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OVERVIEW AND OUTLOOK: COMBINED USE OF SURFACE AND GROUNDWATER

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ABSTRACT

The world's fresh water resources are unequally distributed both in time and in space. Until recently water resource management focused on reallocating water to when and where it was required, a supply-side or fragmented approach. Nowadays there are signs that water resource availability is dwindling – due to both population growth and increased per capita water use – and ecosystems are being damaged. To face this challenge a new holistic approach is needed. This approach includes the integrated or combined use of surface and groundwater resources and takes account of social, economic and environmental factors. Moreover, it recognizes the importance of water quality issues. In this context, the paper examines the main aspects and problems concerned with the planning, design, construction and management of combined use of surface and subsurface water resources, along with its environmental impacts and constraints to sustainable development.

***Keywords:** surface water; groundwater; models; combined use; planning.*

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1. INTRODUCTION

Water resource management should preserve or enhance the environment's buffering capacity to withstand unexpected stress or negative long-term trends. As the environment's carrying capacity is put under increasing pressure, due to the growing needs of the population and improper use of its resources, environmental vulnerability increases too. In this context, mismanagement of water resources, paying only lip service to the environment, has led to water scarcity and water pollution which threaten security and the quality of human life. Giving proper regard to this unsustainable trend, the Second World Water Forum acknowledged the pivotal role that integrated water resource management plays in the process of sustainable development. The term "integrated" embraces the planning and management of water resources, both conventional and non-conventional, and of land. It takes account of social, economic and environmental factors and comprehends surface water, groundwater and the ecosystems through which they flow. Moreover, it recognizes the importance of water qualityissues.

Integrated water resource management depends on co-operation and partnerships at all levels, from individual to governmental and non-governmental, national and international organizations sharing a common political, scientific and ethical commitment to the need for water security and for optimizing water resources use and planning. To achieve this goal, there is a need for coherent national, regional or interregional policies to overcome fragmentation and for transparent and accountable institutions at all levels. To this end, targets should be established and suitable strategies should be devised to meet the challenges inherent in the sustainable use and development of water resources. These resources should be managed at both the river basin and aquifer levels.

Research must be directed towards solving water use and planning problems, gaining a better understanding of the hydrodynamic and hydrochemical processes involved and enhancing water productivity. Action research should cover field and laboratory evaluation, assessment and monitoring, development and implementation of suitable water management strategies. This process requires enhanced basic and applied research and a large variety of tools ranging from field techniques to advanced technology for water control and regulation such as models, Remote Sensing, Geographic Information Systems, Decision Support Systems and spatial analysis procedures. All these tools have to be considered under a broad and integrated approach for addressing the use, planning, conservation and protection of both surface and subsurface water resources, that takes proper account of the environmental impacts and socio-economic effects ofdevelopment.

2. COMBINED USE OF SURFACE ANDGROUNDWATER

2.1 The Concept of CombinedUse

As broadly outlined above, a critical problem that mankind has to face and cope with is how to manage the intensifying competition for water among the expanding urban centres, the agricultural sector and instream water uses dictated by environmental concerns.

In general terms, combined or conjuctive use implies the planned and coordinated management of surface and groundwater, so as to maximize the efficient use of total water resources. Because of the interrelationship existing between surface and subsurface water, it is possible to store during critical periods the surplus of one to tide over the deficit of the other. Thus groundwater may be used to supplement surface water supplies, to cope with peak demands for municipal and irrigation purposes, or to meet deficits in years of low rainfall. On the other hand, surplus surface water may be used in overdraft areas to increase the groundwater storage by artificial recharge. Moreover, surface water, groundwater or both, depending on the surplus available, can be moved from water-plentiful to water-deficit areas through canals and other distribution systems. On the whole the integrated system, correctly managed, will yield more water at more economic rates than separately managed surface and groundwatersystems.

2.2 WaterStorage

In conjunctive use, the two most important issues that planners have to face concern the storage of surplus water and the optimal allocation of water withdrawals.

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With regard to the first problem, a question that needs to be answered is where to store water and which reservoirs to develop: surface or subsurface?

2.2.1 Subsurface WaterStorage

The advantages of subsurface over surface reservoirs are:

- groundwater is less prone to pollution than surface water, and if polluted, pollutants can be diluted during undergroundmovement;
- groundwater can be put to use where and when it is required, with less risk of seepage or evaporation losses during storage andtransmission;
- there is less ecological hazard compared to surface storageprojects;
- groundwater storage is less liable to deterioration than surfacestorage;
- the cost of storing groundwater is less than that of surfacestorage.

In spite of the many advantages mentioned above, there are some constraints that hinder groundwater storage, such as:

- wells interfere adversely when large supplies arerequired;
- groundwater storage withdrawal is a highly energy intensive process, while surface water is often available by gravityflow;
- surface reservoirs are more suitable for multiple uses, including energy production and recreation;
- mineralization is generally lower in surface waterstorage.

Combining so many aspects requires methods of analysis that systematically integrate them in such a way that within the planning process alternative solutions can be defined, tested and chosen.

Normally artificial groundwater recharge is accomplished by means of infiltration basins or injection wells. Other techniques for augmenting subsurface supplies include vegetation management, runoff inducement and increasing seepage from streams by widening the wetted perimeter of channel sections or lowering the groundwater table in the flood plain.

Water quality aspects play a major role in this process. They mainly concern the quality of recharge water and its effects on groundwater quality.

To address the groundwater management problems, the following steps should be considered and carried out:

- general groundwater surveys and identification of the sites that require in-depth studies; these studies provide estimates of water quality and quantity, corroborated up by reliable data;
- integration of the physical characteristics and conditions previously collected and analyzed, with economic and social parameters to formulate suitable strategies and policies for subsurface water use, planning andmanagement.

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2.2.2 Surface WaterStorage

For surface reservoir management the critical elements to be considered are minimum pool elevation and storage losses due to sedimentation. Generally, minimum pool elevation is not defined solely by hydraulic limitations of the outlet or diversion works; more severe constraints may be imposed by recreational interests, habitat values in the reservoirs or by the adverse water-quality effects if the pool is drawn too low.

To account for these factors, generally, a two-step design process is adopted (McMahon, 1992). In the first step, a number of potential reservoir sites are examined, not only for construction requirements, but also in terms of hydrologic patterns in order to establish capacity-yield relationships. This procedure leads to the “preliminary design” framework. In the second step, leading to the "final design", procedures must account for all factors affecting the project design, including fluctuations of inflows and release by season, release restriction during periods of low storage, evaporation losses, minimum pool requirements and supply failureprobability.

Uncertainty is a major element of concern in the design process. It not only affects flow records, where temporal and spatial variability is significant, but also the generation of demand forecasts.

2.3 Combined Use and IrrigationDevelopment

The beneficial effects of combined or conjuctive use in canal commands can be summarized as follows (Karanth, 1987):

- use of groundwater helps cope with peak demands for irrigation and hence reduce size of canals and consequently constructioncosts;
- supplemental supplies from groundwater bodies ensure proper irrigation scheduling, even if rainfall fails or isdelayed;
- groundwater withdrawals lower the water table thus reducing the risk of water-logging, soil salinization and consequent wastage of water for leaching thesoils;
- surface and subsurface outflows are minimized, causing reduction in peakrunoff;
- conjunctive use allows the utilization of saline or brackish ground – or surface – water resources, either by mixing them with freshwater, or by using alternate water resources for irrigationevents.

3. RESEARCH THRUST ANDDEVELOPMENT

Research needs to be focused more effectively than in the past on planning and management problems of conjunctive use of surface and groundwater. This is the main way to provide planners and decision makers with suitable and well-tested technologies for targeted measures designed to enhance conjunctive use efficiency, while protecting the environment. The lack of research, application of research findings and access to new and advanced technology,isseenasoneofthemainreasonsfortheproblemsplaguingthesector:low

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efficiency, environmental degradation, high costs and lack of beneficiary responsiveness. Successful research thrust on sustainable integrated water resource management should include the following actions:

- Data Base Improvement
- ModelingTechnology
- Spatial AnalysisProcedures
- Decision SupportSystems

3.1 Data BaseImprovement

Availability of reliable data on hydro-climatic patterns, water demands, spatial and temporal characteristics of surface and subsurface water bodies is an essential prerequisite for sustainable water resource development. As long as adequate and reliable data are lacking, planning, design and management of water use projects will remain guesswork, water use irrational and wasteful and development unsustainable. Demand management and adaptation are essential components for enhancing project flexibility to deal with uncertainties of climate change. In the main, water use planning programs can only be soundly formulated on the basis of adequate data on soil and its productivity, potentially available water resources, water demands, performance of existing water use projects and other relatedfactors.

3.2 ModelingTechnology

There is no question that modeling technology is already one of the most important and widely used tools for solving long-term environmental problems and will become even more so in the future. Modeling allows to formalize scientific understanding and to integrate the various components and processes involved in the surface/subsurface water system. It also acts as a bridge for knowledge transfer between scientists and policy makers (or the public), as a basis for testing different scenarios and allows to integrate sound planning and management strategies with economic development by means of cost-benefit analyses and finding optimal solutions. Moreover, without modeling technology it would be difficult, if not impossible, to predict the anticipated impacts of any proposed plan and management policy. In the main, the planning, design, management and operation of complex water resource systems depend on modeling technology and its continual development and improvement.

3.2.1 Simulation Models

Simulation models are essential for analyzing complex processes of surface and subsurface flow and transport, because they provide a quantitative framework for synthesizing and handling the large set of characteristics that describe the variability of the phenomena, as well as the spatial and temporal trends of hydrologic parameters and stresses, and historical rainfall, flow rate, water level and solute concentration records.

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For surface hydrology the most widely used simulation models can be grouped into the following classes (De Vries and Hromadka, 1992), according to the types of hydrologic problems they are intended to deal with:

- single event rainfall – runoffmodels;
- continuous – stream flow models, accounting in time for precipitation and water movement through the catchment;
- floodhydraulics;
- waterquality.

With regard to groundwater hydrology, the two kinds of models most commonly used for solving flow and transport equations are based on finite difference or finite element techniques. The choice between a finite difference and a finite element model depends on the problem to be solved and on user preference.

3.2.2 OptimizationModels

One of the major advances in water resource engineering over the last three or four decades, is the development and adoption of optimization techniques for planning, design and management of complex water resource systems. The analysis of these systems may involve thousands of decision variables and constraints. To overcome problems of dimensionality various schemes have been devised, providing decision alternatives which are optimal in some defined sense and which can be used by water managers to assist their decisionmaking.

An extensive literature review of the subject reveals that no general algorithm exists. The choice of method depends on the characteristics of the water system concerned, on the availability of data and on the objectives and constraints specified. Yeh (1985) presented the state of the art and discussed in detail various techniques, mainly for reservoir operations, including linear programming (LP), dynamic programming (DP), non-linear programming (NLP). Combinations of the above methods, along with in-depth analyses, and the merits and limitations of each of them, are also been reported in the literature.

When problems of optimal water resource management include objectives that are difficult to describe due to subjectivity or uncertainty, the principles of fuzzy logic offer a viable approach. The concepts and operational algorithms are available in literature (Zadeh and Kacprzyk, 1992; Parent and Duckstein, 1993; Russel and Campbell, 1996).

More recently neural network approaches (NNAs) have been proposed for solving conjunctive use problems. This technique has been shown to be a powerful tool for both forecasting and optimization purposes, especially when the underlying data – generating processes are uncertain or unknown. Neural network approaches have been used by French et al. (1992) for rainfall forecasting, and by Karunanithi et al (1994) for river flowprediction.

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3.3 Spatial AnalysisProcedures

An integrated system approach to developing and testing modeling technology requires different spatial analysis procedures such as: geostatistic methods, Remote Sensing (RS) and Geographic Information Systems (GIS).

Geostatistics, a set of statistical estimation techniques involving quantities which vary over space and time, has found wide application in surface and subsurface hydrology (Matheron, 1971; De Wrachien, 1976; de Marsily, 1986; Kitanidis, 1992). Geostatistics can help define these standards and provide flexibility for the creation, validation, testing and evaluation of data sets that have distinct temporal and spatialcomponents.

Remote Sensing applications to hydrology are relatively new but are rapidly becoming an important information source for water resources planners and managers (D’Souza and Barret, 1988; Engman, 1992). RS and its continuing advances offer a broad range of techniques for landscape rendering or identifying landscape features, or, in some cases, for actually measuring hydrologic state variables andprocesses.

Geographic Information Systems are computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information (Dodson, 1992; van Dijk and Bos, 2001). GIS technology appears particularly suitable for dealing with data and modeling issues associated with environments involving multi-scale processes, within a complex and heterogeneous domain.

3.4 Decision Support Systems

The repeated use of simulation models, linked with spatial analysis procedures, under different hypotheses, whether for system design or operation and management purposes, is generally called Decision Support System (DSS). DSSs can also aid in real-time, adaptive planning and management, where the decisions to be taken, as well as the procedures involved, are continually updated and improved over time.

DSSs are not only analytical tools, but also serve as a means of communication, training, forecasting and experimentation. They can act as links between scientists and decision-makers by providing different scenarios or alternative future environments against which decisions have to be tested. The goal is not to predict the future but rather to learn to live with uncertainty, to factor it into the decision process and to improve the quality of thinking amongdecision-makers.
In the main Decision Support Systems are suitable for:

- linking simulation and optimization models to determine the values of decision variables or system performanceindicators;
- combined use with GIS and other graphic procedures that permit statistical analyses and map displays of spatialdata;

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- combined use with neural networks able to learn to reproduce results of complex physical and chemical processes and hence provide “black boxes” for the aboveprocesses.

4. CHALLENGES FOR THEFUTURE

At the beginning of the twenty-first century, conjunctive use of surface and groundwater is coming under pressure on a number of fronts. The expected demand for water exceeds available resources, plans fall short of targets, population is increasing, though growth rates are slowing down, and economic crises coupled with environmental concerns further complicate and exacerbate efforts under way to tackle these problems. The scientific and professional communities recognize the causes and effects of the problem. These, in turn, create a number of challenges for the future, which can be summarized as follows (IAHR, 1999):

- Rainfall/Runoff processes andmodeling;
- Groundwater management, monitoring andremediation;

4.1 Rainfall/Runoff Processes andModeling

The quality and performance of rainfall/runoff models have improved but there is still room for further improvement. Future research directions will include adaptation of models for use in the domain of hydroinformatics, refinement of flow and quality modeling, examination of management options (storage and treatment facilities), interactive, dynamic control required in real-time simulationstudies.

4.2 Groundwater Management, Monitoring andRemediation

Today problems in groundwater management are concerned with overexploitation, water table lowering, water deficit and pollution. Improved land management, to increase groundwater recharge by reducing evaporation and, where appropriate, runoff, also warrants investigation. Further problems are created by land subsidence due to over exploitation. Any groundwater management activity has to be based on an adequate and thorough field investigation, calling for improved methods in this area. Accurate monitoring of the groundwater flow and quality, including estimate of techniques discharges and storage is also important. Restoring the quality of polluted groundwater entails not only the elimination of pollution sources but also the remediation of contaminated groundwater in both the saturated and unsaturatedzones.

Dynamic and stochastic simulation models of water flow and solute transport in saturated and unsaturated zones, combined with carefully selected field experiments, are crucial tools for proper assessment and management of groundwater contamination, and need to be further improved.

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5. CONCLUDINGREMARKS

The world's fresh water resources are unevenly distributed in time and space. Until recently water resource management focused mainly on reallocating water when and where it was required, a supply-side or fragmented approach. Nowadays, it is apparent that water availability is dwindling due to both population growth and increased per capita water use causing often irrepairable damage to the environment. To face this challenge a new holistic, systemic approach, relying on conjunctive use of surface and ground water resources is needed to overcome the current fragmented management of water. This implies long-term planning and management strategies with respect to both water quantity and quality.

On the one hand, only the holistic and systemic approach seems capable of providing a deeper understanding of the behavior and evolution of surface and groundwater systems. This approach will also design strategies for maximizing the efficient use and management of available water resources, while preserving or enhancing the buffering capacity of the environment against unexpected stress or negative long-term trends. On the other hand, engineers, economists, ecologists, planners, along with stakeholders, user associations and all sectors of society must be involved in the decision makingprocess.

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