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WATER USE EFFICIENCY IN IRRIGATED AGRICULTURE: AN ANALYTICAL REVIEW

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SUMMARY – The growing water scarcity and the misuse of available water resources are nowadays major threats to sustainable development for most developing arid and semiarid countries of the Mediterranean. For most countries of the region, the important role agriculture could play in not only feeding and clothing burgeoning population is well recognized, but also in increasing the limited available water supply by reducing water losses and by increasing the water use efficiency in the irrigation sector. Avoiding water conflicts among the water user sectors, achieving water security and food security is fundamentally a matter of water use efficient rate in the irrigation sector. The importance of efficiency in water use clearly varies across regions and nations as well as through time. The prevailing geographic, economic and social conditions of the nation play an important role in examining the efficient use of water. In agriculture, water use efficiency may be defined quite differently by a farmer, a manager of an irrigation project, or a river basin authority. Efficiencies in the use of water for irrigation consists in various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential in making most effective use of this vital and scarce source in the Mediterranean agriculture areas. This what will be addressed in the presented analytical review paper.

Key words: water use efficiency, definitions, irrigation.

INTRODUCTION

Water scarcity has been reflected in traditional social and economic systems in arid areas of the Mediterranean region. During the past thirty to forty years, population growth, urbanization and economic development have depleted the region's economically exploitable water resources. Water scarcity, exacerbated by water quality deterioration and the lack of effective water management, has become a major problem in several arid countries, and even in the humid ones.

Water shortage is not a new phenomenon in the Mediterranean countries. What is new, however, is that it is occurring in an increasingly changed environment and this makes it more serious and long-lasting. The most recent droughts in the summers of 1989 and 1990 marked a turning point. They highlighted the vulnerability of water supplies even in the industrialized northern Mediterranean countries which had always relied on adequate per capita of rainfall.

Water crisis is endemic or permanent in some southern Mediterranean areas, but it has now even reached towns and villages in France, Spain, Italy and Greece, obliging them to impose temporary restrictions. The shortfall in quantity has been compounded by a decrease in quality due to contamination of surface or underground water.

Why scarcity emerges as a major problem in most of arid and semi-arid countries of the Mediterranean?

The answer to this question implies several reasons that could be outlined in the following:

- water withdrawals reach the physical limits of available natural water resources (Palestine, Israel, Egypt, Libya and Jordan);
- physical conditions make inter-basin transfers or development of deep aquifers to balance supply and demand very costly, often requiring special provisions for maintenance and operation combined with uncertainties regarding sustainability of the new sources (Morocco, Tunisia);
- low water production efficiencies due to low cost of water or weaknesses in the deployment of recent advances in technology (Algeria); and

- loss of affordable potable water because of pollution and environmental degradation.

Regardless of the specific causes, existing institutions are not amenable to cope with the spiralling increases in aggregate demands for water by municipal, industrial, tourist, and agricultural uses while preventing pollution.

WHAT IS EFFICIENT WATER USE?

The term water use efficiency originates in the economic concept of productivity. Productivity measures the same amount of any given resource that must be expended to produce one unit of any goods or service. Thus, water productivity might be measured by the volume of water taken into a plant to produce a unit of the output. In general, the lower the resource input requirement per unit, the higher the efficiency.

In any environmental resource context, however, the efficiency concept must be extended to include considerations of quality. Any effort to improve water use efficiency should be consistent with maintaining or improving water quality. Taking both quantity and quality into account, the following definition applies.

Water use efficiency includes any measure that reduces the amount of water used per unit of any given activity, consistent with the maintenance or enhancement of water quality.

The importance of efficiency in water use clearly varies across regions and nations, as well as through time. Geographically, for instance, water availability will condition the manner in which use patterns develop. Other things being equal, arid and semi-arid regions require a greater efficiency of water use than humid ones.

Economic conditions will often lead to greater or lesser water use efficiency. Many regions of the world have been assisted in their development through public financing of water development. While the benefits or costs of such projects in efficiency terms are often debatable, the main point here is that economic factors can influence water use efficiency.

Social conditions also play an important role in examining the efficient use of water resources. The literature reveals many areas where public education has led to conservation and better use of available water supplies.

Here it is of interest to report some of the definitions for efficient water use presented by several authors during the International Seminar on "Efficient Water Use", Mexico City (1991).

J. Bau (1991) affirms that the efficient water use consists in optimizing water use.
Walker, Richardson and Seveback (1991) pointed that efficient water use means optimizing water usage and ensuring efficiency in its use.

Arreguin (1991) stated that efficiency may be obtained by optimizing the use of water and infrastructures through active participation by users with a sense of social responsibility.

Gloss (1991) indicated that efficient water use should be considered from different points of view. There is absolute efficiency to use the least amount of water possible, economic efficiency, which seeks to derive maximum economic benefits, social efficiency which strives to fulfill the needs of the user community, ecological efficiency which guarantees natural resource conservation, and institutional efficiency which qualifies the function of an institution regarding its water related tasks. Depending on the conditions of each user system, these non-exclusive definitions can be achieved simultaneously.

The abovementioned definitions indicate that an examination of water use efficiency requires a multi-dimensional approach. In addition to the physical elements, social, economic and environmental factors must be carefully considered.

WATER USE EFFICIENCY IN AGRICULTURE

In agriculture, water use efficiency may be defined quite differently by a farmer, a manager of an irrigation project or a river basin authority. For example, on-farm irrigation efficiencies and project efficiencies may be low, but substantial water losses may infiltrate in the soil, recharge the acquifers and may be pumped up again for re-use, either in the same project area or in another downstream. Other losses, such as overland flow, may feed drainage systems or rivers, and may be pumped or diverted for re-use. By recycling losses, river basin efficiencies could become very high. The water saving gained from introducing new technologies would be restricted to saving in evaporation losses from wetted land surfaces and water puddles, and evaporation losses from non-beneficial vegetation, which may be substantially less than the savings experienced on the farm. Clearly, any water conservation project should be carefully appraised by using adequate geo-hydrological information to study the project's effect on the water balance in the river basin.

In water use a distinction should be made between technical efficiency and economic efficiency. On one hand, technical efficiency may be low in a project area, but may be high in the river basin if water is recycled. On the other hand, water losses in project area and recycling particularly when high pump lifts are involved may reduce economic efficiency.

Initial water losses may lead to undesirable effects, such as waterlogging and salinity. A third way to express water use efficiency is through production per cubic meter of water.

IRRIGATION EFFICIENCIES IN THE MEDITERRANEAN REGION

In the Mediterranean area irrigation represents 72% of the total water withdrawals. Irrigation is extremely water intensive. It takes about 1000 tons of water to grow one ton of grain and 2000 tons to grow one ton of rice.

Despite the high priority and massive resources invested in the water resources development, the performance of large public irrigation systems has fallen short to expectation in developing and developed countries of the Mediterranean area.

Competitive and inefficient use of limited regional water supplies by irrigated agriculture is a major threat to sustainability of water supplies. Very often the conveyance losses of conduits (unlined canals or leak pipes) are much too large, a 30% loss percentage of the available water is common in irrigation systems.

Another cause of inefficient water use is the emphasis on meeting demand by constructing new supply facilities rather than improving the efficiencies of the existing ones.

In most countries of the region, significantly more water is delivered per unit area than is required, leading to low irrigation efficiencies. The area irrigated in many irrigation systems is much less than the area commanded and annual cropping intensities are lower than anticipated. Water deliveries rarely correspond in quantity and timing to the true requirements of the farmer's crops, leading to loss in productivity. In many irrigation systems water is distributed inequitably between farmers near the head-end reaches of the system, where water is short, and those less fortunate farmers located downstream.

The quantities of water consumed by the crops in an irrigation project are considerable. But the volumes of water handled by the project system have to take account of system efficiency, a product of efficiency during:
(i) conveyance,
(ii) distribution,
(iii) field application.

Average losses in irrigation projects suggest that only about 45% of water diverted or extracted for irrigation actually reaches the crops. But losses vary widely, those in the conveyance system taking the water to the irrigation site may vary between 5 and 50 percent. (Table 1) shows the technical irrigation efficiencies that could be expected for conveyance and distribution efficiency in the

Mediterranean region. Project efficiencies range from 30 to 65 percent, depending on the sophistication of the irrigation system and the on-farm irrigation technology in use.

Table 1 - Typical project irrigation efficiencies (in percent)

Category	Conveyance and Distribution	Field Application	Project *
A. Large-scale irrigation			
1. Traditional open canal system (manual control) (e.g. Turkey)	60	50	30
2. Open canal systems with hydraulic control and surface irrigation (e.g. Morocco)	70	60**	40
3. Open canal systems with manual control, on-farm storage and sprinkler/drip (e.g.Jordan)	75	70	55
4. Open canal systems with hydraulic control, buffer or on-farm storage and sprinkler/drip	85	70	60
5. Pipe conveyance systems with sprinkler/drip (e.g. Cyprus)	95	70	65
B. Groundwater irrigation			
6. Lined field channels and on-farm surface (gravity)	80	50	40
7. Pipe systems and on-farm sprinkler/drip	95	70	65

Notes:
* Gravity (surface) irrigation on the farm
** Project efficiencies are rounded to nearest 5 percent

Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots.

Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this vital but scarce source in Mediterranean agricultural areas.

IRRIGATION EFFICIENCY DEFINITIONS

An efficiency is generally defined as the ratio of output over input, and is expressed as a percentage. In irrigation, efficiency was first defined by Israelsen (1932) as "the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period, over the water diverted from a river or other natural source into the farm or project channel or channels during the same period of time".

This definition has not essentially changed in the years that have since passed although numerous definitions of irrigation efficiency were developed (see Appendix). Basically, they can be divided into three main groups:

- Definitions based on measured volumes of water;
- Definitions based on measured depths of application;
- Definitions based on other criteria, mainly related to yield.

A – Definitions based on volumes of water

Most of definitions presented in Appendix are based on ratios of water volumes. These definitions have the advantage of being relatively easy to use: the volume of water delivered to the soil, a field, or a distribution system can be measured, and the volume of water "stored in the rootzone during the irrigation" or "evapotranspired by the crop" can be either measured or calculated.

Definitions based on total volumes delivered to or in a system have disadvantage that, for some efficiencies, the uniformity of application or supply cannot be taken into account: the volume of water delivered can match the volume required, but the division of water can be such that a part of the system or field is under-irrigated and another part is over-irrigated.

B – Definitions based on measured depths of application

The ASCE (1978) “on-farm” efficiency definitions use depths of application. If the application depths are only average values found by dividing the total volume delivered to the system by the area there is no difference between these efficiencies and those based on volumes of water. If, however, the depths are actual values measured at specific – representative – locations in the field, these definitions can, after the measured depths have been processed, also take into account the uniformity of application.

The definitions based on measured depth of field application have the disadvantage that they cannot be used for a whole system: it is impractical or impossible to measure the depth of application in all the fields of irrigation system.

C – Definitions based on other criteria, mainly related to yield

These definitions are seldom used due to the fact that crop yield are influenced by many factors other than water supply alone (fertilizer application, treatment of plant diseases etc.). Crop yields are measure if agricultural production and not of water supply, although managers of irrigation water supply systems are sometimes judged by crop yields.

Many ratios are presented as efficiencies and are called efficiencies although they are not efficiencies in the sense of a ratio of output to input, whereby the output (of some quantity) is a conversion of an input (of the same quantity). Examples are: a “deep percolation efficiency” (Hart et al, 1979), the ratio of “the volume of water required to fill the available rootzone water storage minus the deficit” to “the volume of water absorbed by the soil through infiltration” (the ratio, moreover, is high when the deep percolation is low); an “operation efficiency” (Schuurmans, 1989), as the ratio “effective volume of water supplied” to actually supplied volume of water”.

DEFINITIONS RELATED TO THE CONVEYANCE OF WATER

The efficiencies related to the conveyance of water have not changed much since Israelsen (1932) defined the “water conveyance and delivery efficiency”. Jensen et al. (1967), Bos and Nugteren (1974), and ICID (1978) use the same definitions, except where Isrealsen mentions “water delivered to farms” (in the numerator), Jensen uses “water delivered by the conveyance system”, and ICID uses “water delivered to the distribution system”.

The distribution system consists of tertiary units, each of which can be one farm only, or can incorporate many farms. The distribution system is usually under the control of farmers or groups of farmers. These efficiencies express how much water is delivered from the conveyance system to the distribution system. The not-delivered water includes operational spills, seepage, and evaporation. These definitions do not intend to cover the uniformity of the division of water over the various parts of the distribution system.

DEFINITIONS RELATED TO WATER STORAGE IN THE ROOTZONE

These definitions have the problem that rootzone is not exactly defined. Its dept varies with the growing stage of the crop, the type of crop, the prevailing groundwater depth, etc.

The term “water stored in the rootzone” is used by Hansen (1960) in the numerator of the “water storage efficiency”: the ratio of water stored in the rootzone during irrigation, over water needed in the rootzone prior to irrigation. This ration was introduced because of the inability of the Isrealsen’s “water application efficiency” to reflect conditions of under-irrigation. However, rootzone water storage efficiencies do not cover conditions of over-irrigation: if more water is applied than needed, the excess is not accounted for.

The three definitions of Hart et al. (1979) deal neither with the conveyance of water nor with crop growth. These definitions seem to originate from irrigation at field level because the area to which water is delivered is not explicitly defined. If that area is a field or a farm, the efficiencies do not, for example, cover operation spills in the system or seepage from conveyance channels.

DEFINITIONS RELATED TO WATER USED FOR PLANT GROWTH

These definitions take into consideration:
a) Volume of water used for plant growth, and
b) Volume of water supplied.

Volume of water used for plant growth

The difficult point in irrigation efficiency is to determine the amount of water used for plant growth. In the definitions, this amount is expressed in various ways:

- "irrigation water transpired by the crops" (Isrealsen, 1932),
- "normal consumptive use of water" (Hansen, 1960),
- "useful water applied" (Hall, 1960),
- "volume of water transpired by plants, plus volume of water evaporated from soil" (Jensen et al., 1967),
- "consumptive use – effective rainfall" (Erie, 1968),
- "beneficially applied depth of water" (ASCE, 1978), including applications for such purposes as salt leaching, frost projection, crop cooling,
- "volume of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle" (Bos, 1980).

The actually used volume of water for plant growth will always be an estimate and it can only be measured on an experimental scale. Crop transpiration and evaporation of water the soil are usually combined in evapotranspiration. The reason for the formulation of Bos is that the link between crop water use and "water storage in the rootzone" is not easily made. With this definitions, the problem of how to account for crop water use is shifted from rootzone moisture to evapotranspiration.

A water application efficiency defined as water stored in soil, or in the rootzone, over water delivered to that rootzone is not useful is not related to evapotranspiration. And it is exactly this relationship that is made by Isrealsen' consumptive use efficiency. The product of this consumptive use and the water application efficiency is the ratio between irrigation water transpired by the crop and irrigation water delivered to the farm.

The time period considered is important too. The efficiency of one application at field level, measured with either volumes or depths, gives no information on an average application efficiency for a growing season, irrigation season, or for an area other than the measured field. Hall (1960) defined a "season application efficiency" to extend his "application efficiency" to the entire irrigation season. Israelsen and ICID explicitly mention "growth period" or "growing cycle" in their definitions.

Volume of water supplied

When the numerator is concerned with water used for plant growth, the scope of the denominator determines which efficiency is evaluated. For example Isrealsen's "water application efficiency" concerns "irrigation water delivered to the farm", and Hall's "application efficiency" concerns "gross volume of water delivered to the field". Typically, the broadest scope of "volume of water supplied" is the scheme: Jensen's "irrigation efficiency" deals with "total volume of water diverted, stored, or pumped for irrigation", and ICID's "project or overall efficiency" deals with "volume of water diverted or pumped from the river".

RELATIVE WATER SUPPLY

Relative Water Supply (RWS), proposed by Levine (1982), is the ration of “water supply” to “the demand for water”. Defined as input over output, the RWS resembles the reciprocal of an irrigation efficiency, but there is a difference. Generally, the crop irrigation water requirements is arrived at by subtracting the effective precipitation to be expected from the crop water requirement (potential evapotranspiration), whereas in the definition of RWS, the effective precipitation is taken as a water delivery. The inclusion of seepage and percolation on the demand side (denominator) of the definition suggests that the RWS ratio has been especially formulated to evaluate rice cultivation. Levine (1982) uses rainfall in the numerator of the definition, whereas Weller et al. (1988) use effective rainfall.

THE ICID DEFINITIONS AND WATER SHORTAGE

Water shortage usually implies that the supply of water is not enough for crop growth. The terminology used includes “under-irrigation” or “under-sipply”.

In the ICID’s irrigation efficiencies, the crop irrigation water requirements is Vm – the volume of water needed, and made available for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle. The starting point for Vm is the theoretical crop irrigation water requirement. However, the definition restricts itself to well-watered conditions. This conditions are presumed, and if this presumption were to be strictly adhered to, the ICID (crop related) definitions could be only used for planning and designing irrigation. When Vm is taken as potential evapotranspiration (ETpot), and Vc is the volume diverted or pumped, the value of ETpot/Vc can become greater than 100% under conditions of water shortage. Then, it is not longer an efficiency in the sense of a ratio of output to input. If, however, Vm is taken as actual evapotranspiration (lower than ETpot), values will be high, although never higher than 100%.

Beside “conveyance efficiency”, “distribution efficiency”, “field application efficiency” and “overall or project efficiency” (see Appendix), the ICID also defined a “tertiary unit efficiency” and an “irrigation system efficiency”. They are, when the non-irrigation supplies are neglected, combinations of respectively the distribution and field application processes and the conveyance and distribution processes.

EFFICIENCY AND UNIFORMITY

In irrigation, uniformity is used to express the variation in depths of application or supplied volumes. Christiansen (1942) defined uniformity coefficient CU for the comparison of sprinkler patterns. ICID (1978) extended the use of this coefficient to cover infiltration water too.

Efficiency and uniformity can be described at different levels in an irrigation system: for a field, for a tertiary unit, and for a scheme. Within a river basin, the division of flow over successive irrigated areas can be important, especially if the river flows through several countries or states.

Efficiency and uniformity at field level

Most efficiency definitions concerns volumes only, because these are relatively easy to measure, but, for a field, the total volume delivered is not an absolute measure of how much water each part of the field receives. For sprinkler-irrigated fields, uniformity has been frequently investigated with cans on the field catching the water from the sprinkler. The uniformity of the actual field application is then assumed to be equal to the application depths measured in the cans. For other methods of field application (e.g. basin or furrow), uniformity is more difficult to measure and is then usually estimated. The actual depth of water applied to the soil can be found by measuring the soil moisture content at several – representative – locations in the field before and after irrigation. Because of the practical limitations of these measurements, the depth of water is commonly taken as a function of the opportunity time for water to infiltrate. For the latter assumption to give reliable results, the soil within a field must be reasonable homogeneous.

Till and Bos (1985) assumed a normal distribution of applied water depths to parts of an irrigated field. If the volume of irrigation water equals the volume of water needed for evapotranspiration (field application efficiency is equal to 100%), 50% of the area is under-irrigated and the other 50% is over-irrigated. And about 84% of the area receives less water than the mean plus the standard deviation. If the uniformity of application is not changed and the volume supplied to the field is increased, the efficiency will decrease, but the under-irrigated area of the field will also decrease. The assumption of a normally distributed soil moisture over the field implies that, to give 75% of the area an average supply, the supply should be raised to mean plus 0.67 times the standard deviation. By increasing the volume of water delivered to the field, the field application efficiency decreases, but an increasing part of the field receives more than the mean water supply.

Efficiency and uniformity at tertiary unit level

Within a tertiary unit, water is delivered to fields. The deliveries to these fields can be regarded as observations in a population to which the same statistics can be applied as for fields, provided there are enough data.

Efficiency and uniformity at scheme level

Within a scheme, the uniformity of flow division over the main and secondary channels and tertiary units follows from measured flows. Efficiencies and uniformities can be calculated from the same data.

Wolters et al. (1987) reported on the uniformity of the division of flow over the irrigated lands of the Fayoum Governorate, in Egypt, with gross irrigated area of 151, 865 ha. The division of flow was measured from the main intake down to where the area is subdivided into five parts which are served by a secondary channel (4,155 ha). For each sub-area, the uniformity was expressed by the ratio of actually delivered flow over intended flow. The intended flow for the Fayoum is based on proportional flow division over the irrigable area, for which the system was designed. The results were that:

a) Areas with a disproportional supply are easily spotted;
b) The operation needs improvement throughout the system;
c) The most important improvement in the investigated secondary channel would be to provide it with an adequate quantity of irrigation water.

Making any other improvements in the area would be of little use as long as it remains under-irrigated.

The timeliness specifications of water deliveries might be usefull in schemes where the objective, the design, and the operation rules are very strict as to the timing of the water delivery when water delivered before or after pre-defined period of time is considered as lost.

INCREASES IN THE EFFICIENCY OF IRRIGATION WATER USE

When an increase in the efficiency of irrigation water use is being considered, the following questions arise:

- Is an increased efficiency needed?
- Is an increased efficiency possible?
- It is realistic to expect an increased efficiency from the proposed measures?

The “need for increases” in the efficiency of irrigation water use

The need for increases in the efficiency of water use depends on the balance between the following positive and negative effects of increased efficiencies.

The positive effects of increased efficiency of irrigation water use are:

- a larger area can be irrigated with the same volume of water;
- the competition between water users can be reduced;
- the effect of a water shortage will be less severe;
- water can be kept in storage for the current (or another) season;
- groundwater levels will be lower, which can lead to lower investments costs for the control of waterlogging and salinity;
- there will be less flooding;
- better use will be made of fertilizers and pesticides and there will be less contamination of groundwater and less leaching of minerals;
- health hazards can be reduced;
- energy can be saved;
- there will be fewer irrecoverable losses;
- instream flows, after withdrawals, will be larger, thereby benefitting aquatic life, recreation, and water quality.

The negative effects of increased efficiency of irrigation water use are:

- soil salinity can increase because of reduced leaching;
- wetlands and other wildlife habitats may cease to exist;
- groundwater levels will fall and aquifers will receive less recharge;
- water retention in upstream river basin areas will be reduced;
- there will be a need for more accurate operation and monitoring;
- and a need for a more expensive infrastructure.

When considering measures that could lead to an increase in irrigation efficiencies, the possible effects of the proposed measures on the factors in this list have to be investigated.

Many factors in the list of positive and negative effects of increased irrigation efficiencies have a relationship with the water quality of the components of the water balance, which means that water quality investigations should complement efficiency investigations.

The “possibilities” of increasing the efficiency of irrigation water use

The possibilities of increasing efficiencies are influenced by what is technically possible and, moreover, by the general rule of the economic feasibility of improving the system. The benefits from improvements should outweigh the costs.

Investigating the possibility of increasing the efficiency of irrigation water use implies establishing the components of the water balance of the system. This will often reveal whether, how, and where the efficiency can be increased. If such a comparison reveals that improvements are possible, targets values for one or more efficiencies have to be set and the measures needed to reach these target values have to be taken. Finally, the results of the actions have to be assessed.

Effect of proposed measures to increase irrigation efficiencies

Several issues were recommended as proper tools for the improvement of irrigation efficiencies. Among those issues water charges, lining canals, improvement of irrigation structures and modernization of irrigation systems, … etc.

The analysis of the literature and comparing the results obtained on the irrigation efficiencies by the implementation of the previous mentioned measures, the contraries in the data found by the researchers demonstrates that it is not always realistic to expert increased efficiencies from measures aimed at that goal.

This could be explained on the ground that irrigation efficiencies are basically ratios of volumes in the water balance of an irrigation scheme. The studies carried concentrated mainly on the relationships between the components of the waterbalance of irrigation systems and the factors that might influence these relationships. However, there are other factors that are related to irrigation efficiencies such as the management of crops, the socio-economic and legal environments of irrigation systems, the capacity building in the irrigation sector and the quality of water.

Those factors, together with those related to the components of the water balance of irrigation systems should be fully considered when final decisions are being made on water use in the agricultural sector.

CONCLUSIONS AND RECOMMENDATIONS

- Irrigated agriculture is by far the greater user of water. The limits to the availability of water and land for irrigated agriculture necessitate the careful use of these resources. Nevertheless, an increased water can have negative as well as positive effects.
- Low irrigation efficiencies are mainly attributed to the following common problems:
  1) Lack of measurement devices
  2) Lack of data on water flows and cropping patterns, and
  3) Low irrigation efficiencies because of seepage or excessive water applications

Evaluation of development irrigation “projects” identify additional problems (e.g. inadequate project formulation and discontinuity after donor involvement).

- Lack of data is a serious constraint to improving irrigation. There is a continuous need for data on water flows, crops, state of system repair, and agricultural practices. Monitoring systems should be an integrated part of irrigation system management. Many irrigation schemes, especially those in the formal “modern” sector, do not live up to expectations because of over-optimistic assumptions on:
  1) the time needed for the design, construction, and realization of benefits, leading to higher than expected project costs, and benefits being realized later in time;
  2) irrigation efficiencies, leading to, for instance, a conveyance system that delivers less water than planned, and a lower than expected performance in economic terms.
- There are considerable seasonal variations in efficiencies whereas, usually, the values are only high, and only to be high, for a short period of one or two months in the season. That period is the critical part of the season for design and operation. Further research is needed into the implications of this phenomenon for the design of irrigation systems.
- When considering an increased irrigation efficiency in a certain system, it is more useful to regard that system as unique, and to use the list of positive and negative effects of increased irrigation efficiencies on which to base a decision, rather than to rely on general relationships between characteristics and efficiencies.
- Many factors in the list of positive and negative effects of increased irrigation efficiencies bear a relationship to the water quality of the components of the water balance, which means that water quality investigations should complement efficiency investigations.

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