

MEMORANDUM

TO: Water Right Files 37-22252, 37-22313, 37-22318, and 37-22323
FROM: Aaron Marshall *AM*
DATE: February 12, 2010
SUBJECT: Application for Transfer No. 74449 and Application for Permit No. 37-22252

Recent correspondence with representatives for Dry Lot LLC, Brockway Engineering and Travis Thompson, raised questions about the following topics with Application for Transfer No. 74449 and Application for Permit No. 37-22252.

1. Annual Historic Consumptive Use Volume: On February 11, 2010, Brockway prepared a memo that provides more detailed information on the delivery of water under the rights involved in the transfer. Brockway proposed an average historic consumptive volume of 54.2 acre-feet per year. Using the same historic curtailment data provided by Brockway, I computed an average historic consumptive volume of 52.8 acre-feet per year (Attachment A). My computation likely differed from Brockway's since I used updated 2009 precipitation deficit data from Allen and Robison. Brockway reviewed my computation and concurs with the resulting total, 52.8 acre-feet per year.

2. Irrigation Application Efficiency: I originally proposed using 75% as a reasonable efficiency estimate based on Brockway's statement in a previous memo. Brockway's most recent memo suggests that 65 to 70% would be a reasonable estimate of irrigation efficiency for this project. Literature related to this topic provides various estimates for sprinkler irrigation efficiency ranging from 60 to 85%¹, 60 to 80%², 60 to 80%³, and 70 to 87%⁴. Hunter, specifically discussing turf grass irrigation, explains that "while it is feasible to achieve an application efficiency (EA) rating as high as 80%, an irrigation system with an efficiency rating of 70% is considered very good." IDWR must ensure that any change to a water right and any new appropriation of water is consistent with the conservation of water resources in Idaho. IDWR would not be good stewards of Idaho's limited water resources if it did not promote the efficient use of water and strive to achieve "very good" irrigation efficiency. IDWR should consider 70% as a reasonable estimate of irrigation efficiency in this case and limit the annual diversion volume to 75.4 acre-feet per year (52.8 af/0.70).

3. Temporal Diversion Volume Limit: The intent of a temporal diversion volume limit is to ensure that there will be a benefit from ground water recharge lasting throughout the irrigation season. Brockway suggested using a 30-day period volume limit of 60 acre-feet. However, this could potentially result in diversion of the entire annual volume in just 36 days (75.4 af/1.9835/1.06 cfs) and end recharge by May 20. Allen and Robison⁵ report a total annual average precipitation deficit (P_{DEF}) of 597 mm for irrigated turf near Hailey, ID. The total average P_{DEF} during the growing season prior to June is 71.72 mm, approximately 12% of the annual total. Instead of a 30-day temporal volume limitation, perhaps the diversion volume should be limited to 9.0 acre-feet (75.4 x 0.12) prior to June 1.

Another method to achieve a similar result is to quantify a pre-June volume limit based on authorized flow rate: (30 days in June)(1.06 cfs)(1.98347) = 63.1 af $\rightarrow$ 75.4 af - 63.1 af = 12.3 af limit prior to June 1

This method will provide operational flexibility through the irrigation season while continuing to ensure that the aquifer will be recharged through June or later. This also provides more water in the 30 days of June than would be allowed under Brockway's suggested 60 af limit per 30-day period.

4. Shallow Injection Wells: I will work with IDWR Underground Injection Control (UIC) staff to provide a response to the questions raised by Brockway on this subject. UIC staff confirmed that, as designed, the recharge facilities qualify as shallow injection wells subject to UIC program requirements. The ground water recharge rights should carry a condition similar to the following:

“Prior to diversion and use of water under this right pursuant to Transfer approval 74449, the right holder shall comply with requirements governing the construction and use of injection wells if applicable.”

Some explanation is necessary for terms not previously addressed concerning the use of water under Application for Permit No. 37-22252.

5. Regulation by Watermaster: Approval of this permit is contingent upon mitigation with water from the Big Wood River for ground water recharge. The rights providing mitigation for this permit are subject to control by the watermaster of State Water District No. 37. Due to the permanent and direct connection between this permit and the ground water recharge rights, this permit must also be subject to control by the watermaster of State Water District No. 37. Tim Luke, IDWR Water Distribution Section manager, confirmed that the watermaster has jurisdiction over the use of water under this permit if it is conditioned subject to his control.

¹ Neibling, H. 1997. Irrigation Systems for Idaho Agriculture. University of Idaho. College of Agriculture. Moscow, Idaho.

² Venn, B.J., D.W. Johnson, and L.O. Pochop. 1997. Hydrologic Impacts due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices. Journal of Irrigation and Drainage Engineering. Am Society of Civil Eng. May/June 2004.

³ Hunter Industries, Inc. 2004. Professional Turf Manager's Guide to Efficient Irrigation Practices and Equipment. Hunter Industries Incorporated. San Marcos, California.

⁴ Martin, Edward C. 2006. Determining the Amount of Irrigation Water Applied to a Field. University of Arizona. College of Agriculture. Tucson, Arizona.

⁵ Allen, Richard G. and Clarence W. Robison, 2009. Evapotranspiration and Consumptive Irrigation Water Requirements for Idaho: Supplement updating the Time Series through December 2008, Research Technical Completion Report. Kimberly Research and Extension Center, University of Idaho. Moscow, ID.

CURTAILMENT ANALYSIS FOR 03/24/1883 PRIORITY DATE
USING DATA FROM ALLEN AND ROBISON, 2009, FOR ALFALFA - LESS FREQUENT CUTTINGS
<http://www.kimberly.uidaho.edu/ETIdaho/stcwrstats.php?station=103942&cover=3&stats=Deficit>

[illegible]

21-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
22-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
23-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
24-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
25-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
26-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
27-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
28-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
29-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
30-Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.24	5.24
1-Jul	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4.55	4.55
2-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
3-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
4-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
5-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
6-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
7-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
8-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
9-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
10-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	4.55	4.43
11-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	0.75	1	4.55	4.37
12-Jul	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	0.75	1	4.55	4.37
13-Jul	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0.75	1	4.55	4.25
14-Jul	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0.75	1	4.55	4.25
15-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0.75	1	4.55	4.01
16-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0.75	1	4.55	4.01
17-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0.75	1	4.55	4.01
18-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
19-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
20-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
21-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
22-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
23-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
24-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
25-Jul	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.83
26-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.71
27-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.71
28-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.71
29-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.71
30-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	4.55	3.71
31-Jul	1	1	0.5	1	1	1	1	1	1	0	0	1	0.5	1	1	1	1	0	1	4.55	3.59
1-Aug	1	1	0.5	1	1	1	1	1	1	0	0	1	0.5	1	1	1	1	0	1	5.17	4.08
2-Aug	1	1	0.5	1	1	1	1	1	1	0	0	1	0.5	1	1	1	1	0	1	5.17	4.08
3-Aug	1	1	0.5	1	1	1	1	1	0	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
4-Aug	1	1	0.5	1	1	1	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
5-Aug	1	1	0.5	1	1	1	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
6-Aug	1	1	0.5	1	1	1	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
7-Aug	1	1	0.5	1	1	1	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
8-Aug	1	1	0.5	1	1	1	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.67
9-Aug	1	1	0.5	1	1	0.5	1	0	1	0	0	0.5	0.5	1	1	1	1	0	1	5.17	3.54
10-Aug	1	0.75	0.5	1	1	0.5	1	0	1	0	0	0.5	0	1	1	1	1	0	1	5.17	3.33
11-Aug	1	0.75	0.5	1	1	1	1	0	1	0	0	0.5	0	1	1	1	1	0	1	5.17	3.47
12-Aug	1	0.75	0.5	1	1	1	1	0	1	0	0	0.5	0	1	1	1	1	0	1	5.17	3.47
13-Aug	1	0.5	0.5	1	1	1	1	0	0	0	0	0.5	0	1	1	1	1	0	1	5.17	3.13
14-Aug	1	0.5	0.5	1	1	1	1	0	0	0	0	0.5	0	1	1	0.5	1	0	1	5.17	2.99
15-Aug	1	0.5	0.5	1	1	1	1	0	0	0	0	0.5	0	1	0.5	0.5	0.5	1	0	5.17	2.86
16-Aug	1	0.5	0.5	1	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.72
17-Aug	1	0.5	0.5	1	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.72
18-Aug	1	0.5	0.5	0.75	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.65
19-Aug	1	0.5	0.5	0.75	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.65
20-Aug	1	0.5	0.5	0.75	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.65
21-Aug	1	0.5	0.5	0.75	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.65
22-Aug	1	0.5	0.5	0.75	1	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	1	0	5.17	2.52
23-Aug	0.75	0.5	0.5	0.75	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.5	5.17	2.18
24-Aug	0.75	0.5	0.5	0.75	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.5	5.17	2.18
25-Aug	0.75	0.5	0.5	0.75	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.5	5.17	2.18
26-Aug	0.75	0.5	0.5	0.75	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.5	5.17	2.18
27-Aug	0.75	0.5	0.5	0.5	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	5.17	2.18
28-Aug	0.75	0.5	0.5	0.5	0.5	1	1	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	5.17	2.18
29-Aug	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	5.17	2.04
30-Aug	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	5.17	2.04
31-Aug	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	5.17	2.04
1-Sep	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	2.22	0.88
2-Sep	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	2.22	0.88
3-Sep	0.75	0.5	0.5	0.5	0.5	1	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.75	2.22	0.88

TOTAL (mm)	488.75
TOTAL (in)	19.24
TOTAL (ft)	1.60

Weighted average historic consumptive use volume = $(2436 + 836)/62 \text{ years} = 52.8 \text{ af/yr}$

Marshall, Aaron

From: Erick Powell [erick.powell@brockwayeng.com]
Sent: Friday, February 12, 2010 3:15 PM
To: Marshall, Aaron
Subject: RE: Dry Lot Transfer Worksheet

Hi Aaron,

I just left a message on your voice mail. We agree with the calculated value of historical consumptive use, using the new revised 2009 ET data from Allen and Robison.

If you have any questions, please let me know.

Regards,
Erick

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All information, calculations, maps, drawings, or other documents transmitted via e-mail are preliminary unless explicitly stated in the e-mail text or in the documents themselves.

From: Marshall, Aaron [mailto:Aaron.Marshall@idwr.idaho.gov]
Sent: Friday, February 12, 2010 2:46 PM
To: Charles E. Brockway; Erick Powell
Subject: Dry Lot Transfer Worksheet

Gentlemen,

Please review the attached spreadsheet and provide me with your feedback.

Thanks,

Aaron

<<Dry Lot Transfer Work Sheet.xlsx>>

Marshall, Aaron

From: Erick Powell [erick.powell@brockwayeng.com]
Sent: Thursday, February 11, 2010 11:26 AM
To: Marshall, Aaron; Keen, Shelley; tlt@idahowaters.com; thewoody@cox.net; Jack Levin
Subject: Dry Lot Transfer Memo from Chuck Brockway
Attachments: memo 02112010 a marshall idwr.pdf

Aaron: Attached is a memo I prepared in response to your previous memos and our meeting on the Dry Lot LLC transfer and permit applications. I am also attaching the articles which I cited on turf irrigation application efficiency (including the paper that you referenced the abstract and did not have access to the full paper) and a table showing the commencement and cutoff dates of the Big Wood River water rights proposed for the recharge project.

Again, thanks for meeting with us. I believe this can be the last iteration and hopefully you can proceed with finalizing the conditions and the transfer and permit orders. Please call me if you have any additional questions.
Chuck

Charles E. Brockway P.E. PhD.
Brockway Engineering
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Twin Falls, ID 83301
208 736 8543

All information, calculations, maps, drawings, or other documents transmitted via e-mail are preliminary unless explicitly stated in the e-mail text or in the documents themselves.

Memo to: Aaron Marshall
Idaho Department of Water Resources

From C.E. Brockway

Subject: Application for Transfer No 74449 and Application for Permit 37-22252, Dry Lot LLC

Dear Aaron:

I have reviewed the Memoranda dated November 24, 2009, December 14, 2009, and January 28, 2010 regarding the above applications for Dry Lot LLC. I want to thank you and the staff for meeting with us on January 7, 2010. This was a very productive meeting and I believe will result in an expedited agreement on the elements of the approval for these applications.

First, let me reiterate that, in my experience with transfers and particularly those applications which involve use of vested rights for mitigation of proposed new uses, the conditions imposed on proposed new uses, places of use, points of diversion or periods of use apply only to the water rights to be transferred and any conditions on the transfer are imposed because of historical use and not on proposed new uses or particulars of the proposed new permit.

Following our meeting on January 7, you prepared the memo of January 28 which outlined some changes or modifications of the proposed transfer and permit approval. The following are my comments regarding the proposed changes:

1. You computed an historic seasonal weighted average consumptive use volume for the proposed rights of 51.3 acre feet per year taking into account the fact that the water rights were out of priority in 18 of the 61 years of record used. You indicated that the average length of the period that the 3/24/1883 water rights were on during the years when the rights were cut was 115 days. I believe that you assumed that, if the water rights went out of priority sometime during the irrigation season, according to the Watermaster District 37, that there were zero deliveries after that time. A review of the Water District 37 Annual reports for the period 1948 through 2008 indicates that there were some years when the 3/24/1883 water right was cut or partially reduced for a period and then reinstated because the Big Wood River flows increased later in the season.
2. The attached copies of the priority cut dates from the Watermaster report show the actual days when the 3/24/1883 rights were cut, partially cut and/or reinstated. The attached spreadsheet shows the revised periods when water was being delivered to those rights through the Hiawatha Canal. I assumed that there was no water delivered under the 3/24/1883 rights if the Watermaster report showed a priority cut and no reinstatement for the remainder of the irrigation season. If the Watermaster report showed a cut to 75% of the right or 50% of the right, then that period was included in the weighted average period of delivery for that year.

3. The spreadsheet shows that for the period 1948 through 2008 that the rights were completely cut in 7 of the 61 years and partially cut or cut for a short period in 12 of the 61 years. The average length of time a portion of the water rights were in priority was 188 days in the period 1948 through 2008. The full irrigation season precipitation deficit on the historical place of use is 2.06 feet for alfalfa with less frequent cuttings (Allen and Robison, 2009), as you used in your analysis. Utilizing this value and a deduction on a daily basis of the seasonal P_{def} for the shortened season during the 19 years when the rights were cut results in a historical average annual P_{def} value of 54.2 af/season.
4. Based on the average seasonal P_{def} on the historical place of use, and the published data for irrigated turf grass (1.96 af/acre/season), if the historical P_{def} is available from ground water at the new place of use, then a total of 27.7 acres ($54.2 \text{ af/season} / 1.96 = 27.7 \text{ acres}$) should be allowed for irrigation on the Valley Club place of use.
5. The Department utilized an on-field irrigation efficiency of 75% based on the statement in the Brockway Engineering revised narrative in support of the transfer and permit that, "If a more efficient method of irrigation such as "sprinkler irrigation" is employed, which is probable then the irrigation efficiency would be raised to 75%." This statement is correct in that residential irrigation can likely reach 75% on-field efficiency under the best of conditions. However, published data provides a range of on-field efficiencies for turf irrigation depending on soil types, management levels and climate that range from 60 to 80 percent using solid set sprinklers. Research from various sources show efficiencies for agricultural (not residential) sprinkler irrigation application for solid set sprinklers range from 68 to 70%¹, 60-85%², Design irrigation efficiencies for turf irrigation indicate that 70% is considered very good and for general purposes a manager of a golf course can expect to achieve 60 to 80%³. Based on the soil types and occupancy frequency of many homes in the Valley Club and residential irrigation is more inefficient than agricultural irrigation, a reasonable operating irrigation efficiency for this project is 65 to 70% and should be utilized in any calculations relative to water requirements. Based on an operating irrigation efficiency of 65%, an estimated diversion volume of 83.4 acft should be used ($54.2 \text{ acft} / 0.65 = 83.4 \text{ acft}$).
6. Determination of water requirements for any irrigation project assumes that the objective is a full water supply for the intended crop or vegetation. This full-water-supply objective means that the ET estimate is based on providing water at the correct time and in sufficient amount to meet or exceed the peak water requirements. Meeting the peak requirements with the associated available facilities and management levels requires the assumption of a reasonable irrigation application efficiency. The assumption of any level of water supply less than that required for a well-watered, disease free crop results in deficit irrigation and resulting higher irrigation application efficiency since the definition of application efficiency is the ratio of water utilized by the plant divided by water applied. Calculated irrigation efficiency can reach close to 100% even by flood irrigation⁴, if insufficient water is applied to the crop to satisfy the crop ET.

7. A preliminary volume diversion constraint of 26.6 ac-ft in a 30-day period is proposed for this transfer. This volume constraint is set apparently to assure that no injury to aquifer water right holders occurs due to early large recharge volumes which would not be retained in the aquifer for a sufficient period to prevent some kind of aquifer drawdown. The necessity for a limitation on the early season recharge volume to prevent injury has not been demonstrated. Apparently the value of 26.6 af/30 day period is based on the suggested limit on recharge of 68.4 af/a to be completed by July 1 of any year. It was suggested by Brockway that, if such a limitation is necessary, a July 1 date be set for the earliest time that recharge could be completed to assure that, in a very low water year, the recharge would be complete by the time the Big Wood water rights were out of priority. This constraint can have a severe effect on the operation of the recharge project in that, on average, the Watermaster does not normally begin delivery of these water rights before April 22 and, in some years, not before May 19. For the May 19, date this would mean that only 42 days would be available to recharge the required volume before July 1. The attached table shows the date water delivery was commenced for each of the years when the 3/24/1883 rights were curtailed. Under these conditions the recharge requirement for a late-commencement year would not be able to be completed by July 1 without violating the 30 day limit.

It is suggested that, if a condition is justified to limit the recharge rate in the early season, that it be limited to a recharge of 60 acre feet in any 30 day period or a specific cumulative volume by specific dates. The suggested limit would be calculated as $(83.4 \text{ af/a})/42 \times 30 = 60 \text{ af/30 day period}$.

8. The preliminary transfer determined that the underground infiltration basins are to be classified as a shallow injection well(s) under 42-3902. According to this statute, the definition of a 'shallow injection well' is "an injection well which is less than or equal to eighteen (18) feet in vertical depth below land surface". The proposed infiltration basins do not meet the criteria of a shallow injection well.

An injection well must meet all three requirements in 42-3902 (8): namely, a) it is a bored, drilled or dug hole, or is a driven mine shaft or a driven well point; b) it is deeper than its largest straight-line surface dimension, and c) it is used for or intended to be used for injection. The administrative and legal ramifications for Dry Lot LLC caused by classification of these basins as shallow injection wells are not known by the applicant's representatives nor explained by IDWR. Is an injection well permit and fee required? What is the "list" of injection facilities that is purported to be maintained by the State?

9. Measuring devices are proposed at the Big Wood River Hiawatha Canal diversion which is maintained by the Hiawatha Canal and administered by the Watermaster, District 37. This facility is utilized to measure and administer all rights in the Hiawatha Canal. Dry Lot LLC has two water rights in the canal. Dry Lot has a joint responsibility, along with all other water right

holders in the Hiawatha canal, to assure that this device is maintained, but does not have sole responsibility in the event the Hiawatha Canal Company does not maintain the measuring device. Daily reporting of diversions into the Hiawatha Canal is published by the Watermaster and allowed diversions from the river to Dry Lott LLC will be controlled by the Watermaster. The diversion from the Hiawatha Canal which will be utilized by Dry Lot LLC has been and is maintained by the Valley Club to convey water under rights held by the golf course. This pumping plant and pipeline will be used by Dry Lott LLC to convey water from the Hiawatha Canal to the recharge basins. A flow measuring device is now installed on the pipeline and will be maintained under a joint agreement between Valley Club and Dry Lot LLC. Reporting of diversions from the Hiawatha Canal is performed by the Hiawatha Canal personnel. A recording flow meter is proposed for the diversion from the Valley Club pipeline to the Dry Lott LLC recharge facility. This meter will be an in-line flow meter with totalizer capable of determining daily discharge volumes and instantaneous discharge. Dry Lott LLC will be responsible for maintenance of the recharge flow meter and reporting to IDWR of recharge volumes as required. It is proposed that annual reports be provided of recharge water.

10. Conditions and/or remarks to the effect that ground water diversion under the proposed permit is mitigated by recharge of the surface water rights should be included in the permit. This will prevent potential interpretation in the future that the ground water diversion is governed by the priority of the 3/24/1883 surface water rights.
11. The agreement with the Big Wood Canal Company requires that 0.5 cfs of the water rights purchased by Dry Lot LLC remain in the Big Wood River and not be diverted into the Hiawatha Canal. The purpose of forgoing the diversion of 0.5 cfs was to assure that, if there were any depletions of flow in the river caused by the transfer and recharge project, they would be mitigated and no injury would occur to downstream Big Wood River water right holders including BWCC. The ground water model was used to simulate the recharge/extraction project and provides a simulation of reach flow changes in various reaches of the Big Wood River. The attached graph shows the simulated flow changes per month in the Big Wood River flow from Starweather (near the Hiawatha Canal diversion) downstream to Deer Creek as a result of the proposed project. Note that the red column shows the resulting change per month of groundwater-river interaction in this reach as a result of the project without the BWCC agreement. A positive number reflects more water from the groundwater to the Big Wood River. During June, the model predicted the highest flow contribution from the aquifer to the river of 0.28 cfs; during September, the model predicted the largest deficit of flow in the River. The blue columns show the resultant effect on the change of river flows with the proposed project and leaving 0.5 cfs in the river as agreed. Note that all depletions to the Big Wood River are fully mitigated.

1. Venn, B.J., D.W. Johnson, and L.O. Pochop. 1997. Hydrologic Impacts due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices. *Journal of Irrigation and Drainage Engineering*. Am Society of Civil Eng. May/June 2004.
2. Neibling, H. 1997. Irrigation Systems for Idaho Agriculture. University of Idaho. College of Agriculture. Moscow, Idaho.
3. Hunter Industries, Inc. 2004. Professional Turf Manager's Guide to Efficient Irrigation Practices and Equipment. Hunter Industries Incorporated. San Marcos, California.
4. Samani, Z., T. Sammis, R. Skaggs, N. Alkhatiri, and J. Deras. 2005. Measuring On-Farm Irrigation Efficiency with Chloride Tracing under Deficit Irrigation. *Journal of Irrigation and Drainage Engineering*. Am Society of Civil Eng. Nov/Dec 2005.

Data from WD#37: Priority 3/24/1883 Cut Dates Page											
Year	* cut	%	Remarks	cut	%	Remarks	cut	%	reinstated	%	off
1949	8/22	75	Good								
1960	8/9	75	Good	8/12	50	Good					
1961	7/25	50	Good								
1966	8/17	75	Good	8/26	50	Good					
1973	8/22	50							9/5		
1979	8/8	50							8/10		
1987	8/28	50									
1988	8/2										8/2
1991	8/12										8/12
1992	7/14										7/14
1994	7/1	50									7/12
2000	8/2	50									
2001	7/30	50									8/9
2002	8/15	50									
2003	8/14	50									
2004	8/13	50									9/10
2005	8/22	50									
2007	7/10	75									7/17
2008	8/21	50		8/26	75		9/10	100	9/23	25	

* Water Master Kevin Lakey: interpret "cut date" in WD #37 & 37M books as receiving water on the 'cut date' listed in book...

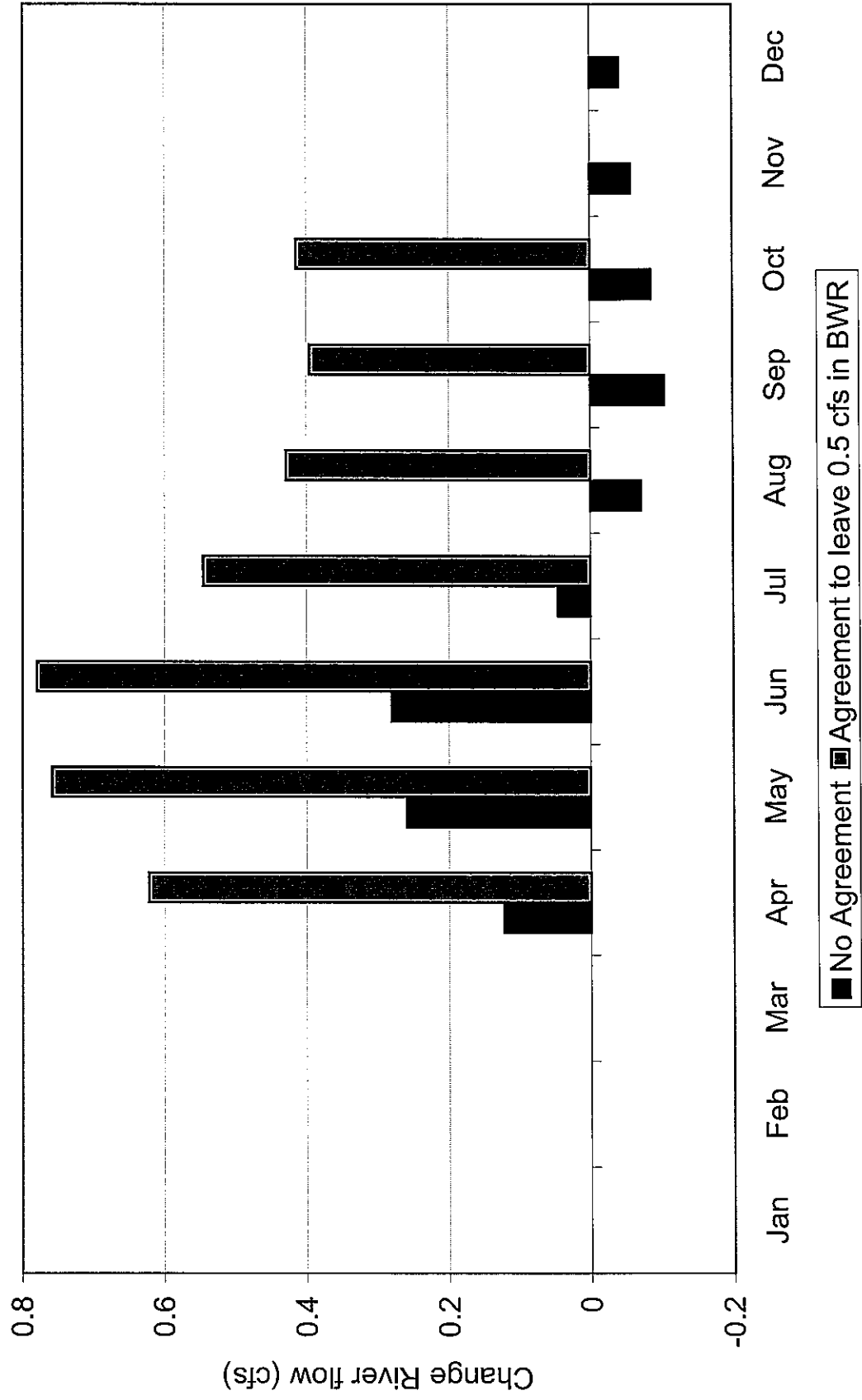
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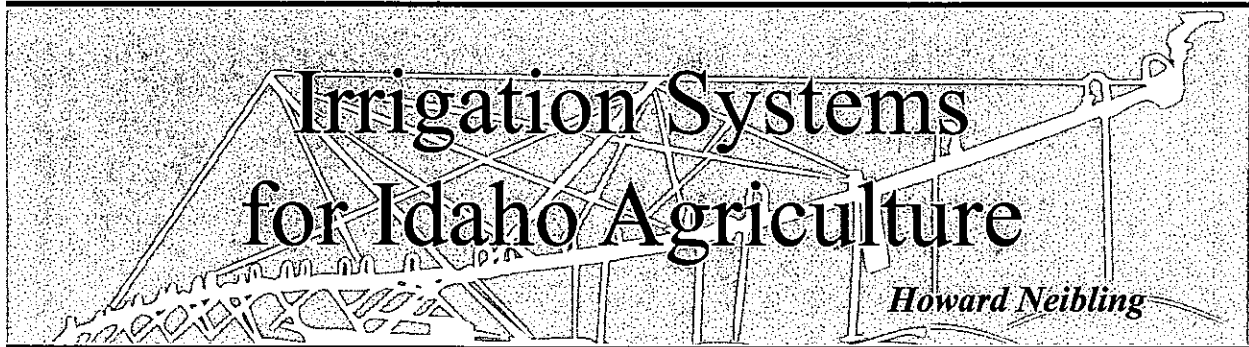
AP:Worksheet

F:\Projects\Valley Club H.O.A.\Hiawatha 03-24-1883 Priority Cuts\Hiawatha Canal Cuts 3-24-1883

Data From WD#37 : Delivery Page for Canal				IDWR Attachment A	Irr Days	Day First H2O in canal	Day Last H2O in canal	Calculated Irr Days	Year	Notes off of Priority Cut Date pages unless noted otherwise
Year	cut	%	Remarks							
1949	8/22	75	Good	130		4/1	9/30	183	1949	9/9 extension by-pass cancelled
1960	8/9	75	Good	117		5/16	9/30	138	1960	
1961	7/25	50	Good	102		4/15	9/30	169	1961	7/25 all water in extension by-pass
1966	8/17	75	Good	134		5/6	9/30	148	1966	
1973	8/22	50		130		5/6	9/30	148	1973	
1979	8/8	50		116		4/16	9/30	168	1979	
1987	8/28	50		136		4/8	9/30	176	1987	
1988	8/2			110		4/1	9/30	183	1988	
1991	8/12			120		5/8	9/30	146	1991	
1992	7/14			91		4/27	9/30	157	1992	8/12 Futile call below Bellevue
1994	7/1	50		78		5/6	7/19	75	1994	8/12 Futile call below Bellevue
2000	8/2	50		110		5/5	9/30	149	2000	
2001	7/30	50		107		4/27	9/30	157	2001	8/28 River Dammed Bellevue- 9/16 removed
2002	8/15	50		123		4/29	9/30	155	2002	
2003	8/14	50		122		5/19	9/30	135	2003	
2004	8/13	50		121		4/26	9/29	157	2004	
2005	8/22	50		130		5/13	9/30	141	2005	WD#37 Book has deliver for 9/31 note AP
2007	7/10	75		87		4/12	9/30	172	2007	WD#37 Book has deliver for 9/31 note AP
2008	8/21	50				5/6	9/30	148	2008	

Change in Big Wood River from Starweather to Deer Creek from Proposed Transfer





Idaho has approximately 4 million acres of irrigated agricultural land. Most of it is in pasture and hay crops, grain crops, potatoes, and sugar beets, in hierarchical order. Table 1 shows the number of irrigated acres in the state by crop for 1994. Nearly all of this land is irrigated by either sprinklers (59 percent) or surface irrigation systems (40 percent), with only a very small amount (less than 1 percent) in micro-irrigation systems (trickle or drip) (table 2).

The selection of an irrigation system, or the decision to continue with a gravity system rather than convert to a sprinkler system, is a matter of tradeoffs among the following factors: initial investment costs, operating costs, site factors, and management skills. A relative comparison of these factors is given on pages 4-5. In general, the higher-investment, higher-water-application-efficiency systems are found in areas where large fields of high-value, water-sensitive crops are grown, or where water supply may be limited or pumping lift is high. Lower-initial-investment surface systems are generally used in short-growing season areas or areas where soil depth or texture limits production. Lack of available three-phase electric power and seed production requirements for dry foliage (for disease control) may also dictate the continued use of surface irrigation.

In a ideal irrigation system, on a field with uniform soil properties, water is supplied uniformly over the entire area of a field at a rate not to exceed the rate at which water will enter the soil (infiltration rate), and with a frequency and

amount to meet the crop need. Since crop water use varies during the year, water application should also vary to just meet this need. Water in excess of crop need should be applied only on

Table 1. 1994 Idaho acreage irrigated by crop (adapted from 1995 *Idaho Agricultural Statistics*, Idaho Agricultural Statistics Service, Boise, ID).

Crop	Acres irrigated
Alfalfa	820,000
Barley	458,000
Beans, dry	138,000
Corn (grain and silage)	97,000
Flower seed	100
Grapes	1,000
Grass seed	500
Hops	4,037
Melons	500
Oats	12,000
Pasture/Hay crops	1,148,363
Potatoes	408,000
Small Fruits	600
Turfgrass/sod	100
Sugar Beets	201,000
Tree Fruits	12,400
Wheat	760,000
Mint	17,500
Onions	8,600
Sweet corn	17,100

fields where soil or water supply quality requires overirrigation for salinity control.

Application Efficiency

Application efficiency is the percentage of water delivered to the head of a field that is actually stored in the crop-root zone. Application efficiencies for typical surface and sprinkler irrigation systems are given in table 3.

Surface Irrigation Systems

Water applied by surface irrigation systems may be stored in the root zone, lost to surface runoff, or lost to deep percolation below the root zone because of excess application. Evaporation losses are minimal compared to sprinkler irrigation. Surface irrigation methods have relatively low application efficiencies because runoff from the field may be up to 20-40 percent of water applied, and deep percolation may be up to 20-40 percent. Application efficiencies for traditional furrow-irrigated systems supplied by siphon tubes or gated

pipe range between 30 and 40 percent, with efficiencies of 50-60 percent possible with excellent management. Land grading to eliminate low spots reduces local overirrigation and raises efficiency by about 5-10 percentage points. Improved systems that give better control over water application rates, or improved management to reduce runoff or deep percolation, will increase the fraction of applied water that is usefully stored and raise application efficiency. Improved surface irrigation systems with good irrigation water management can have application efficiencies comparable to handline or wheelline sprinkler systems.

Sprinkler Systems

Water applied by sprinkler systems may be stored in the root zone, lost to evaporation or wind drift during application, or lost to deep percolation if more water is applied than the root zone can hold. If application rate exceeds the rate at which water can enter the soil, water can also be lost to surface runoff on sloping land. Equipment that applies water closer to the ground with good areal uniformity will reduce losses to evaporation and wind drift and losses to deep percolation or runoff caused by localized areas of excess application.

Micro-irrigation (Drip) Systems

Nearly all water applied by micro-irrigation (drip) systems should be stored in the crop-root zone if water is not overapplied. Since application is at or below the soil surface, evaporation is minimal, runoff should be zero, and deep percolation losses due to nonuniformity of application should be minimal. Therefore, application efficiencies are quite high.

Surface Irrigation Systems

Furrow or Corrugate Irrigation

Before advances in sprinkler design and aluminum pipe production in the 1950s, almost all irrigated land was surface irrigated. Row crops are irrigated by supplying water to the upslope end of furrows that are spaced from 22-36 inches apart, depending on the crop grown. Water is supplied to close-growing crops, such as alfalfa or small grains, by corrugates spaced 24-30 inches apart. Furrows are deeper and wider than corrugates. Water supply to the furrows or corrugates

Table 2. Idaho acreage irrigated by specific irrigation method (adapted from information developed for the 1995 *Annual Irrigation Survey*, Irrigation Journal 46(1):27-28.

Sprinkler systems	Acres irrigated
Center-pivot/Linear-move	841,000
Side-roll (wheelline)	671,700
Hand-move	845,400
Solid-set	74,200
Big-gun	1,600
Total	2,433,900
Low flow/Micro-irrigation systems	
Surface micro-spray	6,100
Surface drip	450
Subsurface drip	200
Total	6,750
Surface/Gravity systems	
Flooding from ditches	733,350
Open ditch/Siphon tube	852,500
Gated pipe	77,100
Lay-flat pipe	1,000
Total	1,663,950

is by feed ditches and cutouts, earthen or concrete head ditches with siphon tubes, or gated pipe. Siphon tubes or gated pipe allow closer, more repeatable control of water discharged into each furrow or corrugate. This allows better water management and improved application efficiencies with little additional labor. It should be emphasized that concrete ditches with siphon tubes or gated pipe do not by themselves improve irrigation efficiency: they are a tool to help improve water management, which does improve efficiencies.

Border or Graded-Border Irrigation

Irrigation of alfalfa, pastures, or small grain may also be accomplished by graded- or level-border irrigation. In border irrigation, water is supplied at the head of 40-100 foot wide borders separated by earthen ridges. Border width is designed so that the entire border width is flooded, and the flood wave moves downslope. Fields with very little sideslope and low infiltration rates will allow wider borders than will fields with higher infiltration rates or more pronounced slope across the border. Water supply may be by large siphon tubes, riser outlets from surface or buried mainline, or gates in a supply ditch.

Wild Flooding

Wild flooding may be the irrigation method of choice when water is plentiful, crop value per acre is relatively low, and improved irrigation management will not yield a significantly higher financial return. Wild flooding involves diverting water from cross-slope ditches at intervals to assure adequate coverage of a slope. The water flows downslope and may concentrate in low areas or skip high areas. The spacing between diversion points on the supply ditch and between successive downslope ditches must be reduced as topography becomes more undulating, soils become more sandy or gravelly (higher infiltration rates), or resistance to water flow increases (plant density at the soil surface increases).

Improved Surface Systems

Surge Irrigation

Surge irrigation is a relatively new technique that reduces tailwater runoff and deep percolation. Initial testing suggests that it can reduce water losses by 30-50 percent. Water is applied to

each furrow in a series of pulses rather than as a continuous stream. A valve controlled by a clock or microprocessor allows flow to be alternated between two adjacent sets of furrows. This surging action in a furrow allows water to travel faster to the lower end, resulting in less deep percolation at the head of the furrow. Changing cycle time within an irrigation can reduce tailwater runoff, saving additional water. This system works best on light, loose soils and is less effective on heavier soils or on soils where compaction occurs during the growing season. Cost is about \$1,500-\$2,000 per surge valve. Typically, one or at most two valves are used per run of gated pipe.

Table 3. Typical irrigation system application efficiencies for surface and sprinkler irrigation systems.

	Application efficiency, %	Water required to put 1 inch in crop-root zone
Surface systems		
Furrow	35-60	1.7-2.8
Corrugate	30-55	1.8-3.3
Border, level	60-75	1.3-1.7
Border, graded	55-75	1.3-1.8
Flood, wild	15-35	2.8-6.7
Surge	50-55	1.8-2.0
Cablegation	50-55	1.8-2.0
Sprinkler systems		
Stationary lateral (wheel- or hand-move)	60-75	1.3-1.7
Solid-set lateral	60-85	1.2-1.7
Traveling big gun	55-67	1.5-1.8
Stationary big gun	50-60	1.7-2.0
Center-pivot lateral	70-85	1.2-1.4
Moving lateral (linear)	80-87	1.1-1.2
Micro-irrigation systems		
Surface drip	90-95	1.05-1.1
Subsurface drip	90-95	1.05-1.1
Micro-spray or mist	85-90	1.1-1.2

Source: Sterling, R., and W. H. Neibling, 1994. *Final Report of the Water Conservation Task Force*. IDWR Report. Idaho Department of Water Resources, Boise.

Cablegation

Cablegation is an automated surface irrigation system that uses a travelling plug inside a gated pipe delivery system. The plug restricts water application to only those gates nearest the plug. Flows nearest the plug are the greatest and advance fastest down the furrows. Flow in any furrow gradually decreases as the plug moves downstream. This nearly matches the natural decrease in infiltration rate with time and thus reduces tailwater runoff. Because the system encourages rapid initial advance and later cutback

of flow, water application is more uniform, and runoff and deep percolation are reduced. Cost is approximately \$100 per acre.

Tailwater Recovery Systems

Tailwater recovery systems are typically used in surface systems where water supply is short or where sediment discharge in runoff must be eliminated. A pond installed at the base of the field catches all runoff and stores it until it is pumped back to the head of the field for irrigating another set of furrows. Tailwater recovery systems can improve application efficiencies to val-

Comparison of irrigation systems in relation to site and situation factors

Site and situation factors	Improved surface systems		
	Redesigned surface systems	Level basins	Intermittent mechanical
Infiltration rate	Moderate to low	Moderate to low	All
Topography	Moderate slopes	Nearly level	Level to rolling
Crops	All	All	Generally short season
Water quality	All but very high salts	All	Salty water not suitable for plants
Efficiency	Average 55-70%	Average 80%	Average 60-70%
Labor requirement	High, training required	Low, some training	Moderate, some training
Capital requirement	Low to moderate	Low to Moderate	Moderate
Energy requirement	Low	Low	Moderate to high
Management skill	Moderate	Moderate	Moderate
Machinery operations	Medium fields	Short field	Medium to long length, small
Duration of use	Short to long	Long	Short to medium
Weather	All	All	Poor in wind conditions
Chemical application	Fair	Fair to good	Good

ues near 70 percent (comparable to sprinkler irrigation) and are compatible with cablegation and traditional gated-pipe or head-ditch systems. Cost is about \$100 to \$200 per acre, depending on distance from the nearest power line to the pond.

Sprinkler Irrigation Systems

Set-Move Systems

Set-move systems are operated for a given set time, usually 5, 11, or 23 hours, and then moved to a new location for operation again. If about one

hour is allowed for moving, then one, two, or four sets can be irrigated per day. Examples of systems most used in Idaho are wheellines (figure 1) and handlines. Initial system cost is about \$250-\$300 per acre for handlines and \$300-\$350 per acre for wheellines. Required operating pressure is about 45-55 psi. Labor is required for moving, but the entire field may be irrigated. Since impact sprinklers are mounted 3-4 feet above the ground, these systems are good for low-growing crops but not for corn. Spacing between nozzles on a lateral is 40 feet and spacing between moves is 50 or 60 feet.

	Sprinkler systems		Micro-irrigation systems
move	Continuous mechanical move	Solid-set and permanent	Bi-wall tubing or drip tubing with in-line emitters
	Medium to high	All	All
ing	Level to rolling	Level to rolling	All, but special design required on rolling topography
orter crops	All but trees and vineyards	All	High value required
ay harm	Salty water may harm plants	Salty water may harm plants	All—can potentially use high salt water
0%	Average 80%	Average 65-75%	Average 90-95%
me training	Low, some training	Low to seasonal high, little training	Low to high, some training
	Moderate to high	High	High
nigh	Moderate to high	Moderate	Low to moderate
	Moderate to high	Moderate	High
ng field interference	Some interference circular fields	Some interference	May have considerable interference
ium	Short to medium	Long term	Long term with good management (10-15 years)
y	Better in windy conditions than other sprinklers	Poor in windy conditions, good for cooling or frost protection	All
	Good	Good	Very good

Solid-Set Systems

Solid-set systems are typically used for center-pivot corners and for potato production. They are like handlines but with enough equipment to cover the entire area to be irrigated without moving pipe. Equipment costs are higher, but labor costs are lower since sets may be started or stopped by adjusting valves and no pipe must be moved. Spacing is usually 40 x 40 or 40 x 50 feet. Equipment cost can be up to \$1,000 per acre.

Center-Pivot Systems

Continuous-move systems typically used in Idaho are center-pivot systems (figure 2) and linear-move systems. Initial center-pivot system cost is \$350-\$450 per acre. Since center-pivot systems irrigate a full- or part-circle pattern, not all of a square or rectangular field can be irrigated by the system. For example, a typical pivot on 160 acres will irrigate about 134 acres. About 10-12 additional acres can be irrigated with a folding attachment that swings out to irrigate more of the corners. Otherwise, the corners must be irrigated by handlines or solid-set systems.

Because of the system geometry, more water must be applied per foot of pivot as one moves outward from the pivot point. This is usually accomplished by closer nozzle spacing and larger nozzles. Typical water application packages for pivots are either a high-pressure impact sprinkler (50-60 psi) mounted on the top of the pivot lateral pipe or a low-pressure system (15-25 psi) mounted about 6 feet off the ground on drop pipes

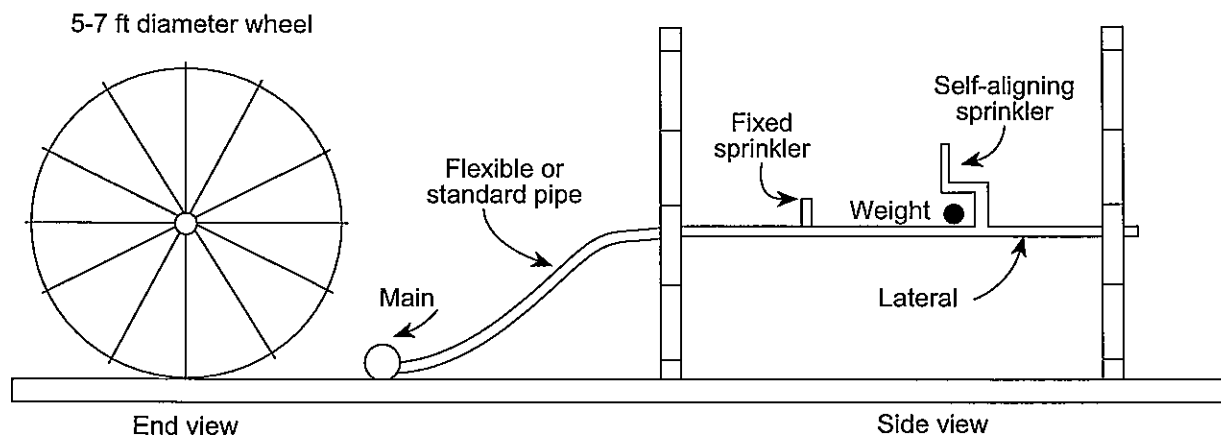
mounted under the pivot lateral pipe. Average system cost is about \$350-\$400 per acre.

If the pump is properly sized and designed for the low-pressure system, considerable energy cost savings may be achieved. However, in the conversion from high to low pressure, many pumps remain unchanged either to reduce capital costs or to support the high-pressure end gun and sprinkler lines necessary to water the corners. In this case, no energy is saved although system uniformity is improved. In many cases, an additional, smaller high-pressure pump can be installed to serve the corners and a booster pump added for the end gun. The larger pivot pump may then be re-worked to reduce energy use and energy costs.

Almost all new pivots are equipped with the low-pressure package, and about half of existing pivots have been converted to low pressure. Because nozzle spacing is closer, application uniformity is improved for low-pressure pivots. With the discharge point closer to the ground, water droplets reach the ground sooner and thus evaporate less. As a result, typical application efficiencies are about 70 percent for a high-pressure pivot and 80-85 percent for a low-pressure pivot. High-pressure impact sprinklers typically cover about a 100-foot wetted diameter, while low-pressure spray nozzles cover about a 20-foot diameter. Since the same amount of water is applied over a 20-foot circle instead of a 100-foot circle, runoff is a problem in soils with low infiltration rates.

One option to avoid surface runoff under low infiltration conditions is to mount a number of spray nozzles along a boom running parallel to

Figure 1. Mechanical-move sprinkler system: Side-roll lateral (hand or mechanical move).



the direction of pivot travel (thus spreading water over about 50-60 feet instead of 20 feet). Another widely used option is the use of "rotators," "spinners," or "wobblers" to apply water at low pressure but over a 40-55 foot wetted diameter. The wetted area may be further increased (to avoid surface runoff) by mounting these devices on offset booms about 5-10 feet in front of and behind the pivot lateral pipe on the outer one-third to one-half of the pivot lateral.

Linear-Move Systems

Linear-move systems are continuous-move systems with water supplied by (1) a dragging hose that must be periodically reattached to another riser, (2) automated mechanical attachment to special risers on a buried mainline, or (3) pumping from a concrete ditch. The first two supply methods are used in Idaho. Linear-move systems have the advantages of irrigating an entire rectangular field and of having excellent water application uniformity. They may be configured as either high- or low-pressure systems, with nearly all new installations being low-pressure systems. Initial system cost is \$600-\$750 per acre.

Micro-irrigation and Drip Irrigation Systems

"Micro-irrigation" describes a number of irrigation systems that supply water in a carefully controlled rate to a limited area of soil adjacent to the plant to be irrigated. This precision placement of water and water-carried fertilizers or

other chemicals also provides higher fertilizer- (or chemical-) use efficiency and less impact to the groundwater than any other type of irrigation system. Because of low flow rates and small orifices, it is extremely important that the supply water be properly filtered before use. These systems can be fully automated, thus reducing labor costs for system operation. Irrigation equipment typically placed in this category includes micro-sprinklers, surface or subsurface drip irrigation with individual emitters, and drip tape.

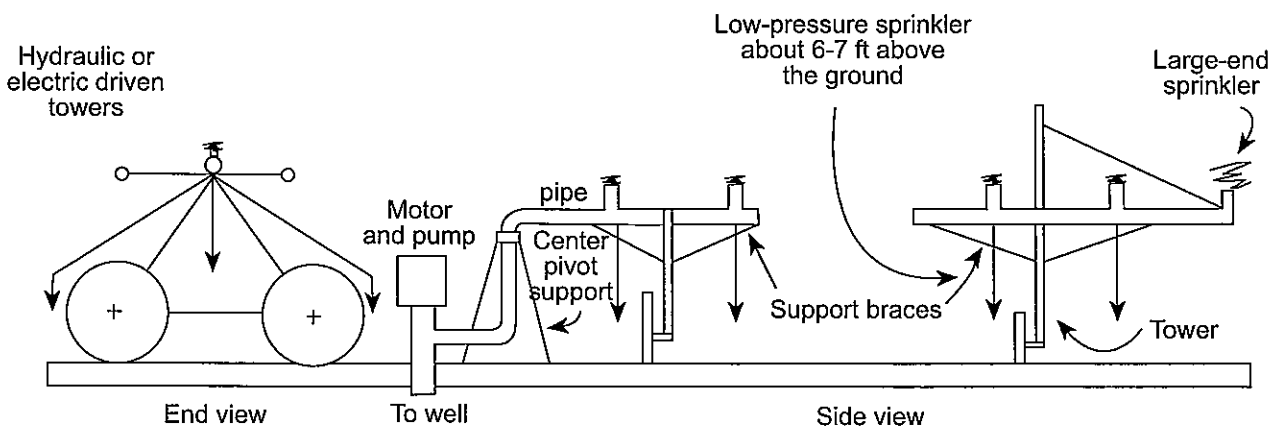
Micro-sprinklers

Micro-sprinklers are miniature impact sprinklers that operate at low pressure and may cover an area only 5-10 feet in diameter. They may be supplied by buried or surface mainlines and laterals. Sprinklers are usually mounted on 1-3 foot risers. One frequent application for this type of system is in orchards, where the trees must be irrigated but the area between the trees can remain dry. Energy and water use per tree are significantly reduced compared to sprinkler irrigation. Supply water must be filtered to remove debris of sufficient size to clog the sprinkler nozzles. Equipment cost is approximately the same as for a solid set sprinkler.

Drip Tubing with Individual Emitters

Drip tubing with individual emitters allows precise water placement with minimal evaporation. Water is supplied to the irrigated area by a properly sized mainline and distributed by submains to each set (the area to be irrigated at

Figure 2. Mechanical-move sprinkler system: Self-propelled (center-pivot) lateral.



any one time). Submains supply a number of lines of rigid plastic drip tubing, which supply individual emitters. In either an orchard or landscape setting, each plant may be watered by one or more emitters, with additional emitters added as the plant grows and water use increases. Water supply filtration requirements are more demanding. Filtration costs of \$300-\$400 per acre for surface water supply can equal the cost of the remaining system hardware.

Bi-wall Drip Tape

Bi-wall drip tape provides a line source of water to row crops. It may be placed either on the surface and retrieved after each crop year (typical in onions) or buried at a depth of 12-16 inches and used for 10-15 years (typical for drip tape used in center pivot corners). This flexible plastic tubing has in-line emitters formed during manufacturing. Available tubing thicknesses range from 6-25 mil, and emitter spacings range from 2-24 inches. Most manufacturers have both a "low flow" tape for heavy soils and a "high flow" tape for sandy soils. For surface placement in row crop applications, one tape is used per row. When buried, tape spacings vary from 3-5 feet, depending on soil properties. Tape cost is about \$0.03-\$0.10 per foot, depending on wall thickness. *Proper supply water filtration is essential*, with costs ranging from \$300-\$500 per acre for surface water supply.

One potential use for bi-wall drip tape is irrigation of center pivot corners. It may be buried 12-16 inches deep with all farming practices performed at a shallower depth. An alternate arrangement installs tape at a depth of 2-3 inches with yearly retrieval. Complete system cost for

installing drip tape in a center-pivot corner (excluding installation labor) is about \$1,000-\$1,300 per acre, depending upon source of water.

For more information . . .

Patterson, Paul E., Bradley A. King, and Robert L. Smathers. 1996. *Economics of Low-pressure Sprinkler Irrigation Systems: Center Pivot and Linear Move*. University of Idaho Cooperative Extension System and College of Agriculture Bulletin 787. Moscow, Idaho \$3.00.

Patterson, Paul E., Bradley A. King, and Robert L. Smathers. 1996. *Economics of Sprinkler Irrigation Systems: Handline, Solid Set, and Wheelline*. University of Idaho Cooperative Extension System and College of Agriculture Bulletin 788. Moscow, Idaho \$3.50.

Smathers, Robert L., Bradley A. King, and Paul E. Patterson. 1995. *Economics of Surface Irrigation Systems*. University of Idaho Cooperative Extension System and College of Agriculture Bulletin 779. Moscow, Idaho. \$1.50.

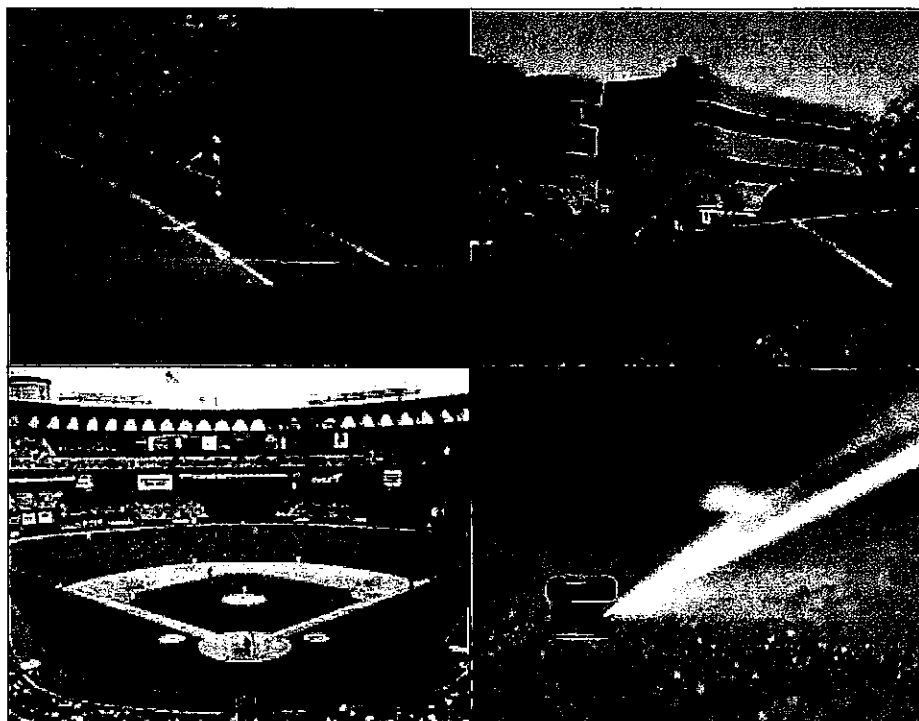
To order publications, contact Ag Publications, University of Idaho, Moscow, ID 83844-2240; (208) 885-7982.

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The information in this booklet was excerpted from Sportsfields: A Manual for Design, Construction and Maintenance, by James Pullhalla, Jeffrey Krans, PhD, and Michael Goatley, PhD. Ann Arbor Press, Ann Arbor, Michigan, 1998. The Manual's chapter on Irrigation was written by Donald J. Turner, professional education manager, Hunter Industries.

Introduction

Professional turf managers for parks, public areas and sports fields are constantly concerned about how their fields look and whether or not they are safe. Playable green turf with minimal risks is the goal of any field manager, and proper irrigation is one of the key elements in reaching that goal.

In this booklet, we will consider the role of irrigation in the Integrated Cultural Management of a turf site. As we review the subject of irrigation, it is important that we distinguish between "irrigation" as a general process and "installed irrigation systems" as one way to accomplish that process. A field can be irrigated in a number of ways; an installed irrigation system is one. We will briefly discuss some of the other irrigation methods in wide use in North America, but the bulk of our discussion will focus on installed irrigation systems, which are by far the most efficient and effective in promoting healthy turfgrass.

Irrigation and Turfgrass Culture

Strong, healthy turf will hold up better under the stress of sporting and other events, and adequate irrigation is critical to promoting that healthy turfgrass culture. Proper irrigation ensures deep and healthy roots, and helps the turf recover quickly from the damage inflicted by competition and other activities. Poorly irrigated sports fields, for example, may fail to recover from any substantial damage, and may become unplayable before the end of a season.

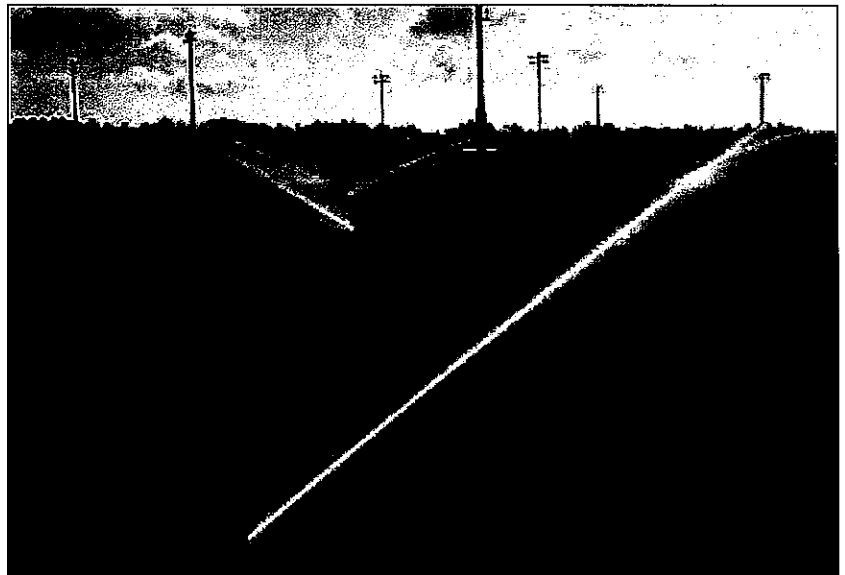
A healthy, properly watered turf will have fewer weeds and insects, reducing the need for fertilizer and pesticide applications. These reduced applications mean lower maintenance costs. Healthy turfgrass culture can have other cost advantages as well, including reduced water usage. When all of the potential savings are tabulated, it becomes increasingly apparent that a properly designed, installed, and maintained irrigation system, combined with a well thought-out watering schedule, can both reduce operating costs and contribute to a healthy turf. Even more important, well-irrigated turf promotes public

safety because it is softer and more uniform. Greener, more visually appealing fields also enhance community spirit and team pride – both among the players and among the team that maintains the facility.

General Principles of Turfgrass Irrigation

Among professional turf managers, the principle of "deep and infrequent" watering remains the norm. While this practice is generally an effective tactic, the physical soil properties must also be considered in planning any watering program. Obviously, a clay soil will not accept as much water as a sandy soil, and will require lighter,

A SAFE GREEN FIELD IS THE GOAL OF ANY TURF MANAGER, AND PROPER IRRIGATION IS ONE OF THE KEY ELEMENTS IN REACHING THAT GOAL.

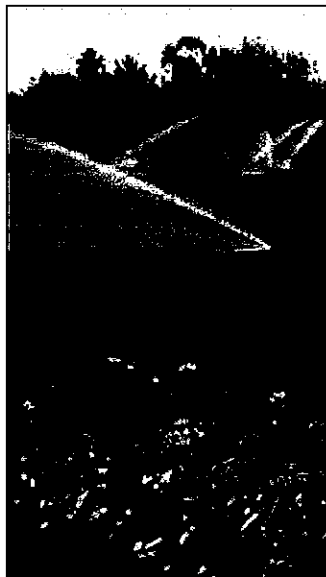


more frequent irrigation. Consideration must also be given to scheduled field usage; heavy irrigation a few hours before a game or public event can result in slippery and even dangerous conditions.

Most turfgrasses, including overseeded bermuda grass, need as much as 1½ to 2 inches of water per week during the growing season to support turf growth. This could come either from rainfall or from supplemental irrigation. If the turf is not receiving enough moisture it will "tell" an attentive manager when it needs watering. Signs like leaf rolling and wilting, sustained foot-printing (failure

INSTALLED AUTOMATIC IRRIGATION SYSTEMS ARE BY FAR THE MOST EFFICIENT AND EFFECTIVE METHOD TO PROMOTE HEALTHY TURFGRASS.

HEALTHY,
PROPERLY WATERED
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FOR FERTILIZER AND
PESTICIDE APPLICATIONS.



THE BEST TIME
TO IRRIGATE TURF IS IN THE
EARLY MORNING HOURS,
JUST PRIOR TO OR JUST
AFTER SUNRISE.

of the turf to spring back quickly after foot or vehicular traffic), and a change in turf to a blue-green color are all characteristic of desiccation or excessive dryness.

The best time to irrigate turf is in the early morning hours, just prior to or just after sunrise. Early morning irrigation does not interfere with play in most situations, and serves to minimize the period of leaf surface wetness. Reducing the time the turf leaves stay wet is an effective way to reduce disease incidence. Early morning irrigation also tends to get more water into the soil for plant use, since evaporation rates at that time of day are minimal. Also, wind disruption of the irrigation pattern is of less concern in the early morning hours. Finally, early morning irrigation usually allows for adequate field drying before a public event or athletic competition, so use can proceed without a slippery surface.

Portable Irrigation Systems

Portable irrigation systems are those which move around the field, either transported by the staff or moving under their own power. Although these systems were once used on many fields, they cannot be considered as efficient as installed systems.

TRAVELING IRRIGATORS

This system consists of a rotating sprinkler attached to a hose, propelling itself along a wire. The sprinkler winds itself along the wire using water pressure to drive an internal winch mechanism. When the traveling irrigator reaches the end of the wire, it turns itself off. The wire then needs to be reset to a new location and the sprinkler moved to the new line. Traveling irrigators require a considerable amount of labor to continually move the equipment, and must be actively supervised by the staff to ensure uniform and adequate irrigation.

Watering is usually restricted to the daytime hours, since traveling equipment is vulnerable to vandalism (or even theft) if left out at night or unattended.

Irrigating with portable equipment, therefore, can often interfere with the park or sports field's usage, reducing the hours available for sporting events or other public activities.

QUICK COUPLER SYSTEMS

These systems are comprised of a series of underground pipes with quick couplers (sometimes called "quick connects") permanently installed flush with the ground. (City water systems usually provide all the water pressure required to operate the system, but where pressure is low, booster pumps may be used.) The valves on these systems are constructed so that a special connecting device, known as a "quick coupler key," must be utilized to turn them on. Hoses or sprinklers can then be attached directly to the system.

Like traveling irrigators, quick coupler systems have many disadvantages. In order to irrigate an area, hoses must be dragged around the field or sprinklers must be moved from valve to valve in a timely manner. Often, the already-burdened staff allows the sprinklers to stay on for irregular amounts of time, so coverage is not uniform. To reduce the time and effort of watering, there is also a tendency to operate too many sprinklers at once. This causes a drop in pressure, and the sprinklers will fail to throw the desired distance, resulting in uneven watering.

Portable systems are cheaper to install than automatic systems. But because of their many disadvantages, portable systems are viable alternatives only where budget limitations prohibit the installation of automatic irrigation.

It should also be noted that portable systems being installed today must have the same type of backflow prevention device required for installed systems. See the section on backflow prevention for more information.

Installed Irrigation Systems

The popularity of installed irrigation systems is growing rapidly because the price of installing an automatic system is decreasing, while the reliability of operation is increasing. Automatic systems save labor costs when compared to the portable alternatives, and the even distribution (and the resulting savings) of water is commonplace on well designed and maintained sports fields and public parks.

DESIGN

As with the design of the field itself, proper design of the irrigation system is a critical step; a poorly designed system cannot be made to work properly with remedial measures later on. The irrigation system design should be driven by player and user safety, as well as the need for dependability, efficiency, and easy maintenance.

It may be tempting to employ the services of a volunteer to design an irrigation project, but an experienced institutional or sports field irrigation designer or consultant will usually allow the turf manager to save both time and money in the long run. Designing an effective system requires knowledge of pipe hydraulics, zoning techniques, head spacing, wire sizing, and the efficiency, features, and reliability of various manufacturers' rotary sprinklers, valves, and controllers. The cost to repair a single error in any of these areas can easily be higher than the fee charged by an experienced designer.

In planning a system, the designer will give a great deal of consideration to choosing the most appropriate equipment, since each project will have its own specific product and budget requirements. Placement of the heads and valves will also be a major consideration, and the designer will place the heads so they are not in heavy traffic areas and the valves so they are well off the field of play.

PIPING

The pipe running from the irrigation system's point of connection (POC) into the service line to the zone control valves is called the "continuous pressure main line" or, simply "main line". It is

a common practice to use solvent welded PVC pipe at a depth of 18 inches below the surface for pipe sizes up to 4 inches, and 24 inches below the surface for pipes larger than 4 inches. Gasketed pipe is sometimes specified and should be placed deeper; 36 inches under the surface for pipes larger than 4 inches is usually considered reasonable. However, higher system pressures may lead the designer to specify deeper installation to hold the pipe securely in place.

The non-pressure pipes which connect the control valves to the sprinkler heads are referred to as "lateral lines." These lines can be installed at a depth of 12 inches, which is standard for the industry.

The backfill surrounding the pipe should be rock free and compacted to the same degree as

DESIGNING AN EFFECTIVE SYSTEM REQUIRES KNOWLEDGE OF PIPE HYDRAULICS, ZONING TECHNIQUES, HEAD SPACING, WIRE SIZING, AND IRRIGATION EQUIPMENT.



the neighboring soil. The rock free backfill will help to prevent pipe breakage, and the consistent compaction will prevent ruts in the turf that are caused by the uneven settling of the soil over the pipe trench.

Poured-in-place concrete "thrust blocks" are sometimes specified where pipe connections must be especially solid. For instance, thrust blocks are typically specified at all changes in direction on all gasketed pipe, for main line pipes over 2 inches in diameter, and on long runs when the system will have higher-than-normal pressure.

SPECIFYING THE PROPER PIPE SIZES HELPS TO MAINTAIN THE CORRECT WATER VELOCITY AND MINIMIZES FRICTION LOSSES THROUGHOUT THE SYSTEM.

CARE SHOULD BE TAKEN TO SELECT SPRINKLERS WITH SMALL EXPOSED SURFACE AREAS AND PROTECTIVE RUBBER COVERS TO MINIMIZE SPORTS FIELD INJURY AND LIABILITY.



PRECIPITATION RATE FOR SPRINKLER SYSTEMS IS THE RATE AT WHICH WATER IS APPLIED OVER THE SURFACE OF THE TURF. MATCHED PRECIPITATION MEANS THE ENTIRE FIELD IS RECEIVING ABOUT THE SAME AMOUNT OF WATER.

Specifying the proper pipe sizes helps to maintain the correct water velocity and minimizes friction losses throughout the system. Water flowing through pipes experiences considerable drag or friction from the pipe itself; when the velocity of the water increases, the pressure loss from friction increases. If the pipe used for the system is too small, the operating pressure will be much lower for the heads at the end of the zone than for the heads closest to the valve serving that zone. Irrigation designers agree that there should be no more than a 10% variation in pressure among all heads on a zone.

Because designers like to maintain about the same pressure from one zone to another, most institutional and sports field irrigation system

designs will show a looped main line. The reduced pressure loss experienced when the water is flowing from two directions in a looped main line helps to achieve a relatively balanced pressure throughout the main line at a reduced cost. The designer would have to size the pipe larger with a single connection main line than is necessary with the looped system. This smaller pipe size saves money while reducing the pressure loss to the furthest valve.

PVC pipe is also used as sleeves for the irrigation system's pipes and wires where they pass under walkways, driveways, and roads. A good rule of thumb for sleeve sizing is two times the size of the pipe being sleeved.

SPRINKLERS, NOZZLES AND SWING JOINTS

A sprinkler head consists of three major components: the main body of the device, the nozzles through which water flows out of the body, and the swing joint at the bottom of the body which maintains the sprinkler's connection to the lateral lines.

Sprinkler heads have been gradually downsized over the years, primarily for safety purposes. Newer heads have a small surface diameter and a protective thick rubber cover which makes them a very safe alternative to the older-style sprinklers. Additionally, many of the newer heads have a strong spring for positive retraction so the head will not endanger the public by staying in the up position after the watering is completed. Many of today's safer heads also have a heavy-duty body cap to stand up to the large equipment now being used in routine maintenance.

Designers also like to choose a rotary sprinkler with a large nozzle selection. The nozzle is chosen to fine-tune the flow of water out of the system. The experienced irrigation system designer will use correct nozzle sizes to obtain "matched precipitation." (The precipitation rate for sprinkler systems is the rate, expressed in inches per hour, at which water is applied over the surface of the turf. "Matched precipitation" means the entire field is receiving about the same amount of water.)

Swing joints can be fabricated on-site by the installers of the system, or can be manufactured parts provided by the supplier. A three-elbow double swing joint will perform efficiently if fabricated correctly. Manufactured double swing joints with O-Ring seals cut down on installation time and are often more dependable. Correctly installed, a double-swing joint provides flexibility and resists breakage when large mowers or other heavy equipment rolls over the sprinkler.

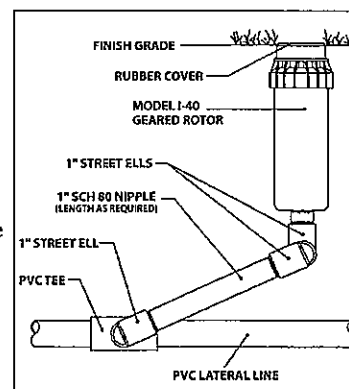


Chart 6-A Double Swing Joint Detail

VALVES

In an irrigation system, there are two basic types of valves: shut-off valves and sprinkler valves. Shut-off valves ("gate valves" or "ball valves") are used in a continuous pressure main line to temporarily turn the water off to the entire system or a section of the system. Sprinkler valves (manual or automatic) are used to deliver the water from the continuous pressure main line to the sprinklers. In the discussion of sprinkler systems, when the term "valve" is used alone, it usually refers to an automatic control valve.

Gate valves have a wheel type handle, and several turns of the handle are required to turn off the flow of water. Gate valves are most commonly used on mainline pipes with high water pressure or high water flow. Because several turns are required, they are easier to turn off and the potential for damage caused by water hammer is reduced. Gate valves have a brass-to-brass seat, which means that they may eventually lose their secure seal. For this reason, gate valves are not recommended for frequent use.

Ball valves have a single arm or lever that requires one-quarter turn to turn on or off. This single action is convenient, but caution should be used and the valve should not be turned on or off too quickly, because damage to the system from water hammer could result. Ball valves have resilient seats which maintain their ability to seal longer than brass-to-brass seats, making ball valves a better choice than gate valves where frequent use is expected.

Among sprinkler valves, **manual zone control valves** are not as common as they once were. The manually controlled sprinkler system requires an operator to time the irrigation of each zone, and to turn valves on and off at the proper time. The operator must be present the entire time the system is operating. Obviously, this type of system does not have the convenience of an automatic system.

Automatic zone control valves are used in conjunction with automatic controllers or timers, and are a much more convenient way to deliver water to the turf. Because these valves can be more precisely controlled, an automatic system allows the sports turf manager to efficiently schedule the delivery of the right amount of water to each zone.

There are many types of automatic control valves. On systems not directly connected to city water lines, choose a valve with an inexpensive self cleaning filtering mechanism. Because of the possibility of higher surge pressure in a large turf system, it is recommended that the valve be able to withstand pressures up to 200 PSI. A pressure regulator can be installed at the beginning of the system, but with the long main line and the potential for high friction loss, it is generally better to have an automatic control valve with a built-in pressure regulator, and control the pressure right at the valve.

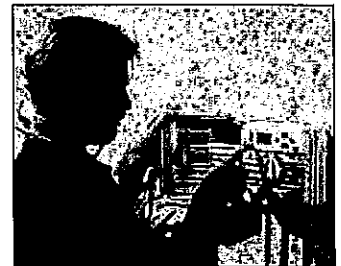
Placement of the valves should be planned with maintenance and safety in mind. Automatic control valves are generally installed in groups, or manifolds, and placed underground in a plastic or concrete valve box. If the valves will be near a field of play, use plastic. The manifolds should be built with plenty of room between valves. The distance between valves is dependent on the size of the valve box; for most standard size boxes, two or three 1 inch valves can be installed in a valve box, while valves larger than 1 inch are usually installed one valve per box.

CONTROLLERS

The controller (or "timer") is the part of an automatic sprinkler system that determines when a valve will turn on and how long the valve will operate. The controller sends a low voltage signal through buried wires to the automatic control valve, which then opens for a predetermined amount of time, allowing water to flow to the sprinklers. When the predetermined watering time is completed, the controller turns off the valve.

A controller should be chosen for its wide range of programming capabilities as well as other convenience features. A nonvolatile memory means the controller will not lose the program due to power outages or surges. Surge protection will protect the controller from serious damage due to nearby lightning strikes or power surges.

IRRIGATION CONTROLLERS CAN BE INSTALLED INDOORS OR OUTDOORS AND CAN BE FITTED WITH A REMOTE CONTROL DEVICE TO PERMIT ACTIVATION FROM ANYWHERE ON A SITE.



A PRESSURE REGULATOR CAN BE INSTALLED AT THE BEGINNING OF THE SYSTEM, BUT IT IS GENERALLY BETTER TO HAVE AN AUTOMATIC CONTROL VALVE WITH A BUILT-IN PRESSURE REGULATOR, AND CONTROL THE PRESSURE RIGHT AT THE VALVE.

INSTALLERS
RECOMMEND THAT THE
WIRE BE BURIED IN THE SAME
TRENCH AS THE MAIN LINE,
TAPED TO THE UNDER SIDE OF
THE PIPE. THIS WILL HELP TO
PROTECT THE WIRE, AND MAKE
IT EASIER TO LOCATE.



IN ORDER TO PROTECT THE
POTABLE (DRINKING) WATER
SUPPLY FROM CONTAMINATION,
MOST STATES AND
MUNICIPALITIES REQUIRE THE
INSTALLATION OF BACKFLOW
PREVENTION DEVICES.

Controllers should be placed in an easily accessible location, in a lockable room or metal outdoor mounting pedestal. In considering the controller, it is important to remember that some systems require a pump to maintain adequate water pressure. Be sure the controller chosen for this type of system includes a pump start feature. If a pump is needed, the two pieces of equipment could be placed in the same enclosure. However, the controller should use a separate electrical circuit to reduce the possibility of damage to the controller due to power surges.

As with any electrical equipment, to prevent injury from high voltage electrical shock, it is essential to specify that a proper ground wire be installed to the controller. Consult local codes for the grounding requirements in a specific area.

WIRES

In an automatic sprinkler system, low voltage direct burial wire is used to carry the signal from the controller to the automatic control valves. The most frequently used wire for commercial applications is single strand, heavy gauge direct burial copper wire. A lighter gauge wire can be used when installing valves close to the controller, but heavier gauge wire is necessary for longer distances, and may be necessary even for short distances on higher pressure systems. An irrigation designer or consultant will specify the necessary wire size when designing the system.

Many specifiers recommend that the wire be buried in the same trench as the main line, taped to the under side of the pipe. This will help to protect the wire, and make it easier to locate. Furthermore, a wire taped to the pipe can serve as a tracer wire to locate the main line should it become necessary to do so.

Wherever control wire will be exposed, it should be installed in a protective conduit. Waterproof wire connectors should be used to connect the solenoid wires to the low voltage irrigation wire.

BACKFLOW PREVENTION

In order to protect the potable (drinking) water supply from contamination, most states and municipalities require the installation of backflow prevention devices on all plumbing systems that

are connected to the public water supply. (These devices prevent water from the system from flowing backward into the supply lines.) In planning or installing an institutional or sports field irrigation system, the designer should consult with the local water company to determine the backflow devices required and their proper installation.

Construction and Reconstruction

Like the designer, an irrigation system installer must be concerned with safety, ease of maintenance, and system longevity. A properly designed system using all of the best products available could still represent a squandered investment if the system is improperly installed. It is important to stress to installers that the designer must be notified of any necessary field changes, so that he or she can verify that the proposed changes will not affect system performance.

Begin the installation process by laying out the system according to the plans. Use small flags for sprinkler placement and marking spray paint or powdered gypsum to indicate pipe locations. Dig the required trenches and begin laying the pipe, working out from the POC, or the system supply line to the valves and then to the heads. For ease of handling, lay out the control wire in the trench when installing the main line, so the wire can be taped under the pipe.

Provide an expansion loop of wire at each change of direction to help reduce the chance of stretching or breaking the wire. For systems that will employ thrust blocks at points where the piping changes direction, make sure that the wire does not get tangled up with the thrust block.

At each valve, make a coil by wrapping two or three feet of wire around a piece of 1 inch diameter pipe prior to connecting it to valves. This will serve two purposes: in areas susceptible to lightning strikes, static and surges from nearby strikes can be released at this coiled area, helping to protect the solenoid; and when performing maintenance on the valve, removing the bonnet or solenoid is easier with the coiled wire.

Take care to install the sprinkler heads at the correct depth according to the manufacturer's specifications. This will protect field users as well as the system itself. It is also important to install the specified nozzles so that the system will operate as efficiently as it was designed to perform.

When installing the valves boxes, lay a brick base under the edges of each box to reduce settling. Set the box in place, then install a 2 to 4 inch layer of gravel in the box under the valve to provide for drainage. To further reduce the amount of dirt that infiltrates the valve box, add filter cloth below the gravel and around the box. The top of the valve box should be installed at turf finish grade. Before going on to the next box, make sure that shut-off valves and control valves will clear the box lid when the valves are in both the fully closed and fully open position.

If a pressure test is required, backfill the center of the pipe, leaving the fittings exposed so that they can be checked for leakage. This center loading will keep the pipe in place while it is under pressure.

It is much easier to make repairs and adjustments before backfilling the entire system. If the plan includes thrust blocks, install those before turning on the system. Make sure the top of the blocks will be safely below the surface, where it will not be damaged by aeration equipment or vehicle traffic later.

After the pressure test is complete, finish backfilling the trenches and compact the soil to the same degree as the neighboring soil. When setting heads to grade, check for proper height, because the heads may settle along with the soil around them.

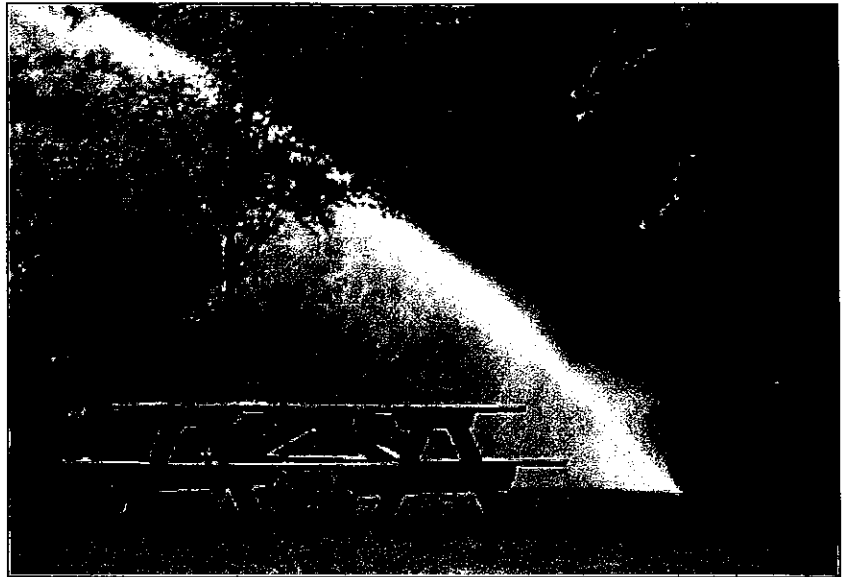
AS-BUILT DRAWINGS AND CONTROLLER CHARTS

Because minor variances are sometimes made during the installation process, it has become customary for the installer to prepare an "as-built drawing." This is a drawing showing the actual installed location of all isolation valves, control valves, sprinkler heads, pipe (including sleeves), and wire runs. Accurate as-builts are very important; they allow the maintenance staff to locate a pipe or wire without having to dig up large areas of the field.

Isolation valves, pipe, and wire runs should be located on the drawing with measurements to two permanent reference points. At a minimum, record exact measurements for pipe and wire at each change of direction, along with their exact depth at these locations. As-built drawings should be updated frequently during the system installation.

A "controller chart" is a site plan showing valves and the zones they cover. This chart can be vital to later maintenance efforts. For quick reference, mark the drawing with a different colored highlighter for each zone, and number the area on the drawing to correspond to the station number on the controller.

WHEN INSTALLING THE VALVES BOXES, LAY A BRICK BASE UNDER THE EDGES OF EACH BOX TO REDUCE SETTLING. SET THE BOX IN PLACE, THEN INSTALL A 2 TO 4 INCH LAYER OF GRAVEL IN THE BOX UNDER THE VALVE TO PROVIDE FOR DRAINAGE.



Renovation

Before considering the subject of irrigation system renovation, it is important to establish that renovation can be useful only when the existing system was properly designed in the first place – so that when the system was in good working order, it distributed water evenly over the entire area. If the system never worked right, complete reconstruction will probably be necessary. The wrong size pipe may have been used. Too few zones may have been installed. There may not be enough pressure to operate

ACCURATE AS-BUILT DRAWINGS ARE VERY IMPORTANT; THEY ALLOW THE MAINTENANCE STAFF TO LOCATE A PIPE OR WIRE WITHOUT HAVING TO DIG UP LARGE AREAS OF THE FIELD.

all the heads in a zone. (If low pressure is the only problem, it can be corrected simply by adding a booster pump.)

For our purposes, we will consider irrigation system renovation to consist mainly of replacing parts that have worn out due to normal usage.

Renovation of a properly installed and maintained automatic irrigation system may be necessary every seven to ten years. Sprinkler heads are the parts most commonly in need of replacement, since these items are in constant mechanical operation and are subjected to possible damage by the activity on the field. Control valves can easily be rebuilt without removing the valve from the system. The valve's diaphragm and solenoid are the only parts of the valve that move and may need replacing. (Pipe and wire rarely need to be replaced, since they have no moving parts.)

When replacing heads, dig down a few inches past the swing joint so the new head can be adjusted for height. When heads are being replaced, it may be wise to replace the swing joints while they are easily accessible.

Repair Couplings. Replacing valves, or repairing a broken pipe in systems fabricated from PVC pipe, is a lot easier with a "slip fix". A slip fix is a PVC telescoping repair part, designed to replace a section of the existing pipe. Remove a section of the pipe near the existing valve (or the pipe that is broken), then remove the old valve and replace it with a new one. The slip fix replaces the section of pipe that was removed. Retract the slip fix and remove enough of the existing pipe to allow the slip fix to fit into the space. Extend the telescoping portion of the slip fix over the existing pipe. Check alignment and then solvent weld (glue) the slip fix in place.

When planning a renovation project, consider the possibility of improving the system. Older heads and valves can be replaced with the newer models that provide better performance. A good working manual system can also be upgraded to an automatic system by changing the manual control valves to automatic control valves. A controller (timer) must be installed and connected by wire to each valve to allow automatic operation.

Winterization of Sprinkler Systems

Winterization of the sprinkler system is the blowing out or draining of water to remove the possibility of it freezing within the system and breaking pipes or components. Winterization is performed in areas of the country which are subject to prolonged freezing.

If the irrigation system is drained by gravity, the process of winterization is simple. The system was installed with drains at the low points and when the water is turned off and the drains are opened, all water in the pipes drain out of the system. In these types of systems, it is critical to have an accurate "as-built" drawing in order to easily locate each drain valve.

More commonly, systems are winterized through a process of "blowing out" the pipes and components. With this method, there is less possibility of leaving water trapped in low areas of the piping. Replacing pipe which has cracked due to trapped and frozen water can be very costly.

A portable air compressor which can produce a high volume of air at lower pressures is necessary when blowing out an irrigation system. Systems consisting of pipe that is three inches or less in diameter can be blown out with a 125 CFM (cubic feet per minute) at 50 PSI air compressor. Systems with pipe that is four inches in diameter or larger may require a compressor capable of producing 250 CFM or more. In no case should the air pressure exceed 80 PSI.

It is highly recommended that blowing out a large turf irrigation system be performed by some one with experience in winterizing large systems. This is a dangerous procedure and the components can be damaged if the winterization is done incorrectly.

Spring Start-up

Spring start-up after a winterization must be done carefully as well. Open the last valve in the system, or the valve closest to the center of a looped main line. Slowly open the isolation valve to allow the water to seep into the system. It is important to be patient during this process so that the water entering the system will not fill the pipe too rapidly

RENOVATION OF A
PROPERLY INSTALLED
AND MAINTAINED
AUTOMATIC IRRIGATION
SYSTEM MAY BE
NECESSARY
EVERY SEVEN TO
TEN YEARS.



WHEN PLANNING A RENOVATION PROJECT, CONSIDER THE POSSIBILITY OF IMPROVING THE SYSTEM. OLDER HEADS AND VALVES CAN BE REPLACED WITH THE NEWER MODELS THAT PROVIDE BETTER PERFORMANCE.

and cause damage to the irrigation system due to water hammer.

When the main line is fully charged with water, open the next to last valve, leaving the previous valve open. When water is flowing out of the second zone, turn off the first zone and proceed to the next valve. Continue doing this with each valve until all valves in the system have been recharged.

Inspection and Maintenance of Irrigation Systems

As with every aspect of professional turf maintenance, the importance of regularly scheduled irrigation inspections cannot be overstated. Preventive maintenance saves money and improves the health and appearance of the turf. Small problems can be spotted and corrected long before they turn into big, costly problems. On the other hand, failure to perform regular maintenance can mean that a component may need to be replaced prematurely, or that the entire system may need a renovation before the end of its normal life cycle.

Once a week, look at the overall appearance of the turf, and test the system by manually running the controller through its cycle. These two quick checks will indicate whether the system is working correctly, or whether further testing is necessary.

When appraising the general appearance of the turf, look for stress areas that indicate poor irrigation coverage. The beginnings of "donuts," dry areas around the heads, can mean there is a pressure problem, that someone has mis-adjusted the radius adjustment screw, or that the wrong nozzle has been installed.

Controllers. Before manually activating the controller, check to see if it is keeping the correct time of day. If not, the controller may have received a power surge, or a power outage may have disrupted its programming. No display, or a default display may suggest a blown fuse caused by faulty wiring, wire connectors, or valve solenoid.

Valves. As the controller activates and deactivates each valve, check for proper opening and closing. Slow or fast opening or closing valves can usually be adjusted with the valve's flow control, but this can sometimes indicate a problem, such as high or low pressure or a torn diaphragm, and may suggest the need for further investigation.

Sprinklers. As the different zones come on, look carefully at the spray. If the water droplets seem too large, the system may be operating at low pressure. If the droplets are too small, or if there is excessive mist, the pressure may be too high. Many times, especially if the system previously worked fine, these conditions can be corrected by adjusting the flow control at the valve.

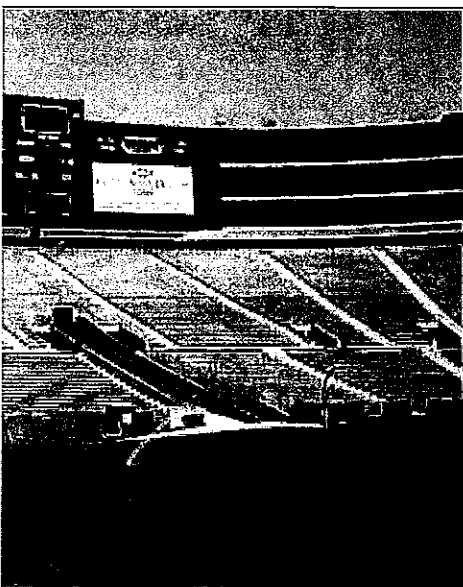
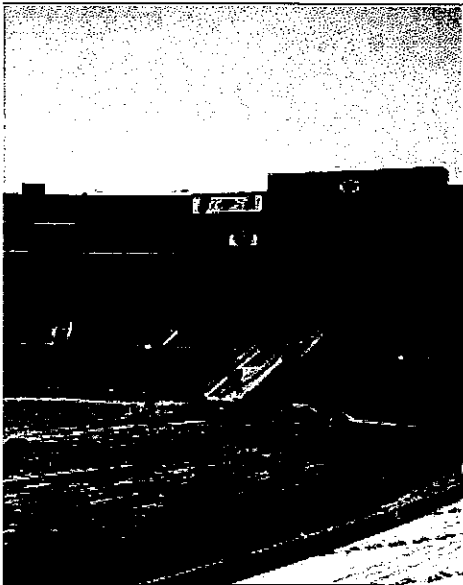
Rotary heads which are not rotating obviously require service. Many times a non-rotating sprinkler means a dirty filter, and can be disassembled and cleaned out quickly and easily. The staff should be instructed to resist the temptation to lubricate sticking heads. Although it may temporarily improve rotation, lubrication will eventually attract dirt and make the problem worse in the long run.

Make sure the heads are at the proper height, that they are adjusted correctly, and they are setting perpendicular to the turf.

Risers. During regular inspections, remember to look for signs of broken risers beneath the sprinklers. Sometimes these signs are obvious; a broken riser will unleash water to create huge geysers. Sometimes the signs are not so obvious; a cracked riser may allow water to boil up around the sprinkler but may not be readily visible. Watch for excessively wet or unusually dry areas.

Wiper Seals. While looking for broken risers and mis-adjustments, inspect the sprinkler for flow-by. A worn wiper seal can allow water to flow out of the sprinkler onto adjacent paved or turf areas, wasting water, damaging turf, and worst of all, causing unsafe conditions. (A wiper seal is located between the cap and the sprinkler's riser.) A very small amount of water emitting past the wiper seal while the system is running is usually acceptable, but a leaking sprinkler head must be repaired or replaced.

It is very important that broken or poorly performing sprinkler heads be replaced as soon



DISTRIBUTION UNIFORMITY (DU) IS CALCULATED BY DIVIDING THE AMOUNT OF WATER FALLING ON THE LEAST WATERED PART OF A ZONE BY THE AVERAGE AMOUNT OF WATER FALLING ON ALL THE ZONES.



IN ORDER TO DETERMINE DISTRIBUTION UNIFORMITY, A CATCHMENT TEST OF THE TURFGRASS AREA SHOULD BE PERFORMED.

as possible. When a specific sprinkler is not operating correctly, the performance of all other heads on the zone is affected. For instance, water flowing unchecked past a wiper seal will cause a loss in pressure to all heads on a zone. Because the pressure in that zone has dropped, the other sprinklers will not adequately irrigate the area.

If water is seeping past the wiper seal long after the system has turned off, the valve needs attention. A seeping valve could mean that debris is caught between the diaphragm and the valve seat, or that the diaphragm is beginning to tear. Replacing the diaphragm is a simple, fast, and inexpensive procedure. But if the torn diaphragm is not replaced, the slow seeping will waste a great deal of water, and could eventually

lead to a zone that is stuck on. If that happens at an inappropriate time, the turf could suffer severe damage.

Regularly scheduled irrigation checks will save time and money if they are performed on a consistent basis. A poorly maintained irrigation system will affect the health of the turfgrass culture and the appearance of the turf. A well maintained system will help to produce a healthy, visually appealing field which holds up well under the stress of public use, sports and other events, and contributes to safe, competitive play.

Distribution Uniformity (DU) Testing

If the irrigation system is currently in operation and field renovations are being considered, the system's "distribution uniformity" (the evenness with which water is distributed over the field) should be checked. Distribution uniformity (DU) is calculated by dividing the amount of water falling on the least watered part of a zone by the average amount of water falling on all the zones. An excellent DU percentage for rotors is 75% to 85%, while a good DU is 65% to 70%.

Once a system's DU is known, an informed decision can be made about whether to repair or completely replace a system (or, if the DU falls within acceptable range, simply to leave the system alone).

THE CATCHMENT TEST

In order to determine distribution uniformity, a catchment test of the turfgrass area should be performed. This is a fairly easy test to conduct and often can uncover fixable problems, even when a system appears to be functioning correctly.

The first step in conducting a catchment test is to determine existing site conditions. Draw a sketch of the field, with measurements, showing head locations. Write down all significant information, including the type of heads used and their condition. Perform an actual head-by-head inspection to determine their condition, model number and the nozzle type. While walking the field, look for signs of poor irrigation coverage, such as brown or bare spots.

Using a soil probe, take a few soil samples from different areas around the field to determine soil type and root depth. This information will be helpful later in writing an irrigation schedule for the system.

Next, turn on one zone at a time and perform a visual inspection. Adjust the radius and the arc of water flow from each head, and align all heads to be perpendicular to the turf for maximum coverage. While adjusting the heads, watch for heavy leaking at the riser seal, and for failure to rotate properly.

Clean any clogged nozzles, and be sure the filters are free of debris. Check for correct pressure, and for "donuts" of brown grass around the heads.

Using a rotor pitot tube and pressure gauge, check the pressure and pressure variation at the rotor's nozzle. (Be sure to write down these pressure readings.) Variations of more than 20% from the highest pressure reading to the lowest within one zone may indicate a problem with the system, and the need for further inspection by an irrigation expert with a background in irrigation hydraulics. Frequently, pressure can be increased or decreased simply by adjusting the flow control on the valve for the zone.

Check the station start times and run times in the controller to see if there is a station with a longer run time than the others. This could indicate a problem with that particular valve or the rotors in that zone; the additional run time may be keeping the grass green and hiding the problem. Check the run times overall. Are dry spots causing longer run times? In most areas, turf will require about 1 1/2 to 2 inches of water per week in the hottest months. Calculate precipitation rates based on manufacturer's published performance information and determine if the run times are close to where they should be.

Check Run Times

Example: The stations have a run time of 40 minutes per day, and the stations are programmed with two start times every day but Friday, Saturday, and Sunday.

Total Weekly Run Time

40 minutes x 2 start times per day x 4 days
or

$40 \times 2 \times 4 = 320$ minutes of run time.
Then, $320 \div 60$ minutes in an hour
= 5.3 hours of run time per week.

Answer

System 1 - A rotor with an approximate precipitation rate of .44 inches per hour would be putting down 2.3 inches of water per week (5.3 hours x .44 inches per hour or $5.3 \times .44 = 2.3$ inches per week).

System 2 - A rotor with an approximate precipitation rate of .85 inches per hour would be putting down 4.5 inches of water per week (5.3 hours x .85 inches per hour or $5.3 \times .85 = 4.5$ inches per week).

Chart 13-A - Station Run Times

If the turf is evenly green in both examples in Chart 13-A, the first rotor system was probably just in need of a tune-up, while the second system, which is putting down over 4 inches of water per week, indicates there may be a problem that is being covered up with overwatering. The turf is being kept healthy, but at the cost of sharply increased water usage.

If problems are discovered in this inspection, make corrections and adjustments before proceeding. Once all adjustments and nozzle and head corrections have been made, and it has been established that the system is operating at the sprinkler manufacturer's recommended pressure, the catchment test itself can be performed.

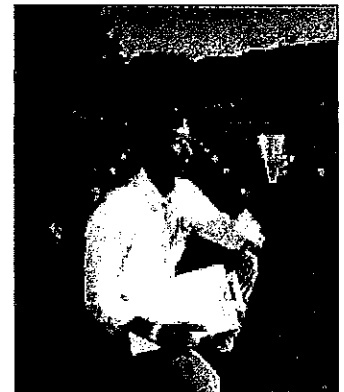
CHECK THE AMOUNT OF WATER BEING APPLIED TO THE FIELD, ONE ZONE AT A TIME, USING SMALL CATCH CANS. ALL OF THE CANS SHOULD BE THE SAME SIZE AND SHAPE, AND SHOULD BE PLACED AT ABOUT THE SAME HEIGHT ABOVE THE TURF.



PERFORMING THE CATCHMENT TEST

Check the amount of water being applied to the field, one zone at a time, using small catch cans. All of the cans should be the same size and shape, and should be placed at about the same height above the turf. Place several catch cans throughout the zone you are testing, marking the location of the cans on the sketch. A catchment test should not be conducted when the wind will cause a distortion in the spray pattern.

Turn on the zone, and allow it to run for 10 to 30 minutes, until the cans have collected on the



VARIATIONS OF MORE THAN 20% FROM THE HIGHEST PRESSURE READING TO THE LOWEST WITHIN ONE ZONE MAY INDICATE A PROBLEM WITH THE SYSTEM.



A BASIC TRUTH OF PLANT IRRIGATION IS THIS: IRRIGATION IS NOT MEANT TO WATER THE PLANTS; RATHER, IT IS MEANT TO REFILL THE RESERVOIR FROM WHICH THOSE PLANTS WILL DRAW THE WATER THEY NEED.

average of at least two to three tenths of an inch of measurable water, or until the rotors have made at least five rotations. Write down how long each zone was allowed to run. Measure the amount of water in each can, and log the results on the sketch next to each can location. Note which zone is affecting the can's volume, and do not empty the catch can between tests if that can is collecting water from more than one zone. Repeat the test for each zone.

To determine the zone's distribution uniformity, list the catch can results from highest to lowest. Add up the lowest 25% of the numbers and divide by the number of cans in the lowest 25% to get the average reading in the lower quartile. Divide this number by the average of all of the catch cans on that zone.

Multiply the result by 100 to obtain the percentage. The formula is:

$$\text{DU \%} = \frac{\text{Average reading in the lowest quartile} \times 100}{\text{Average reading over-all}}$$

Chart 14-A - Distribution Uniformity

Using this formula, it is possible to calculate the DU for a zone, or for the entire system. As noted earlier, a DU of 75% to 85% is excellent, while good distribution is 65% to 70%.

Scheduling Water Usage

Ultimately, the goal of the turfgrass manager is to apply only the amount of water needed, and to apply that water only when it is required. Plants have an effective root zone (RZ), and water in the soil below that root zone is unusable by the plants. The effective root zone for turfgrass is about 6 inches to a foot deep.

A basic truth of plant irrigation is this: Irrigation is not meant to water the plants; rather, it is meant to refill the reservoir from which those plants will draw the water they need.

If the reservoir gets too "empty," the plants begin to wilt. When they are deprived of water for too long, a "permanent wilting point" is reached, and lasting plant damage occurs.

If the reservoir is allowed to get "too full," the soil may reach "field capacity" at levels below the plant's effective root zone, and water would go unused. Field capacity is the upper limit of storable water in a layer of soil after the water has drained through.

It might seem that a slow and constant supply of water would be the best way to fulfill the watering requirement. However, in most circumstances, daily watering is wasteful. Water evaporates quite rapidly from the top few inches of soil; the rate of evaporation can reach as much as 50% per day. The deeper the moisture level in the soil, the lower the daily evaporation rate.

Available Water Holding Capacity. It becomes important then, to manage the amount of water in the root zone to maximize application efficiency. When scheduling irrigation, the turf manager's job is to provide enough water, at the proper times to keep the moisture level at the root zone between the permanent wilting point and the field capacity.

This level of moisture is referred to as "available water holding capacity" (AWHC), and is the water that can be used by the plants. Generally, AWHC is expressed as "inches of water available per foot of soil," or inches/foot.

In order to properly manage the AWHC level and program the controller with the correct watering schedule, the turf manager needs a few pieces of information:

- The amount of water needed for the turf to be healthy.
- The acceptable level of depletion of the AWHC.
- The precipitation rate of the irrigation system, in inches per hour.
- The efficiency of the irrigation system.

With this information and some simple math, the turf manager will have the tools to properly schedule the application of water to the turf area.

AMOUNT OF WATER NEEDED

Evapotranspiration Rate. The amount of water needed by a plant is the sum of the amount lost through the evaporation of moisture at the soil's surface and the transpiration of water through the plant. The daily evapotranspiration or "ET" rate for a specific area may be available from the local extension agent or weather service, or can be determined using the approximate daily values in Chart 15-A.

Crop Coefficient. Different plants have specific watering requirements. The "crop coefficient" allows for the expression of this variation in moisture needs. Chart 15-B provides a guide of the crop coefficients for turf areas as compared to other common plants.

WHEN SCHEDULING IRRIGATION, THE TURF MANAGER'S JOB IS TO PROVIDE ENOUGH WATER AT THE PROPER TIMES TO KEEP THE MOISTURE LEVEL AT THE ROOT ZONE BETWEEN THE PERMANENT WILTING POINT AND THE FIELD CAPACITY.

Climate Type *	Daily Loss (in inches)	Climate Type *	Daily Loss (in inches)
Cool Humid	0.10 - 0.15	Warm Dry	0.20 - 0.25
Cool Dry	0.15 - 0.20	Hot Humid	0.20 - 0.30
Warm Humid	0.15 - 0.20	Hot Dry	0.30 - 0.40

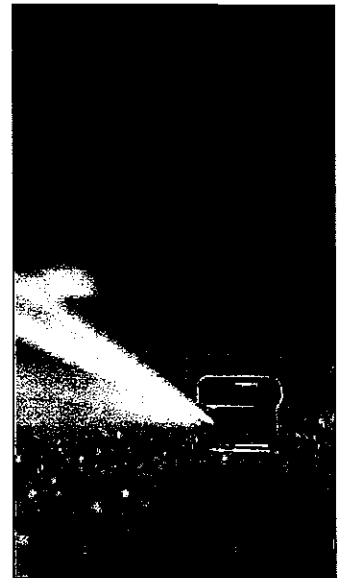
These evapotranspiration (ET) rates are approximate. Actual ET rates may be obtained from an extension agent. If the rate is expressed as a monthly figure, divide the number by 30 for the average daily rate.

* Cool applies to areas with average high summer temperatures in mid-summer of under 70° F. Warm refers to mid-summer highs between 70° F and 90° F. Hot indicates mid-summer averages over 90° F. Areas in which the average relative humidity is over 50% in mid-summer qualify as Humid, while under 50% is considered Dry.

Chart 15-A - Potential Evapotranspiration Rates for Various Climates*

Vegetation Type	Crop Coefficient
Mature Trees	0.80
Shrubs (taller than 4 ft)	0.70
Shrubs (shorter than 4 ft)	1.00
Warm Season Turf	0.50 - 0.70
Cool Season Turf	0.60 - 0.80

Chart 15-B - Crop Coefficient (K_c) For Turf and Other Common Plants



THE AMOUNT OF WATER NEEDED BY A PLANT IS THE SUM OF THE AMOUNT LOST THROUGH THE EVAPORATION OF MOISTURE AT THE SOIL'S SURFACE AND THE TRANSPIRATION OF WATER THROUGH THE PLANT.

THE ACCEPTABLE LEVEL OF DEPLETION, CALLED "MANAGEMENT ALLOWABLE DEPLETION" (MAD), CAN VARY BY SOIL TYPE, COMPACTION, ROOT DEPTH, AND THE STRESS TOLERANCE OF THE PLANT.

AVAILABLE WATER HOLDING CAPACITY (AWHC) DEPLETION

It is best to irrigate as infrequently as possible because of the high evaporation rate at the surface of the soil. Deeper, less frequent watering gets more water to the root zone. However, to avoid damage to the turf due to AWHC falling to a permanent wilting point, the turf manager must schedule irrigation run times before all of the AWHC is depleted. The acceptable level of depletion, called "Management Allowable Depletion" (MAD), can vary by soil type, compaction, root depth, and the stress tolerance of the plant. In most applications, a MAD of 50% of the AWHC will sustain healthy turf. Chart 16-A provides an AWHC guideline for a few soil textural classes.



APPLICATION EFFICIENCY (EA) IS A MEASURE OF HOW MUCH OF THE APPLIED WATER IS AVAILABLE FOR USE IN THE EFFECTIVE ROOT ZONE. IT IS ALSO AN INDICATION OF HOW WELL THE SYSTEM WAS DESIGNED AND INSTALLED, AND HOW WELL IT HAS BEEN MAINTAINED.

Available Water Holding Capacity

Soil Texture Available	Inches of Water per Foot of Soil
Sandy Soil	0.50 - 1.00
Loamy Soils	1.00 - 1.75
Clay Soils	1.75 - 2.5

Chart 16-A - AWHC for Various Soil Textures

PRECIPITATION RATE

The "precipitation rate" (PR) for an individual sprinkler or an entire sprinkler system is the depth of water applied in a given area, expressed in inches per hour. The precipitation rate of a sprinkler is determined by multiplying the gallons per minute output of that sprinkler by a conversion factor of 96.25 (which converts cubic inches of water to inches per square foot per hour), and then dividing by the area the sprinkler covers. The precipitation rate of an irrigation system is found by multiplying the total gallons per minute of the system by 96.25 and dividing by the total area the system covers.

$$\text{Precipitation Rate} = \frac{\text{GPM} \times \text{Applied} \times 96.25}{\text{Area Covered}}$$

Chart 16-B - *Gallons per minute can be approximated using the manufacturer's published nozzle data.

To calculate the precipitation rate on a particular field, use the measurements taken during an irrigation catchment test. Add the total (in inches) of all catch cans and divide by the number of catch cans. Then divide that number by the run time of the test (in minutes), and multiply by 60 minutes to obtain inches applied per hour. This is the average precipitation rate for the field.

$$\text{Average Field PR} = \frac{\text{Total Inches in All Catch Cans}}{\text{Number of Catch Cans} \div \text{Run Time} \times 60}$$

APPLICATION EFFICIENCY

Application efficiency (EA) is a measure of how much of the applied water is available for use in the effective root zone. It is also an indication of how well the system was designed and installed, and how well it has been maintained. Application efficiency is determined by dividing the amount of water in the root zone by the amount of water applied.

A perfect irrigation system where all of the water sprayed out goes directly and evenly to the turf's root zone is unachievable. In fact, while it is feasible to achieve an application efficiency (EA) rating as high as 80%, an irrigation system

with an efficiency rating of 70% is considered very good. Irrigation water can be lost through excessive evaporation (watering during the heat of the day), wind drift, incorrect adjustments, improper designs, high pressure, low pressure, runoff, percolation past the effective root zone, or through the use of the wrong size nozzles or other equipment.

There are several steps and calculations needed to determine irrigation system EA. While these calculations can be very accurate, because of the effects of wind, temperature, humidity, water pressure, soil type, and root depth, EA remains an informed estimate. For general purposes, a manager can expect to achieve an EA of 60% to 80%.

CALCULATING THE IRRIGATION RUN TIME

We now have all of the information necessary to schedule the application of water. The following is a recap of the values that are used in the

Scheduling Equation Values

RZ	Root Zone is the effective depth, in feet, of the roots (0.5' to 1.0' for turf).
ET	Evaporation of soil surface water plus Transpiration of water through the plant. (Chart 15-A)
K _c	Crop coefficient is the specific water requirement of the plant. (Chart 15-B)
AWHC	Available Water Holding Capacity is the moisture level in the soil (expressed in inches per foot) which is above the plant's permanent wilting point, and below the soil's field capacity. (Chart 16-A)
MAD	Management Allowable Depletion of water from the AWHC. In most applications, a MAD of 50% will sustain healthy turf.
PR	Precipitation Rate is the depth of water per unit of time. (Multiply the total gallons per minute of the system by 96.25 and divide by the total area the system covers.) (Chart 16-B)
EA	Application Efficiency is a measure of the overall efficiency of the sprinkler system. (60% to 80%)

Chart 17-A - Scheduling Equation Values

scheduling equation:

Frequency. The frequency (F), or "how often to irrigate the turf," is calculated using the following

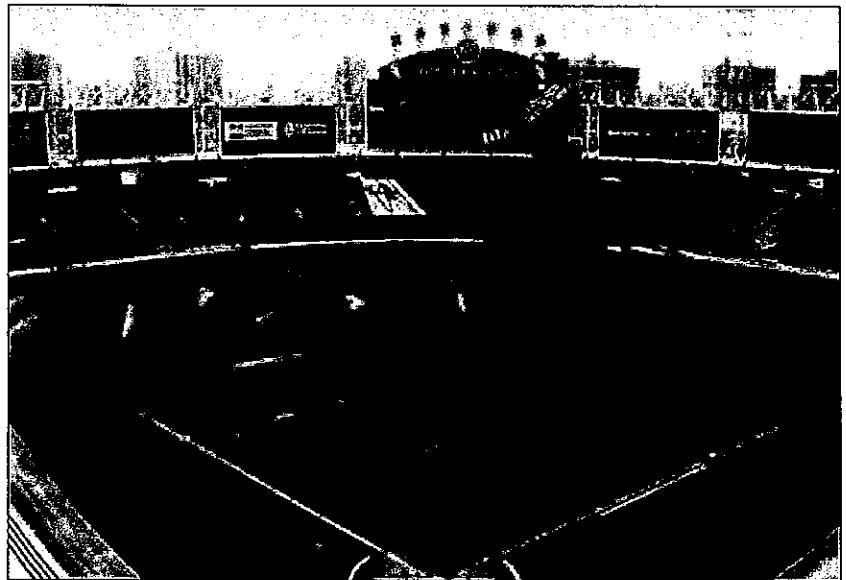
$$\text{Frequency} = \frac{\text{AWHC} \times \text{RZ} \times \text{MAD}}{\text{ET} \times K_c}$$

The amount of run time (RT) is calculated:

$$\text{Run Time} = \frac{60 \times F \times \text{ET} \times K_c}{\text{PR} \times \text{EA}}$$

Chart 17-B - Run Time Formula

PROPER IRRIGATION
TECHNIQUE IS
IMPORTANT IN
DEVELOPING A
DEEP ROOT SYSTEM.
REPLENISHING THE
AWHC WITH FREQUENT
LIGHT WATERING IS THE
WORST POSSIBLE WAY TO
WATER TURF.



Run Time Examples

Example: A valve in your system is irrigating warm season turf which is growing in a sandy loam. The average precipitation rate is 0.49 inches/hour. The system is located in San Marcos, CA, where the daily moisture loss (ET) to be replenished is 0.20 inches. The system application efficiency is approximately 65%.

Answer:

$$\text{Watering Frequency } F = \frac{1.0' \times 0.75' \times 50\%}{0.20 \times 0.70} = \frac{1.0 \times 0.75 \times 0.50}{0.20 \times 0.70} = \frac{0.375}{.14} = 2.68$$

The answer is a 2 or 3 day watering interval. The turf manager may decide to use a 3 day interval (water on day #1, wait day #2 and day #3, and then begin the watering interval again on the next day), and monitor the turf's condition.

$$\text{Run Time per Frequency } RT = \frac{60 \times 3 \times 0.20 \times 0.70}{0.49 \times 65\%} = \frac{180 \times 0.14}{0.49 \times 0.65} = \frac{25.2}{0.319} = 79$$

Irrigate 79 minutes each watering.

Chart 17-C - Run Time Examples

IF THE WATER IS
APPLIED FASTER THAN
THE INTAKE RATE, THE
WATER WILL RUN OFF
AND BE WASTED, AND
MAY CAUSE DAMAGE
TO THE TURF.



formula:

Soil texture will provide a general idea of the rate at which water can be absorbed without runoff. Many times, the precipitation rate and run time will be more than the soil intake rate. As the soil reservoir is refilled and reaches field capacity, the additional, or free water is pulled through the soil by gravity and capillary action. If the water is applied faster than the intake rate, the water will run off and be wasted, and may cause damage to the turf.

In order to determine if the watering run time must be cycled into multiple run times, look at the precipitation rate and compare it to the rate in Chart 18-A.

In the previous example, the precipitation rate was calculated as 0.49 inches per hour. Comparing that to the soil intake chart, the reader can see that one cycle may or may not soak into the sandy loam before runoff, and the turf area in this example should be monitored. If runoff is evident, the 79 minutes should be broken into two 40 minute applications on the same day.

Reprogram the controller at least seasonally to the appropriate run times. Consider performing a catchment test on a periodic basis to reevaluate the system's efficiency.

Proper irrigation technique is important in developing a deep root system. Replenishing the AWHC with frequent light watering is the worst possible way to water turf. This method never allows the soil profile to be wetted to any depth, encouraging shallow root growth and leading to turf which is easily damaged and dependent on frequent watering.

The best method of producing turf with a deep root system is through cyclical watering as described in this booklet. Deeply rooted turf is less susceptible to damage from stress due to high midsummer temperatures and evaporation rates. Parks, sports fields and other large turf areas with deeply rooted turf will be less vulnerable to damage, and will recover faster from the demands of public use and the playing season.

THE BEST METHOD
OF PRODUCING
TURF WITH A DEEP
ROOT SYSTEM IS
THROUGH CYCLICAL
WATERING AS
DESCRIBED IN THIS
BOOKLET.

Soil Texture	Soil Intake Rate inches per hour
Sandy Soil	0.50 - 1.00
Loamy Soils	0.25 - 0.50
Clay Soils	0.10 - 0.25

Chart 18-A - Soil Intake Rates for Various Soil Textures



Hunter Industries

Hunter Industries is among the world's leading manufacturers of irrigation equipment for turf and landscape. Hunter's complete commercial systems – including controllers, gear-driven rotors, spray heads, valves and accessories – are designed for use on residential, large commercial and institutional projects. The irrigation equipment of choice on turf sites around the world, Hunter systems can be found everywhere, from local parks and public areas to professional and collegiate baseball, football and soccer facilities.

Controllers. Thanks to its modular design, a Hunter controller can be custom-tailored to the irrigation requirements of any site. Convenient snap-in modules allow you to expand the controller's operations to handle the particular number of zones you require.

Rotors. From small areas to large expanses of turf, Hunter's entire line-up of rotors boasts heavy duty construction that can stand up to high traffic, yet each is exceptionally easy to service. All rotors also include Hunter's continuously-improved, water lubricated gear drive backed by years of proven reliability...a wide array of nozzle choices to accommodate both typical and specialty needs... integral rubber covers that stay put (as well as some of the smallest exposed sprinkler surface areas in the industry) to keep play areas safe. And most Hunter rotors include the added durability of stainless steel risers as either a standard or optional feature.

Sprays. Hunter offers an institutional-grade spray head built to withstand the harshest environments. No need to substitute a residential grade product when there's a sprinkler built tough as a rotor to handle commercial, institutional and public area applications.

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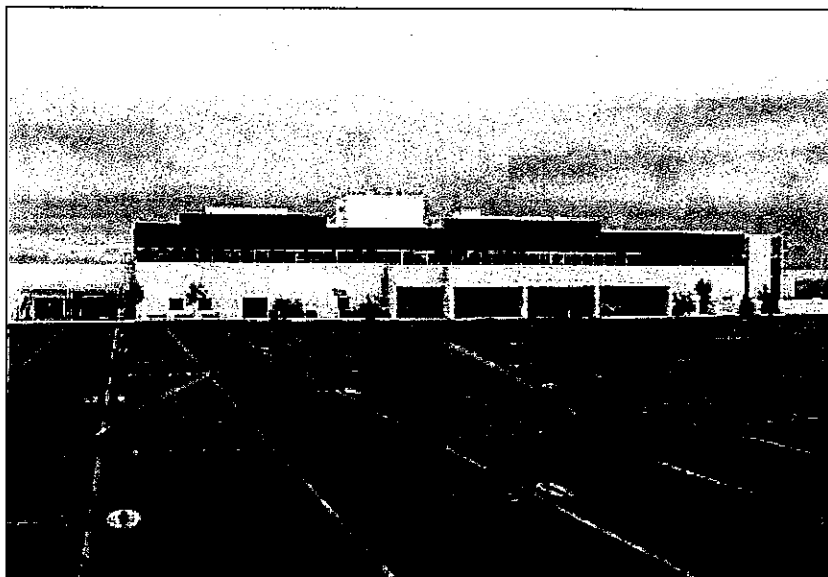
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Hydrologic Impacts due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices

Brian J. Venn, M.ASCE¹; Drew W. Johnson²; and Larry O. Pochop, M.ASCE³

Abstract: Improvements in irrigation efficiency are well documented when changing from flood to sprinkler irrigation methods; however, other impacts to the watershed associated with this change are not well known. The resulting impacts to a river basin hydrology when irrigation and conveyance methods are changed are the focus of this study. In an attempt to improve water application and conveyance efficiencies in the Salt River Basin of western Wyoming, irrigation practices were changed from flood irrigation to sprinkler irrigation beginning in the late 1960s, with completion by the mid-1970s. Based upon a water balance, flow in the Salt River increased an average of 65.62 MCM/year. Return flow timing was also impacted by the conversion to sprinkler irrigation. Flows increased 34% in May and 50% in June, while decreasing 15 and 14% in August and September. These changes may have coincided with decreases in groundwater storage. However, analysis of changes in groundwater levels with time was inconclusive. Surface water total dissolved solids (TDS) appears unaffected by the conversion in irrigation practices, while limited groundwater quality data indicate that TDS values are lower in sprinkler irrigated areas.

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CE Database subject headings: Flood irrigation; Sprinkler irrigation; Conveyance structures; Return flow.

Introduction

The conversion from flood irrigation to sprinkler irrigation provides many benefits to farming communities including savings in water, energy, and labor, which are supplemented with the farmer's ability to produce increased crop yields (Guitjens and Goodrich 1994). Perhaps the greatest benefit to farmers resulting from changing irrigation practices is the increase in total irrigation efficiency. Irrigation efficiency is defined as the ratio of net volume of water beneficially used by the crops to the volume of water applied to the crops (Burt et al. 1997). Many climatic and geologic factors, such as wind, soil type, solar influences, and precipitation, influence irrigation efficiencies. Irrigation efficiencies reported for flood irrigation systems range from 45 to 60%, while sprinkler irrigation efficiencies range from 60 to 80% (Wolter and Bersisavljevic 1991; Zalidis et al. 1997). Battikhi and Abu-Hammad (1994) found that, when converting from flood irrigation to sprinkler irrigation techniques, overall irrigation efficiency increased from 42% (citrus) and 53% (vegetable) with flood irrigation to 68 and 70%, respectively, for sprinkler irrigation. In

most case studies, average irrigation efficiencies increase from approximately 50 to 70% after converting from flood to sprinkler irrigation.

The greater irrigation efficiency of sprinkler systems is the result of applying the water more evenly on the soil surface. The ability to distribute the water more evenly on the surface provides for maximization of water consumption and utilization. Flood or border irrigation distributes irrigation water unevenly over the fields; this increases the crop stress and lowers production. Deep percolation losses of water generally occur with flood irrigation, because overirrigation is necessary near the source to replenish the root zone of the soil farthest away from the source (Benjamin et al. 1998). Many crops, and especially alfalfa, are negatively impacted by oversaturated soil. In addition, flood irrigation water is often of a lower temperature than sprinkler irrigation water. The lower water temperature negatively impacts many crops (Saeed and El-Nadi 1997). Overirrigation can also lead to leaching of fertilizers and pesticides to groundwater (Benjamin et al. 1998), and the conversion to sprinkler irrigation may beneficially impact groundwater quality.

While improvements in irrigation efficiency are well documented when changing from flood to sprinkler irrigation, impacts to the watershed are not well known and are the focus of this study. The change from flood irrigation to sprinkler irrigation techniques affects a river basin hydrology through a variety of mechanisms including changes in seepage and deep percolation, evaporation, crop evapotranspiration, and phreatophyte consumption.

The objectives of this study are to quantify the potential hydrologic impacts to a watershed when irrigation systems are converted from flood to sprinklers and to relate these impacts to the various hydrologic components through which they occur. Specific objectives include the determination of changes in (1) return flow timing; (2) total annual river flow; (3) agricultural production; (4) surface water and groundwater quality; and (5) groundwater levels in the unconfined aquifer impacting river recharge.

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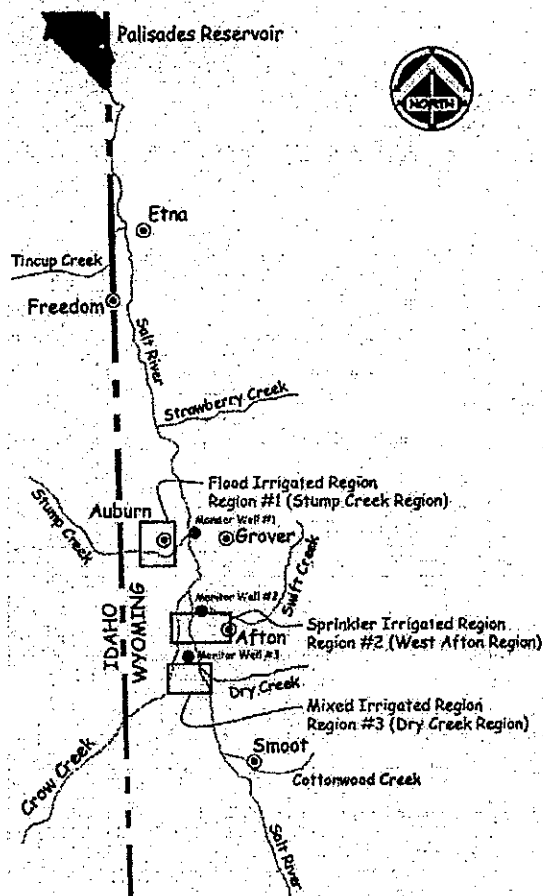


Fig. 1. Locations of Salt River and its tributaries, three monitoring wells, and three regions in study area analyzed for groundwater changes

Background

Site Description

The Star Valley in western Wyoming contains some of the richest farmland in the entire state, and as in other semiarid climatic regions, water for irrigation is a very important resource. Irrigation in the Salt River Valley in western Wyoming has taken place since the late 1800s. In an attempt to improve water application and conveyance efficiencies, irrigation practices were changed from flood irrigation to sprinkler irrigation beginning in the late 1960s, with completion by the mid-1970s. The change to sprinkler irrigation occurred on approximately 75% of the irrigated acreage and included installing several kilometers of underground gravity-pressurized steel and asbestos pipe. The pipes replaced the canal network as the means of conveyance of irrigation water to the fields. Water application with the sprinkler systems was more uniform and the amount of water applied was controlled better than with flood irrigation.

The Salt River Basin is located in the western part of Wyoming, near the Idaho border (Fig. 1). The valley's watershed covers approximately 2,147 km² (829 mi²). The valley is nearly 88 km (55 mi) long and approximately 24 km (15 mi) wide. The Salt River and its tributaries provide irrigation water to the valley. The Salt River is formed from the Salt River mountain range on the east, the Gannett Hills on the south, and the Caribou and Webster

ranges on the west. The river flows north to the Snake River, where it empties into the Palisades Reservoir on the Wyoming and Idaho border.

As of 1997, over 26,300 ha (65,000 acres) of agricultural land were used to produce crops in the Star Valley (SWWRC 1999). The two main crops, alfalfa hay and barley, are produced to support the dairy industry in the area. The crop irrigation requirements for the area are approximately 380 mm (15 in.) of water (Pochop et al. 1992). The Salt River and its tributaries must provide as much as 95% of the irrigation water used in Star Valley, amounting to about 120 million m³ (MCM) (97,500 acre-ft) of water per year. Irrigation occurs throughout the duration of the growing season for the area, which is on average from May 1 to September 15. The majority of the soils in the valley are well-drained silty-sandy or gravelly loams (USDA-NRCS 1976). The valley has no reservoirs or surface storage capabilities, and the cropland is completely dependent on stream diversions and pumping of groundwater aquifers for obtaining irrigation water.

Because of its physical characteristics, the Star Valley presents a unique opportunity to study the hydrologic impacts of irrigation changes. The Greys River contains nearly the same flow as the Salt River and flows through a narrow drainage basin of approximately 1,160 km² (448 mi²) on the adjacent side of the Salt River Mountain Range. However, unlike the Salt River, the Greys River has not been significantly impacted by changes in irrigation practices, because the river only provides water to about 200 ha (500 acres) of irrigated agriculture. As such, a comparison of flows in the two rivers before and after the application of sprinkler systems provides an excellent method to investigate impacts associated with changes in conveyance and application methods.

Methods and Procedures

Double Mass Balance Analysis

Double mass balance plots were created for analyzing the flow consistency over time of the Salt River, utilizing the Greys River as a control. The period of record analyzed was from 1954 through 2000. United States Geological Survey (USGS) stream gauges were used as the primary data resources. USGS station 13027500, located near Etna, Wyoming, above the Palisades Reservoir (latitude N 43°-04'; longitude W 111°-02'), was used to represent the Salt River flows. USGS station 13023000, located near Alpine, Wyoming, above the Palisades Reservoir (latitude N 43°-08'; longitude W 110°-58'), was used to represent the Greys River flows.

Cumulative average monthly flow values for the Salt River and the Greys River were calculated for each month over the period of record. The cumulative values for the two rivers were plotted against each other to graphically depict any changes that might have occurred to the Salt River's hydrology due to the change in irrigation practices. The Greys River was the control in the analysis, and it is assumed that climatic changes do not affect the plots, because climatic variables are considered essentially equivalent for each scenario. Changes in slope in the trend line over the period of record on the double mass balance plot represent changes in the ratio of Salt River flow to Greys River flow, which were attributed to nonclimatic factors, such as changes in irrigation practices.

Previously, in an attempt to identify if and when the Salt River flow responded to the conversion from flood to sprinkler irriga-

Table 1. Evaporation Coefficients, Average Monthly Evaporation, and Total Evaporation in Study Area

Month	Fraction of annual evaporation, C_1	Evaporation loss for conveyance to private property (MCM/year)	Evaporation loss for conveyance on private property (MCM/year)	Total evaporation loss (MCM/year)
May	0.115	0.26	0.32	0.57
June	0.131	0.30	0.35	0.65
July	0.171	0.38	0.46	0.84
August	0.156	0.35	0.42	0.77
September	0.115	0.26	0.31	0.57
		$\Sigma = 1.55$	$\Sigma = 1.86$	$\Sigma = 3.41$

tion, a similar double mass balance analysis for the two rivers was performed by Sando et al. (Sando et al. 1985; Sando 1986). The Sando study covered the years 1954–1985. In this study, we follow the methodology of Sando but extend the period of years to 2000 and also quantify the flow changes and responsible mechanisms.

Streamflow Calculations

Generally, hydrologic modeling is utilized to demonstrate net changes in water balances for a particular area. Limited stream gauge data in the study area present difficulties in constructing a hydrologic model that would demonstrate changes in flow over time due to changes in irrigation practices. As a result, differences in flow ratios between the Salt River and Greys River are used to approximate the net change in annual flow in the Salt River resulting from changes in irrigation practices. Ratios of cumulative monthly flow in the Greys River versus cumulative monthly flow in the Salt River were calculated for flows prior to and after the change to sprinkler irrigation. The difference in ratios between the presprinkler and postsprinkler periods multiplied by the average monthly flow in the Salt River for a month represents the change of average streamflow in the Salt River for that month. The annual change in streamflow (i.e., the conservation of water) was calculated by summing the average monthly changes in flow for the months considered to be statistically significant. Student t-tests, with a confidence level of 95%, were performed to determine the statistical significance of monthly ratio changes.

Mass Balance Calculations

The conversion to sprinkler irrigation impacts the basin hydrology. A mass balance analysis provides a means of relating the changes in stream flows identified in double mass balance plots to changes in irrigation diversions, water use, and river basin hydrology. The mass balance for the system for each irrigation practice is described by

$$R_{\text{outflow}} = R_{\text{inflow}} - E - P - SI - ET + P_r - \Delta \text{Storage} \quad (1)$$

where R_{outflow} = volume of water leaving the study area via the Salt River; R_{inflow} = volume of water entering the study area via the Salt River and its tributaries; E = total amount of water lost through evaporation within the study area; P = amount of water lost through phreatophytic consumption in the study area; SI = water lost via seepage and infiltration losses in the study area; ET = total amount of evapotranspiration occurring in the study area; P_r = annual precipitation in the study area; and $\Delta \text{Storage}$ = any change in storage within the study area. Because there are

no surface water storage capabilities, $\Delta \text{Storage}$ accounts for any possible changes in aquifer storage. Each of these variables is an average annual value.

The change in stream flow in the Salt River due to the switch of irrigation conveyance and application methods can be described by

$$S = R_{\text{outflow-sprinkler}} - R_{\text{outflow-flood}} \quad (2)$$

where S = total average difference in increased stream flow in the Salt River leaving the study area; $R_{\text{outflow-sprinkler}}$ = average annual flow of the Salt River when sprinkler irrigation was used; and $R_{\text{outflow-flood}}$ = estimated average annual flow of the Salt River if flood irrigation techniques were utilized over the same time period. The estimated flows are obtained from the development of flow ratios as described previously.

The parameters presented in Eq. (1) are affected differently by each irrigation practice. The sum of the net change for each parameter in Eq. (1) should account for the total change in annual streamflow in the Salt River after the switch to sprinkler irrigation techniques. Because of the change in conveyance methods (i.e., a change from open ditches to closed pipes), sprinkler irrigation practices in the study area are assumed to have minimal losses for phreatophytic consumption and seepage and infiltration losses in the conveyance process. Therefore, changes in streamflow due to changes in conveyance loss and field application can be calculated as

$$S = \Delta E + P_{\text{flood}} + SI_{\text{flood}} + \Delta ET - \Delta \text{Storage} \quad (3)$$

where ΔE = change in evaporation due to changes in irrigation practices; P_{flood} = average annual phreatophytic consumption during flood irrigation; SI_{flood} = average annual seepage and infiltration losses occurring within the study area during flood irrigation; ΔET = change in evaporation; and $\Delta \text{Storage}$ = change in ground-water storage after the change in irrigation practices.

Evaporation Calculations

Evaporation loss calculations for the open canals were made for two of the larger irrigation districts, the Cottonwood Irrigation District and the Dry Creek Irrigation District. These calculations were then extrapolated to estimate the canal evaporation for the entire drainage basin. Values for canal evaporation losses (E_{flood}) were calculated from the fraction of total annual canal evaporation (C_1) for each month, total annual canal evaporation for the region (C_2), and the calculated total surface area, SA , of water exposed to the atmosphere in the flood irrigation canals as follows:

$$E_{\text{flood}} = C_1 \cdot C_2 \cdot SA \quad (4)$$

C_1 values for each month are provided in Table 1. C_2 for the area is approximately 1.143 m (45 in.) (Lewis 1978). The total surface area, SA , of water within the irrigation canals for the two districts was calculated based upon information obtained from Application Permits for Diversion of Water, maintained by the Wyoming State Engineer's Office. These applications include details on each canal's length, width, slope, and wetted perimeter. From the information on the application permits, it was also possible to approximate the acres the canals supply for irrigation. The total acreage of cropland irrigated by the canals was calculated and used to create a ratio of total canal surface area required per irrigated acre of cropland. This ratio could then be applied to calculate the amount of surface area required to irrigate the 26,300 ha (65,000 acres) of irrigated land along the Salt River. The calculated surface area of the canals for the two irrigation districts was 34.6 ha (85.5 acres), while the irrigated acreage served by the canals was 4,580 ha (11,320 acres). The ratio of canal surface area to irrigated acreage was 0.0076 and canal surface area for the entire basin was 198 ha (490 acres).

Evaporation estimates were also calculated for conveyance on private land. The irrigators utilized V-shaped plows to construct the canals. The canals were approximately 0.30 m (1 ft) to 0.90 m (3 ft) wide and were installed every 30.5 m (100 ft) to 76.20 m (250 ft). Assuming the canals averaged a width of 0.61 m (2 ft) while being installed an average of 61 m (200 ft) apart, a total canal surface area of 219 ha (542 acres) was calculated for conveyance requirements on private property.

Groundwater Hydrology and Water Quality

The groundwater hydrology is impacted by changes in irrigation practices. Direct impacts to groundwater hydrology, such as changes in groundwater level, aquifer capacity, and the hydrologic cycle, occur due to changes in seepage and deep percolation. Deep percolation is the downward movement of water below the crop root zone, while seepage is the water that escapes from canals or on-farm ditches to the water table. During flood irrigation practices, water conveyance occurred within a canal network. For flood irrigation, the unlined irrigation canal network had an estimated length of 354 km (220 mi) traversing gravelly, sandy soils. Seepage and percolation rates in gravelly soils can be very high, and may result in large quantities of aquifer recharge and storage, especially during flood irrigation.

Few long-term monitoring or water supply wells exist in the study area, making it difficult to assess the impacts of changes in irrigation practices on groundwater levels. Well logs obtained from the Groundwater Division at the Wyoming State Engineer's Office for all wells installed in the Star Valley area were analyzed in an attempt to determine any impacts to the groundwater elevation. The well logs contained information on well owners, type of water use, initial static level of the groundwater, initial groundwater depth, well depth, main water bearing zone, approximate location of the well, geology of the soils enclosing the well, and drilling date of the well.

Approximately 25% of the basin was not converted to sprinkler irrigation. Three regions were analyzed to determine changes in groundwater levels over time (Fig. 1). The Stump Creek area, Region 1, was selected and analyzed as an existing flood irrigation area. The West Afton Region, Region 2, was analyzed as a sprinkler irrigated area. The Dry Creek Region, Region 3, contained both flood and sprinkler irrigated areas.

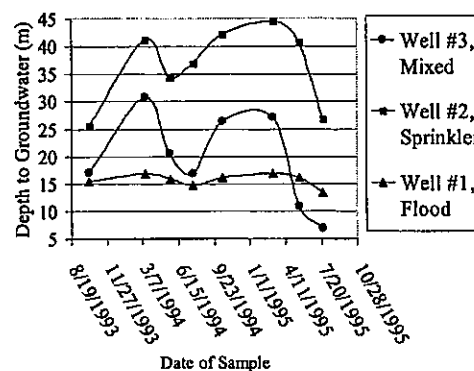


Fig. 2. Monitor well data for study area: monitor well 1 is located in a flood irrigated region; well #2 is located near a sprinkler irrigated area; well #3 is located with a mixed irrigation area

The analysis contained data from 160 wells located within the study area. The wells were selected based upon the density of wells in the study area and the type of irrigation practice. The criteria for selecting wells for comparison was as follows: (1) Wells must be located in close proximity of each other and sections based on township and range were chosen that contained the highest density of well data; and (2) the wells analyzed must be unconfined and likely to influence the recharge of the Salt River. Wells with a depth to the unconfined aquifer of no greater than 28 m (85 ft) from the ground surface for the sprinkler irrigated regions and no greater than 10 m (35 ft) for the flood irrigated regions were included in the analysis. These depth limitations were imposed to ensure selected wells were representative of unconfined aquifers.

Because groundwater elevations fluctuate due to the hydrologic cycle, it was necessary to normalize the groundwater levels for seasonal variations to obtain an accurate prediction of trends over extended periods of time. Monitoring wells located within the study area, which contained only a few years of record, were used to normalize the static water level information obtained from the well logs. Using the groundwater levels for the winter months of February and March as a baseline, a ratio between these months and other months was calculated and used to correct for seasonal variation in groundwater levels (Fig. 2). Plots of seasonally corrected static well levels versus time were created to identify any changes with time in groundwater levels in each of the three designated regions.

The changes in irrigation practices may also have impacts upon the water quality within the watershed. Star Valley contains large saline deposits (Walker 1965), and the leaching of salts during irrigation may cause water quality concerns with respect to domestic and agricultural use. The gauging station, USGS stream gauge No. 13027500, utilized for streamflow analysis on the Salt River contained data on water quality, including salinity, total dissolved solids, and conductance for the period 1965–1975.

Seepage Calculations

The conversion to sprinklers eliminated a majority of canal seepage that occurred prior to the conversion from flood to sprinkler irrigation. During flood irrigation, water was carried to the irrigated fields via an unlined canal network resulting in a large amount of seepage loss.

The soil types in the Star Valley vary depending on location. Soil types were determined from information obtained from per-

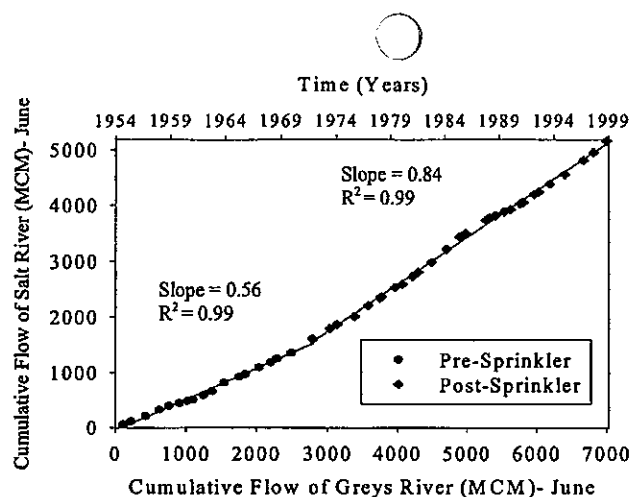


Fig. 3. Double mass balance plot for month of June

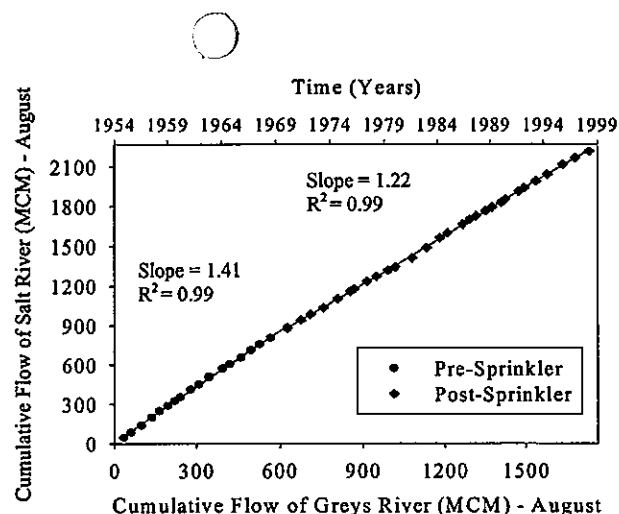


Fig. 4. Double mass balance plot for month of August

mits to divert water and from a soil survey (USDA-NRCS 1976). The permits also include information on canal length, canal wetted perimeter, and the number of acres served by the canal. Using this information, the contact area per acre irrigated was calculated for the two major irrigation districts. This ratio was applied to the entire acreage within the Star Valley to estimate the total seepage area for the flood irrigation system. This area was then multiplied by a soil seepage coefficient of $0.30 \text{ m}^3/\text{m}^2\text{-day}$ for sandy loam soil (Finkle 1982) to obtain the seepage estimate for the presprinkler period. The value of $0.30 \text{ m}^3/\text{m}^2\text{-day}$ was chosen because it most closely relates to the average type of soil located in the study area. Postsprinkler conveyance seepage losses are assumed negligible because water conveyance is with a pipe network.

Results and Discussion

Double Mass Balance Plots

The results of the double mass balance analysis of the Salt River flows versus the Greys River flows are presented for the months of June (Fig. 3) and August (Fig. 4). Double mass balance plots for all months can be found elsewhere (Venn 2002). Inspection of the double mass balance figures reveals a break in the trend line slope beginning in approximately 1971. This time corresponds to the time irrigation practices were changing from flood to sprinkler. To determine if the observed changes in flow ratios were

statistically significant, Student t-tests for all months were conducted on the calculated average ratios for both the presprinkler and postsprinkler periods using a 95% confidence interval (Table 2).

The early irrigation months of May and June show increases of flow in the Salt River relative to the Greys River, after the conversion to sprinkler irrigation (Table 2). The later irrigation months of August and September and the nonirrigation months of October and November show decreases in flow of the Salt River relative to the Greys River after the conversion to sprinkler irrigation. The August through November changes are likely due to changes in groundwater return flow timing due to flood versus sprinkler irrigation practices. This evidence clearly shows changes in hydrology to the Salt River directly related to the conversion from flood to sprinkler irrigation practices and that groundwater levels may be changing in the area. Impacts to groundwater levels are discussed in more detail in the Groundwater Analysis section of this paper. The slopes of the double mass plots for the remaining months of July and December through April reflected little or no change to the return flow of the Salt River relative to the Greys River, and the resulting t-tests for these months estimate confidence levels below 95%.

Stream Flow Changes

Calculations based on the difference in flow ratios provide a means for determining average monthly and yearly amounts of

Table 2. Student t-Test Results of Flow Ratios Determining Statistically Significant Months

Month	Time period	Average flow ratio	Standard deviation	Confidence interval	Student t-test	Significant
January	Pre/post	2.210/2.069	0.251/0.292	0.119/0.106	0.091232	No
February	Pre/post	2.197/2.134	0.212/0.288	0.101/0.105	0.400483	No
March	Pre/post	2.044/2.083	0.226/0.310	0.107/0.113	0.628803	No
April	Pre/post	1.647/1.593	0.387/0.401	0.184/0.146	0.655327	No
May	Pre/post	0.787/1.055	0.167/0.293	0.079/0.107	0.000284	Yes
June	Pre/post	0.538/0.808	0.151/0.193	0.072/0.070	0.000005	Yes
July	Pre/post	0.875/0.913	0.103/0.147	0.049/0.053	0.306508	No
August	Pre/post	1.426/1.216	0.144/0.123	0.068/0.045	0.000021	Yes
September	Pre/post	1.899/1.627	0.124/0.152	0.059/0.055	0.000000	Yes
October	Pre/post	2.061/1.917	0.142/0.140	0.068/0.051	0.002172	Yes
November	Pre/post	2.335/2.137	0.135/0.234	0.071/0.085	0.000342	Yes
December	Pre/post	2.352/2.183	0.297/0.253	0.141/0.092	0.058433	No

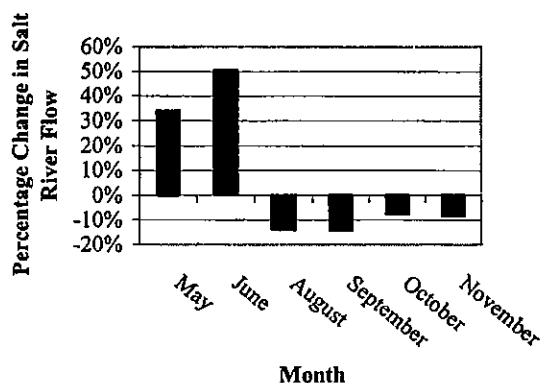


Fig. 5. Annual average percentage of increase or decrease in Salt River flow per statistically significant month due to changes in irrigation practices

water conserved or lost due to eliminating open canals and converting to sprinkler irrigation. The amount of water conserved or lost each month as a percentage of average volume for the month is shown in Fig. 5. The months of May and June show average increases of 34 and 50% in streamflow of the Salt River, respectively, while the months of August and September show average decreases of 15 and 14%, respectively. The overall average annual increase of flow in the Salt River is approximately 65.62 MCM (53,200 acre-ft), which is calculated from the summation of flow changes for each of the statistically significant months. The 65.62 MCM/year of additional water flowing in the Salt River after conversion to sprinkler irrigation is approximately 55% of the average annual consumptive irrigation requirements in the study area, and approximately 10% of the average annual flow of the river.

Crop Yields

The conversion from flood to sprinkler irrigation beneficially impacted crop yields, which increased from 50 to 100% (Sando 1986). As shown in Fig. 6, crop production yields for alfalfa hay increased from an average of 3.6 ton/ha (1.6 t/acre) to an average of 4.7 ton/ha (2.11 ton/acre) after the switch to sprinkler irrigation (USDA-NASS 1999). The increased yields are attributed to more efficient water application and are directly related to the increase in overall irrigation efficiency. Farmers indicated that they are

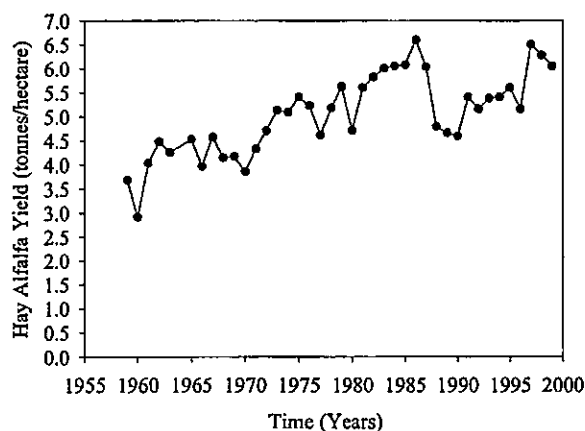


Fig. 6. Crop production yields for hay alfalfa in study area

able to produce a greater crop yield on the same amount of land, because they could deliver irrigation water evenly to the entire field. Second cutting yields of crops by Star Valley farmers increased nearly 100% as compared to second cuttings with flood irrigation practices, which explains the increases in total crop yield.

Evaporation

Canal evaporation, which occurred with the flood irrigation systems, accounts for some of the 65.62 MCM (53,200 acre-ft) annual increase in Salt River flow after conversion to sprinkler irrigation. Estimates of monthly and total canal evaporation that occurred during the flood irrigation period for the entire study area are shown in Table 1. The conveyance evaporation occurring in the basin was approximately 3.4 MCM/year (2800 acre-ft/year) during flood irrigation. It should be noted that evaporation from open canals and ditches could have a higher evaporation loss per unit area than a large open body of water (Burt et al. 1997) because the canal water is moving and mixes more readily with the air, resulting in a higher evaporation rate. The preceding estimates for evaporation are based on reservoir evaporation coefficients; therefore, the evaporative losses for the Star Valley shown in Table 1 are conservative estimates.

There are application evaporation losses with sprinkler methods. Thus, changes in streamflows are affected by both eliminating canal evaporation that occurred during the flood irrigation period and by increasing application evaporation losses during sprinkler irrigation. Sprinkler evaporation losses are typically less than 2% of the discharged water (Thompson et al. 1993). Assuming 2% losses, the evaporative losses from sprinkler evaporation in the study area would result in losses of roughly 1.5 MCM (1,200 acre-ft) of water. The evaporation estimates for conveyance and application during flood irrigation are more than double the amount of evaporation for conveyance and application during sprinkler irrigation. A reasonable estimate for the excess Salt River flow through reduction in evaporation is the difference in the estimates of evaporation for the different irrigation practices. The difference in evaporation estimates is 1.9 MCM per year (1,540 acre-ft). This value can account for some of the increase in streamflow of the Salt River.

The preceding estimated value of evaporation occurring during the presprinkler period only accounts for conveyance and on-field canal networks. Other mechanisms may increase the total amount of evaporation occurring during flood irrigation as compared to sprinkler irrigation. During the presprinkler period, crop irrigation required flooding the entire field in order to irrigate the higher reaches of land. Therefore, some of the crop land was oversaturated and standing water in the oversaturated areas was susceptible to evaporation.

Evapotranspiration (ET) is the combination of evaporation from soil, plant surfaces, and standing water as well as transpiration from plants. Evapotranspiration from plant surfaces and transpiration from the plants should be equivalent for both irrigation techniques. However, early in the growing season, there is a lack of sufficient crop canopy for infant barley and hay crops, and these crops are unable to transpire the entire amount of water provided by the flood irrigation canals and soil surfaces. Under these conditions, a greater amount of water may be lost due to evaporation with flood irrigation techniques as opposed to sprinkler irrigation techniques. ET losses are known to be higher with flood irrigation as compared to sprinkler irrigation, assuming similar conditions and acreage (Guitjens and Goodrich 1994).

Published grass reference ET values exist for the study area, but these values do not differentiate between transpiration from the plants and evaporation from the soil. Hence, it is difficult to estimate how evaporation would change with different application techniques.

Many areas in the Star Valley contained high groundwater levels before the installation of sprinklers. Flood irrigation created many boggy and swampy situations throughout the valley. Several acres within the area had standing water through much of the irrigation season. Evaporation could have also occurred from these standing bodies of water.

Seepage Analysis

The piping network utilized after the conversion to sprinkler irrigation eliminates the majority of seepage that occurred in the canals used with flood irrigation. Seepage refers to the water lost from the canal network in conveyance to the crops, while deep percolation refers to the water escaping the root zone during field application. When utilizing flood irrigation, large quantities of water seep from flood canals and percolate into groundwater aquifers (Voeller and Waren 1997). Some of the water that is applied to the fields may also escape the root zone and percolate. Because of uneven application, percolation may be different between the two applications practices.

The change in canal seepage due to the change in conveyance is approximately 50 MCM (40,000 acre-ft). This represents 42% of the average annual consumptive irrigation requirement for the study area. This estimate agrees well with other reported values. For this region within the State of Wyoming, canal and lateral losses are typically 38–42% of the total diversion for flood irrigation (ADMP 1946). The reduction in seepage that occurred with sprinkler irrigation directly impacted the groundwater hydrology in the Star Valley. The volume of water conserved through reduction in seepage is approximately 76% of the average annual increase of flow in the Salt River after the conversion to sprinkler irrigation practices. However, this estimate cannot be directly applied as true savings, because it is assumed that a large fraction, but not all, of the seepage water eventually returned to the Salt River. The fraction that did not return can be considered the true savings of water that was previously lost through evaporation, phreatophytic vegetation consumption, and to irrecoverable groundwater.

Phreatophytic Vegetation Consumption

Phreatophytic vegetation can be considered to include all the vegetation not utilized by farmers in the Star Valley for productive uses. Through seepage and infiltration mechanisms and the creation of low-lying bogs, the canal network and flood irrigation practice present in the flood irrigation period provided water for phreatophytic vegetation, which included willows, cattails, weeds, cottonwood trees, and grasses. These phreatophytes consumed water and reduced the return flow to the Salt River. Some of the increased Salt River water flow was achieved with the changes in irrigation practices, because phreatophytes were no longer able to utilize irrigation water from the old canal network. It is difficult to accurately estimate the total amount of phreatophytic consumption during flood irrigation, but evidence exists to indicate it was significant. Through interviews with residents and information provided by the Farm Service Agency in Afton, it is known that the amount of phreatophytic vegetation has decreased since the change in irrigation practices. Many boggy wetland

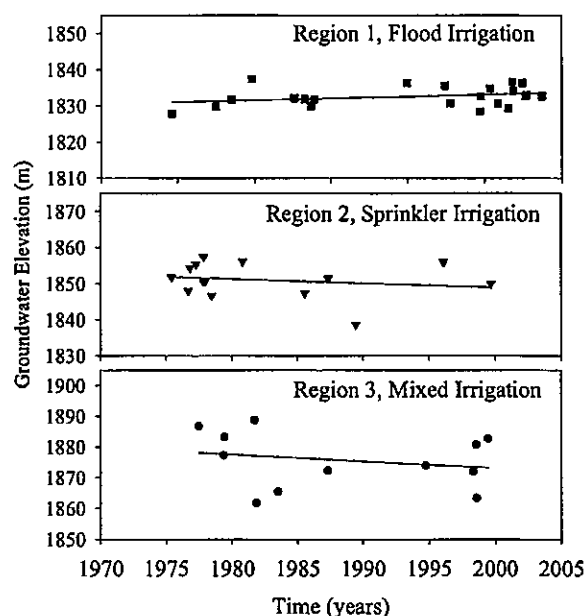


Fig. 7. Scatter plots of groundwater elevation versus time for regions with different irrigation practices

areas that existed during flood irrigation are gone today. This would be consistent with the higher efficiency of the sprinkler irrigation system and suggests a decrease in the groundwater level may have occurred.

Groundwater Analysis and Changes in Storage

Previous studies have shown that groundwater tables and aquifer storage are influenced by changes in irrigation practices. Winger et al. (1995) found that, during 50 years of operating a canal network in central Nebraska, some areas experienced groundwater rises up to 35 m. With the elimination of flood irrigation in the Star Valley, significant quantities of the water are no longer reaching groundwater aquifers and a decrease in groundwater levels can be expected. In order to fulfill the yearly mass balance on the watershed and account for the increased streamflows based upon the sprinkler irrigated acreage within the study area, a decrease in groundwater levels of approximately 0.31 m/year (1.02 ft/year) would be required. Over a period of 30 years, the groundwater table would be expected to show decreases of 6.0 m (20 ft).

Regions in the Star Valley currently containing either sprinkler or flood irrigation practices were analyzed to determine the effects of the conversion on groundwater levels in unconfined aquifers. The unconfined aquifers in the regions were analyzed because they are the main contributing mechanisms of river recharge in the area. Groundwater elevations versus time for areas with different irrigation methods are shown in Fig. 7. There is a large amount of scatter in the groundwater elevation data presented. Some of the scatter can be attributed to the varying well locations within the regions. To minimize this effect, regions were chosen such that elevations do not vary greatly within the narrowly defined regions. Some of the scatter may also be due to different climatic effects with time. Regardless, the amount of scatter in the figure makes determination of changes in the groundwater table for the different areas difficult, and the data does not indicate that statistically significant changes in the groundwater regime have occurred.

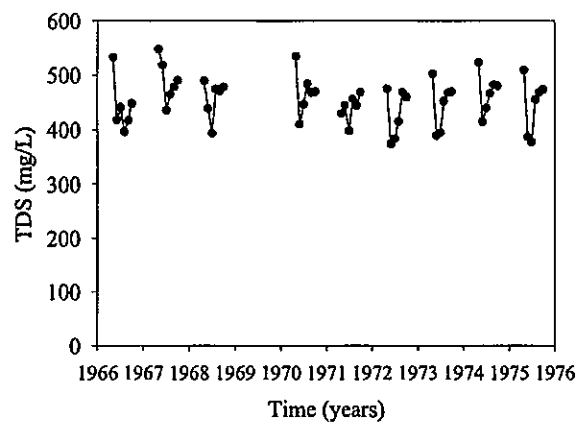


Fig. 8. Total dissolved solids concentrations for Salt River for irrigation months (April–September) during period before and after conversion to sprinkler irrigation

Long-term monitor wells are the most conventional means for determining changes in groundwater elevations over time. In addition to the data used in the groundwater analysis section, there are also three monitoring wells that exist within the study area, each limited to data for a period less than 3 years taken in the early 1990s. Monitor well 1 is located in the flood irrigated region, monitor well 2 is located near the sprinkler irrigated region, and monitor well 3 is located in the mixed flood and sprinkler irrigated region (Fig. 1). The three monitoring wells provide information on seasonal groundwater level fluctuation, but cannot be used to investigate long-term changes in groundwater levels. Fig. 2 shows that groundwater depths fluctuate significantly in sprinkler regions as compared with the flood irrigated region. Monitor well 1 shows annual groundwater fluctuations of less than 1.2 m (4 ft), while the monitoring wells in the sprinkler region and combined region show annual groundwater fluctuations of approximately 5–6 m (14–20 ft).

Very few conclusions can be drawn from the limited monitor well data. One observation might be that the low annual fluctuations in groundwater depth in the flood irrigated region indicates that the aquifer is usually at a high water level and flow is from the aquifer to the river throughout the year. On the other hand, the larger depth fluctuations during the year in the sprinkler and combined regions may be due to deep percolation during the irrigation season, return flows, and perhaps even recharge from the river. However, as stated, the monitor well data is too limited to draw conclusive observations.

Groundwater and Surface Water Total Dissolved Solids

TDS data for the seasonal irrigation months was tabulated and plotted (Fig. 8) for comparisons of the presprinkler and postsprinkler periods. Dissolved solids concentrations within the Salt River for the sprinkler period remained within 10% of the concentrations measured for the presprinkler period. Therefore, no significant impacts to the surface water TDS in relation to the change in irrigation practices in the study area could be documented.

Groundwater quality data was also very limited due to the lack of wells within the study area. TDS concentrations for three groundwater wells located in sprinkler irrigated regions and one located in a flood irrigated region are shown in Table 3. The well in the flood irrigation region had a TDS value more than 250 mg/L higher than the sprinkler wells and average river values. It

Table 3. Groundwater Quality for Wells Located within Study Area

Well permit number	Irrigation practice	Date of sample	Total dissolved solids (mg/L)
P84521W	Sprinkler	7/16/1991	246
P99886W	Sprinkler	9/27/1996	267
P38291W	Mixed	11/2/1977	340
P64767W	Flood	11/1/1983	520

is difficult to accurately predict the changes in groundwater quality due to changes in irrigation practices based on the limited data. The limited results, however, imply that groundwater quality is improved in sprinkler irrigated regions as opposed to flood irrigated regions. This effect on groundwater quality has been well documented in other groundwater quality studies related to different irrigation practices (Beke et al. 1993; Miller and Andersen 1993; Ghassemi et al. 1994).

Summary and Conclusions

The objectives of this study were to quantify the potential hydrologic impacts to a watershed when irrigation systems are converted from flood to sprinklers and to relate these impacts to the various hydrologic components through which they occur. Specific objectives included the determination of changes in (1) return flow timing; (2) total annual river flow; (3) agricultural production; (4) surface water and groundwater quality; and (5) groundwater levels in the unconfined aquifer impacting river recharge.

Return flow timing was impacted by the conversion to sprinkler irrigation. Streamflows increased 34% in May and 50% in June, while decreasing 15 and 14% for August and September. These changes are related to how on-field application efficiency of irrigation water increases with sprinkler irrigation. Because conveyance for sprinkler irrigation now occurs in a pipe network, deep percolation, seepage, and groundwater recharge related to the former flood irrigation practices are eliminated. The change in magnitude and timing of return flows has the potential to influence streamflows and hamper irrigators in the lower end of the valley, because the river flow has decreased during the later part of the irrigation season. Practical solutions for reducing the impacts of the return flow timing include installation of catchments. The early spring runoff could be stored and utilized more beneficially to alleviate the 15% decrease in available in-stream flow at the end of the irrigation season.

The average annual Salt River Flow is approximately 722 MCM (575,000 acre-ft), and the 65.62 MCM of excess flow represents 9% of the average annual Salt River flow. The increased flow is substantial, as it represents approximately 55% of the average annual consumptive irrigation requirement in the study area. These changes may have coincided with decreases in groundwater storage. Analysis of changes in groundwater levels with time was inconclusive; however, if occurring, changes could be very important to the long-term water production of the area.

The increased annual flow occurred even with an increase in crop yields. After the conversion from flood irrigation to sprinklers, average crop yields increased from 1.6 t to 2.1 ton/acre. Crop yields increased because farmers can now more evenly distribute irrigation water to their fields and irrigate higher reaches of their fields.

The surface water quality appears unaffected by the conversion in irrigation practices. Dissolved solids concentrations within

the Salt River for the sprinkler period remained within 10% of the concentrations measured for the presprinkler period. The results of the limited groundwater quality data indicate that TDS values are lower in sprinkler irrigated areas.

The observed impacts to the river basin hydrology are mainly due to canal evaporation, evapotranspiration, phreatophytic consumption, unlined canal seepage, and possible changes to the aquifer system. Unlined canal evaporation estimates account for approximately 1.25 MCM/year (1,500 acre-ft/year) of the increased annual flow. Unlined canal seepage losses were estimated to be 50 MCM/year (40,000 acre-ft/year). The volume of water conserved through reduction in seepage can account for 80% of the increased flow in the Salt River. However, this estimate cannot be directly applied as true savings, because it is assumed that a large fraction but not all of the seepage water eventually returned to the Salt River later in the year. Conclusions of this study are based on limited groundwater information. In the future, a more in-depth study of the changes in groundwater hydrology is necessary. Lysimeters in the study area have been installed in the last 5 years, which should provide additional information on the impacts to the groundwater hydrology.

Water in the semiarid western United States is a vital resource. In an attempt to conserve this valuable commodity, irrigation practices in the Star Valley in western Wyoming were converted from flood to sprinkler irrigation to improve application and conveyance efficiencies. The changes in conveyance and conversion from flood to sprinkler irrigation increased agricultural production, caused changes in return flow timing, appeared to increase annual river flow, and possibly impacted groundwater levels and water quality.

Notation

The following symbols are used in this paper:

- C_1 = fraction of annual evaporation for each month;
- C_2 = total annual evaporation;
- E = volume of water lost through evaporation;
- ET = volume of water lost through evapotranspiration;
- P = volume of water lost through phreatophytic and hydrophytic consumption;
- P_r = volume of water entering study area as precipitation;
- R_{inflow} = volume of water entering study area;
- $R_{outflow}$ = volume of water leaving study area;
- S = annual increased stream flow of Salt River;
- SA = surface area of water in irrigation canals;
- SI = volume of water lost due to seepage and infiltration;
- ΔE = change in evaporation;
- ΔET = change in evapotranspiration; and
- $\Delta Storage$ = change in storage within study area.

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Measuring On-Farm Irrigation Efficiency with Chloride Tracing under Deficit Irrigation

Zohrab Samani¹; Ted Sammis²; Rhonda Skaggs³; N. Alkhatiri⁴; and Jose Deras⁵

Abstract: Water is a limited resource in agricultural production in arid climates. Under such conditions, high irrigation efficiency can be obtained either through implementation of efficient irrigation systems such as drip or sprinkler systems or through the age-old practice of deficit irrigation with gravity systems. The method used to increase irrigation efficiency is often dictated by economic and/or social factors. In either case, the effectiveness of water management at the farm level needs to be evaluated by measuring irrigation efficiency. The objective of this study was to evaluate the irrigation efficiencies for three crops in Southern New Mexico using the chloride technique. The chloride technique is a simple method in which the natural chloride in the irrigation water is used as a tracer to estimate the leaching fraction and the irrigation efficiency at the farm level. Soil samples were collected from various fields in 15 cm increments to a depth of 180 cm at the end of the irrigation season. The samples were analyzed for moisture and chloride content. In addition to the chloride technique, on-farm irrigation efficiencies were measured using applied water, yield, and water production functions. Water production functions and yields were used to estimate total evapotranspiration while flow measurements were used to calculate the amount of applied water. The results showed that high irrigation efficiency can be accomplished using deficit irrigation. Irrigation efficiency values ranged from 83 to 98%. Irrigation efficiencies using the chloride technique were compared with efficiencies estimated from direct flow measurements. The differences between the two methods ranged from 2 to 11.4%. The results showed that even though the chloride technique is subject to sampling errors and simplified theoretical assumptions, it can be used to estimate on-farm irrigation efficiency with considerable accuracy.

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CE Database subject headings: Irrigation systems; Farms; Agriculture; Chlorides; Water management; New Mexico.

Introduction

Water is a limited resource in the arid climate of southern New Mexico. The limited water supply and increasing demands have created the need to identify sources of water loss and water use as well as the economic returns from water under various conditions. Potential sources of water loss include seepage and runoff from delivery systems as well as seepage and runoff losses during on-farm irrigation practices. Irrigation systems such as drip and

sprinkler irrigation are often used to increase on-farm irrigation efficiency. Even gravity systems can achieve high irrigation efficiency if they are designed, maintained, and managed correctly. However, gravity systems are often associated with low irrigation efficiency. A survey of irrigation systems at the national level showed that out of 25.7 million ha of irrigated land in the United States, 50% of irrigation systems used are gravity flow, 45% are sprinkler, and 5% are drip irrigation (*Irrigation Journal*, 2001). In southern New Mexico, more than 95% of the irrigation systems are gravity flow, commonly known as surface irrigation. The major crops in the area are pecan, alfalfa and cotton, which are planted in 75% of the irrigated land. The remaining 25% is planted with vegetable crops such as onion and chile. The generally mild slopes and moderate to slow water intake of soils favor basin and basin-furrow irrigation. Alfalfa and pecan commonly use basin irrigation while cotton and vegetable crops use basin-furrow irrigation. The farmers receive water on a demand basis with a fixed allocation water right, usually 1 ha m/ha. The limited water supply has created an economic necessity for deficit irrigation, especially by commercial farmers. However, information on the efficiency of on-farm irrigation application, the level of deficit irrigation, and the economic return from water is limited. The purpose of this study was to evaluate on-farm irrigation efficiencies for various crops in southern New Mexico using the chloride technique and to verify the technique using direct flow measurements.

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Methodology

The concept of irrigation efficiency has been used to evaluate water management for many years. There are various definitions for irrigation efficiency (Willardson et al. 1994). Traditionally, irrigation efficiency is defined as the quantity of crop evapotranspiration supplied by irrigation divided by the quantity of applied water (Jensen 1981; Willardson et al. 1994).

The leaching fraction (LF) is the fraction of applied water which is lost below the root zone of the crop and therefore not available for crop use. If the leaching fraction is known, then the irrigation efficiency (IE) can be calculated as

$$IE = 1 - LF \quad (1)$$

Chloride is a nonreactive mobile element in the soil and water environments which can be effectively used as a natural tracer to evaluate the fate and transport of soluble nutrients in water (Prat et al. 1978; Stewart 1978; Al-Jamal et al. 1997; Vengosh and Pankratov 1998; Karr et al. 2001; Genereux et al. 2002). Chloride in irrigation water is either taken up by the plant or remains in the water in the soil. Using a simple mass balance in chloride transport, and assuming steady state conditions, Pratt et al. (1978) calculated the irrigation LF as

$$LF = \frac{V_p}{V_i} = \frac{Cl_i}{Cl_p} \quad (2)$$

where V_p =cumulative drainage flux (kg/ha); V_i =cumulative irrigation water applied (kg/ha); Cl_i =concentration of chloride in irrigation water (kg of Cl^- /kg of irrigation water); and Cl_p =concentration of chloride in drainage water (kg of Cl^- /kg of soil water). Eq. (2) assumes steady-state conditions and a single source of irrigation water with no chloride uptake by the crop. In southern New Mexico, crops are irrigated primarily using river water, but additional supplemental irrigation is provided through water wells that have considerably higher salt and chloride concentrations than the river water. Eq. (2) was modified to account for these multiple sources and sinks of the Cl^- as follows:

$$V_i + \sum_1^n V_n = V_p + ET \quad (3)$$

and

$$(V_i)(Cl_i) + \sum_1^n (V_n)(Cl_n) = (V_p)(Cl_p) + Cl_c \quad (4)$$

where V_i and Cl_i =amount and chloride concentration of the primary source of irrigation water; and V_n and Cl_n =irrigation amount and chloride concentrations from supplemental irrigation sources, respectively. Cl_c =chloride uptake by plant (kg/ha); and ET =seasonal crop evapotranspiration (kg/ha).

Combining Eqs. (2)–(4) results in the following equation for leaching fraction:

$$LF = \frac{Cl_i(ET) - Cl_c - \sum_1^n V_n(Cl_i - Cl_n)}{Cl_p(ET) - Cl_c - \sum_1^n V_n(Cl_i - Cl_n)} \quad (5)$$

If a single source of water is used for irrigation, then Eq. (5) can be simplified into

$$LF = \frac{Cl_i(ET) - Cl_c}{Cl_p(ET) - Cl_c} \quad (6)$$

Eqs. (2)–(6) assume steady-state conditions where the soil–water content remains constant over time. However, under real field conditions, steady-state conditions would be difficult to achieve, unless light, and frequent irrigation practices are used (Olson 1978). The assumption of chloride as a nonreactive element would be invalid if chloride precipitation occurs in the soil (Stewart 1978). Despite the limitations, the chloride method was selected for this study because it provides a simple and low cost method for estimating irrigation efficiency.

If the seasonal evapotranspiration (ET) can be estimated, then Eq. (6) can be used to calculate the LF and irrigation efficiency. The seasonal ET can be estimated using yield and crop water production functions. In the absence of ET values, irrigation efficiency can still be estimated from Eq. (6) by ignoring the plant chloride uptake (Cl_c). The plant chloride uptake constitutes only a small fraction of the total chloride flux and its effect on estimating irrigation efficiency is minimal (<3%, Alkhateeri 2001). When irrigation efficiency is calculated, the amount of water applied to the field can also be estimated by dividing the ET by the irrigation efficiency. This provides valuable information on irrigation deliveries at the field turnouts where water measuring devices are not commonly used. In cases where supplemental irrigation is implemented, Eq. (5) can be used to estimate LF and irrigation efficiency, but the amount and chloride concentration of supplemental water needs to be directly measured. It is often easier and more economical to measure the cumulative pump discharge with conventional flow meters rather than measuring the highly variable canal water discharge.

A total of 15 fields were included in the study, for the three major crops of alfalfa, cotton, and pecan. Ten fields were used to estimate irrigation efficiencies over a 3 year period. Five more fields were used for the verification of chloride methods. The field sizes ranged from 4 to 50 ha. All fields were in the Elephant Butte Irrigation District in southern New Mexico. All fields were irrigated using basin irrigation with no runoff. Fields were selected based on availability, access, and adequacy of information on yield and applied water. The data were collected over a period of 3 years and seasonal ET were calculated based on the reported yield, using the water production functions developed by various investigators in the area. Table 1 lists the crop water production functions for each crop.

The amount of chloride taken up by the crop was calculated by multiplying the various crop biomass (kg/ha) components by the chloride concentration in those components. Total biomass was calculated from yield and a harvest index except for alfalfa where yield was the total biomass. Harvest index was defined as the ratio of yield to total biomass (Sinclair 1998). Harvest index was measured by sampling a 1 m² area in the field. The total yield information were obtained from farmers after the harvest. To measure the chloride concentration in crop biomass, plant samples were dried at 68°C and were ground to pass a Number 20 mesh screen. Plant water extract were prepared by adding 25 mL of distilled water to 1 g of ground and sieved plant material, shaken for 15 min, and filtered through Whatman Number 42 filter paper (Bower and Wilcox 1965). Plant extracts were analyzed for chloride concentration using a digital HACH spectrophotometer at the New Mexico State University (NMSU) Soil and Water Testing Laboratory. Irrigation water samples

Table 1. Crop Water Production Functions for Various Crops in Southern New Mexico

Water production function	Crop	Reference
$Y=0.14+0.12*ET$	Alfalfa	Sammis (1981)
$Y=-12.1+0.5168*ET$	Green Chile	Wierenga (1983)
$Y=(134.87+14.25*ET)/1,000$	Cotton	Sammis (1981)
$Y=(-7,309+238.9*ET)/1,000$	Corn	Kallsen et al. (1981)
$Y=(-30.1+22.14*ET)/1,000$	Pecan	Miyamoto (1983)
$Y=-22,495.62+870.51*ET$	Onion	Al-Jamal (1995)
$Y=4,918.62+968.23*ET$	Lettuce	Cortez (1999)
$Y=-7,644.37+1,002.91*ET$	Cabbage	Cortez (1999)

Note: Y=yield in metric ton/ha and ET=seasonal evapotranspiration in centimeters.

Table 2. Results of Chloride Analysis for Alfalfa for 3 Years

Field	Soil type	Year	Yield (t/ha)	Relative yield	ET (estimated) (cm)	Leaching factor (%)	Irrigation efficiency (estimated) (%)	Applied water (estimated) (cm)
A-1	Loam	1996	20.78	0.7	172	2	98	175.5
A-1	Loam	1997	17.97	0.6	148	6	94	157.5
A-1	Loam	1998	18.0	0.6	149	4	96	155.2
A-2	Clay	1996	22.46	0.7	186	13	87	213.8
A-2	Clay	1997	20.21	0.6	167	11	89	187.6
A-2	Clay	1998	18.42	0.6	152	5	95	160.0

Table 3. Results of Chloride Analysis for Pecan

Field	Soil type	Year	Yield (t/ha)	Relative yield	Evapotranspiration (estimated) (cm)	Leaching fraction (%)	Irrigation efficiency (estimated) (%)	Applied water (estimated) (cm)
B-1	Sand	1996	2.02	0.7	92.5	6	94	98.4
B-1	Sand	1997	3.03	1.0	138	7	93	148.4
B-1	Sand	1998	1.8	0.6	82.4	7	93	88.6

Table 4. Results of Chloride Analysis for Cotton

Field	Soil type	Year	Yield (t/ha)	Relative yield	Evapotranspiration (estimated) (cm)	Leaching fraction (%)	Irrigation Efficiency (estimated) (%)	Applied water (estimated) (cm)
C-1	Sand	1996	1.235	0.6	77.2	4	96	80.42
C-1	Sand	1997	1.06	0.5	64.9	6	94	69.0
C-1	Sand	1998	1.404	0.7	89.0	6	94	94.7

Table 5. Comparison between Irrigation Efficiencies for Alfalfa, Pecan, and Cotton Using Two Methods for Estimating Irrigation Efficiencies

Field	Soil type	Year	Crop	Yield (t/ha)	Evapotranspiration estimated from yield (cm)	Irrigation efficiency chloride method (%)	Irrigation efficiency from measured water and yield (%)	Applied water (measured) (cm)	Difference in irrigation efficiency (%)
G-1	Loamy-sand	2000	Alfalfa	19.77	163.6	91	93	176	2
G-2	Sandy-loam	2000	Alfalfa	11.08	91	83	73.4	124	11.4
H-1	Loam	2001	Pecan	1.68	77	92	83	93	10
K-1	Loam	1988	Pecan	2.35	107.5	98	88	122	10
L-1	Loam	2000	Cotton	1.29	81	96	89	91	7

were collected at the beginning, middle, and end of the growing season to evaluate the average value of chloride concentration in the irrigation water. The crops were irrigated either from a single source of water (river water) or a combination of river and well water. In cases where well water was used, the chloride concentration in the well water was measured through periodic sampling. The effect of rainfall on the chloride concentration was not included in this study. The average annual rainfall in southern New Mexico is 200 mm. The rainfall is highly variable both spatially and temporally. No information is available on the effect of rainfall on crop ET or the fraction of rainfall interception by the plant. Due to the light (often less than 5 mm) and frequent nature of rainfall events, it is likely that most of the rainfall gets intercepted by the crop and has minimal effect on the soil chloride balance. Alkhateeri (2001) compared the estimated values of irrigation efficiency with and without rainfall. Assuming no rainfall interception, Alkhateeri (2001) showed that if the rainfall is ignored, the irrigation efficiency can be underestimated by as much as 1.2%.

Field sizes varied from 5 to 40 ha with soil texture ranging from clay to sand (Tables 2–4). At the end of growing season, the fields were divided into four equal sections. Two locations in the middle of each section were sampled for soil cores. Samples were taken in 15 cm increments from 15 to 180 cm of depth using a 7.62 cm diameter bucket auger. Gravimetric soil moisture contents were measured for each sample immediately after sampling in order to minimize error due to water loss. Chloride concentration in soil samples were measured by preparing a saturated extract with distilled water. Soil–water extracts were prepared by adding 25 mL of distilled water to 5 g of dry soil, shaking for 2 h, and filtering through Whatman No. 42 filter paper (Bower and Wilcox 1965). The extracts were then analyzed for chloride concentration using a digital HACH spectrophotometer. Once the ET was estimated from the crop yield, Eqs. (5) and (1) were used to calculate the LF and irrigation efficiency. The amount of irrigation water applied to the field was estimated by dividing the ET by the irrigation efficiency.

Results and Analysis

Tables 2–4 summarize the results of the chloride analysis and the estimated irrigation efficiencies for three crops during 1996–1998. All sites were irrigated from a single source of water and none of the site had flow measuring devices. The irrigation efficiencies in Tables 2–4 were measured using the chloride technique described in this paper. The high irrigation efficiencies of all three crops are attributed to the practice of deficit irrigation. Deficit irrigation is an irrigation practice where the applied water is less than the amount of water required for optimum crop growth.

The purpose of deficit irrigation is to maximize the yield from a unit of water rather than maximizing the yield from a unit of land. Deficit irrigation is a tradition in dry climates of the world where the limited water supplies are stretched over large crop areas in order to maximize total economic return (Hargreaves and Samani 1984).

The exception was the field B-1, where a high irrigation efficiency was obtained by using high flow turnout in a basin irrigation system combined with laser leveled field and irrigation scheduling.

Field Verification

In order to verify the accuracy of the chloride analysis, five independent fields in the Elephant Butte irrigation district were identified where flow measurement devices had been installed and the amount of applied irrigation water was recorded. In Table 5, alfalfa fields were irrigated from two sources (river and well), but pecan and cotton were irrigated from a single source (river water). The chloride method and yield data were used to estimate the total ET and irrigation efficiency. Irrigation efficiency was also calculated by dividing the estimated ET by the amount of measured applied water. The comparison is shown in Table 5.

This comparison shows that the chloride technique can provide reasonably accurate estimates of irrigation efficiencies at the field level. The chloride method combined with yield or ET information can also be used to estimate the total applied water when flow measuring devices are not available. Table 5 shows the chloride technique generally tends to overestimate the irrigation efficiency. The overestimation can be attributed to various factors including error in sampling and analysis, error in flow measurement, and off season evaporation or evapotranspiration and the difference between initial and final soil moisture.

Conclusions

Irrigation efficiencies were measured using the chloride tracer technique and direct field measurements of yield. Three crops and ten sites were used in the evaluation. The results showed that, contrary to conventional belief, high on-farm irrigation efficiencies can be obtained using surface irrigation. Irrigation efficiencies ranged from 83 to 98%. The high irrigation efficiencies in the area were mainly due to deficit irrigation, with the exception of one field, where a high irrigation efficiency was obtained due to use of high flow turnout, laser leveled field, and irrigation scheduling. The chloride technique is subject to potential error due to potential sampling and analysis errors, and simplified assumptions such as the assumption of steady-state flux. However, the comparison between efficiency values measured by the chloride method and the direct field measurement of applied water showed that on-farm irrigation efficiency can be measured using the chloride technique with good accuracy. The differences in irrigation efficiencies measured with the chloride technique and with direct flow and yield measurement ranged from 2 to 11.4%.

Notation

The following symbols are used in this technical note:

- Cl_c = chloride uptake by plant (kg/ha);
- Cl_i = chloride concentration in irrigation water (kg/kg);
- Cl_n = chloride concentration in water source n (kg/kg);
- Cl_p = chloride concentration in drainage water (kg/kg);
- ET = evapotranspiration (kg/ha);
- IE = irrigation efficiency;
- LF = leaching fraction;
- V_i = irrigation water from source i (kg/ha);
- V_n = irrigation water from source n (kg/ha); and
- V_p = drainage flux (kg/ha).

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