P-ISMAR 9

9[TH] INTERNATIONAL SYMPOSIUM ON MANAGEMENT OF AQUIFER RECHARGE, ISMAR-9, POSTERS. MEXICO CITY





9º SIMPOSIO INTERNACIONAL DE GESTIÓN DE LA RECARGA DE ACUÍFEROS, ISMAR-9, PÓSTERS. CIUDAD DE MÉXICO

EDITOR: ENRIQUE FERNÁNDEZ ESCALANTE, MARSOL-TRAGSA

9TH INTERNATIONAL SYMPOSIUM ON MANAGEMENT OF AQUIFER RECHARGE, ISMAR-9, POSTERS. MEXICO CITY.
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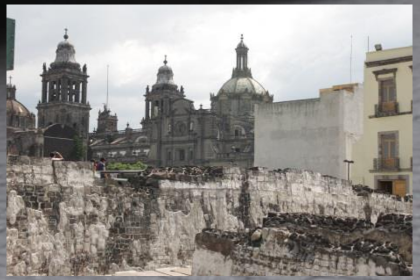

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Revisión de la versión en inglés: Peter Dillon
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Redacción en chino: Wang Weiping

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POSTERS DEL 8º SIMPOSIO INTERNACIONAL DE GESTIÓN DE LA RECARGA DE ACUÍFEROS ISMAR-9, CIUDAD DE MÉXICO.

INTRODUCCIÓN

Entre los días 20 y 24 de junio de 2016 tuvo lugar el congreso ISMAR 9 en la Ciudad de México, promovido en esta nueva edición por el Grupo de Recarga Gestionada de la Asociación Internacional de Hidrogeólogos (AIH), LA UNESCO y la Sociedad Americana de Ingenieros Civiles (ASCE), bajo el lema: *"Sustainable water management solutions to scarcity and climate change."*

El simposio reunió a 225 delegados de 17 países y contó con cuatro cursos de primer día, 113 publicaciones, de las que 83 fueron presentaciones escritas, de las que 71 fueron expuestas de forma oral.

Además se registraron 30 pósters, aunque finalmente fueron presentados y exhibidos 22, dando cobertura a cinco áreas con numerosas líneas temáticas distintas, que fueron Diseño y construcción de dispositivos de recarga gestionada, Operaciones y mantenimiento, Gobernanza, Aplicaciones de la técnica MAR en la gestión hídrica integral y otros temas específicos relacionados con la técnica MAR.

•El texto de unas 30 comunicaciones escritas se encuentra en proceso de selección para quedar recogido en dos "Journals": MDPI J Water sobre "*Water Quality Considerations for Managed Aquifer Recharge Systems*" http://www.mdpi.com/journal/water/special_issues/ARS
O en Springer J of Sustainable Water Resources Management on "*Integrated Water Management Incorporating Managed Aquifer Recharge*" *http://link.springer.com/journal/40899*.

La organización del evento, organizado especialmente por la Universidad Nacional Autónoma de México (UNAM) con el apoyo decidido de la Comisión Nacional del Agua (CONAGUA), la Asociación Nacional de Empresas de Agua Potable y Saneamiento, el Programa Hidrológico Internacional,, de la Sociedad Hidrológica de Arizona y de la Asociación de Aguas Subterráneas de California.

Patrocinaron el evento: Suez, Agua de Puebla para Todos, Consultoría de Ingeniería para Soluciones Integradas, Mantenimiento y Construcción de Acuíferos, Construcciones Fypasa, Veolia, MARhub, Aqualia, la National Groundwater Association, GCA Ingeniería y la Asociación Geohidrológica Mexicana.

Las mayoría de las ponencias orales enviadas por los presentadores con carácter voluntario quedan accesibles vía Internet en la dirección: http://linux.iingen.unam.mx/pub/ISMAR9/Presentations

Otras no facilitadas por los organizadores pueden ser descargadas en la página web de DINA-MAR: http://www.dina-mar.es/post/2016/08/03/ISMAR-9-PRESENTATIONS-AVAILABLE-ON-THE-INTERNET-LA-MAYORIA-DE-LAS-PONENCIAS-DEL-CONGRESO-ISMAR-9-DISPONIBLES-EN-INTERNET.aspx

Las presentaciones tipo póster fueron solicitadas por la organización a los autores, dando continuidad a la serie de libros P-ISMAR iniciada por Tragsa en 2002. algunos de los pósters adjuntos no han tenido proceso de revisión por pares, siendo, por tanto, dudosa su referencia científica. No obstante son registrados como contribuciones a los Simposios ISMAR, documentando actividades y facilitando la conexión entre los autores.
Por estas razones, y prosiguiendo esta importante línea de acción, la Comisión de Recarga Gestionada de la AIH ha animado a Tragsa a seguir adelante con futuras ediciones.

El trabajo de recopilación, clasificación y edición se llevó a cabo en el marco del proyecto de investigación MARSOL a cargo del socio "Tragsa" (en su etapa de difusión y transferencia tecnológica), con la ayuda de los coordinadores de la IAH-MAR-Commission. El resultado es la presente publicación, que consta de 20 pósters de los ficheros digitales facilitados por los autores, que permiten compartir una información que, de otro modo, se habría perdido.

El índice de los pósters allí presentados figura a continuación. No todos los presentados se ajustaban fielmente al programa planificado, pues hubo altas, bajas y sustituciones.

El equipo de investigación de MARSOL ofrece su apoyo para incluir o sustituir los pósters ausentes que pudieran surgir en el futuro, a través de su dirección web http://www.dina-mar.es/ o del Email ismar10@tragsa.es

Agradecemos a todos los autores el apoyo prestado y la cesión de permisos para la difusión en Internet de esta información de carácter científico, así como a la comisión de Recarga Gestionada de la AIH por su apoyo en el desarrollo de esta idea.

Información adicional sobre este evento se encuentra en: http://www.ismar9.org/Default.htm

P-ISMAR 9

POSTERS OF THE 9TH INTERNATIONAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE, MEXICO CITY

INTRODUCTION

ISMAR 9 was held in Mexico City on 20 - 24 June 2016 with the theme *"Sustainable water management solutions to scarcity and climate change."*

225 delegates from 17 countries attended the symposium, which included 4 workshops, 113 presentations and 22 poster papers. The program is at www.ismar9.org and most of the oral presentations are available in the UNAM server: http://linux.iingen.unam.mx/pub/ISMAR9/Presentations A number of authors, icluding poster paper authors, were invited to submit written papers for review for publication in an MDPI J Water thematic issue on "*Water Quality Considerations for Managed Aquifer Recharge Systems"*
http://www.mdpi.com/journal/water/special_issues/ARS
or by Springer J of Sustainable Water Resources Management on "*Integrated Water Management Incorporating Managed Aquifer Recharge"*
http://link.springer.com/journal/40899.

Of the 22 poster papers presented, this book contains the 20 posters whose authors provided them in electronic form, and is mounted on http://www.dina-mar.es/post/2016/08/08/Libros-sobre-la-tecnica-MAR-(repositorio)-MAR-books-repository.aspx

ISMAR9 was supported by the International Association of Hydrogeologists (IAH MAR Commission), UNESCO International Hydrological Programme and the American Society of Civil Engineers (ASCE), in partnership with BSMAR15 of the Arizona Hydrological Society and Groundwater Resources Association of California. ISMAR9 was organized by the National Autonomous University of Mexico (UNAM) , National Water Commission (CONAGUA) and the National Association of Water and Sanitation.

The Poster Papers and Exhibition was sponsored by Suez, Agua de Puebla for All Consulting Engineering for Integrated Solutions, Maintenance and Construction Aquifer, Construcciones Fypasa, Veolia, MAR-Hub, Aqualia, the National Groundwater Association, GCA Engineering and the Mexican Geohydrological Association.

Organizers

The ISMAR9 website also contains daily newsletters of the ISMAR9 symposium, photographs and a link to the oral presentations:
http://www.dina-mar.es/post/2016/08/03/ISMAR-9-PRESENTATIONS-AVAILABLE-ON-THE-INTERNET-LA-MAYORIA-DE-LAS-PONENCIAS-DEL-CONGRESO-ISMAR-9-DISPONIBLES-EN-INTERNET.aspx

Classification of and web-publishing of posters was carried out by the MARSOL project through its partner "Tragsa", as a dissemination and technology transfer activity.

This extends the series of ISMAR poster paper compendiums assembled by Tragsa. Some of the material presented is unreviewed, and as such cannot be relied on as a scientific reference source. However it is made available by Tragsa to record poster papers contributed to ISMAR symposia, to document MAR operations and related activities underway and facilitate future connections to authors. For these reasons, and with this important caveat, the IAH Commission on MAR encourages Tragsa to continue this task.

The titles of the posters and their authors are listed in the index below.

The MARSOL research team provides authors of missing papers to include the missing posters in the future in www.dina-mar.es by emailing ismar10@tragsa.es. We would like to thank all the authors, whose support (including permission to publicise their work) is sincerely appreciated.

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墨西哥城（墨西哥）第九届国际含水层补给管理研讨会展板集
简介
2016年**6**月**20-24**日在墨西哥城召开了主题为“解决水资源短缺和气候变化问题的可持续水资源管理”的第九届国际含水层补给管理研讨会。

本次研讨会有来自**17**个国家的**225**位代表与会，有**4**个会前研讨会、**113**个大会发言和**22**个海报。会议日程详见www.ismar9.org ，并且大部分大会发言的**PPT**（**PDF**格式）可见墨西哥国立自治大学服务器：http://linux.iingen.unam.mx/pub/ISMAR9/Presentations 。一些作者包括部分海报作者被邀请递交书面论文，这些论文审查后会将发表在主题为“含水层补给管理系统的水质问题”的**MDPI**的**Journal Water**期刊上，网址是http://www.mdpi.com/journal/water/special_issues/ARS，或者是发表在主题为“考虑含水层补给管理的综合的水资源管理”的施普林格期刊“**Journal of Sustainable Water Resources Management**”，网址是http://link.springer.com/journal/40899。

这本书包含了作者们以电子版形式提供的**22**篇海报中的**20**篇，请见http://www.dina-mar.es/post/2016/08/08/Libros-sobre-la-tecnica-MAR-(repositorio)-MAR-books-repository.aspx

本次研讨会得到了国际水文地质学家协会（含水层补给委员会）、联合国教科文组织国际水文计划和美国土木工程师协会的支持，并与亚利桑那州水文协会的第十五届两年一次可管理的含水层补给研讨会（**BSMAR15**）、加利福尼亚州地下水资源协会合作。由墨西哥国立自治大学、国家水务委员会和水与卫生设施国家委员会组织这次会议。

海报和展览由以下公司赞助：**Suez, Agua de Puebla for All Consulting Engineering for Integrated Solutions, Maintenance and Construction Aquifer, Construcciones Fypasa, Veolia, MAR-Hub, Aqualia, the National Groundwater Association, GCA Engineering and the Mexican Geohydrological Association**。

DINA-MAR网站同样涵盖了研讨会的时事通讯、照片和会议演讲的链接：goo.gl/b4ehTK

MARSOL项目的承担者之一**“Tragsa”公司作**为一种传播和技术宣传活动承担了**海**报的分类和网上发表。

这次会议海报进一步扩展了由**Tragsa公司**编辑的的历届国际含水层补给研讨会（**ISMAR**）**海**报论文系列丛书。因材料未审核**,所以不能作**为一个科学的参考来**源。然而**，**tragsa 不**仅可以记录有益于国际含水层研讨会的海报论文、**MAR的运行操作以及正在**进行的**相关活**动，还可以进一步的促进和作者之间的联系。**由于**这些原因和重要性，国际水文地质家协会含水层补给委员会鼓励**Tragsa**继续这个工作。

海报的标题及其作者列在下面的索引中。

MARSOL研究团队将会把缺失论文的作者包括缺失的海报通过电子邮件发往**ISMAR10@tragsa.es**。**我**们真诚的感谢所有支持我们的作者 **(包括**许可公开他们的成果**)**。

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Impact in the quality of surface and groundwater generated by the leachates at the Municipal Landfill Linares, Mexico. H. de León-Gómez, R.A. Dávila Pórcel, A. Cruz López
Groundwater modelling of the Coastal Aquifer of Santa Marta, Colombia, under different hydrological and pumping scenarios, including sea-water intrusion, artificial recharge and Interbasin transfer. G. Cifuentes, C. Molano
Temperature measurements during Managed Aquifer Recharge for safeguarding subsurface travel times. C.Sprenger, H.Schwarzmueller, G.Lorenzen, R. Gnirss, G.Gruetzmacher
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Integrated Modeling Approach for Sustainable Water Resources Management: The Case of Mexico City Metropolitan Zone Aquifer. M. C. Hernández-Rendón, E. Abdelshahid, M. Schöniger
The Influence of Filtration Treatment on Soil Aquifer Treatment (SAT) Infiltration Rates and Water Quality. G. Arye, O. Mienis, A. Aharoni, Ido Negev
Infiltration Basin: an Alternative Recharge Method for El Paso’s Managed Aquifer Recharge Program. Z. Sheng, A. Shalamu, G. Miller, S. Reinert, B. Smith, O. Rodriguez
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Problems of Artificial Recharge in Unconfined Aquifers – Examples from Germany and Syria. U. Tröger, M. Wannous
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An account of Artificial Groundwater Recharge in an Overexploited Block with special reference to Kottukal Micro watershed, Kerala S. India, L. Thompson, P. Nair
Groundwater Quality Improvement due to Rainwater Harvesting in Costal Aquifers. N. K. Gontia, P. G. Vadher & Y. Sharma.

Integrated Approach for Artificial Recharge to Groundwater in an Infrastructure Project, Haryana, India

Mexico City, Mexico. June 20th-24th, 2016.

Dr. D.K. Chaddha & S. K. Mohiddin

Principal Advisor, Global Hydrogeological Solutions, devinderchadha27@gmail.com Tel.: +91-9911-38-1139
Scientist, MoWR, RD & GR, New Delhi, mohiddinsk65@gmail.com, +91-9560599977

INTRODUCTION

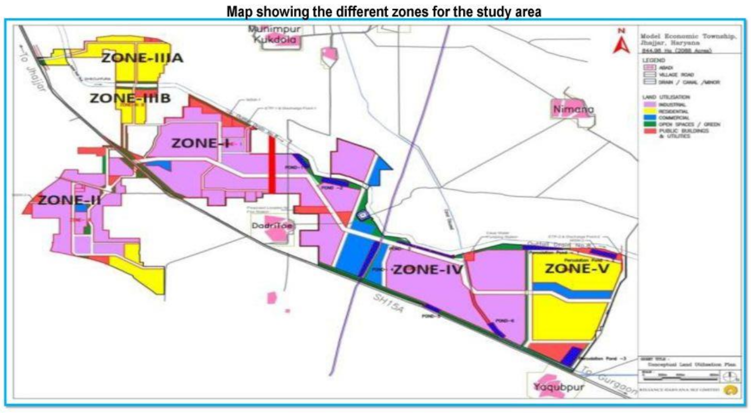
- The study area is fast developing as an infrastructure hub but the water resources, groundwater and surface water, are scares to meet the demand.
- The implementation of MAR projects is mandatory under the urban by laws if the groundwater is to be developed to meet the water requirements.
- As part of Integrated Water Resources Development & Management for supplementing the water resources for an infrastructure project covers an area of 7.53 Sq Km.
- In this area, with the continuous development of groundwater, the water table has declined and the stage of groundwater development has reached 95% of the annual recharge- discharge relationship.

METHODOLOGY

Sub-surface storage capacity of the project area is about 7.53 sq km is about 4.63 MCM and the volume of water which can be recharged is 5.4 MCM.

• The area is divided into 5 zones (catchment) based on the surface slopes (prepared for 5m and 10m), directions and flow of storm water drains and existence of outlets for disposal of final storm water.

Map showing the different zones for the study area

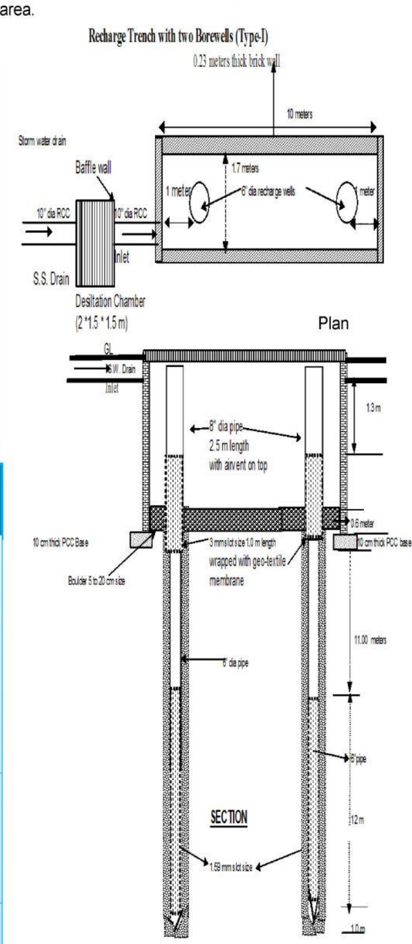


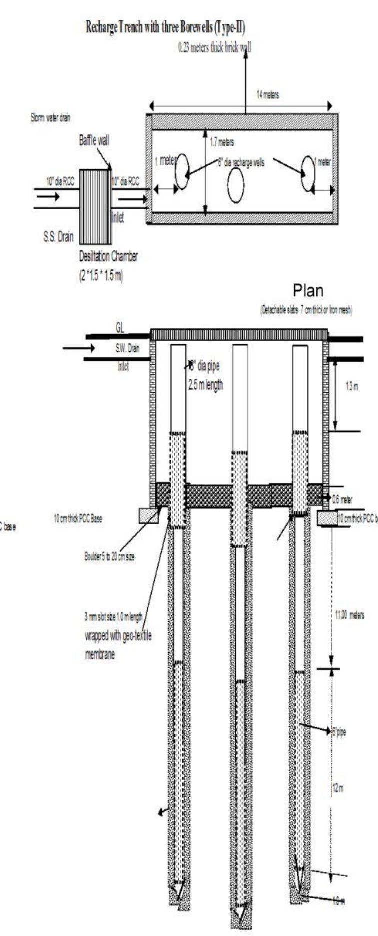
RESULTS

Zone 1	Area in acres (Sq.m) 2	Depth to water level during February, March, 2015 below cut-off level of 3.00 mbgl 3	Volume of unsaturated zone (Cu.mt) 4=(3*2)	Average specific yield 5	Total subsurface storage potential as volume of water (Cu.mt) 6=(4*5)/100	Recharge efficiency (%) 7	Source water requirement (includes both storm water and surface water from the drain) 8	Total annual rain water harvesting capacity (Cu.m)
Zone-I (245 acres)	95acres (384465)	8.00-3.00=5 m	1922325	12%	230679	85%	271387	216645
	110acres(445170)	7-3=4 m	1780680	12%	213682	85%	251390	
	40acres (161880)	5-3=2.0 m	323760	12%	38851	85%	45707	
Zone-II (205 acres)	70 acres (283290)	11-3=8 m	2266320	12%	271958	85%	319951	197309
	135 acres (546345)	9-3=6m	3278070	12%	393368	85%	462786	
Zone-III (145 acres)	60 acres (242820)	11-3=8 m	1942560	12%	233107	85%	274244	111600
	45 acres (182115)	9-3=6 m	1092690	12%	131123	85%	154262	
	40 acres (161880)	5-3=2m	323760	12%	38851	85%	45707	
Zone-IV (860 acres)	700 acres (2832900)	9-3=6 m	16997400	12%	2039688	85%	2399633	826559
	160 acres (647520)	5-3=2 m	1295040	12%	155405	85%	182829	
Zone-V (350 acres)	280 acres (1133160)	9-3=6 m	6798960	12%	815875	85%	959853	449217
	70 acres (283290)	5-3=2 m	566580	12%	67990	85%	79988	

DISCUSSION

Recharge structures are designed and recommended based on the runoff availability in each mini catchment and space available for construction of the recharge structures in green belt. Based on the availability of runoff and land for construction, the recharge structures are recommended. It is recommended to construct two types of recharge trenches with tubewells and percolation ponds in the area.





CONCLUSIONS

- The groundwater regulatory authorities have permitted to draw 1.2MCM of groundwater and in lieu of it was directed to prepare the master plan for generating additional water resources of 1.45MCM.
- The integration of artificial recharge structures which are basically recharge trenches and shafts associated with recharge tubewells (totaling 120 structures) along with 17 percolation ponds which will not only meet the stipulated water demand but will also help in preventing the water logging and improve the recharge capabilities, thus reducing the wastage of storm water runoff which ultimately entering into the drain which carries waste water enroute and cannot be used at later stages.
- More technology interventions like MAR are required for the proper utilization of runoff created during rainy season for its effective utilization.
- Areas where rainfall is not adequate to contain the decline trend of water table, other sources of water like treated wastewater will also be taken into consideration for creating sub-surface storages.

References: Dillon P., Page D., Vanderzalm J. and Chadha D.K. 2013 Water Quality Considerations in Managed Aquifer Recharge: from Artificial Recharge to Managed Aquifer Recharge in India, Journal of Groundwater Research, Vol.2/2, December 2013.
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This is to acknowledge the support given by Gayatri Raju and Anuja Negi for the preparation of paper and poster.

"Sustainable water management solutions to scarcity and climate change"

www.ismar9.org

ISMAR9
Mexico City, Mexico.
June 20th-24th, 2016.

Characterization of the Yucatan karst aquifer: intrinsic vulnerability scenarios and possible solutions

Miguel Moreno, Catalin Stefan and Rudolf Liedl
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INOWAS
www.tu-dresden.de/uw/inowas

INTRODUCTION

- Karst aquifers are the fresh water source for around 25% of the global population, however, intrinsic features as cracks, fissures and sinkholes decrease natural protectiveness, turning them into more susceptible against pollution. The Yucatan karst aquifer (Mexico) undergoes a decrease in groundwater quality due to two main factors: untreated wastewater disposal and increased rainfall concentration due to urbanization.
- The aim of this work was to determine two intrinsic vulnerability scenarios for the Yucatan karst aquifer, the actual situation (2015) and a projection for the year 2060. For both scenarios, the European approach (COP method) for intrinsic vulnerability was adapted to match natural characteristics of the study area, additionally, global change factors were added as indicators of anthropogenic flow concentration.

STUDY AREA

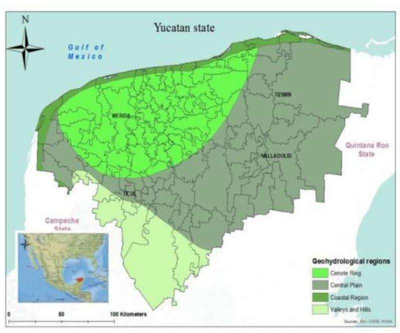


Figure 1 – Geohydrological regions of the study area

The study area (Fig. 1) is the Yucatan state, located in south of Mexico.

Yucatan extension is of about 39,524 km^2 and holds a population number of 2.1 million inhabitants (2015).

The area is flat, with karst features as sinkholes, fissures and cracks.

No streamflow occurs due to low elevation gradients and high permeability of the limestone.

Precipitation is seasonal and volumes vary spatially.

METHODS

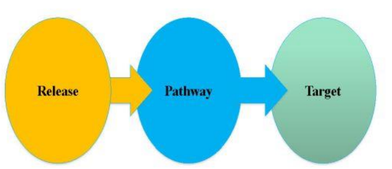


Figure 2 – Intrinsic vulnerability model. Target can be either the groundwater or a spring.

Following a release-target model (Fig. 2), the COP method was developed according to the European COST Action 620 on "Vulnerability mapping for the protection of carbonate (karst) aquifers" [1]

Intrinsic vulnerability maps display the natural protectiveness of certain area and are independent of the nature of the pollutants [2].

- According the model (fig. 2), the surface is considered the release point, the unsaturated zone the pathway and groundwater the target (resource vulnerability). Data used to develop vulnerability maps are displayed in Table 1.

Table 1 – Factors analyzed by the COP method and necessary data for maps developing

Maps	Sub-factor	Necessary data
Concentration of flow C	Slope-vegetation (Sv)	Land use, digital elevation models
	Surface features (Sf)	Swallow holes location, degree of karstification
	Distance to swallow hole (Dh)**	Digital elevation model
	Distance to sinking streams (Ds)**	Digital elevation model
Overlying layers O	Soil (Os)	Soil texture and thickness
	Lithology (Ol)	Boreholes data, field tests
	Confined conditions (Cn)	Boreholes data, field tests
Precipitation P	Quantity (Pq)	Precipitation averages
	Intensity (Pi)	Historic of rainy days

- A combination of population density (Pp) and demography (Pm) resulted in a global change factor (GC) included in the adapted COP method (Table 2) to show anthropogenic flow concentration

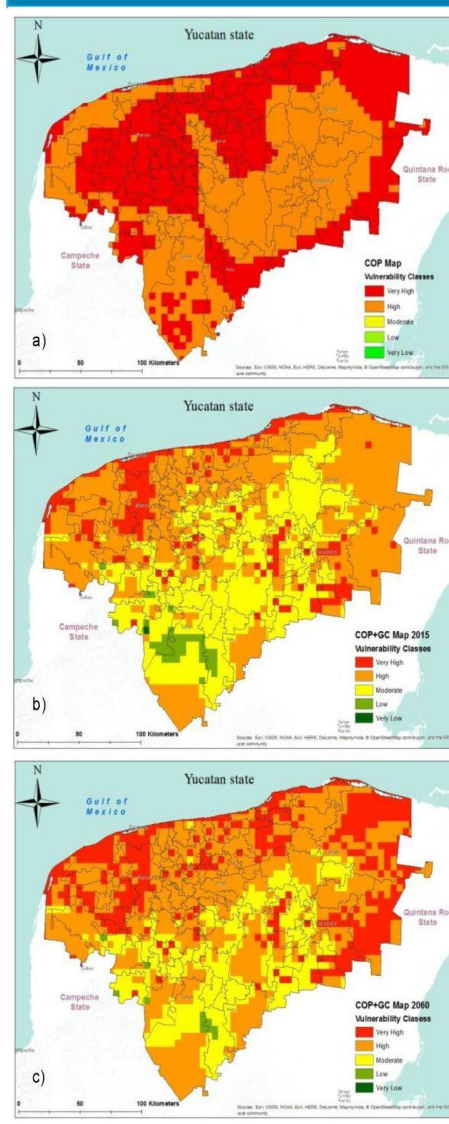
Table 2 – Global change factor and weighing scheme

Demographic Range (inh/municipality)	Demographic weighing factor	Population Density (inh/km2)	Population Density Weighing factor	Global Change Factor	Global Change Vulnerability
< 10,000	5	< 25	0.5	0.5 - 2.5	Very High
10,000 - 25,000	4	25 - 50	1	2.5 - 4.5	High
25,001 - 50,000	3	51 - 100	1.5	4.5 - 6.0	Moderate
50,001 - 100,000	2	101 - 150	2	6.0 - 8.0	Low
> 100,000	1	> 150	2.5	> 8.0	Very Low

- Adapted vulnerability maps (COP+GC) resulted from the overlaying maps:

$$COP + GC = C\ Score * O\ Score * P\ Score * GC\ Score$$

RESULTS



- For the COP map, precipitation is the only factor leading changes in vulnerability (Fig. 3-a).
- Shallow groundwater table, thin soil layers and a high degree of karstification were the key features affecting intrinsic vulnerability.
- Areas with a population number above 50,000 inhabitants (Fig. 3-b) displayed a very high vulnerability.
- Eastern areas, although having a high population number, remain as highly vulnerable due to low Pp values and high precipitation rates.
- Low and very low vulnerabilities counted for 3% of the state, highlighting the effect of urbanization even in low populated areas.
- Vulnerability is expected to be remarkable in the capital city and its surrounding areas (1,800 km^2) where concentrated infiltration is enhanced due to urbanization (Fig. 3-c).
- Changes of vulnerability inside the ring of cenotes, are driven mostly by urbanization rates with no effects driven by precipitation changes.

Figure 3 – a) COP map with default parameters; b) COP+GC map for the 2015 scenario; c) COP+GC map for the 2060 scenario.

CONCLUSIONS

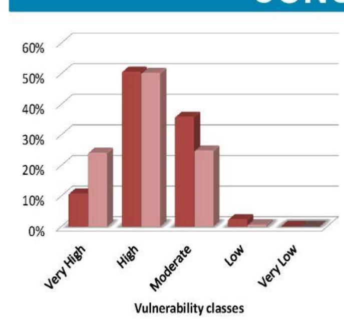


Figure 4 – Vulnerability percentages comparison for actual and projected scenarios.

- Vulnerability maps are important tools to highlight groundwater pollution risk, but adjustments would be necessary when the chosen method has been developed for specific regions.
- Urban flow concentration and changes in precipitation volumes are the main factors driven vulnerability changes for future scenarios (Fig. 4).
- The "ring of cenotes" area is expected to undergo a very high vulnerability in future scenarios due to strong urbanization, therefore, better practices for rainwater disposal must be evaluated and encouraged in this area.

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[1] Zwahlen, F. (2004). Vulnerability and risk mapping for the protection of carbonate (karst) aquifers, final report (COST action 620). European Commission, Directorate-General XII Science. Research and Development, Brussels, 297.
[2] Vrba, J., & Zaporozec, A. (1994). Guidebook on mapping groundwater vulnerability. Heise

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Project NIRWINDU

Measures to mitigate flood risks at RBF sites with a focus on India

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Introduction

The direct entry of floodwater, resultant contamination and damage to groundwater and riverbank filtration (RBF) wells frequently cause the disruption of drinking water production in floodprone areas worldwide, including India (e.g. Uttarakhand, Figs. 1 & 2). Direct flood risks include a deterioration of abstracted water quality (turbid water and microbiological contamination) and damage to well infrastructure (Tab. 1).

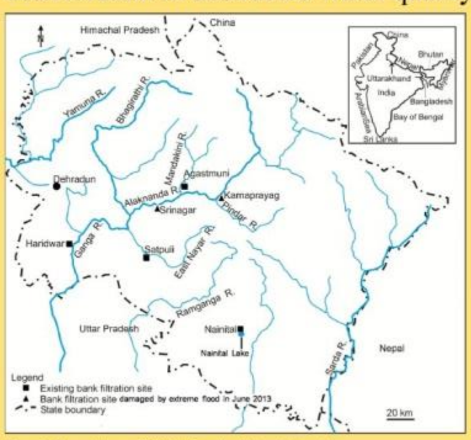

Fig. 1: Locations of RBF sites in Uttarakhand

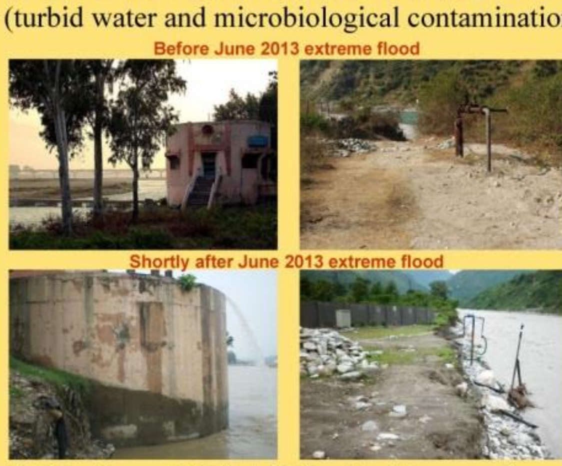

Fig. 2: Flood damage to RBF sites in Haridwar (L) and Karnaprayag (R)

Tab. 1: Direct flood risks to RBF sites in Uttarakhand and critical points on wells

Direct flood risk	Haridwar	Srinagar	Gauchar	Karna-prayag
Well design above ground level				
Absence of well head chamber	n/a	x	x	x
Non-watertight well head or cracks / fissures in caisson	x*	x	x	x
Absence of concrete base around well head (sanitary seal)	x*	n/a	x	x
Non-watertight control panel	n/a	x	n/a	x
Well design below ground level				
Absence of borehole annulus sealing with swelling clay pellets between groundwater table and ground surface	x	x	x	x

x: applicable; x*: applicable for some wells; n/a: not applicable

Field investigations and results

The **watertightness** around the base of a large-diameter caisson RBF well in Haridwar was checked by infiltrating ~0.5 m^3 of NaCl tracer having an electrical conductivity (EC) of 180 mS/cm (Figs. 3 & 4). The EC of the pumped well water increased from its ambient value of 201 µS/cm to a maximum of 488 µS/cm, indicating that 50 % of the peak EC value was observed within a short time of 20 minutes thus emphasizing the high direct risk of contamination (Fig.5).

Fig. 3: RBF well in poor sanitary condition (unsealed base, cracked caisson)

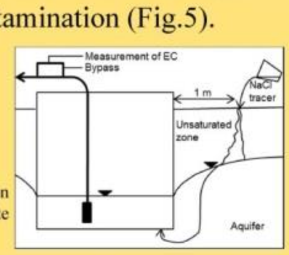

Fig. 4: Tracer infiltration at caisson well to illustrate flood water seepage

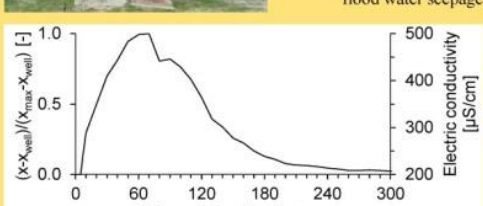

Fig. 5: Breakthrough of 50 % of tracer in RBF well was measured after 20 minutes (t_{50}) [x = EC of pumped water from well; x_{max} = maximum EC of pumped water; x_{well} = ambient EC of well water]

An **impounding experiment** was conducted by filling water into a cylinder placed over the head of a vertical well (Fig. 6). Despite an initial impoundment and a constant inflow of 32.6 L/minute, the water level steadily decreased and could not be maintained constant. With 326 L water pumped into the cylinder, a total of 334 L seeped (incl. 8.2 L from initial impoundment) into the well head chamber (Fig. 7) through gaps in the rubber seal of the well cover and the frame of the cover (Fig. 8).

Fig. 6: Vertical RBF well impounded in Dresden (Germany). The cylinder-base is sealed to well head with swelling clay

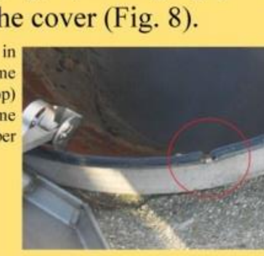

Fig. 8: Gaps in rubber seal of frame of well cover (top) and between frame and well chamber (bottom)

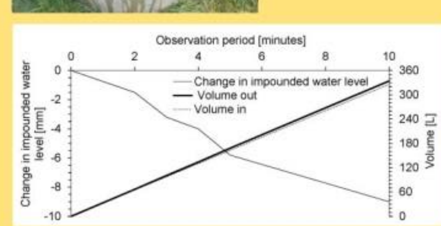

Fig. 7: Seepage into well head chamber during impounding experiment

Direct flood risk mitigation measures

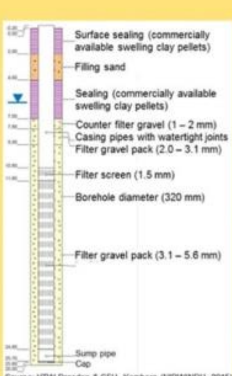

Fig. 9: Proposed sealing of borehole annulus

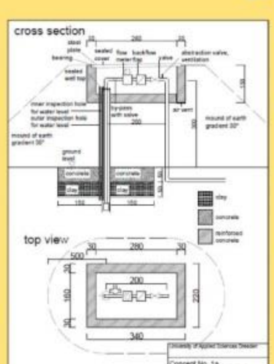

Fig. 10: Design of a cement-concrete flood-proof RBF well head chamber built on elevated mound

- Ensure borehole annulus is sealed with commercial swelling clay pellets (that remain moist year-round) at critical points e.g. at ground surface and at groundwater table depth (Fig. 9).
- Ensure watertight well head covers and interface between well cover and well head by attaching durable rubber seals and sealing interface with inexpensive purpose-built sealants or adhesives.
- Prevent direct flood-water entry and damage to well-infrastructure by placing well head chambers at a sufficient geodetic elevation (Fig. 10).
- Coupling of RBF wells with safe and robust disinfection techniques (e.g. inline-electrolysis) is a step towards ensuring year-round safe drinking water supply (Figs. 11 & 12).

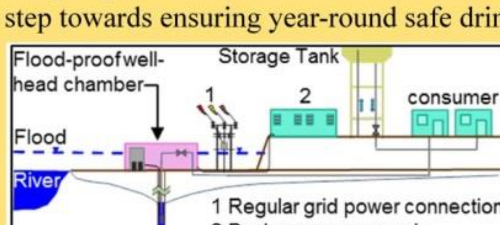

Fig. 11: Conceptualized coupling of RBF with floodproof elements, disinfection by inline-electrolysis and online water quality controls

Fig. 12: Field-trials of an inline-electrolysis disinfection pilot-plant at RBF well 18 in Haridwar (Photo pilot-plant: W. Schmidt, TZW Dresden, 2016)

Further reading

Sandhu C, Grischek T, Macheleidt W, Heisler A, Kimothi PC, Patwal PS (2016) **Measures to mitigate flood-risks at riverbank filtration sites with a focus on India**. Proc. 9th Int. Symp. Managed Aquifer Recharge – ISMAR9, Mexico City, Mexico, 20.-24.06.2016.

Sandhu C, Grischek T, Ronghang M, Mehrotra I, Kumar P, Ghosh NC, Rao YRS, Chakraborty B, Patwal PS, Kimothi PC (2016) **Overview of bank filtration in India and the need for flood-proof RBF systems**. In: Wingtens et al. (Eds.) Natural water treatment systems for safe and sustainable water supply in the Indian context – Saph Pani; IWA Publishing: London, UK, pp. 17-38.

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The Cabo Aquifer System: Regional Groundwater level Dynamics in Recife City (Brazil)

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INTRODUCTION

The uncontrolled population growth in the last decades in the Recife Metropolitan Region (RMR) has increased, consequently, the number of the production wells, principally in the neighborhoods near to the beaches. Due to this, some studies have presented average drawdown of the potentiometric surface close to 40 m in some places of the region during six years (1994-1999) [1]. Recently, studies carried out by a French-Brazilian research in the COQUEIRAL project showed that the RMR has various sources and processes of salinization [2]. Because of the natural conditions, occupation patterns and water management challenges, Recife is a hot spot for groundwater investigations. This work presents some results and analyses of the regional dynamics of the groundwater static levels on the Cabo Aquifer, one of the most exploited formations in the RMR, based in the observed data collections in the Boa Viagem neighborhood and surrounding areas. The study is important for issuing water management strategy for this hot spot area.

MATERIAL AND METHODS

Study Area

- The RMR is located in the coastal region of the Pernambuco State (Northeast of Brazil) and has a total area of 2,769 km^2 (Figure 1);
- The most part of the RMR habitants is concentrated at localities near to Recife downtown and neighborhoods near to the beaches, especially at Boa Viagem beach;
- Estuarine area with a network of secondary waterways and average rainfall around 2,200 mm;
- Around 6,200 private wells licensed by APAC (Pernambuco State Water and Climate Agency) in the RMR and more than 13,000 estimated, including some abandoned one.

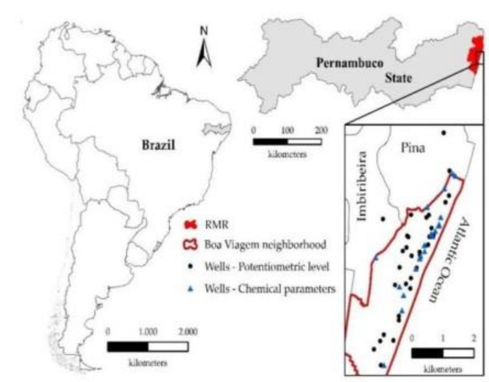

Figure 1 – Recife Metropolitan Region (RMR) location and wells used to collect groundwater static levels and chemical data in the Boa Viagem neighborhood.

Groundwater Static Levels

- The groundwater static level of the Cabo aquifer was obtained from 27 wells (P1 to P27) drilled in the Boa Viagem neighborhood and surrounding areas, as show the black points in Figure 1;
- The growth in the sequence of the numbers is in the south-north direction;
- The data variations were obtained manually through a water level measurer with electrical contact device over nine years (2005-2014).

Electrical Conductivity

- A total of 20 wells on the Cabo aquifer were selected and sampled to the chemical analysis, as show the greys triangles in Figure 1;
- The sequence of the numbers followed the same direction south-north used in the groundwater level wells
- Measurements of the electrical conductivity were made in situ during the campaigns in 2012 and 2013 carried out in the scope of the COQUEIRAL project [7].

RESULTS AND DISCUSSION

In general, it was not observed an abrupt decrease of the groundwater static level as it was detected in another studies performed in the past decades, that presented drawdown upper to tens meters in a few years [5,6]. The exception in the series was observed in the well P10, that experienced the highest drawdown rates in the Cabo aquifer and showed a total decrease of nearly 20 meters for the period 2005-2014.

The wells located in the southernmost area presented drawdown in the period of study, marked by red color (Figure 2). However, despite the drawdown, the differences between the two opposite measurements are equal or lower than 5 meters, except the P10. The majority of the wells showed an increase of groundwater static level, nineteen in total. Seven wells showed an increasing in equal or higher than 10 meters in 9 years when considered the first and last measurement data.

Figure 2 – Spatial distribution of the 27 wells with the information about the increased and decreased groundwater depth

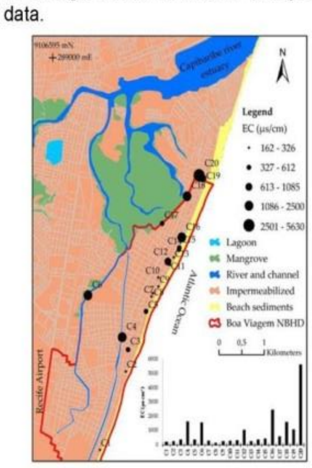

Figure 3 – Spatial distribution of the electric conductivity of 20 wells in campaigns performed in 2012/2013

The electrical conductivity ranged from 162 (C8) to 5,630 (C20) µS cm^{-1}, with mean values of 975 µS cm^{-1} (Figure 3). The majority of wells located near to mangrove, rivers and channels exhibited the highest values of electrical conductivity, greater than 1,000 µS cm^{-1}. This observation may indicate that the river also propagates the salinization.

Implications fot Groundwater Management

- The possibility that the Cabo aquifer been under a recovery process does not preclude other groundwater management strategies being proposed and implemented;
- Managed Aquifer Recharge (MAR) may be considered as a strategy for definite recovery of groundwater levels in the Cabo aquifer and to diminish the risk of seawater intrusion;
- As infiltration may not be a feasible option for MAR in the area, injection wells may be considered as an option for this purpose;
- These issues must be further investigated before it may be considered as groundwater management strategy and an increasing factor for resilience of the aquifer system.

FINAL REMARKS

- The groundwater drawdown rates in the last years in the study area are negligible, except for one well (P10), and show a stabilization and increasing of the groundwater static level in most part of the wells investigated in the Cabo aquifer;
- The highest values found in some wells cannot be attributed to the movement of the saltwater interface to the Cabo aquifer, but the proximity of the river and mangrove;
- The approach taken in this study, in which only the Cabo aquifer was selected, needs to be changed to a regional approach;
- The BRAMAR (BRAzil Managed Aquifer Recharge) project aims to expand the spatial-time monitoring of the groundwater in the RMR and to issue integrated water resources management strategies for Recife area.

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[1] Costa, W.D.; Costa, H.F.; Ferreira, C.A.; Morais, J.F.S; Villa Verde, E.R.; Costa, L.B. Estudo Hidrogeológico de Recife-Olinda-Camaragibe-Jaboatão dos Guararapes-HIDROREC 2. SRH-PE, Recife, 2003, 150p.
[2] Cary, L.; Petelet-Giraud, E.; Bertrand, G.; Kloppmann, W.; Aquilina, L.; Martins, V.; Hirata, R.; Montenegro, S.; Pauwels, H.; Chatton, E.; Franzen, M.; Aurouet, A.; the Team. Origins and processes of groundwater salinization in the urban coastal aquifers of Recife (Pernambuco, Brazil): A multi-isotope approach. Science of the Total Environment, 2015, v. 530-531, pp. 411-429.

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APPLICATION OF CYLINDER INFILTROMETER FOR ANALYZING THE VERTICAL WATER FLOW TO BANK FILTRATION TECHNOLOGY IN BEBERIBE RIVER, PERNAMBUCO - BRAZIL.

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INTRODUCTION

The water supply, besides being performed by surface water can also be obtained by exploiting groundwater where these water sources have interactions that must be considered in the management of water resources.

The River Bank Filtration (RBF) technique appears from the perspective of the interaction between surface water and groundwater as an alternative treatment method and low cost.

Many processes occur during RBF technique, these are dependent of hyporheic zone that is a riverbed region that corresponds to a transition zone between the surface water and the aquifer water.

The water exchange occurs across the hyporheic zone, which carries a control flow and transport of compounds.

AIMS

- Developed in the Beberibe river, State of Pernambuco – Brazil;
- Provide information about the transport of water volumes between the Beberibe river and the aquifer to foster better understanding of the physical processes involved in filtration technology.

MATERIALS AND METHODS

Experimental project

- The experimental area of this research was developed in the Beberibe river basin, Metropolitan Region of Recife (RMR), state of Pernambuco – Brazil;
- The Riverbank Filtration pilot project was developed on the banks of the Beberibe river in Caixa d'Água district in RMR, in the field of COMPESA (Sanitation Company of Pernambuco);
- The pilot project began in March 2008, the physical structure consists of a production well and seven observation wells (SP1, SP2, SP3, SP4, SP5, SP7 and SP8) (Figure 1).

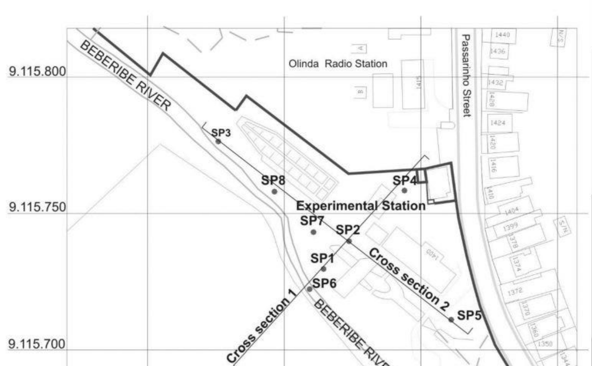

Figure 1 - Location of production well (Well) and observation wells (SP1, SP2, SP3, SP4, SP5, SP6, SP7 and SP8) – Experimental area.

Piezometric monitoring

- Period: May to October 2014;
- Readings of well water levels of production, observation wells and the water depth of the Beberibe river with an analog level meter;
- The water levels of the Beberibe river were monitored through a limnimetric rule.

Grain size distribution

- The samples for grain size distribution analysis were collected in two different locations in the months of November and May 2014;
- Were removed from the sediment with a depth of 0 - 5 cm and 5 - 10 cm, collected with a sampler *corer* with total area of 16.67 cm^2;
- The grain size distribution was determined by sieving and pipetting described by Suguio (1973);
- The data of the size fractions were plotted in SYSGRAN version 3.0 software to obtain the statistical parameters of the average diameter and degree of selection.

Infiltration test

- Were performed every two weeks for 10 months in the period from February to November 2014;
- Were adopted cylinder infiltrometers produced in acrylic, with cross-sectional area of 50.265cm^2, and water reservoirs (hospital plastic bags) with a capacity of about 2 liters of water(Figure 2).

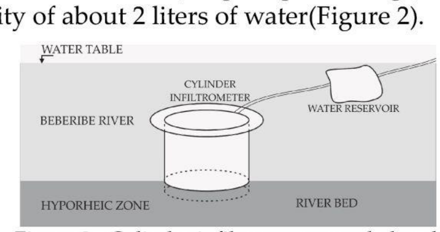

Figure 2 - Cylinder infiltrometer coupled to the water reservoir located in the river

- Water tanks are properly weighed in with electronic scale before being connected to the cylinder and after 20 minutes are weighed again;
- At each point there was the duplication of tests;
- The infiltration rate of water in the bed was calculated by the equation:

$$It = V/(t \times A)$$

Where,

It = infiltration rate [mm/s]; V = infiltrated volume [mm^3]; t = time [s]; A = cylinder area [mm^2].

RESULTS

Piezometric monitoring

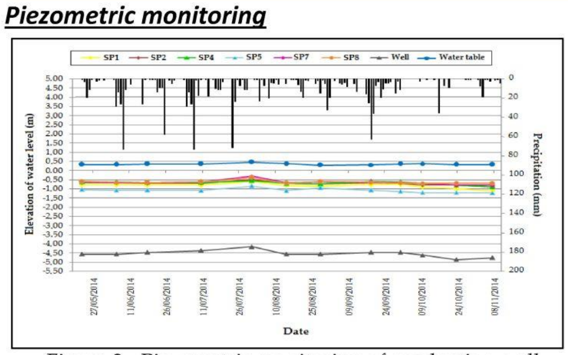

Figure 3 - Piezometric monitoring of production well, observation wells and Beberibe River surface level, in Experimental Station.

- All data were analyzed which define a hydraulic connection between the river and the aquifer;
- The rainy season had gently piezometric levels higher than the dry periods.

Grain size distribution

- The average grain size alternated between the fraction of coarse sand;
- Fine sand and found larger diameter grains in the dry season and the rainy season there was a higher incidence of fines;
- In general, the deeper layer analyzed was marked by grains and by the highest percentages of silt and clay.

Infiltration test

- The Point 1 shows an infiltration rate lightly higher than the Point 2, and the average infiltration rate of Point 1 corresponding to 0.92 mm/s and in the Point 2 it was 0.61 mm/s;
- The Point 2 is composed of sediments finer than Point 1, favoring the process of clogging;
- In the rainy season, or days after the occurrence of rain, the most infiltration rates are presented smaller than during periods of little or no rain (Figure 4).

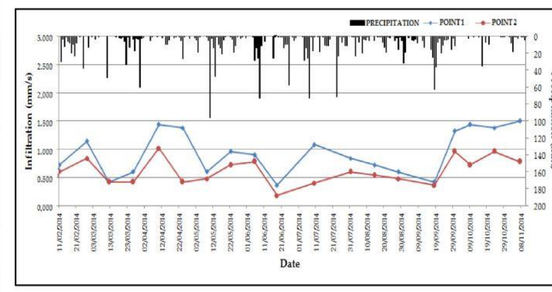

Figure 4 - Precipitation and means of infiltration rates in points 1 and 2 along the Beberibe river.

- Through rain the difference of the hydraulic load between the river and the aquifer was probably modified by promoting changes in water flow configuration;
- During the performance of the water infiltration tests on the Beberibe riverbed, the relationship between the body surface and groundwater, showed an influential condition is characterized by superficial groundwater flow, Figure 5.

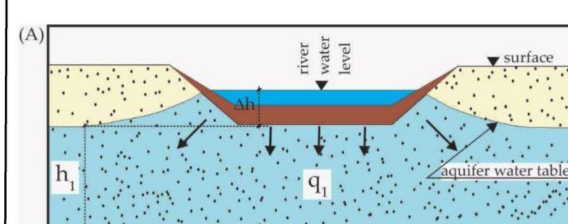

Figure 5 - Interaction between surface water and groundwater - water flow into the aquifer.

- Using the cylinder infiltrometer it is possible to identify areas of greatest aquifer recharge, enabling the sustainable use of water resources.

CONCLUSIONS

- The river-aquifer interface deserves attention for being a place of great influence for the bank filtration technology;
- The results of the piezometric monitoring showed in a good functioning of the bank filtration process in the experimental area;
- From the infiltration experiments with the cylinder infiltrometer, it was possible to observe that the river contributes to the supply of the aquifer through the vertical downward flow, especially when sediments have sandy feature enhancing the percolation of water. However, the contribution river-aquifer can be minimized after the occurrence of precipitation, with a reduction of infiltration.

ACKNOWLEDGMENTS

Assessing infiltration rates and clogging impacts during recycled water managed aquifer recharge (MAR) in Floreat (WA) and Alice Springs (NT), Australia

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To document changes in recharge rates, measures of clogging potential and water quality during operation of two demonstration sites for water recycling via MAR (i.e. infiltration gallery and soil aquifer treatment); to provide recommendations on the management of such schemes to aid greater uptake of water recycling

Methods:

i) MAR via an infiltration gallery located at Floreat in predominantly medium-grained Aeolian sand deposits typical of the coastal plain of WA (Figure 1):

- Galleries were constructed of a series of 6 Atlantis Flo-Tank® modules, each with dimensions of approximately 685 mm x 450 mm x 408 mm (L x H x W) and internal partitions approximately every 340 mm
- Soil moisture was monitored using probes at 5, 15 and 40 cm below the base of the gallery and adjacent to the gallery (45 to 65 cm west); water levels were monitored using 3 PVC wells located within the gallery, and wells located 5 m up-gradient (MB1), 2 m down-gradient (MB2) with background monitoring at 75 m (DN1) and 177 m (DN2) up-gradient
- Preliminary lab studies were used to establish a target level of TSS < 5 mg/L for recharge source water
- Recharge source water and groundwater below the gallery and surrounding area were monitored for field parameters, TSS, Major ions, Nutrients, DOC

ii) MAR via soil aquifer treatment (SAT) using recharge basins located within a mixture of fine and course grained riverine deposits in Alice Springs, NT (Figure 2):

- From 2008-2010, 4-5 basins with a recharge area up to 10,300 m^2, basins then expanded in 2011-2012 to a recharge area of 38,000 m^2, as the original recharge target of 600 ML/yr not reached
- 2014 the DAF (Dissolved Air Floatation) wastewater treatment plant was upgraded to include filtration – DAFF
- Pond levels and water volumes delivered to the basins were monitored via SCADA system
- Field based investigations included: characterization of the 'schmutzdecke' (basin clogging layer); soil beneath the basins; recharge source water and groundwater quality sampling including field parameters, TSS, Major ions, Nutrients, DOC, BOD, Fe and Mn; geophysical surveys were also carried out

Table 2: Summary of infiltration rates and days drying/wetting for the five SAT basins.

	Basin	A	B	C	D	E
DAF	n	57	0[a]	46	30	16
	Infiltration rate (mm/d)	170±100		140±50	500±200	550±460
	Drying Time (d)	7±3		8±5	12±8	12±8
	Wetting Time (d)	4±1		4±1	2±1	2±1
DAFF	n	17	16	14	15	19
	Infiltration rate (mm/d)	250±100	200±30	250±100	1000±400	760±520
	Drying Time (d)	10±2	10±8	10±6	10±5	11±6
	Wetting Time (d)	3±2	2±1	3±1	3±1	3±1
	[a] Basin affected by compaction during construction					

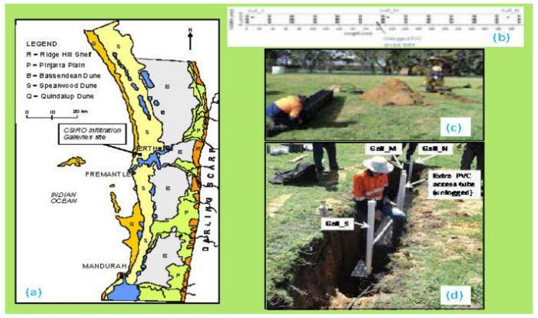

Figure 1(a-d): Location and installation of infiltration galleries (Floreat, WA) (photos: Elise Bekele; images from Bekele *et al.* 2015).

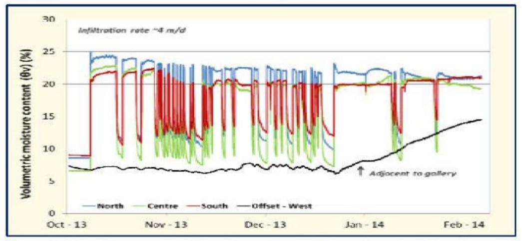

Figure 3 Soil moisture content from the north, middle, south and offset probes at approximately 40 cm depth below the western edge of the infiltration gallery.

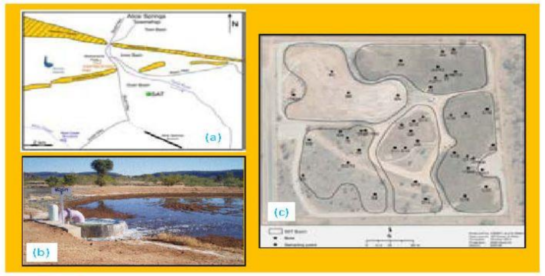

Figure 2(a-c): Location of soil aquifer treatment basins (Alice Springs, NT) and sampling sites (photo: Karen Barry; images from Bekele *et al.* 2015).

Table 1: Source water and ambient groundwater (GW) quality.

	Floreat		Alice Springs		
All units mg/L unless specified	Pre MAR GW (n = 6)	Source (n = 32)	Pre SAT GW (n = 8)	DAF (n=12)	DAFF (n=11)
pH (-)	7.4 ± 0.1	7.0 ± 0.4	7.4 ± 0.2	7.7 ± 0.2	7.6 ± 0.1
EC (µS/cm)	1119 ± 73	1195 ± 80	2398 ± 702	1776 ± 153	1670
TSS	1.8 ± 1.7	8.7 ± 10	-	9 ± 3	<5
Cl	160 ± 20	269 ± 26	399 ± 139	263 ± 30	242 ± 16
TN	8.3 ± 1.8	8.9 ± 2.7	2.8 ± 2.1	13 ± 3	12 ± 1.3
Nitrate-N	7.2 ± 1.3	1.6 ± 1.6	2.6 ± 2.0	1.6 ± 1.4	2.2 ± 0.2
Phosphate - P	<0.01	4.3 ± 2.1	0.05 ± 0.05	0.8 ± 0.7	0.4 ± 0.2
Total soluble - P	0.37[a]	5.3 ± 1.8	0.03 ± 0.03	0.4 ± 0.3	0.2 ± 0.1
BOD	-	8 ± 6[b]	-	8 ± 10	1.3 ± 1.2
DOC	9.4 ± 7.8	26 ± 25	1.6 ± 0.5	9.8 ± 1.4	8.2 ± 1.7
	[a] only one sample; [b] historical data from wastewater treatment plant				

Findings:

i) Infiltration galleries:

- Average recharge rate was 4 m/d and changes were observed to occur spatially in gallery recharge water levels and soil moisture contents surrounding the gallery after 14 weeks (Figure 3)
- Heterogeneous clogging developed locally within the gallery, promoting increased flow of wastewater laterally away from the gallery
- Target TSS of < 5 mg/L was exceeded on some occasions and was 10.4 mg/L on average. The TSS load did not significantly degrade the hydraulic performance of the gallery; however long-term, constant flow requires regular maintenance of the pre-filter

ii) Soil Aquifer Treatment:

- 2,580 ML (2.6 Mm^3) has been delivered to the basins over six years
- Upgrade of the DAF plant to DAFF (filtration) improved the quality of water delivered to the SAT basins, with TSS, BOD and DOC being reduced (Table 1)
- Average infiltration rates have improved 40 % (Table 2) with rates for Basins D and E typically remaining three times higher than Basins A, B and C regardless of source water treatment (DAF or DAFF)
- Basins A and C had an increase in average days drying, 4 to 10 days, between infiltration events over this period (DAF to DAFF), which has also contributed to improved infiltration rates (Table 2)

FOR FURTHER INFORMATION
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REFERENCES
Bekele, E.B., Donn, M.J., Barry, K.E., Vanderzalm, J.L., Kaksonen, A.H., Puzon, G.J., Wylie, J., Miotlinski, K., Cahill, K., Walsh, T., Morgan, M., McFarlane, D. and Dillon, P.J. 2015, Managed Aquifer Recharge and Recycling Options (MARRO): Understanding clogging processes and water quality impacts, Australian Water Recycling Centre of Excellence.

ACKNOWLEDGEMENTS
This research was supported by the Australian Water Recycling Centre of Excellence, CSIRO, Power and Water Corporation, City West Water, Barwon Water and Water Corporation.

Australian Water Recycling Centre of Excellence

Mexico City, Mexico.
June 20th-24th, 2016.

Integrating suitable sites for managed aquifer recharge with drinking water demand in Costa Rica

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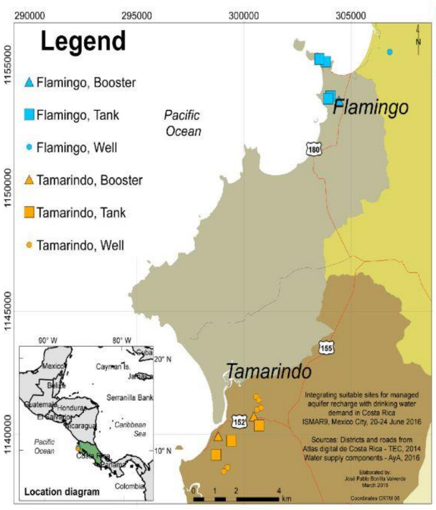

Figure 1: Flamingo and Tamarindo main drinking water supply system components.

INTRODUCTION

- Suitable sites for managed aquifer recharge (MAR) through spreading methods were identified in a previous study in Costa Rica by a GIS multi-criteria decision analysis (GIS-MCDA) [1] based on:
  - hydrogeological aptitude
  - terrain slope
  - soil texture
  - drainage density.
- The map was overlaid with the main components of the water supply systems (WSS) that required investments for increasing their production capacity to meet the demand in the next years in Costa Rica [2].
- Two WSS are shown as an example of the map overlaying of the suitable MAR sites with water demand in Costa Rica: **Flamingo** and **Tamarindo** (**Fig. 1**) .
- Saline water intrusion in the wells used in the past for both WSS was reported; these wells were abandoned and new wells were constructed inland [**3**].

METHODS

1. A GIS-MCDA for the identification of suitable sites for MAR in Costa Rica was developed in a previous study [**1**]; where the suitability map was divided in two zones after the screening: suitable and unsuitable - the first zone was further divided in five classes: very high, high, moderate, low and very low.
2. In this study the main WSS components were overlaid with the MAR suitability map.
3. Three buffer zones (radii 2 km, 5 km and 10 km – see **Fig. 2**) were created around the main components of the two WSS.

RESULTS

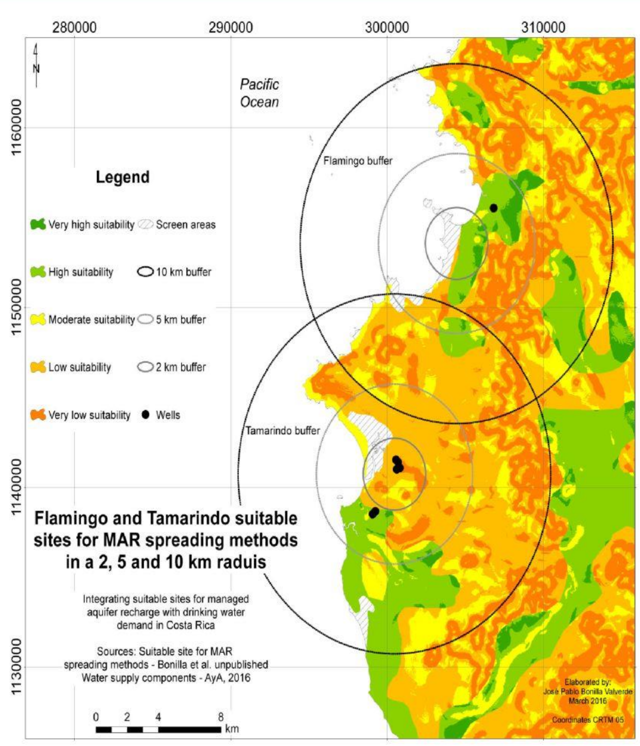

Figure 2: MAR suitable sites map overlaid with the Flamingo and Tamarindo main water supply components and the 2, 5 and 10 km. buffer areas.

DISCUSSION

Flamingo:
- Most areas (>80%) in a 2 km radius are classified as highly and very highly suitable for conducting MAR (**Fig. 3.a**).
- About 400 ha are highly suitable for MAR in a 5 km radius (**Fig. 3.b**).

Tamarindo:
- Moderately suitable areas (<15%) for MAR are found in a 2 km radius (**Fig 2 & Fig. 3.d**).
- More than 800 ha are highly suitable and very highly suitable for MAR in a 5 km radius (**Fig. 3.e**).

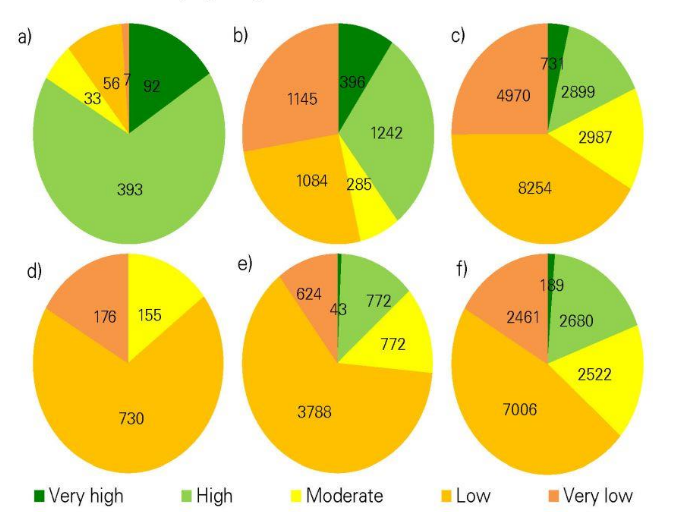

Figure 3: Composition of Flamingo and Tamarindo buffer areas (in ha). a) Flamingo - 2 km, b) Flamingo - 5 km , c) Flamingo - 10 km , d) Tamarindo - 2 km, e) Tamarindo - 5 km and f) Tamarindo - 10 km

CONCLUSIONS AND OUTLOOK

- The MAR suitability map can be a valuable tool for the identification of potential aquifer recharge sites for increasing the production capacity of existing water supply systems.
- Flamingo WSS benefits of the highest percentage of area suitable for MAR and it should be investigated more in detail.
- The prevention of saline intrusion or the restoration of the abandoned wells fields of Flamingo and Tamarindo can be a new line of research.

References:
[1] Bonilla et al. Application of a GIS multi-criteria decision analysis for the identification of intrinsic suitable sites in Costa Rica for the application of managed aquifer recharge (MAR) through spreading methods. Submitted 2016
[2] AyA. Plan Inversiones Institucional 2011-2021; Instituto Costarricense de Acueductos y Alcantarillados: San José, Costa Rica, 2011.
[3] Arellano, F.; Vargas, A. Casos de contaminación por intrusión salina en acuíferos costeros de la Península de Nicoya (Costa Rica). Rev. Geológica América Cent. 2011.

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Abbreviation list:
MAR: managed aquifer recharge
GIS-MCDA: geographical information system – multi-criteria decision analysis
WSS: water supply system

"Sustainable water management solutions to scarcity and climate change"

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GUIDELINES FOR MAR WATER QUALITY INTERNATIONAL OVERVIEW AND LESSONS LEARNT

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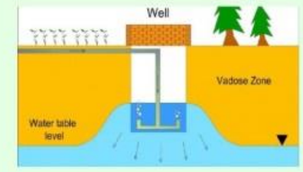
MAR SOL MANAGED AQUIFER RECHARGE SOLUTIONS

dM dina-MAR

INTRODUCTION

The MAR Guidelines affirm that aquifer water quality should be protected beyond a defined attenuation zone in order to sustainably meet all its existing environmental values and beneficial uses, and that recovered water quality should meet the water quality parameters relevant to final uses.

Most of these guidelines specify water quality requirements on recharge water generally without a detailed study of the biogeochemical processes that occur in aquifers a posteriori. Subsequently the achievement of the essential objectives of MAR could be compromised.



MATERIALS

A collection of **12 examples of MAR guidelines** has been gathered from different international sources:

- ❖ **WHO guidelines.**
- ❖ **"Water Quality Guide to Managed Aquifer Recharge in India".** Based on WHO and Australian guidelines stating "Appendix 3. Example applications of these Guidelines to selected recharge sites in India".
- ❖ **Australian water quality guidelines (with parameters)**
  - Document 4 ANZECC (2000) guidelines for fresh and marine water quality
  - Document 6 Australian drinking water guidelines (2011)
  - Document 21 Water recycling guidelines managing health and environmental risks (phase 1) which contains tables for crop and plant protection
  - Document 22 water recycling guidelines: augmentation of drinking water supplies which contains procedures for setting limits for all manner of organic compounds.
- ❖ **Specific regulations from Israel.** Maximum concentrations of **25** parameters in recharged effluents in the Shafdan project.
- ❖ **California (USA):** does not have specific regulation to MAR, however there are regulations for groundwater replenishment with recycled water. There are also 'discharge requirements' for injecting drinking water into aquifers (ASR).
- ❖ **Florida (USA):** The legislators make four distinctions based on the type of recharge and the application of the required tighter limit values.
- ❖ **Chile.** Reglamento Aguas Subterráneas 2014. Art 47 & 48 (content of the technical application).
- ❖ **México.** Norma 14 Conagua (2003), DOF: 18/08/2009 : **71** parameters.
- ❖ **The Netherlands. 73** parameters. These are rather old acts and the limits are currently under debate, however, they are the legal limits right now.
- ❖ **Belgium** MAR quality standards in Flanders. In Belgium the regions, as Flanders, are responsible for drinking water and environmental (e.g. permits) aspects.
- ❖ **Spain.** Specific Royal Decree 1,620/2007. Different quality requirements are set according to the MAR technique, direct injection or percolation. Likewise, the minimum frequency of sampling and analysis for each parameter are also set. **6** Parameters.
- ❖ **Portugal.** No legislation "with numbers". A sentence in DL69_2000 an EIA is needed for several type of projects including: "Groundwater abstraction or artificial recharge of groundwater where the annual volume of water abstracted or recharged is equivalent or greater than 10 million m^3/year". In the Water Law (Lei 58_2005) there is a reference in article 30º, 3r) "Prohibition of direct discharges of pollutants in groundwater unless specific situations indicated in paragraph 4 that do not compromise compliance with environmental objectives and control of artificial recharge of groundwater, including the establishment of a licensing regime".

MAR Guidelines in Spain. RD 1,620/2007

ACTIONS WILLING TO FACE LEGAL CONSTRAINTS

1. LACK OF A HOMOGENEOUS DEFINITION FOR ARTIFICIAL RECHARGE
2. THEORIC INSUFFICIENT EXPERIENCE ON ARTIFICIAL RECHARGE.
3. CONTROL OF THE OPERATION, SURVEILLANCE
4. ENSURE A CERTAIN CONTINUITY OF THE EXPERIENCES

FUTURE LINES OF ACTIONS TO BE ACCOMPLISHED

1. SPECIFIC PROCEDURE FOR AUTHORIZATIONS
2. ARTIFICIAL RECHARGE CONSIDERED AN SPILL IN SOME CASES.
3. FINANCIAL ASPECTS ON ARTIFICIAL RECHARGE OF AQUIFERS.
4. STUDY FOR EACH CASE IF THE PROPOSED TECHNICAL SOLUTIONS ARE LEGALLY VIABLE IN EACH COUNTRY PRIOR ITS PROJECT.

RESULTS

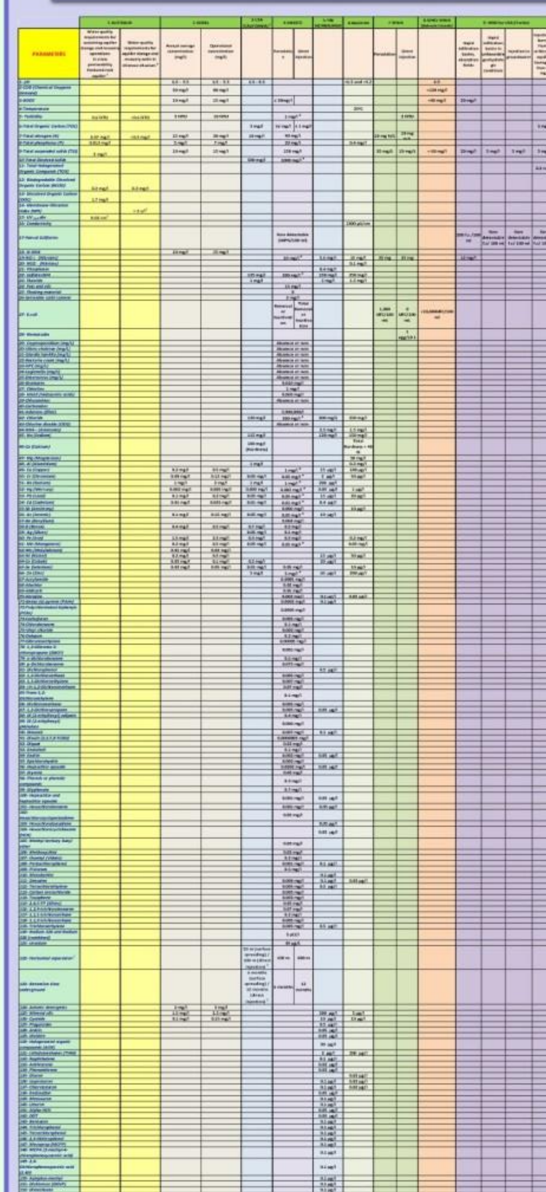
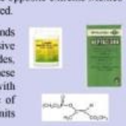
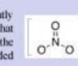


Table gathering the water quality standards for MAR systems in seven different countries.

- ❖ There are some countries such as India, Chile and Portugal with a specific regulation for Managed Aquifer Recharge, but the limits for the different compounds have not been stablished yet.
- ❖ The Australian case is one of the most complexes and any proposed standard is related to an exhaustive study of risks, with assessments for environmental, hydrogeochemical and some other assets.
- ❖ The total number of parameters taken into consideration in the different countries with MAR water quality standard is up to 150. It is worth to remark the vast range in the number of elements or compounds regulated between the chosen countries. There is the case of Spain with a minimum of four parameters for percolation and six for deep injection; and in the opposite extreme Mexico has up to 96 parameters regulated.
- ❖ Mexico and The Netherlands stand out for a comprehensive regulation of herbicides, insecticides or pesticides. These two countries, together with Belgium, Israel and the State of California (USA) establish limits for extensive list of metals.



- ❖ Nitrates (NO_3) is the most frequently regulated parameter. The parameter that stands out for its variability across the different countries is Total suspended solids (TSS).



- ❖ Other common regulated parameters on the quality of the injectant are Turbidity, total Nitrogen, total Phosphorus, chlorides and sulfates.

DISCUSSION

- ➢ As product water is a function of recharge water quality, groundwater quality and aquifer mineralogy, these facts dictate the redox conditions and temperatures which result in quite varied reactions between these three components, but most of the analyzed regulations have avoided further explanations about the context when the procedures have been written and published.
- ➢ It is extremely difficult to stablish a regulation at national level (Sapiano, 2014), due to the wide-ranging amount of different cases and their specific environmental conditions to be considered.
- ➢ Legal development: Insufficient theoretical background on legal aspects of artificial recharge. The table exposed the scarce amount of countries with an specific regulations.
- ➢ Independent surveillance: Once an authorization has been granted, there is a general failure of mechanisms of control of the operations and surveillance.

- ➢ Time discontinuity: Many experiences have been related to R&D projects and when the project finishes and the budget is over, the experience is abandoned and the continuity is, generally, uncertain; so that it is important to get a certain continuity of the experiences to study the real effect of the water-soil-aquifer interaction in the long term.
- ➢ Technical-legal collaboration: It is important to study whether the technical solutions proposed to improve the efficiency of any resources management scheme are legally viable in each country.

PROPOSAL FOR A STANDARD ON GROUNDWATER QUALITY FOR LOS ARENALES AQUIFER

DETERMINATIONS / RANGES	QUALITY STANDARD
TSS 5-8 ppm	TSS < 10 ppm
TDS 101,8 ppm	TDS < 150 ppm
TOC < 5,5 mg/l	TOC < 10 mg/l
DOC 1,8-2,8 mg/l	DOC < 2 mg/l
DO 5,1-8,8-11 mg/l	DO < 8 mg/l
$[CO_2]$= 0,5 – 0,9 mg/l	$[CO_2]$ < 0,50 mg/l
pH = 8	pH < 7,5-8
Cond = 191 µS/cm	Cond < 200 µS/cm
Tª W = 5,9 ºC	Tª water ≈ Tª soil
Tª SOIL = 6,1 ºC	Tª water > Tª aquifer
Alcalinity= 64 mg/l CO_3Ca	Alcalinity <200 mg/l CO_3Ca
$[NO_3]$= 2 mg/l	$[NO_3]$< 10 mg/l
Oversaturation SiO_2 = 35 mg/l.	Oversaturation ≈ 0
Oversaturation Ca Mg $(CO_3)_2$= 37,86 mg/l.	Oversaturation ≈ 0
Salinity = 0.1 – 0.7	Salinity ¿? to be determined
H_2S ≈ 0	Avoid H_2S
MFI: 25 - 30 s/l²	MFI < 3-5 s/l²
Bacteria and virus to be determined	Bacteria and virus to be determined

Quality standard for artificial recharge water in the specific case of Los Arenales aquifer applicable to other parallel scenarios. Data based on bibliographic references and experiences obtained in field, laboratory and office (slightly modified from Fdez. Escalante, 2005).

CONCLUSIONS

1) **"*You don´t need to be a scientist to deploy a MAR project*" (outcomes of the Algarve training workshop, 2015 June), neither a lawyer.**
2) **Before implementing a MAR activity, it is necessary to choose the most appropriate method and study its legal feasibility for each context.**
3) **The majority of the problems raised during MAR devices deployment can be avoided or reduced conducting prior detailed technical and legality studies.**
4) **A joint strategy for the conservation of water, would be an important asset to satisfy the water growing demand.**
5) **It is required a deep knowledge of each aquifer prior conducting a water quality standard for the liquid to be injected inside, not only for hydrogeochemical interactions but also for the general hydrogeological behaviour.**
6) **The examples of independent agencies performing specific studies provide good results as they keep the balance between development and sustainable conservation, e.g. the Water Governance Center (the Netherlands) or the Water Authority Council (Israel).**
7) **The competent authorities should include during the planning, development, and implementation of MAR projects, the joint integration of MAR systems, at national, regional and basin level, as part of the set of strategies to be adopted for modern water management.**

Identification of recharge area for potential flooding recharge in Leizhou Peninsula, Guangdong, China

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Objectives

To identify the recharge area and ameliorate the situation of over utilization of groundwater with potential flooding recharge in Leizhou Peninsula, Guangdong Province

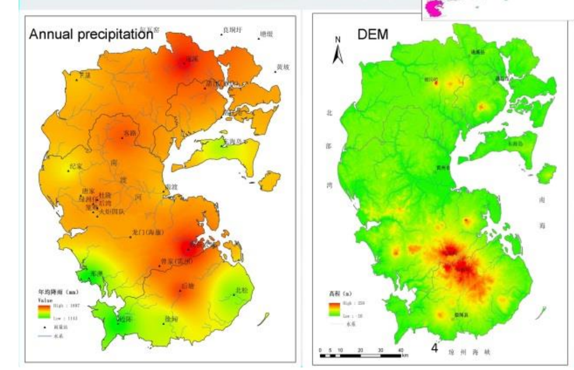
2

Methodologies

- Data collection of hydrological, hydrogeological, land use, vegetation, and meteorological data and etc.
- Field survey and test of hydraulic conductivity, one site every 10x20 km^2
- Groundwater modelling, MODFLOW
- Water samples for ^{14}C, ^{81}Kr, ^{85}Kr

3

Location



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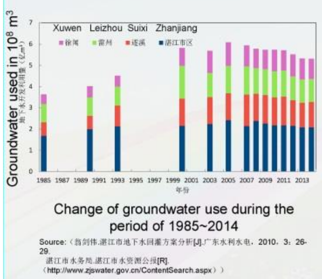
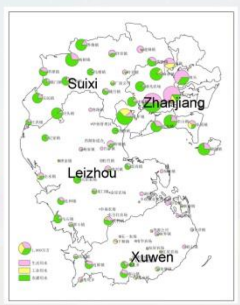
Groundwater use



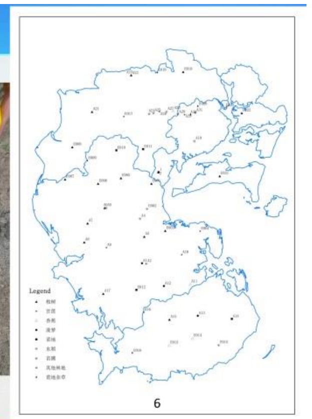
Change of groundwater use during the period of 1985~2014



2013年雷州半岛各地区地下水用水量

5

Field survey and test of K



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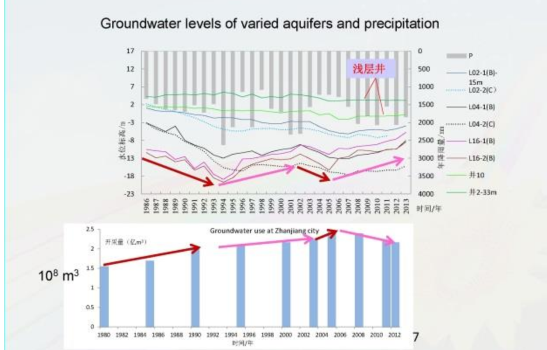
Change of groundwater level during the period of 1986-2013



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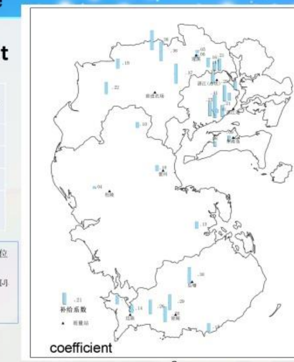
Infiltration rate

- Annual rate/event

Regions	Rate in mm	Coefficient
Leizhou	105	0.09
Suixi	315	0.22
Xuwen	348	0.23
Zhanjiang City	295 (138)	0.19 (0.09)

$dH = 9.082\sum P - 1742.9$



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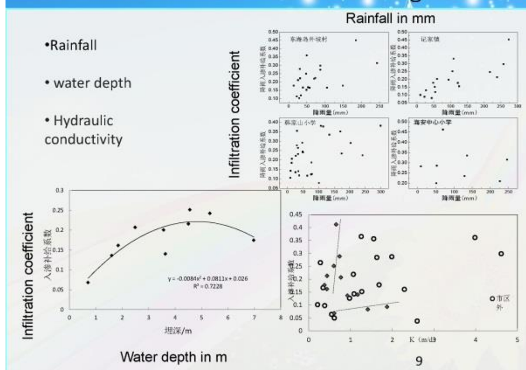
Infiltration rate and affecting factors

- Rainfall
- water depth
- Hydraulic conductivity



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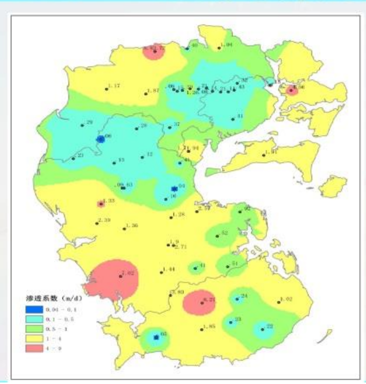
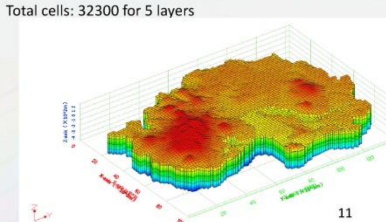
Spatial variation of K



Groundwater simulation

- conceptual model
  - Cell: 1.5Km×1.5Km
  - layers: 5
  - Total cells: 32300 for 5 layers



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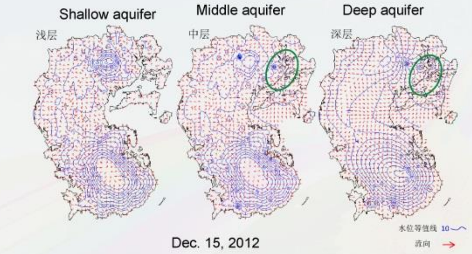
Results of groundwater simulation

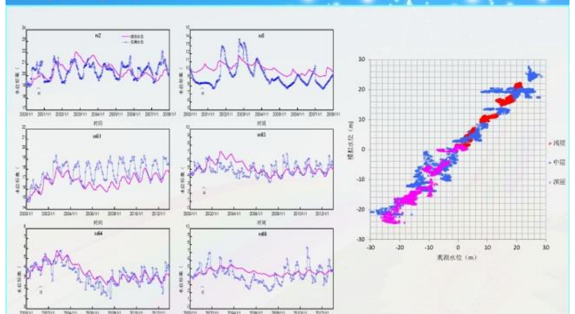
- Flow field



Dec. 15, 2012

12

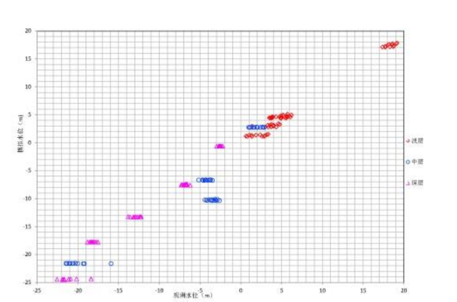
Hydrograph (calibration)



Shallow aquifer

13

Hydrograph (verification)



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Main conclusions

1 Annual average infiltration rate was estimated to be 57-581 mm, with the ratios of infiltration to precipitation to be 0.04-0.41. The ratio was found high in the North and South area, while low in the middle part, corresponding to topography and hydraulic conductivity (K). The ratio was s found affected by the amount of rainfall, groundwater depth and K.

2 Annual and seasonal change of groundwater occur in both shallow aquifer and deep confined aquifers , corresponding to rainfall and rainfall-development respectively. Under one extreme drought in the first half year in 2015, averaged groundwater level dropped down 1-2 m, with 80-160 mm groundwater developed.

15

3 Groundwater levels simulated are consistent with the measured, and could be used to simulate the change of water level under the scenario of extreme drought.

4 Two hilly sites in the North and South area could be selected and operated as recharge areas under flooding events.

16

Controlling the formation of the reaction zone around an injection well during subsurface iron removal (SIR)

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Background

- Subsurface removal of Fe, Mn and As is an alternative to conventional groundwater treatment
- A reaction zone is formed around the well through the periodical injection of oxygen enriched water
- Treatment efficacy is effected by aquifer heterogeneity and water quality, which often varies over the depth (Fig. 1), well screen design, the outward mitigation of the injected water and the oxygen to Fe/Mn/As ratio

Aim

- Investigate and evaluate the possibility to improve the SIR treatment efficacy through depth dependent injection
- Water quality-based formation of an SIR reaction zone

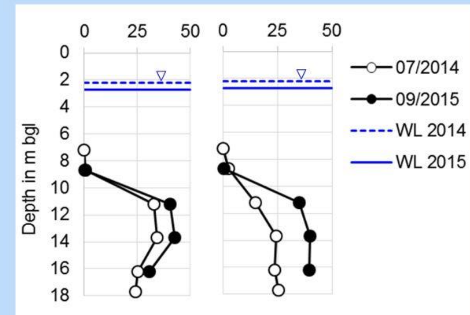

Fig. 1: Iron concentration in groundwater

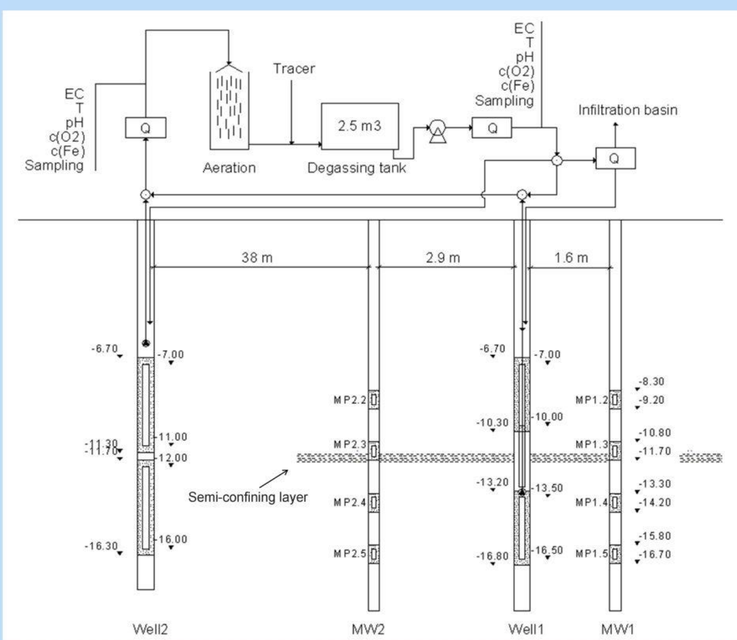

Fig. 2: SIR test set-up

Methodology

- 2 vertical wells were operated alternately as injection and abstraction well (Fig. 2)
- The outward mitigation of the injected water was monitored in 2 monitoring wells (MW) equipped with multilevel sampling systems
- A packer was installed in Well 1 to control the vertical outflow distribution (Fig. 3)
- The packer was evacuated during abstraction; Iron breakthrough curves of uncontrolled and controlled SIR-cycles were evaluated regarding the iron removal

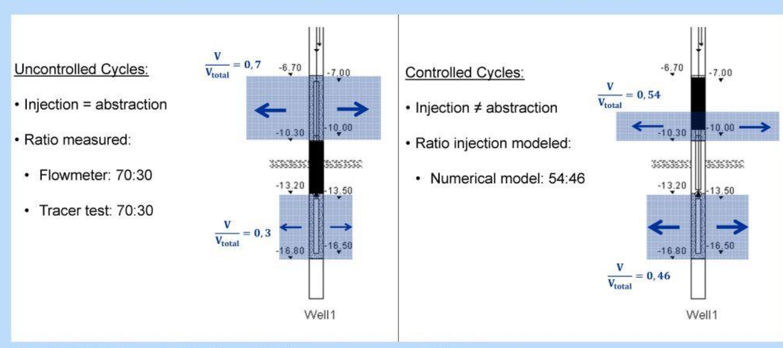

Fig. 3: Out-/inflow distribution ratio between upper and lower screen

Results

- Lower iron concentration during recovery phase, breakthrough was delayed after controlled injection (Fig. 4)
- Iron removal increased by 25 % and mean concentration reduced by 56 % (Tab. 1)
- Tracer breakthrough was successfully controlled (Fig. 5):
  - Injection volume at c/c_0=0.5 in the upper screen increased by 10-36 % (specific Volume↓, goal achieved)
  - Injection volume at c/c_0=0.5 in the lower screen decreased by 16-24 % (specific Volume↑, goal achieved)

Results proved the effect of depth dependent injection but were significantly below expectations, which was attributed to unfavorable water chemistry (pH-value dropped below 5 during SIR due to low alkalinity).

Tab. 1: Mean iron concentration in total abstracted water from Well 1

	Iron concentration before SIR mg/L	Iron concentration uncontrolled injection mg/L	Iron concentration controlled injection mg/L
Upper screen	5.5	n.d.	n.d.
Lower screen	35	n.d.	n.d.
Both screens	16.9	5.4 – 5.8	2.3 – 2.6

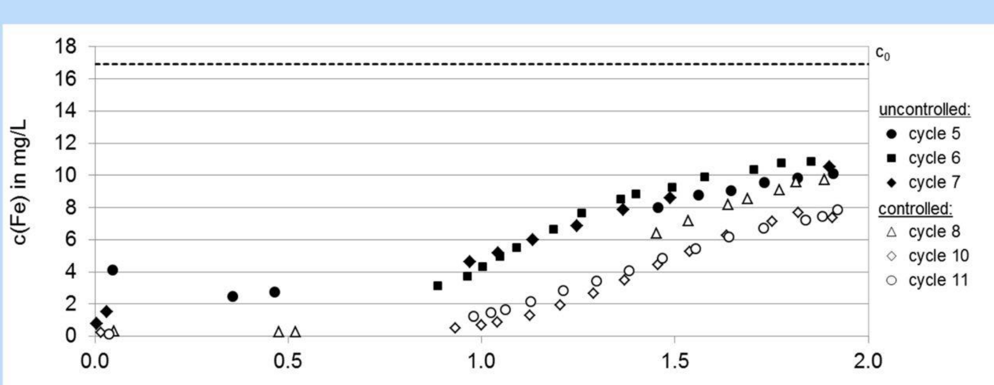

Fig. 4: Iron breakthrough curves with and without controlled injection in Well 1

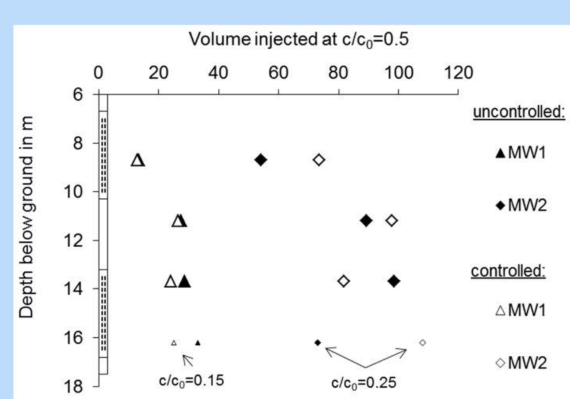

Fig. 5: Comparison of injected volumes around Well 1 at c/c_0=0.5

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Mexico City, Mexico.
June 20th–24th, 2016.

Coupled Surface Water and Groundwater Model to Manage Artificial Recharge for the Valley of Santo Domingo

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INTRODUCTION

The Valley of Santo Domingo is located in the middle of the Mexican state of Baja California Sur in the municipality of Comondú. The climate is characterized by very arid conditions (warm climate at the coast to temperate climate in the Sierra La Giganta mountain range), with a temperature interval ranging from an average maximum of 43.3 ºC to a low of 1.89 ºC. The average annual rainfall reaches only 150 mm (the range of precipitation is between 50 to 300 mm per year), of which 30% occurs in the winter time and 70% during summer [1]. In the summer season, runoff is generated frequently from rainfall caused mainly by tropical cyclones; the hurricane season begins in mid-May and ends in November [2]. The Valley of Santo Domingo is subdivided into three watersheds: Santo Domingo in the north, Las Bramonas in the middle, and the Santa Cruz watershed in the south (Figure 1). This area represents the most important region for agricultural and livestock in the state, where agricultural activities cover an area of 72.409 hectares, commonly known as the Irrigation District 066. The first wells for agriculture use were installed in the late forties and in the 60s, the withdrawals had already reached 250 million m^3 per year, which significantly exceeds the annual average recharge of 188 million m^3, estimated by the Mexican National Water Commission [1]. In the 1970s, the number of wells had exceeded 500 units, and extractions were about 300 million m^3 per year. The highest extractions occurred at the end of the 80s, with withdrawals of up to 450 million m^3 per year, 2.4 times the annual average recharge [3]. Over-exploitation causes a deficit of 5,213 Mio m^3 of water in the aquifer. In order to reduce salinization effects, wells with high salinity were abandoned and the agriculture moved northwards to zones with better water quality, but it lasted in many cases only a short period of time until wells subsequently showed again increases in salinity [4]. Since the 1990s a gradual reduction in the extraction rate began, in order to reduce the negative effects of over pumping and to achieve an equal balance between recharge and extraction. After a heavy reduction of the annual groundwater extraction rate, equilibrium in respect to the medium annual recharge rate was achieved in 2003. Although in the following years the extraction rate nearly equaled the estimated recharge rate of 188 Mm^3 per year and the cone of depression stopped increasing its volume, its size grew, and its center still deepened. As a result of the over-exploitation of 50 years, a change in the hydrochemical composition of the groundwater has been observed [4-7]. This increase of the total mineralization, caused by sea water intrusion, water returns, derived from irrigation, and the mobilization of deeper groundwater with higher mineralization will continue, if an additional input of surface water by means of artificial recharge cannot be achieved.

METHODS

Water Resources Management

With the purpose to plan the artificial recharge of the aquifer with excess surface water, a hydraulic model was developed as a designing tool in order to plan scenarios with different types of artificial aquifer recharge technologies. Surface infiltration systems for artificial recharge can be divided into in-channel and off-channel systems which have to be adapted to the geomorphological conditions. Because the important rain events mainly occur during tropical cyclones, they are characterized by high intensity and short duration. Therefor storm water enters rapidly into the drainage system of the valley where, due to the geomorphological conditions, subsurface drainage is generally incapable to infiltrate an important part of the runoff, which then will flow into the Pacific Ocean. Finally, two different types of dams were considered: **Water retention dams** would be constructed on three sites in the arroyos of the Sierra la Giganta Mountains, which represent the catchment area for the aquifer. An existing fourth water retention dam (El Ihuagil with a retention volume of 5 million m^3), which is located 30 km east-southeast of Ciudad Constitucion is included in the plan. The water retention dams would permit to catch a maximum runoff and release the water toward the recharge zone during a period of no more than three months. **Recharge dams** would be constructed on four sites in the lower part of the aquifer. The idea behind recharge dams is that, by stopping water and retaining it behind structures, more water can be infiltrated and recharge the aquifer. Due to the elevated evaporation rate of the area, water would be released from the water retention dams, during a maximum time of three months.

The most likely areas with higher infiltration potential were defined, based on the soil texture, analyses from 554 farms, and the results of hydraulic tests on eight sites. Finally, four sites were evaluated as feasible for the construction of recharge dams; here a digital elevation model was generated, based on data from a differential–corrected global positioning system with a sub–meter accuracy. A detailed map of the sediment type and texture was elaborated, including information from manual drillings to one meter depth of the riverbed. On each site, an exploratory well was constructed and infiltration tests were conducted. The expected impact from the different recharge facilities on the aquifer system was calculated with a combination of a hydrological model Hec-1 and the hydraulic model Hec-Ras. The results were introduced into the regional groundwater flow model, implemented within the Groundwater Modeling System (GMS). **Model design:** A regional groundwater flow model was constructed using Modflow-2000. The model area includes the following two natural boundaries: to the west the coastline of the Pacific Ocean and to the east the fractured aquitard of the Sierra de la Giganta mountains. To the north and south, the model is limited by no flow conditions, where an influx can be neglected. The finite difference mesh consists of 221 columns and 197 rows with a size of 500 m per cell so that the model includes 43,537 cells and represents an area of 10,781 km^2. Two layers were taken into account: an upper layer, which represents a free aquifer that consists of Quaternary sediments and the deeper confined aquifer that consists of clayey sediments of low permeability which represent a hydraulic limit of the upper aquifer in the Valley of Santo Domingo. The top of the first aquifer was recalculated from the Digital Elevation Model with a resolution of 30 m, obtained from INEGI [8]. The thickness of the aquifer was defined from bore logs and based on geologic cross sections and the re-interpretation of resistivity soundings, documented in [3].**Hydraulic conductivity, specific yield, and specific storage**: The hydraulic conductivity was calculated from the textural classification data of 554 sediment samples in the Irrigation District 066 in the Valley of Santo Domingo, applying the methodology from Shiozawa and Campbell [9]. The initial specific yield and specific storage were obtained from [3]. **Recharge:** The average annual recharge of the aquifer in the Valley of Santo Domingo is 188 million m^3, of which 77% correspond to natural infiltration; the remaining 23% are due to irrigation return flow [1]. Principally the natural recharge results from four different processes, listed here in order of their importance: recharge from direct infiltration of rainfall, recharge resulting from the infiltration of surface water in the arroyos after storm events, horizontal groundwater flow from the Sierra de la Giganta aquitard, and seawater intrusion from the river mouths of the arroyos Santo Domingo and Las Bramonas into the aquifer. As the interaction between intermittently dry streams and the aquifer play an important role in the recharge mechanism of the area, the streamflow package (STR1) was used to simulate the hydraulic inter-connection between surface water and groundwater. The main drainage system was introduced into the groundwater model and via the streamflow module, results from synthetic hydrographs, calculated with the amount of surface water generated in the watershed of the Sierra La Giganta mountains were calculated with the HEC–1 program taken in account different rainfall scenarios; the relation between precipitation and total runoff volume was reported from [3]. **Extractions:** A total of 710 wells with their corresponding extraction rates were introduced into the model, taking in account the variations between recharge and extraction, observed between 1996 [3] and 2007. From 2008 on we assumed near equilibrium conditions as indicated by [10] for the future scenarios. **Time steps:** The well head data, observed during the period of 1996 to 2007, were obtained by the National Water Commission CONAGUA in the order to calibrate the model in transient mode. For each year, the model includes infiltration, caused from runoff during a maximum of 10 days. **Calibration and prognostic model run:** In the calibration process the hydraulic conductivity, specific yield, and specific storage were used in order to achieve the observed hydraulic head levels during the period 1996-2007 (see Figure 2 and 3). After the model calibration, different recharge scenarios were generated maintaining the same infiltration and extraction rates as in 2007, but applying different recharge technics and volumes, based on the analysis of projected water demands. The values for the specific yield, obtained after the calibration step, are ranging between 0.07 to 0.26, where the maximum values correspond to the center of the Irrigation District 066 and the lowest values in the periphery. The final specific storage values range from 0008 to 0043 m- (Figure 3).

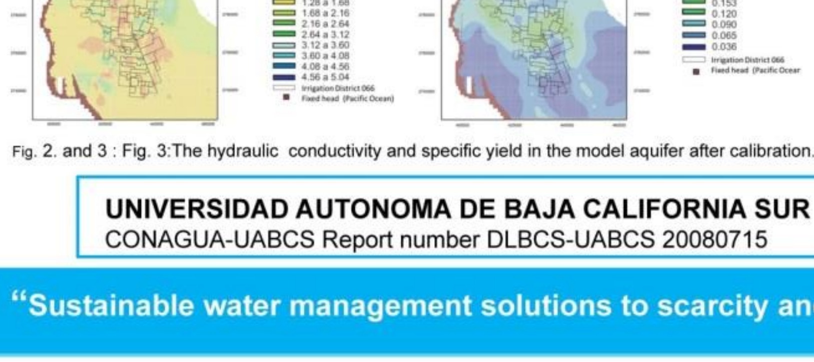

Fig. 2. and 3 : Fig. 3:The hydraulic conductivity and specific yield in the model aquifer after calibration.

RESULTS

The results from the different scenarios provide information on the hydrogeological conditions of the Santo Domingo aquifer. Based on the regional groundwater model it can be concluded that the total runoff, as a result of extreme floods, mainly generated after tropical cyclones, represents an additional source of water that can be infiltrated and recharge the aquifer. Statistically, one tropical cyclone is observed every year. The average rainfall over the Valley of Santo Domingo is 1.342 million m^3. Taking this value as 100%, the direct recharge represents 6%, the runoff is 7%, from which 2% infiltrates and 5% drain into the Pacific Ocean. The remaining 87% evaporate. Under average conditions, the balance for the three watersheds, forming the aquifer indicates that the watershed Las Bramonas presents a deficit of 2.6 million m^3 per year. For the watershed Santo Domingo results in a deficit of 9.7 million m^3 per year, meanwhile, the watershed Santa Cruz presents a positive balance of 13 million m^3. Zones of groundwater with higher mineralization can only partly be linked to the intrusion of saltwater from the coast; there is at least one more source of groundwater with high mineralization. Over-exploitation caused a deficit of 5,213 Mio m^3 of water in the aquifer, which represent 22.2 percent of the total initial water volume. Under the condition of an equality between natural recharge and discharge (conditions of 2007, Figure 6), an additional amount of at least 21.5 million m^3 could be recharged artificially each year. In order to achieve this goal, the runoff from the Sierra de la Giganta Mountains could be accumulated in four reservoirs, with an annual volume of at least 30 million m^3, which would allow feeding smaller dams on four recharging sites, located downstream, during no more than three months of a year (Table 1). In the proposed scenario, the recharge dams are introduced into the model with a storage volume of 206.525 m^3, 524.632 m^3, 757.935 m^3, 572 884 m^3, which could recharge an annual volume of at least 22.6 million m^3.

CONCLUSIONS

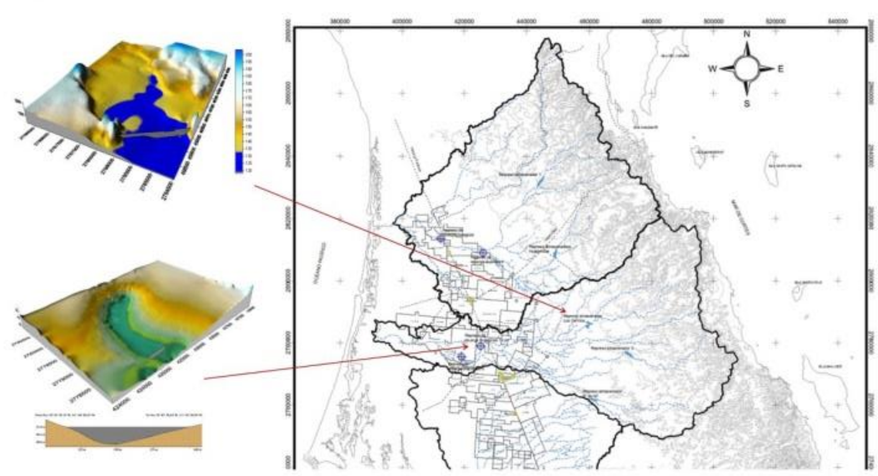

Figure 1. Major cities, important watersheds and geohydrological features in the Valley of Santo Domingo.

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National Water Commission

"Sustainable water management solutions to scarcity and climate change"

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Can village ponds be modified to mitigate floods and meet local irrigation demands?

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INTRODUCTION

- Mitigating devastating floods that occur during the monsoon by storing the floodwater in aquifers to meet irrigation demands in the dry season is referred to as 'Underground Taming of Floods for Irrigation' (or UTFI) (Pavelic et al. 2012, 2015) (Figure 1).
- With the concept well-established, a pilot trial was carried out in a sub-basin in India.
- This study was designed to set up and monitor UTFI pilot operations and evaluate the recharge performance.

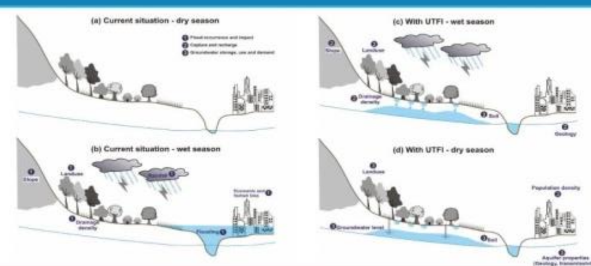
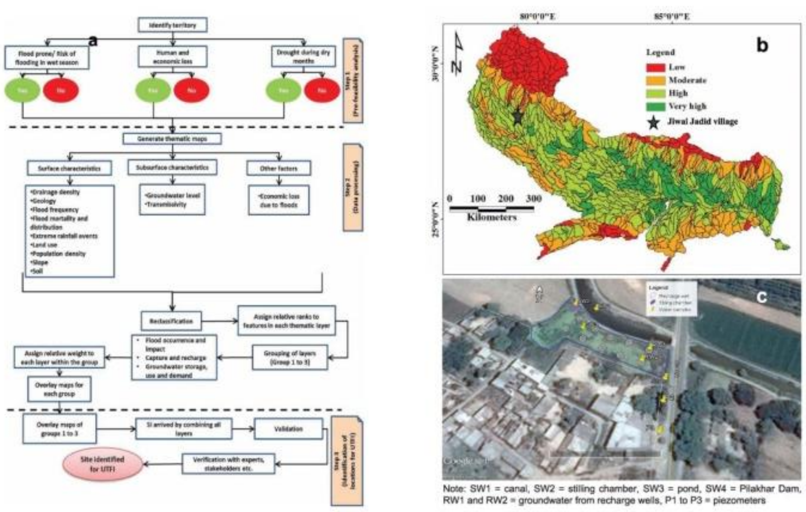


Figure 1. Schematic illustration of UTFI (*source*: Brindha and Pavelic 2016; modified from Pavelic et al. 2012).

METHODS

Site selection

- A simple and rapid assessment method was developed (Figure 2a) for the selection of suitable sites and this was applied to the Ganges River Basin.
- Based on these results (Figure 2b) and field visits to gather input from stakeholders, suitability of the site was analyzed taking into consideration aspects such as ownership of pond, decline in groundwater table, occurrence of floods, etc. Jiwai Jadid village in Rampur District, Uttar Pradesh (in the Ramganga sub-basin) was thus selected for piloting (Figure 2c).



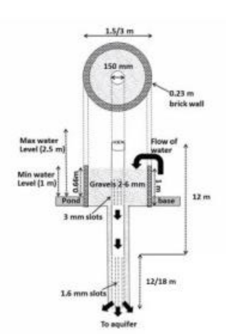
Note: SW1 = canal, SW2 = stilling chamber, SW3 = pond, SW4 = Pilakhar Dam, RW1 and RW2 = groundwater from recharge wells, P1 to P3 = piezometers

Figure 2(a) Methodology used for site selection, **(b)** Suitability index in the central Ganges Basin, and **(c)** UTFI structure and monitoring locations in Jiwai Jadid village, Uttar Pradesh, India (*sources*: (a) and (b): Brindha and Pavelic 2016).

Development of the pilot site

- Due to clayey soil at the base of the pond, it was considered to include recharge wells in the UTFI design (Figure 3).
- Dimensions of the pond were 75 m x 35 m, which was dewatered and excavated up to a depth of 2 m.
- Ten recharge wells were installed each consisting of a PVC pipe surrounded by gravel filter. Five of these recharge wells were of 3 m diameter and five other recharge wells were 1.5 m diameter (Figure 4).
- To measure the recharge rate changes in the wells, two of the wells were modified by raising the height of the brick wall surrounding it by 1 m above the standard design. A hole is present in the side of the wall for the water to enter. This can be closed after the wall is filled with water and the recharge rate can be determined.
- Three piezometers were installed nearby (depth 30 m) along the direction of groundwater flow at 5, 10 and 15 m distances from the nearest edge of the pond for monitoring the response to recharge.
- A stilling chamber is built at the point where the water enters the pond.
- A canal (which provides water for irrigation) that runs right next to the pond will be used to transport excess water (after irrigation requirement) to enable recharge through the village pond by siphon action.
- Water levels were measured using a water level recorder. Water samples were recorded using a field analyzer (total dissolved solids [TDS]) and major ions were determined using standard procedures.

Figure 3(a) Excavation of pond, **(b)** drilling of recharge wells, **(c)** modified recharge well for measuring flow rates (non-modified wells are seen behind), and **(d)** drain constructed to divert wastewater from households away from the pond.



Not to scale, for representation purpose only.

Figure 4. Cross-section of a recharge well

RESULTS

- After retrofitting the pond, recharge operations (Figure 5) were carried out between September 21 and 26, 2015, and from December 10, 2015 to January 14, 2016, i.e., the time during which the Department of Irrigation diverts discharge from the river to the canals.
- Infiltration rate at the base of the pond without the recharge wells was an average of 525 m³/d. Water level in the pond during the recharge is shown in Figure 6.
- With soil and infiltration tests, it was observed that the soil was mostly silt to sand, thus having higher infiltration rates than excepted. Knowing this earlier will help to rethink the design and reduce the cost of retrofitting.
- Recharge rates, including recharge from 10 wells, varied from 3,150 to 7,560 m³/d with an average of 5,400 m³/d.
- Recharge rate of the wells with two different specifications ranged from 423 to 425 m³/d for 3 m diameter wells and from 416 to 419 m³/d for 1.5 m diameter wells.
- Siphoning of flow from the canal to the pond could not be operated when the canal water level is below 0.8 m. This has to be considered as an important criterion to decide when to start and stop the recharging, besides considering the canal water quality. Groundwater level has improved by 0.5 m after recharge operations commenced (Figure 7). Water level in the piezometers have dropped by 2 m, which shows the demand and use of groundwater in the village, and implies the decline in water level during periods of no recharge.
- As the pond was used to hold wastewater from households for a long period of time, this had led to the build-up of nutrients at the bottom of the pond. Hence, TDS was higher in the groundwater from piezometers than the recharge water (Figure 8). Recharge over a period of time will flush out these nutrients and the TDS levels in groundwater will decrease.
- Quality of recharge water and groundwater that was recharged were good and within the prescribed limits of the Bureau of Indian Standards for drinking water quality for major ions and nutrients.

Figure 5(a) Filling of stilling chamber with water from the canal, **(b)** overflowing of stilling chamber and filling up of pond, **(c)** monitoring the recharge well, **(d)** water level in pond below the recharge wells (less than 1 m), **(e)** water level in pond above 1 m, and **(f)** close view of a recharge well.

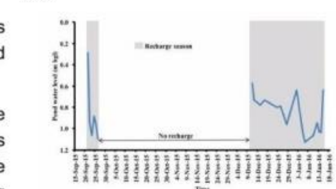


Figure 6. Water levels in the pond during recharge operations.

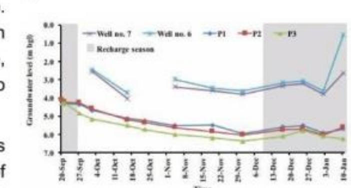


Figure 7. Comparison of water level in piezometers and recharge wells.

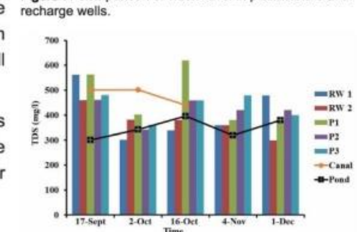


Figure 8. TDS in surface water and groundwater.

CONCLUSIONS

- This pilot study conducted to test the UTFI concept shows that an average of 5,000 m³/d of water can be recharged from one retrofitted village pond.
- Groundwater level in piezometers increased by 0.5 m after the recharge operations.
- TDS was higher in groundwater than pond water due to leaching of nutrients that had built-up in the pond as a result of its long-term use for wastewater disposal.
- Continuous monitoring is carried out to assess these changes and further recharge will commence during the monsoon season.
- This study demonstrates that village ponds are capable of being used to recharge floodwaters and augment groundwater resources, with adaptations to pond design/structure depending on the local geological and hydrological conditions. This can be considered as a reasonable and good way to recharge, especially when the project is cost bound.
- Ultimately, the intention is to hand over this pilot site to the local community so that it can be operated and maintained by themselves.

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Water recharge reduction in the Alto Atoyac subbasin, Oaxaca by climate change, and identification of recharge zones

9th International Symposium on Managed Aquifer Recharge

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INTRODUCTION

According to recent studies almost 80 % of the earth's population is exposed to significant stress factors that endanger the security of drinking water (Vörösmarty et al., 2010). Water stress may result from the overexploitation of groundwater sources as well as the reduction of precipitations, and reservoirs (Parish et al., 2012).

The objective of this study is to estimate the water recharge inside the Alto Atoyac sub-basin based Hydrology Evaluation of Landfill Performance (HELP) software. It also estimates permeable soil loss using remote sensing techniques and geographic information systems (GIS), in one region with poor agriculture practices; growing urbanization and deforestation, adding to CCh and endangering the availability of the water resource in a region whose main economic activity is based on water, with 87.6% of the groundwater resource used for agriculture, and 9.5 % on public and urban services (Pérez et al., 2010).

STUDY AREA

The Alto Atoyac study area is located in the Central Valley Region of the State of Oaxaca. It is comprised of the Etla, Tlacolula, and Zaachila valleys and constitutes one of the eight districts which divides the state., with an approximately extraction surface of 1,130 km2. The sub-basin has a surface of 3,744.64 km2 (CNA, 2003, Pérez et al., 2010). In The Central Valley Region 87.6% of the groundwater resource is used for agricultural purposes, while only 9.5% is used for public-urban services (Pérez et al., 2010).

Figure1. Study area

MATERIAL AND METHODS

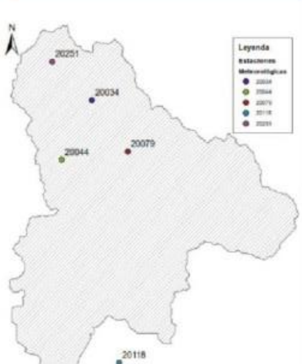


Figura3. climate station distribution

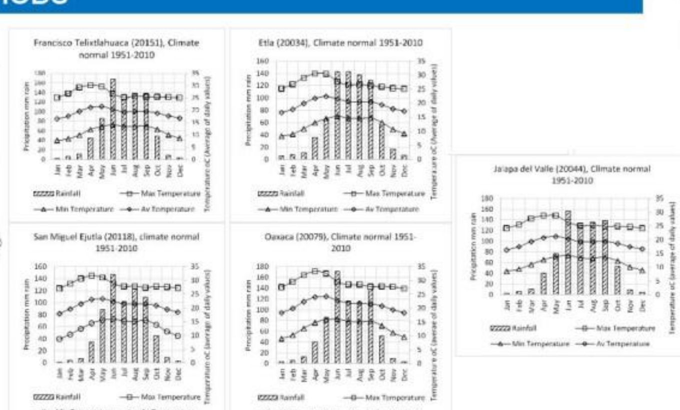


Figure4. Climate Normals

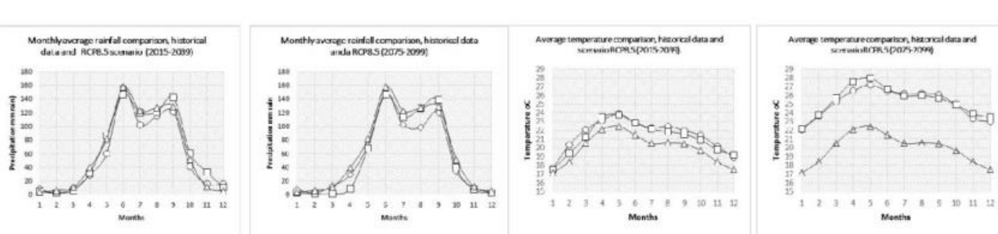


Figure 5. Model circulation Models, GFDL-CM3, HADGEM2-ES. Scenario RCP8.5

HELP Analysis process **(HYDROLOGY EVALUATION OF LANDFILL PERFORMANCE)**

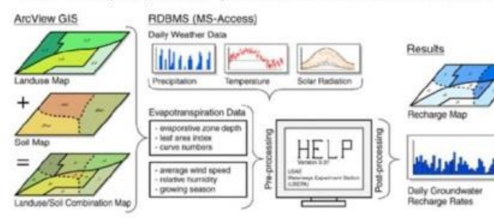


Figure6. HELP Methodology, Taken from Jirkama, 2007.

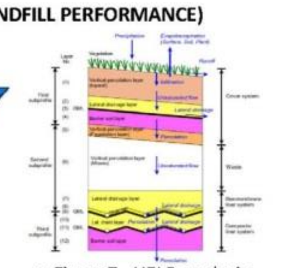
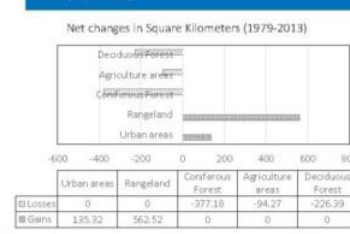


Figure7. HELP analysis


Soil type, Remote sensing analysis and Hydraulic head monitoring

RESULTS



	Urban areas	Rangeland	Coniferous Forest	Agriculture areas	Deciduous Forest
Losses	0	0	-377.18	-94.27	-226.39
Gains	135.32	562.52	0	0	0

Figure 8. Gain and losses net between 1979 and 2013

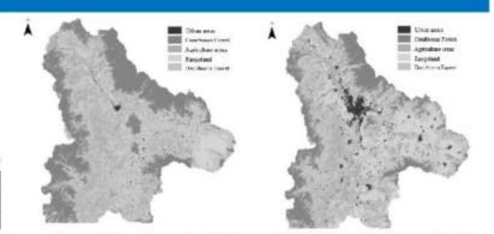


Figure 9. Land use for 1979 and 2013 in the Alto Atoyac Sub basin

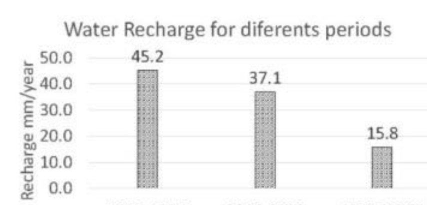


Figure 15. Historical water recharge and water recharge under different climate horizons

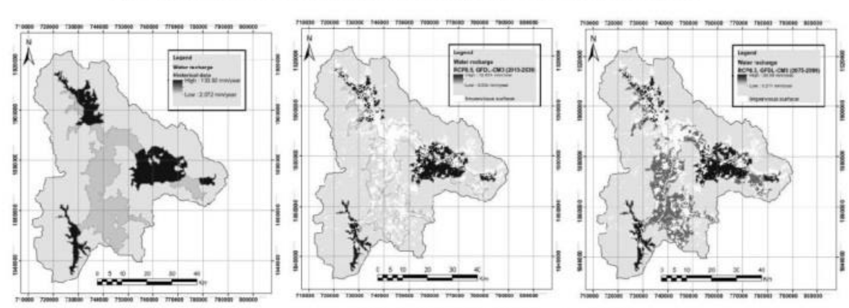


Figure 18. Water recharge map, scenario RCP8.5, 2075-2099, GFDL-CM3.

CONCLUSIONS

•Climatic Change (CCh) and the increase in impervious surfaces will directly affect the water recharge within the Alto Atoyac sub-basin in Oaxaca. GFDL-CM3 model under scenario RCP8.5 shows the most adverse values for the sub-basin area, direct reductions in precipitation, and increases in temperature will directly affect the aquifer water recharge.

•An Increase of 135 km^2 of impervious area represent a loss of 2.65x106 m3 of water, a high amount of water considering additional reductions from precipitation reduction and rising of temperatures. Near and far horizons analyzed under the most adverse scenario of CCh, shown reductions of 17.97% and 65.09% of water recharge within the watershed, which is a challenge in terms of management of the water resources in the coming years; as farming and human consumption are the most important uses of water within the watershed.

•Soil permeability, the geological conditions of their formations and the shallow water table make it sub susceptible to water recharge and also vulnerable to vertical contamination as shown by studies conducted within the study area. The construction of water recharge work previously analyzed, will allow the aquifer to face and adapt for climate change as well as the use of more efficient farming irrigations systems.

Combining aquifer storage and recovery with reverse osmosis (ASRO Westland)

An innovative solution for a sustainable freshwater supply

Koen Zuurbier[1], Marcel Paalman[1], Kjell Haas[2], G. van den Berg[1]

[1] KWR Watercycle Research Institute , [2] Bruine de Bruin BV

Introduction

Coastal areas are marked by high freshwater demands, but yet a low freshwater availibility. Use of the local eco-systems via aquifer storage and recovery (ASR) of temporary freshwater surpluses and reverse osmosis (RO) of brackish-saline groundwater are potential solutions for freshwater supply in coastal areas. Both techniques have their drawbacks, however, since ASR in coastal aquifers is marked by freshwater losses by buoyancy effects in the saline groundwater (water shortage remains), while RO is accompanied by a saline waste stream (unsustainable). In DESSIN we demonstrate that a sustainable and reliable freshwater supply can be achieve by combining both techniques in one system (ASRO).

Context

The Westland area in The Netherlands is the Dutch largest intensive greenhouse horticultural area, justicing its second name 'the glass city'. A mismatch in precipitation and water demand results in a large winter freshwater surplus here, which is discharged to sea as only a small part can be stored in basins or tanks. Fresh irrigation water supply is realized primarily by storing low EC rainwater from greenhouse roofs in basins, complemented by brackish water desalination (RO).

Site description: ASRO Westland

At the Westland field site, the freshwater surplus of 270,000 m^2 of greenhouse roof is collected, filtrated, and injected deep into the target aquifer (23-37 m below sea-level; 4000 – 5000 mg Cl/l) via dedicated, recently developed multiple partially penetrating wells. Upon storage, the water is recovered during spring/summer. Unmixed freshwater is recovered at the aquifer top for direct use. During later recovery, the deep well of the system is used as a 'Freshkeeper' for interception of of brackish-saline groundwater. This water is directly re-injected in a deeper aquifer (2014) or desalinated via RO for use as irrigation water (2015-2018).

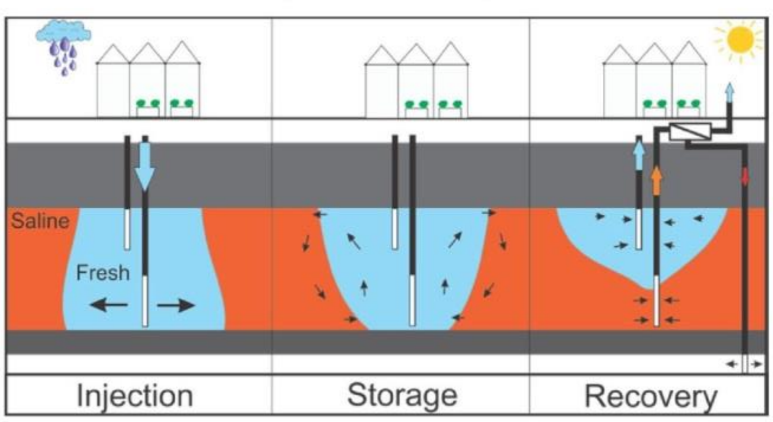


Figure 1: Storage and recovery of freshwater via ASRO

Methodology

The aim of this study is to optimize and demonstrate freshwater supply from brackish aquifers with a combined ASRO system. Specific objectives and corresponding methods are listed in Table 1.

Specific aims	Method
To demonstrate the added value of an ASRO system on freshwater recovery.	Field study, groundwater modelling
Assessment of membrane clogging by varying redox conditions of the RO feedwater	Field study, groundwater modelling
To demonstrate the impact of freshwater supply from brackish aquifers on regional groundwater quality and Water Framework Directive goals.	Regional groundwater modelling
To demonstrate the effect of enhanced subsurface iron removal on membrane clogging.	Field study

Table 1: Specific aims and method for the DESSIN Westland ASRO demonstration

Figure 2: The Westland ASRO well field

Results & Discussion

ASR freshwater recovery at Westland, without RO

In Figure 3, it is shown that the modelled long-term recovery efficiencies for direct use at the Westland demonstration site increases from approximately 30% for a simple, conventional ASR well to >60% when the Freshkeeper (incl. RO) is applied. This increase in freshwater availability underlines the importance of the dedicated design proposed.

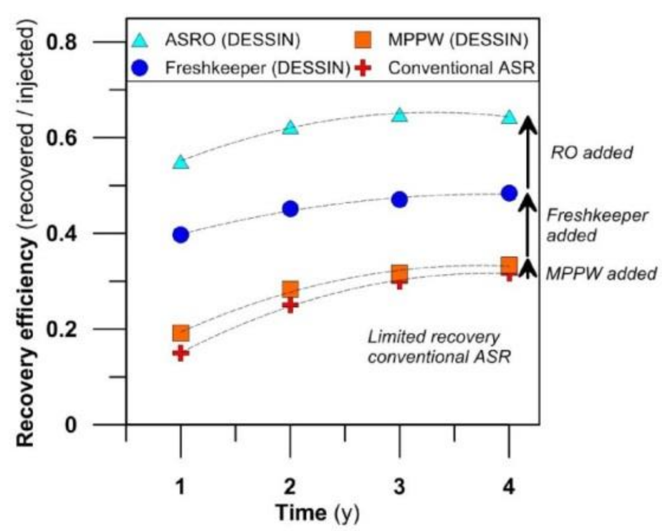


Figure 3: Modelled ASR recovery efficiencies

Additional freshwater production via RO

The Freshkeeper is functioning since 2014. The RO-installation uses brackish water membranes to remove 99.5% of the salts in the water abstracted by the Freshkeeper. Mobilisation of colloids in the target aquifer during rainwater injection are considered the main threat for the RO-application. In the Summer of 2015, however, the plant has been operating on a recovery of 50% without any indication of clogging.

Conclusions

The Westland ASRO demonstration shows the potential of dedicated ASR concepts in coastal aquifers to manage freshwater resources and enable a sustainable freshwater supply. Focus is now on enhanced production via RO and evaluation of the effects on the local and regional groundwater system.

Acknowledgements

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Mexico City, Mexico.
June 20th-24th, 2016.

Multiple barrier processes for indirect potable reuse: a lab-scale study for Mexico City

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INTRODUCTION

The Mezquital Valley is the largest agricultural extension in Mexico where, for more than 100 years, the wastewater generated in Mexico City has been reused for the irrigation of more than 80,000 hectares. This reuse practice has led to the incidental recharge of local aquifers, where soil has served as a treatment process (SAT), and groundwater now supplies the population in the region. Therefore, considering the increase of available groundwater and the growing demand for drinking water in Mexico City, it is now under evaluation whether groundwater from the Mezquital Valley may supply 6.5 m^3/s to Mexico City.

Untreated wastewater has been reused in the region, and some contaminants have been found in groundwater despite the natural soil barrier. Some of these pollutants are present in concentrations above the regulation limits for drinking water. Previous studies have evaluated groundwater quality at the Mezquital Valley and have recommended a membrane treatment (nanofiltration or reverse osmosis), coupled to a pre-treatment to remove those pollutants.

This research is based on those recommendations and presents the results from a preliminary approach at laboratory scale, to treat water with non-conventional groundwater quality with a multiple barrier system.

METHODS

Water treatment experiments with synthetic water were performed, simulating historical mean concentrations found in groundwater from Mezquital Valley, which were documented in more than ten previous studies.

Treatment was evaluated at a laboratory scale plant, with an advanced stage system (Fig. 1) that includes reverse osmosis (RO) and ozonation. Two stages were incorporated as a pretreatment system with multiple filtration (sand/gravel, zeolite, activated carbon) and subsequent ultrafiltration (UF) to feed the reverse osmosis step (Table 1).

Mean concentrations of 13 parameters were simulated in synthetic water; considering their importance for human health, and due to their role in process control. Parameters selected were metals; aluminum, arsenic, cadmium, manganese, iron, and lead; basic parameters such as nitrates, fluorides, chlorides, sulfates and sodium; and microbial indicators, including helminths eggs and fecal coliforms simulated as E. Coli.

Figure 1 – Laboratory scale Plant

Table 1 - Pilot plant characteristics

Mean flow	50 GPD
Influent pressure	20 - 40 psi
RO influent pressure	40 - 80 psi
Rejection	60 - 80 %
Particle removal capability	
Sand	> 20 µ
Zeolite	> 8 µ
Activated carbon	> 15 µ
Ultrafiltration pore	5 µ
Reverse Osmosis	1-10 Å
Ozone dose	0.8 g/h

The water treatment tests consisted on three experiments (salts+metals+pathogens) with the successive addition of the compounds of each group; each experiment was replicated 5 times; 5 sampling points were analyzed: influent, effluent, and after each barrier; sampling by duplicate (including rejection flow); other parameters analyzed: pH, total dissolved solids (TDS), turbidity, and conductivity.

RESULTS

The results obtained from the processes in the pilot plant, indicated a mean removal ≥ 90%. Treated water complies with the Mexican drinking water regulation (NOM-127) for all the parameters tested (Table 2). The pretreatment processes (Filtration and UF) played an important role in the reduction of nitrate, fluoride, arsenic, cadmium, iron, lead, and pathogens. The RO membrane proved to be more efficient for both metal and salts concentrations, and provides an additional removal for the rest of the parameters (higher than 90%).

Table 2 – Pilot plant results: Mean concentrations (mg/L) by barrier process

Parameter	Influent	Filtration	UF	RO	Effluent	NOM-127	Mean Removal %
TDS	1576	1713	1615	45	40	1000	97.5 ± 2.4
Chlorides	377	345	376	25	12	250	95.9 ± 1.8
Fluorides	1.9	1.6	1.7	0.1	0.07	1.5	96.3 ± 2.1
Nitrates	18.9	16.4	16.1	1.9	1.1	10	93.2 ± 3.4
Sulfates	621	594	593	2	2.4	400	99.6 ± 0.6
Sodium	681	676	678	18	13	200	98.0 ± 0.7
Aluminum	0.90	0.70	0.57	0.015	0.003	0.2	99.6 ± 0.9
Arsenic	0.04	0.03	0.02	< DL	< DL	0.025	99.0 ± 0.7
Cadmium	0.23	0.21	0.19	3.0E-05	3.0E-05	0.005	99.9 ± 0.02
Iron	0.09	0.09	0.04	0.014	0.008	0.15	90.4 ± 12
Manganese	0.11	0.11	0.10	4.7E-04	6.0E-04	0.3	99.5 ± 0.8
Lead	0.37	0.06	0.02	2.3E-04	2.3E-04	0.01	99.9 ±0.05
E. Coli	286	11	0	0	0	0	99.9 ± 0.01
Ascaris sp	1	0.1	0	0	0	-	99.9 ± 0.01

DISCUSSION

The behavior of the multiple barrier system indicate that is feasible to produce safe drinking water from an incidentally recharged aquifer:

- ❖ It was observed a mean removal of 97% of *E. Coli* and a complete elimination of *Ascaris*, in the filtration pretreatment.
- ❖ The filtration pretreatment also promotes a 10 – 25% mean removal of nitrates, fluorides, arsenic, cadmium, and reaches an 86% removal of lead (Fig. 2).
- ❖ The UF pretreatment provides an additional mean removal of 10 – 45% for nitrates, fluorides, arsenic, cadmium, and adds a 96% removal of lead and 60% of iron (Fig. 3).
- ❖ The RO membrane improves the removal of arsenic, cadmium and lead, and it is the main barrier for the removal of sulfates and manganese with a mean removal > 99%
- ❖ A mean removal of 93 – 98% in RO membrane is reached for fluorides, chlorides, sodium, and aluminum, while a lower removal is attained for nitrates (88%) and iron (85%) (Fig. 4).

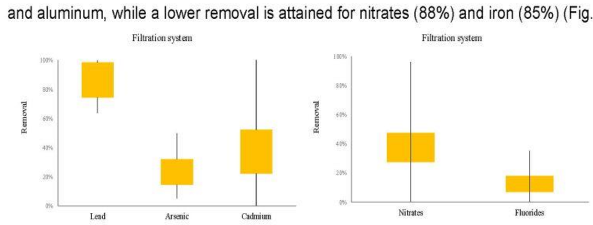

Figure 2 – Removal in Filtration

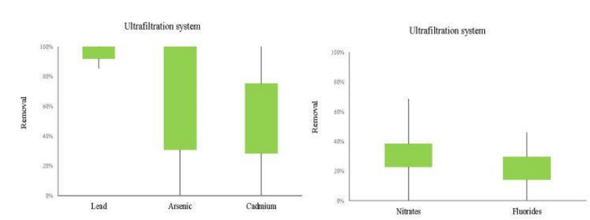

Figure 3 – Removal in Ultrafiltration

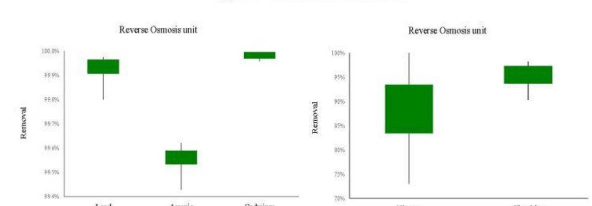

Figure 4 – Removal in Reverse Osmosis

CONCLUSIONS

Pre-treatment processes have an important influence on the removal of initial concentrations of pollutants present in groundwater from an incidentally recharged aquifer. RO provide further reduction of concentrations at acceptable levels of nitrates, fluorides, chlorides, arsenic, cadmium, and lead, to fulfill national drinking water regulations. Additional tests with synthetic water are required with the following aims:

- ❖ Assess the effect of other compounds in removal efficiencies, for example organic matter, silica, and some emerging compounds (endocrine disrupter's compounds such as Nonilphenol, Bisphenol-A, and Butyl benzyl phthalate).
- ❖ Improve pretreatment processes and identify control parameters.
- ❖ Confirm that the scheme of multiple barriers proposed is able to produce safe water, before carrying out tests, at pilot plant scale, on site, with groundwater from the Mezquital Valley.

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"Sustainable water management solutions to scarcity and climate change"   www.ismar9.org

Economic viability of recycled water MAR

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A cost-benefit tool to assess the economics of MAR with recycled water and its application to six Australian case studies

Background

Demand on water resources due to population growth and climate variability has led to growing interest in water recycling via managed aquifer recharge (MAR).

Uptake of MAR for water recycling in Australia has been lower than expected. Despite the benefits that MAR offers, uncertainty regarding economic feasibility is considered an impediment to water recycling via aquifers.

Sharing experience can address the uncertainty regarding economic feasibility of recycled water MAR and can influence decisions to construct and commission MAR schemes.

Case studies

Australian recycled water MAR case studies (Figure 1):

- Infiltration basins (WA)
- Infiltration gallery (Floreat, WA)
- Soil Aquifer Treatment (SAT) (Alice Springs, NT)
- Aquifer Storage and Recovery (ASR) (Bolivar, SA)
- Aquifer Storage Transfer and Recovery (ASTR) (Anglesea, Vic & Beenyup, WA)

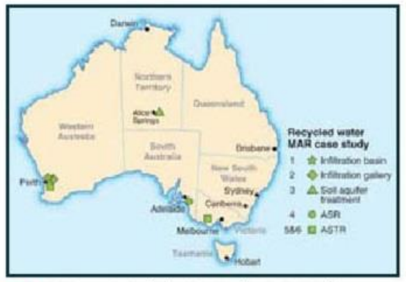

Figure 1: MAR case studies (after Vanderzalm *et al.*, 2015).

Economic assessment method

The economic analysis was conducted using a cost-benefit analysis (CBA) framework with the *Recycled Water Economic Assessment Tool* (AWRCoE 2015a). The *Tool* sets out the timing and magnitude of the costs and benefits and, utilising the principles of discounting, reduces the costs to a net present value (NPV). Levelised cost (or benefit) allows options of different capacity to be compared on a like-for-like basis.

In addition to including capital, operating and maintenance costs of wastewater treatment, water recycling plant, recharge and recovery, and distribution, it also accounts for greenhouse gas emissions, and recovery efficiency of MAR. Benefits include the sales price of recycled water and avoided costs otherwise incurred to meet environmental or water supply security requirements.

The following assumptions were applied to all case studies:

- 50 year evaluation period
- A discount rate of 7% was applied, with sensitivity testing undertaken at 4% and 10%
- Construction of infrastructure completed within the first year, operations commenced in the second year
- No residual value of the infrastructure was included at the end of the evaluation period
- A cost of carbon estimate of $40 per tonne was applied and held constant over the analysis period

Results for six Australia sites

Recycled water MAR costs were A$0.88-$3.56/m^3. Benefits were quantified at A$0.39-$8.50/m^3 (Table 1). Five of the six economic assessments reported favourable benefit to cost ratios (benefit>cost) due to avoided costs associated with surface storage, wastewater treatment or alternative water supply (Figure 2).

The Floreat infiltration gallery (Figure 3) was proposed to sustain groundwater dependent wetlands. Anglesea ASTR assessed water recycling water for eventual inclusion in the drinking water supply, an option not supported by current policy (Figure 4). The Alice Springs SAT scheme was not economically viable due to unquantified and unaccounted externalities. Wastewater treatment capital expenditure is often a sunk cost.

Table 1: Summary of economic assessment of MAR case studies (Vanderzalm *et al.*, 2015)

CASE STUDY	TARGET (Mm^3/yr)	COST/m^3 (A$2014/15)	BENEFIT/m^3 (A$2014/15)	BENEFITS ASSESSED	POTENTIAL BENEFITS NOT QUANTIFIED
Infiltration basins (WA)	0.03	2.68	8.50	• Avoided costs of above ground storage • Aquifer treatment	• Aquifer replenishment
Infiltration gallery, Floreat (WA)	1.8	1.07	2.00	• Avoided cost of maintaining wetland with potable supply	• Ecological benefits due to reduced discharge of wastewater to marine environment
SAT, Alice Springs (NT)	1.2	2.09	0.39	• Avoided wastewater cost (discharge via evaporation basins)	• Health protection against encephalitis • Avoided potable supply cost • Aquifer replenishment
ASR, Bolivar (SA)	9.0	0.88	2.51	• Reduced discharge of wastewater to marine environment	• Increase in crop productivity
ASTR, Anglesea (Vic)	8.9	3.56	4.10	• Avoided wastewater cost • Avoided potable supply cost	• Willingness to pay for water security
ASTR, Beenyup (WA)	14	2.24	3.14	• Avoided cost of desalinated water	• Social and ecological benefits of maintaining groundwater dependent ecosystems

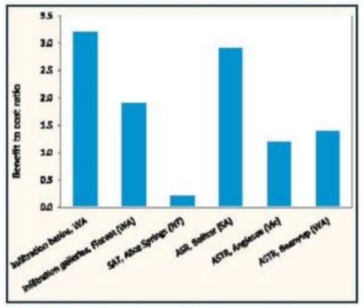

Figure 2: Benefit to cost ratio for case studies.

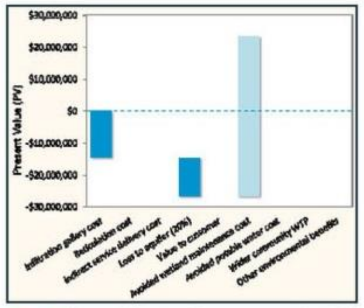

Figure 3: Floreat infiltration gallery economic analysis (A$).

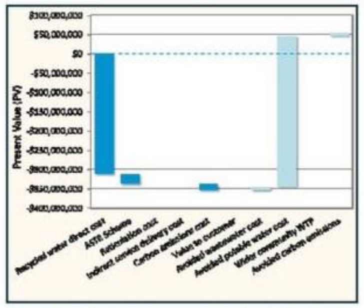

Figure 4: Anglesea ASTR economic analysis ($A).

Summary

The *Tool* was found to be useful in assessing benefits and costs as comprehensively as possible with the data available. Costs varied from A$0.88-$3.56/m^3 for six Australian recycled water MAR case studies with target recharge volumes ranging from 0.03-14 Mm^3/yr (volume weighted mean cost of ~A$2.00/m^3).

Potential benefits associated with water recycling via MAR are currently not well understood and not adequately quantified in cost benefit analysis. Even without a thorough assessment of potential benefits, MAR was found to be economically viable in the majority of recycled water case studies.

FOR FURTHER INFORMATION
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Australian Water Recycling Centre of Excellence

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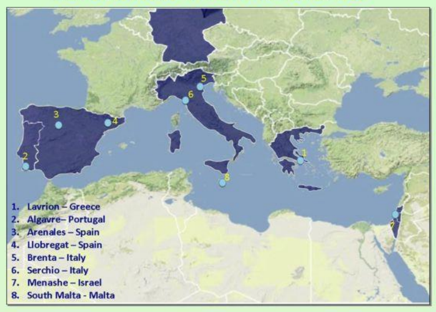
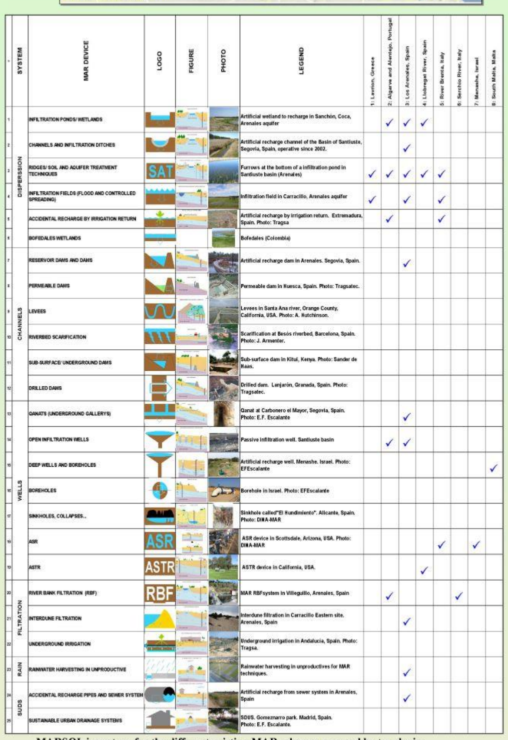
MAR TECHNICAL SOLUTIONS ASSESSMENT. GUIDELINES OBTAINED FROM THE EXPERIENCE OF EIGHT MEDITERRANEAN DEMO SITES

MAR TECHNICAL SOLUTIONS OBTAINED FROM THE EXPERIENCE OF MARSOL PROJECT

MARSOL DEMO SITES





MARSOL inventory for the different existing MAR schemes grouped by typologies

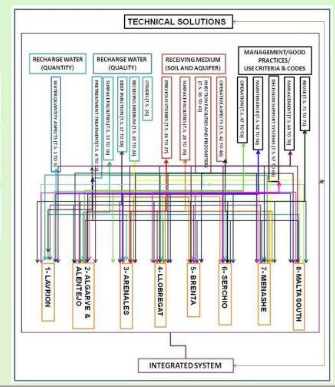
INTRODUCTION

The MARSOL project aims at providing scientists, practitioners and end-users with an engineering-enabled set of technical solutions to improve Managed Aquifer Recharge (MAR) efficiency in areas where it is applied, and consequently, in general water. The main purpose of this article is to provide several sets of "technical solutions" for high efficiency MAR facilities and devices in Mediterranean countries (Portugal, Spain, Italy, Greece, Malta and Israel). Some of these Technical Solutions provide an important know-how on the design of the constructions, water management premises; decision support making and public-private partnership in those countries, so that, the interaction among the users, the smart solution, the demo-site's infrastructure and the repository of experiences has been guaranteed, providing internationally applicable outcomes.

OBJECTIVES

PROBLEMS AT MAR DEMO SITES

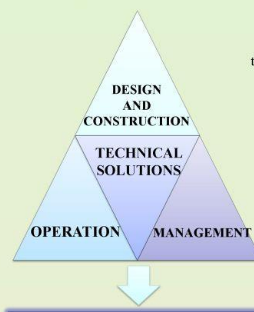
Scarcity (overexploitation and climate change)	Salinity (seawater intrusion)	Heavy metals (mining, industry…)
Agriculture contamination (mainly Nitrogen)	Organic pollution (agrochemical and antibiotics)	Wastewater discharge
Wetland desiccation	Floods	Others



TECHNICAL SOLUTIONS DATABASE STRUCTURE, relating the sort of T.S., the category, the specific T.S. applied and the demo-site where it is being tested and deployed. Notice: This figure might change after the development of the ongoing activities

RESULTS

Design and construction T.S.
Geofabrics installed in the bottom of the MAR canal in Los Arenales Aquifer



Management T.S.
Valves for manual control of the water volume in Los Arenales Aquifer

Operation T.S.
Stagnation systems in Los Arenales Aquifer

73 TECHNICAL SOLUTIONS

RECHARGE WATER (QUANTITY)

1-Preselecting: selective criteria for the origin of recharge water when several sources are available
2-Temporary storage of MAR water in surface reservoirs
3-Control of the flow velocity of MAR Water (stopping devices…)
4-Manage/avoid operations during specific events/periods, e.g. freezing weather, heat waves…
5-Security structures for overflow events, run-off tramps, spillways, etc.

RECHARGE WATER (QUALITY)

6-**Pretreating** of water for MAR in origin: (WWTP, membranes, mud lines, filters, packets…)
7-Pretreating of water for MAR in the heading of the structure: Filtering beds, decantation/stagnation structures, deaeration, etc.
8-Pretreating of MAR water using unsaturated zone as a pretreatment natural filter
9-**Treatment** structures intercalated along the construction for surface facilities, e.g. control of pH by means of mudstone gravel filters
10-Pretreating by Disinfection By Products (DBPs), e.g. Cl, I, O_3, H_2O_2, UV rays, etc.
11-Chemical additives to eliminate clogging layers
12-Combination of different MAR facilities to improve the MAR water quality, e.g. a "triplet scheme" (WWTP, green biofilter, artificial wetland)
13-**SURFACE FACILITIES**: Design and preservation of slope (rubble works, gabions…)
14-Limitation/control of the water layer thickness
15-Denitrification processes/additives (e.g. anammox)
16-Mechanisms to force the mixture of the different layers of MAR water, e.g. for canals let the water jump over or below stopping devices alternatively
17-**DEEP INJECTION FACILITIES**: Employ of anticorrosion materials in the MAR devices
18-Changes in the depth of the pump for wells/boreholes
19-Induced changes in water quality for irrigation. Fertilizers…
20-**RECEIVING MEDIUM**: Avoid aeration on AR waters: communicating vessels, open/buried structures, velocity control
21-Deaeration techniques: piezometers, increase distance between injection-extraction points…
22-Isolation from atmosphere/sunlight structures
23-Avoid natural salinization: Induced recharge, e.g. barriers in salty areas
24-Recycling effect of water in the MAR system (describe)
25-**OTHERS**: Specific fishes/exotic species introduced to reduce clogging (e.g. medaka)

RECEIVING MEDIUM (IN BOTH SOIL AND AQUIFER)

26-**PREVIOUS STUDIES**: The knowledge of the environmental conditions for the receiving medium might be considered sufficient? (describe)
27-Regarding the selection of the site, are there "natural fences" to avoid water to leave the system?
28-**SURFACE FACILITIES**: Changes in the receiving medium design. Furrows in the bottom, width, shape... (describe)
29-Changes in the receiving medium design. Geofabrics in the bottom/slopes
30-Inverse pumping in wells pits close to a MAR canal or pond
31-Backwashing in geo fabrics, membranes and filters
32-Use of jet type cleaning techniques
33-Chemical cleaning (use of chemical additives) (describe)
34-Operations in the bottom: Algae drying, natural bed drying, cryotreating, cracking (cake)
35-Mechanical cleaning (scarification or silting zones and cleaning /replacement)
36-**INJECTION FACILITIES AND PIEZOMETERS**: Alternate normal and inverse pumping and frequency
37-Mechanical cleaning (wall brushing, scratching…)
38-Chemical cleaning (use of chemical additives) techniques for the regeneration of recharge wells
39-Selection of casing materials for wells according to groundwater characteristics (quality, quantity, durability…)
40-Employ of water level control automatic systems (alarm systems, buoys…)
41-Employ of clogging preventive systems, e.g. cathodic protection…
42-**OPERATIVE ASPECTS**: Use of dual systems allowing cleaning of one of them whilst the other is operating
43-Cleaning of the vegetation in the MAR facilities
44-Specific plantation during any season
45-Cleaning techniques frequency
46-Use of Basic Cleaning Vehicles (BCVs) (describe)

MANAGEMENT PARAMETERS AND *EX SITU* TECHNIQUES (INCLUDING MANAGEMENT, GOVERNANCE...)

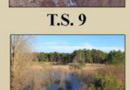
47-**OPERATION**. Management parameters and ex situ techniques related to water management, governance... (describe)
48-Election of the most appropriate period and place to MAR water / obligation due to administrative concessions
49-Initiate 'soft' MAR cycles (start gradually)
50-Input flow and flow water speed control (automatic, manual)
51-Dual systems: duplicated MAR facilities to alternatively manage MAR and cleaning activities
52-Alternative sources of MAR water and management (describe)
53-Monitoring chemical properties of MAR water during recharge cycles
54-**MAINTENANCE**. Specific protocol for clogging control
55-Protocol for proper hydro-mechanical aspects in space and time. e.g. pressure inside a pipeline circuit (describe)
56- Specific cleaning and maintenance programs or decisions made "on the go"?
57-**DECISION SUPPORT SYSTEMS**. Integrated system design: all elements are interconnected
58-Promote participation of farmers or other social agents or stakeholders in water management
59-Limit fertilizers use
60-Decrease untreated spilling in the area
61-Protected perimeter around the MAR facilities
62-Use of protection devices for fauna and people in MAR facilities
63-Public use regulation
64- **MANAGEMENT**. Early adoption of the Best Available Techniques (to what extent new BAT, are tested prior their application)
65-Design and adoption of a proper Watching and Control Program
66-Construction of dams specifically designed for MAR
67-Construction of WWTP specifically designed for MAR
68-For those devices constructed due to a R&D specific project, is there any guaranteeing mechanism to operate the system after the end of the project
69-Are there already specific operative guidelines?
70-Use of sensors to monitor turbidity, dissolved oxygen, temperature… either inlayers or installed in surface facilities
71- **REUSE**. The wells used for MAR were specifically designed or previous wells/shafts were used (change of use)?
72-Use of existing natural previous elements to improve MAR efficiency, e.g. River Bank Filtration (RBF direct or inverse), use of dolines, sinkholes…
73-Use of pre-existing artificial previous elements for MAR e.g. rivers dams, meander scarfs…

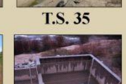

T.S. 9


T.S. 35


T.S. 66


T.S. 16


T.S. 2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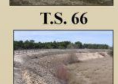
T.S. 13


T.S. 73

CONCLUSIONS

- Managed Aquifer Recharge devices are presented as a serious alternative for water management plans, to be combined with more traditional systems.
- Technical solutions are the group of activities aim at increasing MAR effectiveness.
- Before implementing a MAR system, it is necessary to choose the most appropriate method. It is preferable the surface infiltration systems, since they facilitate the application of the majority of SAT techniques.
- The availability of water for MAR is not guaranteed in long periods of drought. Alternative sources as WWTP or reuse should be considered.
- It is crucial to conduct a prior detailed technical study, specially in complex MAR devices, in order to avoid or reduce problems.

ISMAR9

dM dina-MAR

BENCHMARKING PROPOSAL FOR MAR SYSTEMS. BENCHING AND COMPARING THREE MEDITERRANEAN MARSOL SITES

Tragsa GrupoTragsa Partners in excellence

MAR SOL MANAGED AQUIFER RECHARGE SOLUTIONS

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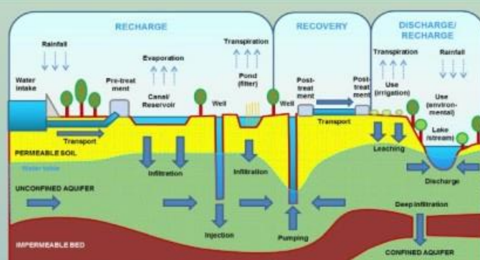
INTRODUCTION

The main aim of the Managed Aquifer Recharge (MAR) cannot be any other but the **amount and quality** of the resource obtained after its pass through the system, so **these two variables have to be the focus of the benchmarking** when comparing three different cases considered in the MARSOL European project .No matter the complicated the scheme could be, the question is the net water recharge. In order to be able to compare the efficiency and efficacy of the MAR based on terms of energy balance or cost/profit, a methodical characterization of the whole process must be carried on to assure functions and devices are clearly comparable independently of size, budget or location.

WHAT IS BENCHMARKING?

- Benchmarking is a question of comparison. It deals with the process of comparing one's business processes and performance metrics to industry bests or bets practices from other companies. Parameters typically measured are **quality, time and cost.**
- Benchmarking is used to measure performance using a specific indicator.



Water recharge and recovery system sketch

MARSOL PROJECT


Infiltration pond filling. Llobregat, Spain. DEMO SITE 4

CHOSEN DEMO SITES

2: ALGARVE, PORTUGAL
4:LLOBREGAT, SPAIN
8:SOUTH MALTA, MALTA

OBJECTIVES

- Adapt benchmarking for Managed Aquifer Recharge
- Present a proposal for specific indicators for MAR operations
- Explanations of a properly designed methodology
- Proposal for a template to insert the benches and indicators


Rio Seco river bed infiltration ponds. Algarve, Portugal. DEMO SITE 2


Infiltration wells. South Malta. DEMO SITE 8

METHODOLOGY

SHEET 1: DEMO SITES

Hidrogeology, Groundwater, Water Use → Problems → MAR-SOL → Characteristics, Functions, Performance → Benchmarking

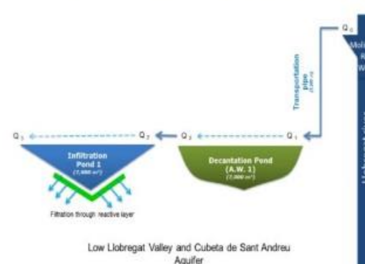
Benchmarking design: From problems to solutions

SHEET 2: DEMO SITE ON ORTOPHOTO

MAR-SOL Devices → Location on map → Dimensions, Geographic conections, Scale


Rio Seco ponds on orthophoto

SHEET 3: DEMO SITE SKETCH



Llobregat general sketch

MAR-SOL Devices → Sketch → Conectivity, MAR system R/T/R, In/Out

SHEET 4: DEMO SITE OPERATION SCHEDULE

MAR-SOL Devices → Schedule → Seasonality, Evolution, Campaigns

RESULTS

PARAMETERS OF WATER QUALITY

Qualitative parameter	Before Abstraction	Aquifer	Before Use	Change
pH	pH	pH	pH	%
Biological Oxygen demand	BOD (mg/l)	BOD (mg/l)	BOD (mg/l)	%
Chemical Oxygen Demand	COD (mg/l)	COD (mg/l)	COD (mg/l)	%
Total Suspended Solids	TSS (mg/l)	TSS (mg/l)	TSS (mg/l)	%
Dissolved Organic Carbon	DOC (mg/l)	DOC (mg/l)	DOC (mg/l)	%
Ammonia as N	NH_3 (mg/l)	NH_3 (mg/l)	NH_3 (mg/l)	%
Total N	N (mg/l)	N (mg/l)	N (mg/l)	%
Phosphorus	P (mg/l)	P (mg/l)	P (mg/l)	%

PARAMETERS OF WATER QUANTITY

Phase	Quantitative parameter	Original resource	Aquifer	End use	% of total
Resources	Water availability	m^3			%
Abstraction	Water abstraction	m^3			%
Pre-treatment	Pre-treated water	m^3			
Recharge	Recharged volume		m^3		%
	Recharge rate		m^3/ha; m^3/sg		%
	Surface/volume rate		m^3/ha		%
Storage	Incremented store		m^3		%
	Water table		m		%
Recovery	Water availability			m^3	%
	Water recovery			m^3	%
Use	Water use			m^3	%

PARAMETERS FOR EFFICENCY IN A MAR SYSTEM

Phase	Efficiency parameter	Original resource	Aquifer	End use	% of total
Abstraction	Energy cost	kWh/m^3			%
	Infrastructure cost	€/m^3			
	O&M cost	€/m^3			
Pre-treatment	Energy cost	kWh/m^3			
	Infrastructure cost	€/m^3			%
	O&M cost		€/m^3		%
Recharge	Energy cost		kWh/m^3		%
	Infrastructure cost		€/m^3		%
	O&M cost		€/m^3		%
	Recharging rate		%		
	Filtration rate		m^3/ m^2		
Recovery	Energy cost			kWh/m^3	%
	Infrastructure cost			€/m^3	%
	O&M cost			€/m^3	%
Use	Energy cost			kWh/m^3	%
	Infrastructure cost			€/m^3	%
	O&M cost			€/m^3	%

Benchmarking MAR facilities needs to take a series of steps.:

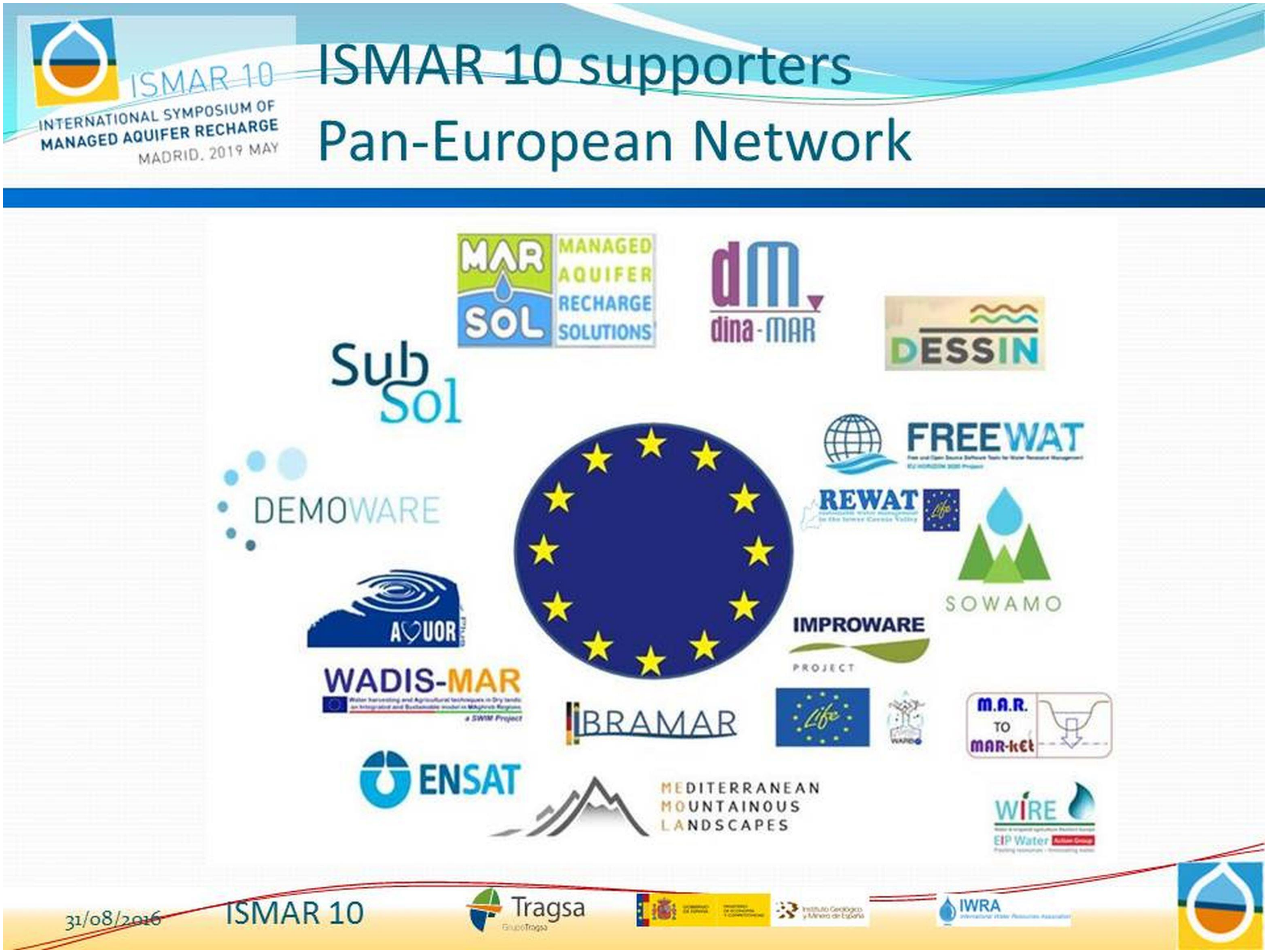
1. **MAR infrastructure measurement (lengths, devices…)**
2. **MAR functions characterization (transport, infiltration…)**
3. **MAR evolution in time and space (maps, sketches…)**

CONCLUSIONS

- This **characterization** covers the technical solution aspect and the local features of the sites where MARSOL is implemented. Measuring MAR displays unlike interpretations depending on scale. Main numbers show different reliability features, considering measurement issues (operational dimensions versus geometrical sizes), deduction (diversion flow/volume or infiltration rates) and time line (cost sharing or lifespan).
- **Mediterranean water irregularity**, amplified by Climate Change previsions, can benefit from MAR in very different functions (flood control, WWT or ecological restoration) not generally seen as goals attached to recharge. No Energy cost and low initial investment can also play an important role in short term to boost MAR development as a real choice in water management planning.

NEXT: P-ISMAR 10

16 coordinators of projects founded by the E.C. and action groups who have supported the Madrid candidacy have integrated the M.A.R. Pan-European Network:



Notes

P-ISMAR 9

"Sustainable water management solutions to scarcity and climate change"

Dr. Fernando González Villarreal

Depósito legal: M-32444-2016

Río Bravo