IRRIGATION TECHNOLOGIES

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FACTORS AFFECTING THE CHOICE OF AN IRRIGATION SYSTEM

Selection of the type of irrigation system to install must consider a number of different factors before making a final choice. These include the crop and crop water requirements, the water supply, the soil characteristics, the topography of the field as well as the size and shape, the climate of the area, and a number of economic factors such as labor requirements, available capital, and resource costs. Many of the factors are interdependent, and while one may or may not indicate a definite need for a particular irrigation method or practice (or even the need for irrigation), the relationships between these factors must be considered.

Water supply factors include the quantity and quality of the source. The kinds and amounts of any salts dissolved in the water must be known. The availability of the water in terms of timing and frequency affect the design and management of the system, and boosts the required supply rate if the supply is not continuous. The size of the available stream may limit the choice of systems to only the most efficient. Also, if water is not available during critical dry periods or critical growth stages, irrigation is moot.

Soil characteristics which must be assessed include: the infiltration rate, water holding capacity, depth, drainage conditions, reaction to water and salts, and soil erodibility. The variability of these properties throughout a field must also be known. The rate at which soil accepts water, the infiltration rate, will often eliminate some methods of irrigation from consideration. The soil water holding capacity and the depth of the soil in conjunction with the crop rooting depth, the crop water requirements and climatic conditions may actually indicate irrigation is not needed, i.e., enough water is held in the soil and available to the crop for the entire growing season or to carry the crop during dry intervals. Typically, this will only be the case for the deeper rooted crops grown on the finer textured soils, or where the dry spells during the summer months are of short duration. Drainage conditions of the soil are extremely important. Soils which do not have adequate natural drainage may rapidly exhibit waterlogged conditions under irrigation. Runoff of applied irrigation water and erosion of valuable topsoil may also occur.

Field size, shape and topography require differing degrees of flexibility in the irrigation system. Topography of the field may be such that extensive land leveling is required to be able to use certain methods. Steep slopes are not recommended for certain methods and require special design requirements for others. All of which increase cost of the system.

Climate is the driving factor in determining crop water requirements and the need for irrigation to provide the portion of the requirement not met by precipitation. The season variation and year to year variation in climate will often decide the need for irrigation to produce high yields of high quality crops in what otherwise appears to be an environment in which irrigation is not needed. This is also the case when irrigation is being used for environmental modification to protect the crop.

Irrigation Efficiencies.

The definition of application efficiency is the ratio of the average depth of irrigation water infiltrated and stored in the root zone available for plant use to the average depth of total irrigation water applied, expressed as a percentage. Application efficiencies will change during the irrigation season and calculated values may even exceed 100% under soil water deficit conditions. Dividing the required depth of water to be applied to refill the root zone by the decimal value of the application efficiency will give the required diversion of water to the field.

Applied water may be lost due to several causes including: surface runoff, deep percolation, and soil evaporation (typically 2-5%). Surface runoff may be as much as 50% of the applied water with poorly designed and managed systems (especially surface irrigation systems). Surface runoff from a field often collects in small off-site depressions and drainage ways. Some of the runoff returns to the rivers and streams, but a substantial portion can collect in off-site depressions and drainage ways. Much of the off-site runoff infiltrates into the soil and contributes to the deep percolation towards the groundwater in the locale. Small wetland areas are often indications of where sustained runoff has collected and percolated towards the water table. Consequently, estimates of deep percolation from irrigation over a broad areas often lump much of the runoff into the recharge calculations (i.e., 80% of losses). However, estimates of deep percolation losses based on current irrigation practices will probably be higher than what will be the case in the next 50 years because of the increased management capability of growers and improved technology.

Some deep percolation is always necessary (generally less than 2% of total annual water application in central WA) under irrigated conditions to prevent salination of soils (leaching requirement). However, excessive amounts of deep percolation also carry fertilizers and other chemicals towards the groundwater and is a cause for concern.

It is highly probable that any future irrigation development in the MonDak Region will be with pressurized irrigation systems because of high pumping lifts and undulating topography. In this case, water supply to the fields would be by pressurized pipelines rather than canals or ditches. Thus, any deep drainage losses from the water delivery system would be extremely small and not a major factor except in the infrequent and brief event of a pipeline structural failure.

It is extremely difficult to obtain reasonable values for deep percolation since it is the only value in the water balance that cannot be measured or calculated with good accuracy. Consequently, deep percolation is the term that contains all the errors from the other parameters. Estimates of deep percolation range from less than 25 mm (1 in) to more than 250 mm (10 in) per growing season depending on the crop and water management practices. It is known, however, that most of the deep percolation losses occur early and very late in the growing season with very little during peak water use periods in the middle. Nevertheless, the values in **Table 1** are probably fairly typical for current high plains conditions during the growing season for irrigation (not including chemigation, frost protection, crop cooling or other ancillary water application practices).

Deep Percolation Losses. Under irrigation, recharge to the groundwater depends on application efficiencies of each irrigation and the uniformity of water applications which are largely functions of system design, management and environmental conditions (i.e., wind). It is greatly affected by soil texture and soil chemical properties as well as crop cover and rooting extent. Deep percolation losses (artificial recharge) will vary by crop because of management and ancillary uses of the irrigation systems such as frost protection or agrichemical applications that are applied for cultural reasons even though soil water levels may already be high.

Current estimates of seasonal deep percolation (water lost below the plant's root zone) depend on soils, crop, soil and water salinity, type of irrigation system and the level of water management. Deficit irrigation strategies can reduce deep percolation within the growing season whereas the use of water for frost protection in orchards and vineyards can be a major source of water loss. Properly managed overcrop sprinklers used for crop cooling will have almost no impact on deep percolation but most of the water is lost by evaporation by design and intent.

Table 1. Comparative average seasonal application efficiencies for various irrigation methods and estimates of a reasonably attainable percent of the applied water resulting as deep percolation with current technology on sandy loam soils (assuming irrigation systems are not also utilized for other uses such as frost protection or fumigation).

Method		**Application Efficiency**		**Estimated % of Applied Water as Deep Percolation**	
		Range	**Average**	**Range**	**Attainable***
Surface:					
	Furrow (rill)	35 - 60	45	10 - 50	25
	Furrow w/land leveling	50 - 65	60	10 - 40	15
	Furrow w/automation**	75 - 80	75	10 - 20	15
	Furrow w/tailwater re-use	75 - 90	85	10 - 20	15
Sprinkle:					
	Hand-move	60 - 70	65	20 - 30	25
	Wheel-move	60 - 70	65	20 - 30	25
	Center pivot/Lateral Move	60 - 85	75	10 - 30	10
	Precision System	80 - 95	90	2 - 10	2
	LEPA	85 - 98	90	2 - 10	5
	Traveling gun	55 - 70	60	20 - 35	20

Method		**Application Efficiency**		**Estimated % of Applied Water as Deep Percolation**	
		Range	**Average**	**Range**	**Attainable***
Microirrigation:	Solid set	60 - 80	70	10 - 30	20
	Drip/trickle	80 - 98	90	2 - 20	5
	Micro-sprayers	80 - 90	85	2 -15	8

* Percentage of deep percolation that is attainable under reasonably good current management practices.
** Automated surge flow furrow irrigation.

COMPARISONS OF IRRIGATION SYSTEMS

Irrigation systems are classified in three basic categories or methods: surface, sprinkle and micro irrigation. Pros and cons of each method in light of the previous discussion, and a comparison of costs follows. A very important comparison is the level of irrigation application efficiency which can be expected. The application efficiency is a measure of a system's effectiveness in applying water to the crop and making it available in the crop's root zone. It also describes the losses which occur during application. Low application efficiencies result in increased water use and potential increases in labor and energy expense.

The amount of water that can be conserved by improved irrigation systems and practices depends on the ability of a particular type of irrigation system to implement improved management. However, the major factor is the knowledge base of the grower and the existence of incentives to adopt the improved practices. A critical link in improved management is the implementation of scientific irrigation scheduling techniques which will be required for any irrigation scheme.

Surface Irrigation

Surface irrigation is the application of water at or near the ground surface and then allowing the forces of gravity to accomplish distribution. Dikes or small channels are used effectively to control water distribution such as with border dikes and furrows (rills).

Advantages of surface irrigation include:

- lower initial capital costs compared to other methods,
- low energy costs
- adaptability to most soils and crops
- little or no mechanical equipment

involved

- low maintenance costs
- wetting of the plant foliage and fruit can be avoided
- soil salinity can be effectively controlled through leaching

Some important disadvantages of surface irrigation are:

- a relatively large water supply stream size is needed due to typically lower efficiency and the need to cover the field as quickly as feasible
- extensive land preparation may be needed, fields must have uniform or level grades, grades steeper than 3% are not recommended
- not practical on soils having high infiltration rates due to difficulty in obtaining uniform water distribution
- labor requirements are high
- irrigation efficiency is usually much lower than other methods unless special design and management practices are implemented
- crops sensitive to steam or crown wetting or lack of aeration in the root zone may suffer, especially on finer-textured soils

Soil erosion is a significant problem in many areas. However, this is being successfully reduced by growers using formulations of polyacrylamide (PAM) in small quantities to essentially halt furrow irrigation induced erosion on thousands of acres in the Pacific Northwest (http://kimberly.ars.usda.gov/pampage.ssi).

Sprinkle Irrigation Technologies

Sprinkle irrigation can be accomplished with a number of different systems currently in use. These include hand move laterals, wheel-move laterals, continuous move systems such as center pivots or travelers, stationary big guns, and solid set systems (movable or permanent). Hand move laterals, traveling guns, stationary guns, and solid set systems are probably not feasible for most eastern Montana farming enterprises. Wheel-move (side roll) and center pivot systems could be used but because of the size of these systems they typically aren't considered.
General advantages of sprinkle irrigation are:

- with correct design water is uniformly and efficiently applied
- the amount and rate of application can be easily controlled
- adaptability to most soils and topographies
- light, frequent applications are feasible
- small supply stream sizes can be used
- labor costs can be low with automation and depending on the system used
- can modify crop environment with solid set
- fertilizers (and other agricultural chemicals, if so labeled) can be applied with the water when done using appropriate injection systems and safety equipment

Some disadvantages include:

- initial capital costs are large
- energy costs are relative large
- wind affects the water distribution
- evaporation losses can be high
- labor requirements for some systems can be high
- some soils may cause problems for continuous move systems
- plant disease or injury problems can arise from wetting or salts in the water, fruit injury and/or fruit loss may also be caused by large droplets
- maintenance costs are relatively high compared to surface systems

Hand move systems are among the most popular and least expensive of sprinkle systems in use today. They do have a relatively high labor requirement and with certain crops and on certain soils, moving laterals is an extremely unpleasant chore. Travelers or traveling big guns have a large amount of flexibility for irrigation of all sizes and shapes of fields. These systems are exceptionally prone to poor distribution uniformity with only slight winds, have very high energy requirements due to the large friction losses in the flexible hose between the gun and reel, and have medium labor requirements. Costs of these systems are substantially higher when designed to obtain high uniformity (closer travel paths) and to obtain proper operating pressure to avoid large droplet sizes which may damage fruit and cause soil surface sealing. Solid set sprinkle systems are laid out with the sprinklers on some fixed spacing to deliver uniform applications at some fixed application rate. Self-propelled center pivot and lateral move irrigation systems are commonly used in the MonDak region.

Self-Propelled Center Pivot and Linear Move Irrigation. A center pivot or lateral move basically consists of pipeline (lateral) mounted on motorized structures (towers) with wheels for locomotion. A center pivot machine rotates around a "pivot" point in the center of the field whereas a lateral move machine travels along a straight path and has a separate guidance system. Sprinkler outlets are installed on the top a pipe supported by steel trusses between adjacent tower structures. The towers are usually 30 to 60 m (90 to 200 ft) apart and each tower has a 1 hp motor and sits on two large rubber or steel tires.

Approximately one third of all irrigation, or about 60% of all sprinkler irrigated lands (about 125,000 machines on approximately 7.9 million ha [19.5 million acres]) or about 29% of the total irrigated area, in the USA utilizes self-propelled irrigation systems, mostly center pivots (CP). These sprinkler irrigation systems have allowed agricultural development of "marginal" lands unsuitable for surface irrigation in many areas across the US, mostly light sandy soils with large variations in topography within the same field.

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These very adaptable water application methods have experienced tremendous growth around the world in recent years due to: 1) their potential for highly efficient and uniform water applications; 2) their high degree of automation requiring less labor than most other irrigation methods; 3) large areal coverage; and 4) their ability to economically apply water and water soluble nutrients over a wide range of soil, crop and topographic conditions. For these reasons, center pivot irrigation in the USA has increased by more than 50% from 1986 to 1996.
A standard 50 ha (125 ac) center pivot system will cost US$35,000 to US$45,000 excluding land and water supply development costs. Water development costs depend on the source of water and power (i.e., electric, diesel or natural gas). Generally, the largest annual costs for these machines are for power or fuel to pump water.

Because of the semi-automatic operation of center pivots and lateral moves, it is relatively easy to carefully manage soil water levels across a field. Almost all crops including sugar cane, orchard and vines as well as more traditional field crops such as maize, potatoes, small grains, alfalfa, and vegetable crops can and have been successfully irrigated with center pivot water application systems under a wide range of conditions. Some center pivot irrigated crops require special cultural practices such as planting in circles or the use of small pits or reservoirs in the furrows to facilitate infiltration on heavy soils and prevent surface runoff. Application efficiencies higher than 80% are possible depending on management and a properly designed installation for the site.

Center pivot and lateral move systems have the potential to be more than water application devices. They also provide an excellent vehicle to apply some chemicals and many fertilizers to exactly match plant requirements. In some areas with very light soils as much as 80% of nitrogen fertilizer is applied through the center pivot system. Substantial crop quality and pest control benefits may accrue when using this method for chemigation.

In addition, center pivot systems provide an especially suitable platform on which to mount various types of sensors since the lateral potentially passes over every part of the field every day. Color video, infrared and reflected wavelength specific sensors could be combined and coupled with pattern recognition software and global positioning systems (GPS) for early detection of stresses due to water, nutrients, disease and insects as well as potentially identify various weed species as well as other problems.

LEPA Systems. A special adaptation of the self-propelled technology is the Low Energy Precision Application (LEPA) method that can be installed on both center pivot and linear move systems. LEPA has “drop” tubes spaced about every meter that extend to the soil surface where a low pressure bubbler is attached in place of a sprinkler. Water is applied directly to the furrow and evaporation losses are minimized since the canopy is not wetted. Under the right soil, topographic and management conditions, these systems can be very efficient (e.g., 95-98%) since evaporation losses (soil evaporation generally less than 2% with alternate row irrigation, although runoff may be as much as 50% with poorly designed and operated systems) are minimal and wind drift losses are eliminated although initial capital costs are higher than standard systems. The best results with LEPA have been obtained on heavier clay soils and they have seen limited use in the PNW (mostly on mint and alfalfa with shallow furrows) because of the light soils with poor lateral spreading.

Crops are usually planted in a circle so that the drops do not damage plants. Sometimes a canvas "sock" or other fabric energy dissipation device is used to prevent soil erosion in the furrows. The use of a machine such as the Dammer-Diker™ is often used to create small reservoirs to store water until it has infiltrated on heavy or steeply sloping soils under both LEPA and regular center pivot and linear move application techniques. Typical quarter mile long (400 m) LEPA systems will have 350 to 450 heads. These systems could also be improved using precision irrigation technologies.

Precision Irrigation with Self-Propelled Irrigation Systems. The goal of most designers is to have the most uniform water application pattern possible along the entire length of the center pivot or linear move. However, this criteria is not necessarily the best in terms of crop quality and environmentally. For example, our research and the research of others (Evans and Han, 1994; Han et al., 1995; Mulla et al., 1996; Mallawatantri and Mulla, 1996) has shown that, *in grossly simplified terms*, that about 75% of the leaching occurs in about 25% of the area in many center pivot irrigated fields in the central Pacific Northwest. Thus, it is evident that the ability to more precisely manage small areas of the field will be necessary to reduce groundwater degradation. Thus, the next advances in center pivot and lateral move irrigation will involved being able to vary water and chemical applications along the length of the pipe depending on its position in the field.

Self-propelled irrigation systems like center pivots and linear moves are particularly amenable to site-specific approaches because of their current level of automation and large area coverage with a single pipe lateral. Microprocessor controlled center pivot and linear move irrigation systems provide a unique control and sensor platform for economical and effective precision irrigated crop management. These technologies have made it potentially possible to vary agrichemical and water applications to meet the specific needs of a crop in each unique zone within a field to optimize crop yield and quality goals while maintaining environmental health (reduced water and agrichemical use) and reducing input costs. The criteria for managing precision water and chemicals with these self-propelled systems is currently under development by numerous universities, government research groups and industry, and is expected to be commonly available within 5 years.

The goal of most designers is to have the most uniform water application pattern possible along the entire length of the center pivot, and they have been very successful. However, despite the inherent high frequency and fairly uniform applications of self-propelled CP irrigation systems, considerable yield variations still exist which are often attributed to spatial variability in soil water holding capacities and related nutrient availability. Variations in water availability across a field result in a farmer managing to: 1) ensure that areas with the lowest water holding capacity maintain adequate water levels; 2) managing the whole field based on average soil water depletions; or 3) managing to avoid overirrigation in wettest areas. All of these cases will cause overirrigation or underirrigation of other areas due to the current inability to differentially irrigate based on soil and plant factors within a single CP irrigated field. Some chemical leaching below the root zone, surface runoff and potential yield decreases may occur in different areas under each management practice.

Center pivots are especially suitable for site specific water application since one pipeline and 100$^+$ sprinklers can irrigate 50$^+$ hectares (125 acres). Automation of a sprinkle irrigation system for precision water applications requires the ability to individually control the net application rate from each head depending on its location in the field. In addition to improved water management and reduced leaching, another obvious advantage of automating individual heads is that the very high application depths near the pivot point can be reduced to levels matching the rest of the system by using larger, non-plugging heads with better water distribution characteristics. Reductions in water applications near the pivot point would also reduce the incidence of fungal diseases. With appropriate sensors, software, feedback and control systems, irrigation efficiencies of 85 to 95% are possible with precision irrigation using center pivots with most of the losses due to evaporation and wind drift. Addition of the precision irrigation hardware and control software adds about $250 per hectare ($100 per acre) to the cost of the machine, however, the agronomic input and monitoring equipment to support management decisions will increase costs.

Microirrigation Technologies.

Drip irrigation, also called trickle irrigation, bubblers and localized small microsprinklers, microspinners and microsprayers are collectively referred to as microirrigation. Microirrigation includes any localized irrigation method that slowly and frequently provides water directly to the plant root zone. The slow rate of water application at discrete locations with associated low pressure and the irrigation of only a portion of the soil volume in the field can result in relatively low cost water delivery systems, as well as reductions in water diversions compared to other irrigation methods. Drippers and bubblers are designed to apply water at atmospheric pressure, whereas microsprinklers apply water from about 50 to more than 250 kPa (7-40 psi).

Photo courtesy of California Farm Water Coalition.

The concept in each case is small, frequent, localized water applications which do not wet the entire soil surface. A number of different variations are available. Drip/trickle irrigation can be accomplished with point source applications such as with individual emitters at each plant, which is usually the case for widely spaced plantings; or with line source applications above or below the soil surface in which case a wetted strip or band forms. Line source type systems are used effectively in row crops and closely spaced plantings. Mini-sprinklers or micro-sprayers are point source applicators like drip emitters, however, they wet a larger portion of the soil surface. These tiny sprinklers are usually not designed for overlapping patterns.

Microirrigation has the potential for precise, high level management and is an extremely flexible irrigation method to design. It can be adapted to almost any cropping situation and climatic zone. Microirrigation can be used over a wide range of terrain conditions, and it has allowed expansion of irrigated crop production into areas with problems soils (either very low or very high infiltration rates) and poor water quality that could not be used with other irrigation methods. It can be installed as either a surface or subsurface water application system. Application efficiencies above 90% are readily possible under good management with well designed systems. These systems can cost $1200 to $3700 per hectare ($500 to $1500 per acre) depending on field size and the crop.

Some advantages of micro irrigation are:

- adaptable to highly variable soil and topographical conditions where other methods have problems
- high efficiency and uniformity if correctly designed
- low energy requirements
- small supply stream size can be used
- amount, rate and location of application are easily controlled
- light, frequent applications are possible
- entire soil surface is not wetted allowing simultaneous cultural operations, reduced evaporation losses, reduced weed growth in dry areas
- fertilizers (and other agricultural chemicals, if so labeled) can be applied with the water when done with appropriate safety equipment and injection systems
- young plants perform better
- fruit and foliage are not wetted with drip/trickle avoiding many disease and injury problems
- irrigation labor costs are low

Disadvantages of micro-irrigation are:

- emitters and orifices are susceptible to plugging, water supply may require filtration and treatment to remove sediment, bacteria, algae, and other debris
- maintenance and management requirements are high, systems are easily automated but require routine field checks
- weed growth may be enhanced in the wetted areas
- initial capital costs are high, water treatment and filtration costs increase system costs dramatically if required
- maintenance costs are high

- rodent damage and mechanical damage to plastic tubing

Micro-irrigation is being used on a variety of different crops around the world: orchard, vineyards, vegetables, raspberries, asparagus, strawberries, hops and even more common field crops such as corn and alfalfa.

Microirrigation can be used on most agricultural crops, although it is most often used with high value speciality crops such as vegetables, ornamentals, vines, berries, olives, avocados, nuts, fruit crops and greenhouse plants. In many cases, it can also be economically used for field crops, golf greens, fairways, cotton and sugarcane. Microirrigation is used almost exclusively on wine grapes in central Washington and Oregon because of its potential to control soil water levels and influence winter hardiness.

The use of microirrigation is rapidly increasing around the world and in the PNW, and it is expected to continue to be a viable irrigation method for agricultural production in the foreseeable future. With increasing demands on limited water resources and the need to minimize environmental consequences of irrigation, microirrigation technology will undoubtedly play an even more important role in the future. Microirrigation provides many unique agronomic and water and energy conservation benefits that address many of the challenges facing irrigated agriculture, now and in the future. Farmers and other microirrigation users (i.e., landscapers and golf course managers) are continually seeking new applications to microirrigation technologies, such as waste water reuse, that will continue to provide new challenges for designers and irrigation managers.

Microirrigation inherently offers tremendous benefits for chemical injection and applications. Consistent soil water contents and wetted soil volumes tend to increase plant uptake efficacy of many chemicals. Water soluble nutrients can be injected to closely match crop requirements, increase nutrient use efficiencies, and reduce costs. Systemic pesticides and some soil fumigants may be injected with high efficacy, if labeled.

Any irrigation system must be compatible with cultural operations associated with a specific crop. Adoption of microirrigation may require new or innovative adaptions to various cultural practices and even the development of new harvest and tillage equipment. For example, surface lateral lines can hinder traditional harvest operations, requiring pre-harvest removal of the tubing or development of a new harvester and harvesting techniques. Lateral lines can also be buried but this generally requires moving to minimal-tillage or permanent bed systems for perennial crops.

An in-depth understanding of the unique benefits and limitations of microirrigation systems is needed to successfully design and manage these systems. As with all other irrigation methods, there are definite tradeoffs with both positive and negative impacts on irrigation scheduling, efficiency, uniformity, ecology, crop responses and economics.

Irrigation Scheduling.

In general, irrigation scheduling as defined involves deciding when to irrigate and how much water to apply. All irrigators schedule their irrigations but do it in many different ways. Some follow a calendar while others irrigate because their neighbor is watering. But, whatever criteria is used, relatively few irrigators currently use an approach based on sound scientific principles--*AKA* "scientific irrigation scheduling".

In general, a fairly large body of literature on studies through out the western United States have shown that scientific irrigation scheduling can, in most cases, reduce the gross amount of water normally pumped ranging from 15% to 44% although water savings of about 20% seems to be a generally achievable level over "non-scientific" methods.

The concept of scientific irrigation scheduling (SIS) involves the concepts of soil water holding capacity, volume balance, application efficiency, crop stress related to productivity and economic benefits, when and how much to irrigate, and how to apply the target amount of water. All SIS methods are based on two fundamental approaches: 1) monitoring soil and/or plant water status; and 2) predicting irrigation schedules from a computed soil water budget that estimates of the water depletion in the root zone. Using the first option provides a direct reading of soil/plant status in the field and water use since the last reading but there is limited potential for forecasting or planning. The second option provides a planning element but, by itself, does not have a "ground truthing" component as a baseline check to ensure accuracy. Thus, most SIS methods use a combination of the two approaches but there is extremely wide variability on how and what is provided in terms of frequency and rigor of ground-truthing activities and the development of new schedules.

SIS is a concept that dates from the early 1950's. However, it is fair to say that, despite decades of promotional efforts by public agencies and private consultants, the success and dissemination of SIS has been limited. But as a result of recent droughts, ground water contamination issues and endangered species programs, growers are much more willing to seriously look at SIS as a viable part of their operations. Farmers in the PNW region are quite sensitive to the large increase in social demands that irrigated agriculture must conserve more water and reduce agrichemical usage by improved irrigation methods and management. The shift away from low energy surface irrigation methods to moderate to high energy pressurized sprinkler and microirrigation techniques is accelerating. This is causing additional demand for electric energy and creating an even greater need to conserve electric power usage in the region. These uncertainties, multiple uses of irrigation systems (e.g., frost protection and crop cooling) and adoption of new irrigation methods is making SIS more and more accepted and interest is rising. In these situations, irrigators are more open to educational opportunities that will help them stay competitive.

It is evident that there are more incentives for adoption of SIS now than there have ever been, and there will be many more in the future. At the present time, the major incentives are related to the cost of SIS services/technology and the cost of water which includes the expense of pumping. Environmental regulations seem certain to provide additional strong incentives in many areas throughout the PNW.

Educational programs are the only way to address problems related to insufficient knowledge on the irrigator's part of: 1) irrigated soil properties, 2) irrigation system application capacities, rates and efficiencies; 3) crop characteristics relative to water use and the patterns of water use; 4) climate and environmental effects on crop water demand and irrigation performance; and 5) economic benefits. In the near term, extension educational and demonstration programs can help irrigators have the necessary confidence and knowledge to successfully integrate SIS into their total farming system. Equally important, however, is that these educational and demonstration programs will also help train consultants, conservation district, electric utility and other agency personnel in climate-plant-soil- irrigation interactions and proper scheduling techniques and processes so that they can work more effectively with growers. In addition, it should be mentioned that an increasing number of farmers and their children are college educated, many with advanced degrees, and these individuals are more open to more technological approaches to farming than earlier generations.

The technical approaches to SIS are complex because they must be based on many factors related to crops, soils, climate, irrigation method and management objectives as well as local experience with constraints imposed by the water delivery system. In addition, generalized SIS procedures must be tailored to each situation since many of these factors are site specific. SIS services must adequately integrate and support other farm management decisions that are perceived by growers to be of greater importance than the irrigation decisions. To be successful in the long term, educational SIS programs must demonstrate the increased value of a range of improved farming practices that are supported by scheduling, such as precision agriculture. This complexity generally requires the assistance of consultants and others (e.g., specific employees of large corporate farms) to provide tailored SIS services since most agricultural producers do not have the time or expertise. Unfortunately, many consultants also lack the necessary knowledge base on which to properly advise irrigators on these subjects. Nevertheless, large farming enterprises are more likely to adopt these types of practices because they are often better capitalized and generally more willing to make long term investments in technology and training.

There has been remarkable progress made in recent years on sensor technologies and automation suitable for SIS and the diversity is enormous. The economic and environmental incentives as well as the educational level of the farmer will dictate which technologies will be adopted for more accurate scheduling. These devices and tools must be tested and evaluated for use in specific situations and the new knowledge made available to growers, utilities, private consultants and other interested parties for inclusion in on-farm SIS programs.

It must be emphasized that in addition to economic benefits, environmental regulations and endangered species programs are providing added impetus for universal irrigator adoption of SIS in the PNW. The successes of past SIS education and demonstration efforts in the region have done much to create the general perception that SIS may actually be a beneficial and requisite practice rather than an inconvenience. The availability of low cost soil/plant sensors are crucial to expanded adoption of SIS, but these are not currently available and it is a major obstacle for growers.

ECONOMIC IMPACTS OF IRRIGATED CROP PRODUCTION

The economic impacts of irrigated agriculture are large. It is well documented that irrigation increases yields and provides stability in food production over rainfed agricultural systems.

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Irrigated lands constitute less than 17% of the world’s cultivated farmland but produce 40% of the total production of food and fiber.

Irrigation as a cultural practice adds a number of costs to production. Initial capital costs vary widely from method to method. The method chosen also affects total costs for irrigation water, energy, labor and land preparation. In considering the economics of irrigation systems, there are trade-offs between capital costs, labor costs, water costs, energy costs and land costs. The system yielding the highest return is a compromise between these resource costs. **Table 2** shows the range of typical capital and annual costs associated with the various irrigation methods. Capital costs include materials and construction of the irrigation system, but does not include the cost of land, land preparation, and water source development costs. Annual costs include labor, amortization of the irrigation system and energy costs (to pressurize the system, if needed), but does not include the cost of water, taxes, interest charges or amortization of the water delivery system (e.g., pumps, wells or delivery ditches). The costs are for new equipment with a surface water supply. **Table 3** presents approximate net returns per hectare for some typical crops grown in the PNW.

Table 2. Comparative approximate range of initial and annual costs per hectare (including labor) of various irrigation methods, not including land purchase, taxes or water development costs.

Method		Capital Costs		Annual Costs	
		Low	High	Low	High h
Surface:		$	$	$	$
	Furrow (rill)	500	1000	250	450
	Furrow w/Land Leveling	600	1500	250	450
	Furrow w/Automation	750	1600	300	500
	Furrow w/Tailwater Reuse	750	1500	300	600
Sprinkle:					
	Aluminum hand-move	875	2000	375	600
	Wheel-move	875	1850	225	500
	Center pivot	1000	2000	375	1100
	Precision System	1250	2500	450	1200
	LEPA	1250	2500	450	1100
	Traveling gun	1000	2000	250	1250

Method		Capital Costs		Annual Costs	
		Low	High	Low	High h
Microirrigation:	Solid set	1850	3700	250	1000
	Drip/trickle	1850	3700	500	1000
	Micro-sprayers	1900	4500	500	1000

Income/employment multipliers of 1.7 are commonly used for irrigation sector impacts. At the state level (1987 data), the total direct agricultural industry employment multiplier generated per job ranges from 1.4 to 2.5 with about 5.4 jobs generated per food processing job. By comparison, the total employment multiplier for the aerospace industry is about 2.3, computers and electronics 2.4 to 2.7, business services 1.7 and 1.2 for fisheries.

Table 3. Estimated current yields and value received for selected irrigated crops in the PNW based on approximate state averages of yields (metric), prices paid and net returns based on Washington Agricultural Statistics data.

Crop	Yield/ha	Unit Price	Gross $/ha	Net $/ha
Alfalfa	13.5 M Tons	$ 97	$ 1,310	$ 230
Apples*	100 bins*	116	11,600	1,110
Asparagus	4,000 kg	1.25	5,000	680
Sweet Cherries	15.7 M Tons	1,260	19,780	1,490
Concord Grapes	22.4 M Tons	198	4,435	715
Irrigated Wheat	6.8 M Tons	110	750	52
Onions	53.3 M Tons	88	4,690	860
Potatoes	62.3 M Tons	88	5,480	445
Sweet Corn	18 M Tons	92	1,660	198
Wine Grapes	9 M Tons	1,012	9,110	1,560
Average Return			$ 6,382	$ 734

* A bin of apples is approximately 450 kg (1000 lbs).

Irrigation Systems
R. G. Evans

FUTURE PRESSURES FOR EXPANDED AGRICULTURAL DEVELOPMENT

By 2050, it is anticipated that there will be world wide demands to increase the global production of animal/fish protein, food and fiber despite advancements in crop breeding, genetic engineering and other technology. The world's population is projected to double to more than 12 billion people which will put a tremendous strain on already stressed worldwide agricultural resources. The current world surpluses in many commodities will not last in the face of increasing population coupled with increasing worldwide decrease in ocean fisheries and the rapid loss of productive lands due to soil salination and erosion. The production of pharmaceuticals from bioengineered plants and animals will undoubtedly add more pressure on the already limited (and declining) arable land base. In addition, there will be a big push for crops to help reduce the world's dependence on petroleum for fuel as well as for chemical plant feedstock.

These external, formidable pressures will necessitate increased investments in irrigation infrastructure. Many areas of the world to increase productivity. Intensive greenhouse culture and aquaculture will also be greatly expanded. There will be large economic and social pressures to expand production in areas such as the MonDak region. Agricultural exports will continue to be important. The environmental concerns will be large; however, the favorable growing conditions, high quality (low salinity) abundant water supplies and minimal problems with salination of soils make the MonDak region very desirable for economically sustainable expansion from a world perspective. Much of any new agricultural development would probably be private rather than public.