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# Economic and Environmental Management of Water Resources: Perspective of Groundwater

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*Abstract-* Subsurface water has a substantial economic value in drinking and irrigation water across the globe. Failure to recognise the economic value has led to wasteful and environmentally damaging uses of the resource. When the groundwater resource gets depleted, groundwater development costs increase and the aquifers ‘capacity to provide the variety of environmental services, decreases with sinking groundwater level and diminished natural discharge. The cost of abstracting the fresh water increases with the need to lift groundwater from increasingly greater depths, and hence the cost-benefit ratio of groundwater use changes over time. The procedure of discounting adjusts for future values of related services by accounting for time differences. Environmental costs are rather difficult to assess and incorporate in groundwater resources management. Environmental damage costs refer to non-use values attached to a healthy functioning aquatic ecosystem, while the costs to those who use the water environment refer to the corresponding use values. This paper highlights the aspects relevant for decisions to groundwater management and rate of storage depletion and its financial implications.

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# Economic and Environmental Management of Water Resources: Perspective of Groundwater

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*Abstract-* Subsurface water has a substantial economic value in drinking and irrigation water across the globe. Failure to recognise the economic value has led to wasteful and environmentally damaging uses of the resource. When the groundwater resource gets depleted, groundwater development costs increase and the aquifer's capacity to provide the variety of environmental services, decreases with sinking groundwater level and diminished natural discharge. The cost of abstracting the fresh water increases with the need to lift groundwater from increasingly greater depths, and hence the cost-benefit ratio of groundwater use changes over time. The procedure of discounting adjusts for future values of related services by accounting for time differences. Environmental costs are rather difficult to assess and incorporate in groundwater resources management. Environmental damage costs refer to non-use values attached to a healthy functioning aquatic ecosystem, while the costs to those who use the water environment refer to the corresponding use values. This paper highlights the aspects relevant for decisions to groundwater management and rate of storage depletion and its financial implications.

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## I. INTRODUCTION

### *a) Economic and Financial Aspects of Storage Depletion*

There are two major problems related to water use. First one is overconsumption that augments water scarcity (e.g. Asian and USA over drafting of ground water Rodell et al 2007; Kumar et al 2005) and the second is pollution (due to Industrial and human activities) which degrades water quality. Both these result in the fact that freshwater is a scarce resource. Water produces both benefits and costs due to consumption and supply. Benefits are increasing at a decreasing rate. It means that consuming more water will have more benefits but the benefits coming from initial quantity of water will decrease with additional quantities. The costs of water are increasing at an increasing rate. This means that the more water is consumed, the more resources are to be explored which may be costly to access and require additional investments in infrastructure without knowing quantitative perspective to future (Lehmann, 2016; Yihdego and Drury, 2016; Yihdego and Paffard, 2016)

It goes without saying that groundwater abstraction has an economic value. However, keeping groundwater in situ has an economic value as well. When the groundwater resource gets depleted, groundwater development costs increase and the aquifer's capacity to provide the variety of environmental services, as described previously, decreases with sinking groundwater level and diminished natural discharge. Then operational cost of ground water extraction will be due to lifting it from increasingly greater depths, and hence the cost-benefit ratio of groundwater use will fluctuate over uncertain future time span. The procedure of discounting adjusts for future values of related services by accounting for time differences. There is a degree of uncertainty involved in assuming an appropriate discount rate and the discounting procedure is in practice less suitable to address values in the very long term. Higher discount rates by giving less weight to future net benefits encourage the present use of the resource (Dewsburya et al., 2016; Yihdego, 2017).

The expenses of groundwater extraction mainly depend on the efficiency of pump, the depth of water to be pumped, and energy cost. These costs increment with the increase in pumping depth and energy and decrease with the improvement in pump efficiency. The value of extraction also includes the price of the opportunity foregone due to extraction and the usage of the water now in preference to at some time in future. The user cost of water will depend on current costs associated with pumping and subsequently lowering of water table as well as the growing expenses of extraction for every future period. The rate of extraction in the present time frame will be effective only if the possibly higher expenses of pumping in future are correctly anticipated. Economic literature about groundwater stresses that when groundwater is pumped in independently competitive manner, pumpers have solid impetuses to disregard the client cost. In these conditions pumpers tend to regard ground water as an open source, with the outcome that rates of groundwater extraction surpass the economically proficient rate (National Research Council, 1997).

Failure to recognise the economic value has led to wasteful and environmentally damaging uses of the resource. In practice, factors contributing to groundwater depletion may include a lacking price signal reflecting the scarcity value of the groundwater threatened by depletion (Van der Gun & Lipponen,

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2010; Yihdego et al., 2016a, 2016b). In general, basic economics require that the price of a service be at least as high as the cost of providing that service. In the context of water supply, sustainable cost recovery, which utilities are encouraged to aim for, includes operating and financing costs as well as the cost of renewing existing infrastructure (Molinos-Senante et al., 2016). Rogers et al. (2002) argue that sustainable and efficient use of water require the tariff to match not only costs of supply (*i.e.*, operation and management, capital costs), but also opportunity costs, economic externality costs, and environmental externality costs. From the perspective of economic theory, there is a so-called contemporaneous opportunity cost for not having the water available for another current use. If current use depletes the groundwater stock to the extent that it makes groundwater unavailable for future, then there is the intertemporal opportunity cost of not having the water available for future use. Water uses may have an additional charge if the use of water renders it unfit for other uses by hurting water quality, hence having negative impacts on other water users (Borrego-Marín et al., 2016).

Groundwater storage depletion and the associated groundwater level declines have two-fold economic impacts for those interested in groundwater abstraction: higher groundwater development cost and a reduced value of the remaining groundwater volume stored. They may have a negative impact as well on groundwater-related environmental functions and conditions. All these consequences constitute an economic loss, only acceptable if balanced or exceeded by the benefits produced by the abstracted groundwater (Kim & Schaible, 2000). How economic and financial aspects are or may be taken into account in decisions on groundwater development depends on the perspective: an exclusive groundwater pumper will have different interests and thus will make different decisions related to the aquifer‘s exploitation than the local community. This will be illustrated below.

A farmer who owns and uses a well for the supply of irrigation water will be unpleasantly surprised if he is confronted by steadily declining groundwater levels, year after year. From the onset, the water level declines will reduce well yield and increase the unit cost of pumping, thus gradually eroding profits of irrigated agriculture. Investments may be needed after some time to deepen the well and to replace the pump by a more powerful one. Whether these investments are made by the farmer or not depends on his judgment on the economic feasibility of continued groundwater pumping and his access to the necessary financing. Many individual farmers will sooner or later decide to give up because the economic profitability of pumping is disappearing or they cannot afford to continue pumping. This effect provides feedback from the users of the aquifer system, contributing to the conservation of groundwater.

The individual farmer will be concerned about increasing pumping costs of his well. However, he usually does not care about how he contributes to a reduction in the volume and economic value of stored groundwater, nor to increased pumping cost of other groundwater users, nor to diminished access to future generations to groundwater, nor to groundwater-related environmental degradation. To him, these aspects are externalities‘, representing costs to be shared by all who make use of the same common pool in this case the aquifer and its related ecosystems. The existence of these externalities explains why decisions made at the individual level may diverge from socially optimal decisions, which is a justification for government interventions.

The Upper Guadiana Basin, where groundwater acts as the primary driver behind the region‘s prosperity by supporting irrigated agriculture for the past decades, illustrates the related management challenges (Marchiori et al., 2012). The development of irrigation based on groundwater from the Mancha Occidental aquifer has come at a significant environmental cost, giving rise to long-standing conflicts, and there are concerns as to its mid-term sustainability. Uncontrolled intensive pumping by individual farmers has dramatically lowered water tables and has caused considerable negative environmental impacts on groundwater-dependent wetlands, streams and rivers. A large proportion of the wells is currently illegal, which makes it difficult to manage water resources (Martínez-Santos et al., 2008; Conan et al., 2003).

At the level of the community, the mentioned externalities should be incorporated into the groundwater quantity management approach. Plans for groundwater management should consider not only the benefits of pumped groundwater and the increase of pumping cost due to storage depletion but also the associated change in the value of groundwater stored and the allocation of all cost and benefits including intergenerational allocation. This involves a rather complex balancing of components, which may be guided by optimisation approaches analogous to those presented by Kessler et al. (1992) for natural resources management in general. In cases that allow simplification, simple decision rules may be helpful. An example is Burt‘s approximate decision rule for intertemporal allocation of groundwater abstraction from remote groundwater reservoirs (Domenico, 1972).

Groundwater availability can be determined by means of the interaction of geological, hydrologic, and financial elements. The quantities of water available now and in the future rely on the interplay of extraction and recharge. The cost of acquiring ground water is determined with the aid of pumping depths, energy prices, and the price assigned to the opportunity foregone as a result of extracting groundwater now as opposed to later. Groundwater value relies upon both the price of acquiring it and the willingness of customers to pay, and willingness to pay depends critically on water quality (National Research Council, 1997).

Environmental costs are rather difficult to assess and incorporate in groundwater resources management (Jasch, 2003). They consist of the environmental damage costs of aquatic ecosystem degradation and depletion caused by a particular water use such as water abstraction. Following the definition in Newig et al. (2005), a distinction can be made between damage costs to the water environment and to those who use the water environment. Interpreted regarding the concept of total economic value, one could argue that the environmental damage costs refer to non-use values attached to a healthy functioning aquatic ecosystem, while the costs to those who use the water environment refer to the corresponding use values. Use values are associated with the actual or potential future use of a natural resource (e.g., drinking water, irrigation water). Non-use values are not related to any actual or potential future use but refer to values attached to the environment and natural resource conservation based on considerations that, for example, the environment should be preserved for future generations (Brouwer et al., 2004). In conclusion, groundwater storage depletion may have significant financial and economic implications. Therefore, these aspects are relevant for both individual decisions to be made and groundwater resources management about the rate of groundwater storage depletion.

### *b) Full value and Full cost of a single water use*

There is a direct value of water to users. This refers to the willingness to pay for water or marginal product of water. There may be net benefits from return flow, for example water for irrigation may recharge groundwater so there will be return benefit from a return flow from irrigation. Net benefits may come from indirect uses of water, for instance water for irrigation may be at the same time available for drinking or livestock feeding. Also, adjustment has to be made for societal objectives such as food security. All these refer to an economic value of water. The intrinsic value of water and economic value of water refer to full value of water as shown in Figure 1 (Lehmann, 2016).

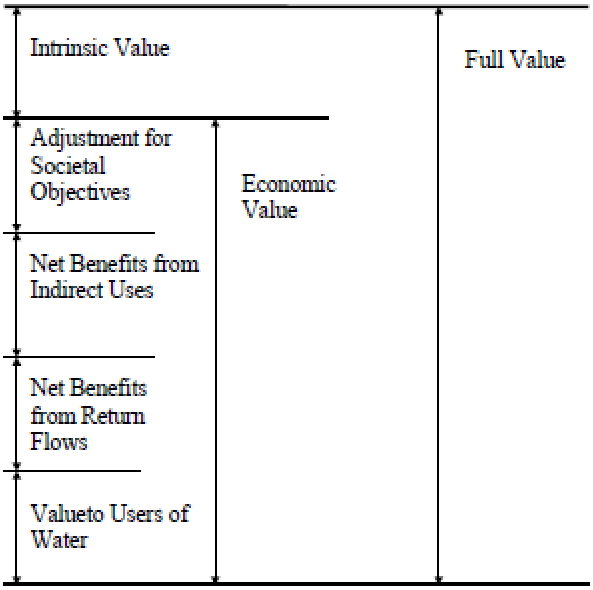

*Figure 1:* Full value of water (Rogers et al., 1998)

The cost of water will start with operation and maintenance of water, which arises from the daily supply of the water system. It includes the cost pumping water, repair cost and treatment cost. Capital costs refer to capital consumption and interest rates that has to be paid for loans. These correspond to the full supply costs of water. There may be opportunity cost by using water for one use and will not be available for other uses. For instance, water used for irrigation may not be available for drinking. Both full supply cost and opportunity cost correspond to full economic cost of water. External cost of water relates to the environmental cost of water. For example, pollution of water will forgo its use for other useful purposes. Full cost and external cost correspond to full cost of water as shown in Figure 2 (Lehmann, 2016).

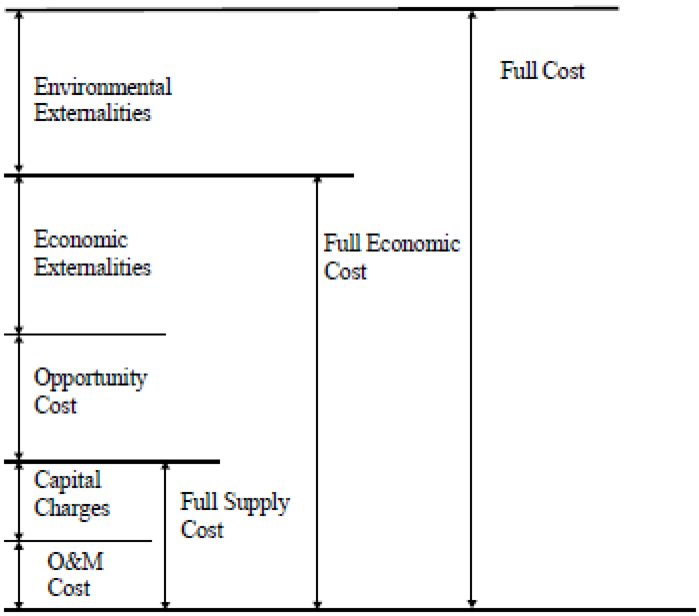

*Figure 2:* Full cost of water (Rogers et al., 1998)

*c) Valuation techniques for groundwater*

Water is regularly underestimated and undervalued. Policy makers and stakeholders are frequently unaware of the total economic value of the resource. For this reason, groundwater is not properly managed and is progressively under the danger of contamination and depletion (e.g. Asian countries like Pakistan, India and Bangladesh are at worse in this case having -2 cm mining per year). For a demanding groundwater management, it is important to determine its economic value and should consider it as an economic resource. Estimates of value can play a prime role in directing policy-makers and public attention on vulnerable undervalued resources. Such estimates are essential for determining the extent of funding in groundwater development, security, tracking, and management which can be financially advocated. The total economic value of groundwater is composed of both use values (for instance, extractive and in situ values) and non-use values (for example, bequest and existence values). In this scenarios the suitable methodologies may be adopted to determine the both use and non-use values for future perspective. (Pulido-Velazquez et al., 2013).

*d) Market-based valuation techniques*

For market value base evaluation, we can measure values via actual costs in market exchanges. For instance, supply of groundwater for irrigation. Since this water has a market value, therefore statistical approaches (econometric techniques) can be used to estimate this. Unfortunately, effects such as enhancements in quality of groundwater, ecosystems that dependent on groundwater etc. are not reflected in market transactions (Pulido-Velazquez et al., 2013). Therefore, it is essential to measure qualitative, quantities and environmental aspects as market transactions to help out policy makers for developing proper framework to incorporate ground water selling.

*e) Non-market valuation techniques*

These approaches are used when costs for goods and services of groundwater do not reflect the real value or when there is no available price but still the value needs to be determined for decision making. These approaches can be grouped into revealed and quantified preference methods.

Revealed preference method is based on actual observable choices and from which actual resource values can be directly inferred, mostly based on actual market prices or costs incurred (for example, hedonic pricing to decide the economic value of groundwater based ecosystems). Stated preference method is based on elicit respondents willingness to pay when the value is not directly observable (for instance, contingent valuation or choice experiments). Some applications to groundwater valuation are the assessment of the benefits of groundwater quality enhancements, or the full cost (environmental and resource expenses) of groundwater deterioration or depletion (Pulido-Velazquez et al., 2013).

The use of these approaches is frequently very costly and tedious, and needs specific skill. One option will be to deduce the estimation of groundwater value by interpreting the results acquired from different areas. Benefit transfer offers a quick and reasonably-priced opportunity to original valuation studies, but we have to be careful of their utility due to the fact a few situations ought to be met on the way to provide consistent estimates (Pulido-Velazquez et al., 2013).

### f) *Problem while defining cost in tragedy of commons*

In market and non-market cost evaluation procedure is bound to some limits which need to defined properly. The simple example attached to ground water scarcities in supply economic supply regime is tragedy of commons proposed by Garret Hardin 1968. In south Asian countries like Pakistan, India and Bangladesh facing the problem with ground water supply system which is commonly cast-offed by individual masses based on their self-interests without knowing that how their selfishness will increase the cost of ground water in market to future. This may be removed by community driven approach to estimate the exact cost of each drop of ground water but it is not inevitable yet.

## II. GROUNDWATER RESOURCES DEVELOPMENT AND SUSTAINABILITY

### a) *Groundwater Storage: Blessing and Concern*

Groundwater systems tend to have large volumes of water in storage, usually equivalent to the recharge of several tens to several thousands of years. These large storage volumes are a blessing, for some reasons. They keep water available during prolonged dry periods when no rain is occurring, and stream flows have become minimal or even zero. As a result, people have been able to settle in areas where otherwise human life would be impossible or onerous due to annually recurring dry seasons (most arid and semi-arid zones). Also even due to the absence of significant rain during the last centuries or millennia (e.g., a large part of Northern Africa, where most recent significant groundwater recharge occurred thousands of years ago) (De Vries et al., 2000). Available groundwater storage does contribute not only to reliable public and industrial water supplies but also to reliable irrigation water supplies. The latter is not only necessary to secure food supplies, but it also has very positive economic impacts. The fact that groundwater sources tend to be more reliable and predictable than surface water sources often results in significantly higher economic returns per cubic meter of water used for irrigation (Shah et al., 2007; Llamas & Martínez-Santos, 2005).

The same groundwater storage provides a reason for concern as well. If surface water users abstract water from streams at a hydrologically unsustainable rate, then most streams will rather quickly give feedback by reducing their flow rates, which forces abstractions to be reduced or even to be stopped. In the case of intensive groundwater abstraction, the feedback is much weaker. Groundwater levels will drop indeed, but the large groundwater volume in storage allows well owners to continue excessive pumping usually for many years. Consequently, pro-active rather than reactive groundwater quantity management is needed to protect the sustainability of the aquifer‘s abstraction potential and its groundwater-related environmental functions. As a sound basis for making the related decisions, groundwater monitoring with sufficient spatial and temporal resolution is required for detecting and observing storage depletion reliably (e.g.India and Pakistan ). Lack of control may lead to practically irreversible losses of aquifer functionalities, in other words, it may undermine sustainability. Yemen is illustrative for countries being exposed to such a risk (Ohisson, 2000).

It is crucial to understand that groundwater overdraft may be economically proficient in some cases. At the point when the advantages of utilization are very high in connection to the expenses of extraction (which include the consumer price), overdraft might be proficient for some timeframe. In times of dry season, for instance, when surface water supplies might be truant or scarcer than regular, overdraft might be productive. But this over drafting will no longer hold profitability if water table will accelerate to mining. In any case, even in circumstances where overdraft is productive, it will eventually act naturally ending. Furthermore, in assessing the monetary desirability of overdraft, we need to account for certain unfavourable impacts, which include land subsidence, salt water intrusion, and harmful outcomes on surface water and aquatic habitats which will be curse to broken if consider the over drafting to be productive (National Research Council, 1997).

### b) *Groundwater Quantity Management is Based on Preferences*

As mentioned before, groundwater pumping causes depletion of groundwater storage and changes the groundwater regime, thus modifying groundwater levels, groundwater in- and outflows and groundwater quality. These modifications have their impacts on people, ecosystems and the environment. In the majority of cases, such effects are negative, as opposed to the predictable positive results to the abstracted groundwater. One should be aware that consequences do not only depend on the rate of abstraction, but also in their spatial arrangement, quantification, quality parameters, pumping schedules and other constraints. Simulation models may help to explore the role of these factors. Furthermore, to what extent an impact is considered negative or positive is a judgment that is both subjective and dependent on time and location. For example, the disappearance of water-logging conditions due to pumping may have been considered fifty years ago by most people as wasteland recovery‘, whereas the same feature in several parts of the world nowadays tends to be considered rather as a loss of a valuable wetland.

It is an illusion to think that proper groundwater management will allow groundwater abstraction to take place without affecting any of the aquifer‘s functions and services negatively. One has to sacrifice almost always something in exchange. Therefore, the designation sustainable 'should not be interpreted too rigorously. As long as groundwater pumping does not threaten to exhaust the aquifer and society consider the benefits from pumping to outweigh the associated negative impacts both integrated over a prolonged period, one may speak of sustainable groundwater development. It is the challenge of groundwater resources management to strike a balance between the gains due to pumping, and the losses pumping may cause as a result of depletion. This balance is based on preferences, not on absolute 'values derived from knowledge. In more technical terms, one may characterise this as a multi-objective decision process moving along the Pareto frontier rather than an optimisation process subject to constraints (Vrugt et al., 2003). It is important to consider who benefits and who loses when the balance and distribution of costs and benefits upon the abstraction of the resource evolves. Hence, equity is a shared objective in the decision process, together with other key objectives such as meeting basic needs for water, sustainability of the water sources and economic efficiency. The decision process requires sufficient reliable local data to be available and will benefit from a proper diagnostic analysis and intelligent use of decision support systems (Simonovic, 1996).

After adopting preferences as a core element of decision-making in groundwater management, it remains to be decided whose preferences should be considered, how to define these preferences and how to incorporate them into the planning process. In most parts of the world, the idea is winning ground that not only technical specialists and politicians should be involved, but local stakeholders as well. After all, their interests are at stake, their perceptions of the local conditions and problems may give valuable guidance, and their support is crucial for the successful implementation of groundwater management measures. Therefore, stakeholder participation is becoming in many parts of the world an important component of groundwater resources management.

### *c) Dominating Concerns and Constraints Vary Geographically*

Although groundwater resources management is based on preferences, geographical variations in physical and socio-economic setting leave their mark as well. Evidently, in water-scarce arid and semi-arid zones where no significant surface water resources are available, people readily sacrifice groundwater-related environmental functions if that will allow them to pump more groundwater. In more humid zones, the relative abundance of water and the presence of surface water as an alternative source of water tend to favour shifting priorities to conserving springs, base flows, wetlands and other groundwater-supported features.

This leads to adopting constraints to groundwater pumping that are much more restrictive than the water budget constraint, especially in wealthy countries that can afford a relatively high cost of water supplies (Kalf & Woolley, 2005). Furthermore, groundwater pumping regimes in coastal areas are first and for all constrained by the priority of preventing intrusion of sea water or upcoming of saline water underlying fresh groundwater. These and other differences in the setting are reflected in distinct geographical patterns of dominating constraints to groundwater pumping.

The topographical substrate of aquifers varies from area to area, with materials starting from coarse sediments to cracked rock. Substrates that consist of fine grained deposits such as clays tend to compact whilst water is eliminated, ensuing in removal of the pore spaces that formerly contained water. Hence expelling water decreases the water holding capability of the aquifer. In addition, the land subsidence may occur when compaction happens in such aquifers. This may bring about serious interruption of utilities, for example, sewer and water lines and harm to structures and streets. Subsidence can likewise bring about flooding, especially in seaside territories (National Research Council, 1997).

### *d) What Matters is Overall Sustainability*

Groundwater systems are important, but their importance from a human perspective lies mainly in the functions and services they provide. Partially, these functions and services are not unique to groundwater systems and may be provided by other water system components as well. This is, in particular, the case for the water supply function: in most regions, one may choose between groundwater and surface water, or even desalinized seawater and non-conventional sources such as treated wastewater, as alternative sources for satisfying the same water demand. Therefore, overall sustainability is necessary, (*i.e.*, the viability of valuable functions and services, rather than the sustainability of the groundwater systems). The consequence is that groundwater development and management should be viewed in an integrated water resources management perspective, or even in a broader regional development context (Wu et al., 2015). The key question then is not whether the elaboration of a particular groundwater system is sustainable, but rather whether the complex of natural resources (to which that groundwater system belongs) allows and supports sustainable socio-economic development and preservation of desired environmental conditions in the region. Even properly planned development of non-renewable groundwater resources indeed a non-sustainable activity in the physical sense could in principle contribute to this overall sustainability.

## III. Conclusions

Sustainability is a very complex concept. Its reasonable interpretation depends on the systems considered, the angle of view, the overall local context and subjective comparisons between alternative futures. Applied to groundwater abstraction, it makes a difference whether one has sustainable pumping in mind or the sustainability of the local society and ecosystems. In the latter perspective, even unsustainable pumping from a non-renewable groundwater resource might contribute to sustainable development, provided that other water resources are available to meet water demands on the long run after the non-renewable groundwater resource is exhausted. Furthermore, the extent of storage depletion due to pumping may vary from case to case, and the same applies to the impacts of storage consumption. Such effects tend to be more severe in arid than in humid climates, because buffering by other components of the water cycle there is less likely to occur. Also, whether one can cope with individual physical impacts varies according to the local conditions. Wealthy developed societies with good access to financial resources and technology are in this respect in a more favourable position than poor developing countries.

Whatever perspective is chosen, it is clear that groundwater development always comes at a cost (environmental, financial or otherwise). It is up to society to decide whether this cost is balanced or outweighed by the benefits of the abstracted groundwater and does not threaten sustainable development. To underpin such a decision adequately, it is important to have a good picture of the groundwater system considered, to understand its response to pumping (avoiding the water budget myth and other erroneous concepts) and to oversee its socio-economic and environmental setting.

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