Planning conjunctive groundwater and surface water development in public irrigation systems

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Abstract In India future demands for water cannot be met entirely from new surface reservoirs and maximum groundwater development can only be obtained by conjunctive use of groundwater and surface water reservoirs. A view of the conjunctive use that is being practised in India suggests that the planning process in vogue does not really envisage the complementary use of both systems. Characteristics of conjunctive use systems have been identified and the principles of planning based on the past experience are detailed for guidance in the actual planning process. A hypothetical example of a canal irrigation system is provided to illustrate how exactly the surface water and groundwater sources of irrigation can be interspersed in the case of a new system and to replace surface water irrigation in the case of an old irrigation system by groundwater in an appropriate manner.

INTRODUCTION

The multiple sources of water resources have a relationship of complementarity and conflict. Their complementarity is known as the hydrological cycle under which water is evaporated from the oceans and other water bodies, is precipitated on land in the form of rain, snow, hail or dew, part of which flows back to the sea, part evaporates or is transpired by plants and the remainder percolates to become groundwater. Groundwater in turn returns to the surface as springs or in streams, sometimes forming the only perennial source for some of the rivers. This cyclic character of complementarity should be used for improved water resources management. Groundwater resources should be used more as a buffer to tide over dry periods; underground aquifers should be recharged regularly with excess surface water during the monsoons; the salinity of evaporating surface water must not be allowed to pass underground to make the groundwater saline, which in turn can pollute fresh runoff water. But the hydrological cycle, as just implied, is not a gift of nature. It is ever more man induced. Water resources management must therefore address itself to these changes in the hydrological cycle brought about by man through river runoff and regulation, groundwater exploitation and the general changes in the environment, so that they make for an increase in the quantity and improvement in the quality of water.
In India, future demands for water cannot be met entirely from new surface reservoirs and maximum groundwater development can only be obtained by conjunctive use of groundwater and surface reservoirs. The management problem is to use these water resources conjunctively to meet the water demands, particularly those of the agricultural sector. The issue is to determine the temporal development subject to development of groundwater within a specified range from environmental and economic considerations. The problem has been studied from several considerations by Smith (1970), Aron (1969) and Buras (1972). However, much work remains to be done on large scale groundwater and surface water development in India, taking into account the intertemporal framework with the construction of storage reservoirs (Chaturvedi & Gupta, 1983). Another important aspect of conjunctive use is to couple it with the energy sector and carry out integrated planning (Chaturvedi, 1979). This problem is important in the northern part of India where groundwater currently accounts for a larger part of power and with the future development, its share may be significant while the surface water accounts for a high percentage of the power through hydroelectric developments.

CONJUNCTIVE USE PLANNING IN INDIA IN RETROSPECT

A number of developments took place in Utter Pradesh, Punjab, Maharahashtra, Tamilnadu and other States in the forties with respect to utilization of groundwater. The Utter Pradesh government took up schemes of tapping deep aquifers (up to 100 m) in tail reaches of canal systems to provide better irrigation facilities. However, the combining of surface water and groundwater was mostly adopted to meet specific requirements without considering optimum utilization. It was from the sixties onwards that increased attention of Central and State governments was focussed on increased use of surface water and groundwater resources conjunctively. Besides providing more water for irrigation, the wells have also helped in vertical drainage thereby controlling water-logging problems. For example, in Punjab, the area under water-logging was 971 000 ha in 1964 which was reduced to about 169 000 ha by 1974 after sinking a large number of tubewells. In Haryana, public tubewells are of two types: (a) augmentation tubewells which are installed along existing canals to add water into canals for utilization in the canal command areas, (b) direct irrigation tubewells which provide local irrigation facilities outside the canal commands. In Bihar, it is only in the command of the Sone Project that groundwater has been used with canal supplies. In Rajasthan, the eastern region is drained by the Chambal and its tributaries and the southern part by the Mahi River. Six per cent of the part of Rajasthan west of the Aravalli hill range is arid and is drained by the Luni and its tributaries. Irrigation by open wells has always been the main source of irrigation in the state, and as there are very few surface water schemes in the state, there is not much scope for conjunctive use. However, conjunctive use of surface water and groundwater has been introduced in certain areas in Chambal Command in Kota and Bundi.
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districts. In Gujarat, government tubewells are being installed in the canal commands of the Mahi, the Dantiwada etc. for integrated use of surface water and groundwater. In Madhya Pradesh the government has taken up a project for conjunctive use of surface water and groundwater in the Chambal command. The Chambal project was envisaged to irrigate 330,000 ha at the planning stage and after completion of the project in 1960, an area of 151,000 ha only could be irrigated (1974 figures) due to the unlined canals and heavy seepage losses through them. After the modernization, the irrigated area increased to 241,800 ha which also included irrigation from groundwater resources.

THE PRINCIPLES OF CONJUNCTIVE USE PLANNING

The fundamental principle of conjunctive use planning is that there must be full recognition of the meaning of conjunctive use. It does not mean independently optimized development of surface water resources and groundwater resources to serve the same general objectives. Rather the objectives, in addition to the general objectives of water resources development, include making optimal use of the complementary aspects of the two sources of water and their related natural resources.

Storage capacity

For conjunctive use planning all potential storage capacity resources and requirements must be assessed. The definition of the system to be utilized in this evaluation must include inflows and outflows not commonly included in the evaluation of surface water storage requirements. The evaluation must also include recharge and potential recharge of groundwater under the modified conditions which will presumably exist when a plan has been implemented. One of the difficult evaluations involves that of recharge by deep percolation under irrigated areas and canal seepage. The magnitudes, times and places of this recharge are determined by the decisions on the degree of development as well as the distributional decisions. Storage capacity requirements thus become an implicit function of both the storage capacity provided and the decisions on the distribution and use of water. Because of this complexity, an iterative evaluation using a total system mass balance over time will usually be required. Furthermore, the concept of "when needed" is now expanded, since water can be stored in a small surface reservoir until "needed" for artificial groundwater recharge, rather than until needed for the ultimate user system. In this way the small reservoir, in conjunction with recharge facilities and a groundwater storage system, may become as effective, or even more effective than a large surface impoundment. Conjunctive use of the surface water and groundwater reservoirs will usually result in a greater total system storage capacity requirement than that indicated by an overall system mass balance.
The advantage comes when the groundwater storage capacity actually capable of being used is limited by the natural recharge rates. In such cases conjunctive use may allow substantial reductions in total surface reservoir requirements.

**Water transport**

Subsurface flow of water from where it originates is usually several orders of magnitude slower than is feasible with surface canals. The latter can be utilized to transfer substantially increased quantities of water to groundwater storage through secondary, artificial recharge sites much closer to the groundwater storage volume being utilized. Not the least of these recharge systems are the agricultural water use systems, and in some cases the seepage from distribution canals. To at least some extent, seepage losses from unlined canals may become useful recharge routes rather than "losses". In turn the latter could greatly influence the design of the well fields used to withdraw the groundwater. Certainly any modifications of the flows in natural stream channels will produce an interaction with the "natural" recharge rates. The interaction may be favourable or adverse, depending on how it is managed. By recognition of these interactions in the planning process and overall operation plans the negative interactions can be minimized and the positive effects maximized.

**Energy production**

Energy is required to extract water from groundwater storage when it is needed. If that energy is unreliable, so is the groundwater resource. Releases from surface water storage systems, in general, provide a release of energy. Unfortunately, the two are not always properly synchronized for most effective conjunctive use of the energy required and that available. The reliability of the water supply from groundwater is no greater than the reliability of the energy supply used to remove the water from the storage. Since that reliability is seasonally variable, this variability should be integrated into the conjunctive use planning process.

**Recharge capacity**

The recharge capability includes the natural watershed recharge, the recharge resulting from water transport and use, particularly by irrigation, and any potential special purpose artificial recharge locations. Should the natural recharge capacity act to limit the utility of the groundwater storage resource or the groundwater transmission resource, then appropriate analysis of the potential artificial recharge locations becomes critical. Indirectly induced recharge, such as that resulting from deep percolation of irrigation water and canal seepage, should be analysed conjunctively in any event. Such "losses" frequently create problems of water-logging and salinity concentration. These
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can usually be avoided or treated in a more cost effective manner by modification of the conjunctive use plan than by special facilities for their prevention or treatment.

Commonality of sources

Both surface water and groundwater systems share a common input of water resources, i.e. the precipitation. Unfortunately the two channels by which the water is allowed or made to flow to its ultimate users are frequently planned, developed and operated as if this were not the case. When the total hydrologic resource does not limit the total development, this will not create any serious problems other than the patchwork of remedies usually required to minimize the adverse interactions.

System time-response

The complementarity inherent in the different response characteristics of the two systems is to be considered in addition. Groundwater development shows very little of the economies of scale, while surface water developments, particularly aqueduct systems, show major unit cost reductions as capacity is increased. In addition, if a surface water storage site is only partially developed initially, it usually is very costly or impossible to develop that site further should this be required later on. These characteristics tend to require rather large scale initial development of surface water systems. Surface systems also generally require longer periods of time for planning authorization and construction. This lead time is of the order of decades before the first unit of water is delivered. The result at a minimum is substantial interest costs which are not covered by a corresponding stream of benefits for long periods of time. There are many cases on record where constructed systems were essentially unused for long periods of time beyond the time forecast for full development. In contrast, first deliveries of water from a groundwater development can occur within a few months. Further development can be gradual or more rapid as the development of water use systems proceeds. Little or no excess capacity needs to exist at any one time and partial development, with a few important legal and social exceptions, does not preclude future further development. This suggests that where the geography supports this complementarity, the scheduling of development could include groundwater development as an interim supply. This could produce major savings in interest charges and much greater assurance regarding the magnitudes of water requirement and the economic feasibility of development. This in turn enhances financial feasibility to a significant extent.

Maintaining control of water

Maintaining control of any water deliberately added to groundwater storage
by artificial recharge, whether this be by special systems or be due to deep percolation from irrigated areas or from canals, deserves serious consideration. So long as the plan provides adequate water supply for everyone's maximum net rate of use, no serious difficulties will arise. However, the economic relationships must be carefully designed so that individuals may be induced to withdraw groundwater when this is desired, to refrain from pumping when extraction is not desired and in general to provide the anticipated amounts of groundwater recharge when and where needed by the plan.

**Waterlogging and salinity**

The water use managers also become involved in another serious surface water-groundwater interaction, that of control of salinity and waterlogging. To correct this condition, drainage systems must be constructed to convey the salt and excess water from the root zone to some point of safe disposal. It need not always be provided initially, but to assure permanence of the economic development it must be included in the development plan. Note that in this context groundwater drawn from aquifers not in relatively direct hydraulic contact with the root zone can create the same problem as surface water. With conjunctive use of surface water and groundwater where a relatively free hydraulic contact exists between the root zone and the aquifer, the waterlogging problem is usually but not always resolved over much of the irrigated area by the lowering of the water table. In such situations with conjunctive use, the maximum operating level of the groundwater can be kept, by design, at some safe distance below the root zone. Both salinity and water balances can then be maintained in the root zone and still allow for adequate aeration thereof.

**Interaction with existing wells**

This is particularly important in India where shallow wells currently support a significant portion of the existing economic use of groundwater. The conjunctive use plan will, in most cases, involve the use of much larger storage capacity volumes in the groundwater system. To store additional water, existing water must be removed. The purpose of storage for water always involved filling and emptying the corresponding storage spaces. For groundwater storage, this may involve frequent lowering of the water table below the bottom of the existing shallow wells. The conjunctive use project thus effectively destroys the reliability of the existing well resources. Alternative supplies must be provided to maintain equity of treatment and to fulfill moral obligations, even if this is not required legally or politically. The supplies of water from these shallow wells in the past have been much more reliable for the water users than is customarily provided for surface water users in India. The moral obligation is not properly compensated by providing surface water of lower reliability. On the other hand, serious problems of apparent inequality of treatment would appear if current shallow
Well owners were given a priority for surface water over other farmers of the district. As an alternative, each current shallow well could be replaced by a tube-well of sufficient depth to provide essentially the same reliability as at present. This usually will require provision of energy supplies alternative to the animal power now in use. These alternative energy supplies must also meet the test of reliability to be equivalent. There is also the problem of the increase in energy cost to the individual well owner.

Reliability enhancement

The basic reasons for the current planning norm of 75% reliability commonly applied to surface water development in India might be explored. Experience here has shown that the cost of significantly increasing the reliability at the required high levels of development is prohibitive. Conversely the annual quantity of supply for any given storage capacity decreases rapidly as the required minimum reliability is increased above the 75% level. However, for conjunctive use planning this is not necessarily the case. Reliabilities of supply can be increased substantially since the combined additional cost of artificial recharge and well field development is usually much less than the additional cost of surface storage. Unless the water tables are high, the evaporation losses from groundwater will usually be significantly less than the losses from surface storage. Evaporation losses over the dry season are major factors influencing the standard of 75% reliability for surface water supplies in India. A carefully designed conjunctive use plan will provide substantially increased reliability of supply for both agriculture and industrial users, without the corresponding exponential increase in unit cost of water and with obvious corresponding economic and social benefits.

A HYPOTHETICAL EXAMPLE

New irrigation system

The only rational way of permanently preventing waterlogging in a canal-irrigated area lies in maintaining the balance of recharge to and discharge from the groundwater reservoir. In its absence the root zone will become saturated with water and salt concentrations build up. Recharge to and discharge from the groundwater reservoir can be balanced by applying canal water by gravity flow to only about half of the canal command area. The other half should be reserved for well irrigation from shallow boreholes/ dugwells/radial water collectors. When planning new projects (like Telugu Ganga Project etc.) these two types of irrigation should be interspersed in fairly big patches, selected on consideration of easy commands, saline/alkali soils and the irrigation suitability of groundwater.
Old irrigation system

Another feasible alternative which is more suitable for meeting waterlogged conditions on ancient established irrigation systems is to replace canal irrigation in the lower half of every irrigation block of a field water course by well irrigation. Every existing distributory will continue to function as before with its outlets undisturbed. The irrigated area on each field water course will be divided into two halves. With the same canal supply irrigating only the upper half of the block, the intensity of irrigation in that part will be doubled. This will take us nearer the goal of constant crop cover for the area. The lower half of each block will be irrigated by a shallow bore/dugwell or a radial water collector as the geohydrologic conditions permit. If the unconfined aquifer has sufficient thickness to enable a conventional borewell/dugwell to yield a discharge equal to that of the corresponding canal outlet the same should be installed. If not, a radial water collector should be used. It should have a discharge equal to the combined supply of two or three outlets. Such a well should irrigate the lower halves of two or three contiguous blocks. A line of such wells will thus be laid out on either side of the drainage line between every two adjoining canal distributories. Interspersing of two types of irrigation will double the water allowance for the entire area and also effectively meet the hazard of waterlogging. Even new canal commands could be designed with a provision for some future layout when the water table rises.

REFERENCES