2.2 SIMULATION APPROACH

The stream-aquifer systems are described by one, two or three dimensional groundwater flow equations. Analytical solutions are available for situations when many simplifications can be made. Various numerical models using finite difference or finite element methods to solve the equations have been used where the equations cannot be solved by analytical solutions. (Vander Heijde et al., 1985).

Chun et al. (1964) were among the first researchers to propose and use distributed parameter simulation models for examining alternative plans for conjunctive groundwater and surfacewater management problems. Young and Bredehoeft (1972) tried to integrate time and space relationships of a stream-aquifer system and the response of water users to hydrologic, economic and institutional conditions in a basin simulation model.

Linear Systems Theory was used in groundwater simulation (Maddock, 1972, Morel-Seytoux and Daly, 1975; Illangasekare and Morel Seytoux, 1986). The modelling approach is to generate unit system response functions and obtain the overall response by superimposition. El-Kadi (1989), while reviewing available watershed models for simulating infiltration and groundwater flow, noted that although such models have been successfully used for managing surface water
resources, their extension to the conjunctive water use is not yet well developed.

2.3 OPTIMIZATION APPROACH

Using simulation models alone to explore different management alternatives is unlikely to yield optimal decisions.

Linear Programming (LP) is the most widely used optimization technique due to reasons such as readily available standard computer packages for application, universality of optimal solutions, ability to accommodate relatively high dimensionality and easy post-optimality and sensitivity analysis. Dracup (1966) while applying Parametric Linear Programming to determine the long term optimal operation of an integrated system found it to be quite flexible in considering alternative decisions. Rogers and Smith (1970) emphasized the physical interactions of a surface water-ground water system within the economic context of irrigation planning and management. Morel-Seytoux (1975) applied the discrete kernel approach and the linear programming technique to a simple stream-aquifer system to illustrate how an optimal legal conjunctive operation of surface and ground water systems can be achieved.

Dynamic programming (DP) with three state variables was used by Buras (1963) while considering a stream-aquifer system in a lumped form thus ignoring physical interactions. Other users of DP for conjunctive use studies include Cochran and Butcher (1970) and Coskunoglu and
Shetty (1981). The above studies considered the physical system as a lumped system. Among the methods advanced in the optimal control literature to lessen the computational burden of conventional DP, differential dynamic programming (DDP) is considered to be significantly superior. Based on the constrained DDP procedure, Jones et al. (1987) illustrated its usefulness in reducing dimensionality due to non-linear (unconfined) unsteady distributed parameter ground water system.

Matsukawa et al (1992) presented a conjunctive use planning and management model for the Mad river basin in California that explicitly incorporated the hydraulics, multiple objectives and operational constraints and solved the model using MINOS, a large scale non-linear programming algorithm.

2.4 COMBINED SIMULATION AND OPTIMIZATION APPROACH

According to Gorelick (1983), ground water management models, which combine simulation with optimization techniques, fall into two general categories: (i) hydraulic management models, and (ii) policy evaluation and allocation models. The former category is primarily aimed at managing system stresses such as pumping and recharge while the latter category includes models that can be used to inspect economic efficiency, institutional issues and complex ground water - surface water interactions. Two approaches viz. the embedding approach and the response matrix approach are available for ground water hydraulic
management. Policy evaluation and allocation models are again of three types: (1) hydraulic - economic response models, (2) linked simulation optimization models, and (3) hierarchal or multilevel models.

2.5 DECOMPOSITION / HIERARCHIAL / MULTILEVEL APPROACH

The problems related to the integrated water use have also been approached based on the concept of the hierarchal - multilevel approach, which is essentially based on the decomposition of complex systems and subsequent modeling of the multi-level subsystems. Normally, each of the smaller local level systems are optimized first before optimizing the regional problem at the higher level via common variables among the sub-regions. Feedback is provided to the lower levels in the iterative optimization process. Applications of the approach to conjunctive use management of surface water and ground water have been presented by many researchers, notably, Yu and Haimes (1974), Haimes and Dreizen (1977). In order to circumvent the dimensionality problem in distributed parameter systems, the concept of response or technological function is commonly used as introduced by Haimes and Dreizen (1977).

2.6 MULTIOBJECTIVE / MULTICRITERIA APPROACH

Bogardi et al (1983) developed a multi-objective dynamic planning model for managing jointly a regional aquifer and a mineral extraction scheme under water hazard. Dynamic compromise programming was used to provide explicit trade-off between the economic objective,
represented by total discounted costs, and the environmental objectives, represented by the fuzzy membership function. Louie et al (1984) developed a multiobjective optimization procedure to be applied in conjunction with simulation models using the influence coefficient method to assist water resources planners to establish a more unified basin-wide management plan which simultaneously considers three major objectives: (i) optimal conjunctive use to satisfy agricultural, municipal and industrial water demands, (ii) water quality control, and, (iii) prevention of undesirable overdraft of the ground water basin.

Datta and Peralta (1986) presented a set of procedures in developing a conjunctive water use/sustained ground water management strategy for an agricultural area in United States of America. Two different objectives, viz. minimization of total cost of water use and maximization of total withdrawal from aquifer, subject to steady state hydraulic constraints were considered.

Randall et al (1990) developed a multiobjective linear Program to study the drought operation of a major metropolitan water supply system comprising of multiple surface and ground water sources and a complex distribution system. Four objectives to maximize net revenue, maximize reliability, maximize streamflow and maximize reservoir storage at the end of the time horizon were considered. The model was used to analyze both long term and short term (real-time) operations.
Raju and Pillai (1998) applied linear compromise programming (LCP) technique for the evaluation of compromise irrigation development strategy in the multi objective context taking Sriramsagar Project as a case study. Three conflicting objectives, namely, net benefits, agricultural production and labour employment were considered. Uncertainty in the inflows arising out of the uncertainty in the rainfall was tackled through chance constrained programming.

Hallaji and Yazicigil (1996) developed seven ground water management models to determine optimal planning and operating policies of a coastal aquifer in Southern Turkey threatened by saltwater intrusion. Steady state and transient finite element simulation models, representing the response of the system, were linked to linear and quadratic optimization models using response functions. Optimal pumpage policies were determined for 93 wells under three management objectives that maximized agricultural water withdrawal and minimized drawdowns and pumping costs subject to constraints related to the systems response equations.

Lohani and Thanh (1978) presented a chance constrained goal programming model for water resources management, which included a reliability parameter and incorporated the probabilistic water quality goals. Zero order decision rule was used to convert the probabilistic goals into the equivalent deterministic goals making it possible to solve by deterministic goal programming techniques.
Soni et al. (1995) applied linear and goal programming techniques for finding out the optimal allocation of land and water for Kansabahal irrigation project, Orissa.

North and Neely et al. (1982) applied Goal Programming successfully to evaluate alternatives for a proposed public investment when the economic and environmental objectives were perceived to be in conflict, using the triangular distribution to analyze weights. They concluded that the goal levels (or weights) established by using a sensitivity analysis improved the credibility of the goal estimating process in a Goal Programming model.

Alkan and Shamir (1980) used the STEM method of multiobjective analysis to plan the development and seasonal operation of a regional water resources system.

Monarchi et al. (1973) applied a sequential multiobjective problem solving technique, SEMOPS, in a case study of regional water quality management.

Duckstein (1982) presented a discrete state case study of the multiobjective planning and management of water in South Arizona by developing a general discrete-time system model with uncertainties. He evaluated nineteen alternative plans on the basis of thirteen criteria.
Peralta (1985) presented a set of models in developing a conjunctive water use/ sustained groundwater yield design for an area in United States of America. The objectives of the models include minimization of unmet water needs, minimization of the regional cost of attempting to satisfy water needs and biobjective optimization between minimizing cost and minimizing unsatisfied water needs.

2.7 RISK AND UNCERTAINTY APPROACH

Nieswand (1970) applied a chance-constrained linear programming approach for the conjunctive use of surface and ground water in the Mullica River Basin, New Jersey.

Flores et al. (1978) considered uncertainties in water demand, natural inputs and physical properties of the system by the use of chance constraints, spectral analysis and conditional probabilities in applying a lumped stochastic model for optimal management of a stream-aquifer system which was represented by a linear reservoir model. The non-linear optimization problem was solved iteratively by using linear programming.

Pioneer work of Buras (1963) based on dynamic programming incorporated random nature of streamflow in a probabilistic manner. Applications of stochastic dynamic programming for optimal operation of conjunctive use systems have also appeared in the literature. e.g. Schweig and Cole (1968). Onta et al. (1991) applied a multistep modelling approach, based on stochastic dynamic programming, system simulation.
and multi-criteria decision-making method, to determine the optimal capacities and operation policies of a conjunctive use system for irrigation.

2.8 GIS AND EXPERT SYSTEM APPROACH

These are the advanced computer related approaches. The manual drawn maps and contours can be transferred to the computer using GIS. All the information pertaining to land use patterns, water resources distribution etc., can be fed and meaningful information can be acquired using GIS. Expert system approach is an interactive approach that uses the artificial intelligence of the computer.

2.9 COMBINATION OF THE ABOVE APPROACHES

Smith (1970) has studied conjunctive surface and groundwater development from canals and tubewells to determine the optimal capacities for canal and groundwater development, maintaining specified water balance and endogenously determining the optimal cropping pattern. First, a deterministic study was carried out using linear programming and later stochastic analysis was carried out using chance-constrained programming. The model was applied for an area of about 5,50,000 hectares in Bangladesh.

Aron and S: 1971) examined the conjunctive use of surface water and groundwater by using dynamic programming with three state variables and twelve decision variables, the three state variables being the two aquifers
in two different basins and seven surface water reservoirs lumped into one subunit. Maddock (1974) introduced a quadratic programming model for operating a stream–aquifer system under stochastic demand and supply. A linear groundwater model (response matrix) was used. Groundwater pumping costs were modelled as quadratic functions of the total lift (drawdown plus initial lift) and the quantity of water pumped. Chaudhry et al. (1974) used a decomposition and multilevel optimization technique for optimal conjunctive use of water in the Indus Basin in Pakistan. The submodel was designed to minimize the cost of supplying water to meet given irrigation water requirements.

Mulvihill (1974) developed a general mathematical model of the conjunctive urban water supply and waste water system with the help of a multilevel solution technique involving linear programming. The objective was to determine the optimal blending of several water sources and the sizing and timing of water and waste water treatment process expansions such that water user quality and quantity constraints and effluent standards are met at minimum cost. Morel-Seytoux (1975) developed a model that combines the classical finite difference method with the efficient systematic generation of solutions by the Green’s function approach, to describe efficiently and accurately the stream aquifer interactive behaviour. Optimal rules of operation are deduced from a well structured mathematical programming formulation for which efficient solution algorithms exist. Flores et al. (1978) developed a simple lumped
parameter stochastic model for optimal water management in a stream connected aquifer system. They used a simple linear reservoir to represent the stream-connected aquifer and an iterative linear programming scheme to solve the chance-constrained optimization problem.

Jamshidi and Heggen (1980) developed a multilevel stochastic management model for Rio Grande basin in New-Mexico. Mass balance ground and surface water stochastic models were developed for four hydrologically linked subbasins. A multilevel management model was formulated such that the local agencies of the sub-basins operated their allocated water to their own best interest, while the regional authority modified allocations to satisfy physical feasibility and legal constraints and improve upon overall regional benefits. Daubert et al (1980) developed a multidisciplinary simulation model composed of several submodels which reflected hydrologic, economic and legal conditions. The external diseconomies imposed on surface water users due to unrestricted ground water use in an interrelated stream aquifer system were measured. The two particular measurement problems were: first, predicting the extent to which senior surface water rights were reduced by pumping, and second, assigning a monetary value to this reduction.

Kasr and Chandra (1982) applied a distributed conjunctive use model to Krishni-Hindon inter-basin which dealt with optimal conjunctive use policy for predefined pattern of surface water availability incorporating
spatially and temporally distributed ground water withdrawals and spatially distributed cropping pattern. Noel and Howitt (1982) proposed a discrete optimal control model for multi-basin conjunctive management of ground and surface water supplies for irrigation. The linear-quadratic control model was solved by a quadratic programming algorithm for a small sample problem. O’Mara and Duloy (1984) examined alternative policies for achieving more efficient conjunctive use in the Indus Basin of Pakistan, using a simulation model which linked the hydrology of a conjunctive stream aquifer system to an economic model of agricultural production. Seifert and Small (1984) described the impact on water quality by the addition of Colorado river water from the Central Arizona project (CAP) to the Salt River Project (SRP) distribution system.

Illangasekare and Morel seytoux (1986) developed a stream-aquifer simulation model to conduct a conjunctive use management study in the South Platte River in Colorado. This model simulated both the physical and operational behaviour of the system. The physical system modelled was comprised of the river and the saturated and unsaturated zones of the aquifer. To model the saturated zone of the aquifer, a technique known as “discrete kernel approach” based on the classical Green’s function method of solution of partial differential equations, was used. Oliver and Macro (1986) presented an optimal control model for real-time management of a conjunctive use system comprising of a reservoir and an aquifer supplying an irrigation zone. The model was made up of three modules: hydrological
forecasting, estimation and optimization. Morel Seytoux (1987) has proposed conjunctive use solution by way of increasing the "opportunity time" in the irrigated areas to increase the recharge to the aquifers in the upper flood plains of the Wadi Jizan in Saudi Arabia.

Saksena (1987) developed a linear programming model to optimize the conjunctive use of surface and ground waters in the upper Ganga canal command area in Uttar Pradesh. Finally, for the optimal cropping pattern, the schedule of monthly releases from canal storage and groundwater were worked out. The number of new groundwater structures required were also worked out. Prasad (1989) identified the unresolved issues in conjunctive use for irrigation. Willis (1989) presented a planning model incorporating non-linear agricultural production functions, and hydraulic response equations of the distributed parameter ground water - surface water system. Application of the non-linear programming model was illustrated in the North China plain case study. Shoemaker and Logan (1990) described an optimization analysis of conjunctive use of ground and surface water that incorporated stochastic inflows and regional variations in ground water quality and availability. They used stochastic dynamic programming technique.

Latif and James (1991) developed a conjunctive use model to maximize users' return under limited and dynamic water supply for long-term conditions. Salt distribution in the crop root zone was modelled and its effect on crop field was also taken into account in the model.
Onta et al (1991) developed a three step modelling approach (in addition to the details already given elsewhere) for comprehensive analysis of the planning problem involving integrated use of surface and ground water in irrigation. They used a stochastic dynamic programming model in the first step, a lumped simulation model in the second step and a multiple-criteria decision-making method in third step. Applicability of the approach is illustrated by a case study of the Bagmati River basin in Nepal. In a conjunctive use study for the Santa Ana basin in Southern California, the objective function used by Yeh et al (1992) consists of the following three objectives: (1) the minimization of the total costs, expressed as a summation of capital costs, operational costs, and imported water costs on an annualized basis as linear functions of the decision variables. (2) the minimization of the total dissolved solids (TDS) in the basin and (3) the minimization of the total inorganic nitrogen. They also used the constraint method to determine the tradeoffs among the three objectives.

Vives et al (1992) presented an approach for incorporating uncertainty of inflows in the optimal management of conjunctive use water resource systems using Bayesian Decision Theory. The approach consists of minimizing the expected losses over a long-term period with respect to short-term operation. Chiew et al (1992) used an integrated surface and ground water modelling approach to estimate the groundwater recharge rates. The daily version of the Manesh Rainfall-Runoff Model,
HYDROLOG, was adopted to represent the surface hydrological processes and the finite element ground water model, AQUIFEM-N, was used to model the ground water flow. The model was applied to both the irrigated and non-irrigated areas in the northern half of the Campaspe River basin in Australia. Onta et al (1994) developed a systematic analytical approach based on the linear programming optimization technique and multiple objectives to identify and analyze different alternative management plans and policies for the integrated use of surface and ground water; for municipal and industrial water supply in Greater Kathmandu, Nepal. The alternatives and their tradeoffs are evaluated using a multiple-criteria decision-making method. Witter and Bogaradi (1994) presented a methodology for integrated water management taking a case study in Netherlands, using systems analytical methods. They used a multi-criteria modelling technique ELECTRE III.

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 using an integrated model which simulated the surface and groundwater processes, as well as the interactions between the processes. An economic analysis to determine the relative merits of various options for the conjunctive use of surface and ground water resources is done. Kholghi et al (1995) presented a methodology of simulation-optimization model for regional management of conjunctive use of stream-aquifer system in Bistoon plain in Iran using
discrete kernel technique for river-aquifer simulation, and multi-objective linear programming (MOLP) model for finding the best set of development alternatives.

Krishnaveni and Karmegam (1995) presented a procedure for zoning of surface and ground water sources. The hydrologic response units were delineated by overlaying the soil and land use maps. Verdhan and Prasad (1996) discussed the problems and prospects of conjunctive use of surface and ground water taking Gandak project as a case study. Sahuquilla and Andreu (1997) solved the ground water flow-equation explicitly and continuously on time in a very efficient way using EIGEN VALUES approach. The methodology has been integrated in AQUATOOL, a decision support system with several modules. It has been applied in several large and complex systems in SPAIN. Willardson (1989) presented an algorithm, which was useful in the evaluation of the potential for conjunctive re-use of saline groundwater. He considered the "threshold salt tolerance" of the crop to be irrigated as one of the principal controlling parameters.

Quinn (1997) presented an approach for the development of optimal drainage management strategies for control of salt and selenium contamination problems in the San Joaquin Valley of California. He used regression model within a Geographic Information system (ARC-INFO) to estimate the depth distribution of groundwater, high in Total Dissolved Salts and Trace Elements. He used SOLTRAK, a finite element model for
the evaluation of the pumping scenarios and WADE model (Westside Agricultural Drainage Economics) to evaluate economic and policy consideration. Peralta (1985) developed a methodology for the sustainable design of conjunctive use using the finite difference form of the linearized Boussineq equation for steady two-dimensional flow through porous media and the constraint method of multiobjective optimization. Mejia (1987) developed a computer model SAMSON to simulate a stream-aquifer system with management and allocational constraints, which consisted of two major components: the decision (allocation) model and the physical model. The allocation model distributed the surface and groundwater in the river basin for daily operations among the water users according to some specified rules of operation. The physical model consisted of many modules, linked together by a strict logical structure, using the results of the allocation model. An application of the model is made to the South Platte River from Denver to the Nebraska border.


Chandrasekhar (1998) developed a conjunctive use model to identify a stable conjunctive use policy and applied this to a case study of Vanivilasasa Reservoir in Chitradurga district, Karnataka. He used Linear Programming and Finite element techniques, taking the reservoir, canal and aquifer irrigation system into account.
Gupta and Onta (1997) stressed the basic principles for sustainable groundwater resources development and illustrated them in two case studies using systems approach and its computational framework of mathematical models.


2.10 APPLICATIONS IN IRRIGATION MANAGEMENT STUDIES

Many of the above approaches have found their application in irrigation water management. Some of the important applications are described here:

Subbaiah and Rao (1993) advocated two location specific root growth models i.e., (i) Modified exponential model and ii) Sigmoidal model. The errors of prediction were observed to be the least in the case of modified exponential model.

Subbaiah (1995) presented the state-of-the-art of empirical and semiempirical endeavours developed for describing the water uptake by plant roots on micro and macro scale.

indicators, water delivery performance at the hydraulic level of unit command area is analyzed and models for designing improvement interventions are proposed.

Uppal et. al. (1965) have made use of multiple linear regression models for the Bist Doab area in PUNJAB, to predict the groundwater levels, an example of which is: \( h = a_0 + a_1 r + a_2 q + a_3 p \); Where "h" is the annual change in water table, "r" is the annual rainfall, "q" is annual stream and canal flow and "p" is annual pumpage.

Seethapathi and Singh of NIH (1986) have presented a methodology to interpolate water table levels at nodal points using least square technique of polynomial regression to fit a trend surface on surface coordinates approximating the water table levels.

Chachadi. and Asha Sinha of NIH (1988) have evolved a conjunctive use model based on the linear programming for optimum agricultural production in the sub-basin of the Ghataprabha command area in Karnataka state.

Seth and Goel of NIH (1983) have documented a source programme in FORTRAN for multiple linear regression analysis to derive relationships among hydrological variables. Varlev (1995) presented practical rules for optimal irrigation management under limited water supply at farm level.
Verdhen and Prasad (1996) discussed the problems and prospects of conjunctive use of surface and groundwater, taking Gandak project as a case study.

IARI (1983) dealt with the methodology of estimation and planning of resources in Mahi Right Bank canal command area, Gujarat for efficient water management.

CBIP (1991 a) dealt with the criteria for scheduling irrigations, irrigation scheduling of crops based on critical growth stages, modelling the soil water balance, modelling the crop yield responses to water in the form of water production functions, optimization models and expert systems in irrigation scheduling.

CBIP (1991 b) dealt with the development of methodology for planning irrigation system improvement strategies in irrigated areas underlain by saline water aquifers with a rising trend in groundwater table. The methodology involved the simulation of groundwater behaviour using a two dimensional finite difference groundwater model and the development of appropriate irrigation system improvement plans using multiobjective optimization model based on linear programming algorithm.

Hargreaves and Samani (1985) explained the economic considerations of deficit irrigation with respect to crop yield.
Singh (1995) applied a physically based, distributed modelling system, known as "European Hydrologic System or "Systeme Hydrologique Europeana (SHE model) to Barna command area in the Narmada Valley in Madhya Pradesh.

Ray (1995) described the four approaches for finding out the optimum irrigation frequency for different crops using plant, soil, combination of plant and soil indicators and climatological approaches.

Teixeira et al (1995) described the simulation model entitled "ISAREG" which was based on the soil water balance method proposed by Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979). Daily computations were made for a multilayered soil with additional consideration of the potential groundwater contribution. The model was applied for summer irrigation of corn and supplemental irrigation of winter wheat in Mediterranean climates. Several strategies for corn irrigation were compared: maximum yield goal, supply restrictions during the peak month adopting an allowable water deficit, a restricted irrigation volume for the entire season, an imposed rigid delivery schedule and a negotiable delivery schedule.

Hongyuan et al (1994) developed the physical and mathematical three level optimization model based on the principle of regional maximum agriculture net benefit to solve the optimum water allocation problem in the water shortage Heilonggang region in China. The first level dynamic
programming (DP) model was a multi-stage decision process model with two state and decision variables. The second level was a nonlinear programming (NLP) model and the third level was a coordination model.

Lohani et al. (1993) presented application of a comprehensive modeling approach based on the model, System Hydrologique Europeana (SHE), which allowed an integrated modeling of all the relevant processes - overland flow, unsaturated zone flow, interception or evapotranspiration, groundwater flow and river-channel flow to irrigation studies. The SHE simulated the advancing front of soil moisture as surface irrigation originated from the head end of a field. Also, the effect of a shortage of water supply at the tail end of an irrigation canal was simulated.

Steiner and Keller (1992) developed the irrigation land management (ILM) model to simulate the demand and response of a multiple-field multicrop irrigation system in a variety of environments in order to assist managers in exploring strategies that can be used to improve system performance. The model was validated using field data from a large irrigation system in Utah.

Raman and Vasudevan (1991) applied linear programming technique for evolving optimal cropping pattern in irrigation commands.

Kripal et al. (1991) of Central Water and Power Research Station (CWPRS) developed three computer models, namely, PLAN, ACCOUNT and SCHEDUL. The PLAN model was designed to assist in
advance planning of cropped area under different canal command units of irrigation system. ACCOUNT model was developed for determining the water requirement at different locations / stages of the canal network and to determine the number of days the canal distributary should be open. SCHEDUL model provided scheduling of branch canals / distributaries on rotational water supply (RWS) principles.

Gosain et al (1991) developed a water management model (WATMAN) to calculate the reference evapotranspiration (ETo), crop evapotranspiration (ETc), crop water requirements, net irrigation requirements, depth and interval of irrigation, field irrigation schedules under deficit water conditions, project irrigation schedules. The model was applied to the Giri Project in Himachal Pradesh.

Narkhade et al (1990) studied the crop production potential under unlimited and limited supply of irrigation water in Girma command with different cropping sequences in shallow, medium deep and deep soils involving cereals, oilseeds, pulses and cash crops like cotton.

Rajput and Michael (1989) developed an integrated canal scheduling model which computed the soil moisture balance of different subcommand areas on daily basis and prepared the delivery schedules of different components of the canal network.
Gupta and Chauhan (1986) studied the stochastic structure of weekly irrigation requirements of a crop. The paddy crop was taken as an example for the modeling. The developed model superposed a periodic-deterministic process and a stochastic component. The deterministic portion of the irrigation requirement series was analyzed using the correlogram and the Fourier series. The periodic component of the irrigation requirement of a paddy crop was found to be represented by the first harmonic only.

Tyagi (1986) formulated multiobjective linear programming models to evaluate the water management strategies for salinity control. The water management strategies essentially aimed at minimizing irrigation return flow (IRF) through structural rehabilitation of the irrigated system.

Bishop and Long (1983) presented a step by step detailed procedure for setting up a rotation delivery schedule for equity between users.

Heermann (1980) presented United States Department of Agriculture (USDA) irrigation scheduling programme which was based on the computation of daily soil water balance in the field.

Lakshminarayana and Rajagopalan (1977) applied a linear programming model to the Bari Doab tract in Punjab. The model gave water releases from two sources, canals and tubewells, to meet crop water requirements and also gave optimal allocation of irrigated land to different
crops so that returns from irrigation activity are maximized subject to a set of constraints.

Stewart et. al (1974) presented a methodology for prediction of optimal irrigation programs at any given level of irrigation water supply.

Stewart and Hagan (1973) presented the functional relations between crop yield and water available under limited conditions.

Kandil and Willardson (1992) developed a methodology, using multiple linear regression analysis, to relate the water-table depth frequency of occurrence to yield. They used the field data of water-table depth fluctuations under cotton grown in Egypt.

Azhar et. al (1992) presented a procedure to estimate the probabilistic irrigation requirements for low land rice cultivation. The procedure uses water balance equation in which rainfall and evapotranspiration are considered as stochastic variables. The leaky law, Total Probability Theorem, SMEMAX and power transformations are tried to estimate weekly rainfall and normal distribution for estimating weekly evapotranspiration.

Raman et. al (1992) developed a methodology for decision support for crop planning during droughts using expert systems and a linear programming model.
Afzal et al (1992) developed a linear programming model to optimize the use of different quality waters by alternative irrigations rather than by blending. In a situation of poor-quality ground water and limited good-quality canal water, the model decided how much land to put under each crop and how much ground water to abstract and apply to each crop in each time period.

Can and Houck (1984) applied preemptive goal programming model to the Green river basin system comprising four multipurpose reservoirs.

Singh and Kumar (1995) developed an integrated water management model linking the irrigation water management model (SIWARE) and ground water model (SGMP). The model was applied in the Haryana state under Bhakra Main Branch canal irrigation system.

De Bruin (1980) studied the influence of persistence on the length of dry and wet spells. He showed empirically that for the description of this influence, an “effective” number of days could be used.

Mukherjee and Kottegoda (1992) developed a stochastic model for soil moisture deficit in irrigated lands. Probability distributions of the soil moisture deficit (SMD) and the critical soil moisture deficit (CSD) were derived adopting a hydrological hazard function. The SMD and CSD were well represented by truncated Weibull distributions.
Prajamwong et al (1997) developed a model called "Command Area Decision Support Model" (CADSM) to estimate aggregate crop-water requirements and to study management options for irrigated areas.

Posnikoff and Knapp (1997) analyzed a farm-level model for reducing the deep percolation flows arising in irrigated agriculture.

Radhey shyam and Chauhan (1995) developed linear programming models for maximization of the aggregate net return and for obtaining optimal cropping patterns under both equity and demand based irrigation water distribution. They applied the models in Golawar Main Canal in Uttar Pradesh and concluded that the change in canal water allocation policy from the equity basis to the demand basis resulted in increase in overall cropped area and the aggregate return.

Sarma and Rao (1997) developed a criterion to identify the critical dry spells in a given climate-crop-soil situation taking into account the soil moisture depletion from crop root zone, stage of crop growth, a root growth model and pan evaporation.

Hussain (1994) reviewed the three internationally well known on-farm water management simulation models, SWASALT model, FAIDS model and SWACROP model and emphasized the need to calibrate and validate these models for the waterlogged command areas to study and manage the soil water balance for sustainable crop production.
Sastry and Veeraiah et al (1993) presented a methodology to develop Design Operation Plan as a basic management tool for operation of irrigation schemes taking a case study of Thandava medium irrigation project in Andhra Pradesh.

Dandekar (1989) presented a modified Rotational Water schedule (RWS) which took into account the crop water requirements, the moisture holding capacity of soils and the timing of water availability.

Martin et al (1997) discussed the usefulness of the models and decision methods which were combined in an integrated decision support system, for sustainable integrated water management taking a case study in Netherlands.

Mohanty et al (1994) presented the results of a study which coupled a geographic information systems database for a 471-hectare watershed in Humboldt county, Iowa, with a groundwater flow model (MODFLOW) and an empirical crop yield loss model to predict long term effects of complete closure of agricultural drainage wells on crop production.

Hussain (1992) presented a methodology to evolve an optimal surface irrigation practice under limited water supply conditions, which aimed at maximizing the benefits of crop production per unit water applied, taking nasagar Project as a case study.
Beke et al. (1993) studied the effect of irrigation on long term groundwater levels using twenty eight years data at nine sites in Southern Alberta, Canada.

2.11 CONCLUDING REMARKS

A review of the available literature on Conjunctive water use modelling for irrigation indicates that there is no single, simple, integrated and comprehensive approach to model building for application to irrigation planning for optimal production at the field level such that the model is not too complicated with large data requirements and yet greatly useful for the irrigation managers in complex day-to-day planning and management of water resources conjunctively in irrigation commands with minimum data requirements for achieving the sustained development without adverse environmental impacts.

In the following chapters, an attempt is made to develop a simple, integrated conjunctive water use model which allocates the precious resources such as land, water, investment and labour for sustainable crop production and predicts the behaviour of groundwater table for different feasible conjunctive water use policies under multiobjective environment using the software widely and easily available.