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FLATHEAD IRRIGATION INFORMATION SYSTEM

SUMMARY REPORT AND IRRIGATION GUIDE

DUTTON Report

PREPARED FOR:

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This project would not have been possible without the interest and efforts of many individuals and organizations. We would like to thank all those who contributed their support and encouragement. First are the local growers who together with Willy Huot, Lake county Extension Agent, stimulated an Integrated Crop and Pest Management Program which identified the need for further work on local irrigation. The Bonneville Power Administration provided funding and encouragement under the direction of Larry King who has contributed in many ways to irrigated agriculture in Montana and the Pacific Northwest. The US Bureau of Reclamation Agrimet staff provided support and technical assistance especially Monty McVay and Alan Powers. The local energy utility Mission Valley Power provided coordination and assistance under direction of Alan Walston. The Flathead Joint Board of Control gave early encouragement and later sponsorship of the DNRC grant which allowed us to continue the project and capture the results in a format which could be used for many years to come by all irrigators. The Lake County Leader newspaper provided space for disseminating crop water use information to the general public.

Last and most important, we would like to express our deepest appreciation to the irrigators who helped initiate the program and who participated in energy audits and irrigation scheduling. Much of the knowledge contained in this report was acquired over years of experience by local irrigators who have been generous in letting us capture this knowledge for the use of all current and future water users.

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1.0 INTRODUCTION

This irrigation guide summarizes the results of a four year program to improve irrigation energy and water use at the Jocko, Mission and Flathead irrigation districts in Lake, Missoula and Sanders counties of west-central Montana. Data collected during this program are summarized and methods are recommended for using water and energy more efficiently. This report is not meant to be a comprehensive design manual but should provide important and useful data for irrigators as well as energy and water managers. The focus of this effort has been sprinkler irrigation systems but many of the principals apply to other irrigation systems. This program and report were completed by a team of two soil scientists, an irrigation system designer, a registered professional engineer and several technicians.

2.0 IRRIGATION SCHEDULING

The goal of irrigation scheduling is to apply the right amount of water at the right time in order to maximize crop production and minimize adverse environmental impacts. Where water is available in unlimited supply, irrigation scheduling attempts to match irrigation applications with actual crop water use (evapotranspiration). Where water supplies are limited, irrigation applications are made at only the most critical crop stages.

When irrigation water is properly applied, runoff and erosion are minimized. Proper application ensures that soil water holding capacity is not exceeded and potential pollutants are not washed through the soil. These pollutants include fertilizers, pesticides and other materials.

2.1 PROGRAM DESCRIPTION

An irrigation scheduling program was developed during this project to help individual irrigators understand their irrigation management better, to collect information about local irrigation practices, to improve irrigation timing and to pass this information on to a larger audience. The program had several important components.

Two automated weather stations were installed at Round Butte (1989) and St. Ignatius (1991) by the U S Bureau of Reclamation staff from the Boise, Idaho AGRIMET center. These stations record and relay weather data to the Boise AGRIMET center via satellite.

Weather data was processed in Boise to calculate daily evapotranspiration and crop water use. These predictions of crop water use were adjusted using field experience gained by Land and Water Consulting. Adjustments were made to account for annual and seasonal climate variation, crop planting dates and soil moisture patterns.

Soil moisture conditions were monitored in 28-47 fields each year representing the range of local climate, soils, crops and water availability. Rain gauges were placed at soil moisture sampling locations in each field to measure irrigation applications and outside each irrigated field to measure rainfall. Soil moisture was evaluated using a combination of neutron probe measurements, gravimetric samples and the "feel method". Work was performed by soil scientists with years of experience evaluating soil moisture conditions and irrigated agriculture.

Information was summarized in a weekly report for each irrigator including soil moisture status, crop development stage, climate data and recommendations for irrigation. A weekly summary of crop water use, soil moisture conditions and irrigation recommendations was published in the local newspaper for general public use. This information included lawn irrigation as well as agricultural crops.

A computer program called AGWATER was adapted for local use in educating irrigators and students about irrigation system performance and irrigation scheduling. This program allows the user to simulate changing nozzles, pressures, spacings, timing and other irrigation factors then see a graphic presentation of the predicted effects on soil moisture. This allows "what if" questioning before investing in major changes.

The results of this project include a better educated group of participating irrigators, a more knowledgeable general irrigator public, a group of educational tools and a compilation of data on current irrigation practices.

2.2 EVAPOTRANSPIRATION AND CROP WATER USE

Evapotranspiration is the amount of water transpired by plants and the amount of water evaporated from the soil surface. Plants transpire water to satisfy physiological requirements such as photosynthesis and solute transport. ET is driven mainly by solar radiation received at the plant and soil surface and by the surrounding vapor pressure gradient of the air. These in turn are determined by temperature, humidity, reflectance, wind, cloud cover and other variables. ET varies on a daily basis as well as an annual basis with mid-day and mid-summer yielding the highest potential ET.

Plants and soil also influence ET. Leaf area, rooting depth, growth stage, soil texture and available soil water all have an effect. It is important to note that if no water is available for ET then ET will not occur no matter how great the demand is. ET is most often estimated using climatic data.

2.21 AGRIMET

The U.S. Bureau of Reclamation operates a satellite-based network of automatic agricultural weather stations called Agrimet. Two stations are located in this area including one at Round Butte and one at Saint Ignatius. Each station monitors air temperature, relative humidity, precipitation, wind and solar radiation. Data are relayed via satellite to the Bureau's Vax computer in Boise, Idaho. The computer calculates ET for an alfalfa-reference crop using the 1982 Kimberly Penman equation. This represents the potential ET for a mature alfalfa crop where water is not limiting. Crop coefficients are used to adjust the alfalfa ET to other crops.

These coefficients take into account the different growth stages and water requirements of these other crops.

2.22 Crop ET

Table 1 illustrates average monthly ET for local agricultural crops based on data from the local Agrimet weather stations. Different start dates are indicated for some annual crops. These data suggest that local alfalfa has an annual ET of 24 to 26 inches. Those areas where growth starts earlier use slightly more water. Winter wheat uses 16-17 inches and spring grains 15-17 inches. Potatoes use 15-18 inches.

TABLE 1. SUMMARY OF AGRIMET CROP WATER USE DATA - Average monthly, average annual and peak daily crop water use in inches.

ST. IGNATIUS ('91 - '92)

CROP & PLANTING	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	ANN	PEAK* DAILY
ALFALFA	0.22	1.87	3.96	4.49	5.57	5.20	3.32	0.38	25.01	0.20
PASTURE	0.29	1.93	3.57	4.00	4.91	4.59	2.98	0.34	22.81	0.18
WTR. GRAIN	0.33	2.13	4.59	5.28	4.08	0.00	0.00	0.00	16.41	0.20
SPR. GRAIN (early)	0.00	0.68	3.65	5.26	5.80	0.42	0.00	0.00	15.81	0.21
SPR. GRAIN (mid.)	0.00	0.32	2.87	5.19	6.19	1.02	0.00	0.00	15.59	0.23
SPR. GRAIN (late)	0.00	0.14	1.99	4.99	6.42	1.84	0.00	0.00	15.38	0.23
POTATOES (early)	0.00	0.00	1.27	3.62	5.96	5.25	1.86	0.00	17.96	0.22
POTATOES (mid.)	0.00	0.00	0.44	2.46	5.60	5.42	2.35	0.00	16.27	0.20
POTATOES (late)	0.00	0.00	0.00	1.41	4.73	5.55	2.76	0.15	14.60	0.20

ROUND BUTTE ('89 - '92)

CROP & PLANTING	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	ANN	PEAK* DAILY
ALFALFA	0.23	2.26	4.13	4.80	5.76	4.74	3.51	0.39	25.82	0.21
PASTURE	0.35	2.29	3.70	4.27	5.09	4.22	3.14	0.24	23.30	0.19
WTR. GRAIN	0.30	2.59	4.83	5.66	3.90	0.00	0.00	0.00	17.28	0.21
SPR. GRAIN (early)	0.00	0.81	3.92	5.65	5.99	0.28	0.00	0.00	16.65	0.22
SPR. GRAIN (mid.)	0.00	0.37	3.15	5.60	6.34	0.50	0.00	0.00	15.96	0.23
SPR. GRAIN (late)	0.00	0.14	2.21	5.45	6.66	1.21	0.00	0.00	15.67	0.24
POTATOES (early)	0.00	0.00	1.41	4.01	6.22	4.79	1.76	0.00	18.19	0.23
POTATOES (mid.)	0.00	0.00	0.52	3.02	5.99	4.97	2.31	0.00	16.81	0.22
POTATOES (late)	0.00	0.00	0.00	1.77	5.24	5.11	2.82	0.08	15.02	0.19
FIELD CORN	0.00	0.00	0.69	2.64	5.74	5.44	3.14	0.00	17.65	0.21

ET does vary slightly across the area as reflected in crop water use figures from the Round Butte and St. Ignatius weather stations. Areas east of highway 93 are likely to have ETs similar to St. Ignatius while the rest of the area is more similar to Round Butte. The Moiese, Dixon and Hot Springs areas may have values slightly higher than Round Butte due to a longer growing season and slightly warmer temperatures. This difference is only 1-3 inches at the most for alfalfa and less for other crops.

These Agrimet-derived ET predictions are similar to those published by the USDA Soil Conservation Service for Climate Zone 3 which covers most of this area. Part of the area, especially near Hot Springs, is listed in Climate Zone 2 which has slightly higher consumptive use (2-3 inches for alfalfa).

Peak daily ET was computed by increasing the average daily ET for the peak month by 13 percent. The 13 percent increase was determined by computing the average alfalfa-reference ET for the highest 10 consecutive days in July and computing the percent increase above the July daily average. A 10 day period was chosen because it is a common length for an irrigation cycle in Western Montana.

Most differences in irrigation practices across the study area were due to water availability and not to differences in ET.

2.23 Local Climate Variations

Climate variations within the local area are significant enough to affect irrigation practices. Annual and growing season rainfall generally increase from west to east across the irrigated valley-bottom lands from Hot Springs on the west to the Mission Mountain foothills on the east. Figure 1 illustrates average growing season rainfall (April 1 - October 1) interpreted from rainfall measurements in alfalfa fields 1989-1992. Growing season rainfall is approximately 5 inches at Hot Springs increasing to 6 inches in Dixon, Moiese, west Round Butte and west Valley View. Growing season rainfall increases rapidly east of Highway 93 to about 10 inches near the Mission Mountain foothills. These differences affect irrigation practices most at the start of the growing season. Crop growth starts 1-3 weeks earlier in the western and southwestern portions of the study area than in the eastern and northern portions.

Rainfall patterns in individual storms usually follow these same general patterns with total amounts increasing eastward. However, rainfall amount may vary tremendously over short distances. Storms were recorded which reversed the normal pattern and left more rain in the western areas than the eastern.

2.3 CROP WATER USE BY LOCAL IRRIGATORS

Most local irrigators do not have sufficient irrigation water available to satisfy crop water needs (ETO) and are therefore practicing **deficit irrigation**. Table 2 lists average rainfall and irrigation for crops evaluated during this four year study. These values are added as the total applied water which can then be compared with the potential crop water use (ETO). Potential crop water use minus the amount of applied water equals the average deficit.

FIGURE 1. AVERAGE GROWING SEASON RAINFALL (April 1 - October 1, in inches)

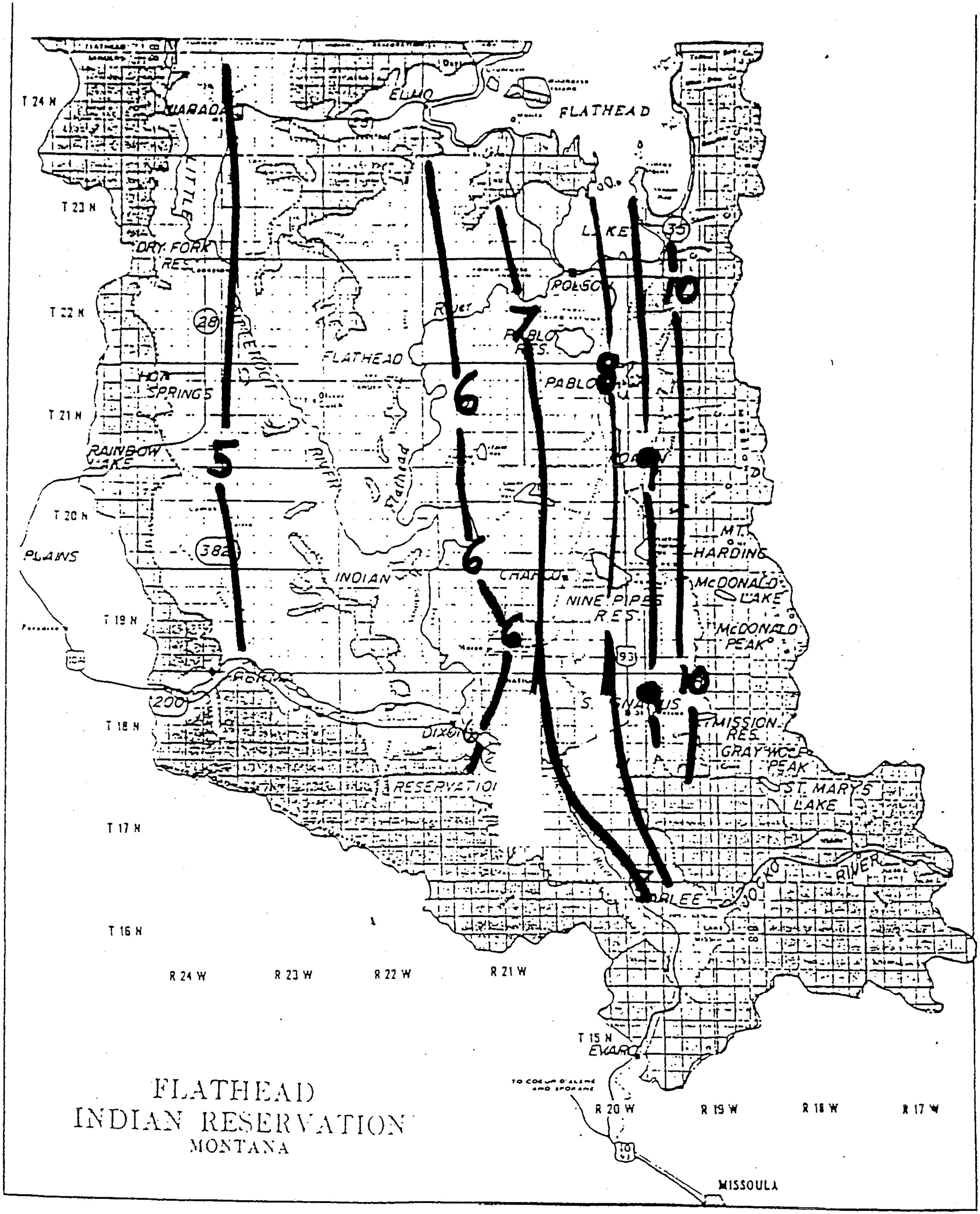


TABLE 2. AVERAGE RAINFALL AND IRRIGATION WATER APPLICATIONS COMPARED WITH POTENTIAL CROP WATER USE (ETO). RANGE OF IRRIGATION APPLICATIONS AND AVERAGE IRRIGATION DEFICIT ARE ALSO LISTED.

COMBINED FOUR YEAR AVERAGES 1989-1992							
CROP	n	RAINFALL	IRRIGATION	RANGE APPLIED (IRRIGATION)	APPLIED[1]	ETO[2]	DEFICIT[3]
ALFALFA	50	7.5	10.2	8.9 - 26.5	17.8	27.5	-9.7
BARLEY	2	5.8	3.6	3.3 - 15.4	9.4	16.1	-6.7
CORN	3	4.0	6.6	8.5 - 12.1	10.6	15.1	-4.5
GRASS HAY	12	6.4	15.6	15.3 - 25.6	22.0	27.2	-5.2
OATS	5	4.5	4.6	5.9 - 15.2	9.1	16.3	-7.2
POTATOES	9	4.4	11.1	9.2 - 28	15.5	20.0	-4.5
SPRING WHEAT	12	4.8	6.9	6.2 - 22.3	11.7	15.7	-4.0
WINTER WHEAT	24	4.7	7.1	6.5 - 18.8	11.8	16.5	-4.8

[1] TOTAL H20 APPLIED = RAINFALL + IRRIGATION

[2] ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)

[3] DEFICIT = TOTAL H20 APPLIED - ETO

Table 2 indicates that these crops are receiving an average of 4-10 inches less water than needed to satisfy crop water needs. This under-watering stresses the crop which reduces yields, quality and profits.

Appendix B compares crop water needs with applied irrigation and rainfall for individual fields throughout the four year study. In approximately 8% of the cases, more irrigation water was applied than needed for crop ET. This only occurred with annual crops such as spring grains or seed potatoes. Most of this water was not lost but was stored lower in the soil profile for use by future crops. Most of these sites are in a crop rotation and the extra moisture is used by subsequent perennial crops which also extract moisture from deeper depths. The monitoring program did not detect widespread over-irrigation sufficient to move agricultural chemicals or other pollutants into ground or surface waters.

Since deficit irrigation is the common local practice, irrigation water use efficiency is very high. This high value reflects the fact that most of the applied water is used by plants and little or none is lost to runoff or deep percolation below the root zone.

Figure 2 illustrates a seasonal soil moisture pattern for an alfalfa crop where the irrigator is attempting to satisfy actual crop water use (ETO). In this case, the irrigator has managed to keep the moisture content reasonably high throughout the season by applying 16 inches of irrigation water. His reward was a yield of approximately 6 tons/acre. Figures 3 and 4 illustrate more common local soil moisture pattern in alfalfa where crops are severely stressed for portions of the year. These irrigators applied 8 - 11 inches of irrigation water and achieved yields of 3 - 4 tons/acre.

Figure 5 illustrates a seasonal soil moisture pattern for a well-irrigated small grain crop where the irrigator is attempting to satisfy actual crop water use (ET). Note that the available water holding capacity increases as rooting depth increases with annual crops. In this case, soil moisture was kept reasonable high throughout the season by applying 10 inches of irrigation water. The result was a yield of approximately 100 bushels/acre.

Figure 6 illustrates a more common local soil moisture pattern in small grains where only one irrigation is applied (near the boot stage). This irrigator applied 3 inches of irrigation water for a yield of approximately 70 bushels/acre. This high yield for only 3 inches of irrigation water was due to slightly higher rainfall and precise timing of the one irrigation.

Figure 7 illustrates the general relationship between maximum potential local alfalfa yield and the total amount of water supplied to the crop. Many factors affect yield and this graph is only presented as an illustration.

2.4 DEFICIT IRRIGATION AND CRITICAL GROWTH PERIODS

Deficit irrigation requires a different strategy than irrigation which attempts to fulfill all crop water use needs (ETO). In deficit irrigation, the goal is to apply the limited water supply for the maximum effect.

Critical growth periods are the growth stages where water supply has the greatest impact on final yield. The first critical growth period is germination/emergence. Rainfall and soil moisture are usually sufficient for local crops during this growth period since most crops are planted in spring or fall when natural soil moisture is highest. The next most critical period for small grains is at heading/flowering and for alfalfa or other hay crops is after cutting. Critical growth periods are identified in the discussions of each local crop.

Local irrigators should concentrate their efforts on applying water at these critical growth periods. These periods are identified in the discussions of individual local crops.

2.5 ROOTING DEPTH

Rooting depth is important in determining the amount of water the soil will hold and how to manage irrigations. Small grain root zones are often considered as up to 3 feet and alfalfa root zones as up to 5 feet. These root zone depths should be used in areas with unlimited water supplies and sandy or gravely soils. However, due to deficit irrigation practices, much of this

FIGURE 2. SOIL MOISTURE PATTERN IN A WELL-IRRIGATED ALFALFA FIELD (Ronan area, clayey soil, sideroll system, 1992, yield = 6 t/a).

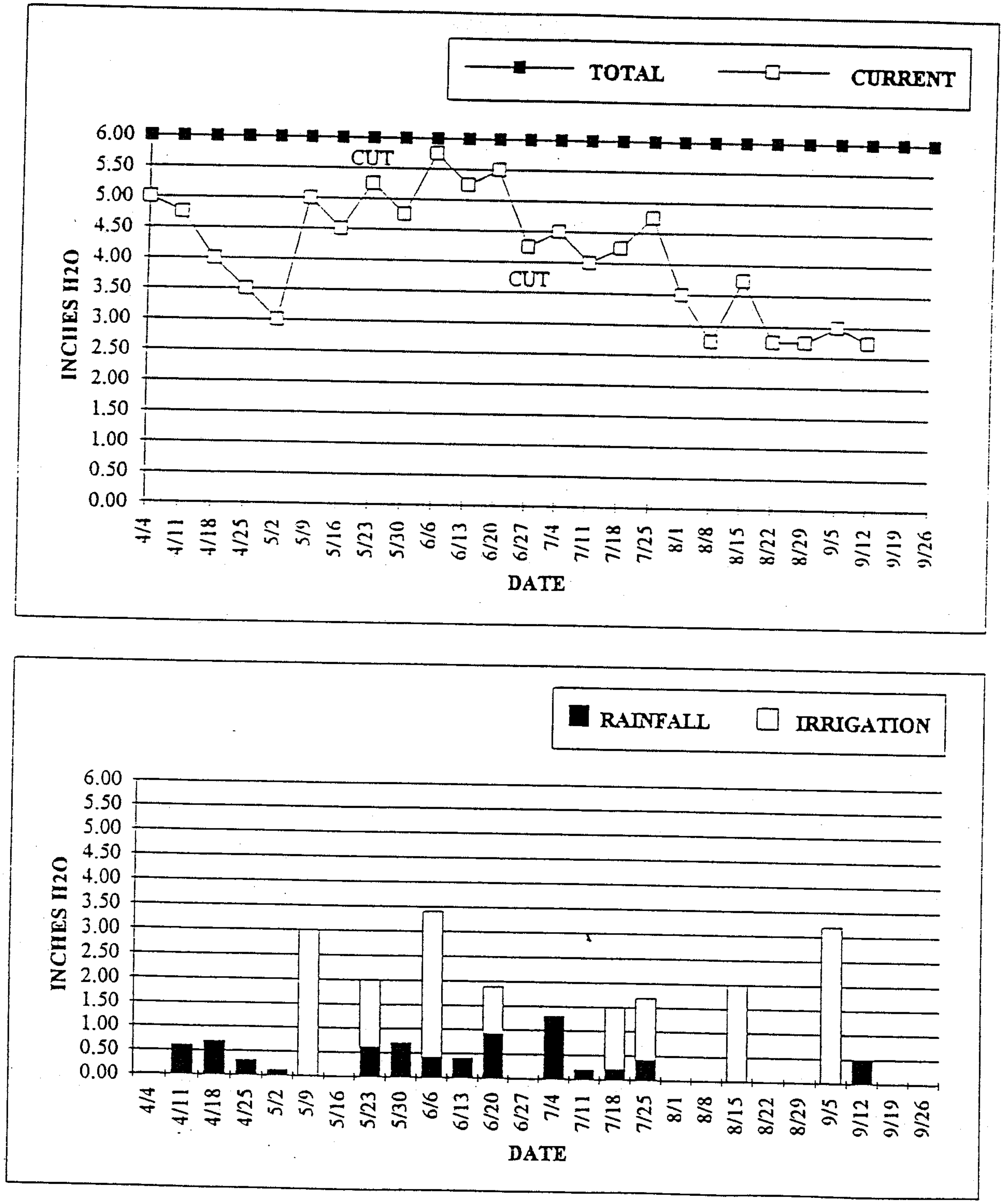
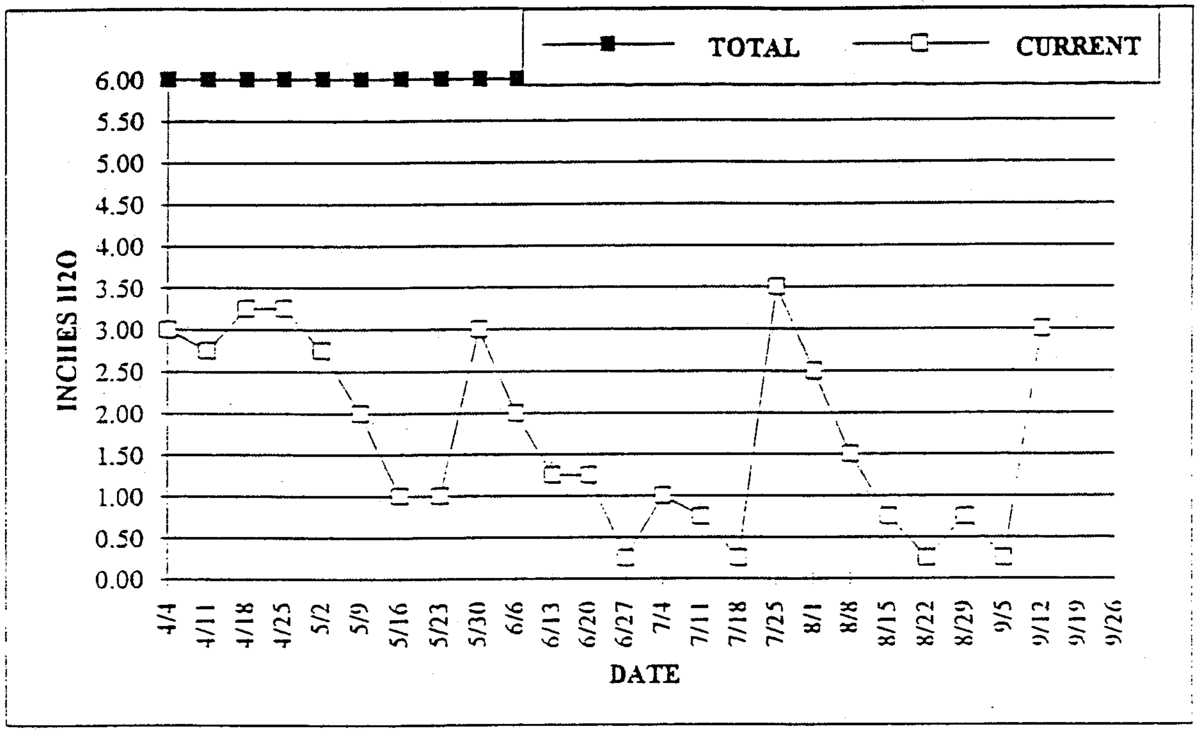


FIGURE 3. SOIL MOISTURE PATTERN IN A CONSERVATIVELY-IRRIGATED ALFALFA FIELD (Valley view area, clayey soil, sideroll system, 1992, yield = 4 t/a).



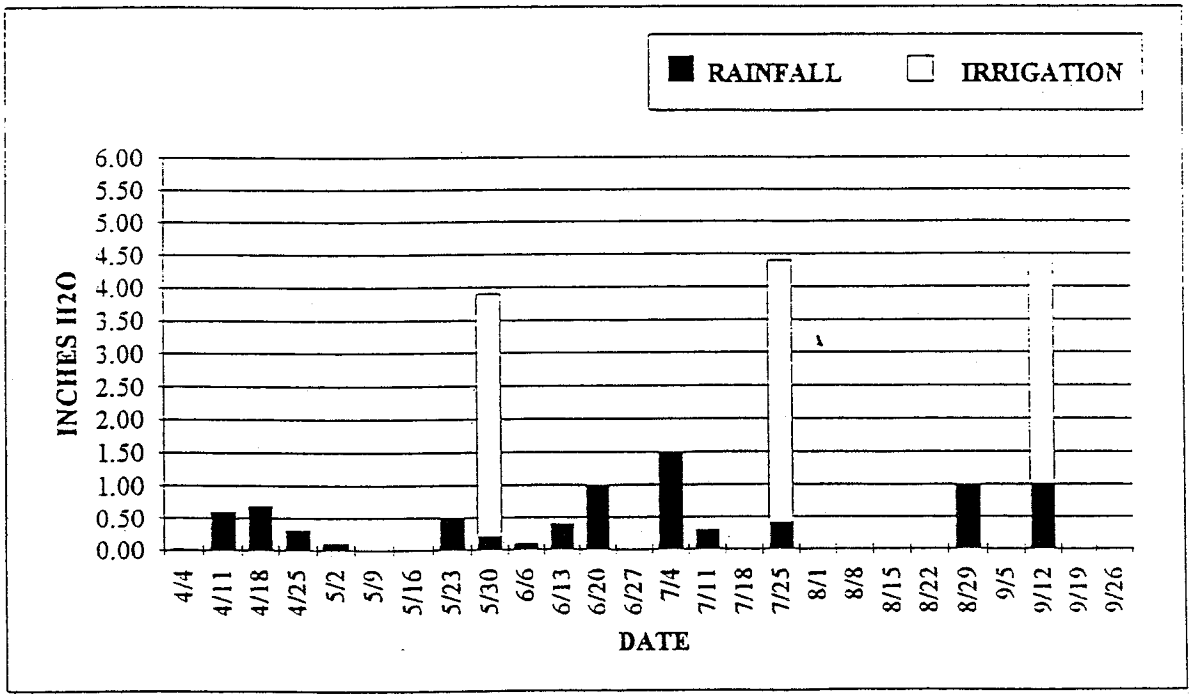
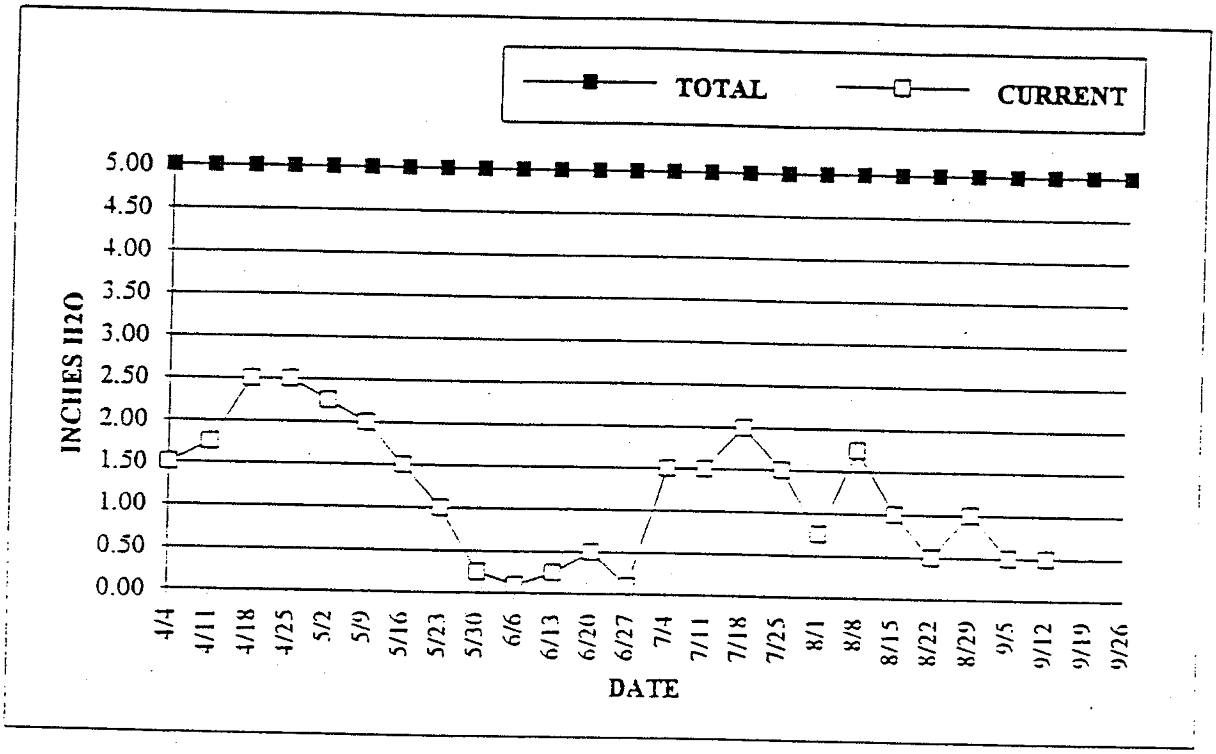


FIGURE 4. SOIL MOISTURE PATTERN IN A CONSERVATIVELY-IRRIGATED ALFALFA FIELD (Polson area, loamy soil, sideroll system, 1992, yield = 3 t/a).



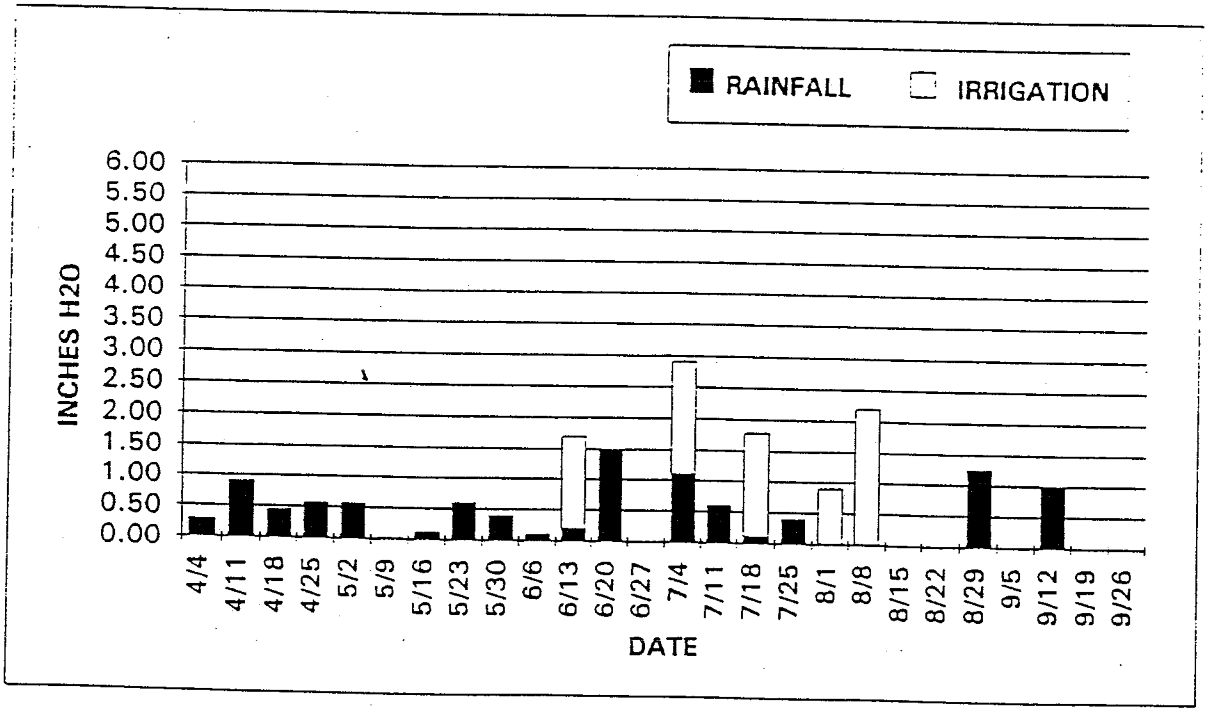
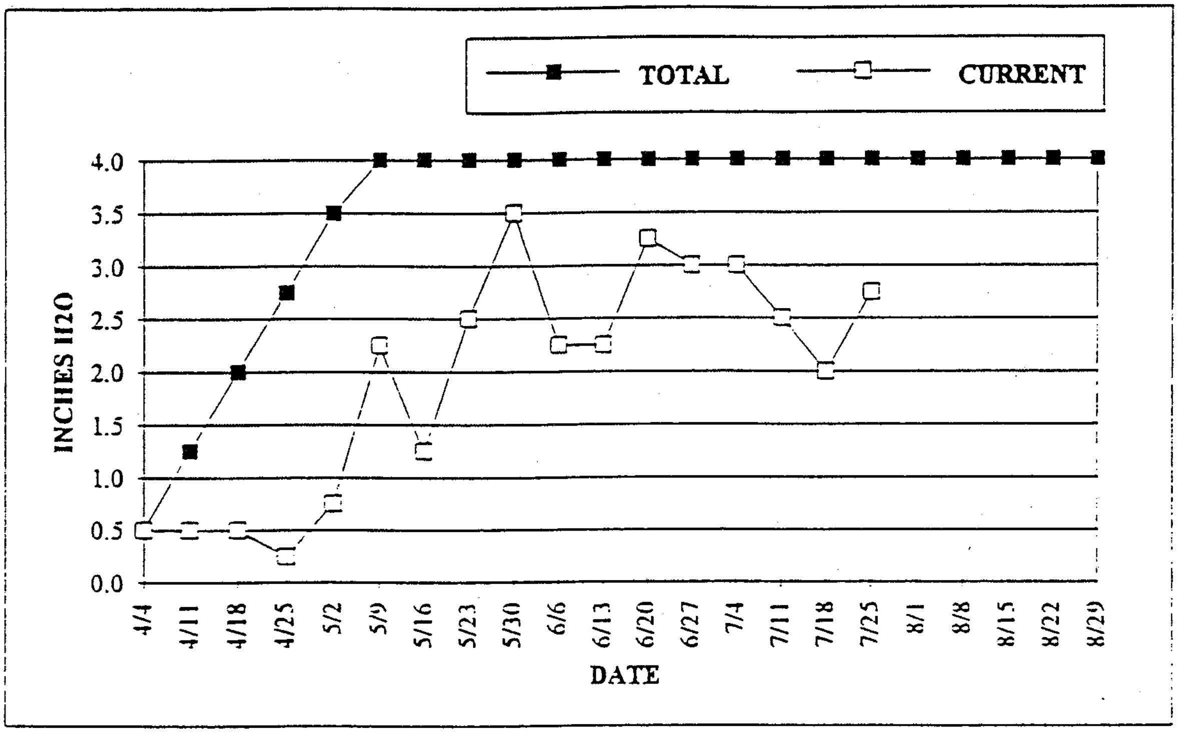


FIGURE 5. SOIL MOISTURE PATTERN IN A WELL-IRRIGATED WINTER WHEAT FIELD (Moiese area, clayey soil, side roll system, 1992, yield = 100 bu/ac).



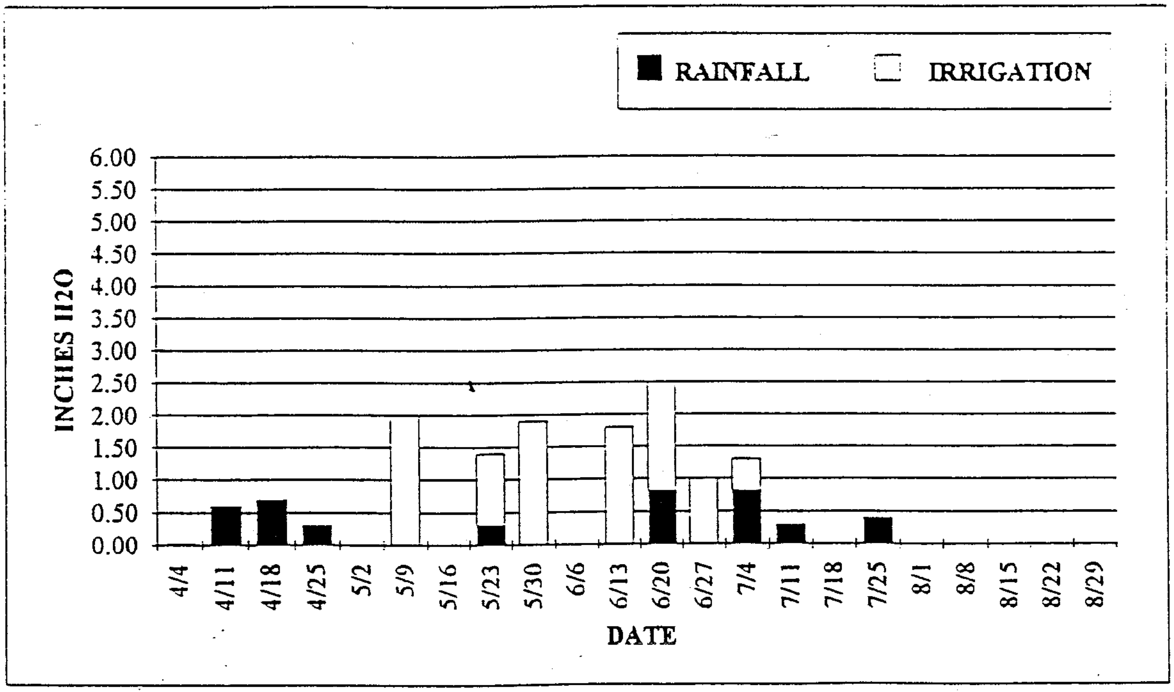
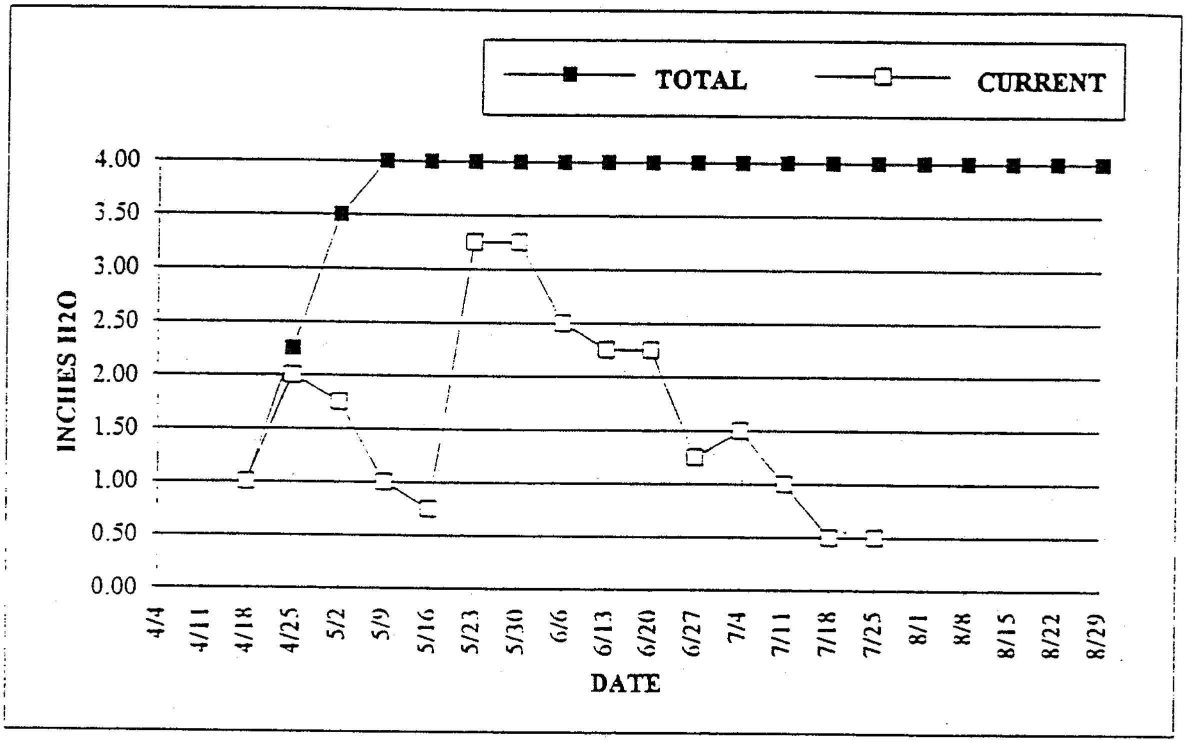


FIGURE 6. SOIL MOISTURE PATTERN IN A CONSERVATIVELY-IRRIGATED BARLEY FIELD (Ronan area, clayey soil, side roll system, 1992, yield = 80 bu/ac).



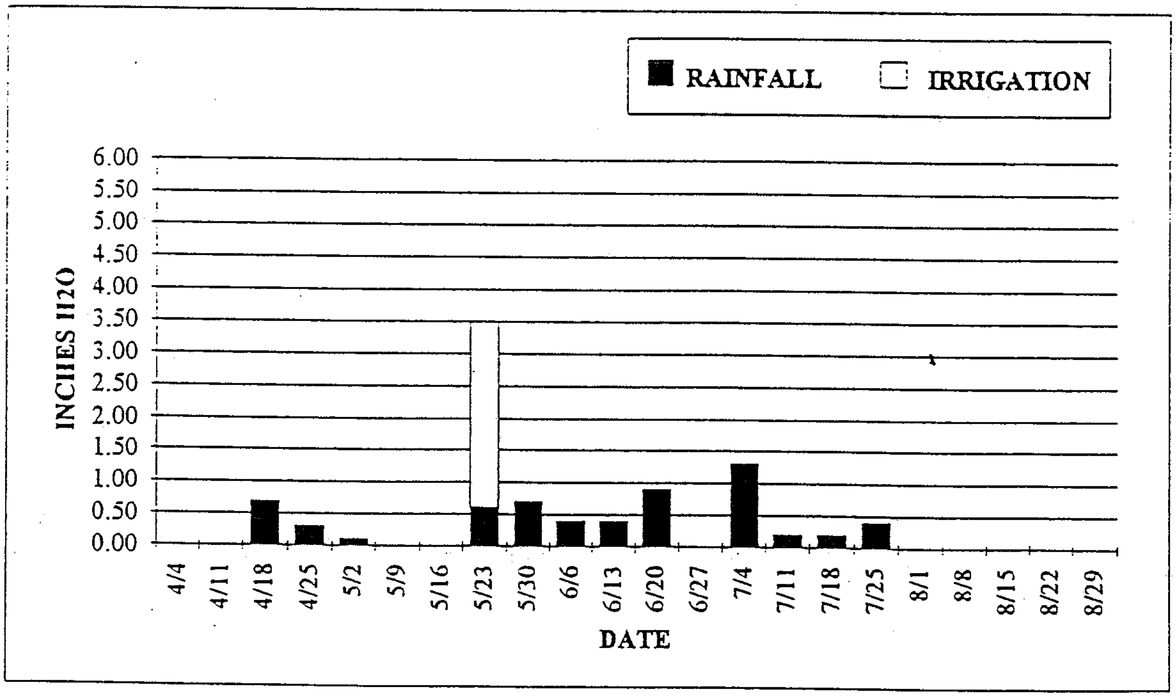
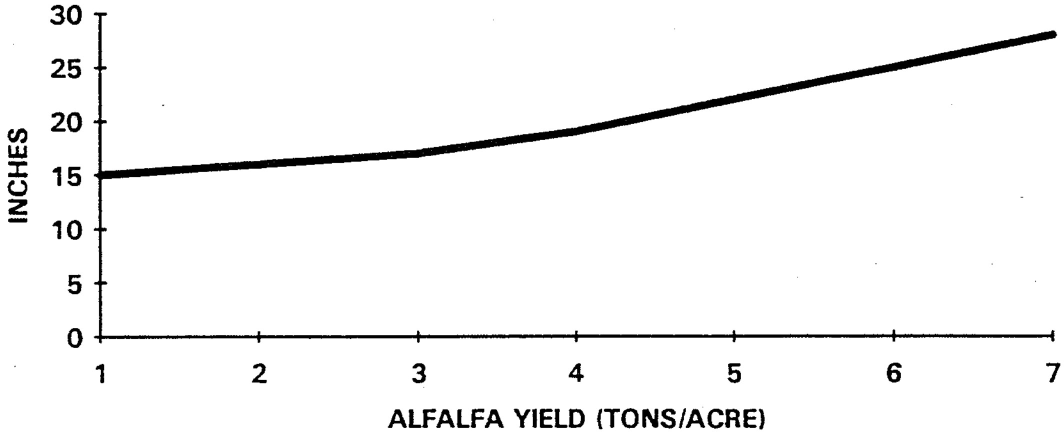


FIGURE 7. GENERAL LOCAL RELATIONSHIP BETWEEN MAXIMUM POTENTIAL ALFALFA YIELD AND TOTAL WATER (INCHES) SUPPLIED TO THE CROP BY RAINFALL AND IRRIGATION.



local area has crop root zones which are shallower than in well-irrigated areas. Many local irrigators apply approximately 3 inches of water per application. This amount of water will moisten a dry sandy soil to 2.0-3.0 feet and a clayey soil to 1.5-2.0 feet. Figure 8 illustrates that even on a medium textured soil (loam), irrigation and rainfall only affected the upper two feet of soil significantly. There was little change in soil moisture content throughout the year below 3-4 feet. Figure 9 illustrates a similar relationship for a clay textured soil.

For the purpose of local irrigation management, we suggest using a small grain root zone of 2 feet and an alfalfa root zone of 3 feet.

Rooting depth increases as crops mature. Annual crops such as grains begin from seed each year and so rooting depth increases as the crop grows. It is possible to overwater in the early season when the root zone is very shallow but in most cases, the extra water will be used by the crop later as the root system develops. Overwatering from sprinkler irrigation in this area is usually a few inches at most on an annual basis. Where we have observed over-watering of grain crops, the extra water has been used by subsequent hay and pasture crops which are much deeper rooted.

2.6 AVAILABLE WATER HOLDING CAPACITY

Available water holding capacity (AWHC) is the amount of water the soil will hold for plant growth. Soil texture, organic matter content and depth are the most important factors of AWHC in this area. AWHC can vary widely. A clayey or silty soil without rocks may hold 6 inches of water in a three foot root zone while a sandy soil with 50% rock content may only

FIGURE 8. SOIL MOISTURE PROFILES THROUGHOUT THE 1992 GROWING SEASON FOR A WINTER WHEAT FIELD WITH LOAM TEXTURED SOIL.

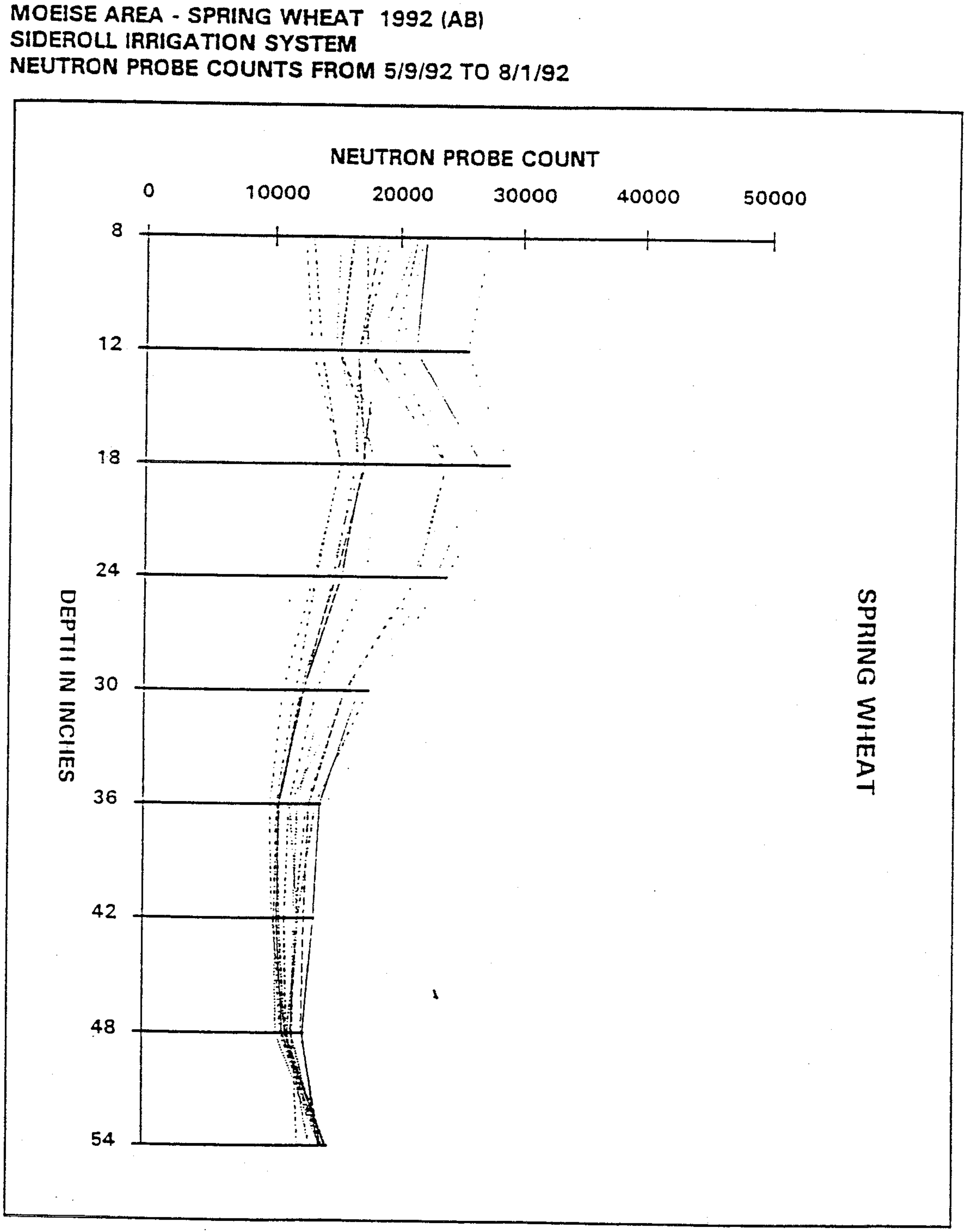
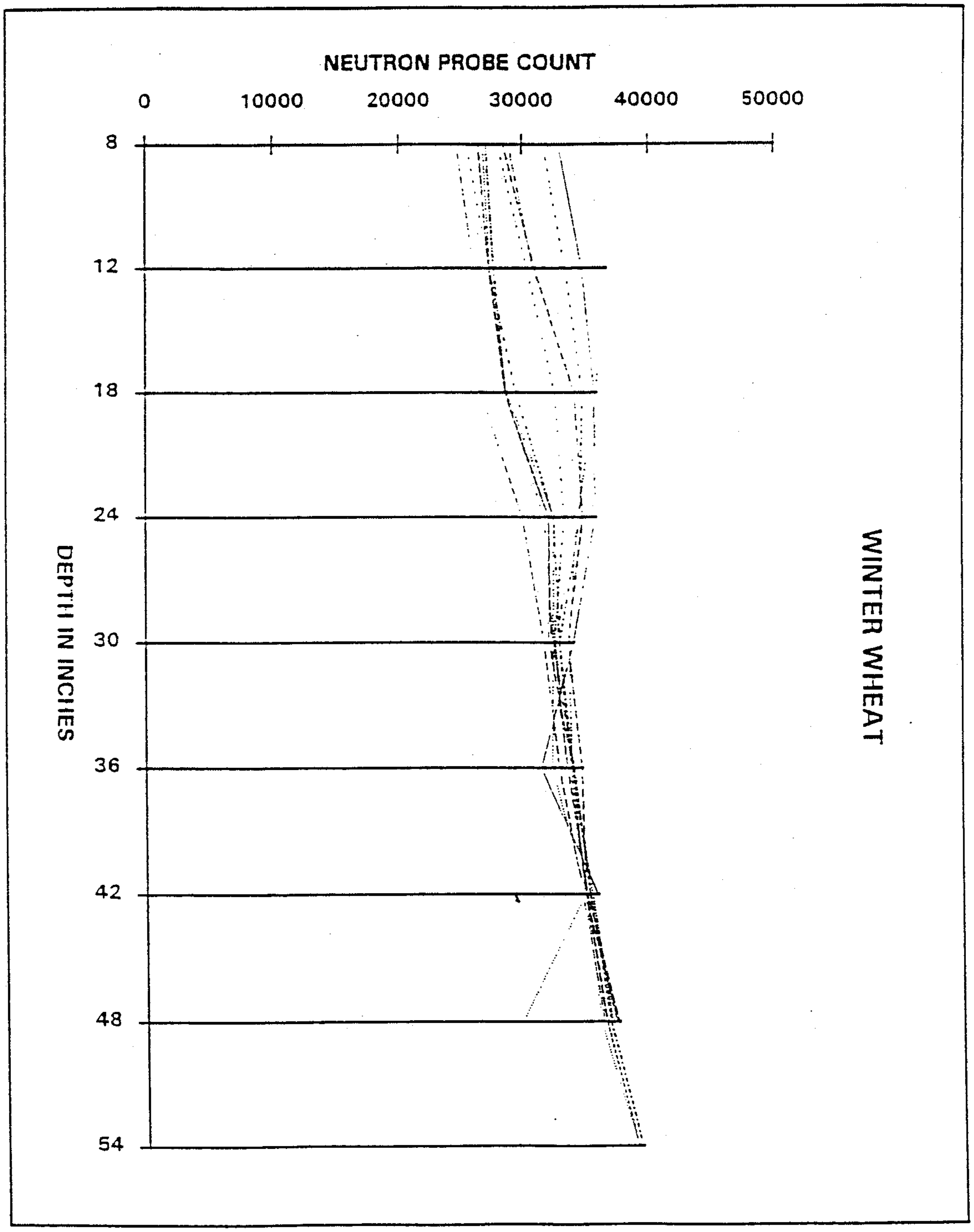


FIGURE 9. SOIL MOISTURE PROFILES THROUGHOUT THE 1992 GROWING SEASON FOR A SPRING WHEAT FIELD WITH CLAY TEXTURED SOIL.

ROUND BUTTE AREA - WINTER WHEAT - 1992 (DE)
SIDEROLL IRRIGATION SYSTEM
NEUTRON PROBE COUNTS FROM 5/9/92 TO 7/25/92



hold 1.5 inches in three feet of soil. Information on AWHC can be generalized from soil maps available from the USDA Soil Conservation Service. Be sure to only use the root zone depths discussed above. AWHC can also be estimated using the following procedure.

STEP 1 - Determine the soil texture of each layer throughout the 2-3 foot root zone using the guides in Appendix C.

STEP 2 - Determine the AWHC of each layer based on its soil texture using the guides. Make reductions based on the rock content.

STEP 3 - Determine the total AWHC of the entire root zone by multiplying the AWHC of individual soil layers by their thicknesses.

EXAMPLE: AWHC of a silt loam/sandy loam soil growing alfalfa in the Valley View area with a 3 foot effective root zone.

DEPTH	SOIL TEXTURE	AWHC	ROCK CONTENT	AWHC
0-1 FT	SILT LOAM	2 IN/FT	0%	2.00 INCHES
1-2 FT	SANDY LOAM	1.5	30%	1.00 INCHES
2-3 FT	SANDY LOAM	1.5	50 %	0.75 INCHES

TOTAL ROOT ZONE = 3.75 INCHES

AWHC can be calculated for different crop stages as rooting depth increases throughout the growing season. For further information see the Montana Pocket Irrigators Guide, the AGWATER computer program or the USDA Soil Conservation Service Montana Irrigation Manual.

Irrigation should not begin until there is sufficient depletion of AWHC to retain the applied water in the root zone. This will prevent over watering and movement of water and agricultural chemicals below the root zone. The **critical moisture level** (also called the management allowed deficit or **MAD**) is the point at which crop stress begins and yield is reduced. This value is usually 40-60% of the AWHC. Under ideal conditions, this is the point at which irrigation water should be applied.

For the example above, the MAD level would be 3.75/2 = 1.89 inches. If water is available and the system is capable of applying this amount, irrigation should begin. Since most local irrigators are practicing deficit irrigation, they typically stress their crops by allowing soil moisture to fall below the MAD level. Attempts are made to boost soil moisture above MAD only at the most important crop growth stages.

2.7 APPLICATION UNIFORMITY

Irrigation application uniformity affects crop yield and quality. The better the uniformity across the field, the more area is getting properly irrigated. Christansens uniformity coefficient is used as a measure of irrigation uniformity with a value of 1 being completely uniform. Center pivot and lateral move irrigation systems have very good application uniformity (>.9). Lateral move sprinkler systems have moderate uniformity coefficients (.4-.7) which may vary widely.

The most common local problem with uniformity distribution is improper or uneven sprinkler pressure. Sprinklers are designed to operate within a set range of pressure. Excessive pressure means reduced drop size and increased drift and evaporation losses. Inadequate pressure prevents proper spray breakup resulting in the "doughnut" pattern around sprinklers.

Uneven pressure along lateral lines is commonly due to elevation changes in sloping and rolling fields. These pressure differences may result in as much as a 1 inch difference in water application during a set from one sprinkler to another. This problem can be solved by installing flow control nozzles or pressure regulators in fields with more than about 20 feet of elevation difference.

Uniformity can be increased on lateral move systems including hand lines by maintaining proper pressure to sprinklers (40-60 psi for standard nozzles) and by installing self-levelers on sprinklers. Reducing sprinkler and lateral spacing increases equipment costs and number of sets but may pay off, especially for high value crops. A 60 foot spacing is commonly used in this area but 60 feet is at the upper end of the performance limits of these sprinklers and any problem with pressure or flow severely impacts uniformity. You can also avoid placing the lateral in the same spot on each irrigation cycle by using alternate risers swing lines, flexible end tubes or offsets.

Uniformity can be increased on center pivot systems by installing drop tubes to decrease wind effects and by proper maintenance to ensure pressure and nozzle performance.

2.8 GENERAL IRRIGATION RECOMMENDATIONS

One of the most striking features of local agriculture is the extreme variation in climate, soils, water availability and other important factors. What increases yield in one location reduces it and causes pollution in another. One soil may store enough moisture to last a month while another in the next field stores only a weeks supply. Due to these variations, not all recommendations work for all irrigators and should be considered as "food for thought" instead of as "the bible".

The comments and recommendations in this report emphasize ideal practices which may serve as targets. Not all suggestions work for all irrigators but some should prove useful or stimulate thought which results in other worthwhile practices. For best results, experiment, pay attention and record the results.

Formulate an over-all irrigation strategy and re-evaluate it each year. Consider the amount of water you think you will have available and how best to use it. Concentrate your water and irrigation efforts on your most valuable crops. It is usually more profitable to irrigate a smaller acreage well than to irrigate a larger acreage poorly. Decide early in drought years which fields will receive little or no irrigation if supply problems develop. Consider your water supply and available manpower.

Try to be aware of critical crop periods and make a special effort to have equipment working properly. It is important to repair breakdowns quickly at these times.

Watch closely during seed emergence and irrigate if soil moisture is inadequate. This is usually only necessary in extremely dry years, in the driest portions of the area or when spring crops are planted very late.

Hard surface crusts may form on some local soils especially those with high silt and clay content and high lime content. The crust usually forms after light rainstorms which moisten a thin layer of surface soil and then evaporate. These crusts may inhibit germination and emergence of grain crops if they form soon after seeding. Irrigation can be used to soften the soil surface and increase seeding success. Watch during emergence if your soil may be affected and weather conditions are appropriate.

Don't start irrigating on the same day each year. Use common sense to judge how much wetter or drier it's been and then get out and look at your soil moisture to confirm it. Don't start irrigating if the soil is obviously moist. On the other hand, watch for signs of stress early when winter moisture recharge has been low. We have observed a 1-3 week variation in when irrigation should begin from one year to another.

2.9 IRRIGATION OF COMMON LOCAL CROPS

These guides were developed for local conditions and should not be applied to other areas. They were compiled from data collected during this project, from interviews with irrigators and from field observations.

Small grains have specific properties important to irrigation. Since wheat, barley and oats are grasses, they can withstand greater moisture stress than many other plants including crops like potatoes and alfalfa. After an adequate plant density is achieved, moisture stress can be severe in the early growth stages.

ALFALFA IRRIGATION TIPS - FJBC AREA

Alfalfa yield is directly related to the amount of water the crop receives. When soil moisture is exhausted, alfalfa plants simply stop growing. Other Montana studies report a 1/6 to 1/5 ton/acre/year yield increase for each inch of water.

CROP WATER USE

This table illustrates average crop water use (ETO) throughout the growing season. Values will vary with a variety of crop and climate factors. Values are in inches of water. Use with forms in Appendix I.

MONTH	WEEKLY (COOL & MOIST)	WEEKLY (HOT & DRY)	MONTHLY AVERAGE
MARCH	.05	.10	.25
APRIL	.25	.75	2.00
MAY	.50	1.25	4.00
JUNE	.50	1.50	4.75
JULY	.75	1.75	5.75
AUGUST	.50	1.50	5.00
SEPTEMBER	.50	1.25	3.50
OCTOBER	.10	.20	.40

CRITICAL MOISTURE PERIODS:

1 GERMINATION/EMERGENCE - The alfalfa seedbed must be kept moist during germination and emergence to ensure a dense, uniform stand. Apply 1-3 light irrigations to keep surface seedbed moist and prevent crusting. Some dedicated alfalfa growers irrigate on 4 or 8 hour sets during the establishment period. Others reseed alfalfa during the spring when rainfall is most likely. When seedlings are established, irrigate deeply to bring the entire potential root zone to field capacity which will stimulate a deep, well-developed root system.

2 CUTTING - Plants are most stressed during and after cutting and this is a common time for weak plants to die. Under ideal conditions, irrigation should occur 5-10 days before cutting to allow sufficient time for the surface soil to dry out and not rut from equipment. Irrigation should be timed just after cutting to minimize stress. If not irrigated before cutting, water should be applied as soon as possible afterwards.

IRRIGATION STRATEGY WHEN WATER IS UNLIMITED

If water is not limited, applications should be made to satisfy crop water needs (ETO). Figure 2 illustrates an example of this type of irrigation practice. Monitor soil moisture to determine application timing. Otherwise, use the alfalfa water use table above and a "checkbook" method (Appendix I). Determine how much water your system applies in one application (Appendix A). Keep track of weekly water use and irrigate when you have used up the amount your system will apply.

As an example of the checkbook method, assume your side roll system applies 3 inches of water in a 12 hour set. In May, two cool are followed by two wet weeks and total ETO is as follows: (.5+.5+1.25+1.25=3.5). This means you have used up more than the 3 inches your system applies. Remember to subtract for rainfall.

Cutting creates severe moisture stress so irrigate before cutting when possible. Irrigate as close to cutting as practical leaving sufficient time for the surface soil to dry and tolerate equipment traffic. Irrigate immediately after cutting if not before. Local experience suggests that irrigation before the first cutting can increase first cutting yield by .5-.75 tons per acre. This is even true east of Highway 93 in most recent dry years. One hazard of irrigating before cutting is the potential for wet weather which combined with the irrigation causes poor hay drying and quality. Cutting reduces ET by 30% early and late in the season and by 60% during the hottest weather.

When producing alfalfa seed crops, avoid excess moisture after seed has started to form (dry conditions help trigger seed production).

IRRIGATION STRATEGY WHEN WATER IS LIMITED

If water is limited, concentrate irrigation at cutting periods. The preferred method is to irrigate once before first cutting (twice if a dry year). If east of highway 93, it may not be necessary to irrigate before first cutting in moist years. Irrigate as soon as possible after each cut. If extra water is available, irrigate 5-10 days before cutting also. Otherwise, watch for signs of serious moisture stress including a dark bluish-green leaf color and limp, wilted leaves.

WINTER WHEAT IRRIGATION TIPS

CROP WATER USE (INCHES OF WATER)

This table illustrates average crop water use (ETO) throughout the growing season. Values will vary with a variety of crop and climate factors and are only presented as a general guide. Use with forms in Appendix I.

MONTH	WEEKLY (COOL & MOIST)	WEEKLY (HOT & DRY)	MONTHLY AVERAGE
MARCH	.05	.10	.30
APRIL	.35	.75	2.40
MAY	.75	1.50	4.75
JUNE	.75	1.50	5.50
JULY	.75	1.25	4.00
AUGUST			0

CRITICAL MOISTURE PERIODS:

1 GERMINATION/EMERGENCE - Winter wheat receives sufficient rainfall and snow melt to germinate and emerge in our area. This may occur over winter and spring resulting in uneven emergence. Irrigators with access to late season water irrigate before or in some cases after planting winter wheat to encourage germination and store soil moisture for spring growth.

2 BOOT TO HEADING - This is the period when yield is most affected by soil moisture. Plan ahead to time irrigation so that most of the field had adequate water during this period. If it takes 11 days to irrigate a field, start before the critical period begins. In some cases, large available water holding capacity and rapid crop water use will allow two irrigations in a row during this period. Be careful not to over-irrigate.

3 JOINTING - Some investigators have found that moisture stress during jointing increases tillering and that some of the new tillers do not produce seed or produce at a low level.

IRRIGATION STRATEGY WHEN WATER IS UNLIMITED

If water is not limited, applications should be made to satisfy crop water needs. Monitor soil moisture if possible to determine application timing. Use the evaporation pan method as an alternative. Otherwise use the winter wheat water use table above and a "checkbook" method. Determine how much water your system applies in one application (Appendix A). Keep track of weekly water use and irrigate when you have used up the amount your system will apply (Appendix I).

For example, your side roll system may apply 3 inches of water in a 12 hour set. In May you have two cool, wet weeks and two hot, dry weeks (.5+.5+1.25+1.25=3.5). This means you have used up more than the 3 inches your system applies. Remember to subtract for rainfall.

Quit irrigating when kernels are in the soft dough stage and there are 2-3 inches of available soil moisture left in the root zone.

Quit irrigating if late-season weeds are present which may impede harvest by over-topping the crop. These include pigeon grass, witchgrass and kochia. The grasses are usually only a problem east of Highway 93 in the Mission Valley.

Quit irrigating if root diseases are present which may increase lodging and reduce yield and test weights.

IRRIGATION STRATEGY WHEN WATER IS LIMITED

When water supply or manpower is severely limited, apply one irrigation at about the boot stage. A second irrigation soon after is the second priority. Irrigation at earlier growth stages is the last priority and is usually not necessary except in the drier portions of the study area. Too much irrigation at early stages can cause excessive height growth and increase lodging.

SPRING GRAIN IRRIGATION TIPS

CROP WATER USE (INCHES OF WATER)

This table illustrates average crop water use (ETO) throughout the growing season for a spring grain crop planted on April 15. Values will vary with planting date and a variety of crop and climate factors. These values are only presented as a general guide. Use with forms in Appendix I.

MONTH	WEEKLY (COOL & MOIST)	WEEKLY (HOT & DRY)	MONTHLY AVERAGE
APRIL	.15	.25	.40
MAY	.25	1.00	3.25
JUNE	.75	1.75	5.25
JULY	.75	1.75	6.00
AUGUST	.10	.50	1.00

CRITICAL MOISTURE PERIODS:

1 GERMINATION/EMERGENCE - Spring grains usually have sufficient rainfall and soil moisture to germinate and emerge in this area. However, in dry years, soil moisture content and crop emergence should be monitored. The later the planting date, the less likely there will be adequate moisture. Growers in the drier parts of the county should pay close attention to soil moisture and emergence. Uneven emergence creates problems for chemical applications and harvesting since crop stage may vary across the field.

2 BOOT TO HEADING - This is the period when yield is most affected by soil moisture. Plan ahead to time irrigation so that most of the field had adequate water during this period. If it takes 11 days to irrigate a field, start before the critical period begins. In some cases, large available water holding capacity and rapid crop water use will allow two irrigations in a row during this period. Be careful not to over-irrigate.

3 JOINTING - Some investigators have found that moisture stress during jointing increases tillering and that some of the new tillers do not produce seed or produce at a low level.

IRRIGATION STRATEGY WHEN WATER IS UNLIMITED

If water is not limited, applications should be made to satisfy crop water needs. Monitor soil moisture if possible to determine application timing. Use the evaporation pan method as an alternative. Otherwise use the spring grain water use table above and a "checkbook" method. Determine how much water your system applies in one application (Appendix A). Keep track of weekly water use and irrigate when you have used up the amount your system will apply (Appendix I).

For example, your side roll system may apply 3 inches of water in a 12 hour set. In May you have two cool, wet weeks and two hot, dry weeks (.5+.5+1.25+1.25=3.5). This means you have used up more than the 3 inches your system applies. Remember to subtract for rainfall.

Quit irrigating when kernels are in the soft dough stage and there are 2-3 inches of available soil moisture left in the root zone.

Quit irrigating if late-season weeds are present which may impede harvest by over-topping the crop. These include pigeon grass, witchgrass and kochia. The grasses are usually only a problem east of Highway 93 in the Mission Valley.

Quit irrigating if root diseases are present which may increase lodging and reduce yield and test weights.

IRRIGATION STRATEGY WHEN WATER IS LIMITED

When water supply or manpower is severely limited, apply one irrigation at about the boot stage. A second irrigation soon after is the second priority. Irrigation at earlier growth stages is the last priority and is usually not necessary except in the drier portions of the study area. Too much irrigation at early stages can cause excessive height growth and increase lodging.

3.0 ENERGY EFFICIENCY

This section describes efforts to conserve electrical energy in local irrigated agriculture. Program history and goals are explained and the results of energy efficiency improvements are summarized. The most common methods for increasing energy efficiency are discussed so that other irrigators can focus their efforts in the most productive manner.

3.1 PROGRAM HISTORY AND GOALS

The energy surplus of the 80's has been used up and new sources of supply are again in the spotlight. Additional concern for fish habitat and water quality, will affect future plans and solutions. The Northwest Power Planning Council (NWPPC) has asked the Bonneville Power Administration (BPA) to identify conservation measures which can offset increasing demands for electrical power.

The WATERWI$E program is one of a family of conservation programs which also includes the Super Good Cents Home program. In WATERWI$E, BPA provides a cost-share incentive through local utilities which encourages sprinkler irrigators to become more efficient users of electricity. The incentive helps irrigators with the cost of retrofitting existing irrigation systems and is paid by participating utilities at a 50% rate after work is completed. Total cost-share is determined by the amount of energy actually saved. Only those systems with significant savings qualify for the incentive.

3.2 PROGRAM DESCRIPTION

The program is a two-stage process. Stage I identifies potential energy savings and Stage II documents savings after retrofitting. All evaluations are performed by a certified irrigation system designer and soil scientist with experience in crop production. Appendix J includes an example irrigation system Stage I Analysis.

3.21 Stage I Analyses

A Stage I analysis is the initial irrigation system evaluation. It tells the irrigator how the system is operating now and where the inefficiencies are. This analysis evaluates pumping plant efficiency, pipe sizes and friction losses, system leaks, field topography and elevations, valves and fittings, watering patterns, nozzles, electrical considerations and crop water usage. System measurement include electrical horsepower (volts, amps and power factor) and flow rates. The irrigator is hand-delivered the results with a brief cover letter containing cost-share information and proposed retrofit conditions. Further questions and dialogue continue throughout the retrofitting process. Recommendations seek to find the greatest amount of energy savings while maintaining or increasing crop production levels.

3.22 Stage II Analyses

Stage II's are performed after retrofit measures are implemented to document actual energy savings and to verify equipment installations.

3.3 HOW ENERGY IS SAVED

The most common ways this program saves energy are by 1) reducing pressure, 2) reducing flow rates, and 3) by increasing pumping plant efficiency.

3.31 Reducing System Pressure

Many irrigation systems produce more pressure than necessary. Reductions in pressure can often reduce energy use without adversely affecting crop quality and yield.

Frequently, there is an excessive amount of pressure in the system due to an oversized pump. This can be corrected by trimming the impeller or replacing the pump. Properly sized valves, fittings and piping are essential for minimizing pressure. Undersized fittings and piping create excessive friction loss. Larger fittings and pipe have a higher capital cost but the pay-back period from energy savings is often quite short. Identifying undersized portions of the system is critical for achieving the lowest operating pressures. Field elevations have an important bearing on design pressures, especially in fields added later to an existing system. Pressure can also be lowered using new technologies for linear-move and center-pivot systems while still maintaining adequate application rates. These are referred to as low-pressure systems.

3.32 Reducing System Flow Rates

Reducing flow rates (amount of water being pumped) also reduces energy use. Flow reductions are recommended whenever application rates exceed soil infiltration capacity and run-off is occurring. This is most common with fine textured soils (clays and silts). Land & Water also recommends reducing flow when more water is being applied at one time than the soil can hold in the root zone. This results in water loss below the root zone and is most common in coarse soils (sands and gravels). The solution to this problem is changing the design to accommodate shallower irrigations that occur more frequently. This is achieved by either adding capacity (more laterals) or shortening set lengths. In any case, the pump must be capable of matching the new design or it must be replaced. Over-watering of this kind also results in leaching fertilizers and pesticides below the root zone.

3.33 Increasing Pumping Plant Efficiency

Pumping plant efficiency (PPE) is a measure of how well electrical energy is converted to water pressure and flow. The pumping plant refers to the motor, pump and electrical equipment. Modern irrigation pumping plants can achieve efficiencies of 70-76%. Systems tested by Land & Water in the past 4 years have ranged from 26-74% with an average of 58%. These efficiencies suggest that there are significant opportunities for energy conservation in local irrigated agriculture.

The 2 main reasons for poor pumping plant efficiency are a worn pump or the wrong pump for the job.

Worn Pumps

Pump wear usually means deterioration of the impeller and wear rings. Poor screening systems that allow the impeller(s) to become clogged also reduce efficiency.

Wrong Pump for the Job

Many sprinkler systems were installed when energy costs weren't much of a consideration, often resulting in too large or too small a pump. Rules of thumb such as "10Hp per line" were often applied inappropriately. It's no accident that pump manufacturers make dozens of different pumps with various hydraulic characteristics to serve a broad range of operating conditions. Choosing a new pump requires careful consideration of the range of operating conditions the irrigator requires. Land & Water has helped irrigators identify pumps with much higher efficiencies to meet their specific needs.

3.34 Other Sources of Energy Savings

Energy savings may also result from a variety of other factors including:

- improved inlet piping (proper sizing, fewer angles)
- improved discharge piping (proper sizing, fewer angles)
- improved screening of debris which may block piping and impellers
- larger mainline
- pump weather protection (especially shade)

3.4 RESULTS OF ENERGY EFFICIENCY EVALUATIONS

Table 3 summarizes test results for the 177 systems examined under this program. Energy savings are presented in kilowatt hours (KwH). Potential energy savings are identified in Stage I analyses and actual energy saved by retrofits is documented in Stage II analyses.

TABLE 3 SUMMARY OF ENERGY EFFICIENCY TESTS

YEAR	# OF STAGE I's	# OF STAGE II's	POTENTIAL KwH SAVED	ACTUAL KwH SAVED
89	23	23	217742	
90	60	40	269331	
91	42	25	267670	78131
92	32	23	193829	106618
93				177969

Table 3 illustrates a potential energy savings of almost 1 million KwH. Of this potential, 362,718 KwH have already been saved through retrofits. Irrigators who implemented retrofits in saved an average of 12,507 Kilowatt hours per year and 7 kilowatts of demand. At todays' power rates ($.036/kwh and 10.84/hp) this represents an annual savings of $552.00 per irrigator. In many cases, the actual energy savings exceeded the potential savings identified by the Stage I examination. One irrigator cut his electric bill in half by following retrofit recommendations.

Identifying potential energy savings is just a first step. Savings are achieved only if the irrigators are persuaded to implement the recommendations. It wasn't until the 3rd year of the program that irrigators started to make the recommended changes. This pattern is typical of other areas in the northwest participating in the BPA program. It often takes irrigators a year or two to plan, budget and finally install the needed retrofit measures.

Land & Water approached each analysis as the first step in a long-term relationship that includes the irrigator, analyst and utility. Information and dialogue between the irrigators and LW continued throughout the off-season. Local irrigation equipment dealers are now familiar with the program and often contact LW for specific information on retrofit needs for individual irrigators. In an effort to achieve maximum energy savings, LW hand-delivered test results, provided follow-up contacts and offered a toll-free 800 phone number.

The response to this program has been overwhelmingly positive. Irrigators save energy, water and time while maintaining or increasing crop production and profits. Utilities benefit from energy savings and help their customers stay in business so they can continue to purchase power. All concerned appreciate energy savings, water quality protection, fisheries improvement and other benefits. Participants enjoy a "good neighbor" attitude from doing something to address the difficult problems facing water and energy users.

3.5 IMPROVING IRRIGATION SYSTEM PERFORMANCE

This section discusses some of the most common subjects of concern among local irrigators who have participated in this program. These discussions are general and are not meant as a substitute for professional irrigation system design. Western Montana conditions are highlighted but much of this information is applicable elsewhere.

Irrigation Pumps

Two types of agricultural irrigation pumps are commonly found in Western Montana - centrifugal and turbine. Centrifugal is the most common mainly because surface irrigation water is widely available. The difference between them is the direction at which the water is discharged relative to the motor shaft. Centrifugal pumps discharge at a right angle to the shaft and turbine discharge is parallel. Each type requires a different impeller geometry to accomplish this. The advantage of the turbine is that the shaft can be extended very long distances allowing the pump to be located far away from the motor. This is desirable when pumping from a deep well and eliminates the need for priming. For most applications under

75 horsepower the centrifugal pumps are slightly more efficient. A third type of pumping plant not very common in Western Montana is a submersible pump and motor. Both the pump and motor are set below the water level in the well. Only the electrical panel and discharge piping are visible at the surface

The two main types of centrifugal pumps are split-case and end-suction. Split-cases tend to be less efficient because the motor shaft has to pass completely through the eye of the impeller. They are easier to open up and inspect though both types can be pulled apart with minimal disturbance of the discharge piping. The split-case requires 2 packing boxes and bearings and can't be mounted vertically.

When a pump is manufactured, its performance is tested at the factory under different head and flow conditions. The results are plotted on a graph with head on the vertical axis and flow on the horizontal axis. This is repeated using several different diameter impellers yielding a wide range of pump capabilities. Together these plots constitute what is called the pump characteristics curve. Most manufacturers will superimpose the pump efficiency and horsepower characteristics on the curve as well. These are strictly pump efficiency and brake horsepower and do not include motor inefficiencies. A single pump can operate under several different horsepower requirements. It is entirely possible that the same pump can be used with a 30 and a 75 horsepower motor depending on the model and application. Therefore, it is highly unlikely that a pump and impeller trim that is right for one system would be right for another. A professional irrigation designer should be consulted before purchasing a new or used pump to see if the pump is right for the application.

Pumps can be connected together either in series or parallel using a manifold. Pumps are usually placed in series when high pressures are required. Parallel pumps are desirable when widely different flow and head conditions are expected to occur for much of the operating season.

Two or more pumps are in parallel when they are each discharging into the same mainline and one is not pumping directly into the suction of the other. If widely different flow conditions are expected from 1/3 to 1/2 of the time then a parallel set-up may be more desirable and efficient than a single pump. Depending on the flow and head conditions required for a particular system, a single pump may be just as efficient. When pumps are in parallel, the flow rate of each pump is additive and the pressure is not. If two pumps connected in parallel are operating at 500 gpm and 150 feet of head each, then the system would be operating at 1000 gpm at 150 feet of head.

Pumps are placed in series when high pressures or high lifts are required. A series connection requires that the discharge of one pump be routed through the suction of another pump. The pressure of each pump then is additive and the flow rate is not. Two pumps connected in series that are capable of 500 gpm each at 150 feet of head will produce a total system head and flow of 500 gpm at 300 feet of head.

Mainline

The mainline is the network of piping that delivers water to the distribution lines or laterals. Buried mainline is either steel, transite or pvc. Above ground mainlines are made of aluminum. Mainline pipe should be sized large enough to avoid water velocities greater than 5 feet/second (fps). Velocities greater than 5 fps will produce excessive friction loss which can lead to under-irrigation or wasted electrical power. The capital outlay required for properly sized mainline is always preferable to a slightly larger pump required to overcome excessive friction loss. The larger pump alternative requires paying for the poor design every time the system is turned on. If velocities in existing systems are approaching 7 fps or higher, it makes economic sense to install a section of parallel mainline alongside the undersized pipe. This is usually a lower cost solution than replacing the existing mainline and risers. Irrigators should seek design assistance when considering the installation of parallel mainline.

The buried mainline material of choice is pvc. There are basically two different types - plastic irrigation pipe (pip) and iron pipe size (ips). Plastic irrigation pipe is more widely used at the lower pressures. Ips is the more common of the two and is better suited to the higher pressure applications. Both types come in an array of lengths, diameters and pressure ratings.

Working pressures should not exceed 70 percent of a pipes pressure rating. The 30 percent buffer is necessary to protect against water surges and hammer. Therefore, if maximum operating pressures expected will be 70 psi then 100 psi pipe would be sufficient. The inside walls of pvc are the smoothest of all the materials. This minimizes the friction loss for a given inside diameter.

The light weight of pvc makes for easier installation. Repairing and replacing pvc is easiest and the life expectancy exceeds all other materials. Steel is susceptible to rusting and electrolysis. Transite is quite heavy and repairs are difficult.

There are several installation considerations that should be observed with pvc. Temperature changes can produce contraction and expansion and may affect the pressure rating. If irrigation water above 72 degrees Fahrenheit is expected to be used then the pressure rating of the pipe may need to be increased. Consult a design professional for this type of assistance. It is advisable that the pipe be purchased and installed at an air temperature that is typical of when the system will be operating.

Thrust blocks are poured cement anchors that are required to prevent the mainline from coming apart due to the thrust created from a change in water direction. The size and type of thrust block depends on pipe size, pressure and soil type. Thrust blocks should always be against a solid trench wall and not compacted backfill. The cement should not come in contact with the coupling area since it can destroy gaskets.

Trench bottoms should be continuous and free of sharp rocks. A minimum depth of 30 inches is required for pipe larger than 4 inches in diameter. Low pressure pipe shouldn't be buried deeper than 4 feet. All pipe should be filled with water prior to backfilling the trench. Keep the pipe full when backfilling. The first 12 to 18 inches of backfill can be thoroughly wetted before tamping. Tamp after each 6 inch layer of backfill.

Laterals

Laterals are the portion of the irrigation system that distributes the water. They take the form of wheel lines (wl), hand lines (hl), center pivots, big guns and others. Center pivots and big guns will be discussed under separate headings.

The most common length of wl's or hl's is 1/4 mile. The most common sprinkler spacing is 40 feet making about 33 sprinklers on a 1/4 mile line. Virtually all wl's and hl's are aluminum and the common section lengths are 20, 30 and 40 feet. Wheel diameters vary from 4 to 7 feet and should be matched to crop height and distance between mainline risers. Pipe diameters vary, but 3, 4 and 5 inch are most common. Hand line pipe diameter is usually the 3 or 4 inch variety. Most 1/4 mile lines carry between 160 and 260 gpm depending on nozzle sizes and pressures. The pressure difference across the lateral should be no more than + or - 10% of the design nozzle pressure. The sprinkler 1/3 of the distance downstream on the lateral is the average pressure on level ground. The designer should aim for the nozzle design pressure to occur at this nozzle when it is at its highest point in the field (or some combination of highest point and furthest distance from the pump depending on field and system conditions).

Common problems with laterals are leaky joints and drain plugs. Leaks of up to 50 gpm have been measured on wl's and hl's. The most common solution is a new gasket, drain plug or ring clamp. Leaks can rob the lateral of pressure which causes under-irrigation. They also cause the pump to operate to the right of the pump curve in a less efficient area. Soil erosion and crop damage can also result from the leaks. Fix leaks as soon as possible.

Nozzles and Sprinklers

Basically there are 3 types of sprinklers in wide use in Western Montana. They are the high pressure big guns (50-120 psi), intermediate pressure impacts (35-60 psi), and low-pressure sprays or rotators (10-30 psi). Big gun sprinklers and rotator types will be discussed under the big gun and center pivot sections respectively.

Impact sprinklers are used exclusively on hl's and wl's and appear on many center pivot applications. A few impact sprinkler systems use a double nozzle system on the sprinkler head but most use a single nozzle per sprinkler. Many irrigators have chosen to mount their sprinklers on self-leveling devices designed to level the sprinkler should the wheel line move or stop on a slope. These devices work well and are recommended especially on sloping fields.

There are basically two nozzle types available for use in impact sprinklers. Standard bore nozzles are a brass nozzle that is most typically found in Western Montana. They range in size from 1/8 to 7/32 inches and come in increments of 1/64 inch. The most commonly found sizes are 11/64, 3/16 and 13/64. The 3/16 size and smaller require a minimum of 40 psi to operate properly. The 13/64 and 7/32 require 45 and 50 psi respectively. Too little pressure results in reduced wetted diameter and an uneven application of water. Too much pressure breaks up the spray into very fine droplets and mist that is easily carried off site by wind or evaporated. The flow rate exiting a standard orifice depends upon the amount of pressure at the nozzle. The flow varies by the square root of the pressure so it takes 4 times the pressure to double the flow rate (square root of 4 is 2). Appendix A contains a chart of flow rates for various nozzle sizes as the pressure changes.

The second type of nozzle available is a flow-control nozzle (fcn). The difference between it and a standard nozzle is a neoprene center that expands and contracts as pressure increases and decreases respectively. Essentially the orifice size varies as the pressure varies. They are available from 2.5 to 10 gpm sizes but not necessarily in 0.5 gpm increments. After the 6.0 gpm size they go up in 1.0 gpm increments. The 7.0 gpm size actually has an output closer to 7.5 gpm which can exceed the soil infiltration rate on clayey soils. This is a bit unfortunate because in the 40 by 60 foot spacings so common in Western Montana a flow rate of 6.5 to 7.0 gpm is often desired. A true 7.0 gpm or 6.5 gpm nozzle is needed. A large advantage of flow control nozzles is they even out the flow rate on sloping land where sharp elevation differences cause wide pressure variations. The manufacturers recommend between 35 and 75 psi operating pressures. Flow control nozzles require some special attention to prevent clogging since sharp objects that could pierce the neoprene cannot be used to clear them. Keep the end nozzle on the line a standard bore 13/64 inch nozzle. Install cone-shaped filters in the lateral pipe where it fits into the riser opener. These can be easily cleaned each time the pipe is moved. Every system should have a good sump cleaning system and screening on the suction piping. Reducing velocities in the suction piping to under 3 fps will help keep debris from entering the system.

Flow rates can be regulated with standard nozzles if pressure regulators are used. Pressure regulators cannot increase pressure but they can reduce a higher input pressure to a lower output pressure. There is a 3 to 5 psi pressure drop across a regulator which adds to the system head requirements. Regulators are susceptible to clogging especially if there is moss in the water.

Spacing and Set Length

The spacing between the sprinkler heads and also between each set as the lateral moves down the mainline determines the square footage to be watered during each set. The most common spacing is 40 feet between sprinkler heads and 60 feet between lateral settings. The most common length of time for irrigating a set is 11.5 hours. For most operations in Western Montana the set-length is fixed at 11.5 hours because of the lack of reliable labor available to change pipe more than twice a day. Some potato farmers will change sets on 8 hour intervals.

The nozzle selection and pressure is then based on supplying the crop-water needs for the square footage and set-lengths determined. The spacings should not exceed 60% of a nozzles wetted diameter in order to get good application uniformity in areas with moderate winds (areas that experience strong winds should not exceed 50% of a nozzles wetted diameter). For example, an 11/64 inch nozzle at 40 psi has a wetted diameter of 92 feet (taken from manufacturers test data). Therefore, the maximum spacing should be 55 feet (.6 x 92 = 55).

This would be insufficient for a 40 by 60 foot spacing by 5 feet if the area was moderately windy and by 14 feet if the area experiences strong winds.

The application uniformity refers to how well the system irrigates the entire area. An ideal uniformity would apply the exact same amount of water to the entire area. Most properly designed systems have a uniformity in the area of 90% on calm days. Windy weather can destroy the uniformity on even the best designed systems. The consequence of a poor uniformity is some portions of the field are either being under-irrigated or over-irrigated. A suggestion for improving uniformity is to not place the wl or hl in exactly the same spot for every irrigation. Alternate the location by rotating the wl one extra wheel revolution every other irrigation. This increases the probability that an area of the field will not be consistently under or over-irrigated.

Efficiency

There are many uses of the term "efficiency" in irrigation. Pump efficiency, motor efficiency and water application efficiency are just 3 of the many. In all cases, the concept of efficiency means the amount of output obtained for a given level of input. For example, if a baseball player gets a hit 5 times for every 10 times at bat he is a 50% efficient hitter. Similarly, if a pump requires 10 horsepower of electricity to get 8 horsepower worth of work on the water, it is considered 80% efficient.

A common statistic measured when evaluating systems is called pumping plant efficiency (ppe). The pumping plant is defined as the pump, motor and electrical parts of the system. An equivalent term is wire-to-water efficiency. Ppe looks at how well the pumping plant converts electrical power to water power. It completely ignores features of the system that are downstream of the pump. Therefore, changing mainlines and nozzles for example does not increase the ppe. However, if their replacement causes the system flow rate to move to a more efficient point on the pump curve they have indirectly affected ppe. With today's high efficiency pumps and motors it is possible to achieve a ppe between 70 and 80% depending on the pump model and application. Pumping plant efficiency ranges from a low of 26% to a high of 75% and averages 57% throughout Western Montana. This means the average irrigator can increase efficiency by a minimum of 13% and possibly by as much as 28%. A discussion of how improvements in ppe affects power bills and savings is contained in the section on Saving Energy.

Water application efficiency (wae) refers to the percentage of water that is put on the field that actually is useful to plant growth. Water lost to wind drift, deep percolation, runoff or evaporation before reaching the plant root zone is not beneficial to plant growth. A center pivot with intermediate pressure impact sprinklers mounted on top has a lower wae than a low-pressure center pivot with properly designed rotators mounted on drop tubes just above the crop canopy. The wae can vary on a daily basis from a high wae on a calm, cloudy, spring day to a low wae on a hot, dry and windy day in midsummer. The average wae for wl's and hl's is 70%. This is an important input when designing a system. If a 2 inch application is required by the crop and a 70% wae exists, 2.85 inches must be applied to realize a 2 inch benefit. Low-pressure center pivots can have a wae as high as 90%.

Saving Energy

The energy savings captured by the program was obtained by either increasing pumping plant efficiency or lowering system pressure requirements or flow rates. All of these factors are directly proportional to power requirements. For example, a 10% decrease in either flow or pressure will produce a 10% decrease in power consumption. Also a 10% increase in efficiency will produce a similar result.

Increasing pumping plant efficiency probably is the most common way of obtaining energy savings. This usually entails rebuilding or replacing the pump. Most rebuilds involve a new wear ring and repairing or replacing the impeller. The wear ring is a brass component that is pressed on the volute case. It maintains a very tight clearance (about 0.01 inches when new) between it and the impeller. As it wears, the clearance increases which allows water to recirculate back to the suction side of the pump. The recirculation of water inside the pump is the cause of the inefficiency. Most pump manufacturers recommend replacement of the wear rings when clearance exceeds 1/32 of an inch. Pump mechanics can measure the clearance with a micrometer.

Another reason for inefficiency is operating outside of the efficient range of the pump as defined by the pump curve. This problem can be caused by worn nozzles, system leaks, replacing nozzles with larger sizes, adding more lines than original design called for or poorly constructed suction piping. Simply installing larger nozzles can throw the pump into an inefficient point on the curve. When changes in the system hardware are made, consideration must be given as to how the pump will perform under the new conditions. Sometimes a new impeller diameter is all that is required and other times another pump may be required. Failure to consider the pump characteristic curve almost always leads to decreased pumping plant efficiency.

As little as 1/150 of an inch of nozzle wear can be enough so that the increased energy costs make it economical to replace them with new ones. Check nozzle wear by inserting a drill bit in the nozzle when it is operating. A steady stream of blowby of about .25 to .5 gpm or greater indicates the nozzles are ready to be replaced.

Recommendations for decreasing system flow rates are made when surface runoff is visible or when irrigation water is being applied well below the rooting depth of the crop. Surface soils low in organic matter and high in clay are most susceptible to surface runoff. Infiltration rates can be as low as 0.10 inches of water per hour and the problem is made considerably worse on sloping fields. For the typical wl/hl system watering alfalfa or grain using a 40 by 60 foot spacing and 12 hour sets, the 13/64 inch nozzle is too large on these heavy clay soils without some special management considerations. These can include building up soil organic matter or mechanically pitting or aerating the soil. A 3/16 inch nozzle with a design pressure of 40 psi is usually a more effective size.

Watering below the crop root zone occurs most often when the crop is very shallow rooted, as with small grains. Watering below a depth of about 2 feet is essentially wasting water and energy. When moisture stress appears in shallow rooted crops, the irrigation frequency or amount applied must be examined. Because less soil is available to hold water for the crop, the supply of available water is exhausted faster than it would be for a deeper rooted crop. Therefore it requires more frequent watering than deep rooted crops. An 11 day irrigation interval is often too long for small grains during peak growth periods.

System head requirements consist of elevation head, mainline friction loss, fittings friction loss, lateral friction loss and the pressure required at the nozzle. Little can be done to reduce elevation head. However, mainline, fittings and laterals can be resized if they are responsible for excessive friction loss and technology has helped to reduce pressure requirements of certain nozzle types. Resizing pipes and fittings doesn't produce energy savings outright. The pump must be resized for the reduced head requirements. Resizing the pump means either changing or trimming the impeller or purchasing a smaller pump. This results in net energy savings. Low pressure conversions for wheel line and hand line systems met with only marginal success. However, low-pressure pivot conversions were extremely popular and effective. Two guidelines for retrofitting piping are: 1- install fittings that increase in diameter gradually instead of suddenly and 2 - size piping to keep velocities below 5 fps in pipes and below 10 fps in fittings.

Retrofitting hand line and wheel line systems with flow control nozzles allows the irrigator to operate with a design pressure of 35 psi instead of the standard requirement of 40 psi. All that is sacrificed is 2 to 3 feet of wetted diameter. The stream is actually broken up better with the flow control nozzles because of the neoprene center. It is worth emphasizing that simply installing FCC's may or may not be an energy saving measure. If it results in a decreased flow rate then it may save energy all by itself. The big energy savings occur when the reduced pressure requirements of flow control nozzles is accompanied by an impeller trim to match the lower head requirements. Further reductions in pressure require the use of offsets and increased labor requirements which proved very unpopular with most irrigators.

Converting center pivots to low pressure involves a new nozzle package that often includes pressure regulators and rotator type sprinklers. This allows the irrigator to trim the pump impeller or replace the existing pump with a smaller one resulting in energy savings. The end pressure can be as low as 10 psi without an end gun and 20 psi if an end gun is to be used. A booster pump is necessary for proper end gun operation. Heavy clay soils, especially on sloping fields, may not be appropriate for low pressure since the application rate increases with the smaller wetted diameters. If the main pump used to supply the center pivot is also used to supply wl's or hl's then the benefit of a low pressure pivot is offset by the larger pressure requirements of hl's/wl's. If the pivot is water driven then a low-pressure conversion must be accompanied by converting the drive units. Electric drive is normally the power of choice.

Suction Piping
The physics of designing the suction piping of a centrifugal pumping system can make or break the performance of the system. Many manufacturers cite suction problems as the number one reason for poor pump performance.

When the water level of the sump is below the centerline of the pump, suction lift exists. Centrifugal pumps don't lift or suck water up. Instead, they depend on the weight of the open atmosphere above the water source to push the water to the impeller eye. This can only be accomplished by creating a vacuum in a sealed suction pipe by pumping the air out (otherwise known as priming a pump). There is no rule-of-thumb concerning the maximum height that centrifugal pumps can be located above an unpressurized water source. This can vary significantly depending on the pump model, head and flow conditions, elevation above sea level, water temperature and piping configuration. Some applications may require that suction lift not exceed 2 feet while others may allow up to 20 feet of suction lift. This is a crucial element of design and cannot be ignored. Irrigators should seek design assistance if they suspect that this is a problem.

The object of the suction set-up is to provide a conduit for calm, slow water to make its way to the impeller eye. When suction lift exists, no point in the suction piping should be higher than the intake of the pump. High points can entrap air which can obstruct the flow of water and disrupt the prime. The minimum amount of turns should be placed in the suction piping. Additional turns are better placed on the discharge side of the pump. No turns should be placed within 4 pipe diameters of the pump intake. If the suction piping is 10 inch size then the nearest turn should be at least 40 inches away from the intake. This allows the water to stop spinning prior to entering the impeller eye. Suction piping should be sized large enough to keep water velocities below 3 fps. An eccentric reducer should be used to reduce down to the pump intake size with the beveled side down. Suction-bells are available for installation on the end of the suction pipe to decrease entrance losses. Approximately 4 feet of submergence and 6 to 12 inches of clearance from the bottom of the sump is ideal for most suction arrangements. The sump water should also be as quiet as possible.

Cavitation is often a result of either a poorly designed suction arrangement or operating outside of the range of the pump. It is often identified as the sound of gravel or rocks passing through the pump. Any pump can be made to cavitate. Cavitation is the process where pockets of water vapor that formed in the impeller eye are collapsing in areas of high pressure inside the pump. This process can damage the pump and reduce pump performance. When the cause of cavitation is the suction piping, the solution is usually to install a larger size of suction pipe or a suction bell to reduce entrance losses. If there is a vortex in the sump causing the cavitation, then increase the submergence of the suction entrance. If the water level has dropped temporarily then placing a piece of plywood over the sump can help.

Electrical Components

Most of the systems in Western Montana are operating on 3-phase power. Phase to phase voltage is usually 240 volts or 480 volts. Power factor varies from 55% to 95% with most falling around 90%. Several systems on single phase service were using phase converters to run 3-phase power.

Most electric motors are the standard efficiency variety averaging about 90% efficiency. Today's high-efficiency motors can achieve 95% efficiency. A typical 40 horsepower pump and motor operating 1200 hours per year at $0.04 per kilowatt-hour could save about

$70.00/year in pumping costs with a high-efficiency motor. The difference in price is about $600.00. This makes about an 11 year pay-back period if the cost of power doesn't change. As rates go up the pay back period gets even more attractive. The average life for electric motors in the 5 to 50 horsepower range is 20 years. One major electrical shop reported only 5% of electric motors failed due to old age (insulation deterioration). The largest killer is overheating the motor. The primary cause of overheating is overloading due to operating the pump outside of its peak efficiency range. Other contributing factors to overheating are direct exposure to sunlight, poor ventilation and voltage imbalances.

Air Vents and Valves

The lack of properly positioned air vents is a very common omission on systems in Western Montana. One of the most common frustrations encountered during an evaluation is an unexplained pressure difference between 2 points in the mainline. Friction loss and elevation head explain only a fraction of the measured pressure difference. Since a large leak would be obvious the best explanation is a pipe obstruction. The most common type of obstruction is entrapped air.

Preventing air from entering the system is impossible so every system must be equipped to vent air. Trapped air acts like any other obstruction by restricting flow and pressure. The positioning of air vents is probably more critical than the sizing. Air normally travels to the highest points in the system but not always. Basically, there are 2 types of air vents - large orifice and small orifice.

Large orifice air vents work to vent large quantities of air during system start-up. They also open up during system shut-down to allow air to reenter the pipeline to avoid creating a vacuum. Once the system is pressurized these vents close and remain closed. They consist of a float that can be closed at a fairly low pressure by either water or air. Their tendency to blow closed from air pressure is a drawback. Recent technology improvements has produced a double chamber design that utilizes the forces of the escaping air to remain open until buoyed by the increasing water level. These vents should be sought out when retrofitting or designing a system. Some general guidelines for placement are as follows:

1. Immediately downstream of gate valves. This will provide vacuum relief if the valve closes suddenly and air expulsion during filling.
2. At all high points in the mainline. This vents air during initial filling.
3. Every 1/4 mile of pipeline.
4. feet from the end of all pipelines.
5. At all branch tees in the pipeline.

Small orifice air vents are designed to expel entrapped air when the system is pressurized. Sometimes these vents are referred to as continuous acting air vents. On average, water consists of 2% dissolved air by volume. As the air bubbles congregate they need a place to escape. Small orifice air vents should be placed at all high points in the mainline in conjunction with the large orifice variety. Consult your irrigation dealer for the proper sizing of both types. The dealer will need to know your mainline sizes to size the vents properly.

Pressure relief valves should be a part of every pressurized irrigation system also. Their purpose is to vent large quantities of water when the system exceeds a predetermined pressure. They do not regulate pressure within the system. This is the best insurance for protecting an expensive mainline installation from water hammer or steady pressure build-up. Common causes of pressure surges are sudden valve closure or pump shutdown and sudden movement of entrapped air. Filling the mainline too rapidly can also cause water hammer. Pressure relief valves should be located where the highest pressures will occur such as:

-the ends of pipelines.
-all low points.
-immediately downstream of check valves.

There are two basic types - diaphragm type and spring action. The spring action type has a quicker reaction time and is preferable.

Check valves are a common installation. They allow water to flow in one direction only. The most common types are a single disc swing type and a single disc angle seat. Modifications are available to provide non-slam closure that protects against surges by regulating the speed of closure. They are normally sized one size smaller than the mainline size, assuming the mainline size is designed properly. They have been installed to prevent back flow of contaminated water into the water source. They are considered inadequate for this purpose and a more positive action anti-back flow device is recommended.

Most systems have a gate or butterfly valve installed just downstream of the pump to regulate pump discharge. Butterfly valves cause more friction loss than similarly sized gate valves. However, when sized properly, the difference in friction loss is small and the relatively lower cost of butterfly valves makes them attractive. They do seem to fail more often than gate valves. Again, if the mainline is sized properly, they are usually the same diameter as the mainline or 1 size smaller. They should not be sized under any circumstances to experience velocities over 10 fps.

Irrigation Water Flow Requirements Based on Crop Water Use

How much water to apply, how fast and how often to apply it are the most critical factors determining the success or failure of an irrigation system. Sprinkler systems should be designed to handle the worst case scenario. For most irrigators in Western Montana this occurs during peak evaporative demand in July.

The peak demand is about 0.25 inches of water per day for alfalfa, potatoes and grain. Assuming a water application efficiency of about 80%, systems should be able to apply 6 gpm/acre to satisfy peak demand. Therefore, a 160 acre field would require a system capacity of about 960 gpm. Beyond this commonality, design specifications vary widely for each individual system depending on such factors as: soil, crop type, available water, available labor and type of sprinkler system to name a few. This is when a good designer is needed to ensure system adequacy.

Typical Example:

A "typical" system in Western Montana might be a 160 acre field broken into 4 - 40 acre square units. Each 40 acre unit is watered by a single 1/4 mile wheel line with 40 feet between sprinklers and 60 feet between mainline risers. This leaves 22 risers or sets per 40 acre unit. Most irrigators change pipe twice a day after 11.5 hour sets requiring 11 days to complete an irrigation. Consider a field of spring wheat. After 11 days of peak evapotranspiration of 0.25 inches/day in July, a total of 2.75 inches of water has been depleted from the soil root zone. Serious stress doesn't occur until about 50% of the soil available water holding capacity has been depleted in the root zone. Spring wheat extracts most moisture from the first 2 to 3 feet of soil when mature. If the soil is a silt loam free of coarse fragments it has an AWHC of about 2.25 inches per foot of soil for a total of 6.75 inches of available water (3 foot root zone). Less than 50% of the root zone AWHC is depleted in 11 days so the crop is not stressed before the next irrigation can begin.

However, if the soil is a sandy loam with 30% coarse fragments, the soil AWHC is reduced to about 1 inch of water per foot of soil for a total AWHC of 3 inches in a 3 foot root zone. Clearly, 11 days of peak demand (11 x .25 = 2.75 in.) reduces the available water in the root zone to well below 50% of AWHC placing the crop in a stressed condition. The solution to this problem is to change the system design to apply more frequent irrigations to the field. Other aspects of the system design such as nozzle selection and pressure can't help the problem given the spacing and labor constraints described above. Deeper irrigations won't help and will lead to increased waste and even lower yields. More frequent irrigations could be accomplished with additional flow capacity and laterals or by converting to a center pivot. All of these options require a complete redesign of the system and technical assistance should be sought.

Center Pivot Irrigation Systems

Most center pivots in Western Montana are 1/4 mile in length and are watering about 130 acres. Very few use corner extensions. Most use an end gun to extend the irrigated radius or have a solid set hand line in the corners. They are being used to water hay, grain, potatoes, mint, rape and other crops. Most pivots have electrically powered tower drives but the water drives are fairly common and there are a few hydraulic oil drive machines too. Most of the older installations (1975 through 1989) are equipped with impact sprinklers mounted on top of the main pivot pipe. Several newer installations are utilizing the latest low pressure technology including rotators, booms, drop tubes and spray nozzles.

A low pressure pivot is defined as a pivot with a nozzle package requiring 20 psi or less at the end of the pivot. This is an arbitrary break point but it is indicative of what is achievable with the technology. Pivots that will use an end gun require 20 psi pressure at the end. The additional pressure requirements of the end gun are met with a booster pump mounted at the end of the pivot (usually 2-3 horsepower). In the absence of an end gun the end pressure can be as low as 10 psi. Because the system is moving, the high pressures required for large wetted diameters are no longer needed. The rotator design can break up the water stream without a lot of pressure. Drop tubes aren't necessarily limited to low pressure situations.

The advantage is lowering the distance above the crop from which the water is applied. This increases the efficiency of the water application by reducing susceptibility to wind drift and evaporation.

The low pressure center pivot applications seem to be doing the best job of agricultural irrigation in Western Montana. The reasons for this include the following:

- -High water application efficiency.
- -Low labor requirements.
- -Least energy consumptive.
- -Superior ability to meet crop water demands.
- -Very uniform applications.

Electric drive pivots are usually the most energy efficient. A typical 1/4 mile machine might have 9 towers each equipped with about a 3/4 horsepower drive motor. The speed of the end tower is adjustable and the other motors cycle on and off as needed to maintain alignment with the end tower. The flow and head conditions of the main pumping plant can be reduced to supply the nozzle requirements. Water drive pivots eliminate the need for the electric drive motors. However, they do require very high water pressure be maintained by the main pumping plant in order to propel the pivot. This leads to higher electrical power consumption than electric drive pivots. Hydraulic oil drive pivots don't use the main pumping plant for hydraulic oil pressure. Instead, they require a separate pumping plant that must operate continuously when the pivot is watering. They range in size from about 15 to 25 horsepower. This also requires more electrical consumption than electric drive pivots.

There are some precautions when it comes to low pressure applications. Low pressure pivots are applying the same amount of water as any other pivot but they are applying it in a smaller wetted diameter. Therefore, the application rate is much higher than with higher pressure systems. The highest application rates on a center pivot occur at the end tower. A possible consequence of this is runoff. Fields that slope and have heavy clay soils are most susceptible to this problem. Technological advances and management practices can help to ease this problem. Booms can be installed that effectively increase the wetted diameter during the application. Nozzle break-up characteristics are better at producing droplet sizes that are less likely to compact the soil. The building up of organic matter and mechanically pitting or aerating the soil can help by improving the soil infiltration rate. Shorter pivots in these soils may be necessary to prevent runoff.

Pivot safety is a must for those working on or around them. It would be prudent to disconnect the power to the pivot before work begins or before climbing on. Often times the same 480 volt service used to power the pumping plant is available at the pivot. The moving parts on a water drive pivot are often very fast and powerful and should be given plenty of clearance when working around a pivot.

Big Guns
Big gun systems are sometimes called traveler sprinkler systems. There are many different types of drive mechanisms for moving the gun. Many are reeled in by the large flexible hose they are connected to and others move the gun and allow the hose to lay out as it travels. They are designed to water in rectangular strips and the intervals between the traveler path can be up to 300 feet. Flow rates vary from 80 to 1000 gpm and pressures vary from 60 to 130 psi. Initial costs may be lower than most mechanical move systems and the labor requirement is fairly low. They work well on very irregularly shaped fields or where trees, power lines and other obstacles exist that limit more rigid conventional sprinkler systems. However, they consume large amounts of electrical power at the pumping plant to produce very high pressures. The power consumption can be twice as much as a conventional hand line or wheel line system for the same acreage and up to 3 times as much as a low pressure center pivot. The long flexible hose is very expensive to replace. This hose must be sized properly to limit the friction loss in the line. The pressure rating of the mainline must be high enough to withstand the high pressures. Operating these systems at reduced pressures can cause severe compaction, crop damage and runoff from the large droplet size and velocities with which they strike the ground.

The end guns on the end of a center pivot are really an intermediate version of the big gun described above. The same precautions regarding operation at reduced pressure applies. Usually, end guns apply 75 to 150 gpm and pressure requirements are 60 to 80 psi. An end gun booster pump is often used to supply the necessary pressure while allowing the rest of the system to operate at much lower pressure.

Maintenance
The electric motor may be the most commonly repaired item in the pump house. Motor rewinds and bearings are not cheap. The motor should be greased at least 3 times a year - at the beginning, end and in the middle. Be sure the fittings and grease are clean and use grease coded EP-2 only, unless your manufacturer specifies otherwise. The right melting temperature is essential for bearing lubrication. All purpose grease is the wrong grease for the job. Remove the grease drain plug and leave it off for a couple of hours after greasing so the old grease can drain out. Keep the motor well ventilated by clearing the rodent screens of grass and debris. Puddles of water near the pump can be blown into the motor by the fan. Motors should be supported well to prevent shaft stress and deformation. Pump shelters are a must for all systems. Every 18 degree Fahrenheit rise above the motor rated temperature can cut the motor life in half. Direct sunlight can easily add 15 to 20 degrees of temperature on a hot summer day. Pump and panel shelters can be as simple as an angled roof supported by 4 studs and 1 wall for the panel or as intricate as a pump house.

The packing can be replaced as needed. A drip rate of about 1 drop per second is plenty. A packing puller tool makes packing replacement easier (use two pullers 180 degrees apart). The lantern ring has two holes 180 degrees apart that can be used to remove it. Check for grooves in the shaft sleeve if the worn packing was left in for any length of time and replace if necessary.

Periodically clean the suction screening to maintain the free flow of water. If pump performance decreases suddenly, check the impeller on the suction and discharge sides for plugging or obstructions. If the pump is an oil lubricated turbine then keep the oil level up.

During shut-down operations drain the pump and all of the piping. Open up all of the valves, especially gate valves. Lubricate the shaft with a light oil. Store rubber diaphragm primers indoors for the winter. Seal all openings with duct tape or other material to protect against debris and animals.

During start-up operations and with the power still off, check all electrical connections and insulation and tighten as necessary. Use a voltmeter to MAKE SURE THE POWER IS OFF. Start the pump with the packing gland loose and tighten slowly to 1 drip per second. Check all laterals for rodent nests. DO NOT raise pipes overhead without checking for power line locations first. Grease the center pivot swivel and properly inflate the tires. Remove the end plugs and flush the system thoroughly.

4.0 SUMMARY

This project has demonstrated that significant improvements in energy and water use can be made through a combination of demonstration, education and incentive programs. The energy and water efficiency improvements resulting from this project will provide both short and long-term savings for irrigators and the general population.

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6.0 APPENDICES

APPENDICIES

APPENDIX A. WATER APPLICATION RATE CHARTS

1) Use nozzle size and pressure to determine nozzle discharge. 2) Use nozzle discharge and sprinkler spacing to determine average application rate. 3) Use application rate and hours of operation to determine the amount of water applied per set. (NOTE: The total water applied per set in these tables is based on an application efficiency of 70% which accounts for evaporation and other losses. To determine the gross water application divide your final figure by 0.7)

NOZZLE DISCHARGE - GALLONS PER MINUTE

	Nozzle Diameter in Inches							
p.s.i.	3/32	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

AVERAGE APPLICATION RATE - INCHES PER HOUR

Spacing	Gallons Per Minute From Each Sprinkler									
Feet	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

WATER APPLIED PER SET - ACRE INCHES AT 70% EFFICIENCY

Hours	Application Rate of System - Inches Per Hour											
Operated Per Set	.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
5	.42	.49	.56	.63	.70	.77	.84	.91	1.05	1.23	1.58	1.93
8	.67	.79	.90	1.01	1.12	1.23	1.34	1.46	1.68	1.96	2.52	3.08
10	.84	.98	1.12	1.26	1.40	1.54	1.68	1.82	2.10	2.45	3.15	3.85
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
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

APPENDIX B. RAINFALL, IRRIGATION AND CROP WATER USE FOR MONITORED CROPS

APPENDIX B1 RAINFALL, IRRIGATION, TOTAL APPLIED WATER. CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP IN 1989

YEAR	GROWER	LOCATION	CROP	RAINFALL	IRRIGATION	TOTAL H20 APPLIED[1]	ETO[2]	DEFICIT[3]
1989	KC	RONAN-WEST	ALFALFA	8.8	13.7	22.5	28.7	-6.2
1989	BW	VALLEY VIEW	ALFALFA	6.7	8.0	14.7	28.7	-14.0
1989	JH	RONAN-WEST	ALFALFA	7.2	9.0	16.2	28.7	-12.5
1989	JJ	ROUND BUTTE	ALFALFA	11.8	7.2	19.0	28.6	-9.7
1989	JJ	ROUND BUTTE	ALFALFA	12.5	14.0	26.5	28.6	-2.1
1989	JMJ	ST IGNATIUS-EAST	ALFALFA	7.5	7.7	15.2	25.0	-9.8
1989	JMJ	ST IGNATIUS-EAST	ALFALFA	7.5	5.2	12.7	25.0	-12.3
1989	LM	VALLEY VIEW	ALFALFA	10.0	5.0	15.0	28.7	-13.7
1989	RR	CHARLO	ALFALFA	9.5	11.4	20.9	28.6	-7.7
1989	JR	ST.IGNATIUS-EAST	ALFALFA/GRASS	12.1	4.0	16.1	28.6	-12.5
1989	JR	ST.IGNATIUS-EAST	ALFALFA/GRASS	11.7	6.8	18.5	28.6	-10.2
1989	BW	VALLEY VIEW	BARLEY	5.7	6.0	11.7	28.7	-17.0
1989	WP	CHARLO	BARLEY	6.6	5.8	12.4	25.0	-12.6
1989	JH	RONAN-WEST	GRASS HAY	7.5	9.8	17.3	28.7	-11.4
1989	WP	CHARLO	GRASS HAY	5.2	12.0	17.2	25.0	-7.8
1989	KC	RONAN-WEST	GRASS PASTURE	7.5	18.1	25.6	28.7	-3.1
1989	RR	CHARLO	OATS	5.1	6.0	11.1	25.0	-13.9
1989	JM	VALLEY VIEW	OATS/ PEAS	1.2	4.5	5.7	25.0	-19.3
1989	EF	MOEISE	POTATOES	5.5	13.5	19.0	25.0	-6.0
1989	LM	VALLEY VIEW	POTATOES	6.2	10.6	16.8	26.6	-9.8
1989	BHO	MOEISE	SPRING WHEAT	6.3	9.1	15.4	25.0	-9.6
1989	BHO	MOEISE	SPRING WHEAT	6.3	12.6	18.9	25.0	-6.1
1989	BL	MOEISE	SPRING WHEAT	6.2	0.0	6.2	25.0	-18.8
1989	DS	MOEISE	SPRING WHEAT	6.2	16.1	22.3	25.0	-2.7
1989	DS	MOEISE	SPRING WHEAT	6.2	13.5	19.7	25.0	-5.3
1989	EW	MOEISE	SPRING WHEAT	6.4	11.0	17.4	25.0	-7.6
1989	EW	MOEISE	SPRING WHEAT	6.8	13.1	19.9	25.0	-5.1
1989	BL	MOEISE	WINTER WHEAT	6.5	0.0	6.5	25.0	-18.5
1989	JM	VALLEY VIEW	WINTER WHEAT	1.2	6.0	7.2	25.0	-17.8
1989	EF	MOEISE	WINTER WHEAT	5.1	11.1	16.2	25.0	-8.8

1 TOTAL H20 APPLIED = RAINFALL + IRRIGATION
2 ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)
3 DEFICIT = TOTAL H20 APPLIED - DEFICIT

APPENDIX B2 RAINFALL, IRRIGATION, TOTAL APPLIED WATER, CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP IN 1990

YEAR	GROWER	LOCATION	CROP	RAINFALL	IRRIGATION	TOTAL H20 APPLIED [1]	ETO [2]	DEFICIT [3]
1990	CV	POLSON-WEST	ALFALFA	6.1	11.2	17.3	27.1	-9.8
1990	DP	VALLEY VIEW	ALFALFA	4.9	6.4	11.3	27.1	-15.8
1990	JK	VALLEY VIEW	ALFALFA	6.7	7.1	13.8	27.9	-14.2
1990	JN	VALLEY VIEW	ALFALFA	4.7	5.0	9.7	24.0	-14.3
1990	KC	RONAN-WEST	ALFALFA	6.4	9.5	15.9	27.1	-11.2
1990	AB	MOEISE	ALFALFA	5.5	13.4	18.9	26.5	-7.6
1990	AB	MOEISE	ALFALFA	5.4	16.0	21.4	26.5	-5.1
1990	BB	RONAN	ALFALFA	6.4	10.3	16.7	27.1	-10.4
1990	BL	MOEISE	ALFALFA	5.8	17.7	23.5	26.5	-3.0
1990	BW	VALLEY VIEW	ALFALFA	4.8	8.5	13.3	26.5	-13.2
1990	DE	ROUND BUTTE	ALFALFA	5.3	16.8	22.1	27.1	-5.0
1990	GS	ROUND BUTTE	ALFALFA	4.9	9.5	14.4	27.1	-12.7
1990	JH	RONAN-WEST	ALFALFA	6.1	2.8	8.9	27.1	-18.3
1990	JH	RONAN-WEST	ALFALFA	6.4	11.2	17.6	27.1	-9.5
1990	JJ	ROUND BUTTE	ALFALFA	5.7	6.6	12.3	27.1	-14.8
1990	JJ	ROUND BUTTE	ALFALFA	5.5	6.6	12.1	27.1	-15.0
1990	JM	VALLEY VIEW	ALFALFA	3.8	14.0	17.8	27.9	-10.1
1990	LM	VALLEY VIEW	ALFALFA	7.0	10.5	17.5	27.9	-10.5
1990	PS	MOEISE	ALFALFA	6.8	14.5	21.3	27.1	-5.8
1990	PS	MOEISE	ALFALFA	6.8	11.0	17.8	27.1	-9.3
1990	JR	ST.IGNATIUS-EAST	ALFALFA/GRASS	10.7	8.0	18.7	27.4	-8.7
1990	AM	POLSON EAST	BARLEY	5.6	3.2	8.8	7.0	1.8
1990	BB	RONAN WEST	BARLEY	4.1	3.0	7.1	8.5	-1.4
1990	DP	VALLEY VIEW	BARLEY	2.2	5.0	7.2	8.5	-1.3
1990	JN	VALLEY VIEW	BARLEY	3.3	0.0	3.3	8.5	-5.3
1990	JR	ST.IGNATIUS-EAST	BARLEY	9.4	6.0	15.4	8.5	6.9
1990	KC	RONAN-WEST	BARLEY	3.9	3.1	7.0	8.5	-1.5
1990	LM	VALLEY VIEW	BARLEY	4.4	1.1	5.5	8.5	-3.0
1990	BW	VALLEY VIEW	OATS	4.2	3.0	7.2	8.5	-1.3
1990	JM	VALLEY VIEW	OATS/ PEAS	4.6	9.3	13.9	27.1	-13.3
1990	BHA	MOEISE	PASTURE	5.3	10.2	15.5	23.8	-8.3
1990	AM	POLSON EAST	POTATOES	5.6	7.8	13.4	13.7	-0.4
1990	EF	MOEISE	POTATOES	4.5	23.5	28.0	28.2	-0.2
1990	MD	MOEISE	SPRING WHEAT	3.6	5.5	9.1	10.6	-1.5
1990	PA	MOEISE	SPRING WHEAT	3.2	10.9	14.1	8.5	5.6
1990	CV	POLSON-WEST	SQUASH	5.0	6.1	11.1		
1990	BHA	MOEISE	WINTER WHEAT	2.8	8.0	10.8	10.6	0.2
1990	BHO	MOEISE	WINTER WHEAT	3.0	11.9	14.9	10.6	4.3
1990	BHO	MOEISE	WINTER WHEAT	3.0	9.1	12.1	10.6	1.5
1990	BL	MOEISE	WINTER WHEAT	3.0	6.1	9.1	10.6	-1.5
1990	DE	ROUND BUTTE	WINTER WHEAT	3.3	6.0	9.3	10.8	-1.5
1990	DK	VALLEY VIEW	WINTER WHEAT	3.4	9.3	12.7	11.1	1.6
1990	DK	VALLEY VIEW	WINTER WHEAT	3.4	7.5	10.9	11.1	-0.2
1990	EF	MOEISE	WINTER WHEAT	3.7	7.5	11.2	11.1	0.1
1990	EW	MOEISE	WINTER WHEAT	2.9	6.7	9.6	11.7	-2.1
1990	EW	MOEISE	WINTER WHEAT	3.0	6.2	9.2	11.7	-2.5
1990	GS	ROUND BUTTE	WINTER WHEAT	2.9	4.7	7.6	8.5	-0.9
1990	JK	VALLEY VIEW	WINTER WHEAT	5.7	2.3	8.0	11.7	-3.8
1990	MD	MOEISE	WINTER WHEAT	3.6	3.0	6.6	10.6	-4.0
1990	PA	MOEISE	WINTER WHEAT	3.2	11.5	14.7	10.6	4.1

[1] TOTAL H20 APPLIED = RAINFALL + IRRIGATION

[2] ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)

[3] DEFICIT = TOTAL H20 APPLIED - DEFICIT

APPENDIX B3 RAINFALL, IRRIGATION, TOTAL APPLIED WATER. CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP IN 1991

YEAR	GROWER	LOCATION	CROP	RAINFALL	IRRIGATION	TOTAL H20 APPLIED [1]	ETO[2]	DEFICIT [3]
1991	AB	MOEISE	ALFALFA	5.7	17.5	23.2	28.9	-5.7
1991	AM	POLSON-EAST	ALFALFA	7.4	4.5	11.9	27.0	-15.1
1991	DE	ROUND BUTTE	ALFALFA	6.1	14.8	20.9	27.9	-7.0
1991	GS	ROUND BUTTE	ALFALFA	6.5	12.2	18.7	27.9	-9.2
1991	JM	VALLEY VIEW	ALFALFA	7.8	5.6	13.4	27.9	-14.5
1991	JN	VALLEY VIEW	ALFALFA	7.3	4.3	11.6	27.9	-16.3
1991	JR	ST IGNATIUS-EAST	ALFALFA	7.9	12.4	20.3	27.0	-6.7
1991	KC	RONAN-WEST	ALFALFA	7.5	12.9	20.4	27.9	-7.5
1991	PD	VALLEY VIEW	ALFALFA	8.0	11.0	19.0	27.2	-8.3
1991	GS	ROUND BUTTE	BARLEY	6.5	3.0	9.5	14.4	-4.9
1991	JM	VALLEY VIEW	BARLEY	8.6	3.5	12.1	14.1	-2.0
1991	JN	VALLEY VIEW	BARLEY	6.8	0.0	6.8	13.6	-6.8
1991	JR	ST IGNATIUS-EAST	BARLEY	7.0	3.0	10.0	13.2	-3.2
1991	KC	RONAN-WEST	BARLEY	7.0	3.2	10.2	14.1	-3.9
1991	AB	MOEISE	CLOVER	4.6	8.7	13.3	20.0	-6.7
1991	EW	MOEISE	CORN	4.9	7.3	12.1	15.5	-3.4
1991	PS	MOEISE	HAY	6.3	20.2	26.5	27.0	-0.6
1991	PS	MOEISE	HAY	6.3	22.9	29.2	27.0	2.2
1991	RM	DIXON	HAY	5.5	17.3	22.8	27.9	-5.1
1991	TH	HOT SPRINGS	HAY	8.2	15.5	23.7	27.9	-4.2
1991	RM	DIXON	OATS	4.1	1.8	5.9	16.9	-11.1
1991	TH	HOT SPRINGS	OATS	6.9	8.3	15.2	20.1	-4.9
1991	EF	MOEISE	POTATOES	3.6	8.8	12.4	15.8	-3.4
1991	WM	ROUND BUTTE	POTATOES	1.6	7.6	9.2	15.7	-6.5
1991	AM	POLSON-EAST	SPRING WHEAT	7.0	0.5	7.5	13.8	-6.3
1991	WM	ROUND BUTTE	SPRING WHEAT	4.8	8.2	13.0	14.1	-1.1
1991	EF	MOEISE	WINTER WHEAT	5.8	3.7	9.5	14.2	-4.7
1991	DE	ROUND BUTTE	WINTER WHEAT	6.5	6.5	13.0	14.4	-1.4
1991	EW	MOEISE	WINTER WHEAT	5.9	7.3	13.2	14.2	-1.1

1 TOTAL H20 APPLIED = RAINFALL + IRRIGATION
2 ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)
3 DEFICIT = TOTAL H20 APPLIED - DEFICIT

APPENDIX B4 RAINFALL, IRRIGATION, TOTAL APPLIED WATER. CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP IN 1992

YEAR	GROWER	LOCATION	CROP	RAINFALL	IRRIGATION	TOTAL H20 APPLIED[1]	ETO[2]	DEFICIT[3]
1992	AB	MOEISE	ALFALFA	5.7	13.5	19.2	27.2	-8.1
1992	AM	POLSON-EAST	ALFALFA	10.2	8.1	18.3	25.7	-7.4
1992	DE	ROUND BUTTE	ALFALFA	8.0	13.3	21.3	27.2	-5.9
1992	DE	ROUND BUTTE	ALFALFA	7.0	11.0	18.0	27.2	-9.2
1992	GS	ROUND BUTTE	ALFALFA	5.3	11.0	16.3	27.2	-10.9
1992	JM	VALLEY VIEW	ALFALFA	8.1	11.2	19.3	27.2	-7.9
1992	JN	VALLEY VIEW	ALFALFA	7.6	10.5	18.1	27.2	-9.1
1992	JR	ST.IGNATIUS EAST	ALFALFA	9.3	8.3	17.6	26.4	-8.8
1992	KC	RONAN-WEST	ALFALFA	7.3	16.2	23.5	27.9	-4.4
1992	PD	VALLEY VIEW	ALFALFA	8.0	11.0	19.0	27.2	-8.3
1992	JM	VALLEY VIEW	BARLEY	5.2	6.0	11.2	16.0	-4.8
1992	JN	VALLEY VIEW	BARLEY	4.4	0.0	4.4	14.5	-10.1
1992	KC	RONAN-WEST	BARLEY	6.2	2.9	9.1	16.0	-6.9
1992	EF	MOEISE	CORN	3.1	5.4	8.5	14.2	-5.8
1992	EW	MOEISE	CORN	3.0	6.7	9.7	15.4	-5.7
1992	PS	ARLEE	GRASS HAY	7.0	15.0	22.0	25.7	-3.7
1992	PS	ARLEE	GRASS HAY	7.0	15.2	22.2	25.7	-3.5
1992	RM	DIXON	GRASS HAY	5.7	15.5	21.2	27.2	-6.1
1992	TH	HOT SPRINGS	GRASS HAY	4.8	10.5	15.3	27.2	-11.9
1992	TH	HOT SPRINGS	GRASS HAY	4.8	16.7	21.5	27.2	-5.7
1992	RM	DIXON	OATS	3.2	4.5	7.7	13.1	-5.4
1992	AM	POLSON-EAST	POTATOES	5.4	5.8	11.2	17.1	-5.9
1992	EF	MOEISE	POTATOES	2.8	11.9	14.7	17.5	-2.8
1992	WM	ROUND BUTTE	POTATOES	3.8	8.1	11.9	17.5	-5.7
1992	AB	MOEISE	SPRING WHEAT	3.5	4.3	7.8	14.5	-6.7
1992	DE	ROUND BUTTE	WINTER WHEAT	5.5	6.3	11.8	16.1	-4.3
1992	EW	MOEISE	WINTER WHEAT	4.2	10.0	14.2	16.1	-1.9
1992	GS	ROUND BUTTE	WINTER WHEAT	5.3	9.0	14.3	16.1	-1.8
1992	WM	ROUND BUTTE	WINTER WHEAT	5.0	13.8	18.8	16.1	2.8

1 TOTAL H20 APPLIED = RAINFALL + IRRIGATION
2 ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)
3 DEFICIT = TOTAL H20 APPLIED - DEFICIT

APPENDIX B5

AVERAGE RAINFALL, IRRIGATION, CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP AND YEAR.

		1989 AVERAGES				
CROP	n	RAINFALL	IRRIGATION	APPLIED[1]	ETO[2]	DEFICIT[3]
ALFALFA	11	9.6	8.4	17.9	28.0	-10.1
BARLEY	2	6.1	5.9	12.0	26.9	-14.8
GRASS	3	6.7	13.3	20.0	27.5	-7.5
OATS	1	5.1	6.0	11.1	25.0	-13.9
POTATOES	2	5.9	12.1	17.9	25.8	-7.9
SPRING WHEAT	7	6.3	10.8	17.1	25.0	-7.9
WINTER WHEAT	3	4.3	5.7	10.0	25.0	-15.1

		1990 AVERAGES				
CROP	n	RAINFALL	IRRIGATION	APPLIED	ETO	DEFICIT
ALFALFA	21	6.0	10.3	16.3	27.0	-10.7
BARLEY	7	4.7	3.1	7.8	8.3	-0.5
OATS	1	4.2	3.0	7.2	8.5	-1.3
POTATOES	2	5.0	15.7	20.7	21.0	-0.3
SPRING WHEAT	2	3.4	8.2	11.6	9.6	2.1
WINTER WHEAT	14	3.3	7.1	10.5	10.8	-0.3

		1991 AVERAGES				
CROP	n	RAINFALL	IRRIGATION	APPLIED	ETO	DEFICIT
ALFALFA	9	7.1	10.6	17.7	27.8	-10.1
BARLEY	5	7.2	2.5	9.7	13.9	-4.1
CLOVER	1	4.6	8.7	13.3	20.0	-6.7
CORN	1	4.9	7.3	12.1	15.5	-3.4
GRASS HAY	4	6.6	19.0	25.5	27.5	-1.9
OATS	2	5.5	5.0	10.5	18.5	-8.0
POTATOES	2	2.6	8.2	10.8	15.7	-4.9
SPRING WHEAT	2	5.9	4.4	10.3	13.9	-3.7
WINTER WHEAT	3	6.1	5.8	11.9	14.3	-2.4

		1992 AVERAGES				
CROP	n	RAINFALL	IRRIGATION	APPLIED	ETO	DEFICIT
ALFALFA	9	7.5	11.8	19.2	27.1	-7.9
BARLEY	3	5.3	3.0	8.2	15.5	-7.3
CORN	2	3.1	6.0	9.1	14.8	-5.7
GRASS HAY	5	5.9	14.6	20.4	26.6	-6.2
OATS	1	3.2	4.5	7.7	13.1	-5.4
POTATOES	3	4.0	8.6	12.6	17.4	-4.8
SPRING WHEAT	1	3.5	4.3	7.8	14.5	-6.7
WINTER WHEAT	4	5.0	9.8	14.8	16.1	-1.3

[1] TOTAL H20 APPLIED = RAINFALL + IRRIGATION
[2] ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)
[3] DEFICIT = TOTAL H20 APPLIED - ETO

APPENDIX B6 AVERAGE RAINFALL, IRRIGATION, CROP WATER USE (ETO), AND DEFICIT, IN INCHES, FOR EACH CROP USING DATA FROM ALL YEARS (1989 TO 1992)

		COMBINED YEAR AVERAGES					
CROP	n	RAINFALL	IRRIGATION	RANGE APPLIED	APPLIED[1]	ETO[2]	DEFICIT[3]
ALFALFA	50	7.5	10.2	8.9 - 26.5	17.8	27.5	-9.7
BARLEY	2	5.8	3.6	3.3 - 15.4	9.4	16.1	-6.7
CLOVER	1	4.6	8.7	13.3	13.3	20.0	-6.7
CORN	3	4.0	6.6	8.5 - 12.1	10.6	15.1	-4.5
GRASS HAY	12	6.4	15.6	15.3 - 25.6	22.0	27.2	-5.2
OATS	5	4.5	4.6	5.9 - 15.2	9.1	16.3	-7.2
POTATOES	9	4.4	11.1	9.2 - 28	15.5	20.0	-4.5
SPRING WHEAT	12	4.8	6.9	6.2 - 22.3	11.7	15.7	-4.0
WINTER WHEAT	24	4.7	7.1	6.5 - 18.8	11.8	16.5	-4.8

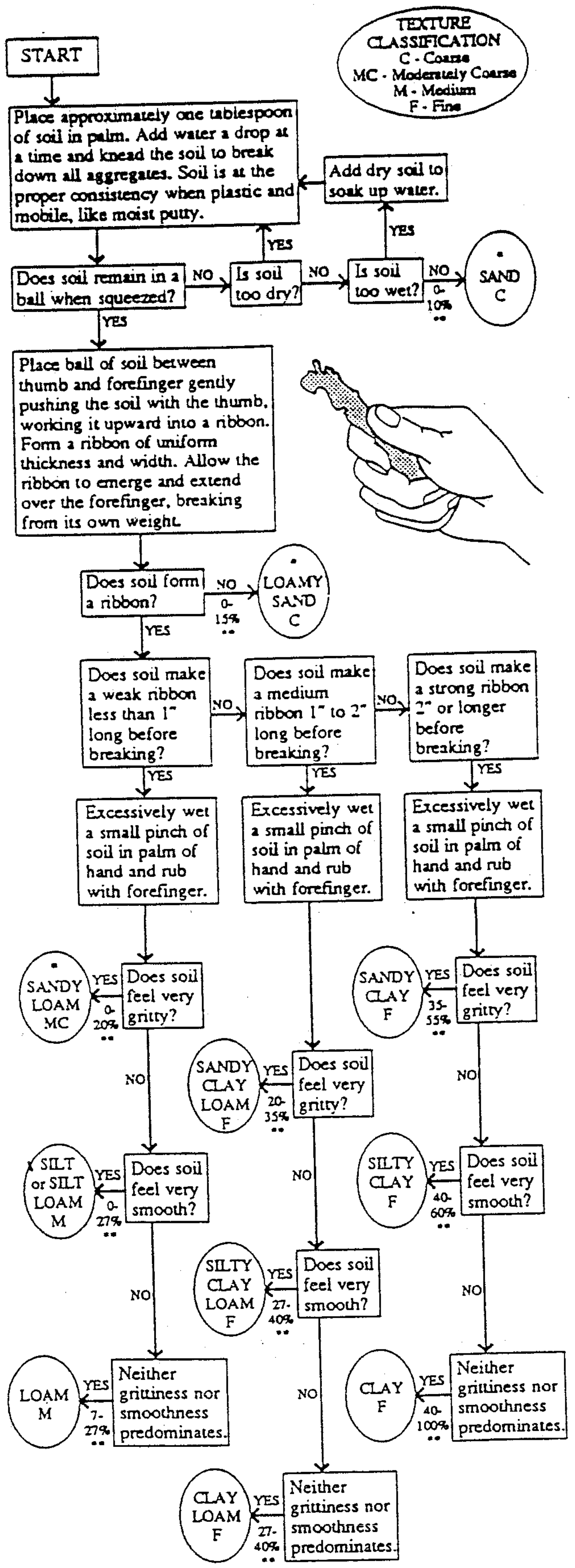
[1] TOTAL H20 APPLIED = RAINFALL + IRRIGATION

[2] ETO = POTENTIAL CROP WATER USE (EVAPOTRANSPIRATION)

[3] DEFICIT = TOTAL H20 APPLIED - ETO

APPENDIX C. GUIDES FOR DETERMINING AWHC

Determining Soil Texture by the "Feel" Method



- * Sand particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of <u>very fine sand</u> are not visible without magnification and there is a gritty feeling to a very small sample ground between teeth. Some <u>fine sand</u> particles may be just visible. <u>Medium sand</u> particles are easily visible. Examples of sand size descriptions where one size is predominant, are: very fine sand, fine sandy loam, loamy coarse sand.

** Clay percentage range.

Adapted from Montana Irrigation Manual, USDA Soil Conservation Service, Bozeman, MT.

Estimate AWC by Soil Texture.

From the following table, estimate inches of AWC per foot of soil according to its texture, and jot it down (see the chart on page 11). Generally, clay soils can hold more water than sandy soils.

Soil AWC (Rough Estimate)

Soil Texture	Inches Water per Foot of Soil	
	(range)	(typical)
Coarse Sand	0.1 - 1.2	0.5
Sand	0.1 - 1.4	0.5
Fine Sand	0.5 - 1.4	1.25
Very fine sand	0.7 - 1.4	1.25
Loamy coarse sand	0.5 - 1.7	1.0
Loamy sand	0.5 - 1.7	1.0
Loamy fine sand	0.7 - 2.2	1.25
Loamy very fine sand	0.7 - 2.2	1.25
Coarse sandy loam	0.7 - 1.9	1.25
Sandy loam	1.0 - 2.2	1.5
Fine sandy loam	1.2 - 2.2	1.5
Very fine sandy loam	1.4 - 2.6	2.0
Loam	1.4 - 2.6	2.0
Silt loam	1.4 - 2.9	2.0
Silt	1.4 - 2.6	2.0
Sandy clay loam	1.4 - 2.6	2.2
Clay loam	1.4 - 2.9	2.2
Silty clay loam	1.4 - 2.9	2.2
Sandy clay	1.2 - 2.9	2.0
Silty clay	1.2 - 2.6	2.0
Clay	1.4 - 2.6	2.0

Adapted from Montana Irrigation Manual, USDA Soil Conservation Service, Bozeman, MT.

APPENDIX D. IRRIGATION SCHEDULING DATA

Approximately 2000 pages of field notes and irrigation scheduling data from this project is available by contacting the Flathead Joint Board of Control.

APPENDIX E. AGWATER COMPUTER PROGRAM BASIC INSTRUCTIONS

AGWATER is a computer program designed to help you better understand your irrigation system and its management. The irrigator first answers a series of questions about his system, crop, and soils. The irrigator then tells the computer when he irrigates and the computer estimates and displays the resulting soil moisture pattern. A more detailed explanation of AGWATER is attached.

IMPORTANT KEYS

Review the attached sheet for the operation of important keys.

RUNNING AGWATER

1 SELECT YOUR CLIMATIC AREA - AGWATER inputs your local rainfall and evapotranspiration information from its files.

2 SELECT YOUR SOIL TYPE - AGWATER inputs your soil information including available water holding capacity and infiltration rates. You may select a soil texture (loam, clay, etc.) or a specific soil series name from the local SCS soil survey (Moeise, Polson, etc.).

3 SELECT YOUR CROP - AGWATER inputs crop information including seasonal moisture use, height and rooting depth.

4 SELECT YOUR IRRIGATION METHOD - AGWATER leads you through a discussion of your system including system type, pressures, nozzles, spacings and other factors.

5 SELECT "NO" UNDER PG$E POWER SCHEDULE - This section is for irrigation customers of Pacific Gas and Electric.

6 SELECT AN IRRIGATION SCHEDULE - This is when things get fun. You now set up you irrigations on a calendar and the computer shows you in color what happens to your soil moisture conditions.

Since irrigation water is not applied evenly over the entire field, the computer displays "average" , "wettest" and "driest" conditions.

The crop root zone is divided into 4 layers with a bucket of water representing each layer. If more water is applied than the root zone soil can hold, the excess is displayed as "deep percolation".

You will generally start by indicating the average number and dates of your irrigations. The computer will then show you what happens to your soil moisture under your current practices.

Now you are ready to play all kinds of "WHAT IF" games such as:

** What if I never irrigated? When would I run out of water?

** What happens if I change nozzles, pressures or other system components?

** How soon after I irrigate can I irrigate again without excessive deep percolation?

** Should I irrigate that last time?

To save the results of each irrigation schedule or change in conditions, you can either print out a paper copy or save each as a file on computer disk.

SUMMARIES AND REPORTS

AGWATER produces a number of summaries and reports automatically to help you understand your irrigation schedule or system modification. Take a look at these reports and print the ones you find helpful.

FURTHER INFORMATION

For more information use the AGWATER manual especially the sections labeled "AGWATER BASICS" and "HANDMOVE SPRINKLERS".

AGWATER©

The AGWATER© program is an interactive learning/teaching tool regarding agricultural irrigation. AGWATER© is unique in that it effectively combines two important irrigation concepts:

1. Irrigation scheduling
2. Distribution uniformity

When these concepts are presented graphically and in tabular form, a person can quickly grasp the broader concept of on-farm irrigation efficiency.

Information regarding the soils, crop, irrigation method, and irrigation schedule for an actual field is put into the program by responding to questions which have been customized for a wide variety of possible conditions. AGWATER© then graphically shows the user how water is supplied and consumed in three "typical" areas of the field: the spot which receives (1) the least amount of water, (2) the average amount, and (3) the most.

By using AGWATER© for approximately 2-3 hours, a farmer can:

1. Understand the concepts of non-uniformity of irrigation water application.
2. Learn how to improve the uniformity of irrigation water application on a specific field of interest.
3. Do many "what-ifs" regarding irrigation scheduling, by being able to easily change irrigation durations and dates and see the effect on plant stress and deep percolation. This knowledge generally takes years to obtain in the field.
4. Understand plant water uptake, effective root zone, deep percolation, and irrigation efficiency concepts.
5. Select an appropriate PG&E power rate schedule to minimize power bills.

An irrigation expert, after receiving information at an ITRC short course, must customize the library data for local conditions before farmers can use the program with good results. The two libraries contain technical details which the farmers are not expected to understand. An example detail is the identification of the percent of soil moisture depletion at which a particular crop (for a particular soil texture) will begin to suffer a reduction in transpiration. Another example is the need for daily reference crop ET (ETo) for a "normal" year in the area, with an ability to create databases for special climatic years.

AGWATER KEYBOARD USAGE

AGWATER and PG&E Library Programs:

<Page Up>
Move to previous window. Current window contents are saved.

<Page Down>
Move to next window when current window is complete.

<Esc>
Abandon any window or activity. If abandoning current window, move to previous window and lose current window contents.

<Enter>
Same as <Down Arrow> key--moves highlight bar to next field.

<Tab> and <Shift><Tab>
Same as <Down Arrow> and <Up Arrow> keys--moves highlight bar to next and previous field, repectively.

<Spacebar>, <+>, <->
Toggle.

<Backspace>
Within selected field, move blinking cursor back one space and delete previous character.

<Delete>
Within selected field, delete current character.

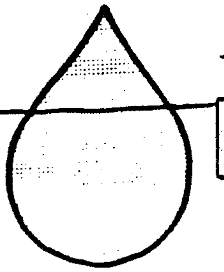
APPENDIX F. EXAMPLE IRRIGATION SCHEDULING FORM

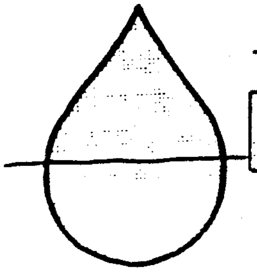
1991 IRRIGATION SCHEDULE

ALL VALUES ARE IN INCHES OF WATER

IRRIGATOR: Tom Grower **DATE:** 6/7 **SCOUT:** BD

CURRENT CONDITIONS	**FIELD 1 -** Winter Wheat	**FIELD 2 -** Alfalfa
CROP STAGE:	Flowering	10% Bloom
AWHC:	4	6
CURRENT SOIL MOISTURE LEVEL:	3	3
AMOUNT NEEDED TO REACH FIELD CAPACITY:	1	3





FORECAST OF CROP WATER USE

ESTIMATED CROP WATER USE OVER THE NEXT 7 DAYS:	1.25	1.25
NUMBER OF DAYS UNTIL SOIL MOISTURE IS EXHAUSTED:	25-30	25-30

WEATHER AND IRRIGATION SUMMARY

WEEKLY RAINFALL:	0	0
WEEKLY IRRIGATION:	2.8	0
TOTAL RAINFALL:	2.2	2.2
TOTAL IRRIGATION:	6.3	5.6
INITIAL SOIL MOISTURE:	1.5	2.25
TOTAL WATER SUPPLIED:	10.0	10.05

SYSTEM CONFIGURATION:

NEUTRON PROBE READINGS:	33007	19207	24923	31192	31522	30952
	24598	24999	26702	34001	33601	37120
	30517			36623	35486	

NOTES:

IRRIGATION HOTLINE 1-800-423-0354

LAND & WATER CONSULTING INC

P O BOX 8254 • MISSOULA, MT 59807 • 406-721-0354 • 721-03

AWHC - Available Water Holding Capacity - the amount of water the soil will hold in the root zone for plant growth - sandy soils usually hold about 1 inch of water per foot of soil, clay soils usually hold about 2 inches per foot. The root zone depth we manage for is 3 feet for perennial crops (hay and pasture) and 2 feet for annual crops (grain, potatoes, etc.) crops only use a very limited amount of water from deeper depths. Note that the root zone increases for annual crops for about the first two months of growth and decreases in the last month.

CURRENT SOIL MOISTURE LEVEL - The amount of water currently available in the root zone for plant growth. Note that root zones increase for annual crops (grains, potatoes, etc.) or newly planted perennial crops (hay and pasture). Crop yeild begins to be affected when the moisture level falls below about 50% of the AWHC.

AMOUNT NEEDED TO REACH FIELD CAPACITY - The amount of water to apply to fill up the root zone. Any amount over this will result in losing water and chemicals below the root zone. Wait to irrigate until the amount you will apply is less than this amount.

ESTIMATED CROP WATER USE OVER THE NEXT 7 DAYS - This is our prediction of crop water use for the next week based on weather predictions, crop stage and other factors.

TOTAL RAINFALL AND IRRIGATION - Total rain and irrigation since crop growth began this year, usually April 1 for perennial crops in most areas (slightly earlier in Moeise) and since emergence for annual or newly planted crops.

TOTAL WATER SUPPLIED - This is the total amount of water supplied to the crop from rainfall, irrigation and initial soil moisture at the start of the growing season.

SYSTEM CONFIGURATION - This is the position of your system in the field at the time of our visit and whether it was on or not. Please contact us if anything really unusual happens (breakdown after partial irrigation, extremely long or short sets, skipped areas of the field, etc.).

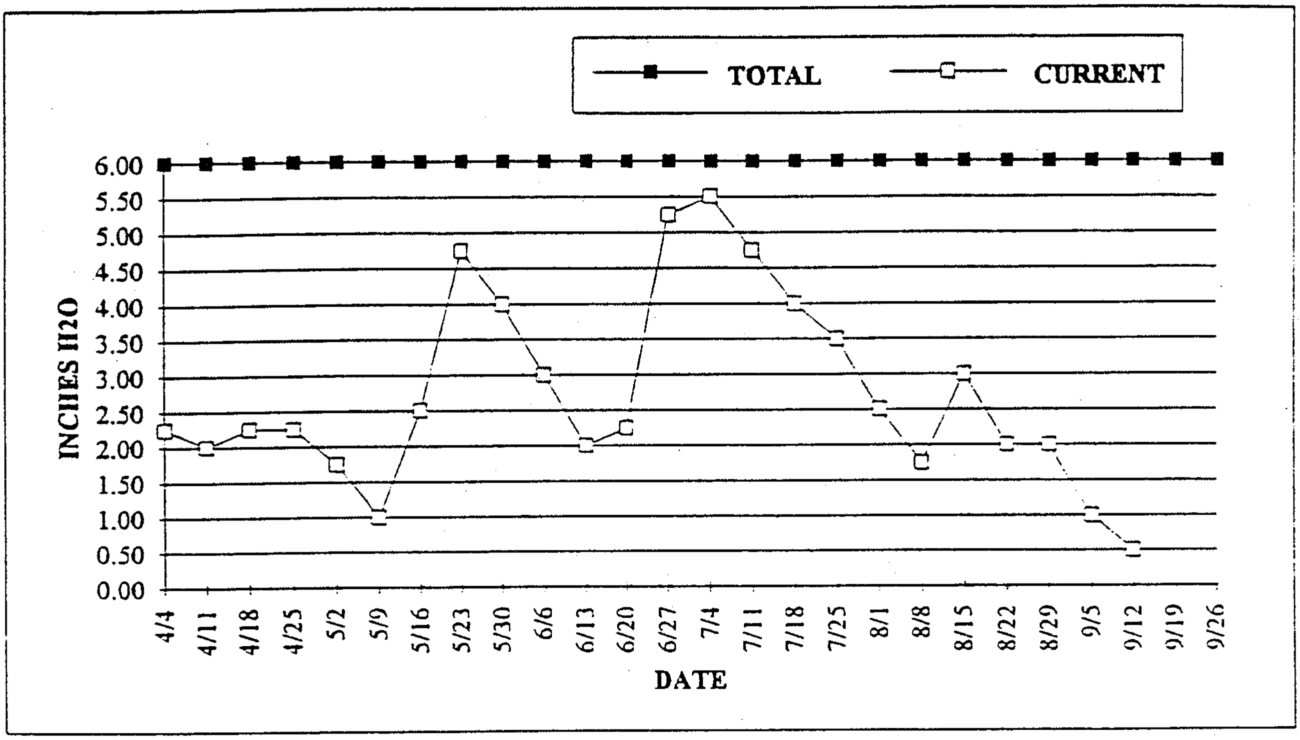
NEUTRON PROBE READINGS - Six spaces are provided for probe readings starting from the surface and reading left to right. Depths are in inches at 8, 12, 18, 24, 30, 36, 42, 48, and 54 inches.

NORTHWEST ALFALFA

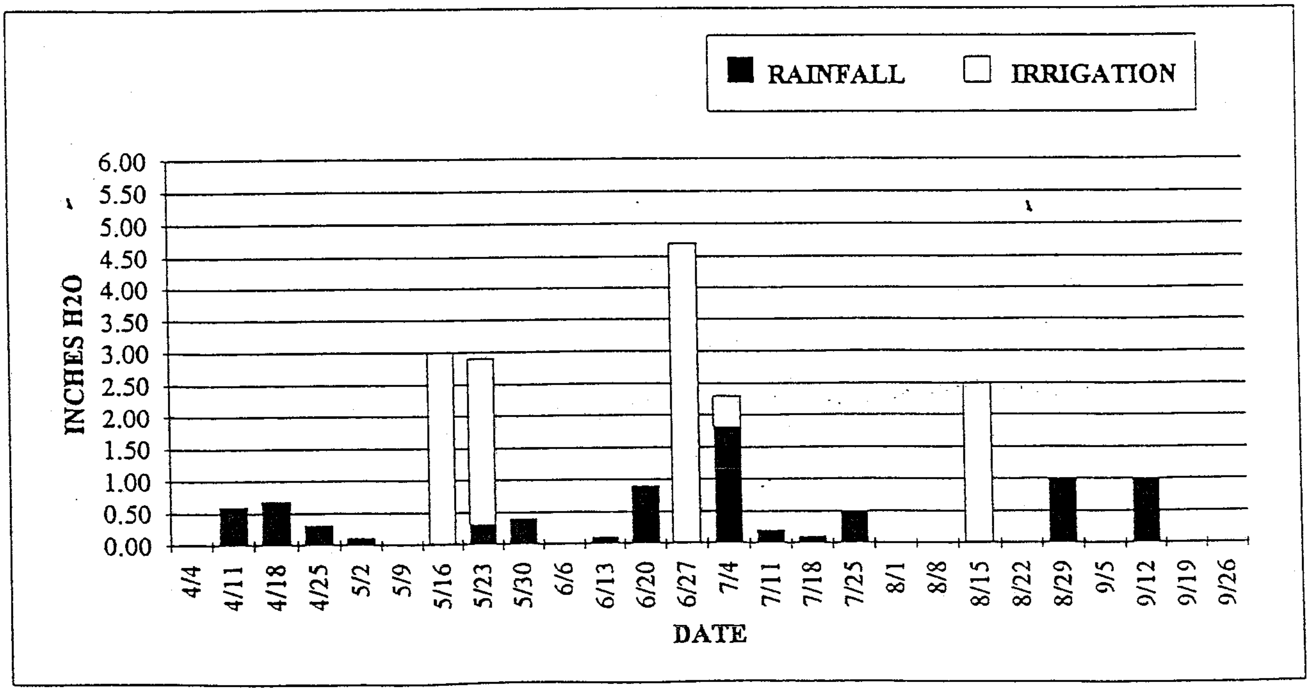
TOTAL AVAILABLE WATER HOLDING CAPACITY AND CURRENT SOIL MOISTURE LEVEL IN INCHES

X **CURRENT SOIL MOISTURE**

--- **7 DAY FORCAST**



RAINFALL (INCHES)

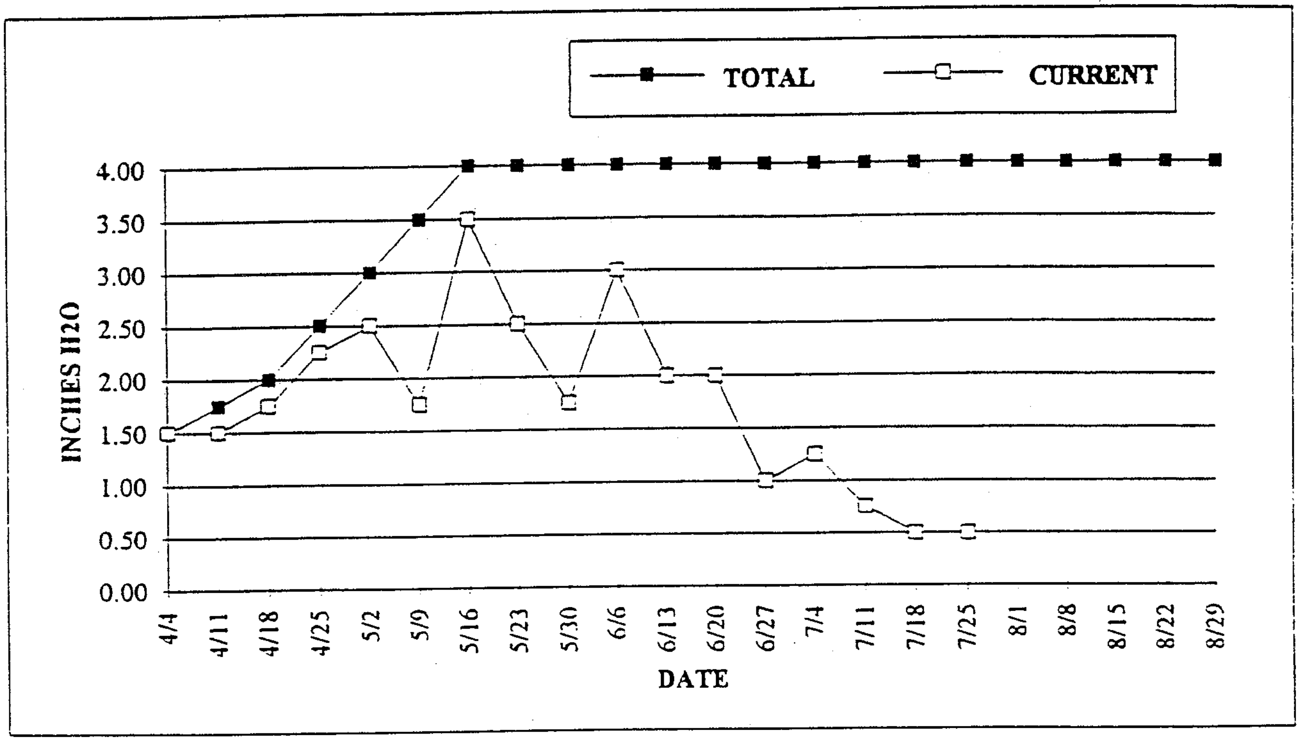


~~1 NORTHEAST WINTER WHEAT~~

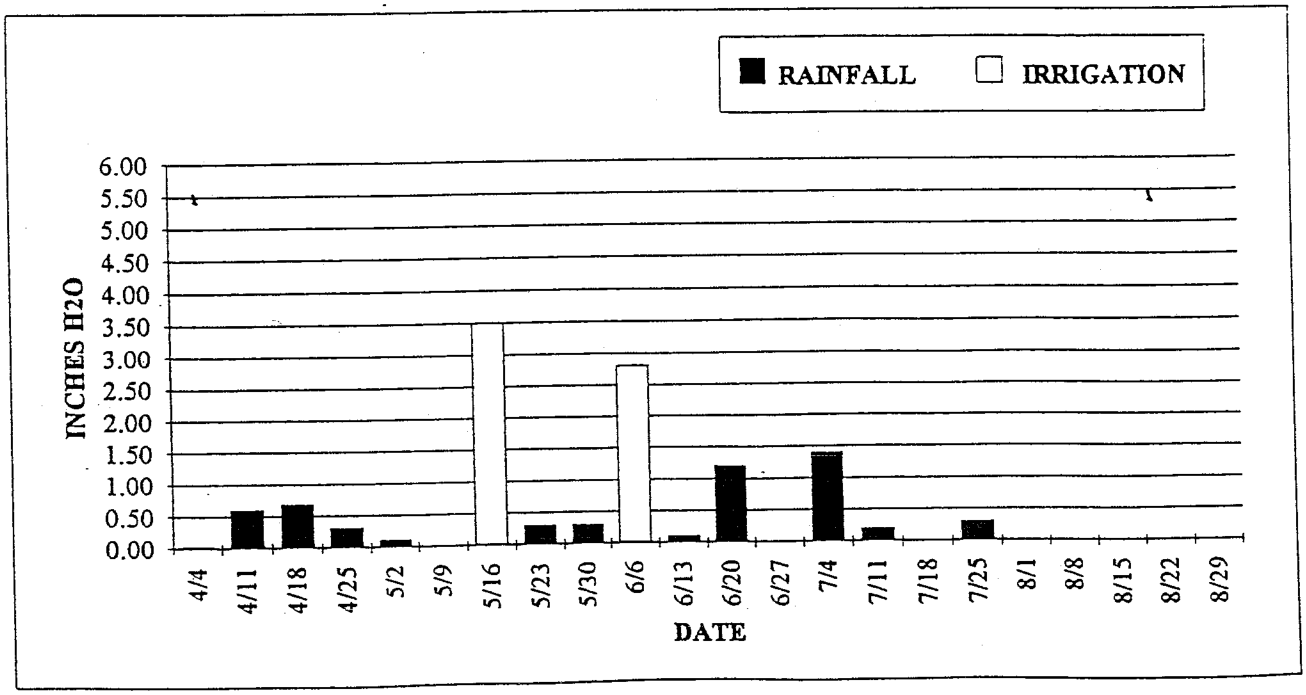
TOTAL AVAILABLE WATER HOLDING CAPACITY AND CURRENT SOIL MOISTURE LEVEL IN INCHES

X **CURRENT SOIL MOISTURE**

- - - **7 DAY FORCAST**



RAINFALL (INCHES)



APPENDIX G. GLOSSARY OF TERMS

deep percolation

APPENDIX H. LIST OF IRRIGATION SCHEDULING PARTICIPANTS

Pat Adley
Barry Baker
Alice Berner
Ken & Lawrence Cornelius
Phil Difani
Marvin Douma
Dan Emerson
Ernie Foust
Bill Halfinger
Ted Hein
Jack Horner
Bill Howell
Jerry Johnson
Jim Johnson
Dick Kerr
Jim & Jeff Knutson
Bill & Kay Largent
Art Mangels
Jon Marchi
Wayne Maughn
Ross Middlemist
Larry Mueller
Jim Nethercott
Warren Perry
Don Petersen
Jerry Roseleip
Ron Roush
Ralph Salomon
David Steindorf
Dean Stipe
George Stonehocker
Bud Strum
Dick & Pat Swartz
Phil Sykes
Chuck Vergeront
Ed Wehrheim
Buddy Westphal

APPENDIX I. CHECKBOOK TYPE IRRIGATION SCHEDULING FORM.

WRITE DOWN AN ESTIMATED CROP WATER USE EACH WEEK (SEE SECTION 2.9) AND ADD UP FOR EACH WEEK SINCE YOU LAST IRRIGATION. SUBTRACT ANY RAINFALL. IRRIGATE WHEN CROP WATER USE HAS EXCEEDED THE AMOUNT YOUR IRRIGATION SYSTEM APPLIES.

WEEK	**CROP WATER USE (ETO IN INCHES)**	**RAINFALL (INCHES)**	**SOIL MOISTURE DEFICIT/SURPLUS**	**ALFALFA ETO RANGE (IN)**
MARCH				
APRIL				
MAY				
JUNE				
JULY				
AUGUST				
SEPTEMBER				

APPENDIX J. EXAMPLE IRRIGATION SYSTEM ENERGY AUDIT

LAND & WATER CONSULTING INC

PRINCIPALS:
BARRY L. DUTTON
ROSS D. MILLER

PO BOX 8254 • MISSOULA, MONTANA 59807 • 406-721-0354 • FAX: 721-0355

24-June-92

RE: IRRIGATION SYSTEM EFFICIENCY EVALUATION

Attached are the results of your irrigation system efficiency test for your 150Hp system. Results show:

PUMPING RATE	TOTAL DYNAMIC HEAD	PUMPING PLANT EFFICIENCY
1900gpm	164ft	51%

An achievable pumping plant efficiency for your system is 72%. Each pump should be sized for peak efficiency when producing 170ft Total Dynamic Head at 950gpm. This will require 2 60Hp pumps and motors. You can install a single 125Hp pump sized for 170ft head and 1900gpm.

You should convert your pivot system to low-pressure. This will require redesigning your nozzle package and pressure control. Drop tubes will help the application efficiency especially on hot, windy days. The 170ft. total dynamic head above will produce 20 psi for end-gun operation. A booster pump for the endgun will be necessary.

The estimated annual energy savings, if all recommendations are followed, is 18349Kwh/year. Based on current rates, pumping costs can be reduced by $1034.00/year ($2.83/acre).

You are estimated to be eligible for up to $4037.00 of cost share. Glacier Electric Cooperative will cost share your improvements at a 50% rate if there is a measureable reduction in energy use. Otherwise (if energy consumption does not decrease), they will provide a minimum guarantee of $2250.00, also at a 50% rate. After the retrofits are completed, a post-test will be conducted to measure energy reduction. Any modifications to these recommendations can affect the energy savings and cost share. If you choose to accept only a portion of the recommendations please contact me before doing so.

If you wish to apply for the cost share, first contact Roy Nollkamper at Glacier Electric Cooperative (873-5566 or 1-800-347-6795). Thank you for participating and feel free to contact us anytime with any questions that develop.

Sincerely,

John Heffernan

HYDROGEOLOGY • WATER RIGHTS • IRRIGATION • SOIL SCIENCE • PLANNING • FORESTRY

tOG¬d@sOBAG123 1990.1

PUMP TEST AND SYSTEM INSPECTION
Bonneville Power Administration

Name...........:
ddress........:
ity,State,ZIP.:
tility........:GLACIER ELECTRIC COOP
Account #......: 26132400
nspector(s)...:JOHN HEFFERNAN

Inspection #...:GEC-2-92
Inspection Date: 23-JUN-92
BPA Area/Dist..:
Irrig Acres..: 365
Crop Type(s)...:GRAIN

****

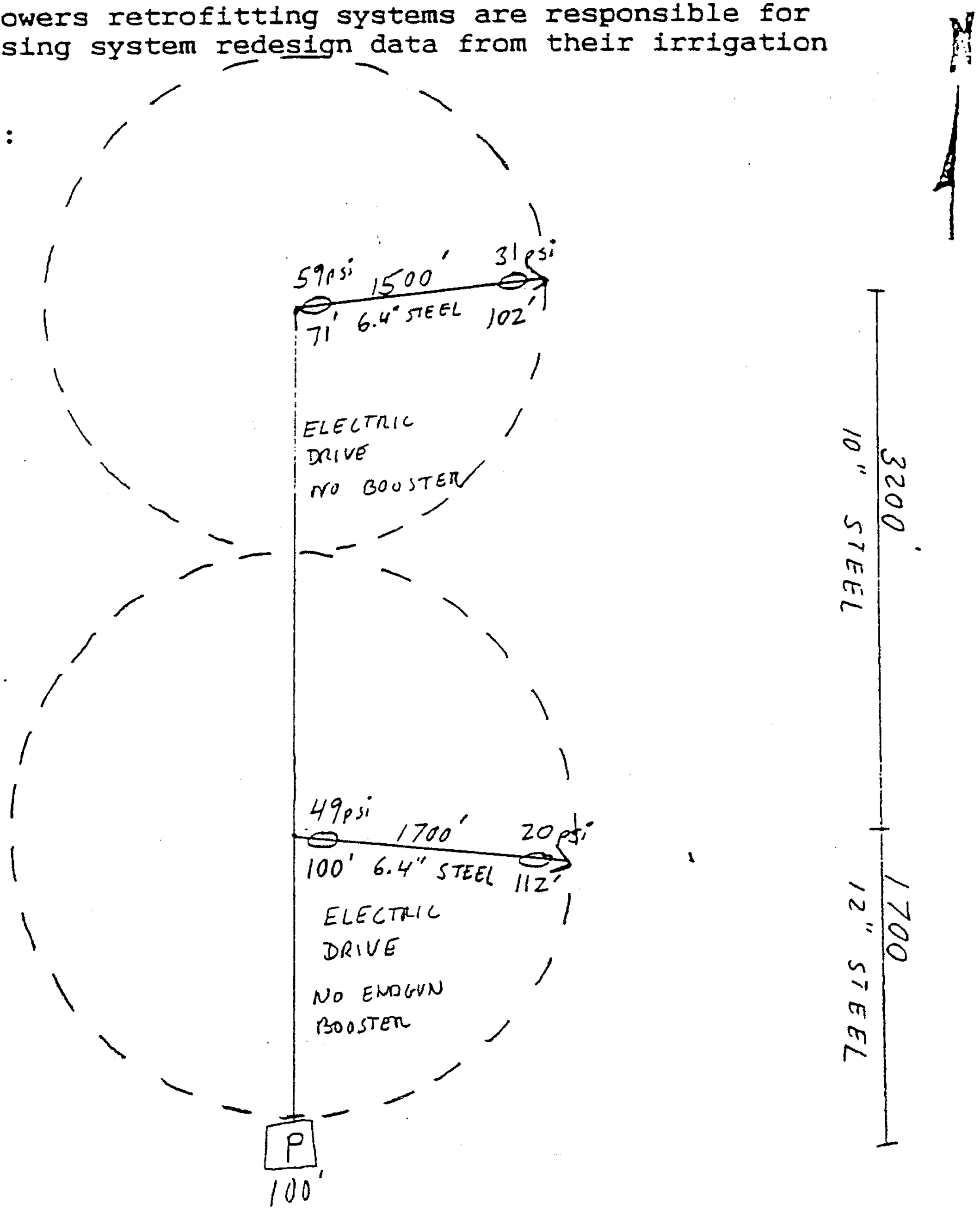
OTE!! This form is intended to determine which conservation retrofit measures are eligible under Bonneville Power Administration's cost share program. It does not provide accurate system redesign information. Growers retrofitting systems are responsible for obtaining and using system redesign data from their irrigation dealers.

YSTEM LAYOUT AS TESTED:

OILS

VGR-L
over
FSL

LL ELEVATIONS ARE
T GROUND HEIGHT.
DD 12' FOR PIVOT



k0G¬d@s0B

Bonneville Power Administration
INITIAL PUMP TEST FORM

Inspection #...:GEC-2-92

A. # of Pumps in System 2 Pump # 1

MAIN BOOSTER SERIES PARALLELX

B. MOTOR DATA

1. Make.......:US ELECTRIC
2. Frame #....: 365TP
3. Rated HP...: 75
4. Rated Volts: 460
5. Rated Amps.: 88
6. RPM........: 1770
7. Meter #....: 8886

C. PUMP DATA

1. Make.......:JOHNSTON
 a Centrifugal:
 b Turbine-Sub:X
2. Model #....: 12 CC
3. Serial #...:TJ229
4. Rated Head.: ft.
5. Rated Flow.: gpm
6. Implr Dia..: in.
7. Intake Dia.: in.
8. Intake Len.: ft.
9. # of Stages:
10. Shaft Dia..: in.
11. Airline Len: ft.
12. Airline psi: psi
13. Calc Lift..: 0.0 ft.

D. POWER INPUT DATA

1. Disc Revolutions...: 10.0
2. Meter Constant Kh..: 57.6
3. CTR................: 1.0
4. PTR/Multiplier.....: 1.0
5. Time...............: 18.0 sec

kW Metered= 115.2 kWe

	1-2	1-3	3-2	Average
6. Line Voltage.......:				0.0
7. Amperage...........:				0.0
8. Power Factor..(%)..:				0.0

kW Measured= 0.0 kWe

E. FLOW AND PRESSURE DATA

1. Measurement Device.:COX
2. Pipe Inside Diam...: 9.80 in.
3. Pipe Material......:STEEL
4. Flow Reading.......: 1900 gpm
5. Discharge Pressure.: 67.0 psi

F. PUMPING WATER LEVEL AND FRICTION LOSSES

1. Pumping Lift.......: 5.0 ft.
2. Suction Head.......: 0.0 ft.
3. Gauge in feet......: 0.0 ft. in Mercury= psi =
4. Water Level Fluct..: 0.0 ft.
5. Misc Frict Losses..: 4.0 ft.

G. EXISTING PUMPING PLANT CHARACTERISTICS

1. Total Dynamic Head.: 164 ft.
2. Flow...............: 1900 gpm
3. Water Horsepower...: 78.6 WHP
4. Input Horsepower...: 154.4 EHP
5. EST BRAKE HP.......: 139.0 BHP
6. Pumping Plant Eff..: 50.9 %

Bonneville Power Administration
INITIAL PUMP TEST FORM

Inspection #...:GEC-2-92

. # of Pumps in System 2 Pump # 2

MAIN BOOSTER SERIES PARALLEL

. MOTOR DATA

1. Make.......:US ELECTRIC
. Frame #....: 365TP
. Rated HP...: 75
4. Rated Volts: 460
. Rated Amps.: 88
. RPM........: 1770
/. Meter #....: 0

C. PUMP DATA

1. Make.......:JOHNSTON
a Centrifugal:
b Turbine-Sub:X
2. Model #....: 12 DC
3. Serial #...:TJ228
4. Rated Head.: ft.
5. Rated Flow.: gpm
6. Implr Dia..: in.
7. Intake Dia.: in.
8. Intake Len.: ft.
9. # of Stages:
10. Shaft Dia..: in.
11. Airline Len: ft.
12. Airline psi: psi
13. Calc Lift..: 0.0 ft.

. POWER INPUT DATA

. Disc Revolutions...:
. Meter Constant Kh..:
3. CTR................:
. PTR/Multiplier.....:
. Time...............: sec
kW Metered= 0.0 kWe

	1-2	1-3	3-2	Average
. Line Voltage.......:				0.0
. Amperage...........:				0.0
8. Power Factor..(%)..:				0.0

kW Measured= 0.0 kWe

. FLOW AND PRESSURE DATA

. Measurement Device.:COX
. Pipe Inside Diam...: in.
3. Pipe Material......:
. Flow Reading.......: gpm
. Discharge Pressure.: psi

F. PUMPING WATER LEVEL AND FRICTION LOSSES

. Pumping Lift.......: ft.
2. Suction Head.......: ft.
. Gauge in feet......: 0.0 ft. in Mercury= psi =
. Water Level Fluct..: ft.
5. Misc Frict Losses..: ft.

. EXISTING PUMPING PLANT CHARACTERISTICS

1. Total Dynamic Head.: 0 ft.
. Flow...............: 0 gpm
. Water Horsepower...: 0.0 WHP
4. Input Horsepower...: 0.0 EHP
. EST BRAKE HP.......: 0.0 BHP
. Pumping Plant Eff..: ERR %

SET SYSTEM # HLines Inspection #...:GEC-2-92
CENTER PIVOT X # WLines

H. FIELD ELEVATIONS AND RUNOFF ASSESMENT

1. Highest Irrigated Field Elevation..: 114.0 ft.
2. Lowest Irrigated Field Elevation...: 60.0 ft.

3. Is Flow or Pressure Control Recommended? yes

4. Elevation of critical sprinkler as tested..........: 112.0 ft.
5. Potential critical sprinkler elevation.............: 112.0 ft.

6. Does a runoff problem appear to exist now? yes
7. After retrofit, will there be a runoff problem? no

I. REQUIRED PRESSURE AT CRITICAL POINT

1. Low Pressure Sprinkler Recommendation......: 20.0 psi
2. Flow or Pressure control loss (2-5psi).....: 2.0 psi
3. REQUIRED OPERATING PRESSURE........: 22.0 psi

J. LATERAL DATA -- If Applicable

	# 1	# 2	# 3	# 4
1. Nozzle Diameter(s)...(in)..:				
2. Average Pressure....(psi)..:				
3. Flow per Sprinkler..(gpm)..:	0.00	0.00	0.00	0.00
4. # of Sprinklers............:				
5. Lateral Flow........(gpm)..:	0	0	0	0
		Total Flow =		0

K. CRITICAL SPRINKLER PRESSURES

1. First Sprinkler Pressure...........: psi
2. Last Sprinkler Pressure............: psi
3. LOWEST/AVERAGE/OTHER PRESSURE......: 20.0 psi
4. Mainline Pressure Adjustment.......: 0.0 psi
5. Elevation Adjustment...............: 0.0 psi
6. ADJUSTED CRITICAL PRESSURE.........: 20.0 psi

L. POTENTIAL TOTAL HEAD SAVINGS

	PSI	FEET
1. ADJUSTED CRITIGAL PRESSURE.................:	20.0	46.2
2. REQUIRED OPERATING PRESSURE................:	22.0	50.8
3. POTENTIAL TOTAL HEAD SAVINGS...............:	-2.0	-4.6

NOTE! A negative number indicates an increase in pressure is suggested

NOTES ON CALCULATIONS OR RUNOFF:

Inspection #..:GEC-2-92

NOTE!! These procedures are not sufficient to fully analyze systems with parallel pipe or pump networks.

M. MAINLINE CALCULATION PROCEDURES:

1. Calculate the velocity in each mainline section with laterals positioned for maximum head conditions.
2. Calculate friction loss in each mainline section.
3. Resize (or size for parallel pipeline) all mainline sections with a velocity greater than 7 fps to reduce velocity to less than 5 fps.
4. Calculate the effect these changes will have on total head.
5. Use the PROPOSED flow for the retrofit condition to determine eligibility.

Mainline Section Number	Length (ft)	Inside Dia (in)	C* Value	Flow (gpm)	Velocity (fps)	Hf/100 (ft)	Total Frictn (ft)	Head Redctn (ft)
1. Current	1700	11.80	100	1900	5.57	1.50	25.49	
Retrofit								0.0
2. Current	3200	9.80	100	900	3.83	0.93	29.68	
Retrofit								0.0
3. Current								
Retrofit								0.0
4. Current								
Retrofit								0.0
5. Current								
Retrofit								0.0
6. Current								
Retrofit								0.0
7. Current								
Retrofit								0.0
8. Current								
Retrofit								0.0
9. Current								
Retrofit								0.0
10. Current								
Retrofit								0.0

11. POTENTIAL TOTAL HEAD REDUCTION (sum section 1 thru 10) | 0.0 |

*Steel.: C=100
Alum..: C=120 Hf/100=1054(gpm^1.852)/(C^1.852*dia^4.8655)
*PVC...: C=150
*Other.: See hydraulic handbook

Inspection #...:GEC-2-92

. ACTION HEAD SAVINGS

1. Install low pressure sprinklers or nozzles = -4.6 ft.
. Retrofit high-energy-loss pipe and fittings
  a. Mainline Friction Loss Savings = 0.0 ft.
  b. Fittings Loss Saving (show work)= 0.0 ft.
  c. Partially Closed Valve Savings = 0.0 ft.
  d. TOTAL (a+b+c) = 0.0 ft.

3. SYSTEM TOTAL HEAD SAVINGS (1+2d) = -4.6 ft.

O. PUMPING PLANTS INFORMATION

. Existing

Pump #	TDH	GPM	WHP	EHP	BHP	EFF
1	163.8	1900.0	78.6	154.4	139.0	50.9
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5						
6						
TOTAL	164.0	1900.0	78.6	154.4	139.0	

2. Proposed

				E S T I M A T E D		
Pump #	TDH	GPM	WHP	EHP	BHP	EFF
1	169.0	950.0	40.5	56.3	50.7	72.0
2	169.0	950.0	40.5	56.3	50.7	72.0
3			0.0	0.0	0.0	
4			0.0	0.0	0.0	
5						
6						
TOTAL	168.6	1900.0	81.1	112.6	101.4	

. SYSTEM INFORMATION

1. Total Plant Efficiency (existing)=(WHPe/EHPe)*100 = 50.9 %
2. Total Plant Efficiency (proposed)=(WHPp/EHPp)*100 = 72.0 %
3. Operating Hours per Year (based on kWh usage)
   (Avg kWh/yr)*(Meter Portion)/kWe = 588 Hrs/Yr
4. Average Acre Inch per Year (based on kWh usage)
   (GPM)*(Op Hrs/Yr)/(452.6 * Acres) = 6.77 Acre inch

Inspection #....:GEC-2-92

Q. HISTORICAL kWh USAGE AND RATE DATA

1. Annual Metered kWh usage

	N/A	Year	kWh
a.		1991	60337
b.		1990	83033
c.		1989	59970
d.	*	1988	24320
e.	*	1987	22530
f.	Average		67780 kWh/Yr

2. Rate Data

a.	HP Charge/month....:	dollars
b.	kWh/hp @ no Charge.:	
c.	Fixed Cost/kWh.....:	4.82 cents
d.	HP Charge/yr.......:	5.00 dollars
e.	Total Nameplate HP.:	150 hp/meter
f.	Average cost/kWh...:	5.93 cents

R. PUMPING PLANT COMPARISONS

		a. INITIAL	b. PROPOSED
1.	Total Head (O1 and O2)	164 FTe	169 FTp
2.	Flow (O1 and O2)	1900 GPMe	1900 GPMp
3.	Pumping Plant Efficiency	50.9 %e	72.0 %p
4.	Input Kilowatts	115.2 kWe	84.0 kWp
5.	Input Horsepower (O1 and O2)	154.4 HPe	112.6 HPp
6.	ESTIMATED BRAKE HORSEPOWER	139.0 BHPe	101.4 BHPp

S. ENERGY SAVINGS, ENERGY CAP AND MINIMUM GUARANTEE

1. Estimated kWh Saved Annually and Estimated Energy Cap:

		ESTIMATED Measure kWh Savings	Eligible Cost Share? (Y/N)	Energy Cap
a.	Low Pressure Savings (N1/R1a)*Avg kWh/Yr =	0	Yes	$0
b.	Mainline Savings (N2a/R1a)*Avg kWh/Yr=	0	No	$0
c.	Fittings Savings (N2b/R1a)*Avg kWh/Yr=	0	No	$0
d.	Flow Savings (Flow diff)*kWh/GPMe=	0	No	$0
e.	Efficiency Savings (Eff diff)*kWh/EFFp =	18349	Yes	$4,037
f.	TOTAL POTENTIAL kWh SAVED AND ENERGY CAP	18349		$4,037

2. MINIMUM GUARANTEE = $15 * (Installed Nameplate HP) =
= $15 * (150) = 2250 dollars

NOTE: Due to weather conditions, crop requirements, water levels, usage patterns, etc., the above estimates may vary from year to year.

THIS SYSTEM IS ELIGIBLE FOR THE MEASURES MARKED ABOVE

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                                CENTRIFIC REVISION 3.0

                              SERIES:W, Y, R, H

                PERFORMANCES SHOWN ARE APPROXIMATE WATER PERFORMANCES

                          CHECK CATALOG FOR FINAL SELECTION


                  :=============================================:
                  : DESIGN POINT  950 GPM 170.00 Ft @ 1775 RPM  :
                  :=============================================:
                  :                          NOMINAL   TRIM     :
                  :    ITEM  MODEL   TRIM  %eff   HP   ANGLE    :
                  :=============================================:
                  :      1     4HH   13.53  81    50    0.0     :
                  :---------------------------------------------:
                  :      2     5RB   12.99  78    52    0.0     :
                  :---------------------------------------------:
                  :      3      5H   13.11  78    52    0.0     :
                  :---------------------------------------------:
                  :      4     4HS   14.24  75    54    0.0     :
                  :---------------------------------------------:
                  :      5      6H   13.15  69    59    0.0     :
                  :---------------------------------------------:
                  :      6     6RB   13.03  56    73    0.0     :
                  :---------------------------------------------:
                  :      7      8H   13.01  49    83    0.0     :
                  :---------------------------------------------:
                  :      8    10RB   13.50  29   141    6.5     :
                  :=============================================:


                               EFFICIENT BY DESIGN

CORNELL PUMP COMPANY       2323 S.E. Harvester Dr.       Portland, Oregon 97222
Phone 503/653-0330         FAX 503/653-0338          TWX 910/453-8377 CORNELL PTL
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CENTRIFIC REVISION 3.0

SERIES:W, Y, R, H

PERFORMANCES SHOWN ARE APPROXIMATE WATER PERFORMANCES

CHECK CATALOG FOR FINAL SELECTION

DESIGN POINT 1900 GPM 170.00 Ft @ 1775 RPM

ITEM	MODEL	TRIM	NOMINAL %eff	HP	TRIM ANGLE
1	6H	14.18	87	94	0.0
2	6HH	13.67	85	96	0.0
3	5HH	14.07	83	98	0.0
4	6RB	13.46	82	100	0.0
5	8H	13.30	76	108	0.0

EFFICIENT BY DESIGN

CORNELL PUMP COMPANY 2323 S.E. Harvester Dr. Portland, Oregon 97222
Phone 503/653-0330 FAX 503/653-0338 TWX 910/453-8377 CORNELL PTL

$\frac{95}{.9} = 106$

$\frac{154-106}{154} \times 67780 \times .22 = \$4647^{00}$

SOME 8" PIVOT PIPE WOULD
ALLOW EVEN LOWER TDH TO
USE A 100 HP PUMP