International Groundwater Resources Assessment Centre

Managed Aquifer Recharge (MAR)

Ebel Smidt, Neno Kukurić and Albert Tuinhof

Amman, December 2012

MAIN MESSAGES

1. Buffering is an ancient answer to crises.
2. Groundwater is a natural buffer, use it wisely.
3. Period of last 60 years of international MAR-experiences offers opportunities for future cooperation in practical and research projects.

Story line

1. Groundwater and buffering – a global and local picture.

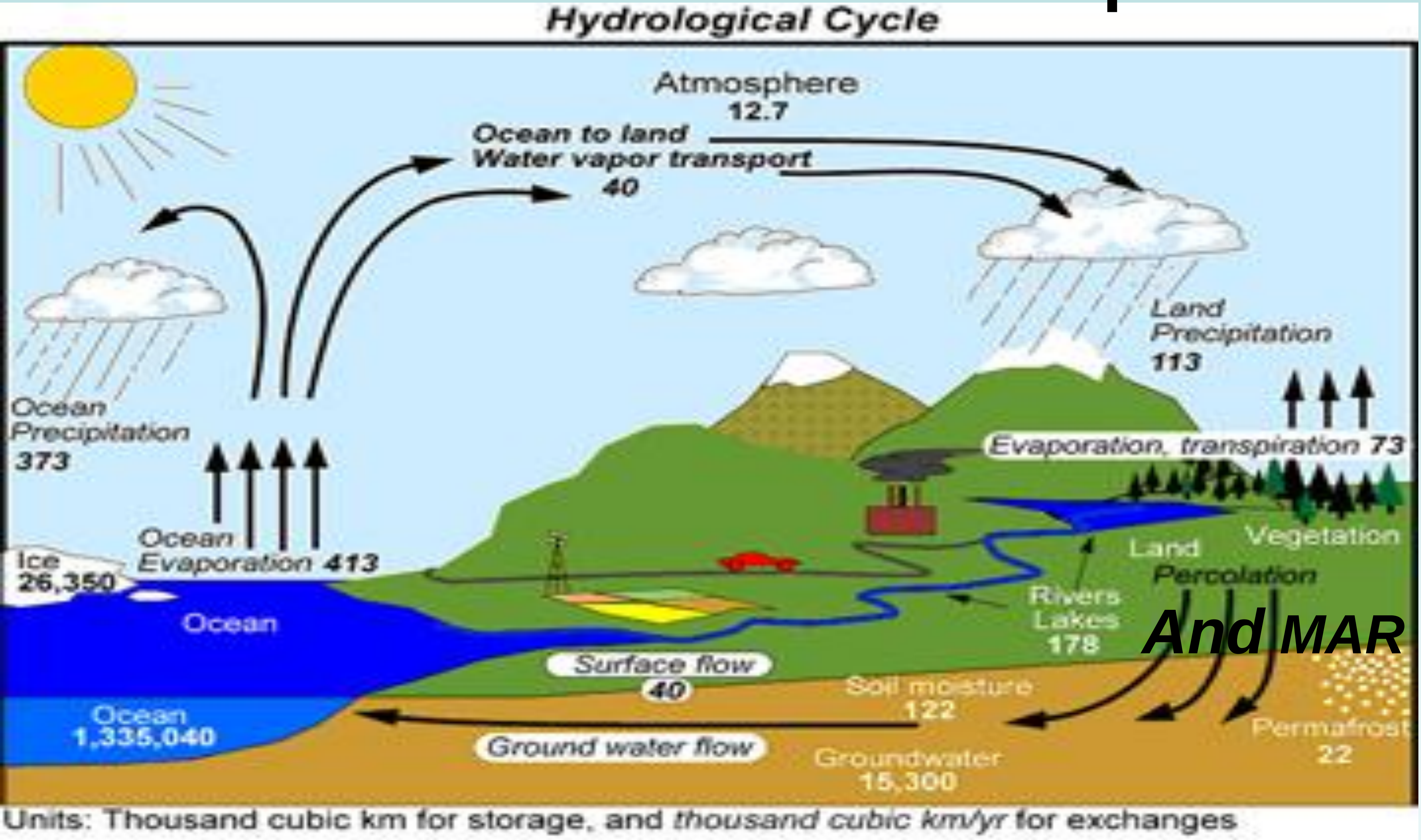
2. Techniques of MAR

3. A look at the economics of MAR

4. A picture on the future

5. Governance aspects - the role of IGRAC

Groundwater from Global Perspective



Fresh groundwater storage and flow

After data compiled by J.Margat (2008) from various sources (mainly Russian authors)
See www.igrac.nl

Total groundwater stock = 23.4 million km3 (=fresh+brackish+saline)

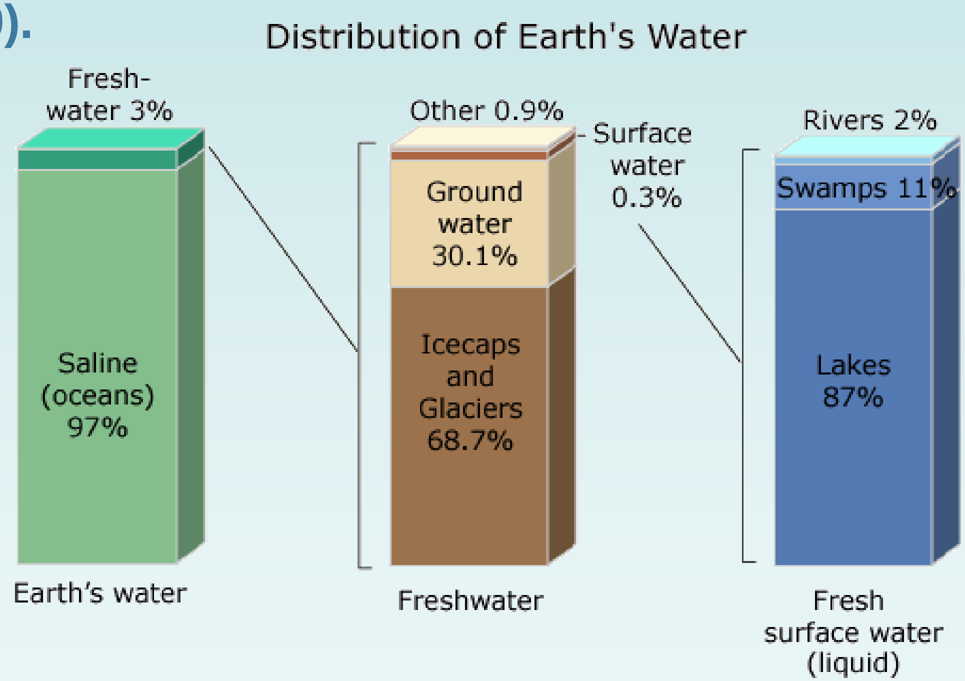
	Total fresh groundwater stock		**Total fresh groundwater flux**		**Mean residence time**
	in million km3	in m of water depth	in km3/a	in mm/a	in years
North & Central America	1.9	78	2160	104	880
South America	1.2	67	4120	231	291
Africa	2.5	83	1600	52	1563
Europe	0.5	48	1120	115	446
Asia	3.4	78	3750	84	907
Australia & Oceania	0.3	34	757	88	396
TOTAL WORLD	**9.8**	**72**	**13325**	**101**	**735**

Approximately 98% of all liquid fresh water stored on earth

Approximately 30% of total terrestrial flux of fresh water

Groundwater from Global Perspective

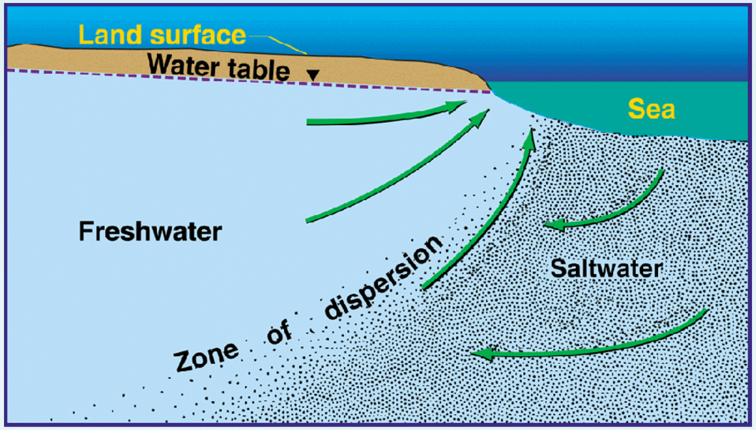
- Groundwater makes up more than **95%** of the unfrozen freshwater reserves on our planet.
- Current GW abstraction is estimated to be ca **1,000 km^3** per year, of which about **67%** is used for irrigation, **22%** for domestic purposes and **11%** for industry (IGRAC, 2010).
- Current GW abstraction represents approximately **26%** of total freshwater withdrawal globally (WWDR, 2012).
- Groundwater supplies almost **half of all drinking water** in the world (WWDR, 2009) and **43%** of the global consumptive use in irrigation (Siebert et al., 2010).



Groundwater from Global Perspective

- Groundwater is often a possible solution for the people **without access** to safe drinking water (1 in 6 worldwide).

- Strong **regeneration and buffering** characteristics of groundwater systems are of great importance in sustaining groundwater fed **wetlands** and **vegetation** and it is a baseflow to **rivers**.



Groundwater also provides strength to **soil matrix** and prevents **sea water intrusion**.

Groundwater in the Changing World

Global change, population growth and climate variability are increasing the pressure on groundwater resources.

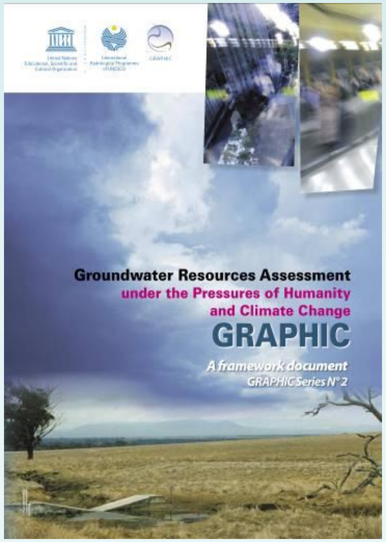
Potential climate risks for groundwater include:

- reduced groundwater recharge,
- sea water intrusion to coastal aquifers,
- contraction of freshwater lenses on small islands,
- increased demand.

However, every risk has its challenge

Groundwater can also be affected by non-climatic drivers, such as:

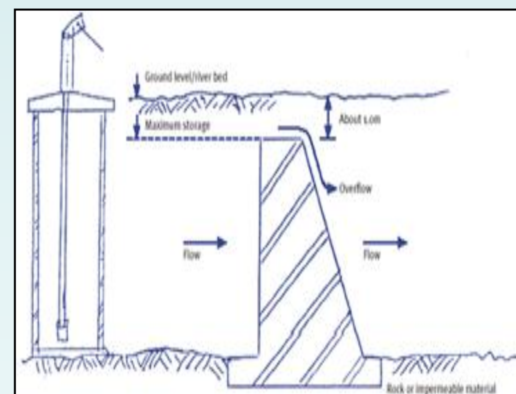
- population growth,
- food demand
- land use change.



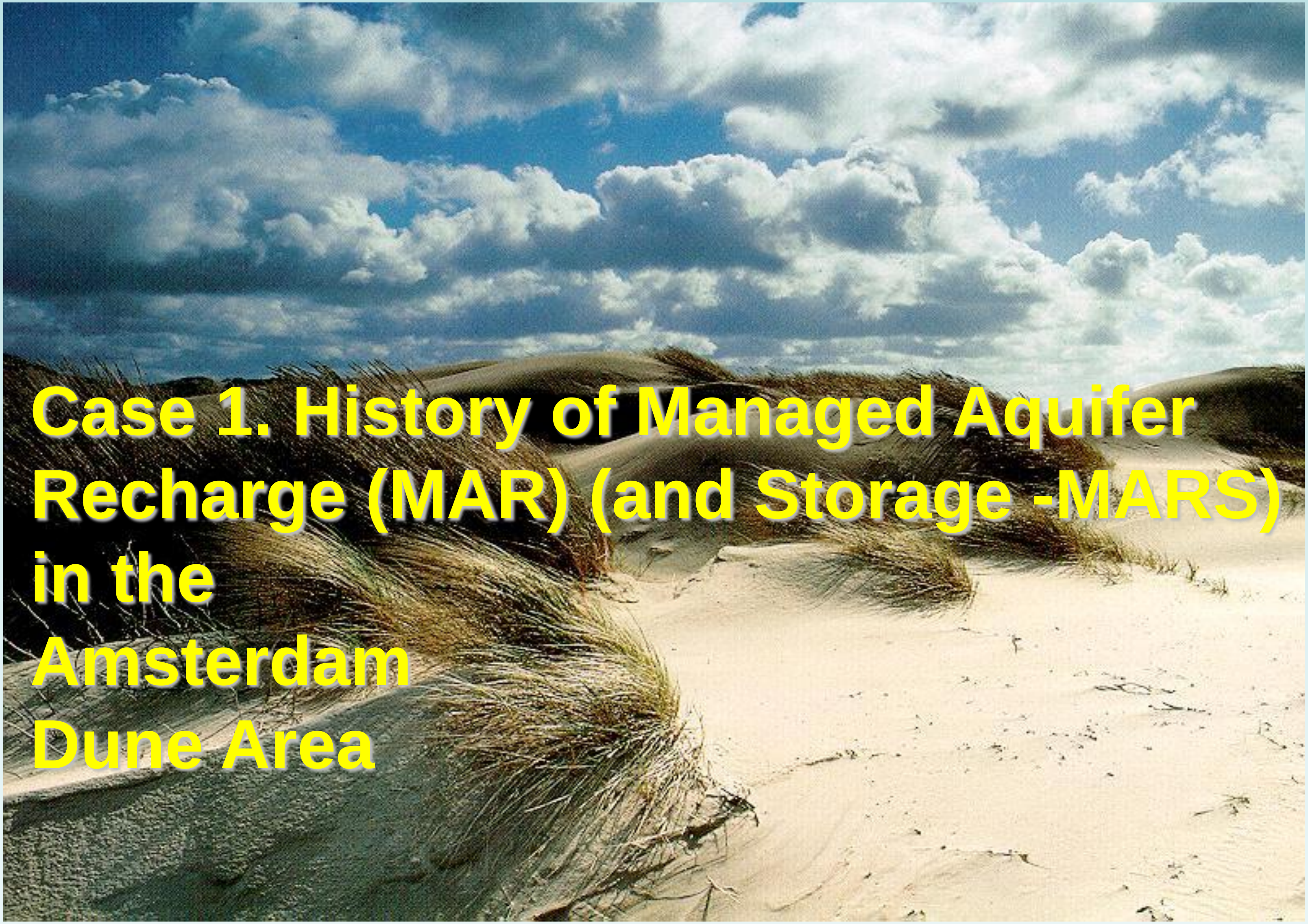
Groundwater and Adaptation Measures

- **Managing Aquifer Recharge (MAR) provides multiple benefits:**
  - storing water for future use
  - stabilising or recovering ground water levels in overexploited aquifers,
  - reducing evaporative losses
  - managing saline intrusion or land subsidence, and
  - enabling reuse of waste or storm water.

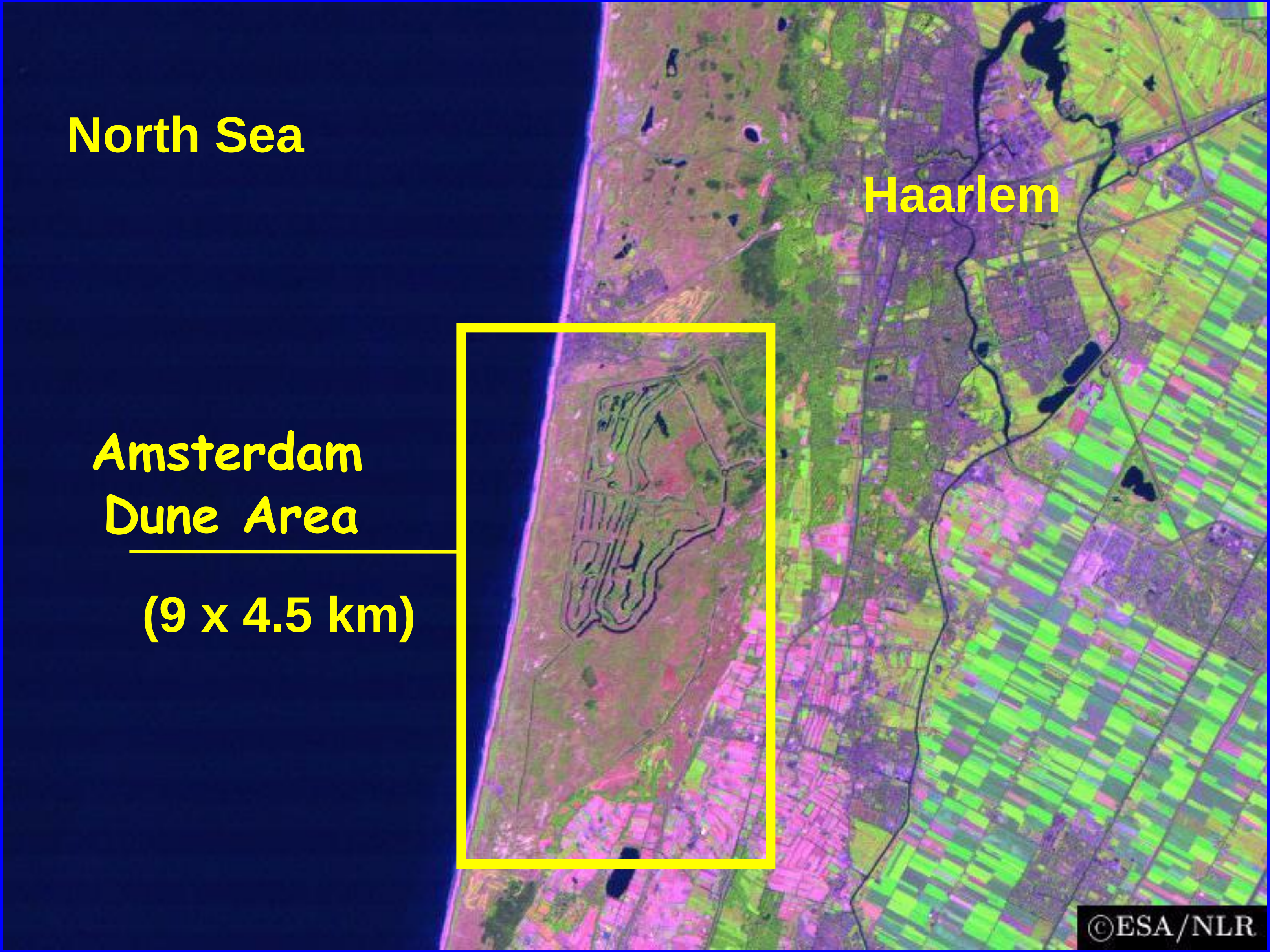
- **Land use change – may provide an opportunity to enhance recharge, to protect groundwater quality and to reduce groundwater losses from evapotranspiration.**

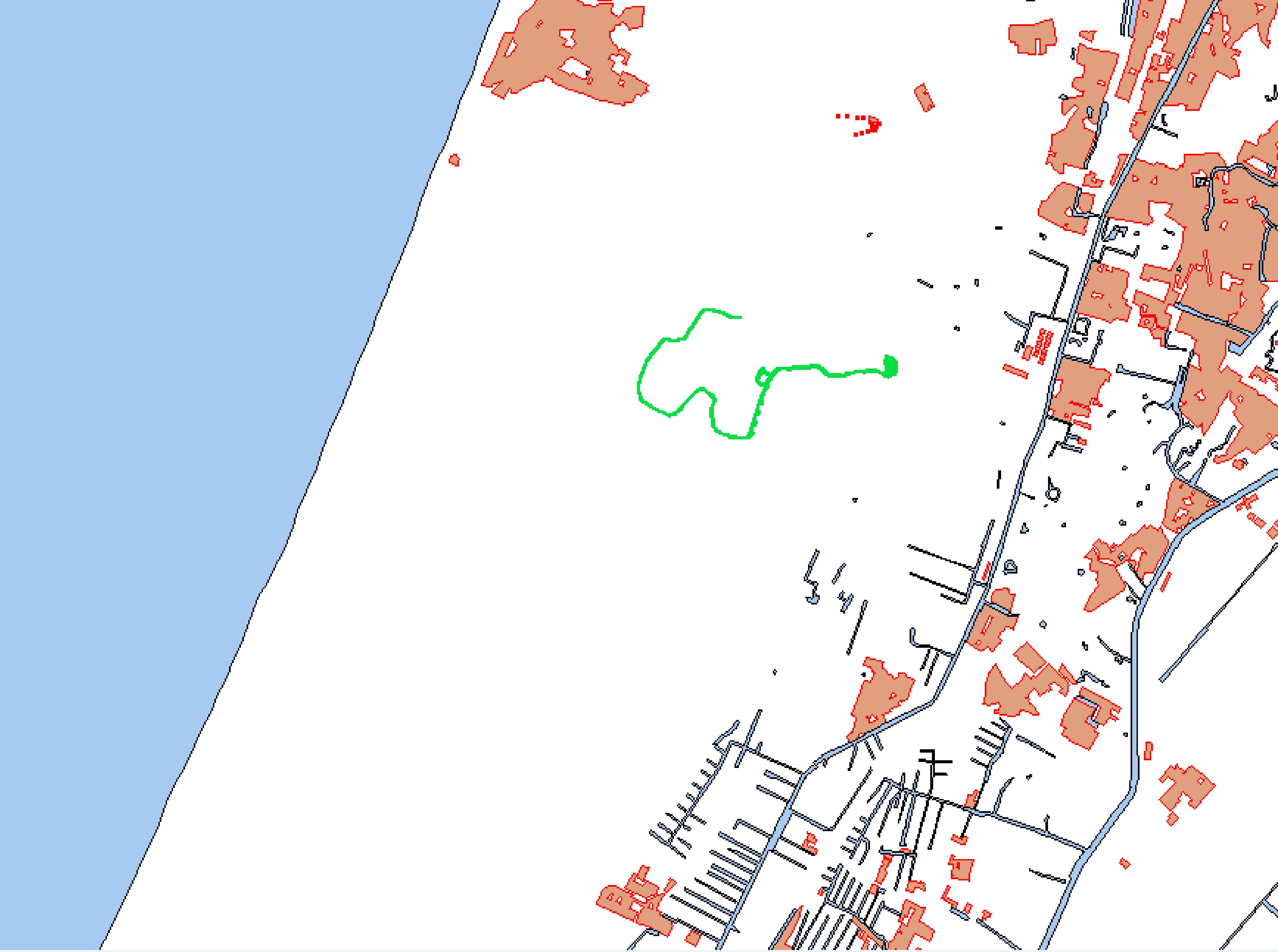


- **Integrating the management of surface water and groundwater resources (also to avoid mutual adversely impact)**



Case 1. History of Managed Aquifer Recharge (MAR) (and Storage -MARS) in the Amsterdam Dune Area

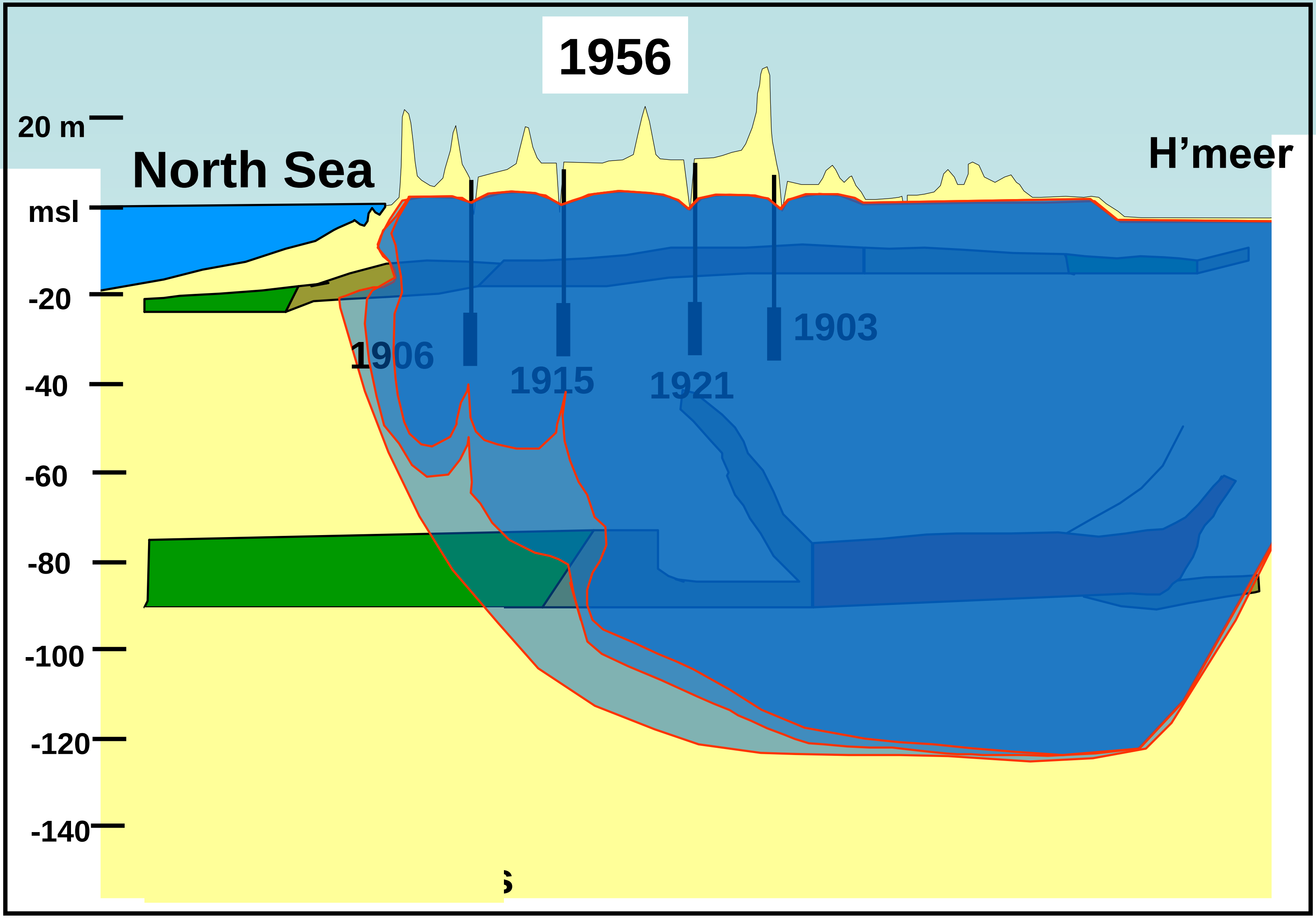

North Sea
Haarlem
Amsterdam
Dune Area
(9 x 4.5 km)
©ESA/NLR



Drinking water from the dunes

- 1853 Start extraction by dug canals
- 1903 Start extraction by wells
- 1957 Start artificial recharge with pretreated river water taken from the Rhine Branch near Utrecht, at 75 km distance.

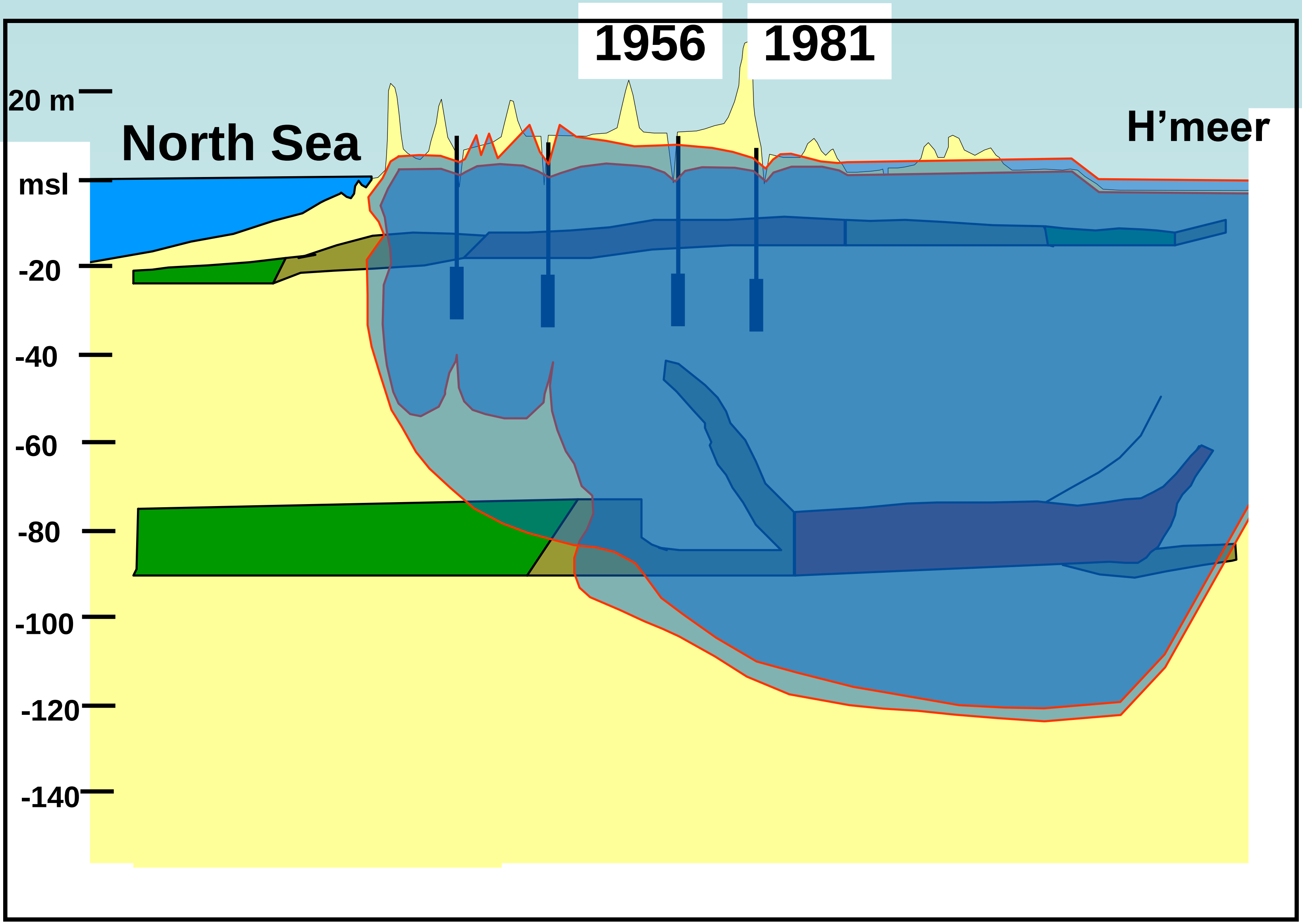
Salt water intrusion 1903-1957



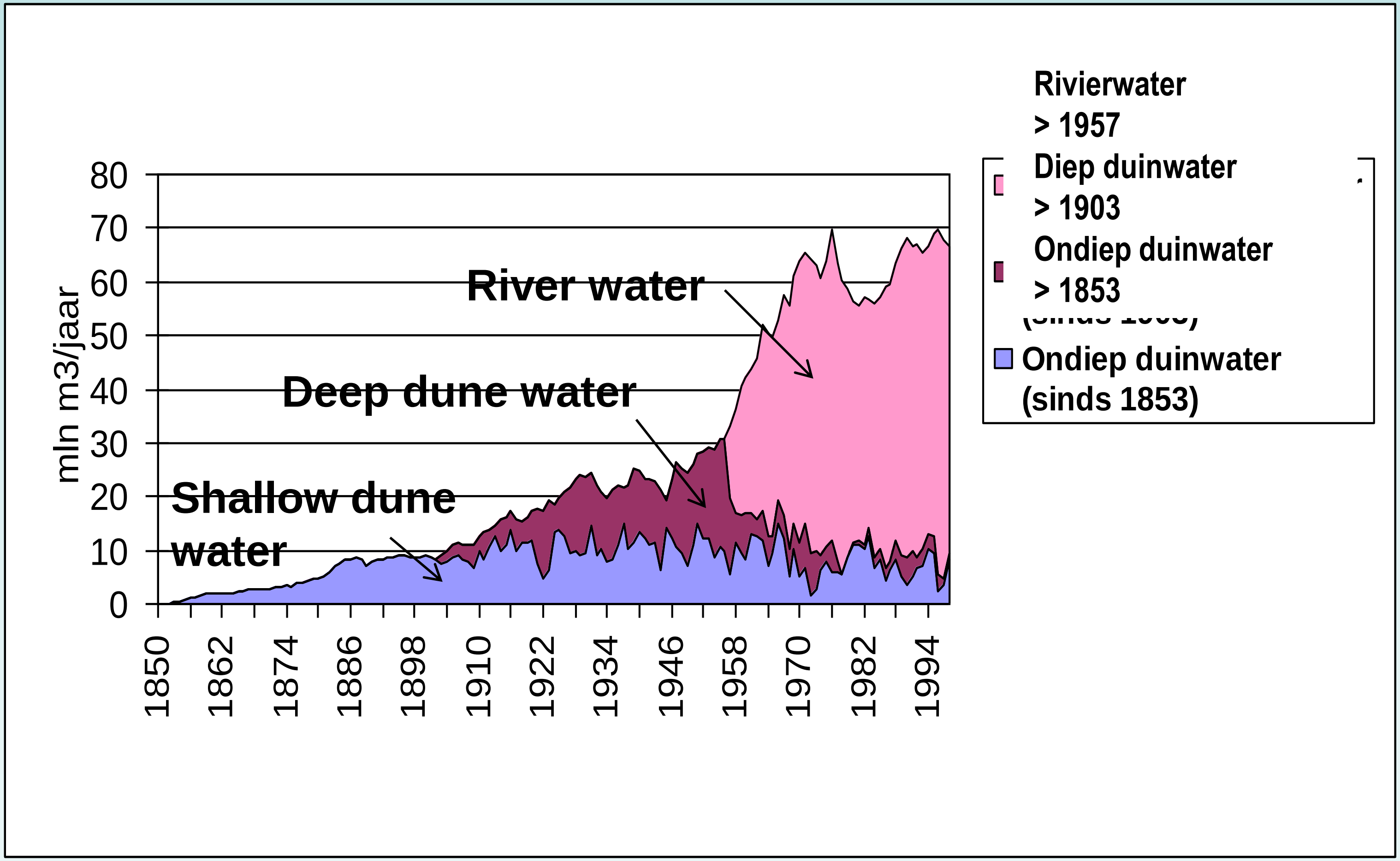
Why artificial recharge of river water?

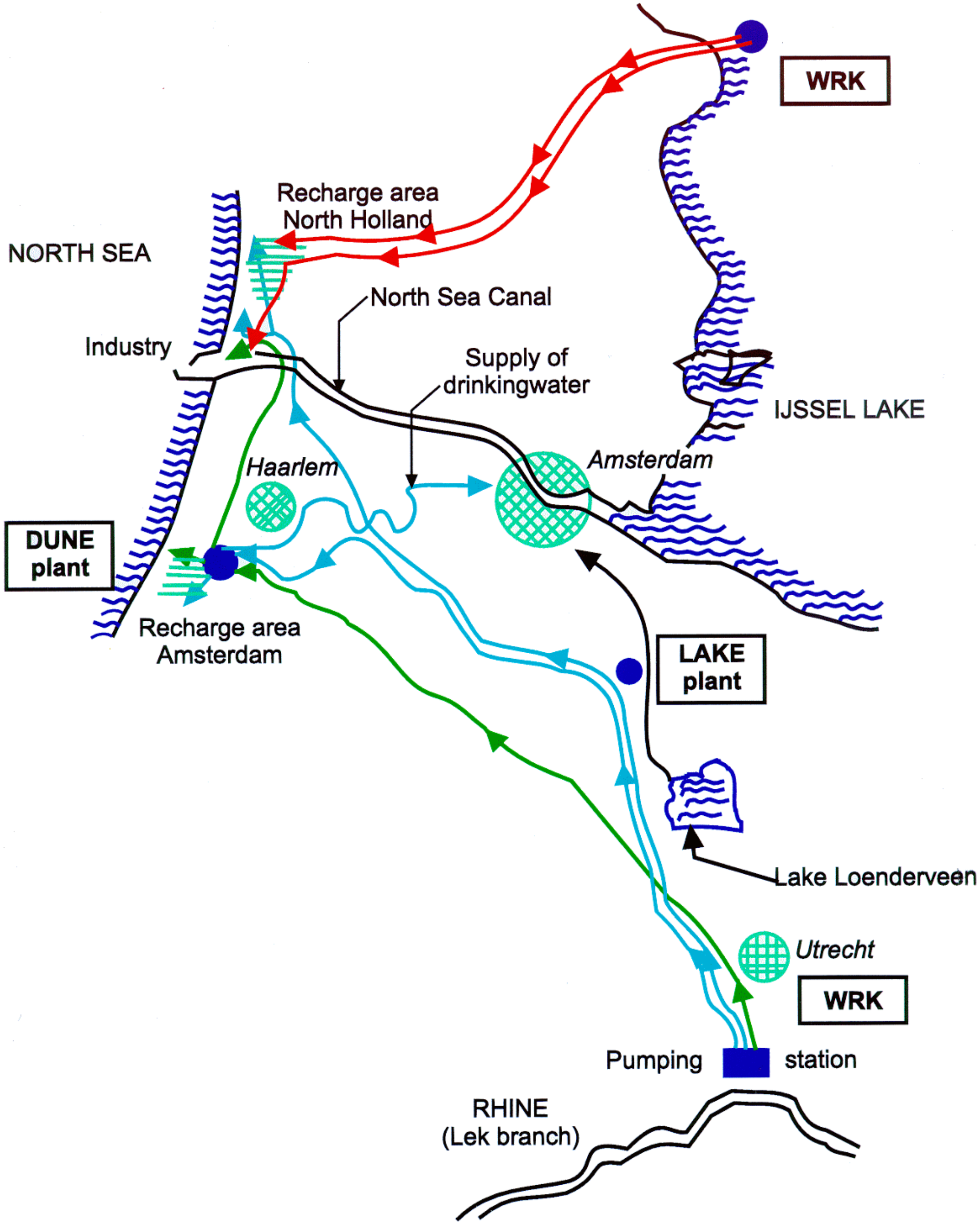
- Smoothing of quality variations and temperature
- Storage of water
- Natural breakdown of pathogens micro-organisms (bacteria, viruses & protozoa)
- Stabilization of dunes, formation of new coasts
- Nature and recreation functions

Restoration of the second aquifer 1957 - 1981



Origin from the drinking water produced from the dune area near Amsterdam 1853-1999



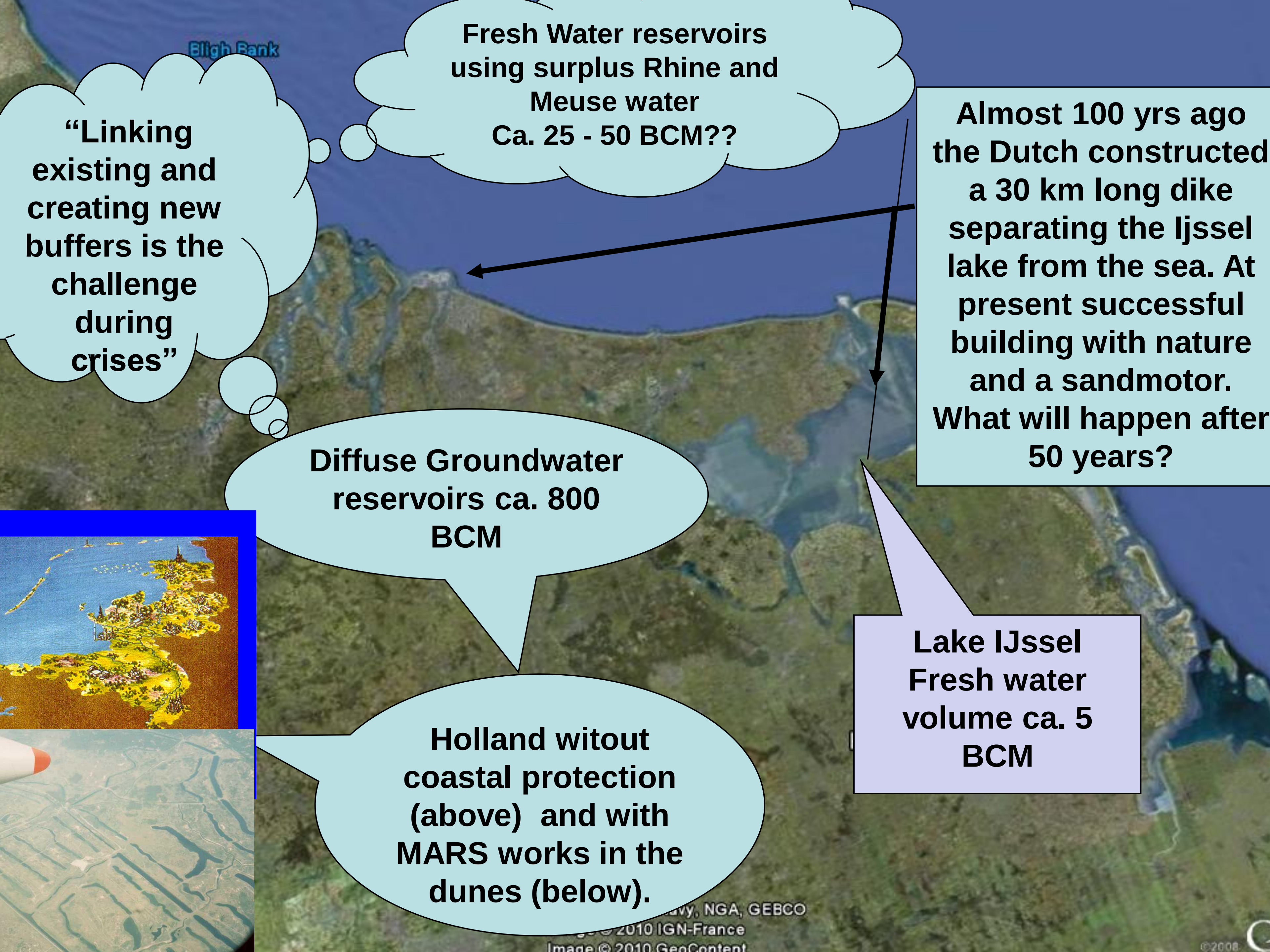

WRK
Recharge area
North Holland
NORTH SEA
North Sea Canal
Industry
Supply of
drinkingwater
IJSSEL LAKE
Amsterdam
Haarlem
DUNE
plant
Recharge area
Amsterdam
LAKE
plant
Lake Loenderveen
Utrecht
WRK
Pumping
station
RHINE
(Lek branch)

RECENT CHANGES: AMSTERDAM WATER SUPPLY COMPANY TO WATERNET

Merger between three organisations

- **Water supply company**
- **Waterboard or Regional Water Authority**
- **Municipal water departments**

→ Merger of Organisations of Water system and water supply and waste water treatment


Bligh Bank
Fresh Water reservoirs using surplus Rhine and Meuse water Ca. 25 - 50 BCM??
“Linking existing and creating new buffers is the challenge during crises”
Almost 100 yrs ago the Dutch constructed a 30 km long dike separating the Ijssel lake from the sea. At present successful building with nature and a sandmotor. What will happen after 50 years?
Diffuse Groundwater reservoirs ca. 800 BCM
Lake IJssel Fresh water volume ca. 5 BCM
Holland witout coastal protection (above) and with MARS works in the dunes (below).

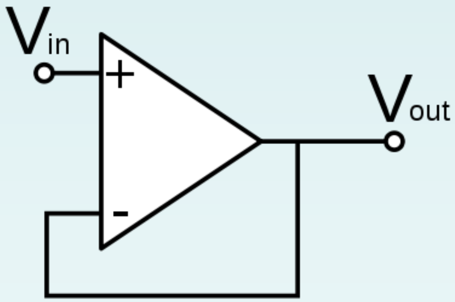
Natural & man-made buffers, MAR or 3R

Recharge, **Retention** and **Reuse** in natural buffers:

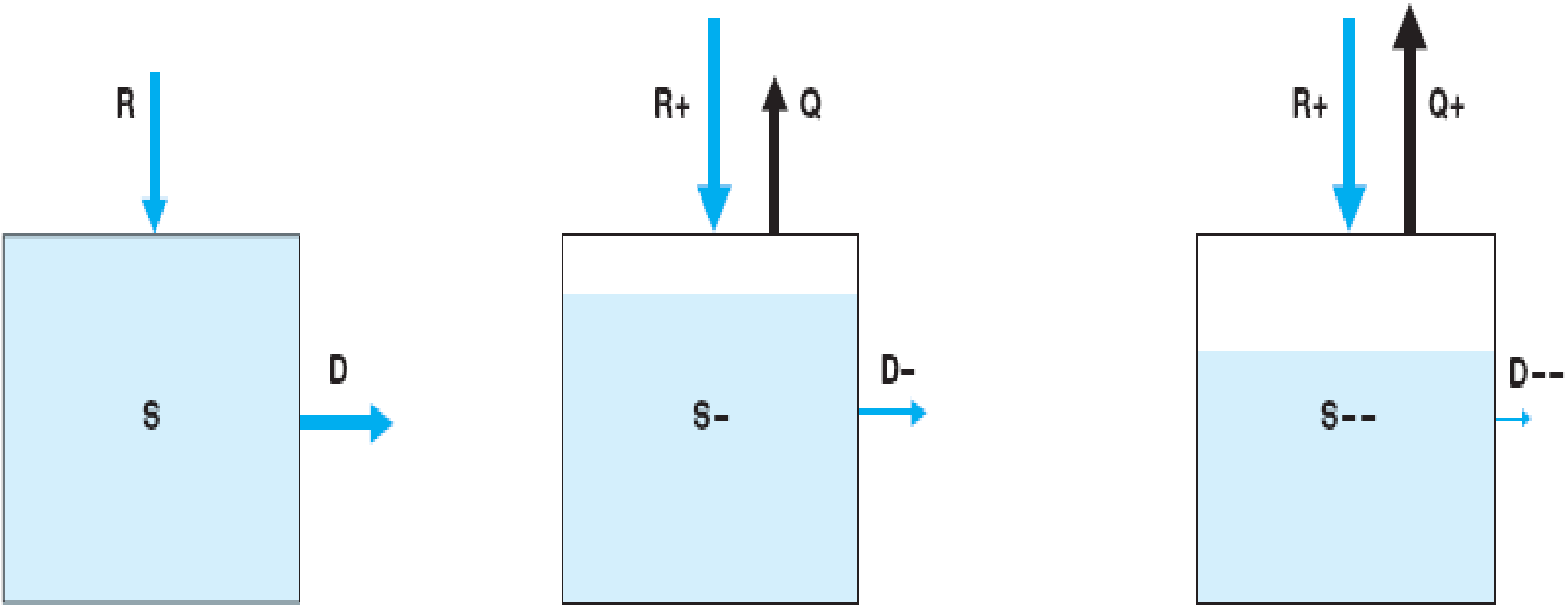
- Surface water
- Ground water
- Soil water

… or in man-made buffers:

- Tank storage



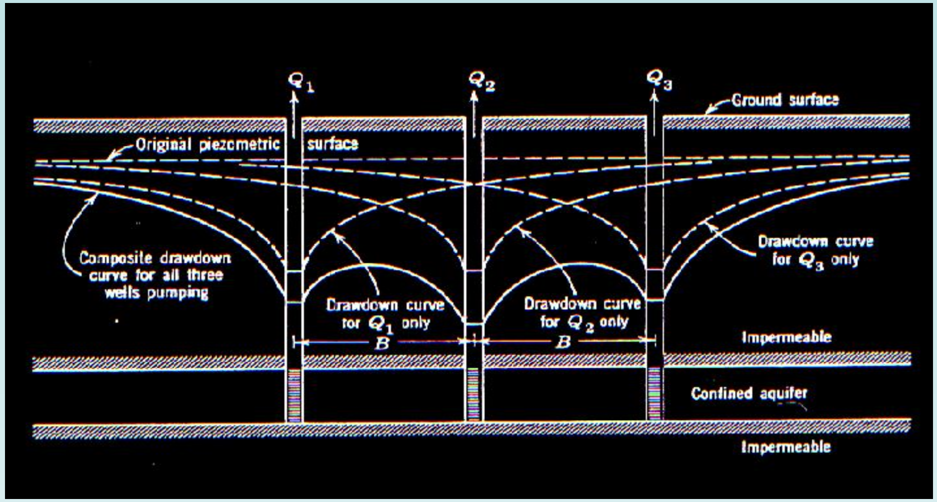
Sustainable use of the water buffer

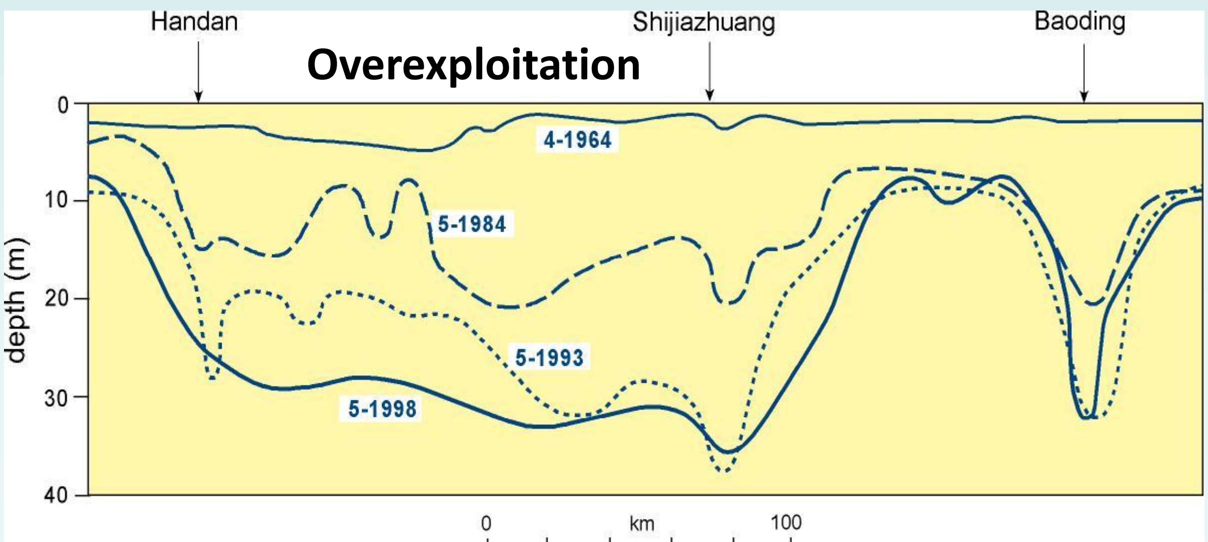


NATURAL CONDITIONS	STABLE GROUNDWATER PUMPING	UNSUSTAINABLE GROUNDWATER PUMPING
in the long term **R** = **D**, and **S** is constant	**Q** is equivalent to reduction in **D** and **S**, plus increase in **R**	**Q+** is greater than **R+** plus **D--** (which reduces to 0) and **S--** decreases continuously

Source: GW•MATE

Multiple groundwater users





Source: GW·MATE

Consequences of overexploitation

REVERSIBLE INTERFERENCE	IRREVERSIBLE DEGRADATION	
• pumping lifts/costs increase • borehole yield reduction • springflow/baseflow reduction	• phreatophytic vegetation stress (both natural and agricultural) • aquifer compaction and transmissivity reduction	• saline water intrusion • ingress of polluted water (from perched aquifer or river) • land subsidence and related impacts (aquitard compaction)

⇒ **for sustainable buffer management: Reuse and Recharge must be in equilibrium over an agreed timespan**

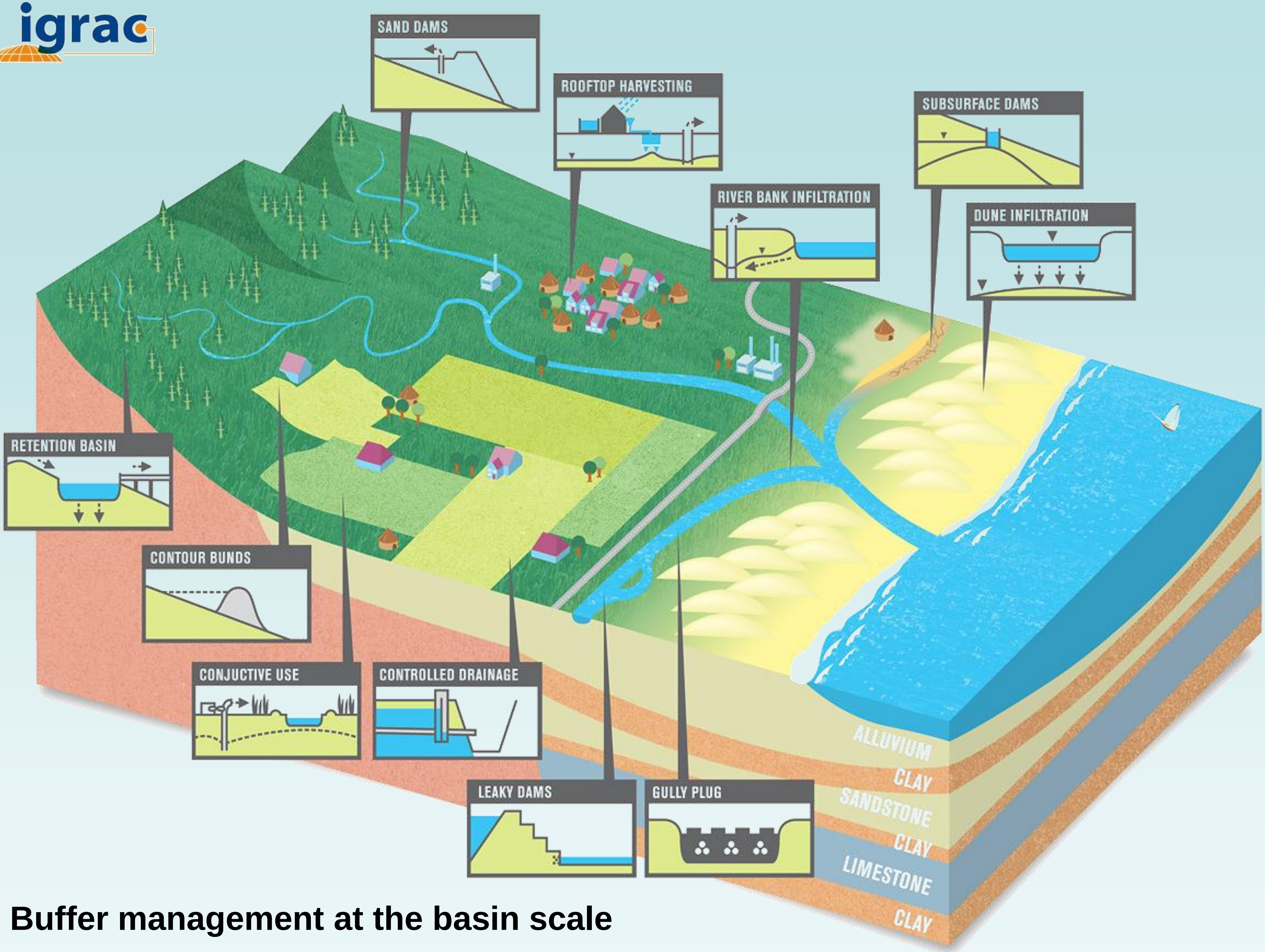
Source: GW•MATE

Managed Aquifer Recharge (MAR) or 3R: a different way of thinking

Recharge ***Retention*** ***Reuse***

Storage = buffering

- 3R concept – Recharge, Retention and Reuse
- Local (cisterns) and subsurface storage (active use of aquifer) of surface water for both water- and food security
- It is s not about allocation scarce water but to catch and retain water and extend the chain of use and reuse as possible within a basin.
- Introduce buffer management at the scale – basin by basin (not piecemeal/scattered).
- Subsurface storage has the largest capacity potential

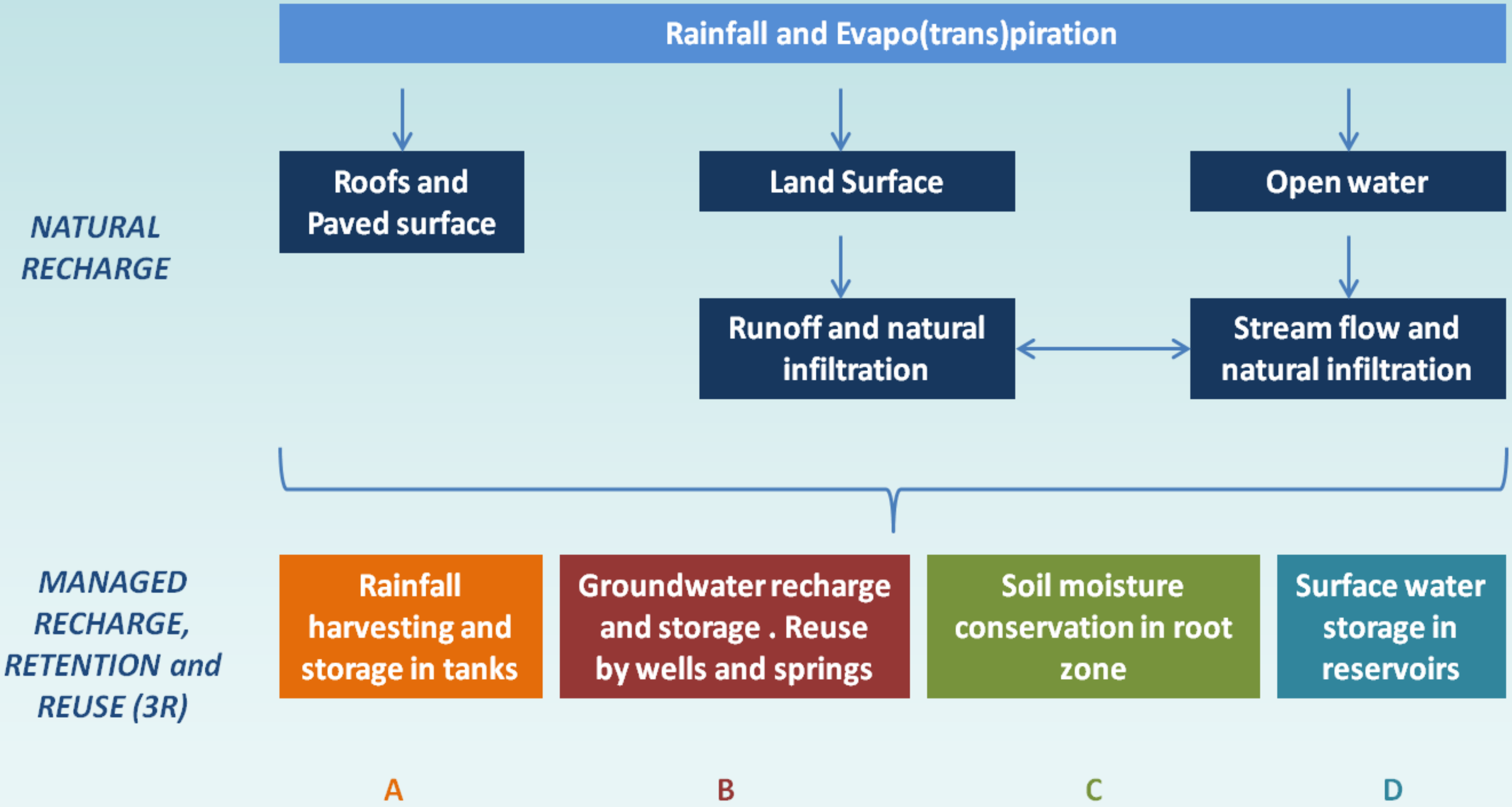


Buffer management at the basin scale

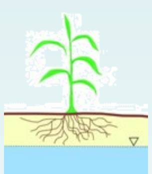
3R Techniques

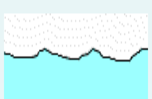
	Technology	Sub type	
Techniques referring primarily to getting water infiltrated	Spreading methods	infiltration ponds & basins	
		flooding	
		ditch, furrow, drains	
		irrigation	
	Induced bank infiltration		
	Well, shaft and borehole recharge	deep well injection	AS(TR)
			ASR
		shallow well/ shaft/ pit infiltration	
Techniques referring primarily to intercepting the water	In-channel modifications	recharge dams	
		sub surface dams	
		sand dams	
		channel spreading	
	Runoff harvesting	barriers and bunds	
		trenches	

Overall Framework



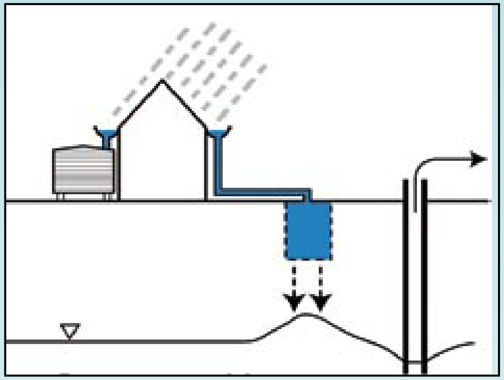
3R Techniques





Retention method	Recharge method	Measures
A. Closed tank storage	1. Rainwater interception	Rooftop harvesting
	2. Fog harvesting	Fog shield and tank
B. Groundwater storage	1. Run-off reduction: riverbed infiltration	River bed modification
		Gully plugging
		Sand dams
		Recharge dams
	2. Land surface infiltration	Infiltration ponds
		Spate irrigation
		Ditches and drains/furrows
	3. Direct aquifer infiltration	Wells
		Riverbank infiltration
C. Soil moisture storage	1. Run-off reduction	Terracing
		Contour bunds
	2. Land surface infiltration	Deep ploughing
		Spate irrigation
	3. Evaporation reduction	Mulching
D. Open water storage	1. In the riverbed	Checkdam
	2. Outside the riverbed	Storage pond

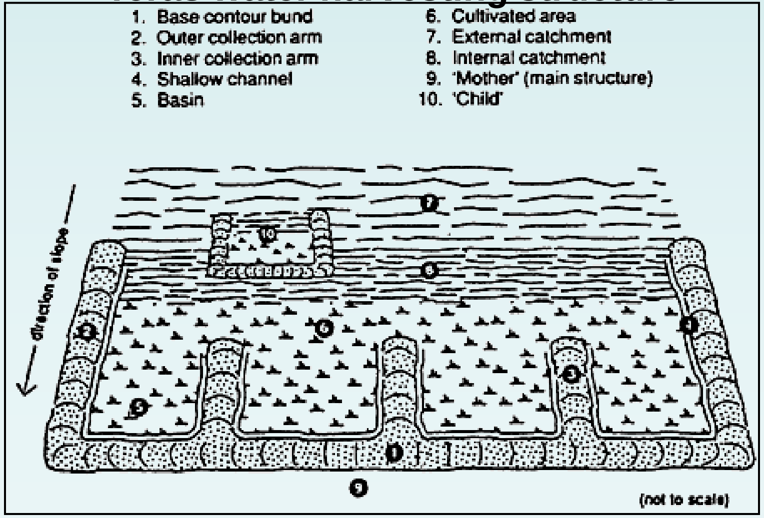
Rainwater harvesting



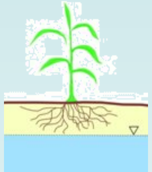
Roof top rainfall harvesting and storage

Runoff harvesting

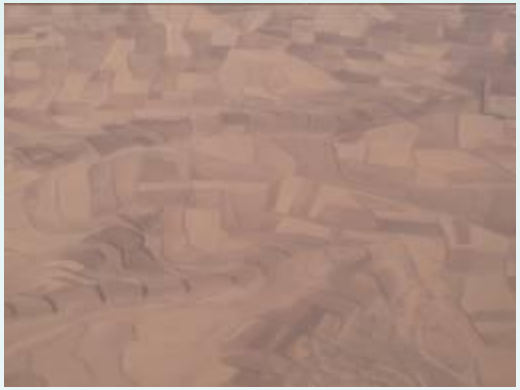
Inspection of base bund as part of Teras water harvesting structure



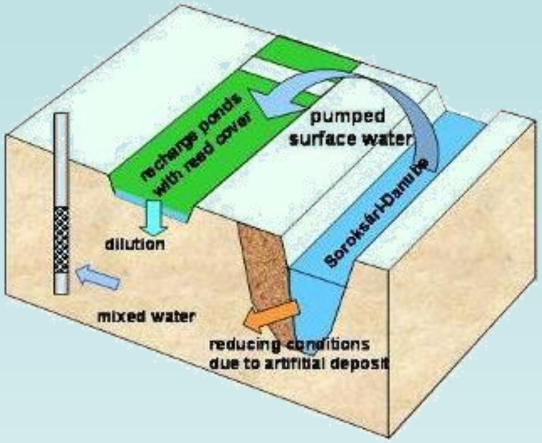
Typical elements of the Teras water harvesting structure



Terracing / spate irrigation Yemen



Riverbank infiltration



Dugwell near river (Maharashtra)

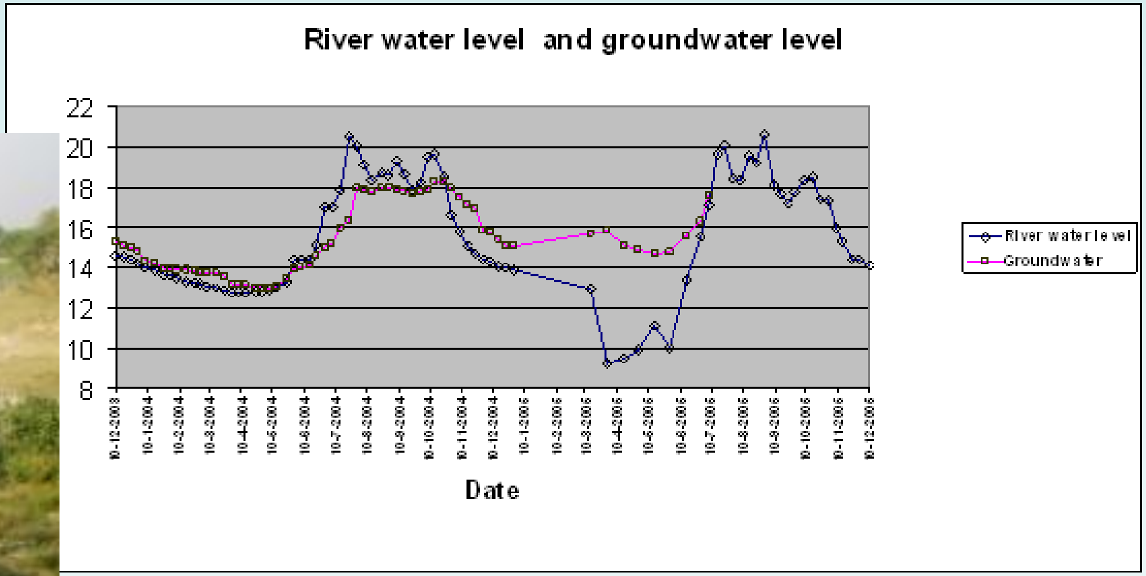
Danube river in Budapest, Hungary. (Source: Sándor, 2005)

Surface water infiltration well (Bangladesh)

Riverbank infiltration

Research example: Chapai Nawabganj

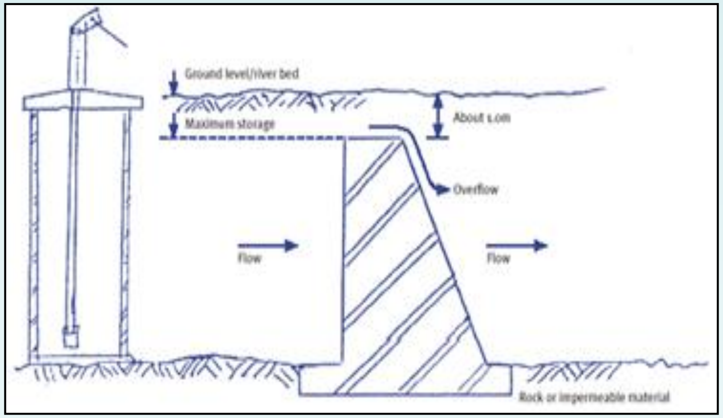
Production wells drilled along the Mohanandan River abstract part of the water from the river. Simulations with a groundwater model and with a Bank Infiltration Simulator (NASRI) show that approximately 30% (dry season) to 60% (wet season) of the pumped water (at 30-50 m) originates from the river with travel times of 5-10 days (wet season) to 30-40 days (dry season).



In channel modifications

recharge dam

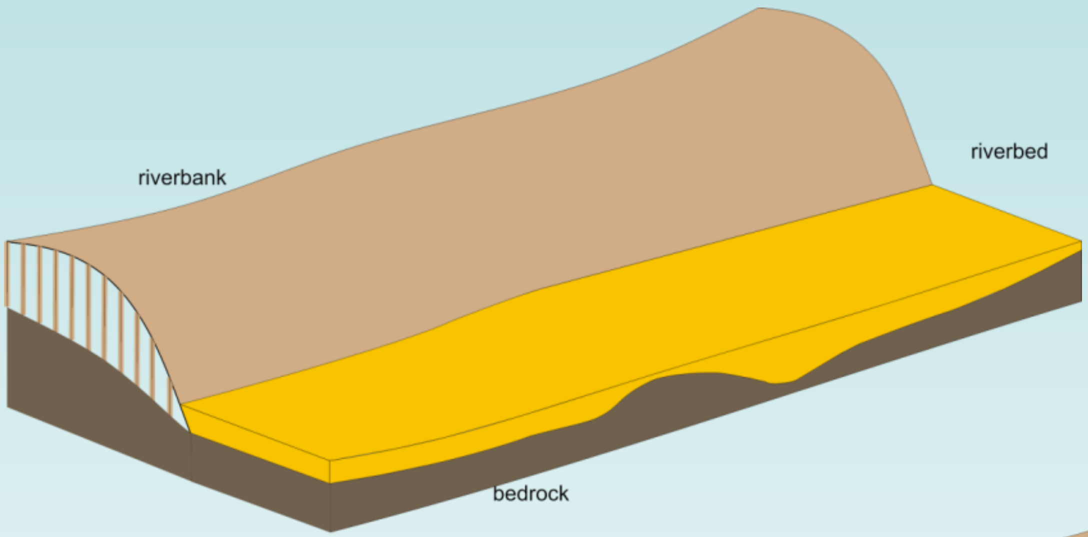
recharge dam (Oman)

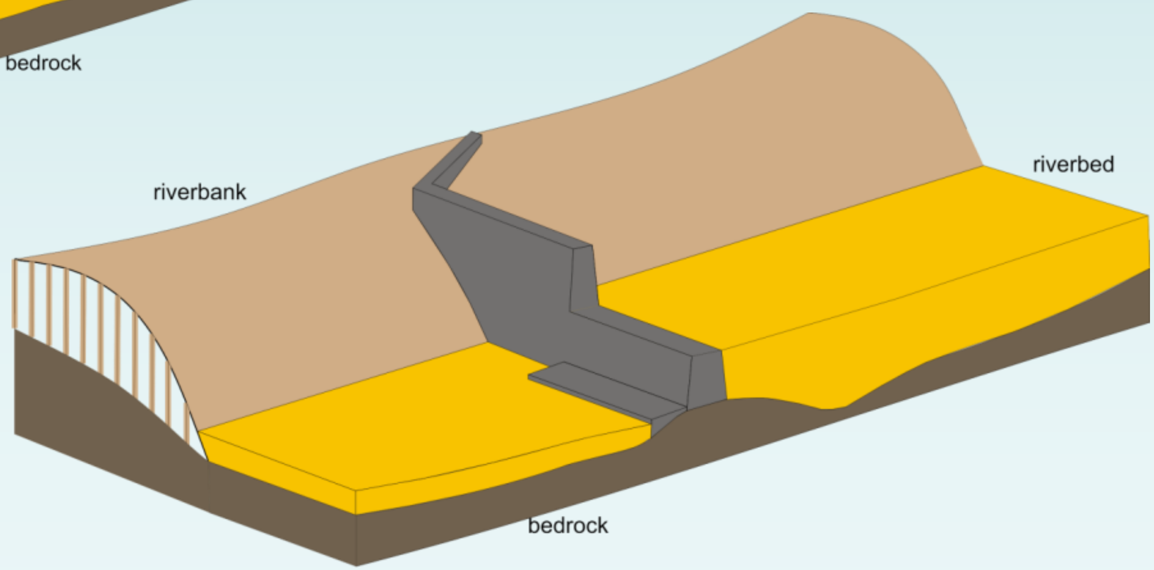


schematic drawing of subsurface dam

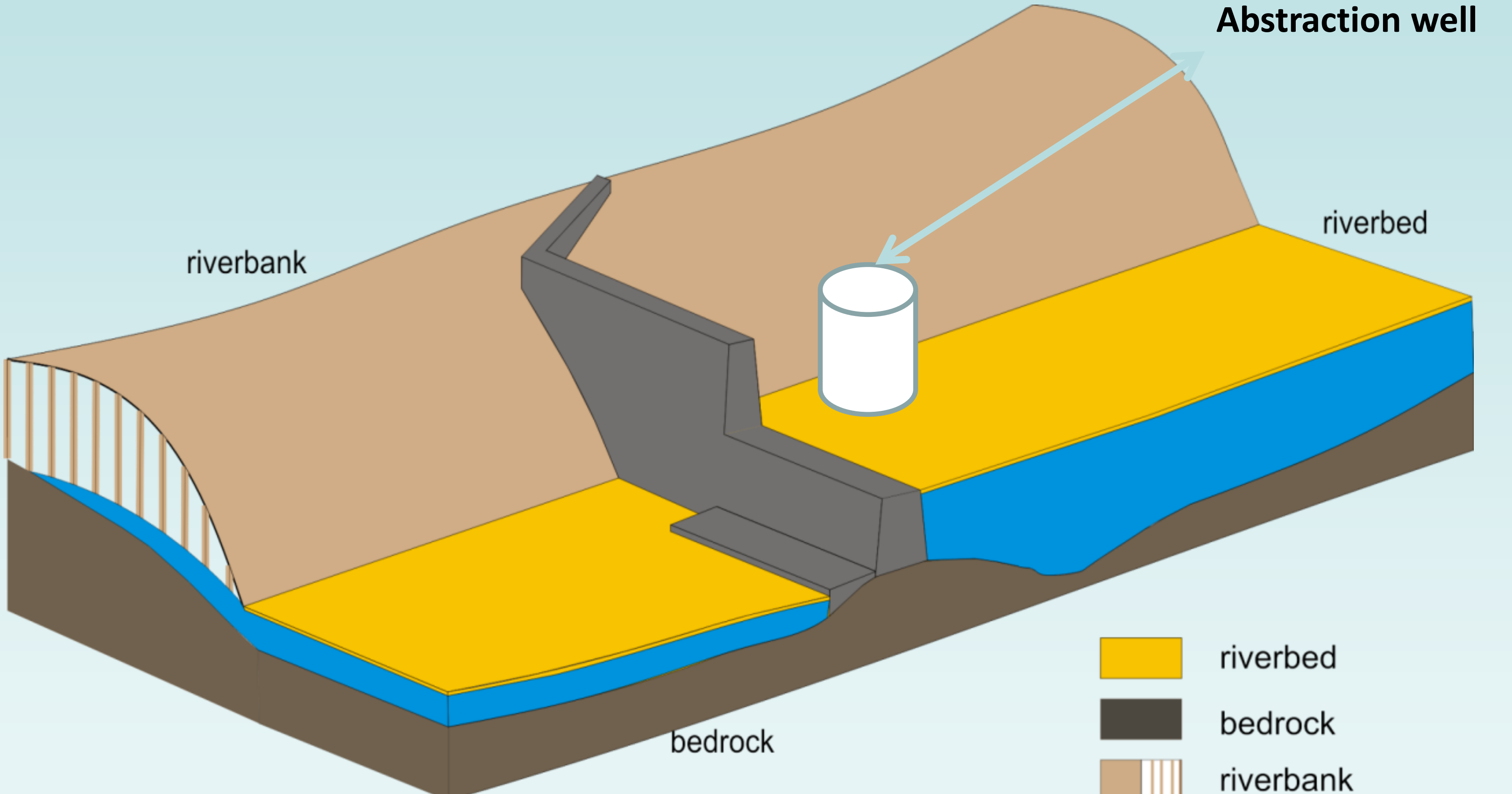
construction of subsurface dam

Example: sand dams





Example: sand dams

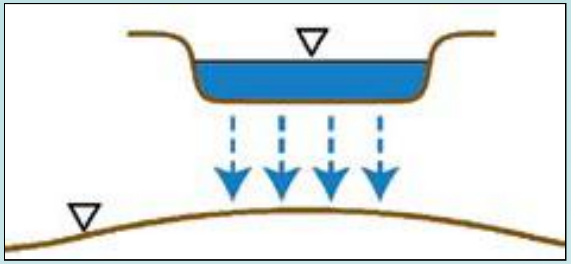


Sand dams functioning

- Dam drops the flow velocity and results in sedimentation and **percolation of water**
- Increasing the water availability by **storing water** in the riverbed and banks
- **Increased availability** of water for domestic and other uses such as livestock, irrigation and regeneration of natural vegetation

Infiltration ponds

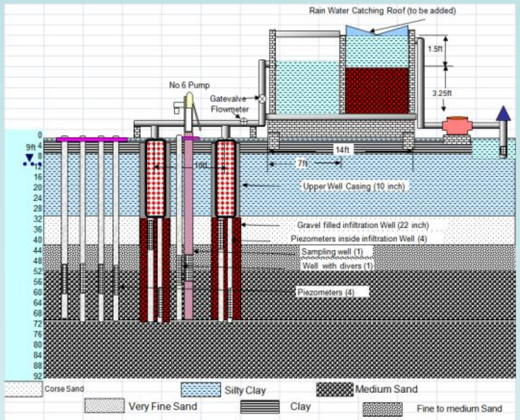
Infiltration pond Atlantis (South Africa)



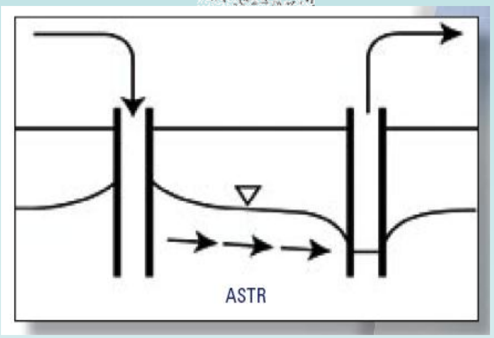
Infiltration ponds
Amsterdam
Water Supply

Recharge pond, Sanaa Plain, Yemen

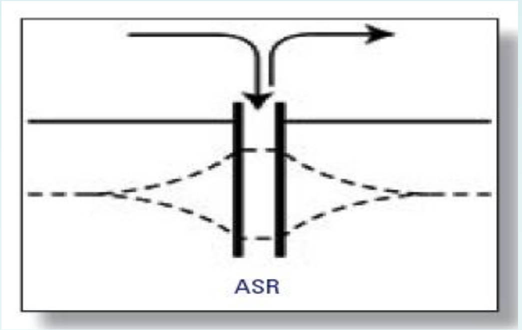
Well, shaft and borehole recharge



Shallow well injection Bangladesh



Maharashtra, India



ASR well; Australia

Recharge pit, Rajasthan, India ASR

Canats

Which technique to choose?

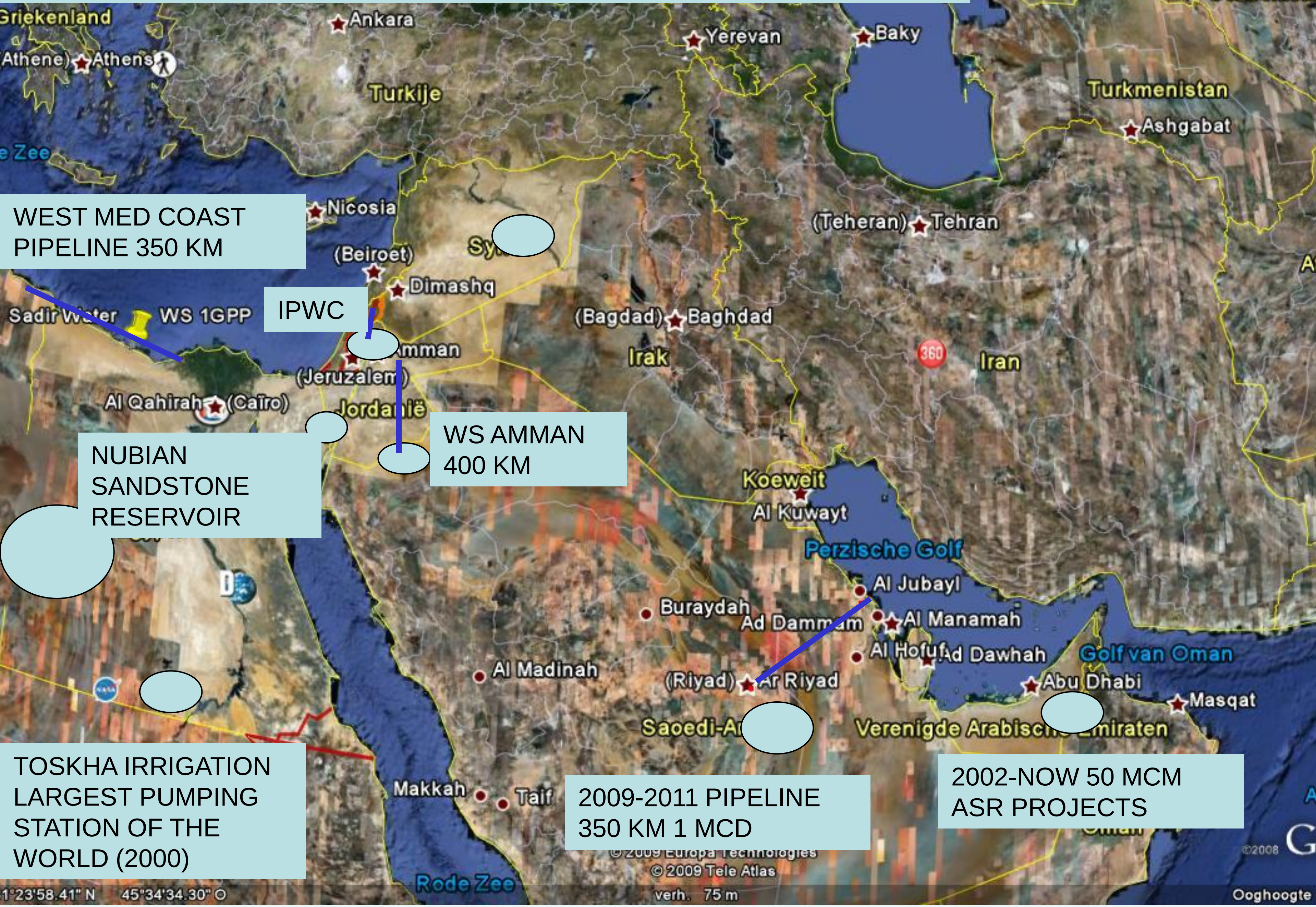
Physical Requirements				
Slope	River / stream	Aquifer	Covering soil layer	Buildings

Scale of benefits			
On-site	Downstream	Upstream	Off-stream

Scale of investments			
Household	Village	Small town	Urban regional

Available investment possibilities		
Spare labor	Payment for watershed services	Credit / Public funds / off-farm income

2012 SOME FACTS ON WATER STORAGE AND TRANSPORT



WEST MED COAST PIPELINE 350 KM

IPWC

WS AMMAN 400 KM

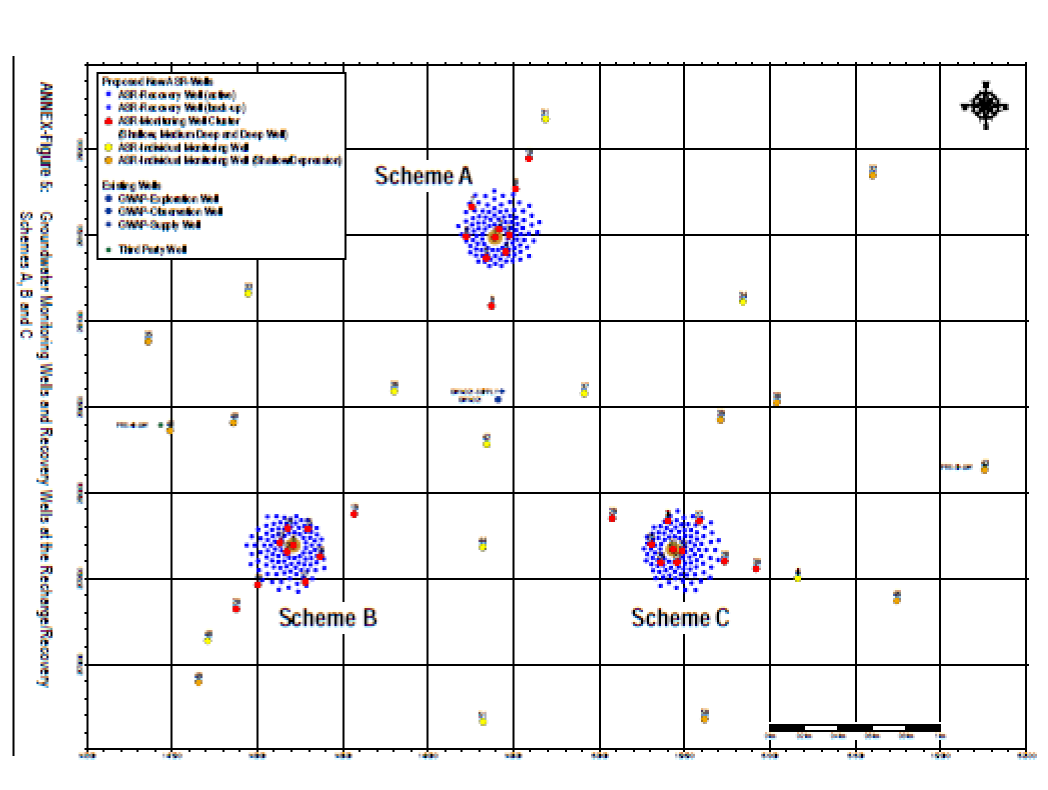
NUBIAN SANDSTONE RESERVOIR

TOSKHA IRRIGATION LARGEST PUMPING STATION OF THE WORLD (2000)

2009-2011 PIPELINE 350 KM 1 MCD

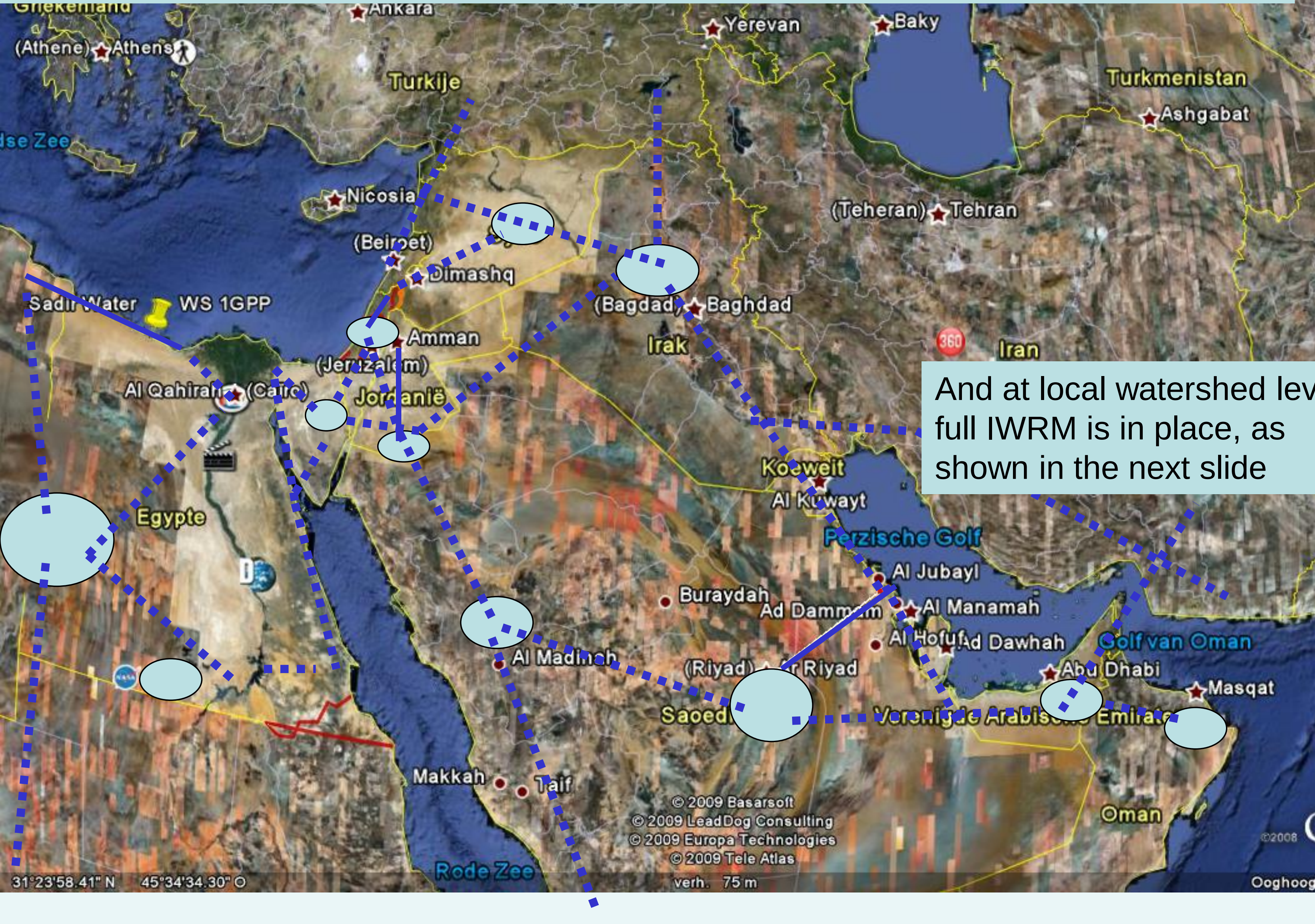
2002-NOW 50 MCM ASR PROJECTS

Abu Dhabi ASR Project

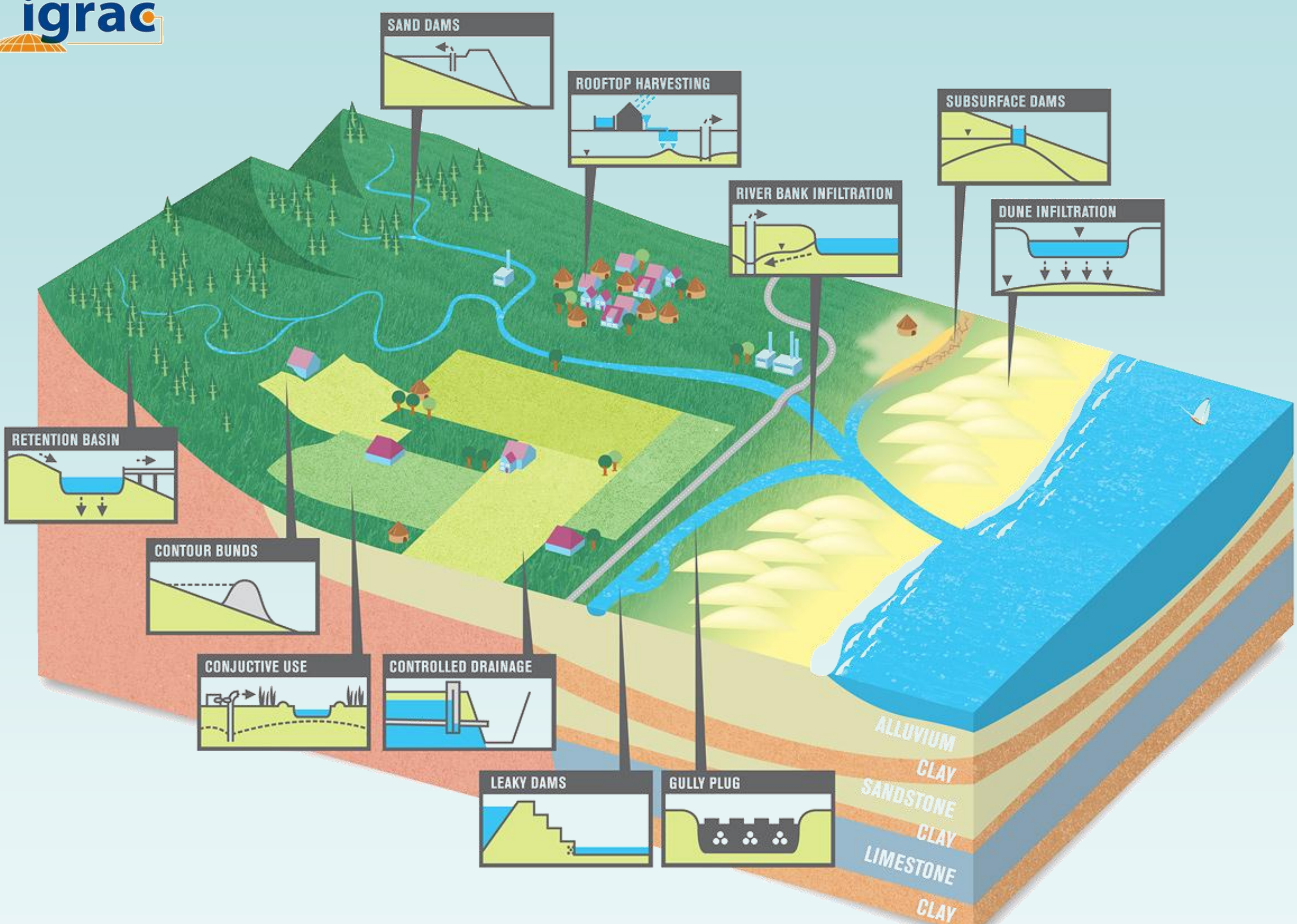


Well Head of Double Casing Monitoring Well in the ASR-Pilot Project Are

2030 POSSIBLE SITUATION WATER STORAGE&TRANSPORT

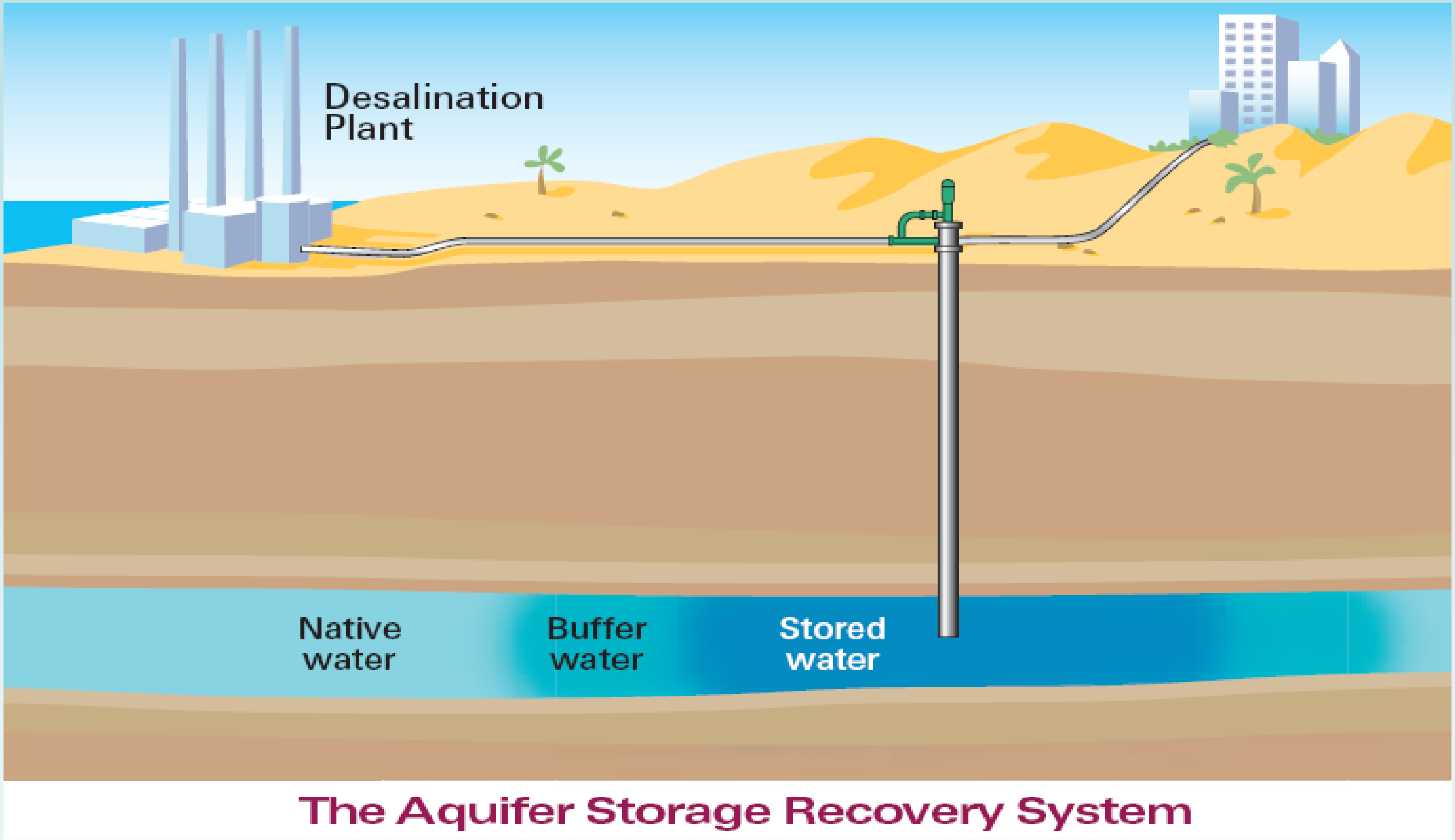


And at local watershed lev
full IWRM is in place, as
shown in the next slide



In 2030 Worldwide functioning buffer management at the basin scale

DESAL-MAR – a simple picture



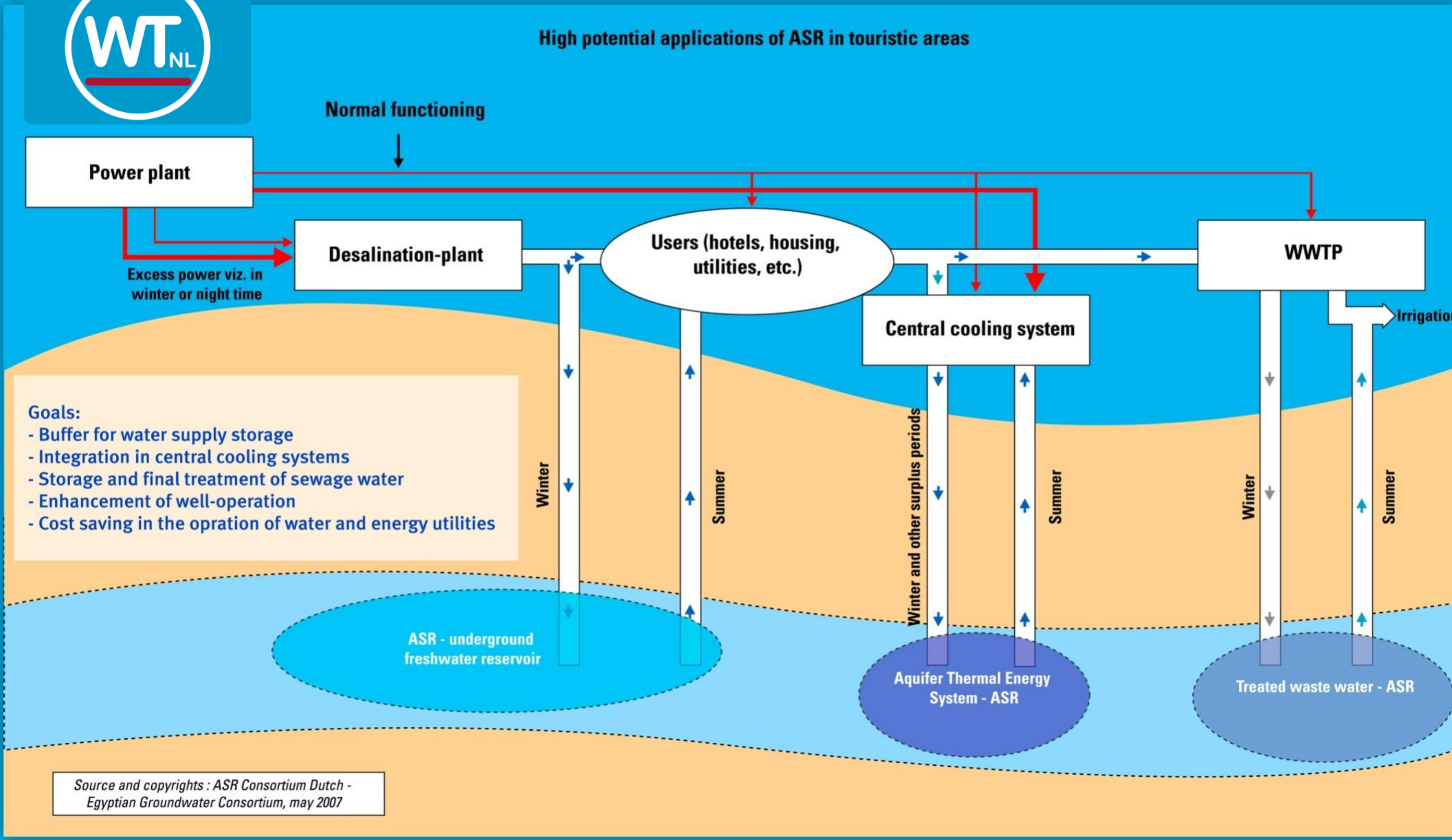
(Source ASR Consortium 2007)

and a more complex one……next slide

Aquifer Storage and Recovery Consortium

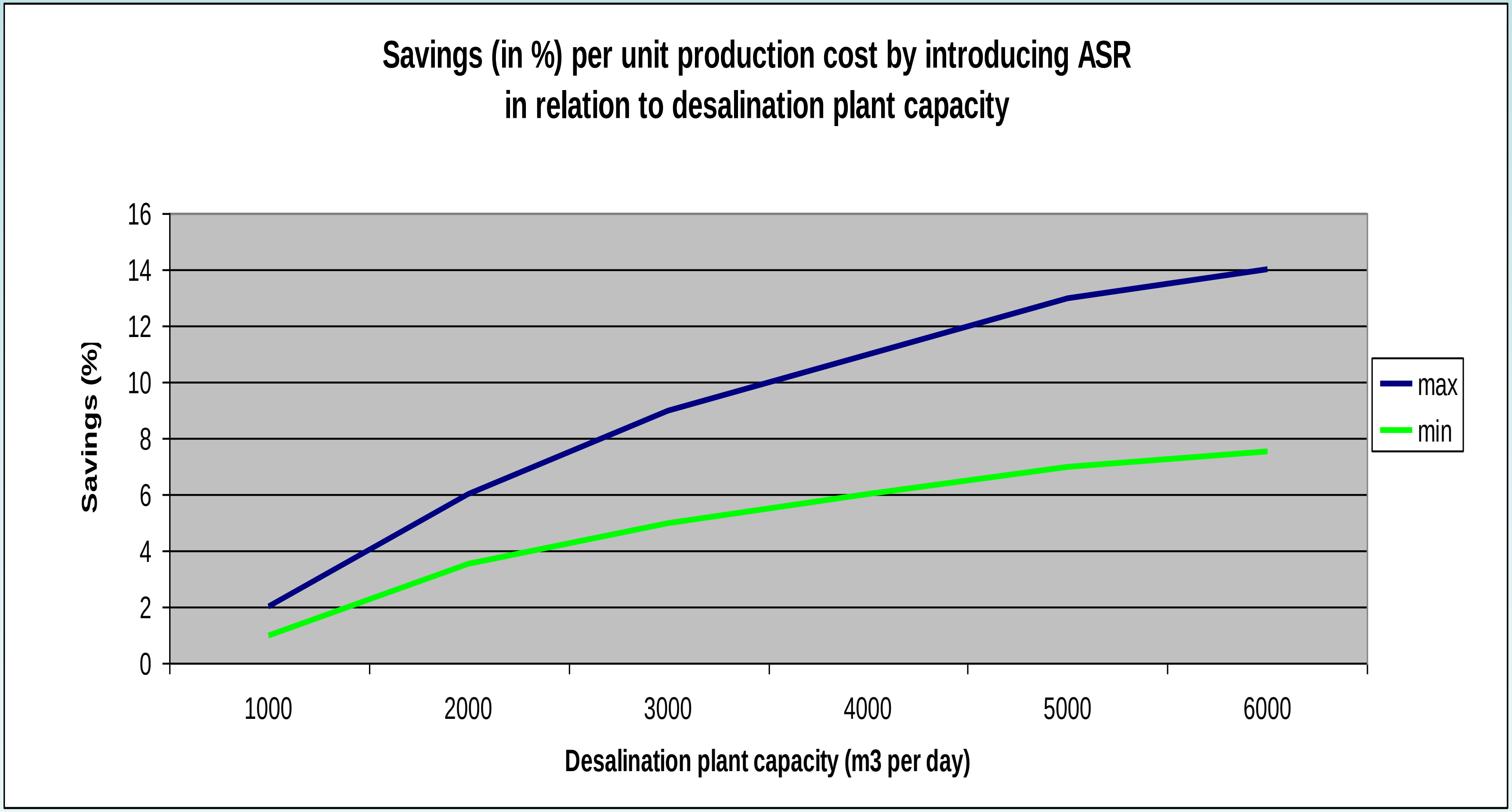
Van Essen Instruments, Smidt Groundwater, Darwish Consultants Engineers - EAP, Kiwa Water Research, Waternet.

ASR Consortium is your partner in solving water shortage and water quality problems. Water shortage and water quality problems occur often during a limited period of time. The underground storage of the required quantity and quality of water forms the core of the ASR solution.

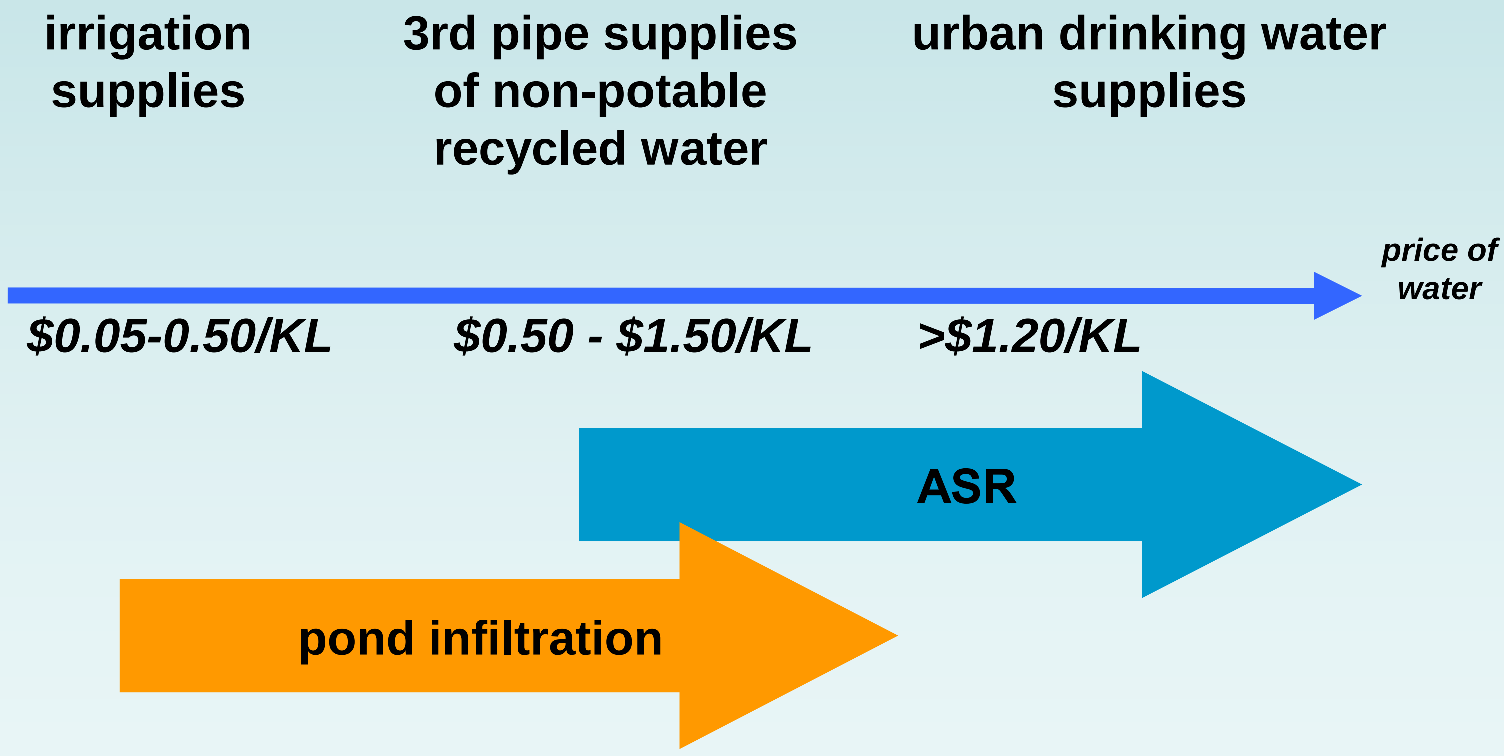


Note: The power plant can be based on green energy: solar energy or geothermal energy.

Economics of combining ASR and Desalination



Cost scale of MAR in relation to typical costs of water supplies for irrigation, non-potable & drinking water supplies



Dillon, P., Pavelic, P., Page, D., Beringen H. and Ward J. (2009) Managed Aquifer Recharge: An Introduction, Waterlines Report No 13, Feb 2009.

Cost comparison of small scale systems

System type	Life time	no cons.	Eff.Storage capacity	Days of storage use	Cons.per cons.	Annualized cost	O&M	Total cost per m^3
	years		m^3	days	lcd	USD/yr	USD/yr	US$/$m^3$
Aquifer storage	15	250	750	200	15	935	800	2.3
Rainwater Harvesting	10	11	10	150	6	75	50	12.6
Reversed Osmosis	10	500	1,200	200	12	7,451	7,000	12.0
Rural Pipes System	15	1,500	13,688	365	25	5,257	4,000	0.7
Water vendor		200	600	200	15	0	4,000	6.7

Water adaptation costs (1)

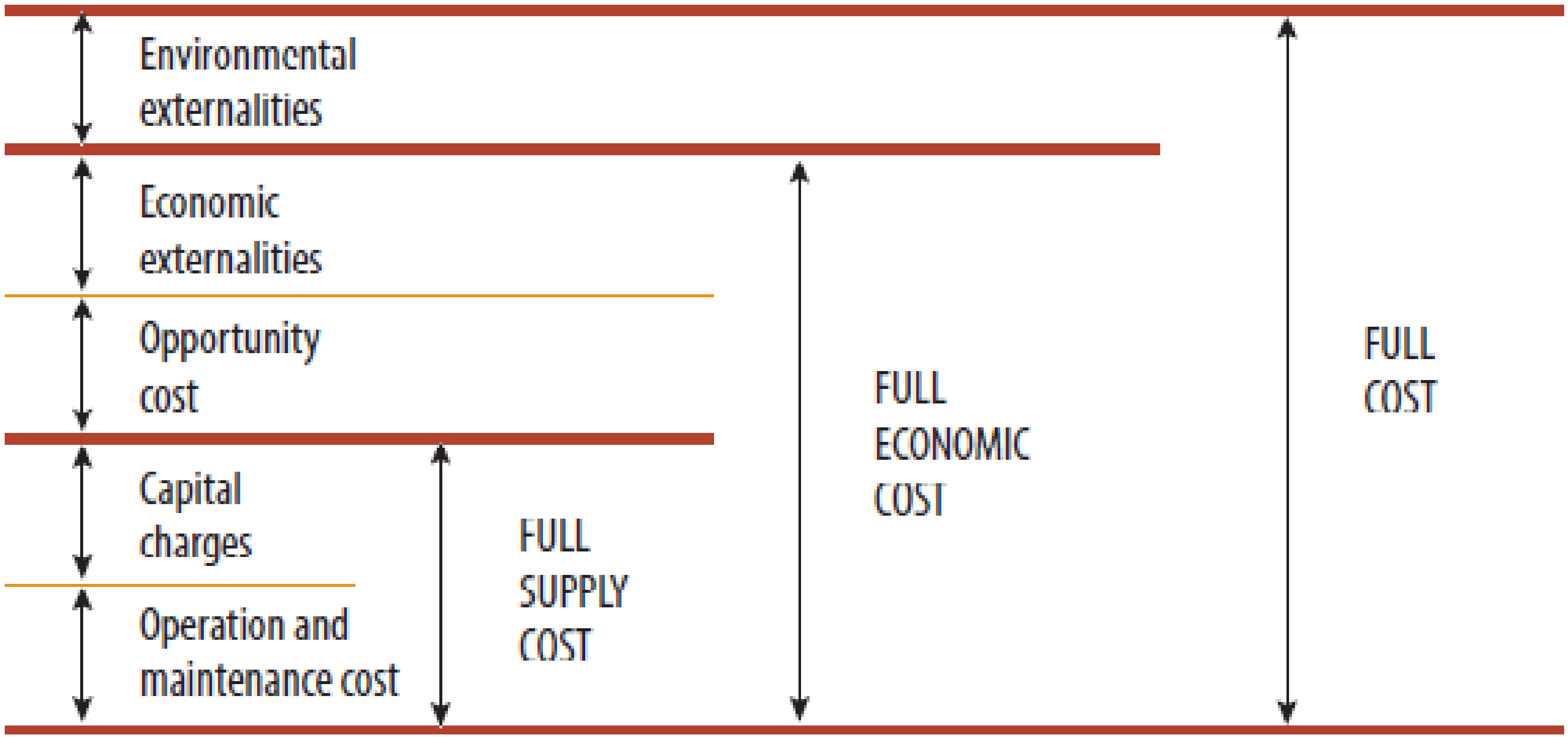
Cost of Water Adaptation Measures

Adaptation measure	Cost (US$/m^3 water)
Improve agricultural practice	0.02
Expand reservoir capacity (small scale)	0.03
Reuse domestic and industrial water	0.03
Reuse irrigation water	0.04
Expand reservoir capacity (large scale)	0.05
Reduce irrigated areas	0.10
Desalinate using renewable energy	1.30
Desalinate using conventional energy	1.85
Reduce domestic and industrial demand	2.00

Source: World Bank 2012.

Water adaptation costs (2)

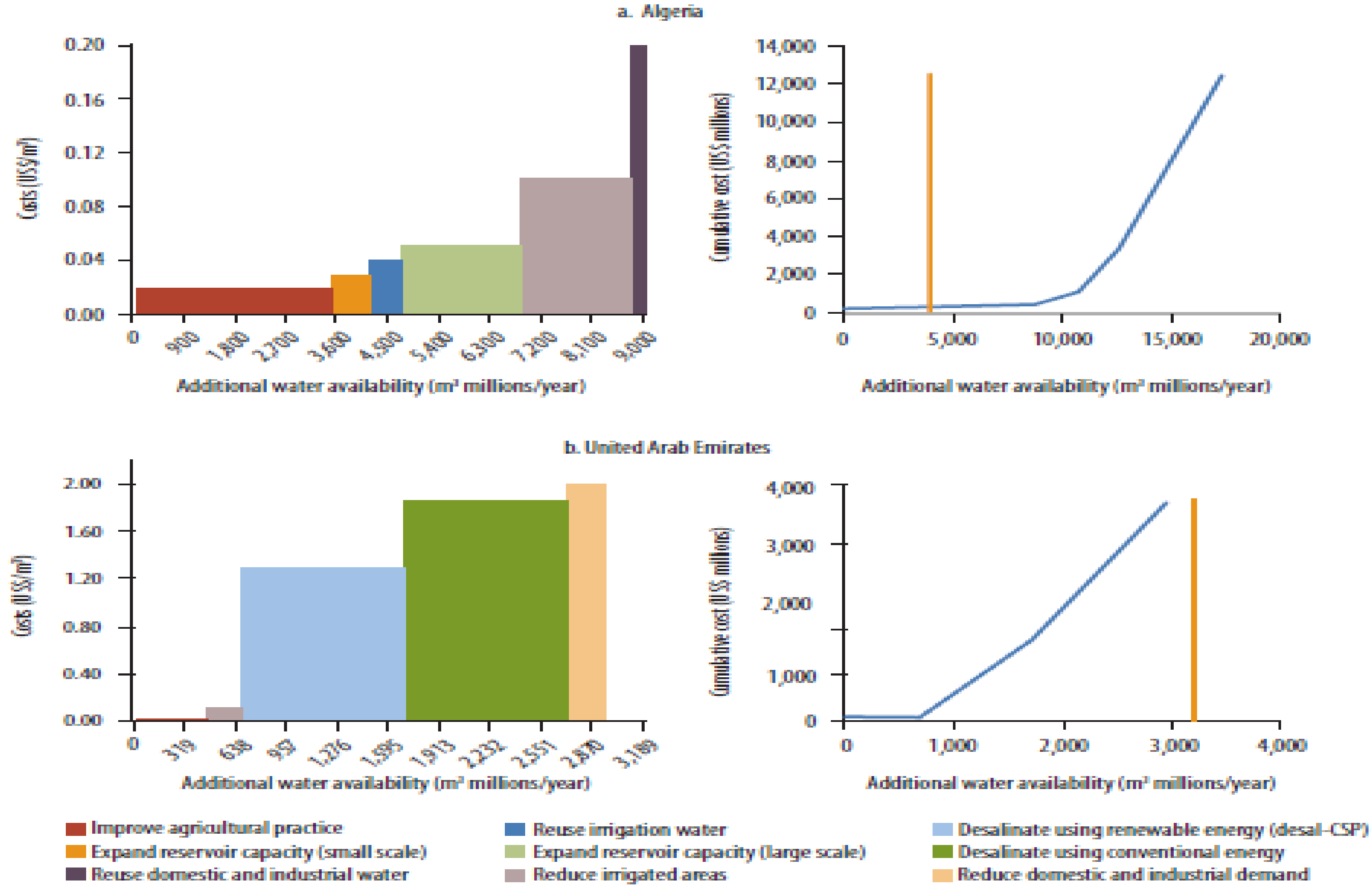
Components of the Full Cost of Water



Source: Agarwal et al. 2000.

Water adaptation costs (3)

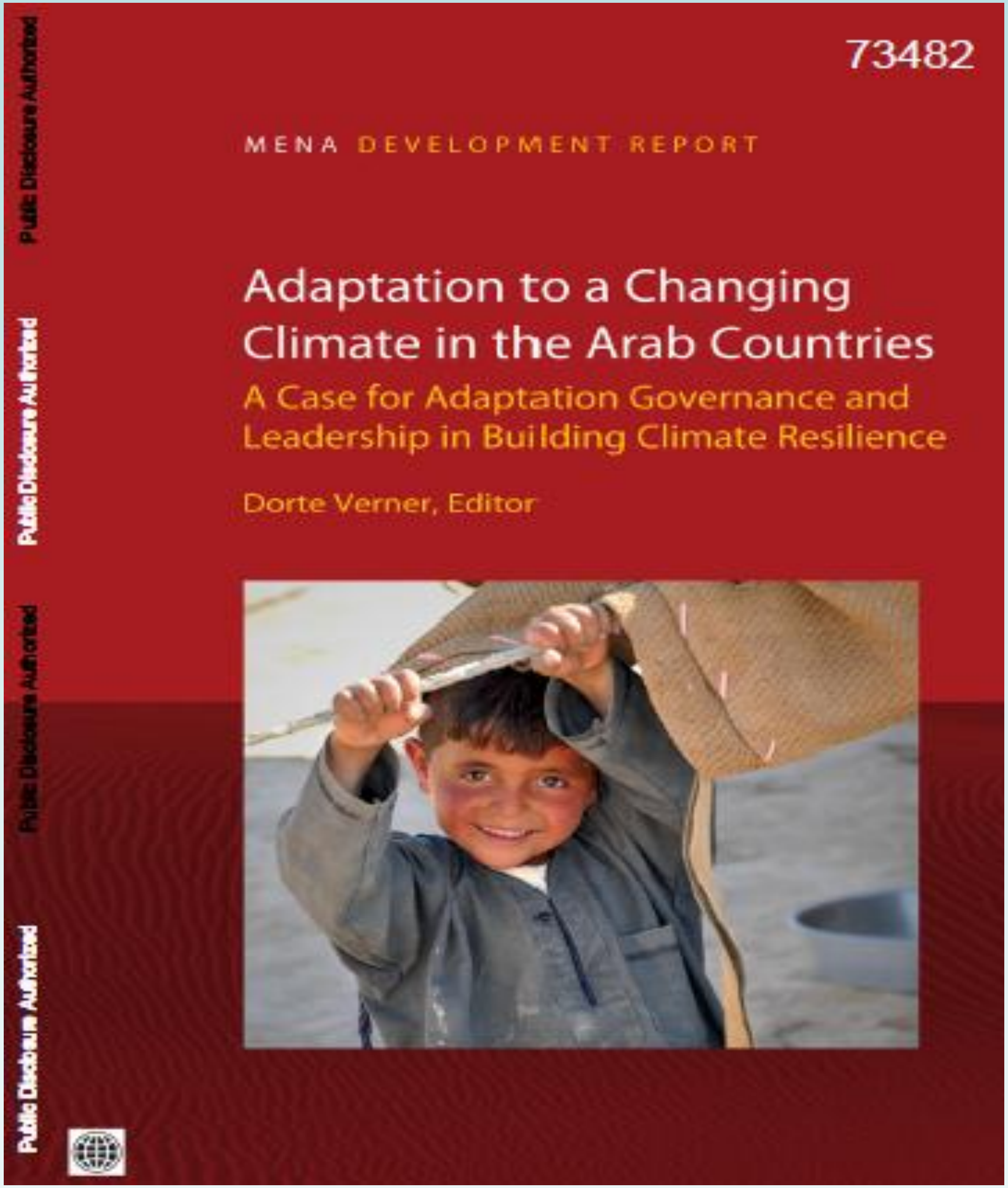
Water Marginal Cost Curves for Algeria and the United Arab Emirates



Source: World Bank 2012. [[AQ: correct reference?]]

Note: Not all measures are illustrated because of varying applicability at country level. "Desal-CSP" denotes desalination using concentrated solar power.

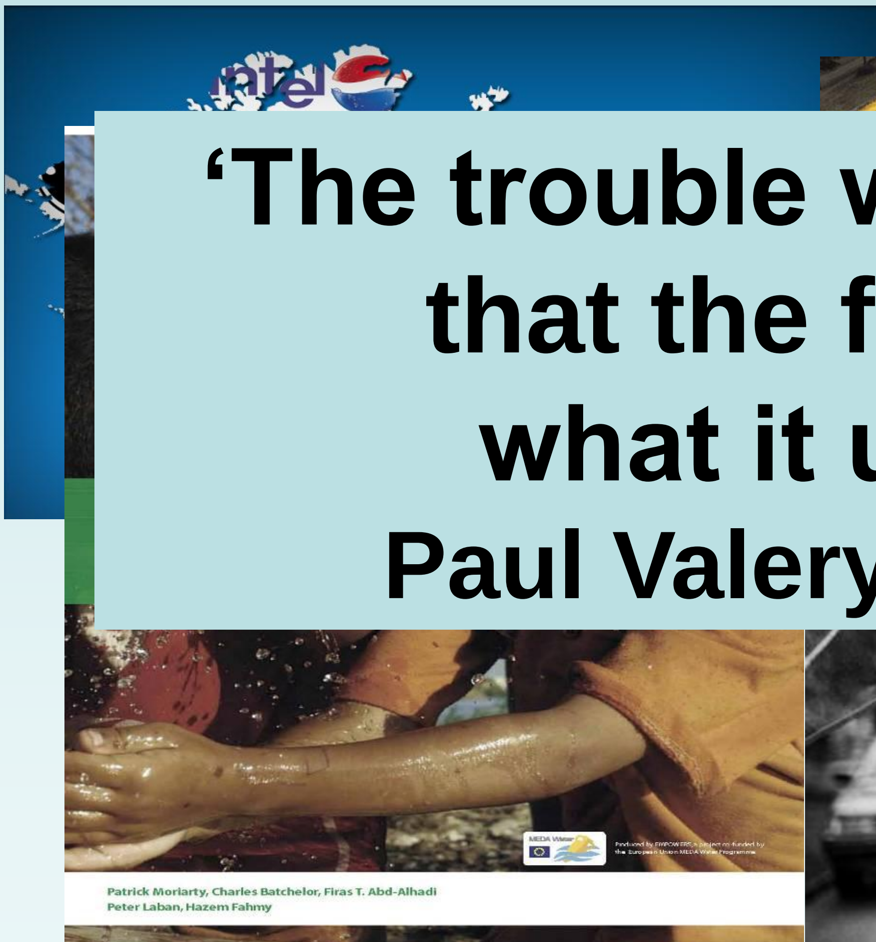
Water adaptation costs (4): source

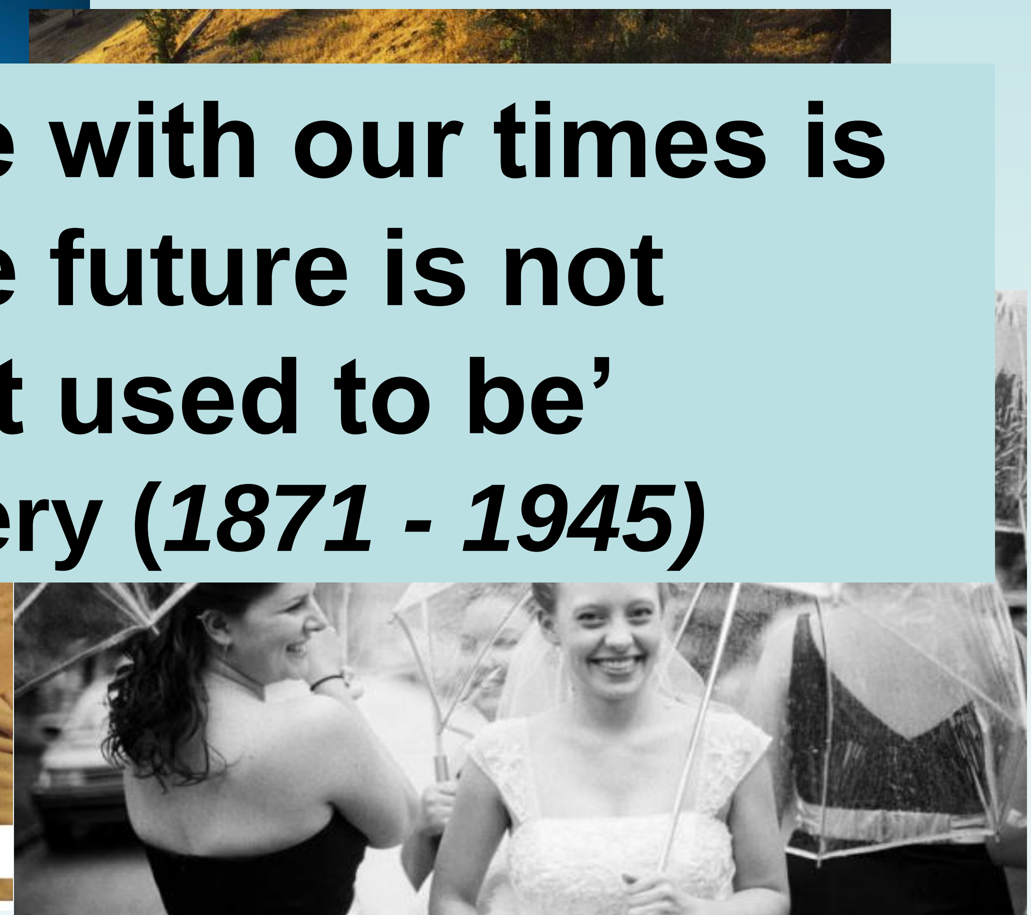


Groundwater Governance in the Changing World

‘The trouble with our times is that the future is not what it used to be’

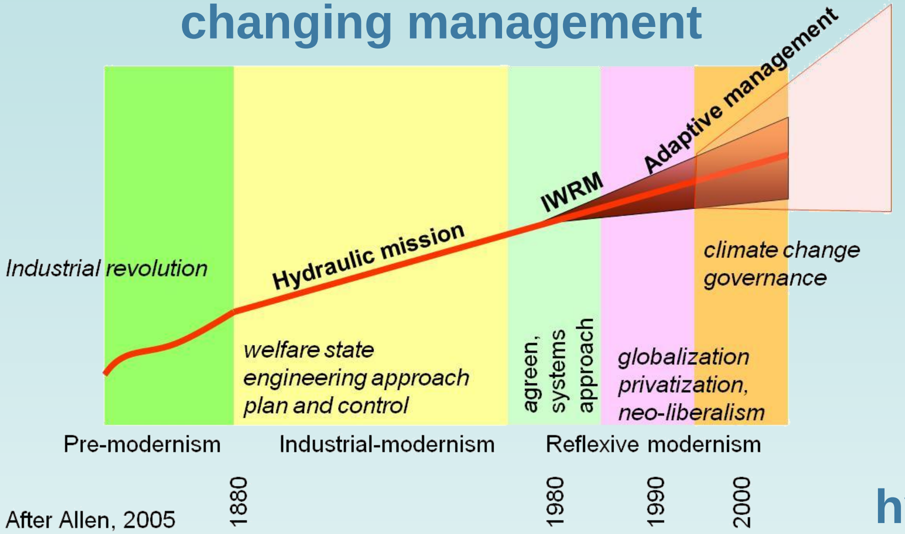
Paul Valery (*1871 - 1945*)

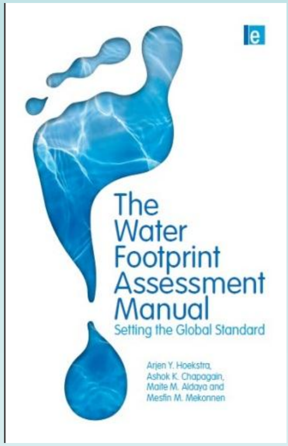




Groundwater in the Changing World

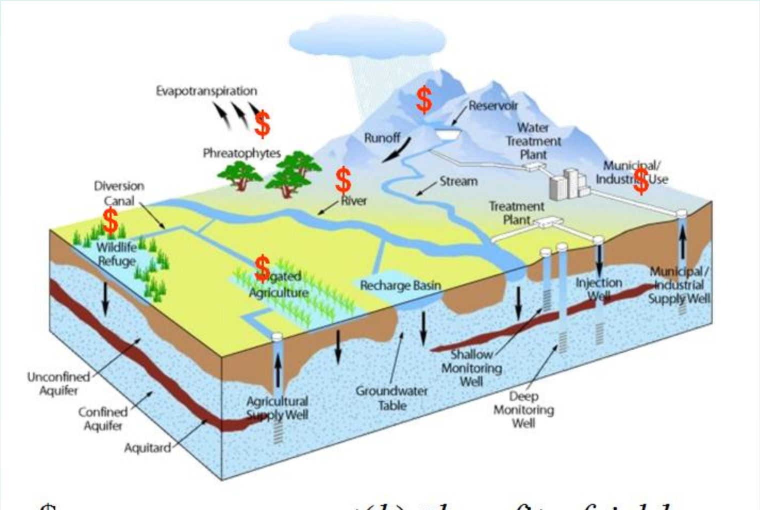
changing management





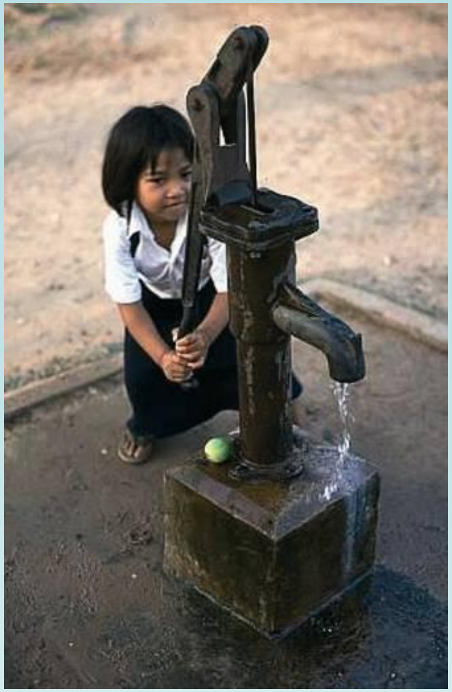
hydro-economic modeling

serious gaming



$$\$_{irrigation} = pump\cos t(h) + benefits of yield$$

International Groundwater Resources Assessment Centre



1. IGRAC's aim: to be one of your main portals to groundwater knowledge.

2. Sharing experiences with information selection and sharing is meta-information, which can help you to solve your Groundwater Governance issues.

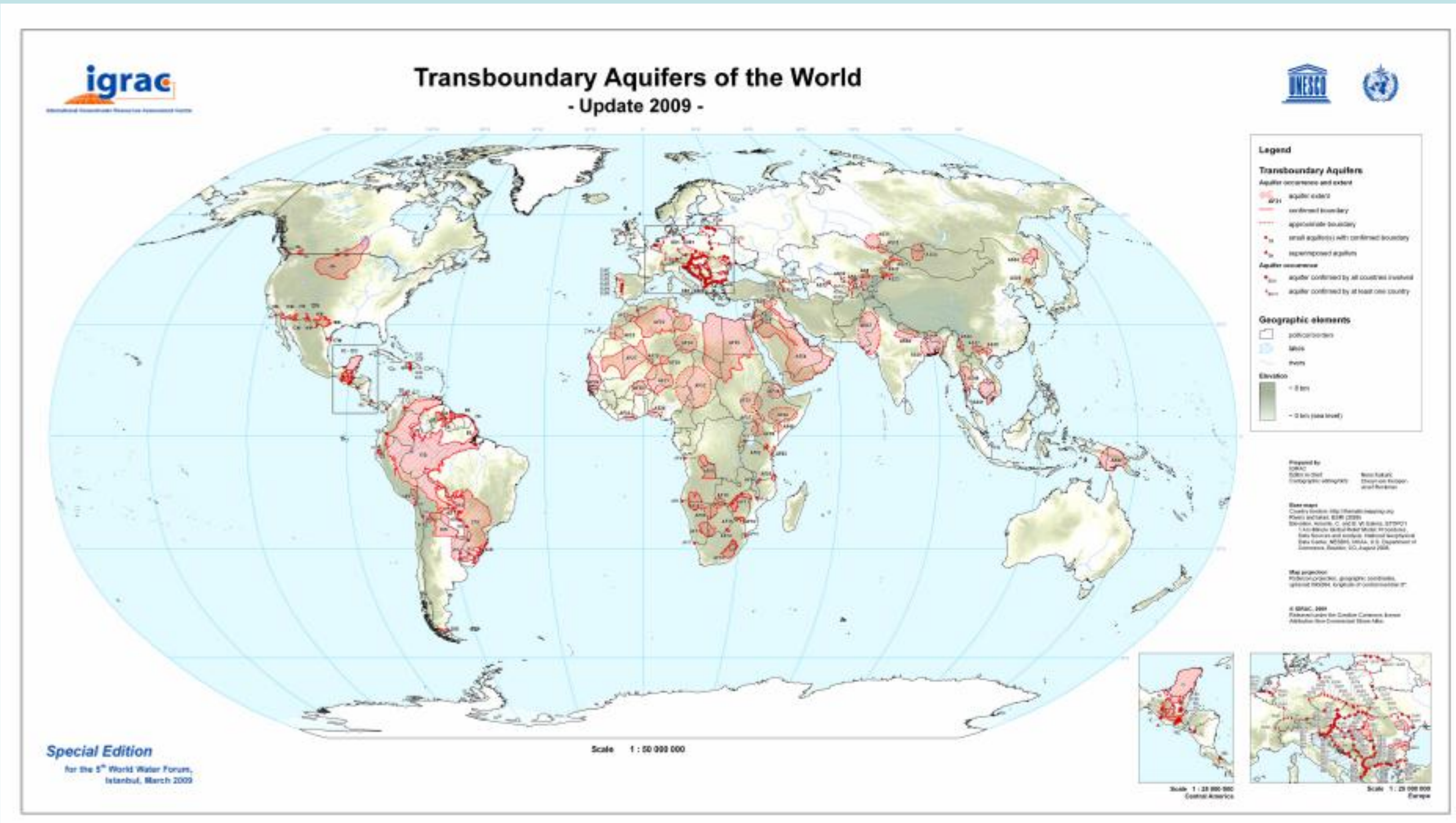
3. So: don't hesitate to contact us.

Groundwater from Global Perspective

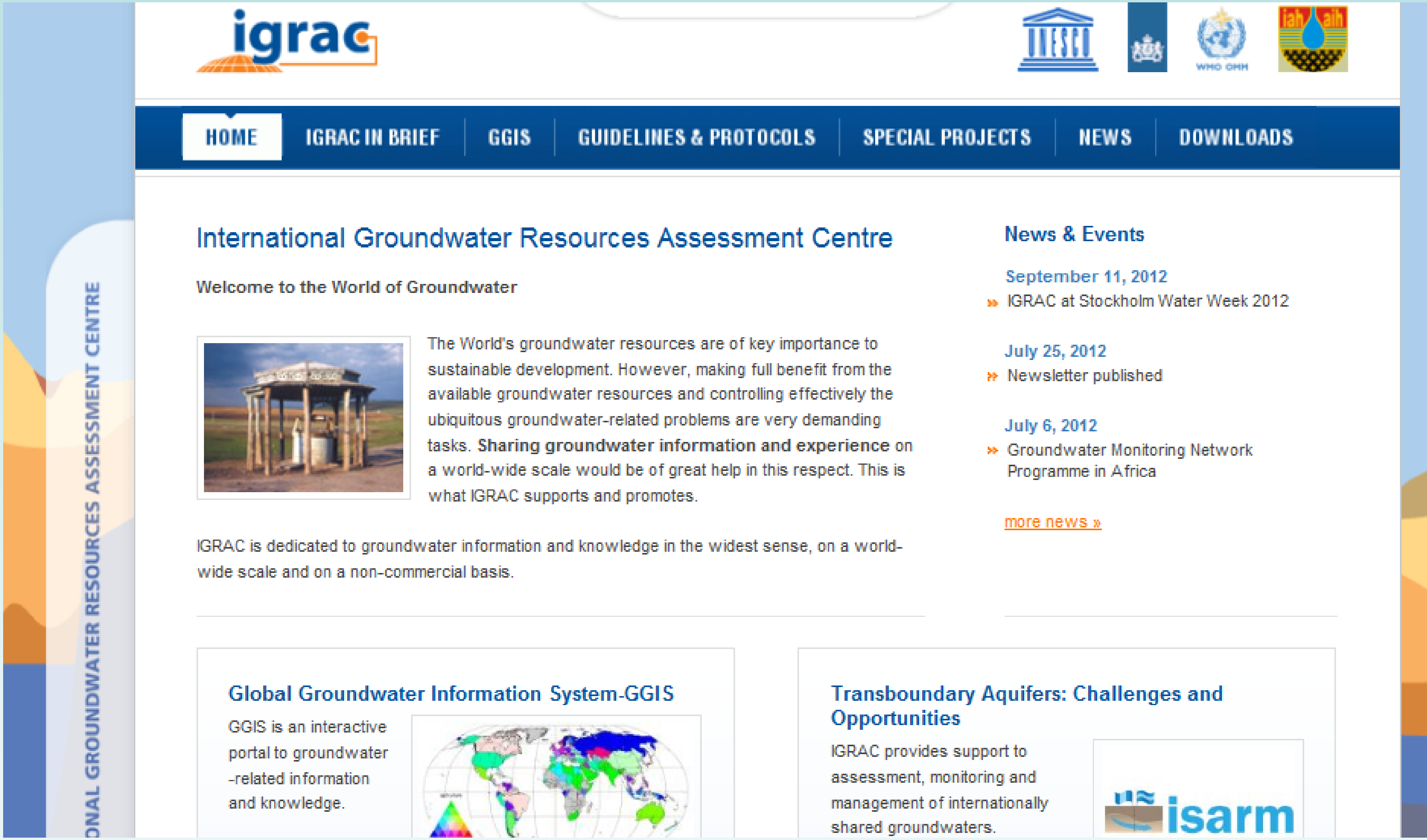
- IGRAC - International Groundwater Resource Assessment Centre is (since 2003) UNESCO and WMO groundwater centre
- IGRAC facilitates and promotes global sharing of information and knowledge required for sustainable groundwater resources development and management
- Focused on information and knowledge management, transboundary aquifer assessment and groundwater monitoring
- Receives financial support from the Government of The Netherlands

- In-house partner of UNESCO-IHE in Delft, The Netherlands

TBAs of the World - 2012



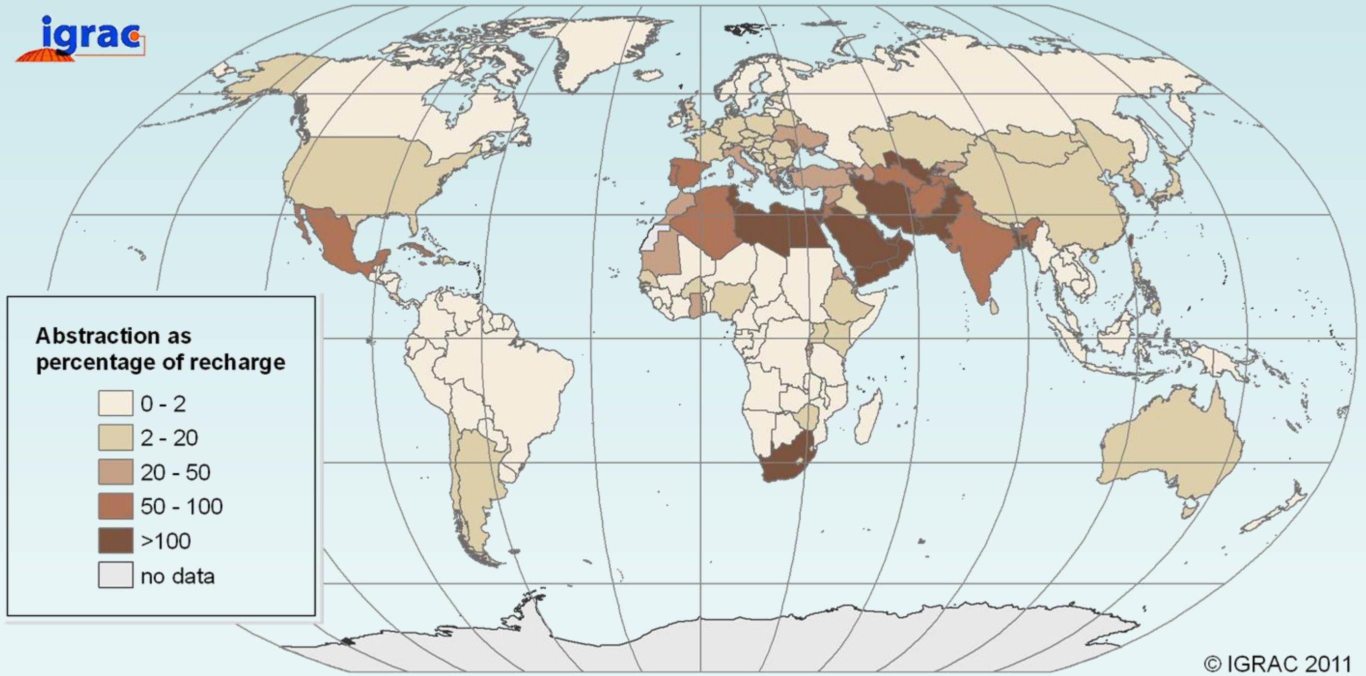
IGRAC Portal



www.un-igrac.org

Global Groundwater Assessment

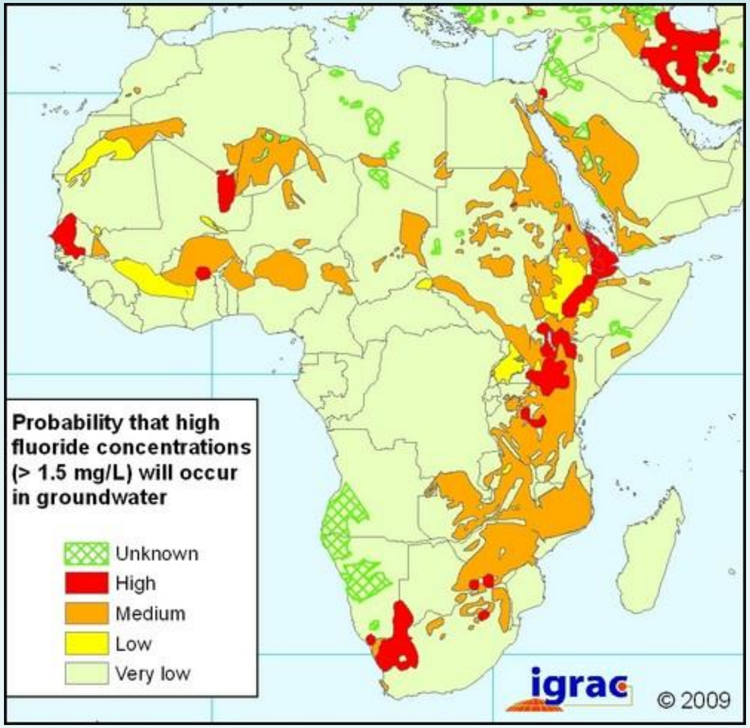
- Regular contribution to the **World Water Development Report** (WWDR) as an orderly insight into the state of global groundwater resources



providing information - building the groundwater case

Global Groundwater Assessment

- Global Inventory of MAR - **Managing Aquifer Recharge**, together with many partners
- Assessment of **Arsenic and Fluoride** worldwide



Groundwater Governance

- is about ‘**fair**’ decision-making
- includes notions of transparency, accountability, inclusiveness, demand-responsiveness…
- in which **equal access** to various kinds of sufficient groundwater data/information is crucial

- **Activities of IGRAC**:
  - Contributes to the GEF **Groundwater Governance** project
  - Process support to TBA mapping activities
  - Development and use of appropriate tools to address governance issues
  - Answers your questions

IGRAC Ambitions

- Continue to provide an independent content and process support to the assessment, monitoring , management and governance of internationally shared groundwater resources
- A truly focal place & sharing hub for the international groundwater community
- Global Groundwater Information System widely used by specialists and public
- Global Groundwater Monitoring Network set up and providing data for
- Global Groundwater Assessment (in the changing world), and
- Transboundary Aquifer Assessment

UNESCO-IHE and IGRAC

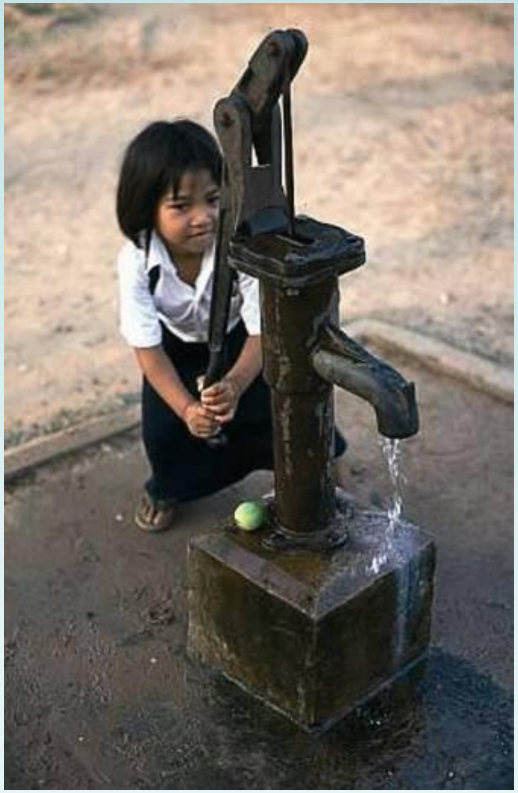
- We belong to the same **UNESCO** family!
- Large **international networks** with focus on developing world
- Water education and research (UNESCO-IHE) is very much **complementary** to (ground)water information sharing, monitoring and assessment.

Opportunities

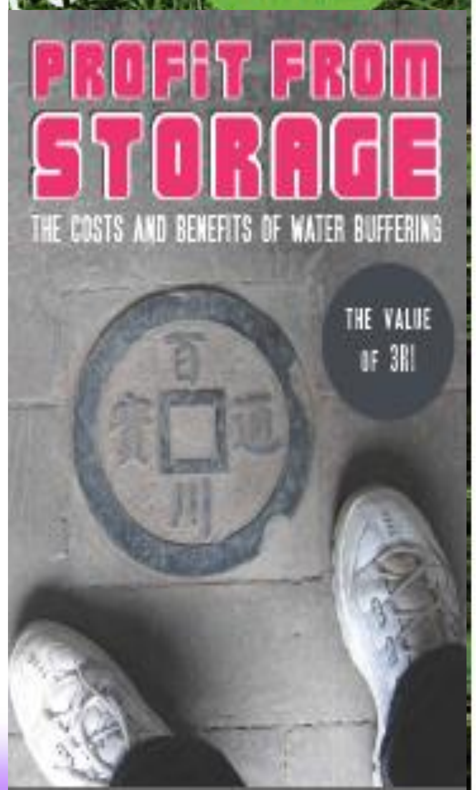
- IGRAC for UNESCO-IHE staff: Joint **acquisition**, development of ideas and **proposals**, project **execution**
- IGRAC for UNESCO-IHE participants: **join IGRAC groundwater activities or spread the word!**
- …we are open for new ideas & initiatives

Closing remarks

- **Conventional water resources are not always feasible to supply rural communities.**
- **Water shortages can for a large part be solved by storing excess water during wet seasons and making it available during dry seasons.**
- **Water storage in the subsurface has many advantages over surface water storage.**
- **Everybody has the right to a BUFFER**



igrac



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RAIN
BGR
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UNESCO
Federal Ministry for Economic Cooperation and Development
World Agroforestry Centre
PARTNERS VOOR WATER
SearNet
GW-MATE

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MAIN MESSAGES

1. **Buffering is an ancient answer to crises.**

2. **Groundwater is a natural buffer, use it wisely.**

3. **Period of last 60 years of international MAR-experiences offers opportunities for future cooperation in practical and research projects.**

Thank you for your attention

Questions?

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