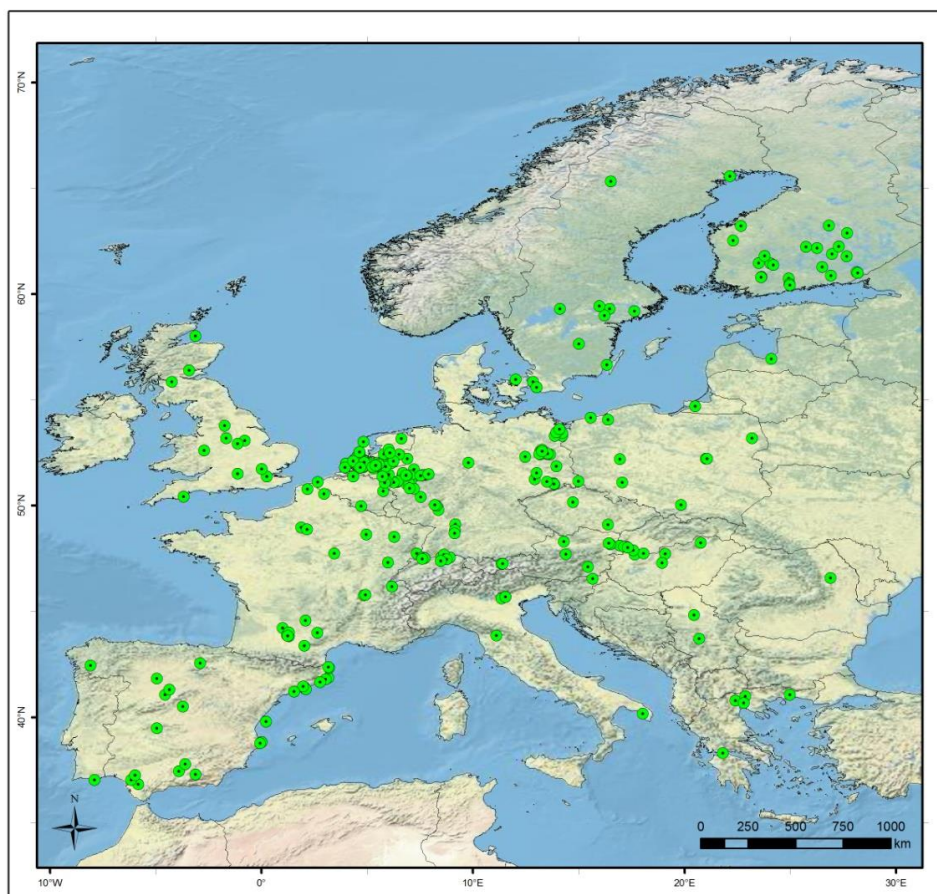


## CATALOGUE OF EUROPEAN MAR APPLICATIONS



The research leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No.308339 (Project DEMEAU).

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**Title: CATALOGUE OF EUROPEAN MAR APPLICATIONS****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 II 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 4), *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.



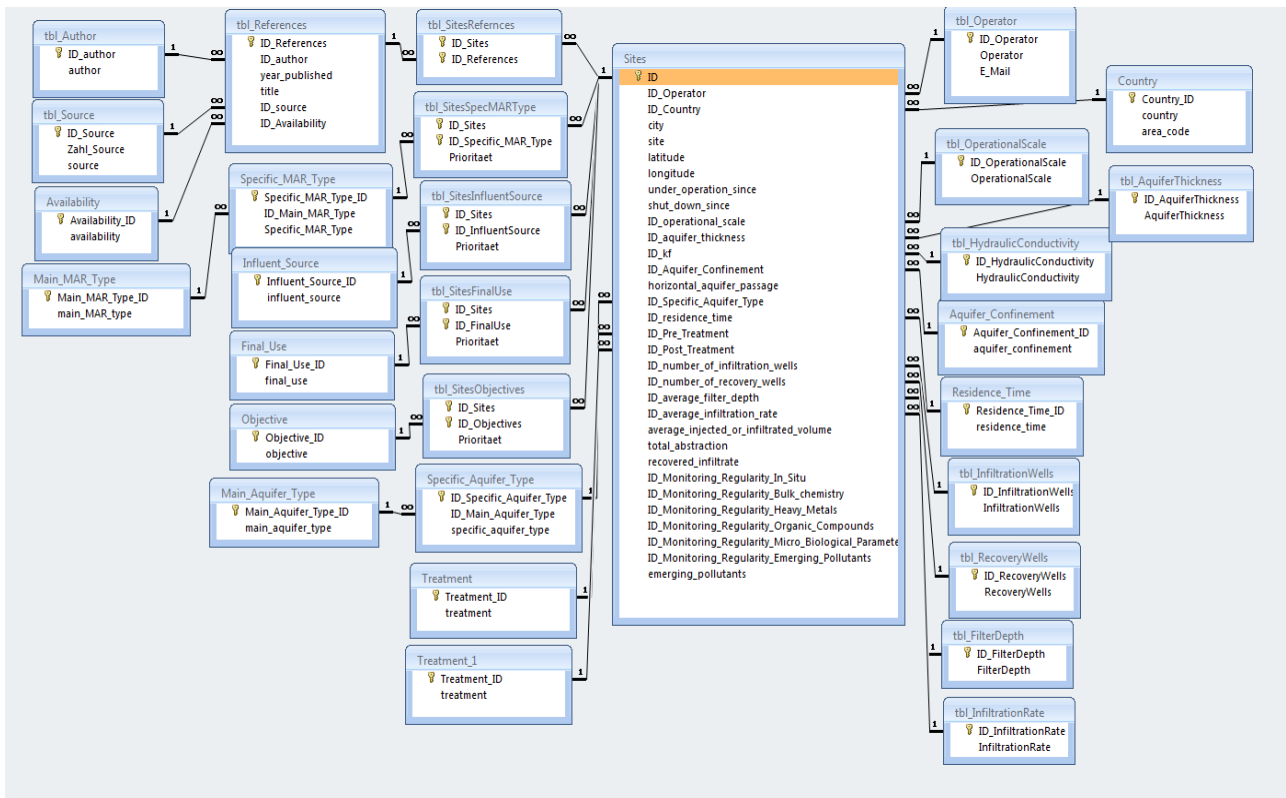


Figure 1: Structure of the MAR database and table relationships

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

#### 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 <i>Main_Aquifer_Type</i>
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	fluvia-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 m<sup>3</sup> 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 (m <sup>3</sup> /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 <i>Sites</i>
ID_Specific_MAR_Type	number	link to table <i>Specific_MAR_Type</i>
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 <i>Main_MAR_Type</i>
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 <i>Sites</i>
ID_FinalUse	number	link to table <i>Final Use</i>
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 <i>Sites</i>
ID_InfluentSource	number	link to table <i>InfluentSource</i>
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 <i>Sites</i>
ID_Objectives	number	link to table <i>Objectives</i>
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<sup>3</sup> 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	<ul style="list-style-type: none"> <li>· reduce abstraction from rivers</li> <li>· maintain the reserve (maintain groundwater levels and in-stream flow requirements)</li> <li>· minor environmental imprint</li> <li>· minimal land use</li> <li>· temperature control (e.g. for industry)</li> </ul>
2	management of water distribution systems	<ul style="list-style-type: none"> <li>· maintenance of distribution system flow &amp; pressure</li> <li>· storage of treated water</li> </ul>
3	maximize natural storage	<ul style="list-style-type: none"> <li>· seasonal storage</li> <li>· long-term storage ("water banking")</li> <li>· emergency storage</li> <li>· diurnal storage</li> </ul>
4	physical aquifer management	<ul style="list-style-type: none"> <li>· restoration of groundwater levels</li> <li>· reduction of land subsidence</li> <li>· prevention of saltwater intrusion</li> <li>· enhancement of well field production</li> <li>· hydraulic control of contaminant plumes</li> </ul>
5	water quality management	<ul style="list-style-type: none"> <li>· water quality improvement</li> <li>· disinfection by-products (DBPs) reduction</li> <li>· nutrient reduction in agricultural runoff</li> <li>· stabilization of aggressive water by storage in calcium carbonate aquifers</li> </ul>
6	other benefits	<ul style="list-style-type: none"> <li>· defer expansion of water facilities</li> <li>· storage of reclaimed water</li> <li>· utilize saline aquifers</li> <li>· storage of huge quantities of water</li> <li>· rapid implementation and staged development</li> <li>· low capital cost</li> <li>· mitigate effects of climate change</li> <li>· savings on evaporation</li> </ul>

#### 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*, *tbl\_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 <i>Sites</i>
ID_References	number	link to table <i>References</i>

#### 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 <i>Author</i>
year_published	number	year of publication
title	text	title of reference
ID_source	number	link to table <i>Source</i>
ID_Availability	number	link to table <i>Availability</i>

#### 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.

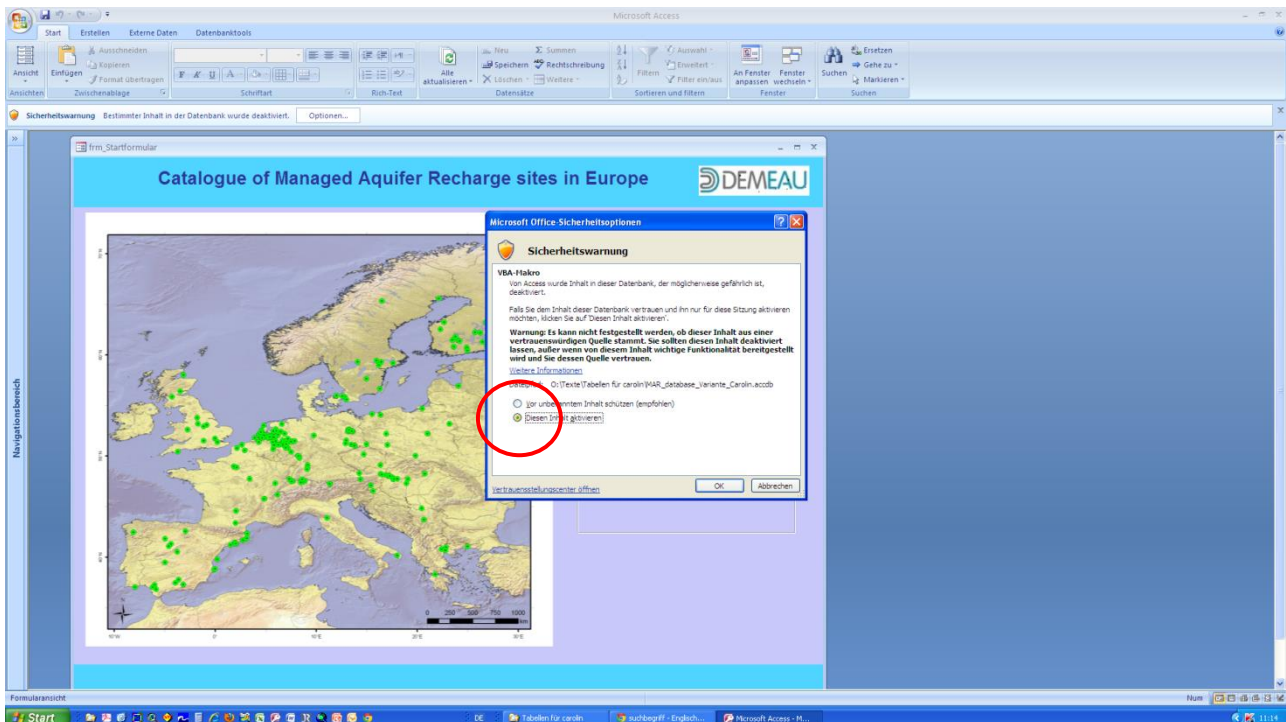


Figure 2: Enable macros before using the database

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

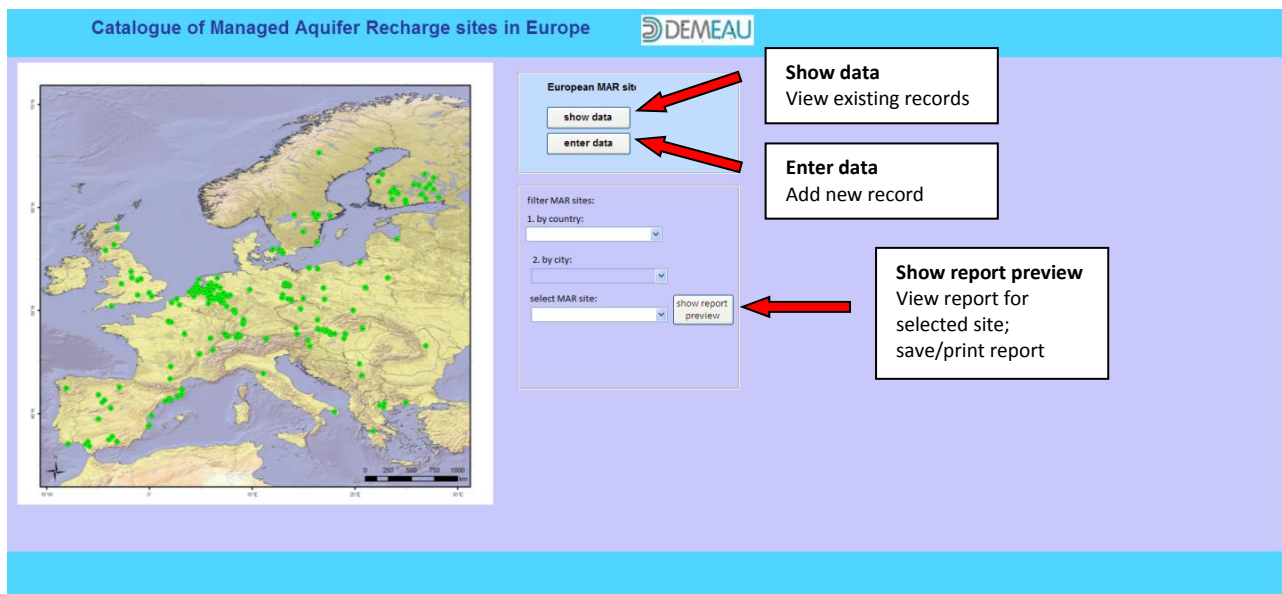


Figure 3: Start display of the database

### 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):

The screenshot shows the 'European MAR sites' form with the following callouts:

- Looking for**: Shows preview of records to be selected (points to the search bar).
- Search**: Search entering a term (points to the search input field).
- Number of MAR site**: Select site ID to directly attain specific site (points to the 'number of MAR sites' indicator).
- Report**: Shows report of currently selected site (points to the 'report' button).
- Close**: Closes *show data* form to go back to the start screen (points to the 'close' button).

The form itself contains the following sections:

- Site information**: name of site (Cubeta de Santuste de San Juan Bautista), country (Spain), city (Segovia), latitude (41.08), longitude (4.57).
- operator**: name (Ministerio de Agricultura (MAPA), Junta de...), contact (jlmarrero@tragsa.es), under operation since (2002), shut down since (empty).
- MAR type**: specific MAR type (infiltration ponds & basins), main MAR type (infiltration ponds & basins), spreading methods (flooding), priority (1).
- Influent source**: river water, priority (1).
- final use**: agricultural, priority (1).
- objectives**: other benefits (priority 1), water quality management (priority 2).
- operational parameter**: number of infiltration wells (>30), operational scale (7300000 bis 18250000), residence time, average infiltration rate (1 bis 3), average filter depth, average injected or infiltrated volume, horizontal aquifer passage, recovered infiltrate.
- aquifer parameter**: hydraulic conductivity (1E-05 bis 1E-04), aquifer confinement (unconfined aquifer), aquifer thickness (30 bis 100), aquifer type (fluvial deposits).
- water quality monitoring**: in situ (regular, non-regular, n.a.), bulk chemistry (regular, non-regular, n.a.), heavy metals (regular, non-regular, n.a.), organic compounds (regular, non-regular, n.a.), micro biological pollutants (regular, non-regular, n.a.), emerging pollutants (regular, non-regular, n.a.).
- References**: Table with columns for author, year, title, Source, availability.

Figure 4a: Form to view existing data (part 1)

This screenshot shows the bottom portion of the 'European MAR sites' form, including the 'References' table and 'add new Reference' buttons.

select References	author	year	title	Source	availability
References	Escalante & Ovejero		Cinco años de recarga artificial en el acuífero de la Cubeta de Santuste (Segovia)	DINA-MAR	soft copy
References	Escalante & Gutierrez	2002	Hydrogeological studies preceding artificial recharge at Los Arenales. Duero basin, Spain.	In: Dillon (ed) (2002): Management of Aquifer Recharge for Sustainability. Proceedings of the 4th International Conference on Artificial Recharge	hard copy
*					

Buttons: add new Reference to list, correction existing Reference data

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).

country	city	site
Spain	Segovia	Cubeta de Santiuste de San Juan Bautis
Spain	Seville	Seville
Spain	Valladolid	Carracillo
Sweden	Dösebacke	Dösebacke
Sweden	Eksjö	Eksjö
Sweden	Eskilstuna	Hyndevad
Sweden	Helsingborg	Örby
Sweden	Katrineholm	Katrineholm
Sweden	Kristinehamn	Bergsjön
Sweden	Landskrona	Landskrona
Sweden	Luleå	Luleå
Sweden	Malmö	Grevie
Sweden	Södertälje	Södertälje
Sweden	Uppsala	Uppsala
Sweden	Västerås	Västerbotten
Switzerland	Basel	Lange Erlen
Switzerland	Basel	Muttенzer Hard
Switzerland	Frauenfeld	River Thur
Switzerland	Geneva	Gessy

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.



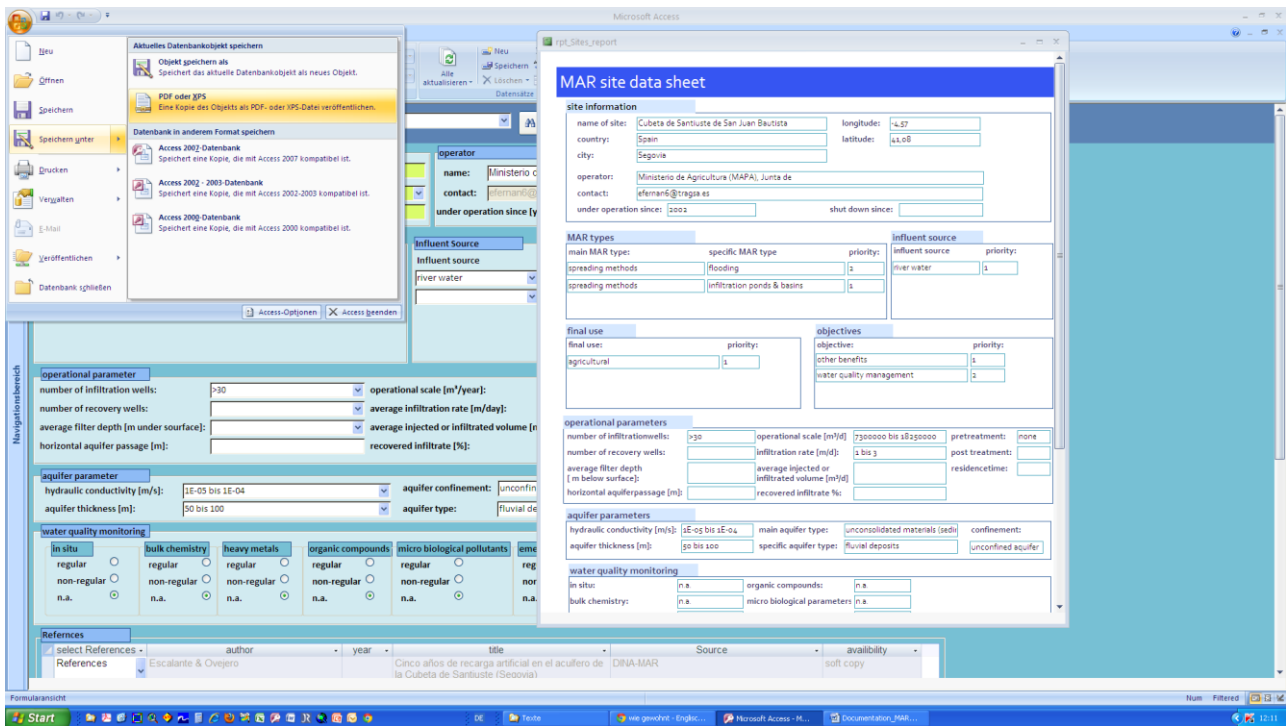


Figure 6: Save the report of the current record

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 ).

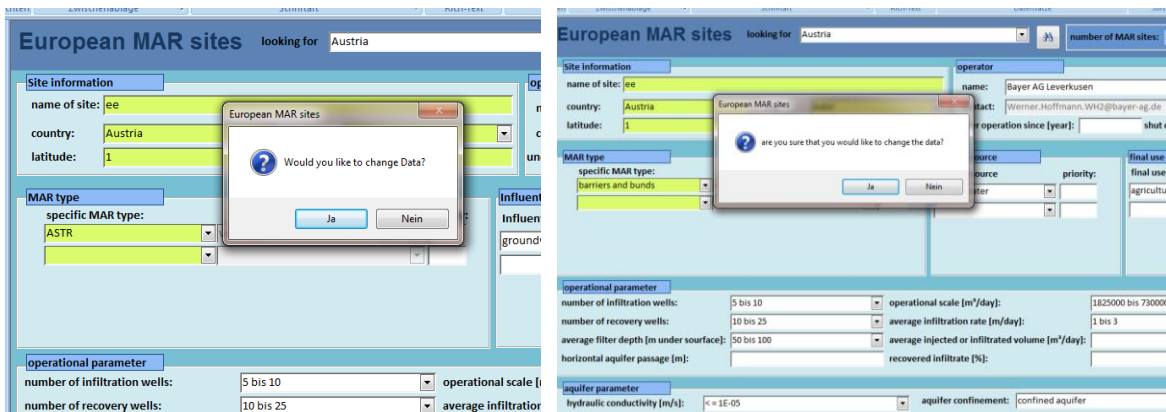


Figure 7: Report window after double clicking the field specific MAR type

### 5.2.2 Data entry

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

The screenshot shows the 'European MAR sites' data entry interface. At the top right, there are three buttons: 'next MAR site', 'close', and 'abort'. Three callout boxes with red arrows point to these buttons:

- Next MAR site:** Enter data for the next MAR site
- Close:** Closes enter data form to go back to the start screen
- Abort:** The current data entry is not being saved and the process is being terminated

The form itself is divided into several sections:

- Site information:** name of site (highlighted), country (dropdown), city (dropdown), latitude (highlighted), longitude (highlighted).
- operator:** name (dropdown), contact (text), under operation since [year] (text), shut down since [year] (text).
- MAR type:** specific MAR type (dropdown), main MAR type (dropdown), priority (dropdown).
- Influent source:** Influent source (dropdown), priority (dropdown).
- final use:** final use (dropdown), priority (dropdown).
- operational parameter:** number of infiltration wells (dropdown), number of recovery wells (dropdown), average filter depth [m under surface] (dropdown), horizontal aquifer passage [m] (text), operational scale [m³/year] (dropdown), average infiltration rate [m/day] (dropdown), average injected or infiltrated volume [m³/day] (text), recovered infiltrate [%] (text), residence time (dropdown), pretreatment (dropdown), posttreatment (dropdown).
- aquifer parameter:** hydraulic conductivity [m/s] (dropdown), aquifer thickness [m] (text), aquifer confinement (dropdown), aquifer type (dropdown).
- water quality monitoring:** Radio buttons for 'In situ', 'bulk chemistry', 'heavy metals', 'organic compounds', 'micro biological pollutants', and 'emerging pollutants', each with 'regular', 'non-regular', and 'n.a.' options.
- References:** A table with columns for 'select References', 'author', 'year', 'title', 'Source', and 'availability'.

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.

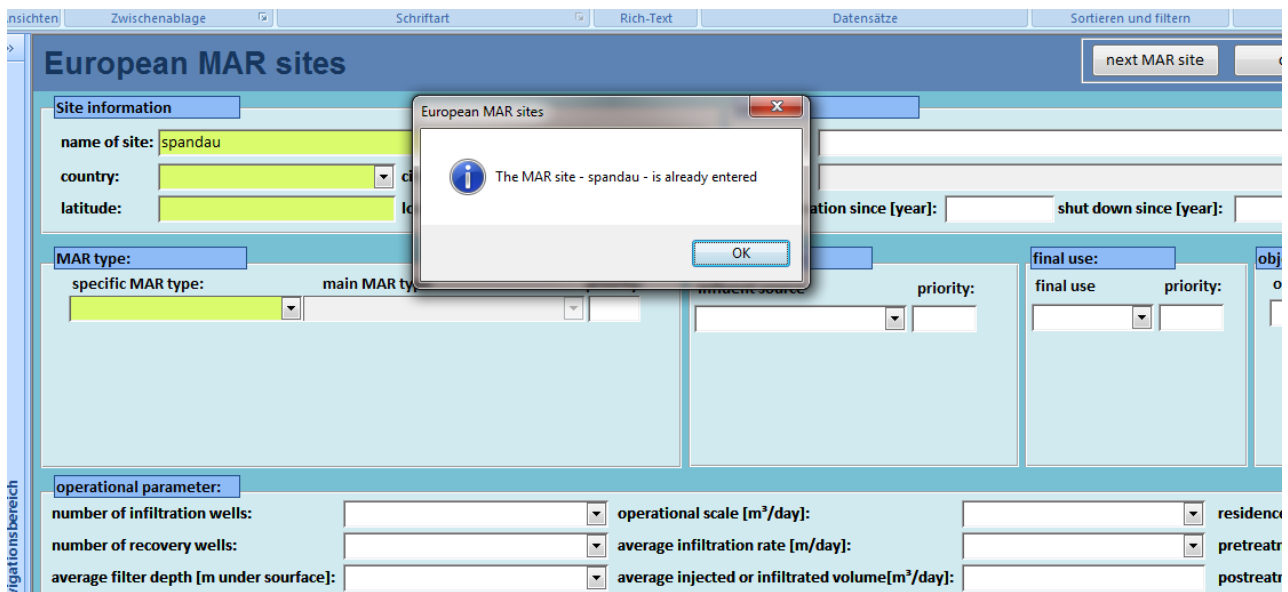


Figure 9: Pop-up window to prevent double site name entries

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*. It 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.

**Close**  
Closes change existing operator data form

**Name**  
Name of the operator

**Contact**  
E-Mail address of the operator

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