IWMI* WATER BRIEF 2

Revisiting the "IWMI Paradigm:"
Increasing the Efficiency and Productivity of Water Use

by

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The International Irrigation Management Institute, one of sixteen centers supported by the Consultative Group on International Agricultural Research (CGIAR), was incorporated by an Act of Parliament in Sri Lanka. The Act is currently under amendment to read as International Water Management Institute (IWMI).

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David Seckler[1]

Everything has been said already, but since no one listens,
one must always start again.

Andre Gide

In 1997, IWMI was invited to a conference to explain and defend what the sponsor referred to as the "IWMI Paradigm." A *paradigm* is an example, exemplar or archetype that often is compared, "side by side" with another, different and opposed, paradigm. The philosopher Thomas Kuhn used this word to describe the conflict between different theories or schools of thought in science. While we had not heard this word applied to IWMI before, it is true that IWMI represents a particular school of thought in the field of irrigation and water resource management. We happily accepted both the challenge and the appellation (Perry 1999).

However, pleasing as it is to have a paradigm of one's own, there are certain disagreeable aspects of this phrase. First, it ignores the fact that people outside of IWMI developed important aspects of the paradigm. Intimations of the paradigm can be traced back in the literature over the past 30 years; and one of the central concepts was formally articulated by Jensen (1977). Other contributions to the concept outside of IWMI were Willardsen, Allen, and Frederiksen 1994, Keller and Keller 1995 and, if I may say so, Seckler, 1993. Major contributions to the paradigm from IWMI staff are noted in the following discussion. Second, the paradigm is gaining adherents outside of IWMI and it is influencing many others.

For these reasons, I believe that a more appropriate way of distinguishing between the contending schools of thought is by following a distinction used in economics between the *classical* and *neoclassical* schools of thought. As in the case of economics, the neoclassical school has grown out of the classical school, and much of the classical position remains valid; but

[1]This note is partly based on Seckler, Molden and Sakthivadivel 1999, which provides a more detailed discussion of technical issues.

the neoclassical refinements eliminate some errors and extend the power and reach of the analysis. Thus the first consequence of revisiting the IWMI paradigm is to eliminate the phrase!

Both schools agree that the ultimate goal of water management is to optimize the beneficial utilization of water in all its dimensions. The classical school approaches this problem piecemeal, by attempting to increase water use efficiency in each use, one after the other. The neoclassical school holds that this piecemeal approach can lead to fundamental mistakes. Instead, the goal can be achieved *only by analyzing water use in the context of the water balance of the river basin*. Only after this is done can it be determined whether a piecemeal change represents a *real* improvement or not. The reason why this basin approach is needed is that water resource systems are highly integrated systems, and apparent gains in one part of the system can be offset by real losses in other parts of the system.

Ideally, this means that water resource analysis is based on a complete hydrological model of the flows and evaporation losses of water in the basin. But it is not easy to create complete hydrological models. IWMI is attempting to find quicker and less expensive ways to create reasonably accurate hydrological models and to develop shortcut methods of estimating the most important hydrological effects in *hydronomic zones*.

Efficiency and all that

I shall begin this discussion with irrigation efficiency and then show how the same considerations apply to water use efficiency in general. The objective of an irrigation system is to satisfy the water requirements of crops. This objective is achieved by delivering sufficient water to the root zones of crops to satisfy their optimal evapotranspiration (Eta) requirements, minus the amount of water supplied by effective precipitation (Pe). This is called NET

$$NET = Eta - Pe \qquad (1)$$

The classical concept of irrigation efficiency may be called the *application efficiency* (Ea). It is the ratio of NET to the amount of water withdrawn from a specific *source* and *delivered* to the field (Ds).

$$Ea = NET/Ds \quad (2)$$

Ea is less than unity because of (a) non-beneficial evaporation from land and water surfaces, and (b) *outflows* from the application system. The outflows are due to

- *seepage* from the conveyance system
- *runoff* from the surface of fields
- *deep-percolation* flows to water tables and aquifers below the root zones of crops

Application efficiency is a valid and highly useful concept for the purposes for which it was developed. In the design of irrigation systems, the amount of NET is divided by Ea to determine how much water has to be withdrawn from the source to meet crop requirements and to size the water conveyance and distribution system.

The problem with application efficiency is that it treats outflows from the application system as though they *vanish from the river basin*. This leads to the belief that this water is wholly "wasted" or "lost." For example, the application efficiency of a conventional gravity irrigation system is only 45%, on the average, while high-efficiency systems (such as sprinkler, surge, level-basin, drip and trickle systems) attain application efficiencies of 70% to 90%. It is commonly inferred from these facts that large amounts of water could be saved and transferred to other uses by converting wasteful gravity systems to high-efficiency systems. In some cases this inference is valid, but in others it is false.

The difference between these cases depends on the degree of beneficial utilization of the outflow (Obu) in the basin. The inference is valid where Obu is zero or negative. Obu can be zero when water flows to *sinks*, such as inland or external seas, or to saline aquifers. Obu can be negative, in the case of flooding, waterlogging, salinization and other forms of pollution. In all of these cases, *application efficiency is a valid concept*, and, if the economics is favorable, *adoption of high Ea irrigation systems should be encouraged*.

In fact, high Ea systems can have other and extremely important benefits over and above those of water efficiency *per se*. Where there is precise control of water, they provide a means of optimizing plant-soil-water relationships and, thus, increase crop yields. Yield increases that are

20% higher than in traditional gravity systems are normal; in certain crops, like vegetables and fruits, yield increases of 50% or more can be attained.

In addition, with precise water control, high efficiency systems can reduce water pollution substantially. Salts and residues from fertilizers and pesticides can be flushed down into the soil profile below the root-zones of crops but above the water table—to a kind of no-man's land—and stored there, out of circulation, in some cases for centuries.

Last, high efficiency systems need to draw less water from the source—rivers, reservoirs, aquifers, etc. And oftentimes water at the source is cleaner and in other ways more valuable than recycled water.

The problem with the concept of application efficiency and the use of high Ea irrigation systems arises where Obu is positive. One example is reflected in the saying, "One farmer's drainage is another farmer's water supply." Most of the paddy (rice) irrigation systems in the world depend on field-to-field irrigation by drainage water. If the upstream farmer uses water more efficiently, the outflow from his fields will be reduced, and the downstream farmer will suffer water shortage. A separate delivery system would have to be constructed to serve the downstream farmer, at considerable cost, little economic gain, and no increase in the overall irrigation efficiency of the system as a whole.

Another extremely important case of positive Obu is where the outflow from applications recharges aquifers. In India, for example, over one-half of the total irrigated area is supplied by tube wells. Tube well irrigation provides reliable supplies of water to farmers and thus is a form of precision irrigation. Yields on tube well irrigated farms may be 20% or more above those on farms irrigated by gravity systems. Thus, aquifers support 60% or more of the food grown on irrigated land in India, which is about 50% of India's total food production. But many of the aquifers in India are being depleted; in some cases the drawdown is one meter or more per year. About one-half of the recharge of aquifers is from the outflow of the irrigation systems, the other one-half from rainwater. Thus, if these systems become more efficient, recharge would decrease and the depletion of the aquifers would increase.

There are few practical alternatives to recharging acquifers by irrigation. Large percolation ponds require enormous amounts of highly scarce agricultural land, and they cause high rates of evaporation loss. Pump injection systems need to inject water of potable quality to avoid polluting the aquifers, upon which most drinking water supplies depend. One approach would be to subsidize farmers to grow rice in special percolation zones, on condition that they do not practice puddling or other kinds of efficient irrigation techniques. Rice is one of the few "wet-foot" crops that can grow in submerged conditions. IRRI has developed a high-yielding variety of deep-water rice that can grow in 1-2 meters of water. This variety would be ideal for agricultural percolation systems. Of course, care must be taken that fertilizer residues and other pollutants are not also percolated into the aquifers by this means. IWMI and others are investigating this and other methods of recharge, but the scale of the problem makes it a formidable challenge.

If the concept of irrigation efficiency is to be valid and useful, it must encompass all of these cases. Fortunately, Jensen (1977) simply and elegantly solved this problem. In slightly different words and expressions than he used, he effectively combined the classical concept of application efficiency with what may be called *recycling efficiency*. This results in an overall *system efficiency* (Es),

$$Es = Ea + bu\,(1 - Ea) \qquad (3)$$

Here "bu" is the percentage of the outflow (1-Ea) that is beneficially recycled. The term, bu(1-Ea) is the recycling efficiency (Er). The expression can be simplified as

$$Es = Ea + Er \qquad (4)$$

It is clear that Ea represents a special case of Es: when bu = 0, Er = 0, and Es = Ea. Thus, the classical concept of irrigation efficiency is subsumed under the neoclassical concept.

This concept of system efficiency represents a fundamental breakthrough in irrigation and water resource analysis that has many important applications. An example mentioned before is the conversion of a gravity irrigation system, with a typical Ea of 45%, to a sprinkler system with a typical Ea of 70%. In terms of application efficiency, the same amount of irrigation could be achieved with (45%/75% =) only 60% as much water. But if 70% of the outflow from the gravity system is beneficially utilized, the system efficiency of the gravity system is

[45% + (0.70 x 0.55) =] 83.5%. This is greater than the application efficiency of the sprinkler system. Of course, some of the outflow from the sprinkler system may also be beneficially utilized, and thus the Es of the sprinkler would be higher than its Ea as well. But the point is that one has to be very careful in talking about efficiency, both in terms of *definitions* and in terms of the *specific conditions of time and place that determine the amount of beneficial utilization of the outflow*.

System efficiency can be defined at different *levels of analysis,* depending on the definition of the system being considered and the boundary conditions of the outflow, i.e., whether the outflow from an application is inside, or outside, the system.

- The *micro-level* is that of the individual user, with beneficial outflows to other users.
- The *meso-level* consists of groups or sectors, such as projects, or the irrigation sector, with beneficial outflows to other sectors.
- The *macro-level* includes all users, groups and sectors at the level of the river basin, with beneficial outflows to *sinks*, such as the seas or saline aquifers.

At each level the difference between Ea and Es depends on the beneficial recycling effects among the relevant units. Molden (1997) provides a system of water accounting for these various levels.

The domestic water sector provides another interesting application of system efficiency. It is commonly believed that adopting such devices as low-flow toilets and showers can save 50% or more of the water used in the domestic sector. Except for lawns, gardens and swimming pools, 10% or even less of the water used in the domestic sector leaves the system in the form of evaporation; the rest is outflow. The question is how much is beneficial outflow?

The answer largely depends on the *destination* of the outflow—and this, in turn, largely depends on the *location* of the application. If a shower is taken in Cairo, Egypt, nearly all of the outflow reenters the Nile River system and is recycled downstream, either in irrigation or (hopefully after treatment) in the domestic and industrial sectors. Thus, a low-flow shower in Cairo would have virtually no effect on the system efficiency of the Egyptian Nile. But if the shower is taken in Alexandria, most of the outflow would enter the Mediterranean, and a low-flow shower would dramatically increase system efficiency. If Egyptians were charged the true opportunity cost of domestic water, the citizens of Alexandria would be charged something like ten times more per unit of water used in a shower than the citizens of Cairo!

Productivity

Water productivity is essentially an economic concept that builds on the physical concepts of the water balance and efficiency. In estimating the productivity of water, we attempt to determine the true economic value of the product of water, as in the value of the "crop per drop." An intermediate stage in this process is estimating the physical productivity of water, such as the kg of crop produced per drop of water defined either in terms of Eta or water deliveries (Ds). But then we estimate the net economic value of the kg of product, including all social and environmental factors, to obtain productivity.

When productivity is measured in terms of crop (C) per drop of water delivered, C/Ds, efficiency effects are included in the estimation of productivity. This is because Eta is only an *intermediate product*, an input into the production of the *final product,* the crop. In economic terms, the demand for Eta is a *derived demand*; it is derived from the value of the crop. Efficiency pertains to the Eta/Ds relationship, whereas productivity pertains to the C/Eta, or C/Ds relationship. In many other uses, water is itself a final product—as in drinking water, or the value of a beautiful river or lake. In these cases, there is no distinction between the productivity and the efficiency of water use. This is the source of much of the confusion over efficiency between irrigation people and others.

The green revolution in agriculture provides a rather remarkable example of increased water productivity. Once a field is adequately irrigated (and the crop canopy is closed), Eta per unit area is constant. Thus, the field can sustain any increase in crop yield with *no additional increase in water use*. The improved seeds, fertilizers and other inputs of the green revolution increased yields on irrigated lands by about 2.5 fold. In addition, the improved seeds reduced the length of the crop season by about 25%. This reduced the amount of Eta per crop season by a similar amount. Overall, the green revolution increased the productivity of irrigation water by 3.3 times! This is a much larger increase in water productivity than has ever been achieved by improved irrigation technology and management. But irrigation people can find consolation in the fact that with the exception of the most favored rain-fed areas, *the green revolution occurred only on irrigated land.*

One of the major ways of increasing productivity is by transferring water from lower- to higher-valued uses. For example, if a vegetable farmer is suffering damage to his crop because a wheat farmer has had the water delivered to his crop, or a city is suffering water shortages because the water has been delivered to irrigation, the productivity of the system may be sub-optimal even though the amount of water in the basin is the same. This is the principle of *allocative efficiency* in economics. The optimal allocation of a scarce resource like water is attained when the marginal productivity of the resource is equal among all uses of the resource at the same point in time.

Under certain conditions, market systems and water prices assure that allocative efficiency is attained. But if the conditions are not satisfied, the market fails. One of the major causes of market failure is "external," or "spillover," effects. The positive and negative effects of outflows, discussed before, are a classic example of these spillover effects. Because of the magnitude of outflows in water resources, this is probably the most externality-ridden sector of any sector of an economy. For water markets to operate correctly they usually have to be regulated to control the external effects; and the transaction cost of regulation may be greater than the gains attained through allocative efficiency. Thus, again, proper water management differs among specific conditions. In some cases water prices and markets can be very productive, in other cases, counterproductive. While this is a subject too large to go into here, the water balance of basins and the concept of system efficiency provide a sound guide to water market and price policies.

Water Supply

Water supply is an especially tricky concept. The first thing to realize is that at the basin or global level, it is the ultimately renewable resource. One uses all of one year's supply of water and then, on the average, the same amount of water is available for use the next year! There is no other resource that is *not subject to depletion over time*.

Second, the fact of water recycling complicates the concept of water supply. The *primary water supply* is provided by precipitation. The *secondary water supply* is provided by recycling the primary supply. An example is that of a series of hydroelectric dams on a river. The primary water supply to the first dam flows out of the turbines into the river bed, where it becomes a secondary source of supply to the second dam; then the outflow from this dam becomes tertiary supply to the third dam, and so on. The total supply to all these dams, the sum of the primary and secondary supplies, is a multiple of the primary water supply. This *water multiplier effect* (Seckler 1993) is extremely important in estimating the productivity of water. For example, if the value of the water flowing through each dam is V and there are X dams, the total value of the primary water used in this system is V times X (in addition to the value of the outflow from the last dam).

There are many other examples of the water multiplier effect. One large thermal plant near the Thames River upstream of London, for example, diverts nearly the entire flow of the river through the plant and returns it, slightly warmer, to the river. It has been estimated that Thames water has been passed through animals or machines over three times before it reaches London.

A major consequence of the water multiplier is that the effective supply of water in a system, the sum of all the deliveries, is much larger—perhaps several times more—than the primary supply. This fact can lead to major mistakes in estimating water scarcity. For example, a well-known engineer became alarmed because the authorities had overcommitted water deliveries in a river basin. They promised to deliver twice as much water as they had in the upstream system (the primary water). But given rather normal parameters for recycling effects, they could easily satisfy these commitments. Also, one of the leading indicators used in estimates of water scarcity of countries is the amount of withdrawals (or deliveries) divided by the amount of annually renewable water resources (the primary supply). This ratio also has to be adjusted substantially for recycled water supply to avoid large overestimations of the degree of water scarcity in countries (Seckler et al. 1998).

Conclusion

The potential for increasing the efficiency and productivity of water use is enormous—sometimes, as in the case of the green revolution, in unexpected and even unintended ways. However, the conceptual and practical challenges to achieving this goal are equally enormous. No simple recipes, “like getting prices right,” or “high efficiency technologies,” or “water users associations,” will work in all times and places. As I hope this brief discussion has shown, water is a unique and even rather mysterious resource, in which not all is as it might appear to be from a superficial perspective.

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