest IPCC projections, the Circum-Mediterranean region will be particularly affected by Global and Climate Change (*cf.* Stocker *et al.*, 2013). These changes include population growth, increase in food, water and energy demands, changes in land use patterns and urbanization/industrialization, while at the same time, the renewable water resources in the Circum-Mediterranean region are predicted to decrease by up to 50% within the next 100 years. In addition, the anticipated reduction of groundwater recharge, due to climate change, of up to 50% and beyond, will exacerbate the occurring problems resulting from water scarcity in many of today's semi-arid zones. Increased water scarcity will also affect the economies of developed countries, including all sectors from agriculture, water supply and wastewater, transportation and tourism, through to the energy sector.

Keywords: artificial groundwater recharge, drought mitigation, improving water availability, water resources management, Mediterranean coastal region.

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1. INTRODUCTION

The economies of most Mediterranean European states, which today strongly depend on agriculture and tourism, will face a fundamental change if the available water resources decrease by more than 50% within the next 50-100 years. Furthermore, the Mediterranean coastal region represents one of the most densely populated regions in the world with currently 180 million inhabitants and 250 million expected by 2025. This population growth will result in a growing water demand and tremendous wastewater and regionally concentrated pollution problems. Some megacities in the Mediterranean area still discharge large parts of their untreated wastewater into the rivers and the sea, having a major impact on the ecology of the Mediterranean Sea. These developments are accentuated by the fact that in many of the Mediterranean countries, the natural renewable water resources are fully exploited or over-exploited already today, while at the same time, the Mediterranean area is a global hot spot of freshwater biodiversity, with a high proportion of endemic and endangered species. Hence, the Mediterranean area is a high priority region for freshwater conservation and restoration. All the existing activities and the new opportunities assume the availability of water, either from rivers, groundwater, desalination plants or from wastewater- and irrigation-return, which cannot be taken for granted considering the long-term resources projections. The expected increase in scarcity will therefore be a forceful driver for the introduction of new water-efficient technologies in all sectors, and also for a better management and economically optimized allocation of the valuable water resources and their protection from pollution.

Being confronted with several water scarcity and drought events in the past decade, the European Commission has taken the initiative to address these challenges. The main overall objective of EU water policy is to ensure access to good quality water in sufficient quantity for all Europeans (EU Policy on Water Scarcity and Droughts), and to ensure the good status of all water bodies across Europe (Water Framework Directive). Policies and actions have been established to prevent and mitigate water scarcity and droughts, with the aim of moving towards a water-efficient and water-saving economy.

MAR will contribute to the implementation of the EU policy on Water Scarcity and Droughts and the adaptation strategies of the White Paper on Climate Change Adaptation.

The new FP7-ENV-2013-WATER-INNO-DEMO MARSOL project, which started Dec. 1st, 2013 (http://www.marsol.eu/, under construction) will improve public access to good quality drinking water and increase the resilience of key economic sectors to climate change. Moreover, MAR will contribute to meeting the environmental objectives of the WFD, i.e. improving surface and groundwater quantity and quality, and healthy ecosystems (ecological flows). MARSOL project will involve pilot sites representative of several areas within the Mediterranean Basin (Portugal, Spain, Italy, Malta, Greece and Israel), demonstrating that MAR can provide solutions for adaptive water resources management, i.e.:

- MAR to sustain urban and industrial water supply.
- MAR to limit seawater intrusion in coastal aquifers.
- MAR to combat nitrate pollution.
- MAR for sustaining drought mitigation and biodiversity goals.
- MAR to countermeasure temporal and spatial misfit of water availability.

In this paper, the work already carried out for Portugal and Spain, is detailed exemplifying MAR as a solution to water scarcity in the Mediterranean coastal region.

2. DESCRIPTION OF GABARDINE PROJECT DEVELOPED IN CAMPINA DE FARO, PORTUGAL

2.1 Context

GABARDINE project (http://www.lnec.pt/organization/dha/nre/estudos_id/gabardine, 2005-2008, *cf.* Lobo-Ferreira *et al.*, (2006), Diamantino *et. al., (*2007 and 2008) and Diamantino, 2007) had the following major objectives: (1) explore the viability of supplementing existing water resources in semi-arid areas with alternative sources of water that could be exploited in the context of an integrated water resources management approach, (2) investigate the feasibility of using aquifers as the primal facility for the large scale storage of these alternative water sources and investigate techniques for their artificial recharge (AR) and injection of the produced alternative water, including a monitoring of water quality and purification by natural attenuation and filtration processes, (3) evaluate and quantify the potential impact of degrading factors, such as climate change, changes in the quality of water, salt water etc. on the global quality and usability of the resource, by developing tools for risk mapping, for modelling and for monitoring, and to propose measures for preventing or minimizing, and mitigating their impact. The alternative water sources were surface water surpluses generated during rainy seasons, treated effluent, surpluses of desalinated water and exploitation of saline water bodies that could be used for adequate agricultural practices or used as raw material for low-cost desalination.

Four test sites have been selected for GABARDINE project in the Circum-Mediterranean area, each representing a different aspect of the problem: (1) the aquifer of Thessaloniki area, in which AR is being considered for controlling seawater intrusion and storage of treated effluent (Greece); (2) the Lower valley of the Llobregat river, where the objective is to mitigate the aquifer from seawater intrusion by means of AR of effluent and or runoff water (Barcelona-Spain); (3) the Campina de Faro aquifer, in Algarve region where the objective is achieving groundwater quality improvement by injecting surface-water (Portugal, which will be detailed hereinafter); (4) the Coastal aquifer shared by Israel and Palestine (Gaza). In Israel most of the recharge technologies are implemented but the quality and mixing aspects need to be investigated and quantified.

2.2 Purpose

In Rio Seco river bed, at Carreiros, two 100 m^2 (20mx5m) infiltration basins were constructed in the river bed and filled in with clean gravels for artificial recharge tests. The source of water is the river water during runoff flow.

The main objective was to investigate this type of artificial recharge structures for surface water infiltration in terms of groundwater quality and quantity assessment in confined and unconfined aquifers. Also tracer tests for infiltration rate assessment and geophysical assessment have been developed during May, 2007. During the second and third year of the Gabardine Project two periods have been researched regarding the river bed infiltration basins: the summer time (irrigation period) from April, 1st to September, 31th 2007 and the winter time (no irrigation period) from October, 1st 2007 to June, 30th 2008.

2.3 Methodology

During November, 2006 two infiltration basins in the river bed, filled with clean gravels, and three monitoring wells (LNEC1, LNEC2 and LNEC3) for groundwater quality and piezometric levels assessment have been constructed (Figure 1). Each well was equipped with multiparametric sensors for quality and water level continuously recording. Each basin surface area is 100 m^2 (20mx5m) and has approximately 5 meters depth. LNEC1 is opened in the unconfined sandy aquifer with 13 meters depth, LNEC2 is opened (possibly) in the confining aquitard at 20 meters depth and LNEC3 is opened in the sandstone confined aquifer, at 40 meters depth. Two concrete sections were constructed and two pneumatic gauges for river water levels control were installed, upstream and downstream of the infiltration basins, during January, 2007. A tracer test experiment was performed in May 2007 during 4 days, in the South infiltration basin, with a NaCl tracer spread uniformly in the basin surface with a constant water discharge (500 kg of NaCl and 100 m^3 of water). Before the tracer experiment a previous 3 days artificial recharge experiment was performed for a preliminary infiltration rate assessment. The source of water for those experiments was extracted from the confined aquifer (LNEC3). Piezometric levels, electric conductivity, Cl and NO_3^- concentrations were measured every minute in the monitoring probes installed in the monitoring wells LNEC1 and LNEC2.

2.4 Results

The first results, during winter time, of the groundwater quality and quantity assessment recorded in the monitoring wells are presented in Figure 2 – the first plot shows the piezometric variation recorded in the 3 monitoring wells (LNEC1, 2 and 3) and the second one shows the NO_3^- concentrations results obtained from the groundwater samples.

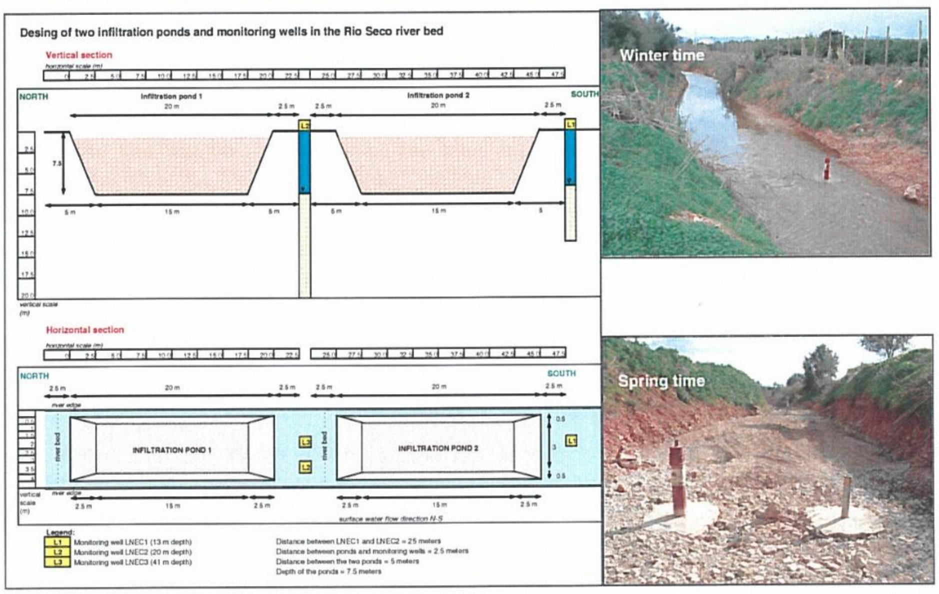

Figure 1. Design configuration of the two infiltration basins in the river bed of rio Seco (Carreiros), winter time and summer time photos

Also the daily precipitation recorded in the nearest climatological station (São Brás de Alportel) is presented in the plot to give an idea of the time periods of eventual surface runoff in the river. The river water NO_3^-concentration could also be determined in two samples plotted with a red cross. It can be observed from this results that piezometric levels tends to increase during the rainy months of November and December - during those months the surface runoff was also infiltrating in the tested basins. NO_3^- concentrations strongly decreased in the same period and tend to be close to the surface water NO_3^- value, especially in the unconfined aquifer wells. This is a relevant result regarding the achievements of Gabardine objectives on the rehabilitation of the polluted unconfined aquifer of Campina de Faro. The results recorded in LNEC1 during the summer period, concerning NO_3^- and Cl^- concentration and electrical conductivity values are presented in Figure 3 and Figure 5. They show an improvement in terms of groundwater quality caused by surface water infiltration during the first flash flood taking place at the end of the summer period. These results are verified by the increase in the depth to the water table recorded in the same period.

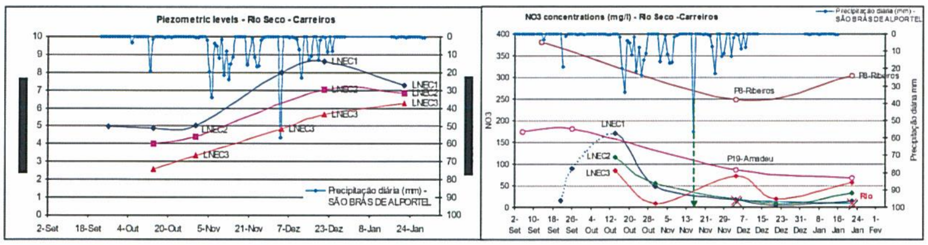

Figure 2. Piezometric levels variation and NO_3^- concentrations recorded between October, 2006 and January, 2007 at Carreiros test site (winter time results)

Results on the tracer test experiments showed the Cl^- concentration breakthrough curve and the arrival time at LNEC1. An infiltration rate of about 120 m^3/day (*i.e.* 5 m^3/h) was measured at the southern basin that has an area of about 100 m^2. Per m^2 the infiltration measured was about 2 m/day. A small monitoring well for water levels and electric conductivity recording installed inside the basin allows to obtained similar values, of 1.8 m/day for an average rate of infiltration.

The real groundwater velocity was estimated after the NaCl tracer experiment (May, 18 to August, 20) at the Rio Seco river bed as follows: arrival at LNEC1 – 27/06 10:30h=39d×24h=936h; V_{int}=6.4 cm/d; K=V×ne/I=6.4×0.35/0.088=25 cm/d=0.25 m/d (arrival at LNEC1 is presented in Figure 5).

2.5 Rio Seco river bed geophysical assessment

During the end of January, 2007 a geophysical campaign was made. Figure 6 shows the results of electrical resistivity profiles, one longitudinal and four transversal profiles performed at the river bed, intersecting the two infiltration basins. These results are essential for assessing the background values of resistivity prior the tracer test experiment developed during May, 2007. The new electrical resistivity profiles performed during the tracer experiment showed a very good correlation with the electrical conductivity values observed in the monitoring wells and allowed the detection of a saline plume migration during the recharge experiment.

The longitudinal profile resistivity values were measured twice a day during the infiltration and tracer test experiments, and also repeated a week after the test conclusion. Some transversal profiles were also measured during the tracer test. Figure 7 presents two examples of the electrical resistivity results obtained in the longitudinal profile before and during the saline injection. In LNEC Report named "Time-lapse resistivity tomography with a saline tracer for the Gabardine Project" (Mota, 2008) a more complete description of this geophysical assessment is presented.

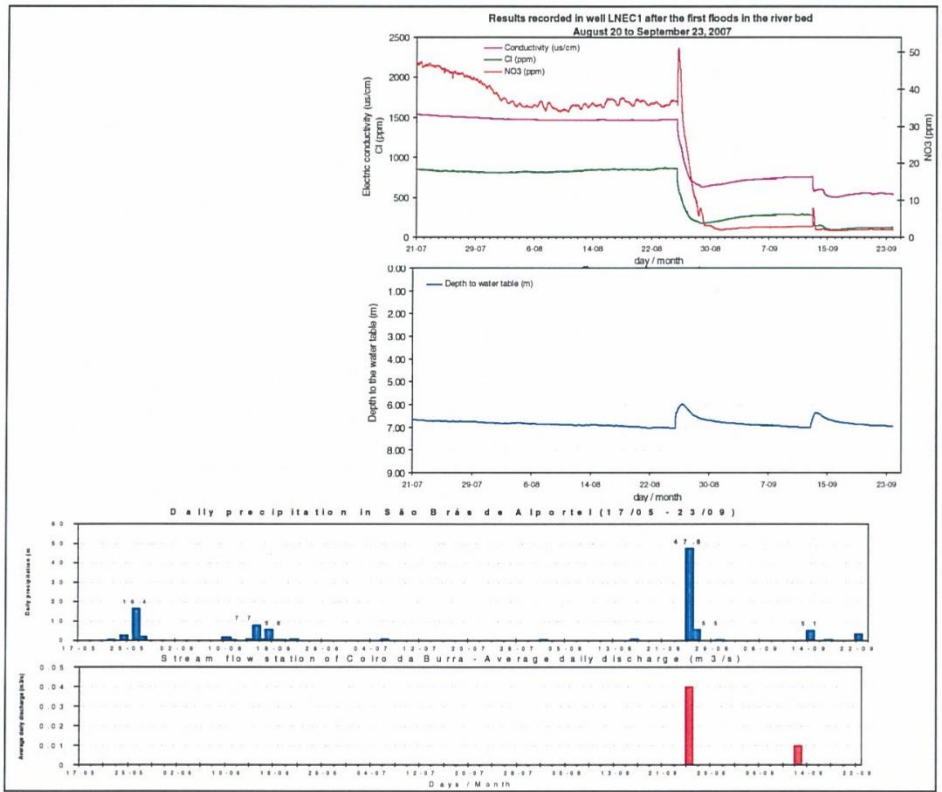

Figure 3. Quality results and depth to water table recorded in LNEC1 after the first floods in the river bed. Results comparison with daily precipitation values recorded in São Brás de Alportel climatological station and with average daily discharge recorded in Coiro da Burra stream flow station, in the same period

2.6 Conclusions of the Portuguese Campina de Faro case study

Besides the know-how in performing tracer experiments in Campina de Faro and the way it was done, enabling the extrapolation of the results gathered as shown in Figure 8 (*cf.* (a) infiltration rates vs. type of technology used (infiltration basins in the field or in river bed and, large and medium diameter recharge wells); and, (b) infiltration rates vs. type of soil available in the Algarve at Campina de Faro and Rio Seco), the main goal of the project was to optimize groundwater rehabilitation through implementation of artificial recharge, minimizing the effects of diffuse pollution caused by agricultural practices. This goal aimed the assessment in the Portuguese study area of problems resulting from the application of these practices. Today they are well documented in terms of groundwater quality. The study area was designated as a vulnerable area concerning nitrate concentration by the application in Portugal of the Nitrate Directive (in 2004). Together with the "good quality status" referred by the Water Framework Directive, these are the main reasons for the implementation of infrastructures aiming the improvement of groundwater quality in a section of this aquifer allowing, on the other hand, increasing groundwater availability with good quality in the Algarve region.

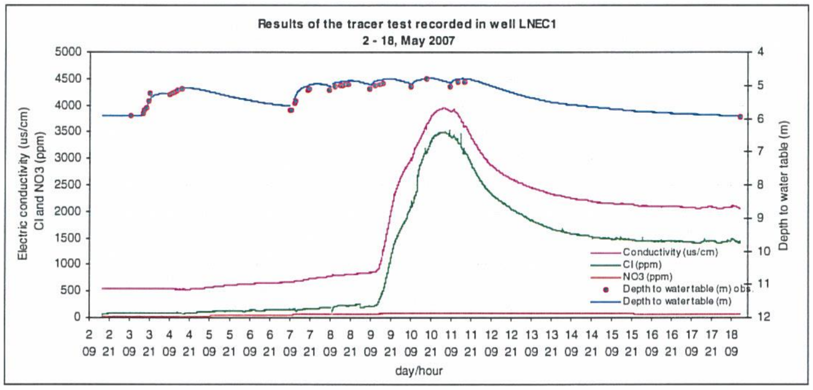

Figure 4. Results of the tracer test experiment recorded in LNEC1, concerning electrical conductivity, Cl^{-} concentrations and depth to water table variations

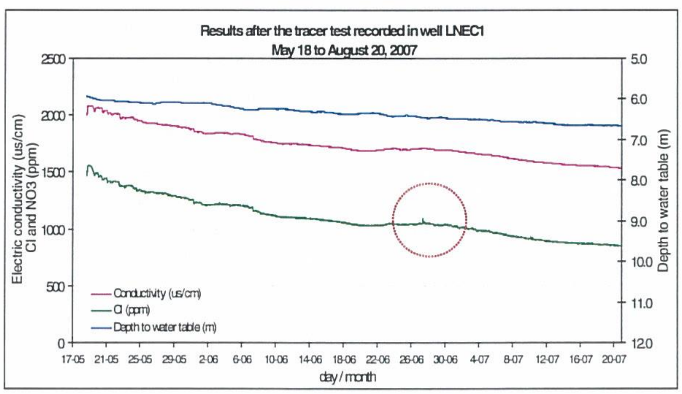

Figure 5. Results after the tracer test experiment recorded in LNEC1, concerning electrical conductivity, Cl concentrations and depth to water table variations (undisturbed groundwater flow)

The Project improved scientific knowledge of several methodology aimed not only to improve groundwater quality but also allowing subterranean storage of water with good quality in wet year periods of major availability and during events of heavy rainfall.

Several artificial recharge experiments were accomplished in the Portuguese case study area during the second year of the Project. The purpose of the experiments was to assess and quantify the effectiveness and applicability of the different groundwater artificial recharge methodologies, in a way that the achieved results can contribute to the development of the Gabardine Decision Support System (GDSS).

Complementarily, it was included a preliminary development of an optimization model that merges restrictions and parameters for the objective function. Its future application will allow selecting more adequate techniques considering the maximization of the improvement of water quality and total cost minimization.

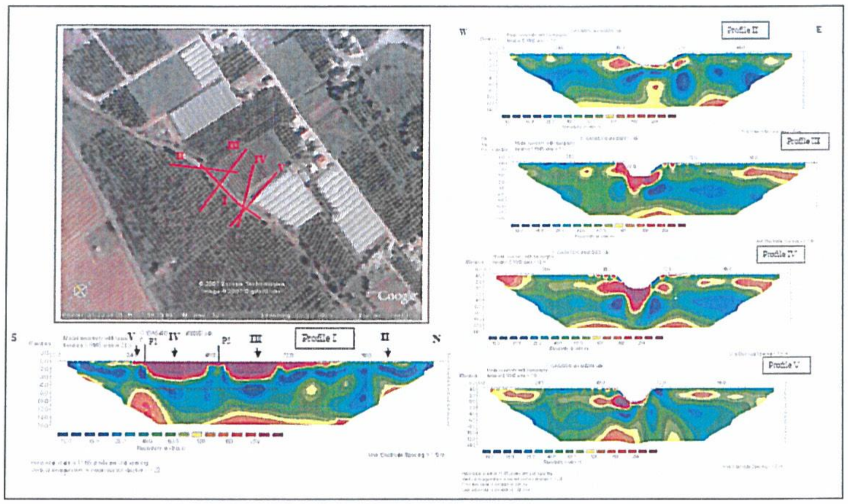

Figure 6. Geophysical assessment using electrical resistivity profiles intersecting the infiltration basins at the river bed (Carreiros test site)

3. EXPERIENCES IN LOS ARENALES AQUIFER (SPAIN) CONDUCTING TO TECHNICAL CRITERIA TO IMPROVE ARTIFICIAL RECHARGE IN INFILTRATION PONDS AND CHANNELS

3.1 Introduction

After ten years of management of the aquifers' artificial recharge facilities or Managed Aquifer Recharge (MAR), which was constructed by the Ministry of the Environment and Rural and Marine Affairs (MARM) and the Castile and Leon Regional Government (JCL) in Los Arenales (a mainly eolic sand aquifer), more specifically in the Cubeta de Santiuste reservoir and the county of Carracillo (Segovia), simultaneous monitoring has been carried out on the artificial recharge, studying the strong and weak points in the facilities (channels, infiltration ponds and large diameter wells).

This paper describes the experience of ten years of "experimental laboratories" and how this monitoring has led to the design and execution of improvements that have come from this experience and which are aimed at increasing the infiltration rate in a pre-operational situation, operational and post-operational stages.

Thus, headway is being made towards highly efficient designs in terms of water management for irrigation, with a view to its future use for urban storage in this aquifer and other analogous ones.

3.2 Framework

Los Arenales aquifer or Hydrogeologic Unit 02-17 covers an area of 1,504 km^2 located in Castille and Leon. Its origin is polygenic with a predominance of Arevalo facies, i.e. sands from a quaternary dune system with variable thickness (up to 50 m) filling a complex substrate from the Miocene epoch, notably argillaceous (Cuestas facies) or arenaceous and argillaceous (Puente Runnel).

The superficial quaternary aquifer exploitation has been intensified in the past few decades, causing the phreatic level to recede by 10 m, also bringing about salinisation and contamination processes. Therefore, three managed aquifer recharge devices for irrigation are being tested. These are shown in Figure 9.

AR first experiences in Los Arenales took place in La Moraña, where a thorough study was carried out to determine AR possibilities, both in the superficial aquifer and in its deeper levels. In the end, this option was discarded on fluvial waters, due to the difficulty in diverting water from the main rivers. This has led to the use of purified water for recharging purposes, which is now in progress.

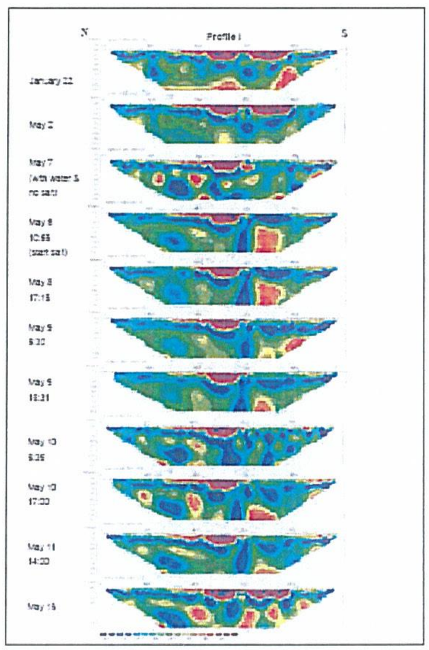

Figure 7. Geophysical assessment in the longitudinal electrical resistivity profile before and during the tracer test at the river bed (Carreiros test site)

Thanks to the actions carried out by MAPA and the i+R&D activities, the Cubeta de Santiuste is now a pretty well-known aquifer, located in the west of the province of Segovia and south west of Valladolid. Lying on the left shore of Voltoya and Eresma rivers, it covers a surface of 48 km^2 and 600 ha of irrigation area. Artificial recharging (AR) began in 2002/03 on a single channel with alternate basins, which has been successively expanded until today. The volume infiltrated into the aquifer has ranged between 0.97 (cycle 2004/05) and 12.19 hm^3 (2006/07). The device has been operating for 8 years and currently consists of 27 km of MAR channel, 5 infiltration ponds, 3 MAR wells, a River Bank Filtration (RBF) system and three artificial wetlands.

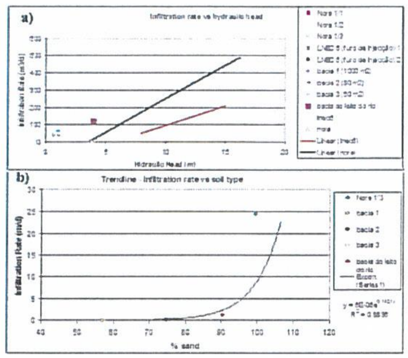

Figure 8. a) Infiltration rates vs. the type of technology used (infiltration basins in the field or in river bed and, large and medium diameter recharge wells); b) Infiltration rates vs. the type of soil available in the Algarve at Campina de Faro and Rio Seco

The county of Carracillo is located about 40 km east from the aforementioned region. It covers an area of about 150 km^2 and it is located at the interfluve of rivers Cega and Pirón. Irrigation has been practised extensively in this area with at least 2,700 ha using underground water. Artificial recharge by means of unlined irrigation ditches has also been practised for quite some time now, even though the largest devices started working in the winter of 2006/07, introducing 8 hm^3 into the aquifer, subsequently increased to 12 hm^3 in the 2009/10 cycle. It is composed by 40.7 km of MAR channel, 3 infiltration ponds, an RBF system and two artificial wetlands.

A thoroughly detailed description of these devices can be found in Fernández (2009) and Fernández *et al.* (2009). These devices have remained the main "experimental laboratories" of the i+R&D DINA-MAR project (http://www.dina-mar.es/) and Tragsa Group since 2002.

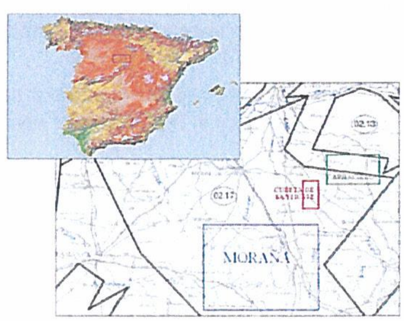

Figure 9. Geographic position of Los Arenales aquifer, also called UHG 02-17 (map scale 1:200.000)

3.3 Objectives

The main objectives include the study of the evolution of artificial recharge in the last ten years, particularly concerning the evolution of the infiltration rate and volume of infiltrated water, so as to analyse the performance of the channels and basins and make them more effective by means of structural improvements and/or by Soil and Aquifer Treatment techniques (SATs).

3.4 Results and discussion

3.4.1 Actions carried out on the morphology of infiltration ponds and channels

Infiltration ponds

In order to improve their effectiveness, the water-environment contact surface has been widened by the ploughing of furrows, which also allow the silts to be deposited in bottom furrows due to gravity, the ridges remaining higher up and relatively cleaned.

In order to quantify the differences between a flat bottom or a ploughed one, approximately 14 infiltration tests in Santiuste basin's decantation and MAR pond were carried out. The first ones with flat bottom (tested in 2007 September). Shortly after and in order to find out the most suitable spacing between furrows to obtain the highest infiltration values, furrows were ploughed in the initial decantation basin at a "wavelength" between 60 and 100 cm with a Roman plough. These tests were repeated in June 2008 and 2009, at the end of each AR cycle and once the basin had dried up (Table 1, Figure 10 and Figure 11).

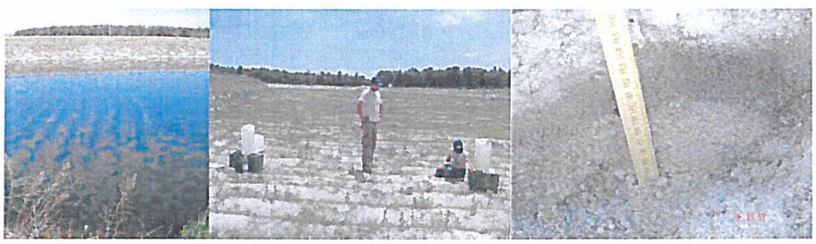

Figure 10. Furrows plugged with different width at the bottom of a decantation and infiltration pond, infiltration test by double ring infiltrometer in the convex and concave surface of them and the clogging profile. Headwater of the Santiuste´ AR device

Comparing results of 2008 and 2009 (June in both cases), with smaller spacing between the ridges (60 cm), infiltration rates fell over fifty percent in the ridges and less in the furrows.

With 80 cm after making the furrows, the rates increased over four times in the ridge and such increase was slightly higher in the valley, with larger drops in the ridges than in the furrows. One year later, they turned 90 and 220 mm/h (ridge/furrow, respectively) with values of 420/232 mm/h.

With 1 m spacing, results were similar to those of 2007 in the ridges, being rather lower in the furrows.

All the results confirm that, according to the test place and conditions, furrows increase the infiltration rate when compared with flat-bottom basins, with higher values in the ridge of the mounds than at the bottom of them. Although it is not possible to set a defined trend, given the few number of tests, furrows with 80 cm spacing perform better in general terms. However, these results are not final.

It is a good practice to open furrows with disc ploughs, which proves to be less harmful than the mouldboard plough.

Table 1. Results of infiltration tests from the headwaters´ infiltration pond. Values collected in 2007 September (pre-operational), 2008 June and 2009 June (post operational) respectively

	Coordinates UTM		Campaigns: t & inf. rate Sept 2007/Jun 08/Jun 09		Characteristics	
STATION	**X**	**Y**	**Test (min)**	**Infiltration rate (mm/h)**	**Site**	**Soil type**
POND 1	369832	4557443	100/255/101	2500/95/38	ridge 0.6m	sand
POND 2	369839	4557436	100/248/100	100/90/65	valley 0.6m	silty sand
POND 3	369821	4557448	148/120/68	90/420/100	ridge 0.8m	sand
POND 4	369803	4557426	180/120/81	220/232/108	valley 0.8m	silty sand
POND 5			150/150/nd	200/350/nd	ridge 1.0 m	sand
POND 6			nd	250/220/44	valley 1.0 m	silty sand

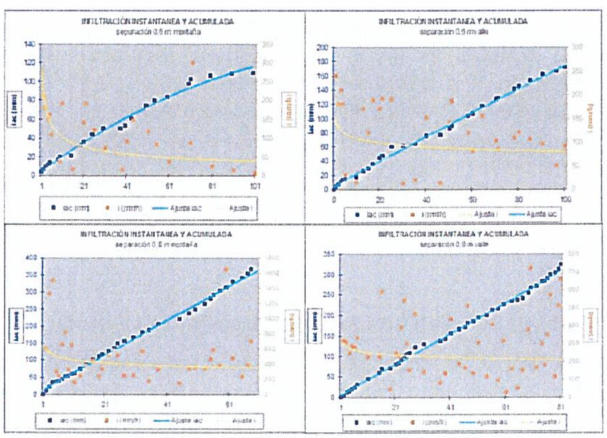

Figure 11. Test interpretation graphs with double ring infiltrometer in basin 3, with 0.6 and 0.8 m spacing. Data collected in from June 2007 to June 2010. Graphs of these results & interpretation of 2008

3.4.2 AR Channels

The main lines of action to increase the infiltration rate and the total infiltrated volume in the channels bottom and walls have focused on the channel morphology itself. They also focus on flow regulation and filtering of silt in the AR water.

From 2008 two sections of the channel have been tested with a longitudinal ridge fitted with a 5 m long geotextile. The section with a higher number of tests is located as from point UTM

30-369417/4559040. The tests are repeated on an annual basis in the section centre and ends (Table 2).

In the 2007 and 2008 campaigns the infiltration rate plunged, which could be consequence of several factors, such as the excess of sediments in the recharge water. However, in 2009, rates went up again. In the geotextile areas there was an actual retention of silt, with an associated infiltration fall. In the areas without geotextile rates were again similar to 2007.

Table 2. Infiltration tests above and just near those channel fragments which count on installed synthetic geotextiles. Values for 2007 September (pre-operational), 2008 June and 2009 June (post-operational) respectively. IV-1 GT 2 was destroyed due to a flood

	Coordinates UTM		Campaigns: t & Inf. rate Sept 2007/Jun 08/Jun 09		Characteristics	
CHANNEL STATION	X	Y	Test (min)	Infiltration rate (mm/h)	Site	Soil type
IV-1 GT-1i	369417	4559044	180/90/80	130/13/44	No geotextil	sand
IV-1 GT-1f	369417	4559045	180/103/90	210/22/38	Above geotextil	silt
IV-1 GT-2i	369714	4557572	120/86/na	90/108/na	Above geotextil	silt
IV-1 GT-2f	369713	4557576	90/70/60	150/160/150	No geotextil	sand

According to the analysis of results, the rate is usually higher in short-term tests, though it is lower in longer-term tests, so, it is believed that there is a higher silt concentration at a certain depth beneath the channel. Besides, although it is convenient to increase the number of tests to draw reliable conclusions, the infiltration trend showed a higher slope in the last tests, where the infiltration curve (marked in a lighter colour) allows reducing the increase of soil sediments, which accumulate in areas of lower hydraulic conductivity (first in the surface and then in the 40 to 60 cm depth range). These results must be considered for maintenance planning.

3.5 Conclusions of the Spanish Los Arenales aquifer case-study

The downward infiltration rate in the channels and basins of Los Arenales aquifer is being reduced through flow regulation and pre-treatment techniques (slit filtering and air reduction) in the AR water. Flow regulation allows reducing the amount of silt and air entering the aquifer. It can be noticed that the most effective recharge occurs at high flows or flows around 150 to 200 l/s. Higher flows reduce the infiltration rate due to water oxygenation and the increase in the suspended particulate matter. Positive results are coming from communicating vessels systems in shut-off devices and buried channel sections fitted with filter pipes.

As for the performance in the morphology of basins and channels, furrows have ultimately increased the infiltration rate in all the tests with respect to those carried out in "flat-bottom" basins. 80 cm spacing between ridges delivered the highest values, with rates that nearly double those obtained at 60 and 100 cm. However, data obtained so far do not render results final. Apparently, disc ploughs present better results than mouldboard Roman ploughs.

In maintenance operations, it is of paramount importance to keep furrows clean, both in basins' furrows and in the longitudinal ridge at the centre of the channel. The installation of low permeability and easy-to-replace geotextiles has been proposed for silt removal. Infiltration rate results were 160 mm/h without geotextile and 108 mm/h with it. The question is whether such minor difference in the infiltration rates makes up for installation costs and removal of "dirty" geotextile.

Test curve infiltration analyses indicate that there is a strip of land, between 40-50 and 60 cm deep, where drops in the vertical permeability ratio (Kv) have been detected, broadly attributable to clogging processes derived from a decrease in temperatures and calcareous precipitations. Therefore, mechanical treatment in conservation tasks should go far deeper in (increasing the strip removed to 40 and up to 60 cm deep).

With certain limitations, all these operational aspects could be applied to scenarios analogous to the Arenales aquifer.

4. FINAL REMARKS

Storing water in aquifers during times of excess can help address water scarcity challenges experienced in many parts of the Mediterranean Basin. Moreover, water quality can be improved through aquifer transport and storage, due to chemical and biological reactions. Managed Aquifer Recharge (MAR), Soil-Aquifer-Treatment (SAT) systems and Aquifer Storage and Recovery (ASR) can be proved as a key to solving Mediterranean's upcoming water crisis by linking water reclamation, water reuse and water resources management. The diversity and complexity of the water problems in the Circum-Mediterranean area call for a clear and focused research program in order to successfully meet the imminent challenges, as well as to direct the ongoing developments towards socioeconomic and ecological sustainability.

Following the fruitful achievements of GABARDINE project in Portugal and the i+R&D DINA-MAR project in Spain, the new FP7-ENV-2013-WATER-INNO-DEMO MARSOL project, which started Dec. 1st, 2013, will envisage advancing the use of MAR as a sound, safe and sustainable strategy for improving water security by demonstrating that Managed Aquifer Recharge is a key solution to water scarcity not only in Portugal and Spain but also in all Circum-Mediterranean region.

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GESTÃO DOS RECURSOS HÍDRICOS: NOVOS DESAFIOS

THE STRATEGIC RESEARCH AND INNOVATION AGENDA OF THE H2020 PIANO PROJECT

Strengthening the international cooperation between Europe and China in the water sector by identifying thematic priorities for joint actions

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Abstract

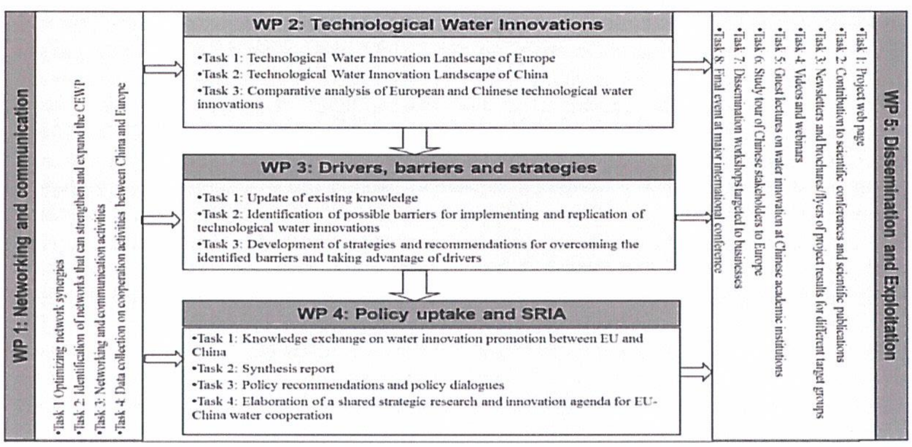
The Strategic Research and Innovation Agenda of the H2020 PIANO project is conceived to be a forward-looking document that sets out the direction of future collaborative EU-China research and innovation activities in the water sector with a special attention to the thematic areas identified and focused by the PIANO project: agricultural, municipal, industrial water management, river basin management, water for energy. This Strategic Research and Innovation Agenda (SRIA) builds on strategic agendas of European and international actors in water management and internal and external consultations among experts and relevant stakeholders of both areas of cooperation. The SRIA elaborated by the PIANO project partners aims to support the activities of the China-Europe Water Platform in its research pillar being the reference document for the implementation of further initiatives of joint international cooperation between Europe and China in water innovation, a sector which offers increasing opportunities to all interested actors, in particular European small and medium enterprises able to produce advanced technological solutions. Researchers, governmental agencies, innovative enterprises and private stakeholders should combine synergies to strengthen innovation capacity and promote social and economic cooperation in both areas of the world. The PIANO SRIA identifies needs and priorities in the EU-China cooperation in water innovation. It also highlights the main opportunities for the development of further collaborative actions engaging public and private partnerships based on the sharing of knowledge and good practices. In this way strategic long-term agreements involving multi-stakeholders in research and innovation applied to water management will be fostered. Moreover, the PIANO SRIA intends to contribute to the achievement of the United Nations' Sustainable Development Goals.

Keywords: policies, innovation, networks, technological water innovations, strategic research and innovation agendas, China –Europe Water Platform, H2020 programme.

Theme: 9 - Investigação em hidráulica e recursos hídricos; Cooperação transfronteiriça (international cooperation in water innovation)

1. INTRODUCTION

The project PIANO (*Policies, Innovation, And Network for enhancing Opportunities for China-Europe water cooperation*) aims at strengthening the international cooperation in the field of water between Europe and China and promoting the creation of networks of companies, SMEs, entrepreneurs, NGOs, policy makers, regulators and funding agencies to create business and social opportunities. The project main objectives are strengthening and expanding the existing network of the China-Europe Water Platform (CEWP) to cover all actors relevant for cooperation between China and Europe in the water research and innovation domain; identification of European technological water innovations and areas for joint development of innovative technological solutions that have a potential for their implementation in China; identification of drivers and barriers concerning this cooperation and elaboration of strategies to overcome such barriers and take advantage of drivers for the implementation and replication of technological water innovations in China; promotion of knowledge exchange and policy dialogue to build an enabling environment for the uptake of technological water innovations with a great potential for implementation, further replication and market uptake in China; consolidation of a shared strategic research and innovation agenda (SRIA) between Europe and China water sector; effective dissemination and mainstreaming of the project results to Chinese, European stakeholders and international target audiences.



Picture 1. Table of the project activities

Relations between the EU and China have developed rapidly since the first diplomatic ties were established in 1975. Since 1998 EU-China summits have been held almost every year. The creation of the EU-China Comprehensive Strategic Partnership in 2003 has deepened and broadened collaboration in a wide range of areas. The EU-China 2020 Strategic Agenda for cooperation jointly signed and adopted in 2013 provides strategic guidance to their relationship in many topics, science, technology and innovation included. In fact, both the EU and China need to foster science, technology and innovation (STI) development to address the economic, social and sustainability challenges they encounter. Interactions between the two areas have also been growing across themes such as environment, energy, climate issues and many others.

In the field of environment water is a priority for the cooperation with China.

An EU-China water platform (CEWP) was established in 2012 to promote policy dialogue, joint research and business development in the water sector between People's Republic of China and the EU and its Member States. The European Commission has been supporting the China-Europe Platform and will continue to promote policy dialogue, joint research and business development in the water sector.

In March 2015 the project PIANO funded by the EU programme for research and innovation Horizon 2020 started its activities to be concluded at the end of May 2018.

The main research areas of this international cooperation focuses on the following water challenges: **agricultural water management; municipal water management; industrial water management; river basin management; water for energy.**

2. MAIN WATER CHALLENGES IN CHINA

Technological water innovations (TWIs) were mapped for both Europe and China for each of these five core thematic areas. A brief note describing the primary Chinese water challenges was developed in collaboration with the CEWP to support and guide the search for suitable TWIs within these domains.

With almost 20% of world's population and only about 6% of global freshwater resources China' s water sector is a high priority for the development plans of that country. Urbanisation and rising environmental awareness are driving rapid growth in urban water supply and wastewater markets. At the same time, water resource restrictions and concerns about food security have underlined the need for water efficient agriculture and irrigation.

About 20% of water resources are located in Northern China where 46% of the population lives, compared to about 80% of water resources which are located in Southern China, where 54% of the population lives and where only 35% of China's total arable land is located. Although there has been some improvement in drinking water quality in recent years, water quality remains an issue especially in rural areas because of greater levels of pollution in lakes, rivers and groundwater from industries, non-point sources, such as agricultural run-off, and urban residential wastewater. Thousands of poorly constructed and aging dams, dykes, river training and irrigation schemes require risk assessment and rehabilitation to ensure safety, resilience and efficient hydropower. Floods have historically impacted China greatly and while many of the major rivers are now controlled with larger hydro-electric dams, extreme events and unregulated small and medium tributaries continue to pose flood risk.

Water availability per capita is only 2,220 cubic meters in China, which is 1/4 of the world average. In the total of 663 cities in China, there are more than 400 cities suffering from water shortage problem, and above 110 cities are in sever water shortage. It is estimated that the daily water shortage of all cities in China is about 16 million cubic meter; the affected industrial production value due to water shortage may reach to more than 200 billion in a year; the affected urban population is about 40 million.

3. MAPPING WATER TECHNOLOGICAL INNOVATIONS

Taking into account these main water challenges in China technological water innovations (TWIs) were identified and prioritized by the PIANO partnership following a two-step procedure. In a first step, TWIs were identified according to the initial categories delineated by the project. The result was a series of 'fact sheets' for each individual technology identified, containing a brief description of the technological solution, expected scope of application, its level of readiness and cost data. The initial categories considered for technological solutions within the *agricultural water management* domain include **water use**: specifically technologies for improving irrigation efficiency and production of fit-for-use water; and **water management**: comprising technologies for groundwater management and pollution mitigation, aquifer recharge and reduction of groundwater mining practices.

Within the domain *municipal water management*, technologies were identified for: **water production** (supply, water use efficiency, alternative water supply); **water treatment** (wastewater management/sanitation, treatment trains); **water management** (integrated urban water management, water systems maintenance/retrofitting, mitigation of non-revenue water); and for **eco-city technological concepts**.

Technological solutions for *industrial water management* were sought focusing in particular on the following categories: **water use efficiency** (water saving technologies and processes); and **water treatment** (wastewater treatment, reuse/recycling technologies).

For the domain *river basin management and flood control*, the focus was on **flood protection technologies** for both urban and large-scale catchment settings (i.e. reactive early warning systems/proofing, e.g. flood abatement technologies, or preventative solutions concerning river training, canal construction, dike performance and hydraulic infrastructure); and decision support systems and monitoring tools to improve **water management** from both the qualitative and quantitative point of view (*cf.* Lobo-Ferreira, 2016a).

The categories considered for the domain *water for energy* were those related to **energy production** (small-scale hydropower, with a particular focus on its development, electricity efficiency, optimization, and retrofitting of existing schemes); and **water management** (tools to predict and map resource flows and assess trade-offs between resources uses; mitigation measures and maintenance of ecological flows, *cf.* Lobo-Ferreira, 2016b).

In a second step, an online survey was created in order to initially validate (i.e. complete) the original gross list of technological solutions, and then prioritize (score) the list of technological solutions collected. The survey was therefore sent out to a number of water technology experts in both Europe and China invited to score the mapped technologies. Experts were asked to determine for each TWI – among other assessments – the degree of European technological leadership and of novelty to China, hence giving indications on the relative innovative performance of the two regions. The resulting inventories of the ranked TWIs thus provide a comparative perspective. Inventory I is the full inventory containing up to 20 European TWIs per sector (shortlisted from a total survey of 119 TWIs).

Sector	Category 1	Category 2	Category 3	Category 4	Category 5	Total
Agricultural water	-	-	15	5	-	20
Municipal water	2	-	14	11	-	27
Industrial water management	-	-	18	19	-	37
River basin management	-	-	6	11	-	17
Water for energy	-	-	5	13	-	18
Total	2	0	58	59		119

Picture 2. Overview of TWI numbers in inventory I for each sector

Inventory II is the targeted inventory containing European TWIs per sector belonging to category 4 (innovative TWIs available in Europe but not in China). It can also be seen in the above table. These are considered to have the highest potential for implementation in helping to solve relevant water challenges in China. With its "Water Sector Goals" laid down in the recent 5-year plans and the "Water Ten Action Plan", and the adjoining more-than-huge investment plans exceeding 1 billion € per week, China will be the scene for new solutions in the water sector. Being present at the Chinese market will be of outmost strategic importance for European companies which with their innovative technologies could contribute to a fast-track achievement of the new Chinese goals for the water sector.

In total around 100 European technologies were identified by the PIANO survey, and 59 have been identified to belong to category 4. Hence, Europe offers a number of innovative technologies with a potential for application in China. These technologies, encompass the following types: monitoring tools to gather data on the state of the environment, infrastructure and process; modelling/DSS tools to interpret monitoring data and integrate with scientific understanding of the behaviour of systems over time to inform decisions on the design and operation of infrastructure and equipment; integrated management systems/controls tools to convey the conclusions from the modelling and DSS systems to the infrastructure-communications and automation; products/processes to improve actual infrastructure and equipment.

4. METHODOLOGY FOR THE ELABORATION OF THE PIANO STRTEGIC AGENDA

Based on this TWIs survey, on the studies performed on barriers and drivers to water innovation in the project research domains and on the guidance documents of European, Chinese and international water-related networks and initiatives, the jointly elaborated PIANO Strategic Research and Innovation Agenda is conceived to be a forward-looking document that sets out the direction of future collaborative EU-China research and innovation activities in the water sector with a special attention to the thematic areas identified and focused by the project.

A study comparing the existing strategic water and research innovation agendas in Europe and China was also carried out in 2016, and updated in 2017, to provide elements useful for the elaboration of the SRIA. This paper is based on the analysis of a set of national and international documents on water strategies. From each reviewed agenda, the priority "***Development and innovation needs in the water sector***" was extracted and highlighted. A series of tables for each agenda was prepared to list research and development actions and needs with the aim of allowing an easy access to the information which is interesting for the PIANO project aims.

Vision, needs and actions highlighted in the agenda of Acqueau, the water industrial cluster of the European programme EUREKA, in the SIRA of the Water Supply and Sanitation Technology Platform WssTP and the implementation plan of the European Innovation Partnership on water (EIP-Water) are close to the general conceptual framework of the PIANO project and are very relevant in identifying key technology areas of interest able to tackle the main present and future water challenges. The Central Chinese Government policy document on water resources management, the Chinese 13th Five Year Plan were also examined to extrapolate the main problems pointed out and to compare measures and solutions proposed. Further contributions to this mapping exercise were also provided by some representatives of the Chinese institutions involved in the PIANO activities.

All documents analysed emphasize the need to join implementation and development of best water technologies with policy and actions to promote proper integrated water management and social awareness.

Successively, relevant contributions were collected through a questionnaire circulated to water experts in China and in Europe. The survey addressed the five research areas of the PIANO project and the main water challenges identified for the joint development of the cooperation between Europe and China. Also the answers received to this questionnaire were analysed, aggregated and taken into consideration for the development of the PIANO SRIA. In particular, the questionnaire was subdivided into 5 main sections, corresponding to the 5 water domains focused by the PIANO project. For each domain, it was required to give a priority level to the actions to be taken (challenges) to achieve the project goals and to state, depending on the actions selected, the application fields considered more relevant: IA – Innovation Actions, RIA – Research and Innovation Actions, RA – Research Actions.

Moreover, it has been considered relevant for the elaboration of the PIANO SRIA a cross analysis and identification of links with some of the Strategic Development Goals (SDGs) fostered by the United Nations. On 1 January 2016, the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development — adopted by world leaders in September 2015 at an historic UN Summit — officially came into force. Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The following SDGs has been identified as priorities for the PIANO project.

	SDG#6: Ensure availability and sustainable management of water and sanitation for all
	SDG#7: Ensure access to affordable, reliable, sustainable and modern energy for all
	SDG#8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
	SDG#9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
	SDG#11: Make cities and human settlements inclusive, safe, resilient and sustainable
	SDG#12: Ensure sustainable consumption and production patterns
	SDG#13: Take urgent action to combat climate change and its impacts
	SDG#14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
	SDG#15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse

Picture 3. Table of the SDGs considered in the PIANO SRIA

5. NEEDS AND THEMATIC PRIORITIES IDENTIFIED

The PIANO SRIA identifies needs and priorities in the EU-China cooperation in water innovation considering the project core domains and some crosscutting themes.

In the agricultural domain these water challenges and actions are identified:

Challenge 1 – Water scarcity

Actions: water reuse, water saving and efficiency in irrigation systems.

Listed among the main challenges facing the Chinese government are the implementation of water-saving policies and technologies, including water recovery and recycling, the development of more efficient systems for abstracting underground water resources, and precision irrigation technologies.

Challenge 2 – Water pollution

Actions: nutrient and pesticide management and removal for water pollution reduction.

Nutrient and pesticide reduction through adequate management is based on technologies for pollution prevention, such as manure separation and treatment, precision irrigation and energy recovery technologies, as well as water-related soil degradation technologies against salinity, erosion, clogging and oxidation. It will be just as necessary to develop appropriate tools (Decision Support Systems) to support the management and extend technologies for pollution monitoring.

Challenge 3 – Extreme events (droughts and floods)

Actions: monitoring and extreme events management.

With the aim of controlling floods and preventing drought, forecasting and early warning systems must be implemented; planning interventions with the related actions is also necessary.

For the domain municipal water management the PIANO SRIA highlights the following thematic priorities:

Challenge 1 – Water scarcity

Actions: water saving technologies and wastewater reuse

Water reuse infrastructures and metering technologies, drinking water production from wastewater resources, desalination and rainwater harvesting technologies, recovery and raw material technologies from sludge and wastewater for energy purposes.

Challenge 2 – Water pollution

Actions: risk assessment and management tools against water pollution

Tools and management approaches to reduce water pollution in municipal areas such as microbiological risk assessment, monitoring technologies and development of methods to remove point and diffuse chemical-biological pollutants linked to real time monitoring and control systems.

Challenge 3 – Extreme events (droughts and floods)

Actions: storm water management and systems for flood and drought assessment

Using nature-based solutions and management systems to improve the sustainable urban drainage system and DSS (Decision Support System).

Challenge 4 – Ecosystem degradation

Actions: methods to determine environmental flow needs.

Approaches and methods to determine environmental flow needs, which could decrease ecosystem degradation.

Challenge 5 – Water infrastructures

Actions: improve wastewater collection under treatment systems through monitoring and management technologies.

Methods-technologies for identification (monitoring) and remediation of corrosion aging related to below ground assets and asset management tools for sustainable maintenance programmes. Moreover, a priority is to improve wastewater collection within existing treatment systems through monitoring and management technologies.

In the industrial water management the priority actions for the following water challenges are:

Challenge 1 - Water scarcity

Actions: technologies and systems to reduce water scarcity

With the aim to close the water cycle gap, developing sustainable use of resources through recovery energy and raw material technologies from sludge and wastewater.

Challenge 2 - Water pollution

Actions: monitoring and treatment technologies against water pollution

New technologies and systems for monitoring water quality and advance water treatment technologies (energy efficient systems: small-scale system technologies for specific pollutants removal). Improving water quality through advanced water treatment technologies (Membrane technologies; Advanced, biological, treatment, solid separation)

Tackling the water challenges identified to improve **the river basin management and flood control** the PIANO SRIA focuses the following actions:

Challenge 1 – Water scarcity

Actions: monitoring and management for water scarcity

Through optimization of water uses and water saving management technologies such as modelling systems and DSS, water scarcity will be reduced. Moreover, monitoring systems and aquifer management technologies are important tools for reaching the goal.

Challenge 2 - Water pollution

Actions: new technologies against water pollution

Technologies for contaminated sites, remediation (passive and active), early warning systems and data integration technologies are important tools to combat water pollution and monitoring parameters such as hydrological parameters and water quality chemical and microbiological standards.

Challenge 3 – Extreme events (droughts and floods)

Actions: flood protection and extreme events prevention

Through new remote sensing technologies such as Doppler radar and wireless sensors, integrated with coastal and fluvial DSS systems, such as hydrological and meteorological models and forecasting monitoring systems, flood and drought risk could be reduced, in particular through the application of risk based decision-making and planning tools.

Challenge 4 – Ecosystem degradation

Actions: ecosystem restoration

The reduction of pressure impacts leading to ecosystem degradation is the main goal to be reached through a new water management scheme, new technologies and research on restoration methodologies for aquatic systems (hydraulic connectivity, sediment transport, etc.).

The domain water for energy is focused on these high priority actions:

Challenge 1 – Water scarcity

Actions: efficiency and new technologies to reduce water scarcity in industrial sector

Energy is needed for water supply and it is crucial for water production. Improving industrial water reuse also in hydropower plants could contribute to reduce water scarcity linked to industrial activities.

6. IMPLEMENTATION OF THE PIANO SRIA

A roadmap to implement the actions identified by the PIANO SRIA should highlight the main opportunities for the development of further collaborative actions engaging public and private partnerships based on the sharing of knowledge and good practices in international cooperation between Europe and China in the water sector. In this way, strategic long-term agreements involving multi-stakeholders in research and innovation applied to water management should be fostered. The Strategic Research and Innovation Action of the H2020 PIANO project calls for an increasing capacity of innovation through the creation of synergies, joint actions, regional networking and strengthening of relationships among public and private actors, pinpointing the relevance of sharing technological knowledge and opportunities.

Moreover, through the co-design of innovations, the implementation of the PIANO SRIA will create new opportunities for private investments in the water sector, also providing a chance to capitalize on already on-going innovations and existing initiatives, while offering opportunities to exploit synergies within and across the different priorities and perspectives for longer-term research and development.

The implementation process of the PIANO SRIA should focus on best practices and activities aimed to identify opportunities and barriers to innovation, to develop policy recommendations and dissemination strategies such as:

- Webinars, info days, workshops and conferences: to support the China Europe Water Platform (CEWP) and ensure that its research, development and innovation (RDI) activities address issues of public interest and are made accessible through appropriate dissemination activities;
- Sharing good practices: workshops for sharing good practices among RDI programme owners and managers in order to provide an efficient instrument of programmes alignment and improve their efficiency across Europe.
- Calls for proposals in collaborative R&I projects: In case of financial agreement, Joint calls will be implemented
- Pilot studies and demonstration projects
- Alignment of national programmes: to better support the EU-China Water Platform it is important to align water research national agendas through the gradual modification of national programmes, priorities or activities.

Moreover, the SRIA should be assimilated in the CEWP periodic work programme and implemented through common actions and trans-disciplinary research.

AKNOWLEGMENTS

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1. INTRODUCTION

In the context of Managed Aquifer Recharge (MAR) numerical modelling has been an important process in several applications, since the prediction of rise of groundwater mounds, to determine where groundwater can be most appropriately pumped, understand quality changes in infiltration water and aquifer water, predict the success of treatment induced by MAR methodologies or to calculate the necessary injected volumes to counter a saltwater intrusion problem. A proper estimation of AR, by means of arithmetic methods, depends firstly on the conceptual approach of the groundwater problem and secondly on the selection of the appropriate AR method (Pliakas et al. 2005), and its widely known that the Success of artificial recharge as a management technique depends highly on how well the system is understood (Sunada et al. 1983). Koukidou et al. (2010) referred numerical modeling as an invaluable tool that enables accurate and reliable assessment of alternative strategic management plans, with the results of well calibrated and verified models as a solid basis for justification of capital investment required for infrastructure that is necessary to support water resources management scenarios. It is then essential, as a state of the art overview, to compile several applications in different demo-areas and scales, where modelling was essential to refine artificial recharge strategies, to help to understand the main impacts of a MAR project or to what to expect in field experiments.

2. DEVELOPING THE LITERARURE REVIEW IN MAR MODELLING STATE OF THE ART

This brief literature review on MAR modelling aimed to understand the most commonly used software and modelling methods such as scale, boundary conditions and inputs and output representation. Data on the software used in MAR modeling exercises was collected, with the objective of create a first-approach library to these software capabilities. Later every case study found was briefly summarized as an example of the software use.

3. FLOW AND TRANSPORT MODELS USED IN MAR

The selection of these models resulted mainly from the literature review – the most used and referenced tools/software were chosen.

1. The CODE_BRIGHT program (originally developed by Olivella et al. 1995) is a tool designed to handle coupled problems in geological media (Restrepo, et al. 2016) was developed on the basis of a new general theory for saline media. Then the program has been generalized for modelling thermo-hydro-mechanical (THM) processes in a coupled way in geological media. Basically, the code couples mechanical, hydraulic and thermal problems in geological media. The theoretical approach consists in a set of governing equations, a set of constitutive laws and a special computational approach. The code is composed by several subroutines and uses GiD (Coll et al. 2016) system for preprocessing and post-processing.

MARSOL WHITE BOOK ON THE STATE OF THE ART IN MANAGED AQUIFER RECHARGE MODELLING

A Literature Review

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Abstract

Of the several themes addressed in "MARSOL White Book on Managed Aquifer Recharge Modelling – Selected Results from the MARSOL Project", a synthesis of the work developed during MARSOL project, one should emphasize the literature review on MAR modelling. There was a collection of MAR models and applications both in terms of flow and transport and of hydrogeochemical modelling.

This paper aims to present a set of successful modelling applications on MAR methodologies as well as to briefly explain and summarize the capabilities of some of the software used. It can also serve as a reflection on MAR modelling throughout time as more complex models have been being developed.

Keywords: MAR, review, numerical modelling.

Theme: 9 - Investigação em hidráulica e recursos hídricos.

2. Accordingly to Li et al. (2009) COMSOL (formerly known as FEMLAB) is a finite element analysis and solver software package for various physics and engineering applications, especially coupled phenomena, or multiphysics. It includes a complete environment for modelling any physical phenomenon that can be described using ordinary or partial differential equations (PDEs). Coupled with Earth Science Module, the software code can handle time-dependent and stationary problems for one-dimensional (1D), 2D, and 3D systems with axisymmetric for 1D and 2D problems of fluid flow, heat transfer, and solute transport.

3. Trefry & Muffels (2007) described FEFLOW as a Finite-Element subsurface FLOW and transport modeling system with an extensive list of functionalities, including variably saturated flow, variable fluid density mass and heat transport, and multi-species reactive transport. It is a proprietary code and not freely available; it supports an array of features of interest in subsurface flow and transport. Theoretical and numerical methods and FEFLOW capabilities are well described in Diersch (2014). This software is applicable in groundwater, porous media and heat transport studies - from local to regional scale.

4. FEMWATER (Finite Element Model of Water Flow Through Saturated-Unsaturated Media) model developed initially by Athens Laboratory of the U.S. Environmental Protection Agency (AERL) and the U.S. Army Engineer Waterways Experiment Station (WES) from 3DFEMWATER (Yeh, 1987). The program structure was reformulated to allow its integration into the Department of Defense Groundwater Modeling System (GMS). FEMWATER capabilities are described by Lin et al. (1997).

5. Accordingly to Yu & Zeng (2010), HYDRUS is a software program for solving Richards equation for water flow and the advection-dispersion equation for heat and solute transport in variably saturated subsurface media. Variably saturated zones are fundamental to understanding many aspects of hydrology, including infiltration, soil moisture storage, evaporation, plant water uptake, groundwater recharge, runoff, and erosion. It uses the finite-element (FE) method to simulate one-, two- or three-dimensional movement of water, heat, and multiple solutes in unsaturated, partially saturated, or fully saturated porous media.

6. MOCDENSE is a two-constituent solute transport model for ground water having variable density developed by Sanford & Konikow (1985). The model couples the ground-water flow equation with the solute-transport equation. The digital computer program uses an iterative strongly-implicit procedure to solve a finite-difference approximation to the ground-water flow equation. The model uses the method of characteristics to solve the solute-transport equation. This incorporates a particle-tracking procedure to represent advective transport and a two-step explicit finite-difference procedure to solve equations that describe the effects of hydrodynamic dispersion and fluid sources. This explicit procedure has several stability criteria associated with it, but the consequent time-step limitations are automatically determined by the program. It is applicable to two-dimensional, cross-sectional problems involving ground water with constant or variable density. The model computes changes in concentration over time caused by the processes of advective transport, hydrodynamic dispersion, mixing or dilution from fluid sources. The concentrations of two independent solutes can be modeled simultaneously. Temperature is assumed to be constant, but fluid density and viscosity are assumed to be a

linear function of the first specified solute. If a second solute is specified, it is assumed to be of a trace amount such that it does not affect the fluid density or viscosity. The aquifer may be heterogeneous and anisotropic. The model has been used mostly in studies of either saltwater intrusion or dense contaminant plumes.

7. The acronym to Transport Of Unsaturated Groundwater and Heat (TOUGH), is a set of multidimensional numerical models for simulating the coupled transport of water, vapor, noncondensible gas, and heat in porous and fractured media (Pruess, 1987). Initially developed primarily for geothermal reservoir engineering, the suite of simulators is widely used for applications to nuclear waste disposal, environmental remediation problems, energy production from geothermal, oil and gas reservoirs as well as gas hydrate deposits, geological carbon sequestration, vadose zone hydrology, and other uses that involve coupled thermal, hydrological, geochemical, and mechanical processes in permeable media.

8. MODFLOW and related programs – MODFLOW is a 3D finite-difference groundwater model that was first published in 1984 (McDonald & Harbaugh, 1984). It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model. MODFLOW-2005 (Harbaugh, 2005) is the most current release of MODFLOW. In this version groundwater flow is simulated using a block-centered finite-difference approach. Layers can be simulated as confined or unconfined. The modular structure consists of a main program and a series of highly independent subroutines. The subroutines are grouped into packages. Each package deals with a specific feature of the hydrologic system that is to be simulated, such as flow from rivers or flow into drains, or with a specific method of solving the set of simultaneous equations resulting from the finite-difference method.

MODPATH, originally published by Pollock (1989) is a particle-tracking post-processing program designed to work with MODFLOW, where the flow data produced in the budget is used by MODPATH to construct the groundwater velocity distribution that forms the basis for particle-tracking calculations. MODPATH Version 7 (Pollock, 2016) is the most recent version of the program.

MT3D-USGS (Bedekar et al. 2016) is a USGS updated release of the groundwater solute transport code MT3DMS (Zheng et al. 2001). MT3D-USGS includes new transport modeling capabilities to accommodate flow terms calculated by MODFLOW packages aiming to provide greater flexibility in the simulation of solute transport and reactive solute transport. Unsaturated-zone transport and transport within streams and lakes, including solute exchange with connected groundwater, are among the program capabilities. MT3DMS can be used to simulate changes in concentrations of miscible contaminants in groundwater considering advection, dispersion, diffusion and some basic chemical reactions, with various types of boundary conditions and external sources or sinks.

The SEAWAT program (Langevin et al. 2008) is a coupled version of MODFLOW and MT3DMS designed to simulate three-dimensional, variable-density, saturated groundwater flow. Accordingly to Guo & Langevin (2002) was developed to simulate three-dimensional, variable density, transient ground-water flow in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations. The SEAWAT code follows a modular structure, and thus, new capabilities can be added with only minor modifications to the main program. SEAWAT reads and writes standard MODFLOW and MT3DMS data sets.

9. MODRET (Computer MODEL to Design RETENTION Ponds) was originally developed in 1990 as a complement to a research and development project for Southwest Florida Water Management District (Jammal & Associates Division, 1993). The MODFLOW model was specifically modified for use with the MODRET model which incorporates modeling of weir and orifice overflow or overflow based on manually-specified elevation vs. flow relationship (rating curve). The scope of this project was to develop a practical design manual for site investigation criteria, laboratory and field testing requirements and guidelines to calculate infiltration losses from stormwater retention ponds in unconfined shallow aquifers.

4. FLOW AND TRANSPORT CASE STUDIES

A brief summary of MAR modelling applications and examples is chronologically presented.

Stefanescu & Dessargues (1998) studied the possibility of increasing the proportion of groundwater usage by increasing storage in shallow aquifer by artificial recharge methods due to scarcity problems encountered during summer and long periods of intense freezing in Bucharest water supply which was highly dependent on surface water. A regional scale 3D numerical model was assembled in MODFLOW, limited by the two main rivers in the region (Arges and Dambovita). MODPATH was used to calculate transport path and travel times.

Chatdarong (2001) aimed to study the recharge behavior in San Joaquin Valley agricultural area as well as the economic feasibility and practicality of artificial recharge facilities in the conjunctive use for irrigation purposes. HYDRUS-2D was used in the simulations if a two-dimensional model based on the study area infiltration ditch.

Woolfenden & Koczot (2001) conducted a study to evaluate the hydraulic effects of artificial recharge, started in 1994, of imported water from Sierra Nevada in Rialto-Colton Basin (San Bernardino County, California). The main objectives were to describe geohydrology and water chemistry, and determine the movement and ultimate disposition of artificial recharged water simulating long-term effects on water levels likely to occur in two different AR scenarios: (1) continued recharge in ponds, (2) discontinued recharge in ponds. MODFLOW finite-difference model was used to simulate flow and MODPATH through particle tracking allowed for the understanding of water movement.

Haimerl (2002) evaluated the effectiveness of groundwater recharge dams by assembling a 2D numerical model using HYDRUS. These structures, built in Wadi Ahin in the north of Oman, were used to store the water on the surface and enable a controlled release for artificial recharge in terms of managed recharge.

Numerical modelling was used to simulate and understand the role of the unsaturated zone directly beneath an unused artificial recharge site in the Cherry Valley alluvial fans, located in

San Gregorio Pass, California (USA) (Flint, 2003). The numerical model was developed in TOUGH2 finite-difference code.

De la Orden et al. (2003) used numerical modelling as a tool to evaluate the effects in groundwater of artificial recharge applied for a period of 10 years in Vergel, Alicante (Spain). The Plana de Gandía-Denia coastal aquifer model was developed using MODFLOW in PMWIN software (Chiang and Kinzelbach, 1998).

In the development and verification of a groundwater artificial recharge system in Xanthi plain, Thrace (Greece) where the main objective is the reactivation of an old stream bed of Kosynthos River, Pliakas et al. (2005) built a finite-difference MODFLOW numerical model as a tool to estimate impact of AR. It was considered by the authors as a significant tool for rational management of groundwater resources in the study area.

Santo Silva et al (2006) applied numerical modeling for studying the applicability of artificial recharge methods in Recife plain (Brazil) to decrease the drawdown observed in Cabo aquifer due to over-exploitation and increasing urban areas, using rainwater injection in wells. A 2D vertical grid aquifer scale model was developed using CODE-BRIGHT coupled with GiD software.

GABARDINE project, which aimed to demonstrate suitability of alternative sources of water in groundwater artificial recharge by developing advanced integrated technologies and management, showed some examples of numerical modelling applied do MAR. Lobo Ferreira et al (2006) compiles the description of numerical models for three different demo-areas in the project. One of the demo-areas was Campina de Faro aquifer system (Portugal), where a finite difference MODFLOW model was developed using Visual MODFLOW software to study the optimization of groundwater rehabilitation through artificial recharge aiming the minimization of diffuse pollution effects caused by typical Portuguese agricultural practices, by promoting artificial in a riverbed.

In Goyal et al. (2009) a finite-element groundwater flow model, using HYDRUS-2D, was used to simulate draw-up and drawdown of piezometric pressure heads in the aquifer storage recovery cycles of varying buffer storage volumes and residence times in a highly brackish, semi-confined aquifer under shallow water-table condition in Hisan region (India).

Lobo Ferreira et al. (2009) used numerical modelling to understand effect of artificial recharge methodologies concerning the use of infiltration basins located in Cap Bon (Tunisia) as a way to increase groundwater quality, the effect of saltwater intrusion and increase water availability for agriculture. The numerical model was assembled in Groundwater Modelling System (GMS) software using FEMWATER.

Koukidou et al. (2010) aimed to characterize the regional groundwater flow system in the Tirnavos alluvial basin and to develop and apply appropriate models for assessing artificial recharge as a way to restore and manage regional groundwater resources in eastern Thessaly (Greece). Simulation of the aquifer system was performed on FEFLOW software and was used for the feasibility assessment of alternative groundwater management strategies based on Aquifer Storage Recovery (ASR).

Carleton (2010) presented numerical modelling tools to provide quantitative methods for estimating the height of groundwater mounds beneath infiltration basins. MODFLOW-2000 was used to simulate the height and extent of groundwater mounds with various aquifer characteristics, recharge conditions, and basin areas, depths, and shapes.

Kareem (2012) used MODFLOW in Groundwater Modeling System (GMS) software to simulate the water conveyance from rainwater collecting ponds to underground reservoirs by well injection in Jolak basin, Karkuk (Iraq).

A three-dimensional MAR model of the Isfara Aquifer, Fergana Valley (Uzbequistan) was developed by Karimov et al. (2013) using Visual MODFLOW software.. The main objective was to evaluate the viability of MAR activities, initiated in Isfara River Basin located in the tail end of the Big Fergana Canal (BFC).

5. HYDROGEOCHEMICAL MODELS USED IN MAR

Accordingly to Barber (2002) field-scale reactions between mixing aqueous phases, minerals, organic carbon and ion exchange phases can be assessed relatively simply using equilibrium mixing-cells which can be used to provide a wide range of assessment of redox and pH-dependent reactions that could impact on the efficiency of an AR system. These assessments could also be used to provide quantitative evaluation of monitoring data of artificial recharge schemes. For the same author, in AR/ASR hydrogeochemical modelling is relevant concerning mineral dissolution that locally can increase hydraulic conductive but have an adverse impact in aquifer structural integrity or mineral precipitation that has the opposite effect contributing to clogging.

1. Accordingly to Dijkhuis & Stuyfzand (1996) and Stuyfzand (1998) INFOMI is the acronym for 'INFiltration Of MIcropollutants'. It is a finite element 1D-model using the 'mixing cells in series' concept, incorporating a highly variable input for the pollutants in surface water; in the infiltration basin,in a specific river segment, at the water/sediment interface and in the saturated zone. Advection and dispersion (+diffusion) in the aquifer system are modelled using algorithms of Appelo & Postma (1993).

2. Accordingly to Jacques and Simunek (2005), HP1 was obtained by coupling the HYDRUS-1D one-dimensional variably-saturated water flow and solute transport model with the PHREEQC geochemical code. The HP1 code incorporates modules simulating (1) transient water flow in variably-saturated media, (2) transport of multiple components, and (3) mixed equilibrium/kinetic geochemical reactions.

3. Commercial software HYDROGEOCHEM is a coupled model of hydrologic transport and geochemical reaction in saturated-unsaturated media. It is designed to simulate transient and/or steady-state transport of aqueous components and transient and/or steady-state mass balance of adsorbent components and ion-exchange sites.

4. Parkhurst and Appelo (2013) describe PHREEQC is a computer program that is designed to perform a wide variety of aqueous geochemical calculations simulating chemical reactions

and transport processes in natural or polluted water, in laboratory experiments, or in industrial processes. The program is based on equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers, and sorption surfaces, which accounts for the original acronym—pH-REdox-EQuilibrium, but the program has evolved to include the capability to model kinetic reactions and 1D (one-dimensional) transport. Rate equations are completely user-specifiable in the form of basic statements. Kinetic and equilibrium reactants can be interconnected, for example, by linking the number of surface sites to the amount of a kinetic reactant that is consumed (or produced) in a model period. A 1D transport algorithm simulates dispersion and diffusion; solute movement in dual porosity media; and multicomponent diffusion, where species have individual, temperature-dependent diffusion coefficients, but ion fluxes are modified to maintain charge balance during transport. An inverse modeling capability allows identification of reactions that account for observed water compositions along a flowline or in the time course of an experiment.

6. HYDROGEOCHEMICAL CASE STUDIES

A brief summary of hydrogeochemical applications in MAR is chronologically presented.

Whitworth (1995) modelled recharge via subsurface injection in El Paso, New Mexico (USA) with PHREEQE (Parkhurst et al. 1980), by first simulating the mixing of the injected water and the ground water to see if mineral precipitation might occur. Parkhurst & Petkewich (2002) used PHREEQC for geochemical modelling of an ASR experiment in Charleston, South Carolina (USA). The purpose of the aquifer storage operation is to store potable drinking water in a sand and limestone aquifer underlying the city of Charleston. Barber (2002) presented a case study where a Soil Aquifer Treatment experiment in China was modelled using PHREEQC to assess possible chemical reactions on mixing of groundwater and injectant (potable water from a reservoir) and to understand reaction exchange with possible aquifer mineral matrices during a ASR experiment.

Prommer & Stuyfzand (2005) carried out a reactive transport modelling study to analyze the data collected during a deep well injection experiment in an anaerobic, pyritic aquifer near Someren (Netherlands). The MODFLOW/MT3DMS-based re-active multicomponent transport model PHT3D (Prommer et al., 2003) was used for the transport simulations of the injection site. PHT3D couples the three-dimensional transport simulator MT3DMS with the geochemical model PHREEQC (v2). Greskowiak et al. (2005) carried out a modelling study to provide a process-based quantitative interpretation of the biogeochemical changes that were observed during an ASR experiment in which reclaimed water was injected into a limestone aquifer at a field-site near Bolivar (Australia). For this a PHT3D model was developed from a calibrated three-dimensional flow and conservative transport. Eckert et al. (2005) applied hydrogeochemical modelling in 1D-reaction transport model PHREEQC (v2) (Parkhurst and Appelo, 1999) to assess the purification processes that occur during riverbank filtration, in order to understand the temporal changes of the river water quality and hydraulics influence of this methodologies. Schmidt et al. (2007) while studying the geochemical effects of induced stream-water and artificial recharge on the Equus Beds Aquifer, Kansas (USA) used PHAST to simulate flow and transport of chloride from the stream through the aquifer into a recovery well. PHREEQC (v2) was also used for major ion and trace metal chemistry modelling providing insight into environmental changes that may be occurring as a result of AR activities.

In a geochemical modelling exercise of an ASR project in Union County, Arkansas (USA), Zhu (2013) used PHREEQC to simulate the scenario of injecting partially treated surface water from Ouachita River into the Sparta aquifer at the city of El Dorado. Lu et al (2014) produced a hydrochemical assessment of the local harvested water and groundwater based on field data, lab experiments, and modelling carried out for artificial recharge proposal in the Pinggu Basin aquifer. PHREEQC coupled with the flow and transport models was used.

7. CONCLUSIONS

Following the literature review for MAR modelling, the main conclusion, considering that for every model there is a different set of input data required, so one of the most important factor in selecting the appropriate model to a specific area/study is to verify what data is available/obtainable in order to feed it as much as possible allowing it to produce reliable results.

Based on the decision making methodology for the application of pollutant transport models proposed by Diamantino et al. (2006) the final decision for the selection and eventually the purchasing of a new model will have to be based on local or regional available skills and knowhow on groundwater modelling at the governmental environmental institution. The authors do firmly support the idea of governmental environmental institution to establish research contracts with local Universities and/or State Research Labs, and, if available, eventually also with private firms with relevant expertise on groundwater assessment and modelling. Also, for the author, this will be a case by case political decision depending on the willingness of the governmental environmental institution to overcome existing or potential groundwater pollution problems that may affect the regional environment and the public health.

Used models vary, but finite difference MODFLOW base software seems to be by far more frequently used, both due to be easily available and well documented, there are several programs adapted to specific problems. Due to its complexity finite elements are not so abundantly used, although the FEM grid is far more adjustable to complex limits of study areas. On the other hand, FEM HYDRUS was commonly selected for simulations in vadose zone. In hydrogeochemical studies related to MAR, free PHREEQC software was the most used, mostly due to its very wide set of capabilities.

Aquifer and local (small area of the aquifer) seems to be the most common scales studied. Small scale models (infiltration basin or aquifer sandbox model recreation) are scarce. MAR modelling, at a large scale, has been used as a decision support tool as basis to decide the suitability of MAR methodologies, most effective measures of environmental problem containment and to explore scarcity scenarios.

MAR modelling is being used worldwide, in particular in semi-arid to arid regions where scarcity problem is common and MAR presents as reliable solution, and in areas the use of recycled water is increasingly used in SAT-MAR as a way to increase water quality and availability.

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Demonstrating managed aquifer recharge as a solution for climate change adaptation: results from Gabardine project and ASEMWaterNet coordination action in the Algarve region (Portugal)

La dimostrazione della ricarica degli acquiferi in condizioni controllate come una soluzione per l'adattamento al cambiamento climatico: i risultati del progetto Gabardine e le azioni di coordinamento di ASENWaterNet nella regione dell'Algarve (Portogallo)

João Paulo Lobo Ferreira, Teresa E. Leitão

Riassunto: Nella regione dell' Algarve, Portogallo meridionale, le attività di ricerca sulla ricarica degli acquiferi in condizioni controllate sono state sviluppate per fornire non solo un surplus di acqua immagazzinata negli acquiferi negli anni piovosi, come nel caso della falda acquifera Querença-Silves (FP6 ASEMWATERNet Coordination Action), ma anche per rendere di qualità migliore le acque sotterranee dell'acquifero di Campina de Faro (progetto FP6 Gabardine). Seguendo le potenzialità della ricerca sulla ricarica delle falde nel sud del Portogallo, il presente contributo descrive gli obiettivi, la dimostrazione concettuale, il background e le funzionalità di uno dei siti pilota circum-mediterranei selezionati (in Portogallo) che sarà oggetto di studio nel nuovo progetto FP7-ENV-2013-WATER-INNO-DEMO MARSOL, che ha avuto inizio il 1 dicembre, 2013 nel sito pilota dell'Algarve, diverse aree studio saranno situate nell'acquifero di Querença-Silves e di Campina de Faro.

Abstract: *In the Algarve southern Portugal region, Managed Aquifer Recharge (MAR) research activities have been developed to provide not only water surplus storage in aquifers during wet years, focusing in the Querença-Silves aquifer (FP6 ASEMWATERNet Coordination Action), but also groundwater quality rehabilitation in the Campina de Faro aquifer (FP6 Gabardine Project). Following MAR research potentialities in southern Portugal, this paper describes the objectives, conceptual demonstration, background and capabilities of one of the selected Circum-Mediterranean pilot sites (in Portugal) that will be researched in the new FP7-ENV-2013-WATER-INNO-DEMO MARSOL project, which started Dec. 1st, 2013. In the Algarve pilot site, several case-study areas will be located in the Querença-Silves aquifer and in the Campina de Faro aquifer.*

Parole chiave: Ricarica degli acquiferi in condizioni controllate, adattamento al cambiamento climatico, esperimenti di infiltrazione attraverso letti di corsi d'acqua, indagini geofisiche, Acquifero di Campina de Faro.

Keywords: *Managed aquifer recharge, Climate change adaptation, River bed infiltration experiments, Geophysical assessment, Campina de Faro aquifer.*

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Introduction

GABARDINE project (http://www.lnec.pt/organization/dha/nre/estudos_id/gabardine, 2005-2008; Lobo-Ferreira et al., 2006; Diamantino et. al., 2007 and 2008 and Diamantino, 2007) had the following major objectives: (1) explore the viability of supplementing existing water resources in semi-arid areas with alternative sources of water that could be exploited in the context of an integrated water resources management approach; (2) investigate the feasibility of using aquifers as the primal facility for the large scale storage of these alternative water sources and investigate techniques for their managed aquifer recharge and injection of the produced alternative water, including a monitoring of water quality and purification by natural attenuation and filtration processes; and (3) evaluate and quantify the potential impact of degrading factors, such as climate change, changes in the quality of water, salt water, etc. on the global quality and usability of the resource, by developing tools for risk mapping, for modelling and for monitoring, and to propose measures for preventing or minimizing, and mitigating their impact. The alternative water sources were surface water surpluses generated during rainy seasons, treated effluent, surpluses of desalinated water and exploitation of saline water bodies that could be used for adequate agricultural practices or used as raw material for low-cost desalination.

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Four test sites have been selected for GABARDINE project in the Circum-Mediterranean area, each representing a different aspect of the problem: (1) the aquifer of Thessaloniki area, in which MAR is being considered for controlling seawater intrusion and storage of treated effluent (Greece); (2) the Lower valley of the Llobregat river, where the objective is to mitigate the aquifer from seawater intrusion by means of MAR of effluent and or runoff water (Barcelona-Spain); (3) the Campina de Faro aquifer, in Algarve region where the objective is achieving groundwater quality improvement by injecting surface-water (Portugal, which will be detailed hereinafter); (4) the Coastal aquifer shared by Israel and Palestine (Gaza). In Israel most of the recharge technologies are implemented but the quality and mixing aspects need to be investigated and quantified.

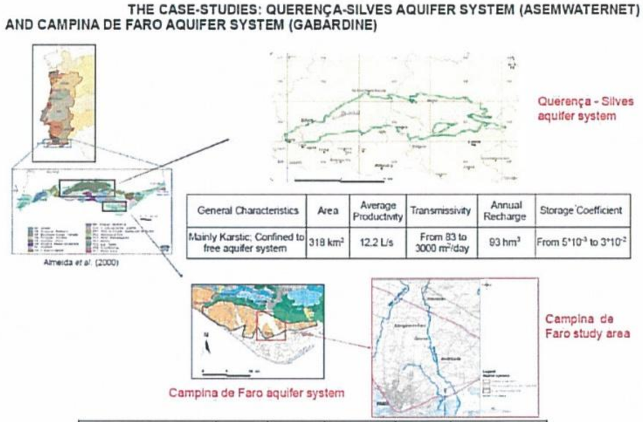
In Portugal two infiltration basins were constructed in the Rio Seco river bed and filled in with clean gravels for MAR tests. The source of water is the river water during runoff flow. The main objective was to investigate this type of MAR structures for surface water infiltration in terms of groundwater quality and quantity assessment in confined and unconfined aquifers. Also tracer tests for infiltration rate assessment and geophysical assessment have been developed during May, 2007. During the second and third year of the GABARDINE project two periods have been researched regarding the river bed infiltration basins: the summer time (irrigation period) from April, 1st to September, 31th 2007 and the winter time (no irrigation period) from October, 1st 2007 to June, 30th 2008.

Location and geological setting

The area of Campina de Faro aquifer system, in the Algarve, Portugal, is around 86.4 km^2, and is limited, in the North, by the less permeable deposits of Cretaceous, in the East, by the city of Olhão, in the West, by the Quarteira aquifer system, with a probable hydraulic connection between them, and in the South, by the sea. Figure 1 shows the identification of the aquifer systems in the Algarve coastal zone by Almeida et al. (2000), including the aquifer system of Campina de Faro (studied in GABARDINE project) and the Querença-Silves aquifer system, studied in ASEMWATERNet Coordination Action (http://www.asemwaternet.org.pt/; Lobo-Ferreira and Oliveira,2008).

The GABARDINE test site in Portugal is a section of the aquifer system of Campina de Faro, located in the Southern Algarve region. This section is located in the central part of Campina de Faro and encompasses an area of approximately 9 km^2. It is bordered by the estuary of Ria Formosa in the South, two aquifer systems in the North, the river Ribeira de Marchil in the West and 2 km to East from the river (rio in Portuguese) Seco (located in the centre of Figure 2). Figure 2 presents the geological map of Campina de Faro aquifer (adapted from Almeida et al., 2000).

Precipitation increases from the South (along the coastal zone) to the North (in the mountain areas). For the average annual precipitation in the Rio Seco basin (Lobo-Ferreira et al., 2006) calculated a value of 745 mm, using the Thiessen poligon method, and a value of 655 mm using the isohyets method. In the case of temperature, the annual medium values calculated were 17.3°C in Faro and 16.8°C in Quarteira.



General Characteristics	Area	Average Productivity	Transmissivity	Annual Recharge	Storage Coefficient
Mainly Karstic; Confined to free aquifer system	318 km^2	12.2 L/s	From 83 to 3000 m^2/day	93 hm^3	From 5*10^{-3} to 3*10^{-2}

General Characteristics	Area	Average Productivity	Average Transmissivity	Annual Recharge	Storage Coefficient
Multilayer system - free aquifer and confined aquifer	86.4 km^2	6 L/s	397 m^2/day	10 hm^3	1.3*10^{-4}

Fig. 1 - The case-studies: Querença-Silves aquifer system (ASEMWATERNET) and Campina de Faro aquifer system (GABARDINE).

Fig. 1 - I casi di studio: il sistema acquifero di Querença-Silves (ASEMWATERNET) e quello di Campina de Faro.

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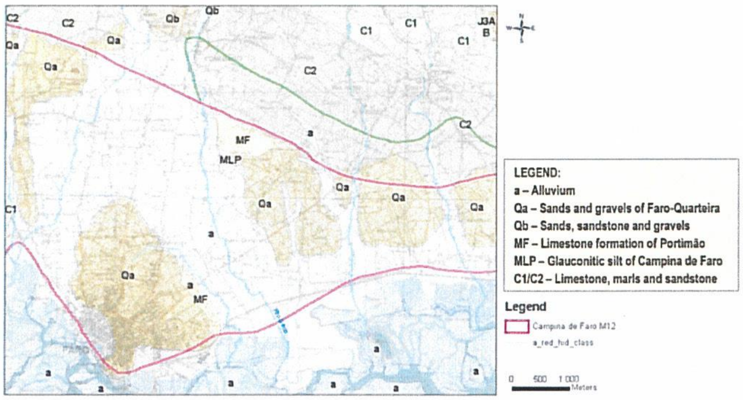

Fig. 2 - Geological map of Campina de Faro aquifer (adapted from Almeida et al., 2000).

Fig. 2 - Carta geologica dell'acquifero di Campina de Faro (adattata da Almeida et al., 2000).

Methodology

During November 2006, two infiltration basins in the riverbed, filled with clean gravels, and three monitoring wells (LNEC1, LNEC2 and LNEC3) for groundwater quality and piezometric levels assessment have been constructed (Figure 3 and Figure 4). Each well was equipped with multiparametric sensors for quality and water level continuous recording. Each basin surface area is 100 m^2 (20m x 5m) and has approximately 7 meters depth. LNEC1 is opened in the unconfined sandy aquifer with 13 meters depth, LNEC2 is opened (possibly) in the confining aquitard at 20 meters depth and LNEC3 is opened in the sandstone confined aquifer, at 40 meters depth.

Two concrete sections were constructed and two pneumatic gauges for river water levels control were installed, upstream and downstream of the infiltration basins, during January 2007.

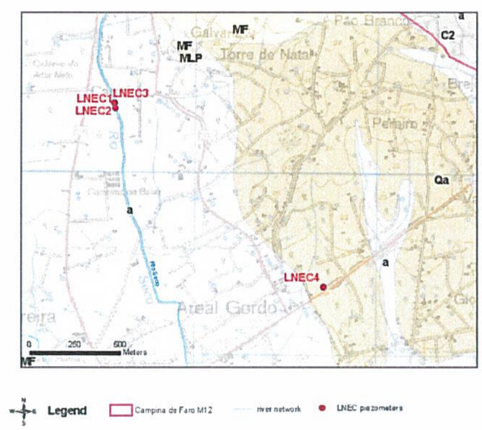

Fig. 3 - Location of LNEC piezometers (LNEC 1, 2 and 3, drilled in rio Seco at Carreiros and, LNEC 4 and 5, drilled in Areal Gordo)

Fig. 3 - Ubicazione dei piezometri LNEC (LNEC 1, 2 e 3, nel Rio Seco a Carreiros e, LNEC 4 e 5, nell' Area di Gordo).

A tracer test experiment was performed in May 2007 during 4 days, in the South infiltration basin, with a NaCl tracer spread uniformly in the basin surface with a constant water discharge (500 kg of NaCl and 100 m^3 of water). Before the tracer experiment a previous 3 days MAR experiment was performed for a preliminary infiltration rate assessment. The source of water for those experiments was extracted from the confined aquifer (LNEC3). Piezometric levels, electric conductivity, Cl and NO_3^- concentrations were measured every minute in the monitoring probes installed in the monitoring wells LNEC1 and LNEC2.

Results

The first results, during winter time, of the groundwater quality and quantity assessment recorded in the monitoring wells are presented in Figure 5 – the first plot shows the piezometric variation recorded in the 3 monitoring wells (LNEC1, 2 and 3) and the second one shows the NO_3^- concentrations results obtained from the groundwater samples.

Also the daily precipitation recorded in the nearest climatological station (São Brás de Alportel, located 12.5 km North of LNEC1, 2 and 3 monitoring wells) is presented in the plot to give an idea of the time periods of eventual surface runoff in the river. The river water NO_3^- concentration could also be determined in two samples plotted with a red cross. It can be observed from this results that piezometric levels tends to increase during the rainy months of November and December - during those months the surface runoff was also infiltrating in the tested basins. NO_3^- concentrations strongly decreased in the same period and tend to be close to the surface water NO_3^- value, especially in the unconfined aquifer wells. This is a relevant result regarding the achievements of GABARDINE objectives on the rehabilitation of the polluted unconfined aquifer of Campina de Faro. The results recorded in LNEC1 during the summer period, concerning NO_3^- and Cl^- concentration and electrical conductivity values are presented in Figure 6 and Figure 7. They show an improvement

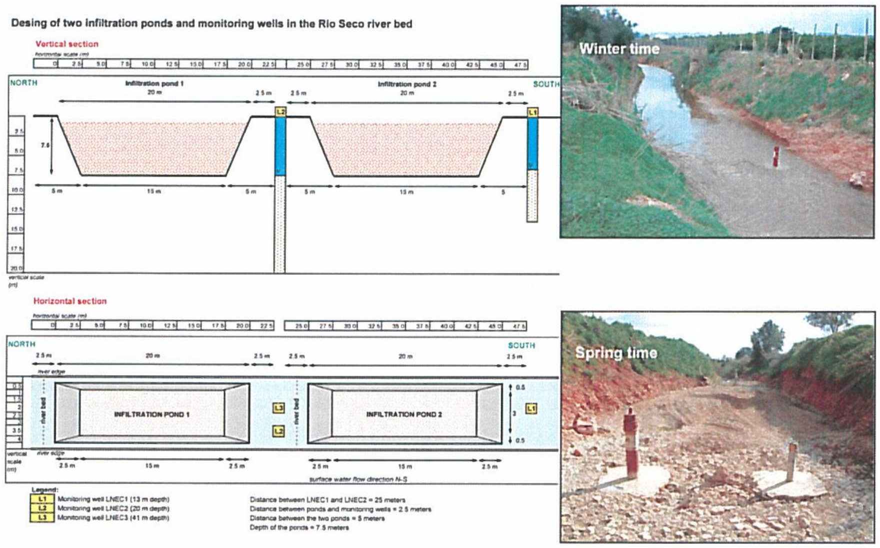

Fig. 4 - Design configuration of the two infiltration basins in the river bed of Rio Seco (at Carreiros), winter time and spring time photos.

Fig. 4 - Schema dei due bacini di infiltrazione nel letto del Rio Seco (a Carreiros), nelle foto il periodo invernale e primaverile.

in terms of groundwater quality caused by surface water infiltration during the first flash flood taking place at the end of the summer period. These results are verified by the increase in the depth to the water table recorded in the same period.

Results of the tracer test experiments (Figure 8) showed the Cl^- concentration breakthrough curve and the arrival time at LNEC1. An infiltration rate of about 120 m^3/day (i.e. 5 m^3/h) was measured at the southern basin that has an area of about 100 m^2. Per m^2 the infiltration is about 1.2 m/day. A small monitoring well for water levels and electric conductivity recording installed inside the basin allows obtaining similar values.

The real groundwater velocity was estimated after the NaCl tracer experiment (May, 18^{th} to August, 20^{th}, 2007) at the Rio Seco river bed as follows: arrival at LNEC1 – 27/06 10:30h=39d´24h=936h; Vint=6.4 cm/d; K=V´ne/I=6.4´0.35/0.088=25 cm/d=0.25 m/d (arrival at LNEC1 is presented in Figure 8).

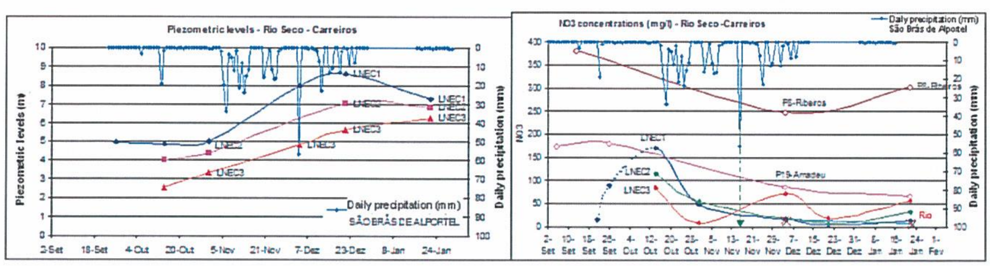

Fig. 5 - Piezometric levels variation and NO_3^- concentrations recorded between October, 2006 and January, 2007 at Carreiros test site (winter time results).

Fig. 5 - Variazione dei livelli piezometrici e della concentrazione di NO_3^- registrati tra ottobre 2006 e gennaio 2007 nel sito test di Carreiros (risultati del periodo invernale).

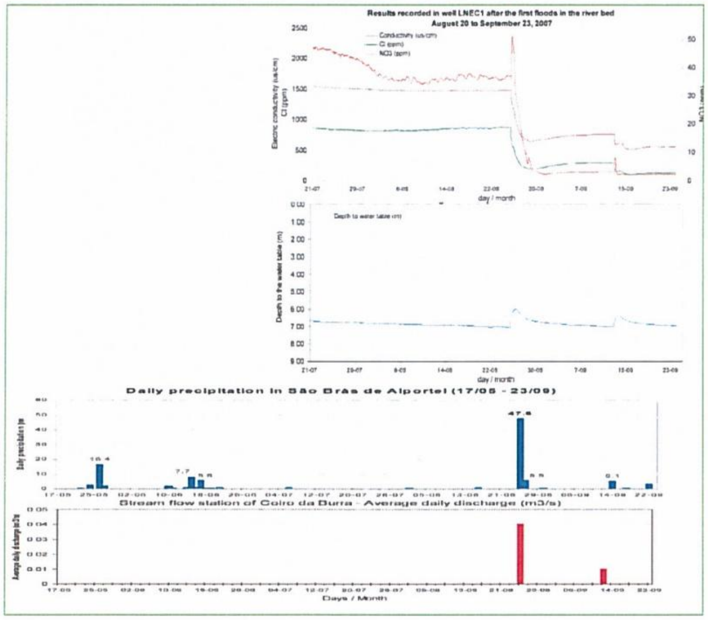

Fig. 6 - Quality results and depth to water table recorded in LNEC1 after the first flood in the river bed. Results comparison with daily precipitation values recorded in São Brás de Alportel climatological station and with average daily discharge recorded in Coiro da Burra stream flow station, in the same period

Fig. 6 - Risultati registrati nel LNEC1 dopo la prima inondazione del letto del fiume. Comparazione dei risultati con i valori delle precipitazioni giornaliere registrate nella stazione climatologica di São Brás de Alportel e con il deflusso medio giornaliero registrato nella stazione idrometrica di Coiro da Burra, nello stesso periodo.

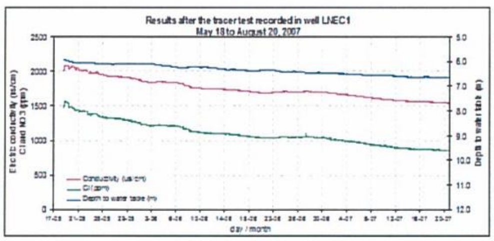

Fig. 7 - Results after the tracer test experiment recorded in LNEC1, concerning electrical conductivity, Cl⁻ concentrations and depth to water table variations (undisturbed groundwater flow).

Fig. 7 - Risultati dopo l'esperimento con tracciante effettuato al LNEC1, riguardante la conducibilità elettrica, la concentrazione di Cl e la variazione del livello piezometrico (in condizioni di deflusso sotterraneo naturale).

Rio Seco river bed geophysical assessment

During the end of January 2007, a geophysical campaign was made. Figure 9 shows the results of electrical resistivity profiles, one longitudinal and four transversal profiles performed at the river bed, intersecting the two infiltration basins. These results are essential for assessing the background values of resistivity prior the tracer test experiment developed during May 2007. The new electrical resistivity profiles performed during the tracer experiment showed a very good correlation with the electrical conductivity values observed in the monitoring wells and allowed the detection of a saline plume migration during the recharge experiment.

The longitudinal profile resistivity values were measured twice a day during the infiltration and tracer test experiments, and also repeated a week after the test conclusion. Some transversal profiles were also measured during the tracer test. Figure 10 presents two examples of the electrical resistivity results obtained in the longitudinal profile before and during the saline injection. In LNEC Report named "Time-lapse resistivity tomography with a saline tracer for the Gabardine Project" (Mota, 2008) a more detailed description of this geophysical assessment is presented.

Complementarily, it was included a preliminary development of an optimization model that merges restrictions and parameters for the objective function. Its future application will allow selecting more adequate techniques considering the maximization of the improvement of water quality and total cost minimization.

Conclusions of the GABARDINE Campina de Faro case study

The main goal of GABARDINE project was to optimize groundwater rehabilitation through implementation of MAR, minimizing the effects of diffuse pollution caused by agricultural practices in Campina de Faro. Besides the development of infiltration tests, several tracer experiments have also conducted in (1) three infiltration basin, with different soil types; (2) two river bed infiltration basins; (3) one 5m diameter infiltration well ("nora") and, (4) one 0,5m diameter infiltration well. The results gathered, depending on hydraulic heads and on soil types, eventually allow the extrapolation of infiltration rates to other case study areas, with similar

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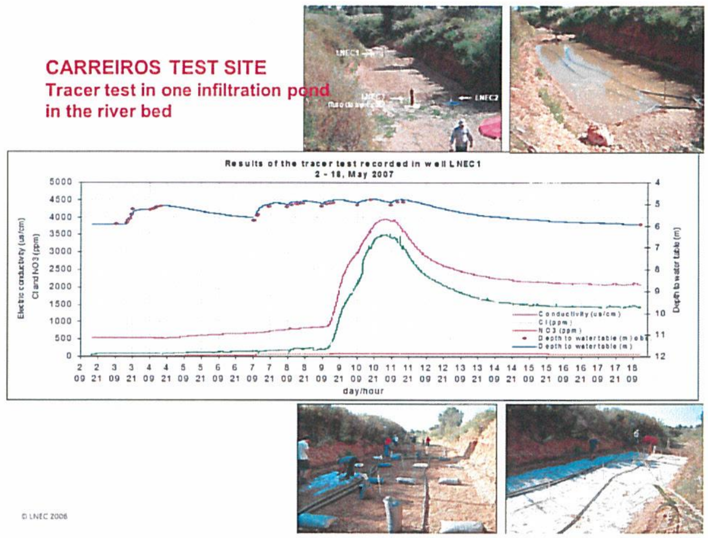

Fig. 8 - Results of the Rio Seco at Carreiros tracer test experiment recorded in LNEC1, concerning electrical conductivity, Cl^- concentrations and depth to water table variation.

Fig. 8 - Risultati del test con tracciante nel Rio Seco a Carreiros registrati nel LNEC1, riguardanti la conducibilità elettrica, la concentrazione di Cl^- e la variazione del livello piezometerico.

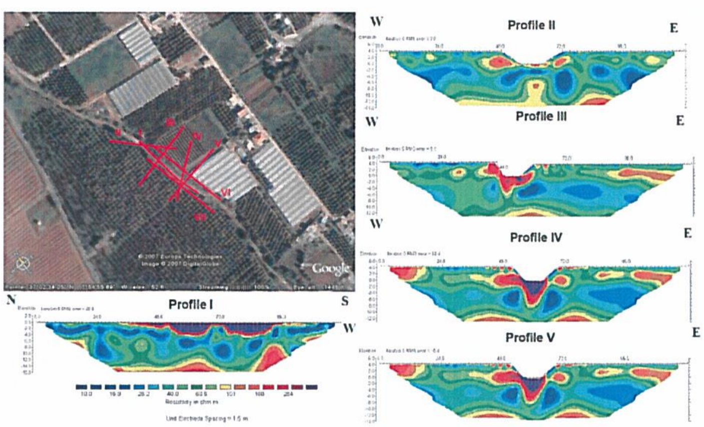

Fig. 9 - Geophysical assessment using electrical resistivity profiles intersecting the infiltration basins at the river bed (Rio Seco at Carreiros test site; Mota, 2008).

Fig. 9 - Analisi geofisica usando i profili di resistività elettrica attraversoi bacini di infiltrazione nel letto del fiume (Rio Seco nel sito test di Carreiros; Mota, 2008).

soil types, as shown in figure 11: (a) infiltration rates vs. type of technology used (infiltration basins in the field or in river bed and, large and medium diameter recharge wells); and, (b) infiltration rates vs. type of soil available in the Algarve at Campina de Faro and Rio Seco). This goal aimed the assessment in the Portuguese study area of problems resulting from the application of these practices. Today they are well documented in terms of groundwater quality. The study area was designated as a vulnerable area concerning nitrate concentration by the application in Portugal of the Nitrates Directive (http://ec.europa.eu/environment/water/water-nitrates/index_en.html). Together with the "good quality status" referred by the Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, http://ec.europa.eu/environment/water/water-framework/index_en.html), these are the main reasons for the implementation of infrastructures aiming at improving the groundwater quality in a section of this aquifer allowing, on the other hand, to increase groundwater availability with good quality in the Algarve region.

The Project improved scientific knowledge of several methodologies aimed not only to improve groundwater quality, but also allowing subterranean storage of water with good quality in wet year periods of major availability and during events of heavy rainfall.

Several MAR experiments were accomplished in the Portuguese case study area during the second year of the Project.

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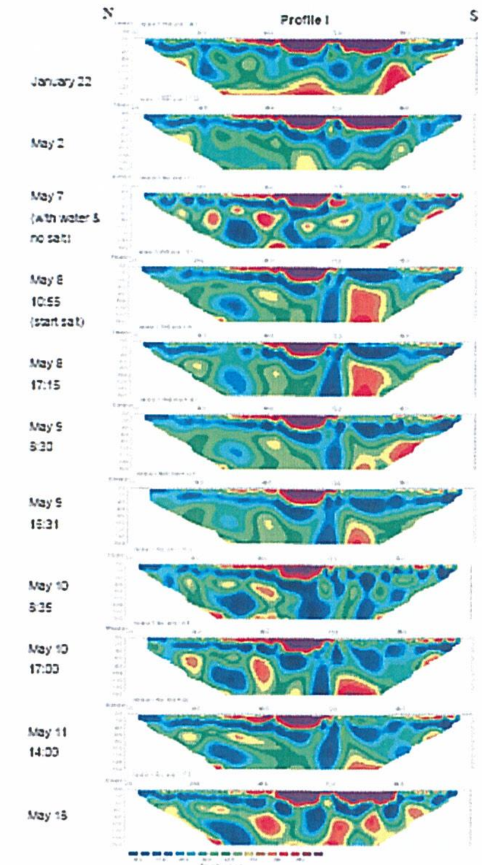

Fig. 10 - Geophysical assessment in the longitudinal electrical resistivity profile before and during the tracer test at the river bed (Rio Seco at Carreiros test site; Mota, 2008).

Fig. 10 - Analisi Geofisica di resistività elettrica lungo il profilo longitudinale prima e durante il test con tracciante nel letto del fiume (Rio Seco nel sito test di Carreiros; Mota, 2008).

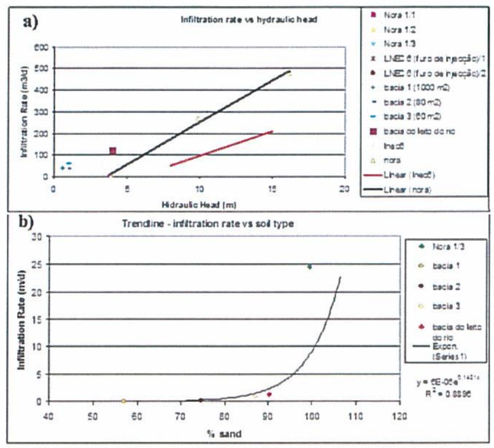

Fig. 11 - a) Infiltration rates vs. the type of technology used (infiltration basins in the field or in river bed and, large and medium diameter recharge wells); b) Infiltration rates vs. the type of soil available in the Algarve at Campina de Faro and Rio Seco.

Fig. 11 - a) Tassi di infiltrazione vs il tipo di tecnologia usata (bacini di infiltrazione in campo o nel letto del fiume, pozzi di ricarica a largo o medio diametro); b) Tassi di infiltrazione vs il tipo di suolo presente nell'Algarve a Campina de Faro e Rio Seco.

The purpose of the experiments was to assess and quantify the effectiveness and applicability of the different MAR methodologies, in a way that the achieved results can contribute to the development of the GABARDINE Decision Support System (GDSS).

Final Remarks

Storing water in aquifers during times of excess can help address water scarcity challenges experienced in many parts of the Mediterranean Basin. Moreover, water quality can be improved through aquifer transport and storage, due to chemical and biological reactions. (MAR), Soil-Aquifer-Treatment (SAT) systems and Aquifer Storage and Recovery (ASR) can be proved as key technologies to solve Mediterranean's upcoming water crisis by linking water reclamation, water reuse and water resources management. The diversity and complexity of the water problems in the Circum-Mediterranean area call for a clear and focused research program in order to successfully meet the imminent challenges, as well as to direct the ongoing developments towards socioeconomic and ecological sustainability.

Following the fruitful achievements of GABARDINE project in Portugal and the i+R&D DINA-MAR project in Spain, the new FP7-ENV-2013-WATER-INNO-DEMO MARSOL project, which started Dec. 1st, 2013, will envisage advancing the use of MAR as a sound, safe and sustainable strategy for improving water security by demonstrating that MAR is a key solution to water scarcity not only in Portugal and Spain but also in all Circum-Mediterranean region.

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THEMATIC ISSUE

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

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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

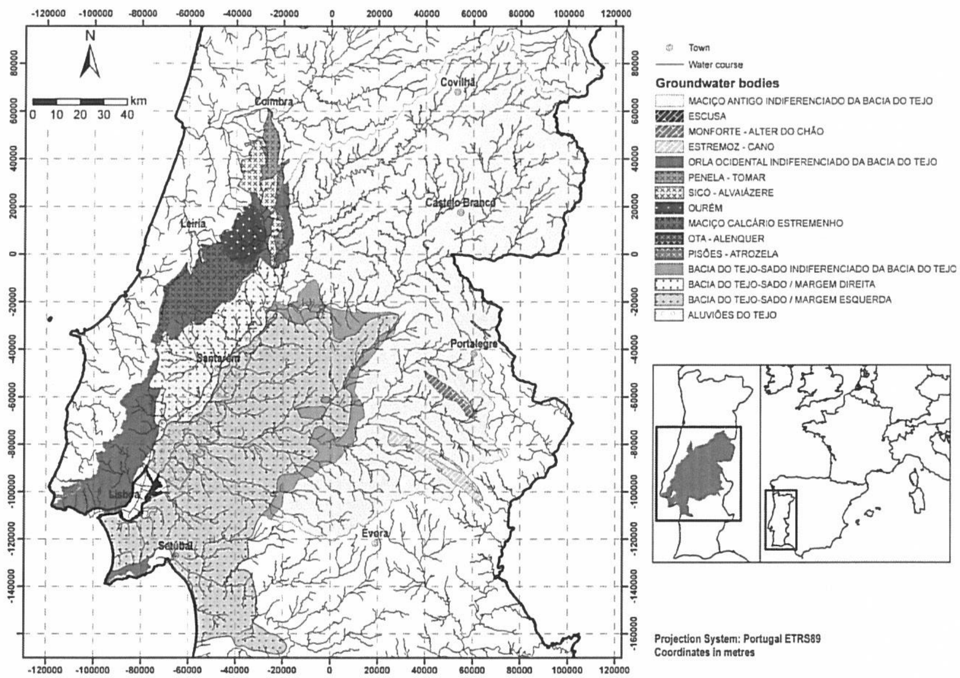


Fig. 1 Groundwater bodies of Tagus RBMPs (Source: adapted from Lobo Ferreira et al. 2011a)

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.

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

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

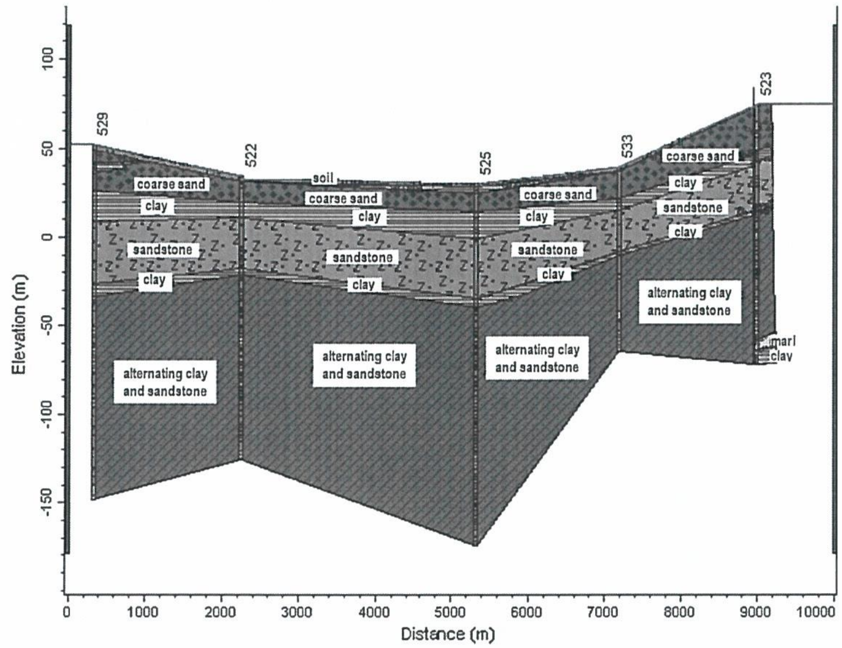


Fig. 2 W-E section in the Torres Vedras aquifer system

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

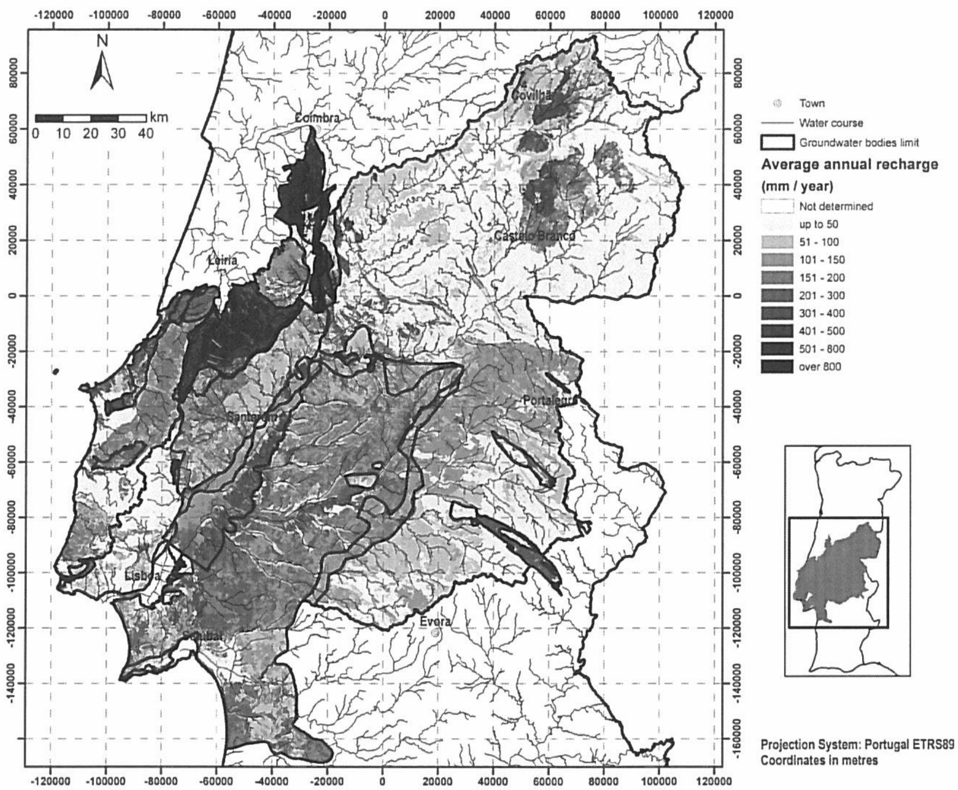


Fig. 3 Annual average recharge distribution for Tagus and West river basin management plans (Source: map created using information from Lobo Ferreira et al. 2011a, b)

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

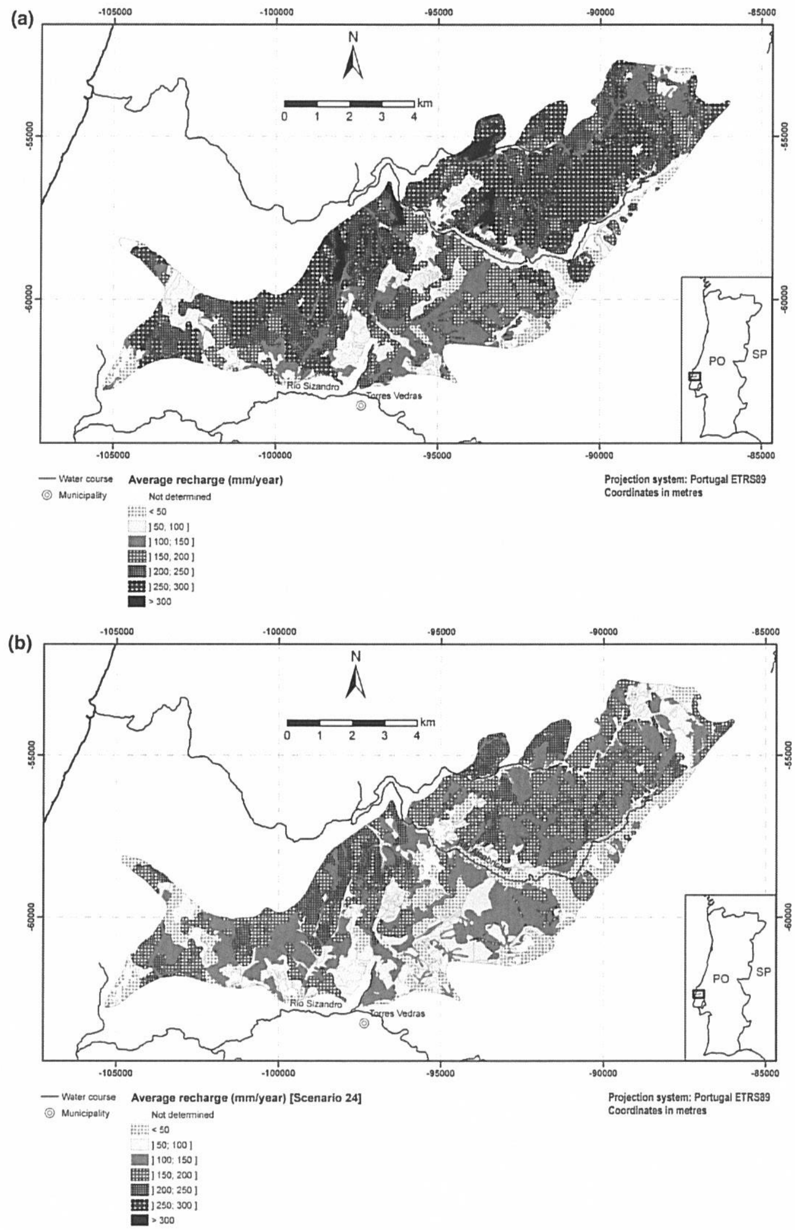


Fig. 4 Projected average annual recharge for Torres Vedras aquifer system. **a** 1979–2009 series. **b** 2071–2100 scenario 24 (Source: adapted from Oliveira et al. 2012)

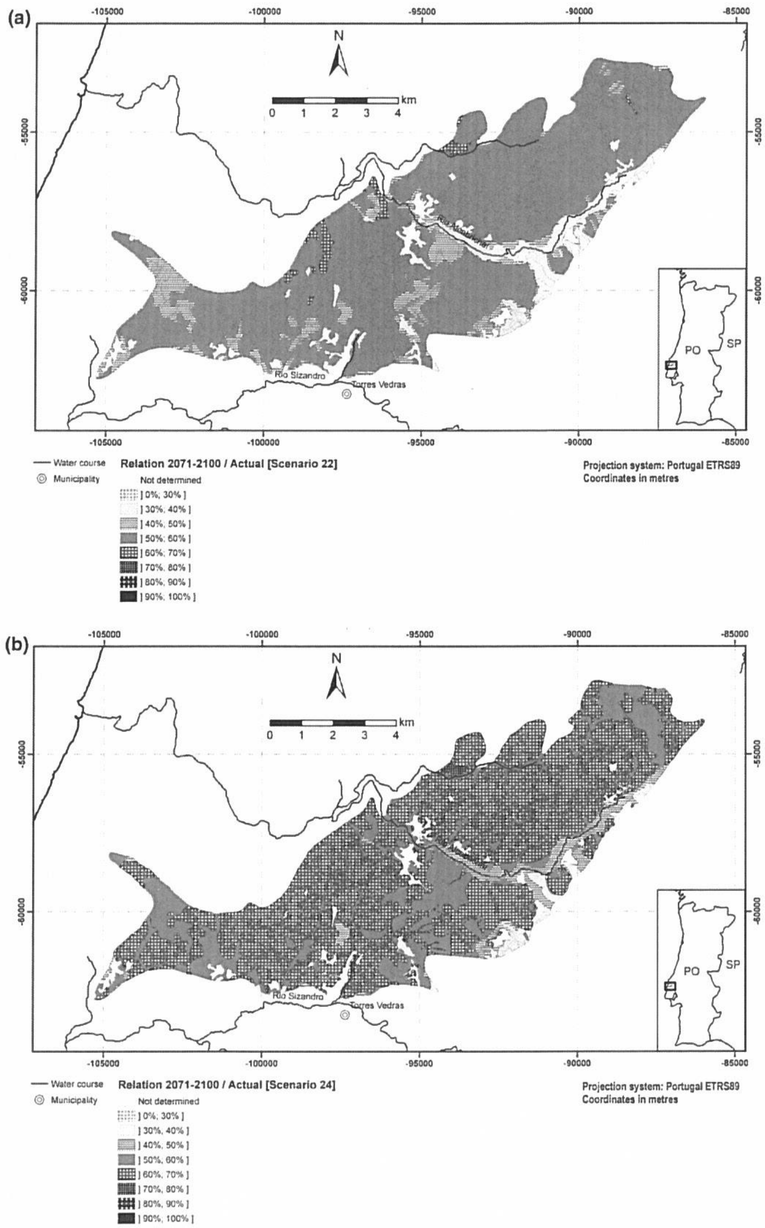


Fig. 5 Relationship between average annual recharge projected for Torres Vedras aquifer system under climate change scenarios and current recharge (1979–2009). **a** Scenario 22, **b** Scenario 24 (Source: adapted from Oliveira et al. 2012)

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

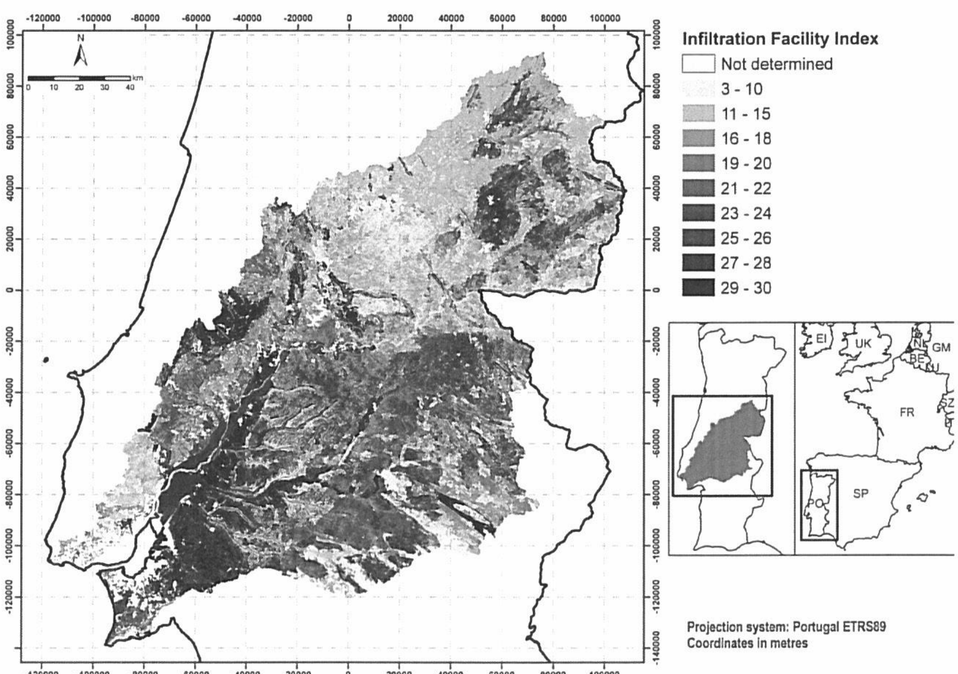


Fig. 6 Tagus RBMPs facility infiltration index mapping (Source: Lobo Ferreira et al. 2011a)

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

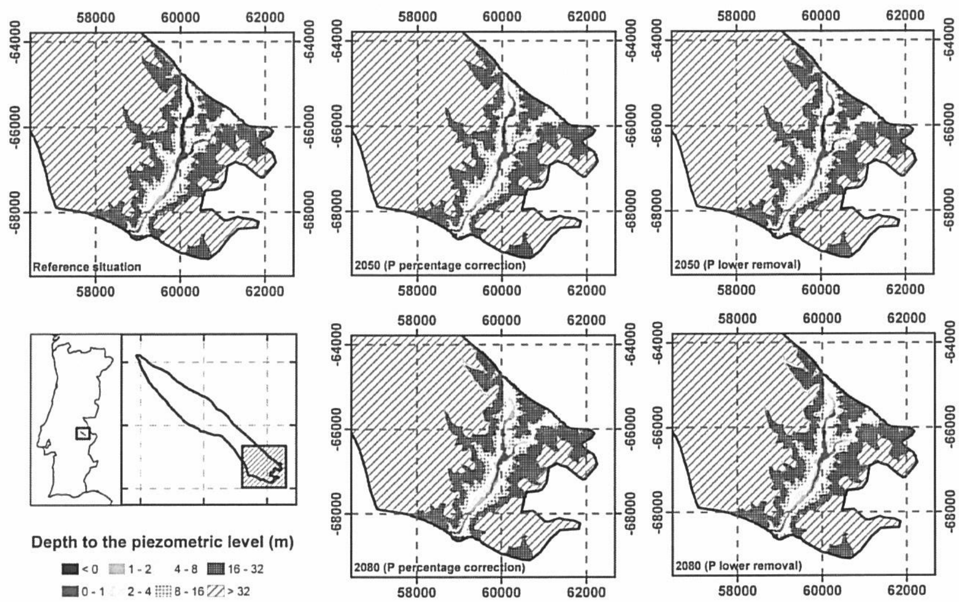


Fig. 8 Wet zones and depth to the piezometric level under climate change scenarios in Monforte-Alter do Chão aquifer system (Source: adapted from Lobo Ferreira et al. 2012b, 2013)

- 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).

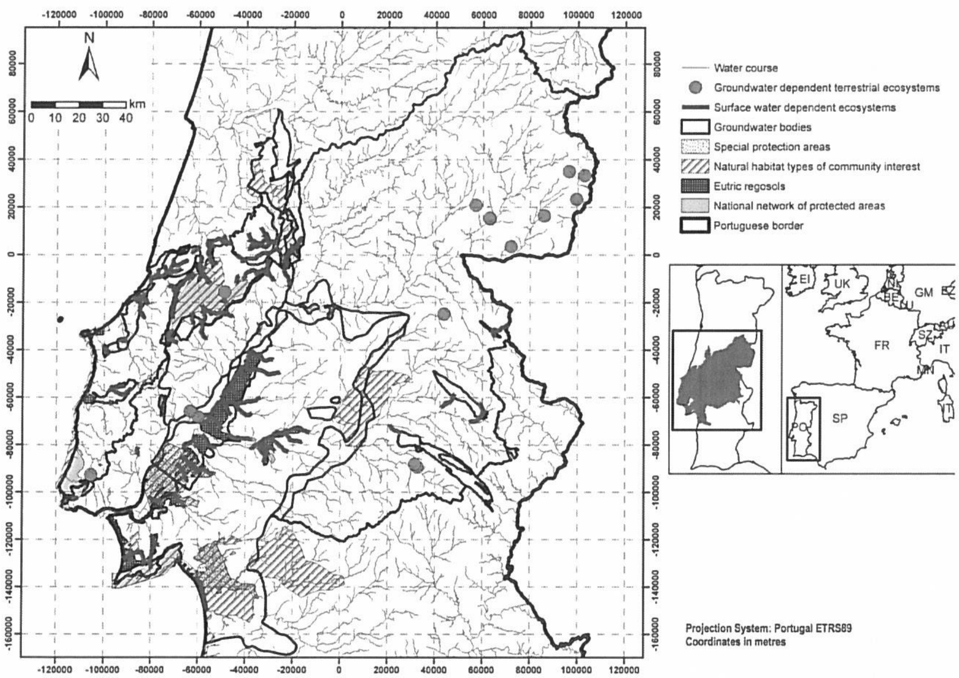


Fig. 7 Groundwater dependent ecosystems represented in the cartographic coverage used for the preparation of Tagus and West RBMPs (Source: adapted from Lobo Ferreira et al. 2011a, b)

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;

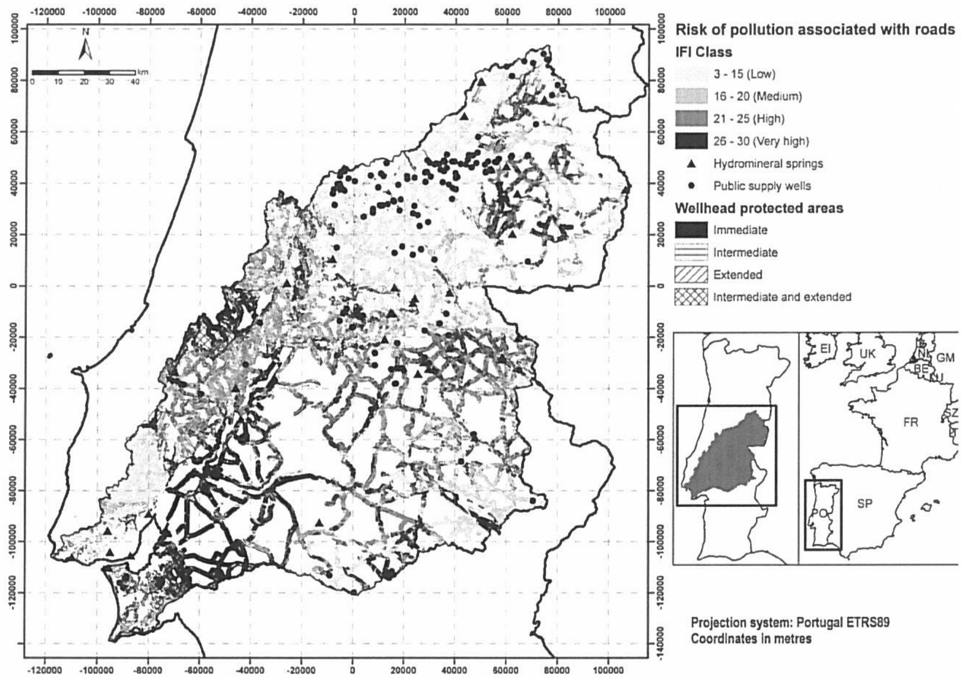


Fig. 9 Map of the risk of pollution associated with roads of Tagus RBMPs area (Source: Lobo Ferreira et al. 2011a)

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

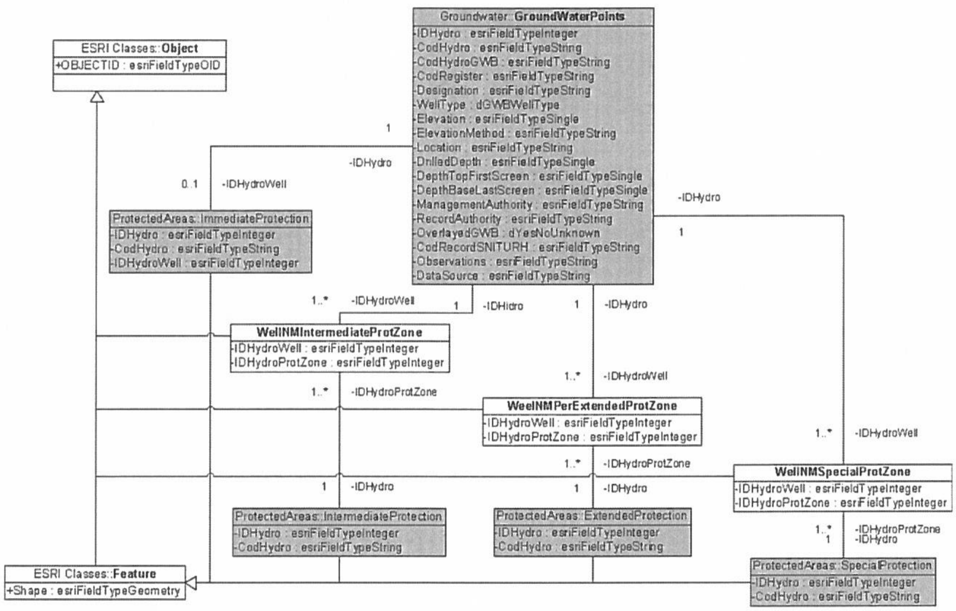


Fig. 10 Class diagram representing the associations between the class of pumping wells (GroundWaterPoints) and the groundwater abstraction protection zoning classes (ImmediateProtection, IntermediateProtection, ExtendedProtection, and SpecialProtection) (Source: adapted from Charneca et al. 2011)

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

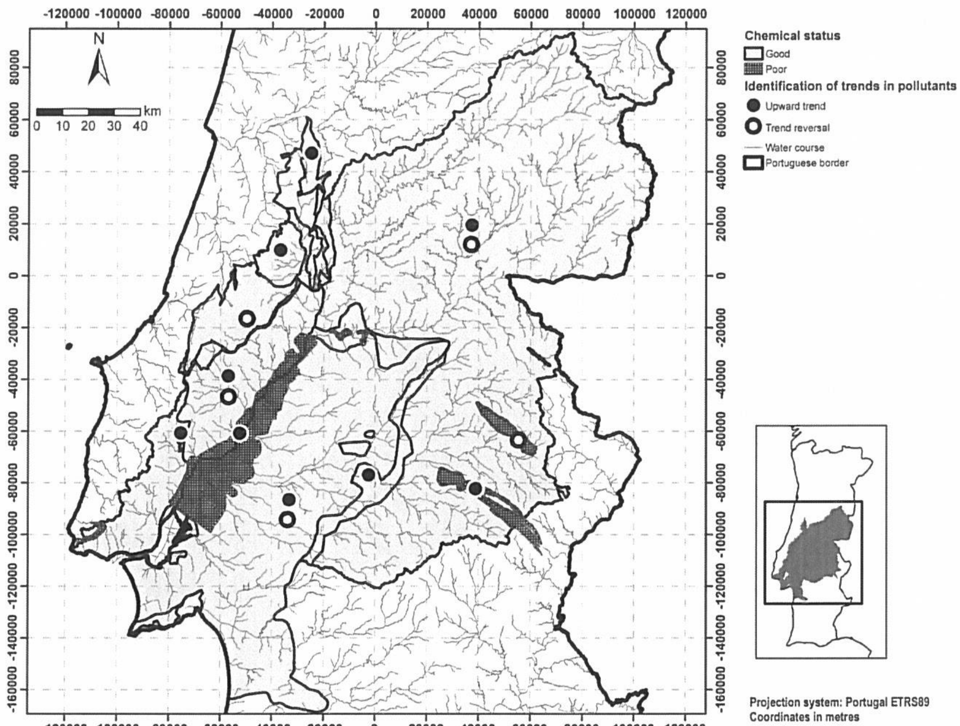
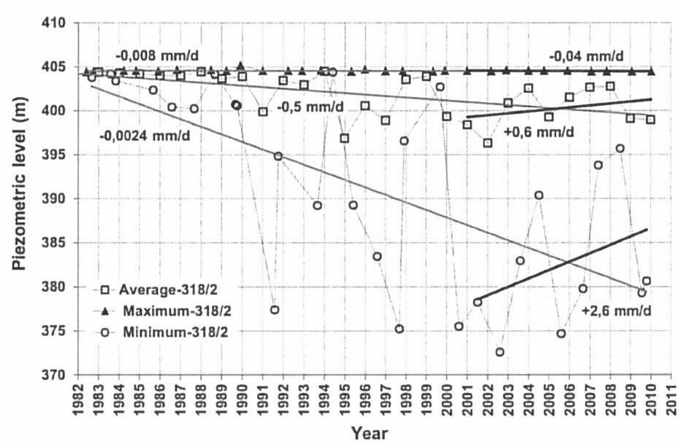


Fig. 11 Summary of the General Chemical Status and the significant and constant groundwater trends in Tagus RBMPs (Source: Lobo Ferreira et al. 2011a)

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)



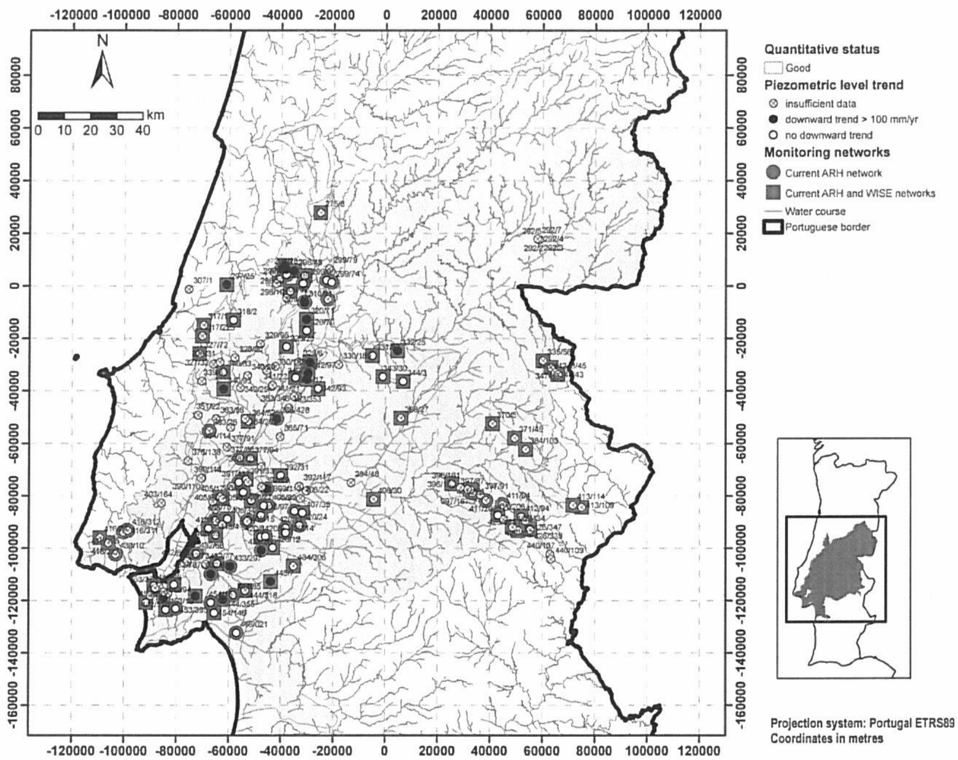


Fig. 13 Evolution of piezometric levels in Tagus RBMPs monitoring wells (Source: Lobo Ferreira et al. 2011a)

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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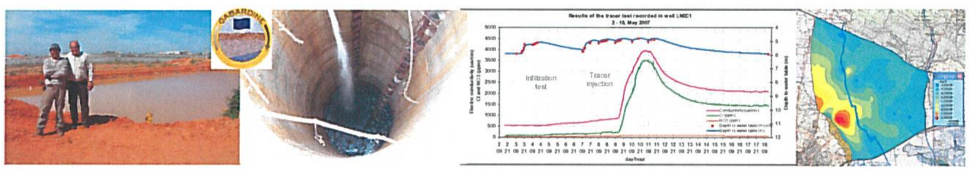
6th Framework Programme Research Project	GABARDINE Project: "Groundwater artificial recharge based on alternative sources of water: advanced integrated technologies and management".
LNEC Research Project	LNEC Applied Research Programme 2005-2008: Project P3: Groundwater resources assessment and numeric modelling in hidrogeology; Study E11: Groundwater artificial recharge (Gabardine Project). LNEC Process n° 0607/11/16252 (0607/17/15405)
Coordinator at LNEC	João Paulo Lobo Ferreira
Gabardine Deliverable 5.4	Portuguese Case-study area contribution



Objective

The main objectives of this Project were: (1) to identify alternative water sources and study the economic and environmental feasibility of its use in semi-arid areas, in the context of an integrated water resources management, (2) to study the aquifers as a main water source for both seasonal and long term storage of these alternative water sources and (3) to improve knowledge about possible methods to introduce these water sources in the aquifer, namely through artificial recharge.
Alternative water sources for groundwater artificial recharge may include the superficial runoff surplus produced during flash flood events, treated urban wastewater, desalinate water surplus or water import.

The development of this study approached several issues related to the subject like: precipitation rate analysis, both water and recharge balance, identification of the potential alternative water sources intended to recharge the aquifer and assessment of existing technologies for its use, development of tools aimed for managing groundwater recourses considering artificial recharge, assessment of aquifer vulnerability and characterization of the vadose zone. Several artificial recharge devices have been developed and implemented in this Project.

Methodology

The Project was structured in Work-packages, from which the following are highlighted: a) Precipitation, aquifer recharge and water balance (WP2); b) Alternative water sources and artificial recharge (study methods, technologies, management and utilization operations) (WP3); c) Assisting methodologies (models, calibration, sensibility analysis, vulnerability) (WP4); d) Case studies (WP5); e) Integration (decision support systems and management) (WP6); f): Socio-economic issues (WP7) and Dissemination (WP8).

Four case studies were selected for real experiments of groundwater artificial recharge systems: Llobregat Valley (Spain), Campina de Faro (Portugal), Israel and Palestine (Gaza) and Thessaloniki Bay (Greece). These case studies face several problems of water supply due to overexploitation, saline intrusion or pollution resulting from wrong agricultural practices, being the artificial recharge resorting to alternative water sources a viable methodology to solve or minimize these problems.

Regarding Campina de Faro case study, the main goal was to optimize groundwater rehabilitation through implementation of artificial recharge, minimizing the effects of diffuse pollution caused by agricultural practices. This goal aimed the assessment in the Portuguese study area of problems resulting from the application of these practices. Today they are well documented in terms of groundwater quality. The study area was designated as a vulnerable area concerning nitrate concentration by the application in Portugal of the Nitrate Directive (in 2004). Together with the "good quality status" referred by the Water Framework Directive, these are the main reasons for the implementation of infrastructures aiming the improvement of groundwater quality in a section of this aquifer allowing, on the other hand, increasing groundwater availability with good quality in the Algarve region.

The Project improved scientific knowledge of several methodology aimed not only to improve groundwater quality but also allowing subterranean storage of water with good quality in wet year periods of major availability and during events of heavy rainfall.

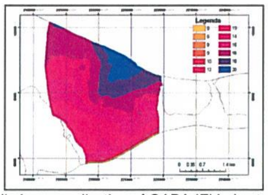


Figure 4 • Preliminary application of GABA-IFI index to the Campina de Faro case study area

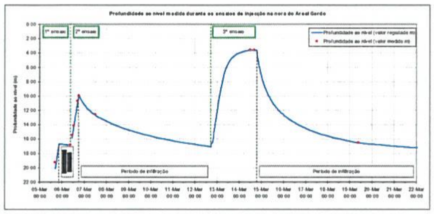


Figure 5 • Injection tests in a large diameter well ("Nora") at Campina de Faro (Areal Gordo)

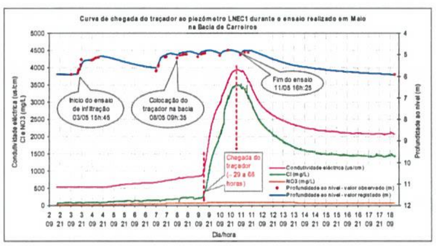


Figure 6 • Breakthrough tracer experiment curves at Rio Seco infiltration basin (Carreiros)

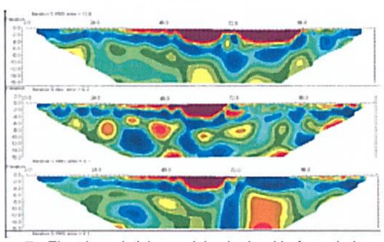


Figure 7 • Electric resistivity models obtained before, during and after the tracer test at the infiltration basin in Rio Seco, Carreiros (Mota, 2007)

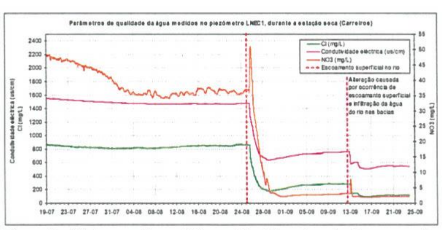


Figure 8 • Water quality variation at the Campina de Faro superior aquifer, after superficial runoff events at rio Seco (Carreiros infiltration basins)

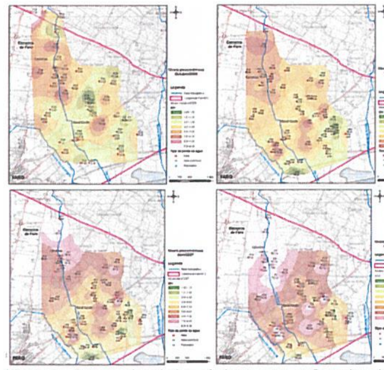


Figure 9 • Seasonal variation of piezometry at Campina de Faro

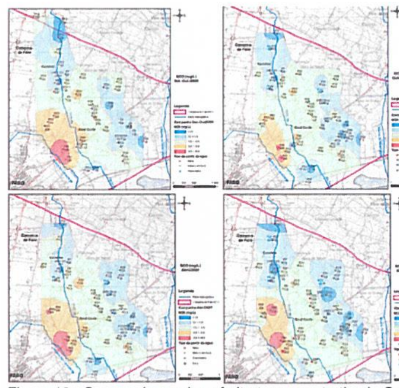


Figure 10 • Seasonal mapping of nitrate concentration in Campina de Faro unconfined aquifer

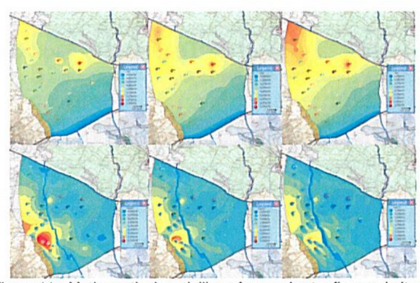


Figure 11 • Mathematical modelling of groundwater flow and nitrate transportation considering different artificial recharge scenarios in the unconfined aquifer of Campina de Faro

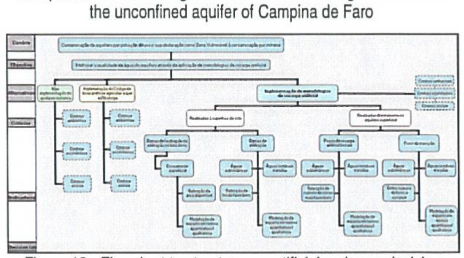


Figure 12 • Flowchart to structure an artificial recharge decision problem with Decision Lab 2000 model

A new indexed method, called GABA-IFI, for the preliminary identification of candidate areas to the installation of groundwater artificial recharge systems was developed during this Project. This new method was applied to both Campina de Faro aquifer and Querença-Silves aquifer.

Several artificial recharge experiments were accomplished in the Portuguese case study area during the second year of the Project. Figure 1, presenting a set of selected pictures, shows an example. The purpose of the experiments was to assess and quantify the effectiveness and applicability of the different groundwater artificial recharge methodologies, in a way that the achieved results can contribute to the development of the Gabardine Decision Support System (GDSS).
Complementarily, it was included a preliminary development of an optimization model that merges restrictions and parameters for the objective function. Its future application will allow selecting more adequate techniques considering the maximization of the improvement of water quality and total cost minimization.

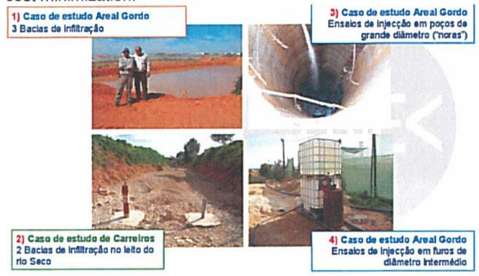


Figure 1 • Artificial recharge tests developed in Campina de Faro, Algarve, Portugal

Main achievements

- Characterization of the five Gabardine case studies, including the Algarve test site in WP5/Deliverable D51, coordinated by LNEC
- Assessment of the main components of groundwater artificial recharge for the Portuguese Case Study - WP2 (Figure 2)
- Quantification of water needs for artificial recharge at Campina de Faro aquifer, aiming the improvement of water quality to fulfil the requirements of the EU Water Framework Directive - WP2/Deliverable D24
- Identification of alternative water sources for artificial recharge and quantification of water volumes - WP3/Deliverable D31
- Development of the GIS platform for the Portuguese case study – WP5/Deliverable D52 (Figure 3)
- Methodology for a preliminary identification of candidate areas for the implementation of artificial recharge (GABA-IFI index) – WP4 (Figure 4)
- Multiple Artificial Recharge tests developed in Campina de Faro case study – WP5/Deliverable D54 (Figure 5, Figure 6, Figure 7)
- Seasonal monitoring of both piezometry and groundwater quality. Continuous monitoring in the infiltration basins (Figure 8, Figure 9, Figure 10)
- Mathematical modeling of groundwater flow and nitrate transportation considering different artificial recharge scenarios at Campina de Faro case study (Figure 11)
- Application of Gabardine decision support system (GDSS) based on a multi-criteria analysis to select artificial recharge methodologies, considering both environmental and economic criteria (Figure 12)
- Organization of a Workshop on *Assessment Methods* in Lisbon (LNEC, Nov., 6th, 2006) – WP8

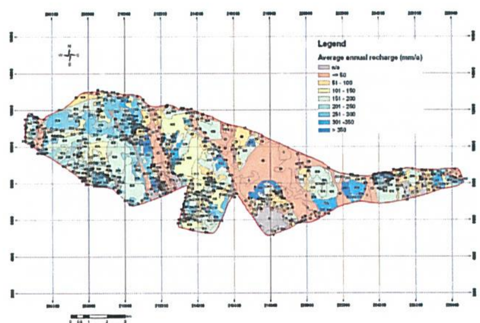


Figure 2 • Aquifer recharge calculated by the numeric model of daily sequential water balance BALSEQ_MOD

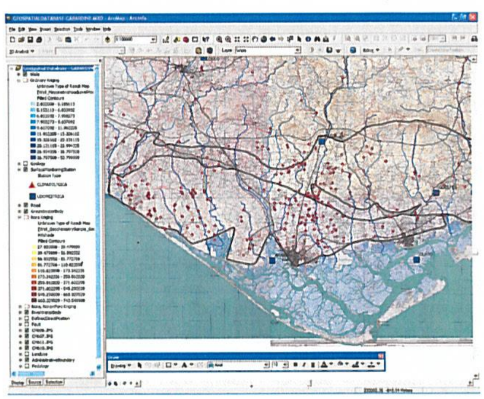


Figura 3 • GIS platform for Campina de Faro case-study

Project Team LNEC	Name	Position
	João Paulo Lobo Ferreira	Principal Research Officer with Habilitation
	Catarina Diamantino	Ph D. (FCT/LNEC) trainee
	Manuel M. Oliveira	Research officer
	Teresa E. Leitão	Senior Research Officer
	Maria João Moinante	Research Trainee
	Maria José Henriques	Principal Technician
	Rogério Mota	Assistant Researcher
	Malva A. Mancuso	Research officer
	Patricia Terceiro	MSc. Trainee
	Luis Oliveira	MSc. Trainee

Project Team External	Name	Observations
	Albino Medeiros	Sub-contracted Geologist
	Piotr Wojda (ULG, Belgium)	GIS platform for Campina de Faro case-study co-author

Financing sources

6th Framework Programme, Project GABARDINE - "Groundwater artificial recharge based on alternative sources of water: advanced integrated technologies and management".

LNEC Applied Research Programme 2005-2008 (Project P3: Groundwater resources assessment and numeric modelling in hidrogeology; Study E11: Groundwater artificial recharge (Gabardine Project).

The Portuguese *Fundação para a Ciência e a Tecnologia* (FCT) co-financed MSc. Catarina Diamantino PhD at LNEC. The Dissertation was completed and delivered to Lisbon University February 2009.

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Models for wellhead protection in regional unconfined aquifers and stratified aquifers

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RESUMEN

En este trabajo son presentados los conceptos matemáticos usados para el desarrollo de la protección de cabezales de pozos y la metodología de zonificación. Ellos están basados en soluciones analíticas, en el flujo del agua subterránea y en la modelación en diferencias finitas del rastreo de partículas. Los límites de la protección de cabezales de pozos están en función no sólo de la geología local, de los parámetros del acuífero y de las características regionales del acuífero, también de los caudales de extracción (o de la productividad del acuífero). Verticalmente el análisis fue realizado usando un modelo de flujo simétrico a un eje asumiendo que el flujo de agua subterránea hacia el pozo es radial. Las herramientas matemáticas fueron desarrolladas para ser robustas y de uso amigable, facilitando la aplicación de la nueva legislación portuguesa relacionada con la protección del agua subterránea. La aplicación de la metodología es ejemplificada en dos estudios de caso, uno desarrollado para el acuífero costero de Bardez, en el estado de Goa, India y el otro en Ramahal, Portugal.

PALABRAS CLAVE: Flujo del agua subterránea, protección de cabezales de pozos, modelación numérica, modelación en diferencias finitas, rastreo de partículas, contaminación.

ABSTRACT

Mathematical concepts are used for the development of wellhead protection and zoning methodologies, based on analytical solutions and on groundwater flow and particle tracking finite differences. Wellhead protection limits are a function of the local geology, of the aquifer parameters and the regional hydraulic characteristics of the aquifer, and of the extraction rates or of the productivity of the aquifer. In the vertical dimension the analysis was performed using an axisymmetric flow model, assuming that groundwater flow into the well is radial. The radial axisymmetric mathematical tools were robust and user friendly, facilitating the application of the new Portuguese legislation regarding groundwater protection. The methodology is exemplified in two case studies, one for the coastal aquifer of the Bardez, Goa State, India and the other in Ramalhal, Portugal.

KEY WORDS: Groundwater flow, wellhead protection zones, numerical modeling, finite difference modeling, particle tracking, contamination.

1. INTRODUCTION

Groundwater resources constitute an important source of water and are important to be preserved. The quality of groundwater resources can be affected by social-economic activities, especially in the case of using and occupying the soil, such as with urban areas, infrastructures, agriculture, etc.

The contamination of the groundwater resources is, in general, persistent, so that the recuperation of the water quality is a slow and difficult process (Leitão, 1997). The protection of the groundwater resources is therefore a strategic objective of major importance. It is important to develop an equilibrated and durable use of these resources.

One preventive instrument to assure the protection of the groundwater resources used for abstraction is setting up protection zones around wells extracting groundwater for public supply. The limits of these areas are a function of the geology, hydraulic characteristics of the concerned aquifer and amount of extracted water. In these defined areas around wells, restrictions should be set up concerning public use and changes of soil uses, in order to protect the quality of the groundwater resources beneath it.

Protection zones around wells are generally defined as travel time zones, either to allow for the attenuation of concentrations of contaminants in the aquifer or to provide a monitoring zone. If a contamination is detected in a monitoring zone, it could be dealt with it before it enters the well. The objective of this project (Krijgsman and Lobo-Ferreira, 2001, and Feseker and Lobo-Ferreira, 2001) was to develop a methodology to delineate the dimensions of such protection zones, in this special case the one corresponding with a travel time of 50 days. This in order to follow the Portuguese Decreto-Lei nº 382/99 of September 22, 1999, which states that groundwater extraction wells should be protected against pollutants, giving for this three zones, one of which corresponds with a travel time of 50 days.

Based on experimental studies developed e.g. in German labs and according with several authors, the limit of 50 days is chosen since this is generally accepted as a limit within virus and pathogenic bacteria are naturally eliminated in groundwater, in particular E. Coli. 99.9% elimination in groundwater of E. Coli is reached after a time ranging from 10 to 100 days, as a function of the soil type, incubation temperature and soil moisture. The limit of 50 days was selected for the development of this paper methodology because, in general, it is accepted that this is the travel time that allows the elimination of virus and pathogenic bacteria in groundwater, in particular E. Coli.

For reaching this goal, hydrogeological studies have to be carried out, in order to determine the perimeters of protection zones. It is however often not possible to conduct detailed studies of individual well fields, since this involves normally considerable time and costs. Instead, it would be easier, faster and cheaper if a more general methodology was available, making possible quickly and without much effort give ranges of the perimeters of the required protection zones.

A semi-confined aquifer is by definition separated from superficial strata by a semi impermeable layer, which implies that considerable time may pass before a pollutant can enter the aquifer after entering the soil.

A confined aquifer is by definition secluded from superficial strata by an impermeable layer, such as clay, by which it is fully protected from pollutants entering the soil above it.

The output of the use of this methodology should be a map, obtained by a Geographic Information Systems (GIS), on which the required dimension of a protection zone could see in colors, without having to study the hydrogeological setting of an area into details.

In order to reach this goal, a general relationship between hydrological parameters and the dimensions of the required 50 day zone was set up, which was validated using a numerical computer program to simulate groundwater flow, Visual Modflow v. 2.7.2.

Once this relationship was validated, it was applied on a case study area in Goa, India.

2. METHODOLOGY FOR DEFINING PERIMETERS OF PROTECTION ZONES

2.1 Analytical solution

In the handbook 'Ground Water and Wellhead Protection'(EPA,1994) the following equation can be found:

$$t_x = \frac{n}{Ki}\left[r_x - \left(\frac{Q}{2\pi Kbi}\right)\ln\left\{1 + \left(\frac{2\pi Kbi}{Q}\right)\cdot r_x\right\}\right]. \qquad (1)$$

In this equation:

t_x = time of travel (days); n = effective porosity;
K = hydraulic conductivity (m/d);
r_x = distance over which groundwater travels in tx before entering a pumping well (m), being negative (-) if downgradient and positive (+) if upgradient;
Q = discharge of pumping well (m^3/d);
b = aquifer thickness (m);
i = hydraulic gradient before pumping.

Equation (1) can be used to calculate the travel time from a point x to a well, in case of a sloping hydraulic gradient, for both up- and down gradient points.

To calculate the distance as function of t, this equation should be written for r as function of t, n, K, Q, b and i.

2.2 Krijgsman and Lobo-Ferreira (2001) equations

To solve Equation (1), Krijgsman and Lobo-Ferreira (2001) developed a new methodology that may be consulted in *http://www.dha.lnec.pt/nas/english/projects/BK_LF_ICT 2001.pdf*. Equations (2), (3) and (4) have been deducted for the evaluation of the up gradient and down gradient distances and also the distance perpendicular to the flow direction:

- For the up gradient protection distance equation:

$$r = (0.00002x^5 - 0.0009x^4 + 0.015x^3 + 0.37x^2 + x)/F \qquad (2)$$

with $x = \sqrt{\frac{2Ft}{A}}$

and $F = 2\pi Kbi / Q$.

- For the down gradient protection distance equation:

$$r = (0.042x^3 + 0.37x^2 + 1.04x)/F. \qquad (3)$$

- For the protection distance perpendicular to the direction of flow equation:

$$r = 4\sqrt{\frac{Q}{n \cdot b}} \cdot \qquad (4)$$

2.3 Limitations

The method can not be applied, in reliable conditions, in all cases. It depends on the availability of data and on the local characteristics of the aquifer systems.

First of all, the area under analysis must be an unconfined aquifer. For confined aquifers the confining strata significantly increase the time required for the pollutant to penetrate the aquifer. The travel time through the confining strata probably would exceed 50 days. In these cases, protection zones around the well should have a minimum value, e.g. those of the already mentioned Portuguese Decreto-Lei n° 382/99 of September 1999, shown in Table 1.

A second set of requirements is related with the need of having reliable input data regarding the following parameters:

- hydraulic conductivity (*K*)
- water levels, from which a gradient (*i*) is derived
- aquifer thickness (*b*)
- effective porosity (*n*)

A problem can be the value of *b*. The law defines this as the saturated thickness of the aquifer in the well. It should be noted that total screen length should not be used as aquifer thickness:

- First, obtained K-values from pumping tests are an average of the total aquifer thickness, including less permeable layers within the aquifer.
- Second, if for example only the top of the aquifer is screened, than still the total thickness of the aquifer will contribute

Table 1

Minimum values for the establishment of the minimum required radii

Aquifer system type	1st protection zone / immediate zone	2nd protection zone / near zone	3rd protection zone /far zone
Type 1	r = 20 m	r is the highest value of 40 m and r_1 (t =50 days)	r is the highest value of 350m and r_1 (t =3500 days)
Type 2	r = 40 m	r is the highest value of 60m and r_2 (t =50 days)	r is the highest value of 500m and r_2 (t =3500 days)
Type 3	r = 30 m	r is the highest value of 50m and r_3 (t =50 days)	r is the highest value of 400m and r_3 (t =3500 days)
Type 4	r = 60 m	r is the highest value of 280m and r_4 (t =50 days)	r is the highest value of 2400m and r_4 (t =3500 days)
Type 5	r = 60 m	r is the highest value of 140m and r_5 (t =50 days)	r is the highest value of 1200m and r_5 (t =3500 days)
Type 6	r = 40 m	r is the highest value of 60m and r_6 (t =50 days)	r is the highest value of 500m and r_6 (t =3500 days)

Type 1 - confined aquifer system with lithological support formed by porous formations
Type 2 - unconfined aquifer system with lithological support formed by porous formations
Type 3 - semi confined aquifer system with lithological support formed by porous formations
Type 4 - aquifer system with carbonated lithological formations
Type 5 - fissured aquifer system with metamorphic and igneous formations
Type 6 - aquifer system with igneous and metamorphic formations having a small degree of fissures and weathering

to well-inflow as a result of non-horizontal flow near the screened part of the well.

With large-diameter wells, vertical flow is especially important, since an important constituent of total inflow will be bottom-inflow.

Data of extraction rates of wells (Q) are not necessarily required of all wells, since an output map can be made assuming average extraction rates. Extraction rates are never constant per well throughout a year and can vary considerably between wells, even in close wells. Depending on the area the methodology is applied depending on the density of data. Different approaches can be made:

a) If a study is made on a single well field, the output map should be based on the period (season or 50 day period) with the maximum extraction rate over a season in the well field.

b) If a study is done on a greater area, one should have some data of extraction rates to know in what range the extractions are. In that case, several maps can be made, using in one map the average and in another the maximum value of Q.

c) If plenty of data of extraction rates are available, a map can be made of the whole area showing the distribution of extraction rate and using this map in the calculation of the distribution of the needed protection area. The limitation on this is that when using the map to define protection areas for a well to be drilled, this well should have an extraction rate corresponding with the extraction rate on the input map of Q-distribution.

3. THE DELINEATION OF WELLHEAD PROTECTION ZONES IN THE VERTICAL DIMENSION

3.1 Definition of the problem

In September 1999, Portugal ratified a new law on groundwater protection. It demands three wellhead protection areas for each public water supply well that abstracts more than 100 m^3 per day or serves more than 500 habitants. If the abstraction rate is lower or if the well supplies less than 500 habitants, only the immediate protection zone is required. Various activities and installations capable of polluting groundwater resources are prohibited within these protection zones in order to prevent contamination of drinking water. The immediate protection area encloses the surroundings of the wellhead, including the installations used for abstracting water. Depending on the type of aquifer, the outer boundary of this inner protection zone is defined at a fixed radial distance from the wellhead and can be easily marked. On the other hand, the intermediate and extended protection areas are defined by the time it takes for groundwater to reach the well from the outer boundary of the protection zone. Consequently, the delineation of the two outer protection areas becomes a complex problem that often requires numerical modelling.

There are many computer programs that can be used to simulate groundwater flow to a well. Two-dimensional flow models commonly use horizontal discretization of the aquifer. Consequently, lateral variations of the aquifer properties are taken into account while the vertical sequence of high- and low-permeability layers within the aquifer system and the position of the screens of the well are neglected. Three-dimensional models allow a more precise spatial description of the aquifer, but on the other hand, the calculations involved are much more complex and time-consuming. Besides, in most cases there is not enough data available to describe the distribution of hydrogeological properties at the same level of accuracy as the spatial discretization of the model grid.

The vertical heterogeneity of the aquifer can be estimated from the lithological logs of the well. The position of the screens of a well is commonly known. As these parameters are important for calculating groundwater flow to a well and because they are available without any further investigations, it is, therefore, desirable to develop a model capable of an efficient simulation using lithological and well screen data. In axisymmetric flow modeling, it is assumed that groundwater flow to a well is radial. In this case, a cylindrical section of the aquifer can be discretized into horizontal layers and vertical shells around the well. Hence, vertical heterogeneity can be conveniently described whereas lateral variations in the hydrogeological properties are ignored. These restrictions fit well with the data that is available for most wells and make axisymmetric flow modeling an appropriate and suitable approach for simulating groundwater flow to a well.

Axisymmetric flow models are based on the assumption that groundwater flow to a well is radial, while the regional hydraulic gradient is negligible. The only driving force of flow is abstraction from the well. Disregarding lateral variations of hydrogeological properties, the resulting cone of depression is perfectly axially symmetric around the well. Thus, a vertical cross-section from the well to the outer limit of the cone of depression sufficiently describes the sloping hydraulic gradient around the well. Therefore, the three-dimensional drawdown can be determined by modelling the distribution of piezometric levels in two dimensions. Following the method of finite differences, the cross-sectional plane of the geological system is divided into cells by columns and rows. However, it is important to note that the cells do not represent rectangular sections of the aquifer like in common two-dimensional grids. As the columns of the axisymmetric grid are concentric cylindrical shells around the well, each cell represents a ring-shaped element. In the neighborhoods of the pumping well, the hydraulic gradient increases and the cross-sectional area of flow decreases. Accordingly, finer discretization of the grid is required close to the well to accurately represent this increasing gradient. As an approximation of the distribution of hydraulic heads, the head value is calculated for the midpoint of each cell. Given that the rate of abstraction is constant, and flow is in a steady-state condition: inflow and outflow are balanced for each cell. The vertical exchange of groundwater between two cells can be determined by applying Darcy's Law. For calculating the horizontal flow of groundwater, the axial symmetry of the model has been taken into account by using the Dupuit-Thiem equation.

4. WELLHEAD PROTECTION AREAS APPLICATION TO A CASE STUDY AREA IN GOA, INDIA

4.1 Introduction

The developed methodology of determining the perimeters of protection zones was applied to a case study area by Krijgsman and Lobo-Ferreira (2001). For this, an area had to be chosen with enough reliable data available. The methodology is developed for use on unconfined aquifers, since these are the most directly vulnerable for pollutants entering from the surface.

First consideration was the Palmela County on the Setúbal Peninsula, near Lisbon, Portugal. This area consists roughly of a superficial (unconfined) aquifer and a deep confined aquifer, separated by an impermeable layer. There are numerous wells with hydrogeological data available, however all of them relate to the confined aquifer; no data are available of the superficial aquifer.

Other areas considered within Portugal were Torres Vedras and Ribeiras do Oeste. These areas displayed the same problem as with the Palmela County.

Another area, on which a research is being set up, is Goa, India, in cooperation with the University of Goa within the EU sponsored INCO-DEV COASTIN Project (Contract No IC 18-CT98-0296, http://www.dha.lnec.pt/nas/estudos/COASTIN.htm). LNEC received detailed data of an area of 8 by 15 km, consisting of a superficial aquifer. Data are available of all the needed parameters: water levels, aquifer thickness, screen length, extraction rates and porosity. Data are available of a maximum of 59 wells in this area; not all wells have data of each parameter.

Goa State, which has a land area of 3702 km², has a tropical climate with three seasons: a wet monsoon period from June to September, providing a precipitation of 2500 to 4300 mm, a winter season from October to January and a summer season from February to May. The population density of Goa is about 316/km² (Census 1991).

The case study area, which consists of a coastal area of 120 km², is situated in the northwestern corner of Goa in the district Bardez, having a population density of 717/km². The lithology consists of superficial laterites and sands, which are used as aquifers, underlain by precambriam metamorphic and crystalline rocks.

The studied area is rural, apart from the coastline, where many tourist resorts are located. The water demand is estimated on 150 liters per day in rural areas, while in tourist resorts this is about 500 liters (Chachadi and Raikar, 2000). To supply this demand, many large diameter wells are dug in the unconfined lateritic and sandy aquifers. A small part of the wells is in lithologies of (weathered) metagraywackes and phyllites. The well density is approximately 25 per km². The wells are normally shallow, not more than 15 m, with a diameter of up to 8 meters.

Available data:

- Water levels (taken on the same date), needed for deriving a hydraulic gradient (*i*): data are available on 57 wells for all seasons.
- Saturated aquifer thickness (*b*): data are available on 53 wells.
- Hydraulic conductivity (*K*): data, are available on 6 wells, ranging between 1.4 and 31 m/day.
- Extraction rate (*Q*): Data are available for two types of aquifers:

For lateritic aquifers: *Q* varies between 86 and 216 m³/d, from which an average of 151 m³/d is taken.

For sandy aquifers: *Q* varies between 155 and 259 m³/d, from which an average of 207 m³/d is taken.

- Effective porosity (*n*): data are available for 2 types of aquifers:

For lateritic aquifers: *n* varies between 0.20 and 0.30, from which an average of 0.25 is taken.
For sandy aquifers: *n* varies between 0.15 and 0.35, from which an average of 0.25 is taken.

4.2 Application of the methodology

4.2.1 Input data

For application of the methodology for delineation of wellhead protection areas, for the graphic outputs the program Surfer, version 6.01 of Golden Software is used.

As input, a data file is needed with information of coordinates of wells, together with data of *i, b, K, Q* and *n*.

From these data, continuous grids are extrapolated, all with the same dimensions to be able to make calculations with several grids.

- A hydraulic gradient, *i*, (rise over run) is derived from an extrapolated grid of water levels.

- For *b*, the saturated aquifer thickness is used. Using the screen length would be inadequate, since a large part of the extracted water in the wells originates from bottom inflow.

- For hydraulic conductivity, *K*, just six values are known, showing no clear correlation with lithology. From these six values a continuous grid is extrapolated.

- For extraction rate, *Q*, only two average values are known for the two lithologies. All wells with a lateritic lithology (37 wells) are given a value of 151 m^3/d, all wells in a sandy lithology (15 wells) are given the value of 259 m^3/d.

- For effective porosity, *n*, a value of 0.25 is taken as constant over the whole area. No grid is made since *n* has in this case a constant value.

Wells with data are well distributed throughout the whole area, except the south-western corner of the area, which is the Indian Ocean. Input data is shown in Figures 1- 4, and the wells are identified in Figures 1, 2 and 4 by the white dots. In Figure 3 the white dots represent the wells used for hydraulic conductivity assessment. There is however no topographical information available linked to the concerning area, because this information has been considered as classified. Therefore, no physical boundaries of the area are known. In this case this is no real obstacle, since this is only a demonstration of the use of the method on a non-hypothetical area.

4.2.2 Output of the methodology and conclusions of the regional 2D analysis

The three dimensions of the needed protection area have been calculated for three different seasons: the (dry) summer season, the wet season and the (dry) winter season. The differences in input between the seasons are the saturated thickness and the hydraulic gradient, both depending on the varying water levels. This could cause a difference in calculation of the protection area, depending on the season the data are used of. Figures 5-7 show the results obtained for the Summer Season.

The results obtained for the summer season, the wet season and the winter season, do not show significant differences per season in the dimensions of the needed protection areas.

The water levels can have a variation throughout the year of up to 6 m, but normally this is not more than 2-3 m. The hydraulic gradient derived from the water levels does not change much throughout the year. The maximum value is about 0.046 in the summer; in the wet season the maximum gradient is just slightly lower with a value of 0.043. Apparently the watertable rises or drops quite uniformly over the area with the change of season.

Due to the varying water levels, the saturated thickness will also vary throughout the year, but the effect on the needed protection area does not seem to be more than a few meters.

Whenever applying the methodology it should of course always be tried to estimate the maximum 50-day distance that is possible to occur in a certain time span. Theoretically, if calculating the upgradient protection distance it should therefore use, if available, the data of a season or year that create the highest hydraulic gradient, have the highest extraction rates or smallest aquifer thickness. The opposite is the case with the downgradient protection distance concerning the hydraulic gradient, thereby making it all more complex which data to use for which calculation.

In this case however, it proves not to result in considerable differences when using data of different seasons, which does not mean that this is always the case. After applying the methodology on more areas it will be possible to say more about this. As grid interpolation method in Surfer®, the default method kriging has been used. A different method could well give different results, as well as changing the options within the kriging method.

No physical boundaries are concerned. It is known that the south-western part of the case study area is the Indian Ocean. The exact location is not known; therefore it is treated as being land where data are missing and interpolated. In this case that does not matter much, since the area is only used for demonstrating the methodology.

Extrapolation of the grid of K-values is based on just six values. It would be a more logical approach to use a lithological map, from which a constant value of hydraulic conductivity per lithological unit is given. In this case there was no lithological map available.

A gradient is derived from data of levels in the wells, while the watertable in between the wells is probably higher. In other words, the gradient is derived from the maximum drawdown values, which are in the wells.

5. WELLHEAD PROTECTION ZONES IN THE VERTICAL DIMENSION

5.1 The computer program 'WellFlow'

In order to study groundwater flow to a well and to facilitate the delineation of wellhead protection areas espe-

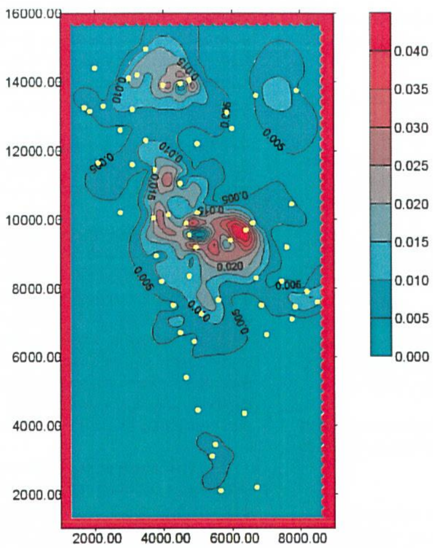

Fig. 1. Extrapolated grid of distribution of hydraulic gradient *i* in the wet season (07-28-2000).

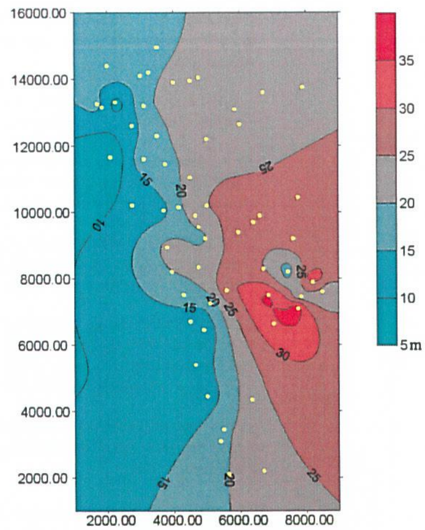

Fig. 2. Extrapolated grid of distribution of saturated aquifer thickness, *b*, for the wet season (07-28-2000)

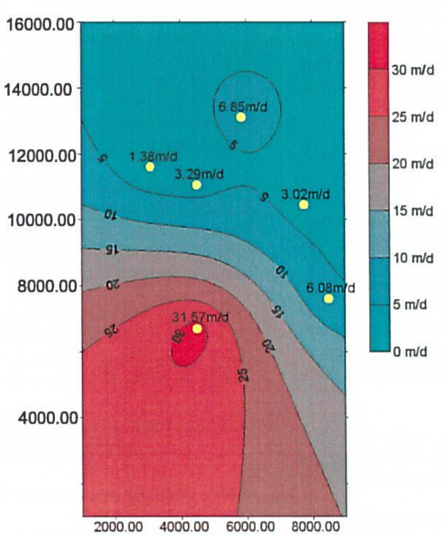

Fig. 3. Extrapolated grid of distribution of hydraulic conductivity, K.

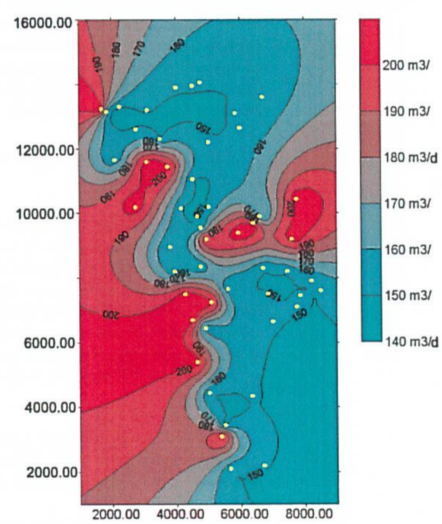

Fig. 4. Extrapolated grid of extraction rate or productivity, Q.

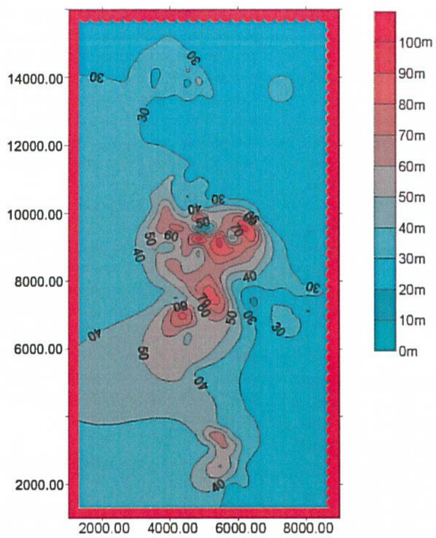

Fig. 5. Upgradient protection distance, as calculated with equation (2).

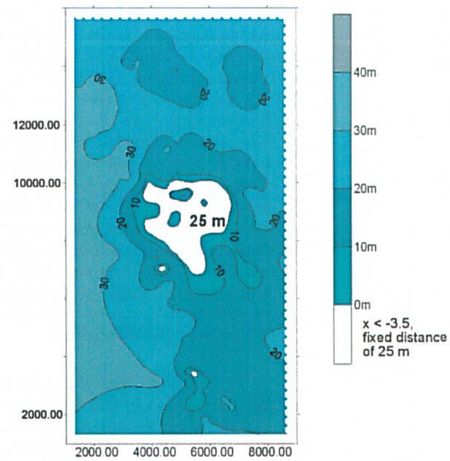

Fig. 6. Downgradient protection distance, as calculated with equation (3).

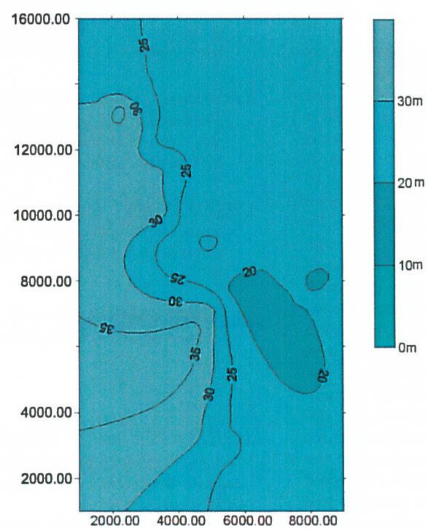

Fig.7. Protection distance perpendicular to direction of flow, as calculated with equation (4).

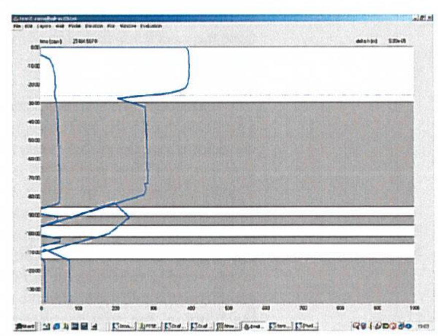

Fig. 8. Example of 50 and 3500 days isochrones with vertical influence (i.e. the stratification) of a potential pollutant, obtained with WellFlow model applied to a real pumping well located in Ramalhal, Portugal.

cially in multi-aquifer settings, the computer program 'WellFlow' was developed by Feseker and Lobo-Ferreira (2001). It is a user-friendly, menu- and mouse-driven stand-alone modeling tool for Windows and Mac OS. Steady-state groundwater flow to a well can be simulated by applying the method of finite differences, following an axisymmetric approach where a vertical cross-section of a cylinder is modeled in 2D. The well is defined by abstraction rate and radius. Hydrogeological units (lithological data) at the position of the well are entered as horizontal layers that are homogenous and bear a constant thickness throughout the model area. A steady-state hydraulic head is assigned to each layer. The head value serves as a fixed head boundary condition on the outer model limit, while the flow between layers resulting from different steady-state heads is taken into account during iteration. Recharge from precipitation surplus can be defined for the top layer of the modeled sequence. The program uses this basic input data to automatically generate a finite difference grid. The distribution of hydraulic heads is solved numerically using an iteration process. Once the desired accuracy is reached, groundwater streamlines, and time of travel distances can be calculated by means of forward and backward particle tracking.

The program can be used to study the effects of different screening and vertical heterogeneity in layered aquifer systems on groundwater flow to a well. Flow to partially penetrating wells can be simulated. In contrast to horizontal two-dimensional models, WellFlow enables the user to calculate travel times for different depths of particle starting points. Thus, the protective effect of low-permeability layers above the aquifer can be examined when determining the size of protection zones. Furthermore, it is possible to apply WellFlow model even before a well is sunk in order to determine the most suitable design of the well as far as protection zones are concerned.

The isochronal line illustrates that the time it takes for a particle to reach the well strongly depends on the depth of the point where the particle enters the aquifer system. As a first test, WellFlow model has been applied to a well in Ramalhal, Portugal. The well is situated in the cretaceous Torres Vedras aquifer, approximately 50 km from Lisbon. It is 135 meters deep and consists of 13 screened and 15 unscreened intervals. The litholog comprises 27 different layers, ranging from clays to sands and conglomerates. By combining the information on the screening of the well with the litholog, the aquifer system can be divided into 8 unscreened and 6-screened layers. The hydrogeological properties of these 14 layers have been estimated from the petrography described in the lithology. The conductivity of the high permeability layers ranges from 1e-5 to 1e-4 m/s, whereas the conductivity of the low permeability layers varies between 1e-9 and 1e-8 m/s. As the model yields approximately the same relation between the abstraction rate and drawdown in the well as documented in the well-performance test, the chosen values for conductivity seem reasonable. For particle tracking, it is assumed that the effective porosities are 0.2 and 0.1, respectively. Figure 8 shows the layers used in the simulation and gives an overview of the distances corresponding to travel times of 50 days and of 3500 days for different depths of particle starting points. It is obvious that the unscreened superficial aquifer and the uppermost aquitard protect the groundwater resources from pollutants injected close to ground surface. Above the first screen, flow velocities are so low that it takes a long time until groundwater from the two upper layers reaches the well. However, if there was a way for pollutants to quickly enter the deeper layers of the aquifer system, e.g. through an abandoned well or bore hole, they would reach the well much faster.

5.2 Conclusion of the axisymmetric radial model analysis

Axisymmetric models are well suited to modeling groundwater flow to a well, because all of the data that are already available for most wells may be included in the simulation. In contrast to horizontal two-dimensional models, both the vertical heterogeneity of multi layered aquifers and the position of the screens can be taken into account. Especially in the context of the delineation of wellhead protection areas, it seems important to include the vertical dimension in travel time calculations.

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