Using the IDWR "Keep-Up" and "Catch-Up" Slide Rule

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A simple but powerful tool has been developed by the Energy Division of Idaho Department of Water Resources (IDWR) to help growers determine how to better manage irrigation water applied by sprinkler systems. By using a "Keep-Up" and "Catch-Up" slide rule growers are able to accurately and efficiently apply water to crops at the appropriate times and in the correct amounts.

To best consider how to manage center-pivot, linear-move, solid-set, and set-move systems, an evaluation is needed of the system constraints that influence management strategies. In center-pivot and linear-move systems, water is applied in a rather narrow band and at a relatively high application rate as the lateral moves across the soil. In these systems, infiltration rates limit the application rate and total depth applied during any one application.

Excessive water application will produce surface runoff, which causes localized soil erosion and non-uniform soil moisture within the field. Therefore, for most soils, maximum application depth is usually limited to 1 inch or less. As a result, deep wetting is difficult to achieve with center-pivot and linear-move systems.

In most cases, system design application rate is less than the peak evapotranspiration (ET) rates. One major consequence of this design decision is that if a grower enters the peak water use portion of the irrigation season "behind," then there is no way to catch up until ET drops to less than the system application rate. This is shown graphically in Fig. 1. Therefore, with center-pivot and linear-move systems, growers must fill the expected root zone depth to field capacity while ET is less than the application rate.

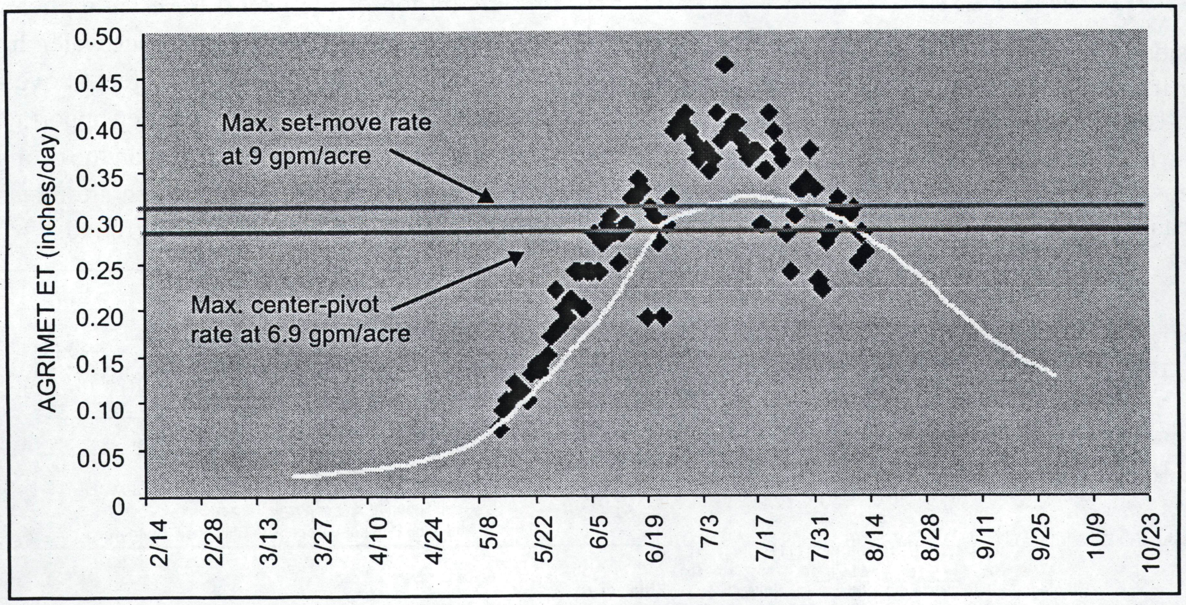

Fig. 1. Sugarbeet ET at Kimberly, Idaho, for 1991-2002, and for 2003.

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Fig. 1 shows typical sugarbeet ET for Kimberly, Idaho, from 1991 to 2002 and for 2003. The 1991 to 2002 average is shown as a curved line, and the 2003 data are indicated by diamonds. Notice that both data sets peak at about the same time. This level is sustained from about mid-June until the end of July.

In 2003, the ET values exceeded 0.3 inch per day for nearly 1 month. At times ET was as high as 0.4 inch per day. The lower horizontal line shown in Fig. 1 indicates center-pivot capacity for a pivot design of 6.9 gallons per minute per acre (gpm/acre). Notice that at this system capacity, the center-pivot cannot provide all the example crop's required water from mid-June until the end of July in an average year.

The pivot was able to supply significantly less water than the crop required during a 6-week period in 2003. The upper horizontal line in Fig. 1 shows a typical set-move application rate based on a design of 9 gpm/acre. In a typical year, this set-move system can meet peak ET, which gives the grower more management options.

In a high water use year, such as 2003, if crops irrigated by either type of system entered mid-June with inadequate soil moisture, the root zone soil moisture would become more deleted with time. Therefore, a grower's irrigation schedule could not catch up with a crop's water needs until the end of July. The crop would be excessively water stressed and yield and/or quality damage would occur.

"Keep-Up" with ET

A two-sided slide rule tool deals with two concepts relative to irrigation water management—"Keep-Up" and "Catch-Up." The keep-up concept describes the time needed to irrigate on a daily or weekly basis for the system to keep-up, or match crop ET demand. As seen in Fig. 1, because crop demand varies with season of the year, the keep-up time will also vary throughout the year.

The keep-up side of the slide rule contains several fixed and moveable scales (Fig. 2). System capacity in gpm is located on the top (fixed) scale "A" and goes from 60 to 2,000. Immediately below it, the top moveable scale ranges from 10 to 250 acres. The calculation window provides gpm/acre.

The second fixed scale gives system rate in inches per day (inch/day), while the next moveable scale gives system application efficiency as a percent. The top moveable scale on the "B" slide gives ET input in inch/day. The calculation window on the bottom gives the keep-up time in terms of hours per day, days per week, or "percent on" time depending on system requirements. In the six examples, note the input numbers and answers are circled.

Application Efficiency

Before beginning use of the "Keep-Up" slide rule, a discussion is needed on the concept of application efficiency, or the percentage of water applied by the irrigation system that is stored in the crop root zone. Some of the applied water is lost to evaporation, surface runoff, non-uniformity, or wind drift.

Application efficiency for low-pressure center pivots is generally considered to be 80 to 85 percent, which

> *Note:* High-pressure systems with impact sprinklers on top of the lateral have an application efficiency of only 70 percent. Since water droplets are released from 12 to 15 feet above the ground, they have a much greater opportunity for evaporation and wind drift than the droplets from a low-pressure pivot, which are released from only 3 to 6 feet above the ground.

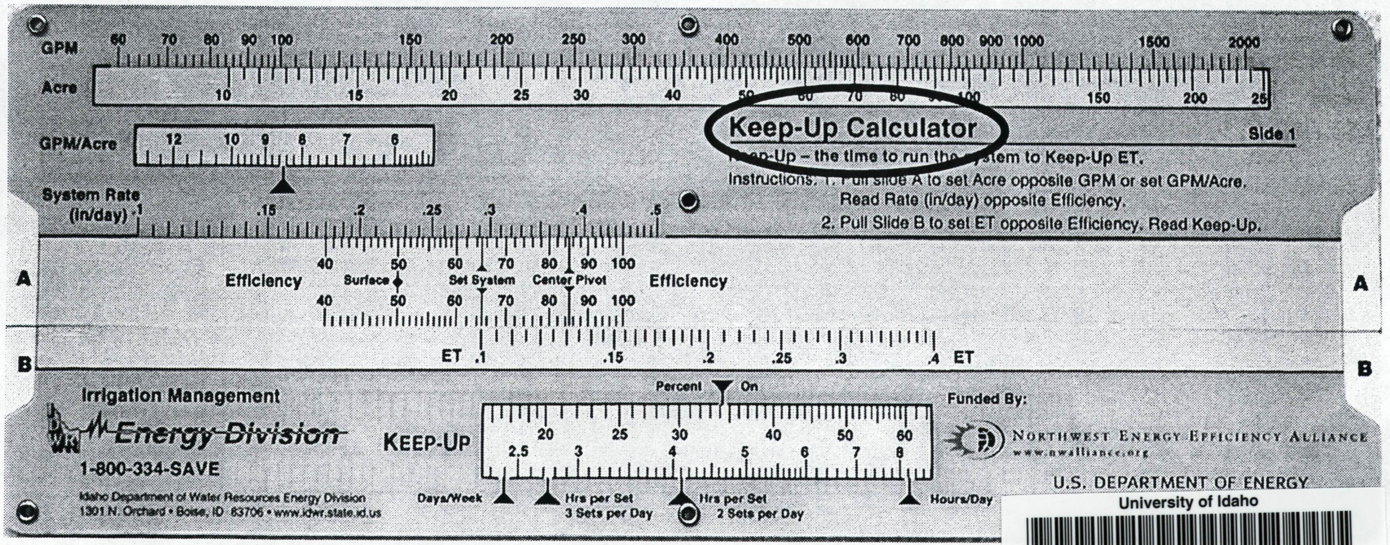

Fig. 2. "Keep-Up" side of the slide rule.

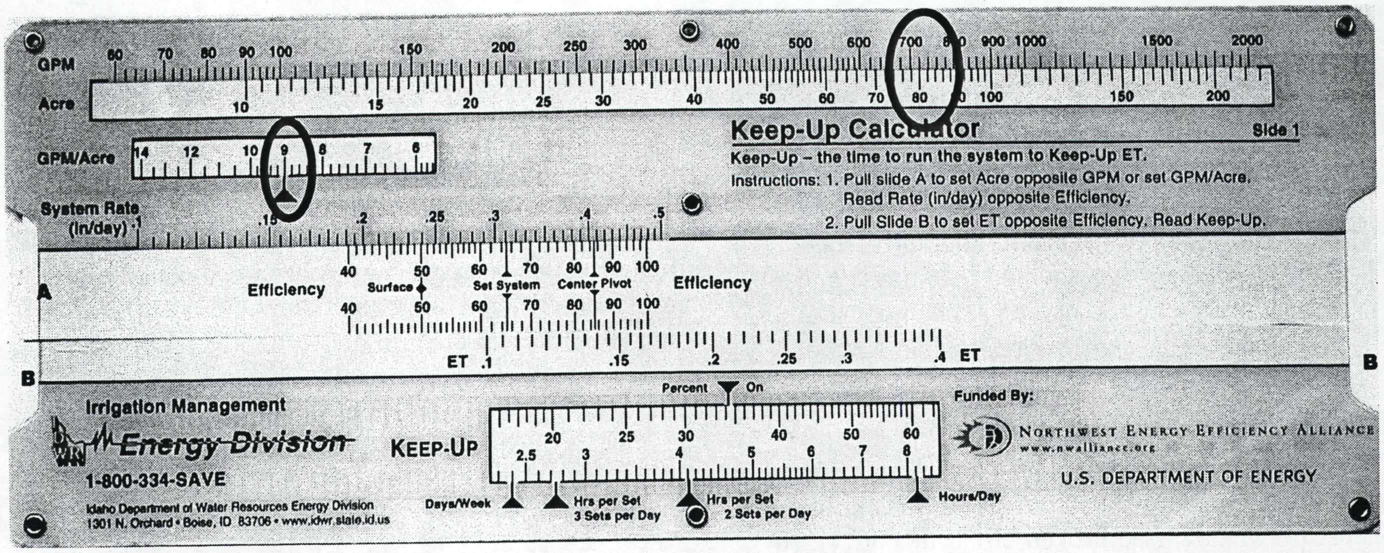

Fig. 3. "Keep-Up" calculation for hand line and wheel line irrigation systems part 1

means that about 85 percent of the water applied is delivered to the soil and can be stored in the crop root zone. Linear-move irrigation system application efficiency is similar.

Average application efficiency of set systems (either set-move or solid-set) is about 65 percent. On windy days this efficiency can decrease to 60 percent. Under calm, nearly ideal conditions, the efficiency can be 70 or 75 percent.

Application efficiency for surface irrigation ranges from 35 to 50 percent. "Losses" in surface irrigation water are surface runoff, which is typically 20 to 30 percent of water applied, and deep percolation, which is about 20 to 30 percent of water applied.

Drip irrigation is 90 to 95 percent efficient. Losses involved with drip irrigation are primarily evaporation from the soil surface and leaks and resulting non-uniformity.

Example 1. Keep-Up Calculation for Set Systems (find length of set time): A sprinkler system composed of four wheel lines irrigates an 80-acre field and has a system capacity of 720 gallons per minute (gpm). ET at this point in the season is 0.23 inch/day. *What length of set times should be used for two and three moves per day to keep-up at this time?*

The first calculation involves locating the flow of 720 gpm on the top fixed scale and moving the A scale to align 720 gpm and 80 acres (Fig. 3). This gives a result of 9.0 gpm/acre.

The next step is to move slide B to align the given ET of 0.23 inch/day with a system efficiency of 65 percent (on the moveable A scale) (Fig. 4). In the bottom calculation window, a reading of about 9 hours per set is seen if two moves per day are used, or about 6 hours per set if operated at three moves per day (see solid circles).

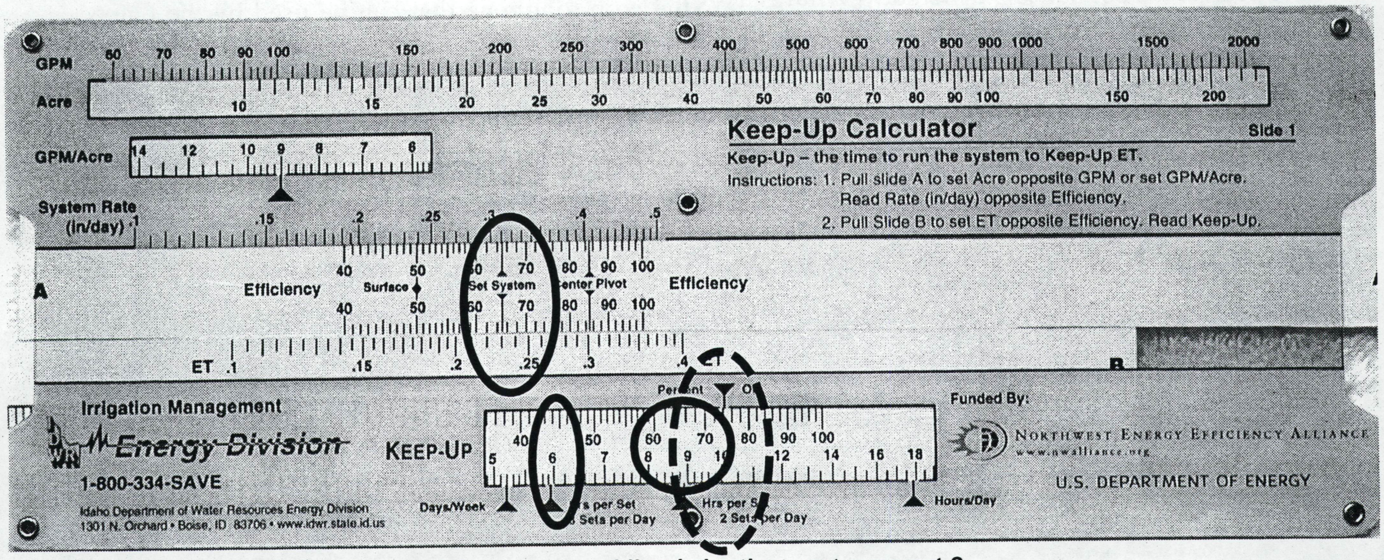

Fig. 4."Keep-Up" calculation for hand line and wheel line irrigation systems part 2

Example 2. Keep-Up Calculation for Set Systems (given 11.5 hour sets) (find time from the start of one irrigation cycle to the start of the next): An alternative operation procedure at this point in the season would be to operate the system with 11.5 hour (h) sets for a complete irrigation cycle (assumed as 6 days) and then shut down for a short period of time. Other conditions are the same as in Example 1. *What should be the length of time from the start of one irrigation cycle to the start of the next?*

The first step would be to align slides A and B as in Example 1, and read "percent on" as 74 percent in the "Keep-Up" window (see broken circle in Fig. 4). An approximate cycle time would be 6 days/0.74, or 8.1 days. This says that the system should be off for 2 days out of every 8.

This is a valid cycle time for a solid-set system where off time is minimal. However, the system is off for 30 minutes at each move on a set-move system. The off time during two moves per day for 6 days would be 12 x 30, or 360 minutes (6 hours). The 2-day off time would then be shortened by another 6 hours to about 1.75 days.

As shown in Fig. 5, the maximum system capacity in inches per day with a water supply of 9 gpm/acre and an 11.5 h set time can be found by aligning 9 gpm/acre in the window by moving slide A, and then moving slide B to align 11.5 h with the "2 Sets per Day" marker. Maximum system capacity is then read opposite the 65 percent efficiency line as 0.30 inch/day. If efficiency is 70 percent, maximum rate is 0.32 inch/day.

Example 3. Keep-Up Calculation for Center-Pivot: A center-pivot irrigates 130 acres. The system capacity is 900 gallons per minute. ET at this point in the season is 0.3 inch/day. *What percentage of the time should the system be run to "keep up" with ET?*

First, determine gpm/acre by aligning 900 gpm with 130 acres on the A scale (Fig. 6). Move the B scale to align the required ET of 0.3 inch/day with the system efficiency of 85 percent. The answer is found in the bottom window by reading "96" below the "percent on" triangle. This means that to deliver 0.3 inch/day with a center-pivot system capacity of 900 gpm on 130 acres a grower would need to operate the pivot 96 percent of the time, or 6.9 days/week.

"Catch-Up" and Return Time Calculations

"Catch-Up" is the time required beyond "Keep-Up" time to increase soil moisture by a specified amount. The reverse side of the slide rule is the "Catch-Up" side (Fig. 7).

Catch-up time depends on soil texture and water-holding capacity (WHC), rooting depth, and the increase in soil moisture content to be achieved. The soil texture and WHC may also be obtained from the USDA-NRCS soil survey of the area. Available soil water (or WHC) is the amount of water that can be held between field capacity and permanent wilting point for a given soil type. For example, a sandy loam has a WHC of 1.7 inches per foot, while a silt loam soil has a WHC of 2.2 to 2.4 inches per foot. Table 1 lists water-holding capacities for several soil textures.

The next concept to be discussed is MAD, or Management Allowable Depletion. This term describes the fraction of soil WHC that can be used or depleted without an objectionable decrease in crop yield or quality. Usable water is the depth of water in inches stored in the crop root zone that can be used by the plants be-

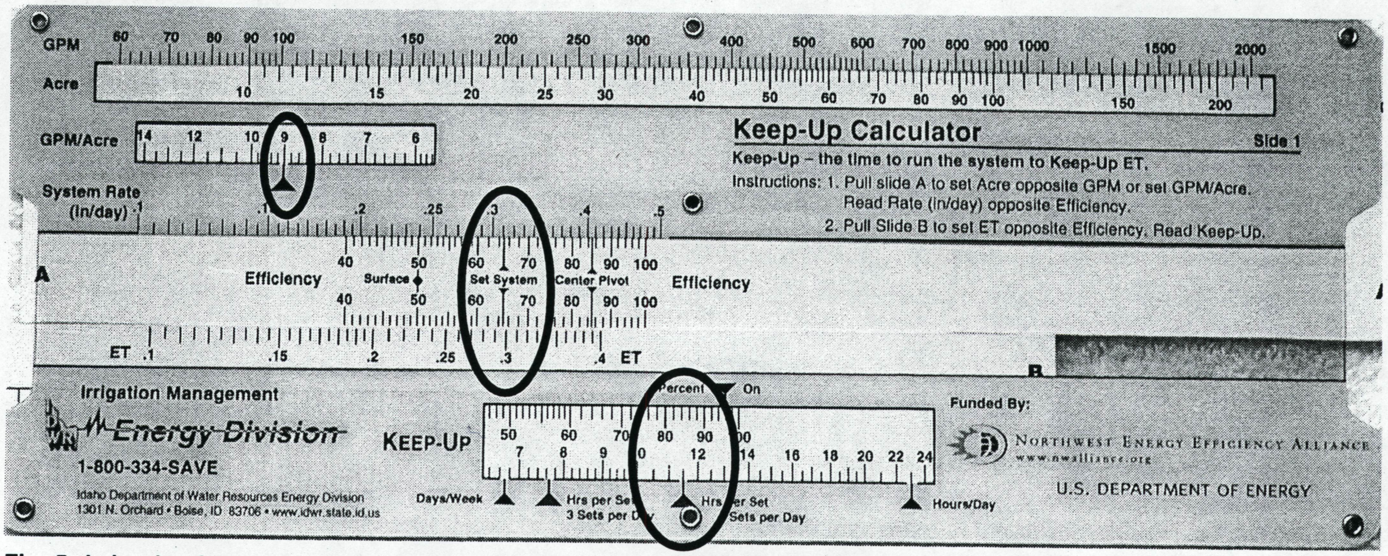

Fig. 5. Irrigation interval for 11.5 hour sets on hand line and wheel line irrigation systems.

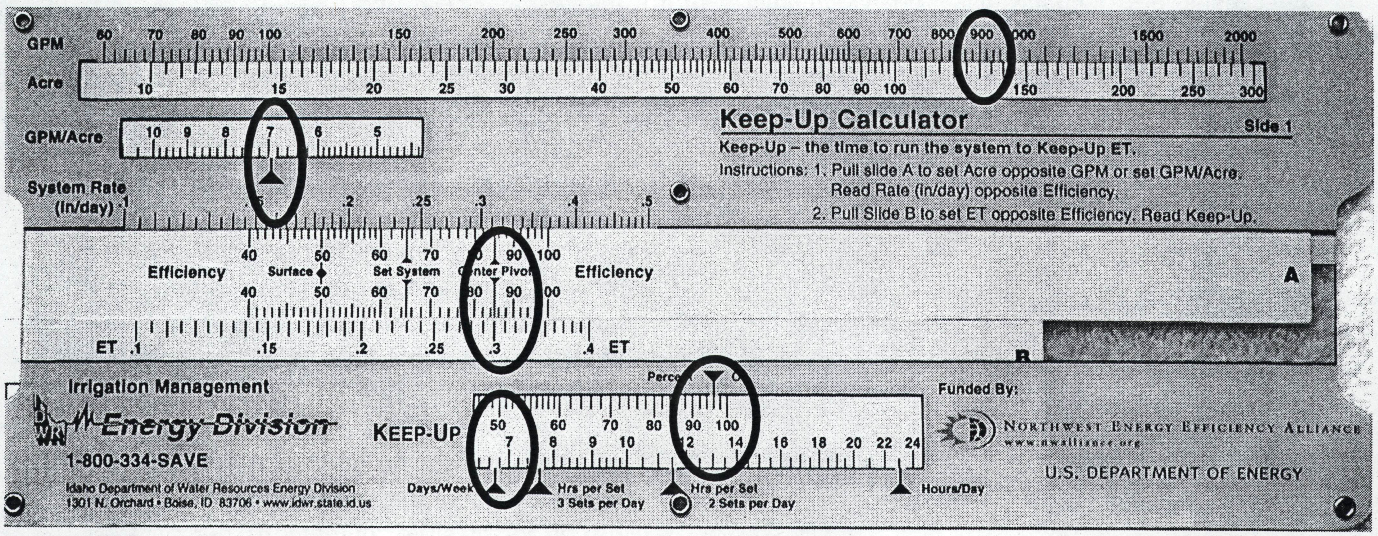

Fig. 6. "Keep-Up" calculation for center-pivot and linear-move systems.

Table 1. Soil water-holding capacity for several soil textures.

Soil texture	WHC (inch/ft)
Sand	0.4
Loamy sand	0.8
Clay loam	1.1
Sandy clay	1.1
Sandy loam	1.7
Clay	1.9
Loamy sand	2.1
Silty clay loam	2.1
Silt	2.1
Silt loam	2.4
Silty clay	2.9

tween irrigations with no objectionable decrease in crop yield or quality. Usable water is calculated as WHC in inches per foot times MAD as a decimal fraction.

Table 2 gives typical values of MAD and root zone depth for several crops. With MAD of 30 to 35 percent, potatoes are a water-sensitive crop, while MAD of 50 percent indicates that alfalfa and sugarbeets are a little more drought tolerant.

Example 4. Catch-Up Calculations: From laboratory analysis, the soil is 25 percent sand, 60 percent silt, and 15 percent clay. Rooting depth is 2 feet, current soil moisture is 80 percent available in the root zone, and target soil moisture is 100 percent available. In other words, applied water should fill the root zone to field capacity. The system application rate, which can be obtained from the keep-up side of the slide rule, is 0.29 inch/day. *How many more hours beyond regular operation are needed to refill the soil from the current moisture content to field capacity?*

The first step in this calculation is to obtain the soil water-holding capacity from the textural triangle or a

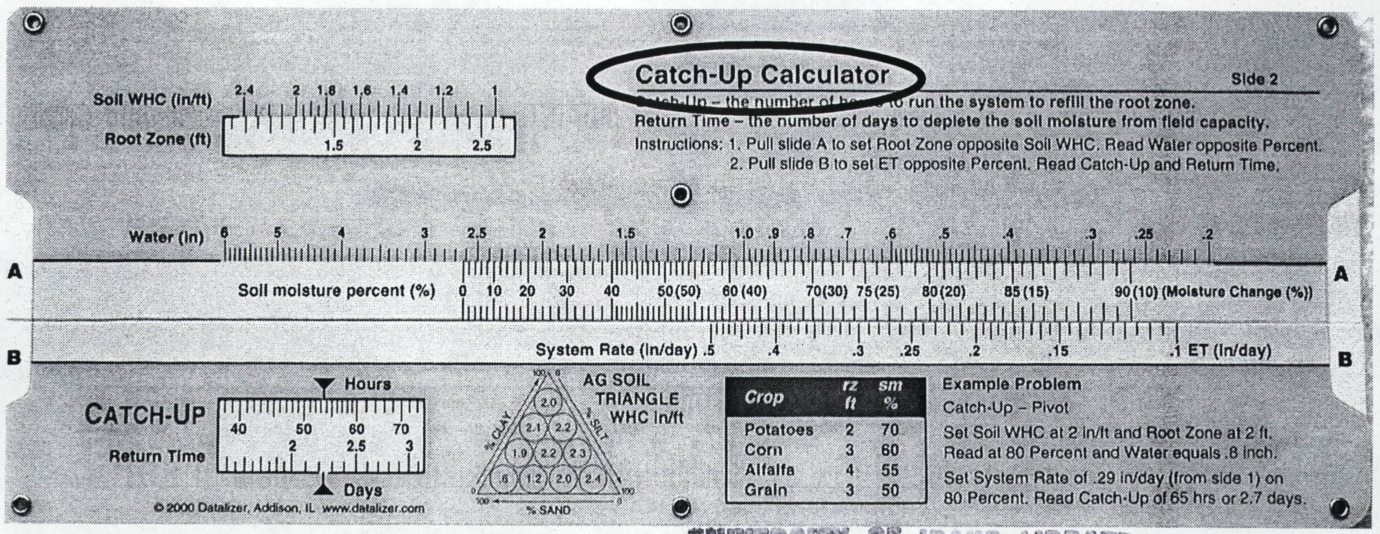

Fig. 7. "Catch-Up" calculation for center-pivot and linear-move systems.

Table 2. Percent of available water that may be used without causing yield or quality losses (Management Allowable Depletion, or MAD).

Crop	Stage of development	% of available water usable without yield or quality loss
Alfalfa	All stages	55
Corn, field	All stages	50
Corn, sweet	All stages	50
Cereal grains	All stages except boot—flowering and ripening of wheat	55
	Boot through flowering	45
	Ripening (wheat)	90
Dry beans	All stages	40
Mint	All stages	40
Onion	First irrigation	40
	All other irrigations	30
Pasture	All stages	50
Potato	All stages except vine kill	35
	Vine kill	50
Sugarbeets	All stages	50

table value. In this case, the texture is silt loam as determined from Fig. 8, and WHC is 2.4 inch/ft from Table 1.

The second step is to move slide A to align the root zone depth with the WHC, as shown in Fig. 9. Water depth required to refill the root zone to field capacity from current soil moisture can then be determined by locating "80%" on the fixed scale and reading the inches of water to catch-up directly above it, which is 0.96 inch. This means that to refill this silt loam soil with a rooting depth of 2 feet from 80 percent available water to field capacity would require 0.96 inch of water.

To determine the number of catch-up hours, move slide B to align the system rate of 0.29 inch/day with 80 percent available soil moisture. The catch-up time of 80 hours, or 3.3 days, can be found in the calculation window. This means that to re-fill the root zone from 80 percent available to field capacity, given system capacity and other factors, the system must be run for 80 hours more than the time required to keep-up with ET.

Example 5. Catch-Up Calculations: The soil is sandy loam, with a crop rooting depth of 2 feet. Current soil moisture is 50 percent available in the root zone, and target soil moisture is 100 percent available. In other words, applied water should fill the root zone to field capacity. The system application rate, which can be obtained from the keep-up side, is 0.29 inch/day. We would like to find the additional hours beyond regular operation required to refill the soil from the current moisture content to 70 percent available (an increase of 20 percentage points).

Water-holding capacity is 1.7 inches per foot from Table 1. Next, align 1.7 inches per foot with a 2-foot root zone using slide A (Fig. 10). Move slide B to align a 20 percent moisture change with the system capacity

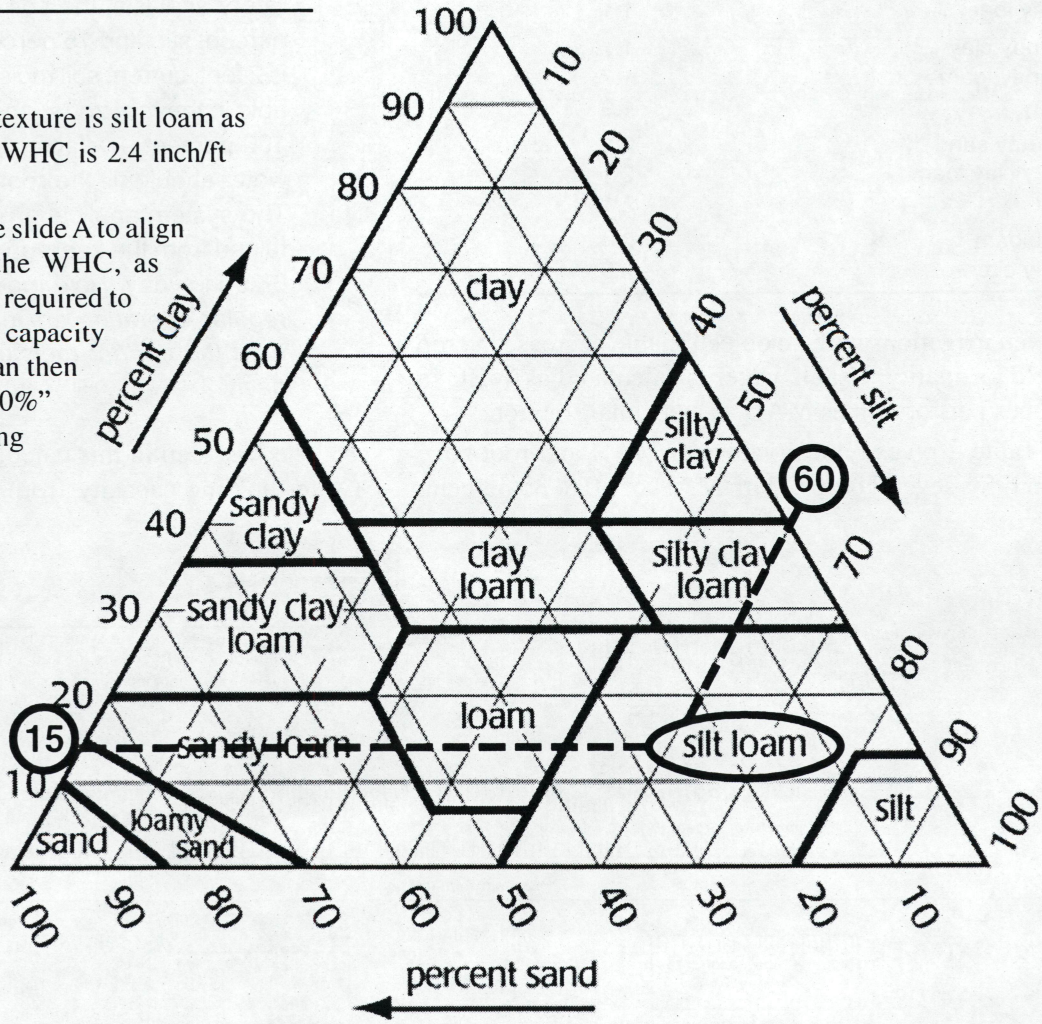

Fig. 8. USDA soil textural classification chart.

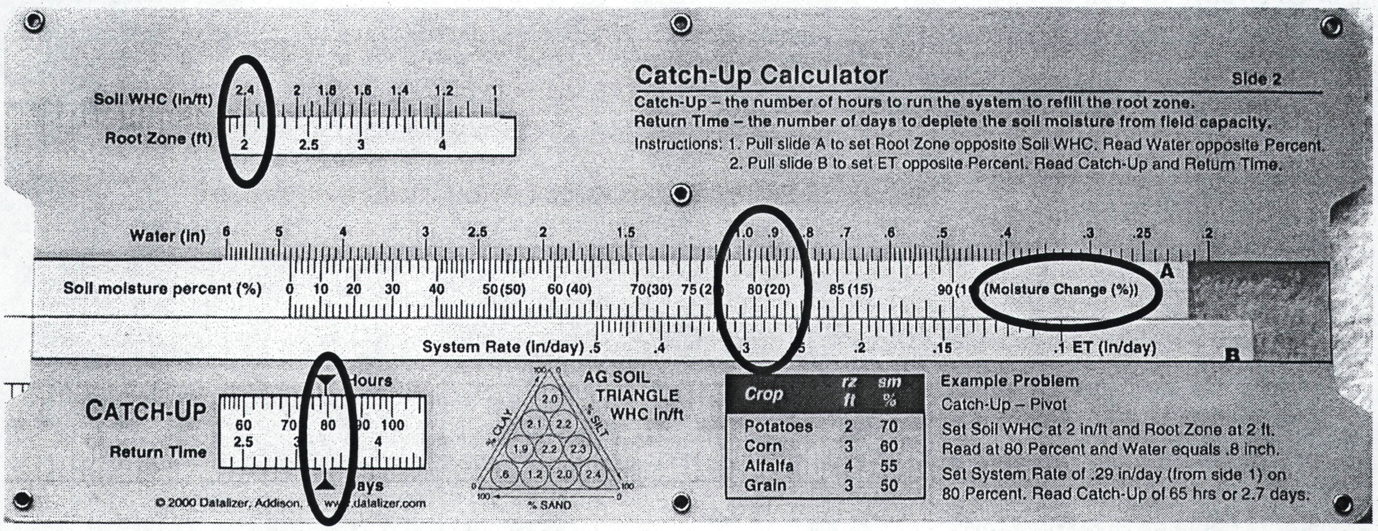

Fig. 9. "Catch-Up" slide rule silt loam example.

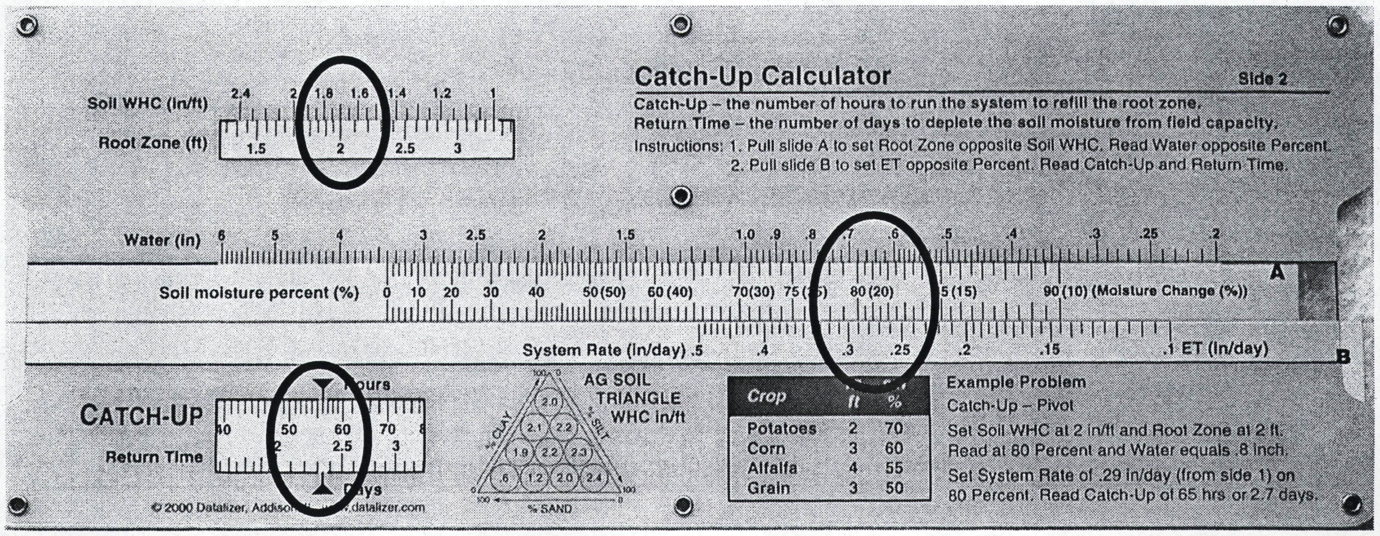

Fig. 10. "Catch-Up" slide rule sandy loam example.

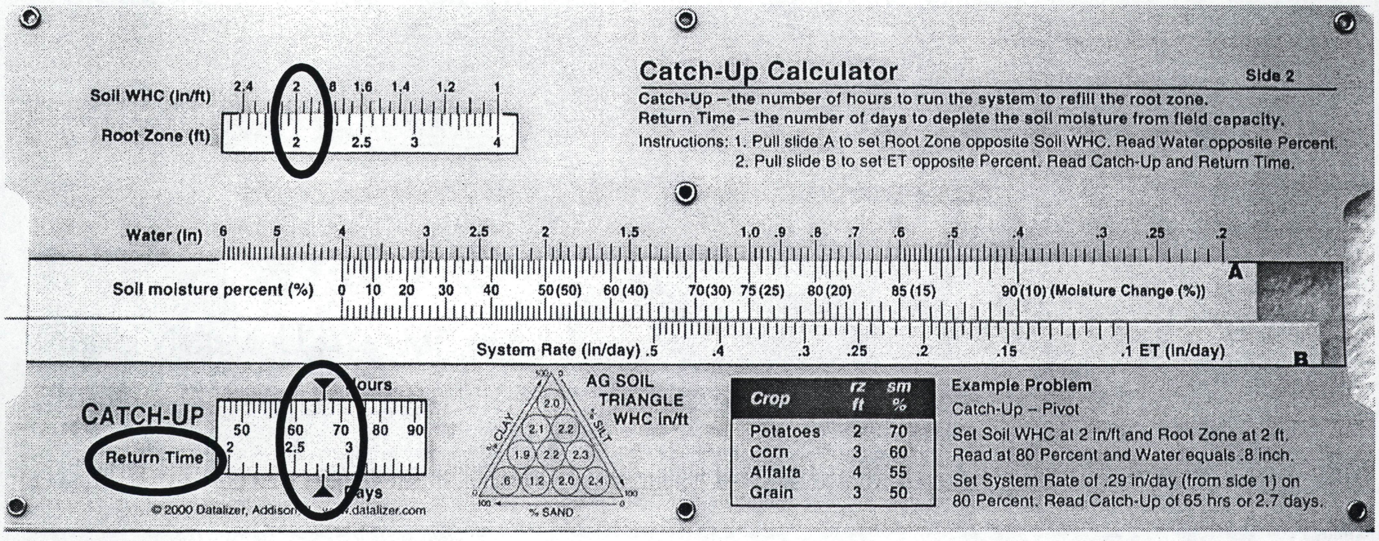

Fig. 11. Return time calculation.

of 0.29 inch/day. A catch-up time of 56 hours, or 2.3 days, is read from the window.

Return time is the number of days before ET depletes usable soil moisture. The concept of return time describes the interval between irrigations at the same point in the field. For example, a return time of 3 days means that it will be 3 days between times for the pivot to wet a certain portion of the field. Return time for a set-move system is the time required to irrigate an area and then all following sets and return to that area again for subsequent irrigation.

Example 6. Return Time Calculations: Given a 2-foot root zone with WHC of 2 inches per foot that is currently at field capacity, with ET at 0.29 inch/day, how many days before the available water is depleted to 80 percent?

With WHC and root zone depth set as before, align the ET value of 0.29 with the 80 percent line as shown in Fig. 11. Read 66 hours, or 2.75 days, to deplete the 0.8 inch.

For Additional Information

The "Keep-Up" and "Catch-Up" slide rule is available free of charge. To obtain a copy of the slide rule, or for additional information on irrigation water management questions, contact:

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For other irrigated related information see the following Web site:

www.uidaho.edu/extension/drought

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