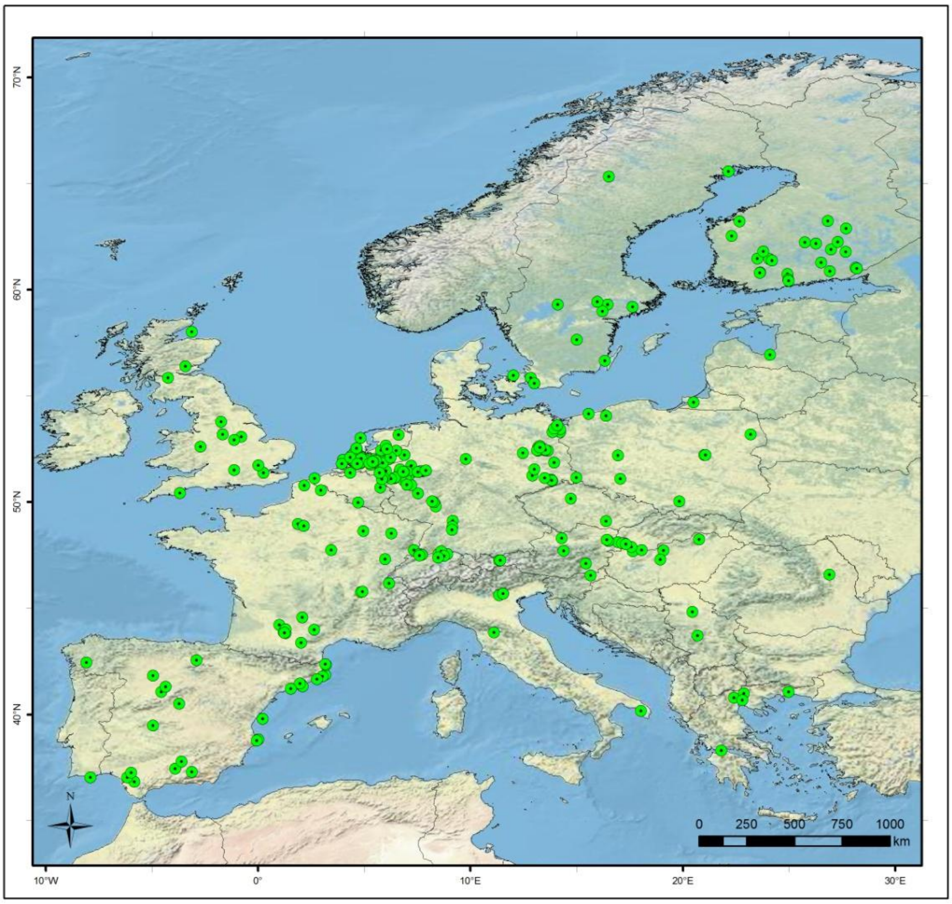
Development of a catalogue on European MAR sites

Documentation



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Title:

DEVELOPMENT OF A CATALOGUE ON EUROPEAN MAR SITES - DOCUMENTATION

Summary:

The EU-funded R&D project DEMEAU addresses the fate of emerging pollutants in water and waste water treatment, e.g. Managed Aquifer Recharge (MAR). For MAR the objectives are to mobilize existing experience from different European study sites and to develop a systematic approach for the authorization of new recharge schemes in compliance with the European water and groundwater directives. The activities will cover the issue of infiltrating and injecting treated wastewater as well as developing guidance on optimum design and operation of infiltration facilities.

In order to demonstrate the effects of typical existing European MAR systems onto groundwater availability and groundwater quality with specific focus on trace organics, a comprehensive relational database (catalogue) on European MAR systems was created to ensure efficient management of available data. By means of the built-in user forms, queries, and reports, database users are enabled to not only view and enter records but also to quickly process the data to extract needed information.

In total, 59 different parameters were selected in order to describe about 270 documented MAR sites in 23 countries in Europe. These parameters were then divided up into four main groups (general information, technical data, hydrogeological parameters and monitoring activities) plus references. The database was created using standard software (MS ACCESS) and references were managed by open source software (JABREF).

The compiled data on European MAR sites was taken from a variety of different source types, including scientific articles, books, PhD, diploma and master's theses, presentations, technical documents, reports from previous national and EU research projects, personal communication with specialists, operators and water authorities, community and operator websites, newspaper articles, and Google Earth (for geographic coordinates to create overview maps).

On the basis of this database a classification system for the MAR sites found in Europe will be developed that can be used for deriving site-specific pre-requisites and design criteria as guidance for the authorization of for new sites.

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1 Objectives and Background

An important objective of Work Package 11 is to demonstrate the effects of typical existing European MAR systems onto groundwater availability and groundwater quality with specific focus on trace organics. To this end, a comprehensive relational database on European MAR systems was created to ensure efficient management of available data. By means of the built-in user forms, queries, and reports, database users are enabled to not only view and enter records but also to quickly process the data to extract needed information.

In total, 43 different parameters were selected in order to describe documented MAR sites in Europe. These parameters were then divided up into 6 tables, the main *Sites* table (Table 1) plus 5 tables linked to the table *Sites*: *Objectives* (Table 41), *Influent Source* (Table 38), *Final Use* (Table 35), *Specific MAR Type* (Table 29) and *References* (Table 44).

The Annex (chapter 6) contains the list of references, which were used to fill the database plus some general literature about managed aquifer recharge.

2 System Requirements

The database was created using Microsoft Access 2007 and saved backward compatible for Access 2003. Thus, the minimum requirement for its usage is a Microsoft Access 2003 Standard Edition. For using the reference management software JABREF, the Java Virtual Machine (version 1.6 or newer) needs to be installed.

3 Data Sources and Literature Library

The compiled data on European MAR sites was taken from a variety of different source types, including scientific articles, books, PhD, diploma and master's theses, presentations, technical documents, reports from previous national and EU research projects, personal communication with specialists and operators, community and operator websites, newspaper articles, and Google Earth (for coordinates).

In order to keep the recording and utilization of bibliographic references simple and efficient, all of the cited scientific sources were stored in a literature library using JABREF; an open source bibliography reference management software which can be downloaded here. JabRef uses BibTeX as its native file format, the standard LaTeX bibliography format. Among the references cited in the MAR database, this literature library also contains a vast number of additional bibliographic references to scientific publications which can offer extensive background information on the subject of managed aquifer recharge in Europe.

4 Development

4.1 Structure of the Database

In Figure 1, the underlying structure of the database is presented. Depicted are all of the existing tables, the fields they contain, and the relationships amongst the tables. The individual tables, their relationships and field definitions are being covered in greater detail in the following section.

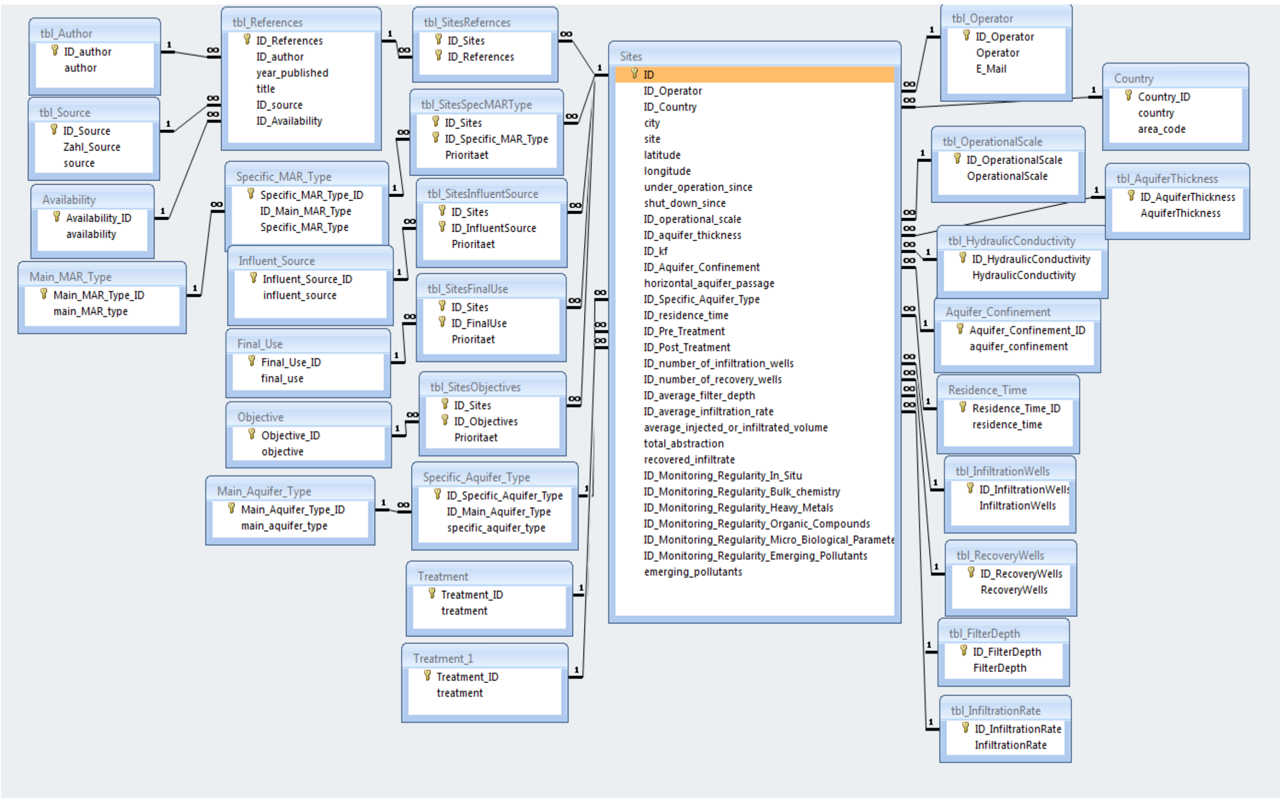

Figure 1: Structure of the MAR database and table relationships

4.2 Tables

Listed below are detailed descriptions of all existing tables and, when appropriate, their content. In case the content of the table's classification is too extensive an additional content table was provided. In order to ensure a high degree of comparability amongst the records, many of the tables contain list boxes with a set classification system which should not be changed. Hence, when using the user form for entering and viewing data, the user of the database is only allowed to add records to a few selected tables.

4.2.1 Sites

The table Sites represents the main table of the database in which the entries of most parameters of the MAR sites are saved and connections are set to 5 other tables, which correlate to *Sites* either in a 1:n or n:m connection. If a n:m relation is the case, the table was related to Sites via an additional link table.

To simplify the data entry and to avoid redundancies codes were provided for several attributes. These codes represent foreign keys to define the relation to the source table.

All tables of *Sites* (green highlighted) are directly linked to this table and can be accessed by choosing the right content.

In total, the table contains 32 fields.

Table 1: *Sites*

field name	data type	description	group
ID	number	primary key (auto number)	general frame / site information
ID_Operator	number	key to connect to table *Operator*	general frame / site information
ID_Country	number	key to connect to table *Country*	general frame / site information
city	text	city name	general frame / site information
site	text	site name	general frame / site information
latitude	number	latitude in decimal degrees (WGS84)	general frame / site information
longitude	number	longitude in decimal degrees (WGS84)	general frame / site information
under_operation_since	number	year in which operation started or will start	general frame / site information
shut_down_since	number	year in which operation ended or will end	general frame / site information
ID_operational_scale	number	key to table *tbl_OperationalScale*	general frame / site information
ID_aquifer_thickness	number	key to table *tbl_AquiferThickness*	general frame / site information
ID_kf	number	key to table *tbl_HydraulicConductivity*	general frame / site information
ID_Aquifer_Confinement	number	key to connect to table *Aquifer_Confinement*	general frame / site information
horizontal_aquifer_passage	number	average horizontal aquifer passage to abstraction well (m)	general frame / site information
ID_Specific_Aquifer_Type	number	key to connect to table *SpecificAquifer_Type*	general frame / site information
ID_residence_time	number	key to connect to table *Residence_Time*	operatational parameters
ID_Pre_Treatment	number	key to connect to table *Treatment*	operatational parameters
ID_Post_Treatment	number	key to connect to table *Treatment*	operatational parameters
ID_number_of_infiltration_wells	number	key to table *tbl_InfiltrationWells*	operatational parameters
ID_number_of_recovery_wells	number	key to table *tbl_RecoveryWells*	operatational parameters
ID_average_filter_depth	number	key to table *tbl_FilterDepth*	operatational parameters
ID_average_infiltration_rate	number	key to table *tbl_InfiltrationRate*	operatational parameters
average_injected_or_infiltrated_volume	number	average injected or infiltrated volume (m^3/d)	operatational parameters
recovered_infiltrate	number	amount of recovered infiltrate (%)	operatational parameters
ID_Monitoring_Regularity_In_Situ	number	key to define *Monitoring_Regularity*	water quality monitoring
ID_Monitoring_Regularity_Bulk_chemistry	number	key to define *Monitoring_Regularity*	water quality monitoring
ID_Monitoring_Regularity_Heavy_Metals	number	key to define *Monitoring_Regularity*	water quality monitoring
ID_Monitoring_Regularity_Organic_Compounds	number	key to define *Monitoring_Regularity*	water quality monitoring
ID_Monitoring_Regularity_Micro_Biological_Parameters	number	key to define *Monitoring_Regularity*	water quality monitoring
ID_Regularity_Emerging_Pollutants	number	key to define *Monitoring_Regularity*	water quality monitoring
emerging_pollutants	text	list of analyzed emerging pollutants (individual substances or substance groups)	water quality monitoring

4.2.1.1 Aquifer Confinement

This table contains information on the confinement of the aquifer.

Table 2: *Aquifer_Confinement*

field name	data type	description
ID_Aquifer_Confinement	number	primary key
aquifer confinement	text	aquifer confinement type (confined | unconfined | semi-confined)

4.2.1.2 Aquifer Thickness

In this table the thickness of the single aquifers is stored (Table 3). For the reason, that the aquifer thickness was classified into five categories, these are shown in Table 4.

Table 3: *tbl_AquiferThickness*

field name	data type	description
ID_Aquifer_thickness	number	primary key
Aquifer Thickness	number	classification of aquifer thickness (m) (Table 4)

Table 4: content of *tbl_AquiferThickness*

ID_Aquifer_Thickness	AquiferThickness
1	< 10
2	10 to 20
3	20 to 50
4	50 to 100
5	> 100

4.2.1.3 Aquifer Type

a) Specific Aquifer Type

The table *Specific_Aquifer_Type* (Table 5) is both linked to the table *Main_Aquifer_Type (b)* and its superior table *Sites*. It contains a list of 11 specific types of aquifer defined according to their lithology (Table 6). This table may be expanded by future users for further specific aquifer types.

Table 5: *Specific_Aquifer_Type*

field name	data type	description

Specific_Aquifer_Type_ID	number	primary key
ID_Main_Aquifer_Type	number	link to table *Main_Aquifer_Type*
specific_aquifer_type	text	specific geology of aquifer (Table 6)

Table 6: content of table *Specific_Aquifer_Type*

Specific_Aquifer_Type_ID	**ID_Main_Aquifer_Type**	**specific_aquifer_type**
1	1	fluvial deposits
2	1	colluvial-fan deposits
3	1	fluvio-glacial detrital sediments
4	2	non-karstic carbonated materials (limestone, dolostone and marl)
5	2	karstic carbonate terrains
6	2	sandstones
7	2	metamorphic basement rocks
8	2	volcanic terrains
9	2	plutonic formations
10	2	evaporitic aquifers (salts or gypsums)
11	1	aeolian deposits

b) Main Aquifer Type

In this table the main geology of the aquifer is divided into two groups; consolidated and unconsolidated materials.

Table 7: *Main_Aquifer_Type*

field name	**data type**	**description**
ID_Main_Aquifer_Type	number	primary key
main_aquifer_type	text	main geology of aquifer (unconsolidated materials - sediments | consolidated materials - rocks)

4.2.1.4 Country

This table contains a list of all European countries.

Table 8: *Country*

field name	**data type**	**description**
ID_Country	number	primary key

country	text	names of all the European countries

4.2.1.5 Filter Depth

The table *tbl_FilterDepth* contains the average depth of the used filters at each site (Table 9). Furthermore the single values were classified into five different categories of depth (Table 10).

Table 9: *tbl_FilterDepth*

field name	data type	description
ID_FilterDepth	number	primary key
FilterDepth	number	classification of filter depth (m) (Table 10)

Table 10: content of *tbl_FilterDepth*

ID_FilterDepth	FilterDepth
1	< 10
2	10 to 20
3	20 to 50
4	50 to 100
5	> 100

4.2.1.6 Hydraulic Conductivity

This tables' content are the kf-values of the single aquifers (Table 11). Table 12 shows the content of *tbl_HydraulicConductivity*, whereupon the single kf-values are displayed in five different classes.

Table 11: *tbl_HydraulicConductivity*

field name	data type	description
ID_HydraulicConductivity	number	primary key
HydraulicConductivity	number	classification of hydraulic conductivity (m/s) (Table 12)

Table 12: content of *tbl_HydraulicConductivity*

ID_HydraulicConductivity	HydraulicConductivity
1	< = 1E-05
2	1E-05 to 1E-04
3	1E-04 to 1E-03
4	1E-03 to 1E-02
5	> 1E-02

4.2.1.7 Infiltration Rate

The table includes the average infiltration rate in meters per day (Table 13). The infiltration rate was divided into three groups, which are shown in Table 14.

Table 13: *tbl_InfiltrationRate*

field name	data type	description
ID_InfiltrationRate	number	primary key
InfiltrationRate	text	classification of infiltration rate (m/day) (Table 14)

Table 14: content of *tbl_InfiltrationRate*

ID_InfiltrationRate	InfiltrationRate
1	< 1
2	1 to 3
3	> 3

4.2.1.8 Infiltration Wells

In this table the number of infiltration wells at the MAR site are listed (Table 15). The amount of infiltration wells for each site was classified into five groups (Table 16).

Table 15: *tbl_InfiltrationWells*

field name	data type	description
ID_InfiltrationWells	number	primary key
InfiltrationWells	number	classification of number of infiltration wells at site (Table 16)

Table 16: content of *tbl_InfiltrationWells*

ID_InfiltrationWells	InfiltrationWells
1	< 5
2	5 to 10
3	10 to 15
4	15 to 30
5	> 30

4.2.1.9 Monitoring Regularity

Table 17 contains three possible values for the regularity of monitoring. For each of the substance groups the monitoring regularity can be assigned individually by choosing the suitable regularity in the check boxes.

This parameter is the only one in the database, which provides several options to select but is not in need of an additional connection to the *Sites* table. This fact is due to the lack of a dropdown menu and the possibility to opt one scope with the provided checkboxes.

Table 17: *Monitoring_Regularity*

field name	data type	description
ID_Monitoring_Regularity	number	primary key
monitoring_regularity	text	regularity of parameter monitoring (Table 18)

Table 18: content of *Monitoring_Regularity*

ID_Monitoring_Regularity	Monitoring_regularity
1	Regular
2	non-regular
3	n/a (no information available)

4.2.1.10 Operational Scale

In the table *tbl_OperationalScale* the average annual operational scale of the sites water treatment is shown in m³ per year (Table 19). Table 20 shows the five classes of annual water extraction.

Table 19: *tbl_OperationalScale*

field name	data type	description
ID_Operational_scale	number	primary key
Operational Scale	number	classification of operational scale (m³/year) (Table 20)

Table 20: content of *tbl_OperationalScale*

ID_Operational_scale	OperationalScale
1	< 1825000
2	1825000 to 7300000
3	7300000 to 18250000
4	18250000 to 36500000
5	> 36500000

4.2.1.11 Operator

In the table *tbl_Operator* the names of the companies that run the MAR sites are listed. In case a MAR scheme is run jointly by two or more operators, only the name of the largest shareholder is given. Note that in compare to other parameters the entries relating to the operator are not predefined and can always be extended.

Table 21: *tbl_Operator*

field name	data type	description
ID_Operator	number	primary key
operator	text	operator name of the MAR site
E-Mail	text	e-mail-address of the operator

4.2.1.12 Recovery Wells

In this table the number of recovery wells at the MAR site are listed (Table 22). The amount of recovery wells for each site was classified into five groups (Table 23).

Table 22: *tbl_RecoveryWells*

field name	data type	description
ID_RecoveryWells	number	primary key
RecoveryWells	number	classification of number of recovery wells at site (Table 23)

Table 23: content of *tbl_RecoveryWells*

ID_RecoveryWells	RecoveryWells
1	< 10
2	10 to 25
3	25 to 50
4	50 to 100
5	> 100

4.2.1.13 Residence Time

The table *Residence_Time* contains five different units of time ranging from days to years. Depending on the average time the water spends underground (i.e. in both the vadose and the saturated zone) the unit which fits best is selected.

Table 24: *Residence_Time*

field name	data type	description
ID_Residence_Time	number	primary key

residence_time	text	approximate residence time of water below the surface or travel time of water (Table 25)

Table 25: content of *Residence_Time*

ID_Residence_Time	Residence_time
1	days
2	weeks
3	months
4	semester
5	years

4.2.1.14 Treatment

This table contains the four main wastewater treatment steps both used in pre- and post-treatment of infiltrated or injected water. A brief summary of the four steps is given below.

Table 26: *Treatment*

field name	data type	description
ID_Treatment	number	primary key
treatment	text	treatment category as used for wastewater treatment plants (Table 27)

Table 27: content of table *Treatment*

ID_Treatment	treatment
1	primary
2	secondary
3	tertiary
4	quaternary
5	none

Primary treatment is designed to remove gross, suspended and floating solids from raw sewage in order to prevent damage to pumps and clogging of pipes. It includes coarse screening and grit chambers to trap solid objects and sedimentation by gravity to remove suspended solids. This level is sometimes referred to as "mechanical treatment", although chemicals are often used to accelerate the sedimentation process.

Secondary (biological) treatment removes the dissolved organic matter that escapes primary treatment. This is achieved by mixing the wastewater with a controlled population of bacteria and an ample supply of oxygen. The microbes consume the organic matter as food and convert it to carbon dioxide, water, and energy for their own growth and reproduction. The biological process is then followed by additional settling tanks ("secondary sedimentation") where the biological solids or sludges are settled by gravity. Secondary treatment technologies include the basic activated sludge process, the variants of pond and constructed wetland systems, trickling filters and other forms of treatment which use biological activity to break down organic matter.

Tertiary treatment has in the past often been defined as any additional (chemical) treatment beyond the secondary, primarily used to remove additional phosphorus and nitrogen from the wastewater and to control pathogens. Phosphorus removal usually involves the addition of ferric chloride, alum or lime to the wastewater, mixing it in a reaction basin, and then sending the mixture to a clarifier to allow the phosphorus-containing precipitate to settle out. Nitrogen can be removed from wastewater using the biological process of nitrification/denitrification and the chemical process of ammonia stripping. Disinfection, typically with chlorine or ultraviolet radiation, can be the final step before discharge of the effluent in order to control disease-causing pathogens. Although tertiary treatment can remove a very high percentage of all the impurities from sewage, it does not successfully remove emerging pollutants.

Quaternary treatment aims at reducing the concentration of micro and emerging pollutants in the treated wastewater. However, so far this treatment step has only rarely been implemented by wastewater treatment plants. It includes the application of activated carbon and other promising technologies such as hybrid ceramic membrane filtration, hybrid advanced oxidation processes, and bioassays.

None implies that no water treatment is performed whatsoever.

4.2.2 Specific MAR Type

The table *Specific MAR Type* represents one of the tables in the database which is linked with both the main table *Sites* and the table *Main_MAR_Type* (Table 31).

Table 33 gives an overview about the single MAR technologies, connecting Main and Specific MAR type in one table.

4.2.2.1 Link Sites and Specific MAR Type

This table links the two tables *Sites* and *SpecMARType* (highlighted rows). Furthermore it gives the option to choose more than one specific MAR type for one site and to set a priority between these for more detailed information about MAR technologies at the site.

Table 28: Link table *tbl_SiteSpecMARType*

field name	data type	description
ID_Sites	number	link to table *Sites*
ID_Specific_MAR_Type	number	link to table *Specific_MAR_Type*
Priority	number	priority for different MAR types at site

4.2.2.2 Specific MAR Type

In table *Specific_MAR_Type* (Table 29) links exist to the table *Main_MAR_Type* (highlighted). It contains a list of 16 specific types of MAR schemes (Table 30) that were chosen based on the classification system described in section 4.2.2.3.

Table 29: *Specific_MAR_Type*

field name	data type	description
ID_Specific_MAR_Type	number	primary key
ID_Main_MAR_Type	number	link to table *Main_MAR_Type*
specific_MAR_type	text	specific MAR Type (Table 30)

Table 30: content of table *Specific_MAR_Type*

ID_Specific_MAR_Type	ID_Main_MAR_Type	Specific_MAR_Type
1	1	infiltration ponds & basins
2	1	flooding
3	1	ditch and furrow
4	1	excess irrigation
5	1	reverse drainage method
6	2	Induced bank filtration
7	3	ASR
8	3	ASTR
9	3	dug well/ shaft/ pit injection
10	4	recharge dams
11	4	sub surface dams
12	4	sand dams
13	4	channel spreading
14	5	rooftop rainwater harvesting
15	5	barriers and bunds
16	5	trenches

4.2.2.3 Main MAR Type

In this table the main types of Managed Aquifer Recharge (Table 31) are listed and grouped into 5 categories (Table 32). The classification system of MAR types applied here is based on two classification systems developed by the International Ground-water Resources Assessment Centre (IGRAC) and Gale & Dillon (2005). It is presented in Table 33. Contrary to the classification system developed by Gale & Dillon (2005), *dune filtration* is not considered a sub type of *induced bank filtration* but defined as the specific MAR type *infiltration ponds & basins*. For practical reasons *induced bank filtration* is considered both a main and a specific MAR type. Detailed and well presented information on the included MAR types can be found in Gale & Dillon (2005), Dillon et al. (2009), or in Bouwer (2002).

Table 31: *Main_MAR_Type*

field name	data type	description
ID_Main_MAR_Type	number	primary key
main_MAR_type	text	main MAR Type (Table 32)

Table 32: content of table *Main_MAR_type*

ID_Main_MAR_Type	Main_MAR_Type
1	spreading methods
2	induced bank filtration
3	well, shaft and borehole recharge
4	in-channel modifications
5	rainwater and run-off harvesting

Table 33: overview of main MAR technologies and subtypes (after IGRAC)

	main MAR type	specific MAR type
Techniques referring primarily to the infiltration method	Spreading methods	infiltration ponds & basins
		flooding
		ditch and furrow
		excess irrigation
		reverse drainage method
	Induced bank infiltration	
	Well, shaft and borehole recharge	ASTR
		ASR
		dug well/ shaft/ pit injection
Techniques referring primarily to the interception method	In-channel modifications	recharge dams
		sub surface dams
		sand dams
		channel spreading
	Rainwater and run-off harvesting	rooftop RWH
		barriers and bunds
		trenches

4.2.3 Final Use

This table is another table which is connected via a link table to *Sites*. It gives different options, in what sector the reclaimed water is going to be used. For the possibility to choose more than one Specific MAR type there is a need to also choose different final usages for different specific MAR types.

4.2.3.1 Link Sites and Final Use

The table *tbl_SitesFinalUse* links the table *FinalUse* with the table *Sites* (highlighted). It also gives the option to choose the priority for different final usages.

Table 34: Link table *tbl_SitesFinalUse*

field name	data type	description
ID_Sites	number	link to table *Sites*
ID_FinalUse	number	link to table *Final Use*
Priority	number	priority for different final usages

4.2.3.2 Final Use

This table contains four categories on information on what the recovered water is being used for. Table 36 shows the classification for the single options of final usage.

Table 35: *FinalUse*

field name	data type	description
ID_Final_Use	number	primary key
final_use	text	further use of the recovered water (Table 36)

Table 36: content of the table *FinalUse*

ID_Final_Use	Final_use
1	agricultural
2	domestic
3	industrial
4	ecological

4.2.4 Influent Source

Artificial groundwater recharge recommends an influence source, which satisfies the aquifer with fresh water. Table 35 gives 10 types of water influent sources.

4.2.4.1 Link Sites and Influent Source

The table *tbl_SitesInfluentSource* connects the table *InfluentSource* with the table *Sites* (highlighted). For the reason that different specific MAR types are available for one site, the influent source can also be chosen individually. The link table gives also the option to set a priority for each source.

Table 37: Link table *tbl_SitesInfluentSource*

field name	data type	description
ID_Sites	number	link to table *Sites*
ID_InfluentSource	number	link to table *InfluentSource*
Priority	number	priority for different final usages

4.2.4.2 Influent Source

This table contains information on what type of water is used for recharging the aquifer (Table 38). The list comprises 10 different influent source types (Table 39).

Table 38: *InfluentSource*

field name	data type	description
ID_Influent_Source	number	primary key
influent_source	text	type of infiltrated or injected water (Table 39)

Table 39: content of table *InfluentSource*

ID_Influent_Source	influent_source
1	groundwater
2	lake water
3	river water
4	storm water
5	reclaimed industrial water
6	reclaimed domestic water
7	mine water
8	brackish water
9	distilled water
10	tap water

4.2.5 Objectives

There is mostly a particular reason why an operator chooses to use managed aquifer recharge. Reasons could be to enhance the local water storage in the aquifer or for water quality improvement. The table *Objectives* gives different options for MAR objectives at one site.

4.2.5.1 Link Sites and Objectives

This table links the tables *Sites* and *Objectives* (highlighted rows). Furthermore it gives the option to choose more than Objective for one specific MAR type at one site and to set a priority between these.

Table 40: Link table *tbl_SitesObjectives*

field name	data type	description
ID_Sites	number	link to table *Sites*
ID_Objectives	number	link to table *Objectives*
Priority	number	priority for different objectives

4.2.5.2 Objectives

In the table *Objectives*, six possible MAR system objective categories are listed (Table 41). Its content is summarized in Table 42 and briefly described below. Since a list of individual objectives for operating a MAR system could be quite extensive only objective categories were considered here.

Table 41: *Objectives*

field name	data type	description
ID_Objectives	number	primary key
objectives	text	objectives for operation of the MAR site (Table 42)

According to Murray et al. (2007), the six main objectives of MAR applications can be described as follows:

Ecological benefits

1) **Reduce abstractions from rivers.** Surface water stored in aquifers during wet months would lead to lower stream diversions during the dry months.
2) **Maintain the reserve.** The reserve could be supported by maintaining groundwater levels and in-stream, low-flow requirements. For example, river water could be transferred to infiltration trenches parallel to rivers during wet months. The water would slowly return to the rivers thereby enhancing flow during the dry months.
3) **Minor environmental imprint.** Artificial recharge offers a means to store and abstract water with minimal environmental impact. Where confined aquifers are used (as is the case with many ASR schemes), there is minimal impact on surface water courses.
4) **Minimal land use.** Artificial recharge schemes, and in particular those that employ borehole injection, require relatively small surface areas. For borehole injection schemes, the land use is measured in square meters, whilst the size of equivalent reservoirs would be tens of hectares. For example, a borehole injection scheme extending over a few square meters that stores $1Mm^3$ is equivalent to a surface reservoir of 4 m depth by 500 m by 500 m. The cost, planning, engineering and environmental issues associated with the latter development are of a far greater scale than borehole injection schemes.
5) **Temperature control.** The insulating properties of the subsurface can be used to maintain water temperatures for industry (e.g. for fish hatcheries).

Management of water distribution systems

1) **Maintenance of distribution system flow and pressure.** Optimally located artificial recharge schemes (usually at the ends of long distribution pipelines) can be used to meet seasonal peak demands and maintain adequate pressures in the supply pipelines.
2) **Storage of treated water.** Storing treated water allows for the supply of water at a rate greater than the capacity of the treatment plant. This allows for the sizing of water treatment works closer to the average needs rather than the peak requirements.

Maximize natural storage

1) **Seasonal storage.** Water is stored during wet months when it is available and recovered during dry months.
2) **Long-term storage (water banking).** Water is stored during wet years, or during years when new supply, treatment and distribution facilities have spare capacity, and is recovered during dry years, or when the capacity of existing treatment facilities is inadequate to meet the demand. Water banking not only provides security against droughts, but it also provides security against uncertainty in future assurances due to climate change.
3) **Emergency storage.** Water is stored locally to provide an emergency supply or reserve when the primary source of supply is unavailable. This is appropriate for systems that rely on a single source and a long transmission pipeline.
4) **Diurnal storage.** Where daytime demands exceed supply capacity, night-time storage is an option (similar to the operation of some hydroelectric plants).

Physical aquifer management

1) **Restore groundwater levels.** Continuing trends in water level decline can be reversed.
2) **Reduce subsidence.** Restoring groundwater levels can reduce land subsidence.
3) **Prevent saltwater intrusion.** Placing recharge facilities between wellfields and the coast or saline aquifers can restrict the movement of the saltwater intrusion front.
4) **Enhance wellfield production.** By enhancing recharge, it is possible to abstract water at higher rates during peak demand months than the long-term sustainable yield of the aquifer.
5) **Hydraulic control of contaminant plumes.** Optimal placing of recharge facilities can create the necessary hydraulic conditions to prevent the migration of contaminant plumes.

Water quality management

1) **Improve water quality.** Certain artificial recharge schemes are designed specifically to improve water quality (e.g. soil aquifer treatment schemes and bank filtration schemes). In such cases and in schemes where the primary goal is storage, improvements in water quality can be significant. Examples include the reduction of nitrate, iron, manganese, hydrogen sulphide, pH stabilization and softening.
2) **Disinfection by-products reduction.** A drawback of chlorinating water prior to recharge is the formation of carcinogenic disinfection by-products (DBPs) such as trihalomethanes (THMs) and

haloacetic acids (HAAs). Recent research, however, has shown that DBPs do attenuate during aquifer storage.

3) **Nutrient reduction in agricultural runoff.** Sub-surface storage of agricultural runoff (causing eutrophication of lakes and reservoirs) can reduce nitrogen concentrations through bacterial denitrification. Some aquifers can reduce phosphorus concentrations through physical-chemical and bacteriological mechanisms.
4) **Stabilize aggressive water.** Aggressive water is frequently treated with calcium carbonate. This can be done naturally by storage in suitable limestone aquifers.

Other benefits

1) **Defer expansion of water facilities.** By optimising conjunctive use of surface and groundwater, and by using artificial recharge principles, expansion of surface water facilities can be deferred, with substantial cost savings. It may be possible to make more efficient use of existing investment in treatment and conveyance capacity by operating these facilities at full capacity throughout the year, and throughout the life of the facility (by incorporating artificial recharge into systems management).
2) **Storage of reclaimed water.** High quality reclaimed water can be stored in fresh or brackish aquifers for reuse. The stored water can be used for a variety of purposes, depending on its quality and post-treatment facilities.
3) **Utilize saline aquifers.** Many ASR schemes utilise saline aquifers that were previously not considered an asset. A fresh water bubble is created around the point of injection, and water quality is managed according to specific targets.
4) **Storage of huge quantities of water**. Aquifers can store huge quantities of water.
5) **Rapid implementation and staged development.** Implementation of artificial recharge schemes is generally rapid in comparison with surface water schemes. An additional advantage is that it is possible to develop schemes incrementally as the demand arises. Initially, one or two boreholes may be used in ASR or ASTR schemes, with expansion to wellfield scale as required.
6) **Low capital cost.** The **overall** costs of artificial recharge operations are invariably much less than the capital cost of conventional water supply alternatives, especially those involving the development of new reservoirs, treatment facilities or extensive.
7) **Mitigate effects of climate change.** Groundwater recharge and storage is expected to decline over the semiarid and arid regions of Southern Africa under currently accepted climate change scenarios (Cave et al, 2003). These changes will require alternative groundwater management practices to control impacts, particularly in situations of groundwater dependency. Artificial recharge may become a useful technology under these conditions.
8) **Savings on evaporation.** Water stored in an aquifer is not subjected to water losses through evaporation associated with water stored at the surface, which can be significant depending on the climatic location and relative surface area of the storage facility.

Table 42: content of table Objectives (after Murray et al., 2007)

ID_Objectives	objectives	description

1	ecological benefits	· reduce abstraction from rivers · maintain the reserve (maintain groundwater levels and in-stream flow requirements) · minor environmental imprint · minimal land use · temperature control (e.g. for industry)
2	management of water distribution systems	· maintenance of distribution system flow & pressure · storage of treated water
3	maximize natural storage	· seasonal storage · long-term storage ("water banking") · emergency storage · diurnal storage
4	physical aquifer management	· restoration of groundwater levels · reduction of land subsidence · prevention of saltwater intrusion · enhancement of well field production · hydraulic control of contaminant plumes
5	water quality management	· water quality improvement · disinfection by-products (DBPs) reduction · nutrient reduction in agricultural runoff · stabilization of aggressive water by storage in calcium carbonate aquifers
6	other benefits	· defer expansion of water facilities · storage of reclaimed water · utilize saline aquifers · storage of huge quantities of water · rapid implementation and staged development · low capital cost · mitigate effects of climate change · savings on evaporation

4.2.6 References

To research on managed aquifer recharge and to get access to the single parameters a database of literature has to be available. The table *References* (Table 44) contains the references, which were collected so far respective the available sites in the database. It is connected to the table *Sites* via an n:m relation, which is implemented by the link table *tbl_SitesReferences*. The attributes Author, Availability and Source are linked with foreign keys to the tables *tbl_Author*, *Availability* and *tbl_Source*. Note that this table has to be expanded by the user for further information about new sites which shall be added to the database.

4.2.6.1 Link of Sites and References

This table connects the table References with the table Sites.

Table 43: Link table *tbl_SitesReferences*

field name	data type	description
ID_Sites	number	link to table *Sites*
ID_References	number	link to table *References*

4.2.6.2 References

This table contents several tables which are all linked to it (highlighted). It includes the information about each reference which provides the single parameters for the sites.

Table 44: *tbl_References*

field name	data type	description
ID_Reference	number	primary key
ID_author	number	link to table *Author*
year_published	number	year of publication
title	text	title of reference
ID_source	number	link to table *Source*
ID_Availability	number	link to table *Availability*

c) Author

The table *tbl_Author* provides the possibility to enter the authors of the reference.

Table 45: *tbl_Author*

field name	data type	description
ID_author	number	primary key
author	text	surname of the author(s)

d) Availability

In this table the availability of the cited references is stored. Note that the available references may be for internal use only.

Table 46: *Availability*

field name	data type	description
ID_Availability	number	primary key
availability	text	availability of the cited reference (Table 47)

Table 47: content of table *Availability*

ID_Availability	availability
1	softcopy
2	hardcopy
3	online resource
4	unavailable

e) Source

The table tbl_Source contains the information about the source of the reference which might be a book as well as a website or a technical report.

Table 48: *tbl_Source*

field name	data type	description
ID_source	number	primary key
source	text	source of reference

5 User Interface and Functionality

5.1 System requirements

The database is based on Microsoft Access 2007. It is not compatible with the older Access version 2002-2003, because the database was developed with an Access 2007 version.

The database was optimized for a screen resolution of 1280 x 1024 (corresponds a monitor size of 19 inches), higher resolutions should not cause any problems, relating to the aspect ratio. Lower screen definitions might cause loss of information like labels or fields not being fully displayed.

The design of the database is related to the operating system or could be influenced by the settings under *Display properties*. For example if the screen is set to "Windows classic" theme, the windows in the database might vary from the shown examples in this documentation.

5.2 Using the database

After opening the Access file *MAR_database.accdb* the start screen of the database is showing (Figure 2 and 3). Before being able to start using the database it is necessary to enable macros of this document.

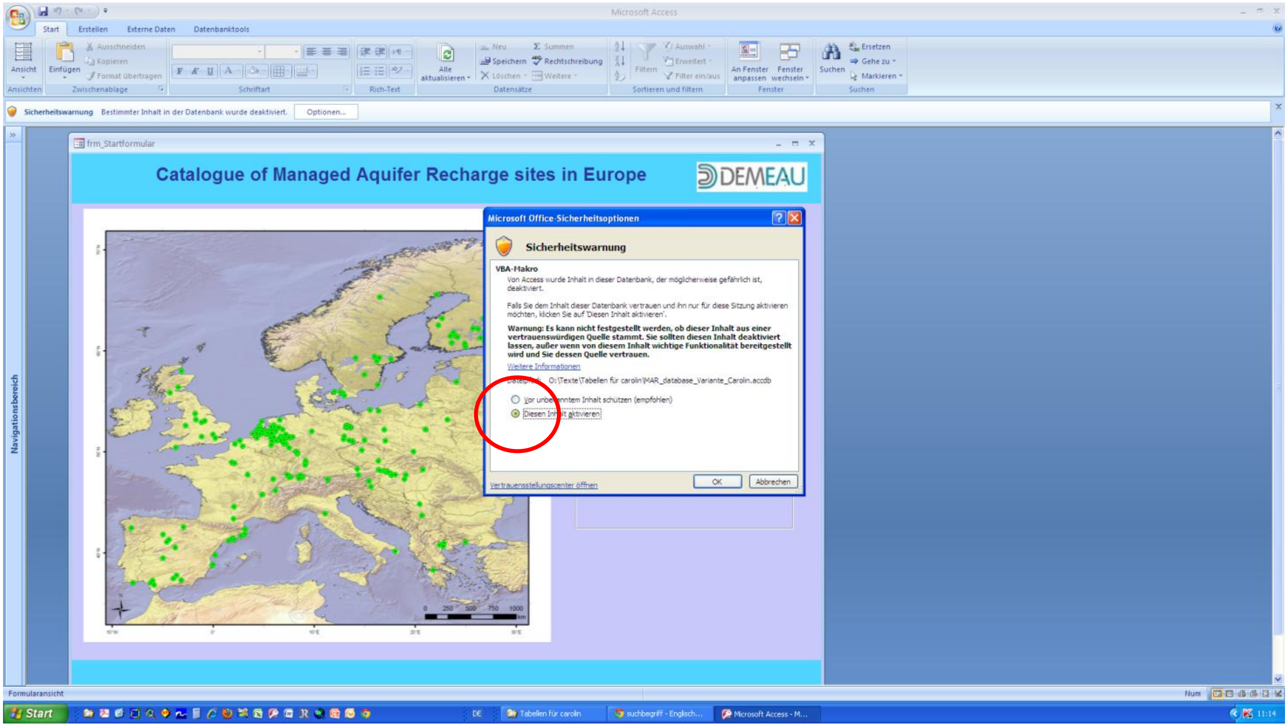

Figure 2: Enable macros before using the database

Now the start screen is fully showing. It gives you several options, which are divided into two major fields:

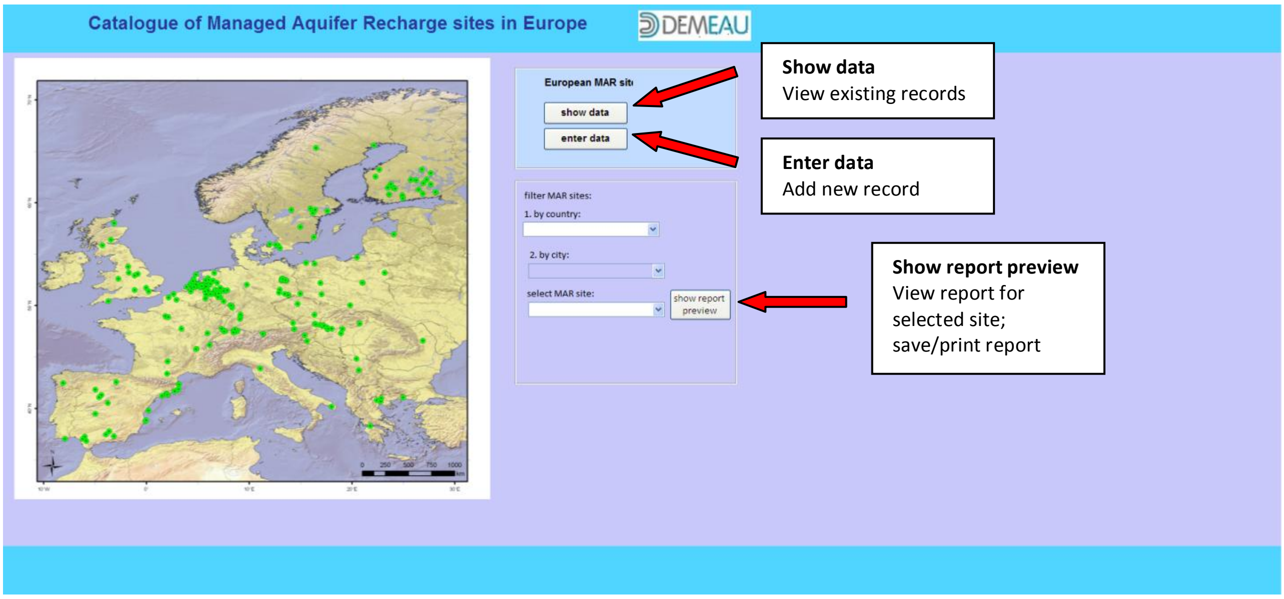

Figure 3: Start display of the database

European MAR sites

- Show data - to view the existing records
- Enter data - to add new records to the database

Filter MAR sites

- select a particular MAR site and being able to process to the full printable report of that site

Now you can proceed to the database's content to view or change it and add new MAR sites.

5.2.1 *View existing records*

After clicking on *show data* the following form is being displayed (Figure 4a and b):

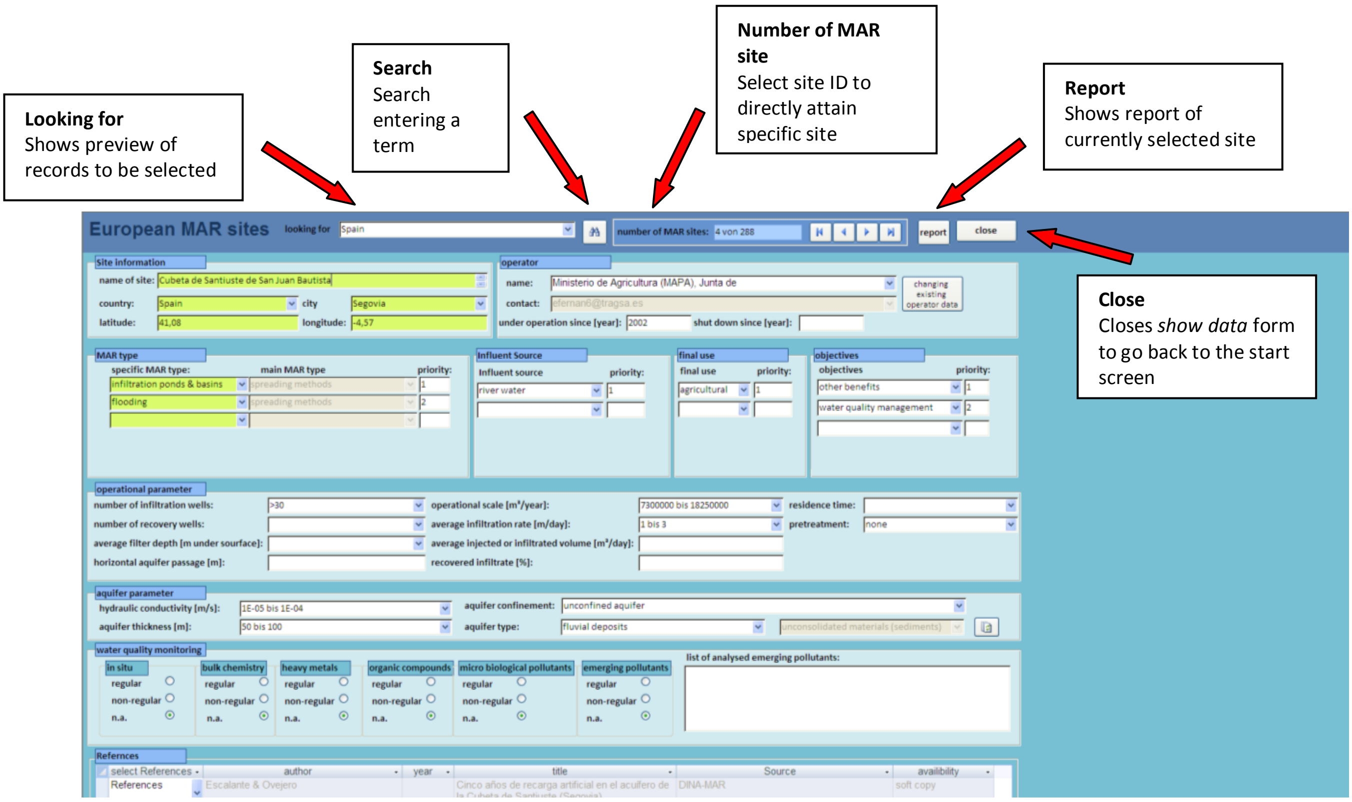

Figure 4a: Form to view existing data (part I)

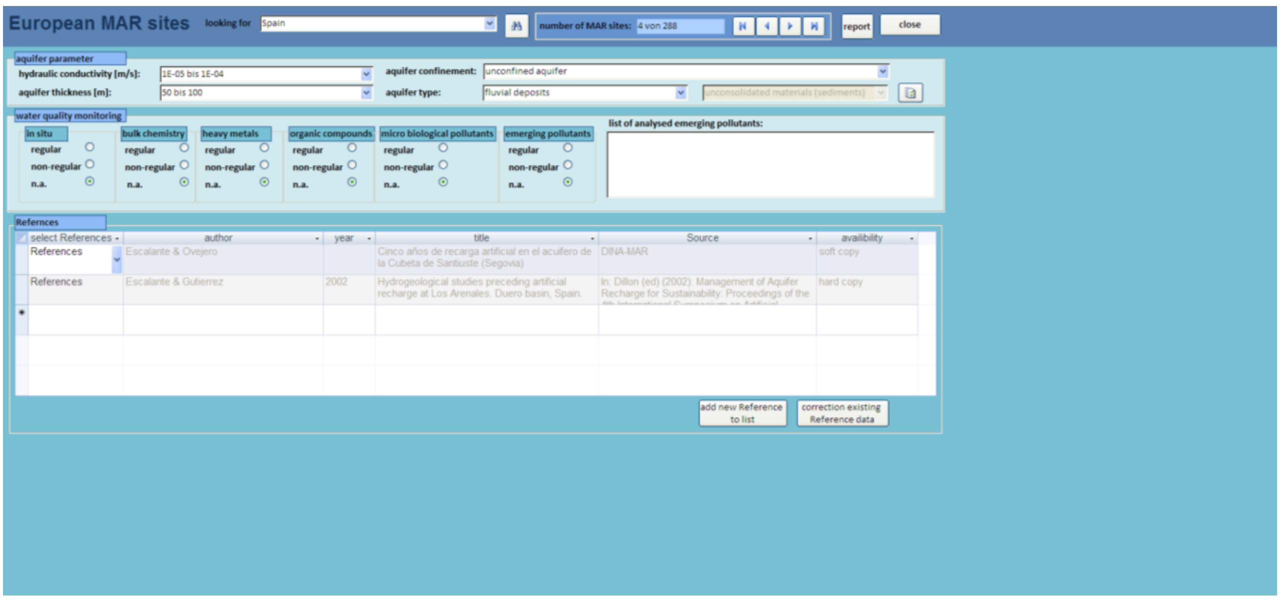

Figure 4b: Form to view existing data (part 2)

The form gives you several possibilities to search for sites. The first field *looking for* gives you a preview over all entries in the database, showing country, city and site name (Figure 5).

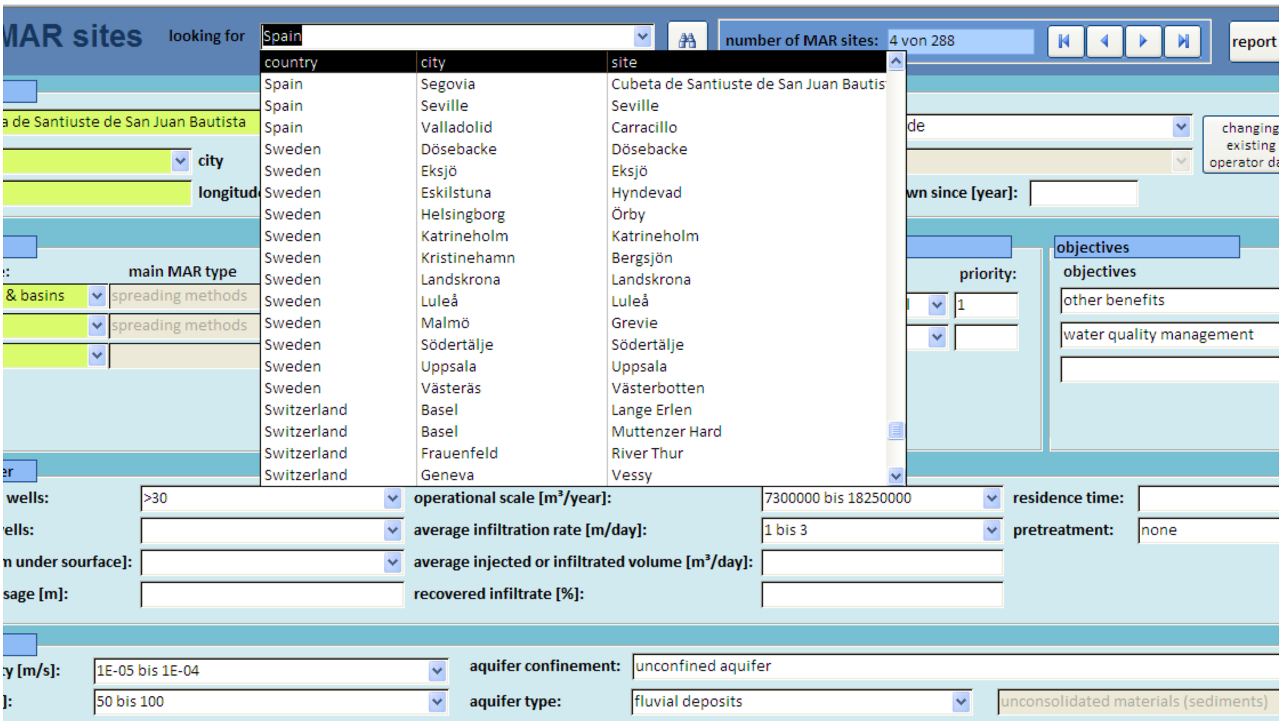

Figure 5: Preview of database entries for easy access to particular entry

Next to the *looking for* field a search button is integrated. By clicking into the field (e.g. *Under operation since*) of the currently showing record for the parameter of another record you are looking for and afterwards clicking *search*, the window *search and replace* is popping up. Now you can enter the parameter for the site you are looking for in the chosen field (e.g. *under operation since*: 1967). Note that the *Replace* function is not available so the records can't easily be replaced (e.g. mistakenly).

Another option to directly attain the site you are looking for is the *number of MAR site* field which allows you to browse through the entries by using the integrated buttons next to the shown site ID, first, back, next and last entry.

If you selected a site you are interested in and you want the full report of the entries, click report. It immediately shows up and gives you the full record of the chosen site. You can now directly print it or save it as PDF file. To save, go to Microsoft Home button, save as and select "PDF or XPS" (Figure 6). Now you can save the file as usual.

With the button *close* you can get back to the start screen of the database if you are done viewing the existing records.

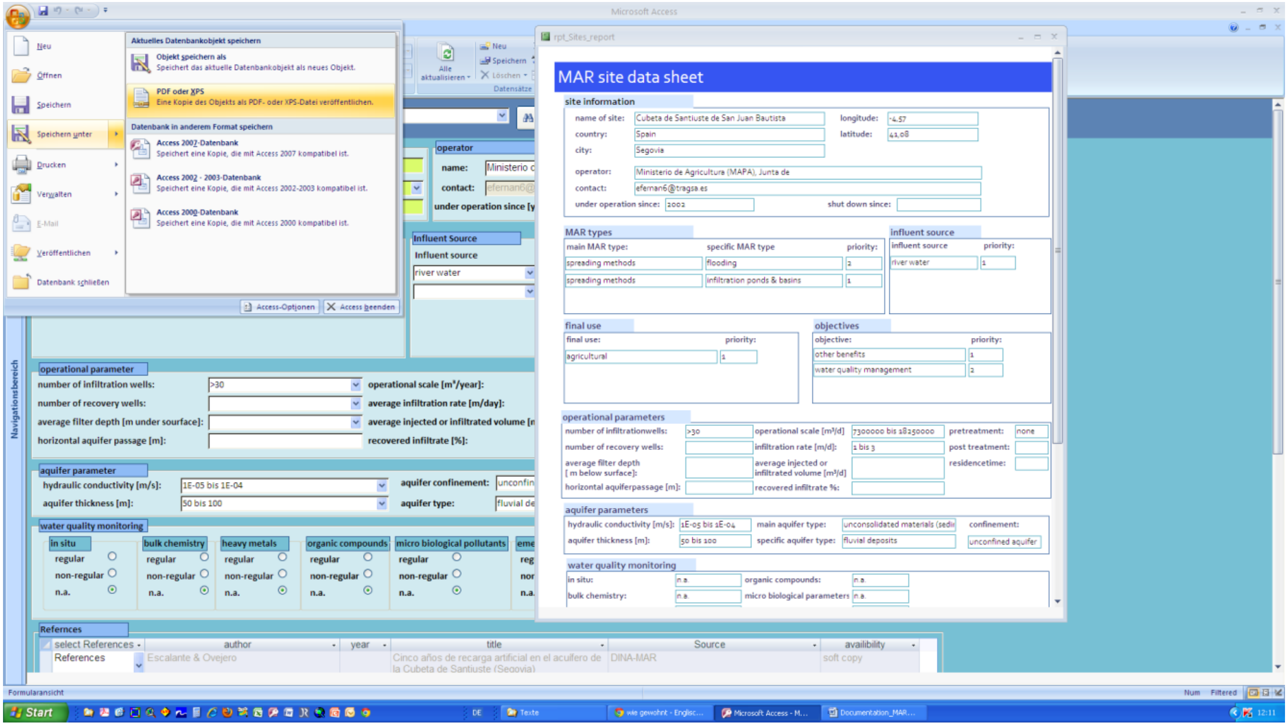

Figure 6: Save the report of the current record

The data in this report are read-only records so they can't be changed directly. If there is however the need to change them the single fields can be edited by double clicking on them.

To protect the data from changes by mistake, a report window pops up to make sure if the existing data should be changed. After rearranging the record you are requested again if you want to change the current entry by saving. After done approval the record is write-protected again (e.g. Figure 7). In mandatory fields (highlighted in green) data can't be deleted, you can just change the entry. For data changing the single entries are subject to the same validity controls as for the data entry (chapter).

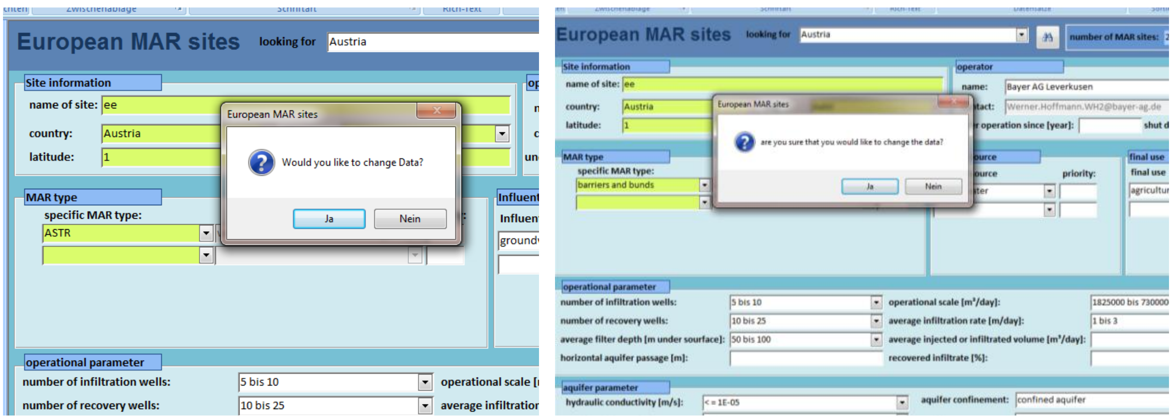

Figure 7: Report window after double clicking the field specific MAR type

5.2.2 Data entry

After clicking on *enter data* in the start menu an empty form is being displayed (Figure 8):

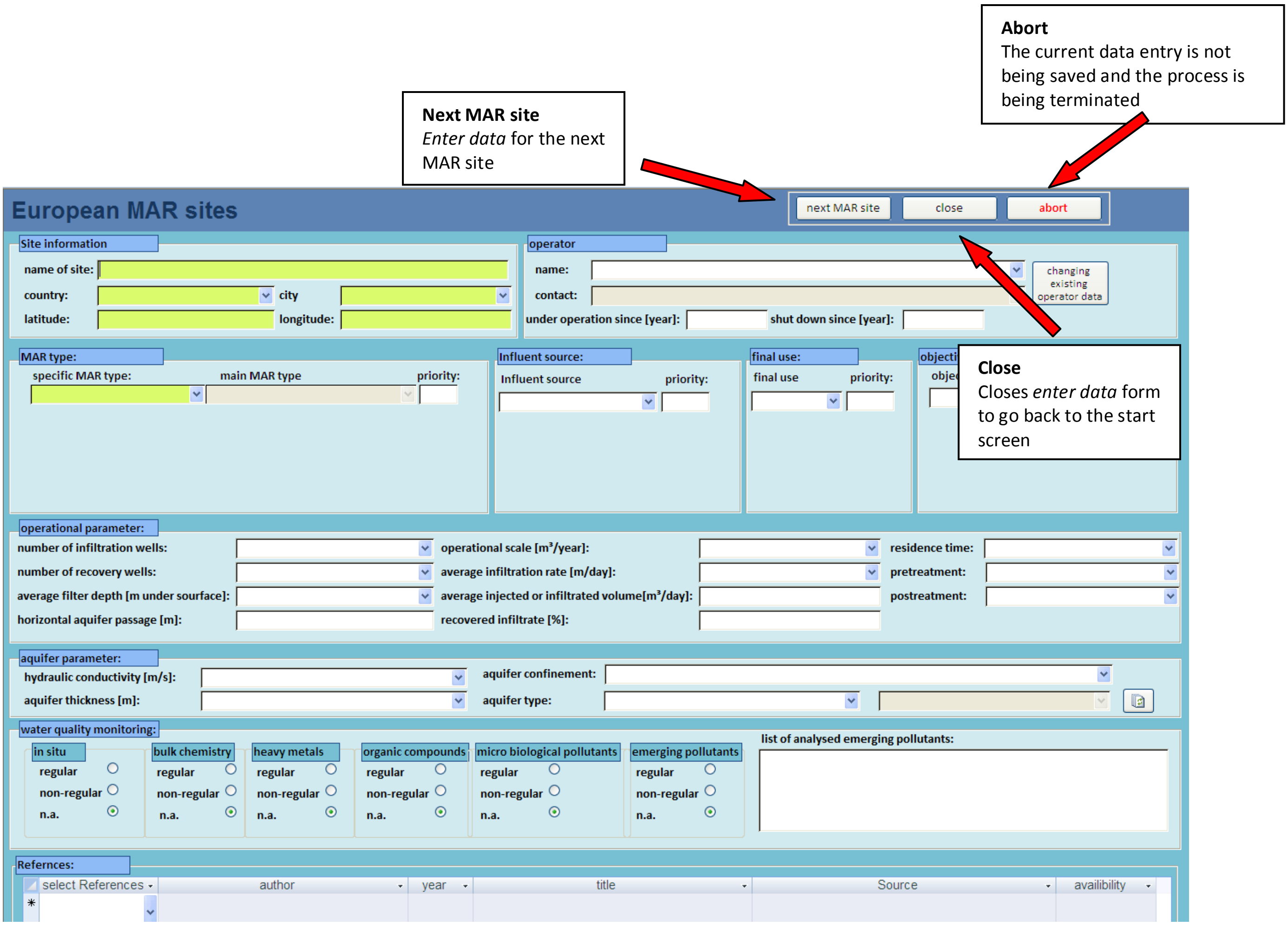

Figure 8: Extract of the *Enter data* form

The single fields are subject to different check-ups relating to validation norms while entering the data. If a rule is being broken a pop-up window is pointing out the mistake and you are requested to change the entry.

The green highlighted fields are mandatory fields for data entry, the white fields can be filled after at least the site name is provided.

Data entry is carried out for most fields by dropdown menus. Some of these dropdown menus can be extended. If the entry in the dropdown menu is too complex, the further data input is carried out in an additional form.

Below the data entry is being shown exemplarily for a choice of fields.

1. First the name of the site should be entered; if the entered name already exists in the database, you are pointed to the mistake.

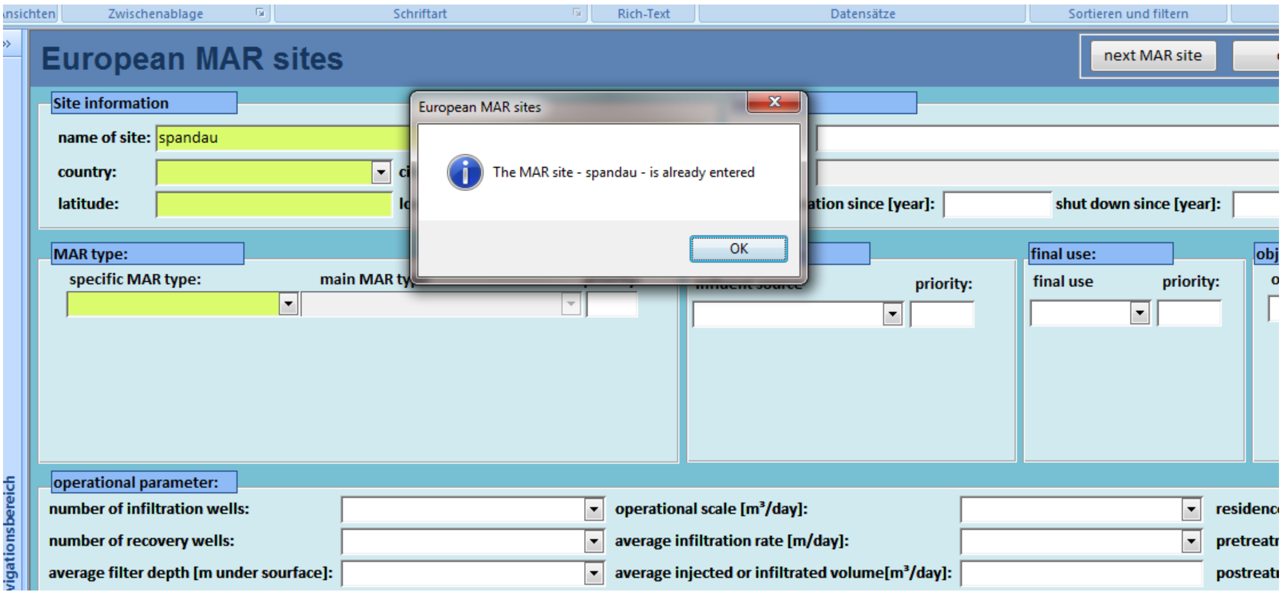

Figure 9: Pop-up window to prevent double site name entries

2. Add country, city, coordinates and MAR type for the site. Note, that the coordinate fields are restricted to number entry and countries to the provided European countries in the dropdown menu. If you want to add two specific MAR types to one site consider, that a specific MAR type can be chosen only once for one site. You can delete a second MAR type but the record has to contain at least one specific MAR type (mandatory field). Enter for more than one specific MAR type the priority, if you have access to that information.
3. The operator field gives you more options again to add new data. You can choose an existing operator by selecting from the dropdown menu, change the existing operator data or add a new record (Figure 10). A new record can be added by clicking into the empty *name* field and pressing the button "changing existing operator data" or entering a new operator name and clicking into any other field outside the *operator* box. Now you are being informed, that you are about to add a new operator to the data. To go on to the entry box (Figure 10) confirm.
4. If possible enter *under operation since* and *shut down since.* If should be noted, that data entry for these fields is restricted to numbers in yyyy-format.
5. Enter influent source, final use and objective. The usage of these fields is similar to the specific MAR type fields.
6. Choose operational parameters as well as hydraulic conductivity, aquifer thickness and aquifer confinement from dropdown list, if these parameters are available for the site. Note, that you can just select from the categories in the fields.
7. For entering the specific aquifer type you have a choice of already available specific aquifer types in the database connected with the two main aquifer types consolidated and unconsolidated. This list might not be satisfying so you have the option to add new specific aquifer types. Always press the "refresh" button after entering a specific aquifer type to either automatically add the corresponding main aquifer type or, in case of a new entry, to add one of the two main aquifer types.

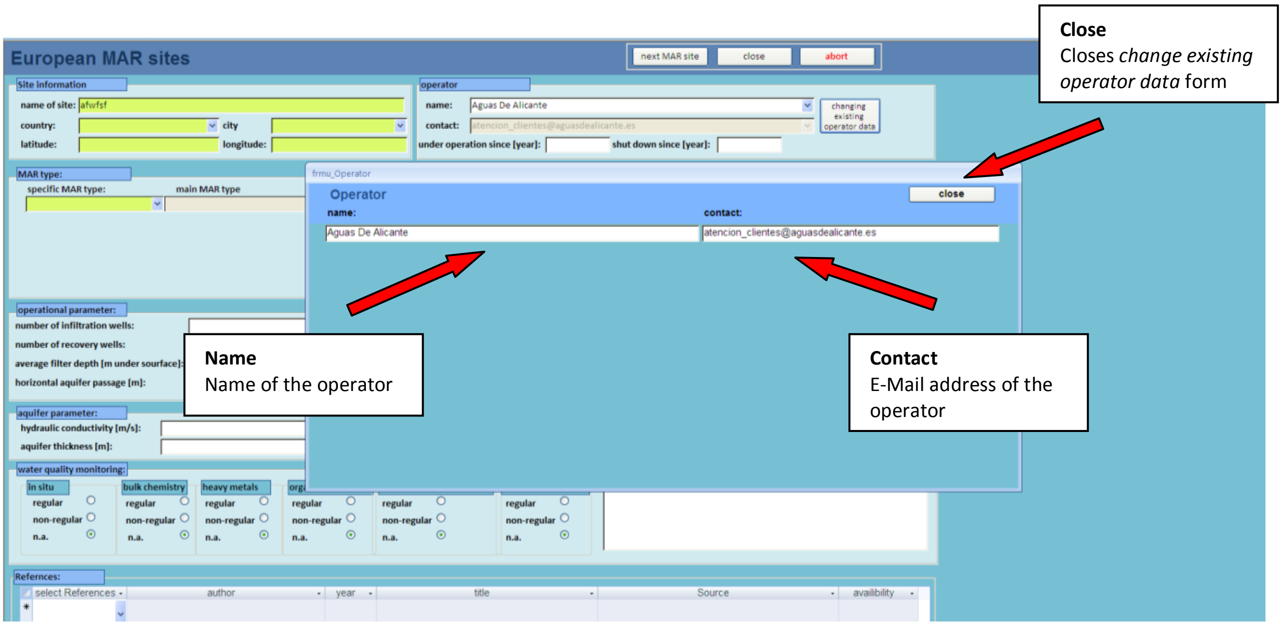

Figure 10: Form to change existing operator (as example) or to enter a new record

8. In the References field you can choose an already existing reference from the database or change it if it might not be correct by choosing it from the dropdown list, pressing "changing existing reference data", go to the field you want to adjust and press "correct" to be able to make entries.
   Additionally you can add new references to the record by pressing "add new reference to list", saving your entries and afterwards choosing it from the dropdown menu.

When you are done entering at least the mandatory fields you can stop the current data entry and save it by pressing "close" or, if you want to add another site, get to the next empty form by pressing "next MAR site".

6 References

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7 Annex

Annex: List of published references

Author	Title	Year	Pages	Vol.	Source	Publisher
Aertgeerts and Angelakis	Health risks in aquifer recharge using reclaimed water — State of the art report.	2004				WHO Regional Office for Europe
Agencia Catalana del Aigua (CatalanWaterAgency) (ACA)	Study of potential MAR devices					
Agencia Catalana del Aigua (CatalanWaterAgency) (ACA)	WFD Implementation	2013				
Angelakis and Bontoux	Wastewater reclamation and reuse in Eureau countries	2001	47-59	3	Water Policy	
Angelakis et al.	Challenges and prospectives for water recycling and reuse in EU countries	2003	59-68	3	Water Supply	
Angelakis et al.	Water Recycling in the Mediterranean Region: Selected Papers of the Iwa Regional Symposium on Water Recycling in the Mediterranean Region, Held in Iraklio, Greece, 26-29 September 2002	2003				IWA Pub.
AQUAREC	Water treatment options in reuse systems	2006				
AQUAREC	Guideline for quality standards for water reuse in Europe	2006				
AQUAREC	Report on integrated water reuse concepts	2006				
AQUAREC	Handbook on feasibility studies for water reuse systems	2006				
AQUAREC	Final Project Report Summary	2006				
ARTESIA Water research unlimited	Infiltration Test-Ossdrecht	2012				
Artimo et al.	Methods for Integrating an Extensive Geodatabase with 3D Modeling and Data Management Tools for the Virttaankangas Artificial Recharge Project, Southwestern Finland	2008	1723-1739	22	WATER RESOURCES MANAGEMENT	
Asano	Artificial Recharge of Groundwater	1985				Butterworth Publishers, Stoneham, USA
Asano et al.	Water Reuse Issues, Technologies, and Applications I	2006				Metcalf & Eddy, AECOM
Ayuso-Gabella et al.	Quantifying the effect of Managed Aquifer Recharge on the microbiological human health risks of irrigating crops with recycled water	2011	93-102	99	Agricultural Water Management	
Bahr et al.	Distributed temperature sensing (DTS) as a hydrostratigraphic characterization tool	2011				
Balke and Zhu	Natural water purification and water management by artificial groundwater recharge	2008	221-226	9	Journal of Zhejiang University: Science B	
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Barrett et al.	Marker species for identifying urban groundwater recharge sources: A review and case study in Nottingham, UK	1999	3083-3097	33	Water Research	

The shown entries represent just an extract of the original literature dataset.

Annex: List of published references

Author	Title	Year	Pages	Vol.	Source	Publisher
Battistello et al.	Esperienze di Ricarica Artificiale Degli Acquiferi in Provincia di Vicenza	2013				
Bekele et al.	Chapter 1- Designed and operation of infiltration galleries and water quality changes	2009				Goverment of Western Australia, Department of Water
Berg et al.	Investigation of introducing water from an artificial recharge plant to an existing groundwater distribution system	2005	25-32	5	Water Science and Technology: Water Supply	
Berliner Wasserbetriebe (BWB)	Wasserwerk Friedrichshagen	2008				
Berliner Wasserbetriebe (BWB)	Wasserwerk Wuhlheide	2008				
Bezirksregierung Koeln	Erläuterungsbericht zur Abgrenzung des Wasserschutzgebietes für die Gewässer im Einzugsgebiet der Wassergewinnungsanlagen Weiler und Worringen-Langel der Gas-, und Elektrizitäts- und Wasserwerke Köln AG	1997				
BHG Brechtel GmbH	Bau von acht Horizontalfilterbrunnen auf der Donauinsel in Wien	2005				
Bienek	Wasserwerk Jungfernheide	2007				
Bissoli	Strategic contents of policies in the water protection plan of Emilia-Romagna region	2006	32	n/a	Regione Emilia-Romagna Assessorato Ambiente e Sviluppo Sostenibile	
Biuletyn informacji publicznej (bip)	Pogotowie Wodociagowe	2013				
Bixio et al.	Municipal wastewater reclamation: where do we stand? An overview of treatment technology and management practice	2005	77-85	5	Water Science and Technology: Water Supply	
Bixio et al.	Wastewater reuse in Europe	2006	89-101	187	Desalination	
Bixio et al.	Water reclamation and reuse: implementation and management issues	2008	13-23	218	Desalination	
Blazejewski	Perspektywy Wykorzystania Sztucznej Infiltracji W Uzadatnianiu Zanieczyszonych Wod Powierzchniowych W Polsce W Swietle Dotychczasowych Doswiadczen	1983	7-12		Sztuczna infiltracja w uzdatnianiu WOD powierzchniowych	
Boeckelmann et al.	Quantitative PCR Monitoring of Antibiotic Resistance Genes and Bacterial Pathogens in Three European Artificial Groundwater Recharge Systems	2008	154-163	75	APPLIED AND ENVIRONMENTAL MICROBIOLOGY	AMER SOC MICROBIOLOGY
Boleda et al.	Behavior of pharmaceuticals and drugs of abuse in a drinking water treatment plant (DWTP) using combined conventional and ultrafiltration and reverse osmosis (UF/RO) treatments	2011	1584-1591	159	Environmental Pollution	
Borràs and Sala	L' aigua a Catalunya: Una perspectiva per als ciutadans (Water in Catalonia: A Perspective for the Citizens).	2006				Càtedra Agbar de la UPC.
Borràs and Sala	LA REGENERACIÓ I LA REUTILITZACIÓ D'AIGÜES A CATALUNYA: EL QUE HEM APRÈS	2006				

The shown entries represent just an extract of the original literature dataset.

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Author	Title	Year	Pages	Vol.	Source	Publisher
Borras et al.	Summary of data concerning the quality of the reclaimed water produced at the Blanes Reclamation Plant (Costa Brava, Girona, Catalonia)	2007				
Bottrell et al.	Isotopic composition of sulfate as a tracer of natural and anthropogenic influences on groundwater geochemistry in an urban sandstone aquifer, Birmingham, UK	2008	2382-2394	23	Applied Geochemistry	
Bourg and Bertin	Biogeochemical processes during the infiltration of river water into an alluvial aquifer.	1993	661-666	27	Environmental Science and Technology	
Bourg and Bertin	Seasonal and spatial trends in manganese solubility in an alluvial aquifer	1994	868-876	28	Environmental Science and Technology	
Bourg et al.	Geochemical filtration of riverbank and migration of heavy metals between the Deûle River and the Ansereuilles alluvion-chalk aquifer (Nord, France)	1989	229-244	44	Geoderma	
Bouwer	Artificial recharge of groundwater: hydrogeology and engineering	2002	121-142	10	Hydrogeology Journal	Springer Berlin / Heidelberg
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Brand	Migrationsverhalten ausgewahlter Schadstoffe bei der Uferfiltration in einem naturlichen Testfeld am Neckar.	1990	311-317	131		GWF - Wasser Abwasser
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Bueso	Dispositivo de recarga artificial en el acuífero plioceno de la unidad hidrogeológica Marbella-Estepona. Marbella (Málaga)	2005	439-444	17	Hidrogeología y Aguas Subterráneas (Publicaciones del Instituto Geológico y Minero de España.)	
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Author	Title	Year	Pages	Vol.	Source	Publisher
Bueso et al.	Las aguas subterraneas en los paises mediterraneos	2006	439-456			Instituto Geológico y Minero de España
Bundermann	30 years of RWW's practical experience with an advanced microbiological water treatment system of Ruhr river water - "The Muelheim Treatment process 1976-2006"	2006	30-38		Recent progress in slow sand filtration and alternative biofiltration processes	IWA publishing
Bußmann et al.	Wo kommt eigentlich unser Trinkwasser her?	2008				
Buzek et al.	Nitrate Pollution of a Water Resource - 15N and 18O Study of Infiltrated Surface Water	2003	197-202			
Cabane et al.	Ein weltweit einzigartiges System. Die Grundwasseranreicherungsanlage in der Langen Erlen	2005				
Cachero et al.	RECARGA ARTIFICIAL MEDIANTE CONSTRUCCIÓN SOBRE EL CAUCE DEL RÍO GIRONA DE PEQUEÑOS DIQUES Y REPRESAS ACUÍFERO DE ORBA (ALICANTE)	2000	105-109		V Congreso Geologico de Espana, Alicante	
Camacho	Evaluation of the Existing Performance of Infiltration Galleries in Alluvial Deposits of the Parapeti River	2003	207-213			
CETaqua et al.	Enhancement of Soil Aquifer Treatment to Improve the Quality of Recharge Water in the Llobregat River Delta Aquifer	2012				
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de Haan et al.	Pyrite oxidation in the tertiary sands of the London Basin aquifer	1994	161-173	9	Applied Geochemistry	
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de Koning et al.	Characterisation and assessment of water treatment technologies for reuse	2008	92-104	218	Desalination	

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de la Orden-Gómez and Díaz	LA RECARGA ARTIFICIAL EN EL ACUÍFERO DE VERGEL (ALICANTE) COMO TÉCNICA PALIATIVA DE LOS EFECTOS DE LA INTRUSIÓN MARINA Y SU EVALUACIÓN MEDIANTE MODELACIÓN MATEMÁTICA.	2003			TECNOLOGÍA DE LA INTRUSIÓN DE AGUA DE MAR EN ACUÍFEROS COSTEROS: PAÍSES MEDITERRÁNEOS	IGME
de la Orden-Gómez and Murillo	Recharge enhancement to prevent saltwater intrusion in coastal Spain	2002	353-356			A. A. BALKEMA
de los Cobos	The aquifer recharge system of Geneva, Switzerland: a 20 year successful experience	2002	49-52			A.A. BALKEMA
de los Cobos	Impacts of a long-term shutting down on the aquifer recharge management. Case of the aquifer recharge of geneva, Switzerland.	2007	296-306			ACACIA Publishing Incorporated, Phoenix, Arizona
de los Cobos	The transboundary aquifer of the Geneva region: successfully managed for 30 years by the state of Geneva and French border communities	n/a	6		GESDEC	
de Ruiter and Stuyfzand	An experiment on well recharge of oxic water into an anoxic aquifer	1998	299-304		Artificial recharge of groundwater: Nieuwegein, Netherlands	Peters et al.
de Vet et al.	Water quality and treatment of river bank filtrate	2010	79-90	3	Drinking Water Engineering and Science	
delta h Ingeneurgesellschaft mbH	Wasserwerk Bochum Stiepel	2010				
Denecke and Schmidt	Langjährige Untersuchungen zur Calcitlösekapazität und Spurenstoffentfernung bei einer aeroben Uferfiltration am Niederrhein bei Wittlaer	2007				Stadtwerke Duisburg AG
Detay and Haeffner	The role of artificial recharge in active groundwater management	1996		15	Specialised Conference on New Developments in Modeling, Monitoring and Control of Water Supply Systems	
Dewettinck et al.	HACCP (Hazard Analysis and Critical Control Points) to guarantee safe water reuse and drinking water production - a case study	2001	31-38	43	WATER SCIENCE AND TECHNOLOGY	
Díaz et al.	Recarga artificial de acuiferos: Sintesis metodologica. Estudios y actuaciones realizadas en la provincia de Alicante. Septiembre 1999	2000				Diputacion Provincial
Díaz et al.	Lessons from groundwater recharge projects in Spain	2002	393-398			A.A. BALKEMA

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Dillon	Management of Aquifer Recharge for Sustainability: Proceedings of the 4th International Symposium on Artificial Recharge of Groundwater, Adelaide, Australia, 22-26 September 2002	2002				Taylor & Francis Group
Dillon	Future management of aquifer recharge	2005	313-316	13	Hydrogeology Journal	Springer Berlin / Heidelberg
Dillon et al.	The potential of riverbank filtration for drinking water supplies in relation to microsystin removal in brackish aquifers	2002	209-221	266	Journal of Hydrology	
Dillon et al.	Managed aquifer recharge: An Introduction	2009		13		National Water Commission
Doussan et al.	River bank filtration: modelling of the changes in water chemistry with emphasis on nitrogen species	1997	129-156	25	Journal of Contaminant Hydrology	
Drews and Gerdes	Überprüfung der Möglichkeit zur Gewinnung von Uferfiltrat aus dem Rhein im Bereich der Wassergewinnung Wiesbaden-Schierstein	2002	104-111	2	GWF Wasser Abwasser	
Edmonds	Improved groundwater vulnerability mapping for the karstic chalk aquifer of south east England	2008	95-108	99	Engineering Geology	
Eksjoe Enerji Ltd.	Vatten & Avlopp	2004				
ENMaR	Water: Local planning and management	2007				
Environmental Agency	River Severn	2012				Environment Agency
Environmental Protection Agency (EPA)	The Class V Underground Injection Control Study. Volume 21. Aquifer Recharge and Aquifer Storage and Recovery Wells	1999		21		
Environmental Protection Agency (EPA)	Long term 2 enhanced treatment rule. Toolbox Guidance Manual	2003				
Escalante and Gutiérrez	Hydrogeological studies preceding artificial recharge at Los Arenales. Duero basin, Spain.	2002	533-536			A.A. BALKEMA
Escalante and Ovejero	CINCO AÑOS DE RECARGA ARTIFICIAL EN EL ACUÍFERO DE LA CUBETA DE SANTIUSTE (SEGOVIA)		1-13			
Eskilstuna Energi & Miljoe	Hyndevads Vattenverk					
EUREAU	WHY IS WATER REUSE SO IMPORTANT THE EU? Drivers, Benefits and Trends	2004				
EUWI	Mediterranean Wastewater Reuse Report . Annex B: Case Studies	2007				
Ferreira	Work Package Achievements and Status of Deliverables -GABARDINE Project "Groundwater artificial recharge based on alternative sources of water: Advanced integrated technologies and management"	2006				
Ferreira	FIRST YEAR ACHIEVEMENTS OF GABARDINE PROJECT IN PORTUGAL	2006	1-10		Associação Portuguesa dos Recursos Hídricos	

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Ferreira et al.	Groundwater artificial recharge based on alternative sources of water: advanced integrated technologies and management. DELIVERABLE 31, Inventory of alternative water sources for each Test site, GABARDINE	2007				
Fischer et al.	Sustainability of riverbank filtration in Dresden, Germany	2005	23-27		Recharge systems for protecting and enhancing groundwater resources	UNESCO
Forizs et al.	Origin of shallow groundwater of Csepel Island (south of Budapest, Hungary, River Danube): isotopic and chemical approach	2005	3299-3312	19	Hydrological Processes	John Wiley & Sons, Ltd.
Fox	Management of Aquifer Recharge for Sustainability: Proceedings of the 6th International Symposium on Managed Artificial Recharge of Groundwater, ISMAR6, Phoenix, Arizona USA	2007				
Fritz et al.	Geochemical and hydraulic investigations of river sediments in a bank filtration system	2002	95-100			A.A. BALKEMA
Furrer et al.	Wasserförderung und -aufbereitung im Rheineinzugsgebiet. Rheinthemen 2.	2000				
Galán-López et al.	CINCO AÑOS DE RECARGA ARTIFICIAL EN EL ACUÍFERO DE LA COMARCA DE “EL CARRACILLO” (SEGOVIA), (1ª PARTE)					
Gale and Dillon	Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas.	2005				UNESCO International Hydrological Programme (IHP)
Gale et al.	ASR-UK: Elucidating the Hydrogeological Issues Associated with Aquifer Storage and Recovery in the UK	2002				UK Water Industry Research Limited
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Gale et al.	Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management	2006				
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Giebel	Hydrogeologie und Grundwasserhaushalt im Neuwieder Becken	1990				Bundesanstalt für Gewässerkunde
Górski and Przybylek	Qualitiy of bank filtrated water in different locations of wells.	2005				
Gramstadt	What are the benefits of the Örby recharge activity to the western region of Scania?	2004	42		INTERREG III B project- "Decision Support" Lund University	
Greskowiak et al.	The impact of variably saturated conditions on hydrogeochemical changes during artificial recharge of groundwater	2005	1409-1426	20	Applied Geochemistry	
Grischek	River Bank Filtration Practice in Germany	2009				
Grischek	Impact of decreasing water demand on bank filtration in Saxony, Germany	2010	11-20	3	Drinking Water Engineering and Science	
Grischek et al.	Bank-Filtration in Europe - An overview of Aquifer Conditions and hydraulic Controls.	2002	485 - 488			
Grischek et al.	What is the appropriate site for RBF?	2007	466-474			ACACIA Publishing Incorporated, Phoenix, Arizona
Grombach et al.	Handbuch der Wasserversorgungstechnik	2000				Oldenbourg Industrieverlag
Grünheid et al.	Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge	2005	3219-3228	39	Water Research	
Günther and Kettrup	Untersuchung über das Verhalten von Triazin-Herbiziden bei der Untergrundpassage.	1995				
Günther et al.	Erneuerung der Rohrwasserleitung des Wasserwerks Mockritz	1992				
Gurwin and Lubczynski	Modeling of complex multi-aquifer systems for groundwater resources evaluation - Swidnica study case (Poland)	2005	627-639	13	HYDROGEOLOGY JOURNAL	
Haas et al.	Bridging Research and Practical Design Applications	2002	7-15			
Haeffner	De la gestion active des aquifères alluviaux. APPLICATION À LA MAÎTRISE DE L'AZOTE EN CONDITIONS DE TRANSFERT RIVIÈRE-NAPPE ET DE RÉALIMENTATION ARTIFICIELLE	1999				ENSMP
Haffner and Grandguillaume	LE PROCEDE BI'EAU: Une solution innovante pour un traitement in-situ des ressources en Eau	2007				
Hamuda and Patkó	Variations in Water Quality of Danube River at. Budapest City	2011	13-30	2	Óbuda University e-Bulletin.	
Hardwasser AG	Rheinwasser Hardwasser Trinkwasser					
Helmisaari et al.	Artificial recharge in Finland through basin and sprinkling infiltration: soil process, retention time and water quality	2005	280-285			United Nations Educational, Scientific and Cultural Organization

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Hernandez et al.	Aquifer recharge for securing water resources: the experience in Llobregat river	2011	220-226	63	Water Science & Technology	IWA Publishing, Alliance House, UK
Hiemstra et al.	'Natural' recharge of groundwater: bank infiltration in the Netherlands	2003	37-47	52	J Water SRT - Aqua	
Hionidi et al.	Groundwater quality considerations related to artificial recharge to the aquifer of the Korinthos Prefecture, Greece	2001			Groundwater Quality: Natural and Enhanced Restoration of Groundwater Pollution	IAHS
Hjerpe	Sustainable Development and Urban Water Management: Linking Theory and Practice of Economic Criteria	2005				
Hlavinek and Hlavac	Source Water Protection and Riverbank Filtration in the Dyje River Basin	2003	p.181-186			
Hoehn and Scholtis	Exchange between a river and groundwater, assessed with hydrochemical data	2010	983-988	7	Hydrology and Earth System Sciences	
Hoorgendoorn	Artificial recharge for sustainability and cost reduction in the eastern Netherlands	2002	53-56			A.A. BALKEMA
Hötzl and Reichert	Schadstoffe im Grundwasser - Band 4: Schadstofftransport und Schadstoffabbau bei der Uferfiltration am Beispiel des Untersuchungsgebietes "Böckinger Wiesen" im Neckartal bei Heilbronn	1996				
Hukka and Seppälä	D41: WaterTime case study - Tampere, Finland	2005				
Hunt	Operation and Maintenance Considerations	2002	61-70			Kluwer Academic Publishers
Industrielle Werke Basel (IWB)	Vom Rohwasser zum Trinkwasser	2008				
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Isomäki et al.	Operation and maintenance of small waterworks	2008				
Jacobs et al.	Geochemical changes along a river-groundwater infiltration flow path: - Glattfelden, Switzerland	1988	2693-2706	52	Geochimica et Cosmochimica Acta	
Jimenez-Martinez et al.	Aquifer recharge. Ploemeur site (Brittany, France)	2011				
Johannson	Groundwater model, Mike She, of the salt water distribution in Anlnarpsströmmen, southern Sweden	2006	10	I	SWIM-SWICA Joint Saltwater Intrusion Conference	
Jorgensen and Helleberg	Stable isotopes (²H and 18O) and chloride as environmental tracers in a stud of artifical recharge in Denmark.	2002	245-250			A.A. BALKEMA
Juhász-Holtermann et al.	Artificial recharge of a lake excavated for gravel extraction	1998	237-242			A.A. BALKEMA
Juuti et al.	Early Experiences of sanitaion in South Africa and Finland	2011	1-86	1	Finnish Journal of Environmental History (YFJEH)	
Karlsen et al.	A post audit and inverse modeling in reactive transport: 50 years of artificial recharge in the Amsterdam Water Supply Dunes	2012	7-25	454-455	Journal of Hydrology	
Kármán et al.	Oxygen isotopic composition in a riverbank ϐiltration system — case study on Szentendre Island, Hungary	2010	1611-1619		Groundwater Quality Sustainability	
Kazner et al.	Water Reclamation Technologies for Safe Managed Aquifer Recharge	2012				IWA Publishing
Kivimäki et al.	Removal of organic matter during bank filtration	1998	107-112			A.A. BALKEMA
Kloppmann et al.	Monitoring Reverse Osmosis Treated Wastewater Recharge into a Coastal Aquifer by Environmental Isotopes (B, Li, O, H)	2008	8759-8765	42	Environmental Science \& Technology	
Kolehmainen et al.	Natural organic matter (NOM) removal and structural changes in the bacterial community during artificial groundwater recharge with humic lake water	2007	2715-2725	41	WATER RESEARCH	
Kolehmainen et al.	Extracellular enzyme activities and nutrient availability during artificial groundwater recharge	2009	405-416	43	Water Research	
Kortelainen and Karhu	Tracing the decomposition of dissolved organic carbon in artificial groundwater recharge using carbon isotope ratios	2006	547-562	21	Applied Geochemistry	
Kortleve et al.	Optimisation Groot Berkheide. Integration of artificial recharge and nature in practice	2002	471-477			A.A. BALKEMA
Kortleve et al.	Ecological engineering of the artificial recharge site Solleveld	2002	489-493			A.A. BALKEMA
Koussis et al.	Analytical single-potential, sharp-interface solutions for regional seawater intrusion in sloping unconfined coastal aquifers, with pumping and recharge	2012	1-11		Journal of Hydrology	

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Kowal	Wykorzystanie infiltracji w oczyszczaniu wody	1999	3-6	74	Ochrona Srodowiska	
Kristinehamns Kommun	Vatten & avlopp					
Kühn and Sontheimer	Treatment: Improvement or deterioration of water quality?	1981	219-233	18	Science of The Total Environment	
Kuster et al.	Fate of selected pesticides, estrogens, progestogens and volatile organic compounds during artificial aquifer recharge using surface waters	2010	880-886	79	Chemosphere	
Kymenlaakso Water Ltd.	Fresh water adds to quality of life	2001				
Lahti et al.	Fate of cyanobacterial hepatotoxins in artificial recharge of groundwater	1998	211-216			A.A. BALKEMA
Landini and Pranzini	Investigations and project for aquifer replenishment in Prato, Italy	2002	279-283			A.A. BALKEMA
Laverman	Potential nitrate removal in a coastal freshwater sediment (Haringvliet Lake, The Netherlands) and response to salinization	2007	p. 3061-3068	41	Water Research	
Lazarova et al.	Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries	2001	25-33	43	WATER SCIENCE AND TECHNOLOGY	
Lazarova et al.	Water quality management of aquifer recharge using advanced tools	2011	1161-1168	64	Water Science \& Technology	
Lehtinen et al.	Risk Management of Environmental Arsenic in Finnish conditions -case Pirkanmaa region	2007				
Leone et al.	Vulnerability and risk evaluation of agricultural nitrogen pollution for Hungary's main aquifer using DRASTIC and GLEAMS models	2009	2969-2978	90	Journal of Environmental Management	
Lindroos et al.	Changes in dissolved organic carbon during artificial recharge of groundwater in a forested esker in Southern Finland	2002	4951-4958	36	Water Research	
López et al.	RECARGA ARTIFICIAL DEL ACUI FERO DE LOS ARENALES EN LA COMARCA DE “EL CARRACILLO” (SEGOVIA)		1-11	1		
LUBW Baden-Wuerttemberg	Wasserwerk Schierstein					
Lundh et al.	Hydrogeology and water treatment perfomance of the Dösebacka artificial recharge plant - the basis for an efficient system for early warning	2005	825-832			United Nations Educational, Scientific and Cultural Organization

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Lynggaard-Jensen	Introduction, ArtDemo Overview and Demonstration Sites	2005				ArtDemo – Artificial Recharge Demonstration, Project Publications Scientific Report, Project - 5th Framework Programme of the EU Environment and sustainable development
Lyonnaise des Eaux	A sustainable management of water resources: The aquifer artificial recharge	2011				
Maeng	Multiple Objective Treatment of Bank Filtration	2010				CRC Press/Balkema
Maeng et al.	Occurrence and fate of bulk organic matter and pharmaceutically active compounds in managed aquifer recharge: A review	2011	3015-3033	45	Water Research	
Malmberg water treatment	Water treatment from offering to commissioning					
Maria-Huerta	Evaluación hidroquímica del sistema de recarga. Efectividad de la capa reactiva.	2012				
Marmonier et al.	Distribution of dissolved organic carbon and bacteria at the interface between the Rhone River and its alluvial aquifer	1995	382-392	14	Journal of the North American Benthological Society	
Martin	Aplicación de la recarga artificial al acuífero terciario detrítico de Madrid por medio de pozos profundos: experiencias de Canal de Isabel II	2011				
Masciopinto and Carrieri	Assessment of Water Quality After 10 Years of Reclaimed Water Injection: The Nardò Fractured Aquifer (Southern Italy)	2002	88-97	22	Ground Water Monitoring \& Remediation	Blackwell Publishing Ltd
Masciopinto et al.	Fate and transport of pathogens in a fractured aquifer in the Salento area, Italy	2008	1-18	44	WATER RESOURCES RESEARCH	
Masciopinto et al.	Managed aquifer recharge of a karstic aquifer in Nardó, Italy	2012			Water Reclamation Technologies for Safe Managed Aquifer Recharge	IWA Publishing
Massmann et al.	Seasonal and spatial distribution of redox zones during lake bank filtration in Berlin, Germany	2008	53-65	54	Environmental Geology	Springer Berlin / Heidelberg
Medema and Stuyfzand	Removal of microorganisms upon basin recharge, deep well injection and river bank filtration in the Netherlands	2002			Management of Aquifer Recharge for Sustainability Proceedings of the Fourth International Symposium on Artificial Recharge	
Meijerink	Determination of infiltration rates in the Amsterdam Water Supply Dunes	2009				

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Meißl	Gebirgwasser in Wien. Die Wasserversorgung der Großstadt im 19. und 20. Jahrhundert.	2005				
Mejuto et al.	Propuesta de plan Constructivo de Presas de Recarga (PCPR) en la Provincia de Alicante	2009				
Melin et al.	Riverbank Filtration: The Future is Now!	2003				National Water Research Institute
Miotlinski et al.	Variable infiltration and river flooding resulting in changing groundwater quality â€“ A case study from Central Europe	2012	211-219		Journal of Hydrology	
Möller and Burgschweiger	Wasserversorgungskonzept für Berlin und das von den BWB versorgte Umfeld (Entwicklung bis 2040)	2008				
Montanari	Water resources management in the Emilia-Romagna region, Italy	2005	28	1	University of Bologna, lecture skript	
Morell et al.	Application of principal components analysis to the study of salinization on the Castellon Plain (Spain)	1996	161-171	177	Science of The Total Environment	
Morris et al.	Assessing the impact of modern recharge on a sandstone aquifer beneath a suburb of Doncaster, UK	2006	979-997	14	HYDROGEOLOGY JOURNAL	
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Murray et al.	Artificial Recharge Strategy: Version 1.3	2007				
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Naturpark Schwalm-Nette	Tiefenwasser für das Elmpter Schwalmbruch					
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Négrel and Petelet-Giraud	Isotopes in groundwater as indicators of climate changes	2011	1279-1290	30	TrAC Trends in Analytical Chemistry	
Nickl and Schmölzer	Projekt KW Stübing der AHP / SSG. Positionspapier GRAZ AG WASSER	2009				
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Olko	ANALIZA ZMIAN JAKO?CI WODY W SIECI WODOCI?GOWEJ MIASTA KRAKOWA					
Olsthoorn and Mosch	Fifty years artificial recharge in the Amsterdam dune area	2002	29-33			A.A. BALKEMA
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Ortuno et al.	Seawater intrusion barrier in the deltaic Llobregat aquifer (Barcelona, Spain): performance and pilot phase results	2012	135-138	21	SWIM21 - 21st Salt Water Intrusion Meeting	

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Otz et al.	Surface water/groundwater interaction in the Piora Aquifer, Switzerland: evidence from dye tracing tests	2003	228-239	11	HYDROGEOLOGY JOURNAL	
Pachón et al.	La instalación piloto de recarga artificial de Los Sotillos (Cádiz)	2001	151-166	2	V Simposio sobre el Agua en Andalucía	
Page et al.	Valuing the subsurface pathogen treatment barrier in water recycling via aquifers for drinking supplies	2010	1841-1852	44	Water Research	
Panagopoulos et al.	Groundwater artificial recharge possibilities at the Tumpa region aquifer system (N. Greece)	2004	8	VII	Protection and restoration of the environment	
Panoras et al.	Groundwater artificial recharge of the Edessaios basin aquifer system, northern Greece, through irrigation wells	2004	47-52	XLI	Agricultural Engineering	
Pawula	Historyczne i sozologiczne aspekty eksploatacji komunalnych ujęć wody miasta Poznania	1993				
Perrin and Luetscher	Inference of the structure of karst conduits using quantitative tracer tests and geological information: example of the Swiss Jura	2008	951-967	16	HYDROGEOLOGY JOURNAL	
Peters	Artificial Recharge of Groundwater: Proceedings of the Third International Symposium - TISAR 98	1998				A.A. BALKEMA
Petrunic et al.	Reductive dissolution of Mn oxides in river-recharged aquifers: a laboratory column study	2005	163-181	301	Journal of Hydrology	
Piekutin	UZDATNIANIE WÓD INFILTRACYJNYCH	2008	109–115	5	INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH	
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Poveda	Recarga Artificial de Acuíferos con excedentes invernales del río Belcaire (Castellon)	2009				
Powell et al.	Microbial contamination of two urban sandstone aquifers in the UK	2003	339-352	37	Water Research	
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Pyne	Aquifer Storage Recovery: Meeting Water Quality Goals for Arsenic, Disinfection Byproducts and Nutrients	2008				
Radio Prag	Tschechisches Trinkwasser - besser als sein Ruf					
Radjenovic et al.	Rejection of pharmaceuticals in nanofiltration and reverse osmosis membrane drinking water treatment	2008	3601-3610	42	Water Research	
Ray	Introduction	2003	1-15			Kluwer Academic Publishers

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Ray et al.	Riverbank Filtration: Improving Source-Water Quality	2003				Kluwer Academic Publishers
Regionalny Zarzad Gospodarki Wodnejw Poznaniu (RZGW)	UZASADNIENIE DO ROZPORZĄDZENIA DYREKTORA REGIONALNEGO ZARZĄDU GOSPODARKI WODNEJ W POZNANIU	2012	3			
Regli et al.	Analysis of aquifer heterogeneity within a well capture zone, comparison of model data with field experiments: A case study from the river Wiese, Switzerland	2003	111-128	65	AQUATIC SCIENCES	
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Riches et al.	Hydrogeochemistry of Aquifer Storage and Recovery in the Lower Greensand (London, UK) for Seasonal and Drought Public Supply	2008	198-208			ACACIA Publishing Incorporated, Phoenix, Arizona
Robins et al.	An aquifer management case study - The chalk of the English South Downs	1999	205-218	13	WATER RESOURCES MANAGEMENT	
Rónai	HYDROGEOLOGICAL STUDY ON THE QUATERNARY DEPOSITS OF THE GREAT HUNGARIAN PLAIN	1964	24-30	9	International Association of Scientific Hydrology. Bulletin	
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Schmidt	Datenbank zum Verhalten organischer Spurenstoffe bei der Uferfiltration.	2005		2	Exportorientierte F\&E auf dem Gebiet der Wasserver- und -entsorgung	
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Schulte-Ebbert	Allgemeine Charakterisierung des Untersuchungsgebietes.	1995	7-32		U. Schüttler, U. Schulte-Ebbert : Schadstoffe im Grundwasser, Band 3, Verhalten von Schadstoffen im Untergrund bei der Infiltration von Oberflächenwasser am Beispiel des Untersuchungsgebietes „Insel Hengsen" im Ruhrtal bei Schwerte	
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Zippel and Huber	Hydrologische Berechnungen zum Nachweis des Grundwasserdargebotes für die Wasserwerke Friedrichshagen, Kaulsdorf, Wuhlheide, Johannisthal, Buch, Altglienicke der Berliner Wasserbetriebe	2007			HYDOR Consult GmbH, not published	
Zühlke	Verhalten von Phenazonderivaten, Carbamazepin und estrogenen Steroiden w{\"a}hrend verschiedener Verfahren der Wasseraufbereitung	2004				
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