EVALUATING EFFECTS OF IRRIGATION SYSTEM REHABILITATION AND MODERNIZATION BY ESTABLISHING THE WATER DEMAND MINIMUM LEVEL FOR PROFITABLE OPERATION

Ion Nicolaescu[1] Emilia Manole[1]

ABSTRACT

A large irrigation scheme having thousands of water users within its command area should be managed as an integrated agricultural production system, capable to generate economic benefits. The irrigation scheme operation intensity is variable in time, depending mainly upon the actual climate conditions and real water demand of the potential customers. This operation intensity can be expressed as the ratio between the net water volume which was applied to the crops and integrally used for increasing agricultural yield, and the net water volume required to irrigate all of the crops within irrigation scheme, calculated for 50% probability level. Evidently, there is a certain water demand minimum level of the irrigation scheme (Dmin), under which, its operation shall not be able to generate profit. In order to calculate this limit (Dmin), the authors developed a model on the base of benefit /cost analysis involving: a specific cropping pattern, irrigation water and pumping water efficiencies, economic input and output due irrigation for every crop etc. There is not any economic reason to start the operation of an irrigation scheme as long as the actual water demand level is under (Dmin) value. On such reason, (Dmin) becomes a synthetic parameter that is able to describe the technique and economic state of an irrigation system. Rehabilitation and modernization works (R&M) should influence the (Dmin) value, in a sense of its decreasing, as long as the volume of applied actions will increase. Using (Dmin) concept in a case study, for three months continuous operation time, this parameter could be decreased by seven types of R&M actions, from the actual value (45%) to the minimum one (33%).

This synthetic parameter (Dmin) seems to be a suitable and sensitive proceeding to establish the proper strategy of the rehabilitation and modernization actions for any irrigation system.

[1]Respectively, Professor and Assistant Professor, Land Reclamation and Environmental Engineering Faculty, Bd. Marasti 59, sector 1, Bucharest , Romania E-mail : nicola@ecoland.ro

INTRODUCTION

Irrigation practice on semiarid to humid areas has a supplemental character playing an insurance role in achieving a specific agriculture yield. The degree of using the irrigation system in such areas is very variable in time, depending on: drought characteristics (severity, duration and frequency); agriculture policy applied on local and governmental level; social and economical situation of rural people; negative impact of irrigation on the environment etc. A new situation has been created on large irrigation schemes of Romania since the law of land restitution to the former owners began to be applied. This law has generated a great number of small land users (with an average of 2.5 ha/family) inducing a lot of difficulties in relations between the O&M enterprises and the new irrigation water users. Under such circumstances, the demand for irrigation water has been decreased dramatically on the last decade and the majority of irrigation systems are operated with very low economical and technical performances. In order to avoid their operation under low performances, a model has been created to establish *the actual water demand minimum level (Dmin) for the irrigation system profitable operation* (Nicolaescu, 1998). The model could be used to solve two major aspects for any irrigation system:

- for *an efficient current operation*, the system must start to run on condition that actual water demand (D) is greater than water demand minimum level (Dmin);
- *rehabilitation & modernization works* must decrease the minimum water demand to a specific value (Dmin) depending on the technical solution types.

An irrigation system has a lot of means for R&M actions and works to be implemented in time. Applying the (Dmin) conceptual model for every technical solution or combination of them, *the proper R&M strategy* can be established for any given irrigation system, i.e. *selecting and prioritizing actions* among potential alternatives on the basis of profit assurance to the end users. In order to respect this criterion, *the real water demand of the irrigation system after rehabilitation and modernization action (D) should be greater than predicted water demand minimum level (Dmin)* evaluated by means of the proposed model. Otherwise, there will not be any guarantee to pay off the investment, which has to be done in rehabilitation and modernization works. In this context, the main topic of this paper is to show the results, which have been obtained applying the (Dmin) model to seven types of rehabilitation and modernization actions applied on a large irrigation system, as a case study.

MODEL DESCRIPTION

As has been shown (Moisa 1995, Nicolaescu 1998) the model is based on the benefit-cost ratio analysis for a given irrigation system i.e.

$$\frac{B}{C} > 1 \quad \text{.....(1)}$$

B - benefit obtained due to irrigation by selling the increment of the crops' yield (y);
C - total cost of the supplementary inputs required to achieve the yield increment.

Both parameters (B, C) are influenced by the irrigation system operation intensity or *actual water demand (D)* which is defined as:

$$\frac{V\max}{Vo} \geq D = \frac{Vr}{Vo} > 0 \quad \text{.....(2)}$$

where:

Vr – net irrigation water volume stored in the active roots depth of the crops within the system command area, during an actual irrigation season. This volume is considered to be consumed integrally by evapotranspiration, [m^3/month or season];

Vo – actual net irrigation water volume required by the crops within the same command area during the irrigation season, calculated for 50% probability, [m^3/month or season];

Vmax –(Vo) corresponding to 80% probability level, accepted on the system design phase,[m^3/month or season].

In view of the above, the actual water demand (D) is involved in the following relationships:

- *Water use efficiency in the irrigation system* as has been demonstrated (Nicolaescu 1992, 1994):

$$Es = \left(\frac{1}{Ea \cdot Ed} + \frac{Vk}{Vr}\right)^{-1} \quad \text{.....(3.1)}$$

or

$$Es = \left(\frac{1}{Ea \cdot Ed} + \frac{v_k \cdot \sum_m^n T_j}{D \cdot S \cdot \sum_m^n I_j} \right)^{-1} \qquad (3.2)$$

where:

Es – overall water using efficiency of the irrigation system;
Ea – field water application efficiency;
Ed – water distribution efficiency within the irrigation plot (on farm);
Vk – volume of water that is lost along the conveyance network by seepage and operational mismanagement losses, during a defined period (month, season);
v_k – the monthly water volume that is lost along the conveyance network, considered to be constant for each month of the irrigation season (m^3/month);

$\sum_m^n I_j$ - net irrigation water demand for a specific crop on month (j) corresponding to 50% probability [m^3/ha.month(j)];

$\sum_m^n T_j$ – chronological months of irrigation system operation $\in$ [April, September];

m – the start operation month;
n – the end operation month;
j –index of the month $\in$[m, n];
S – total irrigation command area of the system [ha].

- *Energy demand for pumping water in the irrigation system*, from the water source to the soil reservoir, E [kWh/ha]:

$$E = e_o \frac{D \cdot \sum_m^n I_j}{10^3 \cdot Es} \qquad (4)$$

where:

e_o – unit-pumping energy computed as the weighted average of all pumping stations within the irrigation system [kWh/1000 m^3 of pumped water], which is:

$$e_o = \frac{\sum_{i=1}^{N} (s \cdot e_o)_i}{S} \quad \text{......} (4.1)$$

N – total number of pumping stations;
s_i – served area by "i" pumping station [ha];
$(e_o)_i$ – unit energy consumed by "i" pumping station [kWh/1000 m^3 of pumped water], calculated with formula:

$$(e_o)_i = 2{,}725 \times \left(\frac{H}{E_p}\right)_i, \quad \text{......} (4.2)$$

H_i – total dynamic pumping head [m of water column];
E_{pi} – pumping station operation efficiency.

- *Relation between the increment of the crop yield (y) and net applied irrigation water* $\left(\sum_m^n I_j\right)$ is a power function type of:

$$y = \alpha \cdot \left(\sum_m^n I_j\right)^\beta \quad \text{......} (5)$$

where:
y – is expressed in kg/ha;
α, β – are individual crop statistical parameters which have been established on the basis of research data for at least ten years of investigation, where $\beta \leq 1$. The influence of (D) on the yield increment value accepted to be:

$$y = \alpha \cdot D\left(\sum_m^n I_j\right)^\beta \quad \text{......} (5.1)$$

Economic input and output data involved in the achievement of agricultural yield increment (y), for each individual crop, are:

- Ca – total supplementary agricultural inputs induced by the technology of irrigated crop, like: seeds, fertilizer, pesticides, extra yield harvesting and transportation etc. [currency units/ha];
- Ci – O&M of the irrigation system, including water applications to the crops, not including the pumping energy cost [currency units/ha];
- C_E – total cost of energy for pumping water [currency units/ha];
- p_e – electric energy unit price [currency units/kWh];
- p_c – unit price of the crop yield sold at the farm-gate [currency units/kg].

Taking in account the involved parameters in relations (2), (3.2), (4), (5.1) and last economic data, the initial condition is rewritten as:

$$\frac{B}{C} = \frac{p_c \cdot D \cdot y}{Ca + Ci + p_e \cdot E} > 1 \qquad (1.1)$$

Finally, at the limit B = C it is achieved the equation of the model, expressed by:

$$Dmin = \frac{\dfrac{10^3}{e_o \cdot p_e} \cdot (Ca + Ci) + \dfrac{v_k \cdot \sum_m^n T_j}{S}}{\sum_m^n I_j \left[\dfrac{10^3}{e_o} \cdot \dfrac{p_c}{p_e} \cdot \alpha \cdot \left(\sum_m^n I_j \right)^{\beta - 1} - \dfrac{1}{Ea \cdot Ed} \right]} \qquad (6)$$

INVOLVING THE MODEL ON REHABILITATION AND MODERNIZATION ACTIONS

It is understandable that an irrigation system becomes more efficient as (Dmin) tends to decrease. In conformity with the model expressed by function (6), this means to minimize the value of the numerator and to maximize the denominator. In order to perform, these conditions should be applied three categories of scenarios, namely:

a) *Rehabilitation an Modernization Actions* involving the following trends concerning the modification of the main parameters:

- $v_k \rightarrow 0$; $Ea \rightarrow 1$; $Ed \rightarrow 1$, for decreasing irrigation water losses throughout the entire hydraulic way in the system;
- $e_o \rightarrow$ *minimum*, for decreasing the water pumping energy consumed by all pumping stations of the system.

b) *Agroeconomical Strategy Actions* applied on the level of entire irrigation system;

- $Ca \rightarrow$ *minimum*, by practicing modern agricultural technologies;
- $\alpha \rightarrow$ *maximum*; $\beta \rightarrow 1$; $p_c \rightarrow$ *as high as possible*, by a proper actual agricultural policy especially the selection of the most efficient and adequate crops.

c) *Institutional Actions*, by promoting the farmers training and increasing the participation degree of them on all stages of the irrigation system life:

- $Ci \rightarrow$ *minimum*; $p_e \rightarrow$ *as low as possible*.

Evidently, these three categories of interventions are interrelated and are desirable to be in a full harmony among them concerning application of the (Dmin) concept. Nevertheless, the rehabilitation and modernization's works represent the most important actions to be done in achieving the maximum potential efficiency of an existing irrigation system. There is a wide range of actions to be implemented for restoration of the system to its original capability by "rehabilitation" or to exceed this one by "modernization" (Replogle, 1999).

On this reason, in table 1 are presented the most important and typical R&M actions for large irrigation schemes depending on the final goals: to save water, pumping energy and labors, and to protect the environment.

Model application to a given irrigation system can be done respecting the following conditions:

- no governmental subsidies;
- entire command area of the system is cultivated with a single crop;
- performance parameters of the system are known for actual stage and evaluated after implementation of every individual type of R&M action;
- a certain water demand minimum level of the potential users after R&M must be established.

The model has been applied to Mihail Kogalniceanu irrigation scheme that is situated on Central Dobrogea zone – one of the driest areas in Romania.

Potential Actions which Might be Applied for the Rehabilitation and Modernization of a Large Irrigation System — Table 1

Main roposal to save:	Code of actions / Scope of actions	Assessment of the principal actions	Performance parameter to be modified
IRRIGATION WATER	W1 / on irrigation plot (on-farm)	improve the water application method or replace it with a better one replace the old irrigation equipment with the modern equipment/installations adapt agricultural technologies to new irrigation method or equipment/installation practice the runoff re-use system	Ea
		replace the open unlined canals with buried pipes line canals control the flow rate and pressure install drainage if this is necessary	Ed
	W2 / on hydraulic convey network	line canals replace the terminal canals with low pressure buried pipes introduction of the automatic control on the network introduce modern devices facilities to measure delivered water	v_k
	W3 / on entire irrigation system	W1 + W2	Ea, Ed, v_k
PUMPING ENERGY	E / on the pumping stations	replace the old and used pump units with modern units decrease the hydraulic head losses introduction of the automatization proceedings on operation of pumping stations decrease the operation pressure of pumping stations in the irrigation plots	e_0

This system is supplied with water from the Danube - Black Sea Canal by a main pumping station. Along the hydraulic open canals of the scheme, there are six repumping stations for lifting water up to the land terraces. The scheme area is divided into 33 irrigation plots, each one having its pressure pumping station. The actual data for model application are:

- S = 23,141 ha; $v_k = 7.8 \times 10^6$ m^3/month; $e_o = 732$ kWh/1000 m^3;
- Ea = 0.75; Ed = 0.92; Ea x Ed = 0.69; $p_e = 0.055$ \$/kWh.

The application conditions of the (Dmin) model to this case study, the R&M types of actions and the results are presented in Table 2 and Figure 1.

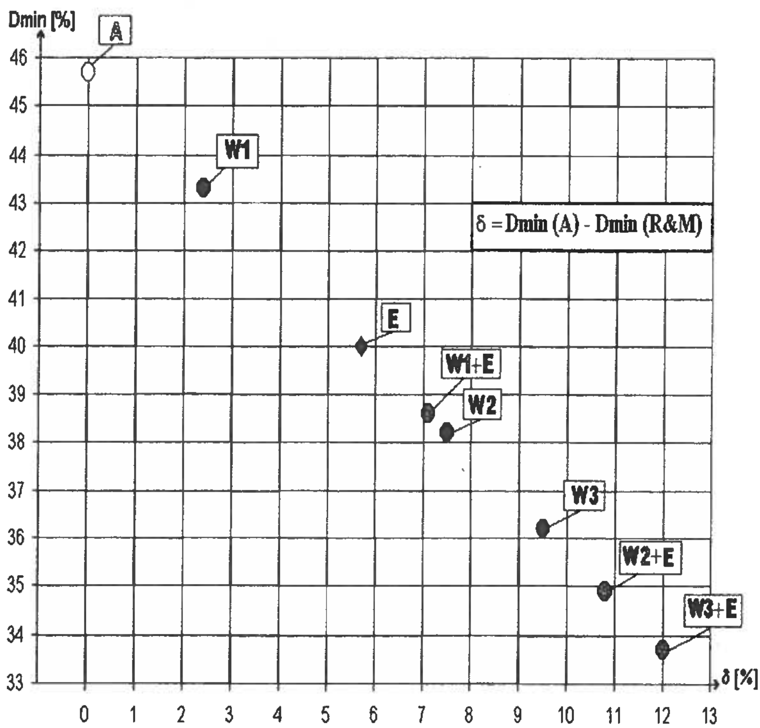

Fig.1. Decreasing Difference Rate (δ) Between the Actual Water Demand Minimum Level and Any of the Seven R&M Actions Applied to Case Study

Basic Data of the (Dmin) Model Testing and Obtained Results for Case Study (Mihail Kogalniceanu Irrigation System) Table 2

Main goals of R&M actions									Actual (no R&M)	Water Saving			Energy saving	Water & Energy Saving		
Cod of R&M action									A	W1	W2	W3	E	W1+E	W2+E	W3+E
Ea									0.75	0.90	0.75	0.90	0.75	0.90	0.75	0.90
Ed									0.92	0.95	0.92	0.95	0.92	0.95	0.92	0.95
v_k [10^6 m^3/month]									7.8	7.8	1.7	1.7	7.8	7.8	1.7	1.7
e_o [kWh/ 1000 m^3]									732	732	732	732	534	534	534	534
No	Crop	Cropping pattern %		α	β	p_c $/kg	Ca+Ci $/ha	ΣI m^3/ha	Dmin (%) for T =3 months operation time:							
		(a)	(b)						A	W1	W2	W3	E	W1+E	W2+E	W3+E
1	Grain Corn	40	30	81	0.55	0.103	121.31	2463	34.6	32.7	27.8	26.3	29.8	28.6	25.2	24.2
2	Corn Forage	(30)	(20)	234	0.65	0.020	122.10	760	46.8	45.5	41.5	40.4	43.3	42.4	39.6	38.8
3	Sugarbeet	6	10	90	0.72	0.042	104.50	2752	14.9	14.5	11.7	11.3	13.2	12.9	10.9	10.7
4	Soybean	6	5	29	0.53	0.267	118.83	1829	51.8	48.5	41.4	38.8	44.1	42.2	37.2	35.6
5	Sunflower	7	10	298	0.20	0.256	116.58	2100	68.5	62.1	54.6	49.5	55.6	52.2	46.8	43.9
6	Wheat	(30)	(20)	47	0.54	0.140	115.12	700	73.1	70.1	64.5	61.9	66.2	64.3	60.2	58.5
7	Potatoes	1	5	55	0.74	0.156	106.05	2394	5.7	5.6	4.5	4.4	5.2	5.2	4.3	4.3
8	Alfalfa	10	20	93	0.72	0.020	128.10	2071	50.7	47.3	41.1	38.4	43.1	41.2	36.8	35.1
Dmin (%) calculated as weight average of cropping pattern							(a)		45.7	43.3	38.2	36.2	40.0	38.6	34.9	33.7
							(b)		43.7	41.2	36.1	34.0	37.8	36.4	32.7	31.5

* T = 1,5 months

[blank box] - actual values (A)

[shaded box] - modified values after R&M actions

REMARKS AND CONCLUSIONS

i. *the sort of the field crop has the highest influence on the (Dmin)* value through its profitable effect due to irrigation, i.e. potatoes and sugarbeet; grain corn and corn forage; alfalfa and soybean; sunflower and wheat;

ii. *the cropping pattern type including a large number of varied crops has a smaller influence on the (Dmin) value.* In this situation, the (Dmin) is mostly dependent by the technical and economical performances of the irrigation system. As can be noted, the calculated value of (Dmin) accordingly with the actual stage of the case study irrigation system is 43.7 and 45.7%, for two types of cropping pattern (b, a);

iii. *rehabilitation & modernization actions have a wide range of the potential effects on the (Dmin),* decreasing its values from the actual (43.7% - 45.7%) to the most efficient R&M actions (31.5% - 33.7%);

iv. according to the seven selected actions for this case study on the base of (Dmin) analyses, *the effect of R&M is increasing on the following rating*:
(W1) → (E) → (W1+E) → (W2) → (W3) → (W2+E) → (W3+E);

v. *the strategy of R&M actions is dependent above all by the guarantee of achieving a specific water demand level (D), after the implementation of rehabilitation and modernization works.* In the situation when the real (D) is less than (Dmin) specific for a type of R&M actions, the irrigation system is not capable to generate profit and the investment in R&M works could not be paid off in useful time. Under this conditions, because the actual (D) of the case study is below 25%, there is not any R&M actions economically justified to be implemented on this irrigation system. As has been previously mentioned, there are needs to increase the actual water demand (D) to the following guaranteed limits:

→ D = 40%, is able to justify the implementation of the R&M actions for:
- water saving (W2; W3) and environment protection;
- saving water and pumping energy (W1+E; W2+E) and environment protection;
- saving pumping energy (E) without protection of the environment;

→ D = 35% is capable to justify economically only two of the R&M actions (W2+E; W3+E), involving the highest values of the investment.

vi. in order to perform a specific guaranteed limit of the irrigation water demand (D) after R&M, it has to provide the institutional, social and agroeconomical policy actions which are the most suitable for a given irrigation system.

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