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Groundwater Management Economically and Sustainability

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Abstract

It is concluded that improving agriculture productivity is lying in promoting efficient and environmentally sound water management practices. Increasing water productivity - gaining more crop yield and value per unit of water - is an effective means of intensifying agricultural production and reducing waterlogging and groundwater mining, simultaneously. Unfortunately this huge system of irrigated agriculture has not provided designed set objectives of poverty reduction. This has been due to lack of coordinated water resources research and its implementation for irrigation management, poor long-term water policies, and especially poor operation and maintenance of the irrigation system. Subsurface water has a substantial economic value in drinking and irrigation water across the globe. Failure to recognize 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.

Keywords: *Economic value; Groundwater; Hydrogeology; Sustainability; Water management; Water resources*

Introduction

Like all over the World, groundwater has become the most important source for agricultural, domestic as well as industrial consumption, in Pakistan. It is the groundwater that has contributed more than the surface water for the increased water requirements almost in every water use sector in the last 30-40 years. Thus, the sustainability of groundwater resources so for, has played the key role in overall development of the country. It is a unique resource, widely available, providing security against cyclical droughts and yet closely linked to surface water resources and the hydrological cycle. Its reliable supply, good quality and suitable temperature, relative turbidity and pollution free, minimal evaporation losses, and low cost of development are attributes making groundwater more attractive. With rapid growth in population, urbanization, industrialization and competition for economic development, groundwater resource has become vulnerable to extreme depletion and degradation. For an effective, efficient and sustainable groundwater resources development and management, the planners and decision makers have future challenges to assess the inextricable logical linkages between water policies and ethical consideration. Groundwater being a hidden resource is often developed without proper understanding of its occurrence in time and space; this is especially true for developing countries where governments do not own this precious resource. Thus, groundwater management on scientific lines under the auspices of the governments is the key for sustainability of this vital resource **(Gurria, 2009).**

The water stored in the aquifer can be compared to money kept in a current account of bank. If you withdraw money at a faster rate than you deposit new money you will eventually start having account-supply problems. Pumping water out of the aquifer faster than it is replenished over the long-term cause's similar problems. The volume of groundwater in storage is decreasing in many areas of the country in response to pumping. Groundwater depletion is primarily caused by sustained groundwater pumping over and above the natural recharge. Some of the emerging negative effects of groundwater depletion in water stressed areas are: drying up of wells, deterioration of groundwater quality; and increasing pumping costs.

Firstly: Groundwater In General

Groundwater is the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to the surface naturally; natural discharge often occurs at springs and seeps, and can from oases or wetlands. Also, groundwater is often withdrawn for agricultural, municipal and industrial use by constructing and operating extraction wells. Sustainable groundwater resources management will require available surface water allocation and aquifer management plans that clearly integrate groundwater and surface water systems. This will require more sensitive and accurate surface water availability and aquifer water balance, to develop management plans which recognize the long timeframes of aquifer and surface water interaction. The important components of this strategy can be to: a-Improve our knowledge of groundwater and surface water connectivity, with significantly connected irrigation systems (as the IBIS is often called the biggest contiguous system in the world) to be managed as one integrated resource; b-Complete the return of currently over-allocated or overused irrigation systems to environmentally sustainable levels of recharge and extraction rates; and c-Improve understanding of sustainable extraction rates and regimes, and develop common approaches to achieving sustainability.

Groundwater: Hydro-Geology

Groundwater systems are composed of saturated rocks and/or sediment in a variety of geological formations. In general if such a formation can produce useable quantities of water it is known as an aquifer. The geological variation in aquifers means that they vary in their physical characteristics, such as whether or not they are replenished or recharged by surface water or precipitation and hence the extent to which they can be seen as renewable or exhaustible resources. In addition, the response of groundwater stocks to abstractions is determined by the geological structure. Therefore in order to understand the dynamics of a particular aquifer, it is important to determine the nature of the particular hydrological and geological environment. The important distinctions between and characteristics of aquifers are outlined in brief below.

Unconfined and Confined Aquifers

Broadly speaking unconfined aquifers are subject to recharge by precipitation and/or surface water, which infiltrates vertically downwards through the overlying ground structure. The upper threshold of an unconfined aquifer is known as the water table, and water contained therein can be considered renewable. A *perched* aquifer represents a special case of an unconfined aquifer and can be thought of as an impermeable shelf in an otherwise permeable ground upon which water infiltrating from above is held for a period of time determined by the permeability of the surrounding ground.

Confined aquifers on the other hand, lie beneath less porous layers of rock, or aquitards, which either preclude recharge altogether or limit recharge to lateral underground flows from recharge zones where the aquitard is absent. Confined aquifers which are not subject to recharge can contain water which was deposited many thousands or even millions of years ago; so called fossil water, and water contained therein can be considered an exhaustible resource.

The distinction between confined and unconfined aquifers often lies in the pressure of the groundwater. Artesian wells such as the great artesian basins of east-central Australia and the south east Kalahari aquifer in Namibia contain water which, once tapped, is under sufficient pressure to reach ground level or higher. Such flows emanate from confined aquifers, which are under more than the atmospheric pressure associated with unconfined aquifers. However, in reality the division between confined and unconfined aquifers is less distinct, and in general both form component parts of a single hydrological system **(Gurria, 2009).**

Conjoined Surface And Groundwater

A further distinction also important, particularly when considering water resource management, is the extent to which aquifers are conjoined to other surface water bodies such as lakes or rivers. Tributary aquifers are those located adjacent to and beneath rivers and other such watercourses. The behavior of these unconfined aquifers is directly linked to that of the watercourse and vice versa. The South Platte River in Colorado, US provide an example of surface water conjoined to an alluvial aquifer. The aquifer is recharged predominantly by the river, whilst abstractions from the aquifer affect the surface water flow. Furthermore, water stored in aquifers may also represent the source of springs and as such any economic use or ecological process linked to these springs will also be linked to the stock, rather than the flow, of groundwater.

Composition And Physical Characteristics

Aquifers vary in their geological composition and hence physical properties, most important of which are storage capacity and the subsurface flows of groundwater e.g. in response to pumping. Some important characteristics are as follows:

Porosity: measures the percentage of a given rock made up by voids or holes (interstices) in which water can be stored. Such voids can represent the nature of the aquifer medium e.g. pores in limestone or inter-granular spaces in sandy aquifers, or from secondary effects such as rock movements or weathering.

Storativity: also known as the coefficient of storage, represents the volume of water that can be extracted from a given surface area of an aquifer per unit change in depth (or head).

Transmissivity: measures the extent to which a reduction in groundwater level due to pumping at a particular point is transmitted to the rest of the aquifer. I.e. the extent to which the water level goes down locally or uniformly across the entire surface area of the aquifer. Where transmissivity is low the water level only recedes locally and in extreme cases giving rise to cones of depression. Where transmissivity is high, local pumping affects the water level across the whole aquifer.

Aquifers also differ in the extent to which they are subject to irreversible changes as a result of abstractions. For example, coastal aquifers are frequently affected by saline/seawater intrusion. This has occurred for example in the Kiti aquifer in Cyprus and the Hermosillo aquifer in Mexico. Once this intrusion has occurred it is either irreversible or reversed at significant cost through the injection of recycled or semi-purified water: artificial injection. Similarly, the collapse of aquifers due to abstraction, and the associated loss of storage, is a common and irreversible occurrence. In central parts of Arizona for example, land surfaces have subsided by up to 9m over the past 20 years as a result of abstractions **(Gurria, 2009).**

The Value Of Groundwater

Groundwater is a valuable resource for a number of reasons. When abstracted groundwater acts as a current input into the conventional economic sectors of industry, agriculture and households, it represents the extractive value of groundwater. When left in the ground, as well as supporting many ecosystem functions as an important component of the wider hydrological and ecological system, it leaves the option of abstraction in the future. Thus, in addition to the direct use or extractive values, groundwater also has an *in situ* value, i.e. a value associated both with saving for the future and maintaining ecosystem functions. In determining the pattern of use, which best fulfills societal objectives it is the tension between extractive and *in situ* values which best describes the trade-offs faced by the resource manager. Determining the trade-off requires the knowledge of all of the economic values associated with groundwater: i.e. the Total Economic Value (TEV).

TEV is defined to include both direct/extractive use and non-use values, i.e. those values generally associated with environmental goods. Whilst the extractive values are well represented and valued by the conventional economic sectors, there are a number of *in situ* values, which require special attention. *In situ* values include:

Buffer values: The insurance value associated with the buffer that stocks of groundwater provide when used conjunctively with uncertain surface water.

Subsidence avoidance: Subsidence is one of the consequences of groundwater abstraction and as such subsidence avoidance is an *in situ* value.

Ecological service: Groundwater reserves are often the source of river base flow, springs, and have other ecosystem linkages. Another ecosystem service is water purification. Maintaining groundwater stocks maintains any associated ecological services.

Recreational services: The maintenance of surface water flows means that any associated recreational and other services are preserved.

Future values: In general, the option to use groundwater in the future is defined as an *in situ* value.

There are a variety of techniques available to make these values commensurate with one another and therefore to allow trade-offs to be made between them in the process of maximizing that value. Economists have generally used monetary values as a yardstick and these values have been estimating the willingness to pay if individuals for the various aspects of groundwater value **(Mehta, 2006).**

Groundwater Scarcity: Demand And Supply Side Factors

Over the past 40 years a number of factors have conspired to reduce both the quantity and quality of groundwater resources to critical levels in many parts of the world.

Groundwater overdraft, defined as using more groundwater than is naturally replenished, has occurred in countries such as Jordan, Mexico, the United States, Namibia and Yemen. The prevalence of these overdrafts is of particular importance in arid countries where groundwater is the predominant source of water such as Jordan, Namibia and Yemen. With the exhaustion of groundwater stocks expensive investments in long distance surface water transfers or desalination are frequently seen as the solution. Clearly these investments should be assessed in light of alternative management strategies for groundwater. Similarly, groundwater quality issues are of particular moment in many countries. One of the most frequently cited examples is that of Bangladesh, where groundwater is polluted by naturally occurring arsenic, causing considerable health problems to poor rural communities. Furthermore, in many areas groundwater stocks have been polluted by agricultural or industrial wastes and residues. This state of affairs has sparked renewed analysis of the causal factors of groundwater depletion and placed the principles of groundwater management under close scrutiny.

The causal factors are frequently categorized as either supply or demand side. On the supply side several factors are often credited with encouraging more intensive and extensive exploitation of groundwater. For example, improvements in pumping technology such as more powerful pumping equipment and submersible pumps naturally make it feasible to tap deeper reserves. Similarly, reductions in the financial cost: investment, operations and maintenance costs, have provided cheap access to groundwater. Naturally government policies concerning the inputs to groundwater pumping, such as the subsidized fuel provided to rural areas of Namibia and subsidized electricity in areas of India and Pakistan, although implemented with the objectives such as rural development and poverty alleviation in mind, have also accelerated the degradation, mining and occasionally the exhaustion of groundwater resources. In combination these supply side factors have allowed existing wells to be exploited more deeply whilst opening the door to further exploitation from new and lower cost wells.

On the demand side population growth puts pressure upon groundwater resources. The demand side pressure that population growth can impose upon groundwater resources is not exclusive to the less developed countries with which levels of national annual population growth of up to 3% are frequently observed. Indeed most countries have experienced localized population growth as a result of rural-urban migration, and many countries experience the seasonal population explosions associated with tourism. Nowhere is this more apparent than in the coastal resorts of the Mediterranean where the exploitation of coastal aquifers is often complete either with regard to quantity or quality (**Mehta, 2006).**

Furthermore, in many countries macro-economic factors such as economic growth have increased the demands for all water resources, particularly groundwater. One way to think about the effect of economic growth is as follows: income growth leads to increased demand for goods which embody groundwater resources; high value foodstuffs, manufactures, electricity, tourism etc. As a result private sector activities and often macro-economic policies reorient to reflect these demands. Irrigated agriculture, which represents perhaps the largest user of groundwater resources in many parts of the world, provides a good example of this. All year demand for seasonal fruits and vegetables combined with access to cheap groundwater resources has provided the backdrop for agricultural policies to promote export lead growth through high value irrigated foodstuffs. The promotion of tourism is another pervasive demand side factor in many island economies of the Mediterranean and Caribbean for example. Similarly groundwater is an essential input to manufacturing and industry, which for a long time and more generally were the main engines of economic growth. On top of this, it is frequently observed that as incomes rise, per capita consumption of water for household and domestic purposes rises in line with the purchase of consumer durables such as dishwashers, swimming pools, large houses with gardens etc.

In many of the above cases, the underlying factor and one of the most important demand side issues in groundwater management is that of water pricing. It is frequently the case that the incidence of groundwater overdraft arises in tandem with policies to subsidize water to household, agricultural and industrial sectors. That the demand and price of goods move in opposite directions is as true for water as it is for most normal economic goods. Therefore pricing policies represent another important determinant of groundwater use. In addition to micro level policies such as water pricing, macro-economic and sectorial policies can also conspire to increase the pressure upon resources. For example, the availability of cheap or subsidized groundwater combined with perverse agricultural policies, such as national food self-sufficiency in arid water scarce countries, can lead to groundwater depletion for the purpose of growing low value goods. In this way groundwater is mined while providing very little contribution to social welfare.

Clearly, population growth, migration, economic growth and other supply and demand side factors reflect wider socio-economic, political and cultural trends making the causes of groundwater scarcity apparently complicated and difficult to disentangle. However, in order to determine whether or not the observed pattern of groundwater use is beneficial to society or represents some a management failure from the perspective of societal welfare it is important define some principles of groundwater management which can act as benchmarks for good practice **(Mehta, 2006).**

Principles Of Groundwater Management

Natural resource economics is perhaps the most relevant discipline from which to derive these benchmarks as it has well defined measures of societal welfare which incorporate natural resource dynamics and allow comparisons between many alternative objectives. The most important of these principles are efficiency, sustainability and equity as follows:

Economic Efficiency (And Inefficiency)

Economic efficiency in resource use is achieved when no rearrangement of resources between individuals or across time can improve the welfare of society. This general definition implies two aspects to economic efficiency: static efficiency (efficient allocation of resources between potential users) and dynamic efficiency (efficient allocation over time). Both aspects can be brought to bear upon the management of groundwater resources and used as a benchmark for management practices.

Groundwater aquifers can be broadly categorized as renewable or non-renewable and the nature of efficient use differs in each case. In both cases however, groundwater represents a stock of resources as distinct from a flow such as a river. As such groundwater can be considered a dynamic resource because changes in the stock that occur today, as a result of recharge or abstraction by humans, have inter-temporal consequences. Hence, the concept of dynamic efficiency is particularly relevant to groundwater. Put loosely, the efficient use of non-renewable groundwater will reflect the long-run since with continued use it will eventually be either physically or economically exhausted i.e. abstraction will become too expensive. On the other hand, renewable groundwater has the potential to be used for all time if abstractions remain equal to recharge. Thus the efficient use of renewable resources will consider the balance between abstractions and recharge (stocks and flows). The management questions that remain concern the date at which aquifers should be exhausted, the path of abstraction over time, whether or not it is efficient to use groundwater sustainably and if so the level of the aquifer stock at which this use is maintained. However, as described above many aquifers are conjoined with surface water and/or are pivotal in maintaining wider ecological functions. Hence it is generally insufficient to consider groundwater in isolation since these wider effects are also important in determining efficient management. This section describes the efficient use of groundwater that would be chosen by a government wishing to maximize social welfare over time and the inefficiencies that arise when decision-making is placed in the hands of individual groundwater users **(Kemper, 2002).**

Efficient Groundwater Management

The management of groundwater resources is deemed economically efficient when groundwater abstraction is chosen such that its allocation over time (time-path), exhaustion date, the stock and the impacts on conjoined resources and other third parties generate the maximum welfare to society. In other words economic efficiency is a question of choosing the temporal pattern of abstraction, which maximizes the TEV of groundwater. This amounts to maximizing the present value of the difference between social benefits and social costs of abstraction **(Mehta, 2006).**

The economic value or social benefits of groundwater are derived from consumption over time by both conventional productive sectors of the economy; households, manufacturing, agricultural, recreational etc., and non-conventional sectors such as the environment. For example, in Colorado groundwater is pumped in order to augment surface water, which also maintains environmental flows. The social costs of abstraction are more complicated however, reflecting the dynamic nature of the resource, and can be usefully categorized as follows:

Contemporary Costs: Contemporary costs are those incurred as pumping occurs. These include the costs of abstraction: the operations and maintenance of pumps for example.

Inter-temporal Costs: Inter-temporal costs refer to the change in the level of the groundwater stock, which in turn affects the availability of groundwater for any of the aforementioned uses in the future. This includes the loss of amenity associated with the groundwater stocks. For example, springs that emerges from the Edwards Aquifer in Texas US support ecosystems containing many varieties of endangered fish. Inter-temporal costs may also include the value of groundwater as an insurance policy against climatic uncertainty or uncertain surface water flows: the so-called 'buffer value' that have been estimated in agricultural communities in many arid and semi-arid environments.

Quality related costs: Lastly there are quality related costs. These costs may be contemporary or inter-temporal and may arise as a result of the pumping itself or as a result of the use to which the groundwater is put. Seawater intrusion is an example of the former whilst groundwater pollution as a result of the infiltration of agricultural herbicide residues is an example of the latter. Both limit the contemporary and future uses to which groundwater can be put.

In short, in addition to the contemporary costs that current users face, abstraction today may preclude abstraction tomorrow as a result of physical or economic exhaustion. E.g., abstraction today may cause irreversible changes in the structure of the aquifer (collapse or compaction, quality reduction), which may make the abstraction of water impossible or too costly tomorrow. Inter-temporal costs reflect the dynamic nature of the groundwater and the value of leaving the resource in the ground. The extent of these costs will be determined as much by the properties of the aquifer as by the abstraction decisions and the demand for water. It is common to label those costs that are not directly faced by those who abstract groundwater as the **user cost** or **scarcity rent** since these values represent the properly reflect the value of the scarce resource in the ground and the economic impact of abstraction **(Kemper, 2002) .**

Determining the efficient use of groundwater is clearly a multidisciplinary task and informational intensive. Firstly, hydrological models are required to characterize the nature and behavior of the aquifer, e.g. the resource stock, storativity, transmissivity etc. Secondly, the socio-economic environment must be described. This requires identifying and placing a commensurate economic value upon all groundwater and conjoined uses and functions. Static efficiency requires allocating groundwater to the highest value uses at a particular point in time. In order to determine a dynamically efficient time path of groundwater use requires combining economic and hydrological models and defining the interaction between the uses/users and the resource. It is then possible to solve for the allocation that maximizes present value of the difference between social benefits and social costs over a predetermined planning horizon. This is usually performed by dynamic optimal control methods.

There are several parameters of interest in determining the efficient allocation of groundwater. Perhaps the most important is the users' responsiveness to changes in the price of groundwater, the so-called price elasticity of demand (PED). This will determine the way in which individual demands for water will change over time in response to the increased pumping costs associated with groundwater depletion. Similarly, it will be important to understand how the demand for water changes over time with incomes. The natural corollary is the need for projections for population and economic growth.

Although modeling these above and below ground aspects and the interface between them is fraught with uncertainty, there have been great advances in hydro-geological modeling, economic modeling and economic valuation techniques. These advances have enabled comprehensive hydro-economic modeling and the determination of efficient abstraction plans. Examples of where dynamic optimal control of aquifers has been undertaken include Ogallala Aquifer, Colorado, the Kiti Aquifer, Cyprus, the South East Kalahari Artesian Aquifer in Namibia etc. Environmental values have been estimated for many aspects of watersheds, including the various values associated with groundwater **(Kemper, 2002).**

Efficiency With Water Transfers And Backstop Technologies

The previous analysis has been assuming almost implicitly that groundwater users are those who occupy the overlying land. Another issue pertinent to the question of efficiency is whether or not the incumbent property rights holders to groundwater represent the highest value to society. This brings to light the potential for the transfer of water outside of the land overlying the aquifer, or even to an entirely separate river basin: an inter-basin transfer. The government or groundwater manager should be aware of such latent societal values in determining the efficient use of groundwater. The issues surrounding the property rights to groundwater and the extent to which they may be transferable to higher value uses either in situ or elsewhere is discussed further below.

Furthermore, the efficient use of groundwater should be not determined in isolation from alternative sources of water. For example, coastal aquifers should not be used if the costs of doing so are greater than for desalination. In Cyprus for example, groundwater augments the supply from desalination, and groundwater is managed such that the costs of abstraction do not rise beyond that of desalination. The existence of a backstop technology, e.g. water transferred from another river basin, also determines the efficient use of groundwater **(Schiffler, 1998).**

Groundwater Quality

As a hypothesis for the formation of the Indus alluvial plain, a picture of a large river system, with an extensive delta, advancing into the ocean has been suggested. In geologic times the deposition of sediments took place in sea water. The sea water further concentrated due to high rates of evaporation in the arid / semi-arid climate of Pakistan. As the alluvial plains built up, water from the rivers flows into the soil and joins the groundwater. In addition, percolation occurs from floods that overtop the river banks. Owing to the slope of the land towards the sea there is a general down-valley movement of groundwater and although this movement is slow, of the order of 1-2 km per 100 years, it cause appreciable effect over geologic times. The down valley flow pushes the sea-water behind by the advancing delta, back to the sea, except for pockets trapped by obstructing rock ridges in the basement.

Almost every year in the past, the river was high; the land was flooded and drained off again when the flood passed. Thus, evaporation occurs from the waste soils and salt is deposited in them. When the next flood arrives the salts are re-dissolved and pass down to join the groundwater. Since the groundwater is slowly flowing down the valley, it picks up more and more salts as it advances. In addition the groundwater reacts with aquifer material and picks up salts from this source also. It would therefore be expected that from source to outfall, in an alluvial river valley system, there would be an increase in groundwater salinity. This is observed to be the case in the Indus Plain. Super-imposed on this overall groundwater pattern are the areas of comparatively fresh water associated with direct seepage from the rivers. Besides this, the percolation of fresh water occurs from rainfall and also from the irrigation system which keeps on increasing with the spread of the irrigation system. As a result of this process fresh groundwater in the Indus Plain is found to be underlain with saline groundwater, the layers of fresh groundwater being thick near to the rivers and other sources of recharge and of almost negligible thickness in areas where recharge is small, in comparison to current groundwater pumping **(Schiffler, 1998).**

Fresh water is therefore found up to considerable depths in wide belts paralleling the major rivers. Saline groundwater occurs down gradient from sources of recharge particularly in the central parts of the Doabs. Gradual increase in mineralization is found to occur with depth and distance from sources of recharge. In the Lower Indus Plain, the Indus flows on a ridge and there is a general groundwater flow away from the river and wide area of fresh groundwater is associated with this flow. Fresh groundwater can also be found under some of the recently abandoned river course in the meander flood plain. A further and very significant recent addition to the total groundwater complex is due to the advent of barrage commanded irrigation. During the past 100 years seepage from canals and deep percolation from irrigated fields have made substantial contributions to the groundwater.

During the course of the groundwater investigations described earlier, groundwater samples were collected from various test holes at various depths and were analyzed in the laboratory, for making qualitative and quantitative assessment of the groundwater storage in the aquifer. Besides a large number of samples of shallow groundwater were also collected from open wells in each area and the same were also analyzed in the laboratory so that the quality of shallow groundwater may also be determined. A brief description of the quality of groundwater in different Doabs, plains, regions, plateaus and valleys in various provinces of the country, as determined from the hydrogeological investigations carried out in those areas.

Secondly: Groundwater Resources Development And Sustainability

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). 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. The same groundwater storage provides a reason for concern as well. If surface water users abstract water from streams at a hydrological 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 **(Villholth, 2006).**

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. 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 unfavorable 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 **(Mehta, 2006).**

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. 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 **(Villholth, 2006).**

This balance is based on preferences, not on absolute ‘values derived from knowledge. In more technical terms, one may characterize this as a multi objective decision process moving along the Pareto frontier rather than an optimization process subject to constraints. 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. 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 **(Qureshi et al. 2010).**

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 favor 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. 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 **(Pearce, 2003).**

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. 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 nonrenewable groundwater resources indeed a non-sustainable activity in the physical sense could in principle contribute to this overall sustainability **(Mehta, 2006).**

Highlights Of Management Approaches Abroad

All over the world, groundwater has long been treated as an infinite resource that can be endlessly exploited. The idea that groundwater, though a common good, belongs to the overlying landowner has shaped thinking about water, even in the developed world. Only after this resource has been overexploited and polluted do governments and users begin to worry about managing its use. Attempts to allocate groundwater and manage these entitlements in a sustainable manner have achieved only limited success and still pose a major challenge to the water sector. The important measure would be to separate the right to groundwater use from land ownership titles. In other words, it is necessary to define property rights in groundwater so that all existing ambiguities are removed. Spain & Mexico reformed their water laws to make groundwater a national property. However, their success in getting water rights of agricultural users registered has been insignificant **(Gurria, 2009).**

Approaches For Sustainable Groundwater Management

International experiences, and experience within India, give insight into the instruments available for groundwater management. This can be categorized as follows:

Rainwater harvesting**:** In many dry regions the revival of historical water harvesting techniques and recharge is now being considered as a possible way of alleviating water scarcity. The term rain water harvesting is understood to mean the collection of surface runoff and its use for irrigated crop production under dry and arid site conditions. Physical structures are built to retain runoff and encourage infiltration to groundwater.

Where cities overlie hard-rock aquifers (for example Rawalpindi and Islamabad) this can lead to severe depletion and pollution of the groundwater body, the same is being observed in these twin cities. Even cities above the extensive alluvial aquifers (Lahore) are finding the underlying water tables inexorably declining. For such cities a balanced policy dovetailing both surface water and groundwater supply and recharge enhancement will need to be developed, under the auspices of empowered and well-organized regulatory agencies. In rural areas, techniques of artificial recharge by modification of natural movement of water through suitable rerouting such as dry river beds (Sukh-Beas) and drains during wet season can be feasible **(Gurria, 2009).**

Groundwater Governance and regulation**:** The first step in groundwater governance is adequate and high-quality information, not only hydrogeological, but also socio-economic as well. In many instances, such information is missing or more possibly not accessible in the public domain due to unwillingness of the governments departments (especially the data) to share it with the general public. Effective regulation becomes extremely difficult when there are very large numbers of small users. Pricing measures, including volumetric charges, taxes, and user fees, can act as incentives to conservation and more efficient allocation of water resources, provided they address concerns of equity and affordability to the poor. Such measures can only be successful for a small numbers of severely threatened resource users.

Demand-side measures**:** Demand side measures aim to reduce consumptive groundwater use, for example through an increase in water tariffs and converting to volumetric billing system in urban settings, or reducing crop water requirements and non-beneficial evapotranspiration from fields in agricultural areas.

Community management of groundwater**:** Community groundwater management refers not to a specific instrument but to a means of implementing management interventions. The key is that the resource user community (instead of the state) is the primary custodian of groundwater and is charged with implementing management measures. Hence, community groundwater management can involve any mix of instruments, including regulation, property rights, and pricing. Some well-publicized examples of successful community self-regulation have occurred in India but have often been dependent on the influence of a charismatic leader. While community-based management of groundwater is clearly a promising approach in India, global experience offers few models of community management that might be applicable in the sub-continent setting, and a homegrown solution will undoubtedly be needed.

Integrated use of surface and groundwater**:** Rainfall is a renewable, natural resource but limited in amount and variable in distribution over space and time. The surface waters from rivers, which are canalized, supplement it and the two together constitute the total available water resource. Similarly, the crop water requirement is spatially variable increasing in downstream direction. The waterlogged areas in canals command offer scope for groundwater development by lowering the water table up to 3-6 m. Thus additional water for irrigation can be saved for use elsewhere and induced deeper water table in these areas will help in rainfall recharge that will help in improvement of soil and water quality. Therefore, rationalizing canal water allocations can help to improve the groundwater situation both in waterlogged and depleted areas **(Mirza and Latif, 2012).**

Thirdly: Expected Climate Change And Its Impact On Surface And Groundwater Availability And Demand

Climate Change And Hydrologic Variability

Climate change is ―an altered state of the climate that can be identified by change in the mean and/or variability of its properties and that persist for an extended period, typically decades or longer‖. It may be due to ―natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use‖. Over the past 150 years, global mean temperatures have increased with the rate of warming accelerated in the past 25 to 50 years. It is considered very likely that this change is largely attributed to anthropogenic influences (in particular increased CO_2 concentrations from burning of fossil fuels), and that global warming will continue in the future.

The Earth‗s climate is projected to become warmer and more variable. Increased global temperatures are projected to affect the hydrologic cycle, leading to changes in precipitation patterns and increases in the intensity and frequency of extreme events; reduced snow cover and widespread melting of ice; rising sea levels; and changes in soil moisture, runoff and groundwater recharge. Increased evaporation and the risk of flooding and drought could adversely affect security of water supply, particularly surface water. Due to these pressures, as well as global population growth, demand for groundwater is likely to increase.

However, it is important to distinguish the impacts generated by socio-economic processes from those attributed exclusively to climate change. In particular, there is a need to develop a sense of the relative importance of climatic and non-climatic factors. This is especially important when considering adaptation strategies. It can be presumed that such vulnerability will establish the pattern of adaptive responses, and that climate change will either reinforce or mitigate the intensity of such adaptations, without altering the basic patterns. The most dominant climate drivers for water availability are precipitation, temperature and evaporative demand (determined by net radiation at the ground, atmospheric humidity and wind speed, and temperature).

Temperature is particularly important in snow-dominated basins and in coastal areas **(Bates et al. 2008).**

Climate change affects groundwater recharge rates (i.e., the renewable groundwater resources) and depths of groundwater tables. As groundwater both changes into and is recharged from surface water, impacts of surface water flow regimes are expected to affect groundwater. Increased precipitation variability may decrease groundwater recharge in humid areas because more frequent heavy precipitation events may result in the infiltration capacity of the soil being exceeded more often. In semi-arid and arid areas, however, increased precipitation variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations due to floods. A combination of increased river flows and increased flood plain pressures suggests that flood hazards could be one of the most serious problems associated with climate change. Higher temperatures and increased variability of precipitation would, in general, lead to increased irrigation water demand, even if the total precipitation during the growing season remains the same **(IPCC, 2007).**

The Importance Of Groundwater In A Changing Climate

The Earth‘s climate is projected to become warmer and more variable in the wake of climate change. According to climate change researchers, increased global temperatures are projected to affect the hydrologic cycle, leading to changes in precipitation patterns and increases in the intensity and frequency of extreme events; reduced snow cover and widespread melting of ice; rising sea levels; and changes in soil moisture, runoff and groundwater recharge. Increased evaporation and the risk of flooding and drought could adversely affect security of water supply, particularly surface water. Due to these pressures, as well as global population growth, demand for groundwater is likely to further increase **(CICERO, 2000).**

Relative to surface water, aquifers have the capacity to store large volumes of water and are naturally buffered against seasonal changes in temperature and rainfall. They provide a significant opportunity to store excess water during high rainfall periods, to reduce evaporative losses and to protect water quality. Nevertheless, tapping the groundwater storage opportunity to its full potential, using the available surface and rainfall patterns is still a big challenge, even for developed countries. The major fault lies in that, these opportunities have received little attention, in part because groundwater was often poorly understood and managed in the past. Effective, long term adaptation to climate change and hydrologic variability requires measures which *protect or enhance groundwater recharge and manage water demand. Adaptation to climate change* can‘t be separated from actions to improve management and governance of water reserves (e.g. education and training, information resources, research and development, governance and institutions).

Fourthly: Economic And Financial Aspects

Economic And Financial Aspects Of Storage Depletion

Here are two major problems related to water use. First one is overconsumption that augments water scarcity 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 **(Shankar, 2011).**

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.

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. 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 inter temporal 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 **(Mirza and Latif, 2012).**

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. 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.

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 **(Provencher, 1995).**

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. Environmental costs are rather difficult to assess and incorporate in groundwater resources management. They consist of the environmental damage costs of aquatic ecosystem degradation and depletion caused by a particular water use such as water abstraction. 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. 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. 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.

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. 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 **(Qureshi and Akhtar 2003).**

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 these scenarios the suitable methodologies may be adopted to determine the both use and non-use values for future perspective. 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 **(Schiffler, 1998).**

Problem While Defining Cost In Tragedy Of Commons

In market and non-market cost evaluation procedure is bound to some limits which need to define properly.

Fifthly: The Economics Of Groundwater Resource Management

Costs of Ground Water Use

Costs of Groundwater Abstraction are of mainly two types- 1) costs paid by users and 2) full economic costs. The costs paid by users consist of two types of costs i.e. Capital cost and Operational & Maintenance cost. On the other hand full economic cost may be divided into three categories such as 1) Water supply cost 2) Social opportunity costs and 3) External cost. Water supply cost may be of three types i.e. a) Capital cost b) Operational & Maintenance cost c) Resource Admin cost. Social opportunity costs may be the Foregone value of Alternative users (present & future) and External cost is the In-Situ value (i.e. cost of saline intrusion, land subsidies, drought buffer etc).

The economic value of a resource depends on what one can do with it and on its relative scarcity compared to alternative resources. Thus the economic value of groundwater in a specific aquifer is derived from the use it can be put to, and from its local availability and quality compared to surface water. For instance, an aquifer in a region with abundant unpolluted surface water will generally have lower economic value than one in a region with polluted surface water or one in an arid region without alternative resources. The economic value of groundwater originates from the benefits that it generates the services that it provides. In many areas of the world, the economic value of groundwater is increasing, due to population growth and economic development (and thus increased water demand), due to pollution of surface water basins and, increasingly, due to climatic variability and the necessity of having a drought-secure resource **(Singh, 2009).**

Values Of Groundwater

The economic value of a given groundwater resource is determined by its prospective use. In the absence of a market price for groundwater, economists often measure its value through user's ***willingness to pay*** for a given quantity and quality of supply. For instance, an industry that needs water as an input for car production will be willing to pay more per unit volume than a fruit farmer. The economic value of groundwater in the area concerned is thus determined by the willingness of industry to pay—up to the point that their demand is met. The economic value of the next volume used by the fruit farmer will be lower, but still higher than what a subsistence farmer would be willing to pay. When 'willingness to pay' is not known (usually the case because groundwater markets revealing true price rarely exist), the ***residual value method*** can be used to value groundwater. This method values all inputs for the good produced at market price, except for the groundwater itself. The residual value of the good, after all other inputs are accounted for, is attributed to the water input.

Groundwater quantity and quality may affect the productivity of land as an input in agricultural production. Where this is so, the structure of land rents and prices will reflect these environmentally determined productivity differentials. Hence, by using data on land rent or land value for different properties, one can in principle identify the contribution which the attribute in question makes to the value of (willingness to pay for) the traded good, land. This identifies an implicit or shadow price for quality (or even quantity) attributes of groundwater. The method commonly used to implement this approach is the ***hedonic technique***. The above are a selection of methods used by economists to determine the value of public goods such as groundwater, and while none are perfect they do provide guidance to decision makers on the valuation of groundwater resources and on possible courses of action. An important consideration in this regard is the distinction between short- and long-term benefits expected from groundwater use. Depending on the discount rate used to estimate the benefit stream from the use of groundwater, it may appear advisable to use the resource more rapidly or more slowly. Thus, the choice of a realistic discount rate is very important and needs careful evaluation **(Kemper, 2002).**

Economic Instruments For Managing Groundwater

That relevant costs and benefits can be measured, but we discuss the pros and cons of the major economic instruments suggested and used for managing both groundwater extraction and pollution. In doing so, we should keep in mind that an economic approach to groundwater depletion and pollution assumes that relevant costs and benefits can be measured, but we discuss the pros and cons of the major economic instruments suggested and used for managing both groundwater extraction and pollution. In doing so, we should keep in mind that an economic approach to groundwater depletion and pollution assumes this is not easy. Moreover, it is not always clear who must comply with particular policy instruments, how their compliance, or performance, will be measured, and how to induce changes in behavior.

Instruments For Managing Groundwater Extraction

Theoretically, a tax can be used to restrain farmers from lowering the groundwater level below a certain standard. The effectiveness of a tax depends on the right estimation of the marginal tax level and on how risk adverse farmers are with respect to damage from reduced water availability (both in quality and in quantity terms). A differentiated tax level has to be created, because of local differences in both the monetary value of reserves and vulnerability of the environment to changes in the groundwater level. An advantage of a tax is that it improves both economic and technical efficiency. Administrative costs are high, since a differentiated tax is not easy to control and monitor. The financial impact on affected parties depends on the restitution of revenues, which affects tax acceptability. Finally, there are practical implementation problems. It is hard to define a good basis for a tax. A volumetric tax on extraction is complicated, since it involves high monitoring costs. A tax on a change in the groundwater level is also complicated, because external and stochastic factors affect the level of groundwater, which is not uniform across any given aquifer **(Schiffler, 1998).**

Charging water boards for lowering surface water levels will not influence an individual farmer's behavior, but it will affect strategy of groups of farmers represented in the governing body of water boards. A subsidy is a reward for meeting a certain groundwater level, which is higher than the desired standard. Subsidies are not economically efficient; they create distortions and do not provide incentives for the adoption of modern technologies. Acceptability, however, is not an issue, since participation in subsidy schemes is voluntary and has positive financial implications. Implementation problems are similar to those of a tax. Another prescription economist's offer in the face of demand-supply imbalances is the introduction of water markets. Such institutions have the capacity to rationalize water scarcity, both qualitatively and quantitatively. Tradable rights improve economic and technical efficiency, since the market determines the price of the right in a dynamic way. The high demand for administrative institutions is a major disadvantage. The financial impact on affected parties and related acceptability depends on the initial allocation of rights. The use of tradable rights for groundwater seems to be complicated in practice, since the impact of changes in the groundwater level on agricultural production and nature depends on location-specific circumstances.

To avoid transferring rights among areas with heterogeneous characteristics, trading has to be restricted. That is, on the one hand, the market approach is embraced, but on the other hand, we need a trade institution for guided trading. A legal groundwater standard or quota can also be introduced. It will be effective if farmers face substantial monetary penalties for lowering the groundwater level below this standard or not adhering to the quota. Standards and quotas do not improve economic efficiency and do not introduce incentives to innovate. The financial impact is not always equitably distributed among affected parties, since there are differences in the vulnerability of areas to changes induced by these instruments. Differentiated standards and quotas, however, will pose a large burden on the administrative capacity. Usually, serious resistance is raised against the introduction of these policy instruments **(Schiffler, 1998).**

The approach to environmental protection has been evolving from a regulation driven, adversarial 'government-push' approach to a more proactive approach involving voluntary and often 'business led' initiatives to self-regulate their environmental performance'. In this spirit, another policy option for controlling groundwater use is voluntary agreements between farmers and government organizations. Participation in such control programs is encouraged by means of positive incentives (a restitution of taxes). Such programs try to convince farmers (through education) of the advantages of fine-tuned groundwater control. Voluntary agreements on controlling groundwater use are efficient, since they rely on specialized knowledge of participants about local conditions. When costs and benefits are not equitably distributed among affected parties, both parties can bargain about compensation payments. The allocation of such payments depends on the assignment of rights. Acceptability is not an issue, since it is a voluntary regime. Because of these advantages, participation of farmers in planning and decision-making at the local level is becoming more common. The principle of allowing the individual members of agricultural organization and water boards to make decisions on issues that affect them rather than leaving those decisions to be made by the whole group, the so-called principle of subsidiary, is widely accepted. An indirect economic instrument for groundwater management derives from agricultural and food trade policies. Since most groundwater is consumed by irrigation, agricultural policies have a major impact. For instance, subsidies encouraging highly water-intensive farming in semi-arid areas (e.g. rice or wheat cultivation) will provide an economic incentive to use groundwater.

From an economic perspective, however, the allocation of groundwater to this type of consumptive use is not very efficient, and agricultural policy should better reflect the scarcity of groundwater resources. Moreover, international trade policy can have an indirect impact on groundwater use—

for instance by creating barriers to the export of high-value agricultural products thereby confining production to local, often low-value, uses. The introduction of economic instruments will depend on current hydrologic, economic, social and political conditions. The **feasibility analysis** should include an assessment of costs and benefits of each instrument and possible combinations. It should also take into account long-term recurrent costs and institutional capacity (for administration, monitoring, and enforcement) and the transaction costs involved to set up systems. The expected costs and benefits would also influence the trade-off between the use of economic instruments and other groundwater management tools **(Krueger, 1992).**

Sixthly: International Experiences In Groundwater Management

Groundwater depletion is a global issue in general, due to its rapid development for agricultural and municipal consumptions. However, the severity of the situation is not the same everywhere; rather the most populous areas are severely affected by groundwater depletion due to increasing demands on the groundwater resources. Across the world, human civilizations depend largely on tapping vast groundwater reservoirs, which have been stored for up to thousands of years in sand, clay and rock deep underground. These massive aquifers — which in some cases stretch across multiple states and country borders **(Villholth and Rajasooriyar, 2010).**

Yet in most of the world's major agricultural regions, including the Central Valley in California, the Nile delta region of *Egypt*, and the Indus and Upper Ganges in Pakistan and India, groundwater demand exceeds their natural recharge. As much as 99% of the fresh, unfrozen water on the planet is groundwater. ―It's this huge reservoir that we have the potential to manage sustainably. Already, different countries and regions tried to manage groundwater in different ways, depending upon their capacity and severity of the situation, as discussed in the following sections:

India

Groundwater and its proper use assume great significance for a country like India. India being a big country is facing different challenges in different areas, so the government has area specific approaches, suitable to the local conditions. The fall in water table in Indian Punjab has been also a serious issue. The main reasons for it has been the early transplanting of rice (before mid-June), which means severe withdrawal of groundwater, as the monsoon is still far away, temperatures are very high and evapo-transpiration rate is maximum. While an array of interventions are likely to be needed in the longer run to reduce groundwater use to sustainable limits, certain technical demand-management interventions related to paddy-rice cultivation (far-and-away the largest consumer of groundwater resources) were identified in India and that were implemented immediately to good effect. In 2008, a state government ordinance was issued prohibiting transplanting of paddy rice until June 10—the onset of monsoonal rain and 35-40 days later than normal. Agronomists identified that evaporation rates from paddy during this period were very high and there was potential for making real water savings by eliminating essentially non-beneficial evaporation totaling more than 90mm. While this change did not necessarily impact on crop yields, it presented some complications for farmers in terms of labor availability for planting seedlings. Thus, Indian Punjab government checked groundwater depletion by imposing ―the Punjab preservation of sub-soil water Act, 2009', and scanty measures for improving the water use efficiency and allocation of surface water to different regions in the state had been the main causes.

The expected water resource saving was equivalent to 50-65 percent of the groundwater overdraft and that of electrical energy statewide amounted to 175 million kWh. The measure was highly successful because a) there was limited farmer resistance because yields were not negatively impacted; b) compliance was more than 95 percent because any violations were highly visible and severely sanctioned (fine of $200/ha plus uprooting of crop); and c) once a critical mass agreed to delay transplanting, farmers who did not comply also faced an increased threat of pest infestation. Additional measures also were considered such as laser-leveling of fields, soil-moisture based irrigation timing for winter wheat, and shorter-duration rice varieties (with 15 days less gestation). These measures were all aimed at increasing crop-water productivity and reducing non-beneficial evaporation so as to eliminate the current groundwater irrigation overdraft **(Villholth, 2006).**

Legislation: In its effort to control and regulate the development of groundwater, India started its efforts since 1970 in the form of Model Bill. The Indian constitution provision stipulates water as a state subject. Persuasion is being made with state governments/union territories (UTs) for inclusion of roof-top rainwater harvesting in building bye-laws, also nine states have already made it mandatory for special category of buildings. In two states, namely Gujarat and Maharashtra, the bill has been passed but not enacted. Action on the model bill has been initiated in 16 states/UTs. In urban areas, the Government of India has amended building bye-laws and made rainwater harvesting, as a means of artificial recharge, mandatory. So far, Tamil Nadu, Delhi, Haryana have taken action. Other states are in the process of amending the building bye-laws to make rainwater harvesting mandatory in the special class of buildings.

Many states in India have yet to legislate on the regulation and management of groundwater. The few states that have legislation in this area, have done so, by adopting (with some modifications) the model groundwater bill. The basic scheme of the model bill is to provide for the establishment of a groundwater authority under the direct control of the government. The authority is given the right to notify areas where it is deemed necessary to regulate the use of groundwater. The final decision is taken by the respective state government. Wells need to be registered even in non-notified areas. Decisions of the authority in granting or denying permits are based on a number of factors which include technical factors such as the availability of groundwater, the quantity and quality of water to be drawn and the spacing between groundwater structures. The states that have adopted legislation that specifically focuses on groundwater include Goa, Himachal Pradesh, Kerala, Tamil Nadu and West Bengal.

They differ in their coverage since some apply only to notified areas while other apply to all groundwater. Central Groundwater Board (CGWB) has been established in India since 1997, in order to cope with the situation of alarming groundwater decline. The main object of constitution of CGWB is the urgent need for regulating the indiscriminate boring and withdrawal of groundwater in the country. No groundwater development is done without prior approval of CGWB. In case of violations, the state governments have been advised to seal the tube well or even seize the drilling equipment.

Recharging efforts: The first line of defense is to augment the available groundwater. Experience of many NGOs as well as pilot studies on artificial recharge at the behest of the Indian CGWB have shown positive results (Government of India, 2007). In an effort to counter the falling water tables, India's CGWB developed a national blueprint for groundwater recharge in the country which aims at recharging surplus runoff of about 36.4 BCM (29.5 MAF) in an area of about 450,000 sq km identified in various parts of the country experiencing a sharp decline in groundwater levels **(Villholth, 2006).**

Concern regarding the looming crisis has been mounting in the government, and in 2005 the Planning Commission constituted an expert group to review the issue of groundwater management and suggest appropriate policy directions. The World Bank's Water Resources Assistance Strategy for India also emphasized groundwater overexploitation as a critical water sector challenge for India, and advocated developing pragmatic solutions instead of continuing the failed command and control approaches. CGWB has encouraged constructing cost efficient structures to a number of individuals eager to take up rainwater harvesting to arrest the declining groundwater levels.

In Delhi, the depth to bed rock ranges from 25 to 42 m at most of the places whereas at very few places, it goes up to 145 m, so the aquifer is shallow. Therefore, with the rapid population growth, the groundwater supplies are not sustainable. Therefore, though Delhi receives normal rainfall of 611.8mm in 27 rainy days, most of which is going waste as runoff of about 193MCM. It is estimated that the total recharge from rainwater harvesting structures for entire NCT, Delhi is 1390 ha.M (13.9 MCM). The task force constituted for implementation of rainwater harvesting schemes in government buildings, colonies and parks has estimated that about 2.9 MCM rainfall recharge will take place, from the rooftop rainwater harvesting structures constructed in Government buildings in NCT, Delhi during normal monsoon in a year. This will facilitate additional rise in groundwater level to the tune of 0.5 m in alluvium areas and about 1.0 m in hard rock areas.

Management efforts: Andhra Pradesh is one of several states underlain by hard-rock aquifers that have suffered considerable depletion of groundwater, largely for irrigation use, in recent decades. The Andhra Pradesh Farmer-Managed Groundwater Systems Project (APFAMGS) has adopted a novel approach to the problem. The core concept of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle, and limited availability. To achieve this end, the project has engaged farmers in data collection and analysis, building their understanding of the dynamics and status of groundwater in the local aquifers. Even farmers with limited literacy skills have demonstrated their ability to collect and analyze rainfall and groundwater data, estimate and regulate their annual water use based on planned cropping patterns, and increase their knowledge of improved agricultural practices through attendance at farmer water schools (at which a third of the facilitators are women). The project does not offer any incentives in the form of cash or subsidies to the farmers: the assumption is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources. The core organizational component of the project is the groundwater management committee, a village-level community-based institution comprising all groundwater users in a community. The committees are in turn grouped into hydrological units. Data gathered through hydrological monitoring of rainfall and groundwater levels are used to estimate the crop water budget, which is an aquifer-level assessment of the quantity of water required for the proposed Rabi (winter) planting. Awareness of this statistic has become one of the essential variables that farmers take into account when making their cropping decisions for the coming season **(Steenbergen and Olienmans, 1997).**

Regulation: The Hon'ble High Court of Kerala in the matter of *Perumatty Grama Panchayat vs. State of Kerala* also known as the landmark ―Coca- Cola Case‖ decided on the issue of the excessive exploitation of groundwater as *"Groundwater is a national wealth and it belongs to the entire society---. The State as a trustee is under a legal duty to protect the natural resources. These resources meant for public use cannot be converted into private ownership.* As regards groundwater regulation, specifically depletion, the Supreme Court of India has passed several orders in 1996, where under, it has issued directions to the Government of India for setting up of Central Ground Water Authority (CGWA) under the Environment (Protection) Act, 1986 and to declare it as an authority under the Environment Protection Act and delegate powers under the said Act to the CGWA for the purposes of regulation and control of groundwater development.

Bangkok, Thailand

Greater Bangkok witnessed widespread exploitation of groundwater starting in the 1950s, and by 1980 the abstractions had reached a point where there was evidence of significant land subsidence damaging urban infrastructure and concerns regarding aquifer sea intrusion. Authority was to eliminate the utility's abstraction in favor of surface water sources, but the increased domestic, commercial, and industrial tariffs for public water supply triggered a massive increase in the drilling of private wells, whose total abstraction reached over 2,000 million liters per day (818 cfs) in the late 1990s. Measures such as banning water well drilling in critical areas and licensing and charging for metered or estimated groundwater abstractions were introduced, but took some years to be implemented. During 1995-2005 even stronger measures were introduced and implemented (including raising groundwater use charges and more aggressive application of sanctions on well drilling, supported by public awareness campaigns) to constrain groundwater abstraction within environmentally tolerable limits. Total abstraction was reduced from 2,700 million liters per day in the year 2000 to 1,500 million liters per day in the year 2005, and land subsidence was also significantly reduced. Political protest by users in some districts was addressed by allowing well users to continue using their wells conjunctively for the period up to their next license renewal (up to 10 years) and to retain their wells as a backup supply for 15 years, provided they were adequately metered and open to inspection **(Sarkar and Ali 2009).**

China

The situation in China concerning groundwater seems to comply with riparian2 rights doctrine to some extent, especially for rural region, allowing anyone who has the right to use land to get access to the groundwater to use it. The free occupancy system supports the legal basis for this action, since it regulates that drawing water for family use, livestock drinking, emergency use or few demands' for irrigation do not need permits. This leaves a kind of misperception: the groundwater rights are attached to land use right. Due to this there is no other rational principle to restrict groundwater abuse, the way of groundwater rights adheres to the land use right‖ has become a kind of regulation established by usage. Riparian rights doctrine is that any person who owns and occupies land on the bank of a natural stream acquires water use rights which are commonly known as "riparian rights" by virtue of the occupation of that land **(Cheema et al. 2013).**

Netherlands

In the Netherlands the regulations related to groundwater roughly fall into two categories. First, related to the protection of the groundwater against pollution. Second and more relevant in this context is related to the groundwater use. The permits for the use of groundwater are a matter for the provinces in the Netherlands (together with the water boards) according to article 11 of the Dutch Groundwater Law. Below a certain quantity no registration and permit is needed. Above this quantity registration with the provincial authorities is required.

Australia

Australia has implemented the following reforms for successful groundwater management:

State has power and replaced the common law riparian rule and groundwater ownership rule with licensing system, soon as agriculture provoked conflict;

Land and water not tied together anymore since 1994, which has created flexibility and retirement of some land from irrigation;

Facilitated water markets and revisions of water allocation amounts; and

Environmental allocations worked out first and the remaining water is the consumptive pool.

Spain

Spain, like many parts of the world, bestowed private property rights over groundwater resources. However, the 1985 Water Act in response to intensive groundwater use changed the rules of the game. For one, groundwater was taken away from the private domain and ownership rights bestowed upon the state. Second, river basin management agencies were given a role in managing groundwater, and finally, they were also vested with the power to grant permits for groundwater use that started after 1985. It also gave authority to the river basin agencies to declare an aquifer as overexploited, and once it was so declared, to formulate an aquifer management plan for recovery of the aquifer. Some features of such a plan were the reduction in volume of withdrawals or rejection of new applications for wells. In addition, all users of the aquifer were required to organize themselves into groundwater user associations in order to encourage user participation. So far, some 16 aquifers have been declared totally or partly overexploited, while such user associations have been formed in only five and implemented in only two aquifer areas. Further amendments to the act were made in 1999 and 2001, which emphasized the role of the groundwater users 'in aquifer management **(Basharat , 2011)**.

Water sector reforms in Mexico

Perhaps no other country has reformed its water laws as extensively as Mexico has since 1992. By the law of the Nation's Waters of 1992, water was declared as a national property and it became mandatory for existing users to legitimizing their rights through procuring water concessions. The National Water Commission (CNA) was entrusted with the responsibility of registering water user associations, set up a regulatory structure to enforce and monitor their concessions granted and also to collect a volumetric fee from all users, except small-scale irrigators. Aquifer Management Councils

(COTAS) were promoted by CNA as user organization aimed at managing groundwater. Response to the reforms so far has been mixed at best. The large industrial and commercial water users have been quick to apply for concession and pay water fees. However, the real challenge has been registering water rights of the agricultural users, who withdraw at least 80% of total volumes withdrawn, and monitor their withdrawals. Among the agricultural users, the tube-well owners have responded to the law quite positively and have applied for water concessions. The major reason for such compliance has been the carrot 'of subsidized electricity that has been promised to tube-well owners who regularize their connection through registration of the wells with the CNA. This shows that farmers respond well to direct economic incentives. Monitoring of actual extraction has proved more intractable.

Pakistan

The issue of groundwater management is multidimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, reuse/recycling, its existing depletion, pollution, and its protection from depletion and degradation. However, like surface water resource management, not much concerted efforts have been made for management of the hidden complex underground water resources in Pakistan. Rather, the groundwater has been developed without considering it long-term impact on its sustainability in terms of quantity and quality. Moreover, it had been wrongly deemed, like there is no link between groundwater and surface water. That is why groundwater is being developed in isolation to surface water, both by the government (mostly in metropolitan cities e.g. Lahore) and about one million private users, mostly concentrated in agriculture areas of the Punjab province **(Basharat and Tariq , 2013).**

Egypt

Renewable groundwater reservoirs are distributed between the Nile Valley (with a stock of approximately 200 billion m3), and the Delta region (with a stock of approximately 400 billion m3). This water is considered part of the Nile water resources. It is estimated that 6.5 billion cubic meters of water have been withdrawn from these reservoirs since 2006. This is considered within the limits of safe clouds, which reach a maximum of about 7.5 billion m3, according to the estimates of the Groundwater Research Institute. It is also characterized by good quality of water with a salinity of about 300-800 parts per million in the southern delta areas. It is not allowed to drain these reservoirs water except when a drought occurs for a long period of time, so this water is of an important strategic value. It is estimated that the withdrawal from these reservoirs will be close to about 7.5 billion m3 after 2017. As for non-renewable aquifers, they extend under the eastern and western deserts and the Sinai Peninsula. The most important of which is the Nubian sandstone reservoir in the Western Desert, whose stock is estimated at about 40 thousand billion m3, as it extends in the Northeast African region and includes the lands of Egypt, Sudan, Libya and Chad, and this reservoir is considered one of the most important sources of fresh groundwater not available in Egypt for use due to the availability of this water on Great depths, which causes an increase in the costs of lifting and pumping. Therefore, what has been withdrawn from that water is about 0.6 billion m3 / year, which is sufficient to irrigate about 150 thousand feddans in Al Owainat area. It is expected that the annual withdrawal rate will increase to about 2.5-3 billion m3 / year as a safe and economical withdrawal limit. In general, the effects resulting from the expected decrease in the level of the underground reservoir should be avoided, by switching from the large-area cultivation system to the farm system with specific areas (2000-5000 feddans) in order to preserve the underground reservoirs for long periods.

Algeria

Algeria is the largest country in Africa, with an economy dominated by petroleum products, a sizeable military and considerable regional influence. Agriculture, supported by irrigation, makes up a small part of the economy. Most people live on the north, Mediterranean, coast. The Saharan desert, which covers the south of the country, is sparsely populated. Over 80% of both the rural and urban population are classed as having access to safe drinking water. Water supply is heavily dependent on groundwater, for drinking, agriculture and industry. Agriculture in the north of Algeria relies on groundwater irrigation, from relatively young and shallow coastal aquifers, which are actively recharged by rainfall. In the south, deep sedimentary aquifers contain vast quantities of 'fossil' groundwater, which is not being actively recharged. Groundwater from these deep aquifers has been used traditionally for centuries, at relatively small scale, through foggaras - water galleries, and there are also larger modern abstractions. Groundwater level decline in some areas shows that some over-exploitation is taking place.

Groundwater abstraction is promoted by subsidies, which make it relatively cheap to use, and discourage water conservation. However, water subsidies are underpinned by revenue from oil and gas, and are threatened by falling world hydrocarbon prices. To protect its hydrocarbon revenues, the Algerian government has proposed developing its large shale gas resources, using hydraulic fracturing, which has met with concern relating to potential groundwater pollution, particularly related to 'fossil' groundwater, which is irreplaceable. Aquifer pollution has occurred in some areas, for example saline intrusion along the coast relating to over-abstraction, and nitrate pollution from agriculture, despite legislation to limit nitrate contamination pollution from agricultural activities. There are a number of different estimates of groundwater abstraction for different uses in Algeria. The volume of groundwater abstracted for agriculture and industry is reviewed annually, but there is considerable uncertainty, as data are scattered and often contradictory.

One estimate of total groundwater abstraction from all sources across the country is 4.3 billion m^3/year. In the northern Atlas region, the National Water Plan estimated that

1.8 billion m³ groundwater is used annually in total. It is estimated that groundwater supplies 63% of total water demand in the Northern (Atlas) region, and 96% of water demand in the Southern (Sahara) region. Irrigation is the largest user of groundwater. In 2012, 69 percent of the area equipped for irrigation was intended to be irrigated by groundwater. Of this, borehole irrigation comprised 41%, wells 26% and springs 2%. Irrigated agriculture provides for 40% of national agricultural production.

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 favorable 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 and other erroneous concepts) and to oversee its socio-economic and environmental setting.

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