EVAPOTRANSPIRATION AND IRRIGATION WATER REQUIREMENTS FOR JORDAN'S NATIONAL WATER MASTER PLAN: GIS-BASED ET CALCULATIONS

Suzan Taha[1]
Richard G. Allen[2]
Klaus Jacobi[3]
Edward Qunqar[4]

ABSTRACT

Evapotranspiration (ET) from irrigated cropland is a significant component of water consumption in Jordan. During 2000 and 2001, the MWI[5] created a large GIS-based system that includes components for processing ET and net irrigation requirements (NIR) for various agroclimatic zones in Jordan. The NIR system, named NIR_Calculator, is programmed within Microsoft Access database using a Visual Basic interface and is highly flexible.

Incorporation of irrigation-specific and culture-specific characteristics for crops has improved the prediction of evaporation and transpiration inside greenhouses and under plastic mulch. Computations include partitioning of irrigated crops into drip, sprinkler and surface irrigated classes, with evaporation from soil surfaces during initial crop development periods and during nongrowing periods calculated for each class separately. A monthly soil water balance determines the impact of stored soil moisture and off-season precipitation on NIR. Evaporation during nongrowing periods is considered when computing annual effective precipitation.

INTRODUCTION

Studies of projected water demand and supply in Jordan have shown that the water deficit is increasing with time, with demands on a finite quantity of good quality water ever increasing. Per capita availability of renewable water today is less than 175 cubic meters, already far below the projected regional average for the year 2025, and will decrease to 90 cubic meters by the year 2020 if water projects are not implemented (Taha and El-Nasser, 2002). In order to meet minimum current water demands for basic uses, over-pumpage of groundwater

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[1] Engineer, Ministry of Water and Irrigation, Amman, Jordan, Suzan_Taha@MWI.gov.jo

[2] Professor, University of Idaho, 3793 N. 3600 E., Kimberly, Idaho 83341, 1 208 423 6601, RALLEN@kimberly.uidaho.edu

[3] AHT International GmbH, Essen, Germany

[4] Chief Engineer, Ministry of Water and Irrigation, Amman, Jordan

[5] Ministry of Water and Irrigation

resources in Jordan is estimated to be at 100% above the safe-yield. Of the total groundwater supplied to all uses in 1998 (485 MCM), irrigated agriculture consumption accounted for about 53%, at some 258 MCM. Nearly 80% of the safe yield of the renewable groundwater resources and 40% of the non-renewable groundwater are currently used for irrigated agriculture throughout the country.

Agriculture constitutes about 70% of the overall water demand in Jordan. Therefore, it is important to obtain accurate and well-organized estimates of current and future water consumption by agriculture. This has motivated MWI to create a software tool for the projection and management of irrigation demand in the nation, given available water quantity and quality information.

BACKGROUND AND OBJECTIVES

In the early 1990's, a UN-DP program assisted MWI in refining a computer-based procedure for structuring and housing water and crop-related data for the country. Software was in the form of early data-bases and most planning computations and summaries used spread-sheets. Beginning in the mid-1990's, and under the scope of work of the Water Sector Planning Support project funded by the GTZ[6], a suite of digital water balance tools was designed and implemented[7]. The objective is to enable the Ministry to carry out nation-wide water balances using recent data and various development scenarios to support efficient water sector planning. Digital water balance tools incorporating nine modules were developed for the assessment of various water demands as well as water resources including wastewater and water losses.

One of the most important tools implemented for the calculation of water demand at MWI is the Irrigation Model. The Irrigation Model consists of 3 separate modules for pre-processing climatic data, calculation of reference ET (ET_0) and computing monthly net irrigation requirements of crops (NIR). These calculations are combined to estimate present and future irrigation demands for the whole country and selected planning/development regions. The Irrigation Model is GIS-based (Jacobi, 2001) and is linked to a Relational Database Management System under Oracle thus allowing for the updating of data and visual presentation of the results.

PRINCIPAL DESIGN OF THE TOOL

The Irrigation Model is implemented under the Microsoft Access database, and is linked to a central Oracle database and GIS databases containing Arc View shape

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[6] German Agency for Technical Cooperation

[7] Conceptual Design was done by Ministry of Water and Irrigation, whereas software development was by AHT International GmbH in close cooperation with GTZ.

files. The software system models irrigation water demand in the future based on existing information regarding cropping patterns, irrigated areas, information on crop water requirements, in combination with application and conveyance methods, and leaching requirements given water quality. Prediction of future water demand is tied to a reference year demand assessment. This permits the evaluation of the current irrigation demand situation in the spatial unit under consideration, with respect to water availability and water quality, prior to proceeding with assumptions regarding the future. Irrigation demand data are aggregated to demand centers such as towns and villages, developed irrigated areas and project areas that are geographically represented via point information in ArcView GIS.

The Irrigation Model requires entry of various data from databases, including:

- Irrigated areas for each crop group and demand center
- Distribution of irrigation methods for irrigated areas under the various application methods
- Leaching requirements for every crop group and salinity class
- Monthly net water requirements (NIR) for each crop group, given the agroclimatic zone in which it is grown
- Application efficiency tables

During operation of the Irrigation Model, selection of individual irrigation centers for which irrigation demand is to be calculated is enforced and performed within Arc View (Figure 1). The selection of demand centers is possible for various spatial units of analysis, such as agroclimatic zone, governorate, groundwater basins, surface water catchments, and subcatchments.

CALCULATION OF NET IRRIGATION REQUIREMENTS (NIR)

Besides statistics on irrigated areas and efficiencies, net irrigation requirements are the principal factors for determining irrigation demand. Net irrigation requirements are calculated using an MS Access-based application, namely the NIR_Calculator and exported to Oracle for further use by the irrigation demand model. The NIR_Calculator uses climatic data and crop factors for various growing stages of crops, with consideration for the application method (surface, drip, and sprinkler) and type of cultivation (open and plastic houses). NIR is calculated on a monthly basis for each crop group, application method, and agroclimatic zone under various year types (median, dry or wet). The application uses monthly ET_0 computed using an early version of the FAO-56 Penman-Monteith equation (FAO, 1990) with monthly precipitation, cropping calendars, and FAO crop coefficients (K_c) for each agroclimatic zone in the country.

The NIR_Calculator was originally coded in a Lotus 123 data base during the early 1990's UNDP work, but has been since converted to an Access application using Visual Basic programming (Jacobi, 2001). Various information compiled by NIR_Calculator includes:

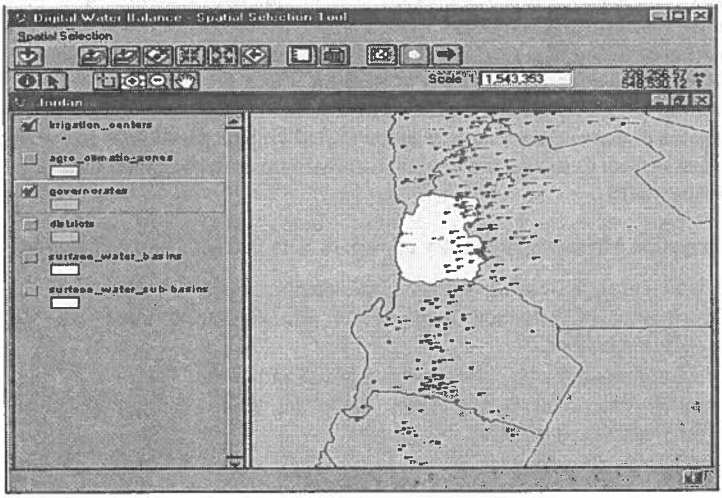


Figure 1: Selection of AgroClimate or Demand Zone within the Irrigation Model (from Taha and El-Naser, 2001)

Crop Factors:

- Length of the crop development stage; initial, development, mid and late seasons (from FAO).
- K_c during the initial, mid and late season
- Minimum possible irrigation depth
- Maximum late season depletion
- Initial root depth of the crop and depth at full development
- Available moisture in the soil
- User specified maximum allowed depletion depending on the crop type.

Meteorological data:

- Reference crop evapotranspiration ET_o
- Number of rainy days
- Rainfall amounts
- Effective rainfall.

Crop coefficients are organized and specified by crop and irrigation method (surface, sprinkler, drip), and cultural environment (open field, greenhouse, open field with plastic mulch, and time of year). This organization allows the values for K_c to be customized to reflect effects of the specific irrigation system type and environment on soil evaporation.

Two separate means for processing rainfall and ET were applied by the Ministry and GTZ: a) the calculation of effective rainfall and ET for historic years and b) a statistical evaluation for dry, median and wet years calculated for agro-climatic zones rather than for individual stations.

The calculations in the NIR_Calculator are subdivided into 5 steps (Figure 2):

Step 1: Calculation of the crop coefficient during the initial growth period, $K_{c\ ini}$

Step 2: Calculation of crop evapotranspiration using ET_0 and crop factors

Step 3: Calculation of net effective precipitation during non-growing season

Step 4: Calculation of NIR

Step 5: Export of NIR results to the relevant database table.

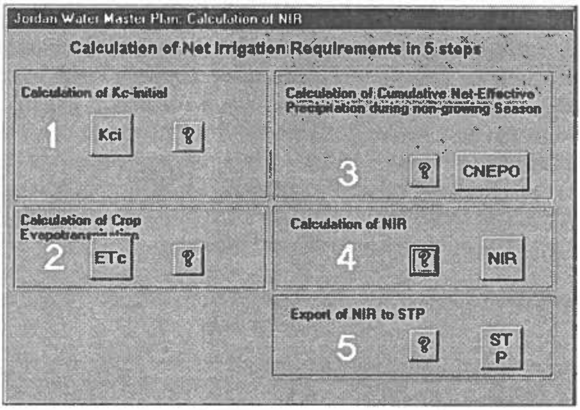


Figure 2: Control screen of the NIR_Calculator Form of MS-Access

PERTINENT CALCULATIONS

This section describes some of the ET and NIR procedures that were developed during the study for use in NIR_Calculator. Several enhancements have been made to the NIR_Calculator to account for effects of late season depletion, off-season precipitation, and preplant irrigation on annual NIR.

Net Irrigation Water Requirement Equation

The NIR for any month "i" is calculated for outside environments as:

$$NIR_i = \text{Maximum}\left((ET_{c\ i} - R_{eff\ i})\,Days_i\ ,\ -0.5\,RAW_i\right) + PPI_i - LSD_i \qquad (1)$$

where $ET_{c\,i}$ and $R_{eff\,i}$ are daily crop ET and effective rainfall for the month (or period) i, $Days_i$ is the number of days in the month, RAW_i is the maximum readily available moisture for month i, PPI_i is any net preplant irrigation requirement for month i (0 unless immediately prior to planting), and LSD is late season depletion during month i (0 unless during the month or months immediately prior to harvest).

The maximum of net $ET_{c\,i}$ and $-0.5\ RAW_i$ in (1) insures any excess precipitation during rainy months (where $ET_{c\,i} - R_{eff\,i}$ is negative) does not exceed the average ability of the soil to retain the excess precipitation in the root zone. This average ability (or capacity) is estimated to be one half of the maximum allowable depletion of the soil for any month. This way, the total NIR includes the benefit and effect of useable excess precipitation during the negative value months.

Limits on Negative NIR

When negative values of NIR are encountered that are caused by effective precipitation exceeding ET requirements, the NIR sub-module calculator compares the negative values to those for the following month to insure that the sum of negative NIR for two or more consecutive months is never more negative than the –RAW. This prevents more storage in the soil than is possible. Excess storage is assumed to become deep percolation from the root zone, and ultimately, ground-water recharge. The RAW used in (1) is based on the maximum rooting depth for the crop. Negative values for cumulative CNIR at the end of the growing season are discarded and set to zero. Table 1 illustrates calculation of NIR with the –RAW limit invoked during wet months.

Table 1. Example NIR calculation for citrus in zone 5 of Jordan for a wet season, months Dec. - Feb.

Month	ET_c, mm/d	R_{eff}, mm/d	$ET_c - R_{eff}$, mm	NIR, mm	□NIR, mm
12	0.97	3.3	-72	-51	-51
1	1.48	3.1	-51	-51	-102
2	1.95	3.2	-35	0	-102

In the case of the citrus example in Table 1, the RAW equals 102 mm, with only one-half of this allowed to be added to soil storage during any month. Beginning with December (the first month having a negative NIR), one would have, by the end of January, a summed negative NIR = -102 mm, which is just OK (i.e., less than or equal to RAW). However, by the end of February, which is the third consecutive month having negative NIR, one would have a summed negative NIR over the three months = -137 mm, which is more "carryover" than the soil can hold. Therefore, the NIR for February is set to 0 mm.

This example presumes that the soil is depleted to RAW at the time of harvest. This is a reasonable assumption for many field crops. For some crops, however, management may keep the soil moisture at higher levels, for example for fruit quality or to make harvesting easier, so that RAW is too large a value to use in estimating month to month storage carryover. One may tend to use a smaller value for RAW in those instances.

Late Season Depletion (LSD)

Late season depletion accounts for the practice of utilizing moisture stored in the root zone near the end of the growing season, without replacing it. This has the effect of reducing the within-season NIR. End of season soil moisture depletion is assumed to be later replenished by precipitation during off-season or by a future pre-plant irrigation. Late season depletion is computed in the NIR Module as the minimum of RAW and a user-specified maximum allowed depletion (USMD) due to cultural or other requirements (Allen, 1991):

$$\mathrm{LSD} = \mathrm{Minimum}[\mathrm{RAW}, \mathrm{USMD}] \tag{2}$$

The RAW in mm is computed as:

$$\mathrm{RAW} = \mathrm{AM}\,\frac{\mathrm{MAD}}{100}\,R_{z\,\max} \tag{3}$$

where AM is the total available water stored in the root zone (one or two days after irrigation) represented by the soil water content between field capacity and wilting point, and $R_{z\,\max}$ is the maximum rooting depth. AM varies with the type of soil and averages about 150 mm/m soil depth. The MAD represents the level of maximum allowed soil water depletion tolerated to maintain potential crop growth and it varies with the type of crop. Values for MAD and $R_{z\,\max}$ are found in Doorenbos and Pruitt (1977) and Allen et al., (1998).

The USMD was set to 10 mm for root crops such as carrots, potatoes and onions to assure moist soil during harvest to facilitate extraction of the crop from the soil without damage. For other crops, such as wheat and barley, which tolerate higher depletion levels, USMD was set to 100 mm.

Cumulative Net Effective Precipitation During The Offseason (CNEPO)

Cumulative Net Effective Precipitation during the off-season is used to predict soil moisture depletion at the beginning of a new crop growing season (i.e., at the planting date). CNEPO is based on the estimated late season depletion amount and net precipitation accumulated between harvest and planting dates. Net effective precipitation for each month is calculated as effective precipitation less ET, where effective precipitation is taken as 0.7 P and ET for each month is calculated using the estimate for $K_{c\,ini}$ during the nongrowing season, referred to as $K_{c\ ngs}$, and which is based on rainfall frequency:

$$\mathrm{CNEPO} = \sum_{1}^{n} \left[R_{\mathrm{eff}\ i} - K_{c\,ngs\ i}\, ET_{o\,i} \right] \mathrm{Days}_i \tag{4}$$

where n is the number of months or periods outside the growing season, and $K_{c\ ngs\ i}$ is K_c during month i of the nongrowing season. Beginning season depletion is calculated as LSD – CNEPO, with a lower limit of 0.

Allowable Depletion During the Initial Period (AD_I)

AD_I is the moisture required to moisten the seed bed and is computed as:

$$AD_I = AM \frac{MAD}{100} R_{z\,I} \tag{5}$$

where $R_{z\,I}$ is root depth during the initial period. $R_{z\,I}$ for annual crops is estimated as the planting depth of the seed plus 5 to 10 cm to represent upward movement of moisture toward the seed and rapid root development. A typical value is 0.15 m. For perennial crops, a typical value is 0.7 m.

Preplant Irrigation Depth (PPI)

The preplant irrigation depth is determined by comparing the minimum physically possible net irrigation depth (MPID) with difference AD_I - P_{eff} and difference LSD – CNEPO. The PPI calculation presumes that the same crop is planted each year, and just once per year, on the same land unit. It is calculated as:

$$\mathrm{PPI} = \mathrm{Minimum}\left[\mathrm{MPID}, \mathrm{Maximum}\left(AD_I - R_{\mathrm{eff}}, \mathrm{LSD} - \mathrm{CNEPO}\right)\right] \tag{6}$$

Minimum Possible Irrigation Depth (MPID)

MPID is the minimum depth of water that can physically be added to the soil due to constraints in the irrigation application system. A surface system may have to apply 40 mm average irrigation depth to push enough water across the basin or along the furrow to just infiltrate 5 mm at the furthest point. Because drip and sprinkler irrigation systems are better controlled, the MPID for these systems is 0.

NIR under greenhouses

Inside greenhouses, there is no effective rainfall, so that:

$$\mathrm{NIR}_{\mathrm{inside}\ i} = ET_{c\ i}\ \mathrm{Days}_i + \mathrm{PPI}_i - \mathrm{LSD}_i \tag{7}$$

The K_c during midseason ($K_{c\ mid}$) and during the late season ($K_{c\ end}$), i.e., the second and third anchor points for the FAO style of K_c curve, are adjusted for predicting ET inside plastic greenhouses by multiplying by 0.75 based on work by Mazahrih (2001) in Jordan Valley.

Calculation of the Crop Coefficient during the Initial Period

K_c during the initial period, $K_{c\ ini}$, is calculated using Cuenca (1987) for reproducing Fig. 6 of Doorenbos and Pruitt (1977). This equation was employed for consistency with past usage by the Ministry. However, the application can also be applied using $K_{c\ ini}$ equations of FAO-56. Wetting events include both rainfall and irrigation. In NIR_Calculator, the $K_{c\ ini}$ method was applied to both the initial period of crops and to periods between crops (nongrowing periods).

Following Cuenca (1987),
If $I_M < 4$ days then:
$K_{c\,ini} = [-0.27\ \mathrm{Ln}(I_M) + 1.286]\ \mathrm{Exp}[(-0.042\ \mathrm{Ln}(I_M) - 0.01)\ ET_o]$Otherwise, if $I_M >= 4$ days then:

$$K_{c\,ini} = 2\ (I_M)^{-0.49}\ \mathrm{Exp}[(-0.04\ \mathrm{Ln}(I_M) - 0.02)\ ET_o] \tag{8}$$

where I_M is the mean wetting interval within the initial cropping period and is based on rainfall frequency and a water balance of the evaporation layer or seedbed of the soil. The depletion layer during the initial period is generally assumed to be 10 to 15 cm in depth, or deeper for perennials, and the water readily available in this layer is AD_I, calculated by (5). Units of ET_o are mm/day. The ET_o, wetting interval and R_{eff} parameters are averages over the initial period.

$K_{c\ ini}$ is calculated using an iterative procedure to find the unknown irrigation interval, I_{irrig}. During the first iteration, $K_{c\ ini}$ is estimated using I_M based on rainfall only, and the subsequent $ET_c = K_{c\ ini}\ ET_o$ is compared to total rainfall:

$$\text{If } K_{c\,ini}\ ET_o > R_{eff} \text{ then } I_{irrig} = \frac{AD_I}{K_{c\,ini} ET_o - R_{eff}} \tag{9}$$

Otherwise, if $K_{c\ ini}\ ET_o <= R_{eff}$, then I_{irrig} is set to an arbitrary 50 days. The I_{irrig} is considered to be necessary, and followed by farmers, to maintain adequate moisture in the seedbed for germinating and establishing the crop. In this manner, impacts of I_{irrig} on evaporation are incorporated.

An average wetting interval is calculated to consider wetting by both rainfall and irrigation, based on a geometric mean (Allen, 1991). The interval mimics an irrigation schedule during the initial period that maintains sufficient moisture in the upper soil layer conducive to seed germination and root development:

$$I_M = \mathrm{Int}\left(\frac{1}{\dfrac{1}{I_{rain}} + \dfrac{1}{I_{irrig}}}\right) + 1 \tag{10}$$

This new estimate for I_M is reinserted into (8) for $K_{c\ ini}$ and a new value for $K_{c\ ini}$ is calculated. The product $K_{c\ ini}$ ET_o is again recomputed and compared to R_{eff} and a new I_{irrig} is computed. The process is repeated until $K_{c\ ini}$ and I_M have stable values.

$K_{c\ ini}$ for Perennials

For perennials, the calculation of $K_{c\ ini}$ requires modification, since the ground surface is not entirely bare, so that the basal condition, $K_{cb} > 0.15$. The calculation of $K_{c\ ini\ perennials}$ considers evaporation from both rainfall and irrigation. However, the evaporation is reduced due to the shading effects of vegetation. The "optimal" irrigation frequency is determined to retain sufficient soil moisture in the initial root zone, which for a perennial is assumed to be substantially close to maximum rooting depth. In the following computations for $K_{c\ ini\ perennials}$, the values for ET_o, I_{rain}, and R_{eff} are averages over all months in the initial period. This procedure, based on Allen (1991 and 2001), uses the Cuenca equation to retain consistency with early work within the Ministry, but is applied to evaporation from a partially vegetated surface from FAO-56, and can be applied with the $K_{c\ ini}$ equations of FAO-56.

Evaporation is regulated under perennials by the fraction of exposed area not covered by vegetation. A simplification of the FAO-56 approach is applied to predict f_{ew} for use with Cuenca's equation, where f_{ew} is the fraction of ground surface that is exposed and wetted by precipitation or irrigation, predicted as:

$$f_{ew} = 1.2 - K_{c\,ini\_residual} \qquad (11)$$

with limits of $0.01 < f_{ew} < 0.99$, where $K_{c\ ini\_residual}$ is the same as the basal K_{cb} for a perennial crop, and represents ET for the crop when it has a dry soil surface.

It is assumed that evaporation from rainfall occurs in the exposed portion of the field, in between beds (i.e., in f_{ew}), when there is no plastic mulch or when the plastic mulch is covered by sufficient soil. For surface or sprinkle irrigation, the total "drying" of the soil is computed as a weighted average based on f_{ew}. The irrigation frequency of perennials for drip with plastic mulch along the beds is less coupled with rainfall. For drip, it is assumed that the bed is mulch covered so that irrigation does not substantially impact $K_{c\ ini}$. The same basic equation for $K_{c\ ini}$, i.e. that by Cuenca (1987) is used, but with ratioing according to f_{ew}.

The evaporation from the f_{cw} area is added to the basal $K_{c\ ini\ residual}$

$$K_{c\,ini\,peren} = K_{c\,ini\,(Eqn.8)}\ f_{ew} + K_{c\,ini\,residual} \qquad (12)$$

where $K_{c\ ini\ (Eqn.\ 8)}$ is $K_{c\ ini}$ from (8). Limits are placed so that:

$$K_{c\ ini\ peren} = \text{Minimum}\left[K_{c\ ini\ peren\,(Eqn.12)}, \text{Maximum}(1.25,\ K_{c\ ini\ residual})\right] \quad (13)$$

Similar to the condition for bare soil, an "optimal" irrigation interval, I_{irrig}, is recommended if predicted evaporation exceeds effective rainfall:

$$\text{If } K_{c\ ini\ peren}\, ET_o > R_{eff} \text{ then } I_{irrig} = \frac{AD_I}{K_{c\ ini\ peren}\, ET_o - R_{eff}} \quad (14)$$

where AD_I is water that is readily available in the rooting zone during the initial period. If $K_{c\ ini\ peren}\ ET_o <= R_{eff}$, then I_{irrig} is set to an arbitrary 50 days. (14) is not invoked for drip irrigation, where it is assumed that the surface is generally wetted within the shade of the vegetation, so that no extra evaporation from irrigation occurs. Therefore, for drip, I_{irrig} = 50 days. Once a value for I_{irrig} is predicted, a geometric mean wetting interval (I_M) is calculated using (10). The process iterates on $K_{c\ ini\ peren}$ and I_{irrig} and I_M until values are stable.

NonGrowing Season ET

The $K_{c\ ini}$ function (8) is applied during the nongrowing season to predict total evaporation and associated effectiveness of precipitation during the nongrowing season. This calculation is part of the prediction of the net change in soil water storage during the period from harvest of one crop until the planting of another. Application of the $K_{c\ ini}$ calculation is made on a monthly basis. The calculation assumes that the soil surface is void of green vegetation. Where green vegetation exists during the nongrowing season, $K_{c\ ini\ peren}$ from (12) can be used to approximate $K_{c\ ngs}$. In the application to the nongrowing period, it is assumed that there is no irrigation, so that I_M in (8) is set equal to I_{Rain}, and no iteration is necessary. However, an upper limit is applied, so that:

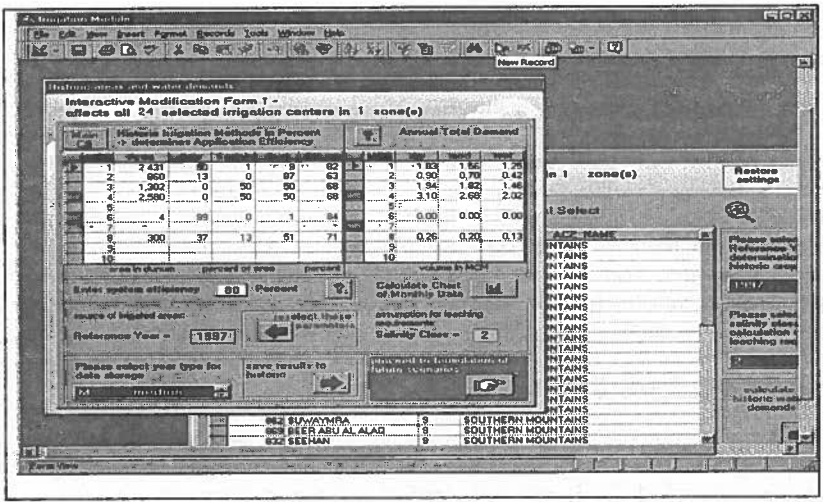
$$\text{If } K_{c\ ngs}\, ET_o > R_{eff} \text{ then } K_{c\ ngs} = \frac{R_{eff}}{ET_o} \quad (15)$$

where $K_{c\ ngs}$ is the K_c during the nongrowing season and is from (8). This conditional limits evaporation to effective rainfall.

OPERATION OF NIR_CALCULATOR FOR IRRIGATION DEMAND

Following the calculation of monthly NIR, results are exported and saved in the relevant tables in the Central Oracle database. Irrigation demand assessment proceeds using the irrigation demand model, which can be linked on-line to this database. Figure 3 illustrates the user interface used in the irrigation model to specify irrigation types and efficiencies, and resulting water demands.

Figure 4 illustrates how monthly water demand data are presented to the user by main crop group (MCG) and month, in tabular and graphical form, under dry, median and wet conditions.



Interactive Modification Form 1 -
affects all 24 selected irrigation centers in 1 zone(s)

Historic Irrigation Methods in Percent -> determines Application Efficiency

1	2 431	80	1	9	82
2	960	13	0	87	63
3	1,302	0	50	50	68
4	2,580	0	50	50	68
5					
6	4	99	0	1	84
7					
8	300	37	13	51	71
9					
10					

area in dunum — percent of area — percent

Annual Total Demand

1	1.83	1.56	1.25
2	0.90	0.70	0.42
3	1.94	1.82	1.46
4	3.10	2.68	2.02
5			
6	0.00	0.00	0.00
7			
8	0.26	0.20	0.13
9			
10			

volume in MCM

Enter system efficiency 80 Percent

Reference Year = 1997

Salinity Class = 2

862	SUWAYMRA	9	SOUTHERN MOUNTAINS
869	BEER ABU AL ALAQ	9	SOUTHERN MOUNTAINS
832	SEEHAN	9	SOUTHERN MOUNTAINS

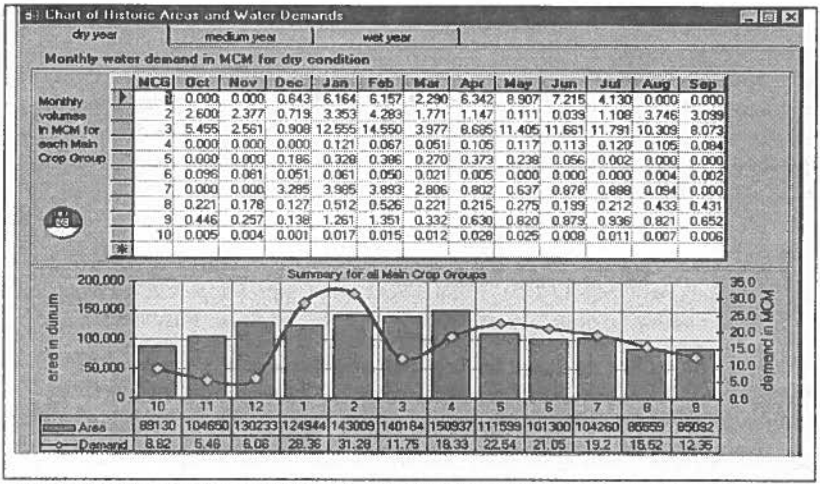
Figure 3: Example of selection of irrigation system type and efficiency and resulting water demand (from Taha and El-Naser, 2001).

Calculation of Future Irrigation Demand

Up to three development scenarios can be considered for the projection of future demand. The scenarios cover the time span until the year 2040 and are performed in five-year intervals. Parameters that can be entered for each interval include:

1) Projected increase or decrease in irrigated areas shown against current figures for the reference year.
2) Projected distribution of irrigation methods; percent drip, percent sprinklers and percent surface.
3) Projected gains in conveyance and application efficiency
4) Projected irrigation water salinity class

Comparisons between irrigation demand predicted from the irrigation model and water diversions and deliveries recorded by the Ministry are providing feedback concerning any need to modify (i.e., reduce) K_c values in NIR_Calculator to reflect impacts of water stress, salnity, low plant density, and water management on total ET. In some areas, the "pristine" assumptions of FAO K_c factors (Allen et al., 1998) may overpredict total ET from an area. Therefore, reducing factors may need to be developed.



Monthly water demand in MCM for dry condition

Monthly volumes in MCM for each Main Crop Group

MCG	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	0.000	0.000	0.643	6.164	6.157	2.290	6.342	8.907	7.215	4.130	0.000	0.000
2	2.600	2.377	0.719	3.353	4.283	1.771	1.147	0.111	0.039	1.108	3.746	3.099
3	5.455	2.561	0.908	12.555	14.550	3.977	8.685	11.405	11.661	11.791	10.309	8.073
4	0.000	0.000	0.000	0.121	0.067	0.051	0.105	0.117	0.113	0.120	0.105	0.084
5	0.000	0.000	0.186	0.328	0.386	0.270	0.373	0.238	0.056	0.002	0.000	0.000
6	0.096	0.061	0.051	0.061	0.050	0.021	0.005	0.000	0.000	0.000	0.004	0.002
7	0.000	0.000	3.285	3.985	3.893	2.806	0.802	0.637	0.878	0.888	0.094	0.000
8	0.221	0.178	0.127	0.512	0.526	0.221	0.215	0.275	0.199	0.212	0.433	0.431
9	0.446	0.257	0.138	1.261	1.351	0.332	0.630	0.820	0.879	0.936	0.821	0.652
10	0.005	0.004	0.001	0.017	0.015	0.012	0.028	0.025	0.008	0.011	0.007	0.006

	10	11	12	1	2	3	4	5	6	7	8	9
Area	88130	104650	130233	124944	143009	140184	150937	111599	101300	104260	86559	85092
Demand	8.82	5.46	6.06	28.36	31.28	11.75	18.33	22.54	21.05	19.2	15.52	12.35

Figure 4: Example computation of monthly historic demand for main crop groups (MCG) (from Taha and El-Naser, 2001).

SUMMARY AND CONCLUSIONS

The irrigation demand model is one of several tools that have been developed to enable the management of the present and future water balance in Jordan. The model aims at prediction and management of irrigation demand given certain development scenarios and based on recent data. As such, the model can be used to evaluate present irrigation demands with respect to actual water use and availability, prevailing cropping patterns, irrigation methods and efficiencies. The tool's reporting flexibility allows digital output of various types of data for additional processing. Being GIS-based, spatial examination and analysis of both the present and future irrigation demands can be made. In addition, the digital nature of the model and its database dependency allows for easy updating of the tool. These features permit more flexible responses to merging new realities and changing conditions.

The interactive feature of the model allows testing the impact of various development scenarios on irrigation demand and subsequently on water balancing, thus allowing for review of water strategies. In addition, scenarios reflecting various water sector strategies and policies can be examined using the model, and as such, the tool can be used as one of several elements to support decision making with regards to demand and supply management strategies, and hence the optimization of water resources.

The NIR calculator is flexible in regard to programming different relationships among NIR components, so that it can be updated according to various countries' needs and to reflect the latest findings in the field.

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