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Assessment of Garmsar Optimum Drainage Design Using a Successful Strategy for Salinity Control

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ABSTRACT

A methodology and computer model is developed to determine economically optimum closed subsurface drainage systems in irrigated areas to control salinity. The model maximizes net benefits by comparing profit driven by crop yield to drain system cost and selects an optimum drain layout. The optimization methodology used is the simplex method. The simplex method was linked to the subsurface drainage model DRAINMOD and to the surface hydraulic model KINE. The selected optimum drainage system maximizes the difference between total revenue and the total cost of installation, operation and management of a particular drainage system. A 42 meter drain spacing at depth of two meter in local loamy soil was almost the optimum drain design. The salt balance of the area was measured before and after installation of drainage system. Salinity was reduced by 44% for first three years of operation. The optimization sub-program provides a workable and simple procedure for optimizing sound environmentally water management simulation models.

KEYWORD

Drainage , DRAINMOD , KINE , Salinity Management , Optimization

INTRODUCTION

Historical records have revealed that many ancient civilizations that relied upon irrigated agriculture have failed. The Sumerian civilization of ancient Mesopotamia declined as agricultural productivity began to decrease due to water logging and soil salinization [1,2]. Skaggs [3] developed DRAINMOD as a tool for field evaluation of drainage systems. Agricultural drainage systems are mainly designed for moisture and salinity control in arid and semi-arid regions. Because drainage water contains agricultural nutrients and other chemicals leached from soils, drainage discharge has been blamed as a major contributor of agricultural non-point pollution [4,5]. Artificial drainage is widely practiced throughout the world for controlling soil salinity and shallow water tables. Of the 1200 Mha of rain fed cropland in the world, about 150–200 Mha have improved drainage [6]. Traditional drainage system management amounts to simply letting the system run continuously without any control, which is deemed necessary to prevent waterlogging and soil salinization. It is also the practice during leaching of salinized soil. However, management measures are needed to regulate flow and reduce the impact of saline drainage water on the environment [7]. Approximately 25–30% of the irrigated lands in the United States have crop yields that are negatively affected by high soil salinity levels [8,9,and 10]. Drainage water in arid irrigated regions may also contain salts, such as NaCl and CaSO4, and elements derived from the soil parent material, such as Se, B, and As. Selenium found in the drainage water originating from the soil on the west side of the San Joaquin Valley was responsible for the environmental problems identified at the Kesterson Reservoir [11]. All of these constituents may have serious negative environmental impacts on the receiving water bodies and downstream water users. Christen et al. [12] in a review of subsurface drainage across Australia, demonstrated that the majority of drainage systems were over-draining, as they were removing far more salt than was applied by irrigation water. Christen and Skean [13] describe the development and implementation of best management practices (BMP) that provide a basis for the design of drainage systems in irrigated areas. Ayars and McWhorter [14] demonstrated that the irrigation and ground water quality, the irrigation system efficiency, the crop salt tolerance, and the projected in situ use of shallow ground water by the crop could be schedule. Walker et al. [15] developed Kinematic-Wave Furrow Irrigation Model (KINE) to evaluate on farm furrow irrigation systems. Gonçalves et al. [16] used KINE model to evaluate furrow irrigation system design. However, studies by [17,18] demonstrated that deep and wide drain lateral placement increases the total salt load being discharged. Northey et al. [19] demonstrated an increase of salinity in the shallow ground water under furrow irrigated fields. Also, they

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showed how the salinity of the ground water varies with depth across time and with irrigation and salinity increases with depth, as is common in irrigated areas. Jia et al. [20] showed, in arid and semi-arid regions, drainage have to cope with the conservative nature of salts leached from soils.

Ayars et al. [21] used Hydrus-2D to model the effect of water table and lateral depth as a criteria on required drain spacing assuming. Kellenersa et al. [22] modeled long term drainage water salinity of pipe drains. Wahba et al. [23]used DRAINMOD-S to demonstrate the effect of doubling the drain spacing by blocking every other drain and modifying the drain depth by installing control structures. Bahc et al. [24] used SaltMod and tested the model with data collected from a pilot area. Houk et al. [25] showed a sophisticated approach for estimating the impact of both water logging and soil salinity on drainage system revenue. Durnford et al. [26] presented a procedure which can be used to identify economically optimum subsurface drainage system designs in an irrigated area. Also a water balance approach for subsurface drainage design has been proposed [27]. Qureshi et al. [28] reveal that the installed drainage systems were initially successful in lowering groundwater table and reducing salinity. Ritzema et al. [29] reported, a hydro salinity model, SALTMOD [30], was used to make long-term predictions of the soil salinity and the depth to water table [31]. The likely performance of an artificial drainage system can be assessed through modelling [32]. Drainage environmental impact study says drainage is bound to result in undesirable environmental effects if left unmanaged [33]. The need to make an economic evaluation of agricultural drainage systems is well recognized among numerous researchers. The method used by Wiser et al. [34], gives an estimation of the effect of water table changes on crop response. The criterion for final system choice is maximization of net benefits [35]. The change in water table height was calculated using an equation developed by Van Schilfgaarde [36], which estimates the water table height at any time due to an assumed pulse input which is uniform over the period. The water table height is a function of the drain spacing, depth and input to the water table.

In order to design an effective environmentally drainage system, the determination of the functional requirements is an essential step. In the Garmsar Irrigation District, with nearly 50,000 Ha cultivated land, the irrigated areas increased rapidly at the beginning of this century. By the 1960's waterlogging and salinity problems began to appear and by the end of 1970's, hectares temporarily went out of production. In 1970, construction was begun on the planned system of closed drainage systems [37].

SITE LOCATION

The Garmsar irrigation district is located approximately 120 km southeast of Tehran, at the southern fringe of the Alburz mountain range, where the HablehRud River emerges and where the Dasht-e-Kavir desert begins. The elevation of the area ranges between 800 to 900 m above sea level with 35°05′ 12″ to 35°16′ 47″ north latitude and 52°17′ 10″ to 52°36′ 50″ east longitude geographic coordination (Figure 1). The water of the HablehRud at BoneKuh has a salinity of about 1 g/l or an electric conductivity (EC) of 1.7 dS/m. This signifies a medium quality for irrigation. In the major part of the alluvial fan, the natural drainage to the underground is high. Hence, enough leaching can take place to avoid soil salinity problems. The major part (90%) of the salts consists of chlorides and sulfates. Sodium salts (60%) are slightly in excess of calcium and magnesium (40%). The residual sodium carbonate content is low, hence the water is not giving serious alkalinity problems [38]. Irrigation is performed by tapping water from the numerous branches of the HablehRud River fanning out over the area. The water is led from here into earthen irrigation canals. Shallow pumped wells are used to supplement the surface water, especially in summer and in periods of drought. Towards the fringes of the alluvial fan at least 30 Ghanats (artificial underground galleries) were dug to abstract water from the aquifer by gravity. In the mid-eighties, a new irrigation system was constructed and in 1990 it was put into operation. The main purpose of the system was to reduce the deep percolation losses from the many natural watercourses (Figure 2). Drainage system can be found in the lower parts of the fan to combat problems of shallow water-tables and water-logging in the wet periods when the HablehRud brings relatively large quantities of water consecutively during a number of years. The recharge of the Garmsar aquifer in the irrigated area rises the water-tables height. The drainage systems to control the water logging and salinity are in the lower parts of the plane consist of open ditch-drains and closed drain pipes.

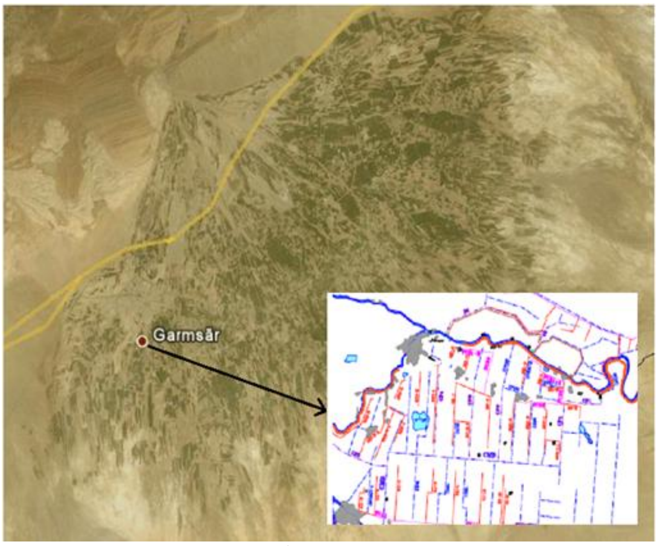

Fig. 1. The Location map of Garmsar, [Google Earth 7.1.2.2041]

PROCEDURE

The following procedure was adapted for maximization of the net benefit. The objective function (Obj), for optimizing the net benefit can be formulated as follows:

$$Obj = maximize\ net\ benefit \qquad (1)$$

To practically compute the objective function, acceptable limits such as the following must be set out:

$\text{min. Spacing} < \text{drain Spacing} < \text{max. Spacing}$

$\text{min. Depth} < \text{drain Depth} < \text{max. Depth}$

$$\min.\mathrm{Diameter} < \mathrm{drain\ Diameter} < \max.\mathrm{Diameter}$$
$$\min.\mathrm{Q} < \mathrm{furrow\ inflow\ Q} < \max.\mathrm{Q}$$
$$min.LF < furrow\ length < max.LF$$

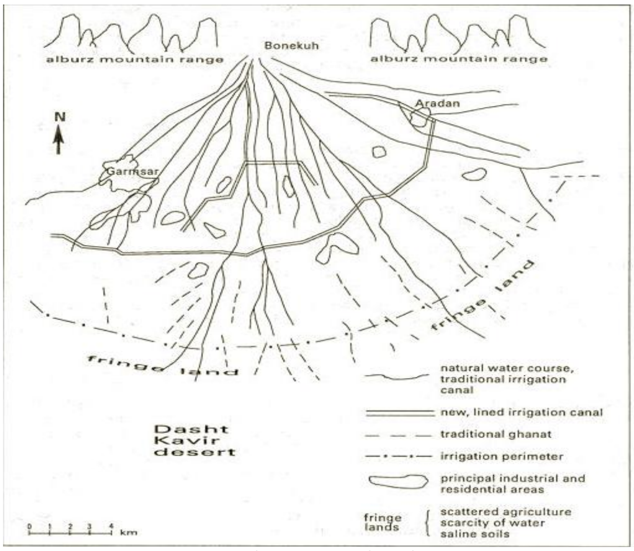

Fig. 2. Sketch of the alluvial fan of Garmsar, [38]

$$min.Zn < depth\ applied\ at\ end\ of\ furrow < max.Zn$$
$$min.F < irrigation\ frequency\ F < max.F$$
$$and,$$
$$Net\ Benefit = Total\ Benefit - Total\ Costs \quad (2)$$

Where, Total Benefit in this case is the income to the farmer crop production (yield), and Total Costs included drainage system costs plus irrigation system costs plus production costs.

Drainage Costs

The total cost of drainage system is a function of several variables as follows:

$$Totcd = CMN + CMA + CTU + CIN + COU + CFI \quad (3)$$
$$Or,$$
$$Toted = (C5/L + (i \times C6 \times Ddepth^{C7}/L) + i \times C8 \times ddiam^{C9}/L) + (i \times CIO/MANL \times L) + (i \times C11/L \times OUTL) + (i \times C21/L) \quad (4)$$

And,

$$C21 = C14 \times 0.00164 \times ddiam^{-0.86} (5)$$

Where $Totcd$ is total drainage cost per unit are, CMN is cost of drain maintenance per unit area, CMA is cost of drain installation per unit are, CTU is cost of tubing per unit are, CIN is cost of man holes per unit are, COU is cost of outlets per unit are, CFI is cost of envelope per unit are, L is drain spacing (m), D depth is drain depth (m), i is the annualized economic factor, $MANL$ is distance between each manhole (m), $OUTL$ is distance between each outlet (m), $C5$, $C6$, $C7$, $C8$, $C9$, $C10$ and $C11$ are cost coefficients. $C21$ is cost per linear meter of envelop material, $C21$ could be approximated by a simple power function (Equation 5), where $ddiam$ is drain diameter (mm), and $C14$ is a cost coefficient.

Irrigation Costs

Total cost of irrigation system is:

$$Totci = Nise\,(Cotlb + Cotwt) + Cothd \quad (6)$$
$$Or,$$
$$Totci = Nise\,((1/60 \times C2 \times C4 \times Tirr) + (C1 \times Nf \times Tco)/Effc)) + C3 \times Wf \quad (7)$$
$$And,$$
$$Noset = Nf/Nfs \quad (8)$$
$$Nfs = Qmax/Qin \quad (9)$$
$$Tirr = Tco \times Noset \quad (10)$$
$$Nf = 10{,}000/Lf \times Fs \quad (11)$$
$$Wf = Nf \times Fs \quad (12)$$

Where, $Totci$ is total cost of the irrigation system, $Nise$ is number of irrigations per season, $Cotlb$ is cost of labor per unit area, $Cotwt$ is water cost, $Cothd$ is cost of head ditch construction per unit area, $Tirr$ is time of irrigation, $Noset$ is number of irrigation sets, Nf is number of furrows per set, $Qmax$ is maximum volume of available water, Qin is volume of inflow to one furrow, Tco is time of inflow cutoff to furrow, Lf is furrow length, Fs is furrow spacing, Wf is head ditch length, $Effc$ is conveyance efficiency, $C1$, $C2$, $C3$ are cost coefficients, and $C4$ is fraction of time. The surface irrigation hydraulic performance was simulated using the KINE model [15].

Production Cost

Cp is the agronomic production cost per ha, excluding the cost of drainage and irrigation system construction and operation. A production cost of 500$/ha is assumed.

Benefit or Unit Income

Total Benefit can be described as:

$$Beft = Ry \times Py \times C1 \quad (13)$$

Where $Beft$ is the total benefit ($ per unit area or $/ha), Ry is relative yield (%). The relative yield has computed using DRAINMOD [39]. Py is potential yield (kg/ha) and $C1$ is price of the corn crop ($/kg).

Solution to the Optimization Problem

Maximization of the net benefit is more comprehensive than minimization of cost in that it incorporates a decision about the desired level of system performance. In this study, benefit will be measured in terms of crop yield value, and the net benefit is defined as that income derived by the farmer from any additional crop yield attributed to installation of a drain system minus the cost of that system. Maximization of net benefits further implies that differing levels of system performance are compared. Assuming that the level of performance as a function of maximizing net benefit can be quantified satisfactorily, then for each performance level there is a consequent minimum system and operation cost at which that performance level is achieved. The relationship between benefits, cost and system performance level can be visualized as shown in Figure 3.

In figure 3 benefits and costs are plotted. The net benefit is the distance between the two curves. In general, it is expected that as the performance level of the system increases, the benefit or yield increases at least to a point. The cost must also increase to obtain the additional performance. In the example shown, it is assumed that some benefit is derived from the land with no artificial drainage. In addition, benefits are shown as leveling off as the crop yields approach some minimum level. Finally, the derived net benefits level off as the crop yield approach some maximum attainable level and may even decline beyond this point i.e. extra contribution of the cost which is due to additional crop protection. In the economic consideration of the particular drainage system, the level of protection should not be increased if the total cost exceeds the total benefit. Therefore, theoretically, the point where marginal cost equal marginal benefit or, in another word, where the slop of the cost function and the benefit function are equal represents an optimum point.

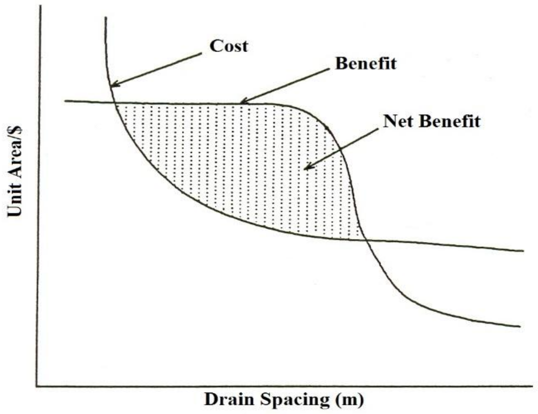

Fig.3. Example curve showing cost relationships between cost, benefit and net benefit, for one system performance level

The problem then is, to define the best system and develop a feasible procedure for finding this system. As above, in this study, it is assumed that the best system is the one which maximizes net benefits on the farm level. The general procedure commonly used to find a solution for the best system can be classified as two types: 1. Simulation and 2. Optimization. Using the best approach, the simulation method, possible drain spacing and depth and surface irrigation parameters and their effects on crop yield and salinity can be determined realistically. The second approach, optimization requires more detailed analysis than the simulation model, but it is capable of including most of the interdependencies inherent in irrigation and drainage systems. A simplified optimization routine which provides most of the advantage of the optimization method, can be employed.

Spendley et al. [40] introduced a clever idea for tracking optimum function conditions by evaluating, from the output form a set of points forming a simplex in the space and called it “SIMPLEX”. The procedure was modified by Nelder and Mead [41]. The name simplex is derived from its shape in space. The Spendley method employs a regular sequential pattern search of points in the design space while maintaining efficiency compared to the simple direct method. The idea is to pick a base point and, rather than attempting to cover the entire range of the variables, to evaluate the design parameters in some pattern about the base point. For example, in two dimensions, a triangular pattern which the best of them (the node with the lowest value of the objective function) would be selected as the next base point around, which to locate the next pattern of points. If none of the corner points is better than the base point, the scale of the grid is reduced and the search continues.

In this method the search to optimize the objective function, trail X vectors Figure 4, can be selected as a point in space, at the vertices of the simplex. The objective function can be evaluated at each of the vertices of the simplex, and a projection made from the point yielding the highest value of the objective function (point x_1 in Figure 4) through the centroid of the simplex. Point x_1 is deleted and a new simplex is formed by reflection, expansion or contraction. The simplex is then composed of remaining old points and the one new point, and then the procedure continues until a prescribed error tolerance is met and optimization reaches final convergence.

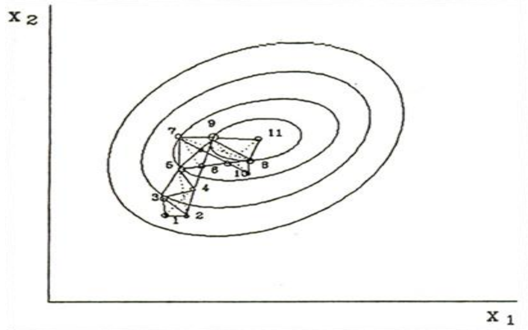

Fig.4. An outlook of the Simplex Method with sequence of Simplexes obtained in maximization of the objective function

Some definitions are as follows from Nelder and Mead [41]. Reflection: the reflection of P_h is denoted by P^*, and its coordinates are defined by the relation:

$$P^* = (1 + \alpha)\bar{P} - \alpha P_h \qquad (14)$$

Where α is positive constant, the reflection coefficient, $\bar{P}$ is centered of simplex, and P_h is value of vertex with function in highest value (the suffix of h, l are to define high and low respectively).

If y^* is less thany_l, i.e. if reflection produced a new minimum, then we expand P^* to P^{**} by the relation:

$$P^{**} = \gamma P^* + (1 - \gamma)\bar{P} \qquad (15)$$

Where γ is expansion coefficient, which is greater than unity and finally if on reflecting P to P^* it is found that y^* is bigger than y_i for all $i\#h$, i.e. that replacing P by P^* leaves y^* the maximum, (y is function value at P_i) then we define a new P_h to be either the old P_h or P^*, whichever has the lower function value and form:

$$P^{**} = \beta\, P_h + (1 - \beta)\,\bar{P} \qquad (16)$$

Where β is contraction coefficient which lies between 0 to 1. The final point of concern is halting the procedure which is concerned with the variation in the y values over the simplex. The form chosen is to compare the standard error of y’s in the form of:

$$Err = \sqrt{\{\sum(y_i - \bar{y})^2 / n\}} \qquad (17)$$

Where $\bar{y}$ is mean value of y, n is number of vertices that are compared to a present value (Err) or to so-called error tolerances and to stop when the value falls below this value.

RESULTS

The Simplex method is a useful technique for optimizing simulation models. The method was used to optimize interaction between irrigation and drainage requirement of the crop. The drainage system optimization model could be used for comparing a wide range of design parameter values and to produce a series of graphs that will allow practicing drainage engineers and farmers to select a subsurface drainage system optimized for a given set of conditions.

The estimated costs of drain installation and materials are shown in Table 1. The drain design computed by the drainage optimization model is the least cost system for the highest level of yield that would be achieved based on the input cost data, soil conditions, crop production, and one particular irrigation layout (table 2). The computational procedure, as described, is an iterative process. For example, for a field situation where a single corn crop is planted each year, and the costs for a closed drain system are shown in Table 3. By using these values and an initial trial drain spacing of, for example, 60 meters (Table 3), a relative yield of 82% would be determined using the drainage system design results with the yield model. The net benefit from this particular system was determined to be 170$/ha/year. The optimization model then evaluates a second alternative spacing of 69 meters and determines a corresponding relative yield of 68% and net benefit of 3$/ha/year. Therefore, the net benefit gradient is negative and the net benefit will decrease if the spacing is increased. Since a higher net benefit is required, the optimization sub-model decrease the spacing to 58 meters and re-evaluates the corresponding costs and benefits, and the gradient for the new results is determined. Table 3 shows the sequence of data obtained by following this iteration method of optimization. When the change in the net benefits is less than a per-defined tolerance, the optimization sub-model will end the procedure and the chosen system would be the system giving the highest annual net return, using the current input data. Convergence occurs fairly quickly in a few iterations. The numerical values of net benefit for different combinations of hydraulic conductivity and for one interest rate, one amortization period and one installation cost are shown in Figure 5 for different soil permeability. Of all the various hydraulic parameters considered in the conductivity has the greater on drain spacing net benefit. Figure 5 indicates the drain spacing needed to achieve the maximum annual net benefit from subsurface drainage for various values of hydraulic conductivity increases with hydraulic conductivity.

Tab. 1. Costs assumed for closed drain systems and irrigations water management practices

Variable	Cost Assumed	Units	Explanation
C1	0.01	$\$/m^3$	Water cost
C2	4	$/hr	Labor cost
C3	3.1	$/m	Annual cost of ditch construction
C4	1	-	Fraction of time
C5	0.0311	$/m/year	maint cost
C6	0.277	$/m	inst. cost
C7	2.18	$/m	inst. cost
C8	0.02	$/m	tubing cost
C9	0.76	$/m	tubing cost
C10	175	$/unit	manhole cost
C11	100	$/unit	Outlet cost
C14	8.76	$\$/m^3$	Envelope cost
Price/kg	0.12	$/kg	Price of crop
Rate	0.132	-	-

Tab. 2. Summary of the input data used in drainage and optimization model

Input Parameters	Value	Input Parameters	Value
Years of simulation	2011-2014	Length of furrow (m)	200,300
Rainfall station (#)	12345678	Furrow spacing (m)	1
Temperature station (#)	23456789	Roughness coefficient	0.04
Crop type	Corn	Field slop (m/m)	0.014
Planting date (Julian day)	105	Hydraulic section parameters	0.66,2.87
Growing season (days)	130,142	Furrow geometry parameter	0.96,0.604
Drain depth (cm)	180,200,220	Kostiakov-Lewis infiltration parameters	0.0088,0.212,0.00017
Drain spacing (cm)	40,005,000	Flow rate (1/s)	0.5-0.07
Profile depth (cm)	230	Water applied at end of furrow (m)	0.05-0.07
Drain tubing (mm)	104	Maximum flow available (m3/sec)	10
Soil layers	2	Potential yield (kg/ha)	10000
Saturated hydraulic conductivity (cm/hr)	2,3,4,5	Distance between each manhole (m)	500
Infiltration parameters A and B	3.3,1	Distance between each outlet (m)	500
	6,1	Irrigation frequencies	10-20
	9.2,1		

Tab. 3. Sequence for optimization trail in one particular case

#	Spacing (m)	Relative Yield (%)	Net benefit ($/ha)
1	60	82	170
2	69	68	130
3	58	86	213
4	53	92	270
5	47	97	325
6	34	100	314
7	43	98	334
8	53	92	270
9	38	99	333
10	33	100	315
11	41	99	335

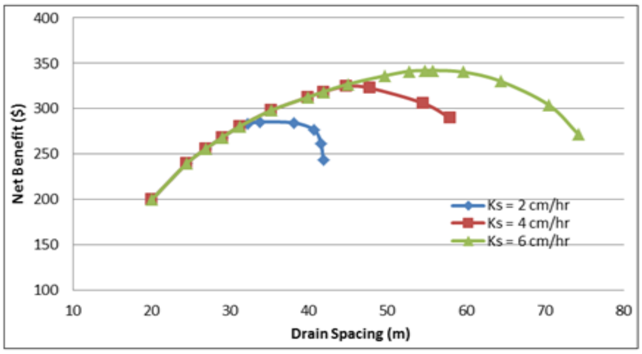

Fig.5Net benefit due to subsurface drainage for various soil hydraulic conductivity values

The sensitivity analyses of model as a function of drain spacing was evaluated by varying the surface irrigation design parameters such as length and furrow inflow. Figure 6 shows the effect of various furrow length on annual net benefit due to the subsurface drainage system. Figure 7 indicates that the furrow inflow is a major parameter influence on the net benefit. It is obvious from figures 6 and 7 that changes in the cost of the system components which could affect system design, would change the net benefit, and it could significantly affecting the drain spacing. A 42 meter drain spacing at depth of two meter in local loamy soil was almost the optimum drain design.

Model 32-50 Conductivity Salinity meter is used to measure salinity of the drain effluent water. The three years of monthly data collected is shown in Figure 8. Figure 8 shows effect of installed drainage system before and after three years of operation in the Garmsar province. It shows the value of salinity has reduced dramatically by 44% as it is supported by [42,43,44,and 45].

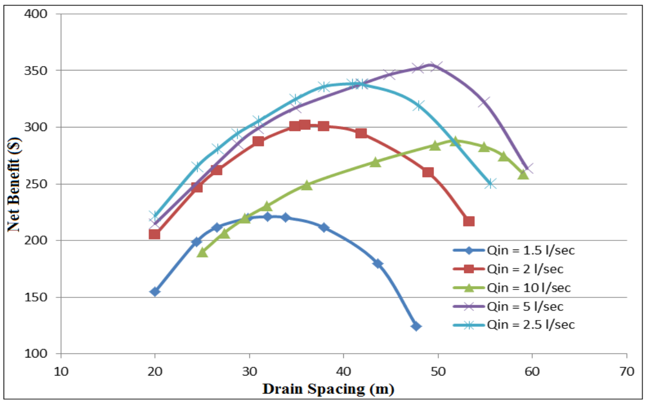

Fig. 6.Effect of various furrow inflow rates on annual net benefit due to the subsurface drainage system

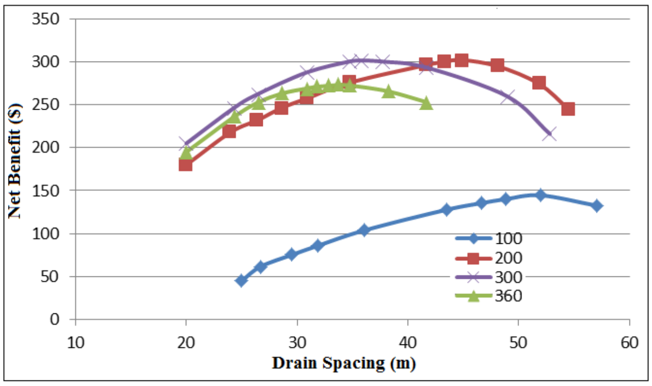

Fig. 7. Effect of various furrow length (m) on annual net benefit due to the subsurface drainage system

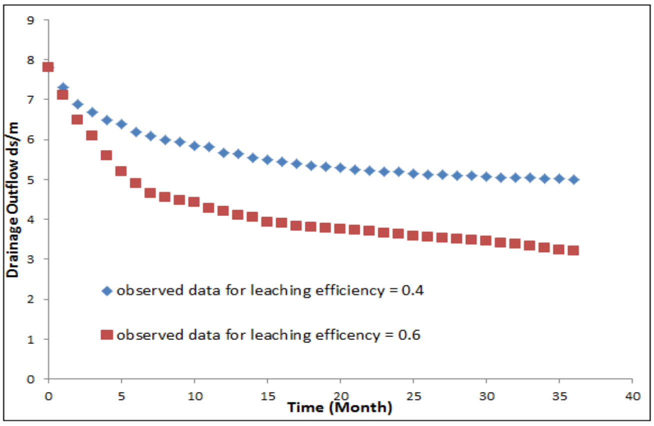

Fig. 8. Effect of drainage system installation on drain effluent

CONCLUSIONS

The procedure concluded in this study introduces the use of state-of-the-art computer simulation techniques to optimize environmentally water management models. The Simplex algorithm was linked together with the surface irrigation and subsurface drainage model to optimize environmentally water management decisions in irrigated agriculture. The optimization routine is proven to be an effective methodology.

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REFERENCES

[1] **Hillel, D.** *Salinity Management for Sustainable Irrigation: Integrating Science, Environment, and Economics. World Bank, 2000, Washington, DC.*

[2] **Tanji, K.K.***Agricultural Salinity Assessment and Management.1990, American Society of Civil Engineers, New York.*

[3] **Skaggs, R.W.** *Field evaluation of a water management simulation model. Transaction of ASAE 25 :(3), 1982, 666-674.*

[4] **Evans, R.O., Skaggs, R.W., Gilliam, J.W.** *Controlled versus conventional drainage effects on water quality. J. Irrig. Drain. Eng. 121: (4), 1995, 271–276.*

[5] **Skaggs, R.W., Breve, M.A., Gilliam, J.W.** *Hydrologic and water quality impacts of agricultural drainage. Crit. Rev. Environ. Sci. Technol. 24: (1), 1994, 1–32.*

[6] **Smedema, L.K., Adbel-Dayem, S., Ochs, W.J.** *Drainage and agricultural development. Irrigation and Drainage Systems 14, 2000, 223–235.*

[7] **Hornbuckle, J.W., Christen, E.W., Ayars, J.E., Faulkner, R.** *Controlled water table management as a strategy for reducing salt loads from subsurface drainage under perennial agriculture in semi-arid Australia. Irrig. Drain. Syst. 19, 2005, 145–159.*

[8] **Postel, S.***Water for Agriculture: Facing the Limits. Worldwatch Paper 93, Worldwatch Institute, 1989, Washington, DC.*

[9] **Ghassemi, F., Jakeman, A.J., Nix, H.A**. *Salinization of Land and Water Resources: Human Causes, Extent, Management, and Case Studies. University of New South Wales Press Ltd., 1995, Sydney, Australia.*

[10] **Wichelns, D.** *An economic model of waterlogging and salinization in arid regions. Ecol. Econ. 30, 1999, 475–491.*

[11] **San Joaquin Valley Drainage Program.** *The problem. In: U.S. Department of Interior and California Resources Agency (Eds.), A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley. California Department of Water Resources, Sacramento CA p. 1990, 183.*

[12] **Christen, E.W., Ayars, J.E., Hornbuckle, J.** *Subsurface drainage design and management in irrigated areas of Australia. Irrig. Sci. 21, 2001, 35–43.*

[13] **Christen, E.W., Skehan, D.***Design and management of subsurface horizontal drainage to reduce salt loads. ASCE J. Irrig. Drain. Eng. 127, 2001, 148–155.*

[14] **Ayars, J.E., McWhorter, D.B.** *Incorporating crop water use in drainage design in arid areas. In: Keyes, C.G., Ward, T.J. (Eds.), Proceedings of the Specialty Conference on Development and Management Aspects of Irrigation and Drainage Systems, Irrigation and Drainage Division. American Society of Civil Engineers New York NY pp. 1985, 380–389.*

[15] **Walker, W. and Humpherys, A.***Kinematic-Wave Furrow Irrigation Model. J. Irrig. Drain Eng. 109:(4), 1983, 377–392.*

[16] **Gonçalves, J., Muga, A., Horst, M., and Pereira, L.** *Furrow irrigation design with multicriteria analysis. Biosystems Engineering 109:(4), 2011, 266-275.*

[17] **Grismer, M.E.** *(1989) Drainage efficiency and drain water quality. In: Dodd, V.A., Grace, P.M. (Eds.), Proceedings of the 11th International Congress on Agricultural Engineering, vol. 1, Land and Water Use, Dublin, September 4–8. A.A. Balkema, Rotterdam, 1989, pp. 285–290.*

[18] **Ayars, J.E., Christen, E.W., Soppe, R.W., Meyer, W**. *Resource potential of shallow ground for crop water use a review. Irrig. Sci. 24, 2006, 147–160.*

[19] **Northey, J.E., Christen, E.W., Ayars, J.E., Jankowski, J.***Occurrence and measurement of salinity stratification in shallow ground water in the Murrumbidgee Irrigation Area, south-eastern Australia. Agric. Water Manage. 81, 2006, 23–40.*

[20] **Jia Z., W. Luob, J. Xieb, Y. Panb, Y. Chena, S. Tangb, W. Liub,***(2011) Salinity dynamics of wetland ditches receiving drainage from irrigate agricultural land in arid and semi-arid regions. Agricultural Water Management 100, 2011, 9–17.*

[21] **Ayars, J.E., Grismer, M.E., Guitjens, J.C.** *Water quality as design criterion in drainage water management system. J. Irrig. Drain. Eng. 123, 1997, 148–153.*

[22] **Kellenersa, T.J. S.K. Kamrab, R.K. Jhorarc.** *Prediction of long term drainage water salinity of pipe drains. Journal of Hydrology 234, 2000, 249–263.*

[23] **Wahba, M.A.S., Christen, E.W., Amer, M.H.** *Irrigation water saving by management of existing subsurface drainage in Egypt. J. Irrig. Drain. 54, 2005, 1–11.*

[24] **Bahc¸ Idris, Nazmi Dinc, Ali Fuat Tarı, Ahmet I. Agar c, Bulent Sonmez,** *Water and salt balance studies, using SaltMod, to improve subsurface drainage design in the Konya–C¸ umra Plain, Turkey Agricultural Water Management 85, 2006, 26 –27.*

[25] **Houk, Eric, Marshall Frasier, Eric Schuck**, *The agricultural impacts of irrigation induced waterlogging and soil salinity in the Arkansas Basin. Agricultural Water Management 85, 2006, 175–183.*

[26] **Durnford, D.S., T.H. Podmore and E.V. Richardson.,** *Drainage: An incremental net benefit approach for optimal design. In: Advances in Drainage, Proceedings of the Forth National Drainage Symposium, ASAE 12:82, 1982, 42-49.*

[27] **Bhattacharya, A.K. and Broughton R.S.,** *(1979) Spacing drains to maximize revenue increases. Transactions of ASAE 22(2) 351-356.*

[28] **Qureshi, A.S., P.G. McCornick, M. Qadir, Z. Aslam**. *Managing salinity and waterlogging in the Indus Basin of Pakistan. Agricultural Water Management 95, 2008, 1–10.*

[29] **Ritzema H.P., T.V. Satyanarayana, S. Raman, J. Boonstra.** *Subsurface drainage to combat waterlogging and salinity in*

irrigated lands in India: Lessons learned in farmers. Fields Agricultural Water Management 95, 2008, 179–189.

[30] ***Oosterbaan, R.J.,****SALTMOD – Description of principles, user manual and examples of application. Special Report ILRI Wageningen, 2000, 80 pp.*

[31] ***Srinivasulu, A., Sujani Rao, Ch., Lakshmi, G.V., Satyanarayana, T.V., Boonstra, J****. Model studies on salt and water balances at Konanki pilot area, Andhra Pradesh, India. Irrig. Drain. Syst. 18, 2004, 1–17.*

[32] ***Ale, S., Bowling, L.C., Owens, P.R., Brouder, S.M., Frankenberger, J.R.****Development and application of a distributed modelling approach to assess the watershed-scale impacts of drainage water management. Agricultural Water Management 107, 2012, 23–33.*

[33] ***Spaling, H., Smit, B.*** *A conceptual model of cumulative environmental effects of agricultural land drainage. Agriculture, Ecosystems and Environment 53, 1995, 99–108.*

[34] ***Wiser, E.H., R.C Ward and D.A. Link.,*** *Optimized design of subsurface drainage system. Transaction of ASAE 17(1), 1974, 175-178 182.*

[35] ***Gideon O., Yoel D., Leonid G., Itsik David, Rao V.P****. Improved saline-water use under subsurface drip irrigation. Agricultural Water Management, 39:1, 1999, 19–33.*

[36] ***Van Schilfgaarde, J.,****Transient design of drainage system. Journal of Irrigation and Drainage Division, ASAE, 91(IR3), 1965, 9-22.*

[37] ***http://abvarzan.ir/en****/2012-12-08-19-50-41/2012-09-16-06-42-02/irrigation-drainage-networks/item/94-complementary-studies-of-the-first-phase-of-garmsar-irrigation-and-drainage-network-taking-soil-logs-permeability-infiltration-and-measurement-of-hydraulic-conductivity.html*

[38] ***Oosterbaan, R.J.*** *Irrigation, groundwater, drainage and soil salinity control in the alluvial fan of Garmsar, Iran Consultancy assignment to the Food and Agriculture Organization (FAO) of the United Nations. International Institute for Land Reclamation and Improvement (ILRI), 2000, Wageningen, the Netherlands.*

[39] ***Skaggs, R.W., S. Hardjoamidjojo, E.H. Wiser and E.H. Hiler.,****Simulation of crop response to surface and subsurface drainage system. Transaction of ASAE 25:6, 1982, 1673-1678.*

[40] ***Spendley, W., G. R. Hext, and F. R. Himsworth****., (1962) Sequential Application of Simplex Design in Optimization and Evolutionary Operation. Technimetrics, 4, 1962, 441.*

[41] ***Nelder, J.A., R. Mead****, A simplex method for function minimization. The Computer Journal 7:4, 1965, 308-313.*

[42] ***Visconti F., J. M. de Paz, J. L. Rubio, J. Sánchez****. Comparison of four steady-state models of increasing complexity for assessing the leaching requirement in agricultural salt-threatened soils. Spanish Journal of Agricultural Research, 10:1, 2012, 1.*

[43] ***Dennis L. Corwin a, James D. Rhoades b, Jirka Simunek****. Leaching requirement for soil salinity control: Steady-state versus transient models. Agricultural Water Management, 90, 2007, 165 –180.*

[44] ***Hoffman, G.****Drainage required to manage salinity. J. Irrig. Drain. Div. ASCE 111, 1985, 199–206.*

[45] ***U.S. Salinity Laboratory Staff****. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Dept. Agriculture, Handbook 60. U.S. Government Printing Office, 1954, Washington, DC.*