CHAPTER - 3

LITERATURE REVIEW

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3.1 GENERAL

The deliberate optimum combined use of groundwater and surface water or any water from two sources is commonly termed "conjunctive use." Conjunctive use helps actively managing aquifer system as an underground reservoir. During wet years, when more surface water is available, it is stored underground by recharging the aquifers. During dry years, the stored water in the aquifer system is available to supplement or replenish diminished surface water supplies. Conjunctive use is an effective tool for increasing the overall water supply. A linear programming technique can determine the optimal cropping pattern and the release policy for the conjunctive use.

3.2 LITERATURE STUDY

As related to the topic of study, numerous research papers have been reviewed from various international and national journals, proceedings of symposiums/seminars/conferences, out of which few of them are discussed below, and some are presented in the enclosed CD.

To formulate the linear programming technique to optimize the cropping pattern and release policy, the literature review carried out as under following different categories

1) Fuzzy linear programming technique
2) Linear programming technique
3) Cropping pattern
4) Management problems of conjunctive use
5) Conjunctive utilization
6) Case studies

3.2.1 Fuzzy Linear Programming Technique

(a) Fuller (1989) focused this study on the problem of stability (with respect to changes of centers of fuzzy parameters) of the solution in fuzzy linear programming (FLP) problems with symmetrical triangular fuzzy numbers and extended operations and inequalities.

(b) Fuller and Zimmerman (1993) interpreted fuzzy linear programming (FLP) problems (where some or all coefficients can be fuzzy sets and the inequality relations between fuzzy sets can be given by a certain fuzzy relation) as multiple fuzzy reasoning schemes (MFR), where the antecedents of the scheme correspond to the constraints of the FLP problem and the fact of the scheme is the objective of the FLP problem. Then the solution process consists of two steps first, for every decision variable $x \in Rn$, we compute the maximizing fuzzy set, MAX(x), via sup-min convolution of the antecedents/constraints and the fact/objective, then an (optimal) solution to FLP problem is any point which produces a maximal element of the set $\{MAX(x) \mid x \in Rn\}$ (in the sense of the given inequality relation). They showed that their solution process for a classical (crisp) LP problem results in a solution in the classical sense. Furthermore, they showed how to extend the proposed solution principle to non-linear programming problems with fuzzy coefficients.

(c) Wu and Guu (2001) proposed Two-phase approach to generate an efficient solution for the multiple objective linear programming problems [MOLP]. They discussed a revised two-phase approach to the case of the fuzzy multiple objectives linear programming problems [FMOLP]. This revised model improves the optimal decision obtained from min operator. Moreover, a compromise model embedded two-phase approach and average operator yield a fuzzy-efficient solution between non compensatory and fully compensatory. More precisely, one compromise index to the membership function can be adjusted by decision-maker to

reveal the way of change on degree of satisfaction for each objective and fuzzy constraint.

(d) Suryanarayana and Shete (2004) carried out the study for conjunctive use planning of surface water and ground water for four minors of Navsari Branch of Kakrapar L.B.M.C. command area, Gujarat, India. The study was aimed at evaluation of ground water conditions demand and availability of surface water, economic analysis and strategic development of conjunctive utilization. The objective functions and constraints were formulated and the tolerance limits for the constraints developed are taken into consideration to solve the fuzzy linear programming. The optimal cropping pattern is worked out for optimum irrigation intensity by fuzzy linear programming.

(e) Shete and Suryanarayana (2004) carried out the study for conjunctive use planning of surface water and ground water for four minors of Navsari Branch of Kakrapar L.B.M.C. command area, Gujarat, India. The maximum net benefit for optimal cropping pattern and optimal irrigation intensity is obtained by fuzzy linear programming. The optimum designed irrigation intensity of 220%, 120%, 90% and 300% can be achieved in C.C.A. of these minors respectively.

(f) Energy consumption in agriculture depends on different types of crop cultivation in different seasons. Cultivation of crops is done mainly on the basis of agro-climatic conditions, potentials of resources of the region and different types of commercial and non-commercial energy application at the farm level. Jana and Chattopadhyay (2005), offered a model which attempts to optimize the direct energy use for different operations in the agricultural sector, taking into consideration certain objective functions against a set of constraints. The exercise is essentially the application of multi-objective fuzzy linear programming techniques in which efforts are made to arrive at a compromise solution among the objectives in a fuzzy

environment. This model is capable of accommodating the needs at local level to provide solutions which are sectorally, spatially and sectionally realistic. The dominance of agriculture in the economy has prompted testing its applicability in the situation of a backward community development block, Narayangarh, which is situated in the state of West Bengal in India and hence finding out the capability of the model to provide validation-based recommendation for the purpose of direct energy use for agricultural operations.

3.2.2 Linear Programming Technique

(a) There is a class of water-supply headworks models that uses network linear programming to assign water within the network. The choice of algorithm and computer code to solve the network linear programs formulated by such models becomes important when doing planning studies that may involve thousands of replicates of future stream-flow and demand conditions. The computational performance of two public-domain FORTRAN codes, NETFLO and RELAX, representing efficient implementations of the primal-simplex and primal-dual algorithms, were compared for two headworks systems. Kuczera (1993) showed the results that for the two small network linear programs typical of headworks modeling, the RELAX code used without prior flow information was about 100% faster than the NETFLO code. When prior flow information was employed, further substantial gains in speed were realized. The second and subsequent iterations within a time step were solved in about one-third of the time for the first iteration. The actual overall speed gain depends on whether the prior information is used across time steps or just between the iterations in a time step.

(b) Linear programming (LP) irrigation planning model is developed for the evolution of irrigation development strategy and applied to a case study of Sri Ram Sagar Project, Andhra Pradesh, India with the objective of maximization of net benefits. Uncertainty in the flows arising out of the

uncertainty in the rainfall is tackled through chance constrained (Stochastic) programming. Raju (1999) considered the inflows at 4 levels of dependability viz., 75%, 80%, 85% and 90% to obtain various possible optimal cropping patterns and optimal operating policies. It is observed that net benefits at 75% dependability level are 68.8% more than those at 90% dependability level. Comparison of the results indicated that the methodology is quite versatile and can be used in other similar situations, as well, with suitable modifications.

(c) Wardlaw and Bhaktikul (2004) discussed about a genetic algorithm (GA) developed for solution of two lateral canal scheduling problems. The GA formulations use very similar objective functions for both problems. Results obtained with the GA approach are compared with previously published results obtained through linear and integer programming. The GA approach has been demonstrated to be robust and very efficient in application to lateral canal scheduling problems. It is also easily set up and would be easily applied by practitioners.

(d) Samani and Mottaghi (2006) determined optimum design of municipal water distribution networks for a single loading condition, by the branch and bound integer linear programming technique. The hydraulic and optimization analyses are linked through an iterative procedure. This procedure enables us to design a water distribution system that satisfies all required constraints with a minimum total cost. The constraints include pipe sizes, which are limited to the commercially available sizes, reservoir levels, pipe flow velocities, and nodal pressures. Accuracy of the developed model has been assessed using a network with limited solution alternatives, the optimal solution of which can be determined without employing optimization techniques. The proposed model has also been applied to a network solved by others. Comparison of the results indicates that the accuracy and convergence of the proposed method is quite satisfactory.

3.2.3 Cropping Pattern

(a) In water resources development the decision of cropping pattern plays a vital role during the pre project period and post project period. The optimal cropping pattern fixation is generally being done manually with a trial and error method which takes a considerable time. Due to advent of computerization this can be avoided and operation research techniques can be utilized. Linear programme is one of such techniques. Gurumurthy and Shankar (1992) made a study of LP for fixing cropping pattern for preliminary study of the project. The user has to formulate the LP model with a considerable skill to arrive a feasible solution. This not only reduces considerable time but also gives a clear idea about the adopted while preparing the demands.

(b) Suryanarayana et al. (2003) have undertaken conjunctive use planning of surface water and ground water for minors 1 to 4 of Waghodia Branch of Deo Irrigation Project, Gujarat, India. They calculated the unit cost of Surface water as Rs.10,041.10/ha.m and that of ground water as Rs.10,689.48/ha.m for kharif, Rs.11,073.69/ha.m for rabi and Rs.11,540.25/ha.m for hot weather seasons. They also calculated the total annual recharge for all the four minors as 80.364 ha.m, 100.696 ha.m, 53.113 ha.m and 92.230 ha.m respectively.

(c) Coordinated use of surface water and ground water ensures optimal utilization of water resources. Conjunctive use model consists of ground water model and optimization model with the main objective of maximization of net benefits and subjected to following constraints: Water requirement of crops, surface water and ground water availability and area availability. Rao and Patel (2004) applied it to SATAK command area (a tributary to Narmada river, Kasrawad block of Khargone district of Madhya pradesh) to obtain optimal cropping patterns and their impact on ground water table behavior. Optimal cropping pattern New1 was studied by selecting five major crops (sugarcane, wheat, cotton, groundnut and

moong) from existing cropping pattern by introducing area constraint (5-10%). Optimal cropping pattern New2 was studied, by considering the area constraints on three crops of New1 cropping pattern (sugarcane, wheat and cotton 10-20 %). It is concluded that New1 and New2 cropping patterns are increasing the net cumulative benefits in the range of 20% and 25% respectively. The ground water table is stabilizing around 10m for New1 and 10.2m for New2 cropping patterns and for existing cropping pattern it is dropping in the range of 9.5 – 8.5m. The coordinated approach of Government and individual enterprise will be effective in the efficient implementation of optimal cropping patterns.

3.2.4 Management Problems of Conjunctive Use

(a) In river basins where aquifers are intimately associated with streams, the unrestricted development of ground water can reduce stream flows and hence jeopardize the rights to the flow of surface water. A simulation model to aid in the solution of such problems was developed. The model is composed of (1) a hydrologic model that represents the physical response of the stream-aquifer system to changes in river flows, diversions and pumping and treats stream flow as a stochastic input and (2) an economic model that represents that response of irrigation water users to variations in water supply and cost. These elements were incorporated into a decision framework so that the net income to the water resource system associated with alternative management schemes could be measured. Bredehoeft and Young (1972) reported the results of operating the model with parameters representing conditions in the south Platte valley of eastern Colorado under alternative institutional and hydrologic conditions.

(b) The intense irrigation in arid and semiarid regions conduces in the long-term to variations in the soil and ground water qualities. Besides of salinization the origin of this development focuses in the use of contaminating substances like fertilizers and pesticides. Correa and Billib

(1990) presented a general concept that considers the quality aspects in the ground water management of the irrigation project Sanjuan/Argentinien. Besides other elements the analyzed system includes: surface and groundwater reservoirs, installations for artificial groundwater recharge and pumping fields connected with the channel distribution system. Management procedures for the groundwater recharges and extractions are developed from given and/or simulated concentrations of contaminants in surface and groundwater.

(c) For developing hypersensitive conjunctive use model for a small command, Shete and Trivedi (1999) selected minor-5 of Waghodia branch canal of Deo Irrigation Project in Gujarat, India. They concluded that the optimum release policy is obtained when space and time integration strategy is adopted.

(d) Khatri et al. (2003) have studied the conjunctive use planning of surface water and ground water for minors 1 to 4 of Waghodia branch canal of Deo irrigation project during 1997-98. The study is carried out for strategy I: considering unit costs of surface water and ground water. The sensitivity analysis is also carried out by 6 different ways for the same strategy and the changes in the optimum are observed. Maximum possible designed irrigation intensity of 100 % for minor-2, 160 % in minor-4 and 170 % for minors-1 and 3 can be achieved in the command. The intensities for minors-1 and 3 are the highest. But, the highest optimal area is 203.78 ha and the maximum ground water lifted is 16.23 ha.m for minor-4. The benefits in Rs.17,85,700/ha.m are also highest for minor-4.

(e) Fayad and Peralta (2004) in their paper presented a simulation/optimization model based on artificial neural networks and genetic algorithms for solving multi-objective conjunctive water use problems. The model simulates and optimizes water flows in a hydraulically connected reservoir-stream-aquifer system. It is a powerful

tool to help water managers and authorities in developing conjunctive water management strategies and evaluating tradeoffs between conflicting goals.

(f) To better understand agricultural demands for water in uncertain conditions and evaluate potential benefits of conjunctive use operations, a two-stage quadratic programming model is proposed. The model simulates decisions in the agricultural sector for allocation of water and land among permanent crops and annual crops. Decisions regarding permanent crops are made in the first stage while annual crop decision occurs in the second stage, based on the probability of water available in a given year. The objective function maximizes the net expected value of agricultural production and uses a non-linear production function that reflects competitive market marginal conditions calibrated with supply elasticity data. Stress irrigation is included to represent possible curtailing supplies to permanent crops in the second stage. Land can also be allocated to artificial recharge facilities (infiltration ponds) to allow groundwater storage of surplus water and pumping in dry years. Results show significant benefits by reducing uncertainty in water supply and increasing production when conjunctive use operations are applied. Marques et al.(2004) used Lagrange multipliers of groundwater pumping and land constraints, to estimate the agricultural sector willingness to pay to engage in conjunctive management operations. The model is developed using the general algebraic modeling system (GAMS) package.

(g) Groundwater use in irrigated agriculture has been exponentially growing for about 40 years, thanks to the generalisation of mechanised techniques for drilling and pumping. This evolution is noticed in many regions where irrigation was traditionally practised with surface water and is now engaged in "conjunctive use". As a consequence of extensive groundwater exploitation, cropping intensities have increased and have

contributed to the objectives of increasing food production. However, this exploitation has also lead to severe overdrafts of groundwater resources, falling water tables, what seriously threatens their sustainability as well as the agricultural production in a close future. In conjunctive use systems, resources management policies were originally designed to optimize agricultural production in a simple set: in irrigated schemes where large hydraulic works are used, surface water is centrally managed, and the control over the resource is quite easily achievable. In opposition to this, groundwater access is individual in most cases: this may be a clear advantage in terms of public cost, but also results in practical difficulties to regulate the access to groundwater and drives to the classical tragedy of the commons. As a result, very few is practically implemented by resource managers. Groundwater resources remain unmanaged, and go on decreasing. Far from "integrated resources management", allocation and distribution of surface water is still governed by obsolete rules, ignoring complementary resources that sometimes account for the major part of the supply. However this inability to interfere in groundwater management should be tempered, when considering the tight links between resources in conjunctive use systems. In such systems, groundwater is generally used as a complement to surface water, and water demand for both resources are mutually dependent. Moreover, in case study in Tadla (Morocco) illustrated by Petitguyot and Rieu (2004), infiltration of surface water in irrigated schemes is responsible for a major part of aquifer replenishing. They proposed to reconsider the design of surface management as an indirect tool to improve conjunctive use of water resources. A different management of the surface water resources can improve the comprehensive water management. Design of different release rules from the dam, at an annual space time, taking into account some information related to the level of the aquifer as an indicator of the tapping intensity is studied. Results enlighten that, when the manager considers the global use of water from different origins, he may allow a

more variable release from the dam, as this variability is mostly softened by groundwater's use, that acts as a "second buffer" in the system. An important percentage of farms doesn't have access to groundwater and that can raise some equity concerns for those who don't get a reliable access to water.

(h) Shete and Suryanarayana (2004) developed a conjunctive use model using linear programming technique for space – time integration strategy in which model decides allocation of water resources with respect to space and time for minors 1 to 4 of Waghodia branch of Deo Irrigation Project. Maximum possible designed irrigation intensity of 160 % for minor 1, 120 % for minor 2, 170 % for minors 3 and 4; can be achieved in the command. The intensities for minors 3 and 4 are the highest. But the highest optimal area and the maximum ground water lifted for minor 4 are 217.00 ha and 34.00 ha.m respectively. The benefits in Rs.15,17,500/ ha.m are the highest for minor 4

(i) Kirsch (2005) created a model that combines both the hydrologic and economic forces at work within the system into a single, integrated program. A stochastic reservoir simulation comprises the hydrologic portion of the model, while the economic portion makes decisions in response to the hydrologic conditions. Given the number of permanent rights and options the city owns at the beginning of the year, the initial condition of the reservoir, and the lease/exercise threshold values (α and β), the model determines the expected values of the portfolio cost and reliability. The model also determines the expected number of exercised options and the profile of lease purchases throughout the year. The stochastic nature of the model provides not just the expected values of the results mentioned above, but the ranges and extreme values of those results. Such data allow the variability and risk of the portfolio to be characterized to an extent that could not be matched by linear programming techniques.

3.2.5 Conjunctive Utilization

(a) Bredehoeft and Young (1983) examined the south Platte system in Colorado where surface water and ground water are used conjunctively for irrigation. Actual installed well capacity is approximately sufficient to irrigate the entire area. This would appear to be an over investment in well capacity. To what extent ground water is being developed as insurance against periods of low stream flow is examined. Using a simulation model which couples the hydrology of a conjunctive stream aquifer system to a behavioral-economic model which incorporates farmer behavior in such a system, we have investigated the economics of an area patterned after a reach of the south Platte valley in Colorado is investigated. The results suggest that under current economic conditions the most reasonable ground water pumping capacity is a total capacity capable of irrigating the available acreage with ground water. Installing sufficient well capacity to irrigate all available acreage has two benefits: (1) this capacity maximizes the expected net benefits and (2) this capacity also minimizes the variation in annual income; it reduces the variance to essentially zero. As pumping capacity is installed in a conjunctive use system, the value of flow forecasts is diminished. Poor forecasts are compensated for by pumping ground water.

(b) Maheswari and Maheswari (1984) explained that throughout the history of mankind water has been main sources of civilization. Per capita use of water is the index of development of country. The irrigation is the biggest user of water, may it be surface or ground. Keeping in view the ecological balances, the food and fiber needs of growing population can only be met by conjunctive use of surface and ground water. Neither alone can meet the total water requirement of irrigation industry and domestic supply apart from other minor uses. There are definite advantages and disadvantages of using either surface or ground water alone and only answer is conjunctive use of both. It will also give maximum production per unit use of water. Joint operation of the surface water and ground water system

would require systematic management on basinwide scale. This in turn requires an understanding of the ground water system, its responses to the stresses imposed upon it and an understanding of the economics of water resources allocation.

(c) Gupta and Asthana (1985) described that the recently constructed canal projects for intensive irrigation have been shown the tendency of rapid rise in water table in their commands even at partial utilization in a short period. At the planning stage of these projects, little consideration was given to the effects which the canal irrigation would cause on ground water behavior in the command area. Vertical drainage is now being considered as a curative measure in these project areas. The success of this measure depends on the possible use of the pumped water conjunctively with canal water for irrigation purposes. A lumped linear programming model has been discussed for the study of conjunctive use and its availability has been illustrated in case of Sarda Shayak project. It is suggested that while planning future canal irrigation projects, the possible change in ground water status as a result of surface irrigation should be studied along with the feasibility of conjunctive use.

(d) As per the guidelines given by Central Water Commission (1995) for planning conjunctive use of surface water and ground water in irrigation projects, the sensitivity of the model for linear programming is studied by Trivedi, et al. (1996) for different groundwater potentials between minimum necessary and maximum permissible groundwater drawals.

(e) Director of Water Management Research (1998 – 1999) have reported with these strategies for utilizing the saline ground water in conjunction with canal water without any adverse effect on crop yield and soil health. They presented the results of the study conducted at Bathinda.

(f) Jehangir et al. (2003), described a study of canal and supplemental ground water used by 544 farmers for wheat growing in the Rechna Doab

catchment in Pakistan. The main objective was to assess the on-farm financial gains through alternate modes of irrigation and comparing them with conjunctive water use. For econometric analysis, a linear relationship between the wheat production and different determinant variables was assumed.The results highlighted the problem of increased use of tubewell water in the saline groundwater zones that had resulted in the deterioration of the groundwater quality and led to the problem of permanent upconing of saline groundwater. Conjunctive water management increased the farm income by about Rs.1,000 and 5,000 per hectare compared to only using the canal and tubewell water respectively. The results of financial analysis show that the net gains were 30 percent higher on the farms using conjunctive water management as compared to the farms using only tubewell irrigation.

(g) Syaukat et al. (2004) studied and investigated the degree of economic inefficiency of the current institutional arrangements for surface and ground water management in meeting urban water demand in the Jakarta region. A numerical model of integrated surface and ground water management is developed using general algebraic modelling system (GAMS) software. The model maximizes the net present value of social benefits from piped water and ground water consumption across all users over time from 1999 to 2025. Four policy scenarios are examined: the status quo, the social planner's solution, and two ground water pumping quota scenarios: an aggregate ground water pumping quota and a partial quota applied to commercial and industrial users. Three variations in each policy scenario are considered: investment in water infrastructure of the Jakarta water enterprise, water demand growth, and discount rates. The status quo, depending on the investment option, the growth of water demand, and the discount rate, results in a 7.4 to 47.8 percent loss in economic efficiency relative to the social planner's solution. The partial quota is the most feasible, applicable, and manageable scenario. The optimal investment option could increase the volume of piped water supply

and reduce the cost of water production. The volume of water delivery could increase by up to 156 percent, but it implies only a 35 percent increase in the surface raw water demands above the current level. However, it does not significantly reduce cumulative ground water extraction over the time period considered.

(h) Khatri and Shete (2004) developed a hypersensitive conjunctive use model by linear programming technique using time integration strategy, in which surface water is utilized in kharif and rabi seasons & ground water is used in hot weather season only for minors 1 to 4 of Whagodia Branch of Deo Irrigation Project. Maximum possible designed irrigation intensity of 170% for minors 1 and 3; 160% for minor 4 and 140% for minor 2 can be achieved in the command. The intensities for minors 1 and 3 are the highest. But the highest optimal area is 203.78 ha. for minor 4 and the maximum ground water lifted is 44.75 ha.m for minor 2. The benefits in Rs. 7,60,080 /ha.m are also the highest for minor 4.

(i) Rao et al. (2004) developed a regional conjunctive use model for a near-real deltaic aquifer system, irrigated from a diversion system, with some reference to hydrogeoclimatic conditions prevalent in the east coastal deltas of India. Water resources are sufficiently available in these regions under average monsoon rainfall conditions, but their distribution in space and time has been ever challenging to water managers. Surface-water availability shows temporal fluctuations in terms of floods and droughts, and groundwater availability shows mainly spatial variability in terms of quality and quantity due to the hydrogeologic setting, boundary conditions, and aquifer properties. The combined simulation-optimization model proposed in this study is solved as a nonlinear, nonconvex combinatorial problem using a simulated annealing algorithm and an existing sharp interface model. The computational burden is managed within practical time frames by replacing the flow simulator with artificial neural networks and using efficient algorithmic guidance.

(j) Karamouz et al. (2005) developed, a methodology for conjunctive use of surface and groundwater resources with emphasis on water quality, using genetic algorithms (GAs) and the artificial neural networks (ANNs). Water supply with acceptable quality, reduction of pumping costs, and controlling the groundwater table fluctuations are considered in the objective function of the model. In the proposed methodology, the results of a groundwater simulation model are used to train the ANNs based simulation model. This model is then linked to the GA based optimization model to develop the monthly conjunctive use operating policies. The proposed model is applied to the surface and groundwater allocation in the irrigation networks in the southern part of Tehran, of Iran. Tehran metropolitan area has annual domestic water consumption close to one billion cubic meters. The sewer system is mainly consisted of the traditional absorption wells. Some part of this sewage is drained into local rivers and drainage channels and partially contaminates the surface runoff and local flows. These polluted surface waters are used in conjunction with groundwater for irrigation purposes in the Southern part of the Tehran. The results of the proposed model show the significance of an integrated systems approach to surface and groundwater resources allocation in the study area. For example, the cumulative groundwater table variations in each zone, which has experienced a total fluctuation of more than ± 20 meters in the last 20 years, is limited to ± 5 meters over the planning horizon.

3.2.6 Case Studies

(a) Ground water can be used in conjunction to modify temporal imbalance in supply and demand. But such conjunctive use may have regional implications and these need to be evaluated in comprehensive study of any administrative or planning region.

Chaube (1984) used the deterministic linear programming models to evaluate impact of conjunctive use of surface and ground water on

irrigation policy in the commands of major surface water supply project in Gandak, Kosi and Son sub basins. The study relates to a future stage when the major projects under construction and some prospective major projects in India and Nepal are likely to come under operation. The models were used to analyze irrigation development in each of the three major tributary subsystems under three conditions namely a) when only surface water is used for irrigation, b) when surface and ground water are conjunctively used, and c) when kharif channels are used to artificially recharge the aquifers and ground water use is confined for irrigation during rabi and summer seasons. Operating constraints relating to availability of water, land and structural capacities under each of the three conditions have been brought out in the study. The irrigation command areas and canal diversion capacities are defined on the basis of administrative jurisdiction of Nepal, Bihar and Madhya Pradesh, thus enabling to find irrigated areas in each of these regions from the concerned projects.

The study indicates that ground water development and its conjunctive use may become an important policy issue in view of its regional implications as providing irrigation to larger areas, control of floods and augmentation of lean season flows. kharif channel recharge is possible only after mining ground water in rabi and in summer seasons so as to provide space for additional storage under the ground. Such large scale depletion of ground water table will have ecological and environmental implications also. These issues, though not considered in the model studies have been highlighted.

(b) RadheyShyam (1985) presented a linear programming model with an objective function to maximize the aggregated annual return from an area. An optimal cropping pattern, matching the available land and water supplies, against the existing socio – economic constraints has been recommended. Three tubewell water supply levels with two canal water

levels have been considered. Increase in irrigation water supply levels in general and during peak demand periods in particular results in increase in total return of the area selected for study.

(c) Paul et al. (1988) recognized the significance and importance of concentrations of various monomineralic ions like $(Na)^+$, $(HCO_3)^-$ and $(CL)^-$, the ground waters of the Punjab state have been surveyed, tested and evaluated. Introducing a new concept of monomineralic classification of irrigation waters, the carbonic classification, sodic classification and chloridic classification, of the ground waters of the state have been attempted on a regional basis identifying various sub groups within each classification, the availability and the areal distribution of different monomineralic ground waters have been illustrated by means of separate regional carbonic, sodic and chloridic classification maps of the Punjab and there from the occurrence of highly mineralized ground water in the south western parts of Punjab has been established. Highlighting the importance of such maps as handy tools for devising optimum regional crop pattern, various irrigation practices, including conjunctive use and rotational irrigation, have been recommended in aid of strategic planning and management of saline ground water for irrigation in the problematic south – western zone of the Punjab.

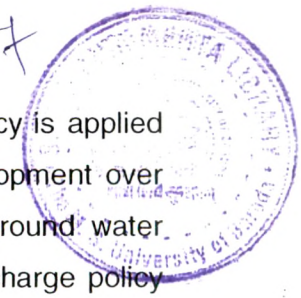
(d) In the Mahanadi delta command of Orissa the yield has remained low and stagnant due to prevalent ill drainage condition. The depth to ground water table is 0.9, 1.8 and 3.3 m during rainy, winter and summer seasons. Proper utilization of this high quality shallow ground water by indigenous means or through low head pumps will augment the available water resources and remove drainage congestion. Ray and Rath (1990) studied for such utilization in a doab with a culturable command area of 47,000 ha showing the benefit cost ratio 2.1.

(e) Chiew et al. (1995) described a technical and feasibility study of increasing ground water usage to supplement surface water use in the Campaspe Valley in south – eastern Australia. An integrated model which simulates the surface and ground water processes, as well as the interactions between the processes, is used to determine the sustainable long term ground water pumping yields. The model also provides estimates of ground water fluxes for various management options of increasing ground water usage. These estimates are used to assist an economic analysis to determine the relative merits of various options for the conjunctive use of surface and ground water resources. The pumping costs, value of water and tangible salinity benefits from lowering high water tables and reducing salt load are considered in the economic analysis. The methodology is also relevant for other studies looking into conjunctive use of surface and ground water resources throughout the Murry Basin and elsewhere.

(f) The ground water assessment carried out for the state of Andhra Pradesh has revealed that about 90% of ground water resources available in the state is from command areas of surface water projects. To meet the growing demand for assured irrigation and to reclaim waterlogged and other affected areas it has become imperative to take up conjunctive use more seriously. Extensive studies have been carried out in the four selected command areas of major projects in the state in order to identify waterlogged and prone to waterlogging, and to suggest remedial measures. Rao (1997) discussed the behavior of water levels in a command area. The ground water levels were observed to be rising in the early stages of canal releases leading to waterlogging conditions particularly in head and middle reaches of main canal resulting in reduced crop yields. Hence, the reclamation measures such as conjunctive utilization is recommended as a remedy.

(g) 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 conjunctive use of surface and ground water resources and takes account of social, economic and environmental factors. Moreover, it recognizes the importance of water quality issues. In this context, Wrachein and Fasso (2002) examined in this paper the main aspects and problems concerned with the planning, design, construction and management of conjunctive use of surface and subsurface water resources, along with its environmental impacts and constraints to sustainable development. The importance and role of research thrust, technology transfer, institutional strengthening, effective partnerships between governments and stakeholders, and sound financial frameworks are also examined. Finally, the challenges and benchmarks for future actions that the scientific community and planners have to face and deal with, are briefly outlined.

(h) One of the key economic issues faced by the managers of the two water boards in the Burdekin River Delta in north eastern Australia is the allocation of surface water between immediate use on farm for irrigation and storage in the aquifer for future use. Because of the significance of the interaction between surface water and groundwater and the return flow externalities within the delta, policies on surface water and groundwater need to be determined simultaneously. A model is formulated of the dynamic system of surface water and ground water in the delta with water demand, ground water extraction cost and stochastic recharge and surface water availability. Hafi (2003) derived the optimal pumping/artificial recharge policies for each state of the joint surface water and ground



water system for the southern part of the delta and this policy is applied over a large number of years to derive the expected development over time of extraction/artificial recharge and the state of the ground water system. The implications of the optimal pumping/artificial recharge policy for any review of existing allocations of surface water and ground water are discussed.

(i) The Tehran metropolitan area is one of the mega cities of the world and has an annual domestic water consumption close to one billion cubic meters. The sewer system mainly consists of traditional absorption wells. Therefore, the return flow from the domestic consumption has been one of the main sources of groundwater recharge. Some part of this sewage is drained into local rivers and drainage channels and partially contaminates the surface runoff and local flows. These polluted surface waters are used in conjunction with groundwater for irrigation purposes in the southern part of the Tehran. A systematic approach to surface and groundwater resources modeling in the study area is with its complex system of water supply, groundwater recharge, and discharge, is discussed by Karamouz et al. (2003) who developed a dynamic programming optimization model for conjunctive use planning. The objective function of this model is to meet the agricultural water demands, to reduce pumping costs, and to control groundwater table fluctuations. To develop the response function of the aquifers located in the study area, a mathematical model for simulation of the Tehran aquifer water table fluctuations has been developed and calibrated with the available data. Different scenarios are defined to study the long-term impacts of the development projects on conjunctive use policies and water table fluctuations. Comparison of the results showed how significant is the effects of an integrated approach to the surface and groundwater resources allocation in Tehran metropolitan area.

(j) Shete and Khatri (2004) developed a hypersensitive conjunctive use model by linear programming technique by time integration strategy, in

which surface water is utilized in kharif and hot weather seasons & ground water is used in rabi season only for minors 1 to 4 of Wahgodia Branch of Deo Irrigation project. Maximum possible designed irrigation intensity of 170% for minors 1 and 3, 160% for minor 4 and 130% for minor 2 can be achieved in the command. The intensities for minors 1 and 3 are the highest. But the highest optimal area and the maximum ground water lifted for minor 4 are 203.78 ha and 61.25 ha.m respectively. The benefits in Rs. 8,73,950 /ha.m are highest for minor 1.

(k) Suryanarayana and Shete (2004) developed a conjunctive use linear programming model using space integration strategy, by allocating only ground water to particular crops and only surface water to rest of the crops for minors 1 to 4 of Waghodia Branch of Deo Irrigation Project. Maximum possible designed irrigation intensity of 150 % for minor 1, 110 % for minor 2, 170 % for minors 3 and 4 can be achieved in the command. The intensities for minors 3 and 4 are the highest. But the highest optimal area is 216.52 ha for minor 4 and ground water lifted is 17.94 ha.m for minor 4. The benefits in Rs.16,88,100 /ha.m are also the highest for minor 4.