BLACKFOOT IRRIGATION SCHEDULING PROGRAM

SPRINKLER IRRIGATION GUIDE 1.01

Rev. March 2020

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1.0 INTRODUCTION AND IRRIGATION SUMMARY

This guide provides information to help irrigators in the Blackfoot drainage apply the right amount of water at the right time to produce the best crops. Sprinkler irrigation is highlighted but most of the information applies to all irrigators.

The **Irrigation Summary** is a quick look at the most important factors of irrigation systems, climate, soils, crop water use and related topics which all irrigators should know. How much water does my system apply, how much does rainfall contribute, how much water do crops use each week?

Following the **Irrigation Summary** are individual chapters with more detailed discussions of each topic and some additional ones including:

- Crop Water Use
- Weather
- Soils
- Irrigation System Performance
- Irrigation Scheduling Options
- Critical Periods and Crop Stress Indicators
- Dry Year Drought Strategies
- Wet Year Opportunities
- Flood Irrigation
- Water Rights, Water Regulation and the Future
- Irrigation History

Irrigation applications and crop water use are discussed throughout this report in terms of **inches of water** since this is the language most irrigators speak. Inches of stored soil moisture, soil water holding capacity, rainfall, and irrigation are compared with inches of crop water use.

How Much Effort Should Irrigators Make to Improve Their Irrigation Practices?
Farmers and ranchers have lots of tasks to do and irrigation is only one of them. Irrigators should at least know the basics listed in the Irrigation Summary on page 2. During 7 years of monitoring individual sprinkler irrigators in the Blackfoot drainage, it's obvious that most irrigators are already doing a good job. It is therefore difficult to encourage big upgrades to soil moisture sensors, checkbook scheduling or other methods that require substantial time and money when they are unlikely to result in corresponding improvements. Over-irrigation is often cited as a major concern but no cases of over-irrigation have been observed during this program with sprinkler irrigators. Many folks do not over-irrigate since they simply run out of water. Others have irrigation systems designed when crop water use was lower (10-30 years ago) and simply cannot put on more water than crops now use in most years. Most local sprinkler irrigators apply less water than their crops could use (deficit irrigation), could make improvements in the timing of irrigations and could actually increase water use.

IRRIGATION SUMMARY

DAILY CROP WATER USE

Local hay crops use slightly less than 1/10th of an inch of water per day at the start and end of the growing season and as much as 3/10th of an inch per day at peak growth. Alfalfa use is slightly higher.

Local hay crops use about ½ inch of water per week at the start and end of the growing season and as much as 2 inches at the peak of growth.

Pasture crops use slightly less water than hay crops since a portion of the crops is removed (eaten).

Annual crops and new seedings of course use less as they emerge and begin early growth, but catch up to mature crops within the first month and most annual crops have peak water use slightly higher than hay crops.

GROWING SEASON POTENTIAL CROP WATER USE – MAY 1 TO SEPTEMBER 30

Average potential hay water use is about 25 inches for the entire growing season and about 12 inches prior to first cutting. This is about the average amount local sprinkler irrigators apply to hay before cutting (however 20-35% of this is lost due to the efficiency of the system and is hopefully made up by rainfall and stored soil moisture). Average potential water use for annual crops is about 15 inches. Not only is this amount lower than hay and pasture crops but **water use is finished before streamflows become a concern.**

The range of values represent dry-wet years	Hay Crops	Pasture	Annual Crops	Rainfall	Effective Rainfall
Growing Season May 1[1]- Sept 30	**19-30 in.**	**18-25 in.**	**13-18 in.**	**2-8 in.**	**1-4 in.**
Pre-Cutting May 1[1] - July 10	**10-15 in.**	**10-14 in.**	**8-16 in.**	**2-6 in.**	**1-3 in.**
Blackfoot Program Participant Average and (Range)	**12 in. (5-23)**	**12 in. (5-23)**	**8 in. (5-18)**		

[1]May 1 is used throughout this report as the start of the growing season however, climate change has pushed the start back to April 1 in recent years which adds another inch of water use for most crops.

RAINFALL

Blackfoot croplands average about 7 inches of rainfall in the growing season (May-Sept) but only about 3 inches is effective (enters the soil and contributes to crop water use). The remainder evaporates quickly from crop and soil surfaces. Some years receive almost no effective rainfall. Rainfall is usually slightly higher in the upper drainage but can vary widely in any one storm or year.

SOILS

Blackfoot croplands include a full range of soils from rocky sand to rock-free silt and clay as well as wet and organic soils. These surface soils hold 1.0-2.0 inches of water per foot. Subsoils hold 0.5 to 2 inches per foot. Local soils start the growing season (May 1) with about 3 inches of water in an average year due to snowmelt and spring rains (half of their water holding capacity). In wet years the best soils may have almost 6 inches and in dry years almost none in the poorest soils. Soils used to have more water at the start of the growing season but snows are melting earlier leaving a longer period for soils to dry out before crops start growth.

IRRIGATION

All program participants applied less than the potential crop water use (deficit irrigation) as opposed to over-irrigating. The best irrigators applied close to the full potential water use prior to the first cutting or annual crop harvest and then reduced or stopped irrigation the rest of the season.

GENERALIZED SUMMARY OF SPRINKLER IRRIGATION ON HAY IN THE BLACKFOOT DRAINAGE THROUGHOUT THE GROWING SEASON
(all values are inches of water)

AVERAGE POTENTIAL CROP WATER USE VS AVERAGE WATER AVAILABLE

Average Potential Hay Water Use = 25 inches

Average water available = 3 (effective rain) + 3 soil storage + 12 irrigation = 18 inches total

Average Potential Hay Water Use **by 1st Cutting** = 13 inches

Average water available **by 1st Cutting** = 2 (effective rain) + 3 soil storage + 10 irrigation = 15 inches

Here's what irrigators face on the average:

BF CROPS CAN USE UP TO 25 INCHES OF WATER IN AN AVERAGE YEAR

19 - 30 inches for hay crops (entire growing season)

10 - 15 inches for hay crops (by 1st cutting - June 10)

½ to 2 inches per week depending on crop and weather conditions

BF CROPLANDS GET 3-4 INCHES OF EFFECTIVE RAIN IN AN AVERAGE YEAR

2 - 10 Inches – Varies by location and year

1 - 4 Inches - Effective Rain (the amount that actually enters the soil and contributes to crop production)

1 - 3 Inches - Effective rain that falls by 1st cutting (June 10)

BF SOILS STORE ABOUT 3 INCHES OF WATER IN AN AVERAGE YEAR

2 - 6 Inches – can be stored in the 3-foot hay root zone of local soils (0.5 TO 2.0 INCHES PER FOOT)

1 - 5 Inches – Actual average amount of water stored and available May 1

BF IRRIGATORS APPLY ABOUT 12 INCHES OF WATER IN AN AVERAGE YEAR

5 - 23 Inches – Average amount applied by local irrigators
(This is half the potential crop water use but most irrigators have limited water or just irrigate for the first cutting.)

5 - 15 Inches – Amount applied by 1st cutting

THE BLACKFOOT DRAINAGE IRRIGATION SEASON IN BRIEF

This is a summary of general activities and recommendations for the whole season (more detail in the irrigation guide).

APRIL – GET READY AND PLAN YOUR IRRIGATION STRATEGY!

- Get your irrigation system ready – perform maintenance and test system.
- Evaluate soil moisture conditions and weather predictions. Start irrigation if needed. Plan for drought?

MAY – CHECK SOIL MOISTURE & BE READY FOR UNUSUAL HEAT OR COLD!

- Check soil moisture content of root zone at start of growing season and fill up the soil to its water holding capacity during early irrigations (2-4 inches).
- Watch for dry soil conditions, especially with new plantings and apply water to ensure good germination and emergence.
- Irrigate deeply at least once early in the season to promote deep root growth.
- Apply 2-5 inches of irrigation to hay and pasture crops in May depending on weather. Apply 0-2 inches to spring grains and new plantings as needed based on weather and growth. Apply extra water to fill up the soil (2-4 in).

JUNE – THIS IS THE TIME TO MAKE YOUR BIGGEST EFFORT SO POUR IT ON!

- Apply 1 - 2 ½ inches of irrigation per week in June to mature crops totaling 5-8 inches depending on weather.
- Consider irrigating deeply to fill up soil root zone and promote deep root growth.
- Be sure small grains are irrigated well during their critical periods of boot, bloom and early heading.

JULY – POUR IT ON UNTIL HARVEST AND RETURN QUICKLY

- Apply 1 - 2 ½ inches of irrigation per week in July to mature crops totaling 5-10 inches depending on weather.
- Cutting is a critical stress period for hay crops, especially alfalfa so irrigate deeply to fill up the root zone before cutting then get back across the field quickly after cutting.

Crop water use declines when hay is cut so this is a good opportunity to fill up the soil again. Irrigate at least once after cutting. Small grains harvested for seed are usually irrigated up to the milk to soft dough stage but be sure soil moisture remains to prevent kernel shriveling. Small grains for forage are often harvested earlier when plants are less dry and seeds soft.

AUGUST- KEEP IRRIGATING SMALL GRAINS UNTIL DESIRED MATURITY, BE DROUGHT AWARE!

- Apply 1 - 2 inches of irrigation per week in August to hay and pasture crops for full production depending on weather. Irrigate new plantings as needed.
- Many folks irrigate for pasture following their one hay cutting. Irrigate according to how much pasture you seek and with consideration for other water needs in the drainage, especially in drought years.
- Reduce river withdrawals by rotating systems and reducing the amount of irrigation at one time. Stop irrigating if you can to preserve streamflows.

SEPTEMBER – APPLY AS NEEDED/AVAILABLE & GET READY FOR SPRING!

- Apply ½ - 1 ½ inches of irrigation per week in September to hay and pasture crops for full production depending on weather. Irrigate new plantings as needed. Prepare the system for winter and an early start next spring. Stop irrigating if you can to preserve streamflows. Review the year's irrigation and plan ahead for next year with contingency plans for drought conditions or (less often) for abundant water.

2.0 CROP WATER USE

Crop Water Use as discussed in this report includes rainfall/irrigation water that evaporates from soil and crop surfaces (**evaporation**) and rainfall/irrigation water that is taken up by roots and returned to the atmosphere through plant leaves (**transpiration**). Together we call them ET or potential evapotranspiration. ET increases with temperature, wind and crop development and decreases with humidity. Plants do not have tiny pumps in their roots. The driving force behind plant transpiration is the difference in vapor pressure between the soil atmosphere and the above-ground atmosphere. The plant can be viewed as a straw connecting these two areas of different pressures and allowing flow between the two much like connecting a wire between the contacts of a battery. Water or electrons flow from the area of lots to the area of less.

Blackfoot drainage croplands only receive about half as much moisture in rain and snow as the potential ET – which is why we have to make up the rest with irrigation (**Table 1**).

Table 1 lists potential crop water use across the drainage for common crops. The growing season totals are important to those producing pasture, second cutting or who otherwise irrigate for the entire growing season. However, many local irrigators concentrate their efforts prior to first hay cutting or grain harvest. A more relaxed schedule is often followed after cutting that provides only a fraction of the potential crop water use. ET totals up through the first week of July are listed as Pre-cutting ET for those who want to concentrate efforts during this period. **Table 1** also lists rainfall for these three periods. Effective rainfall is that portion of the total that does not evaporate quickly from soil and plant surfaces and actually contributes to crop growth.

Table 1. Range of Blackfoot Drainage Potential Crop Water Use and Rainfall for the Entire Growing Season and up to July 15, 1st Cutting for Hay (inches of water). The range of values represents wet and dry years.

	Hay Crops	Pasture	Spring Grains	Rainfall	Effective Rainfall
Growing Season May 1[1]- Sept 30	19-30 in.	18-25, in.	13-16 in.	2-8 in.	1-4 in.
Pre-Cutting May 1[1] - July 15	10-15 in.	10-14 in,	8-16 in.	2-6 in.	1-3 in.
Blackfoot Program Participant Average and (Range)	12 in. (5-23)	12 in. (5-23)	7 in. (5-9)		

[1]May 1 is used throughout this report as the start of the growing season however, climate change has pushed the start back to April 1 in recent years, which adds another inch of water use.

Figure 1 illustrates the long-term average weekly crop water use for hay, which totals 22 inches for the year. Weekly crop water use is also shown for 2013 a very hot and dry year and 2011 in a cool year where it snowed into June.

Figure 1. Weekly Hay Crop Water Use in Average Wet and Dry Years.
Weekly water use ranges from less than ½ inch to almost 2 inches per week. Annual water use ranges from 19 inches in 2011 to 29 inches in 2015 and 2017.

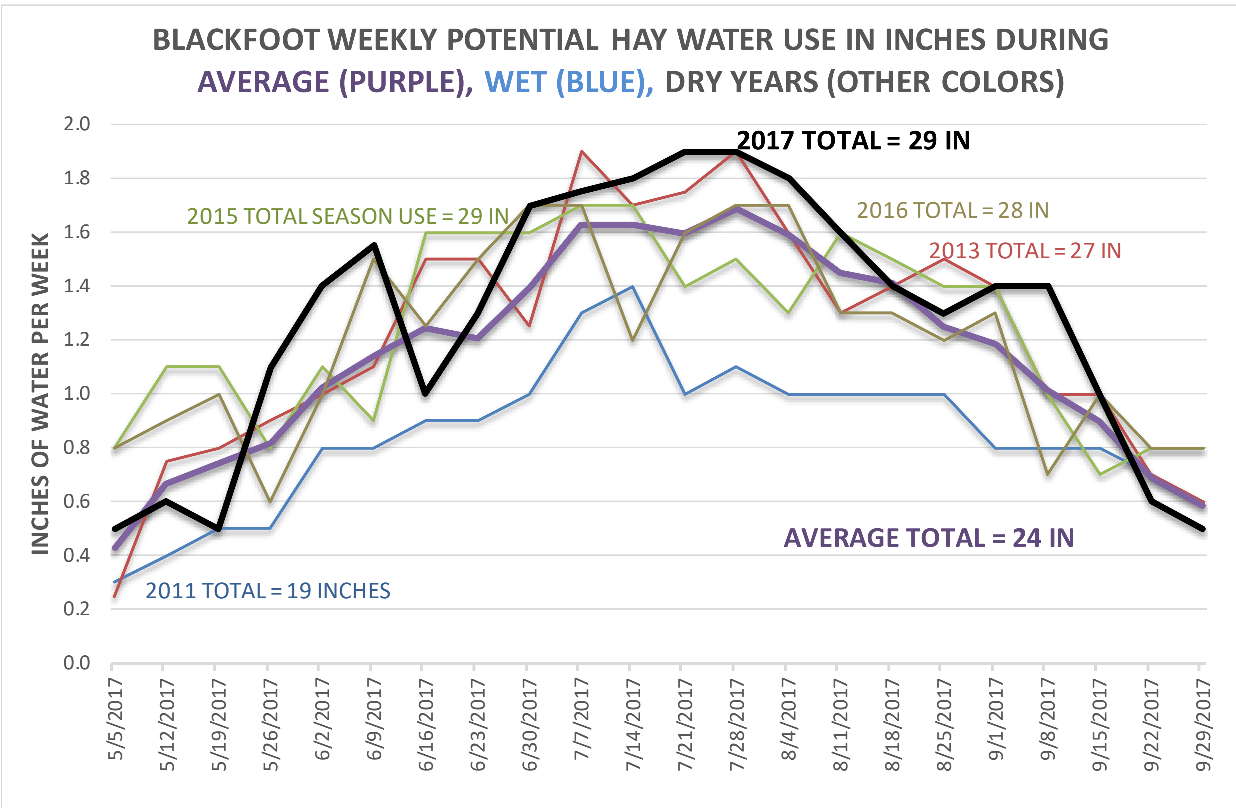


Table 2 lists potential crop water use for common crops in the Blackfoot drainage. You can use monthly and weekly values to get a general idea of how much water to apply. Use the daily values to estimate how long irrigations applications will last. For example, if you apply 1 inch to hay in an average June, your daily use is about 0.20 inches so 1 divided by 0.20 is 5 days. In hot weather 1 inch lasts only 3 days. Remember that to build up soil moisture you must apply more than the crop water use and also account for evaporation loss (efficiency). Extreme conditions (very hot and windy) can result in even higher crop water use. **In the main growing season, hay crops use about 1 inch a week during cool periods and 1.5 - 2 inches during hot weeks. These are general figures you should commit to memory and try to match with irrigation.**

Crop Water Use and Rainfall in the Blackfoot River Drainage.

CROP WATER USE IN INCHES - ALFALFA, MIXED GRASS HAY, LAWN

	May	June	July	Aug	Sept	Season Total
Monthly Average	3.50	6.00	6.50	5.50	3.50	25.00
Weekly Average	0.75	1.25	1.50	1.25	0.75	
Hot, Windy Week	1.25	2.25	2.50	2.25	1.25	
Cool Week	0.30	0.75	0.90	0.75	0.30	
Daily Average	0.14	0.20	0.25	0.20	0.14	
Hot, Windy Day	0.20	0.30	0.35	0.30	0.20	
Cool Day	0.05	0.10	0.13	0.10	0.05	
Average Rainfall	2.00	2.00	1.50	1.00	1.00	7.50
Average Effective Rainfall	1.25	1.25	0.50	0	0	3.00

CROP WATER USE IN INCHES – PASTURE

	May	June	July	Aug	Sept	Season Total
Monthly Average	2.25	4.25	5.00	4.25	2.25	18.00
Weekly Average	0.50	1.10	1.30	1.10	0.50	
Hot, Windy Week	1.10	1.90	2.20	2.00	1.10	
Cool Week	0.20	0.50	0.80	0.50	0.20	
Daily Average	0.07	0.16	0.19	0.16	0.07	
Hot, Windy Day	0.15	0.25	0.30	0.25	0.15	
Cool Day	0.04	0.08	0.11	0.08	0.04	

CROP WATER USE IN INCHES – SMALL GRAINS[1]

	May	June	July	Aug	Sept	Season Total
Monthly Average	2.00	5.00	6.00	2.00	0.00	15.00
Weekly Average	0.50	1.25	1.50	0.50	0.00	
Hot, Windy Week	0.90	2.25	2.75	0.90	0.00	
Cool Week	0.20	0.70	0.90	0.20	0.00	
Daily Average	0.06	0.18	0.21	0.06	0.00	
Hot, Windy Day	0.13	0.32	0.36	0.13	0.00	
Cool Day	0.03	0.10	0.13	0.03	0.00	

[1]Assumes a May 1 planting date and a mid-August harvest, adjust for other dates.

It is important to remember that these ***potential crop water use*** figures are for a dense, robust stand that is well-irrigated, well-fertilized and mostly disease/insect free. Crops not in such good condition use less water. Actual crop water use across the drainage varies dramatically due to limitations in water, fertilizer, stand quality, micro-climate, management style, and many other factors. Working with individual irrigators across the drainage has allowed us to re-calibrate regional crop water use information to the Blackfoot area. It also has provided accurate information for these irrigators at specific fields throughout the season and a record of using water efficiently.

One of the most significant results of this program is that it continues to reveal that over-irrigation is not common among sprinkler irrigators. Many sprinkler irrigators in the drainage apply only 50-75% of the *potential* crop water use when you consider the entire irrigation season. However, if you just consider the period before cutting, many irrigators participating in this program apply 75-100% of the *potential* crop water demand. This suggests irrigators are smartly concentrating on their first cutting which is where the most production is and the biggest bang for the buck. They then may irrigate in a more relaxed manner to produce pasture for the remainder of the season or cease irrigating due to water availability, water rights, streamflows or other reasons.

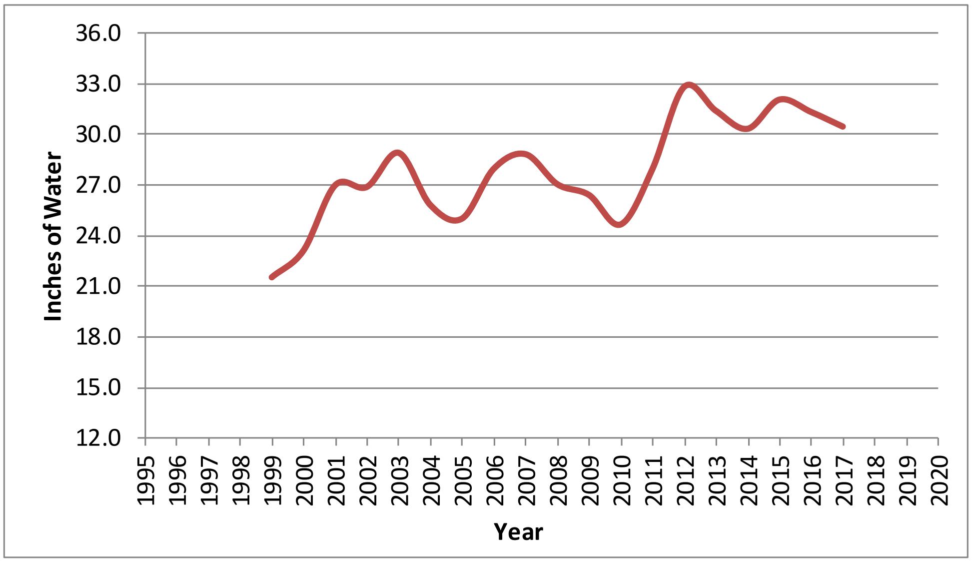
Almost all sprinkler irrigators who participated in this program applied less than the actual crop water use, which is called ***deficit irrigation***, and this is the common practice among all local irrigators***.*** This helps conserve water for other purposes, like fisheries, stream health, and recreationists. It also protects water quality by preventing fertilizers, herbicides or other chemicals from reaching ground or surface waters.

CROP WATER USE TRENDS

Crop water use in the Blackfoot drainage has increased dramatically in recent time. The growing season is longer, hotter and perhaps windier. You have to go back to cold, rainy 2011 to get a below average year. Figure 1 includes crop water use comparing recent warm and cool years with the average.

This trend of increasing crop water use is also reflected in the Deer Lodge Agrimet weather station data. Figure 2 illustrates annual hay water use since the station was installed in 1998. Hay water use in 2017 was 30% higher than in 1999 (the first full year of data). Annual hay use in 2012-2017 was all above average. This has serious implications for the future of local irrigation. Water rights adjudication and low flow restrictions on the Blackfoot River prevent future irrigation increases despite this apparent potential need for future adjustments. The only option for local irrigators will be to increase water use efficiency through irrigation management practices and crop selection. Drought management will likely be a routine instead of a rarity. NRCS irrigation guides suggest a similar increase in crop water use over the past three decades. The 1986 NRCS irrigation guide lists average crop water use for alfalfa and grass hay at about 15 inches in the Blackfoot drainage. Today that figure is about 25 inches – a dramatic increase.

Figure 2. Annual Crop Water Use for Hay from the Deer Lodge Agrimet Weather Station showing a 30% increase from 1998 to 2017.



2017	30.5
2016	31.4
2015	32.1
2014	30.4
2013	31.4
2012	32.9
2011	28.0
2010	24.7
2009	26.4
2008	27.1
2007	28.9
2006	28.0
2005	25.0
2004	25.8
2003	28.9
2002	26.9
2001	27.0
2000	23.1
1999	21.6
AVERAGE	27.8

3.0 WEATHER

It's always dangerous to talk about the weather to local experts (irrigators) but here are a few observations to compare with your own experience. While relative humidity, wind and air pressure are also important irrigation factors, rainfall is the center of attention unless you are actually calculating crop water use.

Rainfall

Blackfoot drainage croplands receive 2-10 inches of rainfall between May 1 and September 30 depending on the year and location. There tends to be a slight increase with elevation. However, during any individual storm or from year-to-year, these effects can be reversed with Potomac having MORE rainfall than Helmville. Then there are events like the 2011 cloudburst in Douglas Creek that left 2 inches in a few hours.

Net Rainfall

Not all the rain that falls is used by the crop. Net rainfall is the amount that does actually enter crop roots and contribute to yield. The total rainfall is reduced by:

- **Interception** – Crop leaves intercept and evaporate rain before it reaches the soil. I have measured as much as ½ inch of interception (dense alfalfa).
- **Soil Surface Evaporation** – Some of the water that reaches the soil simply evaporates from the surface before infiltrating. This varies widely depending on soil temperature, color, surface mulch/vegetation cover and other factors.
- **Runoff** – If rainfall intensity exceeds the soils ability to absorb it (infiltration) then runoff may occur and that water is lost to crop production.
- **Deep Percolation** – If rainfall amounts exceed the water holding capacity of the crop root zone, water may move too deeply in the soil for the crop to reach. This is uncommon in the Blackfoot drainage since rainfall amounts are relatively small

compared with root zone capacities. This may occur when storms are large and soils are already full, especially on sandy and rocky soils.

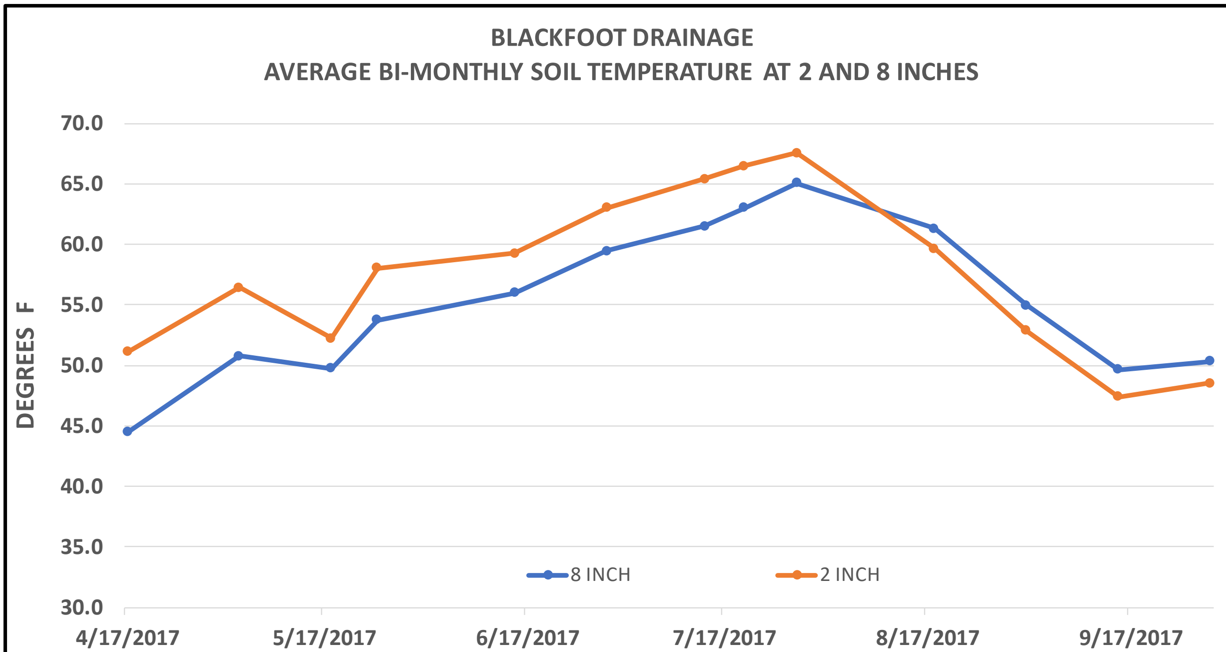
While 2-10 inches of rain may fall on Blackfoot croplands during the growing season (May 1-September 30), only 1-5 of it is effective and contributes to soil moisture.

How Important Is Rain to Local Crop Production?
You can see that if it takes 10-15 inches of water to produce a first cutting or 20-25 to produce a full season of hay, 1-5 inches of effective rainfall is a small contribution. This is why we irrigate. Rainy periods do however reduce crop water use by higher humidity and cooler temperatures.

Soil Temperatures
In 2017 I conducted a soil temperature survey to evaluate changes across the drainage and the potential for expanded crop choices. Agricultural factors related to soil temperature include growing season start and end, microbial activity, nutrient availability, crop choices and others.

Temperatures were measured at 2 and 4 inches depth at sites from the Potomac to the Helmville area. Average temperatures across the drainage are presented below.

2017 Blackfoot Drainage Average Soil Temperatures at 2 and 8 inches



	4/17/2017	5/4/2017	5/18/2017	5/25/2017	6/15/2017	6/29/2017	7/14/2017	7/20/2017	7/28/2017	8/18/2017	9/1/2017	9/15/2017	9/29/2017
8 INCH	44.5	50.8	49.8	53.7	56.0	59.5	61.5	63.0	65.1	61.3	55.0	49.7	50.3
2 INCH	51.1	56.4	52.2	58.0	59.3	63.0	65.4	66.5	67.5	59.6	52.9	47.4	48.5

Here are a few observations from these soil temperature measurements:

- Soil temperatures started out mostly in the 40s in April and peaked in the 60s and 70s in August.

- Until August, soil temperatures at 2 inches were higher than those at 8 inches then the pattern reversed for the rest of the season.

- Soil temperatures were as much as 20 degrees warmer on some sites than others (sandy, rocky soils).

- Applying 1 inch of water with a pivot immediately lowered soil temperature 1-3 degrees.

- Surface soil temperatures in the Blackfoot drainage are warm enough (>65F) to include warm season crop species in cover crop, hay and pasture mixes.

- Although elevations ranged from 3700 feet near Potomac to 4445 feet near Helmville (745 feet difference), there was not the expected decrease in soil temperature with increasing elevation. Elevation had less effect than soil type, landscape position or geographic area. Potomac had the lowest elevation **and** coolest soil temperatures. It is a cold air sink and also has a cool, shallow groundwater table under the entire lower valley area. Soil temperature is more likely related to the overall size of each sub-drainage, the amount of cold air drainage above, the amount of south aspects nearby and other factors.

- Soil type had more of an effect on temperature than location or elevation with sandy and rocky soils, usually 5-10 degrees warmer than silty and clayey soils. Sandy and rocky soils hold less water which has a very high specific heat and takes a lot of solar radiation to warm.

- Landscape position had more of an effect on temperature than elevation with sites on the valley bottoms (floodplain and first terrace), usually 1-3 degrees cooler than hillside or upper terrace levels.

A concern has been whether to *"fine-tune"* irrigation scheduling recommendations for each geographic area of the Blackfoot drainage. I decided over time that crop water use did not vary enough in a consistent manner to make multiple recommendations worth the effort. It seemed that management, soils, landscape position and other factors had greater influence on crop water use. These soil temperature measurements seem to support providing a single crop water use estimate for the entire drainage.

Your Own Weather Station

Weather stations customized for irrigation are becoming less expensive and more common. They may eventually replace AGRIMET and similar cooperative programs. These new stations not only record weather parameters but also calculate crop water use on a daily basis. It is likely they will become standard equipment on pivots in the near future.

4.0 SOILS AND IRRIGATION

Soil is the storage system for crop water and the protector of groundwater. Under ideal conditions, irrigation water:

1. passes into soil without runoff and erosion,
2. is held within the crop root zone until used by plants, and
3. does not carry undesirable substances through the soil to ground and surface waters.

The soil properties most important to irrigation include soil texture, infiltration rate and water holding capacity. These properties affect how far water and crop roots penetrate into the soil.

Soil Texture

Soil texture is the amount of sand, silt and clay particles and is described in terms like *sandy loam, silty clay loam* and *loam*. Soil texture also is modified by rock content and described in terms like *gravelly silt loam* and *very gravelly sandy loam*. You can easily tell sand because when wet it feels gritty. You can tell clay because when moist it feels sticky and holds together well like silly putty. You can tell silt because it feels smooth like flour and doesn't hold together well. Appendix F describes how to determine your soil texture.

Rocky and Sandy Soil Formed in Stream Deposits

Sandy, Rock-free Soil Formed in Lake Deposits

Clay Soil with Shallow Water Table and Capillary Action

Infiltration Rate, Runoff and Erosion

Soil infiltration rates determine the ability of water to penetrate the soil surface. When the infiltration rate is exceeded, runoff and erosion occur which may transport sediment to surface waters. Most modern irrigation systems are designed so they do not exceed soil runoff under normal operation. However, slowing pivot speed or increasing the time for each set with wheel or hand lines can cause runoff. Runoff may also occur on steeper slopes with clay soils. Irrigators simply need to pay attention and reduce water application if runoff occurs. Runoff can be detected by direct observation or by the presence of rills, gullies or sediment deposits. Runoff from Blackfoot drainage sprinkler irrigated fields usually only occurs in clay-rich soils or in compacted wheel tracks.

Water holding capacity

Water holding capacity (WHC) is one of the most important functions of agricultural soils. Water is held in soils by surface tension. Coarse-textured soils (sandy) have less surface area and hold less water than fine-textured soils (silty and clayey). Rocks hold little or no water so water holding capacity is directly reduced by the amount of rock. Some of the water held by fine-textured soils is held so tightly that it cannot be extracted by plants so the term Available Water Holding Capacity (AWHC) is commonly used. For most Blackfoot Drainage agricultural soils, water holding capacity and *available water holding capacity* are not very different and the distinction is not emphasized here. The table below lists water holding capacity for soil texture groups. These values must be lowered to account for rock content (30% rocks means 30% less WHC).

Available Water Holding Capacity of Soil Groups

Soil Texture Group	Available Water Holding Capacity (AWHC)[1] Inches of water held per foot of soil
Very Coarse – fine sand, loamy fine sand	**1.0** (0.5-1.5)
Coarse – sandy loam, fine sandy loam	**1.5** (1.0-1.75)
Medium – loam, silt loam, sandy clay loam	**1.75** (1.5-2.0)
Fine – Clay, clay loam, silty clay loam	**2.0** (1.5-2.5)

[1]Reduce by the percentage rock content (coarse soil with 50% rock = 1.5 x .5 = .75 inches per foot).

Soil Organic Matter Increases Water Holding Capacity and Infiltration

The water holding capacities listed above by soil texture can be increased significantly by increasing organic matter content. Infiltration is also enhanced by adding organic matter and runoff is decreased by maintaining crop residue at the surface.

The figure on the following page illustrates soil textures and water holding capacities. Most local agricultural soils have water holding capacities of 1-2 inches per foot. Hay and pasture crops take most of their water from the surface three feet of soil called the ***managed root zone***. Most local agricultural soils will hold 3-4 inches in this zone. Very rocky and sandy soils may hold as little as 2 inches and rock-free clay-rich soils as much as 6 inches.

EXAMPLE SOIL TEXTURES AND WATER HOLDING CAPACITIES

Typical Soil with MEDIUM textures = 4 INCHES
(Loam, Sandy loam, Silt loam)

DEPTH	SOIL TEXTURE	WATER HOLDING CAPACITY
0-1 FT	LOAM	1.50 INCHES
1-2 FT	SANDY LOAM	1.25 INCHES
2-3 FT	GRAVELLY SANDY LOAM	1.25 INCHES
	TOTAL	**4.00 INCHES**

Hay and pasture crops managed root zone = 3 feet = 3.75 inches of water holding capacity
Annual grain crop managed root zone = 2 feet = 2.75 inches of water holding capacity

Typical Soil with COARSE textures = 2 INCHES
(Sand, Loamy sand, Sandy loam, and rocks)

DEPTH	SOIL TEXTURE	WATER HOLDING CAPACITY
0-1 FT	GRAVELLY LOAM	1.00 INCHES
1-2 FT	VERY GRAVELLY SANDY LOAM	0.75 INCHES
2-3 FT	VERY GRAVELLY SAND	0.25 INCHES
	TOTAL	**2.00 INCHES**

Hay and pasture crops managed root zone = 3 feet = 2.0 inches of water holding capacity
Annual grain crop managed root zone = 2 feet = 1.75 inches of water holding capacity

Typical Soil with FINE textures = 6.0 INCHES
(Clay, Clay loam, Silty clay loam)

DEPTH	SOIL TEXTURE	WATER HOLDING CAPACITY
0-1 FT	SILTY CLAY LOAM	2.0 INCHES
1-2 FT	CLAY LOAM	2.0 INCHES
2-3 FT	CLAY	2.0 INCHES
	TOTAL	**6.0 INCHES**

Hay and pasture crops managed root zone = 3 feet = 6.0 inches of water holding capacity
Annual grain crop managed root zone = 2 feet = 3.0 inches of water holding capacity

Appendix F provides guides for determining soil texture, water holding capacity and soil moisture content at individual fields.

Field Capacity

When irrigation is applied at a high rate, all the soil pores become filled with water and this condition is called **saturation**. Water then moves downward draining out of the larger soil pores due to gravity. The water that remains is mostly held in the smaller soil pores and the soil is said to be at its full water holding capacity or ***field capacity***.

Rooting Depth

Most crops extract most water and nutrients from the surface 1-3 feet of soil but some can have much deeper root systems. Rooting depth increases during initial crop stages and irrigators must pay attention to the zone roots are actually using at the time.

Although alfalfa can root to 10 feet or more, the standard managed root zone is 3 feet. The managed root zone for small grains is 2 feet. In wet years, lower soil layers may provide significant amounts of water and help boost yield.

Remember that roots do not go looking for water through dry soil, they grow in moist soil and stop at the dry boundary. Neither do roots exert a “sucking” force that draws water to them. Water is obtained by roots and root hairs growing to the water location. You encourage roots to grow deep by watering deep.

Many irrigators wind up using less of the root zone than they expect due to their irrigation practices. If the soil is allowed to substantially dry out between irrigations, small new applications will not penetrate far into the soil. For instance, a 1-inch pivot application will penetrate less than 6 inches in a fine textured soil or 12 inches in a coarse soil. If you do this repeatedly you train your plants to only root that deep. This requires them to get all their water and nutrients from this limited zone. It is important to irrigate deeply on a regular basis to encourage deep root growth.

Irrigation systems that apply more than the managed root zone can hold do not necessarily waste this extra water. Deeper soil layers can also fill to their water holding capacities and some roots are likely to penetrate below the managed root zone and utilize this water, though at a slower rate.

Management Allowed Depletion (MAD) – 50% of Water Holding Capacity

MAD is how low you should deplete soil moisture to achieve maximum production. The MAD for Blackfoot area crops (alfalfa, grass, grains) is 50% of the field capacity. MAD is an important concept for high value crops in high production areas where water is available and irrigators attempt to completely satisfy crop water demand. However, in the Blackfoot drainage many irrigators practice deficit irrigation on lower value crops and soil moisture levels are generally not maintained above 50% of the field capacity for the entire growing season. However, the best producers do attempt to keep soil moisture levels high for the main irrigation season in June. Most hay producers only take one cutting and then irrigate less aggressively. Grain producers stop irrigating after harvest. Those irrigators keeping their soil moisture levels above the MAD level show significantly better harvests.

Soil Survey Maps and Field Verification

Soil surveys provide a general idea of the kinds of soils that occur across the landscape but often are not accurate at specific sites. Soil properties related to irrigation can be obtained from local soil surveys but should be verified in the field. In many cases multiple soils are present under individual irrigation systems and management must be adjusted to the most limiting soil or the system managed to accommodate variations.

5.0 IRRIGATION SYSTEM PERFORMANCE

The first thing you need to know is how much water your system applies and how uniformly it is applied across the field. The amount of water applied is determined by the application rate and time irrigated. The application efficiency is determined by the type of system and weather factors.

Application Rates

Most sprinkler irrigation systems were designed to apply water at a rate that will not cause overland flow and surface erosion. If you routinely observe runoff you may consider changing sprinkler packages, pressures or speed to reduce runoff. Runoff problems are common when hay fields are converted to annual crops since the soil surface is no longer protected by permanent vegetation.

Application Amounts

The total amount of water applied is determined by the application rate and the length of time irrigated. Modern pivots have control systems that let you set the application rate and total amount applied per irrigation. Older variable-speed pivots use a chart listing application based on speed. Single-speed pivots are designed to apply a specific amount so to apply more you simply keep on going around. Wheel-line and hand-line systems are designed to apply at a specific amount in a standard 11-hour period or "set." They may apply this amount all at once when moved to each successive mainline riser across a field or more often are designed to apply one-half at a time connected to every other riser.

You can measure your application using one rain gauge but first set out several within a 10 foot area to determine the best spot for your one gauge. Watch as your system passes to be sure you are not right under a sprinkler where drip will overfill your gauge.

Our experience testing pivot irrigation systems is that 25% or so do not apply the amount indicated by the control system or chart. The most common reasons are worn sprinklers and incorrect pressures. However, we have tested several new pivots where the control computer was set up with incorrect information such as pivot length. These systems were applying much less water than the irrigator thought. Luckily we happened to test these systems and identify the problem or the irrigator may have trusted his controller for who knows how long.

Irrigators can check their application amount simply and quickly with rain gauges. If there is an accurate flow meter available you can easily calculate the application amount based on the acreage. **Appendix E** describes how to determine application amounts by several methods.

Most pivot irrigators in the Blackfoot drainage apply about 1 inch at a time but those with concerns over ruts apply about ½ inch at a time. Remember that each time you irrigate you lose water to immediate evaporation and applying less at a time will require more water overall. A pivot applying 1 inch will lose about 0.1 inch to evaporation in May, 0.15 inch in June and 0.2 inch in July (more if unusually hot or windy). Most wheel-line and hand-line irrigators apply 2-4 inches at a time and again, those that irrigate on every other set lose more overall since the full application occurs in two events as you go across the field with ½ and come back with the other ½.

Application Uniformity

Better application uniformity means higher yields because all parts of the field receive the right amount of water. Pivot systems provide the best uniformity with most spots getting almost the same amount. Wheel and hand-line systems are much less uniform (if the target is 3 inches – some spots get less than 2 while others more than 4).

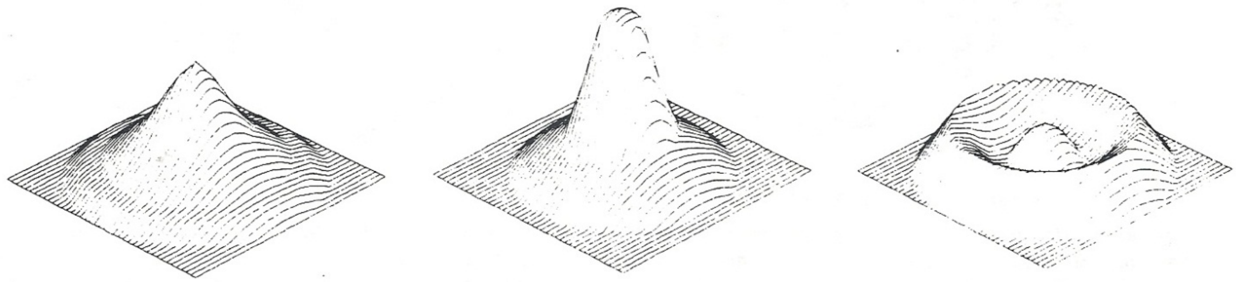
Sometimes you can plainly see uniformity problems.

20 rain gauge uniformity test

Uniformity is most affected by nozzle condition, especially plugging. Those with plugging from sand, debris, moss or other material must be checked regularly or appropriate filters installed. The next most common problem with uniformity is pressure below minimum nozzle requirements. Besides equipment, wind can also dramatically affect uniformity. About 25% of the systems tested in the Blackfoot drainage showed poor uniformity and the Challenge sponsored a nozzle package cost-share program to correct this for many systems. You can evaluate uniformity yourself by setting out 10-30 rain gauges and letting the system pass over them. You can also use any straight-sided container (such as tin cans) and a tape measure. **Appendix G** describes how to evaluate uniformity.

Uniformity is Affected by Pressure and System Type

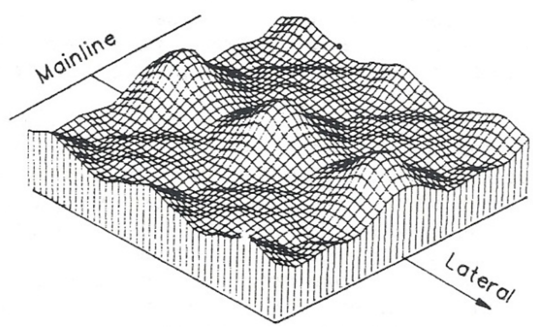
The first figure below illustrates proper sprinkler pressure which results in an even cone pattern decreasing evenly away from each sprinkler. Too high a pressure over-applies right around the sprinkler. Low pressure concentrates water in a doughnut pattern.

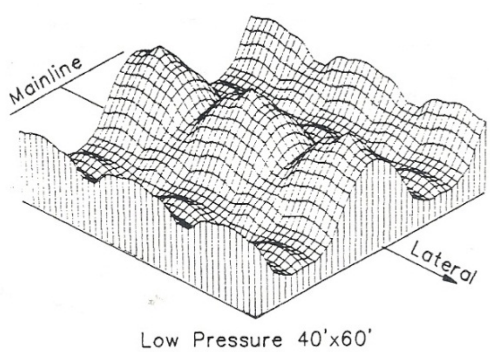


PROPER PRESSURE TOO HIGH TOO LOW

WHEEL-LINE / HAND-LINE UNIFORMITY ACROSS THE FIELD

Wheel-line and hand-line systems apply water much less uniformly than pivots. The first figure below illustrates the amount of water applied across a field after multiple sets. Each 'mountain' is where a sprinkler sat and the valleys between are the areas between sprinklers. The mountains are higher near the mainline due to higher pressure. When pressure is too low, the mountains and valleys become exaggerated with most of the water falling in doughnut patterns around each sprinkler and not reaching out far enough. This leaves more area under-irrigated. By comparison, a pivot produces a figure that is nearly flat, without the peaks and valleys of over- and under- irrigation.





Proper pressure 40' x 60' Spacing

Application Efficiency

The percentage of water that actually reaches the crop is called the application efficiency. Not all the water that comes out of the sprinkler actually gets to the crop. Some portion is always through evaporation. Systems apply too much in some spots and not enough in others. Dark crop and soil surfaces lose more than light ones. Dense tall crops intercept more than young annual crops. Some water moves below the root zone before it can be used and some runs off especially with flood irrigation or clay soils.

Commonly cited efficiencies are:

Center Pivots	80%
Wheel-lines	70%
Hand-lines	65%
Flood	40-50%

When setting a pivot for 1 inch, only 0.8 inch gets to the crop on average. When a wheel-line applies 3 inches, only 2.1 inches gets to the crop on average.

It's important to realize that the amount of water you apply that reaches the crop can vary widely, which is why you should always check your soil and not rely on application controls or charts. One inch of water applied on a cool day in May to a sandy soil with a new seeding will almost entirely enter the soil for crop use (95% efficient). One inch applied on a hot, windy day in July to a dense alfalfa stand may see only half an inch enter (50% efficient). This is why we encourage folks to apply as much water at one time as possible if they don't have infiltration, rutting or other concerns.

Gusty and erratic windy days can leave spots with little or no water reaching the soil. This is another reason to evaluate soil moisture in more than one spot. Careful management of your system, even flood systems, can result in higher efficiencies than those listed above.

6.0 IRRIGATION SCHEDULING – DECIDING WHEN AND HOW MUCH

The goal of ***Irrigation Scheduling*** is to apply the right amount of water at the right time to maximize production/profit and prevent unwanted effects. Some crops require very precise irrigation such as row crops to accommodate rapid growth periods, sugar beets to control sugar content, grapes to enhance flavor and alfalfa to boost protein content. However, in the short growing season of the Blackfoot drainage, irrigation is practiced in a more casual manner for the alfalfa hay, grass hay, pasture and annual crops grown locally. Most Blackfoot drainage irrigators practice *deficit irrigation* – applying less water than the potential crop water use. This is due to many reasons, most often because of junior water rights that end water access. Other reasons include personal goals and fields that have other limiting factors like fertility, weeds, pests, disease and sparse stands. Water is applied at the most critical periods when most growth occurs and is allowed to drop to low levels at other times.

This section describes the important components of irrigation scheduling and several methods for using it to improve crop production. Irrigation scheduling can get very complicated and time-consuming so these methods provide a range of options with increasing levels of effort and accuracy.

How Much Effort Should Irrigators Make to Improve Their Irrigation Scheduling?
Farmers and ranchers have lots to do and irrigation is only one task. During seven years of monitoring individual irrigators in the Blackfoot drainage, it's obvious that the

best irrigators are already doing a great job. It is difficult to encourage big upgrades to soil moisture sensors, checkbook scheduling or other methods that require substantial time and money when they are unlikely to result in corresponding improvements.

Irrigation technology is increasing rapidly and we are likely to see soil sensors, onsite weather stations with crop water use readouts and other systems to make it much easier to improve irrigation with **LESS** effort. I encourage those with an interest and the time/money to invest in sensors to do so but warn that they are not for everyone. The Blackfoot Challenge sponsored a sensor installation program prior to 2010 but none of those sensors are still in use. None were properly calibrated, few users understood what the readings meant and rodents destroyed most of the wiring. Only one sensor site per field was installed, which presents challenges for those with multiple contrasting soils and crops. For most good irrigators I suggest you wait for technology and products that are easy to install, use and that do not take up your valuable time. It may be that soon irrigation systems will apply water based on satellite imagery that considers the entire field including different crops and soils without onsite sensors.

Listed below are some options for irrigation scheduling that you can use now.

METHOD 1: LOW-TECH

Direct Observation – Just Dig It Up and Look at It Dude!

The simplest way to practice irrigation scheduling is to go out and observe your soil moisture content. **If the soil feels dry – irrigate!** It really is that simple. A shovel or soil probe is all you need. Blackfoot drainage crops all have a MAD level of 50% meaning that productivity goes down when the soil moisture level is below 50% of the available water holding capacity. When the soil is full, it looks moist – you can see shiny wet surfaces, it is soft and can be formed into a ball. When the soil is dry you cannot see shiny surfaces, it is hard unless very sandy, and cannot be formed into a ball. A guide for estimating soil moisture content is available from the NRCS and is listed in the "*Sources of Information*" section. Although folks sometimes have difficulty estimating the precise amount of water in the soil, they can usually tell if it is on the wet side (don't irrigate) or the dry side (irrigate). Even if too much water were occasionally applied, the soil moisture holding capacity acts as a buffer to prevent deep percolation below the root zone. Under ideal conditions, irrigation water would not penetrate very far below the managed root zone (3 feet for hay and pasture, 2 feet for annual crops). The advantage of this method is that it avoids the complexity that is a common part of scheduling and a barrier to participation such as weather observations, computer modeling of crop water use, complex soil moisture monitoring and detailed recordkeeping. It also allows quick multiple observations across a field instead of relying on one spot. Irrigators can actually see for themselves how quickly the soil dries after irrigation and can to detect application, uniformity or other problems.

Just Do What You're Told!

The Blackfoot Challenge provides weekly irrigation reports summarizing crop water use and irrigation suggestions. Customized local reports like these are only available to a small percentage of irrigators across the country. They provide timely reminders during a period of sleep-deprived over-work. Of course most irrigators will not do everything they are told but customized reports provide goals and targets that should produce results. At least check that you are not way off the yellow-brick road.

Washtub Scheduling and Other Methods
There are a variety of interesting methods that can be used for teaching or for actual scheduling. You can approximate crop water use with a washtub although in this age of smartphones you may need to search antique stores to find one. In this method you place a washtub in the field, your yard, or other convenient location with a water source. You measure the drop in water level weekly which is surprisingly close to the potential crop water use of fully developed crops. See Montana Agricultural Extension Service Montguide MT8343 by Dr. Jim Bauder for details. It also makes a great school, home garden or kid's project.

METHOD 2: AWARENESS OF THE BASICS

Although you can schedule irrigations just by observing the soil moisture content, many irrigators gain a basic awareness of important factors and use them over time in an informal way to make decisions. The more you know about these subjects, the better your irrigation will be. These subjects are discussed throughout the growing season in the Blackfoot Challenge weekly irrigation report. The calendar on page 4 gives a general recommendation for activities throughout the season.

Following these guidelines can significantly improve irrigation without a major effort even with multiple fields. These improvements do not require special field equipment, computers or other resources.

- **Application Amount and Uniformity** – Confirm how much water you are putting on and how uniformly. See **Appendix E** for information on testing application amount and uniformity. Watch for obvious sprinkler problems during the season.

- **Crop Water Use** - Have at least a general idea of your crop water use which ranges from 1 to 2 inches per week during the main irrigation season. Realize that water use drops for several weeks following hay cutting. See **Section 2.0** for more information on crop water use. Tables on page 2 and 7 provide a general guide for irrigation amounts. Remember to consider application efficiency – less water reached the crop than what you apply. Generally pivots are 80% efficient but all systems are less efficient during hot and windy weather, which makes it important to actually look in the soil to see if your irrigation was actually effective.

- **Soil Water Holding Capacity** – Know your soil water holding capacity so you know the maximum you should apply and don't over irrigate. Most soils hold 1-2 inches of water per foot of soil. See **Section 4.0** and **Appendix D** for help to determine water holding capacity. General information may also be available from the soil survey or local NRCS office.

- **Critical Growth Periods** – These are the times that it are most important to irrigate well to maximize production. Critical periods for hay crops are during establishment and after cutting, for small grains they are during establishment, boot, bloom and heading stages. In the Blackfoot drainage, the entire month of June could be considered a critical period since this is when all crops grow most vigorously. **Section 7.0** includes additional information on critical periods and crop stress indicators.

- **Drought Strategies** – Be aware of soil moisture levels at the start of the season as well as snowpack, streamflows and weather predictions. **Section 6.0** discusses options for irrigation practices during drought.

- **Special Local Concerns** – Be aware of special concerns such as the needs of other water uses including recreationists and fish.

- **Soil Moisture Observations** – You should always periodically observe your soil moisture and compare this with where you think it is. Guidance is presented in **Appendix D** including a form for this purpose. It is especially helpful to know how much water you have at the start of the season and during critical periods. You can walk backwards around your pivot and see how quickly your irrigation water is used by the crop – often more quickly than you think.

METHOD 3: BASIC RECORD-KEEPING

The next step is basic record-keeping to track rainfall and irrigation versus potential crop water use. For those with poorer memories, this preserves what you did last week, last month and last year. It also keeps you thinking each week about how much you apply versus how much you use. You must have an awareness of the basics described above.

Appendix C includes a blank calendar for the irrigation season. Use this form to record irrigations and weekly crop water use. If you can, determine soil moisture content and record it as well, especially the starting soil moisture about May 1. Add rainfall from a rain gauge at the site or the nearest location available. Add irrigations as you apply them. Add crop water use information from the general values on the form, from the weekly Blackfoot Irrigation Scheduling Report (best source) or from regional Agrimet weather stations. Note that the Round Butte Agrimet station seems to most closely match crop water use in the Blackfoot drainage during the main portion of the season. The Deer Lodge Agrimet station is physically closer, but seems to report values that are often significantly higher than those observed in the Blackfoot drainage.

Once again, periodically check your soil moisture and compare this with where you think it is. Guidance is presented in **Appendix D**.

It is often most useful to leave this form (or simple calendar) in the irrigation system control box. As you irrigate, compare the amount of your irrigations with the crop water use and try to keep up, especially during critical periods and especially the month of June. Compare your irrigation with weekly, pre-cutting and total season figures. Also use this record to compare fields or to compare crops year to year. This method is similar to the more detailed checkbook scheduling described below under High-Tech methods.

METHOD 4: HIGH-TECH

The irrigation scheduling methods described above can help many irrigators improve their practices significantly. To go beyond these basic concepts requires a significantly greater effort involving more detailed measurements and recordkeeping. The greatest challenge for using most of these higher tech methods is the extra time needed and also the extra computer skills.

Direct Observation with Soil Moisture Sensors

This is similar to the Low-Tech Direct Observation Method described above but uses soil moisture sensors instead of the dig-it-up-and-feel-it method. The great advantage of this method is that ideally it is fast and easy. If properly installed, acclimatized and calibrated, they can provide an instant answer for how much soil moisture is available at multiple depths. With sensors at multiple depths, you can ensure deep irrigation and good root penetration. Some of the considerations for installing sensors include:

- Sensors must be installed at a site and depth that represents conditions across the entire system and many fields have multiple soils and crops requiring multiple sensors, installation, calibration and monitoring.
- Models with sensor wires or post-mounted field meters are often plowed up, eaten by rodents, destroyed by livestock or otherwise disconnected so only purchase wireless models.
- Loosened soil in the installation hole may provide a more permeable route for moisture penetration to the sensor, which then doesn't represent the surrounding undisturbed soil. Over-compaction of the installation hole may prevent moisture penetration similar to the adjacent undisturbed soil.
- Calibration is required so readings accurately reflect soil moisture conditions and irrigators know how to read the meter and interpret graphs. It is important to determine readings for the water-holding capacity, maximum allowed deficit and moisture exhaustion levels. It is also most useful to convert readings to inches of water so irrigators can plan ahead
- Irrigators who practice deficit irrigation and only apply an inch or less at a time and who have fine-textured soils will have problems using this method since the sensors don't work well at shallow depths. Fine-textured soils will hold an inch of water in 6 inches or less of soil depth.

- Sensor outputs must be converted to a language that irrigators understand and can easily use to make decisions. Currently the language of irrigators is INCHES OF WATER including rainfall, crop water use and irrigation. Irrigators often lose interest due to problems, time investment, lack of accurate calibration, weird readings and the black box nature of the readings (such as centibars of tension which can't be easily related to inches of rain, irrigation and crop water use).
- One of the greatest problems with most measurement devices is the tie to one, or at most, a few locations in a field. A specific site may become "contaminated" or rendered useless by a variety of events. Recent examples from the Blackfoot drainage include a malfunctioning sprinkler that applied 3.5 inches of water to the soil moisture measurement site while the rest of the field received 1 inch. In another case, electrical problems caused a pivot to sit at one spot and put on over 4 inches right at the measurement site. In another case, wind came up right when the pivot passed the measurement site and almost no water reached the measurement site. Many problems make the site useless for weeks until crop water use or additional irrigation occurs to overcome the problem. In other cases, a site may become useless for years due to factors such as the livestock compaction around one field meter post.

When using moisture sensors, it is also prudent to regularly observe soil moisture directly with shovel or soil probe to spot check for sensor correlation and potential problems. Although the feel method may not be quite as precise, it lets you observe soil moisture at many points and depths quickly giving you a better overall picture of soil moisture across a field.

Checkbook Irrigation Scheduling (with and without calibration by feel or sensors)
The *Checkbook Irrigation Scheduling Method* works just like your bank checkbook. You start by determining your initial balance (how much stored soil moisture you have at the start of the growing season). You keep track of deposits (effective rainfall and irrigation) and add them to your soil moisture account. You also keep track of crop water use and subtract it. **Appendix C** contains an example checkbook schedule for the 2012 growing season. Records can be kept on a daily or weekly basis. Weekly summaries are helpful because weekly crop water use is in the ½- to 2-inch range, which is similar to common irrigation amounts. Daily values are usually in the 0.05- to 0.35-inch range – numbers most of us are less comfortable with.

To use this method you need to know your **water holding capacity** which you can determine using guides listed in Section 5.0 and **Appendix F**.

You also need to know your **crop water use,** which is provided in weekly reports by the Blackfoot Challenge program. You can also find crop water use on the AGRIMET web site at http://www.usbr.gov/pn/agrimet/. There is no AGRIMET station in the Blackfoot drainage. The Round Butte, Montana, station seemed to most closely represent conditions in the Blackfoot. You can also look at the Deer Lodge station but its values seem to be considerably higher than experience in the Blackfoot. If you have no other option, you can use the general guides provided in Section 3 and **Appendix E** for crop water use by month and during average, cool or hot weeks.

You can track **rainfall** with a simple rain gauge available at any hardware store. You can make your schedule more accurate by reducing rainfall and irrigation amounts as indicated (**Appendix F**) to account for immediate evaporation. The remainder actually contributes to soil moisture and future crop growth.

Checkbook Calibration

Checkbook scheduling always requires some adjustments throughout the season as you can see on the example pivot schedule in **Appendix C**. It is not meant to be absolutely precise, but to get you closer to the ideal timing and amount of irrigations.

You can improve on the checkbook method by periodic soil moisture observations to check what the checkbook says against what is actually in the soil. The most common way to check soil moisture is using the feel method. **Appendix E** explains how to check your soil moisture and record it in inches.

Calibration can also be accomplished with soil moisture sensors. These sensors must themselves be calibrated first to determine the relationship between reading and the specific soil conditions at the site. It is especially important to know sensor readings at field capacity and across the range of moisture from dry to full (field capacity).

The Montana NRCS has developed a more detailed checkbook spreadsheet for Montana irrigators that is available on their web site (http://www.mt.nrcs.usda.gov/technical/eng/software.html). If you cannot locate it, contact the state irrigation specialist in their Bozeman office.

7.0 CRITICAL GROWTH PERIODS AND CROP STRESS INDICATORS

Each crop has critical growth periods when water has the greatest effect on yield and/or quality. Irrigators should make special efforts to keep soil moisture levels high during these periods. These are the times to make special efforts to repair broken equipment, adjust schedules and prioritize irrigation. Each crop also has distinct stress indicators to watch for that indicate water depletion.

All Crops

The first critical growth period for all crops is establishment. If a dense, healthy stand of alfalfa, grass hay, grain or other crop is not established at the start, it can never produce a high yield. Since most crops are planted in spring, rainfall usually provides the moisture needed for establishment. However, during dry years irrigators should pay attention to seedbed moisture conditions and apply water if needed. The later in the growing season that planting occurs, the more likely irrigation will be needed.

Soil crusts are another thing to look for during crop establishment on some soils (high silt, clay and lime content). Soil crusts may form at the surface following a light rain as lime is mobilized by the water and then cements the soil surface together into a crust upon drying. Crop seedlings may not be able to penetrate this crust and can be found curled beneath it. A light irrigation application can dissolve this crust and allow seedlings to emerge. In the Blackfoot area, crusts are rare but sometime occur on glacial lake soils such as the Hanaker series.

Alfalfa and Mixed Hay Crops

The first critical growth period for alfalfa is at stand establishment. When starting from seed, apply light irrigations if needed to keep the seedbed moist for germination. When seedlings are established, apply water until the entire root zone is full to promote deep root penetration. This provides plants with a much larger volume of soil to draw water and nutrients from.

The time just after cutting is the next critical growth period for alfalfa. Plants are very stressed when just cut and will die or go dormant if not irrigated soon after cutting. If plants do not die, they may lose significant vigor and not produce at pre-cut levels. The best strategy is to irrigate as close to cutting as possible and then apply irrigation water as soon as possible afterwards. Note that the surface soil will need to dry out before cutting, so stop irrigating at least 2-4 days before cutting on sandy soils and 4-7 days on silt and clay soils. When irrigating after cutting, remember to factor in that it may take many days to get across the entire field with a side-roll or hand-line sprinkler system. Many irrigators with wheel lines skip every other riser when irrigating after cutting. This cuts the time to get across the field in half and reduces plant stress.

Stress indicators for alfalfa include a bluish-green color followed by wilted leaves. However, alfalfa may not always show obvious stress indicators but will simply stop growing until additional water is supplied.

Alfalfa and grass hay have a potential crop water use of about 22 inches for the entire Blackfoot drainage growing season. However, most irrigators concentrate their efforts on the first cutting and the potential water use is 9-10 inches for this period.

Pasture
The most critical growth period for pasture is at stand establishment where the stand density and composition is determined. As with alfalfa, you want to irrigate deeply to promote root penetration at least once during the early part of the growing season.

Stress indicators for grasses are often not obvious since grasses are by nature well-adapted to moisture stress. Grasses may not look significantly different when stressed but will simply stop growing until more moisture is provided. When stress indicators do appear for grass hay or pasture they are usually a dull green color followed by wilting.

Small Grains
Stand establishment is usually not a problem with small grains, since fall and spring rains coincide with the main planting periods. However, late spring planting or unusually dry conditions sometimes do not provide enough moisture to get uniform germination and emergence. Observe the crop, soil moisture and weather to decide if irrigation is needed. Be sure to fill up the root zone water holding capacity early in the crop season to promote deep root penetration.

The most critical crop growth periods for small grains includes the Boot, Bloom and Early Heading stages. Stop irrigating at the milk to soft dough stage. Watch late season moisture levels closely and be sure there is sufficient water to keep kernels from shriveling.

Since small grains are grasses, they also show fewer signs of stress and may simply stop growing during dry periods. Stress indicators for small grains include a dark green color followed by reddish, yellowish and brownish colors on lower leaves.

Critical Irrigation Period for All Blackfoot Crops
The month of June could be considered the critical irrigation period for crops in the Blackfoot drainage and the main period to apply water. Most crops get sufficient moisture in May for establishment and early growth. Hay and pasture are the most common crops in the drainage and most irrigators only get one cutting (in early July). Therefore, most local irrigators concentrate their efforts prior to the first cutting and irrigate on a more relaxed schedule thereafter. Those growing small grains also concentrate their efforts in June when most growth occurs and do not irrigate at all after harvest in July.

For these reasons, all local irrigators are encouraged to concentrate their efforts in June to keep soil moisture levels high and apply additional water at the full potential crop water use rates. Crop water use rates can be estimated from Table 2 or can be obtained from the Blackfoot Challenge weekly irrigation reports.

8.0 DRY YEAR DROUGHT STRATEGIES

Drought conditions seem to be more common these days and more attention is focused on the consequences for crops and stream flows. Practices for dealing with drought are summarized below. Some of these can have negative consequences for irrigators (potentially lower yield) so must be implemented after careful consideration.

- Fill up your soil to its water holding capacity at the beginning of the season and try to keep it there.
- Save water for critical growth periods.
- Concentrate your efforts on the first cutting, irrigate after cutting and then reduce or cease irrigation.
- Concentrate your efforts during the cooler periods and reduce or stop irrigation during the highest crop water use period which coincides with the lowest stream flow period.
- Rotate irrigation systems during low river flows to reduce the amount withdrawn.
- Apply more water during each application to increase soil moisture storage.
- Reduce your irrigated acreage and do a good job irrigating on a smaller acreage.
- Plant crops that use less water (small grains).
- Practice irrigation scheduling.
- Monitor irrigation system performance so you put on the right amount uniformly.
- **Be more aware and more flexible of changing spring conditions**.

Some strategies can be used immediately and others require planning ahead and can be used in future years. Each of these ideas can have negative consequences for irrigators (usually lower yield or loss of alfalfa plants). Some options for reducing water use in the critical stream flow period of July-August are:

Fill Up Your Soil at the Beginning of the Season and Try to Keep it Near Full
Fill up your soil's Available Water Holding Capacity (AWHC) so when you get asked to cut back you can do so knowing you have plenty of crop water stored. Sandy soils can store 2-4 inches in a 3-foot root zone. Local silty, loamy and clayey soils can store 4-6 inches in a 3-foot root zone.

Rotate Irrigation Systems During Low River Flows
Streamflows can be increased by reducing the amount of diverted irrigation water. Reduce the number of pivots, wheel-lines, hand-lines or other systems operating at one time in order to leave more water in the stream for other users.

Save Water for Critical Growth Periods
Each crop has critical growth periods when yield is most affected by a lack of water. For hay crops, this is during stand establishment and immediately after cutting. For small grains, this is during stand establishment, boot, blossom and early head stage.

You can also consider the main growth period as a critical period for crops since this is the time when you get most of your production, especially for hay crops. For hay crops in the Blackfoot drainage, this period is the month of June (with a little of May and July thrown in during some years). If you want to get good production you must try to match your irrigation with crop water use during this period.

Reduce Irrigated Acreage

You can produce a larger crop by irrigating a smaller area ***well*** than by irrigating a larger area ***poorly***. If you reduce your acreage, you may also be able to reduce your costs for other inputs such as fertilizer, herbicides, seed, fuel and labor. This choice is tricky since it requires you to predict the future or take the work of weathermen.

Concentrate Your Efforts on the First Cutting

Most irrigators in the Blackfoot drainage harvest one cutting on hay crops and then pasture the field or leave it to go dormant. Even if you manage to get a second cutting or some pasture, the first cutting is where most of your production comes from so make your best effort here. Begin irrigating in May if needed and make a real effort throughout June when most of your production occurs and when crop water use is lower than in July and August due to lower temperatures. Be sure to irrigate at least once after cutting to aid plant recovery from cutting stress.

Grow Your Crop During Cooler Periods

Plant annual crops early and harvest early before the hottest weather. For permanent crops, irrigate heavily during the most productive period for a first cutting (June). Reduce or stop irrigation during the hottest, driest period in July-August. Resume when crop water use is lower and more water is available.

Apply More Water During Each Application

Each time you irrigate you lose .10 - .25 inches of water from evaporation off crop leaves and the soil surface. The gross irrigation amount is how much comes out of the sprinklers. The net irrigation amount is how much makes it into the soil. If you apply ½ inch twice instead of 1 inch once, you lose twice as much to evaporation.

Pivots

Application rates can be increased by slowing the pivot speed on variable systems. Of course, it may not be possible to increase the application rate on soils with high clay contents and low infiltration rates. In this case you can just keep the pivot running at a lower application rate and make another application.

There is another concern for sandy soils with low water-holding capacity. This concern is whether you will slow down so much that the soil moisture or MAD is exhausted before you get back to that spot. For instance, if your pivot applies 1 inch at a time, and it's a hot, dry week in July, that 1 inch will only last 3-4 days. If your pivot takes longer than that to apply 1 inch you will exhaust your soil moisture before you apply more. In this case, it is better to run your pivot at higher speeds so soil moisture is not completely exhausted before more water is applied.

Wheel- and Hand-lines
Application rates can be increased on some systems by increasing nozzle size or nozzle flow rating if the pump and piping components have sufficient capacity and runoff/erosion is not an issue.

Plant Crops That Use Less Water
Alfalfa and hay crops use the most water (22 inches average in the Blackfoot drainage). Pasture uses slightly less (18 inches) and small grains or other annual crops use the least (15 inches).

Practice Irrigation Scheduling
Keep track of your irrigation and compare it with crop water use to maintain good soil moisture levels. Observe your soil moisture at the season start and during the main irrigation period. Apply the right amount of water at the right time for maximum crop yield especially during June when you get the biggest bang for your buck. Know your critical crop water periods and concentrate your efforts then.

Improve Irrigation System Performance
Irrigation is most effective when the system works properly. Know how much your system applies per irrigation. Check for proper operating pressures and flow rates from pumps and sprinklers. Adjust the application rate if necessary by changing pumping pressure and nozzle sizes/flow rates. Improve irrigation uniformity by keeping nozzles clear, replacing work components, using flow control nozzles and pressure regulators, or by reducing sprinkler and lateral spacings.

Plan For a Lower Yield and Reduce Other Crop Inputs to Match
If irrigation water supplies are predicted to be low, then don't plan for a high yield crop. Choose a production target that is reasonable for the predicted water supply and adjust other crop inputs accordingly. Do not fertilize for a 100-bushel per acre grain crop if there will only be enough water to grow a 70-bushel per acre crop.

Be More Flexible with Changing Seasonal and Year-to-Year Conditions
It seems that each year, one part of the drainage has an extra storm with 2-3 inches of rainfall. If the timing is good this helps. If not, it runs off too quickly or ruins harvest. Another important lesson from this program has been the dramatic difference between one year and the next. It seems increasingly important for irrigators to pay attention to spring conditions and weather predictions. Whether this is the same old story or a product of climate change is unknown, but we seem to be getting warmer and more variable conditions. In the past few years the active part of the growing season has started anywhere from late-April to mid-June. This is when there is enough sun and warm temperatures to stimulate the crops full growing potential. This variation in the peak growing season can hurt production unless growers can be equally flexible. In 2011 when cool, cloudy, rainy conditions persisted into June, those who cut on their regular schedule had a smaller crop. Those who waited an extra week or two saw dramatic increases in production due to that wait. By comparison, in 2018 when warm,

dry weather began in late April and persisted through June, those who irrigated early and took advantage of this period had much better crops than those who waited until their normal irrigation startup in late May or early June. The lesson is to look ahead and be more flexible.

9.0 WET YEAR OPPORTUNITIES

Wet years present their own challenges and opportunities. It's good to look ahead and have a plan or some options if water looks abundant. Remember though that drought conditions can return quickly with hot dry weather so be flexible. Some potential options include:

Re-Seedings
Abundant moisture, especially later in the season, can ensure a good reseeding effort. Plant germination, emergence and early growth will more likely produce an even healthy stand.

Second Cuttings
Our ever-lengthening growing season provides more opportunities for second cuttings that are worth the effort.

Fall Pasture
When it's hot, it often doesn't pay to irrigate for fall pasture since so much water is lost to evaporation. Unless you can apply many inches of water, you may have little to show for it. But in wet years, water may be available and cooler weather more efficient for irrigation.

Cover Crops
Cover crops can provide tremendous soil health benefits and additional high-value forage for livestock. Cover crops are typically grown after the main crop is harvested. This is usually an annual crop but they can also be planted before hay crops are rejuvenated/reseeded. Unfortunately, in the Blackfoot drainage this is the time of highest crop water use and lowest stream flows. But some wet years should provide enough late-season water to make this possible.

Profitability
Wet years may just provide the extra yield and reduced costs that let you make a profit. Don't feel compelled to do anything extra if putting money in the bank is your immediate priority.

One first cutting of alfalfa in 2018 yielded 4 tons of alfalfa with only 1 inch of irrigation. The producer's silty clay loam soil held 2 inches of water per foot and was almost full at the start of the growing season. He received about 6 inches of rain by first cutting and since it was cool about 5 inches was effective. These figures suggest that the irrigator produced each ton of alfalfa with only about 3 inches of water. This is lower than the 4-5 inches per ton cited by most research in Montana and Idaho. So where is the extra water coming from? Plants are accessing soil moisture deeper than the 3-foot zone that is typically managed for alfalfa irrigation. This deep moisture simply is not there in most years. Alfalfa can root beyond 10 feet and grasses beyond 5 feet. Also, good management has increased the soil organic matter content and Water Holding Capacity of the soil.

The Question of Late-Season Irrigation – To Irrigate or Not To Irrigate
Your first hay cutting is over and your grain crops are harvested. You have water available so should you turn the pumps back on or not? There are good reasons to keep irrigating – new plantings, second cuttings, cover crops or fall pasture. But it's important to recognize the challenges that come later in the season and make irrigation less effective and less profitable (mid-July to mid-September). Not everyone can turn late season irrigation dollars into a profit or benefit. Some factors of late season irrigation are:

- Less water reaches the crop since more is evaporated from crop and soil surfaces (up to ½ inch per irrigation).
- Crop water use usually peaks at about ¼ inch per day during first cutting but may hit ½ inch later.
- There may be little profit or a net loss from late season irrigation when yields are compared with costs. If lots of water is available, you have more chance of making money.
- Water availability may end any time as regulatory limits are reached or drought management plans kick in.
- Late-season irrigation does not contribute to spring soil moisture levels unless you have enough water to irrigate deeply (2-4 feet). Surface soils simply dry out in most years due to the increasing length of time between when snow melts and crops begin vigorous growth.
- Other water users are focusing increased scrutiny on irrigation and late season stream flows.

10.0 FLOOD IRRIGATION

This guide is focused on sprinkler irrigation but there are more acres irrigated by flood methods in the Blackfoot drainage. Although the challenges to irrigate effectively and efficiently are different, many of the same principles apply.

Crop Water Use
Crop water use is the same regardless of the irrigation method. Plants use water in relation to the same weather factors of temperature, humidity and wind.

Total Water Use
Whereas sprinkler systems can apply the exact amount of water the crop needs, flood systems usually apply much more. The excess water that is not retained by the soil either percolates to groundwater or runs off to streams.

Application Amount
It is more difficult to determine the amount of water applied during each irrigation, however measurement devices including ramp flumes, other flume types, and flow meters can provide reasonable estimates.

Application Uniformity
Achieving good uniformity in flood systems is much more difficult than with sprinklers. The most common challenges are topography that is variable (high spots and low spots) and soils that are permeable (water wants to sink in rather than spread out evenly). Permeable soils are those with high sand and rock contents while less permeable soils are those with clay. This is not to say that you cannot ever get good uniformity with a flood irrigation system. Two flood systems evaluated during this program showed uniformity almost as good as sprinklers due to extreme efforts by the irrigators.

Good Uniformity with Flood Irrigation

Uniformity at flood-irrigated fields can be evaluated in several ways. You can simply observe water flows during irrigation since it is on the surface and can see where water flows or does not. After an irrigation you can use a probe or shovel to randomly sample across the field to determine the depth of water penetration or estimate the amount of water present by the feel method.

You may also see dry and wet patterns from the ground or using air/satellite photos. Remember that Google Earth now posts new images each summer on which you can see great detail.

Conversion of Flood Irrigation to Sprinkler
There has much discussion about the benefits and negative impacts of converting from flood to sprinkler irrigation. Potential benefits include better uniformity, higher production and less water use. Potential negative impacts include less groundwater recharge and lower late-season streamflows.

Where flood irrigation areas are adjacent to streams, excess water applied may return quickly to the stream by deep percolation or overland runoff. However, these waters may carry ag chemicals, animal waste and other organic materials that create algae blooms, decrease oxygen levels or directly harm aquatic life. Surface runoff may be warmer than streams and cause temperature problems for fish.

However, flood irrigation may provide a variety of benefits from a water resource, cultural and aesthetic standpoint. Flood irrigation areas act like wetlands, absorbing and then slowly releasing excess water to groundwater and streams. As hydrologic modeling become more precise it should be possible to evaluate these potential positive and negative effects. Some sites are simply difficult to irrigate with sprinklers such as irregularly shaped fields and those with multiple meandering streams.

Aesthetic and cultural concerns also have become an issue. Sprinkler systems are viewed by some as unattractive compared with flooded areas. Some landowners simply wish to practice flood irrigation as a way to maintain the character of the landscape and the heritage of past practices. Conservation easements and other land use protection tools have begun to include requirements for future irrigation methods.

Future of Flood Irrigation
As water becomes scarcer and more valuable, there will be increasing pressure on irrigators to convert from flood systems to sprinklers, drip and other methods. Flood systems present the greatest opportunity for improving efficiency and freeing water for use elsewhere by sale, lease or other agreement. It is likely that water sales/leases will become an important part of farm/ranch income in the future.

11.0 WATER RIGHTS, WATER REGULATION AND THE FUTURE

The oldest active Blackfoot drainage water right in the current DNRC system is granted to the Montana State Board of Land Commissioners with a date of 1858. There are a number of other water rights from 1858 all of which cite Ashby Creek as the water source. There are almost 12,000 active water rights listed for the Blackfoot drainage including about 2,000 for irrigation. Like most drainages, these rights make claim to more water than actually exists so Montana uses the principle of *first in time – first in right* meaning the oldest water rights get priority.

The Blackfoot drainage was recently adjudicated meaning that all water rights were reviewed to confirm the priority date, current use, place of use and that the amount of water claimed is reasonable. Disputes were settled in the Montana Water Court.

Montana's rigorous system for regulating water rights provides water users some of the best protections in the country. Unlike Arizona and California, we have regulated groundwater and consider surface and groundwater to be connected (as they are). This has prevented the tyranny of the law of the biggest pump which has created chaos in other states.

If the climate continues to warm, the Blackfoot drainage is in a reasonably good position due to factors such as:

Location-Location-Location
There are lots of GOOD things about the future of water management in the Blackfoot drainage and the first is that we are at the top of the Columbia River system touching the Continental Divide. There's no one upstream from here to try and take our water or to argue over management (at least until they start talking about transcontinental water pipelines). Downstream are millions of water users that are potential future customers/clients/leases/purchasers of our water. We will also have the potential to influence, contribute to, or direct a wide range of future downstream natural resource projects needing water.

Storage
Another good thing is that we have a large reservoir at Nevada Creek and numerous smaller reservoirs. These are dependable, drought-busting sources of water that can store spring runoff for use in even the driest years. Even if you don't have direct access to stored water, we all benefit from leakage and late season flow enhancements similar to what wetlands provide.

Wetlands, Aquifers, Lakes and Streams
A tremendous volume of water is stored by wetlands and slowly released to surface and groundwater systems. This keeps rivers flowing and lakes full. Some flood irrigation systems act in a similar manner by soaking up and slowly releasing water not used by crops. Water is also stored in shallow stream-side aquifers and deeper valley aquifers that contribute to stream flows, especially late in the season. Our abundant lakes and

streams also represent huge volumes of water and the more water in the system the more resilient is the entire hydrologic system.

Vegetation

The Blackfoot drainage has a diverse and abundant vegetation cover from forests to rangelands to riparian areas, croplands and wetlands. There is an incredible amount of water contained in this vegetation, which adds to our overall hydrologic health. This vegetation provides a buffer to rapid desertification (if you don't know this word, search and read about how much of the world such as the *Garden of Eden* is now desert).

THE FUTURE

If climate change continues as it has in the past 20-30 years, we could soon reach a situation where only senior water users have water in most years. Junior rights could become increasingly less useful and valuable. In the end, water will likely follow the money with use determined by those who can afford to purchase the best water rights.

Water is an essential part of human existence and the demand will likely increase for some time while the supply continues to diminish in the Blackfoot and beyond. Agriculture will continue to be scrutinized for water conservation opportunities and the value of that water will increase. For the past couple decades, Los Angeles has paid tens of millions for water use and conservation measures in the irrigated Imperial Valley. In return, they get to use the conserved water without being able to claim is as a water right. Similar options will occur for Blackfoot irrigators as people from here to Portland need more water.

There will be many opportunities for new and innovative water rights, water valuations and water marketing. Changes in Montana water law may provide more flexibility to manage water to benefit many resources. Irrigation rights could be moved from the worst to the best soils or from water-limited stream segments to places with excesses. Conservation easement concepts could be applied to water rights and water leasing could become more widespread. This may all someday be made irrelevant when we solve the energy challenge of desalinization and other water treatments. Hopefully this will not occur before your grandkids sell some of their water right to Acme Electric Coop for a bazillion dollars.

12.0 SOIL HEALTH

Soil Health is a hot topic these days but what does it really mean for crops in the Blackfoot drainage? Healthy soils are just as important here as anywhere but our area has its own unique opportunities and challenges. Our short growing season and limited crop choices dictate the soil health improvements we should focus on and how we can achieve them.

Soil health in the Blackfoot will always benefit from increases in:

- Soil Organic Matter – Generally we have good levels of organic matter in local surface soils but the more the merrier (organic matter increases aeration, infiltration, microbial activity, water holding capacity and more).
- Aeration – Roots and microbes need to breath.
- Infiltration – Water needs to enter soil quickly before it runs off or evaporates.
- Microbial Activity – Microbes decompose organic matter and make nutrients available, the more microbes and the greater diversity of microbes, the better.

Much of the soil health discussion across the country is focused on cover crops which currently are rare in the Blackfoot Drainage. Cover crops don't fit into a hay and pasture landscape during most years since hay fields and pastures are infrequently replanted. Cover crops are most common in annual crop cycles where they are grown in the late summer after the main crop is harvested. Unfortunately, this corresponds to the low-flow period for local streams when fish and recreation concerns are highest and water rights most restrictive. Therefore, cover crops may only be practical for many folks in wet years with prolonged streamflows. This doesn't mean cover crops don't work in the Blackfoot drainage but that they take more planning.

Cover crops elsewhere in western Montana have included warm season species like sorghum, sunflower, collards, radishes, turnips, rapeseed, millet, corn, buckwheat, Teff grass and mung beans. Cool season species have included forage peas, barley, vetch, oats and some brassicas.

Cover crops are popular because they address all the concerns listed above – organic matter, aeration, infiltration and microbes. However, there are many other ways to promote soil health. Don't feel like you are being left out of the soil health revolution just because you are not planting cover crops.

Soil health is also improved by expanding the number and type of species included in hay and pasture plantings. Options being evaluated in western Montana include tall wheatgrass, pubesecent wheatgrass, thickspike wheatgrass, basin wildrye, flax, coneflower, hairy vetch, western yarrow, phacelia., milkvetch, chicory and sainfoil.

Soil Health Monitoring for the Regular Guy

There is a lot of information out there about how to monitor soil health. Many tests have been developed in recent time but are not yet calibrated to traditional soil tests and crop performance. Some tests can be performed with little equipment while others require elaborate laboratory analysis. Here are three types of testing that you should consider:

Organic Matter

The most important factor of soil health is organic matter content. Organic matter is the fuel that runs the soil nutrient engine. Most irrigators are familiar with how to sample organic matter and interpret results. Organic matter gives topsoil its dark brown color. Topsoil thickness and darkness are good indicators of soil health, which should be monitored over time. Your goal is to increase soil organic matter in both the surface and subsoil.

Microbes

Those with the time and money should consider microbial testing to provide baseline info and for future comparison of trends. You can also compare fields or treatments including fertilizer, irrigation, herbicides, crop choices. Soil microbiological activity may be measured by respiration (microbes exhale CO_2 just like us) or by counting the actual numbers of various microbe groups (bacteria, fungi, protozoa, nematodes, etc.). Sampling and testing are affected by moisture, temperature and other factors so it's very important to do it right.

Soil Infiltration

Infiltration reflects several important soil health factors including organic matter content, aggregate stability, compaction and rooting depth. Soil infiltration can be easily measured by irrigators themselves without fancy equipment. You basically need an infiltration ring, a stopwatch and some water. The best rings are made with steel pipe by beveling the outside edge. Test at least three spots in a field and continue readings at each spot until you get consistent readings. This test works very well a day after irrigating when the surface soil is at field capacity but not saturated. You can also search the web for a method such as this one:
https://www.youtube.com/watch?v=IqB4z7lGzsg .

Soil Health Laboratory Testing

Well, if you were not confused enough by soil testing in the past, get ready to interpret your levels of algae, fungi, bacteria and other organisms. What exactly does 4,327 nematodes mean? The good news is that you probably don't have to jump on the soil health testing wagon just yet unless you have a special interest and some extra time on your hands.

Over the past 50 years crop nutrient needs have become well established. We generally know how much of each major nutrient a crop needs. Over this same period, soil testing has been correlated reasonably well with fertilizer applications to produce target yields. This system emphasizes

NPK (nitrogen, phosphorous, potassium) and then attempts to diagnose additional deficiencies if necessary.

One concept of ***Soil Health*** is to supply crop nutrients by enhancing natural biological processes in order to reduce or eliminate imported fertilizer. The primary mechanism is to mobilize more nutrients from the recycling of organic matter. To do this you need organic matter and lot of busy soil microbes. Soil tests (or more often – groups of tests) have recently evolved to meet this new interest. Most combine some traditional soil tests like total organic matter and water-extractable nutrients with measures of microbial numbers or activity levels. Many companies are trying to develop or refine tests of this type. Three of the most popular currently are:

Comprehensive Assessment of Soil Health (CASH). This test was developed by Cornell University and includes both traditional soil analyses and biological testing.

Haney Soil Health Test. This test is probably the most commonly used to date and is currently endorsed for cost-share payments under NRCS programs including EQUIP.

Solvita Test. This is a do-it yourself testing kit and represents the current goal to develop relatively easy, quick and inexpensive tests.

All the current testing options have both promoters and critics. Everyone seems to agree that a biological component to testing is needed. However, there is not yet a large body of data from any of these new test procedures or good correlations to yield. There is also the inherent variability of biological systems. Changes in conditions like temperature, moisture content and soil texture directly affect biological activity and have been shown to produce highly variable results. As always, the location, date, moisture conditions and other variables must be carefully considered when taking soil samples for testing. Without these controls it may be difficult to compare results from one year to another. Hopefully, we can begin to collect baseline information to identify the range of local microbes and their activity levels. It also seems appropriate to conduct testing on paired sites to evaluate management or treatment effects.

You Don't Need a Test to Improve Soil Health

Remember that it doesn't take soil testing to improve soil health. We already know how to make soil microbes happy. Soil microbes want what we want – food (organic matter), air (they mostly breath too and need good aeration), water (moist but not saturated).

13.0 IRRIGATION HISTORY

By 4,000 years ago there were about 20 million acres under irrigation worldwide. Now we have about 600 million with 2 million of them in Montana. The "first" water measurement device was the *"Nilometer"* – essentially a staff gauge placed in the Nile River about 5,500 years ago. The first irrigation ditch was dug over 10,000 years ago. The first large irrigation systems were built in Egypt and Mesopotamia about 6000 BC. The first lawn sprinkler was invented by J. Lesser in 1871. The impact sprinkler was invented in 1933 by Orton Englehart. The first drip system was invented in 1959 by Simcha Blass.

Water and irrigation have a fascinating history in the world, the western United States and Montana. The classic book on western irrigation is *Cadillac Desert by Marc Reisner* (also a video available on YouTube). The books *Topsoil and Civilization* and *Dirt* tell how civilizations collapsed due to irrigation interruptions.

Historians have noted that societies based on irrigation have lasted longer than others. The usual explanation is that irrigation requires cooperation to build dams, diversions, canals and ditches since you can't do it yourself. It also requires administration to negotiate distribution and sharing of water. These cooperative efforts spill over into other areas of society making in more cooperative in general.

14.0 A BMP STRATEGY FOR BLACKFOOT IRRIGATORS?

This program was designed to help individual irrigators, which in turn might help water management across the entire drainage. We have combined experience from the best local irrigators with our own knowledge and with results from monitoring to fine tune recommendations. We have spread this wealth of information as irrigation tips in our weekly reports and irrigation guide. This strategy is condensed into our irrigation calendar (page 4).

Our individual recommendations have come together in an overall strategy for irrigation that can ***provide both good crop production and late-season stream flows*** for fish and recreationists. This might be considered a best management practice for irrigation in the Blackfoot drainage and a landscape-scale solution for water resources. The main points of this practice are:

- early evaluation of the coming irrigation season in April.
- planting part of the acreage in annual crops that are harvested before low stream flows.
- heavy irrigation early in the season to fill up the soil water holding capacity.
- heavy irrigation throughout June and up to cutting in early-mid July.
- reduced irrigation or no irrigation during low water flows in late July and August.
- cover crops planted only in wet years with abundant water.

Despite the very dry years such as 2017, 2016, 2015 and 2013, irrigators who applied water early and kept pouring it on up until haying or annual crop harvest in mid-July had excellent crops. During these years, warm temperatures gave us an extra month of very active growing season on the front end (April-May). Irrigators who recognized the early year took advantage of it and had some of the best crops ever, then felt good about reducing irrigation during the low flow period when fish needed it.

There is little doubt that the future will only get more challenging for Blackfoot irrigators. However, with this challenge will likely come opportunities to influence critical water decisions and participate in future water markets from here to the Pacific Ocean. All while living and irrigating in a great place!

15.0 SUMMARY

Irrigation can be a casual hobby or an exacting science. Most irrigators use a practical approach that fits within their individual goals and resources. This irrigation guide provides a variety of tools to help improve irrigation practices, get better production and adapt to droughts and pressures from other water users.

Blackfoot drainage irrigators can get the greatest return by concentrating their efforts in the month of June. This is the main crop growth period when all local crops respond most to applied water. Many local sprinkler irrigators apply less than the potential crop water use and may increase yield with more water if other factors do not limit growth (fertility, weed, pests, stand conditon).

Current sprinkler irrigation practices prevent fertilizer or other agricultural chemicals from leaching into ground waters since they apply less at a time than the soil will hold and less over the season than the crop can use (deficit irrigation).

Some of the **most effective ways local irrigators can make improvements are:**

- Know how much your system applies and that it does so evenly then watch for problems during irrigation season.
- Increase early season irrigation and “fill up” the soil to its water holding capacity by the start of the active growing period in mid-May.
- Irrigate deeply early in the season to encourage root penetration and access to a larger volume of soil nutrients and moisture.
- Know your crop water use – about ½ inch per week in May and September, 1 ½ inch per week in June, July and August – almost double for hot, windy weather.

- Know your soil water holding capacity and don't over-irrigate.

- Concentrate efforts in June – the main irrigation period for small grains and first cuttings.

- Increase irrigation towards the full potential crop water use on the best fields in coordination with reseeding, fertilizing, weed control and other improvements.

- Think about drought strategies and options ahead of time and have a plan.

- Be flexible with your schedule and respond to warm spring conditions with irrigation or cold, wet springs by delaying harvest.

- Reap the fruits of your success and enjoy some of the best views in the world of irrigated agriculture.

16.0 APPENDICIES

Appendix A. Sources of Information

Appendix B. Example 2012 Checkbook Irrigation Schedule

Appendix C. Example Blank Irrigation and Rainfall Calendar

Appendix D. Example Soil Moisture Estimation Form for the Feel Method

Appendix E. Application Amount and Uniformity Testing with Rain Gauges

Appendix F. Conversion Factors

Appendix A
Sources of Information

Baldridge, D., H. Bowman and R. Ditterline. 2008. Growing Alfalfa for Hay. Montana State University Extension. 6p.

Bauder, J. 2010. High Volume Low Frequency Irrigations vs Low Volume High Frequency Irrigation. Montana State University Extension. 2p.

Bauder, J. 2010. Making a Ton of Hay. Montana State University Extension. 1p. *http://waterquality.montana.edu/docs/irrigation/tonofhay.shtml*

Bauder, J. 2010. Early Season Alfalfa Irrigation Strategies. Montana State University Extension. 2p. *http://waterquality.montana.edu/docs/irrigation/earlyalfalfa.shtml*

Bauder, J. 2010. Irrigating Alfalfa: Some Guidelines. Montana State University Extension. 2p. *http://www.msuextension.org/ruralliving/irrigation_alfalfa.html*

Bauder, J. 1985. Irrigating With Limited Water Supplies. Montana State University Extension Service Circular 1262. 18p.

Bauder, J., L. King and G. Westesen. 1983. Using Evaporation Tubs to Schedule Irrigations. Montana State University Extension Service Montguide MT8343. 3p.

Bauder, J., P. Brown, J. Jacobsen and H. Ferguson. 1987. Estimating Small Grain Yield Potential from Stored Soil Water and Rainfall Probabilities. Montana State University Extension. Montguide MT8325. 7p.

Cash, D. 2005. Managing Alfalfa for Optimum Hay-Stockpiling Production in Montana. Montana State University Extension. Montguide MT200111AG. 3p.

Cash, D., M. Manoukian and Rachel Soto. 2009. Alfalfa Growers: Watch Your Last Hay Cutting Dates or Proper Harvest Management of Alfalfa in 2009. Montana State University Extension. 2p.

Goldhamer, D. and R. Snyder (eds). 1989. Irrigation Scheduling: A Guide for Efficient On-Farm Water Management. University of California Division of Agricultural Sciences and Natural Resources Pub. 21454. 67p.

Hinman, H., J. Kugler and W. Woodward. 2002. 2002 Cost of Producing Alfalfa Hay Under Pivot Irrigation in the Columbia Basin of Washington State. Washington State University Extension Service. Farm Business Management Report: EB1942E. 20p.

Montana State University Extension Service Staff. 1989. Irrigation Water Management: When and How Much to Irrigate. Montguide MT200111AG. 6p.

Morris, M. 2006. Soil Moisture Monitoring: Low-Cost Tools and Methods. National Sustainable Agriculture Information Service. 11p. *http://attra.ncat.org/attra-pub/soil_moisture.html*

Natural Resources Conservation Service. 1998. Estimating Soil Moisture by Feel and Appearance. Program Aid No. 1619. 11p.

Natural Resources Conservation Service. No Date. Montana Irrigation Guide. No Page numbers.

Natural Resources Conservation Service. 2012. Irrigation Water Management by Checkbook. An Excel spreadsheet for checkbook irrigation scheduling. Available at: http://www.mt.nrcs.usda.gov/technical/eng/software.html

Reisner. M. 1986. Cadillac Desert: The American West and Its Disappearing Water. Penguin Press. 582 p.

Reisner, M. and S. Bates. 1990. Overtapped Oasis: Reform or Revolution for Western Water. Island Press. 200p.

Shewmaker, G., J. Wright and R. Allen. Alfalfa Irrigation. Kimberly Agricultural Experiment Station. *http://www.uiweb.uidaho.edu/extension/drought/irrigatingalfalfa.pdf*

Sullivan, P. 2002. Drought Resistant Soil. National Center for Appropriate Technology Agronomy Technical Note. 7p. *http://www.attra.ncat.org/attra-pub/PDF/drought.pdf*

Bureau of Reclamation. 2010. Agrimet: The Pacific Northwest Cooperative Agricultural Weather Network. Source of information on weather, crop water use and irrigation. *http://www.usbr.gov/pn/agrimet/*

Wright, J. 1988. Daily and seasonal evapotranspiration and yield of irrigated alfalfa in southern Idaho. Agron. J. 80:662-669.

Wright, J. 2002. Irrigation Scheduling Checkbook Method. University of Wisconsin Extension Service pub. WW-01322. *http://www.extension.umn.edu/distribution/cropsystems/DC1322.html*

Sources for Rain gauges:
Most hardware stores, home improvement stores, ranch supply stores or online at: *http://www.taylorusa.com/* or Google taylor rain gauges or rain gauges

Sources for "Brown" Soil Probes
AMS, American Falls, Idaho http://www.ams-samplers.com/

Appendix B

Example 2012 Checkbook Irrigation Schedule

This example irrigation schedule table and chart show a well-irrigated field of alfalfa/grass hay.

The field received 2.64 inches of rain, of which 1.4 inches was effective.

The soil moisture content was 3 inches at the start.

The irrigator applied 13.65 inches of water as irrigation + 3 inches stored + 1.4 inches = 18 inches

The potential crop water for the entire season was 25.7 inches for hay crops in 2012.

The 18 inches of water supplied to the crop is less than the 25.7 inches of potential crop water use. However, if you just look at the period before cutting, there was 11.5 inches of water supplied to the crop compared with 9.3 inches of crop water use. This means that crop water use was met and there was a little extra to contribute to soil moisture.

The chart following the checkbook schedule illustrates soil moisture throughout the season. The soil water holding capacity is 6 inches and the maximum allowed deficit is 3 inches (50% of water holding capacity). You can see that before cutting (about June 6) the soil moisture level was kept high except for a short period in May when it dipped below 3 inches (50%).

You can also see that after cutting it is hard to catch up again due to the high crop water use in July and August.

HAPPY RANCH 2012 GROWING SEASON RAINFALL, IRRIGATION, SOIL MOISTURE AND CROP WATER USE ***(ALL VALUES ARE INCHES OF WATER)***

	RAIN		IRRIGATION & SOIL MOISTURE					ACTUAL 2012 CROP WATER USE[7]					ESTIMATED CROP WATER USE[8]		
DATE	RAIN	NET RAIN[1]	PIVOT1 IRRIG[2]	PIVOT1 SOIL MOISTURE CONTENT[3]	WATER HOLDING CAPACITY[4]	MAX ALLOWED DEFICIT[5]	MAX TO APPLY TO PIVOT1[6]	HAY CROPS[9]	PASTURE	GRAINS 5-1 START	GRAINS 6-1 START	LAWNS	AVERAGE WEEKLY ALFALFA WATER USE	HOT WEEK ALFALFA WATER USE	COOL WEEK ALFALFA WATER USE
5/4/2012	0.20	0.10	0.00	2.75	5.00	2.50	2.25	0.30	0.40	0.10	0.10	0.40	0.40	0.60	0.20
5/11/2012	0.10	0.00	0.00	2.35	5.00	2.50	2.65	0.40	0.50	0.10	0.10	0.60	0.50	0.70	0.30
5/18/2012	0.00	0.00	0.50	2.00	5.00	2.50	3.00	0.75	0.60	0.20	0.10	0.75	0.60	0.80	0.40
5/25/2012	0.25	0.15	0.50	1.80	5.00	2.50	3.20	0.85	0.75	0.20	0.10	0.85	0.80	1.00	0.60
6/1/2012	0.35	0.25	1.50	3.25	5.00	2.50	1.75	0.70	0.65	0.25	0.10	0.65	0.90	1.20	0.80
6/8/2012	0.50	0.35	0.00	2.80	5.00	2.50	2.20	0.80	0.75	0.40	0.25	0.75	1.00	1.30	0.90
6/15/2012	0.10	0.00	2.50	3.50	5.00	2.50	1.50	1.00	0.80	0.70	0.40	0.90	1.20	1.50	1.00
6/22/2012	0.10	0.00	0.00	2.25	5.00	2.50	2.75	1.25	1.00	1.10	0.70	1.25	1.30	1.70	1.10
6/29/2012	0.10	0.00	0.75	2.00	5.00	2.50	3.00	1.50	1.25	1.50	1.20	1.30	1.40	1.90	1.10
7/6/2012	0.01	0.00	0.00	0.25	5.00	2.50	4.75	1.75	1.50	1.80	1.80	1.75	1.50	2.00	1.20
7/13/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	1.80	1.60	2.00	2.00	1.80	1.60	2.10	1.20
7/20/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	1.80	1.60	2.00	2.00	1.70	1.50	2.20	1.30
7/27/2012	0.70	0.50	2.20	2.00	5.00	2.50	3.00	2.00	1.70	2.20	2.20	1.80	1.40	2.10	1.10
8/3/2012	0.01	0.00	0.00	1.00	5.00	2.50	4.00	2.10	1.80	2.20	2.20	2.00	1.40	1.90	1.10
8/10/2012	0.20	0.05	2.00	2.00	5.00	2.50	3.00	1.70	1.30	1.90	1.90	1.60	1.30	1.70	1.00
8/17/2012	0.01	0.00	0.00	0.50	5.00	2.50	4.50	1.60	1.20	0.50	1.70	1.50	1.20	1.50	0.90
8/24/2012	0.01	0.00	1.70	1.25	5.00	2.50	3.75	1.40	1.10	0.25	1.25	1.30	1.00	1.30	0.70
8/31/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	1.30	1.00	0.00	1.00	1.20	0.80	1.00	0.50
9/7/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	1.00	0.80	0.00	0.00	0.90	0.70	0.80	0.40
9/14/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	0.80	0.60	0.00	0.00	0.70	0.60	0.70	0.30
9/21/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	0.50	0.40	0.00	0.00	0.40	0.50	0.70	0.30
9/28/2012	0.00	0.00	0.00	0.00	5.00	2.50	5.00	0.40	0.30	0.00	0.00	0.30	0.40	0.60	0.20
TOTAL	**2.64**	**1.40**	**11.65**					**25.70**	**21.60**	**17.40**	**19.10**	**24.40**	**22.00**	**29.30**	**16.60**

1 The amount in the raingauge (gross) minus an amount for immediate evaporation from crop and soil surfaces (0.1 in May and Sept, 0.15 in June and August, 0.2 in July)

2 The amount the irrigation system applied minus an amount for immediate evaporation from crop and soil surfaces (0.1 in May and Sept, 0.15 in June and August, 0.2 in July)

3 The total water in the crop root zone. Bolded values are based on site visits and other values are calculated (= last weeks soil moisture+net rainfall+net irrigation-this weeks crop water use).

4 The total water holding capacity of your crops root zone. Obtain from your consultant or by using the irrigation guide method. Alfalfa and Hay 3ft, Grains 2ft, Lawns 1ft.

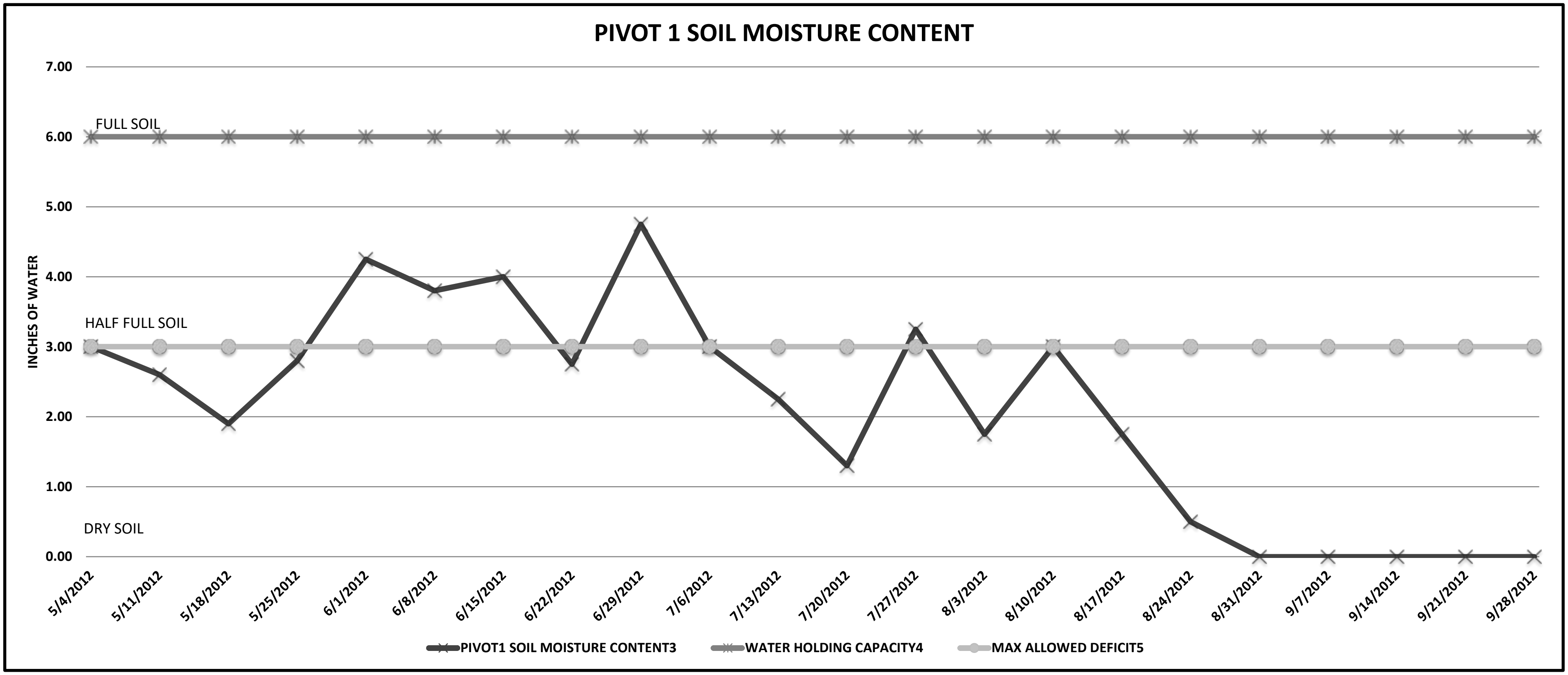
5 Maximum production is achieved when you maintain soil moisture above this level (50% of the Water Holding Capacity)

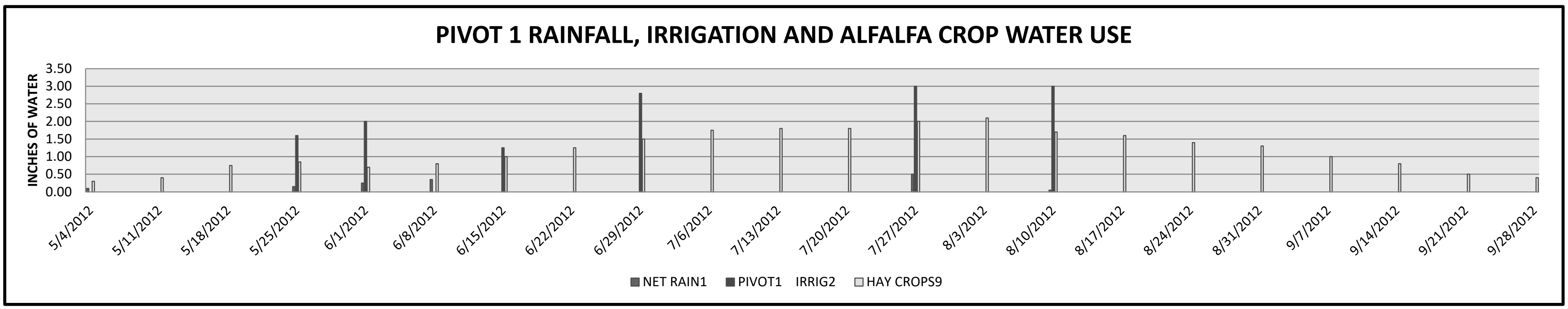
6 The most water you can apply without losing it below the root zone. This amount will "fill up" your soil profile (= root zone water holding capacity - current soil moisture content).

7 The amount of water used by each crop each week in the Blackfoot Drainage during 2012 (Start May 1). May be slightly higher in the lower drainage and slighty lower in the upper drainage.

8 The average amount of water used by each crop each week based on historic data. These figures can be used to plan ahead or for checkbook scheduling where other data is not available.

9 Hay Crop water use should be reduced by approximately 2/3 the first week after cutting, 1/2 the second and 1/3 the third.


PIVOT 1 SOIL MOISTURE CONTENT
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
FULL SOIL
HALF FULL SOIL
DRY SOIL
INCHES OF WATER
5/4/2012
5/11/2012
5/18/2012
5/25/2012
6/1/2012
6/8/2012
6/15/2012
6/22/2012
6/29/2012
7/6/2012
7/13/2012
7/20/2012
7/27/2012
8/3/2012
8/10/2012
8/17/2012
8/24/2012
8/31/2012
9/7/2012
9/14/2012
9/21/2012
9/28/2012
PIVOT1 SOIL MOISTURE CONTENT3
WATER HOLDING CAPACITY4
MAX ALLOWED DEFICIT5


PIVOT 1 RAINFALL, IRRIGATION AND ALFALFA CROP WATER USE
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
INCHES OF WATER
5/4/2012
5/11/2012
5/18/2012
5/25/2012
6/1/2012
6/8/2012
6/15/2012
6/22/2012
6/29/2012
7/6/2012
7/13/2012
7/20/2012
7/27/2012
8/3/2012
8/10/2012
8/17/2012
8/24/2012
8/31/2012
9/7/2012
9/14/2012
9/21/2012
9/28/2012
NET RAIN1
PIVOT1 IRRIG2
HAY CROPS9

Appendix C

Example Blank Irrigation and Rainfall Calendar

Record your irrigations, rainfall and crop water use each day or week. Average weekly crop water use values are listed. Actual crop water use can be obtained from the Blackfoot Challenge weekly irrigation report (available by email on request). Also note harvest/cutting dates and other important information. Note there may be more weeks than you need for each month since there may be 4-5 weeks in a given month – you can leave the extras blank. Write the actual dates down if you like during any individual year.

BLACKFOOT IRRIGATION SEASON RECORD *(ALL VALUES ARE INCHES OF WATER)*							
FIELD:							
Soil Water Holding Capacity = 1st foot____ + 2nd foot____ +3rdfoot____ = ______**INCHES**							
		ADD		**SUBTRACT**	**AVERAGE POTENTIAL CROP WATER USE[4]**		
	SOIL MOISTURE CONTENT[3]	**RAIN[1]**	**IRRIGATION[1]**	**CROP WATER USE[2]**	**LONGTERM AVERAGE ALFALFA USE**	**HOT WEEK ALFALFA HAY WATER USE**	**COOL WEEK ALFALFA HAY WATER USE**
STARTING SOIL MOISTURE							
WEEK 1 - MAY					0.40	0.60	0.20
WEEK 2 - MAY					0.50	0.70	0.30
WEEK 3 - MAY					0.60	0.80	0.40
WEEK 4 - MAY					0.80	1.00	0.60
WEEK 5 - MAY/JUNE					0.90	1.20	0.80
WEEK 6 - JUNE					1.00	1.30	0.90
WEEK 7 - JUNE					1.20	1.50	1.00
WEEK 8 - JUNE					1.30	1.70	1.10
WEEK 9 - JUNE					1.40	1.90	1.10
WEEK 10 - JUNE/JULY[5]					1.50	2.00	1.20
WEEK 11 - JULY[5]					1.60	2.10	1.30
WEEK 12 - JULY[5]					1.60	2.10	1.30
WEEK 13 - JULY[5]					1.60	2.10	1.30
WEEK14 - JULY[5]					1.50	2.00	1.20
WEEK 15 - JULY/AUGUST[5]					1.40	2.20	1.10
WEEK 16 - AUGUST					1.30	1.70	1.00
WEEK 17 - AUGUST					1.20	1.50	0.90
WEEK 18 - AUGUST					1.00	1.30	0.70
WEEK 19 - AUGUST					0.80	1.00	0.50
WEEK 20 - AUGUST/SEPTEMBER					0.80	0.90	0.50
WEEK 21 - SEPTEMBER					0.70	0.80	0.40
WEEK 22 - SEPTEMBER					0.60	0.70	0.30
WEEK 23 - SEPTEMBER					0.50	0.70	0.30
WEEK 24 - SEPTEMBER					0.40	0.60	0.20
TOTAL		**0.00**		**0.00**	**22.00**	**29.30**	**16.60**
Soil Water Holding Capacity = 1st foot____ + 2nd foot____ +3rdfoot____ = ______**INCHES**							

[1] Actual rain and irrigation applied - reduce to account for immediate evaporation from crop and soil surfaces (0.1 in May and Sept, 0.15 in June and August, 0.2 in July)

[2] Actual water used by your crop each week in the Blackfoot Drainage (slightly higher in the lower drainage and lower in the upper).

[3] The total inches of water in the crop root zone (3 feet for permanent crops, 2 feet for annual crops).

[4] The average potential amount of water used by each crop each week based on historic data.

[5] Hay Crop water use should be reduced by approximately 2/3 the first week after cutting, 1/2 the second and 1/3 the third.

Appendix D

Example Soil Moisture Estimation Form for the Feel Method

To estimate soil moisture at any point in the field:

1. Dig up or probe for a sample of each soil layer in your crops root zone (2 foot root for annual crops, 3 foot root zone for permanent crops).
2. Determine the soil texture group using the guide on the following page.
3. Determine the soil available water holding capacity for each foot of soil using the table below. Reduce for rock content (if you have a soil with 25% rock then reduce by 25%).
4. Estimate the moisture content of each soil layer between 0 and the AWHC. If the soil is completely dry it has 0. If its wet it has the AWHC. This should be the case in the surface soil just after irrigation. If the soil feels in between dry and wet – make a guess. Use the NRCS soil moisture estimation guide for help.
5. Add up the total water available in each soil layer in the entire root zone.
6. Compare this number with the expected crop water use to decide when to irrigate and how much.

Available Water Holding Capacity of Soil Groups

Soil Texture Group	**Available Water Holding Capacity (AWHC)[1]** **Inches of water held per foot of soil**
Very Coarse – fine sand, loamy fine sand	**1.0** (0.5-1.5)
Coarse – sandy loam, fine sandy loam	**1.5** (1.0-1.75)
Medium – loam, silt loam, sandy clay loam	**1.75** (1.5-2.0)
Fine – Clay, clay loam, silty clay loam	**2.0** (1.5-2.5)

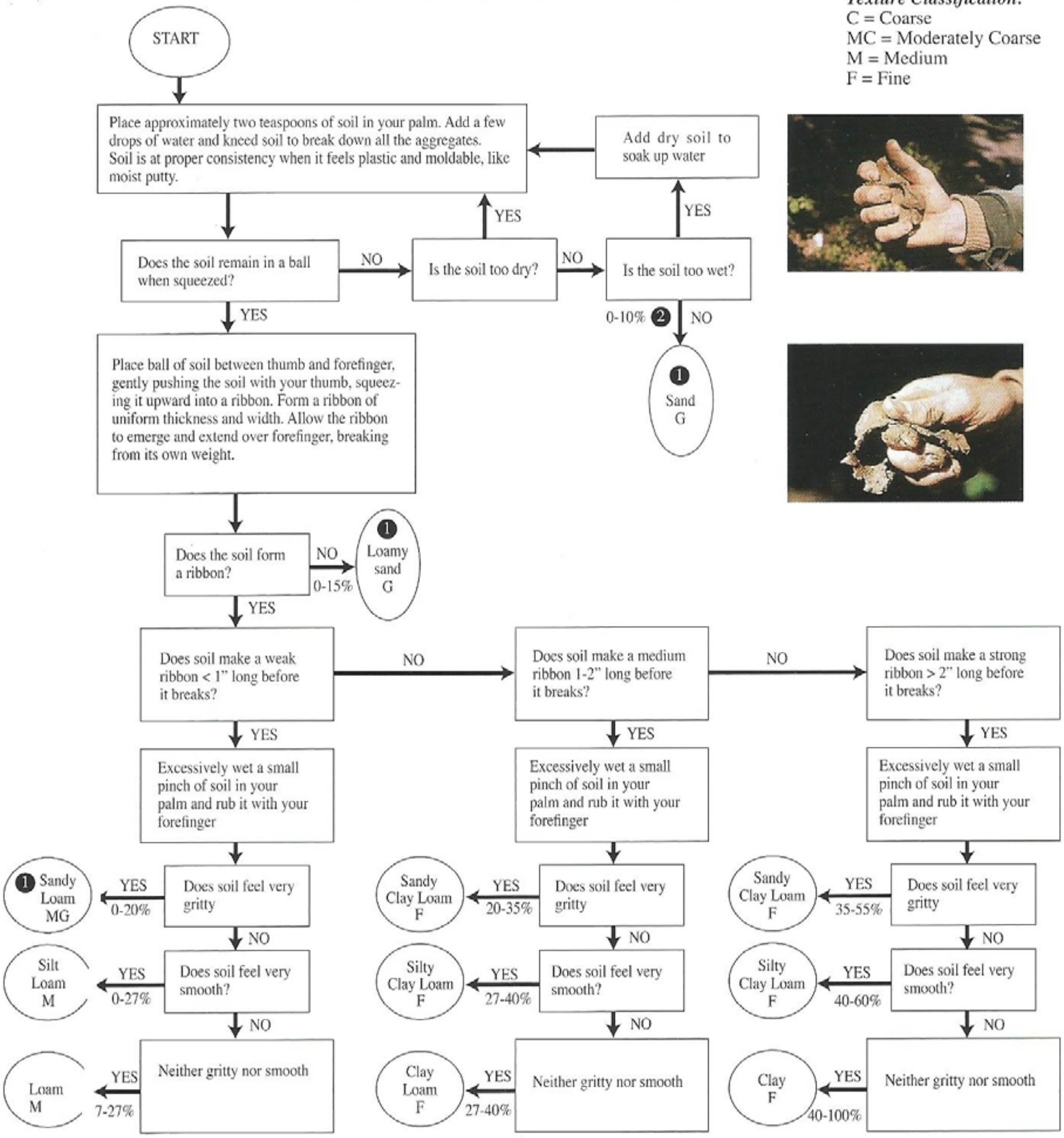
[1]Reduce by the percentage rock content (coarse soil with 50% rock = 1.5 x .5 = .75 inches per foot).

For a color guide to estimating the amount of moisture in your soil, Google:

Estimating Soil Moisture Content by Feel and Appearance

SOIL TEXTURE BY FEEL FLOW CHART [3]

Texture Classification:
C = Coarse
MC = Moderately Coarse
M = Medium
F = Fine



1 Sand paricle size [illegible]ould be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sa[illegible] are not visible without magnification and there is a gritty feeling to a very small sample ground betwe[illegible] teeth. Some find sand particles may be just visible. Medium sand particles are easily visible. Examples of [illegible]nd size descriptions where one size is predominate are: very fine sand, fine sandy loam, and loamy coa[illegible] sand.

2 Clay percentage range

3 Modified from: Thien. Steve J., Kansas State University, 1979 Jour. Agronomy Education.

BLACKFOOT IRRIGATION SCHEDULING PROGRAM SOIL MOISTURE DATA SHEET

NAME: ____________________ **LOCATION:** ____

DATE						
RAIN (IN)						
IRRIGATION (IN)						
SOIL DEPTH	**SOIL TEXTURE**	**WATER HOLDING CAPACITY (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**
1ST FOOT						
2ND FOOT						
3RD FOOT						
4TH FOOT						
5TH FOOT						
TOTAL						
SYSTEM ON?						
SYSTEM POSITION AND DIRECTION						
NOTES						

DATE						
RAIN (IN)						
IRRIGATION (IN)						
SOIL DEPTH	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**	**ESTIMATED SOIL MOISTURE (IN)**
1ST FOOT						
2ND FOOT						
3RD FOOT						
4TH FOOT						
5TH FOOT						
TOTAL						
SYSTEM ON?						
SYSTEM POSITION AND DIRECTION						
NOTES						

Appendix E

APPLICATION AMOUNT AND UNIFORMITY TESTING

While trust is a great thing, you should test your system to ensure that it is putting on the amount of water you think it is (and your application chart says). Many of the systems tested in the past were putting on much less than the owner thought. One new system was simply programed incorrectly (wrong pivot length) and the owner may never have known he was under-irrigating without a test. Many of the systems tested had poor uniformity suggesting the need for maintenance to clear nozzels, new sprinkler packages or improvements to pumping systems.

APPLICATION AMOUNT USING WATER VOLUME AND ACREAGE – ALL SYSTEMS:
If you know the acreage of your field and have a flow meter, you can calculate your application rate. Take the gallons pumped divided by the acreage of the field divided by 27,158 (the number of gallons in one acre-inch – see Appendix H). This works for all irrigation methods – pivot, hand, wheel, flood.

Gallons pumped / Acres / 27,158 = Inches of Water Applied

*Note that if you don't have a flow meter you can estimate your gallons pumped by converting your electric usage. This is most accurate for systems with a recent pump test that correlates flow with electric use.

APPLICATION AMOUNT USING PRESSURE GAUGE – WHEEL AND HAND LINES:
You can determine the amount of water applied to wheel- and hand-line irrigated fields without a flow meter using a pressure gauge and published tables. Determine the nozzle sizes of your hand- or wheel-line system by reading the size on each nozzle and by confirming them with drill bits of the same size. Determine the pressure using a pressure gauge and pitot tube (tube sized smaller than the nozzle size). Take the pressure at several points along the entire line or at a nozzle about 1/3 of the distance from the mainline to the end (this usually yeilds a good average for the entire line). Use Chart 1 below to determine the average flow rate per sprinkler. Note if you have flow control nozzles you will already know the flow rate per sprinkler.

Calculate Applied Water Using Gallons Pumped and Acreage:

Flow Rate Per Sprinkler X Number Of Sprinklers X Length Of Sets X Number Of Sets = Gallons Pumped (Use this figure and your acreage to determine the application amount as shown above.)

- OR -

Calculate Applied Water Using Pressure, Spacing and Set Length Charts:
Estimate your application rate based on your measured pressure and the Charts 1-3 below for pressure, spacing and set length.

APPLICATION AMOUNT USING RAIN GAUGES – PIVOTS:
You can also determine the application amount directly with rain gauges. These can be official rain gauges or you can use any strait-sided container such as tin cans and a tape measure. This method works best for pivots due to their better uniformity. Set out at least three cans under a pivot, the more

the better. Set them out in the middle of the pivot and not at the last two towers. Try to position them so they are not directly below a sprinkler or very near a tower. You can do this by setting them out where the pivot is setting or by pacing between wheel marks elsewhere in the field. Choose an “*average*” location and not one such as where the pivot goes up or down a steep hill. Try to watch when the system goes over the gauges to note anything important (gauge right below nozzle, wind blowing, nozzle malfunction).

APPLICATION AMOUNT USING RAIN GAUGES – WHEEL- AND HAND-LINES:
If you are testing wheel- or hand-lines, you have a much greater challenge since these systems apply water much less uniformally. Choose a sprinkler about 1/3 of the distance down the lateral from the mainline. Set out at least 6 gauges targeted around this single sprinkler. Set one or two between the sprinkler and the next one on either side (don’t put them right under the lateral line but about 2 feet out on either side. Set out one or two about 4 feet to 8 feet on either side of the lateral line adjacent to the target sprinkler (X = sprinkler   * = raingauge). Average these amounts and multiply by 0.7 to account for efficiency).

```
                                         *

                          *       *
-----------------X-----------------------------X-----------------------------X-----------------

                                                *       *

                                         *
```

UNIFORMITY TESTING USING RAIN GAUGES
Besides testing to confirm the application rate, you can also test for uniformity. Uniformity is very important for getting peak production. One of the main advantages of pivot systems is their uniformity – each part of the field recieves the same amount of water and results in even production across the entire field. If you apply 1 inch of water, every part of the field receives 1 inch.

Wheel-line and hand-line systems are not nearly as uniform as pivots. If your system should put on 3 inches in a set, parts of the field receive 3 inches but other spots may receive more than 4 and parts less than 2.

You can evaluate uniformity yourself by setting out at least 15 rain gauges and letting the system pass over them. You can also use any straight-sided container (such as tin cans) and a tape measure. Try to set gauges or cans out between and not directly underneath sprinklers. If it is windy when the system passes over, you will see how some spots may receive no irrigation if the wind comes. Repeat the experiment when it is calm.

For pivots, set out gauges or cans away from towers and not immediately under sprinklers. Note that both ends of a pivot usually get more water (first 2-3 towers). Short windy periods affect the outer portion of the pivot more since it is moving faster.

Conduct tests when crop is low at season start or after cutting and before crop overtops the rain gauges.

DETERMINING SPRINKLER APPLICATION RATES – HAND-LINES AND WHEEL-LINES

1. Measure nozzle pressure along lateral line and use an average – or measure one nozzle pressure about 1/3 of the way down the lateral from the mainline. Check nozzle sizes as you go. Use drill bits to confirm sizes if they are too worn to read. A pressure gauge with a pitot tube is used to measure pressure.
2. Use Chart 1 – ***Nozzle Discharge*** to determine the gallons per minute from each nozzle. (Note: This number times the number of nozzles to get your total system discharge.)
3. Use Chart 2 – **Average *Application Rate*** to determine the inches per hour you are applying.
4. Use Chart 3 – ***Water Applied per Set*** to determine the total amount of water you apply.
5. You can **measure** your average application by setting out rain gauges or straight-sided containers. Choose sprinklers about 1/3 of the distance from the mainline. Place containers about halfway between two adjacent sprinklers and within 10 feet of the lateral line. Be aware that closer to the sprinklers you will get more water applied.

CHART 1: NOZZLE DISCHARGE – GALLONS PER MINUTE

PRESSURE	NOZZLE SIZE							
PSI	3/21	1/8	9/64	5/32	11/64	3/16	13/64	7/32
20	1.17	2.09	2.65	3.26	3.92	4.69	5.51	6.37
25	1.31	2.34	2.96	3.64	4.38	5.25	6.16	7.13
30	1.44	2.56	3.26	4.01	4.83	5.75	6.80	7.86
35	1.55	2.77	3.50	4.31	5.18	6.21	7.30	8.43
40	1.66	2.96	3.74	4.61	5.54	6.64	7.80	9.02
45	1.76	3.13	3.99	4.91	5.91	7.03	8.30	9.60
50	1.85	3.30	4.18	5.15	6.19	7.41	8.71	10.10
55	1.94	3.46	4.37	5.39	6.48	7.77	9.12	10.50
60	2.03	3.62	4.50	5.65	6.80	8.12	9.56	11.05
65	2.11	3.77	4.76	5.87	7.06	8.45	9.92	11.45
70	2.19	3.91	4.96	6.10	7.34	8.78	10.32	11.95
75	2.27	4.05	5.12	6.30	7.58	9.08	10.66	12.32
80	2.35	4.18	5.29	6.52	7.84	9.39	11.02	12.74
85	2.42	4.31	5.45	6.71	8.07	9.67	11.35	13.11
90	2.49	4.43	5.61	6.91	8.31	9.95	11.69	13.51
95	2.56	4.56	5.76	7.09	8.53	10.2	11.99	13.86
100	2.63	4.67	5.91	7.29	8.76	10.5	12.32	14.23

CHART 2:

AVERAGE APPLICATION RATE - INCHES PER HOUR

Spacing Feet	Gallons Per Minute From Each Sprinkler 2	3	4	5	6	7	8	9	10	12
20X20	.48	.72	.96	1.20	1.44	1.70	1.93	2.16	2.40	
20X30	.32	.48	.64	.80	.96	1.12	1.28	1.43	1.60	1.93
20X40	.24	.36	.48	.60	.72	.84	.96	1.08	1.20	1.45
30X30	.21	.32	.43	.54	.64	.75	.88	.96	1.07	1.28
30X40	.16	.24	.32	.40	.48	.56	.64	.72	.80	.95
30X50	.13	.19	.25	.32	.38	.45	.51	.58	.64	.76
40X40	.12	.18	.24	.30	.36	.42	.48	.54	.60	.72
40X50	.10	.14	.19	.24	.29	.34	.38	.43	.48	.58
40X60		.12	.16	.20	.24	.28	.32	.36	.40	.48

CHART 3: WATER APPLIED PER SET – INCHES AT 70% EFFICIENCY

(30% LOSS DUE TO INTERCEPTION, EVAPORATION, NON-UNIFORMITY)

SET HRS	------------------IRRIGATION SYSTEM APPLICATION RATE FROM CHART 2------------------- .12	.14	.16	.18	.20	.22	.24	.26	.30	.35	.45	.55
1	.08	.10	.11	.13	.14	.15	.17	.18	.21	.25	.32	.39
2	.17	.20	.22	.25	.28	.31	.34	.36	.42	.49	.63	.77
3	.25	.29	.34	.38	.42	.46	.50	.55	.63	.74	.95	1.16
4	.34	.39	.45	.50	.56	.62	.67	.73	.84	.98	1.26	1.54
5	.42	.49	.56	.63	.70	.77	.84	.91	1.05	1.23	1.58	1.93
6	.50	.59	.67	.76	.84	.92	1.01	1.09	1.26	1.47	1.89	2.31
7	.59	.69	.78	.88	.98	1.08	1.18	1.27	1.47	1.72	2.21	2.70
8	.67	.79	.90	1.01	1.12	1.23	1.34	1.46	1.68	1.96	2.52	3.08
9	.76	.88	1.01	1.13	1.26	1.39	1.51	1.64	1.89	2.21	2.84	3.47
10	.84	.98	1.12	1.26	1.40	1.54	1.68	1.82	2.10	2.45	3.15	3.84
11	.92	1.08	1.23	1.39	1.54	1.69	1.85	2.00	2.31	2.70	3.47	4.24
12	1.01	1.18	1.34	1.51	1.68	1.85	2.02	2.18	2.52	2.94	3.78	4.62
15	1.26	1.47	1.68	1.89	2.10	2.31	2.52	2.73	3.15	3.68	4.73	5.78
18	1.51	1.76	2.02	2.27	2.52	2.77	3.02	3.28	3.78	4.41	5.67	6.93
21	1.76	2.06	2.35	2.65	2.94	3.23	3.53	3.82	4.41	5.15	6.62	8.09
24	2.02	2.35	2.69	3.02	3.36	3.70	4.03	4.37	5.04	5.88	7.56	9.24
30	2.52	2.94	3.36	3.78	4.20	4.62	5.04	5.46	6.30	7.35	9.45	11.55

Appendix F

CONVERSION FACTORS

1 cubic foot of water……………..7.48 gallons…………62.4 pounds of water

1 acre-foot……………………43,560 cubic feet…………………325,900 gallons
(An acre-foot covers one acre of land one foot deep)

1 acre-inch………………………3,630 cubic feet…………………27,158 gallons
(field acreage and inches applied can be converted to gallons)

1 cubic feet per second (CFS)……..…………448 gallons per minute (GPM)

1 CFS……………40 Montana Miners Inches……….646,272 gallons per day

1 CFS for:
24 hours……..1.98 acre-feet
30 days……59.5 acre-feet
1 year….724 acre-feet

1 million gallons……………………………………………………..3.07 acre-feet

1 million gallons per day (MGD)……………………..1,122 acre-feet per year

1,000 gallons per minute (GPM)……………………………………..2.23 CFS

1,000 gallons per minute (GPM)………………………..4.42 acre-feet per day

THE AUTHOR

Barry Dutton graduated from Great Falls High in 1970 and the University of Montana in 1976 with a degree in Forestry and Soils. He worked for a few years as a soil scientist for state and federal agencies before starting a natural resource consulting firm called Land & Water Consulting. He mapped several million acres of soils, vegetation and wetlands across the western United States and his projects have included forests, rangelands, wetlands, farmlands, parklands and developments (soil is connected to everything). As an irrigation consultant, Barry helped develop the AGRIMET weather station system in Western Montana and has gone field to field over the past three decades working with individual irrigators to monitor soil moisture and make improve water use. From 2010-present he has consulted for the Blackfoot Challenge to provide weekly reports summarizing crop water use, weather, soil moisture, soil health, drought issues and related topics. When not digging soil pits he loves dogs, skiing, hiking and guitars.