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Sustainable Groundwater Management
Concepts & Tools

Briefing Note Series Note 15

Groundwater Dependent Ecosystems

the challenge of balanced assessment and adequate conservation

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Why is an integrated vision of groundwater and ecosystems needed?

- Groundwater plays an integral role in sustaining certain types of aquatic, terrestrial and coastal ecosystems, and the associated landscapes, both in humid and arid climatic regions. It is thus a key factor in efforts to maintain the ecological integrity of some key ecosystems.

- Lack of control over groundwater resource development and protection has already had negative impacts (via changes in groundwater flow and quality) on certain aquatic flora and fauna. In some intensively-developed aquifers (especially in arid and/or densely populated regions) the 'ecological function' of groundwater has already been largely lost, as a result of water-table lowering. And for others it is threatened by deterioration in groundwater quality due to diffuse pollution (especially from nutrients and pesticides).

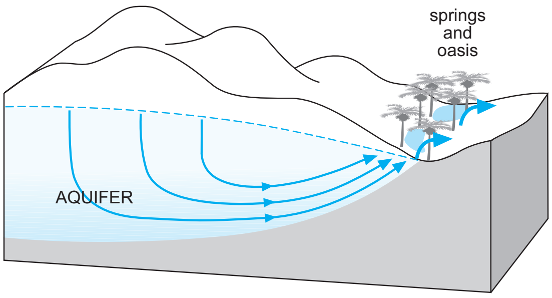
- While groundwater is ***only one factor in ecosystem sustainability*** (and various others such as agricultural land drainage, soil erosion, urban development and introduction of foreign vegetation can be equally or more significant) efforts are needed to make groundwater use and environmental conservation more compatible.

What are the main types of groundwater-related ecosystem?

- One way of classifying groundwater-related ecosystems is by their geomorphological setting (aquatic, terrestrial, coastal etc.) and associated groundwater flow mechanism (deep or shallow). On this basis a number of different classes are recognized (***Figure 1A-E*** illustrates the more important of these):
  - natural discharge from relatively deep groundwater flow systems rising to form distinctive springs with associated (often unique) aquatic ecosystems
  - wetland ecosystems related to the discharge of shallow (and sometimes perched) groundwater flow systems as seepages in land surface depressions
  - groundwater discharge from extensive aquifers providing (in part perennial and elsewhere ephemeral) dry-weather flow in the upper reaches of river systems which represent aquatic ecosystems
  - discharge of groundwater flow systems to coastal lagoons, which is critical in diluting salinity from marine influences and providing unique habitats
  - some extensive semi-arid and humid terrestrial ecosystems without standing water, but with very deep-rooted phreatophytic vegetation extracting moisture directly from the water-table.

Additionally upland, surface-water fed, marshes widely form natural groundwater recharge areas, and must also be included, since their integrity can be threatened by excessive groundwater extraction. There will often be some uncertainty as to whether the above ecosystems are strictly 'groundwater-dependent' or just 'groundwater-using' (that is capable of surviving without access to the water-table or discharging groundwater.

Figure 1: Main classes of groundwater-related ecosystem and their associated groundwater flow regimes

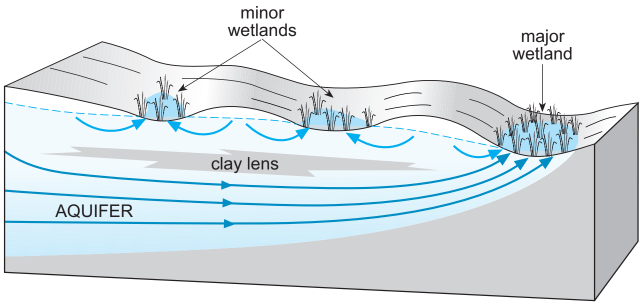


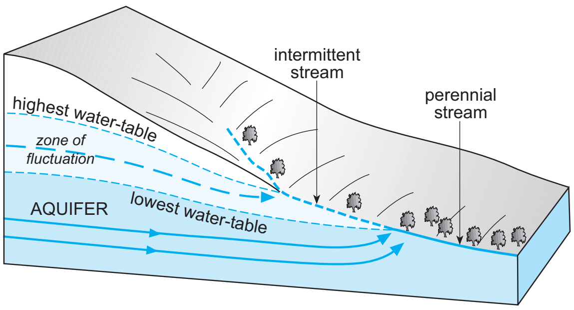
(A) WETLAND ECOSYSTEM IN ARID REGION

dependent upon deep groundwater flow system, sometimes with only limited contemporary replenishment and fossil aquifer flow

(B) WETLAND ECOSYSTEM IN HUMID REGION

individual ecosystems can be dependent upon (or using) groundwater from different depths in a multi-layered aquifer flow system



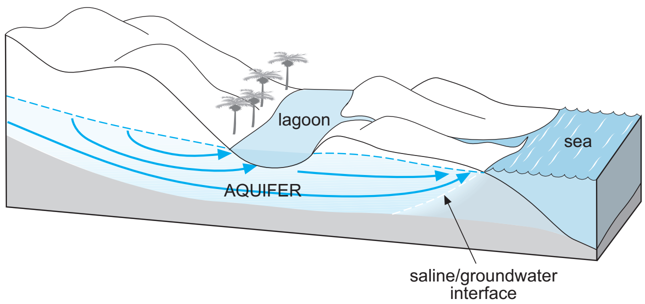


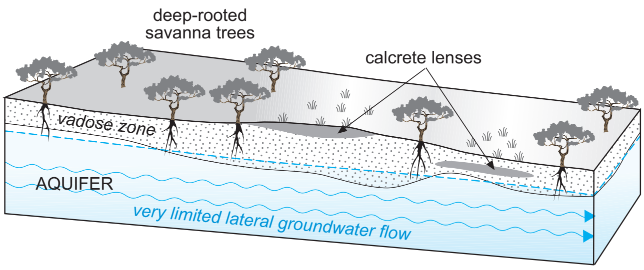
(C) AQUATIC STREAM-BED ECOSYSTEM IN HUMID REGION

variable ecosystem along upper reaches of river system in part fed by perennial groundwater discharge and in part by intermittent groundwater flow

(D) COASTAL LAGOON ECOSYSTEM

ecosystem dependent upon slightly brackish water generated by mixing of fresh groundwater discharge and limited sea water incursion at exceptionally high tides





(E) TERRESTRIAL ECOSYSTEM IN ARID REGION

savanna ecosystem dependent upon exceptionally deep rooted trees and bushes which tap water table or its capillary fringe directly (distribution limited by thickness and degree of consolidation of sediments in the vadose zone)

How does degradation of groundwater-dependent ecosystems arise?

- All groundwater pumping from an aquifer system has some impact on water table levels. But in terms of ecosystem impacts the main physical concern is where the cumulative effects of extraction (usually for agricultural irrigation or urban water supply) cause substantial and persistent water table lowering. This can sometimes also arise, without intensive groundwater use, in situations where the recharge zones of groundwater systems suffer major changes due to deforestation or afforestation, either of which can result in important reductions in aquifer recharge under some circumstances.

- An example of groundwater-fed wetland ecosystems is shown in ***Figure 2***. There is often uncertainty about the reaction of individual species to hydrological change and the interdependence of species within a given ecosystem, and thus in defining what level of change in a groundwater system will result in a significant impact. Those species that are naturally exposed to variations in groundwaterbehavior (for example in ephemeral groundwater-fed streams) are likely to show greatest resilience.

- In practice potential ecosystem impacts can be even more complex because:
  - the effect of groundwater quality deterioration, notably increases of nitrate, ammonium or phosphate (even at low concentrations) and/or trace contamination by pesticides, may lead to greater impact than some levels of groundwater flow modification.
  - it is the way in which groundwater discharges into, and interacts with, the surface environment (via the hyporheic zone) that is sometimes critical to aquatic life ***(Figure 3)***, and not just the presence of free water
  - whilst certain irreversible changes can occur in relatively short periods (such as the oxidation of wetland or streambed sediments), some species are extremely well adapted to survive during hydrologic extremes and re-appear when groundwater levels rise again

Figure 2: Potential interference of groundwater pumping from a multi-layeded aquifer with different types of associated wetland habitat

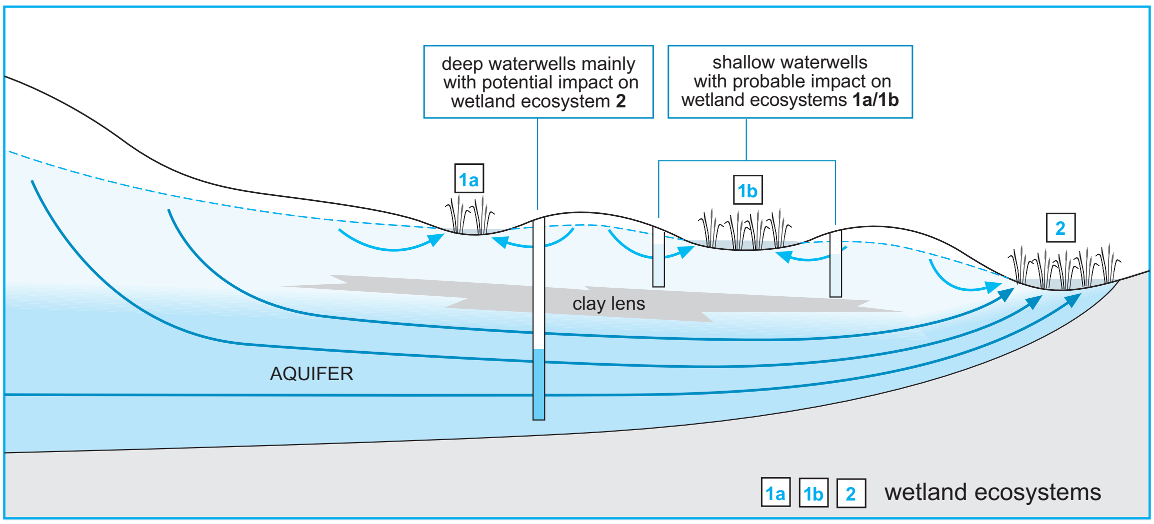
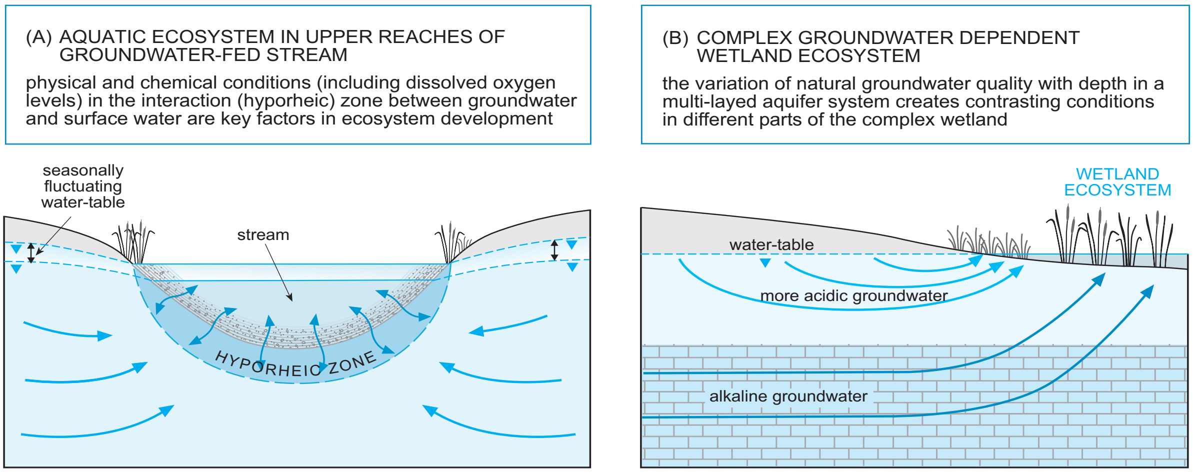


Figure 3: Role of groundwater discharge mechanism in creating some wetland habitats



What can be done to protect groundwater-dependent ecosystems?

- All measures that strengthen the overall governance and practical management of groundwater can contribute, or be adapted, to the cause of protecting dependent ecosystems – this by including criteria to maintain groundwater levels and conserve groundwater quality to meet the requirements of the ecosystem receptor.

- This will often imply greater constraints on the volume and distribution of groundwater extraction than would otherwise have been necessary, together with more severe controls over the generation of groundwater contaminant load than those needed to conserve groundwater at drinking-water quality. A debate is thus often likely to arise over the balance between improving rural livelihoods and sustaining ecosystem health – and this debate needs to be informed by sound technical and socio-economic analysis. But it will always be of central importance for groundwater and environmental 'management planning instruments' to take into account groundwater ecosystem interaction.

- However, social pressures for agricultural development and urban water-supply may be such as to prevent the control of groundwater levels and quality overall in an aquifer system in the interest of ecosystem conservation, and alternatives may need to be pursued such as:
  - lacting selectively to introduce 'protection zones' around wetland ecosystems, capable of assuring the quality of shallow groundwater flow to wetlands and reducing the degree of groundwater level intef-erence
  - artificial groundwater recharge to supplement groundwater flows and improve groundwater quality over limited areas in the interest of wetland conservation, or even pumped compensation flows from aquifersto wetlands when groundwater levels fall below some critical level.

How can the value of groundwater-dependent ecosystems be assessed?

- The functions performed by groundwater-related ecosystems are an important component of the overall environmental services provided by a groundwater system. An economic assessment of the groundwater-related ecosystems will require clear definition of the benefits of the services provided by the ecosystem concerned (**Table 1**) including :
  - the direct values to the human population in terms of fish and plant production
  - the indirect values from sustaining species biodiversity, habitat and landscape.

  And in the latter context it has to be realized that groundwater-related wetlands in arid regions are likely to be of greater significance than hydrogeologically-similar wetlands in more humid regions.

Table 1: Estimation of Total Economic Value of Groundwater-Related Ecosystem

ECONOMIC CATEGORY		DESCRIPTION OF VALUE	EXAMPLE OF VALUE	VALUATION METHOD
USE VALUE	*Direct Use Value*	arises from specific actual and/or planned use of service	wildlife harvesting recreation or amenity	***Hedonic Pricing**** ***Residual Value**** and other methods **
USE VALUE	*Indirect Use Value*	value of array of resource functions that benefit community indirectly	nutrient retention pollution abatement flood control ecosystem support shoreline stabilization soil erosion control	***Contingent Valuation*** (in which a sample of individuals in the population is asked to state their willingness to pay for hypothetical scenarios of environmental protection) and ***Choice Experiment*** (involving highly-structured data generation relying on carefully designed experiments that reveal the factors which influence individual choice)
USE VALUE	*Option Value*	willingness to pay for guarantee of availability of service for future use	potential future benefits of direct and indirect uses	
NON-USE VALUE	*Quasi-Option Value*	willingness to pay to avoid an irreversible commitment to development with uncertain impacts given expectation of improved future knowledge	future value of information from biodiversity conversation	
NON-USE VALUE	*Existence Value*	arising from understanding service will continue to exist independently of any possible use	species biodiversity cultural heritage	
NON-USE VALUE	*Bequest Value*	individual valuation of fact that future generations will have opportunity to enjoy the environmental service		
NON-USE VALUE	*Altruistic Value*	concern that service should be available to others in current generation even if individuals themselves may (or do) not use it		

[shaded] indicates approach of primary importance in context of most developing nations and thus only these are discussed in the text

* see *GW-MATE Briefing Note 7*

** including ***Product Function*** (involving calculation of the implicit value by measuring the contribution of water to profit in cases where it is important in the production process) and ***Replacement Cost*** (the additional expenditure arising in response to an environmental change or averting such a change)

- The assessment of groundwater-dependent ecosystem value should preferably take into account both the direct financial benefits to humankind of such ecosystems and also their indirect benefits (arising from social, cultural, aesthetic and ethical considerations). However, in the developing nation context it is recognized that the following direct use values are likely to be of overriding importance:
  - the productivity of harvested plant and animal species
  - 'natural landscapes' and 'wild habitats' of cultural and recreational value for tourism

  While the livelihoods of more people depend directly upon the functioning of groundwater-related ecosystems these people are often the most poor and vulnerable members of society, and there is thus a risk that ecosystem value may sometimes be systematically under-estimated.

- In most cases the protection of groundwater-dependent ecosystems will imply greater constraint on the volume and distribution of groundwater extraction than would otherwise have been necessary – together with controls over the generation of contaminant load which could be as severe as those needed to conserve groundwater at drinking-water quality

- Disputes are thus often likely to arise over the balance between improving rural livelihoods and sustaining healthy ecosystems. Decision-making needs to be informed by sound technical and economic analysis, and it is thus important to incorporate economic evaluation into the analysis of management options, through identifying and optimizing their welfare benefits and distributional effects.

- An economic analysis for this purpose will normally entail a relative assessment of the :
  - ***cost of protection*** in terms of the loss of alternative uses of groundwater and land, and the administration of the land-use and groundwater control policy
  - ***benefits of protection*** in terms of in-situ value of groundwater and groundwater-related ecosystem services.

  In this context an analysis based on marginal costs and benefits is likely to be more realistic of the situation on the ground, and scenarios of partial protection (as opposed to total protection) of the groundwater-dependent ecosystem also need to be considered. It should also be apparent that the economic cost-benefit analysis to inform protection policy for groundwater-dependent ecosystems is rather distinct from the subsequent need for a cost effectiveness assessment of different ecosystem protection options.

What particular institutional and legal arrangements can facilitate the consideration and protection of groundwater environmental functions?

- In developing countries in particular, strong social pressures are likely to arise for further agricultural and urban development, which are likely to impact groundwater-related ecosystems either directly (through increased groundwater extraction) or indirectly (through increased groundwater contaminant load). Thus an important issue in relation to the implementation of groundwater management to protect groundwater-dependent ecosystems is who should be the stakeholder representing the interests of a given ecosystem.

  There are a number of possible stakeholders :
  - an NGO representing the local community dependent upon the functioning of the ecosystem or generally interested in ecosystem conservation

- the local land authority representing the balance of interests of all local land-owners
- an environmental agency at national or local territorial level.

Without the existence of a groundwater use rights system ***(GW-MATE Briefing Note 5)*** and the participation of a clearly identified stakeholder group ***(GW-MATE Briefing Note 6)***, it is unlikely that the interests of groundwater-dependent ecosystem sustainability will get an adequate hearing in the discussion of land and water development options.

- Given the likelihood of significant uncertainty over the precise level of impacts on groundwater-dependent ecosystems likely to arise from a given water resource and/or land development proposal, the regulatory agency ***(GW-MATE Briefing Note 4)*** generally needs to adopt a decision-making strategy and this will normally have to embrace one or other of the following :
  - the **precautionary principle** of not authorizing any development until ecosystem risks are established and managed (this usually will be too conservative for most developing countries where the needs for land and water development are very pressing)
  - **pragmatic initial development** of groundwater resources with careful monitoring ***(GW-MATE Briefing Note 9)***, evaluation and adaptation of development plans in the event of significant impacts.
  - **reserving specific environmental flows** within the overall groundwater resource management strategy and planning ***(GW-MATE Briefing Notes 3 &10)*** to sustain key wetlands.

- The complexity of estimating the impacts of groundwater extraction and pollution make it difficult to define limits that can be readily measured and legally enforced – but legislation can provide for this by stipulating that 'in cases where stakeholders do not agree with the regulatory authority's determination they can undertake more detailed studies at their own cost'.

Further Reading

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Publication Arrangements

The GW•MATE Case Profile Collection is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

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