Managed Aquifer Recharge (MAR)

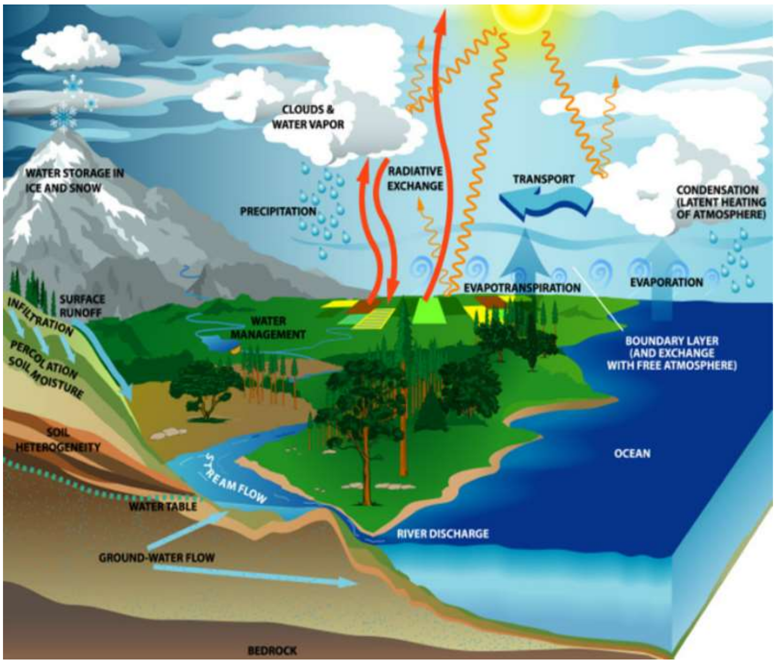
Groundwater

Managed Aquifer Recharge (MAR)

United Nations Educational, Scientific and Cultural Organization

i-WSSM International Centre for Water Security and Sustainable Management

Groundwater in the cycle of water



Modern groundwater
(<50yrs old)

nature geoscience ARTICLES
PUBLISHED ONLINE: 16 NOVEMBER 2015 | DOI: 10.1038/NGEO2590

The global volume and distribution of modern groundwater

Tom Gleeson[1,2*], Kevin M. Befus[3], Scott Jasechko[4], Elco Luijendijk[2,5] and M. Bayani Cardenas[3]

- The total GW volume in the upper 2 km of continental curst is approx. 22.6 M km^3
- Modern GW (younger than 50 yrs old) volume is 0.35 M km^3 (1.6%)
- Volume of Modern GW is much larger than those of surface water, soil water, water in atmosphere and vegetation.

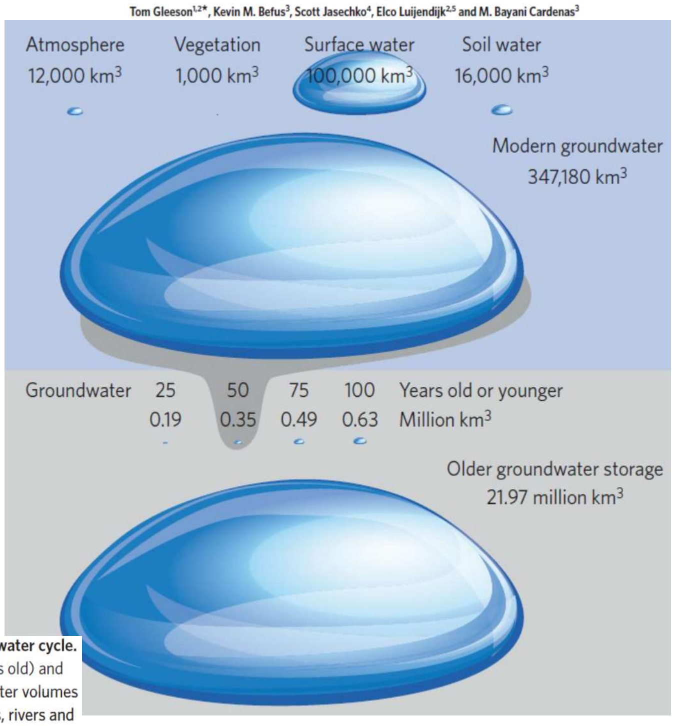
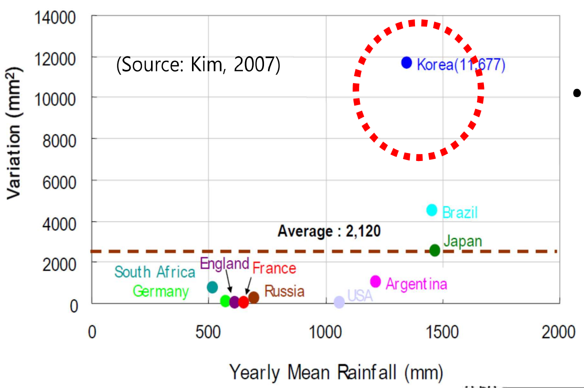


Figure 5 | The different volumes of water stored in the global water cycle. Global volumes of young (<100 years old), modern (<50 years old) and total groundwater to 2 km depth compared with other fresh water volumes stored in the atmosphere[33], in surface waters (that is, wetlands, rivers and lakes)[33], within plants or in soils[33].

3

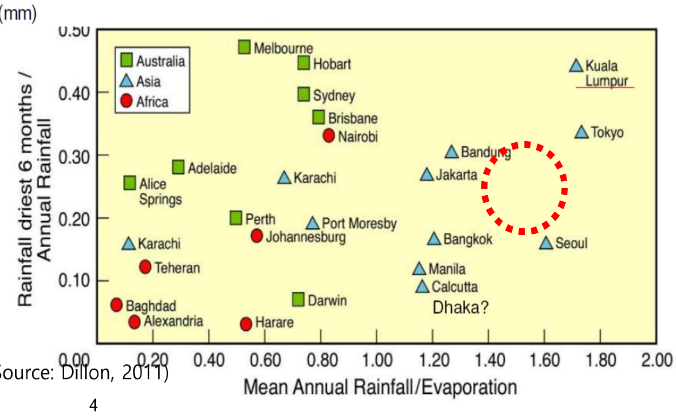
3

Opportunity of MAR in Korea



- High variation in annual mean rainfall compared to other countries

- Necessity of seasonal storage due to high seasonal variation in PPT

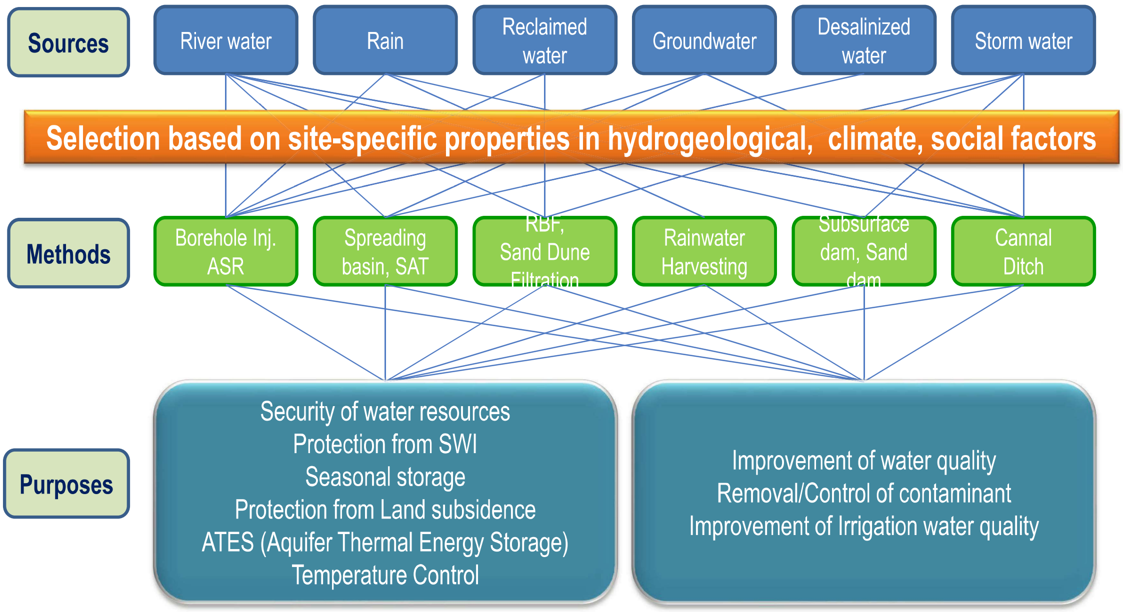


(Source: Dillon, 2011)

4

Various MAR schemes

Combinations of different types of sources, methods, and purposes



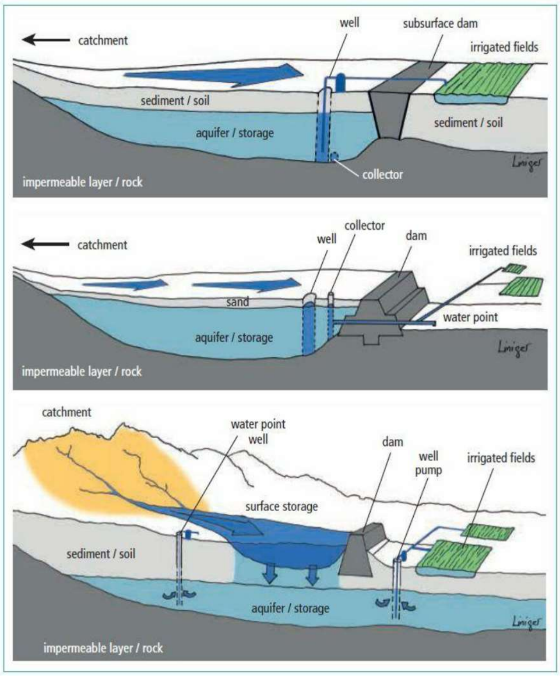
MAR Activities in KOREA

- Underground Dam for Agri., Domestic or Drinking Water
- River Bank Filtration for Drinking Water
- ASTR-type MAR in Volcanic Island Aquifer
- Rainwater Harvesting from Greenhouse Roof
- MAR for sustainability in Shallow Geothermal Greenhouse Field

6

Groundwater dams (Retention weirs)

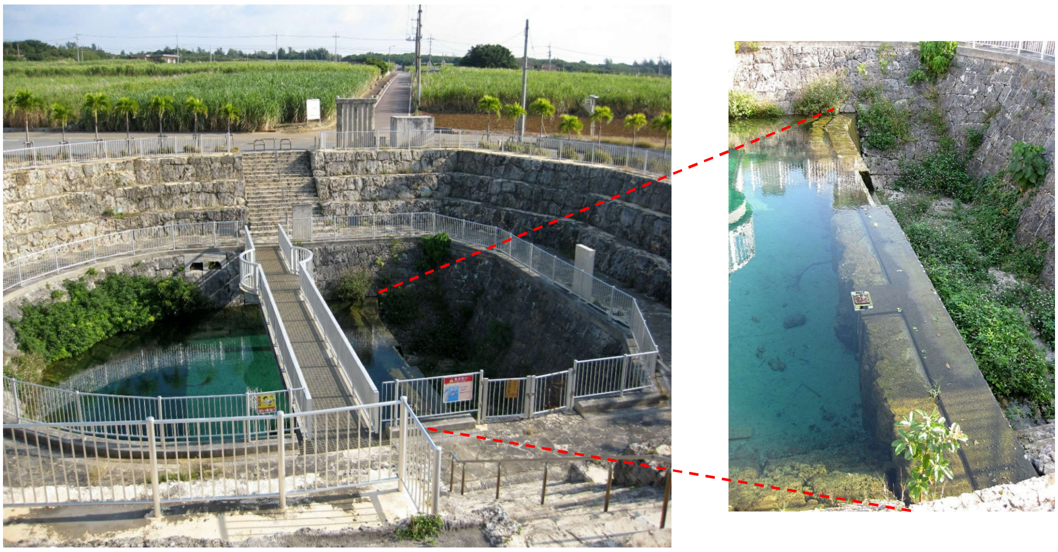
- Subsurface (underground) dam
  - built entirely underground into sandy riverbeds of seasonal water cours
- Sand dam
  - larger than subsurface dams and weirs as they can be raised to several
- Percolation dam
  - do not block ground water flow as the previous systems.
  - They serve three purposes: (a) to reduce the speed of surface flow, (b) i nents.



Source: https://www.geo.fu-berlin.de
Image credit: Mekdaschi & Liniger (2013)

Fukuzato underground dam, Japan

underground dam constructed in Miyakojima, Okinawa Prefecture



Source: Wikipedia.org

1. Agricultural use at Inland Area (KRC)

Location	Purposes	Watershed area(km^2)	Capacity (m^3/d)	Cut-off wall length (m)	Administration	Year
I-an (Sangju, KB)	Agricultural	21.3	24,000	230	KRC	1983
Namsong(Yungil, KB)	Agricultural	153.0	27,000	89	KRC	1986
Okseong (Kongju, CN)	Agricultural	275.0	27,900	482	KRC	1986
Gocheon (Jeongeup, JB)	Agricultural	27.0	25,110	192	KRC	1986
U-il (Jeongeup, JB)	Agricultural	22.0	16,200	778	KRC	1986
Ssangcheon (Sokcho, GW)	Domestic	65.3	43,000	800	KRC	2000

- Provinces (KB: Kyungbuk; CN: Chungnam; JB: Jeonbuk; GW: Gangwon)
- KRC: Korea Rural Community Corporation

9

1. Agricultural use at Inland Area (KRC)

Item \ Name	I-an	Namsong	Okseong	Gocheon	U-il	Ssangcheon
Location	Gyeongbuk Sangju	Gyeongbuk Pohang	Chungnam Gongju	Chonbuk Chongup	Chonbuk Chongup	Gangwon Sokcho
Storage type	Subsurface	Subsurface	Subsurface	Subsurface	Subsurface	Subsurface
Water usage	Agricultural	Agricultural	Agricultural	Agricultural	Agricultural	Drinking
Purpose	Increase storage	Combination	Increase storage	Increase storage	Increase storage	Combination
Wall type	Retention	Overflow	Overflow	Overflow	Overflow	Overflow
Technique for constructing wall	SGR + Concrete Replacement	JSP	Injection (Microcement)	Ferroconcrete Replacement	Clay Replacement	CBSW + Concrete Replacement
Wall length(m)	230(194+36)	89	482	192	778	840(800+40)
Wall depth(m)	5	18.8	9.16	7.5	6.7	
Well type (number)	R.C.W. (4)	R.C.W. (4)	R.C.W. (4)	R.C.W. (5)	R.C.W. (4)	R.C.W. (4)
W.A.(ha)	2,130	15,300	27,500	2,700	2,200	6,533
Ave. alluvial layer thick(m)	4.5~7	10~15	10 ±	6~7	6.5	16
Coefficient of transmissibility (m^2/D)	268~403	300	113~183		133	
T.S.C.(m^3)	4,143,000	4,017,000	2,850,000	1,534,000	2,457,000	
T.S.C./W.A. (m^3/ha)	1,945	262	103	568	1,116	
Abstraction rate (m^3/D)	24,000	27,000	27,900	25,110	16,200	27,000
Geology	Granitic gneiss (Age unknown)	Uncemented Sedimentary rocks (Tertiary)	Banded gneiss	Schistose granite (Mesozoic)	Gneissose granite (Mesozoic)	Banded gneiss (Precambrian)
Aquifer	Sand & Gravel	Sand & Gravel	Sand & Gravel	Sand & Gravel	Sand & Gravel	Sand & Gravel
Completion	1983	1986	1986	1986	1986	2000

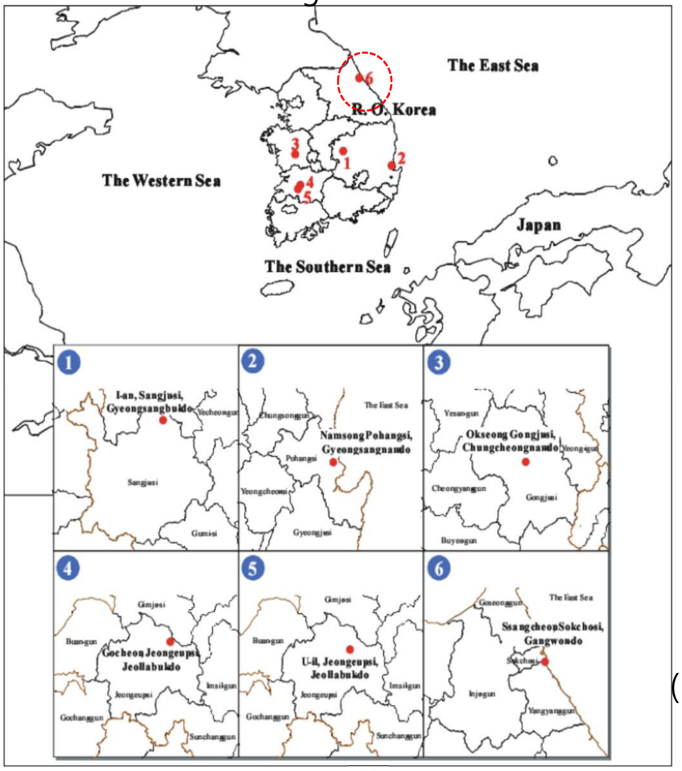
* W.A. ; Watershed Area, Ave. ; Average, R.C.W. ; Radial collector well, T.S.C. ; Total storage capacity
SGR ; Space grouting rocket system, J.S.P ; Jumbo special pattern system,
CBSW ; Cement bentonite slurry wall

(Source: KRC, 2006)

10

1. Agricultural use at Inland Area (KRC)

Location of Underground Dams in Korea



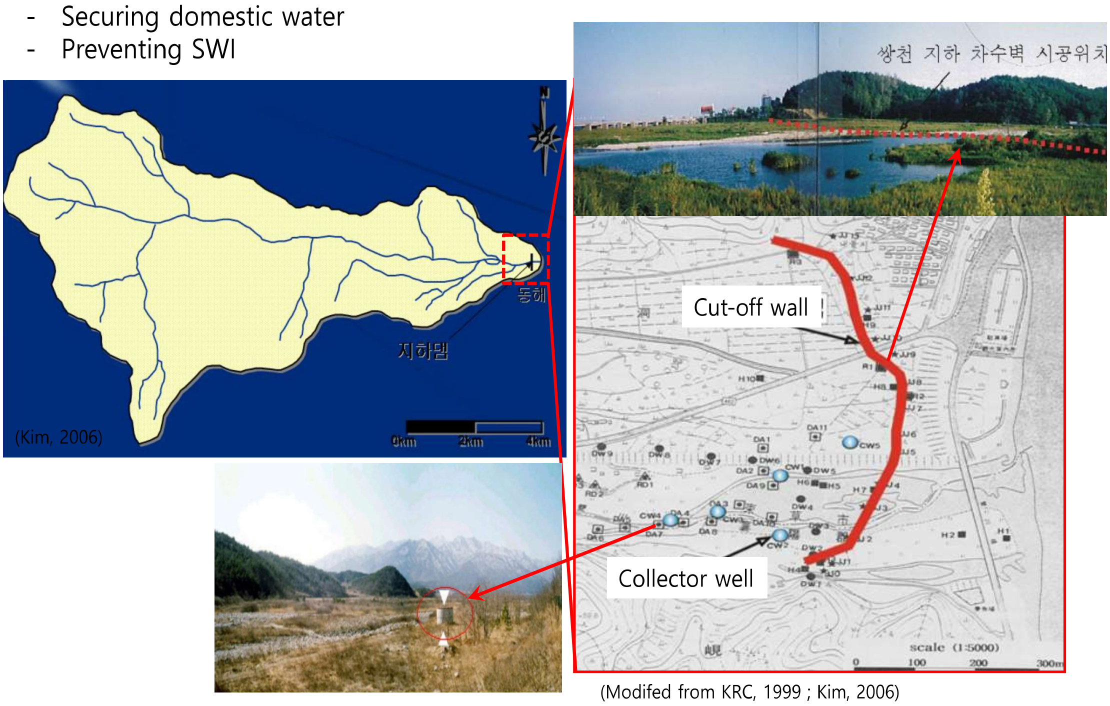
(MIST,2004)

11

1. Agricultural use at Inland Area (KRC)

Ssangcheon Underground Dam

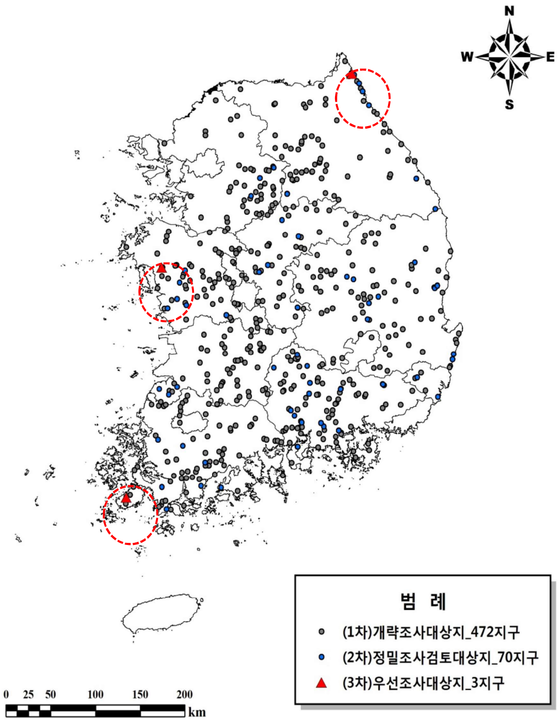
- Securing domestic water
- Preventing SWI



(Modifed from KRC, 1999 ; Kim, 2006)

12

1. Agricultural use at Inland Area (KRC)



Recent plan for underground dam

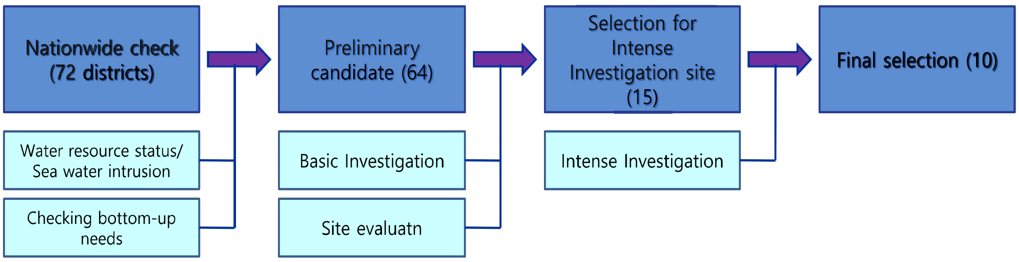
- Preliminary candidates
  - 472 sites (Grey circle)
- Intense candidates
  - 70 sites (blue circle)
  - Selection based on field examination
- Priority sites for comprehensive investigation
  - 3 sites (red triagle)
    - Hongseong, ChoongNam PV
    - Goseong, Gangwon PV
    - Jindo, Jeonnam PV
  - Selection criteria
    - *High drought frequency*
    - *Low supply/demand ratio*
    - *No alternative methods such as surface water supply system*
    - And others

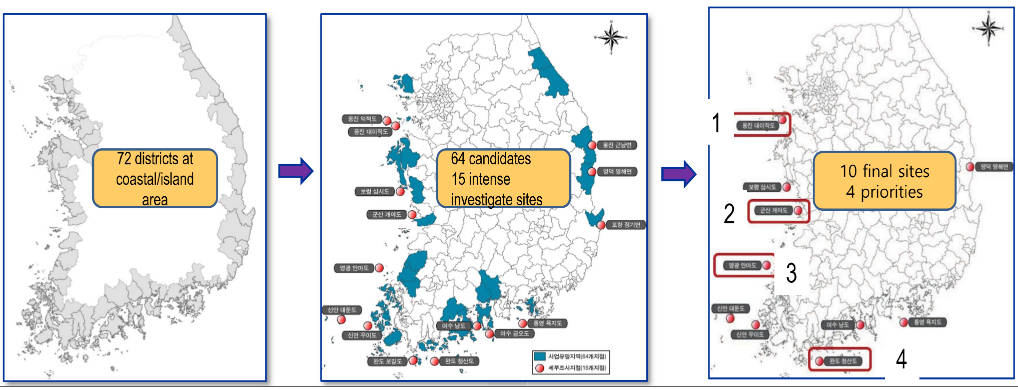
(Source(personal contact)
Seong-Ho Song,2018)

13

2. Domestic use at Island/Coastal Area (K-water)

- Basic investigation (Jul. 2011- Dec. 2012) : final10 sites
- Feasibility investigation (May-Dec. 2013) : 4 priority sites
- Basic and construction design (may-Dec. 2014) :2 sites (Anma island, Daeijak island)

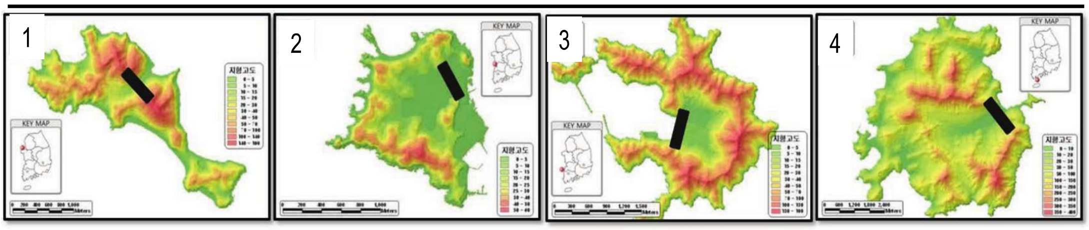


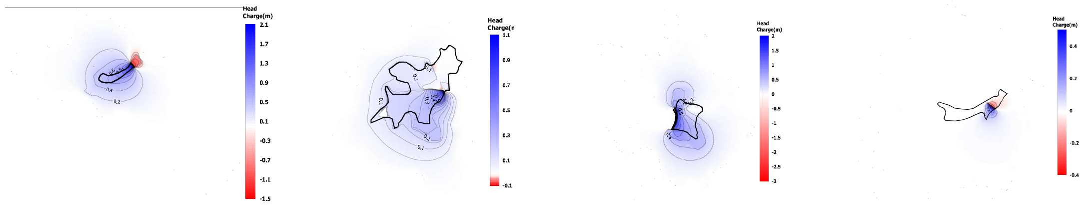


2. Domestic use at Island/Coastal Area (K-water)

- 4 Priority sites (Group A)

Location	Demands by 2025 (m^3/d)	Watershed area (km^2)	Supply/ Capacity (m^3/d)	Cut-off method	wall length/ depth (m)	No. of Intake Wells
1. Daeijak-do	**-109**	**0.35**	**110 / 180**	**Open cut**	**80 / 11.3**	**3**
2. Gaeya-do	-129		130	Inj. Well (3-line)	271 / 23	5
3. Anma-do	**-93**	**1.17**	**100**	**Inj. Well (3-line)**	**480 / 31**	**6**
4. Cheongsan-do	-323		330	Inj. Well (3-line)	400 / 25	10





15

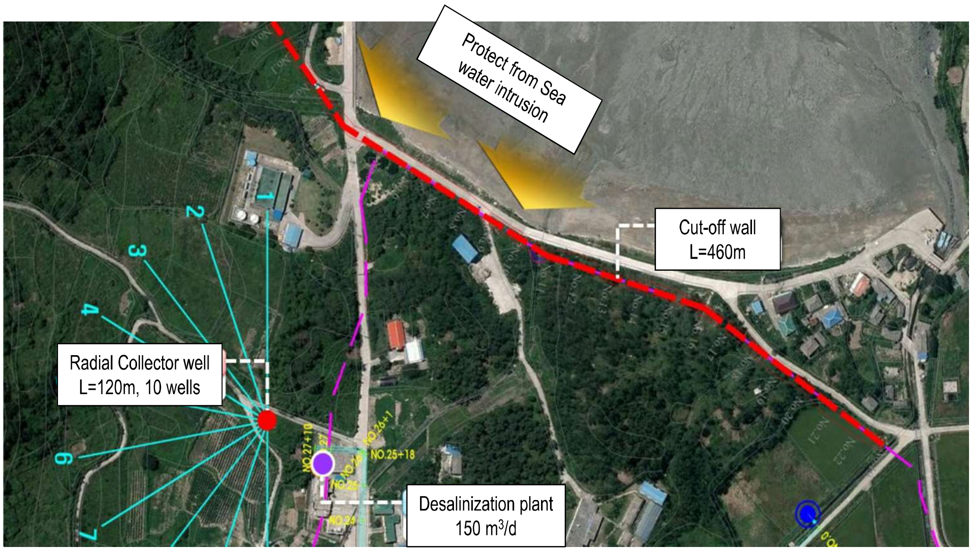
2. Domestic use at Island/Coastal Area (K-water)

1. Daeijak-do

16

2. Domestic use at Island/Coastal Area (K-water)

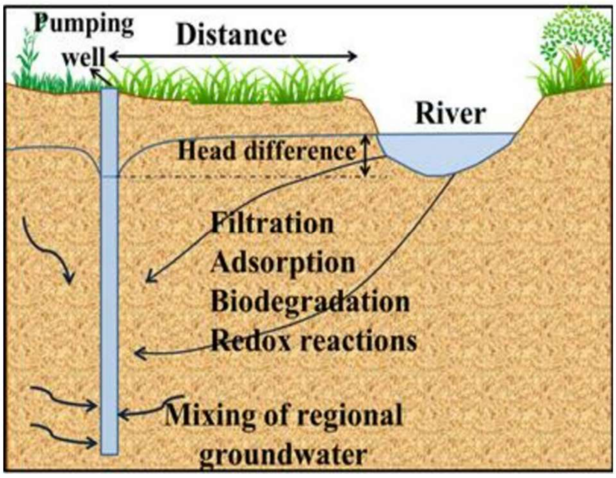
3. Anma-do



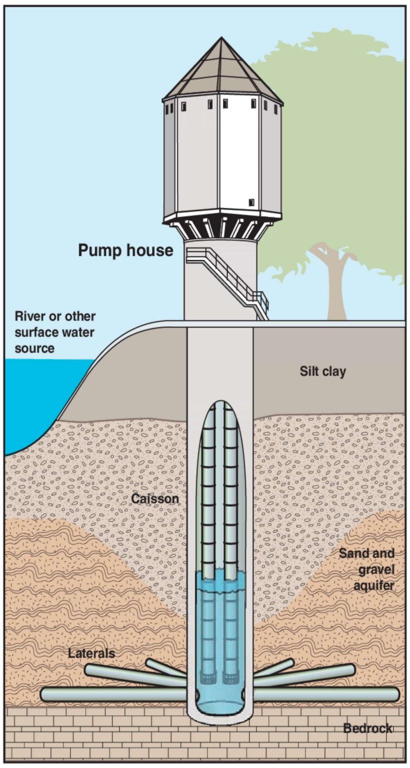
17

River bank filtration

A technology that operates
by pumping out water from boreholes
drilled along the banks of a river or lake



Mauro & Utari, 2011 (Water Practice and Technology (2011) 6 (4): wpt20110073.)



Schematic courtesy of Reynolds Inc., Orleans, Ind.

PARTINOUDI, VASILIKI & Collins, Michael. (2007)

River bank filtration in Korea

- 18 sites (as of 2016)
  - Radial : vertical : others = 12 (67%) : 4 (22%) : 2
- Total facility capacity: 1,106,210 m^3/d
  - Radial : vertical : others = 926 (84%) : 110 (10%) : 70
- Pumping capacity per well (m^3/d)
  - Radial (16,500), vertical (1,400)
- Purposes
  - Water works(7), agriculture(5), stream discharge(3), others (2)
- Watershed
  - Han-river (5 sites, 188,000m^3/d)
  - Nakdong-river (6 sites, 709,000 m^3/d)

19

River bank filtration in Korea

- First RBF : domestic water supply for a military base from Han-river bank at Seoul in 1970's
  - 20 Vertical wells / 10,000 m^3/d
- Largest facility:
  - 351,000 (Changneung-Jeungsan phase 1)
- Most active MAR method in Korea

Source: https://cnews.co.kr/uhtml/read.jsp?idxno=201112271107425210440&section=S1N10

20

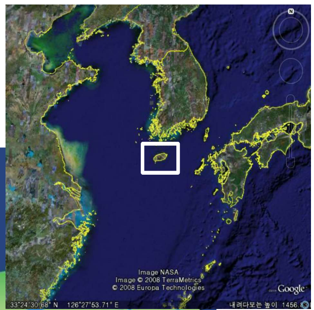
Till 1960, Jeju was ...

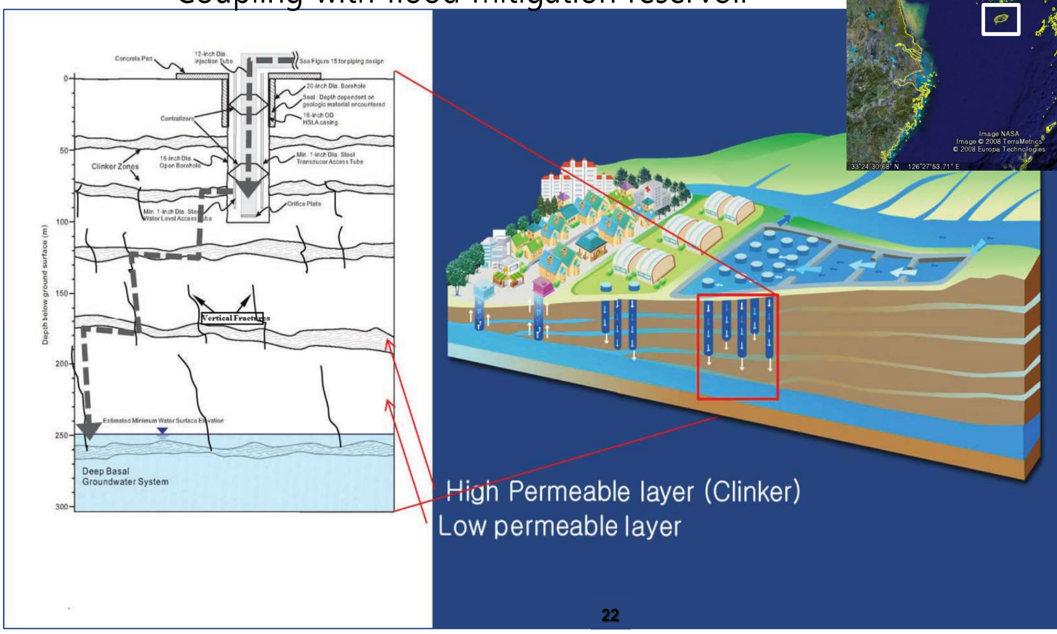
- Spring and rainwater dependent island
- Water delivering jar, "Mulheobuk"

- Now, water supply from GW is 100%
- But, demand gradually increases due to migration and tourism
- therefore, securing more water resources for the future is needed

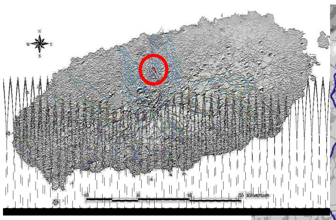
MAR by vadose zone injection with storm water

- Site specific method for Jeju island
  - Highly permeable layers in unsaturated zone
  - Large unsaturated zone thickness
  - Coupling with flood mitigation reservoir

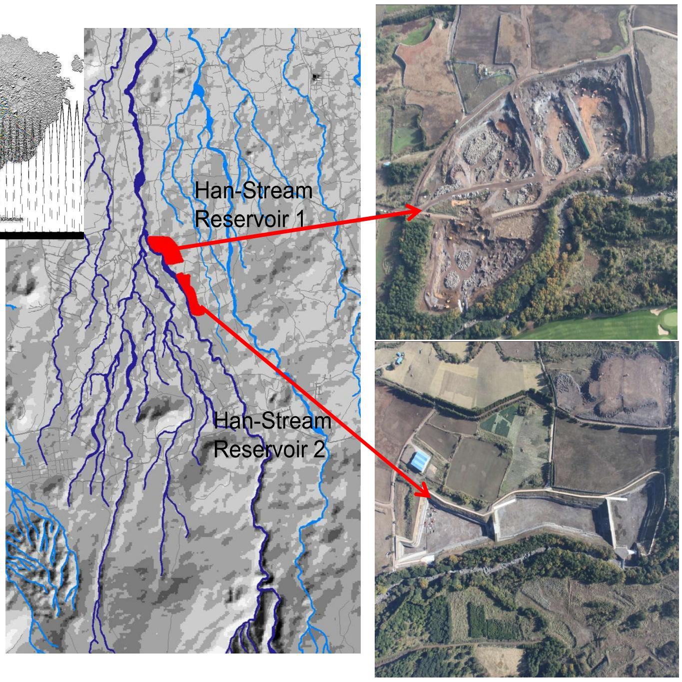




MAR coupled with flood mitigation reservoir

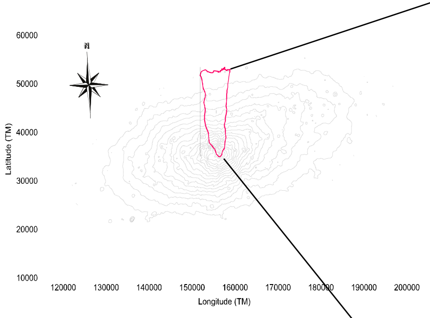


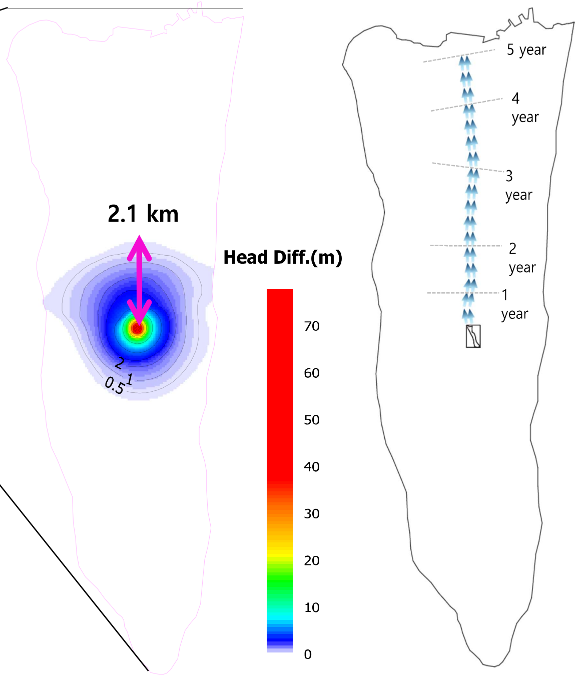
◆pilot site
- Reservoirs : ~ 900,000 m^3
- Injection wells : 20
  (Ø450mm, depth : 40-50m)
- Recharge capacity per well
  : 3,000 m^3/hr
- Recharge plan
  : > 3.0 M m^3/yr



23

ASTR-type MAR with long residence time





- MODPATH Package
- GW velocity : 1,538m/yr
- ROI: 2.1 km
- Residence time in aquifer: more than 5 years

24

MAR for GW security and flood control

- In 2010, total 2,500,000 m^3 of water had been injected through bottom infiltration.
- Through reservoir bottom infiltration, the flood mitigation reservoir can be increased its capacity up to 300,000 m^3/day (33% of reservoir capacity increase) without further construction.

25

Rainwater harvesting in Jeju Island

- Since 2004
- Facilities: 176
- Recharge amount : 1,276,000 m^3 in 2011

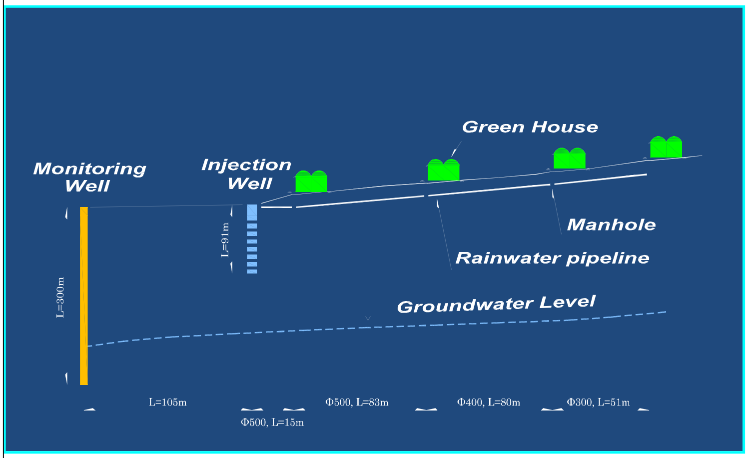
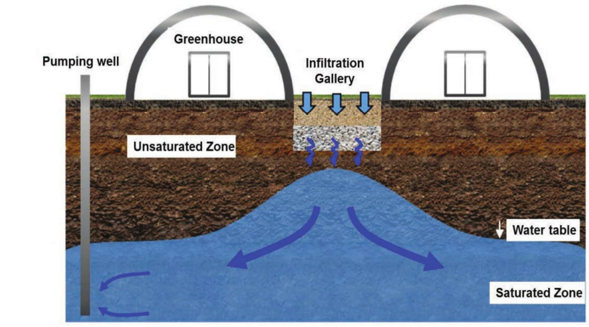
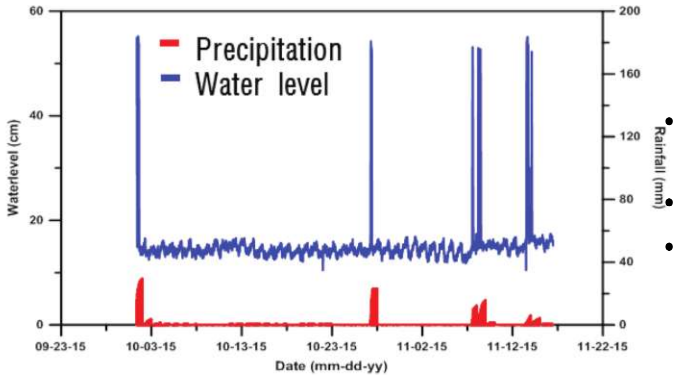


Photo by Kiwon Koh

26

Rainwater harvesting at a separated greenhouses





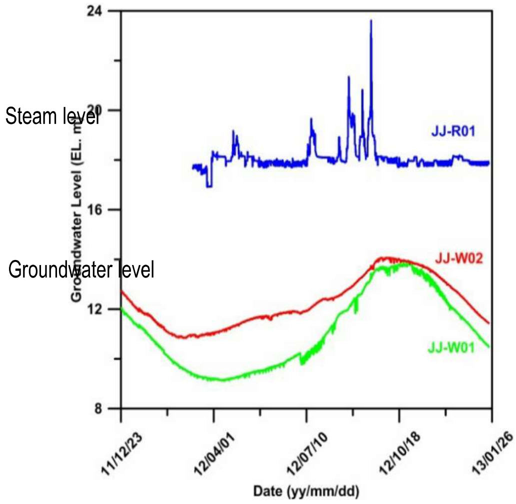
- Recharge through infiltration gallery btw greenhouses
- Pilot research
- Recharge amount : 28% of rainfall

27

MAR for Sustainability in greenhouse complex

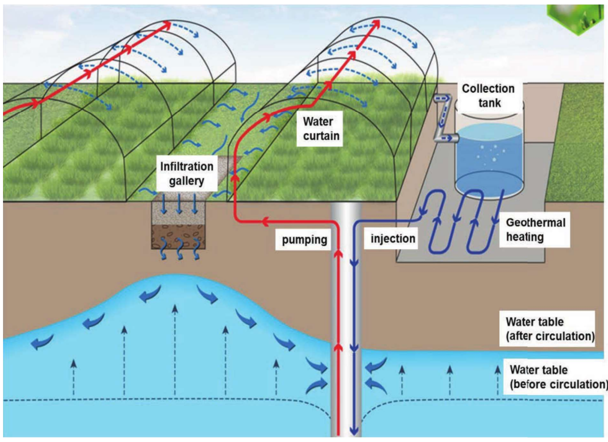
- Water curtain insulated greenhouse complex

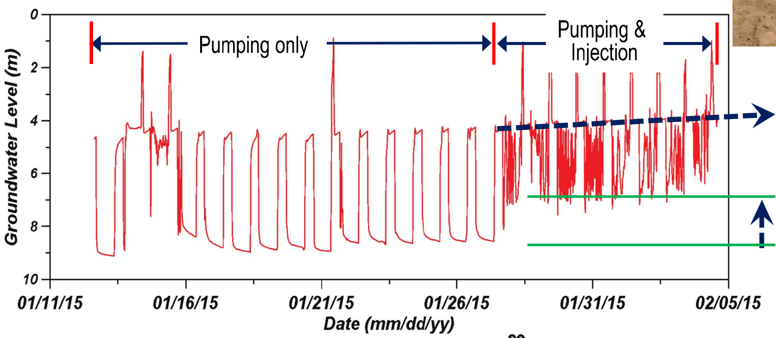
- Losing stream by groundwater level decline



28

MAR for Sustainability in greenhouse complex





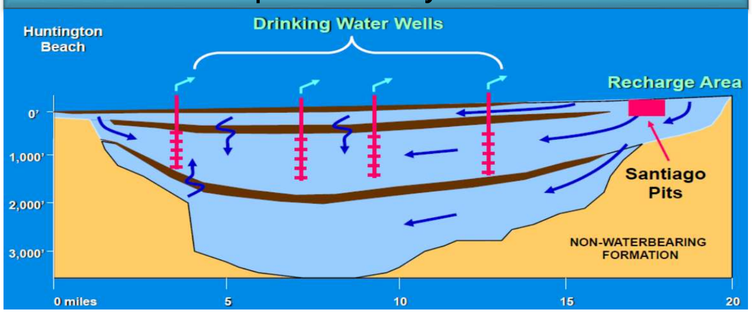
Rising water level
: 4.2 -> 3.6 m BGL

Increase in min. level
: 8.5 -> 6.3 m BGL

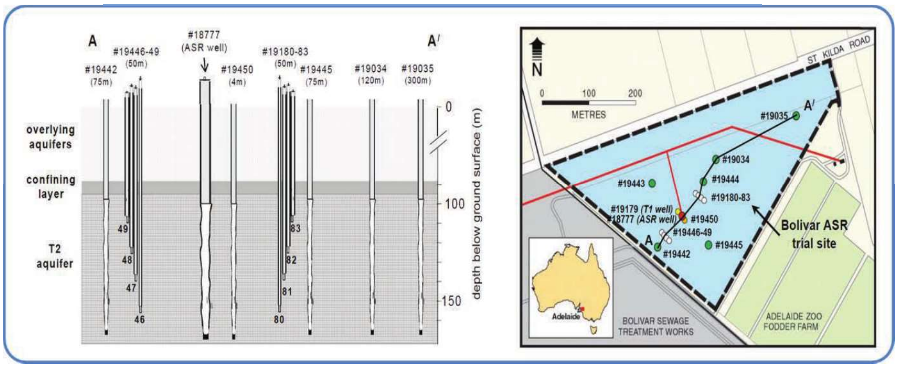
29

MAR using reclaimed water

Groundwater Replenishment System, California, USA

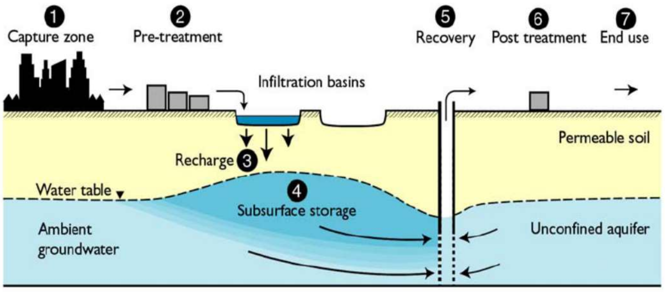


Bolivar ASR systems, Australia



MAR using reclaimed water

Unconfined aquifer (SAT; soil aquifer treatment)

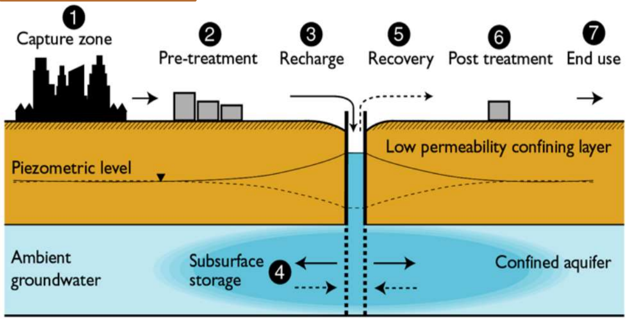


As the effluent moves through the soil and the aquifer, it can undergo significant qual ity improvements through physical, chemi cal and biological processes - Attenuati on

The water is stored in the underlying unco nfined aquifer generally for subsequent re use, such as irrigation. This is a valuable water resources management method in a reas with high evaporation rates.

Confined aquifer

In confined conditions, artificial recharge has in general to be achieved using infiltration wells a s the potentiometric groundwater surface is ab ove the confining layer



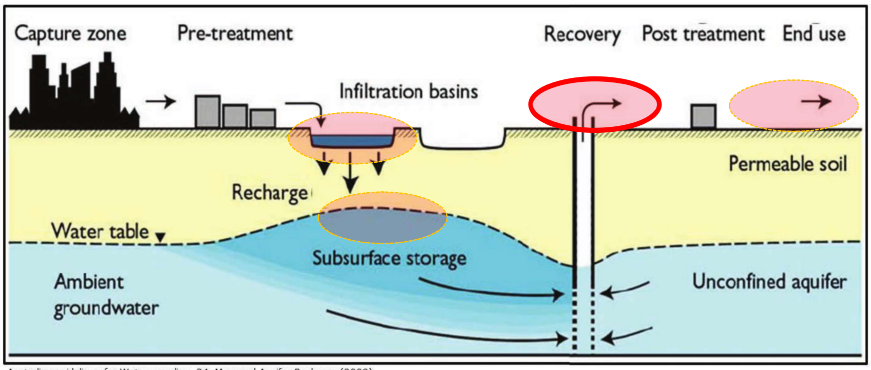
Australian guidelines for Water recycling, 24: Managed Aquifer Recharge (2009)

SAT

- If Point of Compliance is at the extraction point

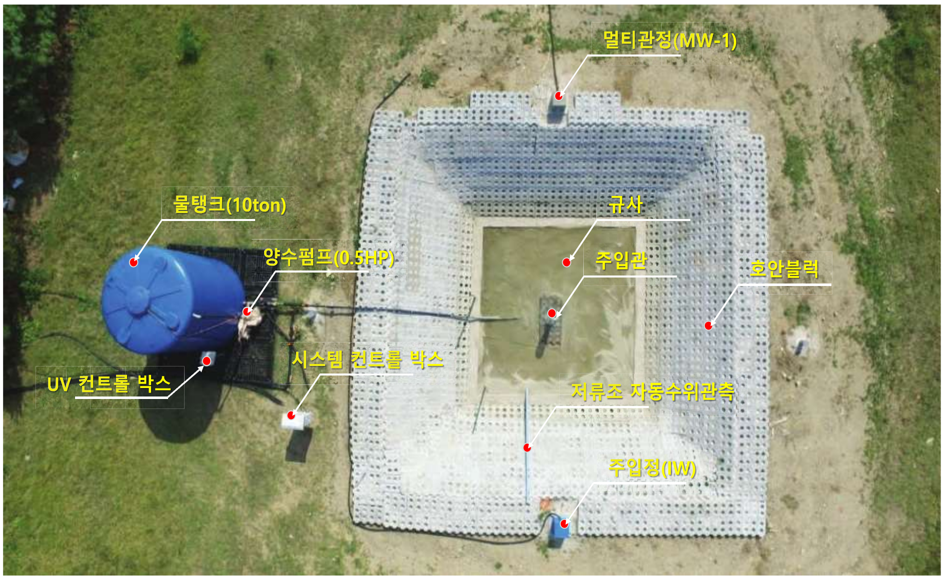
Pessimistic **Neglecting the main advantage of MAR = degradation processes in subsurface**
‚worst case scenario': infiltrated water conc = extracted water conc < legal limit for use

Optimistic **Defined minimum degradation in the subsurface to meet regulations at recovery**
‚maximum faith scenario': infiltrated water conc > extracted water conc < legal limit for use

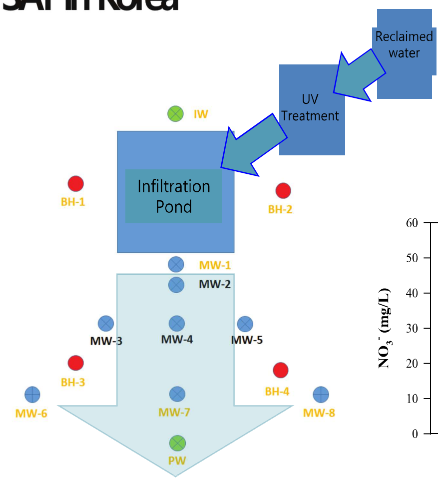


Australian guidelines for Water recycling, 24: Managed Aquifer Recharge (2009)

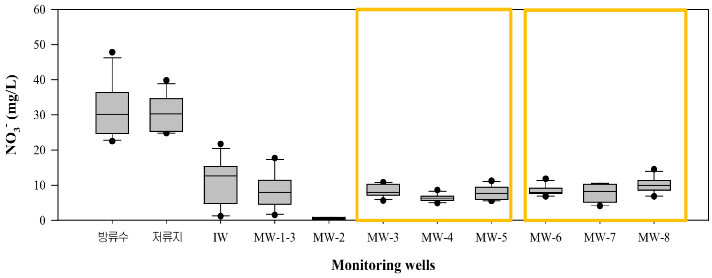
SAT in Korea

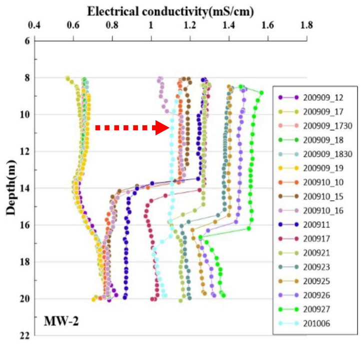


SAT in Korea

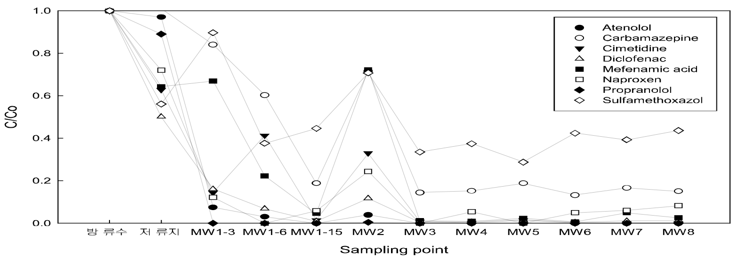


Nitrate reduction





Emerging contaminants



A potential MAR scheme for arid/semi-arid area

Site-Specific MAR methods based on their hydro-geo-meteorological properties

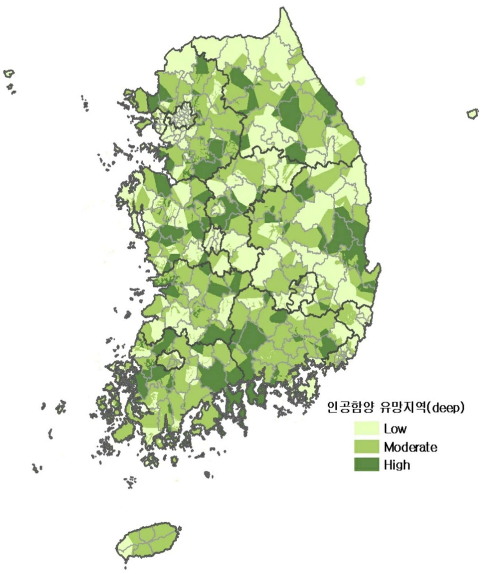
- Aquifer recharge of surplus desalinized water with renewable solar energy
- Challenge but chance for get sustainable Energy-Water Nexus

- Liwa ASR system, Abu Dhabi
  - Store the surplus desalinized water in oasis aquifer and
  - Supply in times of emergency
  - Pipe line = 130km
  - First phase (to be completed by 2012)
    7 million imperial gallons a day – injection rate
    40 million imperial gallons a day – recovery rate
  - Second phase
    10 million imperial gallons a day- injection rate
    100 million imperial gallons a day- recovery rate

(Liwa ASR system, Abu Dhabi)

Potential of MAR under changing climate

Potential map of MAR in Korea



(Seo et al., 2011)

- Various MAR schemes has been known as promising climate-adapting methods to secure additional water resources.
- Korea has experiences on various MAR methods to augment groundwater resources such as underground dam, RBF, rainwater harvesting and ASTR/ARR-MAR.
- MAR is one of the important key words in water security issues all over the world, especially in arid/semi-arid area and even in wet area with high seasonal variation.

36


Thank you very much