Workshop C
IRRIGATION SYSTEM CONVERSIONS

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Conversion of irrigation systems encompasses a wide range of topics. In this session, we will discuss several aspects of conversion, including conversion between sprinkler and gravity type systems, conversion of gravity systems to such automated systems as cablegation and surge, conversion of sprinkler systems from one type head to another, and conversion of irrigation pumping plants from one fuel to another. We will discuss the effects of such conversions on the total pumping required and the cost of pumping, as well as other related considerations. My discussion is limited to conversions of the irrigation system itself; fuel conversions will be discussed in the following section.

SPRINKLER VS GRAVITY IRRIGATION SYSTEMS

Each type of irrigation system is best adapted to certain combinations of conditions. In the High Plains, the most commonly considered conversions between sprinkler and gravity systems are from furrow irrigation to center pivot/lateral move sprinklers or *vice versa*, and those are the systems primarily discussed here. The primary considerations in such conversions are the water infiltration rate of the soil, the topography on which the irrigation system is to be installed, the cost of pumping and the capital cost of conversion. Other considerations include the water flow rate available, the amount of labor available for irrigation and the cost of land.

Soil intake rates and the slope of the soil surface greatly effect the suitability of a site for a particular irrigation system. Soils with high intake rates require short field lengths when irrigating with gravity systems to control excessive percolation below the root zone. Low water flow rates and flat slopes require even shorter field length. Sandy soils, usually associated with high intake rates, also require frequent light irrigations. Sprinkler systems are ideally suited to such irrigation frequency. Heavy soils, which usually have lower infiltration rates, hold more water, thus irrigations may be less frequent and larger amounts of water can be applied. On the other hand, because the infiltration rates are lower, heavy soils tend to produce more surface runoff. A properly designed and managed gravity irrigation system can perform well on such soils, but sprinkler systems may have difficulty getting enough water into the soil without having surface runoff.

The uniformity of water infiltration over a field is important to most efficient use of water. When infiltration is not uniform, some areas of the field receive too little water and the crop yields are reduced. Some areas receive too much, which increases pumping costs, leaches fertilizer and may contaminate the water supply. The uniformity of water application under surface irrigation systems is directly related to the infiltration rate and the management. For sprinkler irrigation systems, on the other hand, the uniformity of application is controlled largely by the irrigation machine itself. Only when water runs across the surface from one place to another does the soil infiltration rate influence the uniformity of application under a sprinkler.

Once an irrigation system is installed, the infiltration characteristics of the soil may be partially compensated by tillage practices. For example, when furrow irrigating on soils of high intake rate, packing furrows with a tractor wheel or dragging a "torpedo" to smooth the furrow can increase the rate of water advance and improve uniformity. Minimum tillage practices, even on soils of low intake rate may sufficiently impede flow down the furrow and increase infiltration rates that the application uniformity becomes unsatisfactorily low. Under sprinkler irrigation systems, on the other hand, increased infiltration, whether from minimum tillage practices, chiseling or similar practices, will reduce runoff and improve irrigation uniformity. When infiltration rates under sprinkler systems are low or the soil slope is high, special tillage such as furrow diking or pitting may be warranted.

Surface irrigation systems are best suited to relatively flat slopes, although on some soils surface irrigation may be satisfactorily used on slopes of 3 to as much as 5 percent. Probably more important to performance of gravity irrigation systems than slope is the uniformity of slope down the field. In many cases, land leveling is necessary to achieve satisfactory performance. Sprinkler irrigation systems, on the other hand, are relatively little influenced by the soil slope or uniformity of slope. The fact that land leveling is seldom needed for sprinkler irrigation systems may partially offset the added cost of a sprinkler system. Although sprinkler manufacturers sometimes advertise their systems as capable of moving over slopes up to 30 percent, few soils can be irrigated at a practical rate on such slopes without runoff.

Yet another consideration in the decision whether to convert between gravity and sprinkler irrigation systems is the availability of labor. While a single irrigator may be able to handle irrigation of 1000 to 2000 acres under center pivot machines, he can seldom deep up with more than 300 to 500 acres of surface irrigated land, depending on the type of delivery system used. In situations where minimal tillage is needed and labor intensive operations such as planting or harvest can be handled by seasonal labor or custom operations, the saving in labor costs can go far toward paying the extra capital and operating expenses of sprinkler irrigation systems.

When considering conversion to self-propelled sprinklers, the type of machine-- whether conventional center pivot, corner pivot or linear move-- is important so far as the capital cost. The linear move system is the most readily designed for good application uniformity, since each length of the system covers the same area of ground. These systems have the disadvantage, however, that they must be moved to a second portion of the field for the return trip to the starting point, be moved across a portion of the field without irrigating or else begin a new irrigation over that area most recently irrigated. The corner pivot, like its parent system, has the advantage of always ending an irrigation at the point in the field that will need water first (assuming full circle rotation and a single crop, that is). In addition, it is capable of irrigating 90 percent or more of a square field. On the negative side, the corner machine add considerably to the complexity, thus initial cost and expected breakdown frequency, of the pivot. On a per-acre basis, the machine cost for land irrigated under the corner apparatus may be two to three times that under the basic circle. Additionally, the changing area of coverage as the corner apparatus turns on or off changes the operating characteristics of the pump, and may significantly effect the uniformity of application and cost of pumping a given volume of water. The primary disadvantage of the basic center pivot is the fact that it irrigates in a circle whereas the land survey system of the U.S. usually results in square landholdings. Thus, some 20 to 22 percent of the land area may be unirrigated. Where land costs and crop value are high, this fact may justify installation of a machine which covers a larger portion of the land area.

AUTOMATION OF GRAVITY IRRIGATION SYSTEMS

Over the past two decades or so, researchers have developed many systems for automation of gravity irrigation. Unfortunately, few of these systems have seen enough farmer interest to prompt commercial manufacture of the components to make them readily available. Two notable exceptions are recently developed concepts called *cablegation* and *surge irrigation*.

Cablegation is a fully automated system developed by the USDA-ARS at Kimberley, Idaho. A cablegation system consists of a pipeline large enough that water will flow without spilling from outlets made near the top of the pipe. A moving plug is fitted into the pipe. This plug is pushed down the pipe by water pressure, and its speed is controlled by spooling out a cable attached to the plug. The pipe is placed on a uniform grade, sloping downward in the direction of water flow, or else the outlets are fitted with pipe extensions that are set carefully to a uniform grade. The plug backs water up in the pipe so that it spills out several of the outlets upstream of the plug. Because the water pressure is greatest nearest the plug, the water flow rate into the furrow is greatest when the plug first passes an opening and reduces as the plug moves further downstream. This high initial flow rate moves water to the end of the field rapidly. The reducing flow rate during the infiltration phase corresponds to the reducing intake rate of the soil.

Cablegation systems are almost completely automated once installed and the proper plug speed is determined. Because they must either be installed on a precise grade or the outlets adjusted to a precise grade, it is not practical to move a cable irrigation system for cultural operations once installed for the season. The cost of a cable system is not great, once the pipe is available. Sufficient pipe must be available to reach across the head of the field. The remainder of the cost is for the plug, a headbox to get the water into the pipe and for the cable restraining device or brake.

Initial installations and farmer training for cablegation equipment were made on a demonstration basis by the government scientists who developed the system. As a result, the number of systems that could be installed was very limited. Over the past few years, the developers have trained numerous SCS technicians to design the systems, and a local Kimberley firm manufactures all components necessary for the irrigator to convert his own pipe to a cablegation system. The total number of cablegation systems in the U.S. at the present time is probably on the order of one hundred.

Surge irrigation is a concept developed by engineers at Utah State University. It consists of alternately running water into one set, then another at intervals ranging from perhaps 5 minutes to two hours. During the period following a pulse or "surge" of water in a set, the furrow dewaters and the soil intake rate generally undergoes a reduction beyond that which would have occurred had water flowed continuously. Thus, when water is reintroduced in the next surge, it moves down the field at a faster rate. Particularly for soils with a high intake rate, the rate of advance down the field is increased over that which would have occurred with a continuous inflow and less water is required to reach the end of the field. This results in a more uniform application of water from one end to the other and gives the potential for greater application efficiency. After advance, proper adjustment of the surge cycle times can effectively reduce the tailwater runoff to further improve the irrigation application. In general, advance rates are improved more for soils with high intake rates, and the runoff reductions are greater for low intake soils.

Commercial development of surge irrigation systems began very soon after the development of the concept, and equipment was often ahead of the researcher's understanding of the concept and how best to operate surge systems. The most common method of implementing surge irrigation is that using a "Tee" valve configuration in gated pipe. The tee valve is attached to either a surface pipeline from the water source (if sufficient head is available between a ditch and the field, the valve may be connected directly) or to a hydrant attached to an underground pipeline. Gated pipe is attached to both sides of the valve, so that first one side, then the other receives water as the valve shifts one way then the other. When surface pipe is used to deliver the water, the surge valve may be located in the center of the field, with half the field covered from each side of the valve. In such a case, the irrigator may have to open and close outlets along the gated pipe to change from one pair of sets to another. When underground pipe with risers is available, two or more surge valves may be used in sequence to lay out more than one pair of irrigation sets at once. Moving the pipe and surge valve in "leap-frog" fashion from one pair of sets to the next can substantially reduce the amount of gated pipe required. When the first pair is finished, water is changed to the second pair by opening and closing the hydrants, just as with manually controlled operation. The irrigator then gets two irrigation sets completed for the labor normally required for one set, plus gets the advantage of more uniform irrigation, less tailwater and improved irrigation efficiency.

Some half dozen manufacturers currently make surge control valves. These valves have an electronic timing and control device. The valve in moved by an electric motor powered from a solar charged battery. Thus, the entire surge apparatus is in a single, self-contained unit. The price of the complete system is about $1000 to $1500, depending upon the size and features desired. More details are given in another section of these proceedings.

Any of these automation systems requires a higher level of management than the irrigator may currently utilize for gravity irrigation. He must judge whether water advance rates are proper, when and how much to adjust plug speed or surge cycle times, and when an irrigation is completed. Thus, although either system reduces the amount of irrigation labor required, a higher quality of labor may be needed.

SPRINKLER HEAD CONVERSIONS

A very popular cost-saving measure in recent years among sprinkler irrigators has been that of changing from "high pressure" (about 75 psi at the pivot) sprinkler heads to medium pressure impact (about 50 psi at pivot) or spray (35 psi at pivot) type heads. There is no question that such conversion, when done properly, will result in a lower pumping head and lower pumping costs. Such results are not always achieved, however, and other considerations come into play in making the decision to convert to "low pressure". The only possibility for pumping water at less cost is to reduce the total head (lift plus pressure plus friction) at which the pump operates. In fact, the cost of pumping is almost directly proportional to the total head against which the pump operates (the efficiency of the pump is also dependent on the operating head). Placing a valve in the discharge line of the pump to reduce pressure will certainly accomplish that, but does nothing to reduce pumping costs.

Pressure vs Application Rate

In general, the lower the pressure at which a sprinkler head operates, the smaller the distance the water is thrown from the sprinkler. For a given pumping rate, a smaller radius of throw means higher water application rates under a sprinkler. For example, a 1/4 mile center pivot operating with 23 degree heads at a minimum of 45 psi may apply water over a diameter of 130 feet at a maximum rate of one to two inches per hour. Conversion of the pivot to medium pressure impact heads (25 psi) may reduce this application pattern to 80 feet, at the same time increasing the maximum application rate to 1.6 to 3.2 inches per hour. Further reducing the pressure by installing spray type heads operated at 10 psi may reduce the wetted pattern to 30 feet, increasing the application rate to a whopping 4.3 to 8.7 inches per hour. Only the highest intake rate soils on flat ground can take such high application rates without producing runoff. This problem is sometimes overcome when using spray heads by using booms perpendicular to the pivot line to spread the water over a greater pattern width.

Pressure vs Intake Rates

The pressure at which a sprinkler operates also has a direct effect on the soil intake rate. Just as a "hard, driving rain" packs the soil and produces a lot of runoff, so large droplets from the sprinkler strike the ground with greater energy, tending to pack the soil and reduce the intake rate. Thus, on heavy soils with low intake rates, it may be advisable to operate at a higher pressure to provide greater breakup of droplets to prevent compaction. Special nozzles have been developed which improve the breakup of droplets at lower pressures. These nozzles are often either square or elliptical in shape, and are effective in allowing operation at somewhat lower pressures than conventional circular nozzles. Combining high application rates under low pressure systems with special tillage practices, such as minimum tillage, no till, furrow diking or deep chiseling may be effective, particularly on flat ground.

Pressure vs Evaporation and Drift

While smaller droplets have a positive benefit regarding soil intake rates, small droplets are more subject to evaporation while airborne and to greater distortion of the spray pattern from wind drift. This evaporation can reduce the effective water application on the field, and wind drift can seriously reduce the uniformity of application along the pivot. Both these effects are reduced by making sure that the water strikes the canopy as soon as practical after leaving the nozzle. Many irrigators attach "drops" to the pivot to lower spray heads to within a few feet of the ground. This practice further reduces the wetted pattern width, and increases the maximum application rate, so should be implemented with caution. An often practical method of reducing wind effects with impact sprinklers is to install *low angle* heads, which throw the water into the air at a 5 or 6 degree angle above horizontal rather than the 23 to 27 degree angle of conventional heads. Although this design reduces the wetted pattern width somewhat, it also reduces the height of water trajectory considerably, thus reducing wind effects.

PUMP MODIFICATIONS

No irrigation system conversion is complete without careful consideration of modifying the pump characteristics. Because it can well cost several times more to pull and modify a pump than to change the sprinkler package, this is an often overlooked factor in conversion.

When one converts from gravity irrigation to sprinkler, the effect of the required pressure on pump performance is usually so dramatic that pump modification cannot be overlooked. However, the effect of many other conversions on pump performance is not so obvious.

Virtually all irrigation pumps, whether deepwell turbine or horizontal shaft centrifugal, operate on the principle of centrifugal force. The output of the pump declines as the operating head increases, and *vice versa*. Thus, when a pivot is converted from high pressure to low without modifying the pump, the pressure at the pivot tends to drop and the flow rate goes up. This increased flow rate causes more head loss in the inner lengths of the sprinkler pipeline than originally, and the pivot pressure will undoubtedly be greater than anticipated. As a result, more water will be applied to the inner areas under the sprinkler than under the outer areas. In severe cases, this extra water pumped may more than compensate for the anticipated savings in energy from the reduced pressure. If part of the water runs off because application rates are too high, pumping costs may well be greater for the "low pressure" system.

In addition to the relationship between pumping rate and head, the efficiency of a centrifugal pump is related to the flow rate. If the pump was properly designed to operate at a good efficiency for the original application, changing the application, such as from high pressure to spray heads or sprinkler irrigation to gated pipe will have a negative impact on pump efficiency. The change in efficiency alone will often overshadow the reduced cost anticipated from decreasing operating pressure.

Pump Modifications

When combustion engines are used to pump water, the water flow rate and pressure can often be changed by simply changing the speed of the engine. Within a limited range, the efficiency of the pump is not greatly influenced by speed, and it may be feasible to make the conversion quite simply. The irrigator is cautioned, however, that significant changes in operating characteristics invariably reduce efficiency, and a careful pumping plant efficiency test must be conducted to determine whether pump operation is satisfactory when operating under these changed conditions. No such option exists with electrically powered units, as the electric motor speed cannot be changed.

The first modification that comes to mind to many operators is to simply put a valve in the discharge line and choke down the output until the desired pressure is obtained. As mentioned earlier, such "modification" has virtually no effect and the pump operates at the same efficiency, head and cost as before.

In a like manner, with some styles of pump having open or semi-open impellers, the head and flow rate can be reduced by tightening the line shaft nut to raise the impellers off the bowl. Although usually somewhat more effective than valving the pump output, such a practice also effects the efficiency of the pump and may cause physical damage, particularly in deep wells where the lineshaft stretches significantly as the pressure comes up.

Effective pump modifications invariably require that the pump be pulled and disassembled. If the pump is in otherwise good condition, it may be possible to simply change the number of bowls or stages to retain the desired flow rate with the needed pressure head. Adding a stage to a pump has the effect of keeping the same discharge but raising the outlet pressure in direct proportion to the number of stages. Thus, adding or deleting bowls can only be expected to change the pump characteristics in "steps", and is not likely to be adequate in itself.

Most pump modifications will require some modification of the characteristics of each stage. This modification is made, while maintaining the efficiency of the pump, by trimming the individual impellers. The pump must be disassembled and each impeller placed in a lathe to turn it to a diameter calculated to give the desired head and flow rate.

It may be unfeasible to utilize the old pump efficiently in a new installation. In such cases, the only alternative in conversion is to purchase a new pump carefully matched to the new irrigation system. Whether the old pump is modified or a new pump installed, a competent independent testing company should be retained to assure that the newly installed pumping plant operates at 100% of Nebraska Standard efficiency (65% "wire-to-water" efficiency for an electric powered pump).