Sustainable Groundwater Management: Concepts and Tools

Briefing Note 3

Groundwater Management Strategies

facets of the integrated approach

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What approaches are needed to stabilize heavily-stressed aquifers?

- This briefing note explains the technical strategies to confront situations of excessive and unstable groundwater exploitation, but the institutional framework for implementation is dealt with elsewhere (**Briefing Notes 4, 5 & 6**). In this regard the following fundamental sub-division of resource management options (Table 1) is useful:
  - **demand-side management interventions**
  - **supply-side engineering measures.**

- Although groundwater management is conducted at local aquifer level, **national food and energy policies** can exert an overriding influence on the behavior of groundwater abstractors (**Briefing Note** 7), and thus on resource development pressures and management strains. Among these, subsidies on rural electricity, well drilling, pumpsets, grain and milk prices are probably the most significant. In general terms these subsidies should always be reviewed, and consideration be given to re-targeting the revenue involved into water-saving technology and/or assisting only the neediest members of the community.

- It is always essential to address the issue of constraining demand for groundwater abstraction (Table 1), since this will normally contribute more to achieving the groundwater balance, and in the more arid and densely-populated areas will always be required in the longer run. The **concept of real water savings** is critical in this regard—these savings include only reductions in evaporation (that is consumptive use) and in loss to saline water bodies, but not those reductions which would have generated aquifer recharge. For example, in urban areas, real water savings can be made by reducing water-mains leakage and wastewater seepage, but only where they generate discharge to brackish water bodies or create drainage problems.

- Complementary local supply-side measures (Table 1), such as **rainwater harvesting, aquifer recharge enhancement** (with excess surface run-off), and **urban wastewater reuse** should always be encouraged,

MYTH ▶ **water transfer and other supply-side measures are a prerequisite for the recuperation of overdrafted aquifers**

REALITY ▶ *focused demand management will more often make the critical contribution and will anyway generally be essential in the longer term*

Table 1: Demand-side and supply-side actions for groundwater resource management

LEVEL OF ACTION	DEMAND-SIDE MANAGEMENT INTERVENTIONS	SUPPLY-SIDE ENGINEERING MEASURES
Irrigated Agriculture	● real water-savings secured in part from: – low-pressure water distribution pipes – promoting crop change and/or reducing irrigated area – agronomic water conservation	● local water harvesting techniques ● appropriate recharge enhancement structures (either capturing local surface runoff or sometimes with surface water transfer)
Main Urban Centers	● real water-savings sometimes secured from – mains leakage and/or water use reduction – reducing luxury consumption (garden watering, car washing)	● urban wastewater recycling and reuse (including controlled and/or incidental aquifer recharge by both *in situ* sanitation and mains sewerage) (**Briefing Note 12**)

especially where conditions are favorable. They are often important in terms of building better relationships with groundwater users and can provide an initial focus for their participation in aquifer management.

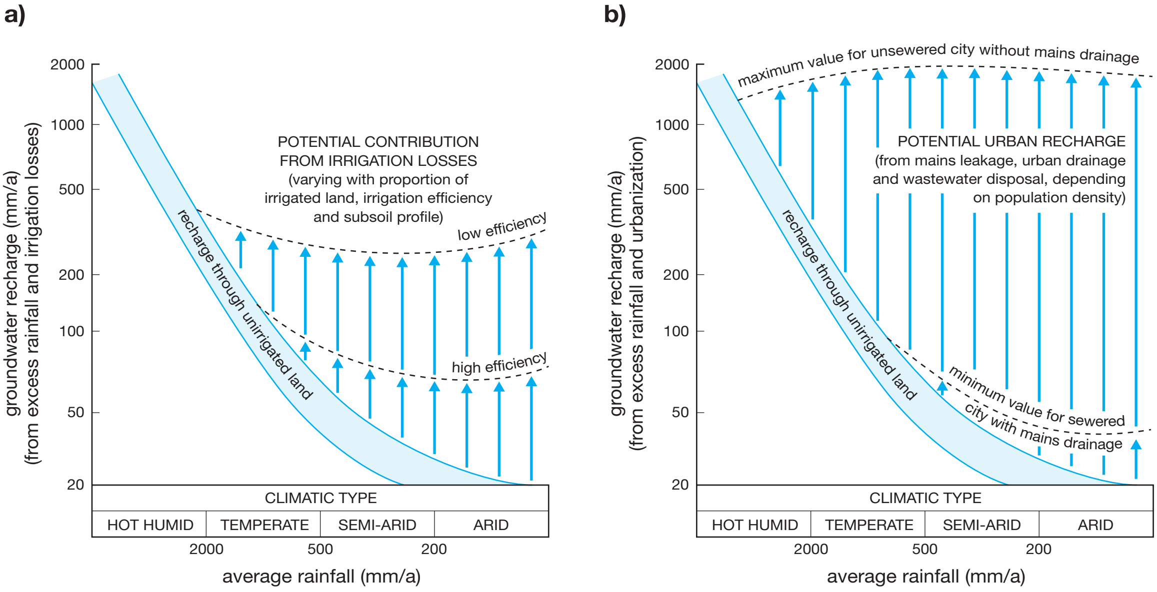
Can groundwater resource use for irrigated agriculture be reduced?

- This subject must assume primary importance given that, in most regions, agriculture is the predominant consumer of groundwater resources. Moreover, excess irrigation often forms an important component of aquifer recharge (Figure 1), and a resource in turn normally available to other groundwater users or as baseflow in downstream rivers. It follows that while increasing irrigation efficiency represents 'an energy saving' (since less pumping will be required), it does not necessarily represent 'a water resource saving' (because the water may anyway have returned to the aquifer).

- In some instances improvements in irrigation water-use efficiency while generating improvements in water-use productivity and farmer incomes, lead to a deterioration in the groundwater resources balance as a result of:
  - substituting increased field-level evaporation/evapotranspiration (in spray irrigation) for major groundwater irrigation-return flows (occurring in flood irrigation)
  - making feasible the expansion of irrigation command and the area actually under cultivation (due to the capacity of pressurized water delivery)
  - facilitating the introduction of higher-value crops, which make it viable for farmers to deepen wells and to pump groundwater against greater hydraulic heads.

- Only those modifications to irrigation and cropping practices that reduce '**non-beneficial evapotranspiration**' or '**non-beneficial discharges to saline water bodies**' actually represent 'real water savings' (although these components may not be easy to quantify accurately). Thus the primary aim of agricultural demand management for groundwater resource conservation should be to reduce (a) evaporation from the irrigation water distribution system, (b) soil evaporation from between crop rows, (c) evapotranspiration by the crop itself ineffective in producing yield, (d) direct phreatic evapotranspiration by unwanted vegetation and (e) direct evaporation during spray irrigation.

Figure 1: Typical effect on groundwater recharge rates of: a) irrigated agriculture; and b) urban water infrastructure



- *the vertical arrows indicate the potential increase in groundwater recharge in scenarios of varying water-use efficiency, assuming that irrigation losses and urban leakage freely infiltrate to an unconfined aquifer*
- *the effects of this man-made recharge will be more apparent in the aquifer when imported surface water (and not local groundwater) is the primary source for irrigation and urban supply*

- There is generally considerable scope for these types of agricultural water savings by:
  - **engineering measures**: such as irrigation water distribution through low-pressure pipes (instead of earth canals) and irrigation water application by drip and micro-sprinkler technology
  - **management measures:** to improve irrigation water scheduling and soil moisture management
  - **agronomic measures:** such as deep ploughing, straw and plastic mulching, and the use of improved strains/seeds and drought-resistant agents.

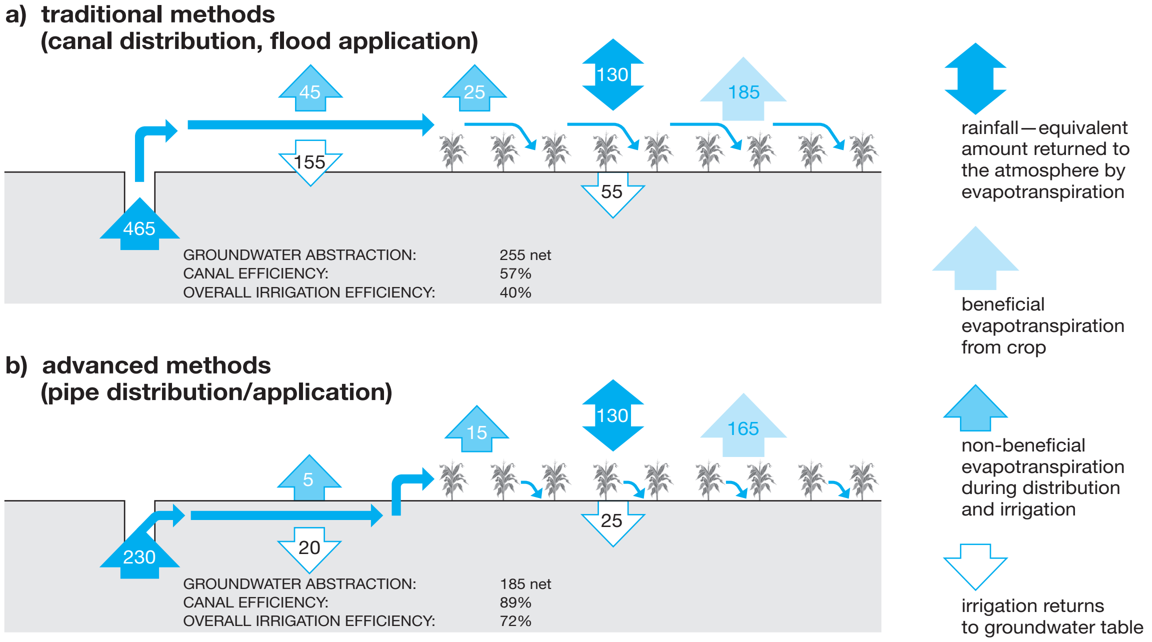
  If larger water savings are needed, then consideration should also be given to changes in crop type and land use (e.g. through higher-value crops under greenhouse cultivation or returning a proportion of the area to dryland cultivation of drought-resistant crops). An even more radical option would be to place a ban on the cultivation of certain types of irrigated crop in critical groundwater areas.

- The success of agricultural water-saving measures in reducing the decline in aquifer water levels depends directly on these savings being translated into permanent reductions in well abstraction rights and actual pumping. It is essential that water savings are not used to expand the irrigated area or to increase water usage in other sectors. This will require a flexible system of abstraction rights and clear incentives for users to act in the collective interest of resource conservation. At the urban-rural

MYTH ▶ **increasing 'irrigation water-use efficiency' necessarily leads to 'groundwater resource conservation'**

REALITY ▶ *in practice the reverse can often be the case as a result of major reductions in the irrigation return flow, increased evaporation at field level and expansion of the irrigated area*

Figure 2: Improved techniques of agricultural irrigation leading to real water-resource savings



a) traditional methods (canal distribution, flood application)

b) advanced methods (pipe distribution/application)

- *gross groundwater abstraction is reduced by 235 (465–230) (representing a pump energy saving of 51%)—this is often incorrectly claimed also to be the water saving, but in reality irrigation returns to groundwater need to be considered and the real water saving is a reduction in net groundwater abstraction of 70 (255–185) or 27%*
- *the data presented are derived from a comparative monitored field trial on the North China Plain—units are equivalent mm over the 65 ha irrigated area of winter wheat during dry-season cultivation*

interface resource reallocation to more productive commercial and industrial use can be best promoted if the corresponding municipality finances improvements in agricultural irrigation (generating real water savings) in return for abstraction rights over a proportion of groundwater saved. It should be noted, however, that the position will be significantly different where surface water is the primary source for irrigation and/or where the groundwater table is very shallow, since in such cases drainage to mitigate soil waterlogging and salinization will be the major concern.

How should the natural storage capacity of aquifers be used?

- In many ways the vast storage of groundwater systems—whose magnitude varies significantly with geological build (**Briefing Note 2**)—is their most valuable asset. This storage capacity includes not only groundwater already stored in aquifer systems but also the potential of their void space (and elastic storage) to receive enhanced recharge (in part resulting from dewatering by pumping) (Table 2).

- It is important that groundwater resources are properly considered in national strategic planning. Addressing the policy question 'what services are most required from groundwater' is necessary to provide targets for local management action, but it is one which is frequently ignored. On the one hand, important components of the value of groundwater (such as pumping costs, individual accessibility, sustaining freshwater wetlands and dry weather streamflow) depend on the depth to water-table and not on the volume in storage. On the other hand, in many situations groundwater storage is the only source of freshwater in extended drought, and ways need to be found to exploit this resource while mitigating

MYTH ▶ **groundwater storage is severely depleted on a widespread basis and should be 'written off' as a future solution for water-supply problems**

REALITY ▶ *uncontrolled groundwater exploitation leading to negative side-effects has occurred quite widely, but there is still much scope (although not enough practical experience) in controlled engineering of aquifer storage for water supply*

the impacts on aquifer water-level related services. The more widespread, and socially-sustainable, use of groundwater storage to combat water-demand variability resulting from persistent drought and climatic change (on a scale of months to decades and beyond) is urgently needed.

- Water resource management strategy in which groundwater and surface water are used in tandem, making use of the comparative advantages of both is termed **conjunctive use.** Examples include:
  - use of surface water for inefficient flood irrigation to enhance aquifer recharge in the wet season
  - use of groundwater in dry periods for irrigation to replace the normal surface water supply

  Currently, conjunctive use (where practiced) tends to have arisen more by accident than design.

- Aquifer recharge enhancement (Table 2) and manipulation of subsurface storage will allow increased long-term average rates of groundwater abstraction benefiting all users. The opportunities for enhancing aquifer recharge vary widely with hydrological basin setting:
  - in **closed basins** (no water reaching sea) upstream recharge enhancement will result in diminution of downstream availability for existing users, but may still represent more beneficial water use

Table 2: Summary of types of aquifer recharge enhancement structures

TYPE	GENERAL FEATURES	PREFERRED APPLICATION
Water Harvesting	**dug shafts/tanks** to which local storm runoff is led under gravity for infiltration	in villages of relatively low-density population with permeable subsoil
	field soil/water conservation through terracing/ contour ploughing/aforrestation	widely applicable but especially on sloping land in upper parts of catchments
In-Channel Structures	**check/rubber dams** to detain runoff with first retaining sediment and generating clearwater	in gulleys with uncertain runoff frequency and high stream-slope
	recharge dam with reservoir used for bed infiltration and generating clearwater	upper valley with sufficient runoff and on deep water-table aquifer
	riverbed baffling to deflect flow and increase infiltration	wide braided rivers on piedmont plain
	subsurface cut-off by impermeable membrane and/or puddle clay in trench to impound underflow	only wide valleys with thin alluvium overlying impermeable bedrock
Off-Channel Techniques	**artificial basins/canals** into which storm runoff diverted to with pre-basin for sediment removal	where superficial alluvial deposits of low permeability
	land spreading by flooding of riparian land sometimes cultivated with flood-tolerant crops	on permeable alluvium, with flood relief benefits also
Injection Wells	**recharge boreholes** into permeable aquifer horizons used alternately for injection/pumping	storage/recovery of surplus water from potable treatment plants

  - in **open basins** (continuous flow to sea) recharge enhancement can be practiced but will only increase the marginal value of water during extreme drought
  - in **semi-closed basins** (intermittent outflow to sea) major opportunities for recharge enhancement of potentially high value are likely to be present.

- A range of structures can be used for recharge enhancement (Table 2), but it is important that technique selection is closely related to hydrgeological site conditions. It will further be necessary to consider:
  - the quality of water for recharge (after consideration of natural contaminant attenuation processes) so as not to degrade the groundwater body
  - institutional issues in terms of raising investment (who pays?), use priorities (who benefits?) and management arrangements (who controls?).

- The first structures emplaced in a given area should be regarded as 'pilots' and monitored systematically over a 5-year period to analyze their cost-effectiveness (in US$/m^3 of water harvested). The rigorous technical and economic evaluation of the effectiveness of recharge enhancement structures is, however, far from straightforward because of uncertainty over rainfall-runoff relations. The key requirement is to estimate the additional runoff that is recharged over and above that which would have occurred naturally (i.e. the difference between the 'with project' and 'without project' conditions).

Further Reading

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