International Association of Hydrogeologists

Strategic Overview Series

CLIMATE-CHANGE ADAPTATION & GROUNDWATER

KEY MESSAGES

- climate-change is predicted to have a major impact on water resources, with more frequent surface-water droughts and intense rainfall events, and adaptation to avoid future water-supply crises will require better use of water storage

- groundwater has always displayed excellent drought resilience, and the presence of aquifers (with their large volumes of stored water) provides a 'natural solution' for deployment in climate-change adaptation

- groundwater management widely requires 'strategic rethinking' to ensure resource reliability for climate-change adaptation, with increased investment in conjunctive use, demand-side/supply-side management and quality protection

- the key criteria which determine the potential role an aquifer can play in climate-change adaptation are storage availability, supply productivity, natural quality and pollution vulnerability

- there remains uncertainty over the long-term effects of climate-change on groundwater recharge in different regions, but global warming could lead to reduced groundwater recharge impacting the reserves of low-storage shallow aquifers

Why are groundwater systems and aquifer storage of major importance for climate-change adaptation ?

Accelerated global warming, resulting primarily from over-dependence on 'fossil fuels', has rightly become the pre-dominant environmental concern of our times. Even if this can be rapidly curtailed, climate-change is widely predicted to have a major impact on water resources, causing more frequent surface-water droughts, higher evaporation from lakes, reservoirs and wetlands, and more intense rainfall events with land flooding and 'flashy' streamflow. The geographical distribution of these impacts is still subject to considerable uncertainty, but they are likely to be more severe in the semi-arid climatic zones.

Whilst acting to reduce 'net carbon emissions' greatly, we also need to focus on climate-change adaptation. This will widely require making better use of (and developing more) water storage in one form or another.

SURFACE-WATER RESERVOIR IMPACTED BY MULTI ANNUAL DROUGHT — THEEWATERSKLOOF, CAPE TOWN, (SOUTH AFRICA) IN 2018

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

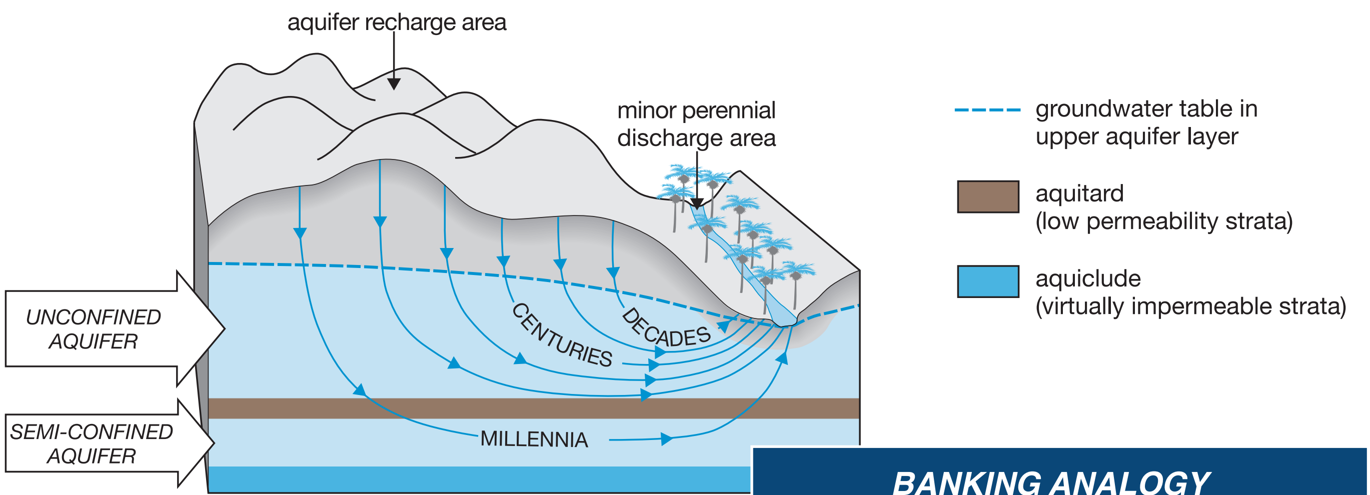
Historically groundwater systems (aquifers and their storage capacity), being 'naturally-buffered' against drought impact, have provided excellent water-supply security. It is interesting to reflect that access to groundwater (via springheads) was a key element in the survival of numerous early human settlements during periods of extended drought, especially around the Mediterranean and in the Middle East.

Groundwater systems are favourably distributed to offer sustainable, decentralised, cost-effective solutions to improve water-supply drought resilience for climate-change adaptation. Unlike surface-water storage they are much less affected by reduced inflow during protracted drought and increased evaporation due to global warming. System retention times are from 'decades to centuries or millenia', and generally several hundred years even for 'modern shallow ground-water circulation' (with the notable exception of karstic limestone aquifers). Moreover, deeper aquifer storage is less vulnerable to pollution.

In principle the presence of aquifers considerably increases water-supply security by providing a 'natural buffer' against riverflow variability, because of the large volume of groundwater they hold in storage. This reality must be taken fully into account as a key indicator of physical water-security – whether its application is at the scale of a specific city or river sub-basin.

It is essential that groundwater systems and their dependent ecosystems are viewed conjunctively with surface water resources if we are to face the challenge of ensuring water-supply security while adapting to climate change. However, few countries have, as yet, fully embraced the principles of conjunctive use and integrated water resources management (IWRM) at the practical operational level, and there have been various recent examples of urban water-supply crises (eg : Cape Town and Sao Paulo) as a result. A better example of conjunctive use is the Central Valley of California, where water-use switches from about 70% surface water during wet periods to 70% groundwater in dry periods, but this area still has to confront serious long-term aquifer depletion.

Various criteria are key to assessing the potential role a given groundwater system can play (in conjunctive use with local surface water) for climate-change adaptation, and the level of management it will require to fulfill this role – storage availability, supply productivity, natural quality and pollution vulnerability.



BANKING ANALOGY

income = recharge/inflow
expenditure = discharge/withdrawal
balance = inheritance + income-expenditure

DYNAMICS OF A TYPICAL GROUNDWATER FLOW SYSTEM WITH THE 'AQUIFER BANKING ANALOGY'

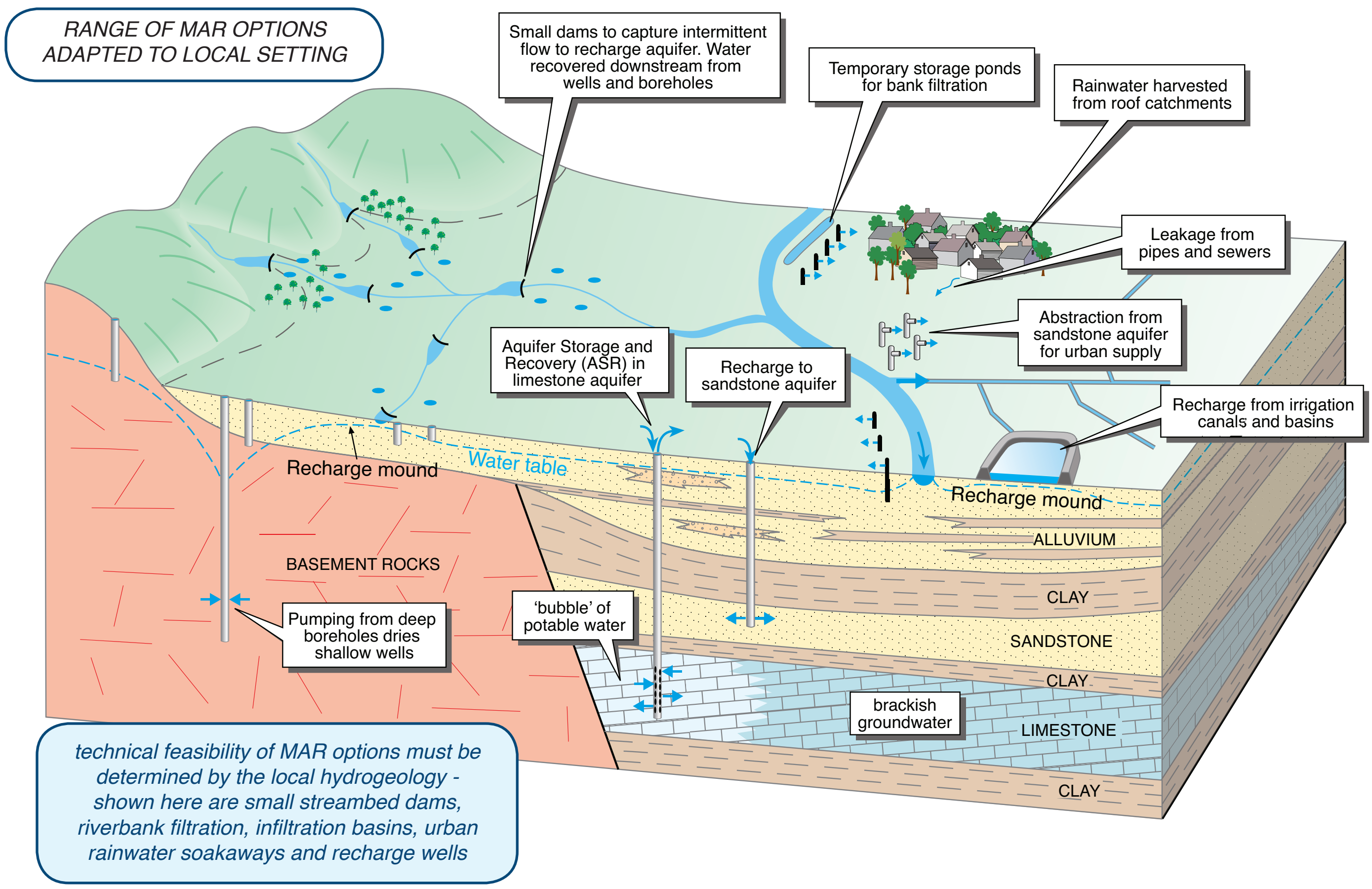
Which management measures are needed to secure groundwater resource sustainability under climate-change scenarios ?

If groundwater systems are to perform their potentially critical role in climate-change adaptation, they will require (like any other 'infrastructure') proper management. The action required must embrace both :

- **demand-side** management to ensure that groundwater withdrawals are revised in alignment with realistic assessments of average renewable resources, taking into account the need to conserve environmental discharges and to minimise dependence on non-renewable groundwater
- **supply-side** management by promoting an appropriate range of recharge enhancement measures, taking into account potential climate-change induced changes in rainfall patterns and the need to ensure adequate water quality for aquifer recharge.

The specification of these measures will require significant investigation and financial investment, since at present the level of funding allocated for 'managing natural infrastructure' and for implementing IWRM, in most cases, remains totally inadequate. Harvesting of urban rainfall and stormwater run-off can, in effect, be 'banked' in aquifers for subsequent recovery during drought.

The predicted increase in the frequency of intense rainfall episodes at many latitudes, as a result of global warming, favours and necessitates much greater attention to 'managed aquifer recharge' (MAR). It is important that the MAR technique selected is appropriate for the hydrological setting of the given location. The performance of different MAR techniques is now well documented, although they are often challenging to operationalise. In some countries they contribute up to 10% of the abstracted groundwater resource, but globally the ratio is nearer 1%.



FLOOD RUN-OFF FROM HIGH-INTENSITY RAINFALL OF TYPE PREDICTED IN GLOBAL-WARMING SCENARIOS — EXAMPLE FROM SOUTHERN SPAIN IN 2018

Urban wastewater can also be used for MAR, provided that careful attention is paid to its chemical and biological quality, and the required level of treatment for this purpose. However, the current level of wastewater re-use in all modes remains disappointingly low in most countries.

Changing water resource availability and quality as a result of climate change must be taken into account. If MAR is economic it is likely to be replicated, but it should not be deployed in over-allocated surface water catchments and will always need to be complemented by improved groundwater governance and management (such that withdrawal allocations are aligned with the changing reality of resource availability).

Increased ambient temperatures will inevitably lead to increased groundwater demand for irrigated agriculture and for human use, and potential increases in waterwell abstraction could accelerate the rate of depletion of aquifer reserves. Intensive waterwell abstraction with serious resource depletion is globally a relatively recent phenomenon, but one that has even become embedded in international food trade. While the development of effective governance provisions and management systems for groundwater is still in its infancy, putting effective arrangements in place has to be a high priority if these resources are to be secured for climate-change adaptation.

Among the critical elements will be the formation of independent local water-resource agencies and community organisations for groundwater management, the engagement of a full range of stakeholders to avoid water conflicts, issuing abstraction licences on the basis of capping consumptive use, controlling polluting discharges, providing clear incentives for land owners to enhance groundwater recharge, establishing a clear institutional framework for 'groundwater banks', and improving monitoring networks to provide the detailed feedback essential for adaptive sustainable management.

What has to be done to protect groundwater quality under pressure from climate-change adaptation ?

If groundwater resources are going to play their full potential role in climate-change adaptation then they will need to be more effectively protected against progressive pollution and salinisation – noting that some of the anthropogenic pressures currently threatening groundwater quality are likely to become greater under many climate-change scenarios.

The major challenges that need to be faced at the local level through better integration of economic development and environmental management are :

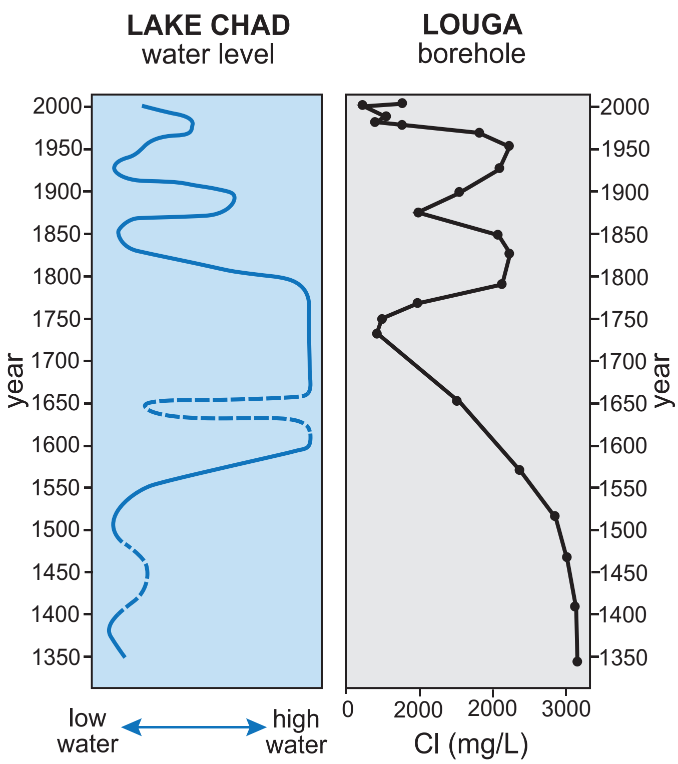
- controlling agricultural cropping practices and cropped areas to reduce excessive leaching of nutrients and pesticides to groundwater (recognising that pollution vulnerability will increase with increasing rainfall intensity)
- making more effective decisions on wastewater collection/treatment in areas of rapid urbanisation and industrialisation, so as to avoid creation of excessive subsurface contaminant loads
- insisting on adequate groundwater protection practices in areas affected by mining

enterprises, with collection of an adequate 'environment fund' to deal with post-mine closure issues
- recognising that sea-level rise, increased storm-surge risk and rising water-supply demand due to global warming will require more focused management of coastal aquifers to prevent saline-water intrusion.

In efforts to conserve groundwater quality it will be important to establish, maintain and improve monitoring networks, since the information they provide will be essential for making 'adaptive adjustments' to groundwater resource policy and land-use management to ensure ground-water sustainability.

Special protection zones around important drinking-water sources (waterwells and springs) in use for piped public-supply, however imprecisely defined, should be established to engage the population on the importance of land-use management to preserve potable groundwater quality – given the critical role that these sources will have to play in ensuring water-supply security for climate-change adaptation.

EFFECT OF HISTORIC CLIMATE-VARIABILITY ON GROUND-WATER RECHARGE SALINITY IN NORTHWEST SENEGAL



good correlation between Lake Chad low water-levels and high unsaturated zone chloride/salinity concentrations in Louga borehole

Are any major changes in groundwater recharge and flow regimes likely to be induced by climate change ?

The question inevitably arises as to just how naturally resilient are our groundwater reserves themselves to climate change ? In discussing this it is necessary to distinguish groundwater system resilience to short-term inter-annual 'climate shocks' from longer-term inter-decadal 'climate change'. It is also important to recognise that the natural rates of climate (and land-cover) change experienced over the past 100,000 years or more were very much slower (about 10 times less) than those currently occurring as a result of anthropogenic impact.

The long-term response to natural climate variability can be clearly discerned in paleo-environmental evidence from some semi-arid regions (such as isotope and chloride analyses from groundwater and from unsaturated zone moisture profiles above aquifers). They reveal marked oscillations in recharge rates and salinity during drought cycles over the past 500 years or so and that most historic groundwater recharge occurred during wetter climatic episodes during the past 5,000 to 500,000 years.

This raises concern about possible reductions in recharge rates from current global warming trends and effects on groundwater reserves in low-storage shallow aquifers. Nevertheless, there remains significant uncertainty over the long-term effect of climate-change on

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groundwater in different climatic regions :

- on the one hand higher ambient temperatures will trigger more intense (but fewer) major rainfall events and increased recharge may result, offsetting inevitably greater evapotranspiration rates from the land surface and, in some instances, could lead to so-called 'groundwater flooding'.
- on the other hand fewer heavier rainfall events could result in soil drying-out and compaction, accompanied by erosion and gullying, which would accelerate surface run-off and reduce infiltration to groundwater
- vegetation and/or crop changes in response to warmer conditions and modified rainfall regime will change evapotranspiration rates and thus water demand
- in mountainous catchments changes in the precipitation balance between snow and rain, and earlier snow-melt, will affect groundwater recharge in downstream alluvial tracts.

FURTHER READING

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PRIORITY ACTIONS

- **every water-resource agency and corresponding water-utility should develop a plan for future water-supply taking into account climate and other changes, and setting reliability criteria for each water-supply source**
- **aquifer management measures, protection strategies and monitoring networks will require much increased financial investment if groundwater is to perform a critical role in climate-change adaptation**
- **local water-resource agencies and community organisations must bring licensed waterwell abstraction in line with the changing reality of resource availability under climate-change pressures to ensure long-term groundwater sustainability**
- **MAR techniques to enhance groundwater recharge are available but water-resource agencies must select techniques appropriate to hydrogeologic settings, and establish both water-harvesting guidelines and demonstration projects**
- **in urban areas harvesting of storm-water runoff and recycled wastewater to groundwater need to be encouraged with appropriate quality controls**
- **more studies need to be undertaken on the long-term effect of climate-change on groundwater in different climatic regions given the current lack of definitive data**

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