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Validation of Applying Simulation Models for Different Irrigation Systems: Review Article

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Abstract

In Egypt, agriculture is shaped by two goals. The first goal is maximum national production per unit area and the second goal is maximum production per cubic meter of water. Therefore, this strategy relates the utilization of national resources, soil and water, and to do this in a proper way we need tools and technologies which will allow to develop these resources in a suitable manner. The design and managing of irrigation systems must have its base in criteria that are relevant, which implies to take into account agronomic, soil, hydraulic, economic, energetic, and environmental factors. The optimal design and managing of irrigation systems at farm level is the first important factor for a rational use of water, economic development of agriculture and its environmental sustainability. Computer simulation models have the potential to improve the efficiency of irrigation systems and thus deliver significant water savings. This can be achieved by optimizing the design and management decisions at the field level. Irrigation simulation models are useful tools both at the design and management stages of irrigation systems. When used for irrigation design purposes, simulation models help to optimize irrigation variables such as field slope, length of the field and the design flow rate...etc. These models can aid the designer in making decisions as to the appropriate values of variables that produce the best performance. This is mostly applicable to newly established fields or when converting from one irrigation system to another. In the majority of the irrigation simulation models currently in use, previous field characteristics are used to optimize future irrigations. However, numerous researchers have established that these characteristics change both with time and space, and hence the accuracy of such models may be affected. Therefore, the aim of this article is to analyse knowledge and investigations that enable to identify the principal criteria and processes that allow improving the design and managing of the irrigation systems, based on using irrigation systems simulation models to develop agriculture more efficient and sustainable, as well as using them as a tool for farmers, researchers, and decision makers.

Keywords: Validation process, Irrigation systems, SALTMED, SIRMOD, G-Pipe, Simulation models.

1. Introduction

What is Simulation Model?

A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Also, a model is “A representation of an object, system or idea in some form other than that of the entity itself”. Its purpose is usually to aid in explaining, understanding or improving performance of a system. A model is, by definition “A simplified version of a part of reality, not a one to one copy”. This simplification makes models useful because it offers a comprehensive description of a problem situation [1].

Simulation is defined as “Reproducing the essence of a system without reproducing the system itself”. In simulation the essential characteristics of the system are reproduced in a model, which is then studied in an abbreviated time scale [2]

What are Models Types?

Depending upon the purpose for which it is designed the models are classified into different groups or types. Kuhne [3] reported a few of them are:

a. Statistical models: These models express the relationship between independent components and dependent parameters. In these models relationships are measured in a system using statistical techniques.
b. Dynamic models: Time is included as a variable. Both dependent and independent variables are having values which remain constant over a given period of time.

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c. Static: Time is not included as a variable. Dependent and independent variables having values remain constant over a given period of time.

d. Simulation models: Computer models, in general, are a mathematical representation of a real world system.

What are the Theory of Simulation Models and its Validation?

Figure 1 illustrates a Real World and a Simulation World. We first discuss the Real World. System or problem entity exists in the real world of which an understanding of it is desired. System theories describe the characteristics and the causal relationships of the system (or problem entity) and possibly its behavior (including data). System data and results are obtained by conducting experiments (experimenting) on the system. System theories are developed by abstracting what has been observed from the system and by hypothesizing from the system data and results [4].

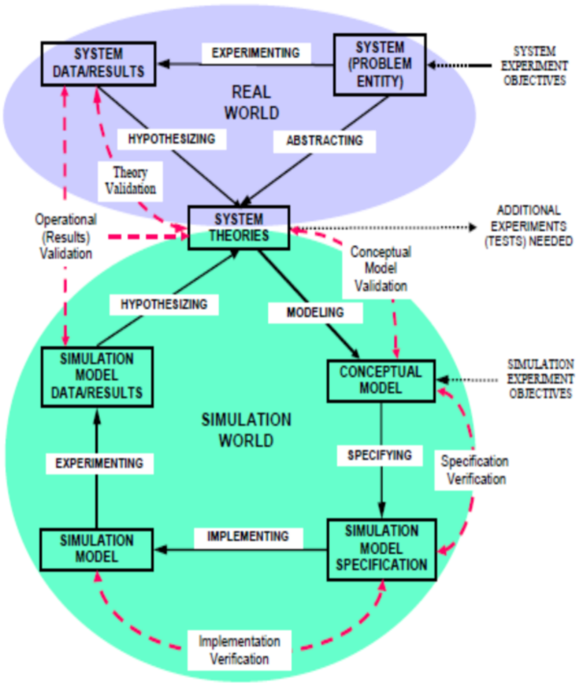


Fig 1: Real World and Simulation World Relationships with Verification and Validation.

If a simulation model exists of this system, then hypothesizing of system theories can also be done from simulation data and results. System theories are validated by performing theory validation. Theory validation involves the comparison of system theories against system data and results over the domain the theory is applicable for to determine if there is agreement. This process requires numerous experiments to be conducted on the real system.

The Simulation World shows a slightly more complicated model development process than the previous paradigm (Fig. 1). A simulation model should only be developed for a set of well-defined objectives. The conceptual model is the mathematical/logical/verbal representation (mimic) of the system developed for the objectives of a particular study. The simulation model specification is a written detailed description of the software design and specification for programming and implementing the conceptual model on a particular computer system. The simulation model is the conceptual model running on a computer system such that experiments can be conducted on the simulation model. The simulation model data and results are the data and results from experiments conducted (experimenting) on the simulation model. The conceptual model is developed by modelling the system for the objectives of the simulation study using the understanding of the system contained in the system theories. The simulation model is obtained by implementing the model on the specified computer system, which includes programming the conceptual model whose specifications are contained in the simulation model specification. Inferences about the system are made from data obtained by conducting computer experiments (experimenting) on the simulation model.

According to Rafea and Shaalan [5] validation is the process of evaluating software at the end of the software development process to ensure compliance with software requirements. This process aims at making sure that the software is valid from the point of view of the domain expert.

Wentworth *et al.* [6] indicated that validation is the process of determining that the system actually fulfils the purpose for which it was intended in such a way that it answers the question "is it the right system?", "is the knowledge base correct?" or :is the program doing the job it was intended to do?".

What is Validation Technique?

Predictive Validation: The model is used to predict (forecast) the system's behaviour, and then comparisons are made between the system's behaviour and the model's forecast to determine if they are the same. The system data may come from an operational system or be obtained by conducting experiments on the system, e.g., field tests [4].

As mentioned before, to build a conceptual model we must have sufficient data on the problem entity to develop theories that can be used to build the model, to develop mathematical and logical relationships for use in the model that will allow the model to adequately represent the problem entity for its intended purpose, and to test the model's underlying assumptions. In addition, behavioural data are needed on the problem entity to be used in the operational validity step of comparing the problem entity's behaviour with the model's behaviour.

There are two basic approaches used in comparing the simulation model output behaviour to either the system output behaviour or model output behaviour: 1. the use of graphs to make a subjective decision, and 2. the use of confidence intervals to make an objective decision. It is preferable to use confidence intervals tests for the comparisons because these allow for objective decisions. So, the use of graphs and statistical confidence tests (t-test, correlation and regression) are the most commonly used approach for simulation model operational validity.

Validation of some irrigation systems simulation models

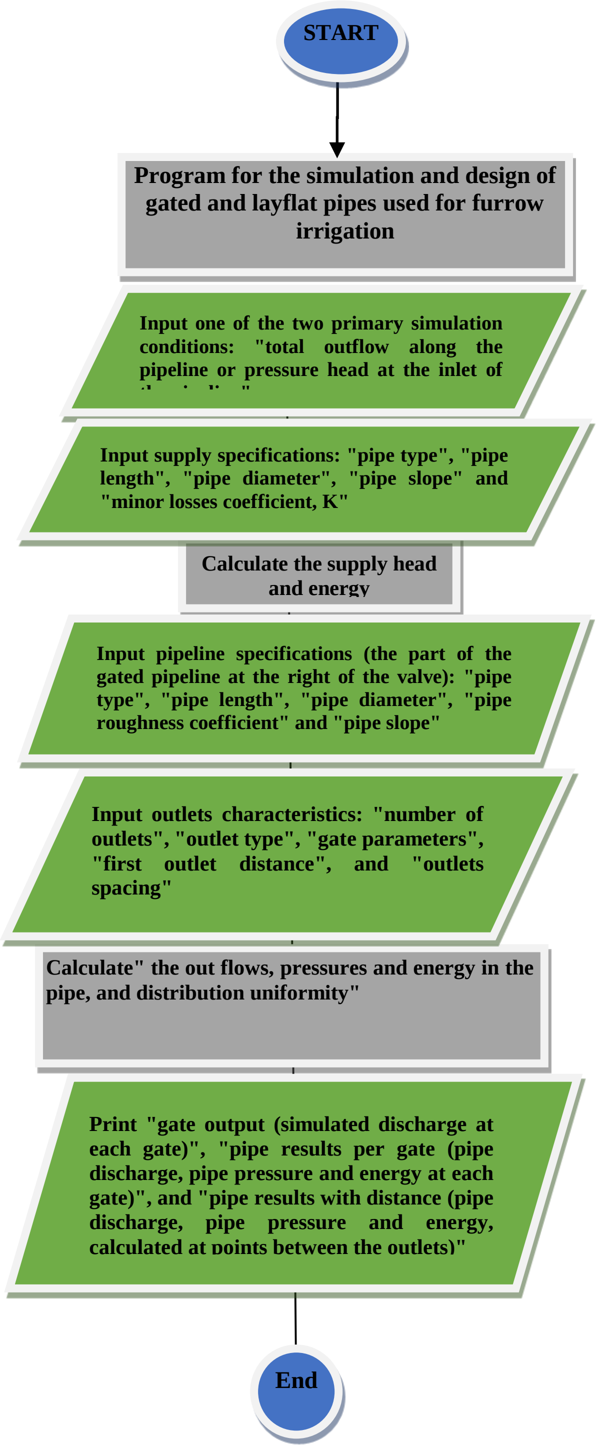
In this part some irrigation systems simulation models and its validity will be presented and their validity will be discussed.

1. G-Pipe Simulation Model:

Gated pipes are usually constructed of aluminium or light weight steel tubing. Small slide gates are spaced along the side of the pipe. The gate is often placed in a rubber-gasket, which provides a water lubricated bearing surface for the slide. A water flow can be regulated by the degree the gates are opened. Gated pipe is usually manufactured in lengths of about 6 meters. Individual pipes can be connected to each other with clamp coupling to assemble a system of the length required.

There are many engineering factors affecting gated pipes water distribution rates and uniformity, Morcos *et al.* [7] concluded these factors as: the length of the gated pipe, the inside gated pipe diameter, the suitable orifice diameters required to discharge the flow rate needed from each orifice, the number of orifices operating simultaneously, the orifice spacing drilled along the gated pipe, the orifice Reynold's number and coefficient of discharge for orifice along the gated pipe system, the roughness of the inside walls of the pipe line, the maximum flow rates of irrigation water to be conveyed by the pipe line, and the pressure head of irrigation water at piping system inlet.

G-Pipe simulation model has been developed which aims to simulate water distribution along the pipeline of the irrigation system for making a decision to select the optimal specification of the irrigation system [8].



Flow chart 1: Components of G-Pipe simulation model program for simulating outflow and pressure at gates along the pipeline of gated pipes irrigation system.

1.1. Description of G-Pipe Simulation Model:

Flow chart 1 shows the steps of running G-Pipe simulation model to get the required outputs. G-Pipe offers two different options for specifying the pipe characteristics, termed Normal and Advanced input modes, Figure 2. The normal input option is activated

by default when G-Pipe is started. If you want to specify different dimensions/characteristics for each outlet you need to move to the advanced input screen. In this mode you must add each outlet individually and then specify the parameters of each outlet. The pipe characteristics for each segment of the pipe refer to that section of the pipe between that outlet and the next upstream outlet. You may access each pipe segment by clicking on the screen or entering a number into the Selected Segment box. This screen has the advantage that you can custom build your pipeline and accesses any individual outlet quickly.
G-Pipes Simulation Model Outputs:

When the simulation is complete G-Pipe offers several outputs:

a. Pipe drawing, Figure 3.
b. Pipe results per gate, Figure 4.
c. Gate output, Figure 5.
d. Pipe Results with Distance, Figure 6.

1.2. Validation of G-Pipe simulation model:

Mehanna [9], and El-Noemani *et al.* [10] validated G-Pipe simulation model under different field conditions such as pipeline length and field slope, they indicated that G-Pipe simulation model is acceptable to predict outflow and head pressure from each gate, by comparing measured and predicted head and flow rate at each gate, using outflow primary input. These results were in the same concern with El-Awady *et al.* [11].

2. SIRMOD Simulation Model:

SIRMOD (surface irrigation simulation, evaluation and design) is a comprehensive simulation software package for simulating surface irrigation hydraulics. SIRMOD [12], developed by Utah State University, has been widely accepted as the standard for the evaluation and optimization of furrow irrigation and can also be used to simulate basin and border irrigation [13] [14]. The software is based on the full hydrodynamic model but is also capable of applying the volume balance model to determine the infiltration characteristics of an irrigated furrow from two points on the advance curve. As a design tool, SIRMOD is used to predict the irrigation performance under alternative field parameters (length and slope).

2.1. Description of SIRMOD Simulation Model:

The SIRMOD model simulates the hydraulics of surface irrigation (border, basin and furrow) at the field level. The simulation routine used in SIRMOD is based on the numerical solution of the Saint-Venant equations for conservation of mass and momentum as described by Walker and Skogerboe [15]. Flow chart 2 shows the steps of running SIRMOD.

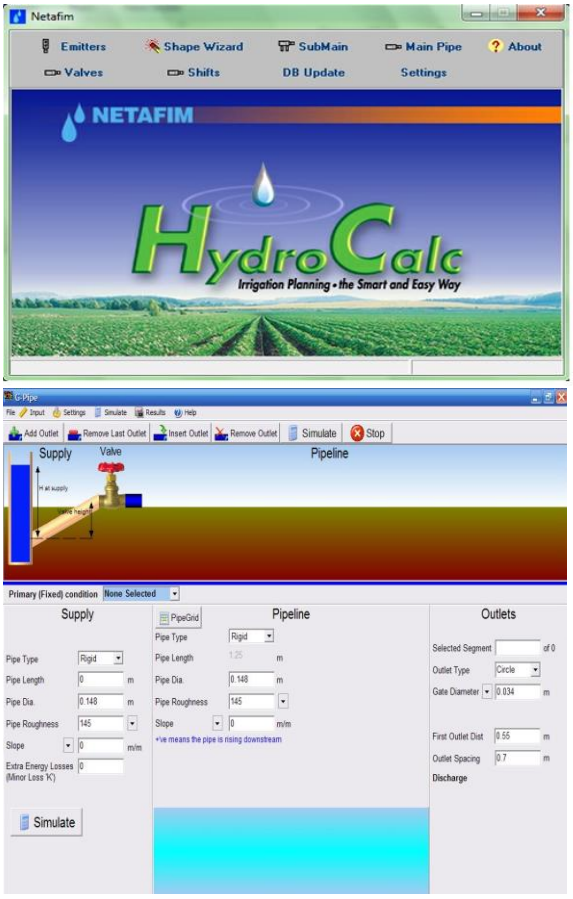


Fig. 2: The normal input screen.

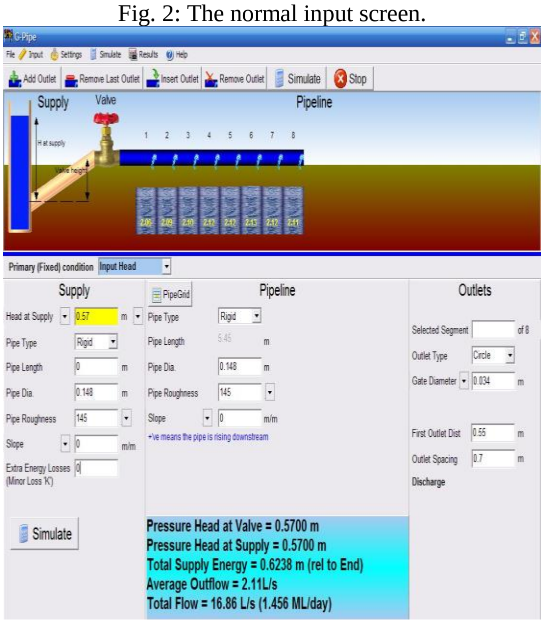


Fig. 3: The stimulation screen.

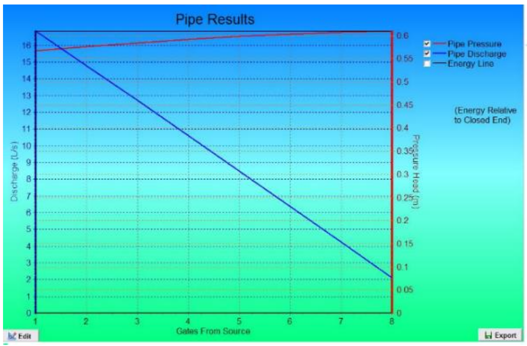


Fig. 4: Pipe results per gate screen.

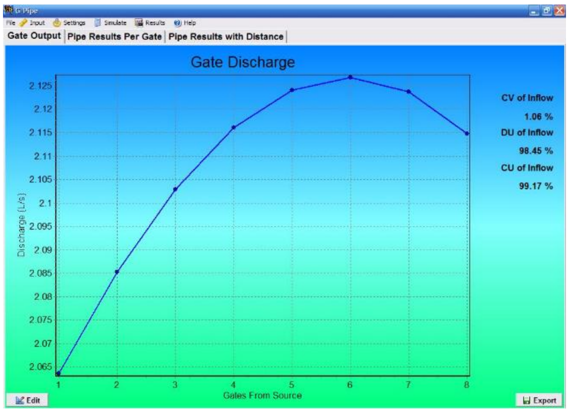


Fig. 5: Gate output screen.

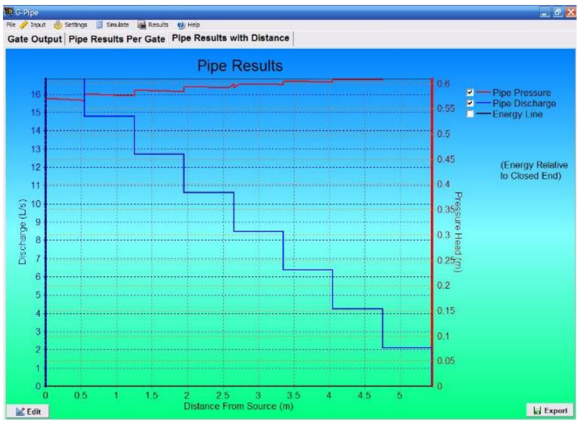


Fig. 6: Pipe results with distance screen.

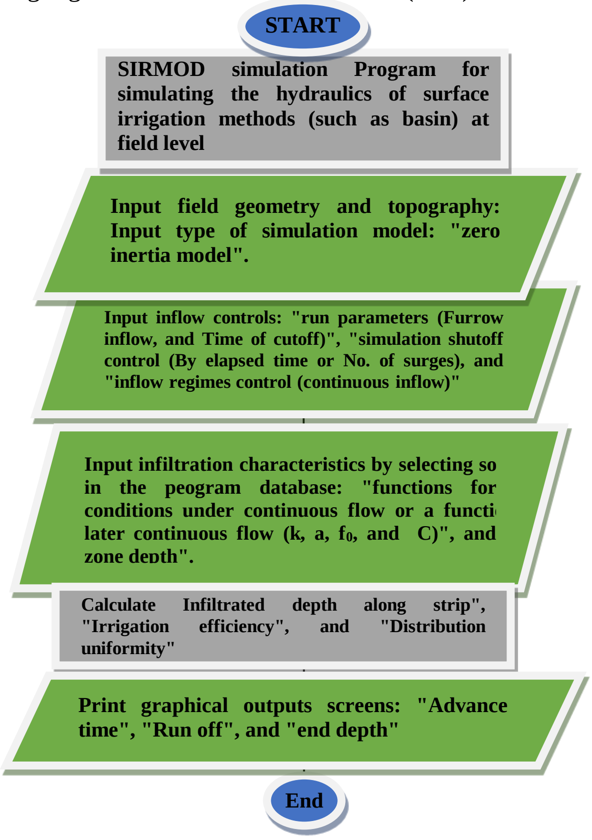
Inputs required for the model to simulate an irrigation event include the infiltration characteristic, hydraulic resistance (Manning's n), furrow geometry, furrow slope, furrow length, inflow rate and advance cut-off time Figures 7 and 8. These inputs have also been found to be the most sensitive in the SIRMOD model. Infiltration characteristics of a furrow are represented in the SIRMOD model with the Kostiakov-Lewis infiltration equation Figure 9, which is given by: $Z = k\,t^a + f_0\,t$

Where Z is cumulative infiltration (m^3/m); t is the time (min) that water is available for infiltration; a, k are fitted parameters; and f_0 ($m^3/min/m$) is the steady or final infiltration rate [14]. Infiltration characteristics can be determined from the furrow advance rate as described by McClymont and Smith [16] Figure 10 which is the output of SIRMOD.

2.2. Validation of SIRMOD Simulation Model:

Hornbuckle *et al.* [17] The SIRMOD simulation model was found to adequately predict furrow irrigation characteristics on irrigation layouts and soil conditions. Comparisons of infiltrated volumes predicted by SIRMOD with measured infiltrated volumes gave a strong relationship providing confidence that SIRMOD was able to adequately model furrow irrigation systems. The same results were found also by Koech *et al.* [13]; Behbani and Babazadeh [18]; and Mousavi and Boroomand-Nasab [19].

Mehanna *et al.* [14] and [20] indicated that by running the SIRMOD model under different Egyptians filed conditions, such as clay and calcareous soils, furrow length, and field slope, accepted predications were obtained by comparing the measured and predicted application efficiencies of furrow and basin irrigation methods. These relationships were described by linear equations with strong regression and correlation values (>0.9).



Flow Chart 2: Components of SIRMOD simulation model program for simulating the hydraulics of surface irrigation at field level.

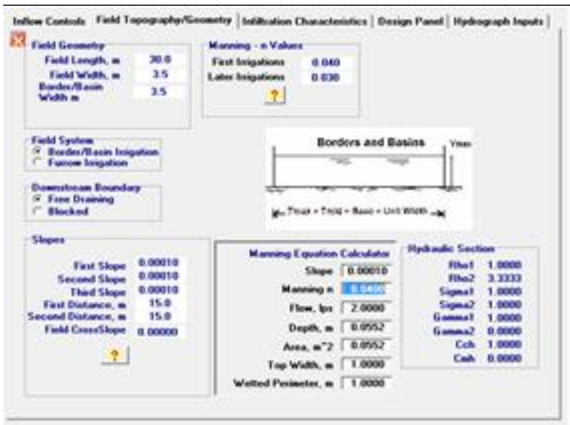


Fig. 7: Field topography input

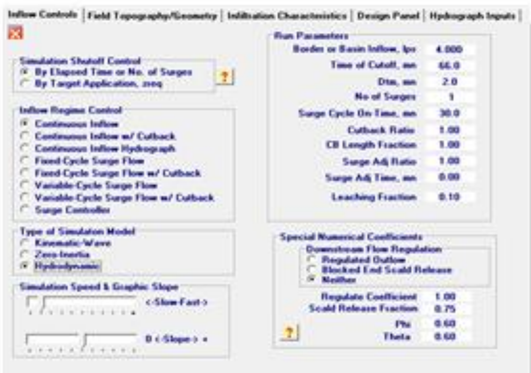


Fig. 8: Infiltration characteristics input.

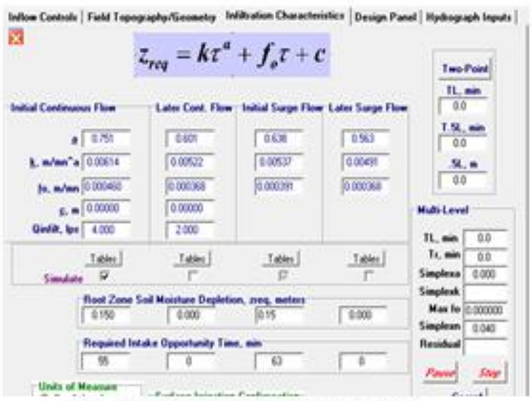


Fig. 9: Infiltration characteristics input.

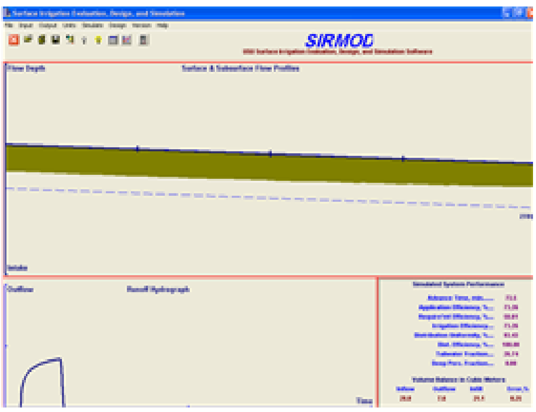


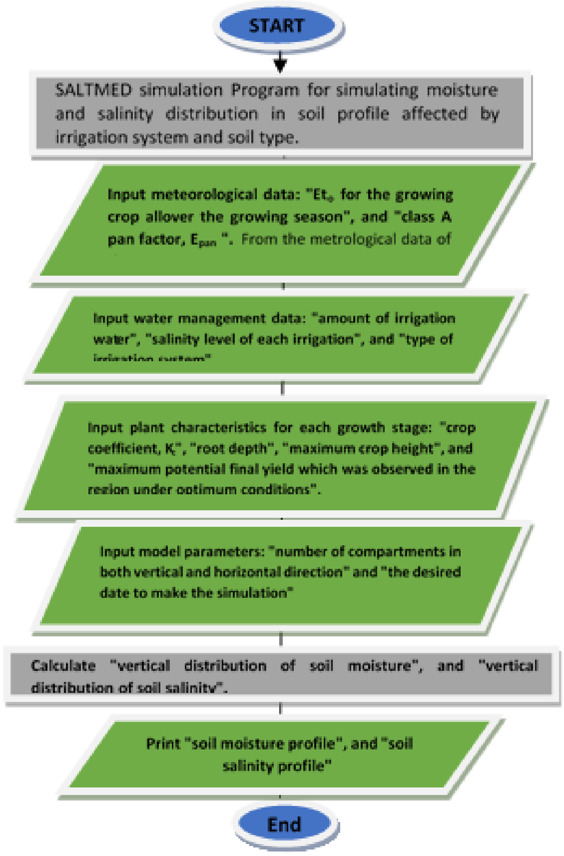
Fig. 10: Output screen.

3. SALTMED Simulation Model:

Ragab [21] indicated that there is a shortage in models of a generic nature, models that can be used for a variety of irrigation systems, soil types, soil stratifications, crops and trees, water management strategies, leaching requirements and water quality. He developed SALTMED model for such generic applications. The model employs established water and solute transport, evapotranspiration and crop water uptake equations. The model has been run with five examples of applications for one growing season using data from the literature. The model successfully illustrated the effect of the irrigation system, the soil type, irrigation and irrigation salinity level on soil moisture and salinity distribution, leaching requirements, and crop yield.

3.1. Description of SALTMED Simulation Model:

As shown in Flow chart 3 the model successfully predicted the impact of salinity on yield, water uptake, and soil moisture and salinity distribution with reasonable degree of accuracy. The model provides the academics with a research tool and field managers with a powerful tool to manage their water, crop and soil in effective way to save water and protect the environment Figures from 11 to 17.



Flow chart 3: Components of SALTMED simulation model program for simulating moisture and salinity distributions in soil profile affected by irrigation system and soil type.

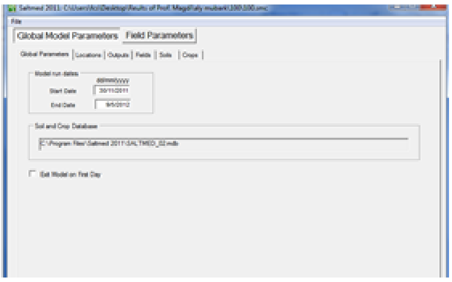


Fig. 11: The main window for the global model parameters

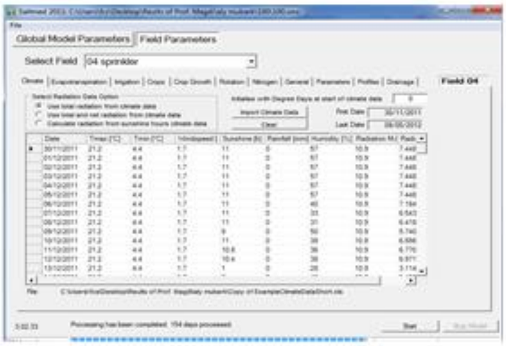


Fig. 12: Field parameters window (from the left - Climate data).

Fig. 13: Evapotranspiration window data.

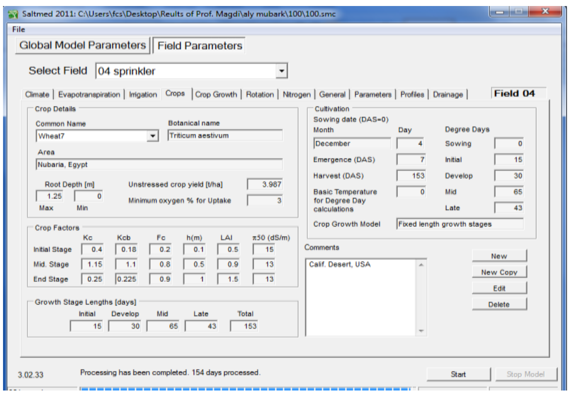


Fig. 14: Crop parameters window..

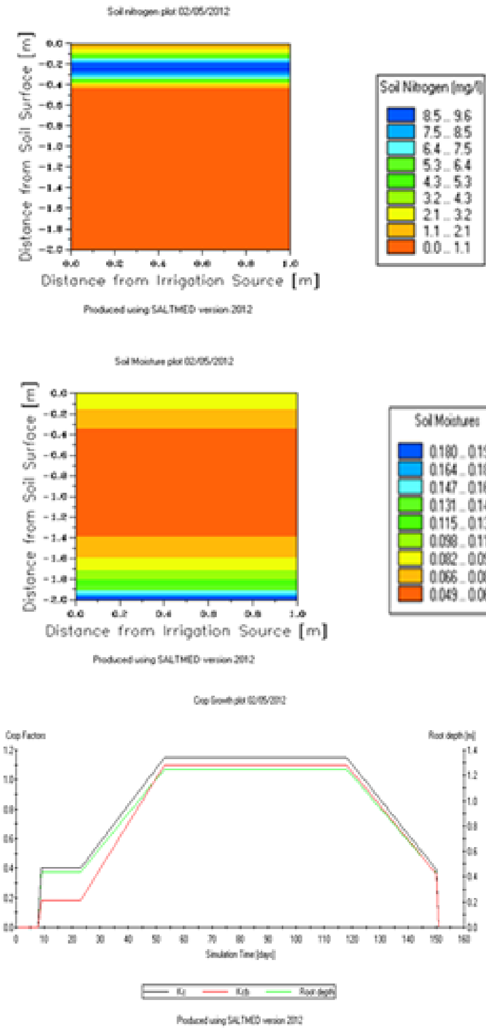


Fig. 17: SALTMED outputs.

3.2. Validation of SALTMED Simulation Model:

Malash *et al.* [22]; Hajnajib *et al.* [23]; Pulvento *et al.* [24]; Hirich *et al.* [25] and Mehanna [10] reported that the SALTMED model is a good tool to help in the management of water irrigation as well as the fertilizers (future studying aim) under different field conditions of different irrigation systems. The model was able to successfully simulate yield, soil moisture, and salinity profiles to give a sight of what will happen in the soil by using different arguments in the farm and the effect of them on the yield to the farm managers or farmers for deciding the proper amounts of irrigation water and fertilizers amounts. Finally, the right decisions will reduce costs and increase the income.

Summary & Conclusion

Irrigated agriculture has always been dependent on the conservation of natural water resources through storage dams for surface water use. Countries with a semi-arid and arid climate depend heavily on adding water for different crops using irrigation systems. For these countries, a water conservation plan is a necessity, not only for the purpose of saving water, but also for better management of the irrigation water in order to match the crop water requirement, and to guarantee a better yield.

Irrigation systems should be a relevant agent to give solutions to the increasing demand of food, and to the development, sustainability and productivity of the agricultural sector. The design, managing, and operation of irrigation systems are crucial factors to achieve an efficient use of the water resources and the success in the production of crops and orchards. This can be achieved by optimizing the design and management decisions at the field level. So, there are many computer simulation models have the potential to improve the efficiency of irrigation systems and thus deliver significant water savings. Moreover, validation is the process of evaluating software at the end of the software development process to ensure compliance with software requirements. This process aims to make sure that the software is valid from the point of view of the domain expert.

Many Researchers worked on this concern to validate many irrigation systems simulation models, such as Hydro-Calc, G-Pipe, SIRMOD, and SALTMED. They mentioned that these simulation models are good tools for making the appropriate decisions for design, management, as well as water saving for used irrigation systems under different Egyptians field conditions.

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