

# Managed aquifer recharge (MAR)

## Classification and inventory of typologies at the international level

#	SYSTEM	MAR DEVICE	LOGO	FIGURE	PHOTO	LEGEND
1	EXPRESSION	INFILTRATION PONDS/WETLANDS				Artificial wetland to recharge in Sachin, Coca, Sagrada (Spain). Photo: DWA MAR
2		CHANNELS AND INFILTRATION DITCHES				Artificial recharge channel of the Basin of Santians, Segovia, Spain, operative since 2002. Photo: DWA MAR
3		RIDGES/ SOIL AND AQUIFER TREATMENT TECHNIQUES				Ridges in the bottom of a infiltration pond. California. Photo: D. Peyton
4		INFILTRATION FIELDS (FLOOD AND CONTROLLED SPREADING)				Infiltration field in Oradai (Arabia). Photo: G. Treloar
5		ACCIDENTAL RECHARGE BY IRRIGATION RETURN				Artificial recharge by irrigation return. Extremadura, Spain. Photo: Tragsa
6		ROFODALE'S WETLANDS				Rofodale (Colombia)
7	CHANNELS	RESERVOIR DAMS AND DAMS				Artificial recharge dam in basin head. Alicante, Spain.
8		PERMEABLE DAMS				Permeable dam in Huesca, Spain. Photo: Tragsa
9		LEVEES				Levees in Santa Ana river, Orange County, California, USA. Photo: A. Hatchman
10		RIVERBED SCARIFICATION				Scarification at Besós (river), Barcelona, Spain. Photo: J. Amador
11		SUB-SURFACE/ UNDERGROUND DAMS				Sub-surface dam in Kiri, Kenya. Photo: Sander de Haan
12		DRIELED DAMS				Dried dam. Luján, Granada, Spain. Photo: Tragsa

WELLS	13	QANATS (UNDERGROUND GALERIES)				Qanat of Calhazosa de Mayor, Segovia, Spain. Photo: E.J. Escalante	
	14	OPEN INFILTRATION WELLS				Infiltration well, Arizona, USA. Photo: DWA MAR	
	15	DEEP WELLS AND BOREHOLES				Artificial recharge well. Coruña, Barcelona, Spain. Photo: DWA MAR	
	16	BOREHOLES				Borehole (BSR) in Andalusia. Photo: P. Dillon	
	17	SHAKHOLES, COLLAPSES...				Shakhole called "El Infiltramiento", Alicante, Spain. Photo: DWA MAR	
	18	ASR				ASR device in Scottsdale, Arizona, USA. Photo: DWA MAR	
FILTRATION	19	ASTR				ASTR device in California, USA.	
	20	RIVER BANK FILTRATION (RBF)				RBF RBF system in Eriksen. Photo: A. Tashraf	
	21	INTERLINE FILTRATION				Interline filtration near Amsterdam, Netherlands. Photo: Allan	
	22	UNDERGROUND IRRIGATION				Underground irrigation in Andalusia, Spain. Photo: Tragsa	
	RAIN	23	RAINWATER HARVESTING IN UNPRODUCTIVE				Rainwater harvesting in unproductive for MAR techniques.
		24	ACCIDENTAL RECHARGE PIPES AND SEWER SYSTEM				Artificial recharge from sewer system in Spain. Photo: Tragsa
SOLUS	25	SUSTAINABLE URBAN DRAINAGE SYSTEMS				SUS. Comarrosa park, Madrid, Spain. Photo: E.J. Escalante	

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Modified from DWA-MAR, 2011

# Clasificación

- ◆ The one by Ian Gale & Peter Dillon (2005) describes a total of 15 devices for MAR grouped in 5 classes:
  - Distribution methods
  - Modifications inside canals
  - Recharge by wells, tunnels, boreholes
  - Induced bank filtration
  - Rainwater harvesting
- ◆ This proposal was increased by DINA-MAR with 9 new devices (2010) and MARSOL including one more (2014) resulting a classification of 25 devices in six systems

DISPERSIÓN

CANALS

WELLS

FILTRATION

RAINWATER

SUDS

## Methodologies for MAR

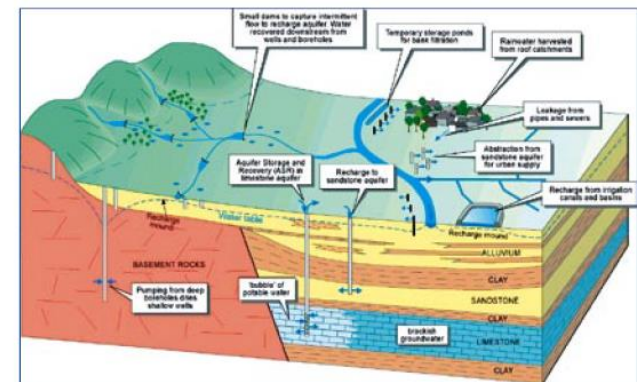
MAR techniques have been applied for millennia to manage available water resources. Methodologies range in complexity from simple rainwater harvesting to deep-well injection of reclaimed water into a saline aquifer. Methodologies applied should be appropriate to meet the defined objectives which, at the most basic level, will be storage and treatment of water. Clogging is a key issue that needs to be understood so the impacts can be minimised and managed in a cost-effective manner.

Numerous schemes exist to enhance recharge of groundwater and they are as varied as the ingenuity of those involved in their construction and operation. These schemes are designed with the prime objective of enhancing recharge (intentional recharge) but aquifers can also be recharged unintentionally (incidental recharge) whilst undertaking other activities, for example irrigation. Intentional methods are aimed at enhancing groundwater supplies but may also achieve other purposes, such as flood mitigation, reduced soil erosion or change of land use. Here we focus on intentional recharge, the methodologies applied being broadly grouped into the following categories, most of which are illustrated in the figure:

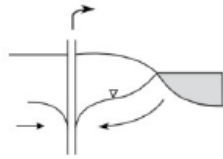
- Spreading methods
  - Infiltration ponds and basins
  - Soil Aquifer Treatment (SAT)
  - Controlled flooding
  - Incidental recharge from irrigation
- In-channel modifications
  - Percolation ponds behind check-

- dams, gabions, etc.
- Sand storage dams
- Subsurface dams
- Leaky dams and recharge releases
- Well, shaft and borehole recharge
  - Open wells and shafts,
  - Aquifer Storage and Recovery (ASR)
- Induced bank infiltration,
  - Bank filtration
  - Inter-dune filtration
- Rainwater harvesting
  - Field bunds etc.
  - Roof-top rainwater harvesting

Many schemes require low levels of technology and can be (and have been for centuries) implemented with little engineering knowledge. This would include water-harvesting techniques to enhance recharge, field bunding and small bunds across ephemeral streams. Well digging skills have been developed over generations and diversion of surface flow into these (despite potential pollution problems),

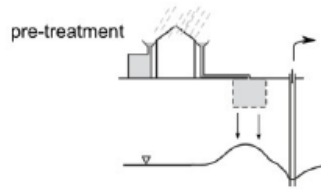


### Bank filtration

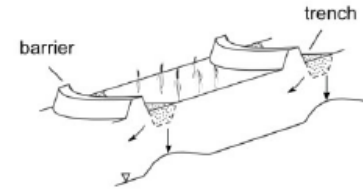


River/ Lakebank filtration

### Rainwater and run-off harvesting

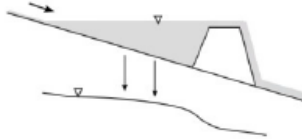


Rooftop harvesting

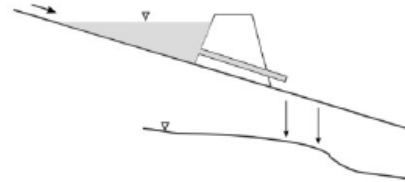


Barriers and trenches

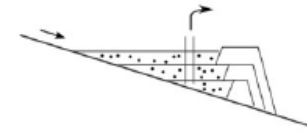
### In-channel modifications



Check dam

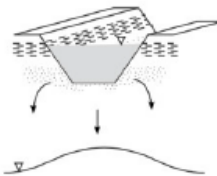


Recharge releases

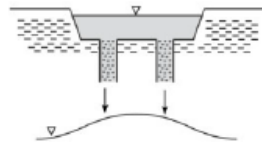


Sand dam

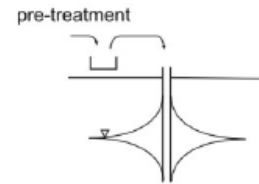
### Well, shaft, dam, borehole recharge



Shaft recharge



Borehole recharge

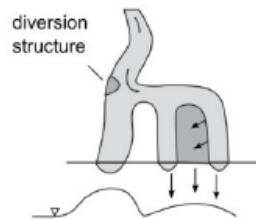


Aquifer storage and recovery

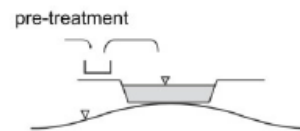


Underground dam

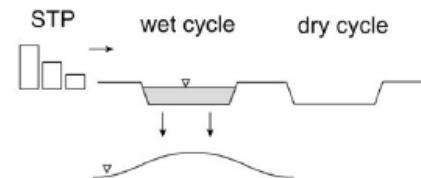
### Spreading methods



Surface water spreading



Infiltration pond



Soil aquifer treatment

# 1. Dispersion systems

## DISPERSIÓN

- INFILTRATION PONDS
- INFILTRATION CANALS
- SAT
- INFILTRATION FIELDS
- IRRIGATION RETURN

## CANALS

## WELLS

## FILTRATION

## RAINWATER

## SUDS

◆ Permeable geological formations

◆ Big terrain surface

◆ Recharge water infiltrates into the aquifer by gravity

◆ General improvement of the water quality

- Filtered across the Unsaturated Zone
- Filtered across the aquifer

# 1. Dispersion systems

- ◆ Infiltration ponds
- ◆ Infiltration canals





BALSA DE INFILTRACIÓN  
CARRACILLO  
(GOMEZSERRACÍN)  
LOS ARENALES, SPAIN



BALSA DE INFILTRACIÓN  
SANTIUSTE (SEGOVIA)

# BALSA DE INFILTRACIÓN ATLANTIS (S.A.)





CANAL DE INFILTRACIÓN  
SANTIUSTE (SEGOVIA)



CANAL DE INFILTRACIÓN  
CARRACILLO  
(NARROS DE CUÉLLAR)

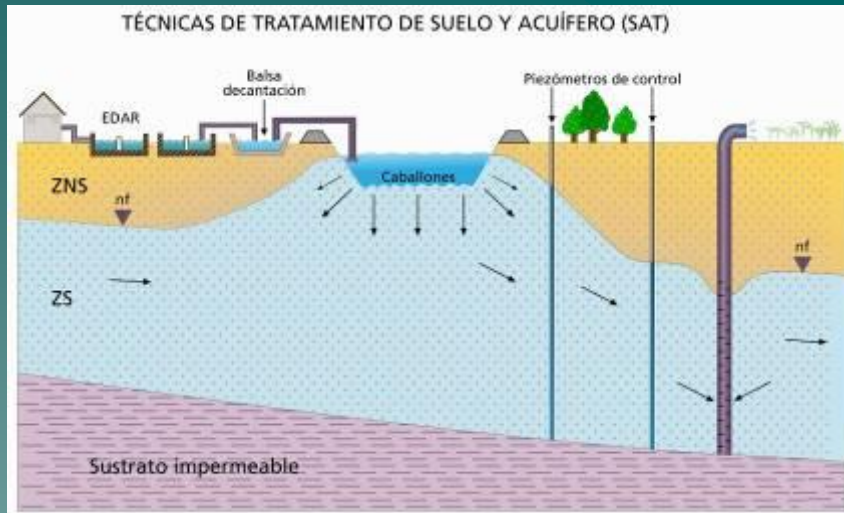


INFILTRATION DITCHES  
HIDANGO (CHILE.2005)



# 1. Dispersion systems

## SAT (Soil and aquifer Treatment Techniques)



FURROWS AT THE BOTTOM OF AN  
INFILTRATION POND  
(CALIFORNIA, USA)



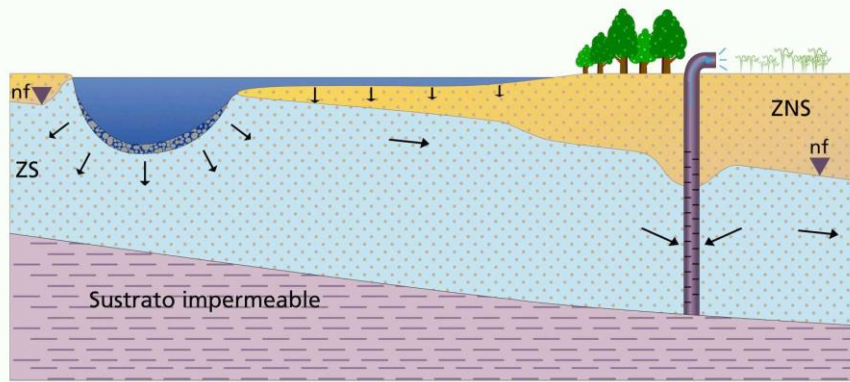
# 1. Dispersion systems

## Infiltration fields

INFILTRATION FIELD  
OMDEL RIVER (NAMIBIA)



CAMPOS DE INFILTRACIÓN (INUNDACIÓN Y DIFUSIÓN CONTROLADA)



CONTROLLED FLOODING  
SCHEMES

# 1. Dispersion systems

## Accidental recharge by irrigation returns

E.g. Stimulation for the water volume employed to irrigate rice...

- ± 60% → plant
- 40% → groundwater

(Fuente: Instituto Internacional de Gestión del Agua , 2002)



VEGA DEL GUADIANA  
RICE CROP FIELD

## 2. In-channel modification systems

DISPERSION

CANALS

- RETENTION DYKE
- PERMEABLE DYKES
- SUBSURFACE DYKE
- PERFORATED DYKES
- LEVEES
- RIVERBED SCARIFICATION

WELLS

FILTRATION

RAINWATER

SUDS

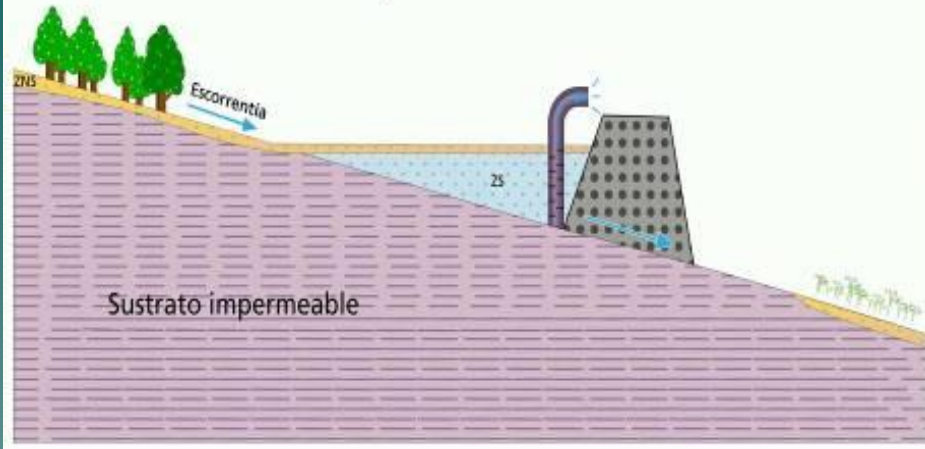
Increase the river basin  
water residence time



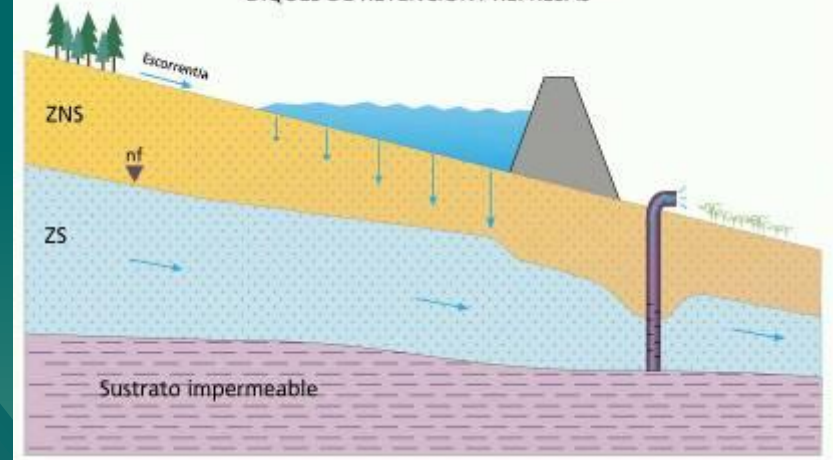
ENHANCES NATURAL INFILTRATION

# Dyke typologies

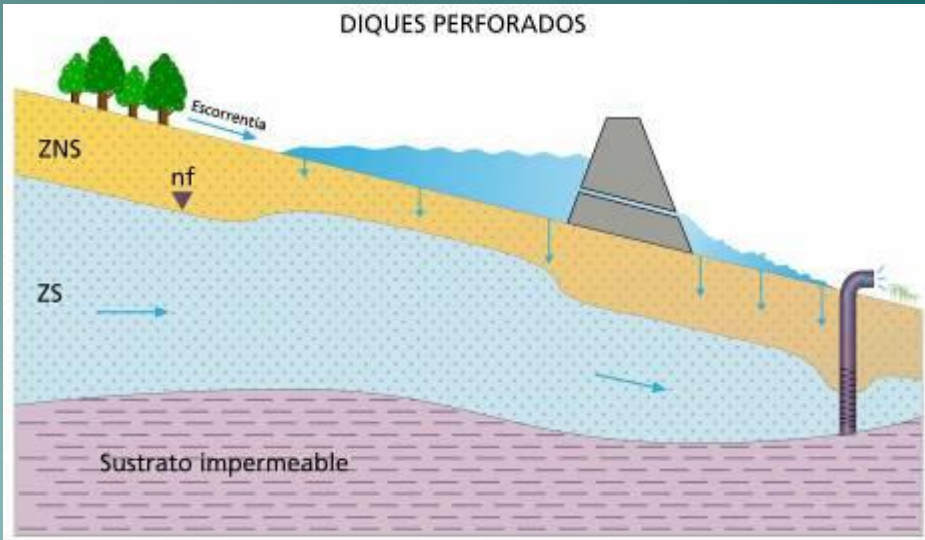
## DIQUES PERMEABLES



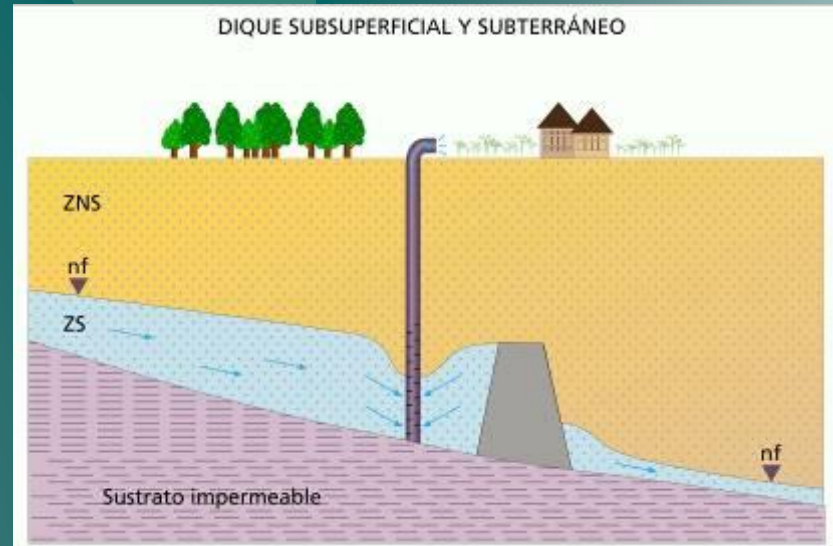
## DIQUES DE RETENCIÓN / REPRESAS



## DIQUES PERFORADOS



## DIQUE SUBSUPERFICIAL Y SUBTERRÁNEO



BARRANCO DE LAS OVEJAS  
(ALICANTE)

PERMEABLE DYKES AND  
SAND DAMS



BARRANCO PAJCHA  
(BOLIVIA)

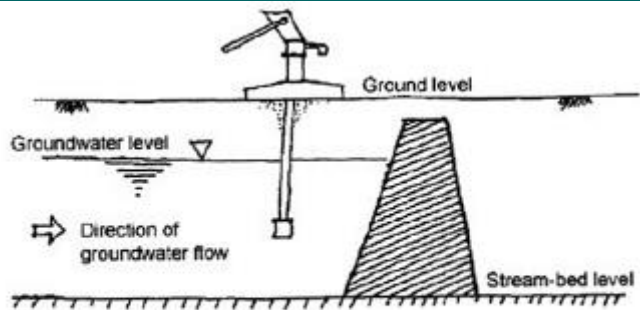


# RETENTION DYKE (ALICANTE)



# PERFORATED DYKE SANTA CRUZ DE LA ZARZA (TOLEDO)





## SUBSURFACE DYKE KITUI (KENYA)



## SUBSURFACE DYKE SCHEME

(Source: Smart Water Harvesting Solutions.)

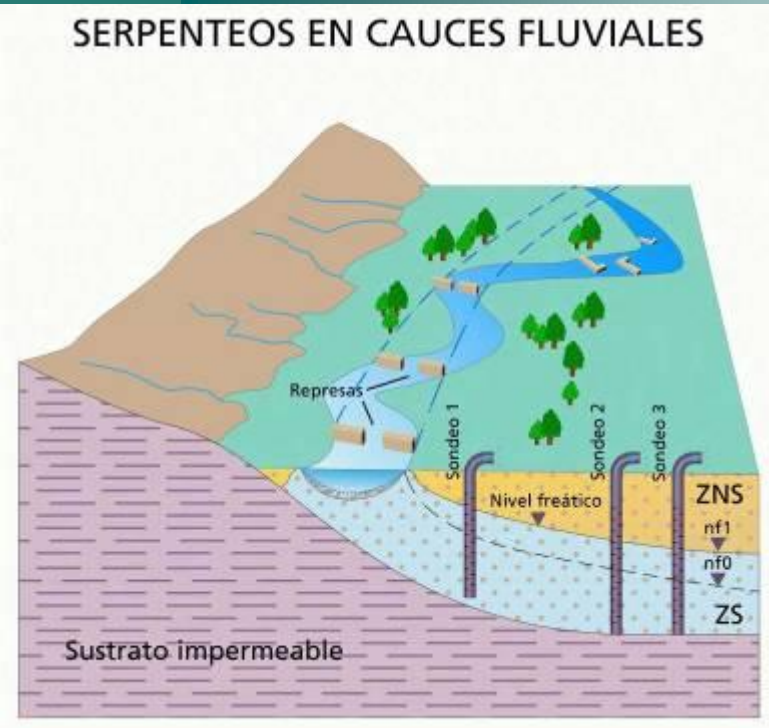


## 2. In-channel modification systems



### RIVERBED SCARIFICATION

### LEVEES IN THE RIVER RUNWAY



RIVERBED SCARIFICATION  
LLOBREGAT RIVER  
(BARCELONA, SPAIN)





# LEVEES, SANTA ANA RIVER, CALIFORNIA (USA)



# 3. Wells, shafts and boreholes recharge

DISPERSION

CANALS

POZOS

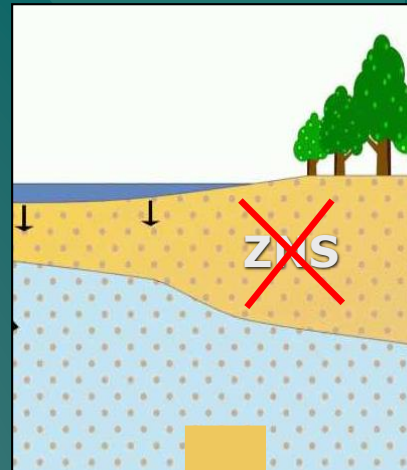
- QANATS
- DOLINES & COLAPSeS
- WELLS
- DEEP WELLS
- BOREHOLES
- ASR
- ASTR

FILTRATION

RAINWATER

SUDS

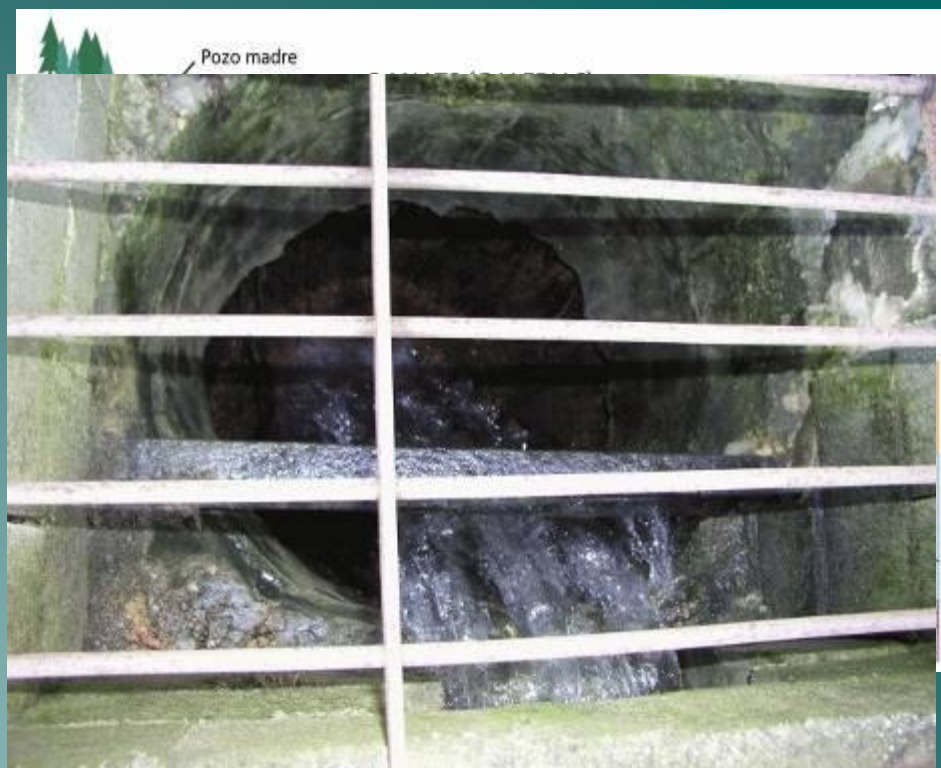
- ◆ Scarce terrain availability
- ◆ Low transmissivity aquifers
- ◆ Alternation of permeable and impermeable levels
- ◆ Outcrops of low permeability superficial layers



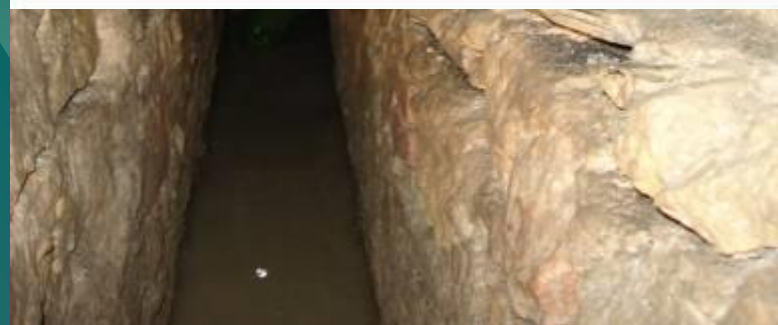
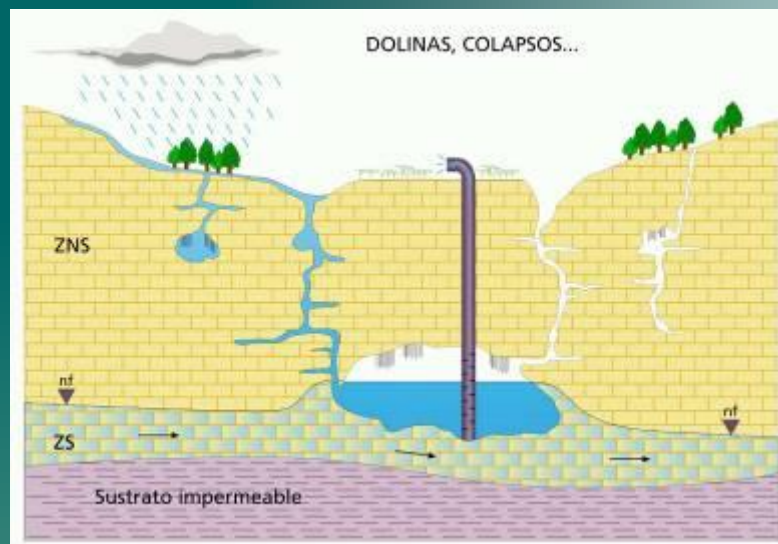
1/2 RECHARGE WATER QUALITY IMPROVEMENT

### 3. Wells, shafts and boreholes recharge. Qanats & dolines

- ◆ Qanats (underground galleries)
- ◆ Dolines, colapses...



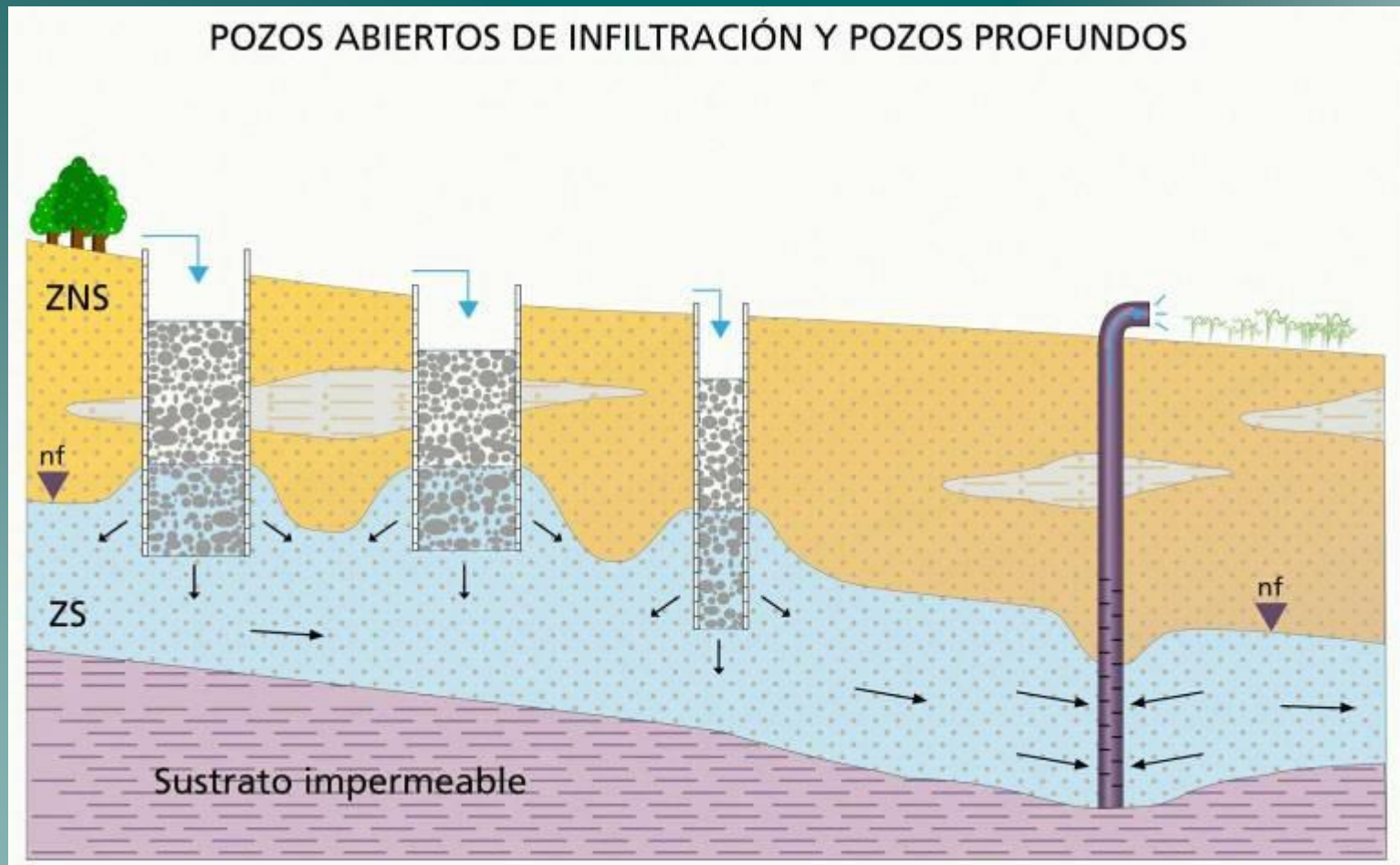
DOLINE FOR MAR  
(ALICANTE)



QANAT, CARBONERO EL MAYOR  
(SEGOVIA)

### 3. Wells, shafts and boreholes recharge. Wells

- ◆ Infiltration opened wells
- ◆ Deep wells





DEEP WELL  
(THE NETHERLANDS)

INFILTRATION OPENED WELLS  
ARIZONA (USA)



### 3. Wells, shafts and boreholes recharge. Boreholes, ASR & ASTR

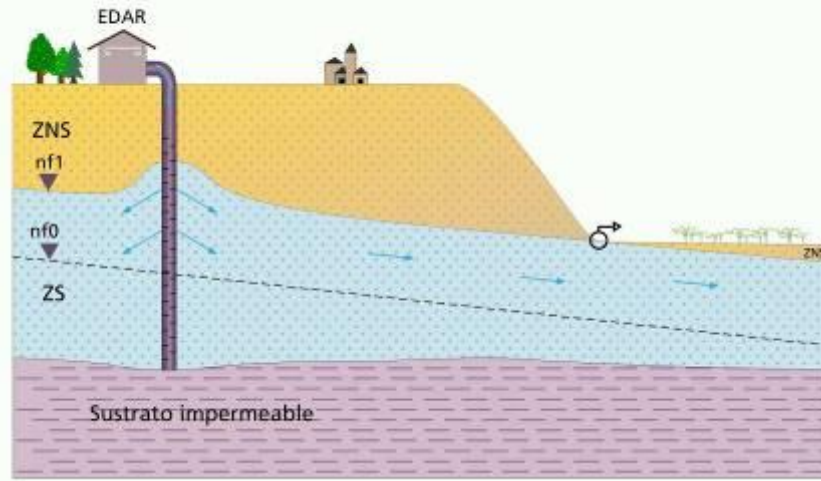
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WATER IS INJECTED INTO THE AQUIFER BY INVERSE PUMPING OR OTHER ACTIVE TECHNIQUES

- ◆ Injection boreholes  
Injected water flows according to hydraulic gradient
- ◆ ASR (Aquifer Storage Recovery). Water is injected and recovered in a borehole alone
- ◆ ASTR (Aquifer Storage Transfer and Recovery). Water is injected in a well different of the one where is recovered later, which is usually several kms away.



## SONDEOS DE INYECCIÓN



## INJECTION BOREHOLE SCHEME

ALICANTE

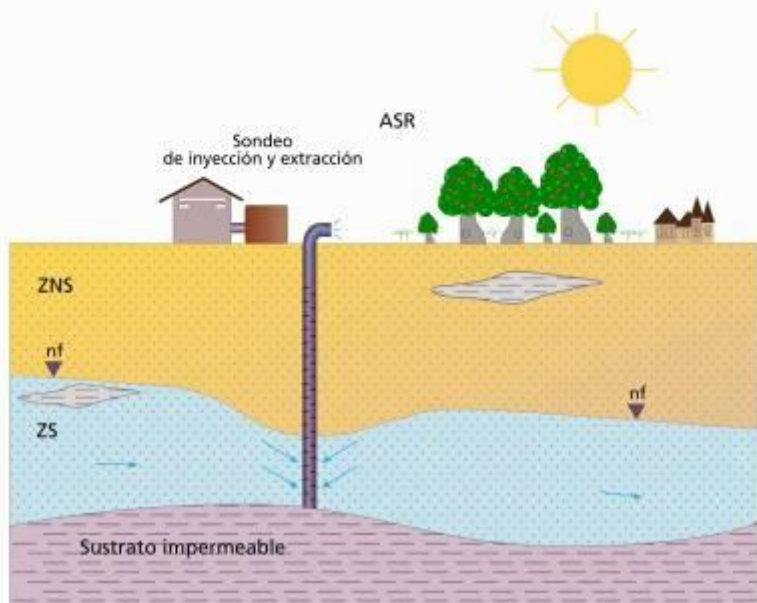
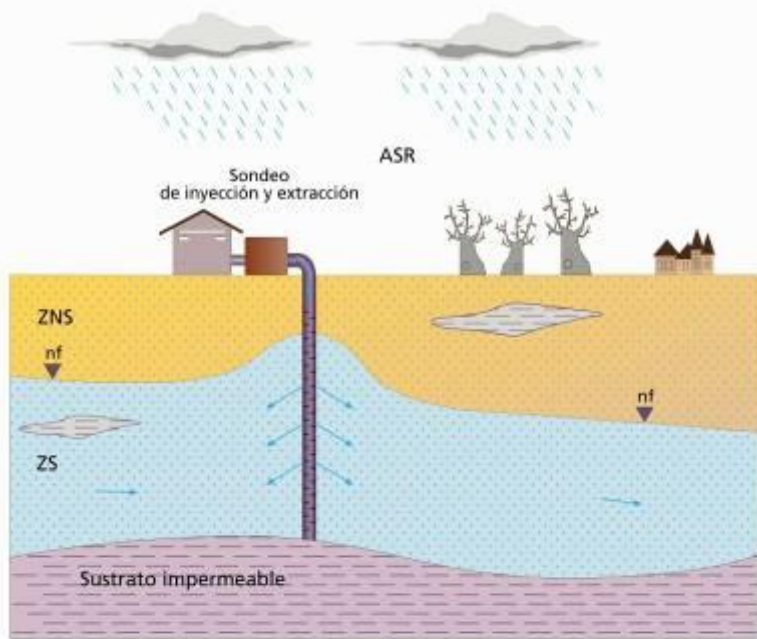


CORNELLÁ (BARCELONA)



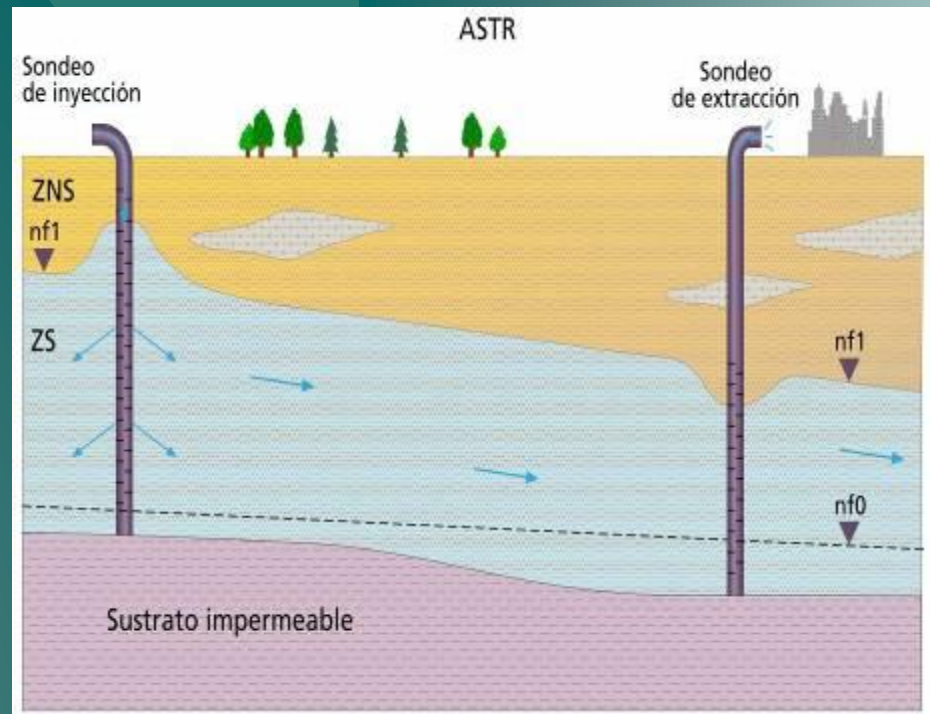
# ASR

## Aquifer Storage & Recovery



# ASTR

## Aquifer Storage Transfer and Recovery (with transport)





## ASR EXAMPLES

ARIZONA (USA)

ADELAIDE (AUSTRALIA)

MADRID, SPAIN



# 4. Filtration systems

DISPERSION

CANALS

WELLS

FILTRATION

● RBF

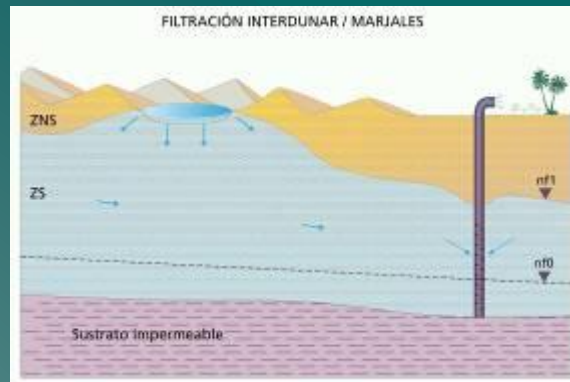
● INTERDUNES INFILTRATION

● UNDERGROUND IRRIGATION

RAINWATER

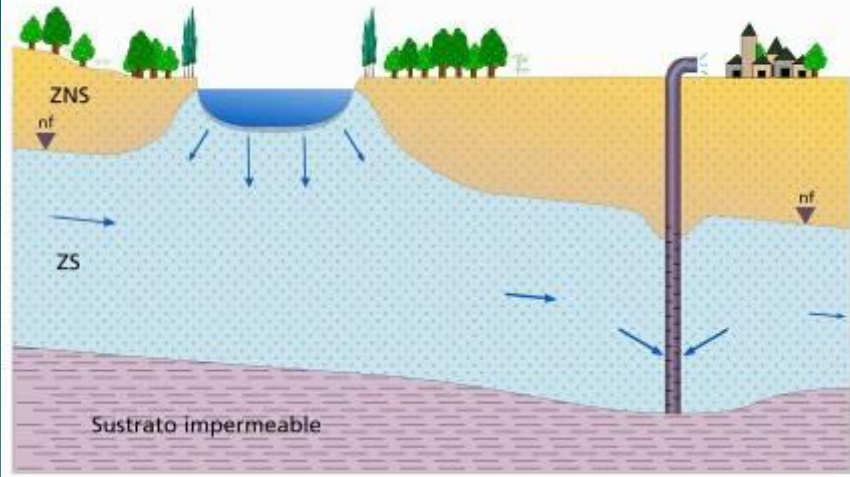
SUDS

Devices based on the increase of the soil infiltration rate



- ◆ Combat seawater intrusion
- ◆ Improve the water quality in coastal aquifers
- ◆ Creation of wetlands, deep wet areas and artificial water tables (phreatic level)

### BANCOS FILTRANTES EN LECHOS DE RÍOS (RBF)



## RBF schemes (River Bank Filtration)

### INDUCED INFILTRATION IN THE DANUBIO RIVER BANK (BUDAPEST)



### FILTRATION WELL DRILLED IN THE RIVER PATHWAY (ALLUVIAL). ERITREA





# INTERDUNE INFILTRATION SYSTEM

AMSTERDAM  
(THE NETHERLANDS)



# 5. Rainwater harvesting systems

- DISPERSION
- CANALS
- WELLS
- FILTRATION
- RAINWATER
- SUDS

AR Sistem +

- ◆ Erosion control method
- ◆ Floods control method
- ◆ Total Suspended Solids es reduced along the pathway to the network



## RAINWATER IN SEMIARID ZONES

15-30% PLANTS

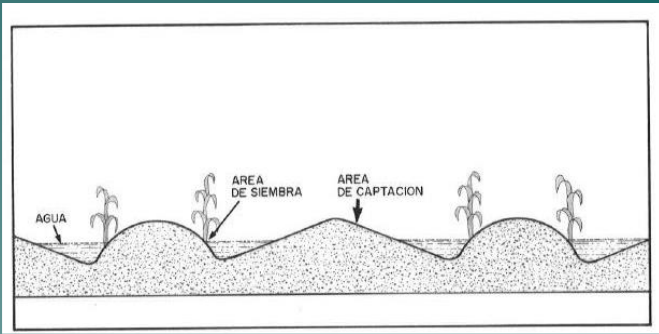
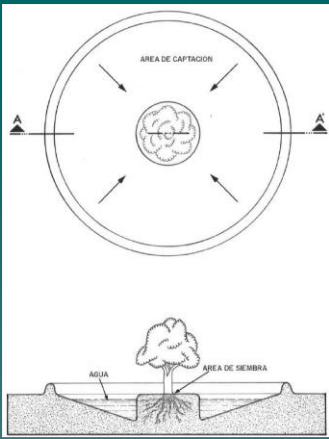
30-50% EVAPORATION

10-20% GROUNDWATER

10-25% RUNOFF

(Source: van Leeuwen & Beernaerts, 2002).

# RAINWATER HARVESTING FOR IRRIGATION



## ACTIVE BARRIERS



## PASSIVE OR DEAD BARRIERS





# 6. SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

DISPERSION

CANALS

WELLS...

FILTRATION

RAINWATER

SUDS

- ◆ Unintended recharge from conductions, piping, sewer leakage...
- ◆ SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)






## PERMEABLE PAVING AND SUDS CELLS (MADRID)

PARQUE GOMEZNARRO  
(MADRID)

## PERMEABLE PARKING (GIJÓN)

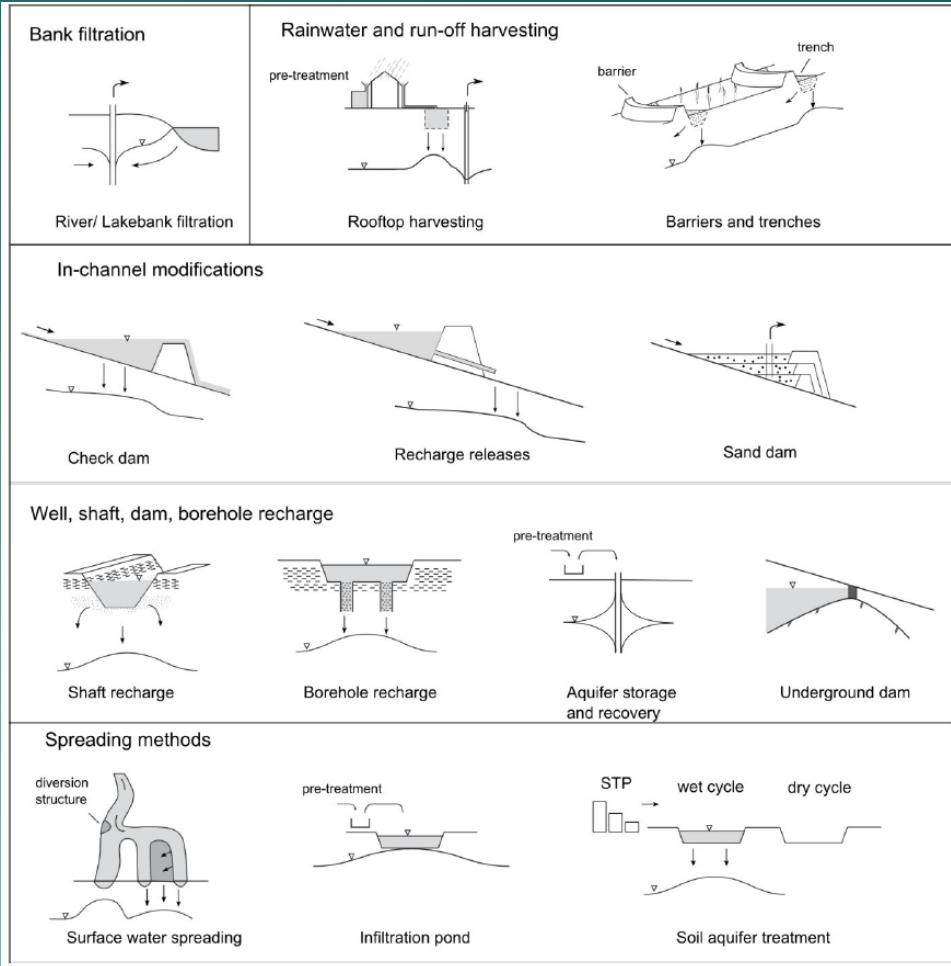


<https://dinamar.tragsa.es/pdf/GIAE%20English.pdf>

 **Grupo Tragsa**  
Garantía Profesional. Servicio Público



## GREEN ROOF EXAMPLES



n	SYSTEM	MAR DEVICE	LOGO	FIGURE	PHOTO	LEGEND
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2		CHANNELS AND INFILTRATION DITCHES				Artificial recharge channel of the Basin of Santillán, Segovia, Spain, operates since 2002. Photo: DINA MAR
3		RIDGE'S SOIL AND AQUIFER TREATMENT TECHNIQUES	SAT			Ridges in the bottom of a infiltration pond, California. Photo: D. Payton
4		INFILTRATION FIELDS (FLOOD AND CONTROLLED SPREADING)				Infiltration field in Omsiel (Rambouillet, France). Photo: G. Trebois
5		ACCIDENTAL RECHARGE BY IRRIGATION RETURN				Artificial recharge by irrigation return. Extremadura, Spain. Photo: Traga
6		BORDEALES WETLANDS				Bordesales (Colombia)
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9		LEVEES				Levees in Santa Ana river, Orange County, California, USA. Photo: A. Hatchison
10		IMPERVED SCARIFICATION				Scarification at Breda (Netherlands), Barcelona, Spain. Photo: J. Amador
11		SUB-SURFACE UNDERGROUND DAMS				Sub-surface dam in Khul, Kenya. Photo: Sander de Haan
12		DRILLED DAMS				Drilled dam. Luján, Granada, Spain. Photo: Traga
13	WELLS	GARATS (UNDERGROUND GALLERIES)				Dam at Carboneras de Mayar, Segovia, Spain. Photo: E.F. Escalante
14		OPEN INFILTRATION WELLS				Infiltration well, Arizona, USA. Photo: DINA MAR
15		DEEP WELLS AND BOREHOLES				Artificial recharge well, Cornellà, Barcelona, Spain. Photo: DINA MAR
16		BOREHOLES				Borehole (ASR) in Adelaida. Photo: P. Dillon
17		SINKHOLES, COLLAPSES...				Sinkhole called "El Hundierto", Alicante, Spain. Photo: DINA MAR
18		ASR	ASR			ASR device in Scottsdale, Arizona, USA. Photo: DINA MAR
19	ASTR	ASTR			ASTR device in California, USA	
20	FILTRATION	RIVER BANK FILTRATION (RBF)	RBF			RBF RBF system in Eritrea. Photo: A. Tachef
21		INTERDIGINE FILTRATION				Interdigine filtration near Amsterdam, Netherlands. Photo: Alho
22		UNDERGROUND IRRIGATION				Underground irrigation in Andalucía, Spain. Photo: Traga
23	RAIN	RAINWATER HARVESTING IN UNPRODUCTIVE				Rainwater harvesting in unproductive for RBF techniques.
24	SEWERS	ACCIDENTAL RECHARGE PIPES AND SEWER SYSTEM				Artificial recharge from sewer system in Spain. Photo: Traga
25		SUSTAINABLE URBAN DRAINAGE SYSTEMS				SUDS, Camazorra park, Madrid, Spain. Photo: E.F. Escalante



# ANNEX I: CONDITIONING FACTORS TO SELECT THE BEST MAR DEVICE: (IT IS DESIRABLE, PROS, CONS Y ENVIRONMENTAL ASPECTS)

N	SIST	SORT OF DEVICE	CONDITIONING FACTORS	
1		INFILTRATION PONDS/ WETLANDS	IT IS DESIRABLE	High permeability receiving medium Lithology detrital, alluvial or karstic Suitable in irrigation areas with groundwater Slopes under 10 % or terraces Groundwater table close to the surface (max. 50 m depth) Suitable for areas with treatment by lagooning Sources of availability of water in less than 10 km
			PROS	Only for unconfined aquifers
			CONS	Surface land occupation Need fenced perimeter Stable slopes depending on each lithology Need for cleaning and maintenance in dry Need access to medium-heavy machinery Flooding in alluvial by overflows problems In the case of very uneven quality of water, induction techniques should be used
			ENVIRONMENTAL ASPECTS	Possibility to use for water supply (forest fires...) Possibility settlement of avifauna Water regeneration ability of degraded wetlands



# Conclusions

- ◆ There is a large number of artificial recharge devices adaptable to very different environments and situations
- ◆ MAR has become a first row water management technology used worldwide
- ◆ We must be ready for climate change combat

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**Monitored and Intentional Recharge (MIR): A Model for Managed Aquifer Recharge (MAR) Guideline and Regulation Formulation**

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