CHAPTER 21

EVALUATING PERFORMANCE

Joseph M. Lord, Jr. (JMLord, Inc., Fresno, California)
James E. Ayars (USDA-ARS, Parlier, California)

Abstract. *Evaluating irrigation system performance requires more than simply monitoring the hydraulic operation of a given system. It requires understanding where irrigation fits in the farm management, water requirements of a crop, soil hydraulic characteristics, field conditions, and economics of the operation. In this chapter we discuss the background and need for a comprehensive investigation of the system operation in the context of the overall farm management. This requires an investigation of the management variables that affect the operation, i.e., water supply constraints, agronomic constraints, and labor constraints. Measures of performance that characterize the system management and operation are discussed. The unique characteristics of each irrigation system type are discussed to highlight the differences in approach to evaluation. Finally, suggestions are provided to cover the performance evaluation, data interpretation, report preparation, and recommendations.*

Keywords. *Distribution uniformity, Irrigation efficiency, Irrigation system performance, Irrigation system performance evaluation, Microirrigation, Sprinkler irrigation, Surface irrigation.*

21.1 INTRODUCTION

The Central Valley of California has experienced a rapid escalation in the cost of agricultural water since the drought period 1989-1993, and, consequently, has seen heightened competition for water supplies among urban, environmental, fish and wildlife, and agricultural interests. Water charges have doubled and sometimes tripled. In 1994, a state-controlled water bank developed a market value for agricultural water of \$101/1000 m^3. This value generated considerable interest in the agricultural community and in some areas of the investment community, and they looked for even the smallest opportunities to reduce water use in the agricultural sector.

The increased demand for water and the concerns related to disposal of agricultural drainage water, environmental issues, and water allocations for agricultural use have motivated government agencies (state and federal) to fund major programs to evaluate on-farm irrigation system performance. Reasons commonly expressed by water agencies and water districts for performing evaluations of farm irrigation systems include water conservation, improving "beneficial" water use, and reducing losses to deep percolation. However, farmers are more interested in improving crop yields, financial returns, and making a limited supply go further.

The California Mobile Laboratory Program was developed to conduct on-farm evaluation of irrigation systems by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) and the State of California's Department of Water Resources. The expressed objectives of the Mobile Laboratory Program are to assess the uniformity and efficiency of an irrigation event; to identify problems with system design or management; and to identify opportunities for improvement. In 1996, approximately 60 water agencies in California were cost-sharing with California's Mobile Labs (Department of Water Resources, 1996).

Regardless of who is paying for the service, the evaluation of on-farm irrigation is usually done for the owner/operator by some technical entity or professional service. Even though funded or financed by the water district or another interested party, the evaluation still should be oriented to the operator/owner of the system. It is counterproductive and does not make economic sense to evaluate something and not try to suggest design changes or improve the management of a system to address identified shortcomings.

It is important for the engineer and scientist to recognize that, despite popular belief, most farm irrigation systems were not designed by engineers or scientists, but were developed from local practices and past successes. Until the early 1980s, the USBR considered 160 acres to be a farming unit (Reclamation Law) and it is not hard to believe that many of the major U.S. Bureau of Reclamation (USBR) projects were conceived as 160-acre replications of identical irrigation units.

The engineer and scientist must recognize that most owners and operators are not interested in the technical details of the evaluation, but how the results can most effectively help them produce better crops and/or lower their production costs. In this regard, evaluations should be object-oriented—*how* to improve the performance of the specific system. A system evaluation should not only measure and record hydraulic and other data (discharge, pressure, etc.), but should also consider how important performance measures can be improved. Recommendations to the owner/operator for changes in the irrigation system design, management, and operation are as important as the data being collected.

There has been considerable material written on how to collect data on irrigation performance. This has been addressed in other chapters and other books including Merriam and Keller (1978), Merriam et al. (1983), Burt and Lehmkuhl (1991), and Burt et al. (1997). Most terminology for defining irrigation system performance has generally been agreed upon, although some terms are frequently misused. There are numerous parameters that are used to describe farm irrigation system performance, e.g., application rate, application efficiency, and distribution uniformity (as summarized in Chapter 5). However, to adequately describe system performance, these measures need to be viewed in a larger context than simply involving one field and one irrigation event. The methods and formulas by which performance measures can be determined are also reasonably well defined and widely accepted, recognizing that different irrigation methods entail difference procedures for evaluation.

The objective of this chapter is to present processes for evaluating the performance of on-farm irrigation systems for the benefit of the owner/operator. It incorporates agronomic as well as engineering factors to determine an irrigation system's performance. It also addresses the practical aspects of evaluating a functioning irrigation system within a production agriculture environment by understanding and considering the operator's labor, water supply, and other operational constraints in the analysis.

21.2 MANAGEMENT VARIABLES

The first step in evaluating an irrigation system is to define the management variables and the scope of the system. A farm irrigation system can be defined as a set of physical and social elements employed to: (1) acquire water from a source (well, ditch, pipeline, or turnout); (2) facilitate and control the movement of this water in and on a defined area; and (3) disperse this water into the root zone of the crops being grown (Small and Svendsen, 1992). Major variables used in defining the scope and operation of the system are discussed in the following sections.

21.2.1 Water Supply

An important step in the evaluation of an irrigation system is to determine and understand the limitations of the water supply. There are physical, chemical, and temporal constraints associated with most agricultural water supplies, and in most water district operations there are contractual limits to consider. When evaluating the system performance, it is essential that the evaluator recognize the cause-and-effect relationships between the water supply and operation of the system. All resulting recommendations must consider these relationships.

In system evaluations, ingenuity is commonly needed to describe the system potential accurately when dealing with water supply constraints. For example, the owner/operator can adjust the amount being applied in a 24-hour set without a change in pressure and flow by adopting a spacing change in a hand move sprinkler system, which results in a loss of distribution uniformity for a single irrigation but enables recovering this loss through alternate sets. It is important that the operator understands that the alternate sets must be moved a half set, or between the previous sets. This can even improve the system's overall distribution uniformity, as long as the field is not being deficit irrigated. "Deficit irrigated," as used here, suggests that the irrigation event did *not* refill the root zone reservoir and that soil moisture depletion will remain on completion of this irrigation.

21.2.2 Agronomic Constraints

Surprisingly, scheduling an irrigation is more often determined by cultural operations rather than the cultural operations being scheduled by the need for irrigation. Stand establishment, weed control, maintenance of crop vigor, control of disease, and seedbed preparation are all agronomic considerations that impact irrigation system performance and need to be considered in an evaluation.

Westlands Water District was one of the sponsoring agencies for many of the on-farm irrigation evaluations conducted in Central California (Burt and Katen, 1988). The district required that all evaluations had to be performed under the direct supervision of a team consisting of an agronomist (or soil and water scientist), as well as an engineer specializing in irrigation. This highlights the importance of including the agronomy of the field in the evaluation.

21.2.3 Operations

Who makes the decision of when and how much to irrigate, and who executes this decision, are questions that are often overlooked in evaluating an irrigation system. The decision to irrigate is generally made by the owner/operator and is relayed to an irrigator who executes the instruction. The irrigator is often a hired laborer who has a basic understanding of the irrigation process, but no formal training in irrigation management methods that could be used to improve performance. Irrigation set time is similarly driven by the availability of labor and water and not well-defined crop water requirements. Water availability from the provider will also impact performance, i.e., whether it is an on-demand system or a rotational delivery.

Labor regulations in the U.S. have greatly reduced the availability of nighttime irrigators. It is common in a short-furrow field to irrigate two sets per day: one 10 hours long and the other 14 hours long. The 10-h set is typically made over a specific number of furrows; the 14-h set is made over a significantly larger number of furrows. Both sets commonly have the same flow rate and consequently will differ significantly in application rate, application efficiency, distribution uniformity, and irrigation efficiency (see Section 21.3) because of the change in area being irrigated and duration of the set.

The effect of the field operation on the total system performance may be overlooked if a serious effort is not expended in a pre-evaluation of the farm. Understanding the owner/operator's situation will pay big dividends in both how well the evaluation is received and the quality of the evaluation.

21.2.4 Environmental Concerns

The relationship between irrigation system management and any underlying groundwater resource is a significant environmental concern that should be recognized in evaluating a farm irrigation system. A perched water table within 3 m of the soil surface is one situation; a regional water table at a depth of 30 m under well-drained soils is a totally different situation. This latter condition has created opportunities for conjunctive use and groundwater recharge; what is one field's loss may be another field's supply. Again, in a real-life situation, deep percolation, even greater than the leaching requirement, can be beneficial when it is considered groundwater recharge provided the water quality is not significantly degraded. In areas of intense irrigation development, groundwater is often an integral part of the water resource. In these situations, surface and groundwater resources should be operated and managed conjunctively, and all system evaluations should recognize this interrelationship.

21.2.5 Structural Considerations

Two major agricultural suppliers of Colorado River water in Southern California have opposing environmental restrictions on their water users. One district facilitates tailwater leaving the farm; the other restricts the water user from discharging any surface water from the farm. An evaluation needs to be conducted accordingly.

Both policies are based on environmental concerns, so it is not readily apparent why these districts have such differing operating policies, particularly as both districts ultimately discharge return flows into the same salt sink. The first district was formed and designed 40 years before the second district and, as a result, may reflect the early philosophies of the USBR that the value of water is more in having and using it as opposed to using it beneficially and efficiently. This differing philosophy may also have been brought about by increased competition for surface water supplies, specifically Colorado River water.

The water district established first, at the start of the 20th century, constructed a deep, open drain next to each of its open delivery laterals on a spacing of 800 m to facilitate removal of farm surface and subsurface drainage water. The other system, developed in the 1940s, utilized pipelines to deliver water, and its drainage system was designed to receive only subsurface farm drainage water. It is with some interest to note that the last major irrigation scheme developed by the USBR, the San Luis Unit of the Central Valley Project in the 1960s, was authorized without any drainage facilities even though the drainage needs were recognized.

The previous examples emphasized that understanding how on-farm systems were designed and operated in the context of district facilities and policy is essential to the interpretation of the system management data. A water user discharging 30% of a field supply to a salt sink is less than 70% efficient in water use, no matter how productive and uniformly the remaining water is used. Conversely, to fault or recommend change to the irrigation management without understanding the constraints on the system and operating policies is far more questionable.

21.2.6 Economic Considerations

Energy, labor, hardware, and water costs will greatly influence the management of an irrigation system while most evaluations focus on the hydraulics and hydrology of an irrigation event. It is important to consider the trade-offs between associated costs: less labor and more hardware, or vice versa. Total cost per unit of production is the real definition of economic efficiency, but this is usually beyond the scope of on-farm irrigation system evaluations. A multi-year study is required to determine the impact of irrigation operations on agricultural production and is generally not undertaken because of the cost and time involved.

21.3 MEASURES OF PERFORMANCE

At the core of each evaluation are the system's performance measures. When discussing performance, it is valuable to recognize that every irrigation system has a life cycle and an event performance cycle. Some of the most valuable data produced for the owner/operator are changes within the system's life cycle. The performance cycle can be short term and typically happens within an irrigation event. It can be as simple as a pressure fluctuation due to back-flushing, or sequencing between different irrigation blocks. The instantaneous performance of a system is almost always affected by hydraulics, filtration, and elevation. Probably the most difficult performance changes to evaluate are those associated with seasonal changes, such as the infiltration rate of soils being furrow irrigated.

There is a longer-term cycle associated with the performance life of the system's hardware components, such as emission devices or pumps. These are subtle changes, typically in hydraulics, which occur over long times due to corrosion and erosion within high-pressure systems, such as erosion of a pump's impeller and sprinkler nozzles by sand in water. Similarly, without careful and frequent system maintenance, a microirrigation system using water with high levels of dissolved minerals can have emitter performance influenced by precipitation of the minerals. Both the short- and long-term cycles should be recognized and accounted for in the data analysis.

The indirect benefits associated with field losses are also difficult to quantify. These primarily include the water losses associated with salt management, deep percolation, and/or surface runoff. When these losses contribute to other irrigation supplies or to groundwater recharge, they need to be recognized for these secondary benefits in the evaluation of performance. For example, a post-season irrigation for weed germination may be considered as beneficial use. This irrigation may also contribute to salinity management so the volume actually used for weed germination is not easily quantified.

Multiple evaluations are required to quantify changes in system performance; unfortunately, most evaluation procedures are designed around a single event. The California Mobile Lab Program originally specified one evaluation per owner/operator. These single evaluations can develop all of the essential performance measures, but they produce only a snapshot of the system's total performance, and more importantly, have the potential to misrepresent the system's overall performance. The value of multiple evaluations cannot be over emphasized, particularly where only a few farm/field evaluations are used to represent entire irrigation districts and agricultural water use in general.

The measures most valuable to document a system's performance are application rate, application efficiency, distribution uniformity, operational characteristics, and irrigation efficiency. These measures are listed in order of their value to the owner/operator.

21.3.1 Application Rate

The system application rate is basic to all irrigation management decisions and it is the value that all water managers must know, regardless of how they schedule their irrigations. It is the rate water is applied to a given area and is usually expressed as a depth per unit time. Knowing the application rate, the farmer can then determine the required set time to apply a designated amount. The application rate does not involve efficiency or uniformity.

21.3.2 Distribution Uniformity

Distribution uniformity is used to indicate the system's distribution problems and is colloquially often used interchangeably with the terms *emission uniformity* or *Christensen's Uniformity Coefficient* (see also Chapter 5, Section 5.3.7). One common calculation for distribution uniformity, DU, is

$$DU = \frac{D_{lq}}{D_{av}} \tag{21.1}$$

where D_{lq} = the average depth infiltrated in the lowest catches for one-quarter of the field

D_{av} = the average depth infiltrated over the entire field.

There are other expressions used to define the evenness of irrigation application, but, unfortunately, as many as there are, there is not a perfect method of determining uniformity. Economy of time and effort limits how many measurements can be made in any one evaluation.

The real value of the distribution uniformity calculation is that it focuses on the system as opposed to management. How a system is operated will influence an irrigation's distribution uniformity, but it is strongly influenced by the system's design and hardware.

An irrigation system can have high uniformity and be inefficient through over-irrigation, or have low uniformity and be 100% efficient through deficit irrigation. Another consideration is the example of hand move sprinklers having a low measured distribution uniformity for a single event. By splitting the move on alternate sets and integrating the system's application patterns, the distribution uniformity for two sequential events can become quite high—but the evaluators have to measure the effects of two separate events.

21.3.3 Application Efficiency

The application efficiency is the performance measure that has the most confusion surrounding it. The application efficiency, defined in Chapter 5 as Equation 5.2, incorporates management decisions in the evaluation. The definition is:

$$e_a = \frac{V_s}{V_f} \tag{21.2}$$

where e_a = the water application efficiency
V_s = the volume of irrigation water stored for evapotranspiration by the crop
V_f = volume of water delivered to the field.
The term is commonly misused as the system's irrigation efficiency. A less common but far greater mistake is to confuse this value with the system's distribution uniformity.

21.3.4 Irrigation Efficiency

Irrigation efficiency is seemingly the performance measure that is the focus of everyone except the owners/operators. It is not that they do not care how inefficient their system might be; it is just that it is very difficult to convince them that some amount, any amount, of an irrigation is *not* beneficial to their crop. Irrigation efficiency previously expressed as Equation 5.4 is defined as:

$$e_i = \frac{V_b}{V_f} \tag{21.3}$$

where e_i = the irrigation efficiency
V_b = the volume of water beneficially used
V_f = the volume of water delivered to the field.

The realistic aspect to this calculated value is that it is more often misinformation than information. It really has little value, unless an effort is made to identify what is represented by a statement of efficiency. Because of these interpretive problems, a major water district in California has expanded considerable effort and money in forming and promoting the three definitions listed below (Westlands Water District, 1989a).

Pre-plant irrigation efficiency is the efficiency of a pre-plant irrigation and is the ratio of the sum of the depth of water used for soil water replacement (*SMR*) and cultural practices (*CP*) to the depth of applied water (*AW*). No leaching requirement is included, but there will be a leaching benefit derived particularly in the top portion of the soil profile. Pre-plant irrigation efficiency (*PIE*) is calculated as:

$$PIE = \frac{SMR_1 + CP_1}{AW_1} \tag{21.4}$$

Seasonal irrigation efficiency integrates the efficiency of one or more regular seasonal on-farm irrigations. It is the ratio of the sum of soil moisture replacement water and water used for cultural practices for each irrigation after the pre-plant irrigation to the sum of water applied during these irrigations. No leaching requirement is included. Seasonal irrigation efficiency (*SIE*) can be determined by:

$$SIE = \sum_{i=2}^{n} \frac{SMR_i + CP_i}{AW_i} \tag{21.5}$$

Annual irrigation efficiency is used to calculate the efficiency of all on-farm irrigations and is the ratio of the sum of the soil water replacement water and water used for cultural practices for all irrigations, plus the water to satisfy the seasonal leaching requirement (L_r), to the sum of the depths of water applied during all irrigations, including the pre-plant irrigation. The annual irrigation efficiency (*AIE*) is:

$$\text{AIE} = \sum_{i=1}^{n} \frac{SMR_i + CP_i + L_r}{AW_i} \tag{21.6}$$

Another critical aspect of irrigation efficiency calculations is that the interpretation can easily become flawed because of the mathematics. When early-season irrigations are excessive, as they commonly are, and late-season irrigations do not refill the soil reservoir and some crop water stress commonly occurs, their sums can be misleading. Arithmetically, a minus and a plus can cancel each other. The problem is that plants are not mathematicians and early season excesses do not compensate for late season shortages. This is particularly true when full crop ET is used to determine what water is potentially beneficially used. It is valuable to understand that *no* irrigation event or series of events are 100% efficient in real life, but water applied under a deficit irrigation condition is normally used beneficially.

It is imperative to obtain sufficient data on farm irrigation performance to determine a farm's irrigation efficiency, a water district's water use efficiency, or to make an expression of the overall efficiency of agricultural water use. Without these data *and* a well-founded understanding of what they represent, reported values are often questionable, subjective and, in some cases, incorrect and misleading.

21.3.5 Field Characteristics

There are a number of measurements and field assessments that are important to every evaluation of farm irrigation, including:

- crop growth stage
- root zone depth
- soil water-holding capacity
- soil water status
- crop evapotranspiration
- field dimensions

These data are seemingly minor and easy to obtain in the total process of evaluating an irrigation system, but unless a concerted effort is made by the evaluator to determine each one, errors will commonly occur in the evaluation. Be assured, these field characteristics are essential to the value and ultimate interpretation of irrigation performance. It is also paramount that these values are included in the final evaluation report. It not only allows the owner/operator to assess his/her future irrigation practices, but it gives the next evaluator a frame of reference for any future evaluations.

21.4 FIELD EVALUATION METHODS

This chapter is not intended to provide the detailed evaluation procedures that each irrigation method requires. However, it is important to discuss the design and operational concepts and attributes unique and critical to the general types of irrigation methods. To facilitate this, the many irrigation systems being used today have been grouped into three basic irrigation categories: surface, sprinkler, and microirrigation.

21.4.1 Surface Irrigation

In 2002, surface irrigation was reported to be the method of choice on land irrigated in the U.S. (Irrigation Journal, 1997). Worldwide, it is estimated by the Food and Agriculture Organization of the United Nations (FAO) to be the method used on 73% of irrigated lands (Pallas, 1993).

Despite its widespread use, surface irrigation has the most controversy surrounding its evaluation. To begin with, it has been labeled as "inefficient" by those who do not completely understand the method. Secondly, the procedures for evaluating this method are distinctly different from procedures used for sprinkler and microirrigation methods. Thirdly, this irrigation method has been relegated to a position of limited economic value by the general irrigation industry because it involves little or no hardware (aluminum, brass, or plastic) and its design is most often done by a practitioner (land leveler).

Soil characteristics have a major influence on surface irrigation performance. Soils often dictate a field's physical configuration (slope and length) as well as its operational requirements (irrigation frequency and duration). These components are all part of standard evaluation procedures. What typically is not included in the evaluation process is the uniformity of a field's slope and the homogeneity of its soils. These factors can be partially defined through pre-evaluation activities and by discussions with the owner/operator.

The evaluation of surface irrigation systems is time dependent. Measuring advance and recession rates of water flows at enough locations to be representative of the entire field can be time consuming. However, it is critical where surface system performance is being compared to sprinkler and microirrigation methods that the data samples also be comparable.

21.4.2 Sprinkler Irrigation

Sprinkler irrigation (i.e., high-volume sprinklers having discharge rates of at least 4 L/min.) is the most studied, best understood, and most fully documented irrigation system of the three major methods. Flow, pressure, and discharge are system characteristics that are easily measured and quickly recorded. Computer interpretation of catch-can test data has simplified many aspects of data collection and interpretation. A primary concern in sprinkler irrigation is uniformity of application since wind can distort sprinkler patterns. However, this problem is generally intermittent and almost impossible to design or operate around without turning off the system under severe wind conditions.

There are considerable amounts of test data on sprinkler operational characteristics, which are available from manufacturers and independent testing agencies. These published performance data will facilitate pre-evaluation planning and assist in evaluation interpretation.

21.4.3 Microirrigation

This method of irrigation (including low-volume sprinklers of less than 4 L/min discharge, as well as trickle irrigation, low-volume bubblers, etc.) is relatively new and has been evolving at a fast pace. Recent developments in its use on row crops and in buried configurations have created a need for new evaluation techniques. Most of the current procedures are minor modifications of sprinkler evaluation techniques. Microsprinklers are being used extensively in permanent plantings and the designs do not call for overlap of wetted patterns or even a totally wetted surface. Most designs use one or more emission devices per tree.

A potentially beneficial operational feature of a microirrigation system is to irrigate daily, or even more frequently. High-frequency irrigation has resulted in improved yields and improved water use efficiency in many crops, particularly those with high water requirements. This mode of operation requires extensive automation and as a result many growers have been slow to utilize this potential benefit. Microirrigation systems have an added requirement for accurate and current evaluation data because their management may involve replacing the crop's daily water use. Good management is predicated on having a thorough understanding of the system and accurate quantification of the crop's daily water use and feedback control of the system.

The microirrigation system's critical design feature is its wetted soil volume. Early design specifications suggested a minimum wetted soil volume of not less than 33% of the total root zone volume (Keller and Karmeli, 1975). Practice and experience have shown that 50% wetted volume is a better design and, with good management (daily operation), 60% to 80% of the wetted soil volume is realistic. Percent of wetted volume, as used here, is the percent of the total root zone volume (for row crops and permanent crops) that is wetted by irrigation.

21.5 ECONOMICS

To influence changes in any commercial enterprise, there needs to be some financial reward or economic return and this is true for conservation of water by production agriculture. The reality of this becomes obvious when it is understood that, in many cases, water conservation has no tangible benefit to the owner/operator who is conserving the water. In most cases, it is believed that some inefficiency is actually the owner/operator's insurance policy for those periods of drought and restricted water supplies. There is a thread of commonality in this belief with the appropriation doctrine of water law—"use it or lose it."

The way to address this issue is by establishing the economics of improved water management. In evaluating the performance of an irrigation system, the operational costs and system hardware costs are, in reality, the only two areas of opportunity to develop system costs. Real and tangible benefits from system evaluations are associated with the quantity and quality of crop production. Improved irrigation performance should translate into enhanced quantity and/or quality of the crop's yield. To accurately quantify these benefits is generally not within the scope of evaluating a farm irrigation system. However, they should be discussed by the evaluator with the owner/operator, when appropriate.

21.5.1 Operational Costs

The operational costs of an irrigation system are best determined in the pre-evaluation period. Typically, these operational costs are water, energy, labor (includes management), agronomic practices (fertilizers and cultivations), and pest and disease control.

The cost of water should reflect the highest rate, particularly when tiered pricing is used. When using groundwater, it should include the cost of a well and its maintenance and development cost. Energy costs should include pump and motor efficiency as well as the plant's operation and maintenance costs. When it is beyond the scope of the evaluation to determine these data, it is reasonable to assign values and record these as assigned or estimated values. They should not become an issue as long as the owner/operator recognizes that they are assigned.

Quantifying the cost of labor is even a greater challenge. Highly skilled labor costs more than less-skilled labor and the change in labor cost may reflect changes in labor. What is critical for the evaluator to recognize is that most farming operations are highly motivated to conserve labor and operators will gladly trade water conservation, if they have it, for labor savings.

21.5.2 System Costs

System costs principally translate into the hardware costs, i.e., re-nozzling a sprinkler system, or cutting a furrow length in half by buying/leasing/renting additional gated pipe. When suggesting alternative systems or system changes, the full and reasonable cost should be identified. The critical element in developing these costs is to be sure the evaluation is practical and realistic. If one element of the cost estimate looks unrealistic or a component of the recommended change such as labor is overlooked, the grower will quickly disregard the suggested change.

21.6 ANALYSIS AND INTERPRETATION

Equally important to data collection is the analysis and interpretation and this goes back to the "Who for Whom" criteria mentioned earlier. Where the owner/operator has hired a consultant or formally requested an independent service (NRCS or Cooperative Extension) to perform the evaluation, this question has less significance. However, when a third party is paying for this service, or an agency is out soliciting fields to evaluate, this "Who for Whom" question becomes more meaningful.

The initial step is to determine if this will be an evaluation of a single-event performance or seasonal performance. It is more valuable if the evaluation is for the seasonal performance of the system and the system is evaluated at least two times in the same season. A seasonal water budget can then be developed. This is particularly important if the system is a large-volume, low-frequency system (surface or sprinkler). If it is a low-volume, high-frequency (micro) system, a single evaluation may suffice. These latter systems are not as dependent on soils, and, by knowing the following, a reasonable seasonal performance can be calculated:

- seasonal crop water use
- seasonal effective precipitation
- application rate
- distribution uniformity
- total hours of operation (season)

To estimate seasonal performance from a single evaluation of a surface or sprinkler system requires some operational data not typically maintained by the owner/operator or routinely available. These data are the soil water status, before and after each irrigation throughout the season, including the initial soil water content and any pre-plant irrigation. Without understanding the impacts of irrigation on the root zone reservoir, the seasonal efficiency of any irrigation system is difficult to assess. With high-volume, low-frequency systems, the error can be great, particularly where the soil' intake characteristics change during the season. It is common for early irrigations to be excessive and late season irrigations to be deficient. If the crop is stressed at any time, this will invalidate the evaluation. The accumulated effects are easily misinterpreted as efficient, or, if only one event is evaluated, it would not be representative.

Conversely, it should be understood that carefully managed crop water stress can be important to the grower's agronomic objective. For example, deficit irrigation is very valuable to viticulture and grape quality, and also plays a valuable role in achieving top cotton production. With some small grains, managed crop water stress during rapid stem elongation can shorten the straw length and reduce lodging without loss of yield or quality.

Water districts can undertake an effort to evaluate district-wide irrigation events during an irrigation season, and, through random sampling of irrigation events, develop a valid representation. But care needs to be exercised in how cooperators are selected. There have been several instances where participants were selected on a first-come, first-served basis from a district-wide mailing. A cursory assessment of these participants might show that these were the progressive owners/operators in the district. The district has to recognize these potential biases and make an effort to evaluate systems of some of the owners/operators who take a less active and consistent interest in their operations.

21.7 MOBILE LABS

The Mobile Lab concept developed in California has some valuable features. These labs or system evaluation teams were started in 1985 through a cooperative effort by the California Department of Water Resources and the USDA NRCS. Technical support was provided by researchers at California State University at San Luis Obispo (Cal Poly). The program has been instrumental in developing and standardizing field test procedures for field evaluations of on-farm irrigation systems. The Mobile Lab approach has effectively demonstrated to production agriculture and the water resources industry the value of accurate and detailed data on irrigation system performance. Before evaluating on-farm water use, Westlands Water District made a case that their district-wide farm irrigation efficiency was over 80%. After collecting data on 335 fields over two irrigation seasons, their efficiency was calculated to be 77% and these were arguably the District's more progressive owners/operators (Westlands Water District, 1989b).

There have been several criticisms of the Mobile Lab program. Since the Mobile Lab provides its services to growers for free, this tends to devalue the concept. The Mobile Lab also employs summer students and recent college graduates to perform the field work. This creates a situation where often a person with little practical field irrigation experience is evaluating a system being operated by someone with considerable experience. The evaluator is also there by courtesy of the owner, and if the evaluator wants to come back in the future to retest this system or another system, the evaluator better not be too critical. The evaluations developed in these situations seldom fully address the management problems.

21.8 OUTLINE FOR EVALUATIONS

21.8.1 Pre-Evaluation Interview with the Grower

The following information should be collected during an interview with the grower prior to the field evaluation:

- Operational information: How are irrigations scheduled? What is this event's objective? What is the fertilizer program? What is the cropping pattern, its history and future plans? What is the labor/work force situation? Are there any recent data on soil salinity or irrigation water quality?
- Field physical information, including a map showing water source and field dimensions, the row/furrow spacing (for furrow irrigation), the slope of the field, and information about the system features (pumps, filters, etc.).
- Crop information, including the date planted/age/emergence, date to be harvested or terminated, the depth of the root zone (actual or managed), and annual estimated crop ET.
- Economic information, including the cost of water, energy, and labor (including management).

21.8.2 Collection of Field Data

Each type of system should have its own data sheet. These are available from most manuals or how-to books. These forms should include the date, start and finish times, name of evaluator, and weather conditions. The field map should be attached to the data sheet and noted to reflect where readings and evaluations were taken (Merriam and Keller, 1978; Burt and Lehmkuhl, 1991).

21.8.3 Report

The report should contain at least a procedures section, a results section, and a recommendations section. The results section should include a summary report along with a copy of the actual field data. As a minimum, the report should record the following field characteristics and how they were determined: crop, root zone depth, soil water-holding capacity, soil water status (starting and finish), and evapotranspiration of crop to date. Also include the following measures of performance: application rate, distribution uniformity, application efficiency, and irrigation efficiency.

21.9 CONCLUSIONS

A skillfully executed evaluation of on-farm irrigation system performance requires more than simply measuring the hydraulic performance of the system. It requires an evaluation of the entire system including the agronomic and social systems affecting the operation. The evaluation should be done by either a qualified and experienced professional or an individual operating under the supervision of an experienced professional. There is no irrigation system for which a thorough and complete evaluation will not identify one or more opportunities to improve the system or its performance. However, these improvements are of little or no consequence to the owner/operator if they *only* address the hydraulics and system performance and do not include the effect major enhancements of irrigation performance will have on crop performance and real economic returns. The effectiveness with which these opportunities are presented to the operator/owner will determine how valuable the evaluation is to them.

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