The 21st Century Water Quality Challenges for Managed Aquifer Recharge

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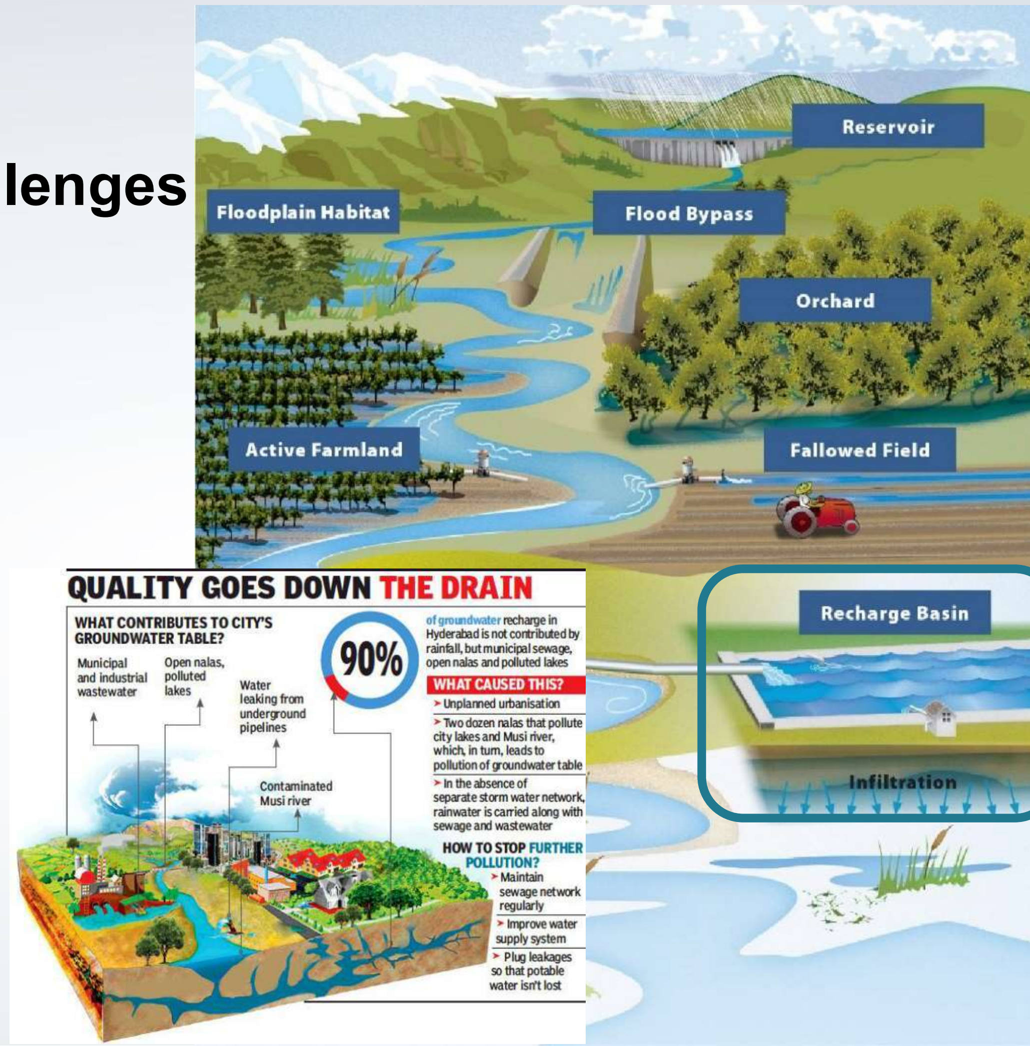
Water Resources Research Center of U Arizona Brown Bag Webinar

2023.01.18

Outline

Incidental/Un-Managed Recharge Pollute Groundwater in Farms and Cities

I. 21st Century Water Quality Challenges for Managed Aquifer Recharge
II. Reasons for MAR regulations
III. Improving MAR Governance
  1980 Arizona
  2009 Australian Guideline
  2014 California
  2017 EU Min qual rpt



Managed aquifer recharge (MAR), also called groundwater replenishment, water banking and artificial recharge, is the ***purposeful*** recharge of water to aquifers for **subsequent recovery or environmental benefit**.

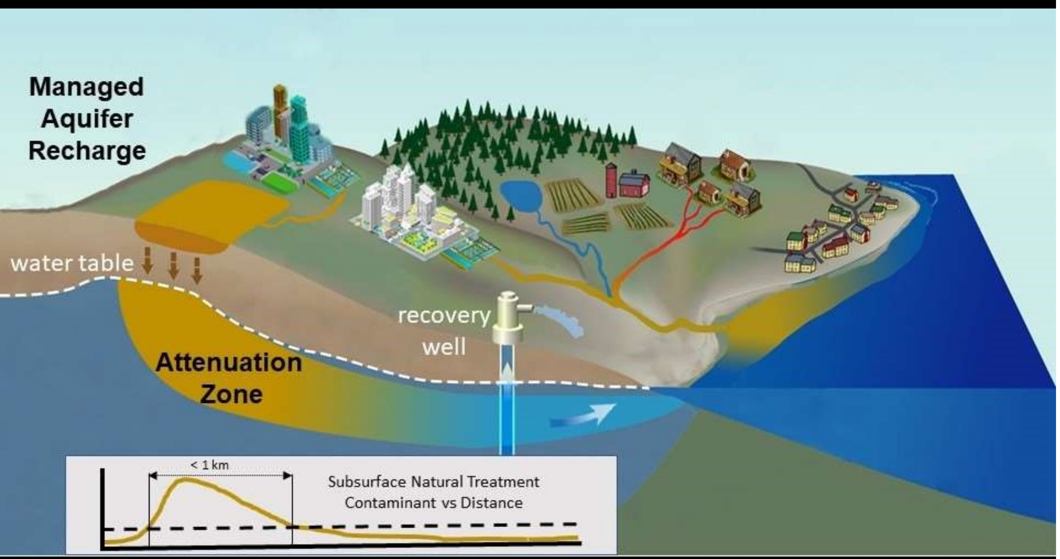
----- IAH-MAR Commission

Towards a Risk-Based Regulatory Approach

- Challenges in Governance:

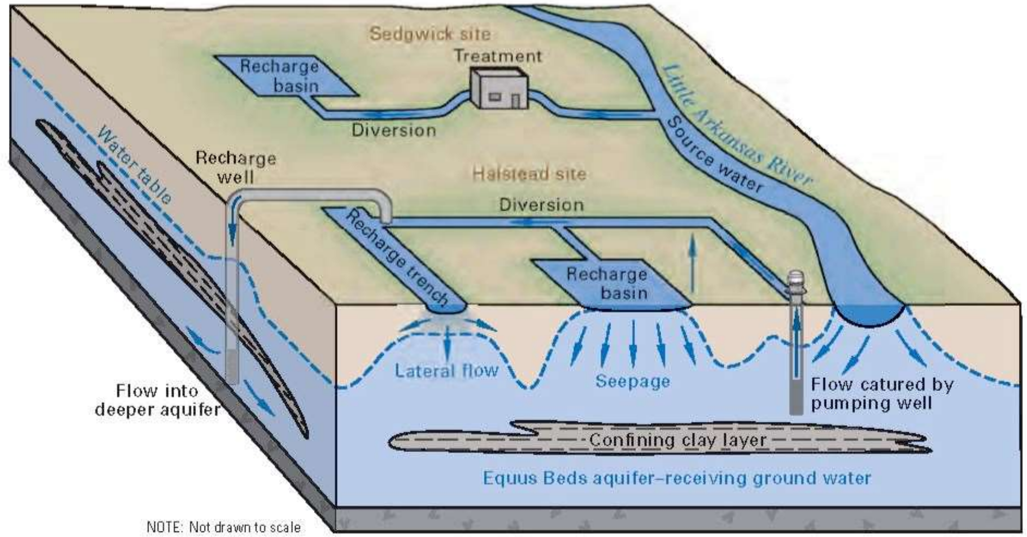
water rights and water quality risks

Dillon, P., W. Alley, Y. Zheng, and J. Vanderzalm (eds.), 2022, Managed Aquifer Recharge: Overview and Governance. IAH Special Publication. https://recharge.iah.org/ ISBN 978-1-3999-2814-4



Zheng et al. (2022) The 21st Century Water Quality Challenges for Managed Aquifer Recharge: Towards a Risk-Based Regulatory Approach. Hydrogeol J

Water Resource Infrastructure



Surface:

- *Recharge Basin/Ditch/Pond*
- *Soil Aquifer Treatment (SAT)*
- *River Bank Filtration (RBF)*
- *In-Channel Modification*

Sub-surface:

- *Recharge Well*
- *Aquifer Storage Recovery (ASR)*

Source Water:

- *Natural & Drinking Water*
- *Storm & Flood Water*
- *Recycled Water & Blends*

https://recharge.iah.org/unesco-iah-mar-publications

- ✓ **Cost-benefit** and **sustainability analysis** of 28 diverse Managed Aquifer Recharge (MAR) cases in operation over many years;
- ✓ Irrefutable evidence that MAR produces a wealth of benefits from **integrated management** of a wide range of **conventional and un-conventional water resources**, paving the way for global adoption to achieve sustainable development goals for water.

5 North America cases:
Orange County, California; Platte Riv. Nebraska; Hilton Head Island, South Carolina; Central Arizona; San Luis Río Colorado, Sonora, Mexico

Zheng, Y., Ross, A., Villholth, K.G. and Dillon, P. (eds.), 2021. Managing Aquifer Recharge: A Showcase for Resilience and Sustainability. Paris, UNESCO, pp379.

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Part I

21st Century Water Quality Challenges for Managed Aquifer Recharge

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21st Century Water Quality Challenges

Novel chemical and biological entities ➡ unsafe operating space?

Rockström
Nature 2009

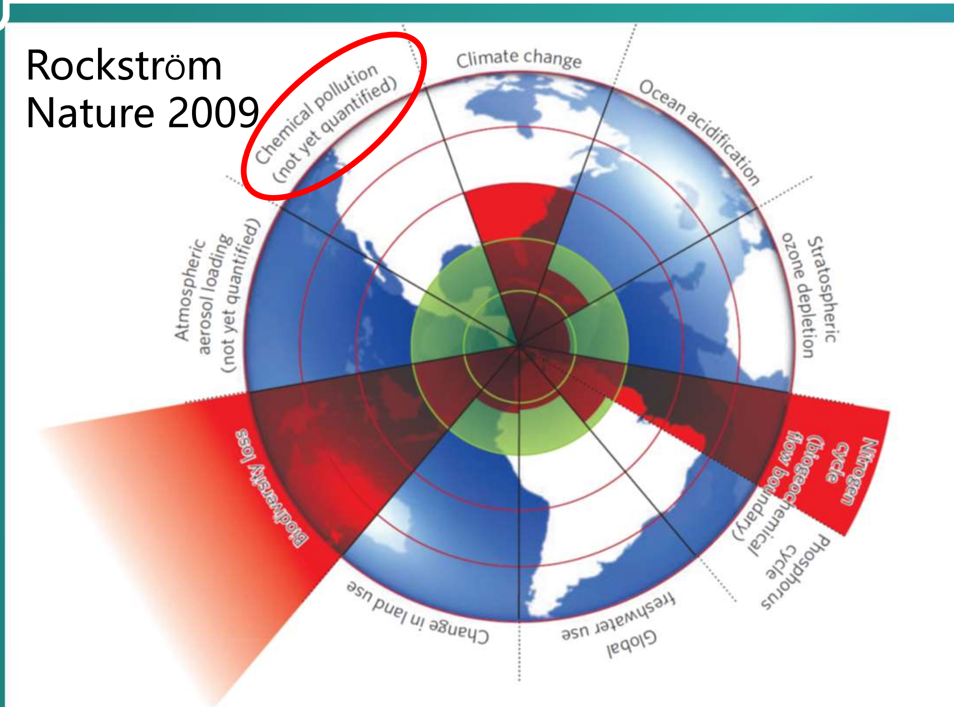
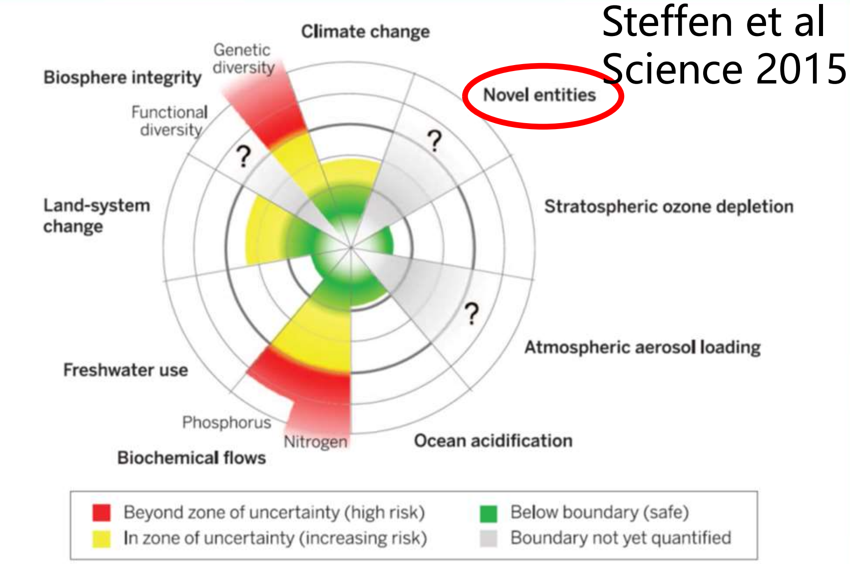


Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

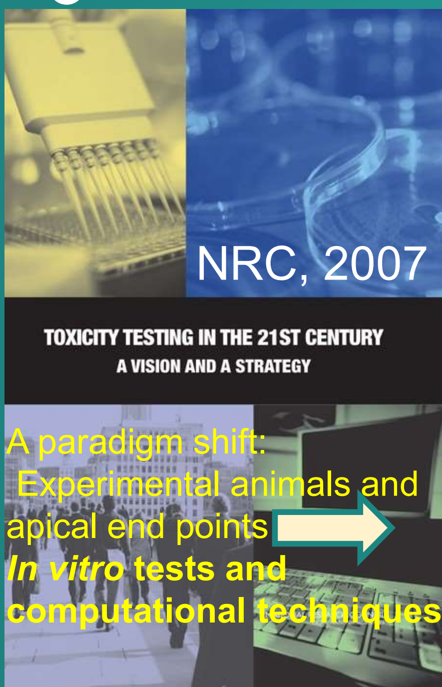
Steffen et al
Science 2015



Current status of the control variables for seven of the planetary boundaries. The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone. The planetary boundary itself lies at the intersection of the green and yellow zones. The control variables have been normalized for the zone of uncertainty; the center of the figure therefore does not represent values of 0 for the control variables. The control variable shown for climate change is atmospheric CO_2 concentration. Processes for which global-level boundaries cannot yet be quantified are represented by gray wedges; these are atmospheric aerosol loading, novel entities, and the functional role of biosphere integrity.

21st Century Water Quality Challenges

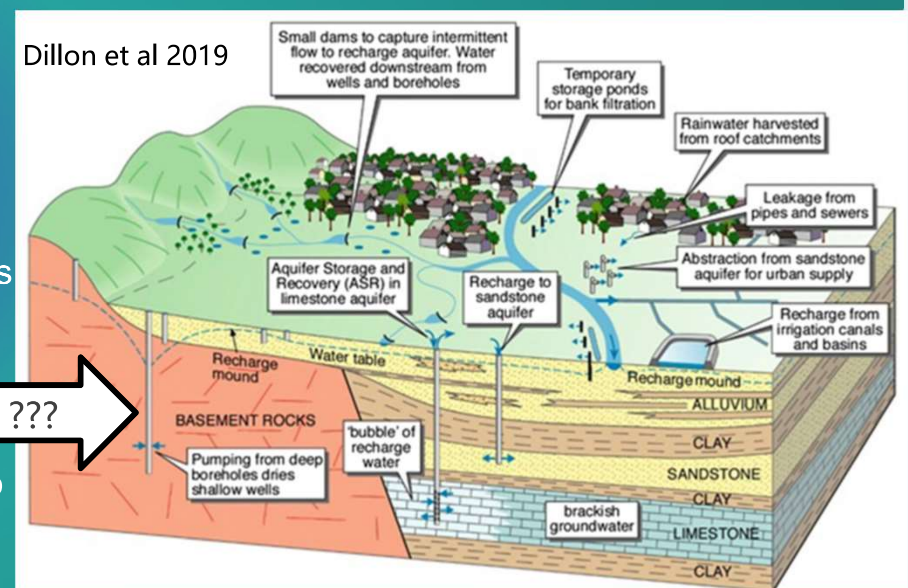
Mismatch in goals and scales of toxicology based environmental health risk assessment and systems approach based risk assessment



Validity of Toxicity Assessment: Metabolism

in vitro tests problems:
(a) modeling **human metabolism**
(b) maintaining tissue-specific function *in vitro*
(c) selecting an appropriate **xenobiotic** metabolizing system
(d) keeping enzyme activity stable over time
(e) the adverse effects to toxicity-indicator cells of subcellular metabolizing fractions
(f) the testing of **mixtures** of chemicals that might require different enzyme systems
(g) the inactivation of exogenous biotransformation systems, due to exposure to certain solvents and test substance

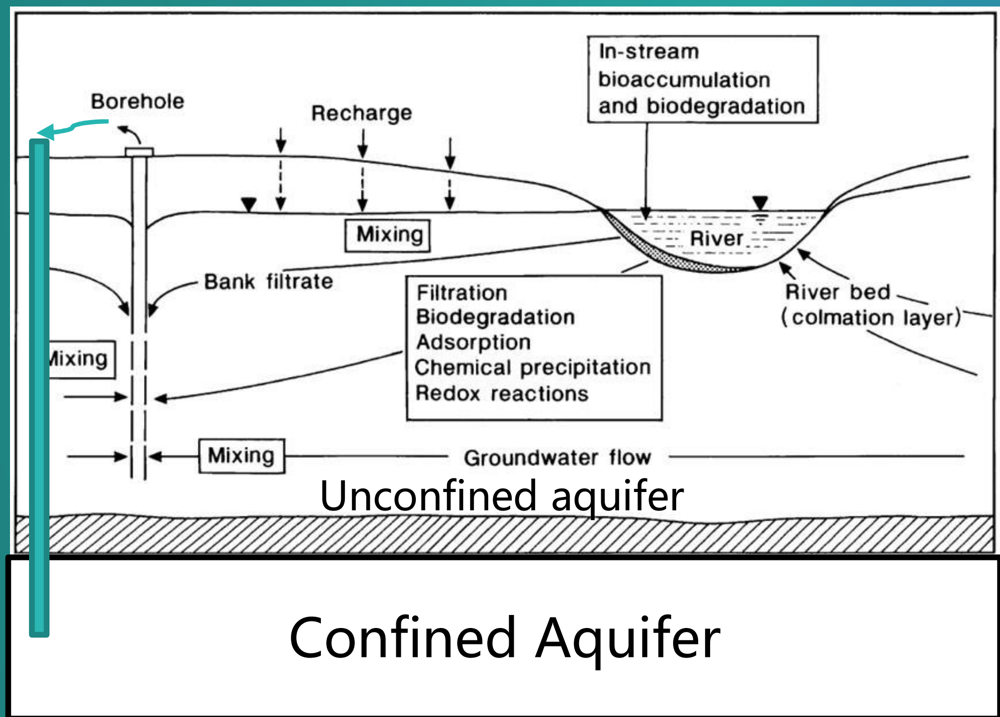
???



Priority: Human health>aquatic organisms>microbes>groundwater>soil?

21st Century Water Quality Challenges

Uncertain human and ecosystem health risks from novel entities



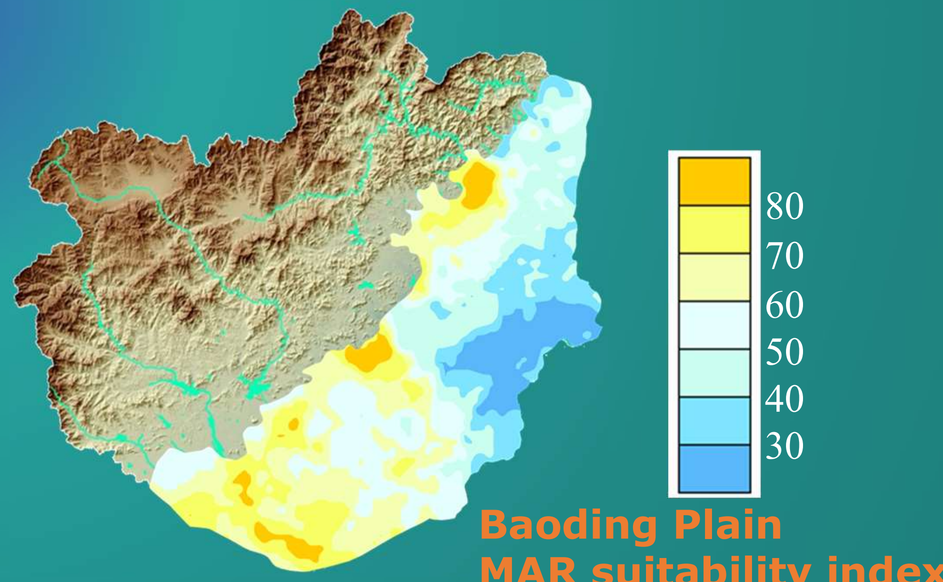
https://www.mar-china.geus.dk/

SMART

Hellauer et al (2018) J Hydrol
Redox manipulation; Berlin Germany

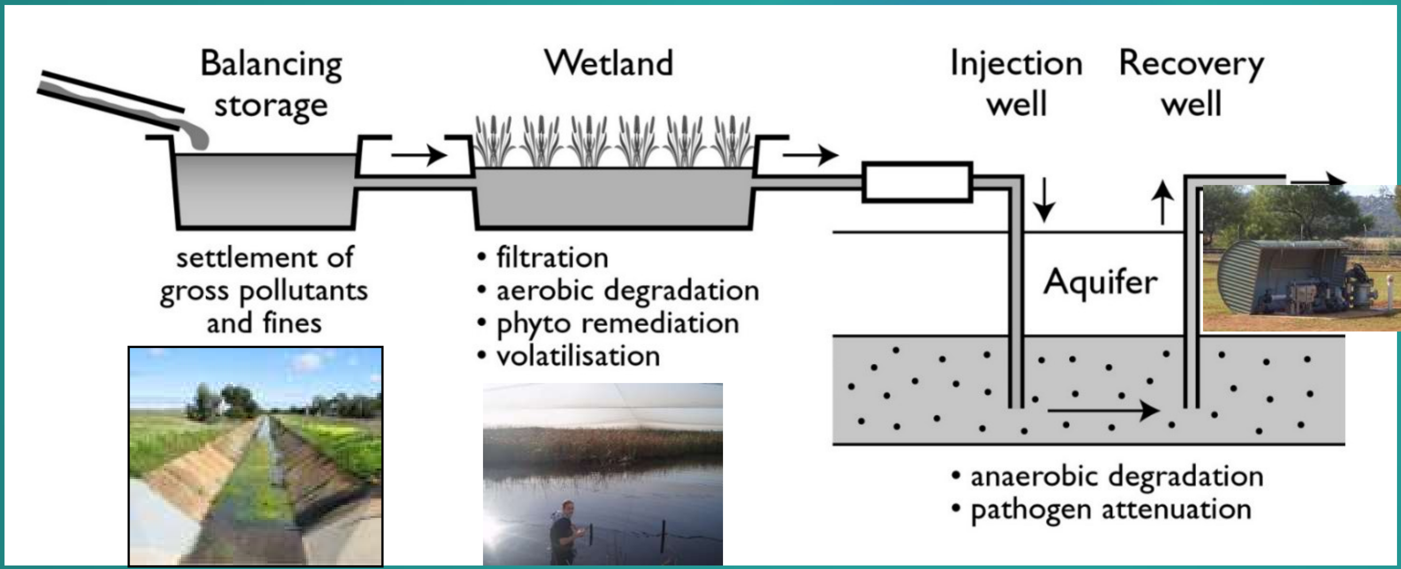
Sequential MAR Technology

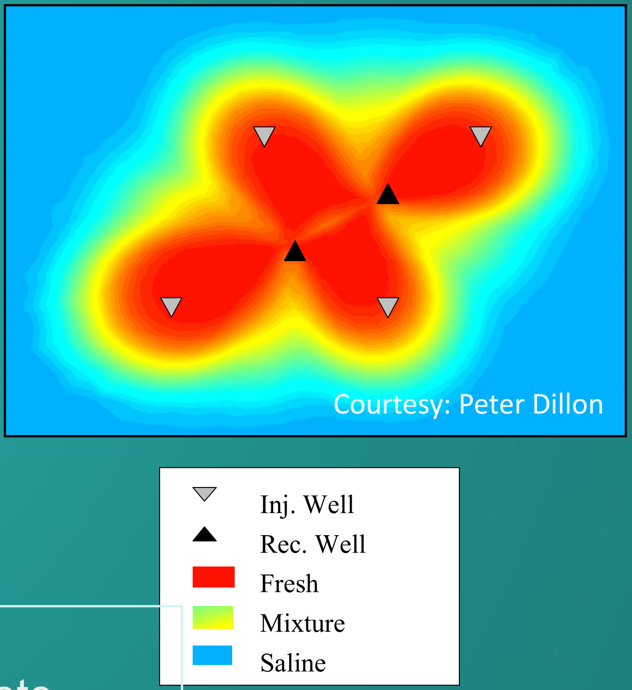
Surface -> unconfined -> confined



21st Century Water Quality Challenges

~ 350,000 chemicals, ~80,000 in frequent use,
>80% with uncertain or unknown toxicity





MAR regulates hydraulic retention time:
log reduction of virus, biodegradation of trace organic contaminants, etc

Page et al (2010) Wat Res

Ma, M. et al (2019) EST; Ma, Y. et al (2010) Wat Res (2021)

Managed Aquifer Recharge in North China Plain

https://www.mar-china.geus.dk/

MAR CHINA

Home | About MAR-China | Field Sites | Modelling

WELCOME TO MAR CHINA

– Managed Aquifer Recharge in the North China Plain

The project will address the potential of utilizing "low value" reclaimed water (treated waste water) and floodwater through Managed Aquifer Recharge (MAR) to replenish the groundwater aquifers in the North China Plain (NCP) region. Our aim is to investigate how MAR can contribute to rehabilitation of groundwater aquifers. This requires an improved knowledge of the treatment and degradation processes occurring during MAR and subsequent storage. In addition, the full potential is best explored using spatially distributed hydrological modelling to quantify the effects of realistic MAR implementation through scenario analysis.

The project aims at three outcomes:

- Development of a knowledge base to access the quantitative aspects of the large scale potential of MAR as a tool for water scarcity alleviation
- Development of a knowledge base to access the water qualitative aspects of MAR in NCP
- Increase the knowledge on MAR among stakeholders, practitioners and policy makers

The aims of the object are linked to three work packages:

- WP1: Integrated hydrological modelling of coupled surface-water and groundwater systems
- WP2: Water quality improvements through managed aquifer recharge in the North China Plain
- WP3: Dissemination of results

News

The MAR-China project group got together in Copenhagen for a workshop at GEUS; August 19-23. 2019.

For more information direct to:
https://www.mar-china.geus.dk/about-mar-china/activities/

The MAR-China project group attended the 10th International Symposium on

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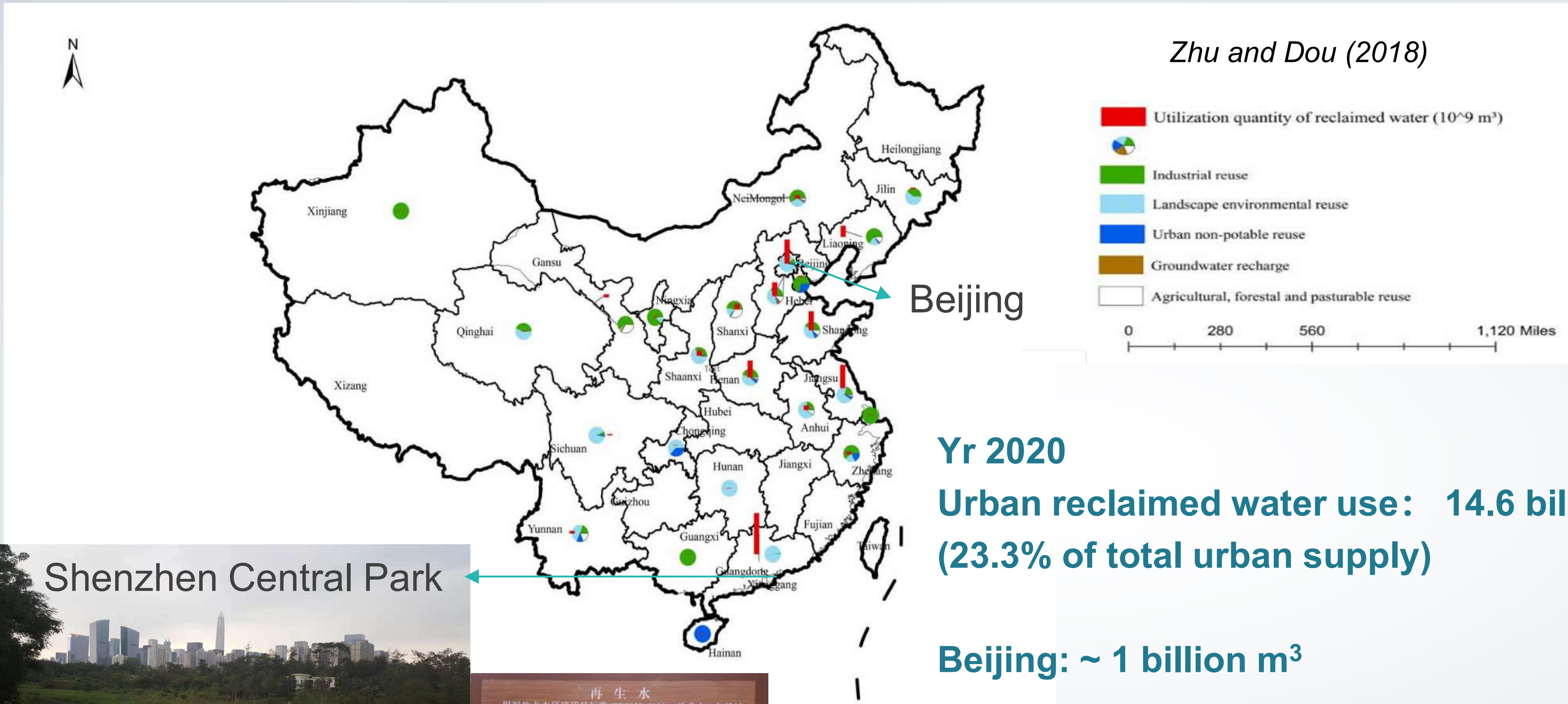
Treated waste water reclaimed for landscaping & env. use



Beijing

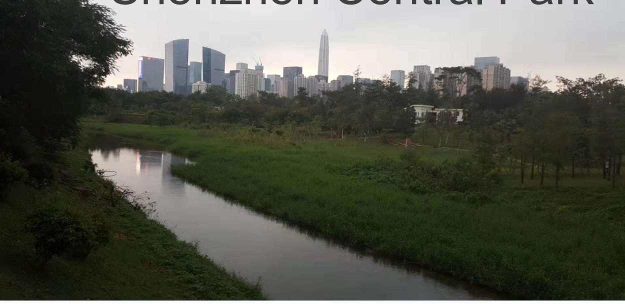
Yr 2020

Urban reclaimed water use： 14.6 billion m^3

(23.3% of total urban supply)

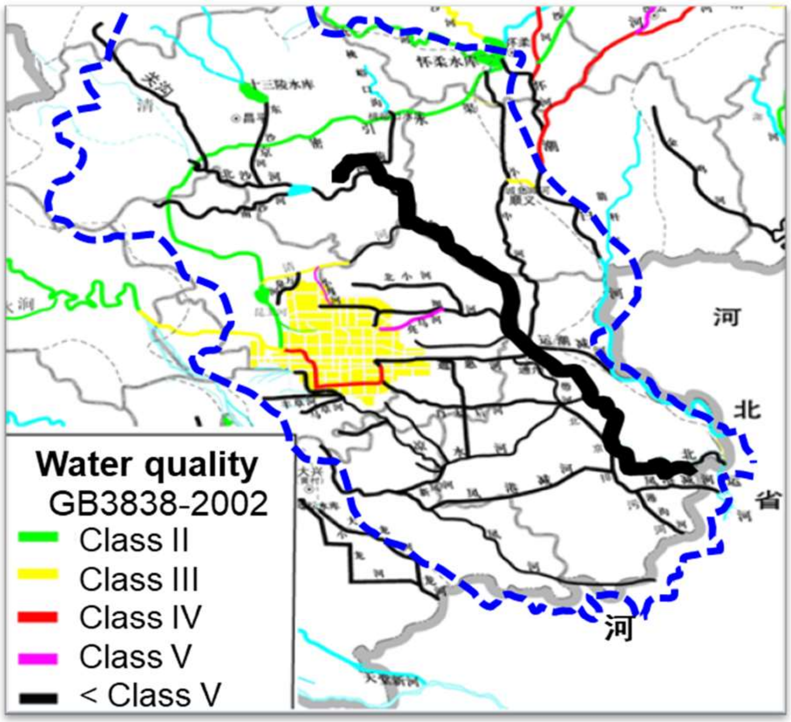
Beijing: ~ 1 billion m^3

Shenzhen Central Park

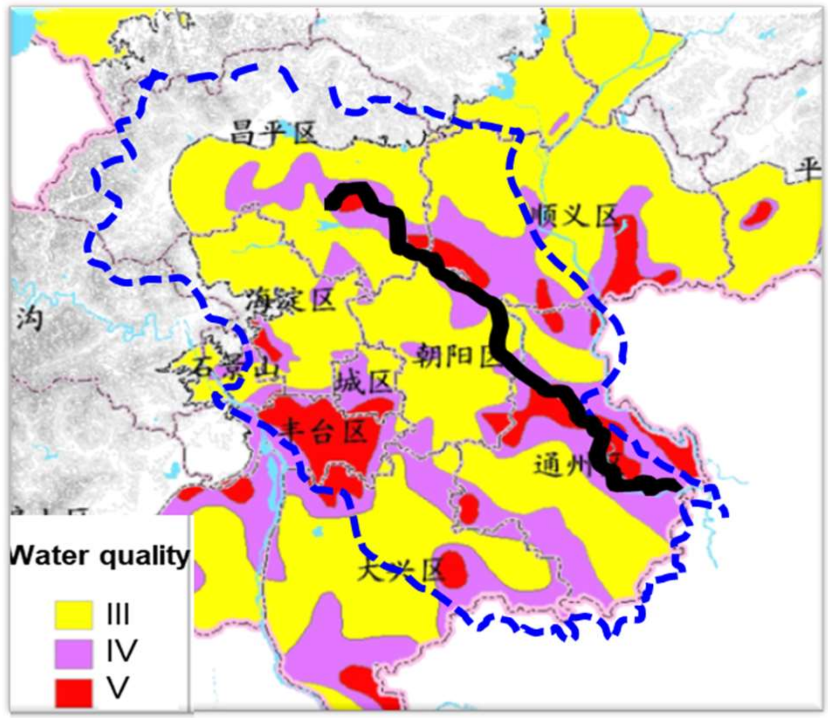


Risks from incidental recharge during environ. reuse

Surface water



Shallow groundwater



Beiyun River in Beijing, the North China Plain: **>90%** of flow is reclaimed water.

(Beijing Institute of Geo-Environment Monitoring 2018&2019)

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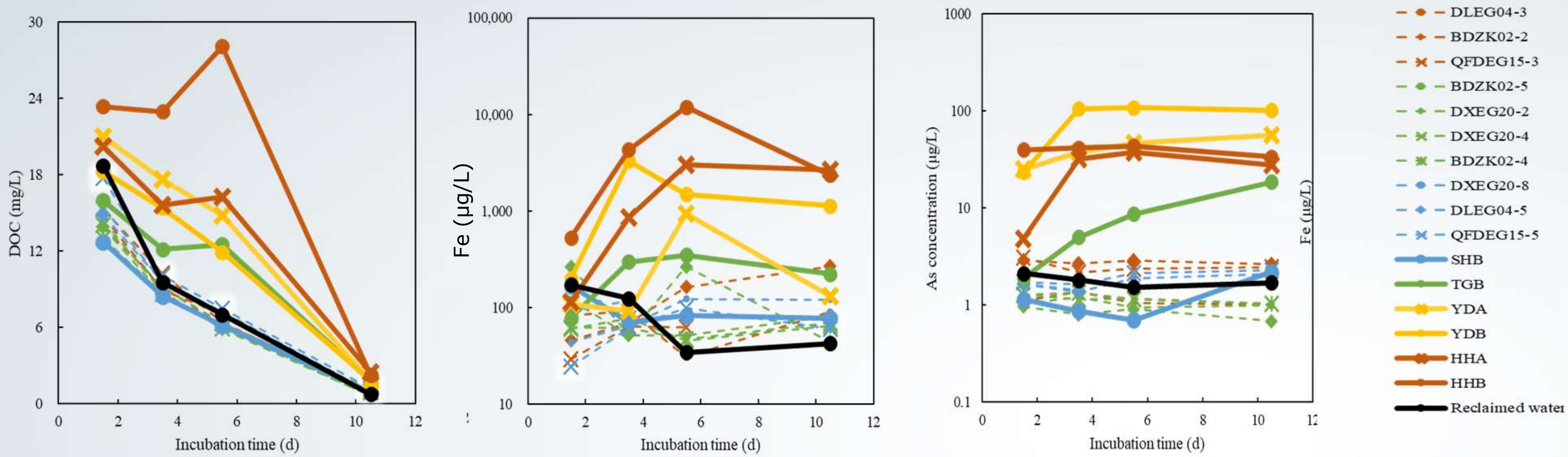
Risk I: Mobilization of Arsenic Revealed by Batch Incubation Experiments

DOC consumption → Fe dissolution → As mobilization



NCP aquifer sediments

Beiyun riverbed sediments

(Yuxia Yang, Master thesis, 2020)

- Five out of six Beiyun organic rich riverbed sediments incubated show > 10 μg/L As released concurrent with Fe mobilization and DOC consumption.
- Consumption of DOC did not trigger much Fe and As release for all 10 organic poor, Baoding Plain aquifer sediment

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Batch and Column Experiment Key Findings

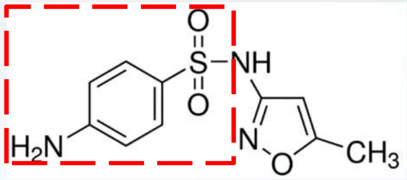
→ Batch:

Redox-dependent biotransformation of sulfonamide antibiotics exceeds sorption and mineralization (Ma et al 2021).

→ Column:

Substrate limitation is associated with slow biodegradation of sulfonamide antibiotics across oxic to anoxic conditions (Ma et al in prep).

Sulfonamides : SMX, SDZ, SMZ



Unknown metabolites/intermediate biodegration products are concerning.

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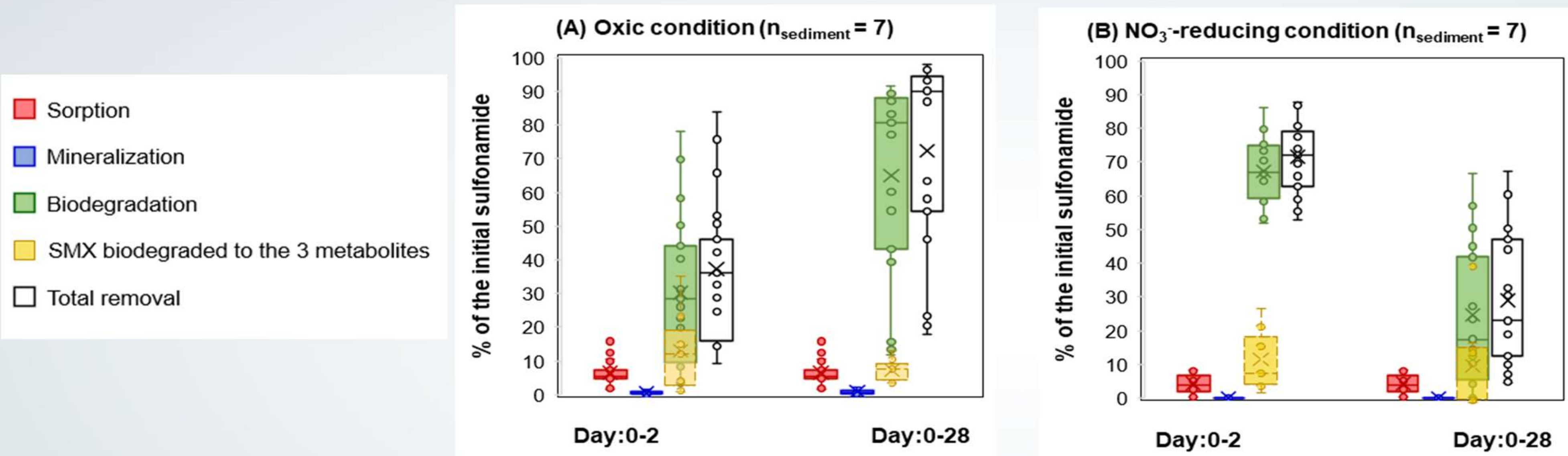
Sulfonamide Removal: biodegration >> sorption > mineralization

- Batch-1: Sorption tests
- Batch-2: Mineralization tests
- Batch-3: Removal tests → Biodegradation

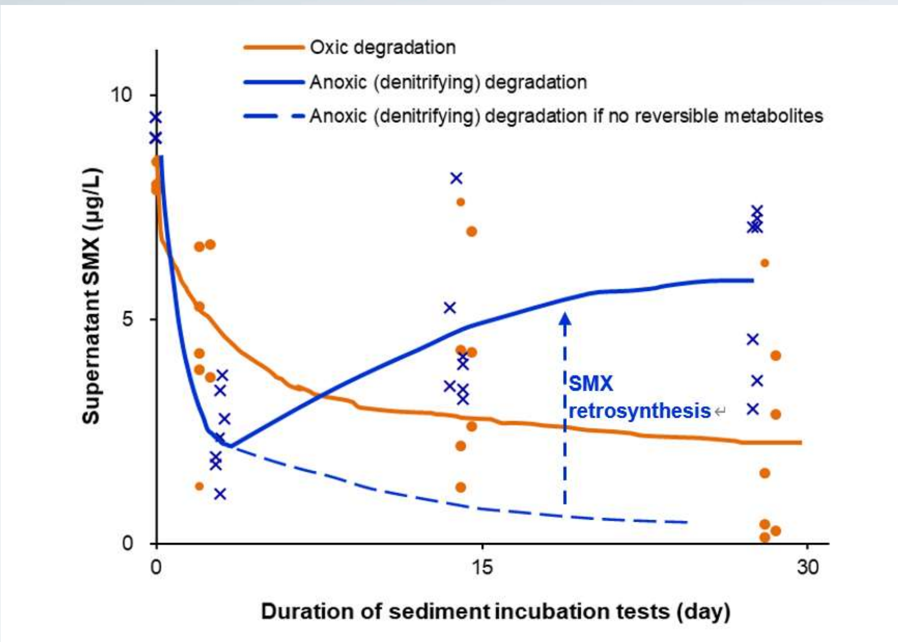


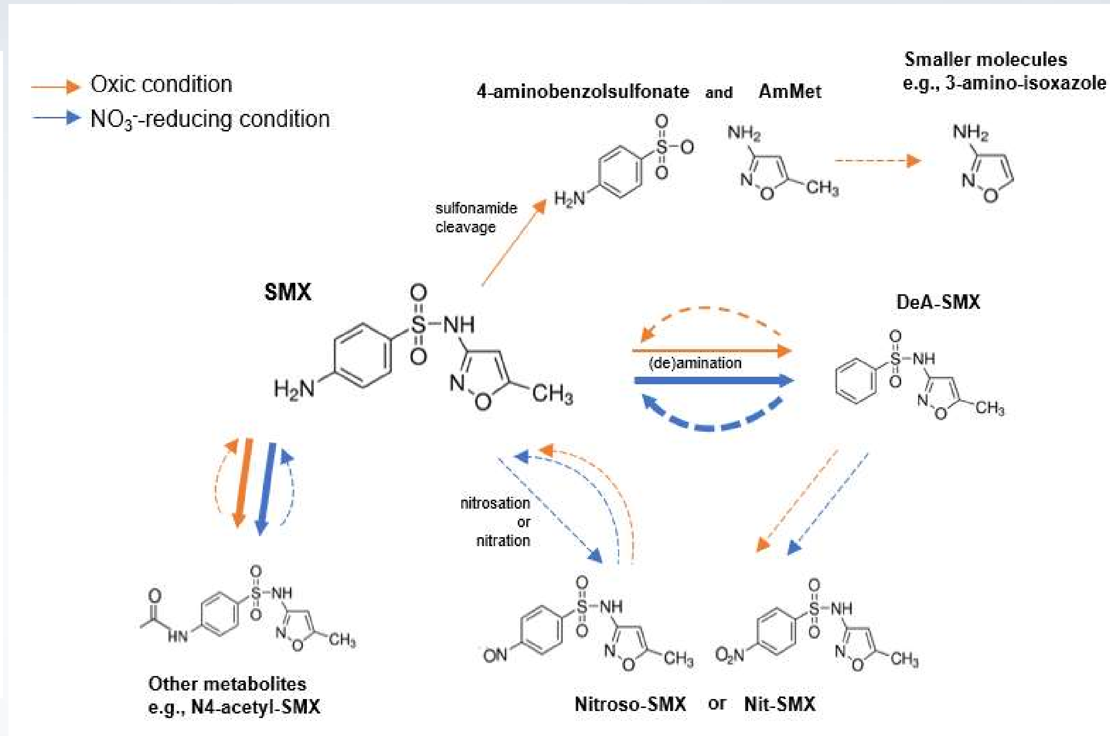
Percentage of removal attributed to sorption, mineralization, and biodegradation during (A) oxic and (B) anoxic (NO_3^--reducing) degradation tests.

(Yunjie Ma et al , Water Res. 2021)

SMX Degradation Kinetics: Oxic > Anoxic

Yunjie Ma et al, Water Res. 2021





The first-order degradation kinetics

$t_{1/2,oxic}$ = 12 ± 11 days

$t_{1/2,anoxic,\ day\ 28}$ = 69 ± 25 days

$t_{1/2,anoxic,\ day\ 2}$ = 1.1 ± 0.3 days

Proposed transformation processes in SMX biodegradation under oxic and anoxic conditions.

In situ experiment $t_{1/2,suboxic/anoxic}$:3.1 ± 0.2 days; 6.5 ± 0.6 days *Meng Ma et al, ES&T, 2019*

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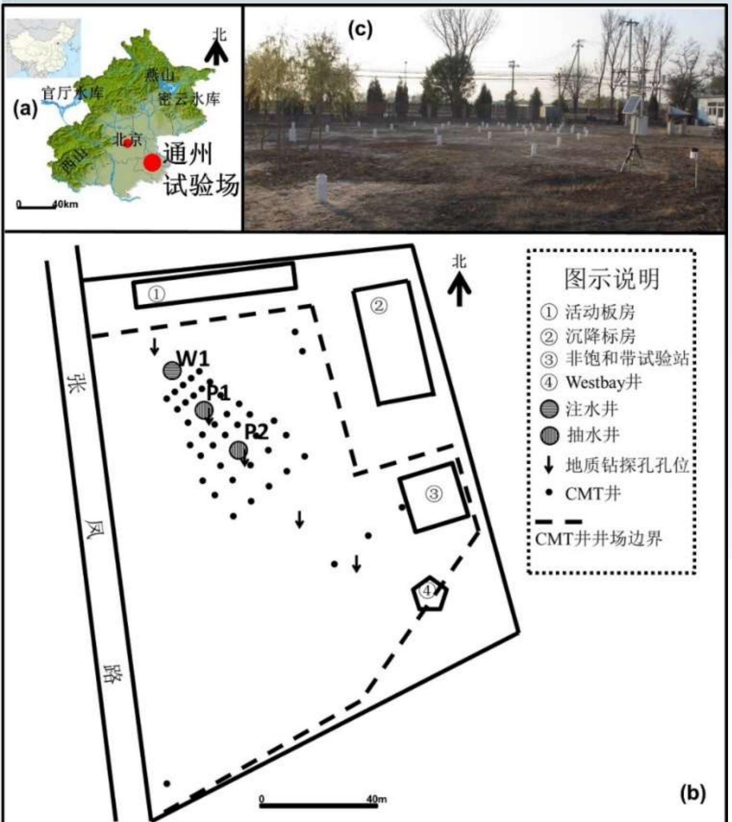
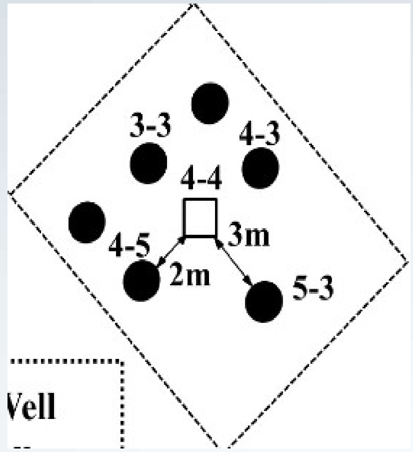
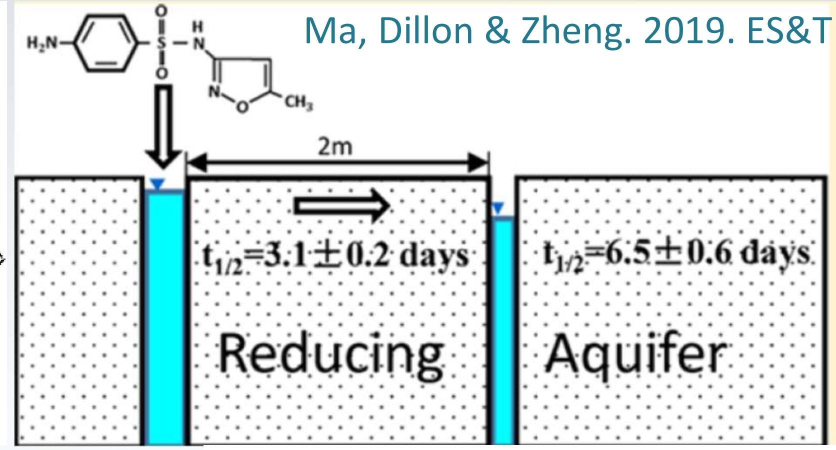
Sulfamethoxazole (SMX) degradation rates through *in situ* experiment

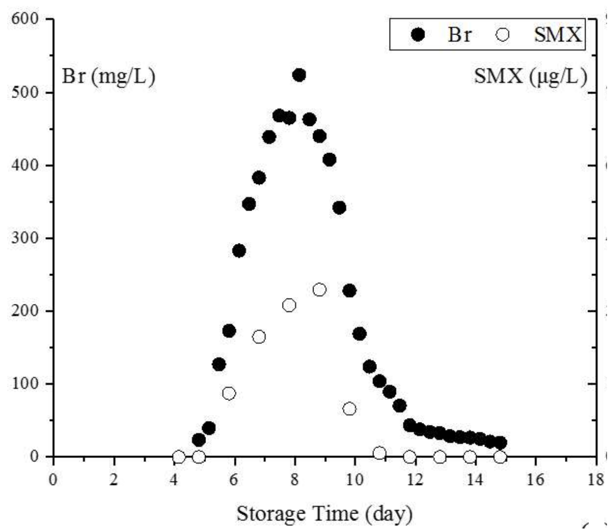




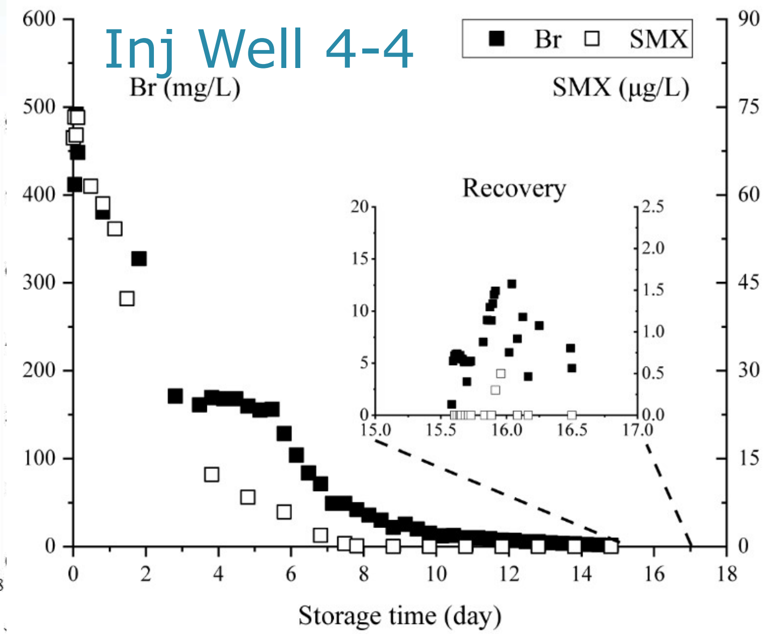
Ma, Dillon & Zheng. 2019. ES&T



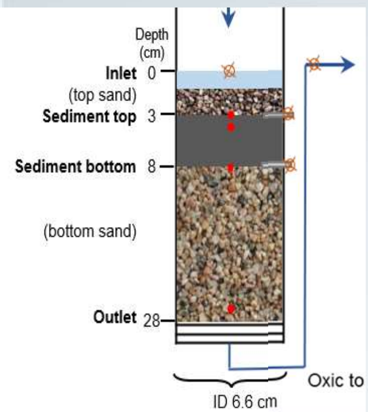
Exp Well 4-5



Inj Well 4-4



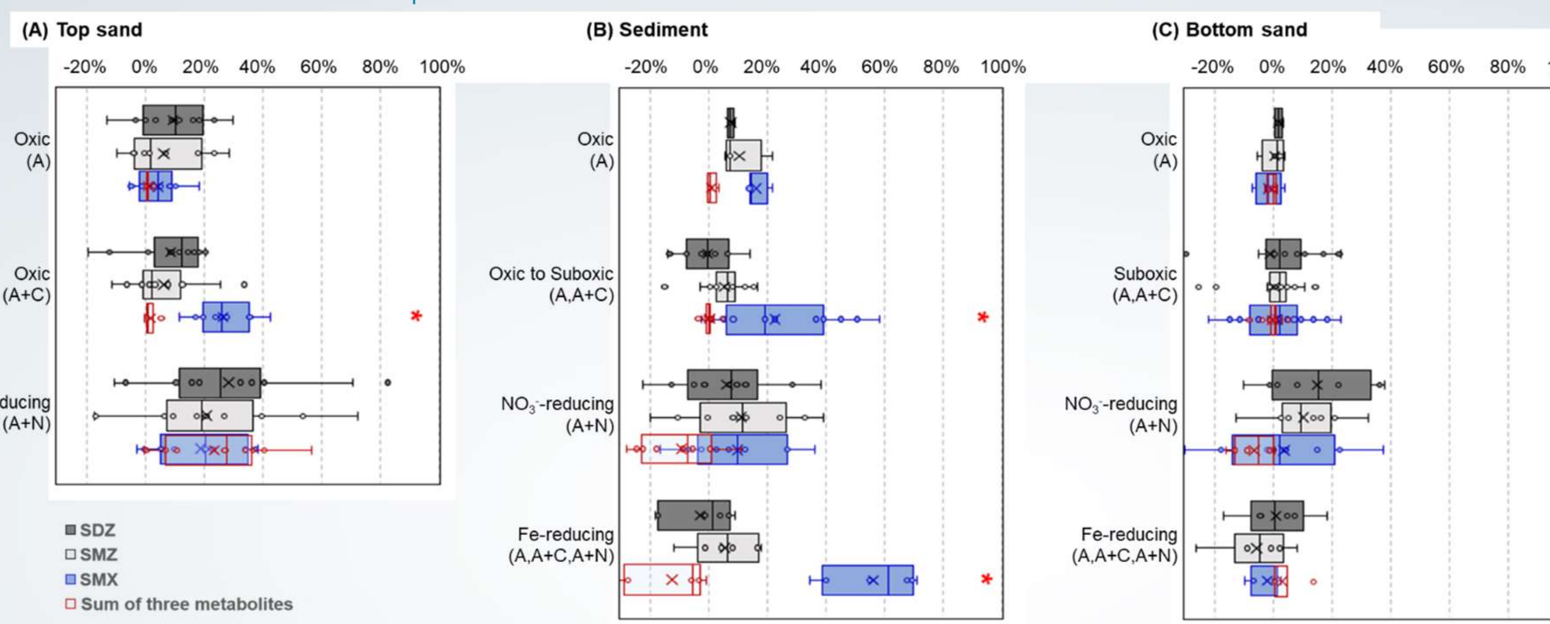
Removal is limited by substrates and reaction time!



Removal: +C $+NH_4$

Some removal

Little removal



Sulfonamide removal (%) of SDZ, SMZ and SMX, and the total production of three SMX metabolites (% to initial SMX concentrations) in different redox zones over 120-day infiltration.

(Yunjie Ma, submitted to Water Research)

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Summary

- Incidental recharge due to large scale reclaimed water use for landscaping and environmental flow purposes in the North China Plain is a threat to groundwater quality by introducing not-so-biodegradable contaminants of emerging concerns such as sulfonamide antibiotics and by mobilizing geogenic contaminant such as arsenic.

- In water-sediment systems, the removal of sulfonamide antibiotics is primarily via biodegradation involving microbes, however, it is redox-dependent, usually incomplete with unknown metabolites, with variable degradation kinetics possibly influenced by substrate availability and retention time. Acceleration of biodegradation and full mineralization through manipulation of hydraulic retention time, primary substrates, and redox conditions etc. need to be investigated.

- To protect human and ecosystem health, regulations governing water recycling will do well to address risks associated with incidental recharge, and better yet, developed with enabling managed aquifer recharge to take advantage of the soil-aquifer systems natural attenuation abilities.

Danida Fellowship Centre
- sustaining development through research and learning

国家自然科学基金委员会
National Natural Science Foundation of China

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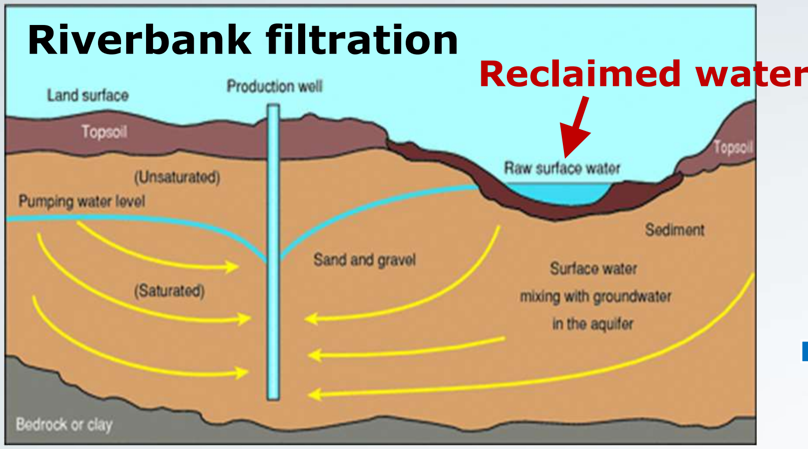
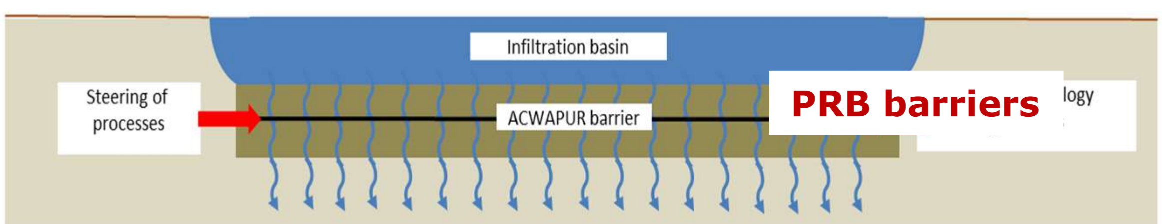
Next: How to accelerate & enhance biodegradation?



Robert Maliva, Thomas Missimer (2012)

Engineering:
Redox & retention time manipulation

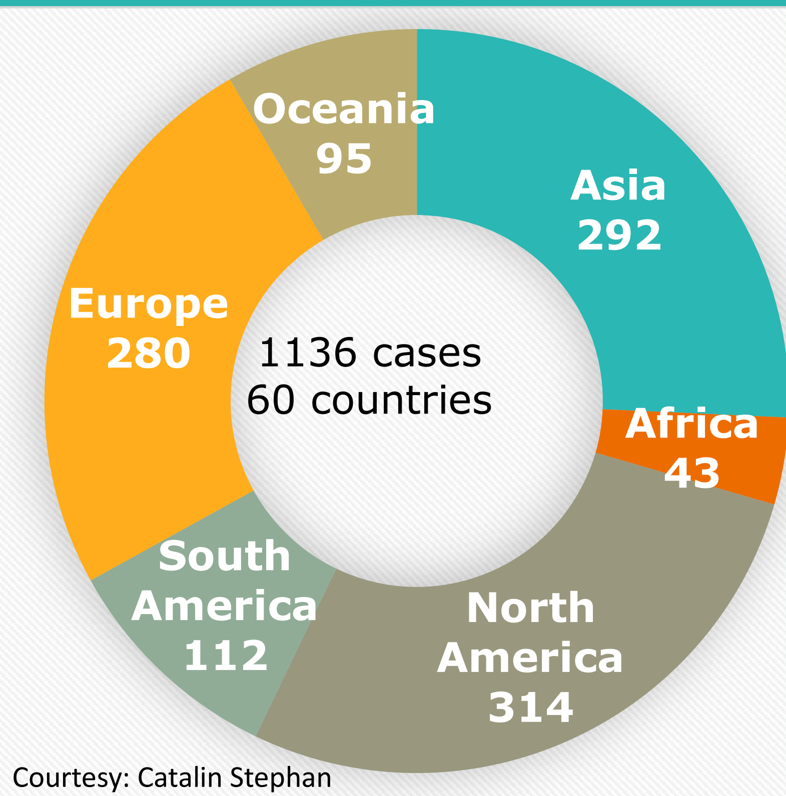


Courtesy: Jens Aamand of GEUS

Part II

Reasons for MAR regulations

Global MAR Inventory



https://recharge.iah.org/

Quantity (km³/yr)

	Groundwater Use in 2010	MAR Quantity in 2015	%MAR of GW Use
Global	982	9.9	1.0%
USA	112	2.5	2.3%
Australia	4.96	0.41	8.3%
China	112	0.106	0.1%
India (5 states)	39.8	3.07	7.7%
Denmark	0.65	0.00025	0.0004%
Finland	0.28	0.065	23.2%

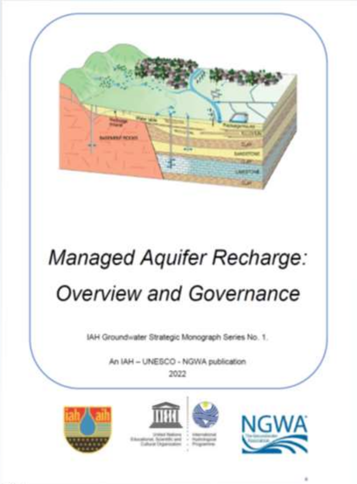
Sixty years of global progress in managed aquifer recharge

Hydrogeology Journal (2019) 27:1–30

P. Dillon[1,2] • P. Stuyfzand[3,4] • T. Grischek[5] • M. Lluria[6] • R. D. G. Pyne[7] • R. C. Jain[8] • J. Bear[9] • J. Schwarz[10] • W. Wang[11] • E. Fernandez[12] • C. Stefan[13] • M. Pettenati[14] • J. van der Gun[15] • C. Sprenger[16] • G. Massmann[17] • B. R. Scanlon[18] • J. Xanke[19] • P. Jokela[20] • Y. Zheng[21] • R. Rossetto[22] • M. Shamrukh[23] • P. Pavelic[24] • E. Murray[25] • A. Ross[26] • J. P. Bonilla Valverde[27] • A. Palma Nava[28] • N. Ansems[29] • K. Posavec[30] • K. Ha[31] • R. Martin[32] • M. Sapiano[33]

Reason I

Lack of clarity in governance amplifies other barriers for MAR as a tool to integrate surface water and groundwater management



Perception of Risks

Too many unknown risks, therefore not worth taking them

Fear of using MAR to dispose of waste water

Groundwater storage is invisible

Scientific Understanding of Risks and Benefits

Not enough in-depth investigations

Project implemented without research

Engineering Know-How

Mostly surface methods: In-channel, spreading, and induced bank infiltration

Limited role of private sector

Governance

Few have detailed guidelines like Australia

Few have enacted regulations like Arizona

Dillon, P., W. Alley, Y. Zheng, and J. Vanderzalm (editors), 2022, Managed Aquifer Recharge: Overview and Governance. IAH Special Publication. https://recharge.iah.org/ ISBN 978-1-3999-2814-4

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Chaobai River, Beijing MAR

SNWD water from Sept 2015:

- Total amount of recharge: 270 Mm^3
- More in wetter years

SNWD

Alternating Dry & Wet Recharge

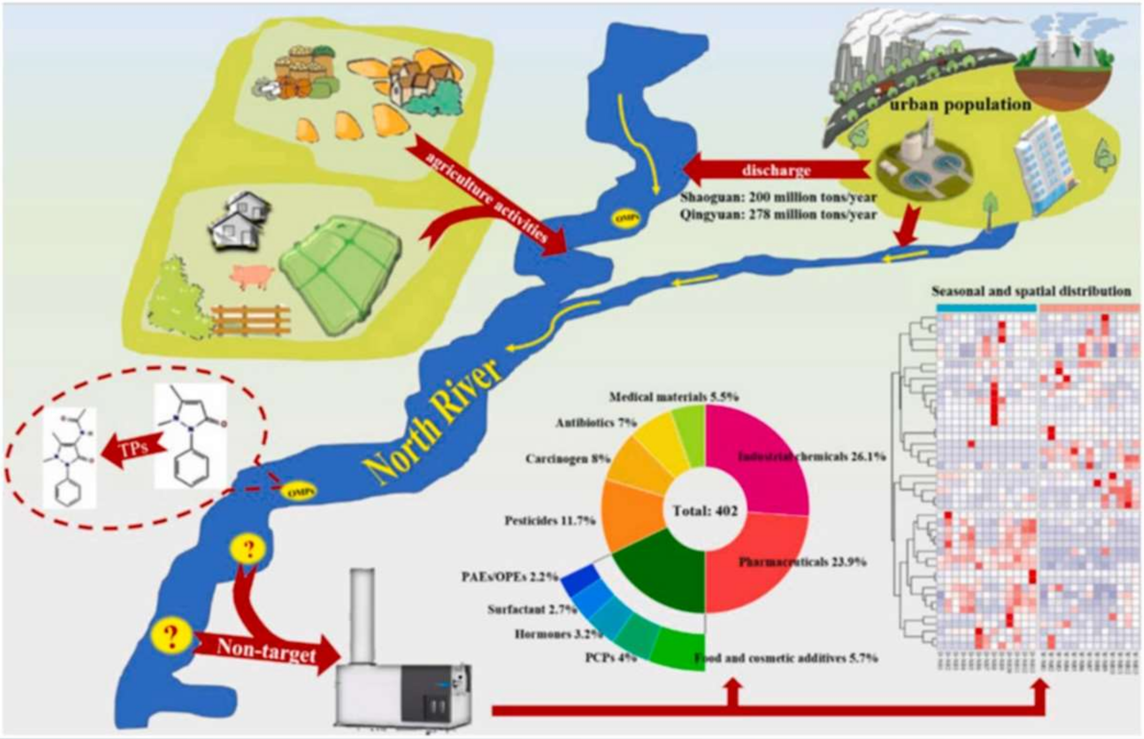
Courtesy: Binghua Li/BWSTI

2021 GWMRC

Artificial recharge of groundwater shall comply with the relevant water quality standards and shall never deteriorate groundwater quality.

Reason II

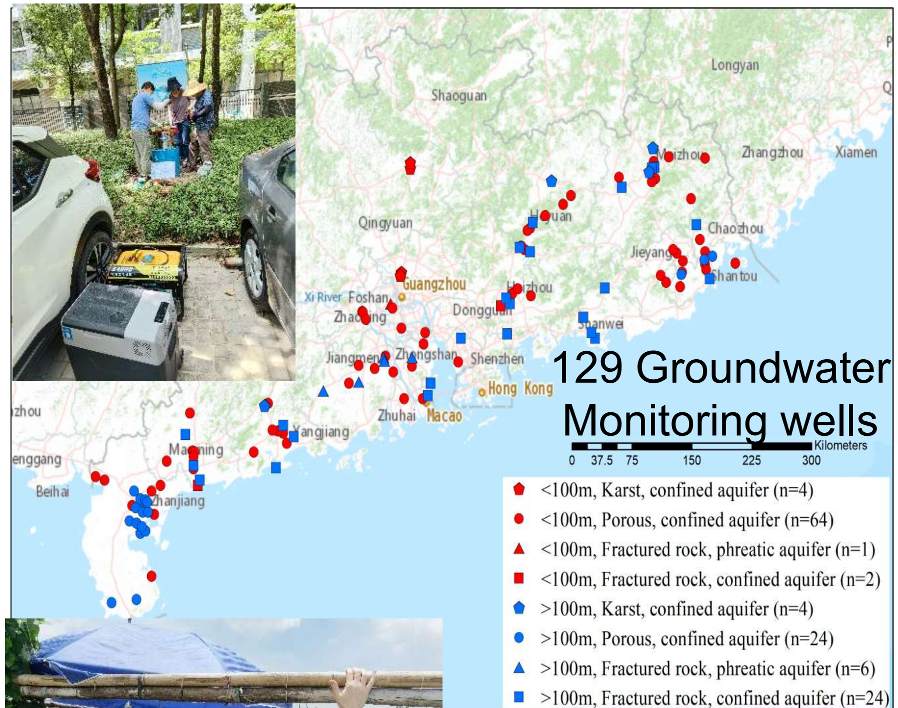
Source water for recharge and groundwater quality risks during in-channel & spreading basin MAR need management



Drinking water source for Guangzhou: North River

402 trace organic pollutants

Zhao et al. 2021. Screening of organic chemicals in surface water of the North River by high resolution mass spectrometry. Chemosphere. 290:133174



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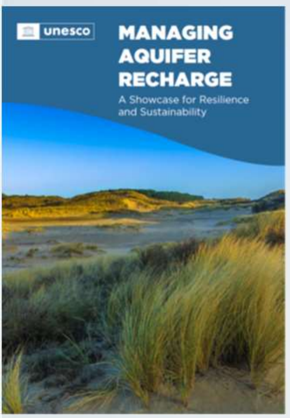
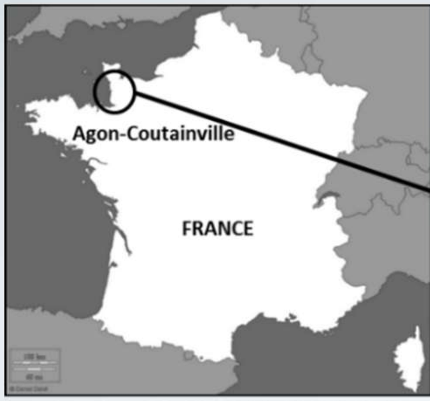
Successful Reclaimed Water MAR

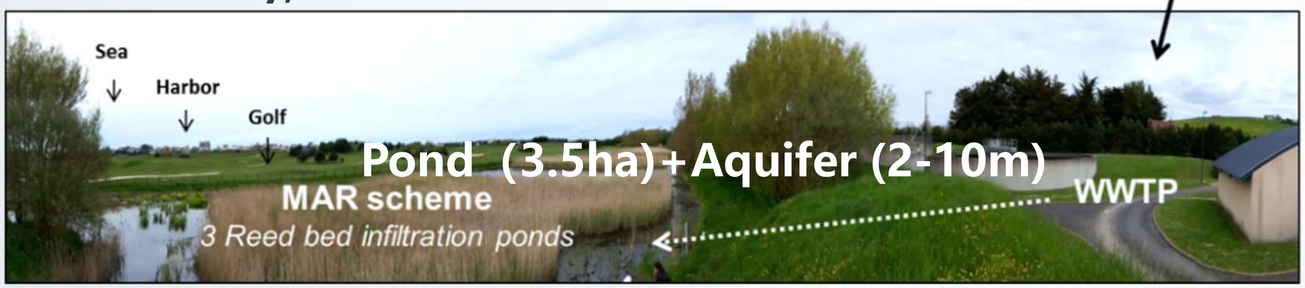


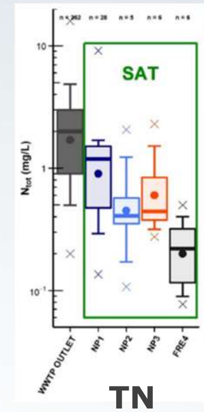


Location: 49° 03'18.8"N, 1° 35'40.2"W

Quaternary sand dune
Brioverian bedrock

Normandy, France





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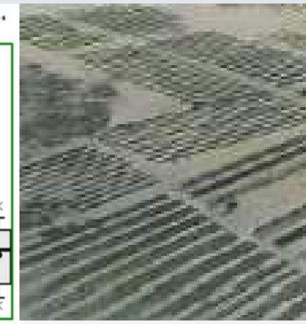

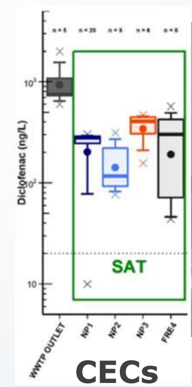

CECs

Purpose: Environmental ; Treated Waste Water Recharged: 500 – 5000 m^3 per day

Picot-Colbeaux et al. (2021). Case Study 17: Sustainable coastal MAR-SAT system in Agon-Coutainville, Normandy, France in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.

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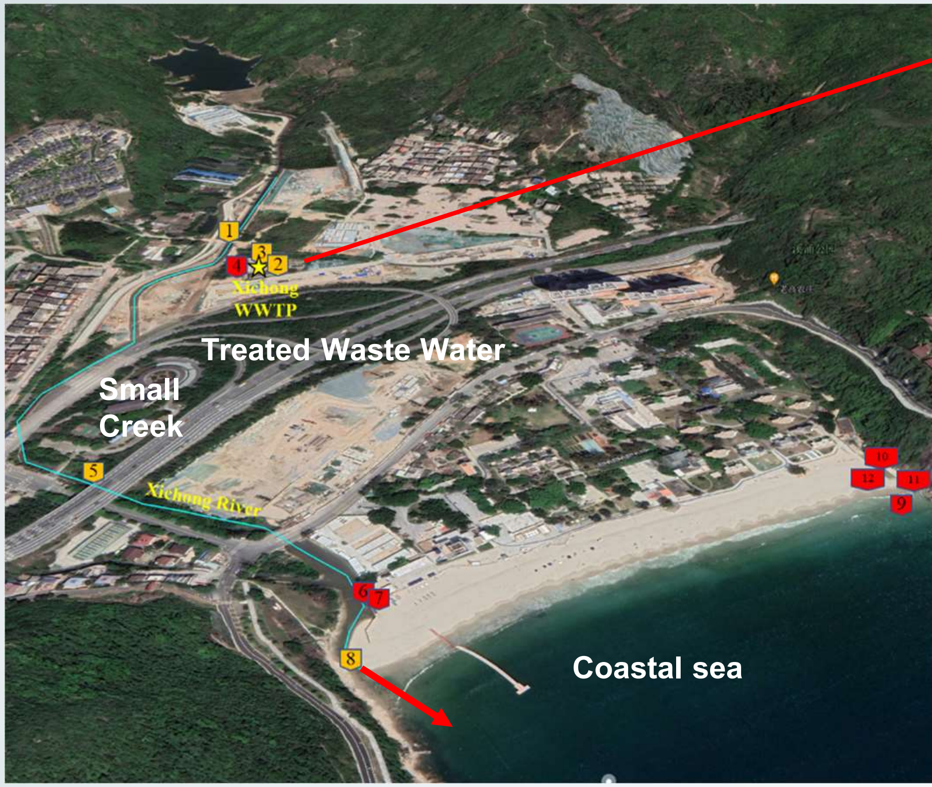
Reason III

Underutilization of natural treatment ability and storage capacity of coastal brackish aquifer



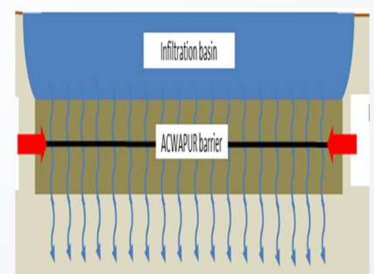
Shenzhen Coast

WWTP: Secondary

MAR:

Wetland + SAT

+ in-channel PRB



Reclaimed water with high nitrogen, phosphorus and other pollutants threatening vulnerable coastal ocean ecosystems.

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Bangladesh: Micro MAR

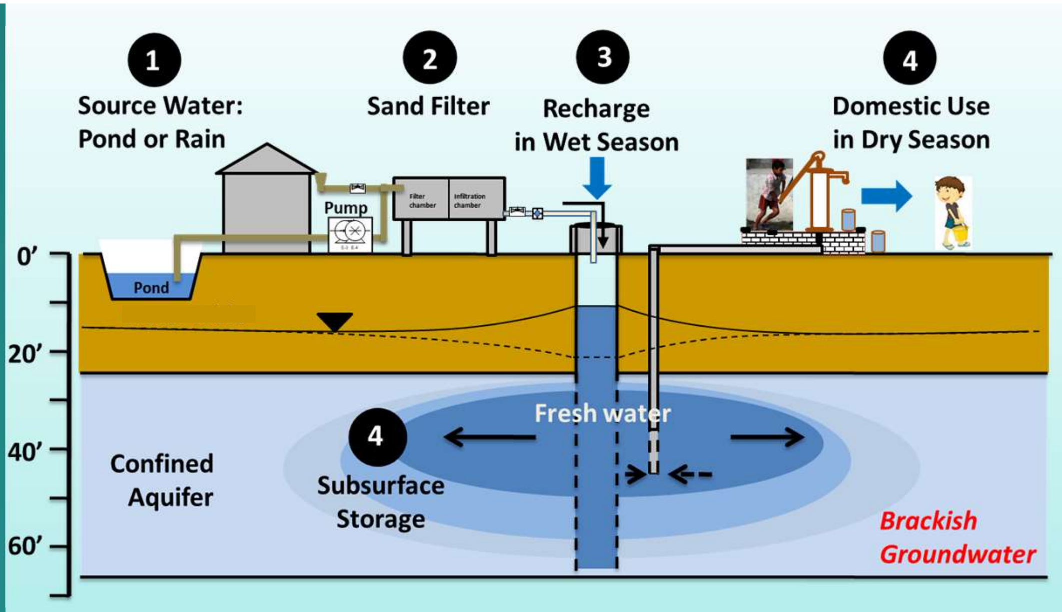
Purpose: Recharge and store freshwater for drinking in 9-months long dry season.

- Year constructed: 2010
- Annual Recharge: 0.000667 million m^3
- Annual Recovery: 0.000226 million m^3
- Cost of Recovered Water: US$ 5.3 per m^3
- Benefit Cost Ratio: 1.5 (compared to RO)
- Sustainability Rating: Good (1.3)
- Risks: clogging

  arsenic in ~ 10% of the schemes

Ahmed et al. (2021). Case Study 1: A resilient drinking water supply using aquifer storage recovery for coastal communities in Batiaghata, Khulna, Bangladesh. in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.

Sultana et al. (2015). Low-Cost Aquifer Storage and Recovery: Implications for Improving Drinking Water Access for Rural Communities in Coastal Bangladesh. J. Hydrol. Eng. , 10.1061/(ASCE)HE.1943-5584.0001100 , B5014007.

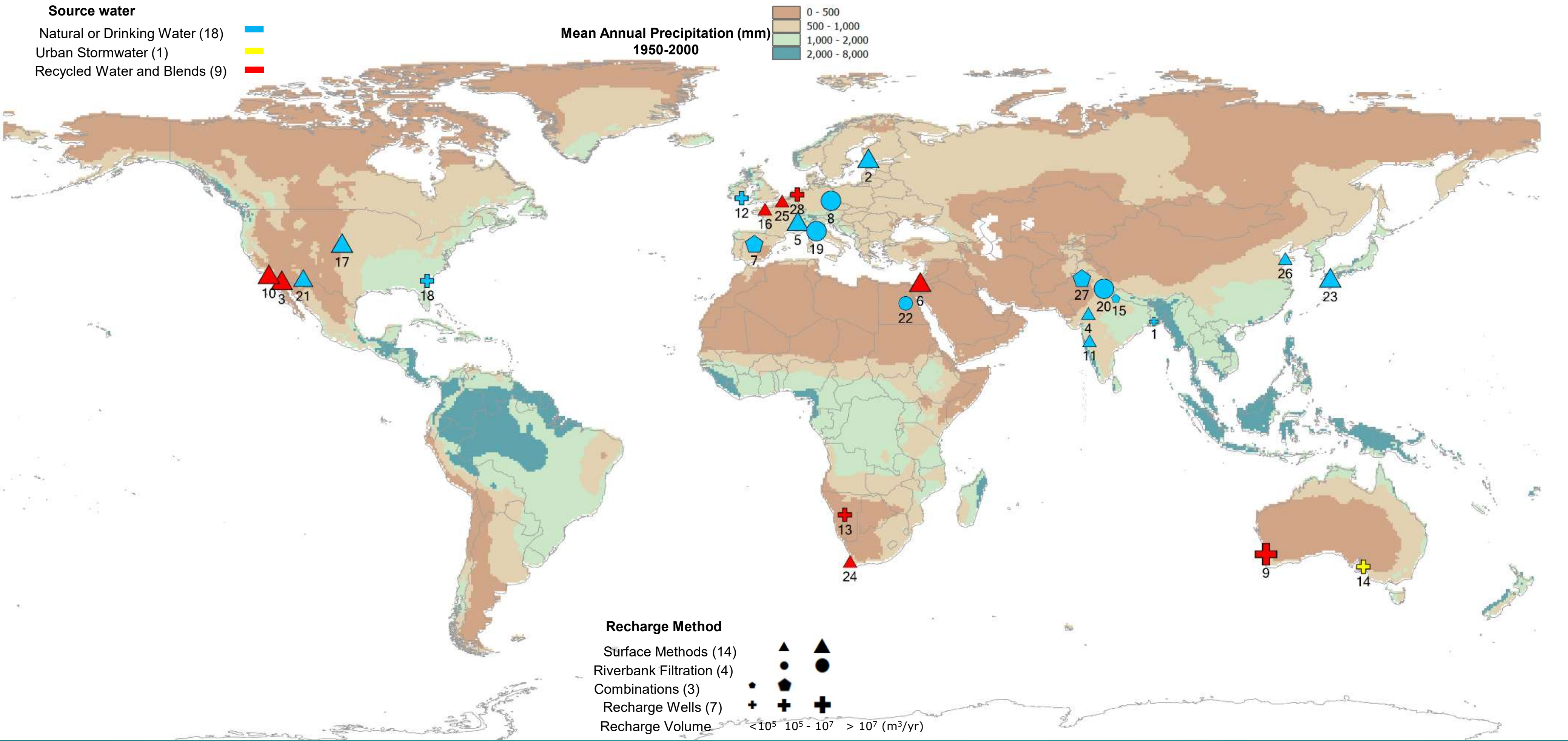


Construction of Recharge Wells in Coastal Bangladesh

Part III

Improving MAR Governance

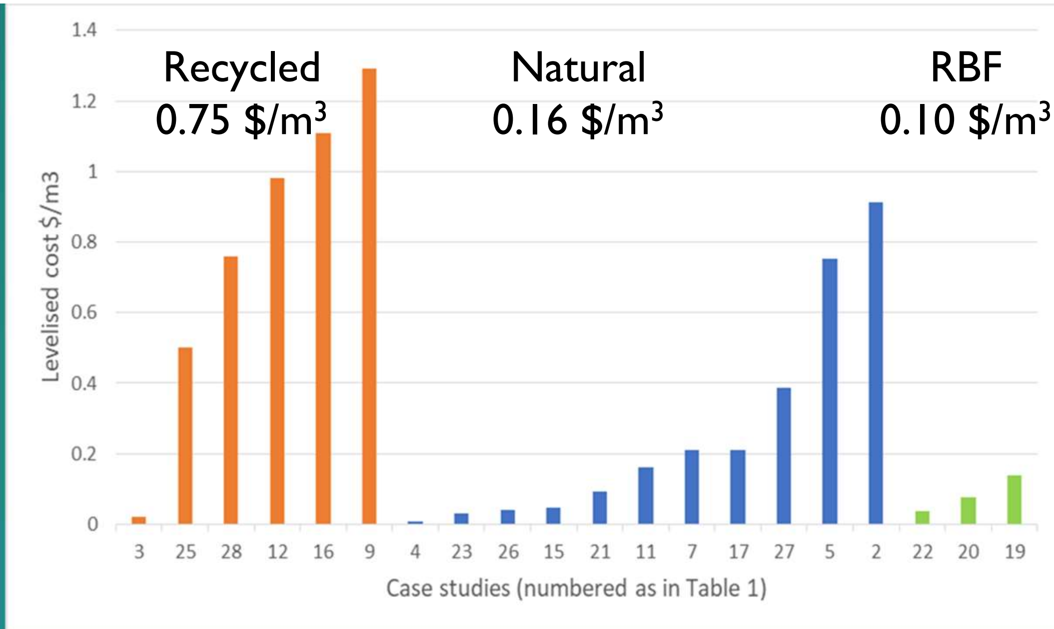
Locations of 28 MAR Schemes: Recharge methods and volume, source water types

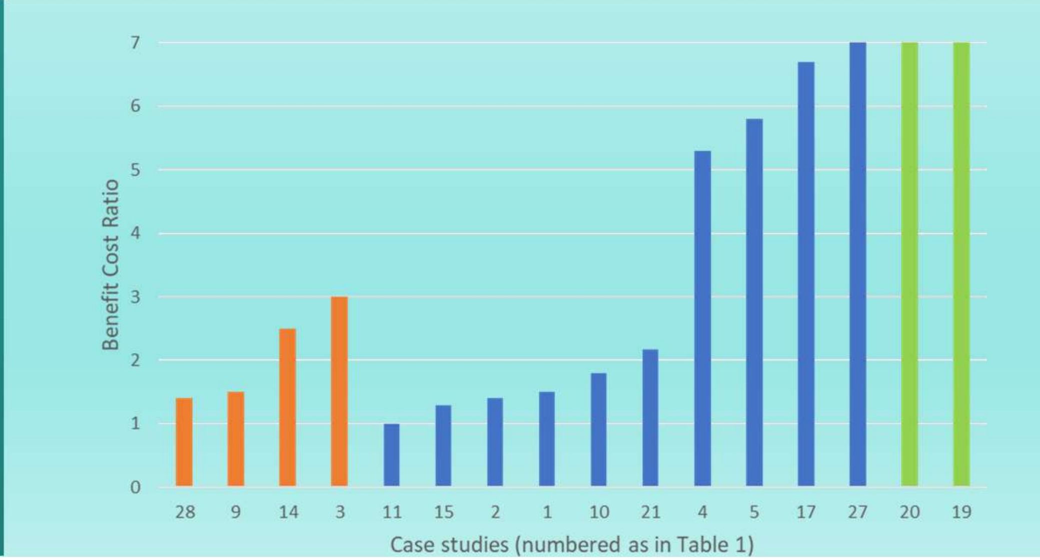


Zheng, Y., Ross, A., Villholth, K and Dillon, P. (eds) 2021. Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris, France, pp.365

MAR is cost effective

- MAR schemes achieved the same purpose at less than half the cost of alternatives.
- Unit cost is higher for recycled water schemes than that of natural water schemes.





Ross, A. (2021). Chapter 4. Economic Costs and Benefits of Managed Aquifer Recharge Case Studies. in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.

MAR is sustainable

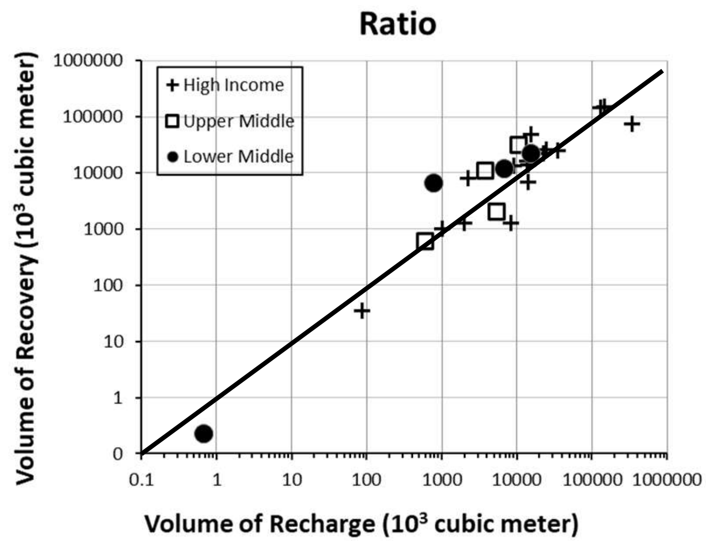
- MAR helps to maintain groundwater balance, though recharging recycled water can be energy intensive.

$V_{recovered}/V_{recharged}$ (n=26)
- Range: 0.0-8.3
- Mean: 1.4 ± 1.7

River Bank Filtration (n=3):
- 1.1, 1.2, 1.4

$V_{recovered}/V_{recharged}$>2 (n=4)
- London UK for drought: 3.2
- Sergovia Spain for drought: 3.6
- Windhoek Namibia for drought: 2.9
- Rajasthan India for drought: 8.3

Zheng et al (2021). Chapter 3. Assessment of Environmental and Social Sustainability of Managed Aquifer Recharge Case Studies. in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.



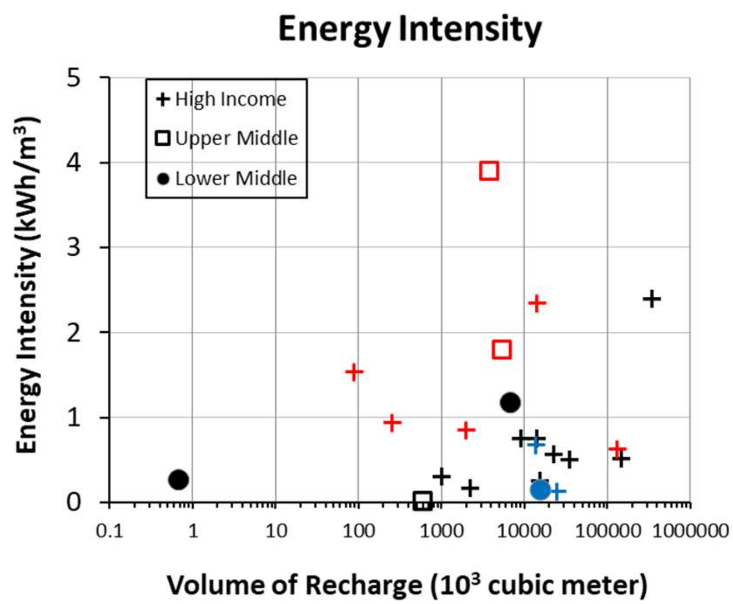


Table 4. Location, Purpose, Technique, Size, and Energy Intensity of MAR Cases from 5 North American Countries from Zheng et al 2021											
Country	Location	Purpose	MAR Technique[a]	Recharge		Recover/Discharge		Total	Ratio	Rating by Two Experts	Indicator[1]:
				Volume (1000 m^3/yr)	Energy Intensity (kWh/m^3)	Volume (1000 m^3/yr)	Energy Intensity (kWh/m^3)	Energy Intensity (kWh/m^3)	$V_{recovered}/V_{recharged}$		Expert Mean [2]
USA	Orange County, CA	Domestic/Drinking	IBs for Santa Ana River	148000	0.06	148000	0.45	0.51	1.0	Good	2.1
	Platte River, NE	Ecological Flow	Rehabilitated Irrigation Canals	8380		1290			0.2	Good	2.4
	Hilton Head, SC	Domestic/Drinking	ASR of Drinking Water	1000		1000	0.3	0.30	1.0	Good	1.2
	Arizona	Water Banking	IBs+ for Colorado River	342000	1.23 - 2.16	76000	0.48 - 0.91	2.39	0.2	Good	1.5
Mexico	Sonora	Agricultural	Infiltration Basins of Treated Effl	10500	0.08[b]	31500	0.175		**3.0**	Acceptable	0.9

[a] IB = Infiltration basin, ASR = Aquifer Storage and Recovery, ASTR = Aquifer Storage Transfer and Recovery, RBF = Riverbank Filtration, UF = Ultra-Filtration, RO = Reverse Osmosis
UV = Ultra-violet

[b] Excluding waste water treatment energy, for water conveyance to infiltration basins only

MAR using treated effluent is marked in red with a high mean energy intensity of 1.71 kWh/m^3; RBF is marked in blue with a mean energy intensity of 0.32 kWh/m^3;

Zheng et al (2021). Chapter 3. Assessment of Environmental and Social Sustainability of Managed Aquifer Recharge Case Studies. in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.

Table 3.
Six Environmental and Three Social Indicators Established for MAR Schemes following USEPA Framework of Sustainability Indicators. Source: Own elaboration

	Score*
I. Environmental Sustainability Indicators	
A. Resource Integrity	
A.1 Water Quantity	
1. Monitoring of groundwater table demonstrates acceptable changes over 10 years, or > 3 years with high likelihood of maintaining resource integrity	7.6
2. The ratio of volume of recovered water vs infiltrated water on an annual basis	6.8
For large schemes, change in renewable groundwater resources in target aquifer per capita (m^3/year per capita)	1.6
A.2 Water Quality	
3. Exceedance rate based on time-series monitoring of recovered or ambient water quality parameters	7.8
4. Exceedance rate based on time-series monitoring of source water quality parameters	7.5
For large schemes, percentage use as drinking water sourced from target aquifer	3.1
B. Ecosystem Services	
5. Changes in ecological flow (m^3/yr) and improvement in water quality in ecosystem needing protection identified in a catchment water management plan	4.9
Change in peak flow (m^3/s) for MAR intended for flooding control	1.3
C. Stressors	
6. Energy requirements in KWh per cubic meter of recovered water, including monitoring and treating recovered water, solving clogging and low recovery efficiency issues	7.0
No unacceptable seepage, waterlogging, discharge occurs	3.4

II. Social Sustainability Indicators	
A. Resource Security/Human Health	
7. Clearly defined, transparent regulatory framework for MAR, preferably one that requires monitoring of resource integrity	8.6
8. Permit granting process is based on sound risk assessment aimed to protect human health	8.9
Assists resilience to adverse impacts of climate change	5.5
B. Sustainable Community/Participation/Education/Environmental Justice	
9. Systematic Institutional arrangements for public and stakeholder consultation, preferably with regular publicly available reports of scheme outcomes	7.4

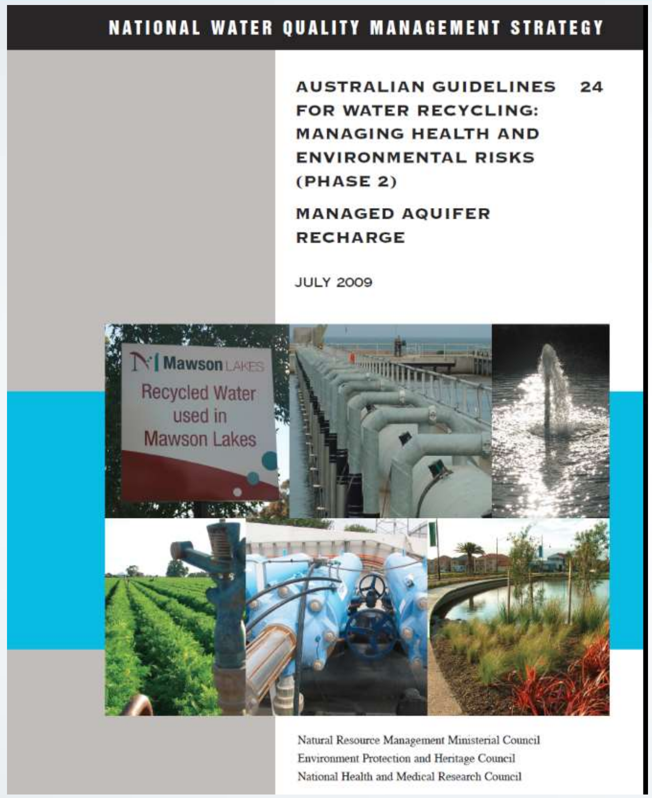
*Average score by 11 participants. Score scale: Do not include 0, OK to include 4, Good to include 7, Must include 10.

Zheng et al (2021). Chapter 3. Assessment of Environmental and Social Sustainability of Managed Aquifer Recharge Case Studies. in Zheng et al (eds). Managing Aquifer Recharge: A Showcase for Resilience and Sustainability, UNESCO, Paris.

Examples of guidelines and regulations

Risk-based approach adopted for MAR in the Australian guideline for water recycling Phase 2 & groundwater banking credit in Arizona have encouraged uptake of MAR to restore groundwater balance and to improve water quality.

Australia

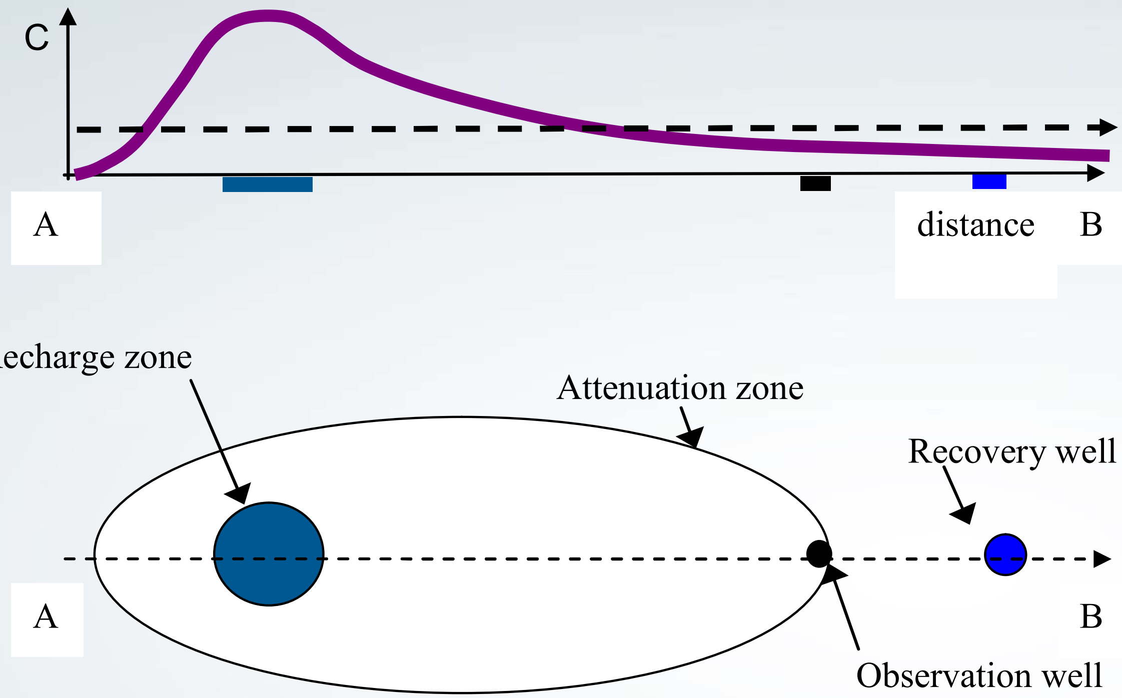


Arizona, USA

- In 1980, the **Groundwater Management Act** is signed into law by then Governor Babbitt.
- The Act established the Arizona Department of Water Resources to **secure long-term dependable water supplies**.
- Groundwater Banking Innovation**: Credit**

http://www.environment.gov.au/water/quality/publications/nwqms-australian-guidelines-water-recycling-managing-health-phase2-aquifer-recharge

Australian Guideline： Attenuation Zone



- Provides adequate **residence time** of recharged water for natural attenuation of all hazards to meet environmental values
- **Some hazards** may not attenuate and these should be **reduced to acceptable concentrations before recharge**

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Water Reuse: EU Perspective

European Commission

JRC SCIENCE FOR POLICY REPORT

Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge

Towards a water reuse regulatory instrument at EU level

Alcalde-Sanz, L. and Gawlik, B.M,

Closing the loop – An EU action plan for the circular economy” COM (2015)614: Actions to promote the reuse of treated wastewaters, including development of a regulatory instrument on **minimum quality requirements** for water reuse in **agricultural irrigation** and **aquifer recharge**.

One of the main barriers identified is the lack of harmonization in the regulatory framework to manage health and environmental risks related to water reuse at the EU level, and thus a lack of confidence in the health and environmental safety of water reuse practices.

Lesson from Australia: Follow risk-based approach, consider end use and develop guidelines in phases

Following the risk management approach, the Australian government developed the Australian Guidelines for Water Recycling and the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011). The Australian Guidelines for Water Recycling provide a generic framework for management of reclaimed water quality and use that applies to all combinations of reclaimed water and end uses, including agricultural irrigation and aquifer recharge. These guidelines are structured in two phases. Phase I document (NRMMC-EPHC-AHMC, 2006) provides the scientific basis to assist and manage health and environmental risks. The three Phase II documents cover the specialized requirements for augmentation of drinking water supplies (NRMMC-EPHC-NHMRC, 2008), storm water harvesting and reuse, and managed aquifer recharge (NRMMC-EPHC–NHMRC, 2009). It is to note that the Australian Guidelines for Water Recycling are currently under a review that will draw on the advances and implementation of water recycling schemes.

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Lesson from California: Work with waste water treatment, urban planning, agriculture, groundwater, and health experts

The State of California has been a pioneer in issuing water reuse regulations and the water quality requirements that California establishes have become a global benchmark, and they have provided a basis for the development of water reuse regulations worldwide. The State of California regulatory approach on water reuse is based on stringent treatment technology targets with specific performance requirements for several uses, including also agricultural irrigation. Statutes and regulations related to water reuse in California are based on a risk assessment and the multiple-barrier principle and are included in the California Health and Safety Code, the California Water Code, and the California Code of Regulations. In the last update of the water reuse regulations, the Division of Drinking Water (DDW) (formerly known as CDPH) included also indirect potable reuse considering aquifer replenishment by surface and subsurface application (CDPH, 2014).

The United States Environmental Protection Agency (USEPA) issued, in 2012, the last version of the Guidelines for Water Reuse (USEPA, 2012). These guidelines include a wide range of reuse applications (e.g. agricultural irrigation and aquifer recharge) and apply a similar approach as described in the WHO and the Australian guidelines for controlling health and environmental risks.

Harmonize the regulatory framework to protect groundwater and to recycle water

— Assembly of a risk management team.

— Description of the water reuse system.

— Identification of hazards and hazardous events, and risk assessment.

— Determination of preventive measures to limit risks.

— Development of operational procedures.

— Verification of the water quality and the receiving environment.

— Validation of processes and procedures.

— Management of incidents and emergencies.

In this context, it is of paramount importance that MS apply the principles of a risk management framework for the safe use of reclaimed water for agricultural irrigation and aquifer recharge.

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✓A soon-to-be-effective European Union Directive 2020/741 has set minimum requirements for water quality, as well as monitoring and provisions on risk management applications for agricultural use of reclaimed water.

✓A risk-based EU directive specific for MAR to further expand water reuse and recycling is a logical next step for the EU and any designated regulatory entities to consider.

This article is part of the topical collection "International Year of Groundwater"

Hydrogeology Journal
https://doi.org/10.1007/s10040-022-02543-z

The 21st century water quality challenges for managed aquifer recharge: towards a risk-based regulatory approach

Yan Zheng[1] · Joanne Vanderzalm[2] · Niels Hartog[3] · Enrique Fernández Escalante[4] · Catalin Stefan[5]

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Seamlessly integrating MAR into a treatment train

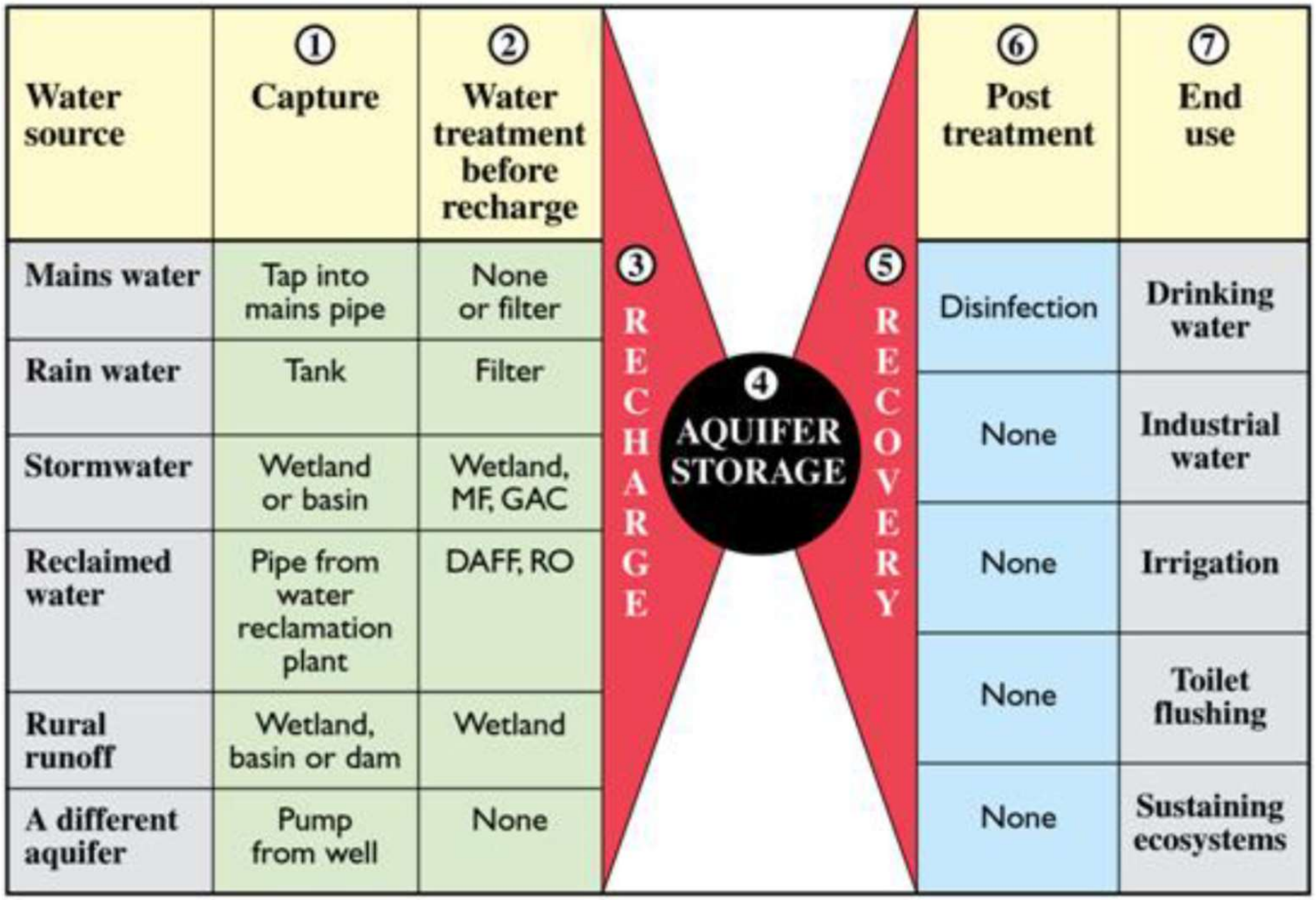
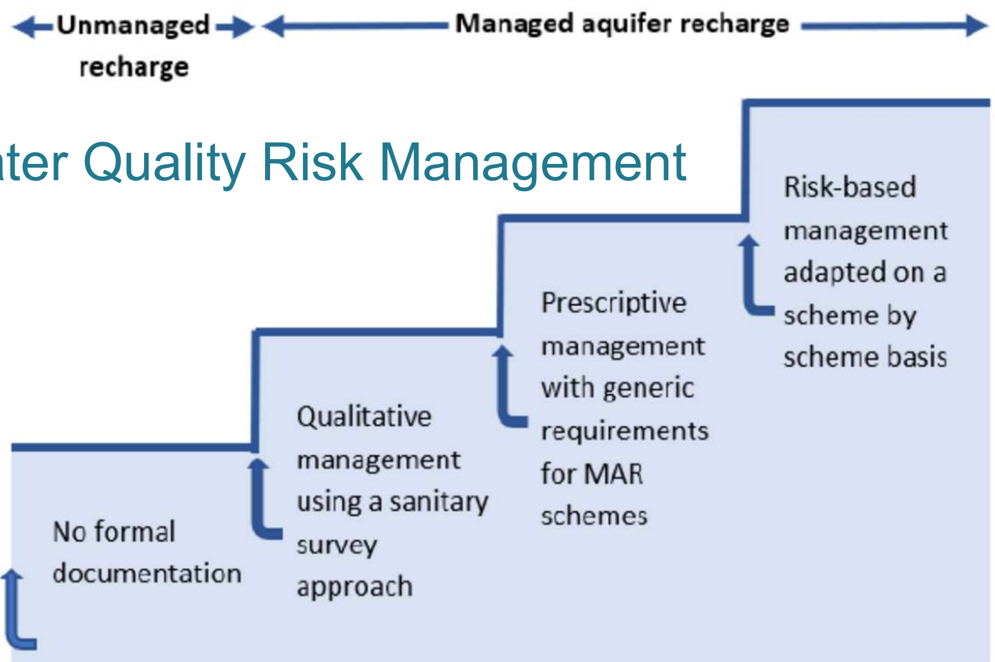


Figure 12 - All sources of water with appropriate treatment can be used for MAR. Water treatment requirements in MAR depend on the recharge source, aquifer, recharge method, intended water use, and other preventive measures to manage risks (from Dillon et al., 2009).

Vanderzalm, J., D. Page, P. Dillon, and Y. Zheng, 2022, Considerations for Water Quality Management, in Managed Aquifer Recharge: Overview and Governance. IAH Special Publication. https://recharge.iah.org/ ISBN 978-1-3999-2814-4

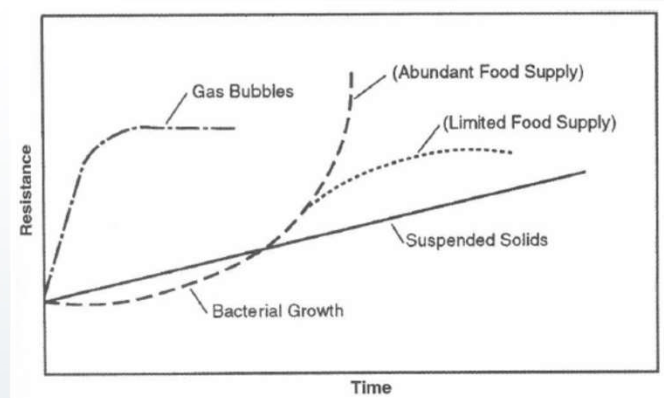
Stages of Water Quality Risk Management



Water quality focus:	Not explicit	Public health	Public health & environment	Public health & environment
Risk assessment:	None	Qualitative	Assumed generic	Quantitative
Sampling and analysis required:	None	Visual observations only	Generic analyte list	Analytes based on locally assessed risk
Level of safety:	Unknown	Safer	Safer	Safest

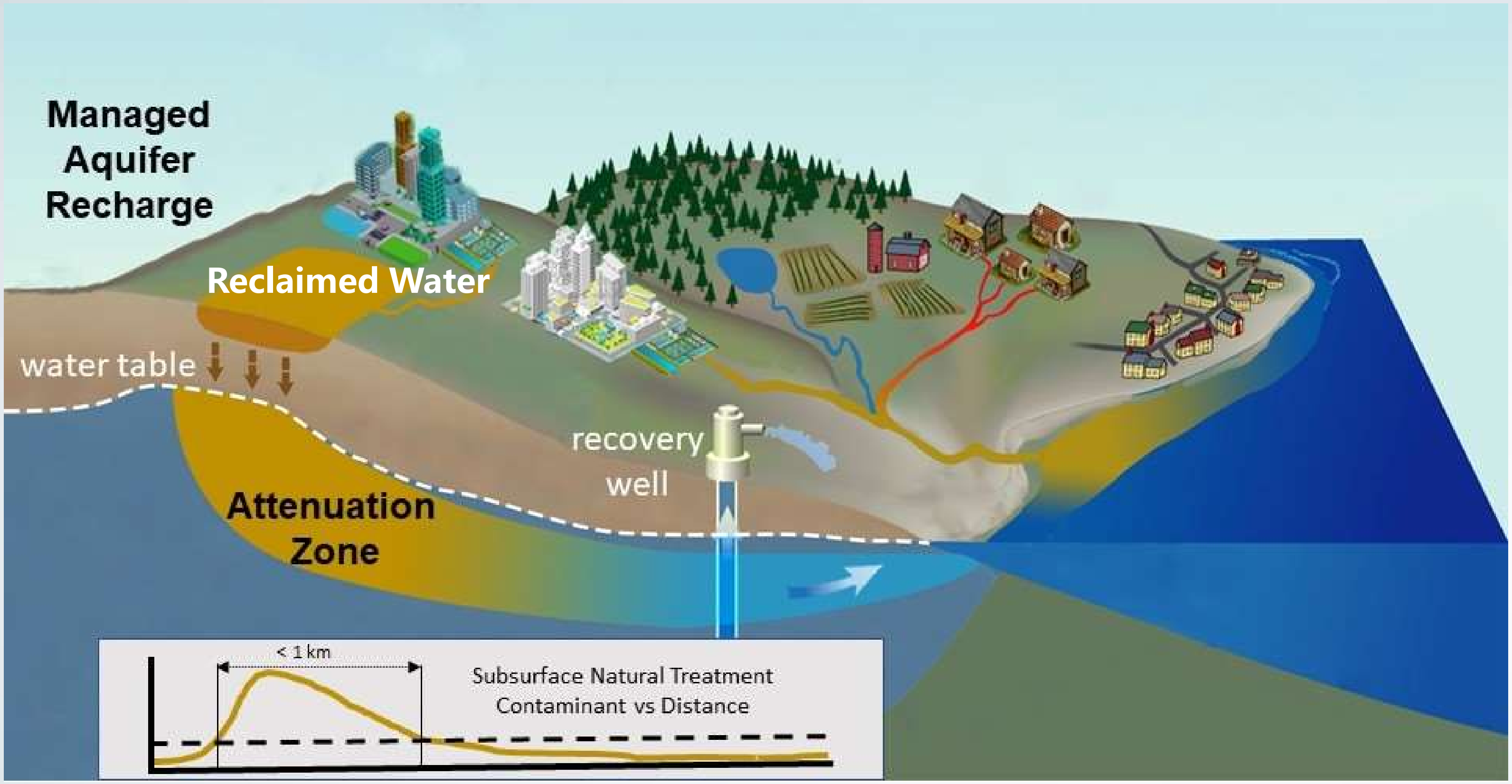
Figure 14 - Approaches for management of water quality in MAR progressing toward risk-based management of public health and the environment (modified from Dillon et al., 2014).

Pathogen/indicator	**Removal time for 90% loss (T_{90}) (d)**
Escherichia coli	0.1-1.5
Enterococcus fecalis	1-2.5
Salmonella enterica	0.7-2
Coxsackievirus	17-169
Adenovirus	28-65
Rotavirus	34-185
Cryptosporidium parvum	38-120



Typical aquifer hydraulic response for different clogging mechanisms (Pyne, 2005).

Towards a Risk-Based Regulatory Approach : Designate a Subsurface Attenuation Zone



Zheng et al. (2022) The 21st Century Water Quality Challenges for Managed Aquifer Recharge: Towards a Risk-Based Regulatory Approach. Hydrogeol J

SUSTech

Law, Land Use, and Groundwater Recharge

Dave Owen*
Harry D. Sunderland Professor of Law, University of California, Hastings College o

Abstract. Groundwater is one of the world's most important natural resources, and its importance will increase as climate change continues and the human population grows. But groundwater management has traditionally been governed by lax and uneven legal regimes. To the extent those regimes exist, they tend to focus on the extraction of groundwater rather than the processes—referred to as groundwater recharge—through which water enters the subsurface. Yet groundwater recharge is crucially important to the maintenance of groundwater supplies, and it is also highly susceptible to human influences, particularly through our pervasive manipulation of land uses.

This Article discusses the underdeveloped law of groundwater recharge. It explains why groundwater-recharge law, or the lack thereof, is important; it discusses existing legal doctrines that affect groundwater recharge, occasionally by design but usually inadvertently; and it explains how more intentional and effective systems of groundwater-recharge law can be constructed. It also sets forth criteria for judging when regulation of groundwater recharge will make sense, and it argues that a communitarian ethic, rather than the currently prevalent laissez-faire approaches, should underpin those regulatory approaches. Finally, it suggests using regulatory fees as a key (but not exclusive) instrument of groundwater-recharge regulation.

Stanford Law Review
Volume 73 May 2021

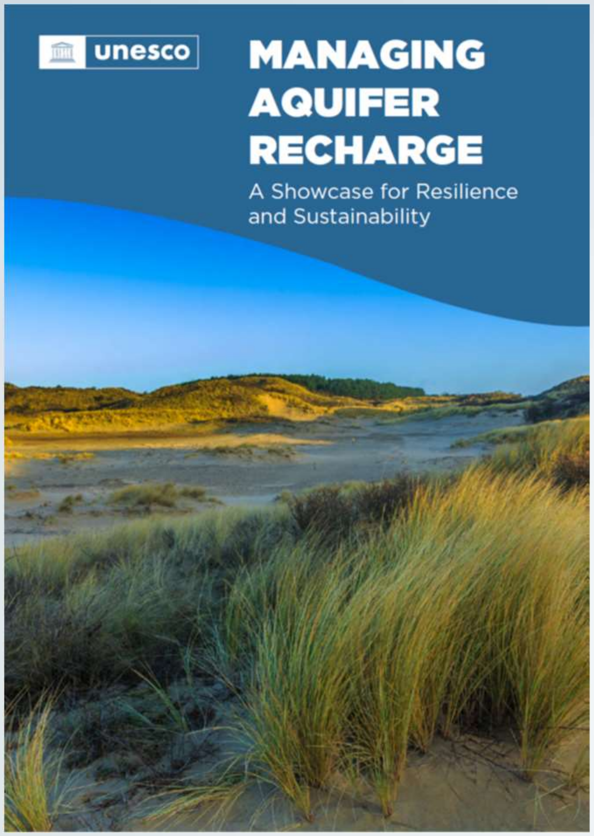
Recommendations

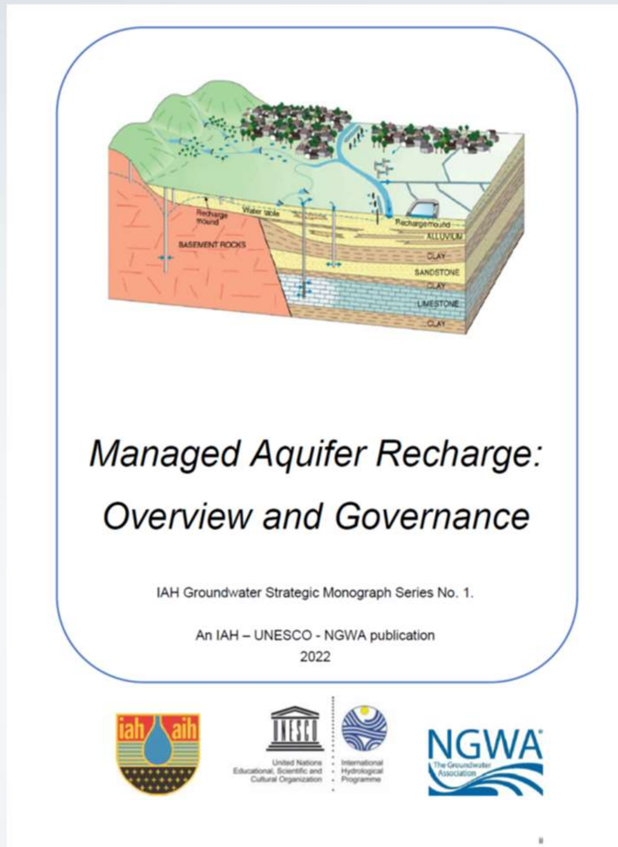
MAR regulations should be part of water recycling and reuse regulations

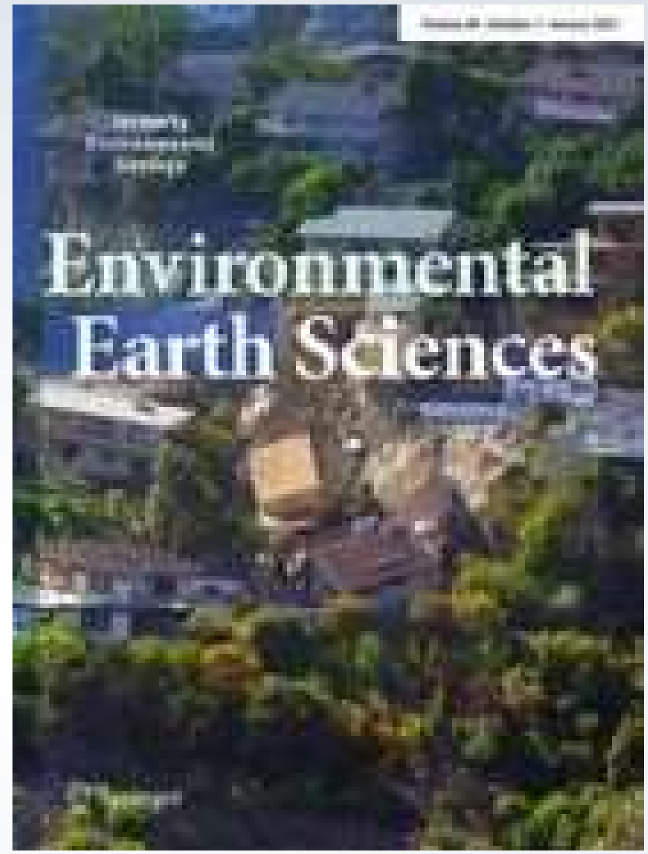
- ✓ A risk-based approach over a prescriptive parametric approach
- ✓ Committee drafting the regulations should have expertise including but not limited to water resources management, waste water treatment, urban planning, agriculture, groundwater, ecology and health.

A communitarian ethic grounded in the precautionary principle.

Thank You







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