A Study of Irrigation Scheduling Practices in the Northwest

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Executive Summary

Introduction

Irrigation scheduling is one of the component activities of Bonneville Power Administration's Conservation & Renewables Discount rate. This study was commissioned by the Bonneville Power Administration (Bonneville), in a collaborative effort with the Pacific Northwest Generating Cooperative, the Northwest Power Planning Council, and the Northwest Energy Efficiency Alliance to evaluate approaches to and levels of irrigation scheduling practices in the region so that a well-informed basis for future planning and program development may be established. The study is being carried out with assistance from a technical advisory team of irrigation experts from Bonneville, Oregon State University Department of Bioengineering, and IRZ Consulting, an irrigation consultancy in Oregon. The primary goal of this study was two-fold:

1. Developing a better understanding of and establishing an accurate baseline for current levels and methods of irrigation scheduling in different sub-regions of the Northwest.
2. Estimating the relative effects of different levels of irrigation scheduling practice on water and energy use so that a simplified methodology for calculation of deemed savings might be developed.

The research is being conducted in two phases. Phase I focuses on developing a baseline of regional irrigation scheduling practices through a survey of a representative sample of farms in the Northwest. Phase II will consist of more detailed field measurement and metering of actual water and energy use on a sub-sample of farms studied in Phase I. This report summarizes the results of Phase I of the study and provides a conceptual plan for Phase II.

Overview of Irrigation Practices

The timing of crop irrigation and the amount of water used is determined by a number of factors including soil properties, soil-water relationship, crop type, stage of crop development, availability of water, and climate factors such as rainfall. The critical element in irrigation scheduling is the basis for determining irrigation requirements, i.e., knowledge of the necessary volume of water to be applied and the depth of application.[1] The importance of scientific irrigation scheduling is that it enables the irrigator to apply the right

[1] Irrigation requirement is defined as: net water requirement/irrigation system efficiency; where, net water requirement = ET – (rainfall + useable antecedent soil moisture).

amount of water to achieve specific goals. This increases irrigation efficiency and helps avoid over-irrigation or unintended under-irrigation.

Our definition of irrigation scheduling methods is based on the proposition that *all* farmers use certain irrigation regimes. What distinguishes these regimes is the basis on which irrigation decisions are made. In the context of this study, we define irrigation scheduling methods strictly in terms of three criteria:

1. Knowledge of crop consumptive use [evapotranspiration (ET)]
2. Appropriate measurement of soil and/or crop moisture
3. Measurement of the actual amounts of water applied.

Scientific irrigation scheduling methods are defined here as techniques used to determine the required timing and amount of irrigation for each field and application of appropriate metering to determine the actual amounts of applied water during a specific period.

Irrigation scheduling may be practiced with different levels of intensity, regularity, and sophistication. In differentiating among various levels of irrigation scheduling practices, we identified three distinct practice levels based on the combinations of techniques used to determine irrigation requirements. The three combinations are shown diagrammatically in Table 1-1. In this study, we consider only practice levels I and II as "scientific" practices.

Table I.1: Definition of Irrigation Scheduling Practices

Practice Level	Use of scheduling services	Measurement of soil moisture or plant water status	Use of Evapotranspiration	Measurement of applied water
I	Yes			
		Yes	Yes	Yes
II		Yes	Yes	
			Yes	Yes
III		Yes		
			Yes	

Study Design and Data Development

The sample frame for this study was a list of 20,657 farms and ranches in the 4 states of the Pacific Northwest, Idaho, Montana, Oregon, and Washington, purchased from Dun & Bradstreet. Since this study focused primarily on utilities in Bonneville's service area, only farms served by public utilities that agreed to participate in the study were retained in the sample frame.

A phone survey of 776 farms in the region provided the main source of data. Surveys were administered from January through March 2003 before the start of the planting season. Surveys were also completed for 10 additional farms in the Benton-Umatilla area that received commercial irrigation scheduling services in order to better understand the types and scope of services offered by such providers.

A comparison of survey results with respect to geographic and size distributions with the results of the 1988 Northwest Farm and Ranch Survey indicates that Washington, and to a lesser extent Oregon, are overrepresented in the sample. This largely reflects locations of utilities willing to participate in the study; but with respect to farm size, the two surveys show a close correspondence.

Summary of Findings

Farm Characteristics

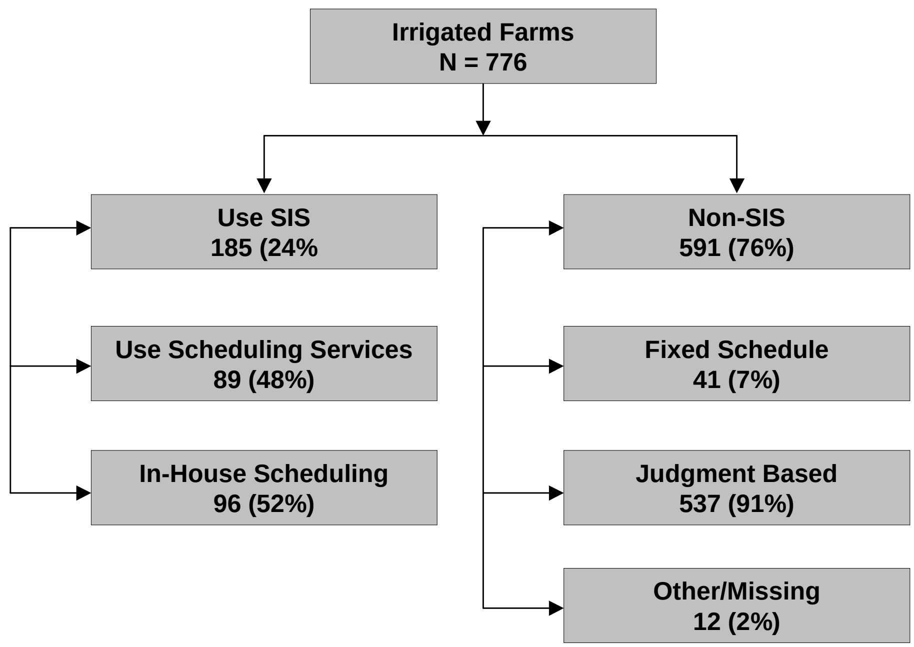
The survey was designed to solicit information on four general areas of farm and crop characteristics, irrigation system type and configuration, irrigation management and scheduling approaches, and general demographics. The principal findings on farm characteristics are as follows.

- Alfalfa is the dominant crop in the region. Fifty-six percent of all surveyed farms report planting alfalfa, and in 38 percent of cases alfalfa was the primary crop. Alfalfa accounted for nearly one-third of the planted acreage. Corn (15 percent), potatoes (7 percent), and grass seed are the other prominent crops.
- Sources for irrigation water vary widely across the region. Groundwater—mainly from wells, irrigation districts and local surface water from rivers and ponds—are the primary sources for irrigation water in the region. Water from irrigation districts is reported as the main source and accounts for 44.3 percent of total irrigated acreage surveyed.
- In general, 94 percent of farms use pressurized pump systems for irrigation, and in 87 percent of cases the local utility is the source of power for pumping. Sprinklers are by far the most extensively used irrigation system; they are used as the primary irrigation system in 82 percent of the surveyed farms, and gravity irrigation is the primary system in 15 percent of farms. Only 4 percent report using on-site generation or non-electric energy sources for pumping.

Irrigation Scheduling Methods

As shown in Figure 1-1, scientific irrigation scheduling is practiced in 185 (24 percent) of the surveyed farms. Eighty-nine (48 percent) of these report using commercial irrigation scheduling services on a contract basis, while 96 (52 percent) use on-farm equipment and methods for scheduling. A large majority (76 percent) of farmers report using nonscientific irrigation scheduling methods. Of these, 91 percent rely on "judgment" and 7 percent use a fixed, or routine, schedule in deciding when and how much to irrigate.

Figure I.1: Irrigation Scheduling Methods



Commercial irrigation scheduling services generally provide farmers with all necessary data to meet an optimal irrigation schedule by providing customized information on ET and collecting information on soil moisture and/or plant water status. Of the sites surveyed, 89 (11.5 percent) report using a commercial irrigation scheduling service currently, and 165 (21 percent) had used such services in the past. Of the 254 farms that use or have used a service, 75 (29.5 percent) received financial assistance from a utility or local agency for the services they received.

Sources for information on ET include on-line services such as AgriMet, farm-related publications, personal weather stations, and commercial irrigation services. Survey results suggest that only 89 farms (12 percent) use ET data on a regular basis. On-line services, primarily AgriMet, are the most commonly used source for obtaining this information and account for 45 percent of cases. These figures, however, under-represent the actual use of ET information, particularly from AgriMet, since they do not take into account cases where commercial irrigation service providers provide this data.

The results show that approximately 15 percent of farmers, particularly in larger farms, perform soil moisture measurement using various techniques and equipment. Neutron probes and tensiometers are by far the most commonly used devices, accounting for 45 percent and 23 percent of cases respectively. Measurement of plant water status is far less common than soil moisture measurement for determining plant water requirements and is almost always used in conjunction with soil moisture measurement. Less than 2 percent of respondents report using plant water status techniques.

Reliable measurement of applied water is integral to the practice of scientific irrigation scheduling because without it, the knowledge of how much water should be applied becomes virtually useless. Of the surveyed farms, 171 (22 percent) report using techniques for applied water measurement that are deemed acceptable with respect to accuracy.

Irrigation Scheduling Practices

As shown in Table 1-3, a large majority, 79 percent, of the surveyed farms in the Northwest do not use scientific irrigation-use practices. However, these cases account for about 57 percent of total irrigated acreage, indicating that non-scientific irrigation scheduling practices are more common among smaller farms. Practice level I, although reportedly used in only 12 percent of surveyed farms, accounts for 32 percent of irrigated acreage and is most common in larger farms, generally more than 500 irrigated acres.

In general, survey results show a strong relationship between farm size and level of sophistication in irrigation scheduling – the larger the farm, the greater the tendency to apply scientific irrigation scheduling techniques. Despite the high concentration of scientific irrigation scheduling in large-size farms, it does not necessarily follow that these methods are widespread. Survey results show that of the farms with 500 or more irrigated acres, Level I is practices on 38% of the irrigated acreage, Level II on 11%, and over one-half of the acreage is still irrigated under Practice Level III.

Table I.2: Frequency of Irrigation Scheduling Practices by Number of Farms and Irrigated Acreage

Practice	Farms	Percent	Irrigated Acres	Percent
I	90	12	155,175	32
II	75	10	52,339	11
III	611	79	274,270	57

The more sophisticated irrigation scheduling practices are more prevalent in Horse Heaven (Washington), Moses Lake (Washington), Twin Falls (Idaho), and Hermiston (Oregon) sub-regions. The proportions of irrigated acres within practice level I in the Horse Heaven and Moses Lake sub-regions are significantly higher than in other regions. In utility service areas such Benton County PUD No. 1 and Umatilla Electric Co-Op, where scientific irrigation scheduling methods have been promoted rather aggressively in the past few years, the proportion of farms practicing level I irrigation scheduling methods is higher than the regional average (14 percent compared to 11 percent). However, once variations in average farm size across different regions are taken into account, the difference becomes much more pronounced. The survey results show scientific irrigation scheduling methods are applied to 65 percent of the irrigated acreage is the two utilities' service areas, compared to 23 percent region wide.

Application of irrigation scheduling practices also varies across crops. Practice levels I and III are the most prevalent approaches to irrigation scheduling practices for most crops. The survey results also suggest that the more sophisticated irrigation scheduling practices are more likely to be utilized for higher value crops.

Water Use

Survey respondents were asked to report the actual amount of water in inches or feet per acre applied to each to each crop they grow. The main objective in collecting this information was to determine whether water use varies depending on irrigation scheduling practice.

Examination of reported water use and their deviations from known irrigation requirements indicate that by and large farms in practice level I tend to use less water than farms that use less sophisticated practices. Comparison of mean water use derived from a regression model of water use shows that application of the combination of methods used in practice levels I and II are likely to result in water savings of approximately 12 percent and 10 percent respectively.

Conclusions and Recommendations

Phase I of this study was an attempt to develop an understanding of and to establish an empirical baseline for irrigation scheduling methods and practices in the Northwest. A comparison of the geographic distributions of farms between this sample and the 1998 Farm and Ranch Survey sample shows that in spite of differences in geographic distributions, the two samples are similar with respect to farm-size distributions. This comparison also reveals several marked differences in the results relating to irrigation scheduling practices. Prevalence of soil moisture sensing devices in this study is considerably greater than the 6 percent reported in the 1998 Census.

The proportion of surveyed farms reporting use of commercial services also stands at a significantly higher level than the 4 percent reported in the 1998 Census. These differences may in part be due to the size characteristics of farms in the survey sample. There may also have been an increase in the adoption of these technologies since 1998 due to the influence of recent market transformation initiatives and programmatic efforts sponsored by several utilities aimed at improving irrigation scheduling practices in the region. Adoption of scientific irrigation scheduling practices, nevertheless, still stands at a relatively low level throughout the region, even in larger farms.

Based on reported levels of water use, it appears that more advanced irrigation scheduling practices do indeed result in reductions in water use. Comparison of reported water use with estimated net water requirements, however, reveals a pervasive pattern of deficit irrigation. Arguably, the consistency in this pattern raises questions concerning the accuracy of these self- reports. These findings therefore are to be interpreted as *indicative*, rather than *conclusive*. In our view, more accurate and definitive assessment of the impacts of advanced irrigation scheduling techniques on water—and electricity—will have to be postponed until the second phase of this study is completed.

I. Introduction

This report summarizes the results of a study of irrigation scheduling practices in the Pacific Northwest. Irrigation scheduling is one of the component activities that qualify for Bonneville Power Administration's Conservation & Renewables Discount rate. This study was commissioned by the Bonneville Power Administration (Bonneville), in a collaborative effort with the Pacific Northwest Generating Cooperative (PNGC), the Northwest Power Planning Council (NWPPC), and the Northwest Energy Efficiency Alliance (Alliance) to evaluate approaches to and levels of irrigation scheduling practices in the region so that a well-informed basis for future planning and program development efforts may be established.

The primary goals of this study were two-fold:

1. Developing a better understanding of and establishing an accurate baseline for current levels and methods of irrigation scheduling in different sub-regions of the Northwest.
2. Estimating the relative effects of different irrigation scheduling practices on water and energy use for the purpose of developing estimates of parameters for a simplified methodology for calculation of deemed savings associated with irrigation scheduling.

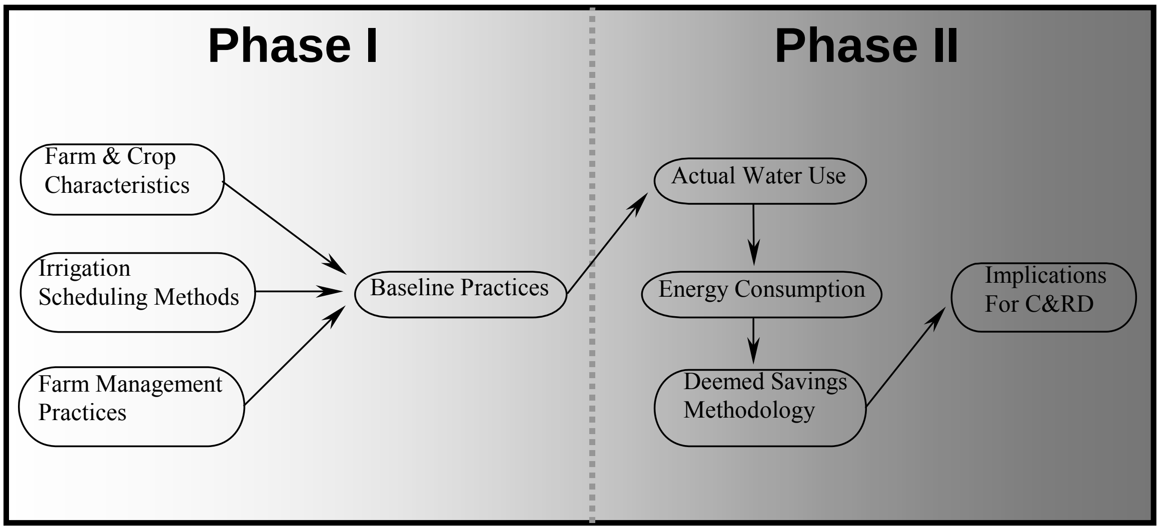
The research is being conducted in two phases. Phase I focuses on developing a baseline of regional irrigation scheduling practices through a survey of a representative sample of farms in the Northwest. Phase II will consist of more detailed field measurement and metering of actual water and energy use on a sub-sample of farms studied in Phase I. The broad context and the elements of the study are shown in Figure I.1. This report summarizes the results of Phase I of the study and provides a conceptual plan for Phase II.

The study is being conducted under the guidance of an advisory group comprised of representatives from Bonneville, PNGC, NWPPC, Alliance, and two public utilities, Benton Co. PUD, and Umatilla Electric Cooperative. The study is managed by KEMA-XENERGY with assistance from a technical advisory team of irrigation experts from Bonneville, Oregon State University Department of Bioengineering, and IRZ Consulting, an irrigation consultancy in Oregon.

Irrigation Scheduling: an Overview

Many crops in the Northwest are irrigated over a wide range of soil and climate conditions and crop production practices. The importance of scientific irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve specific goals. This increases irrigation efficiency and helps avoid over-irrigation. Over-irrigation wastes water, energy, and labor; leaches expensive nutrients below the root zone out of reach of plants; and reduces soil aeration and can diminish crop yields. Unintended under-irrigation, on the other hand, stresses the plant and causes yield reduction.

Figure I.1: Study of Irrigation Scheduling Practices Research Context and Elements



The timing of crop irrigation and the amount of water used is determined by a number of factors, including soil properties, soil-water relationship, crop type, stage of crop development, availability of water, and climate factors such as rainfall that mitigate the need for irrigation. A critical element in irrigation scheduling is the knowledge of the necessary volume of water to be applied and the depth of application. A farmer cannot manage water to maximum efficiency without knowing how much water to apply.

Irrigation decisions generally also depend on the irrigation criteria, strategy, and goal. The practice of irrigation scheduling varies greatly with respect to levels and methods and may range from no scheduling to the application of automated computerized systems. In general, the level and timing of irrigation scheduling depend on irrigation criteria, that is, the indicators used to determine the need for irrigation. Effective irrigation scheduling can help to maximize crop yield and profits for farmers and to minimizing water and energy use

Irrigation scheduling methods consist of an irrigation criterion that triggers irrigation and an irrigation strategy that determines how much water to apply. Irrigation scheduling methods differ by the irrigation criterion or by the method used to estimate or measure this criterion. A common and widely used irrigation criterion is soil moisture status and soil moisture tension.

Scientific irrigation scheduling generally refers to the practice of meeting crop moisture requirements by supplying the right amount of water at the right time based on measurement of actual soil moisture and evapotranspiration. An optimal irrigation scheduling practice also requires knowledge of the actual amounts of water that are applied. In the context of this study we define scientific irrigation scheduling strictly as a practice that involves:

1. Knowledge of crop evapotranspiration
2. Appropriate measurement of soil moisture
3. Measurement of the actual amounts of water applied.

Phase I of this study was an effort to define the range of irrigation scheduling practices in the Northwest, to identify various elements that comprise each practice, and to empirically determine the scope and intensity of various practices in the region.

II. Phase I Results

Sample Development

The sample frame for this study was a list of 20,657 farms and ranches in the 4 states of the Pacific Northwest, Idaho, Montana, Oregon, and Washington, purchased from Dun & Bradstreet. For each farm, this database contained complete contact information, data on primary production, general farm characteristics, management and ownership structures, and location coordinates. Contact and location data were the only information in the database that was used in this study.

To ensure that the survey sample would represent the various soil types, irrigation requirements, and irrigation practices in the Northwest, cases in the sample frame were assigned to 11 agricultural sub-regions, based on the intensity of irrigated farming and variations in prominent crops and soil types. A total of 6,438 farms were mapped to the 11 sub-regions. Farms in the sample frame were also mapped to utility service areas by ZIP code to identify local electric utilities. Since this study focused on utilities in Bonneville Power Administration's (Bonneville's) service area, only farms served by public utilities that agreed to participate in the study were retained in the sample frame. This restriction eliminated all cases in Montana, since none of the utilities in that state showed an interest in participating in this study, and reduced the sample frame to 5,065 cases. See Table II.1.

Table II.1: Sample Frame Development

Sample From Dun & Bradstreet	20,657
Farms Within Study Regions	6,438
Farms Within Participating Utility Territories	5,065

Survey Design and Implementation

The survey instrument was designed to solicit information on four general areas of farm and crop characteristics, irrigation system type and configuration, irrigation management and scheduling approaches, and general demographics. The design of the survey instrument was a collaborative effort among KEMA-XENERGY, Oregon State University Department of Bioengineering, IRZ Consulting, and Bonneville. Respondents were also asked to provide estimates of actual water use during the previous planting season for all their major crops. A summary of data elements comprising the questionnaire is shown in Table II.2.

Surveys were administered by phone from January through March 2003. An important consideration in timing was to complete the surveys before the start of the planting season to ensure that respondents would be available and to minimize intrusiveness.

Table II.2: Survey Focus and Main Data Elements

Data Category	Data Elements
Basic Farm Characteristics	Acreage Irrigated acreage Main crops Soil type Water application
Irrigation Systems	Water sources Irrigation systems Pumping system characteristics
Irrigation Practices	Management approach Applied water measurement Soil moisture measurement Plant water status measurement Application & source of ET Use of an irrigation consulting service
Demographics	Years of experience farming Education level, etc.

Survey Results

The final call list consisted of 5,065 farms in Idaho, Oregon, and Washington. Seven hundred and ninety-one cases (16 percent) were found to have invalid phone numbers and were dropped from the list. Response rates were generally high and only 248 (5 percent) of potential respondents refused to participate in the survey. A total of 1,633 calls were completed; 857 of the farms contacted reportedly did not use irrigation. The final sample of completed surveys consisted of 776 farms. Disposition of the telephone calls is summarized in Table II.3.

Sample Characteristics

Distribution of completed surveys by number of farms and irrigated acreage across the region are shown in Table II.4. A comparison of this distribution with that reported in the 1998 Northwest Farm and Ranch Survey indicates that Washington, and to a lesser extent Oregon, are overrepresented in the sample. This primarily is a reflection of the fact that the study sample frame was restricted to utilities willing to participate in the survey.

Table II.3: Call Disposition

Status	Farms	Percentage
Sample Frame	5,065	100
Valid Phone Numbers	4,274	84
Refusals	248	5
Completed Calls	1,633	32
Farms Not Irrigated	857	17
Completed Surveys	776	15

Table II.4: Comparison of Sample Distribution with the 1988 Census Data

State	Sample	Survey Sample		Census of Agriculture	
	Farms %	Farms %	Irrigated Acres %	Farms %	Irrigated Acres %
Idaho	12%	11%	16%	40%	51%
Oregon	24%	14%	13%	32%	24%
Washington	64%	75%	71%	28%	25%

Comparison of survey results with the Census data, however, shows a closer correspondence between the two with respect to size distribution (see Table II.5). Distribution of the farms in the study sample is comparable to that of the 1998 Census in most size categories, except for the largest size category, where the study sample appears to be skewed towards larger farms. Overrepresentation of larger farms is partly due to the characteristics of utilities represented in the study. It seems reasonable to expect that utilities with more intensive agricultural activity and greater irrigation loads were more likely to have an interest in participating in the survey. This also might have been because smaller farms tend to be more difficult to reach by phone.

Distribution of farms by agricultural region, as shown in Table II.6, indicates that all major agricultural regions are well represented. The regional distribution also shows a close correspondence between the number of farms and irrigated acres, indicating an even distribution of different farm sizes across the sub-regions.

Table II.5: Distribution of Farms by Size with 1998 Census of Agriculture Data

Irrigated Acreage	2002 Survey		1998 Census	
	Farms %	Irrigated Acres %	Farms %	Irrigated Acres %
1 – 9	3%	<1%	21%	1%
10 – 49	5%	<1%	33%	4%
50 – 99	13%	1%	11%	4%
100 – 199	18%	4%	13%	9%
200 – 499	28%	14%	12%	18%
500 – 999	18%	20%	6%	21%
1000 +	16%	61%	4%	44%

Table II.6: Distribution of Farms by State and Agricultural Region

Region	Farms	Percentage	Irrigated acres	Percentage
Oregon				
Willamette	5	0.6%	3,855	0.8%
Central	24	3.1%	6,802	1.4%
Hermiston	77	9.9%	50,326	10.5%
Washington				
Omak	30	3.9%	9,325	1.9%
Ellensburg	4	0.5%	584	0.1%
Moses Lake	351	45.2%	266,013	55.2%
Ritzville	22	2.8%	7,366	1.5%
Yakima	164	21.1%	47,180	9.8%
Horse Heaven	11	1.4%	11,623	2.4%
Idaho				
Twin Falls	73	9.4%	73,360	15.2%
Teton	15	1.9%	5,350	1.2%

The initial data collection plan called for a focus on public utilities. However, since ZIP code was the only practical means of matching farms with utility service areas and many ZIP code areas are served by more than one utility, inevitably a number of farms served by investor-owned utilities were surveyed. For the same reason, in a very small number of cases, we were unable to effectively screen out all farms served by utilities that had not expressed an interest in participating in the study.

Distribution of the final sample by utility is shown in Table II.7. Thirteen public utilities are represented in the sample. Approximately one-quarter of surveyed farms are in the service territories of investor-owned and other unidentified utilities, and in about 4 percent of cases the utility was not identified. In evaluating the distribution of farms across the participating utilities, it is important to keep in mind that farm counts are not necessarily indicative of the level of agricultural activity and, hence, the utility's irrigation load. Simple farm count does not take into account the fact that average farm sizes, and more importantly irrigation loads, may vary significantly across utility service areas. Estimates of each utility's share of total irrigation loads for all 13 public utilities (column 4 in Table II.7) show that in the majority of cases the sample distribution is proportional to the utility's irrigation load. Two utilities, Benton County PUD and Umatilla Electric, are somewhat underrepresented in the sample relative to their share of total irrigation load.

Table II.7: Utilities Represented

Utilities	Number of Farms	Percentage	Share of Irrigation Loads (%)
Public Utilities			
Benton County PUD No. 1	58	8%	18%
Benton Rural Electrical Assoc.	22	3%	5%
Big Bend Electric Co-Op	106	14%	14%
Central Electric Co-Op	15	2%	1%
Consumer's Power, Inc.	3	<1%	2%
Douglas County PUD	18	2%	2%
Franklin County PUD No. 1	28	4%	7%
Grant County PUD	183	24%	25%
Inland Power and Light	33	4%	1%
Raft River Rural Electric Co-Op	20	3%	8%
South Side Electric	7	<1%	1%
Umatilla Electric Co-Op	40	5%	15%
United Electric	15	2%	2%
Investor-Owned Utilities			
Avista	16	2%	
Idaho Power	26	3%	
PacifiCorp	147	19%	
Other	33	4%	
Total	*776*	*100%*	

Farm Characteristics

Crop information was obtained by asking the respondents to report by type and number of acres the three main irrigated crops they planted during the 2002 growing season. Reported crops were then classified into three groups, primary, secondary, and tertiary, based on acreage. The results, summarized in Table II.8, show that 56 percent of all the surveyed farms planted alfalfa and that in 38 percent of cases, alfalfa was the primary crop. In terms of the total irrigated acres, alfalfa accounted for nearly one-third of the planted acreage. Wheat (17 percent), vegetables (10 percent), grain and sweet corn (15 percent), potatoes (7 percent), and grass seed (6 percent) were the other most prominent crops. Orchards, despite a high frequency, 103 cases, only account for approximately 3 percent of the reported irrigated acreage.

Respondents were also asked to report on the type(s) of soil in their farms. Seventy-three of the respondents (9.4 percent) reported soil types that were ambiguous or deemed in our judgment to be inaccurate. We had assumed that farmers in general are aware of the type(s) of soils on their farm, but many responses could not be matched with known soil types in the region and some of the reported soil types were so generic as to be useless. For example, in nine cases the soil types reported were described as "dirt," "rocks," or "rocky." Since soil type is an important aspect of determining irrigation requirements, hence irrigation scheduling practice, the 73 ambiguous survey results on soil type were not used in the analysis. Instead, data on soil types for each of these farms were separately identified based on farm location as mapped in NRCS soil surveys, which contain data on all sub-regions in the Northwest.

Table II.8: Farming Activity by Crop

Crop	Primary Crop		Secondary Crop		Tertiary Crop		Irrigated Acres	
	Farms	%	Farms	%	Farms	%	Acres	%
Alfalfa	295	38%	62	12%	17	6%	119,105	31%
Beans	17	2%	23	5%	18	6%	9,311	2%
Corn (Grain)	45	6%	49	10%	17	6%	35,988	9%
Corn (Sweet)	14	2%	15	3%	13	4%	21,699	6%
Grapes	46	6%	14	3%	11	4%	6,690	2%
Grass	57	7%	36	7%	24	8%	24,442	6%
Orchards-Trees	108	14%	60	12%	35	12%	16,020	4%
Other - Grain	28	3%	32	6%	21	7%	16,993	4%
Pasture	34	4%	40	8%	25	9%	6,612	2%
Potatoes	32	4%	30	6%	28	10%	27,641	7%
Vegetables - Mint	44	5%	53	10%	35	12%	35,921	10%
Wheat	56	7%	95	19%	51	17%	65,623	17%
Total	*776*	*100%*	*509*	*100%*	*295*	*100%*	*386,045*	*100%*

Irrigation Water Source and Systems

Sources for irrigation water vary widely across the region. As shown in Table II.9, irrigation districts, groundwater mainly from wells, and local surface water from rivers and ponds are the primary sources for irrigation water in the region. Water from irrigation districts is reported as the main source of irrigation water and accounts for nearly 45 percent of total irrigated acreage surveyed. Based on the survey results, approximately 29 percent of the irrigated acreage relies on groundwater and 23.7 percent uses local surface water as the primary source of water for irrigation. Water for 3 percent of irrigated acres is supplied from recaptured tailwater and wastewater from other farming activities.

With respect to irrigation systems, sprinklers are by far the most extensively used, being the primary irrigation system in 82 percent of the surveyed farms. As can be seen in Table II.10, gravity irrigation is the primary system for 15 percent of farms; 3 percent of the farms use micro irrigation as their primary irrigation system.

Table II.9: Irrigation Water Sources

Source	Irrigated Acres	Percentage
Groundwater or On-Farm Wells	139,589	29.0%
Irrigation District or Off-Farm Provider	213,307	44.3%
Recaptured Tailwater or Return Flows	4,028	0.8%
Local Surface Water (river, stream, pond, etc.)	114,158	23.7%
Wastewater from a Non-Irrigation Activity	9,303	1.9%
Other	1,400	0.3%

Table II.10: Primary Irrigation Systems (N-770)

System	Number of Farms	Percentage
Sprinklers	632	82%
Micro Irrigation	22	3%
Gravity	116	15%

Survey results show that 85 percent of farms use pressurized pump systems for irrigation and in 87 percent of cases the local utility is the source of power for pumping. Only 4 percent of farms report using on-site generation or non-electric energy sources for pumping. Diesel engines account for the majority (82 percent) of the 22 farms using non-electric pump systems. (See Table II.11.)

Table II.11: Sources of Power for Irrigation System (n = 795)

Power Source	Farms	Percentage
Electric Utility	688	87%
Electric Generator	8	1%
Non-Electric Source	22	3%
Diesel	18	82%
Gasoline	2	9%
Propane	2	9%
Other	33	4%
No Pumping	44	6%

Irrigation Scheduling Methods

We define irrigation scheduling methods in terms of the levels of sophistication in the set of techniques used by farmers and farm managers to determine crop water requirements, to decide when to irrigate, and to measure how much water has been applied. Our definition is based on the proposition that all farmers use certain irrigation regime. What distinguishes these regimes is the basis on which irrigation decisions rest. Based on the survey results, we identified two broad classes of irrigation scheduling approaches: scientific and nonscientific. Scientific irrigation scheduling (SIS) refers to the use of technically advanced methods and accurate data as the basis for when and how much to irrigate. This may be accomplished either using internal (on-farm) resources or by contracting with a commercial irrigation service provider. Nonscientific irrigation scheduling methods generally rely either on fixed schedules based on established routine, water delivery schedules, and published guidelines or are judgment based using visual or manual checks of crop and soil conditions.

As shown in Figure II.1, scientific irrigation scheduling is practiced in 185 (24 percent) of the surveyed farms. Eighty-nine (48 percent) of these report using commercial irrigation scheduling services on a contract basis, while 96 (52 percent) use on-farm equipment and methods for scheduling. A large majority (76 percent) of farmers report using nonscientific irrigation scheduling methods. Of these, 91 percent rely on judgment in deciding when and how much to irrigate.

Scientific Irrigation Scheduling

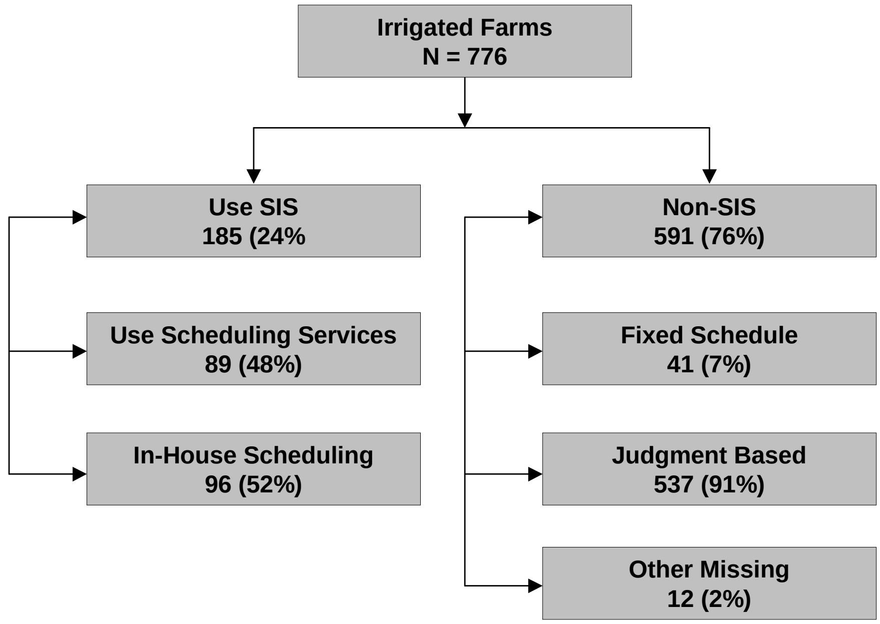
Scientific irrigation scheduling methods are defined here as techniques used to determine the required timing and amount of irrigation for each field and application of appropriate metering to determine the actual amounts of applied water during a specific period. The level of soil moisture depletion at which a crop begins to experience stress determines the appropriate timing of irrigations. The field should be irrigated on or before the day that level of depletion is reached. The irrigation requirement is defined as:

Irrigation Requirement =
Net Water Requirement / Irrigation System Efficiency

Where,

- Net Water Requirement = Evapotranspiration (ET) - Rainfall - Useable Antecedent Soil Moisture

Figure II.11: Irrigation Scheduling Methods



Application of scientific irrigation scheduling, therefore, requires using appropriate scientific tools and techniques to determine ET, rainfall and soil moisture or plant water status, utilizing these factors to determine plant water needs, and measuring the amount of water that is actually applied. Farmers may make these determinations themselves or by contracting out all or portions of these services.

Use of Commercial Irrigation Scheduling Services

Commercial irrigation scheduling services generally provide farmers with all necessary data to meet an optimal irrigation schedule by providing customized information on ET and collecting information on soil moisture and/or plant water status. We consider that use of commercial irrigation scheduling services is among the highest levels of irrigation scheduling practice. Of the sites surveyed, 89 (11.5 percent) report using a commercial irrigation scheduling service currently, and 165 (21 percent) had used such services in the past. As shown in Table II.12, of the 254 that use or have used a service, 75 (29.5 percent) received financial assistance from a utility or local agency for the services they received. The proportion of surveyed farms reporting use of commercial services stands at a significantly higher level than the 4 percent reported in the 1998 Census. This difference in part may be explained by the preponderance of larger farms in the sample, which are more likely to invest in SIS. It may also be due to irrigation scheduling initiatives sponsored by local utilities in several of the surveyed areas in the sample.

To gain a better understanding of the type and scope of such services, we surveyed 10 farms served by IRZ Consulting in the Umatilla area. These surveys were performed primarily as a qualitative assessment rather than a statistically representative characterization of such services. The results show the scope of services offered to farmers sufficiently satisfy the criteria for a scientific approach to irrigation scheduling as we have defined it here:

- Sampled farms tend to be very large (over 500 acres) and use pressurized irrigation systems powered by electricity supplied by the local utility.
- In all cases ET information, calibrated based on local weather, soil, and crop conditions, is made available on line through a local network.
- In nearly all cases soil moisture is measured weekly on a sample of fields using neutron probes. In many cases crop condition and irrigation system performance is also assessed via aerial infrared thermography.
- Amounts of applied water are tracked and compared with irrigation requirements on a regular basis
- The service is supported with financial assistance of the local utility.

Use of Information on ET

ET is the process by which water is lost from the soil due to evaporation and from the plant due to transpiration. It varies by crop and location. Reference evapotranspiration (RET) for each crop at a particular location is used to determine crop water requirement or *consumptive use,* one of the most important components of scientific irrigation scheduling.[2] There are a number of different sources for ET data including on-line services such as AgriMet, farm-related publications, personal weather stations and computer models, and irrigation consulting services.

The survey results suggest that a relatively small fraction (12%) of farms directly obtain and use ET data on a regular basis. On-line services, primarily AgriMet, are the most commonly used source for obtaining this information and account for 45 percent of cases.[3] Twenty-seven percent of farms that use ET information rely on media as their main source and sixteen percent (16 percent) use personal weather stations. Irrigation consulting services are

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2 See Oregon Crop Water Use and Irrigation Requirements, Oregon State University, Department of Bioengineering, Miscellaneous Publication 8530, October 1992.

3 It is important to note that this fraction does not necessarily represent the actual application of ET information, nor use of AgriMet for such data, for it does not take into account utilization of ET information and AgriMet by commercial irrigation scheduling service providers.

reported as the primary source for ET information in 12 percent of cases. See Table II.13.

Table II.12: Use of Irrigation Scheduling Services

Use of irrigation scheduling services	Farms	%
Yes – Currently Using	89	11%
Yes – Used in the Past	165	21%
No	520	67%
Total	*774*	*100%*
Support for Irrigation Services	254	100%
Received Financial Assistance	75	30%
Did not Receive Financial Assistance	174	69%

Table II.13: ET Sources (n=89)

ET Sources	% OF Farms
On-line Services	45%
Newspapers, Radio, or Television	27%
Personal Weather Stations or Software	16%
Consulting Service	12%

Note: Respondents may use more than one method.

Resources for Irrigation Management Decisions

To gain a better understanding on irrigation management practices and the intensity of information on which irrigation decisions are based, survey respondents were asked to report on source of information, local and regional organizations, and publications they commonly rely on for forming their irrigation decisions. Survey questions focused on three specific areas: general resources, farm organizations, and farm-related published media.

As shown in Table II.14, personal experience is the most frequently cited source for irrigation management decisions. Other informal resources such as employees in the field and friends and family are reported as primary sources of information in 15 percent of cases. Based on the survey results shown in Table II.15, 40 percent of respondents use farm organizations as a resource for information for irrigation decisions. Farm Bureau, local commodity organizations, and water users associations are the most frequently cited resource in this category.

More than 60 journals and newsletters were cited as sources of information on irrigation. The eight most frequently cited publications are listed in Table II.16. Among the cited publications, the Farm Journal seems to have the highest readership among regional farmers. Other popular publications appear to be Successful Farming (13 percent), Capital Press (13 percent), and Good Fruit Grower (8 percent).

Table II.14: Resources for Information on Irrigation Management Decisions
(n = 1,017)

	% of Responses
Personal experience	39%
Employees in the field	8%
Contract crop advisor or irrigation consultant	8%
Extension Services	7%
Friends, family or other farmers	7%
Fertilizer, pesticide, or herbicide suppliers	7%
Irrigation equipment dealers	6%
Soil and Water Conservation District (SWCD)	6%
Media (newspaper, radio, TV, Internet)	6%
Irrigation district	3%
Natural Resource Conservation Service (NRCS)	2%
Other	1%

Note: Respondents may report more than one resource.

Table II.15: Farm Organization Sources for Irrigation Management Information (n = 766)

	% of Responses
Farm Bureau	16%
Commodity Organization (wheat growers league, potato growers organization, etc.)	12%
Water Users Association (such as an irrigation district)	6%
Quasi Governmental Organization	2%
Farming, irrigation, or supply company	1%
Extension Service	1%
Other farm organization (SPECIFY):	1%
General Farm Organization	<1%
Government Agency	<1%
None	60%

Note: Respondents may report more than one resource.

Table II.16: Published Information Sources (n =1,379)

Published Information Sources	% of Responses
Farm Journal	25%
Successful Farming	13%
Capital Press	13%
Good Fruit Grower	8%
Oregon Farmer-Stockman	3%
Washington Farmer-Stockman	2%
Irrigation Age	2%
Western Farmer-Stockman	2%
Other[4]	23%
None	10%

Note: Respondents may report more than one resource.

Measurement of Plant Water Requirements

A variety of methods are available for determining plant water needs either by measuring the moisture content of the soil or directly measuring the water status of the plant. These approaches generally rely on different techniques with varying degrees of accuracy and sophistication, ranging from feeling soil moisture by hand or visually inspecting the plant condition to using soil probes and plant water sensors.

Soil Moisture Measurement Techniques. A variety of instruments and methods are used to measure soil moisture including neutron probes, tensiometers, watermark sensors, capacitance probes, gravimeter sampling, and gypsum blocks. Survey results show that approximately 15 percent of respondents use one or more of these soil moisture measurement techniques. As shown in Table II.17, neutron probes and tensiometers are by far the most commonly used devices for soil moisture measurement, accounting for 45 and 23 percent of cases respectively. The results also indicate that these techniques

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4 Other includes sources with less than 2%: AG Weekly, Agri Times, American Fruit Grower, American Hereford Journal, American Vegetable Grower, American Vineyard, Basin Farmer (webzine), Beef Magazine, Beef Times, Beef Today, Dairy Herd Management, Dairy Today, Drover's Journal, Farm & Ranch, Farm Forum, Farm Show, Farm Times, Feedstuffs, Fruit Growers News, The Furrow, Good Fruit Grower, The Grape Grower, Growers' Guide, Hay & Forage Grower, High Plains Journal, Hoard's Dairyman, Idaho Farmer-Stockman, Irrigation Business and Technology, Irrigation Journal, Livestock Reporter, National Hog Farmer, Onion World, On-line information services / web or internet groups, Oregon Wheat, Potato Grower, Pro Farmer, Progressive Dairyman, Progressive Farmer, Progressive Hay Grower, Quarter Horse News, Range, Seed World, Spudman, Stockman Grass Farmer, Sugar Producer, Sugarbeet Grower, The Angus Journal, The Packer, Top Farmer, Top Producer, Vegetables West, Western Cowman, Western Dairy Business, Western Fruit Grower, Western Horseman, Western Livestock Journal, Western Livestock Reporter, Wheat Life, Wine Business Monthly.

are particularly common in larger farms, and together they account for approximately 86 percent of the total irrigated acreage in the sample.

Table II.17: Soil Moisture Measurement Methods (n = 132)

Soil Moisture Measurement Methods	% of Farms	% of Acres
Neutron Probe	45%	55%
Tensiometers	23%	31%
Watermark Sensors	14%	7%
TDR or Capacitance Probe	10%	8%
Gravimetric Sampling	5%	5%
Gypsum Blocks	2%	1%

Note: Respondents may use more than one method.

The prevalence of soil moisture sensing devices in this study is considerably greater than the 6 percent reported in the 1998 Census, which may in part be due to the size characteristics of the sample There may also have been an increase in the adoption of these technologies since 1998 due to the influence of recent market transformation initiatives and utility-sponsored programmatic efforts aimed at improving irrigation scheduling practices in the region.

Plant Water Status Measurement Techniques. The measurement of plant water status is far less prevalent than soil moisture measurement for determining plant water requirements and is almost always used in conjunction with soil moisture measurement. Less than 2 percent of respondents report using plant water status techniques. Five sites used infrared thermometry. Other plant water status measurement techniques were rarely reported. See Table II.18.

Table II.18: Plant Water Status Measurement Methods (n = 13)

Plant Water Status Measurement Methods	% of Farms	% of Acres
Infrared Thermometry	38%	26%
Pressure Bomb	15%	11%
Porometer or Stomatal Conductance	15%	10%
Leaf Push	15%	10%
Heat Pulse or Sap Flow	8%	2%
Stem Diameter	8%	1%

Note: Respondents may use more than one method.

Applied Water Measurement. Reliable measurement of applied water is integral to the practice of scientific irrigation scheduling because, without it, the knowledge of how much water should be applied becomes virtually useless. There are a number of different methods farmers use to gauge how much water they apply to their fields. Of the methods we considered acceptable, some are more consistently reliable than others. The use of an in-line flow meter or precipitation gauge or determinations by an irrigation service generally yield more accurate measurements than relying on system discharge rates, head gate delivery rates, or an irrigation district's measurements, which can vary in accuracy from farm to farm. Of the 593 sites reporting acceptable applied water measurement techniques, 171 (29 percent) fell in the former category, while 422 (71 percent) fell in the latter.

As shown in Table II.19, there were 680 instances of the application of water measurement techniques. In nearly one-half of cases the use of head gate delivery rates was cited as a method for measurement of applied water; and 20 percent of respondents reported using system discharge rates. More reliable methods such as in-line flow meters, precipitation gages, and hour meters are reportedly used in nearly one-third of cases.

Table II.19: Applied Water Measurement Methods (N = 680)

	% of Farms	% of Acres
Head Gate Delivery Rates	48%	31%
System Discharge Rates	20%	16%
In-Line Flow Meter	18%	31%
Precipitation Gauge	9%	12%
Hour Meter	5%	19%
Irrigation District Measurements	<1%	<1%
Consulting or Water Monitoring Service	<1%	<1%

Note: Respondents may use more than one method.

Aerial Field Monitoring. Aerial photographic or infrared images of fields can help spot problems that might not be immediately visible at ground level. These techniques, however, are more commonly used to detect irrigation system problems than to determine crop water status. From the sample, 97 sites (12.5 percent) report using aerial monitoring of their fields. Twenty-five respondents reported using aerial monitoring for irrigation decisions; but only 6 cited irrigation scheduling as the sole purpose of monitoring. As aerial monitoring of fields seems to be primarily used for problem detection, we did not include it when defining different irrigation scheduling practices, though the information gained from such monitoring is certainly applicable to irrigation system management.

Definition of Irrigation Scheduling Practices

Irrigation scheduling may be practiced with different levels of intensity, regularity, and sophistication. Within the context of this study, we define scientific irrigation scheduling as a practice to determine net irrigation requirements and appropriate irrigation timing based on the determination of RET, accurate measurement of soil moisture or plant water status, and regular measurement of applied water. In differentiating between various levels of irrigation scheduling practices, we identified three distinct levels based on the sophistication of the techniques used to determine net irrigation requirements:

- Practice Level I: Use of commercial irrigation scheduling services *or* Use of RET in combination with measurement of *both* water status (soil or plant), *and* applied water
- Practice Level II: Use of RET in combination with measurement of *either* water status (soil or plant), *or* applied water
- Practice Level III: Use of RET *or* water status (soil or plant) or neither.

The three different levels of irrigation scheduling practices and their constituent elements are shown in Table II.20. Plant water status measurement, because of its infrequency and because it was most often used in conjunction with soil moisture measurement, was combined with the latter in one category.

Table II.20: Definition of Irrigation Scheduling Practices

Practice Level	Use of Scheduling Services	Soil Moisture or Plant Water Status	Use of ET	Applied Water Measurement
I	Yes			
		Yes	Yes	Yes
II		Yes	Yes	
			Yes	Yes
III		Yes		
			Yes	

The frequency of reported applications of various irrigation-scheduling practices in terms of number of farms and proportions of irrigated acreage are reported in Table II.21. A large majority (79 percent) of the farms surveyed do not utilize scientific irrigation scheduling methods (Practice Level III). However, these cases account for about 57 percent of total irrigated acreage, indicating that this practice is more common among smaller farms. Practice Level I, although reportedly used in only 12 percent of surveyed farms, accounts for 32 percent of irrigated acreage, pointing to the fact that larger farms are more likely to employ more advanced irrigation scheduling practices. Practice Level II is reported in 10 percent of farms, which account for 11 percent of the surveyed irrigated acreage.

The overall distribution of the three levels of irrigation scheduling practices by farm size, as shown in Table II.22, indicates a close correspondence between farm size and application of scientific irrigation scheduling practices. A visual inspection of the figures in Table II.19 shows a nearly linear relationship between farm size and application of scientific irrigation techniques. This relationship is also supported statistically through of a chi square test of dependence ($X^2 = 69$), which is statistically significant at a 0.999 level of confidence.

Distribution of farms *within* each practice level, as shown in Table II.23, further indicates that Practice Level I is far more common among larger farms. Larger farms with over 500 irrigated acres constitute nearly 70 percent of farms in this category. At the other end of the spectrum, within Practice III, the distribution of farms and irrigated acreage mirror the overall distribution of farms and irrigated acreage in the survey, though with less representation of larger farms.

Although scientific irrigation scheduling methods tend to be mostly concentrated in large-size farms, it does not necessarily follow that these methods are widespread among these farms. Survey results show that of the farms with 500 or more irrigated acres, Level I is practices on 38% of the irrigated acreage, Level II on 11%, and over 51 % of the acreage is still irrigated under Practice Level III.

Table II.21: Irrigation Scheduling Practices by Farms and Irrigated Acreage

Practice	No. Farms	Percentage	Irrigated Acres	Percentage
I	90	12%	155,175	32%
II	75	10%	52,339	11%
III	611	79%	274,270	57%

Table II.22: **Distribution of Farms by Farm Size and Irrigation Scheduling Practice Levels**

Farm Size (Acres)	Practice Level		
	I	II	III
1 – 9	0%	0%	2.9%
10 – 49	0.3%	0.4%	4.7%
50 – 99	0.8%	1.3%	10.9%
100 – 199	0.9%	2.1%	14.5%
200 – 499	1.9%	2.6%	23.8%
500 – 999	3.6%	1.7%	12.6%
1000 +	4.4%	1.8%	9.5%
Cumulative Percentage	12%	10%	79%

Table II.23: Distribution of Farms by Farm Size within Practice Levels

Farm Size (acres)	Practice Level		
	I	II	III
1 – 9	0%	0%	3.6%
10 – 49	2.2%	2.7%	5.9%
50 – 99	5.5%	12.2%	13.9%
100 – 199	7.8%	21.6%	18.5%
200 – 499	15.6%	27.0%	30.2%
500 – 999	31.1%	17.6%	16.0%
1000 +	37.8%	18.9%	11.9%
Cumulative Percentage	100%	100%	100%

The results of the study show marked regional differences in application of specific irrigation scheduling practices. The more sophisticated irrigation scheduling practices are more prevalent in Horse Heaven (Washington), Moses Lake (Washington), Twin Falls (Idaho), and Hermiston (Oregon) sub-regions. The proportions of irrigated acres within Practice Level I in the Horse Heaven and Moses Lake sub-regions are significantly higher than they are in other regions (see Table II.24). The highest proportions of farms using Practice Level II fall in the Central Oregon, Hermiston, and Twin Falls sub-regions.

Application of irrigation scheduling practices does not vary markedly across utility service areas in terms of the number of farms. For example, in the Benton County PUD No. 1 and Umatilla Electric Co-Op, where scientific irrigation scheduling methods have been promoted rather aggressively in the past few years, the proportion of farms practicing Level I irrigation scheduling methods is slightly higher than the regional average (14 percent compared to 11 percent). However, as shown in Table II.25, once variations in average farm size across various regions are taken into account, the difference becomes much more pronounced. The survey results show scientific irrigation scheduling methods are applied to 23 percent of the irrigated acreage in the region. In the Benton County PUD No.1 and Umatilla Electric Co-Op service areas, nearly 65 percent of the farm acreage is irrigated under Practice Level I.

Table II.24: Distribution of Irrigation Scheduling Practices by Region (% of Irrigated Acres)

State and Region	Practice Level		
	I	II	III
Oregon			
Willamette	0%	5%	95%
Central	0%	19%	81%
Hermiston	16%	22%	62%
Washington			
Omak	9%	1%	90%
Ellensburg	0%	0%	100%
Moses Lake	47%	8%	45%
Ritzville	0%	0%	100%
Yakima	6%	8%	86%
Horse Heaven	54%	1%	45%
Idaho			
Twin Falls	17%	20%	63%
Teton	2%	0%	98%

Application of irrigation scheduling practices also varies across crops. Distribution of irrigation scheduling practices was analyzed across eight major crop groups. The results, shown in Table II.26, indicate that Practice Levels I and III are most prevalent approaches to irrigation scheduling practices for most crops. The survey results also suggest that the more sophisticated irrigation scheduling practices are more likely to be utilized for higher value crops.

Table II.25: Distribution of Irrigation Scheduling Practices Selected Utility Areas

Utility Service Area	Practice Level I		Practice Level II		Practice Level III	
	Farms	Irrigated Acreage	Farms	Irrigated Acreage	Farms	Irrigated Acreage
Benton Co. PUD, Umatilla E. Co-op	14%	63%	12%	8%	76%	29%
All Other Utilities	11%	23%	8%	12%	80%	65%

Table II.26: Distribution of Irrigation Scheduling Practice Groups by Major Crops

Crop	Survey Total		Practice Groups			
			% of Irrigated Acres			
	Irrigated Acres	% Irrigated Acres	1	2	3	Total
Alfalfa Hay	115,197	42%	17%	7%	76%	100%
Corn – Grain	35,788	13%	46%	3%	51%	100%
Grass Hay	11,176	4%	14%	5%	81%	100%
Orchard	12,558	5%	12%	21%	68%	100%
Pasture	6,612	2%	1%	14%	85%	100%
Potatoes	27,296	10%	37%	14%	49%	100%
Spring Wheat	18,658	7%	17%	18%	65%	100%
Winter Wheat	46,965	17%	33%	20%	47%	100%

Irrigation Water Use

Survey respondents were asked to report the actual amount of water in inches or feet per acre applied to each crop they grow. As a measure to ensure validity and accuracy of the responses, respondents were asked to indicate whether the reported water use figures were based on estimates or actual measurement. Our analysis used only water-use figures reported as being based on actual measurement. A primary objective in collecting information on water use was to see if water-use levels vary depending on the differences in application of different irrigation scheduling practices.

Table II.27 shows reported water use for each of the three irrigation scheduling practice levels for each crop. Since the amount of water required for irrigation depends on soil type, climate, and type of irrigation system, in analyzing the variations in water use it is important to take into account actual net water and irrigation requirements on a case-by-case basis.

Ideally, the reported water use (the total water applied by the farmer) and the irrigation requirement should compare reasonably well.[5] Comparison of reported water use and net water and irrigation requirements, as shown in Table II.28, indicates that for nearly all crops the reported water use is lower than the estimated net irrigation requirement, which underscores a surprisingly consistent pattern of under-irrigation. The practice of deficit irrigation, i.e., deliberate under-irrigation of a crop, has been analyzed in previous studies of irrigation.[6]

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5 Note that the net water requirement does not account for irrigation system efficiency and so is not directly comparable to the other two quantities.

6 See English, Marshall, J. and Gary S. Nuss, "Designing for Deficit Irrigation," Proceedings, American Society of Civil Engineers, June 1982.

Deficit irrigation, if carefully managed and if the deficits are not large, has been shown to have the potential to reduce the water, energy, and system design costs without loss of income to farmers. Moreover, it has been argued that deficit irrigation can increase income by allowing the farmer to bring additional acreage under production. It is reasonable to expect that certain levels of deficit irrigation might have been exercised by farmers in response to rising energy costs in the region during 2001. Water shortage during the 2001 to 2002 period might have also contributed to under-irrigation. When asked whether all of their water requirements are met during a typical irrigation season, only 68% of respondents answered yes. During a dry year, the percentage of respondents indicating that available water sources meet all their irrigation requirements drops to 51%. However, in our view, the pervasive and consistent pattern of under-irrigation observed in this study is not fully explained by intentional deficit irrigation.

Using last year's seasonal ET for each crop, seasonal rainfall, and an estimate of the antecedent soil moisture based on soil type, we calculated an average net water requirement for each crop in each agricultural zone. We then estimated irrigation requirements for each crop based on the efficiency of the primary irrigation system. System efficiency rates are based on typical mean values for each system type and were provided by the Oregon State University Department of Bioengineering.[7] Crop-specific average net irrigation requirements vary across irrigation scheduling practice levels and farm locations.

However, in our view, the discrepancy between the reported water use and required irrigation is in all likelihood the result of either inaccurate measurement or underreporting. For some crops, such as wheat, which is drought tolerant and sometimes is intentionally deficit irrigated, the mean values are not unreasonable. Alfalfa, though usually a high-value crop, is deep rooted and tolerant of stress. Corn is sometimes intentionally deficit irrigated, but has a sensitive growth phase where it is often heavily watered. The reported under-watering of potatoes, however, appears to contradict common practice. Under-irrigated potatoes tend to deform, and deformed potatoes have little value. Indeed, farmers generally tend to over-irrigate potatoes to avoid any risk of deformities.

[7] See Appendix B for a complete list of typical efficiency ratings by type of irrigation system and crop.

Table II.27: Reported Water Use, Net Water and Irrigation Requirements by Irrigation Scheduling Practice Group (Inch/Acre)

Crop	Water Application	Practice Level		
		I	II	III
Alfalfa	Reported Water Use	28.6	27.3	28.1
	Net Water Requirement	33.4	32.2	32.1
	Irrigation Requirement	44.1	42.5	42.3
Corn-Grain	Reported Water Use	31.1	21.3	32.7
	Net Water Requirement	20.5	20.1	19.4
	Irrigation Requirement	28.6	28.0	27.0
Grass	Reported Water Use	20.6	- - -	23.2
	Net Water Requirement	33.1	- - -	34.4
	Irrigation Requirement	47.0	- - -	49.0
Orchard - Treed	Reported Water Use	29.3	25.7	28.0
	Net Water Requirement	28.0	29.1	28.0
	Irrigation Requirement	33.0	34.3	33.0
Pasture	Reported Water Use	24.0	10.1	33.6
	Net Water Requirement	25.1	30.5	25.3
	Irrigation Requirement	35.7	43.3	36.0
Potatoes	Reported Water Use	26.8	19.4	29.1
	Net Water Requirement	22.9	22.0	23.5
	Irrigation Requirement	37.9	36.6	39.0
Wheat	Reported Water Use	18.3	20.8	18.0
	Net Water Requirement	17.8	19.5	17.6
	Irrigation Requirement	25.3	27.7	25.3

Table II.28: Deviation of Reported Water Use from Net Water and Irrigation Requirements (Inches/Acre)

	Practice Level		
	I	II	III
Alfalfa Hay	-17.4	-13.6	-15.8
Corn	-7.1	-5.9	5.5
Grass	-32.4		-25.9
Orchard-Trees	6.0	-4.5	-3.4
Pasture	-11.7	-21.3	-5.1
Potatoes	-12.9	-15.8	-9.9
Wheat	-7.3	-6.9	-7.0

Examination of reported water use and its deviations from net water and irrigation requirements by crop, as shown in Table II.28, indicate that, by and large, farms in Practice Level I tend to use less water. The only exception is orchards, where the results indicate over-watering under Practice Level I. Although Practice Level II is shown to result in moderate reductions in water use, the results across various crops are mixed.

To gain a better perspective on the effects of more rigorous irrigation scheduling practices on water use, regression analysis was used to explore differences in reported water use across the three scheduling practices. The advantage of this approach is that it allows for the analysis of variations in water use while controlling for the effects of crop type, soil characteristics, and precipitation. The regression equation was specified as:

$$Water\ Use = \alpha + \beta_1 NIR + \beta_2 PG_1 + \beta_3 PG_2 + e$$

Where,

- Water Use is reported water use in inches per acre
- NIR is estimated net crop water requirement
- PG_1 is a dummy variable with values of 1 for Practice Level I, and 0 otherwise
- PG_2 is a dummy variable with values of 1 for Practice Level II, and 0 otherwise
- And (e) is the error term.

Parameters for the specified model were estimated by ordinary least squares (OLS) procedure. The results, shown in Table II.29, indicate that the model does explain variations in reported water use moderately well. The estimated parameters all have the right signs and are statistically significant with estimated probabilities of 18% or better.

Table II.29: **Estimated Model Parameters**

Variable	Parameter Estimate	T- Statistic	Probability
Intercept	α: 14.7	5.0	<. 0001
Net Irrigation Requirement	β_1: 0.31	3.9	.0001
Practice Level I	β_2: -2.7	1.7	0.08
Practice Level II	β_3: -2.6	2.1	0.18

Potential savings resulting from the adoption of Practice Levels I and II can be estimated by substituting crop weighted mean value for net irrigation requirements from Table II.23. Note that the intercept represents water use for Practice Level III; and estimated parameters β_2 and β_3 represent reductions in water use respectively for practice levels I and II relative to level III.

Using the crop-weighted mean net irrigation requirement of approximately 30 acre-inches per acre, we obtain mean water use for each practice levels as follows:

- Mean Water (Use Practice Level I) =
  14.7 + 0.31*30.0 – 2.7 = 21.3

- Mean Water (Use Practice Level II) =
  14.7 + 0.31*31.8 – 2.6 = 21.9
- Mean Water (Use Practice Level III) =
  14.7 + 0.31*32.0 = 24.5

Comparison of mean water use values across the three practice groups show that application of the combination of methods used in practice levels I and II are likely to result in very similar water savings of approximately 12 percent and 10 percent respectively. These results suggest that, based on the reported water use by survey respondents, the adoption of better irrigation scheduling practices involving more rigorous measurement techniques can be expected to result in modest reductions in water use of approximately 10 percent. Due to the possible inaccuracies in reported water use, which appear to be generally lower than what is indicated by our estimates of net irrigation requirements, we believe that these findings should be considered as indicative, rather than conclusive. Although the findings clearly indicate that adoption of better irrigation scheduling have a beneficial effect on water use, the magnitudes of these effects at this point are preliminary. More accurate estimates must rely on the experimental design and direct measurements of water use planned for Phase II of this study.

III. Phase II Conceptual Plan

Introduction

The work under Phase I of this study focused on providing a systematic definition of various levels of irrigation scheduling methods and establishing a baseline in terms of the intensity with which they are practiced in the Northwest. The results from Phase I concerning the effect of scientific irrigation scheduling on water use have shown that application of more sophisticated irrigation scheduling practices tend to reduce consumption of water. The reported levels of water use, compared with expected irrigation requirements, however, have indicated a pervasive pattern of under-irrigation. This, coupled with potential errors in measurement and reporting, suggest that the Phase I results concerning the effects of scientific irrigation scheduling on water use should be considered as indicative, rather than conclusive.

Based on the survey results and on-site observations at several large farms in the Hermiston area, the investigators have also concluded that, given the size of the typical pump station, multiple motors, and the large numbers of irrigated fields, the use of utility consumption histories would be an impractical means of measuring the effects of scientific irrigation scheduling on electricity consumption. The findings of Phase I of the study clearly indicate that further investigation with more precise, on-site measurement of water and electricity use will be needed to establish these relationships with an acceptable level of accuracy.

Phase II Plan

Phase II of this study is intended to provide reasonable and accurate estimates of reductions in water and electricity use resulting from the application of scientific irrigation scheduling techniques defined in Phase I. Research products resulting from Phase II will also help in developing a simplified algorithm for calculating water and energy savings and will help to guide future program development efforts aimed at irrigation efficiency improvements.

Phase II will be carried out in three stages:

1. Review of existing research
2. Review and analysis of available data on a small sample of farms
3. In-field measurement of water and electricity use.

Stage 1: Research Literature Review

A review of published research reports and previous studies on the energy impacts of scientific irrigation scheduling will be a preliminary step in Phase II of this study. This review will focus on determining the strength of the methodologies, the validity of their findings, and whether their results are applicable in the current study. This review will also provide important insight into the design and implementation of the next stages of Phase II research.

Stage 2: Review and Analysis of Available Data

This stage of the analysis will rely primarily of historical data that is available on a number of farms that have participated in utility-sponsored irrigation scheduling programs in the Umatilla-Hermiston area. The technical team will review the available data and assess their applicability for deriving estimates of electricity savings. If the data are judged to be reasonably complete and adequate for calculation of savings, then it will be analyzed and the results will be reported. It is expected that this stage of the analysis will provide valuable anecdotal evidence of electricity savings from irrigation scheduling.

Stage 3: Field Measurement and Monitoring

The focus of field measurements will be on obtaining accurate information on irrigation system efficiency, pumping electricity use, and water use. The research will be based on a quasi-experimental research design involving a comparison of electricity use between a sample of fields irrigated with scientific irrigation scheduling techniques as defined in Phase I (treatment group) and a comparable group of fields, which do not (the control group). The treatment group will be comprised of both farms where scientific irrigation scheduling is done through professional irrigation services supported by assistance from local utilities and those that practice scientific irrigation independently. To ensure comparability of the two groups, both samples will be selected from farms in the same general geographic area with the same crops. We expect that samples of 25 fields each for the treatment and control groups will be sufficient to obtain reasonably accurate measures of electricity savings. Moreover, to reduce variation in the two samples, we propose to focus only on two common cash crops, possibly corn, alfalfa and potatoes.

The field data collected in this phase of the study will also provide the basis for testing the validity and utility of billing information and, t the extent that the data may be extrapolated to other areas in the region, developing a simplified algorithm for measurement of the effects of irrigation scheduling practices on water use and electricity consumption.

Measurement Plan. For each sample, field observations and measurements will be made for at least the following parameters:

- Irrigation system specification

- Number of pumps and motors
- Motor nameplate data
- System efficiency
- Number of spouts and discharge capacities
- Motor(s) voltage and amperage
- Water use.

Water use will be measured for the duration of the irrigation season using a combination of combined pressure gages equipped with data loggers and periodic spot measurements using ultrasonic flow meters. Under this plan, we propose to calculate electric consumption by measuring voltage and amperage and using the water pressure gages as a proxy indicator of run time. Together, these measurements will provide the data necessary for calculating total electric consumption.

Instrumentation. The proposed instrumentation package in each field will include digital pressure gages installed at the input point of each irrigation system and a digital memory device that will receive and accumulate the pressure data at 15-minute intervals on a continuous basis. This will provide a continuous record of the "on" time of each irrigation system and the operating pressure of that system.

In addition, two portable, high-precision, ultrasonic flow meters will be used to make periodic measurements of the rates of flow into each irrigation system. These non-intrusive flow meters will measure the flow in the pipe externally, and therefore will require no drilling or cutting of the irrigation pipe.

Using the ultrasonic flow meters to measure the flow rates in each irrigation system several times during the season will enable the analytical team to determine the precise relationship between recorded pressure and the rate of water use at several specific points in time. Fluctuations in pressure (caused by variations in pipeline pressures as farm water use rates change during the season) will cause variations in irrigation system delivery rates. It will therefore be necessary to develop procedures to adjust the flow rates to account for these pressure variations. This will be done in one of two ways. If pressure regulators are not being used in the irrigation system, variations in rates of flow of water can be calculated directly from the pressure changes using the fundamental mathematical relationship between pressure and nozzle discharge. Alternatively, if pressure regulation is built into the irrigation system, manufacturer's specific performance data for the pressure regulators will be used, in place of the mathematical formula, to adjust flow rates.

The above system can be expected to determine water use within a few percentage points (e.g., within 3 percent of true water use). This is comparable to the accuracy of an in-line flow meter that is permanently installed in an irrigation system.

Due to its limited accuracy, the use of rain gages as an alternative approach to measurement of water use was ruled out because these devices do not account for spray losses (water lost to evaporation and wind drift between the sprinkler head and the rain gage).

Using the above instrumentation will enable the team to determine the actual deliveries of water at any given time in the irrigation season. This has several advantages over an "accumulating" flow meter that only provide data on total water use over long intervals of time between meter readings. One advantage is the ability to determine the timing of irrigations. (If a farmer applies the right amount of water but applies it at the wrong times, much of the water may be wasted and the farmer's production suffers as well.) It also provides key information on energy use since the combination of pressure and flow rate at the point of water delivery can be used to directly calculate energy use by the irrigation system. However, it does not provide for determining the energy used by a remote pump or the energy losses in complex farm pipe networks. Total energy usage can be determined by direct measurements of energy use and flow rates at the pumps. The energy losses at the pump and between the pump and the specific fields participating in the study can then be estimated.

Appendix A. Questionnaire

Bonneville Power Administration

Irrigation Scheduling

Practices in the Pacific Northwest

Irrigation Scheduling Farm D&B No.:____________________________________

First we would like to ask you some questions about your farm, crops, soil, and irrigation practices. This will help us interpret your answers in the context of your specific farm conditions. It is helpful for us to know what information you use when making your scheduling decisions and which factors influence how much you irrigate.

1. How many acres do you actively farm? (owned plus leased) _____________acres
2. How many acres of the active farmland are irrigated?______________________acres
3. What electric utility serves your irrigation pumping needs? _____________________
4. Is your main activity crop production or livestock?

   ❍ Crop Production ❍ Livestock ❍ Both
5. Last year, how many acres of the irrigated farmland was dedicated to your main 3 crop type(s), and what is the predominant soil type (according to the soil survey) they were grown on?

Crop 1 Crop Type:________________ Varieties:______________________

Soil Type:_________________ Acres: ____________________acres

Do you use Scientific Irrigation Scheduling for this crop? ⑧ Yes ❍ No

Crop 2 Crop Type:________________ Varieties:______________________

Soil Type:_________________ Acres: ____________________acres

Do you use Scientific Irrigation Scheduling for this crop? ⑧ Yes
❍ No

Crop 3 Crop Type:________________
Varieties:______________________

Soil Type:_________________ Acres:
____________________acres

Do you use Scientific Irrigation Scheduling for this crop? ⑧ Yes
❍ No

6. Last year, over the entire season, approximately how much water did you apply per acre to your main 3 crops in acre-feet or acre-inches, whichever is more convenient?

   Crop 1: Acre-Feet:_________ per acre or Acre-Inches:_________ per acre

   Crop 2: Acre-Feet:_________ per acre or Acre-Inches:_________ per acre

   Crop 3: Acre-Feet:_________ per acre or Acre-Inches:_________ per acre

   How accurate do you think your estimate is?

   ❍ Pretty close ❍ Ballpark ❍ No estimate

7. How do you determine the total amount of water actually applied to the field?

   ❍ From system discharge rates (time & pumping rate: gallons/minute or inches/hour)

   ❍ In-line flow meter

   ❍ Head gate delivery rate

   ❍ Hour meter

   ❍ Precipitation gage

   ❍ Not explicitly determined or measured

8. How do you decide when to apply water?

   ❍ Schedule determined in advance (check all that apply)

   ❍ Based on your own established routine

   ❍ Based on published guidelines

   ❍ Based on scheduled water delivery (not controlled by you)

   ❍ Based on system design, as recommended by system supplier

   ❍ Flexible Schedule based on your own judgment (check all that apply)

   ❍ Based on visible check of crop condition (color, turgor, leaf angle)

   ❍ Based on soil conditions (feel of the soil, visual check of the soil)

- ❍ Flexible Schedule using scientific irrigation scheduling (check all that apply)
  - ❍ Measurements of soil water content or soil water tension
  - ❍ Measurements of plant water status

    (For example leaf water potential, canopy temperature, stem diameter)
- ❍ Estimated ET
  - ❍ Computer models of crop water use based on ET estimates and soil-moisture measurements
- ❍ Don't know techniques used

9. If soil moisture measurements are made, what measurement techniques are used? (check all that apply)

❍ Neutron Probe ❍ Watermark Sensors

❍ TDR or Capacitance Probes ❍ Gravimetric Sampling

❍ Tensiometers ❍ Gypsum Blocks

❍Don't Know ❍ Other:___________________________

How often do you measure soil moisture in a week? ________________

How many locations do you sample in a single field? ________________

How many fields do you sample? ________________

10. If plant water status is measured, what measurement techniques are used? (check all that apply)?

❍ Pressure bomb (leaf water potential) ❍ Infrared thermometry

❍ Heat pulse (sap flow) ❍ Stem diameter

❍ Leaf push ❍ Porometer (stomatal conductance)

❍ Other:___________________________ ❍ Don't Know

11. If you use estimated ET, where or how do you get estimates of ET? (check all that apply)

On-line services (check all that apply)

❍ Agrimet ❍ PAWS ❍ WISE

❍ CIMIS ❍ IRZ Northwest Irrigation Network

❍ Media (newspapers, radio, or TV)

❍ Your own weather stations and software

❍ Other:____________________________

❍ Don't Know

12. Do you use aerial photography or aerial infrared monitoring of fields? ❍ Yes ❍ No

❍ Don't Know

If so, what platform is used? ❍ Aircraft ❍ Ultralight ❍ Satellite ❍ Model Airplane

Do you use these observations for problem detection or deciding when to irrigate?

❍ Problem detection ❍ Irrigation decision ❍ Both

13. Do you now, or have you in the past, used the services of an irrigation scheduling or consulting company that advised you on when and how much to irrigate?

❍ Yes-currently ❍ Yes-in the past ❍ No

Which service company did you use? ___________________

For how many years? ___________________

Did you receive financial assistance from a utility or local agency to use this service?

❍ Yes ❍ No

Did the company provide soil moisture monitoring? ❍ Yes ❍ No ❍ Don't Know

Did it provide crop evapotranspiration estimates? ❍ Yes ❍ No ❍ Don't Know

Irrigation Water

We would also like to understand how you irrigate, what your water sources are, and how you meet your pumping energy needs.

14. Which irrigation district(s), canal company(ies), or groundwater district(s) is your farm located in?

____

____

15. What are your water sources? (check all that apply)

Ground Water from on-farm wells

What percent of your water supply? ______________%

What is the pumping lift? ______________feet

What is the pressure at the pump? ______________psi

What is the total pump horsepower? ______________HP

Surface water not provided by a water supply organization (ditch, stream, pond, etc.)

What percent of your water supply? ______________%

What is the pumping lift? ______________feet

What is the pressure at the pump? ______________psi

What is the total pump horsepower? ______________HP

Water supplied by an irrigation district or other off-farm provider

What percent of your water supply? ______________%

What is the pumping lift? ______________feet

What is the pressure at the pump? ______________psi

What is the total pump horsepower? ______________HP

How is delivery scheduled?

❍ Continuous Flow ❍ Rotation ❍ Scheduled On-Demand

Recaptured tailwater or return flows

What percent of your water supply? ______________%

What is the pumping lift? ______________feet

What is the pressure at the pump? ______________psi

What is the total pump horsepower? ______________HP

From what sources? ❍ Tailwater pump-back from the end of the field

❍ Pickup from drainage ditches or ponds

❍ Both

Other:____

What percent of your water supply? ______________%

What is the pumping lift? ______________feet

What is the pressure at the pump? _____________psi

What is the total pump horsepower? _____________HP

16. What percent of the farm irrigation requirements would you estimate is satisfied by the water supply?

In an average year: _____________%

In a drought year: _____________%

17. How many acres of the farmland were irrigated with the following systems? (check all that apply)

Sprinklers:

- ❍ Center Pivot _____________ acres
- ❍ Linear Move _____________ acres
- ❍ Wheel Line _____________ acres
- ❍ Traveling Big Gun _____________ acres
- ❍ Hand Move _____________ acres
- ❍ Solid Set, Permanent _____________ acres

Micro-Irrigation:

- ❍ Surface Drip _____________ acres
- ❍ Sub-Surface Drip _____________ acres
- ❍ Micro-Spray _____________ acres

Gravity Irrigation:

- ❍ Furrows or Corrugations _____________ acres
- ❍ Border Strip _____________ acres
- ❍ Basin _____________ acres
- ❍ Contour Strip, Wild Flooding _____________ acres
- ❍ Other _____________ acres

18. Do you know how many inches of water are applied by your systems in each set or rotation or per hour?

❍ Yes ❍ No

19. What percent of your irrigation pumping needs are supplied by the following?

Electric - From Utility ____________%

Electric - From On-Site Generator ____________%

Non-Electric (internal combustion) ____________%

20. If your irrigation pumping energy comes from an on-site generator or an internal combustion engine, what fuels do you use? (Please check all that apply)

❍Diesel ❍ Gasoline ❍ Propane ❍ Other

Information Sources

Finally, we would like to know about your farming history, your preferred information sources, and your current participation in the farming community. Your participation in this study is enormously helpful, and we are grateful for your time and consideration. As mentioned in the cover letter, all the responses will be aggregated, and your response will not be identifiable in any published report.

21. Which of the following best describes your position?

❍ Owner - On Site (participate in day-to-day farm operations)

❍ Owner - Off Site

❍ General Manager (oversee operation of entire farm)

❍ Irrigation Manager (oversee irrigation operations)

❍ Employee (carry out irrigation instructions from someone else)

❍ Employee (not involved with irrigation)

❍ Other

22. Did you grow up on a farm? ❍ Yes ❍ No

23. How many years of experience do you have farming (not including growing up)?
____

24. Which degrees do you have?

❍ High School ❍ BA or BS Degree

❍ AA Degree ❍ Graduate Degree

25. Have you participated in any irrigation scheduling and/or soil moisture-monitoring programs sponsored by your local utility or local agencies during the past 5 years?

❍ Yes ❍ No

26. What sources of information do you use to decide when and how much to irrigate?

❍ Employees in the field ❍ Associates, friends, family

❍ Extension bulletins ❍ Extension workshops

❍ Irrigation district ❍ Contract crop advisors

❍ Irrigation equipment dealers ❍ Media (newspaper, radio, TV)

❍ Soil and Water Conservation District (SWCD)

❍ Natural Resource Conservation Service (NRCS) (Soil Conservation Service)

❍ Other:________________________

27. Do you belong to farm organizations that provide information on irrigation management?

❍ Farm Bureau

❍ Commodity Organization (wheat growers league, potato growers organization, etc.)

❍ Water Users Association (such as an irrigation district)

❍ Other farm organization(s):____

28. What trade and farm publications or other information sources do you subscribe to?

❍ Irrigation Age ❍ Oregon Farmer-Stockman

❍ Irrigation Business & Technology ❍ Capital Press

❍ Irrigation Journal ❍ Successful Farming

❍ Farm Journal ❍ On-line information services

❍ Other:_________________________

An important part of our research involves quantifying the irrigation energy needs of farmers and ranchers. To accurately do this, we would like to obtain one year of electricity usage histories for your farm from your local utility. We can then correlate this with crop and soil type, climate, and irrigation practices to get a sharper picture of the irrigation energy needs of the Northwest. Again, all this information will be absolutely confidential and used for statistical analysis only. We will need you to sign a form that gives us permission to receive this data. May I mail that form to you?

❍ Yes - Irrigation Contact ❍ Yes - Utility Contact ❍ No

Irrigation Contact:

Name:____

Phone1: ( ) _______________________ Phone2: ( ) ______________________

Current Farm Name:____

Address:____

City, State, Zip:____

Utility Contact:

Name:____

Phone1: ( ) _______________________ Phone2: ( ) ______________________

Current Farm Name:____

Address:____

City, State, Zip:____

Also, we are planning on performing in-field measurements in a small subset of farms this coming growing season. We will use these actual measurements to fine tune the data we gather through this phone survey. If your farm were chosen, would you consider participating in the field portion of our research?

❍

❍ Yes ❍ No

Appendix B. Application Definitions

Table B.1: Application Efficiency Definitions

Irrigation Method	Alfalfa	Wheat	Orchard	Grass	Corn	Pasture	Potatoes
Sprinklers							
Center Pivot	80	75	N/A	75	75	75	65
Linear Move	80	75	N/A	75	75	75	65
Traveling Big Gun	70	62	N/A	62	62	62	52
Solid Set	75	70	85	70	73	70	60
Wheel Line	75	70	85	70	73	70	60
Hand Lines	75	70	85	70	73	70	60
Micro							
Surface Drip	N/A	N/A	85	N/A	N/A	N/A	80
Sub-Surface Drip	N/A	N/A	85	N/A	N/A	N/A	80
Micro Spray	N/A	N/A	85	N/A	N/A	N/A	80
Gravity							
Furrows, Rills, Corrugations	63	55	75	55	55	55	40
Border Strip	58	50	70	50	45	50	35
Basin	58	50	70	50	45	50	35
Contour Strip, Wild Flooding	58	50	70	50	45	50	35