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Review Paper

# An overview of the optimization modelling applications

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SUMMARY

The optimal use of available resources is of paramount importance in the backdrop of the increasing food, fiber, and other demands of the burgeoning global population and the shrinking resources. The optimal use of these resources can be determined by employing an optimization technique. The comprehensive reviews on the use of various programming techniques for the solution of different optimization problems have been provided in this paper. The past reviews are grouped into nine sections based on the solutions of the theme-based real world problems. The sections include: use of optimization modelling for conjunctive use planning, groundwater management, seawater intrusion management, irrigation management, achieving optimal cropping pattern, management of reservoir systems operation, management of resources in arid and semi-arid regions, solid waste management, and miscellaneous uses which comprise, managing problems of hydropower generation and sugar industry. Conclusions are drawn where gaps exist and more research needs to be focused.



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## 1. Introduction

The global population is increasing rapidly and expected to touch the 9.30 billion mark by 2050 from the 7 billion in 2011 (United Nations, 2010). The optimal use of available resources is of paramount importance in order to fulfil food, fibre, and other requirements of the burgeoning global population (Davies and Simonovic, 2011; Singh and Panda, 2012a,b,c). For instance, the present global agricultural production needs to be increased by about 33% to feed the world in 2050 (Singh, 2012a). This can be done by either bringing more area under cultivation or by increasing production per unit area of available land and water resources. Bringing additional area under cultivation, however, is difficult due to urbanisation and a reluctance to disturb natural environments. Also, the availability of water for irrigation will decrease because

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expected increase in water demand for domestic, industrial, and hydroelectric generation purposes (Singh, 2012b). For example, in India the irrigation allocation will probably decrease from the present level of 83% to about 69% by the year 2050 (Panjiar, 2010). Therefore, it is essential to optimize available land and water resources to achieve maximum returns.

Optimization is a simple tool for utilizing the power of linear and nonlinear formulations to solve the large problems concisely and analyzing the solutions. It helps to find the answer that yields the best result; attains the highest profit, output, or happiness; or achieves the lowest cost, waste, or discomfort. Often these problems involve making the most efficient use of available resources including money, time, machinery, staff, inventory, and land and water. These problems have been solved by using different optimization techniques from the researchers from worldwide (Anwar and Clarke, 2001; Ayvaz and Karahan, 2008; Azaiez et al., 2005; Bar et al., 2009; Bardossy et al., 1990; Chiadamrong and Kawtummachai, 2008; de Vries and Anwar, 2006; Easa and Hossain, 2008; Hsu and Wei, 2007; Hsu et al., 2008; Hugo, 2004; Joubert et al., 2007; Kale et al., 2008; Karmakar and Mujumdar, 2006; Majone et al., 2010; Mattilal and Duley, 1998; Pathumnakul et al., 2011; Ravirala and Grivas, 1995; Sadeghpour et al., 2006; Salazar et al., 2005; Stray et al., 2012; Wei and Hsu, 2009; Zhang and Huang, 2011).

The optimization techniques have been used for irrigation management (Li et al., 2011; Reca et al., 2001a,b; Saruwatari and Yomota, 1995; Yang et al., 2009), groundwater management (Andricevic and Kitanidis, 1990; Ayvaz, 2009; Gaur et al., 2011; Mantoglou, 2003; Tan et al., 2011), seawater intrusion management (Cheng and Ouazar, 2004; Hallaji and Yazicigil, 1996; Katsifarakis and Petala, 2006; Mayer et al., 2002; Sreekanth and Datta, 2010), reservoir systems operation management (Alemu et al., 2011; El-Shafie et al., 2007; Fontane et al., 1997; Mouatasim, 2012; Wang et al., 2005; Yang et al., 2007), solid waste management (Costi et al., 2004; Huang et al., 2001; Minciardi et al., 2008; Rawal et al., 2012; Yeomans et al., 2003), management of problems of sugar industry (Higgins, 2006; Jiao et al., 2005; Le Gal et al., 2008; Piewthongngam et al., 2009), and management of hydropower generation (Barros et al., 2003; McLaughlin and Velasco, 1990; Reznicek and Simonovic, 1992; Yoo, 2009). None of the previous studies considered solutions of various theme-based real world problems; rather they have considered solution of only a particular problem by using optimization modelling. This paper presents a comprehensive review on the use of various programming techniques for the solution of different optimization problems.

The past reviews are grouped into nine sections based on the solutions of the theme-based real world problems. The sections include: use of optimization modelling for conjunctive use planning, groundwater management, seawater intrusion management, irrigation management, achieving optimal cropping pattern, managing reservoir systems operation, managing resources in arid and semi-arid regions, solid waste management, and miscellaneous uses which comprise, managing problems of hydropower generation and sugar industry.

## 2. Conjunctive use planning

The water resources is the major limiting factor in crop production in arid and semi-arid regions (Ji et al., 2007; Li et al., 2004; Singh et al., 2010) as annual rainfall is low and uncertain (Singh, 2011). Shortages of surface water supplies have increased the need of groundwater development in many canal commands. The potential of groundwater can be used to develop conjunctive use water management plans for supplementing canal water supplies and to increase agricultural productivity (Khare et al., 2006). Literature related to conjunctive use problems is plentiful and covers a broad spectrum. The objective of conjunctive use is to increase yield, reliability of supply and general efficiency of a water resources system by combining two or more components of hydrologic cycle when a single source of water is inadequate to meet the demand with sustainability. The components can be different but interrelated with hydrologic, economic and environmental characteristics and can be achieved by diverting water from streams or surface reservoirs, recycling of drainage water, rainwater harvesting and lifting groundwater. The direct benefits may be the economic advantage (Chaturvedi, 1973) and reduction of the adverse environmental impact.

Various optimization techniques have been used for the conjunctive use of available surface and groundwater resources for the maximization of net benefits from irrigated agriculture. Application of linear programming (LP) and dynamic programming (DP) techniques to irrigation management have been very popular. Stochastic or chance constrained linear programming (CCLP) is one of the approaches of LP under risk wherein some or all parameters of the problem are described by random variables. Non-linear programming (NLP), however, has not been widely used because of rigorous mathematics involved in its development and high computation time and memory required. Optimization models based upon LP technique has been used extensively in water resources system analysis and planning (Loucks et al., 1981). These models compare various combinations of surface water and groundwater and select an optimal combination based on hydrological, economic or allocation criteria; for example minimum conveyance, least cost, desirable water quality or resource conservation (Castle and Lindeborg, 1960; Duckstein and Kisiel, 1968; Gorelick, 1986; Lingen and Buras, 1987; Maknoon and Burges, 1978; O'Mara, 1988; Philbrick and Kitanidis, 1998; Senapati, 1988; Shrestha, 1991; Vincent and Dempsey, 1991).

Many attempts have been made by researchers to study optimal allocation of land, water and other resources for various uses. Initially the studies were qualitative in nature while quantitative aspects gained importance afterwards. A number of approaches to the solution of such problems, using formal methods of optimization have been appeared in the past (Aron and Scott, 1971; Buras, 1963; Haimes and Dreizen, 1977; Illangasekare et al., 1984; Karamouz et al., 2004; Matsukawa et al., 1992; Onta et al., 1991; Rao et al., 2004a; Reichard, 1995; Singh, 2012b; Singh et al., 2001; Tyagi and Narayana, 1981; Vedula et al., 2005; Watkins and McKinney, 1998; Young and Bredehoeft, 1972). An LP model was used by Boster and Martin (1979) in irrigated farms in Arizona to predict agricultural adjustments to new water from the Central Arizona Project. The developed model has broad application to similar water resource projects involving the conjunctive use of multiple water sources of different qualities through mixing the waters. Latif and James (1991) applied an LP model in the Indus basin in Pakistan to maximize the net income of irrigators through cycles of wet and dry years over the long period. The model determines the optimal groundwater extraction for supplementing canal water to avoid adverse effects of high (waterlogging and salinity) or low (depletion and high pumping cost) groundwater level. Similarly, Male and Mueller (1992) presented a dual-objective LP-based conjunctive use model, for the fixation of groundwater withdrawal permits, considering the use of groundwater without depletion of stream. Stream aquifer interaction was modelled using a linear lumped model, which uses stream depletion factor to represent basin characteristics. Peralta et al. (1995) developed an LP-based simulation cum optimization model to obtain the sustainable groundwater extractions over a period of five decades under a conjunctive water use scenario.