Using the IDWR "Keep-up, Catch-up Slide Rule

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A simple but powerful tool has been developed by the Energy Division of IDWR (Idaho Department of Water Resources) to determine how to better manage irrigation water applied by sprinkler systems. To best consider how to manage center pivots, linear move, solid set and set move systems, we need to look at some of the system constraints that influence management strategies.

In center pivots 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, causing local 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 these systems.

In most cases, system design application rate is less than the peak 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 Figure 1.

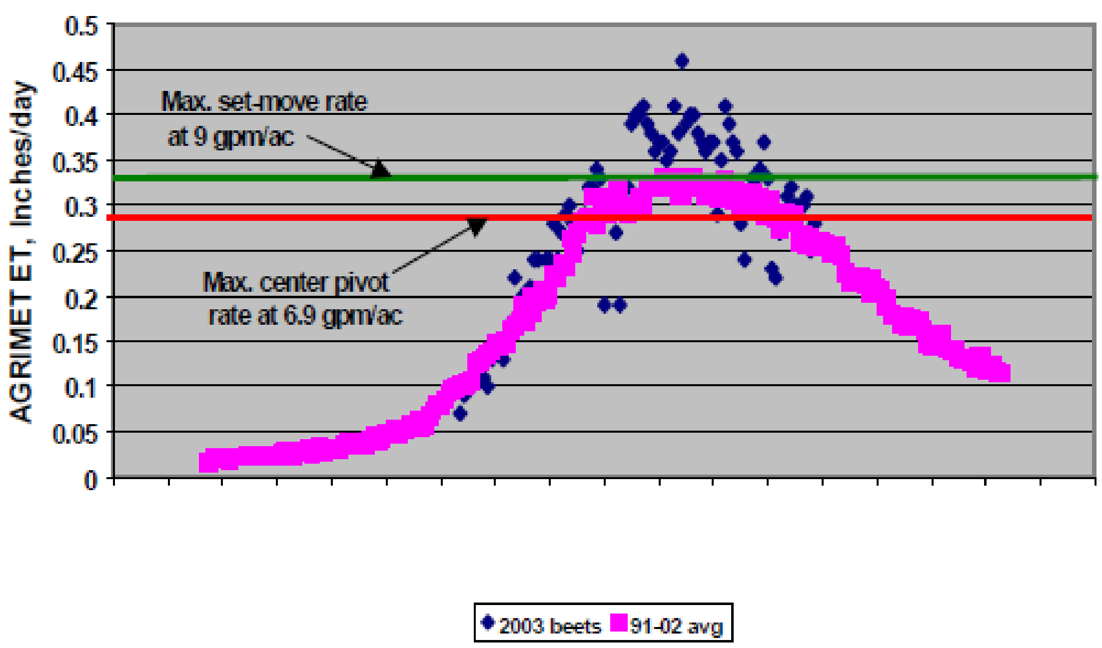

Figure 1. Sugarbeet ET at Kimberly, Idaho for 1991-2002, and for 2003.

Therefore with pivots and linears, you must fill the expected root zone depth to field capacity while ET is less than the application rate. Figure 1 shows typical sugarbeet ET for the Kimberly location. These data are from 2003. The long-term average is shown as a purple line and the 2003 data are shown as blue diamonds. Notice that both curves peak at approximately the same time. This level is sustained from about the middle of June until the end of July. In 2003, the ET values exceeded 0.3 inch per day for nearly one month. At times ET was as high as 0.4 inch per day. The red line shown on Figure 1 indicates center pivot capacity for a pivot design of 6.9 gallons per minute per acre (gpm/ac). Notice that at this system capacity, the center pivot cannot provide all the required water from mid-June until the end of July in an average year. In 2003 the pivot was able to supply significantly less water than the crop required during that six-week period. As you can see, if a farmer entered mid-June with inadequate soil moisture, the root zone soil moisture would become more depleted with time. Therefore, the farmer could not catch up until the end of July. The crop would be excessively water stressed and yield / quality damage would occur.

"Keep-Up", the time per set required to keep up with ET

This slide rule deals with two concepts relative to irrigation water management. The first concept is that of "keep up". The keep up concept describes the time one needs to irrigate on a daily or weekly basis for the system to keep up, or match crop ET demand. As can be seen from Figure 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 calculator contains several fixed and moveable scales as shown in Figure 2.

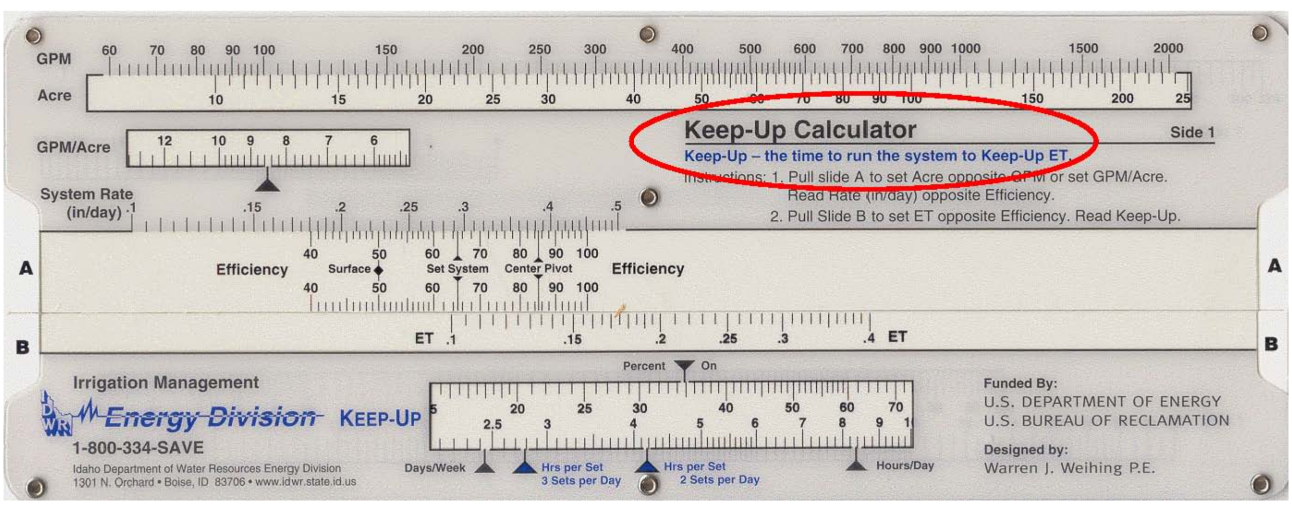

Figure 2. Keep-up side of slide rule.

System capacity in gpm is located on the top (fixed) scale and goes from 60 to 2,000. Immediately below it, the top moveable scale ranges from 10-250 acres. The calculation window provides gpm/ac. The second fixed scale gives system rate in inches per 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 in/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 all the following examples, input numbers are circled in red and answers are circled in green.

Application Efficiency: At this point we need to discuss the concept of application efficiency. This is the percentage of water applied by the irrigation system that is stored in the crop root zone. The remainder 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 80-85 percent. This means that about 85 percent of the water applied is delivered to the soil and can be stored in the crop root zone. Application efficiency for linear move systems is similar. Notice that 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 3-6 feet above the ground. Average application efficiency of set systems (either set move or solid set systems) is about 65 percent. On very windy days this efficiency can decrease to as low as 60 percent. Under calm, nearly ideal conditions, the efficiency can be as high as 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 also 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.

<u>Example 1,</u> Keep Up Calculation -. Set Systems (find length of set time): A sprinkler system composed of 4 wheel lines irrigates an 80-acre field and has a system capacity of 720 gallons per minute. ET at this point in the season is 0.23 in/day. What length of set times should be used for 2 and 3 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 as shown in Figure 3. This gives a result of 9.0 gpm/ac. The next step is to move slide B to align the given ET of 0.23 in/day with a system efficiency of 65 percent (on the moveable A scale). In the bottom calculation window, we can now read about 9 hours per set if we used 2 moves per day or about 6 hours per set if we operate at 3 moves per day as shown by the green circles. We can also read the net system application rate as 0.31 in/day, which considers both water applied and application efficiency, but assumes no down time for moving. This would, however, be an appropriate application rate for a solid set system where down time is minimal.

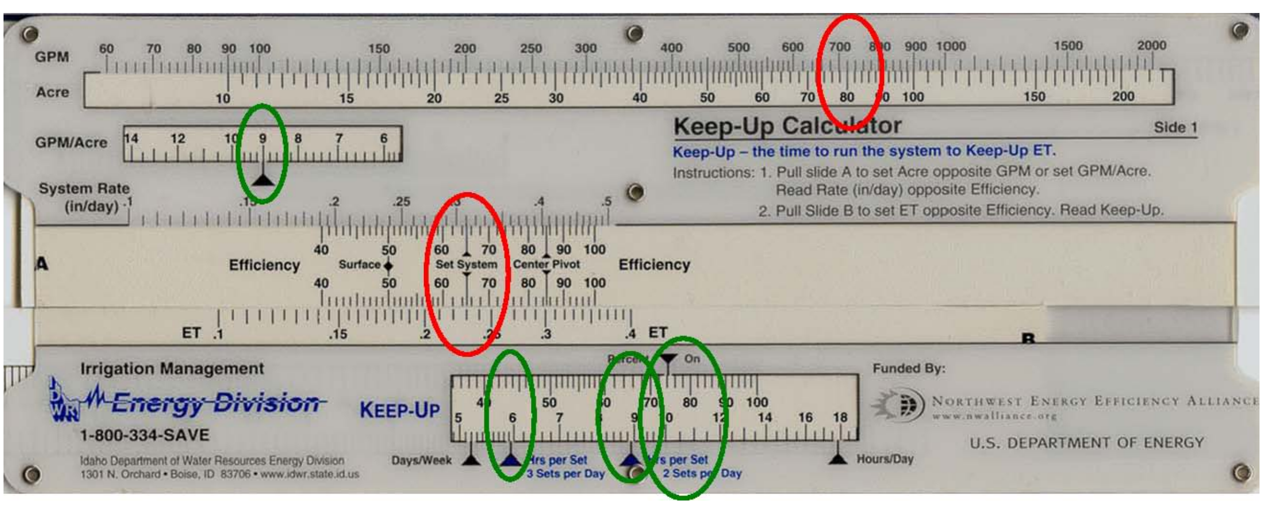

Figure 3. Keep up calculation for solid set, hand line and wheel line.

<u>Example 2,</u> Keep Up Calculation -. Set Systems (given 11.5 h 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 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 2, and read “percent on” as 74% in the “Keep – Up” window as shown in Figure 3. 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 2 moves per day for 6 days would be 12 * 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 Figure 4, the maximum system capacity in inches per day with a water supply of 9 gpm/ac and an 11.5 hour set time can be found by aligning 9 gpm/ac in the window by moving slide A, and then moving slide B to align 11.5 hours with the “2 Sets per Day” marker. Maximum system capacity is then read opposite the 65% efficiency line as 0.29 inches per day. If efficiency is 70%, maximum rate is 0.32 in/day.

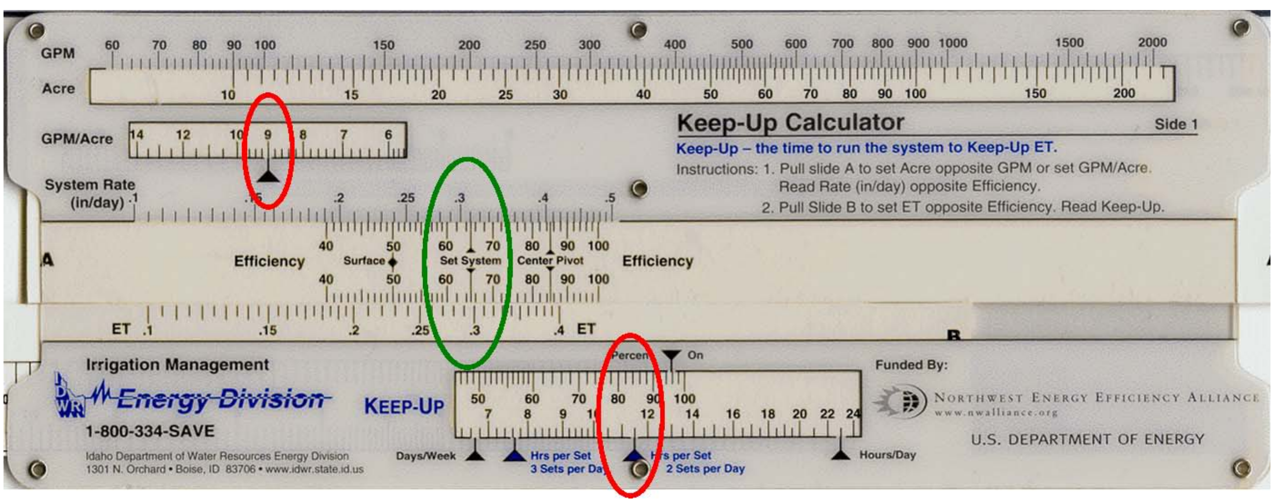

Figure 4. Irrigation interval for 11.5 hour sets on hand line and wheel line.

<u>**Example 2,**</u> **Keep Up Calculation - 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 in/day. What percentage of the time should the system be run to “keep up” with ET?

First, determine gpm/ac by aligning 900 gpm with 130 acres on the A scale as shown in Figure 5. Move the B scale to align the required ET of 0.3 inch per 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 inches per day with a center pivot system capacity of 900 gpm on 130 acres we would need to operate the pivot 96 percent of the time (or 6.9 days/week).

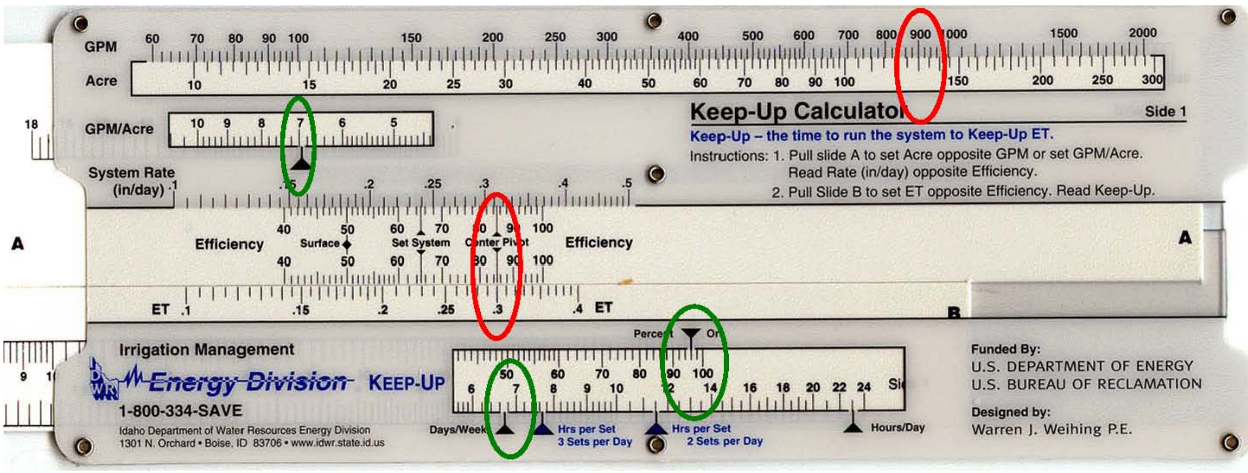

Figure 5. Keep-Up calculation for center pivot and linear move systems.

“Catch-Up” and Return Time Calculations

“Catch-Up”: Time required beyond “Keep-Up” time to increase soil moisture by a specified amount.

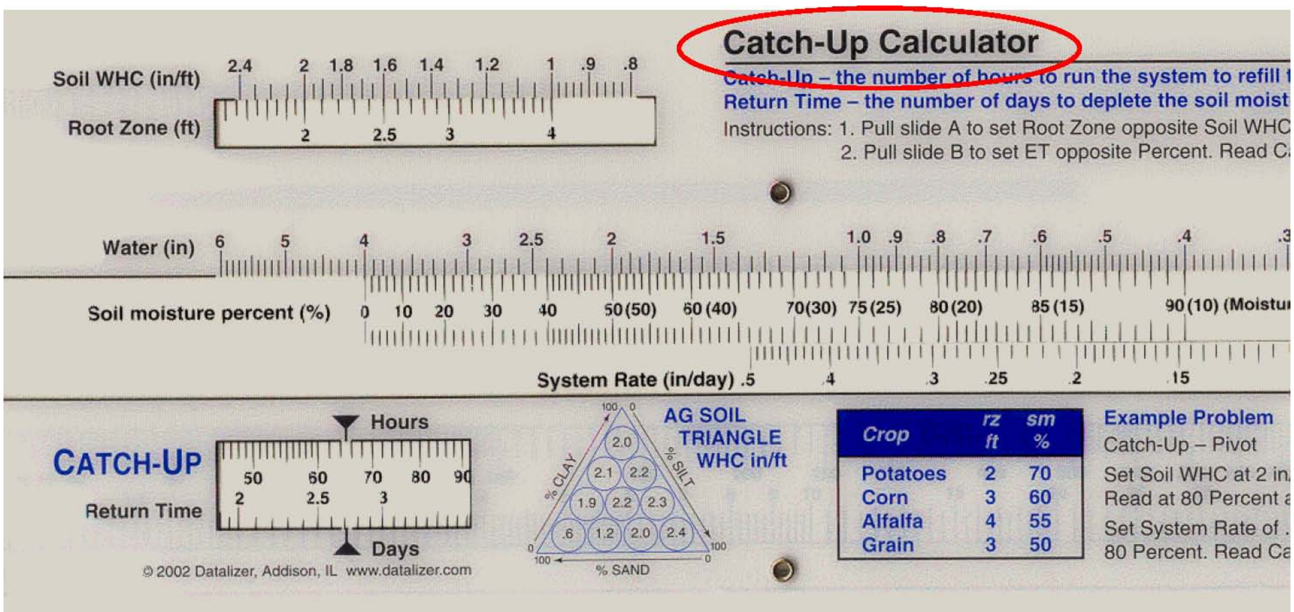

Figure 6. Catch up calculation for center pivot and linear move systems.

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 water holding capacity may also be obtained from the USDA-NRCS soil survey of the area. Available soil water (or water holding capacity) 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 water holding capacity of 1.7 inches per foot while a silt loam soil has a water holding capacity of 2.2 – 2.4 inches per foot.

The next concept that we need to discuss is MAD or Management Allowable Depletion. This term describes the fraction of soil water holding capacity 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 between irrigations with no objectionable decrease in your quality. Usable water is calculated as water holding capacity in inches per foot times MAD as a decimal fraction. Table 2 gives typical values of MAD and root zone depth for a number of crops. With MAD of 30-35%, potatoes are a water-sensitive crop, while MAD of 50% indicates that alfalfa and sugarbeets are a little more drought tolerant.

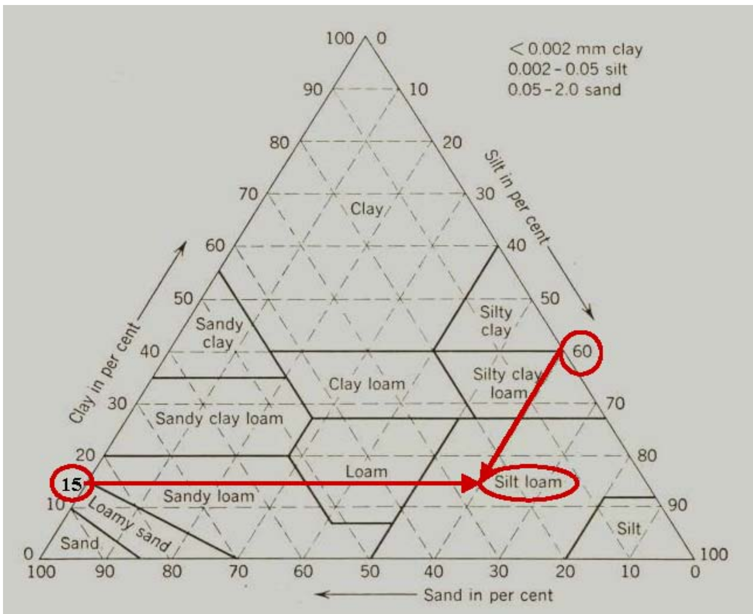

Figure 7. USDA soil textural classification chart.

Table 1. Soil water holding capacity (WHC) for a number of soil textures.

Soil Texture	WHC, in/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

Crop	Stage of Development	Pe V

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Silty Clay Loam	2.1
Silt	2.1
Silt Loam	2.4
Silty Clay	2.9

Crop	Stage of Development	Percent 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

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

Example 3. Catch-up calculations: From laboratory analysis, the soil is 25% sand, 60% silt and 15% 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) is 0.29 in/day. We would like to find the additional hours beyond regular operation required 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 table value. In this case, the texture is silt loam as determined from Figure 6 and WHC is 2.4 in/ft from Table 1. The second step is to move slide A to align the root zone depth with the water holding capacity, as shown in Figure 8. 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 as 0.96 inches. This says 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 in/d with 80% 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 refill the root zone from 80% 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.

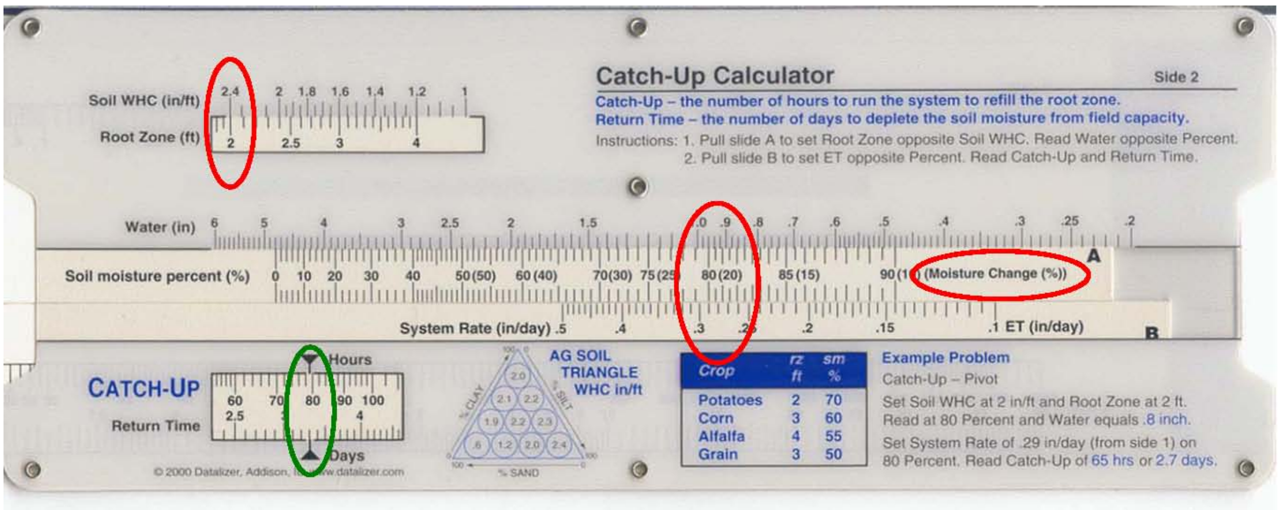

Figure 8. Catch-up slide rule silt loam example.

Example 4. 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 in/day. We would like to find the additional hours beyond regular operation required to refill the soil from the current moisture content to 70% available (an increase of 20 percentage points).

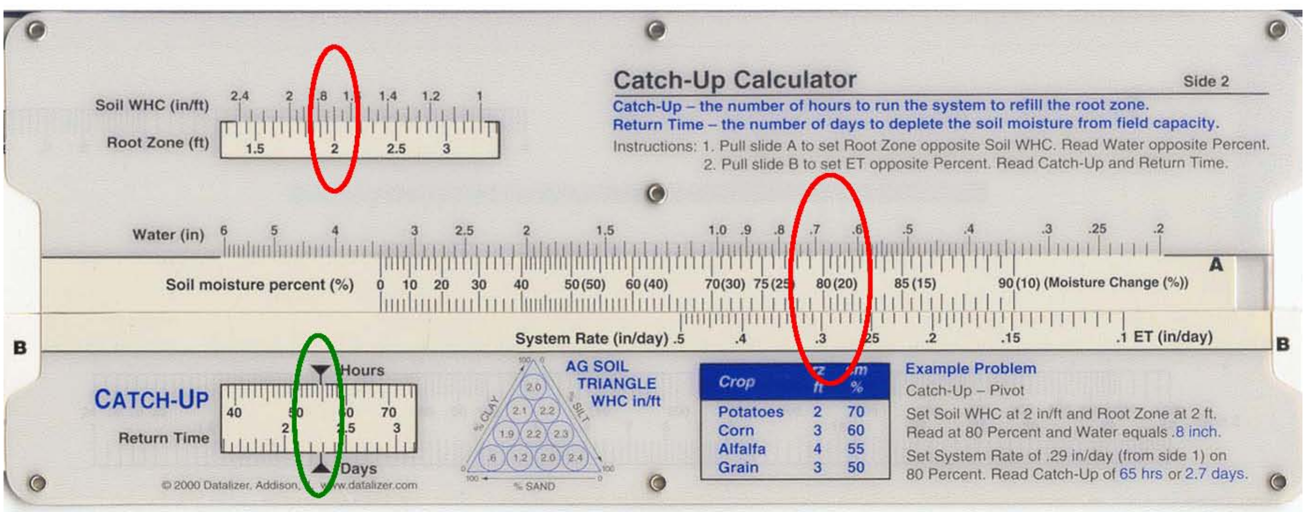

Figure 9. Catch-up slide rule sandy loam example

Water holding capacity is 1.7 inches per foot from Table 1. Next, align1.7 inches per foot with a 2 foot root zone using slide A. Move slide B to align a 20% moisture change with the system capacity of 0.29 inches per day. A catch up time of 55 hours (2.3 days) is read from the window.

Return Time: 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 three days means that it will be three 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 5, Return Time Calculations: Given a 2 foot root zone with WHC of 2 in/ft that is currently at field capacity, with ET at 0.29 in/day, how many days before the available water is depleted to 80%?

With WHC and root zone depth set as before, align the ET value of 0.29 with the 80% line as shown in Figure 8. Read 65 hours or 2.7 days to deplete the 0.8 inches.

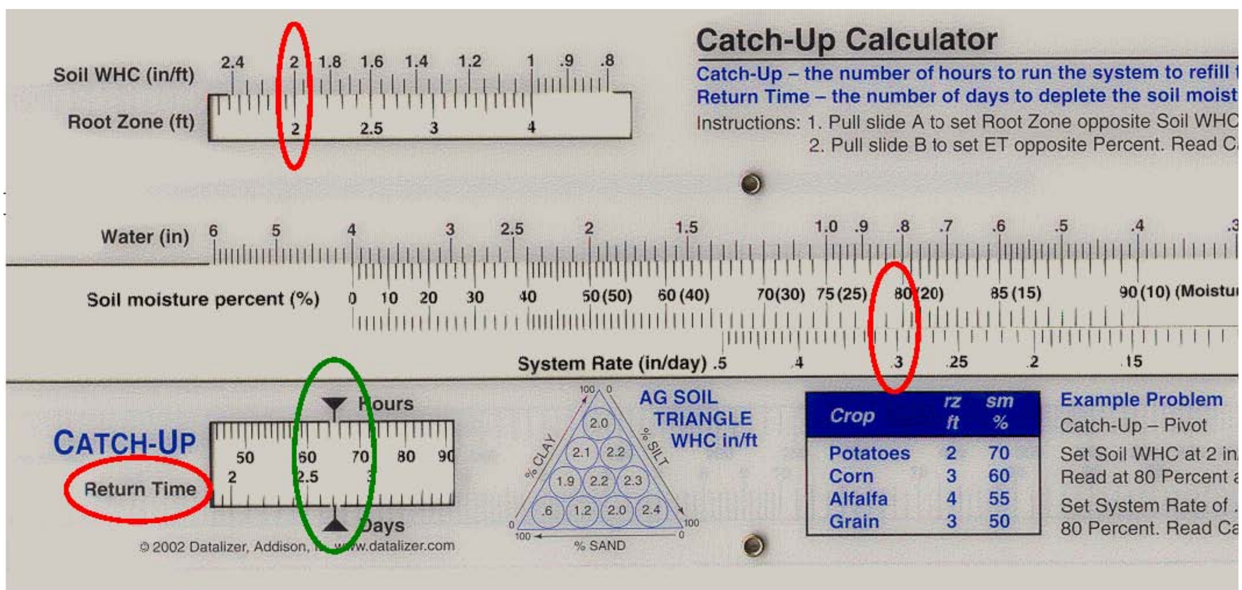

Figure 10. Return time calculation.

For additional information on how to use this slide rule, contact IDWR at (208)327-7961, or Howard Neibling at (208)736-3631 or hneiblin@ uidaho.edu.