Water Application and Irrigation Efficiencies in Selected Fields in the Arkansas River Valley (CO)

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Abstract. During the 2004 growing season (May 20 - August 20), irrigation activities were monitored along the 160-mile stretch between Fowler and Holly in Colorado's Lower Arkansas Valley. Fifteen fields were monitored to evaluate ongoing water use practices with an eye toward potential improvement. Ten of the monitored fields were surface irrigated, two by center pivot sprinkler systems and two by subsurface drip irrigation systems. Where possible, measurements of total irrigation water inflow and outflow were made. Infiltration tests were conducted, and water was sampled for salinity, phosphate, and nitrate concentrations. To carry out these activities, flumes (Cutthroat and Parshall), existent flow-meters (for sprinkler and drip systems), GPS units, conductimeters, and pressure transducers (water level sensors) were employed. As more than one growing season is required to establish an accurate baseline and understanding of the region's water use practices, the results presented in this paper are all preliminary.

1. Introduction

Before making suggestions on how to improve water use in a region, evaluations of ongoing practices must be made. In the irrigated alluvial lands of the Arkansas River Basin in Colorado, there is a need to determine the baseline for irrigation application practices and efficiency. This paper describes the types of studies that have been conducted at the field-scale in the Arkansas River Valley to better understand the effects of salinity and water table depth in the region. Field studies of the amounts of irrigation water applied and runoff, evapotranspiration, infiltration, precipitation and soil properties enable the investigator to estimate the amounts of water stored for plant use and lost to deep percolation. With losses accounted for, the efficiency of irrigation events can be computed. The data gathered in the Lower Arkansas River Valley is also being used to fine-tune the CSU-ID model, a numerical

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model developed by the Integrated Decision Support (IDS) Group for the simulation, design, and management of conjunctive irrigation and drainage systems.

2. Methods

To pick representative fields for monitoring, reconnaissance visits were made to the upstream and downstream areas of the Arkansas River Valley. To be considered, fields needed to be accessible and their inflows and outflows had to be simple to measure with standard water flow devices. Fields under sprinkler and drip irrigation were only selected if they were equipped with flow meters for facilitating the quantification of water applied over the season. Two types of water level recorders were used: Wescor S-7701 and TROLL 8000 and 9000. Figure 1, shows the locations of the inflow and outflow flow measurement devices in a North La Junta Field.

Eventually sixteen fields distributed between Fowler (upstream) and Granada (downstream) were selected to be monitored for irrigation timing and amount in 2004. The final selection of the fields was based on the type of irrigation method utilized.

Fields under drip, sprinkler and surface irrigation (borders and furrows) were chosen. For each of the fields, at least three[2] irrigation events were monitored. Water applied and surface runoff was measured using standard Parshall and Cutthroat flumes, which were equipped with automatic water sensors and pressure transducers (water level recorders). Infiltration tests were performed on two different sites within each field using the traditional double cylinder technique. Automatic rainfall gauges and atmometers were installed in the monitored fields to account for precipitation and evapotranspiration variables.

Salinity surveys were conducted on each of the fields using EM38 technology. The EM38 transmits a small electromagnetic signal through the soil and picks up a "reflected" signal from beneath the soil surface. The strength of the response depends on the electrical conductivity of the soil; the higher the electrical conductivity of the soil, the higher the salt concentration and the higher the concentration of salt, the stronger the return signal to the EM38 device. The data generated in the salinity surveys will be utilized to establish relationships and correlations with water applications and irrigation efficiencies.

2.1. Fields Monitored

Table 1 lists the sixteen fields monitored during 2004, and describes their irrigation system and the monitoring equipment installed in them.

[2] Where possible; some fields have received irrigation water in fewer times.

Figure 1. Locations of flumes at one of the monitoring fields (North La Junta)

Table 1. Fields Monitored in 2004

FIELD ID	Method of Irrigation	N° events monitored	ET Guage Installed?	Raingauge Installed	Well Drilled?
IRR-US-1	Surface - gated	3	Yes	Yes	Yes
IRR-US-2	Surface - surge	2	No	No	No
IRR-US-3	Central Pivot	3 - season	Yes	Yes	No
IRR-US-5	Surface - gated	2	Yes	Yes	Yes
IRR-US-6	Surface - Drip	Season	Yes	Yes	Yes
IRR-US-7	Drip	Season	No	No	Yes
IRR-US-8	Surface - cut-out	Season	Yes	Yes	Yes
IRR-US-9	Drip	Season	No	No	No
IRR-US-10	Surface - siphon	4	Yes	Yes	Yes
IRR-US-11	Surface - siphon	2	Yes	Yes	Yes
IRR-DS-1	Surface - cut-out	2	Yes	Yes	Yes
IRR-DS-2	Surface - gated	3	No	No	Yes
IRR-DS-3	Surface - gated	3	No	No	Yes
IRR-DS-4	Central Pivot	Season	Yes	Yes	Yes
IRR-DS-5	Surface - gated	1	Yes	Yes	Yes
IRR-DS-6	Surface - cut-out	1	No	No	Yes

For surface irrigated fields, there is no predictable time at which the field is certain to be irrigated nor is there a standard irrigation duration. Consequently, great effort has been invested in equipping surface irrigated fields with water level sensors. However, given the number of fields being monitored and the requirement that each field contain at least two sensors, there have not been enough sensors available to cover all the fields, and some irrigation events have been missed.

3. Equipment

The equipment used for these evaluations has been as previously noted: Flumes (Parshall, Cutthroat and Trapezoidal), water level recorders, dataloggers, GPS units, weirs, infiltrometers, chronometers, ET gauges and raingauges.

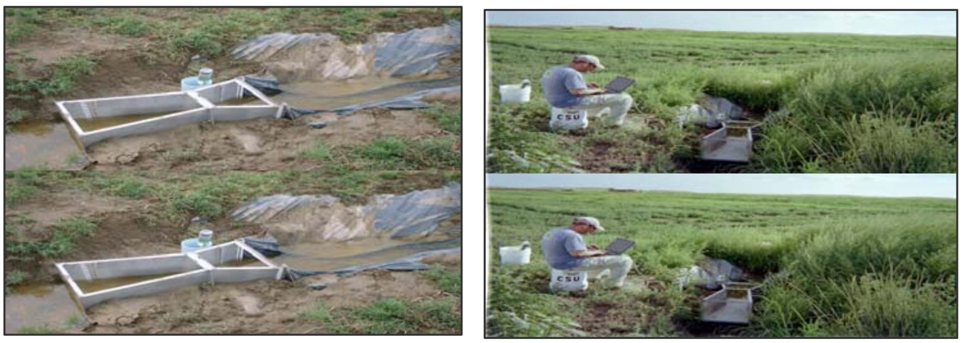

Figure 2. Water Measuring Devises and Water Level Sensors Utilized.

4. Data Analysis

4.1. Irrigation Efficiency

According to Jebson (2000), technical estimations of irrigation efficiency should take into account spatial uniformity of application depth, the average application depth, and the soil's capacity to store water at the time of irrigation. Therefore, irrigation efficiency not only varies with the site, soil type, and application system, but also varies with each water application throughout the season. Ideally, and especially when it comes to surface irrigation, it is necessary to evaluate the performance of irrigation events throughout the season in order to determine seasonal application and irrigation efficiencies. One sole irrigation event can be extremely misleading.

Once total inflow and outflow (total water application) has been determined for an individual irrigation event, the most complex part of analyzing irrigation efficiency needs to be tackled. For practical purposes, it is customary to combine two independent efficiency measures: application efficiency and distribution pattern efficiency. The combination of these two assessments provides a measure of how much of the water that is applied during an irrigation event is actually retained within the effective plant root zone. In order to determine the distribution pattern efficiency very close monitoring of the soil moisture within the field, involving several soil moisture sensors installed at multiple sites, is required, or the phenomenon must be modeled using a computer program. Currently, the IDS Group is considering additions to its CSU-ID Model to simulate the distribution of the wetted front in an irrigated field while taking into consideration variables such soil type, topography, infiltration parameters, Manning coefficients, and irrigation times.

4.2 Application Efficiency

Application efficiency is the ratio between the volume of water stored in the root zone in the target area after the irrigation event and the total volume of water applied.

$$E_a = \frac{\text{Volume of water added to the root zone}}{\text{Volume of water applied to the field}} \tag{1}$$

According to Walker (1989), this efficiency is a function of the soil's water content before the irrigation, the depth of water that infiltrates into the soil, and the soil's water retention characteristics. All of these factors have a high degree of spatial variability, which significantly affects this measure. Figure 3 is a schematic diagram showing the infiltration profile, the required depth and the infiltration depth.

Often this efficiency is calculated using the average application depth to represent the volume of water applied, and the soil water deficit at the time of irrigation to represent the change in the volume of stored water. This approach usually overestimates the real application efficiency because it does not account for the non-uniformity of application depth. The IDS Group is also studying how to include the influence of the non-uniformity of application depth into the CSU-ID Model when calculating efficiencies.

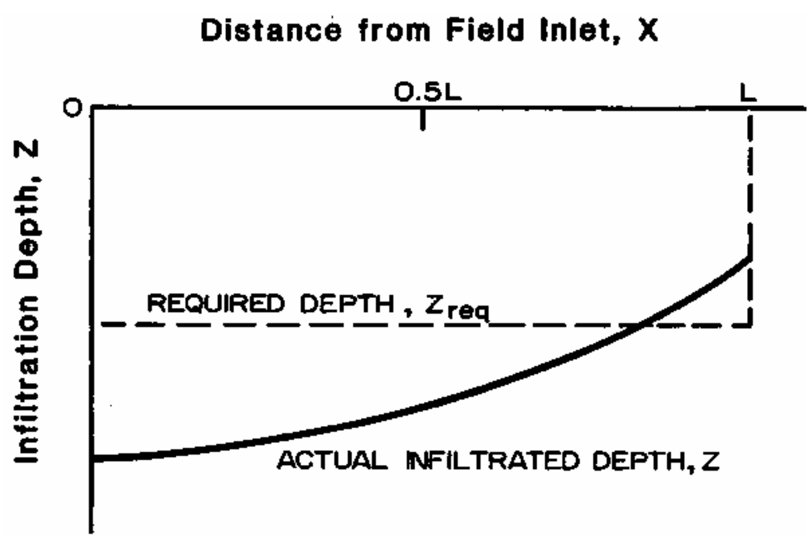

Figure 3. Infiltration Profile in the Soil and the Required Depth

Losses from the field occur as either deep percolation (depths greater than the targeted area, Zreq), or runoff (tailwater). In order to compute application efficiency, it is necessary to identify at least one of these losses as well as the amount of water stored in the root zone, which is, as noted previously a complex factor.

4.3 Water requirement efficiency

The water requirement efficiency, $\mathbf{E_r}$, or storage efficiency, is theoretically defined as:

$$\mathbf{E_r} = \frac{\text{Volume of water added to root zone storage}}{\text{Potential soil moisture storage volume}} \quad (2)$$

The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone (targeted zone). The value of $\mathbf{E_r}$ is very important to consider when irrigation events tend to leave major portions of the field under-irrigated, a frequent occurrence in water scarce areas using surface irrigation. $\mathbf{E_r}$ is the variable most directly related to crop yield since it reflects the degree of soil moisture stress the plants experience.

4.4 Deep percolation ratio

Losses of water through deep percolation beyond the root zone are estimated using the deep percolation ratio, **DPR**, (Walker, 1989)

$$\mathbf{DPR} = \frac{\text{Volume of deep percolation}}{\text{Volume of water applied to the field}} \quad (3)$$

These types of losses exacerbate waterlogging and salinity problems, while leaching precious crop nutrients from the root zone. When the water quality of the groundwater basin is not the best, deep percolation can cause major problems. Hence, it is important to determine how much water is deep infiltrated in the monitored fields. This knowledge will be helpful to calibrate farm-level and regional models.

4.5 Tailwater ratio

Losses from the irrigation system via runoff from the end of the field are accounted for through the tailwater ratio, **TWR**:

$$\mathbf{TWR} = \frac{\text{Volume of runoff}}{\text{Volume of water applied to the field}} \quad (4)$$

Tailwater runoff results in erosion of topsoil and the obstruction of conveyance and control structures downstream.

4.6 Inflow – Outflow Hydrographs

As part of the analyses performed on the data collected, inflow – outflow hydrographs, like those shown in Figures 4 through 6, have been made for the monitored irrigation events. By identifying management, practices and system configurations, more information will be generated to determine what practices could be implemented to improve irrigation efficiency. Surface irrigation systems are complex and dynamic hydrologic systems and, thus, the evaluation processes are important to optimize the use of water resources in these schemes.

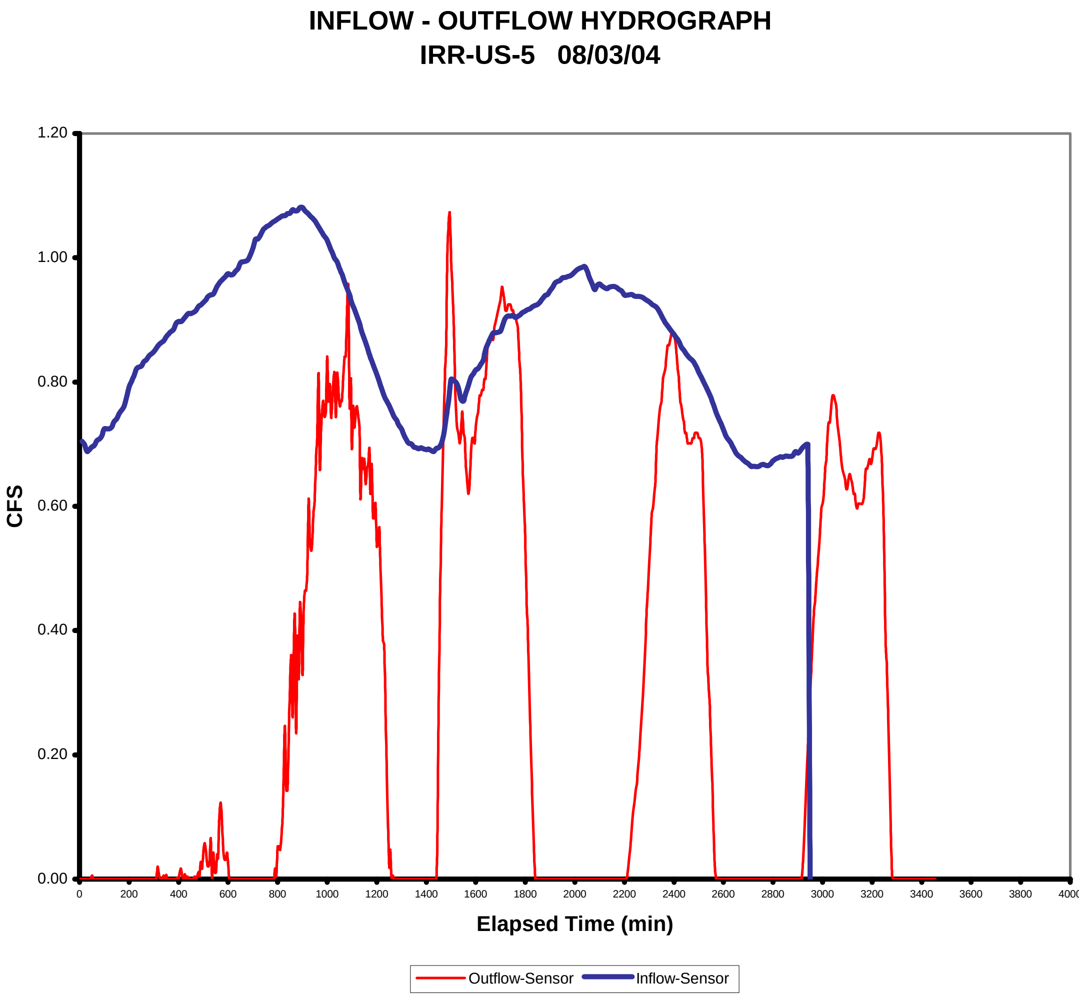

Figure 4. Sample Inflow - Outflow Hydrograph

Table 2, shows the preliminary results of total Inflows and Outflows for selected fields.

Table 2. Application Depths in Some of the Monitored Fields in the Arkansas River Valley, CO.

FIELD - DATE	INFLOW AF	OUTFLOW AF	INFILTRATED (mm)	INFILTRATED (in)	AREA Acre	AREA Ha
IRR-US1 08/14/2004	4.70	0.60	47.3	**1.9**	26.4	10.7
IRR-US1 08/05/2004	3.60	0.10	40.3	**1.6**	26.4	10.7
IRR-US1 07/25/2004	10.90	3.50	85.3	**3.4**	26.4	10.7
IRR-US2 08/06/2004	7.50	0.03	94.7	**3.7**	24.0	9.73
IRR-US2 08/13/2004	4.60	0.13	56.7	**2.2**	24.0	9.73
IRR-US3 [2] 08/18/2004	0.01	0.00	0.6	**0.0**	2.5	1
IRR-US5 06/28/04	3.90	1.20	55.5	**2.2**	14.8	6
IRR-US5 08/03/04	3.50	1.30	57.7	**2.3**	11.6	4.7
IRR-US9 06/02/04	8.30	0.62	67.7	**2.7**	34.6	14
IRR-US9 06/22/04	36.30	5.06	275.2	**10.8**	34.6	14
IRR-US9 07/23/04	41.00	0.72	354.9	**14.0**	34.6	14
IRR-US10 07/08/04	11.10	0.60	189.6	**7.5**	16.9	6.83
IRR-DS1 07/02/04	7.00	1.19	98.2	**3.9**	18.0	7.3
IRR-DS2 07/14/04	6.90	1.66	64.6	**2.5**	24.7	10
IRR-DS3 06/21/04	7.90	4.70	56.1	**2.2**	17.4	7.03
IRR-DS3 06/30/04	8.11	0.0	90.9	**3.6**	27.2	11
IRR-DS5 [3] 05/17/04	27.90	6.6	245.5	**9.7**	26.4	10.7
IRR-DS6 07/25/04 [4]	18.50	3.9	168.3	**6.6**	26.4	10.7

Remarks
[1] Assumed to be uniformly distributed - [2] Conversion from Gallons/ Ha - [3] Data for only one set - [4] Sensor data lost, estimated using manual readings

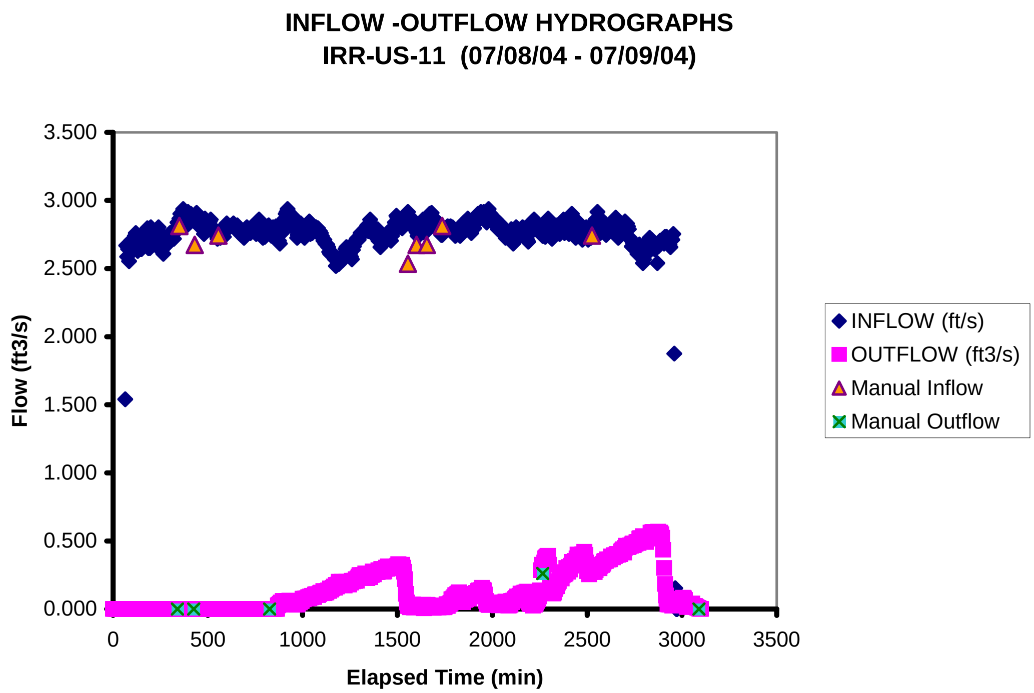

Figure 5. Inflow - Outflow Hydrograph Dutton's Field

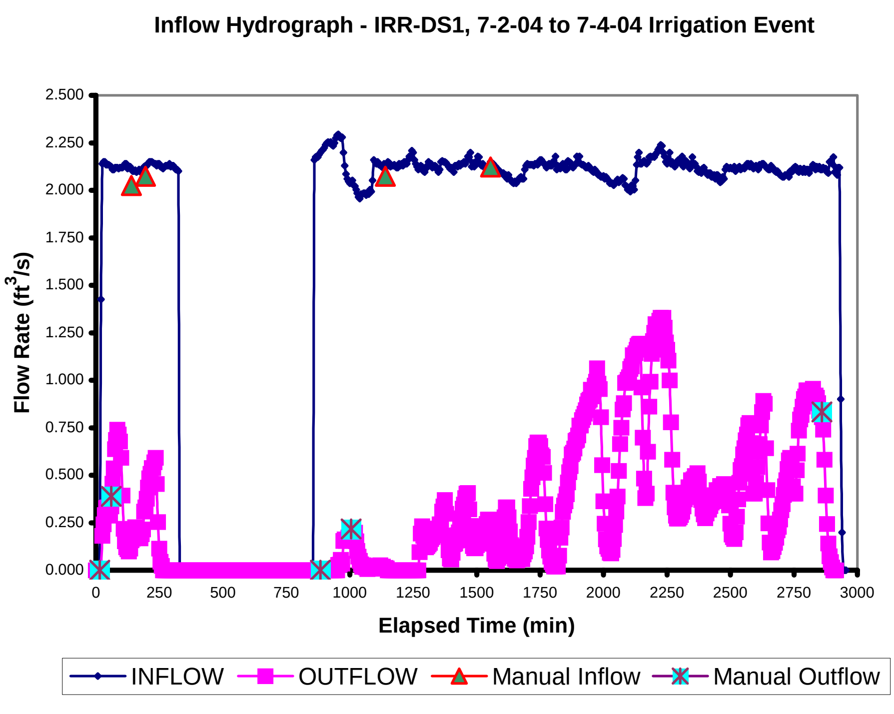

Figure 6. Inflow - Outflow Hydrograph Hemphill Farms

6. Summary and Conclusions

Due to the complexity of interconnections among water storage and delivery systems and between groundwater and surface water use, irrigation efficiencies in the Arkansas River Valley need to be assessed and effectively estimated. Poorly timed irrigation applications and excessive amounts of water applied in a single event also contribute to salinity-induced crop yield losses.

During the summers of 2003 (pre-study year) and 2004, field observation indicated that most irrigation water is applied without following technical procedures. Current estimates of water demand and application are almost non-existent and are left to the empiric criterion of the ditch-rider. For legal issues, such as water rights transfers, these engineering estimates are made by the two parties directly involved in the negotiations and are based, for the most part, on outdated information found in literature which is not about the particular region. The author agrees with Burt, (1998) in when he states that on-farm water management is no longer a positive goal; it is a requirement now in most areas where irrigation takes place.

The data collected during the assessment of irrigation efficiencies in selected fields in the Arkansas Valley, will be used for the validation and fine-tuning of the CSU-ID model. CSU-ID, is a computer-based Decision Support System (DSS) for the design and management of conjunctive irrigation and drainage systems. The model is used to compute and estimate the spatial and temporal distribution of soil water and salinity as they are affected by irrigation, drainage, and the management practices. The model explicitly considers variability due to the diverse soil types, crop properties and irrigation practices in multiple fields in an area. Some classic irrigation efficiency calculations will have to be carried out as baseline for automating processes in the model. The data generated in 2004 and 2005, will enlighten the investigators about how to channel the efforts to better understand the water-soil-plant relations occurring in the Arkansas River Valley.

For the year 2005, more monitoring schemes will be put in place in selected and representative fields at different reaches of the Arkansas River.

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