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AUTOMATIC CONTROLS FOR SURFACE IRRIGATION SYSTEMS[1/]

By

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ABSTRACT

Automatic irrigation controls, such as gates, checks, valves, timers, soil moisture sensors and related devices, are described. These increase worker productivity and give better control of farm irrigation water. Most semi-automatic irrigation systems use mechanical timers to control irrigation and its duration, whereas automatic systems use sensors and programmed timers. Automatic and semi-automatic gates and checks are used in open channel systems to divert water through different kinds of openings. Low pressure valves and controls are being developed and tested for automating gated pipe systems.

INTRODUCTION

Irrigation usually requires the uniform distribution of 2.5 to 15 cm (1 to 6 in.) of water over a farm field at 3-to 20-day intervals to supply the moisture needs of a growing crop. With surface irrigation, water is applied in large or small furrows or the soil surface is flooded within areas confined by low dikes. The size and shape of irrigated fields vary, depending on the soils and field topography. Traditionally, irrigation has been an undesirable chore requiring much labor. The labor required and the water-use efficiency attainable depend, in part, on the on-farm irrigation facilities. The initial cost of these facilities at current prices must not exceed about $500-$1,250 per ha ($200-$500 per acre) for irrigated farms to remain competitive in producing food and fiber. In the past, extra labor and water were commonly used to minimize the investment in irrigation facilities. In recent years, because of the scarcity and high cost of labor, there has been a tendency to sacrifice good water control and substitute fertilizer for labor inputs where water and fertilizer were plentiful and inexpensive. These practices generally have resulted in relatively low irrigation efficiencies.

Either additional labor or mechanization and automatic controls are needed to increase irrigation efficiency on most well-managed farms. Irrigation is one of the last farm operations considered for automation. Surface irrigation in particular has not received the impetus of commercial development that sprinkler irrigation and other types of farm mechanization have received. Actually, because the surface irrigated acreage is larger, surface irrigation equipment may have a greater potential market than sprinkler equipment. Automatic irrigation controls can increase worker productivity

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and may be the most feasible way to achieve better water control without increasing labor input. Increased demands for food and fiber may require that irrigators use their water supply more efficiently to increase production per unit volume of irrigation water diverted. Also, water quality control regulations will require better water control to decrease irrigation-related pollution. Better water control facilities can decrease runoff and the amount of sediment leaving an irrigated area.

Automatic controls for surface irrigation consist of a combination of gates, structures, valves, timers, soil moisture sensors and other devices to automatically divert water to an agricultural field and distribute it uniformly in the proper amount and at the proper time to replenish soil water used by a growing crop. These controls may be semi-automatic or fully automatic, depending on their method of operation. Some parts of a system may be semi-automatic or manual, while others are automatic. The water supply and delivery system often determines the kind of controls needed.

Semi-automatic systems and controls normally cost less and are simpler than automatic controls, but require some manual attention at each irrigation. Most semi-automatic systems use mechanical timers or electric or hydraulic devices to activate control structures at a predetermined time. The irrigator usually determines when to begin irrigation and its duration, and manually resets, or returns the devices to their original positions or moves them from one location to another before the next irrigation.

Automatic controls are often more complex and do not require the operator to perform some of the manual functions required for semi-automatic controls. Automatic systems normally operate without attention from the operator other than for periodic inspections and routine maintenance. However, the irrigator often determines when and for how long to irrigate, turns water into the system, and/or starts programmed controllers, before the automated portions of the system function. Fully automatic systems may have sensors, such as tensiometers or electrical resistance blocks, to indicate the need for irrigation. These activate electrical controls when soil water is depleted to predetermined levels. Meteorological data can also be used to predict when to irrigate, or the output from a small computer can be used to begin irrigation. Water is then diverted into the farm distribution channels, and the irrigation is completed without operator intervention. Irrigation duration may be controlled by programmed timers, soil moisture sensors, or surface-water sensors. Most fully automatic systems require a water supply available on demand, such as from wells or farm reservoirs. However, most farm systems do not have the flexibility required for complete automation.

CONTROLLERS AND SENSORS

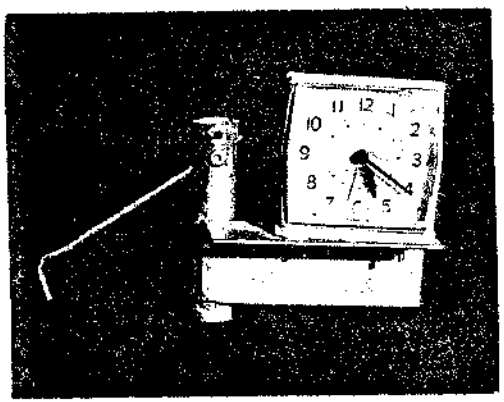
The farmer may determine when to irrigate and the amount or duration of irrigation and set time controllers accordingly, or he may use soil water sensors. He may use computers to schedule when to irrigate and indicate how much water to apply, based on climate-crop-soil data. Devices that sense the need for irrigation and output from irrigation-scheduling programs can be used directly to begin an irrigation where water is available on demand. Once water is diverted to a given field or section of the farm,

irrigation can then proceed automatically from one set to another, utilizing one of the various timing methods.

Mechanical Timers

After water is diverted to the system, timers activate structures, valves, or other devices at predetermined times to either divert water on or off a field or to divert it from one portion of a farm to another. The timer, usually mounted on or near the water control structure, activates the structure mechanically or electrically. Semi-automatic irrigation timers must be dependable. They should be corrosion resistant and well protected from moisture and dust. They should have a built-in trigger or trip from which a gate latch, electrical switch, or other tripping mechanism can be operated. Timers are usually set according to the required duration of a given irrigation, rather than by the time of day. A minimum time capability of 24 hours is preferred; however, 12-hour timers are commonly used. Timers should have an escapement start-stop feature, so that they can be preset, but do not start until activated by a float. Thus, the total time that a group of timers and their associated structures can be programmed may range from one day to several days, depending upon the number of timers used, because the timers operate in series with only one unit running at a time.

Alarm clocks, although commonly used, do not satisfy most of the requirements of a good irrigation timer. Their enclosures normally are not sealed to prevent entry of dust and water. Also, since they do not have a built-in trip device, the tripping mechanism must operate without requiring energy from the alarm or clock spring (Figure 1).



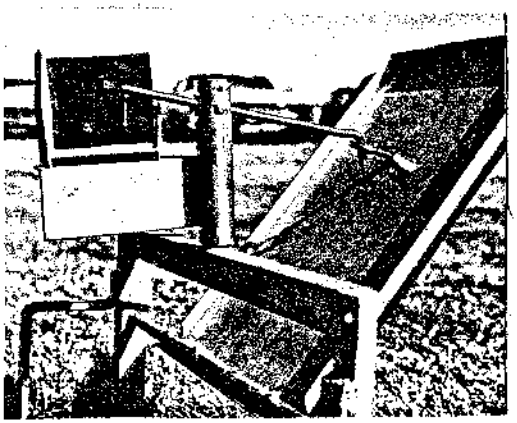
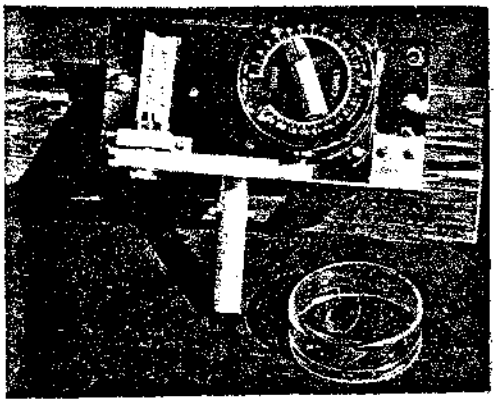


Figure 1. Alarm clock timer with trip and portable mount (a)--pipe mount either fits over a mating pin or inside of another short pipe permanently attached to the structure (b).

A commercial, 24-hour timer[3/] satisfying the above criteria has been used successfully (Figure 2). It has a main spring windup and direct-reading



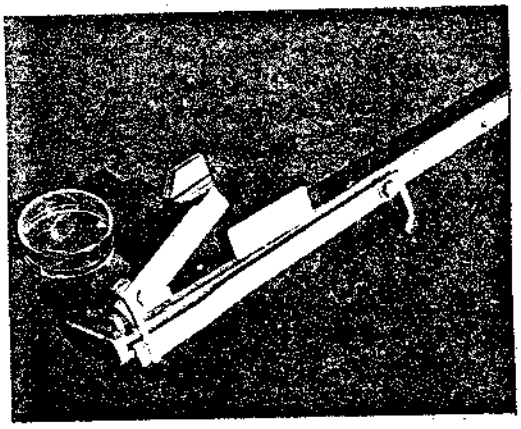


Figure 2. Twenty-four hour irrigation timers with portable mounts.

time indicator integral on the same shaft, and it also has a built-in latch or trip release and an optional start-stop feature.

Trip wires leading from one structure to another have sometimes been used to reduce the number of timers. The wires are rigged so that the opening or closing action of one structure will trigger a simultaneous action in another structure (see Figure 9). This arrangement has not been satisfactory unless the structures are very close to one another. The trip wires are a nuisance and are often accidently tripped by dogs, birds, rodents, cattle, farm machinery or the farm operator. Preferably, one timer should be provided for each opening or closing operation, even though this requires twice as many timers and, in some cases, two timers on one structure. Timers can be mounted for easy movement from one location to another (Figure 2). Then, since only enough units are needed for 1 or 2 days' irrigation sets, their total cost is not large.

Electrical Timers

High-voltage electric clocks normally are not used on individual structures or valves for safety reasons, and electrical power is seldom available in the field. However, programmable electric timer-controllers designed for sprinkler and turf irrigation are easily adapted to agricultural fields and can be used in surface systems. These are especially convenient where water is available on demand, where short, frequent irrigations are desired, and where solid-set gated pipe systems are used.

[3/] Brumley-Donaldson Company, Huntington Park, California. Reference to a company or product is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by the U.S. Department of Agriculture.

With recent advances in technology, battery-powered electronic timers may become practical for automatic irrigation. These require little energy and can be produced in quantity at a cost competitive with mechanical timers. They are suitable for use where a low energy output can be used to trigger some action in the system. They have no moving parts, can be sealed for protection from dust and water, and potentially have a long trouble-free service life. An electronic timer programmed for automatic flow cutback irrigation is being developed and tested at the Snake River Conservation Research Center.

A new electrical elapsed time meter[4/] may also be used for some applications. The operation of this unit is based on a mercury microcoulombmeter in which mercury in a small glass capillary tube is transferred electrochemically from the anode end of the tube across a gap to the cathode end at a rate proportional to the current. Timing is determined by the time required for the mercury to transfer and can be varied by changing the current. This unit can be obtained complete with an optical switch and a potentiometer for making time settings. Its disadvantages are its low load current capability, which complicates interfacing with other components, and its susceptibility to mechanical damage.

Water/Soil Moisture Sensors

Irrigation may be started or stopped by instruments or sensors that activate controls electrically when soil moisture reaches predetermined levels. The two commonly used sensors are the tensiometer and soil moisture resistance block. Tensiometers are used to indicate soil moisture tension in the low range from field capacity (approximately 200 mb) to about 700 mb. They are well suited for use with crops sensitive to soil moisture stress and in sandy soils. They can be obtained with a magnetic switch for use with automatic controls. Soil moisture resistance blocks are not as widely used, but are suited for use in soils low in salts and with crops that can withstand moisture stresses beyond the tensiometer range. Moisture blocks vary and usually must be individually calibrated, or their sensing point set, and require an electronic readout.

Floats or electrode-type water contact sensors and radio transmitter/receiver units provide another means of time control. With these sensors, the duration of irrigation is determined by the time it takes water to reach the water sensor/transmitter unit near the lower end of the field. When water reaches this point, the transmitter is activated and sends a coded signal to the receiver at the upper end of the field to turn off or redirect the water. This system works well with borders where it is not desirable or necessary for runoff to occur. The transmitter/sensor unit used to stop water diversion into the border is placed at the point where up-field surface water storage will complete the irrigation. With furrow irrigation, it is necessary to have some runoff for adequate irrigation of the lower end of the field. Thus, the method of operation, location, and

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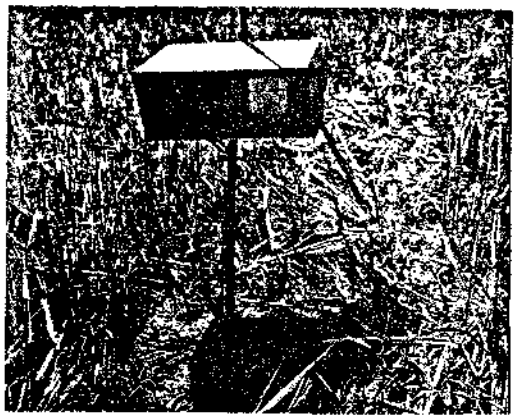
4/ Curtis Instruments, Inc., Mount Kisco, New York.

setting of the sensor/transmitter unit would be different. Figure 3 shows radio transmitter/receiver units, developed at Montana State University (2),



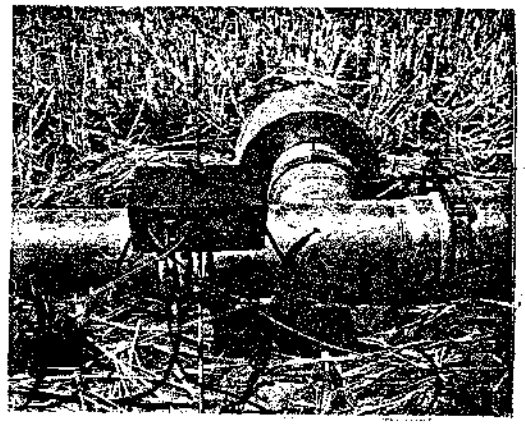


Figure 3. Radio transmitter/receiver units used to control irrigation valves for border irrigation.

being tested at the Snake River Research Center. These units were used to control the discharge from low pressure pipeline valves for border irrigation. Recent advances in electronic technology, should make radio transmitter/receiver systems more feasible. They may also be used to monitor runoff from the lower end of an irrigated field to reduce runoff and sediment discharge. Radio signals can activate controls at the upper end of the field to make appropriate flow adjustments automatically.

AUTOMATIC CONTROLS FOR OPEN CHANNEL SYSTEMS

Discharge and water levels must be controlled where irrigation water is automatically distributed to a field surface from open channels. Border and surface flooding systems are easiest to automate because, with uniform field topography, the water is distributed over the entire soil surface between dikes from a single outlet. Furrow systems require additional controls to regulate the flow of water to individual furrows.

Discharge Controls for Furrow Irrigation Systems

Gated surface pipe is recommended for automatic furrow irrigation systems; however, some open channel systems distribute water to individual furrows from an open ditch. One automatic flow cutback system (4) uses metal or plastic furrow tubes in the side of a lined ditch to supply water to the furrows. The ditch is divided into sections or bays, with all of the tubes in each bay at the same elevation. The tubes in each consecutive downstream bay are at successively lower elevations. Water flows onto the field from two bays, simultaneously, with a high initial flow from the downstream (lower elevation) outlets, and a reduced or cutback stream from the upstream (higher elevation) outlets. Irrigation is accomplished by sequentially ponding water above the openings with automatic or semi-automatic check gates.

Similarly, tubes, orifices, small rectangular chutes, and notched weir outlets in the sides of either lined or unlined distribution ditches have been used. Discharge relationships for these outlets have been developed by other investigators (1, 6, 8, 9). A disadvantage of these type of outlets for flow control is the labor required to install and maintain the system. Accurate elevation settings are necessary for good control. Also, the design is rigid, and it is sometimes difficult to adapt the system to different crop row spacings and to vary the flow in individual furrows.

Ditch Gates and Checks

Gates and checks are placed in both lined and unlined supply ditches to raise the water level in the ditches and to control the flow through outlets to the field. They are used with a variety of timing, electrical, and hydraulic control devices. A commonly used semi-automatic structure for open channel systems is the drop gate (Figure 4), which usually is a single

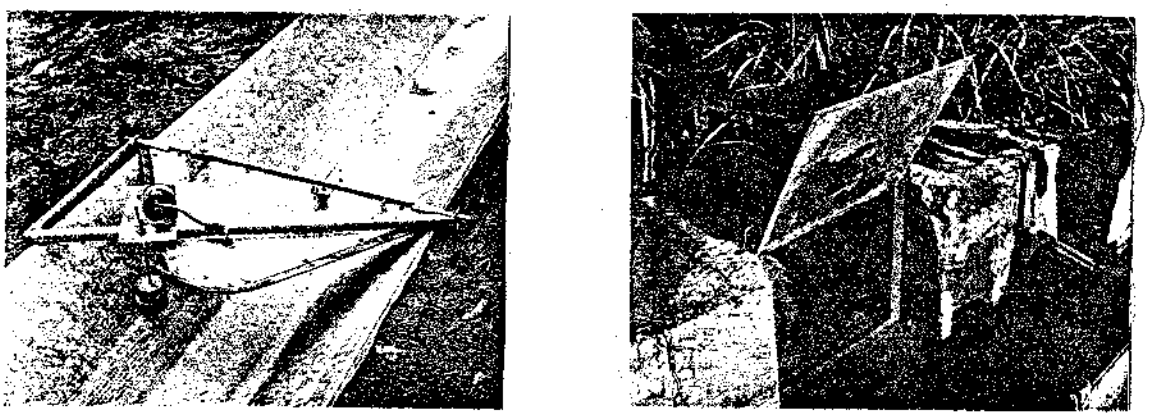


Figure 4. Drop gate for lined ditch (a) and mounted on a portable frame for use in existing checkboard-type structures, (b).

leaf gate hinged at the top and, when open, extends over the ditch. When released, it falls by its own weight to stop the flow of water in the ditch or through the opening where it is placed. It can be permanently mounted on various types of cutoff walls or on a portable frame for moving from one location to another.

The drop-open gate is commonly used as a companion structure to the drop gate. Four designs of this type gate have been developed: (7) (a) apron gate, (b) drawstring check, (c) center-of-pressure gate, and (d) the tube outlet gate. The metal apron gate (Figure 5) is hinged at the bottom, and when its top edge is released by a timer, it opens to allow water to flow downstream. The gate lays flat in the bottom of the ditch when open or not in use. A series of these check gates can be used in a ditch to release water sequentially downstream.

The drawstring check gate consists of a flexible, nylon-reinforced, butyl rubber material supported in a metal frame designed to fit the ditch cross

Figure 5. Apron gates for unlined ditches with timers having a float-operated start/stop.

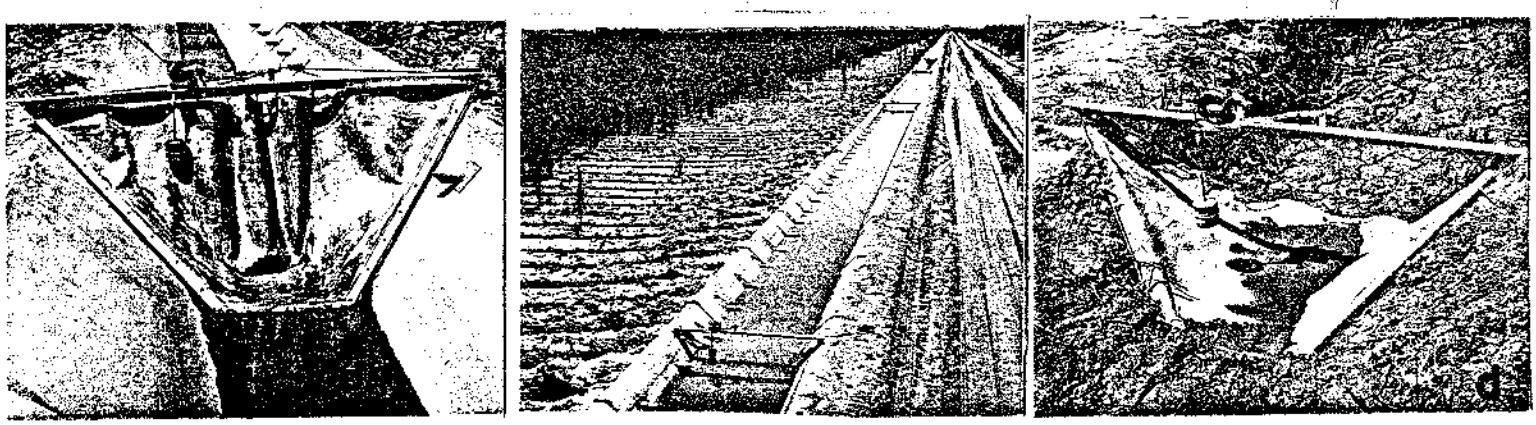


Figure 6. Portable, timer-controlled irrigation check for lined ditches (a, b) and drawstring check for unlined ditches (c).

section (Figure 6). When closed, the top edge of the flexible dam is supported by a 3.2-mm (1/8") plastic-covered steel cable threaded through grommets. The cable is released at the end of the desired irrigation period by a timer or other means to allow the top edge to drop, permitting the water to flow downstream. This check, when designed for a lined ditch, is portable and can be easily moved from one location to another. It is well suited for use in the automatic furrow cutback system described above. Its use in this system has reduced labor requirements from 1.2 man hours per ha per irrigation to 0.08 compared to siphon tube irrigation. A modified design can be used in an unlined ditch (Figure 6c).

The pressure check gate is designed to automatically open when water reaches a predetermined depth in the ditch (Figure 7). It uses the principle of

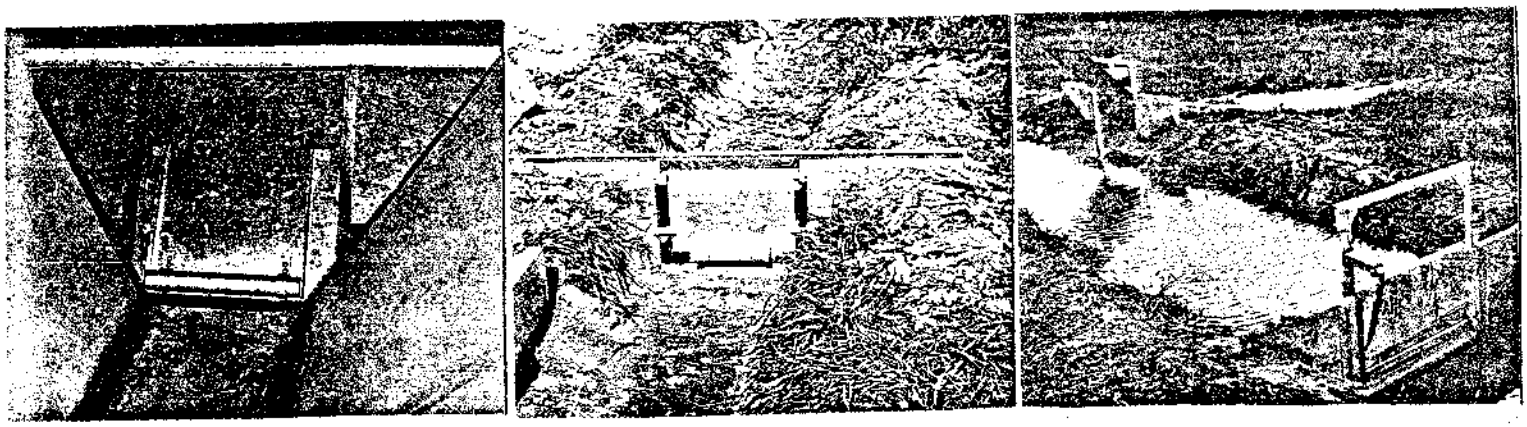


Figure 7. Center-of-pressure check gate for lined ditches (a) and for unlined ditches (b, c). The gate in (c) is counterbalanced with a constant-force return spring.

hydrostatic pressure distribution and the resultant center-of-pressure force to open the gate. It is well suited for use as a companion structure to the drop gate. About 3- to 4-cm rise in the water surface is needed to trip the pressure gate after the drop gate closes. When the gate is counterbalanced by a constant-force spring or a weight, it automatically closes after water recedes from the ditch.

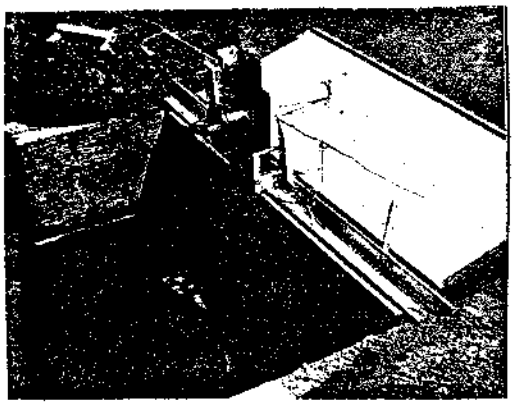
A tube outlet gate (Figure 8) is useful in automating pipe turnouts in

Figure 8. Tube outlet gate and drop gate on a concrete pipe turnout structure.

border or other flooding-type systems. The flexible tube is made easily and is clamped to the outlet end of a pipe turnout to form a watertight

closure. A tube hanger and trip device are also mounted on the clamping band.

Combination turnout gates are needed in most border irrigation systems where more than one turnout exists between ditch check gates. They are used where it is necessary to first divert water through an opening into a field border, and then terminate irrigation by closing the opening. One combination consists of a drop gate and an apron or other drop-open gate on the same structure (Figure 9). Two timers are used--one to open and one



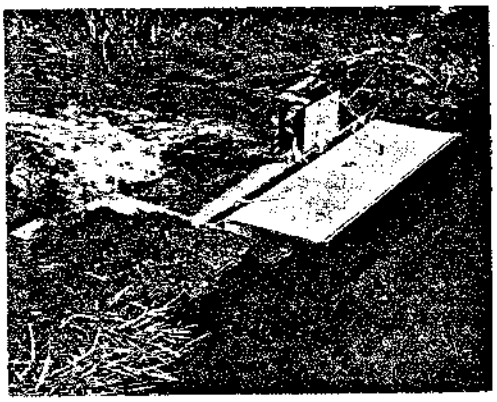


Figure 9. Combination border turnout gate comprised of a drop gate on the upstream side and an apron gate on the downstream side.

to close the opening. The timers are set with a slight time overlap so that the next gate opens before the preceding one closes. Conventional, concrete pipe turnouts can be fitted with a drop gate and a tube outlet gate to form a relatively inexpensive combination gate, using existing structures (Figure 8).

These open channel structures can be used in either lined or unlined ditches. Many of them can be built in a farm shop to minimize cost. Data from semi-automatic surface systems indicate that irrigation labor can be reduced as much as 90% compared to conventional systems. In addition, water can be more effectively used, since its application can depend upon the length of time necessary to replenish the soil moisture rather than upon the farmer's work schedule. Normal work schedules in Idaho usually result in either 12- or 24-hour sets regardless of soil moisture replenishment needs.

AUTOMATIC CONTROLS FOR PIPELINE SYSTEMS

Water for pipeline systems is usually supplied from pumped wells or from open or closed gravity flow systems, either with or without a booster pump. Gated pipe, with an adjustable gate or outlet for each furrow, is the most acceptable means of distributing the water to furrows in an automated system. When gated pipe is used, automatic controls are needed to sequence irrigation from one set or section of pipe to another. Automatic controls

consist of automatic pipeline valves and the associated timers, sensors, and controllers (discussed earlier). With these controls, automated portable, semi-portable, and solid set surface systems are possible. Automated pipeline systems with good water control can provide greater flexibility in management so that short, frequent irrigations, cutback flow and other water-conserving practices can be used. Most installations use the double pipe system with one pipe (either buried or on the surface) used for conveyance and the second pipe (gated) used for water distribution to the furrows. Automatic controls are being developed for pipe outlet gates, so that gated pipe can serve both conveyance and distribution functions.

Lo-Pressure Automatic Valves

Snake River lo-pressure automatic pipeline valves, developed at the Snake River Conservation Research Center, are designed so that the water pressure within the pipe is used to close the valves. Other investigators use pneumatically operated valves (3, 5). The working part of the Snake River valve is a water-inflated bladder or diaphragm within the valve housing (Figure 10).

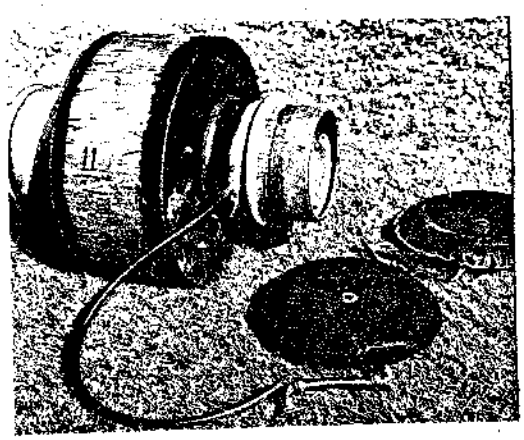


Figure 10. Snake River irrigation valve showing two types of water-inflatable bladders used inside the valve body.

The bladder is a modified small tire inner tube with a rubber membrane covering vulcanized to each side. The bladder is positioned inside the valve body between two parallel surfaces with a seat or seal ring on each surface (Figure 11). When the bladder is filled with water from the pipeline, it expands to fill or seal the flow area, thereby closing the valve. When the bladder is drained, the valve opens to permit flow. The force of the flowing water completely collapses and flattens the bladder. Two bladder designs are used, one for pipeline pressures of less than about 28 kN/m^2 (4 psi), and one for pressures between 28 and approximately 83 kN/m^2 (12 psi). The latter has full nylon-reinforced covers, completely surrounding the tube, to support the higher internal pressures. The valves are designed for an open/close operation. When used to modulate the flow, vibrations may occur as the valve approaches its fully closed position. However, with special controls they can be used for this purpose within most of the flow range. Valves have been

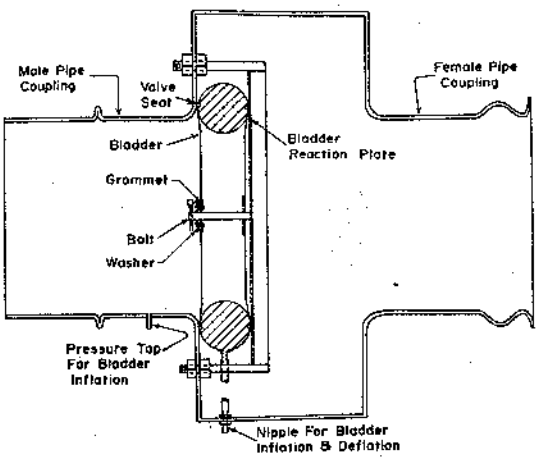


Figure 11. Schematic cross section view of Snake River lo-pressure irrigation valve.

developed for 6-, 8- and 10-inch pipe. They can be constructed as single units with one or two outlets or as dual units which have each outlet controlled individually (Figure 12). Laboratory hydraulic tests were made to

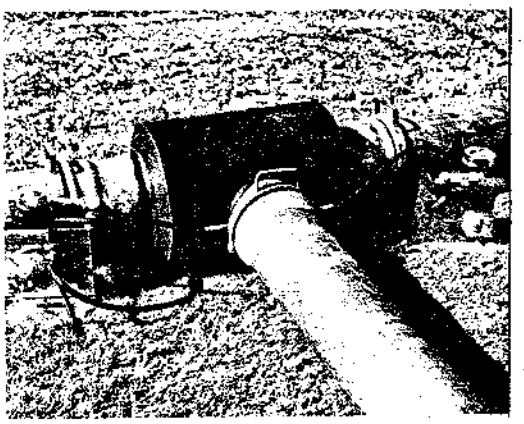


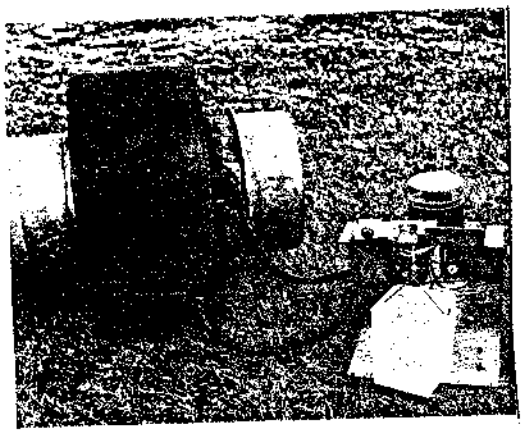
Figure 12. Dual irrigation valve with each outlet individually controlled.

determine the head loss versus discharge relationships. Laboratory endurance tests were made with two test valves subjected to over 5,000 open/close cycles at 83 kN/m^2 (12 psi). No deterioration or damage to the bladders could be detected.

Valve Controls

A 3-way brass stopcock selector valve controls filling and emptying of the irrigation valve diaphragm. This small valve is operated by a 3-volt DC motor, powered by 2 D-cell batteries. Stainless steel ladder chain on Delrin sprockets is used to drive the pilot valve through a 90° rotation from one position to the next. The motor rotation is reversed by changing the battery voltage polarity with a DPDT switch. In some cases, the DPDT switch can also be used as a limit switch. The irrigation valve, with its associated control unit, can operate independently, requires no energy from an outside source for operation, and is easily controlled. The motor/selector-valve unit can be controlled by a mechanical timer, an electronic timer, a programmed timer/controller, or by a radio transmitter/receiver unit.

A selector valve control unit, used with a 24-hour mechanical timer, is shown in Figure 13a. The timer opens the valve by activating a DPDT switch



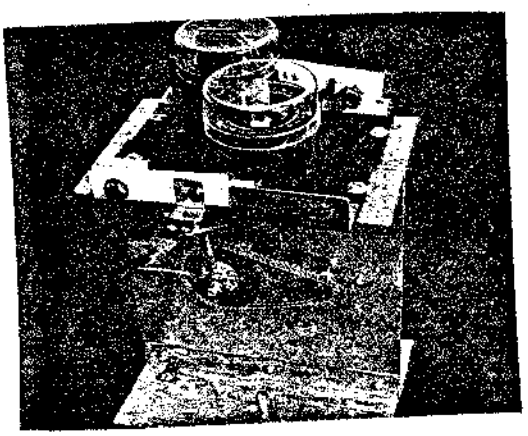


Figure 13. Selector valve control unit with a 24-hour timer to open an irrigation valve and a water-filled container to close the valve (a) and a control unit with two timers--one to open and one to close the irrigation valve (b).

when it trips. The valve is closed when water from the next irrigation set is used to fill the water container shown. This activates the DPDT switch to reverse the drive motor. This arrangement can be used when the end of the gated pipe of the next set is adjacent to the valve of the preceding set, so that water to close the valve can be taken a short distance to the container. This eliminates one timer and assures that the next valve is open before the preceding one closes. Instead of using the water container, two timers can be used--one to open and one to close the valve (Figure 13b).

Electronic timers are also used at the Snake River Conservation Research Center to control the irrigation valves. One timer is designed for use with tensiometers and controls two valves in a predetermined sequence for automatic flow cutback irrigation. This system was used to irrigate a field of corn in 1973. First, one valve was opened until water completely wet the furrows to the end of the field. The first valve then closed, and the valve for the second set opened. After the furrows were completely wet on the

second set, the first valve opened again and the entire stream of water was distributed between both sets to give a reduced or cutback stream size. Irrigation was stopped when the soil moisture tension, as determined by a tensiometer, reached a predetermined value.

Another electronic timer was designed to activate stepping relays on two or more control units (Figure 14a). With this system, a number of valves can

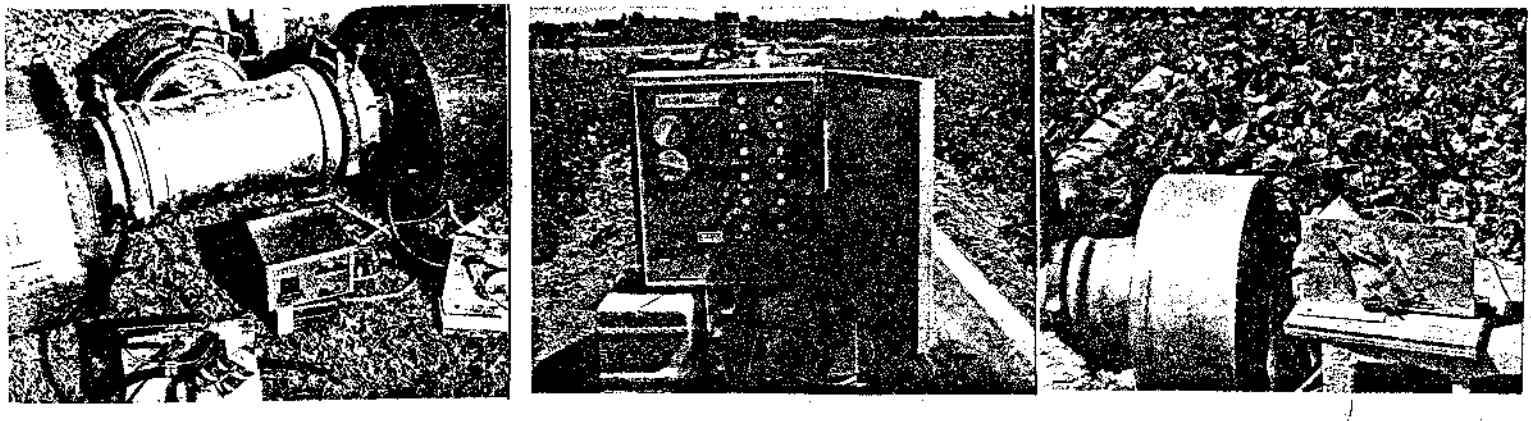


Figure 14. Irrigation valves with an electronic timer and the associated selector valve control units (a), a commercial programmable irrigation controller (b), and a selector valve control unit used with the commercial controller (c).

be controlled with one timer. Each time an electrical pulse is produced by the timer, each relay advances one position. The relay positions are staggered to operate the valves in the desired sequence. A disadvantage of this system is that wires are needed in the field between the timer and each valve.

The selector valve control unit is easy to use with programmed controllers designed for sprinkler and turf irrigation (Figure 14b). Programmed controllers commonly use 24-volt AC power for their control functions. Automatic irrigation valves tested in this type of system, during 1973, used a 24-volt relay with a DPDT limit switch on the selector valve control unit (Figure 14c). The valves and their associated controls were used in a multiset irrigation system to irrigate beans with short frequent irrigations.

SUMMARY AND CONCLUSIONS

Automatic controls for surface irrigation systems consist of a combination of gates, structures, valves, timers, soil moisture sensors and related devices. These can be either semi-automatic or automatic, and are used to divert and distribute irrigation water to agricultural fields from open channels or pipelines. Mechanical timers, including alarm clocks and a commercial 24-hour irrigation timer, currently are used mainly in semi-automatic irrigation systems. Programmable timers and soil moisture sensors, such as tensiometers and moisture blocks, can be used in both semi-automatic

and automatic systems. In open channel systems, both drop gates and drop-open gates have been designed to control water discharge into borders and furrows. Gated pipe is recommended for distributing water to the field in an automatic furrow irrigation system. Automatic valves developed for gated pipeline systems are controlled by battery-powered control units and use water from the pipeline for operation.

Automatic on-farm controls for surface irrigation are not used extensively. Some are in the experimental stage while others are awaiting further commercial development and manufacture. Most field installations have been made in response to pressing water-related or labor problems. For example, irrigation of over 35,000 acres of sugar cane in Hawaii have been semi-automated as a result of a critical labor and water shortage. This has resulted in a saving of water and has reduced labor requirements about 2/3. Currently, a number of factors are expected to increase the use of on-farm automatic irrigation controls. Among these are:

1. The scarcity and high cost of farm labor.
2. An increasing awareness of the need to conserve soil and water resources and decrease irrigation-related pollution.
3. Enactment of legislation to force efficient and prudent use and conservation of the farm's soil and water resources.
4. Use of agricultural land for waste disposal. This will require greater use of automatic controls which can also be used for general irrigation.
5. Improved irrigation management practices and technology, which will require better on-farm water control and improved irrigation facilities.
6. Improved farm economic conditions, which can result in larger capital investments in irrigation facilities.
7. Advancements in electronic, materials, and manufacturing technology, which will make some controls more feasible for irrigation.
8. The energy shortage, which will make automatic surface irrigation systems more attractive because of their lower energy requirement when compared to sprinkler irrigation.
9. The increased use of gated pipe for furrow irrigation, which is easier to automate than discharge openings from open channels.

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