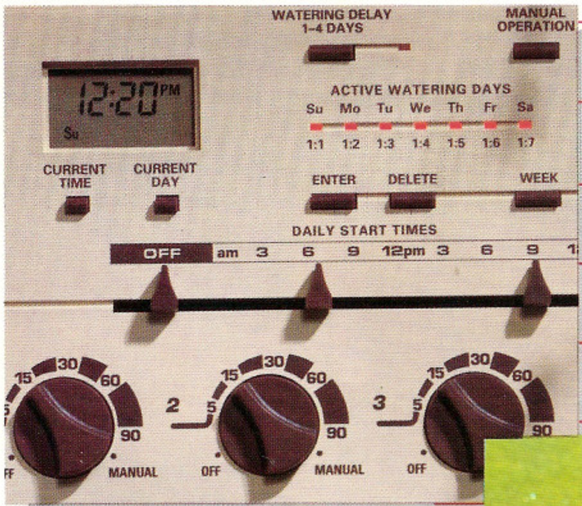
The Educator Series Vol:1 No. 1

Automatic Sprinkler System Scheduling



TORO®

Excellence in Irrigation®

Landscape water conservation is of the utmost importance if we are to continue to build and enjoy our green environment. Water is a valuable, finite resource that must be shared with other segments of our society. The Green Industry enjoys a major share of urban water use and is under constant criticism to use it more effectively.

The Toro Company *manufactures a full product range to handle any irrigation challenge, no matter how complex the situation or individual the water requirement. Yet even with these, the most sophisticated systems available, the basic principles of efficient design and operation must be followed if water conservation is to be attained and the Green Industry is to continue enriching peoples lives with beautiful gardens and turfs.*

This edition of **'The Educator Series'** *restates the basic soil/water principles and describes how accurate Scheduling of Automatic Sprinkler Systems can increase efficiency by minimizing system losses.*

The Soil Reservoir

Soil is composed of sand, silt and clay **Particles**. The percentage of each of these particles, called 'factions' or **Separates**, determines the **Texture** of a specific soil. See Figure 1.

Combined with decayed organic matter, the separates arrange into larger, more complex particles called soil **Structure**. Spaces between the separates, called **Pore Space**, can contain air and water. A soil most favorable to plant root growth will contain approximately 50% pore space.

When water first moves into soil, its molecules form a film around the soil particles by electrical attraction, called **Adhesion**. As more water is applied, **Cohesion** (the water molecules' attraction to each other), allows the film to enlarge and fill the pore spaces. Further additions of water allows **Gravity** to drain it to deeper layers. See Figure 2. Water is absorbed by soil at a speed measured as **Infiltration Rate (Ir)** which varies with soil texture and structure. See Table 1.

Depending upon soil texture, drainage is rapid at first, but decreases over time until there is a balance between gravity and cohesion. At this point the soil is holding all the water possible and is at **Field Capacity (FC)**.

Natural Water Loss.

The main cause of water loss is solar **Evaporation**. Water moves by capillary action to the soil surface and evaporates. Additionally, water absorbed by the roots of a plant is passed upwards through its tissue and evaporates from the stomata of the leaves. This **Transpiration** process helps to cool the plant and moves nutrients within it. These related processes are called **Evapotranspiration (ET)**, which is the key to efficient Sprinkler System Scheduling. **The ET Rate** is a measurement of the amount of water loss. See Figure 3.

As plants transpire and evaporation draws water from the soil, the film of water becomes thinner and its adhesion to the soil particle is stronger than the roots' ability to extract it, slowing the ET Rate and causing water stress visible in the plant. This is called the **Permanent Wilting Point (PWP)**. As the reservoir is depleted the ET Rate does not slow until the approach of the PWP.

Separate	**Diameter** (inches)
Very coarse sand	.080 - .040
Coarse sand	.040 - .020
Medium sand	.020 - .010
Fine sand	.010 - .0040
Very fine sand	.0040 - .0020
Silt	.0020 - .000080
Clay	Less than .000080

Figure 1.

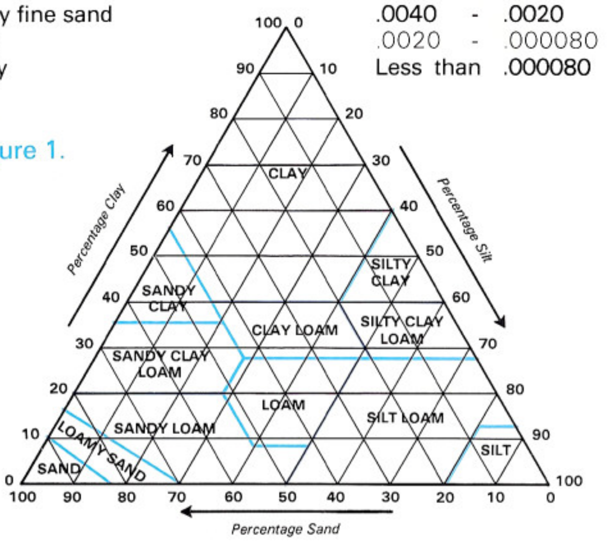


Figure 1. *Soil Texture* classes and particle size reflects the relative percentages of sand, silt and clay.

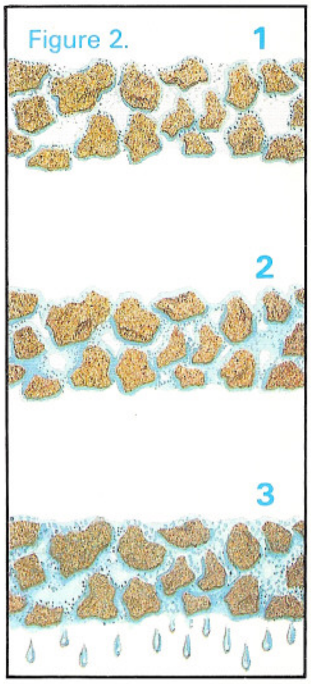


Figure 2. *Water molecules* form a film around soil particles (1). As more water is applied, the film enlarges to fill the pores (2) and gravity takes it to lower levels (3). Ideally, it should reach only the bottom of the root zone, below which it becomes wasteful.

The difference in the amount of water in the soil at field capacity and the amount contained at the PWP - the water which is usable by the plant roots - is the **Available Water (AW)** as:

FC - PWP = AW

See Table 2.

Root depth will vary with soil texture, depth, substrata layers and cultural regime. As an example, a turf-type tall Fescue grown in a uniform soil will have a rooting depth of 15-18'' if cutting height is 4''. Lowering the cut to 3'' shows a proportional reduction in the root depth. The depth of the roots defines the **Soil Reservoir** and when multiplied by the Available Water per foot gives the **Soil Reservoir Capacity (SRC)**, as:

Root Depth x AW = SRC

Keeping the soil at Field Capacity by using a set watering schedule without considering the ET Rate can damage roots and be extremely water-wasteful. Allowing plants to constantly approach PWP puts them in stress that can make them susceptible to disease and poor quality.

For continued healthy growth an efficient schedule plans an irrigation well before PWP. This is the **Allowable Depletion (AD)**. Experimentation and judgement are needed to select a reasonable AD level of the Soil Reservoir Capacity, which is based on the value of the planting, plant type, soil texture and the season. A medium-value turf is typically managed at 50% AD. Whereas a low-value turf could have an AD of 75% of the SRC. See Figure 4.

Figure 3.

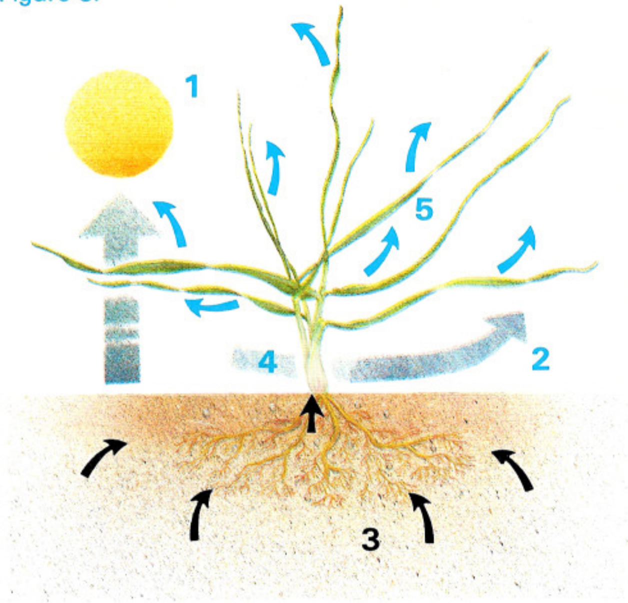
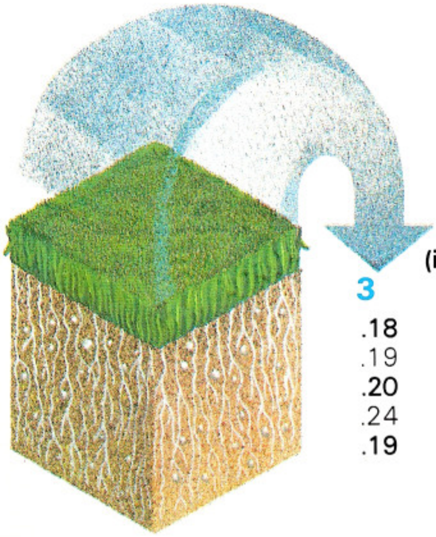


Figure 3. *The Evapotranspiration Cycle.* The sun (1) and wind (2) evaporate water from both the soil and the plant. Water is absorbed by the plant roots (3), is passed upward via its tissues (4) and evaporates through stomata in leaves (5). This transpiration process cools the leaves and aids the absorption of nutrients. The two systems form Evapotranspiration (ET).

Figure 4.



1	2	3	4	5
Soil Reservoir Capacity 2.00''	Allowable Depletion 50% = 1.00''	.18	Day 1	.18''
		.19	Day 2	.37''
		.20	Day 3	.57''
		.24	Day 4	.81''
		.19	Day 5	1.00''

ET Rate (inches/day)

Figure 4. *Allowable Depletion.* The ET Rate is the measurement of all water loss from Soil Reservoir and is the key to irrigation scheduling. By knowing the Soil Reservoir Capacity (1), an Allowable Depletion level (2) is calculated for the crop and its growing medium. Known ET Rate per day (3) and the number of days (4) will accumulate until the Allowable Depletion is reached (5). Scheduling an irrigation to replace the amount results in healthy plant growth and economical water use.

When to irrigate? = 5 days

How much water? = 1.00'' inch

Guides to determining ET Rates.

The ET Rate is affected by the atmospheric factor of solar radiation, air temperature, humidity and wind velocity. Thus, in a hot and dry area during the normal growing season, a series of cloudy, cool days with high humidity, would dramatically lower the seasons' average ET Rate. The percent of soil shaded by plants effects the ET Rate as the leaf surfaces intercept the sunlight. Measurements indicate that when 70-80% of ground cover is present, maximum ET Rates may be assumed.

There is an excellent correlation between plant ET and evaporation from a free water surface. The U.S. Weather Bureau Class A Pan is the standard reference for evaporation ET and pan evaporation is expressed as a **Crop Coefficient (Kp)***.

Check with your local county agent, co-operative extension specialist or soil conservation office for the Kp values of the plants you are irrigating. In many areas of the country either Class A pan readings or an ET Rate for turfgrass is shown in newspapers or broadcast daily on radio or TV.

moisture sensor will not allow a scheduled irrigation cycle to occur. Using soil moisture sensors with automatic controllers has proven to be effective in reducing water use by as much as 40% compared to using ET as the basis of irrigation scheduling.

Minimizing System Losses.

Runoff is a serious irrigation loss that can be minimized by insuring that the Precipitation Rate (Pr) does not exceed the Infiltration Rate (Ir) of the soil. See Table 1. If a summer thundershower drops one inch of rain in 20 minutes, as much as 75% may be runoff, the remainder is added to the soil reservoir as **'Effective Rainfall'.** An efficient schedule will allow for such adjustments and show that more water may be required.

Deep **Percolation** below the soil reservoir is wasteful and is caused by excessive or non-uniform application to the planted area. When planning sprinkler spacing, consider their positioning in relation to manufacturers recommendations and seasonal **Wind Speed**. See Table 5.

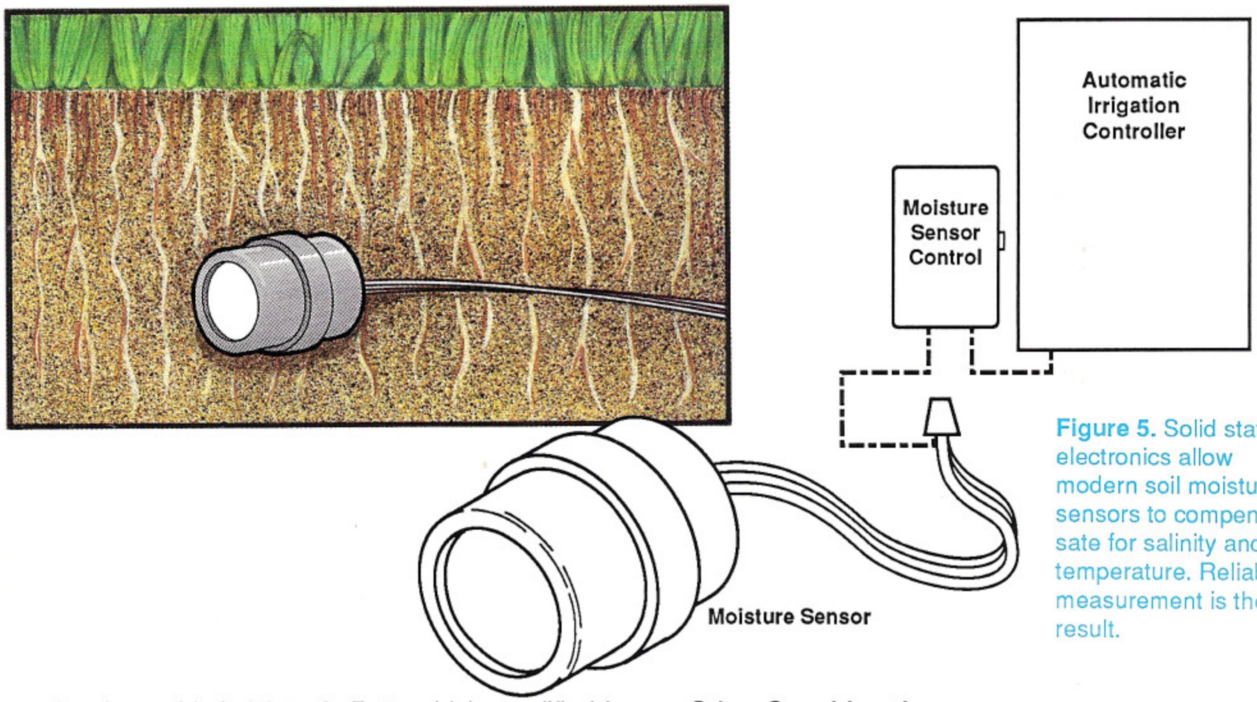


Figure 5. Solid state electronics allow modern soil moisture sensors to compensate for salinity and temperature. Reliable measurement is the result.

Another guide is **Historic Data** which, modified for local current conditions, is an excellent point of departure in your planning. The best source of such data is the book 490-1358: "Rainfall - Evapotranspiration Data" published by Toro, which gives the average rainfall over a period of 30 years for 342 climate zones throughout the U.S. and Canada. See Table 3.

Soil moisture sensors (Figure 5) are placed in the plant's root zone and monitor the amount of available water. If the root zone has adequate water, the soil

Other Considerations

A Hydraulic **Analysis** of the system to avoid pressure differentials and a periodic **Pressure Test** will greatly contribute to efficiency.

At the beginning of your growing season, estimate the amount of water **Stored** in the soil or irrigate to bring it to Field Capacity.

Where off-season rainfall is low, the **Leaching** of accumulated salts from the root zone may be necessary. While normally satisfied by winter rains or the spring snow melt, leaching will effect the over-all

* Crop factors determination - Doorenbos & Pruitt, 1977.

water requirement. Samples sent to the local soil laboratory for a **Test** will reveal salt content and indicate a leaching requirement.

Irrigation Water Requirements

The speed at which water is applied to soil from sprinkler sources is measured as **Precipitation Rate (Pr)** and can be calculated using the following formula which gives Total Gallonage as inch/Hour.
Where GPM = U.S. Gallons Per Minute.

See Figure 5 and Table 4.

General Formula:

$$\frac{\text{Total GPM of Area Irrigated} \times 96.3}{\text{Area Irrigated in Sq. Ft.}} = \text{Pr}$$

Formula for Square Sprinkler Pattern:

$$\frac{\text{GPM of Full Circle Sprinkler} \times 96.3}{(\text{Spacing})^2} = \text{Pr}$$

Formula for Triangular Sprinkler Pattern:

$$\frac{\text{GPM of Full Circle Sprinkler} \times 96.3}{(\text{Spacing})^2\,(.866)} = \text{Pr}$$

Irrigation Water Requirements = ET Rate + System Losses – Effective Rainfall

$$\textbf{Irrigation Efficiency} = \frac{\textbf{Water Available to Plants}}{\textbf{Total Water Applied}}$$

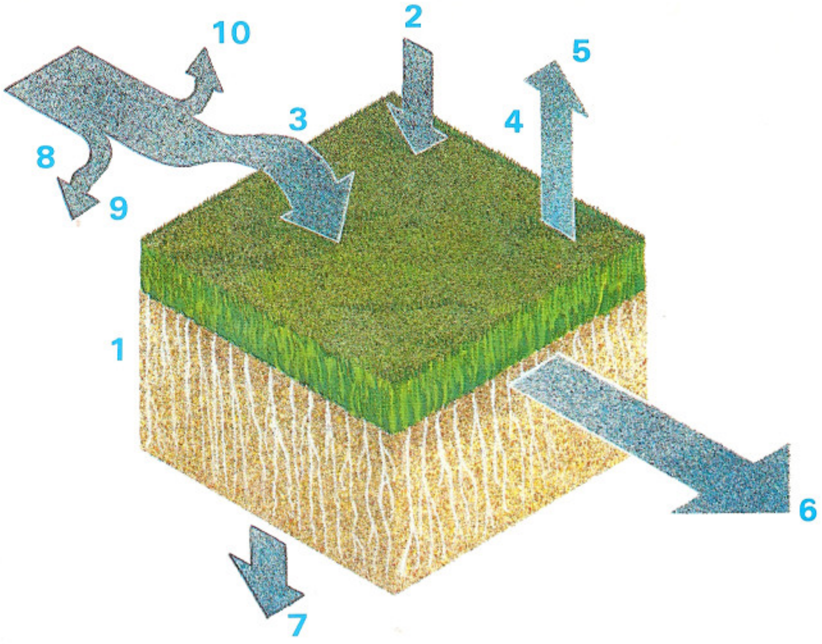


Figure 6. ***The Soil Reservoir*** (1) is the root zone of subject plants. The zone receives water from rainfall (2) and irrigation (3) and loses it from wind (4) and solar Evaporation (5). Plants power their food production by Transpiration using water and solar energy. Some water losses from runoff (6) can be minimized and recirculated but deep percolation (7), system leaks (8), pressure variations (9), improper sprinkler spacing and timing (10) are inefficient and wasteful.

Table 1: ***Average infiltration rates for various percents of slope.***

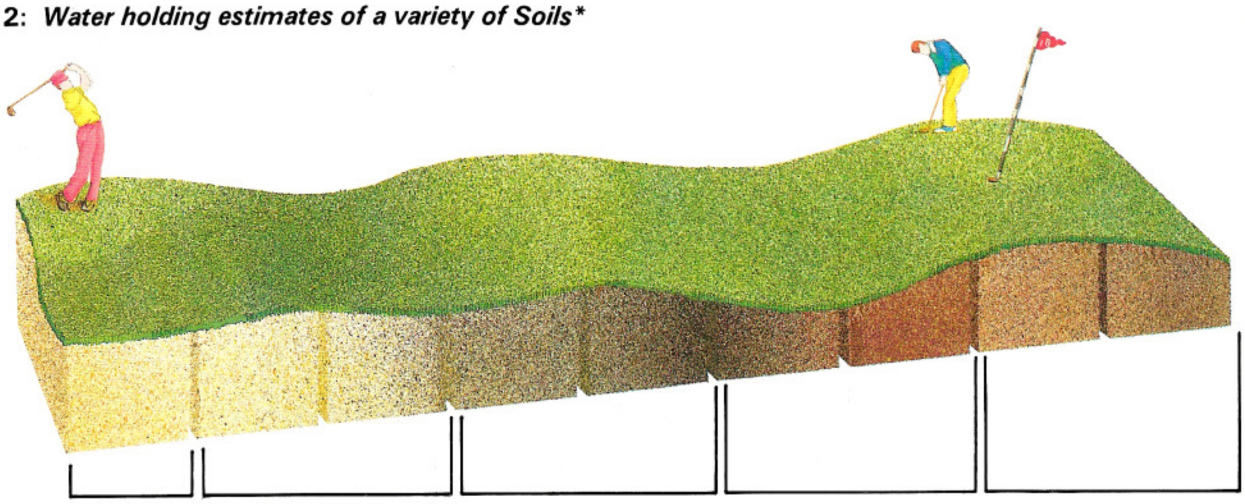
Soil Texture Type	**Percent of Slope**	0-4%	5-8%	8-12%	12-16%	Over 16%
	Infiltration Rate (Ir)					
Coarse Sand	**Inches/Hour**	1.25	1.00	.75	.50	.31
Medium Sand		1.06	.85	.64	.42	.27
Fine Sand		.94	.75	.56	.38	.24
Loamy Sand		.88	.70	.53	.35	.22
Sandy Loam		.75	.60	.45	.30	.19
Fine Sandy Loam		.63	.50	.38	.25	.16
V. Fine Sandy Loam		.59	.47	.35	.24	.15
Loam		.54	.43	.33	.22	.14
Silt Loam		.50	.40	.30	.20	.13
Silt		.44	.35	.26	.18	.11
Sandy Clay		.31	.25	.19	.12	.08
Clay Loam		.25	.20	.15	.10	.06
Silty Clay		.19	.15	.11	.08	.05
Clay		.13	.10	.08	.05	.03

Note: Rates based on full cover. These figures decrease with time and percent of cover. Derived from USDA information.

Known percent of slope and Infiltration Rate (Ir) of soil affect design and sprinkler positioning.

Available Water and its Allowable Depletion depends on soil texture. High sand content holds less, dries out fast. Clay holds more water, drains slowly.

Table 2: ***Water holding estimates of a variety of Soils****



Soil	Very Coarse Gravelly coarse	Coarse Sand Fine sand Loamy coarse sand	Moderately Coarse Loamy fine sand Sandy loam Fine sandy loam	Medium & Fine Fine sandy loam Loam Silt loam Silt sandy clay Silty clay Clay	Moderately Fine Sandy clay loam Clay loam Silty clay loam
AW - Inches/ft.	**.5″**	**1.0″**	**1.5″**	**2.0″**	**2.2″**
AW - Gallons per cubic foot	**1/3 rd.**	**2/3 rds.**	**1**	**1-1/3 rd.**	**1-2/3 rds.**

**From the Soil Conservation Service Handbook.*

Scheduling Procedures:

Based on the Water Budget Method of scheduling, the step-by-step procedure shown below will result in maximum Automatic sprinkler efficiency for a Summer growing season, April - October. The same sequence is used for Winter or can be customized by factoring-in your local conditions.

Step 1: Site Information.

Season:................ **Summer (April/October)**
Number of Days: 214
Environment:........... **Sacramento Valley, Ca.**
Topography: .... Average 6% slope
Crop:.................. **Medium Value Turf**
Rooting Depth:......... 12" (one foot)
Soil Type: .... **Very Fine Sandy Loam**
Precipitation Rate: ...... System design is .4"/Hr.

Step 2: Determine the ET Rate.

$$\text{Estimated ET Rate} = \frac{\text{Seasonal ET}}{\text{Days in Season}}$$

From Table 3 - Sacramento Valley, CA. (Hot & Dry)

$$\frac{\text{Seasonal ET } 40.7''}{\text{Number of Days } 214} = .19''/\text{Day}$$

Estimated ET Rate = .19"/Day

Step 3: Determine Irrigation Frequency.

$$\text{Irrigation Frequency} = \frac{\text{AD}}{\text{Estimated ET Rate}}$$

AW from Table 2 = 2.0"/ft.
To obtain Soil Reservoir Capacity (SRC)
Multiply by Root Depth: 1' ft. x 2.0"/ft. = 2.0" SRC
AD for Medium Value Turf assumed at 50%:
SRC 2.0" x 50% = 1.0" AD.

$$\frac{\text{AD } 1.0''}{\text{Estimated ET Rate } .19''/\text{Day}} = 5.26 \text{ Days between Irrigations}$$

Adjustment to even number of days gives:
Adjusted Irrigation frequency = 5 Days
Adjusted AD = 5 Days at .19"/Day = .95"

Step 4: Determine Water Requirement.

$$\text{Water Requirement} = \frac{\text{AD}}{\text{System Efficiency}}$$

System Efficiency from Table 4 - Hot and Dry = 70% (.70)

$$\frac{\text{AD } .95''}{\text{System Efficiency } .70} = 1.36'' \text{ Water Requirement}$$

Water Requirement = 1.36"

Step 5: Determine Station Run Time.

$$\text{Station Run Time} = \frac{\text{Water Application}}{\text{System Pr}}$$

Pr should be Less Than or Equal to Ir to minimize Runoff.
Assign Ir as maximum Water Application.
Use Ir from Table 1 for soil type and slope, as: Ir = .47"/Hr.
Therefore .47" = Water Application

$$\frac{\text{Water Application } .47''}{\text{System Pr } .4''/\text{Hr.}} = 1.175 \text{ Hrs. Run Time}$$

Station Run Time = 1.175 Hrs. or 70.5 Min.

Step 6: Determine Irrigation Cycle.

$$\text{Irrigation Cycle} = \frac{\text{Water Requirement}}{\text{Water Application}}$$

To obtain the number of times the Station must operate per day to satisfy the Water Requirement:

$$\frac{\text{Water Requirement } 1.36''}{\text{Water Appication } .47''} = 2.89 \text{ Cycles}$$

Adjust to even number = 3 Cycles per Day.

The results so far gives the Automatic Sprinkler System Schedule as:

Irrigation Frequency
to replace AD every:....... 5 Days
Station Run Time
each Cycle: .... 70.5 mins.
Irrigation Cycles
number of starts to meet
Water Requirement:....... 3 Cycles

Step 7. Adjust Schedule to Equipment.

Example: If Controllers' maximum Station Run Time is: 60 Min.
Adjust to 4 Cycles, divide Water Requirement by Cycles:

$$\text{Adjusted Water Application} = \frac{\text{Water Requirement}}{\text{Adjusted Cycles}}$$

$$\frac{\text{Water Requirement } 1.36''}{\text{Adjusted Cycles } 4} = .34'' \text{ (Water Application)}$$

$$\frac{\text{Adjusted Water Application } .34''}{\text{System Pr } .4''/\text{Hr.}} = .85 \text{ Hrs.}$$

Adjusted Station run time = .85 Hrs. or 51 Min.

Resulting in an Automatic Sprinkler System Schedule of:

Irrigation Frequency
to replace AD every:....... 5 Days
Station Run Time
each Cycle: .... 51 minutes
Irrigation Cycle
number of starts to meet
Water Requirement:....... 4 Cycles

Note: If Pr is greater than Ir, then Irrigation Cycles should be separated by 1 hour to minimize Runoff. The time interval between cycles is executed by the Controller which sequences through all other station run times before completing the remaining cycles. Elapsed time between cycles will depend upon Controller setting and specification. **See Summary - Page 9**

Table 4: ***Estimated sprinkler efficiencies by climate zone.***

Climate	*Average Efficiencies*
Low Desert	60%
High Desert	65%
Hot, Dry	70%
Moderate	75%
Cool, Humid	80%

Table 5: ***Maximum Sprinkler spacing for Wind.***

Wind Speed MPH	Square Spacing	Triangular Spacing
0 to 7	50%	55%
8 to 10	45%	50%
over 10	40%	45%

Based on Toro recommended sprinkler diameter.

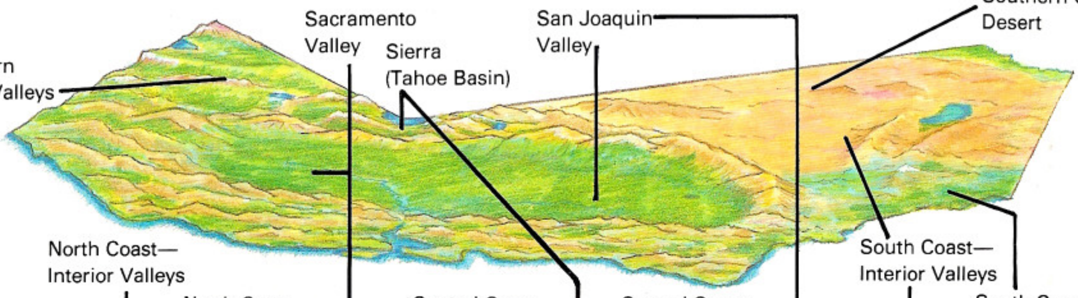
Typical controller schedules for the growing and non-growing seasons are widely spaced even in this California example.

System Designers consider prevailing wind speed essential in sprinkler spacing by determining correct precipitation pattern overlap and ensuring even water application, thus using the wind as a design tool.

Table 6: ***Sample Controller Schedule.*** *Results may be adjusted to equipment used and other variables.*

Season		Station	Operating Time	Cycles	Frequency
Summer	**April to October**	1	51 minutes	4	5 days
Winter	**November to March**	1	60 minutes	3	16 days

Table 3: ***Daily and Seasonal ET rates in California* (inches per day)***



	Northeastern Mountain Valleys	North Coast—Interior Valleys	North Coast—Coastal Valleys and Plains	Sacramento Valley	Central Coast—Coastal Valleys and Plains	Sierra (Tahoe Basin)	Central Coast—Interior Valleys	San Joaquin Valley	South Coast—Interior Valleys	South Coast—Coastal Valleys and Plains	Southern California Desert
January	0.02	0.03	0.02	0.04	0.06	—	0.05	0.03	0.06	0.06	0.09
February	0.04	0.04	0.04	0.06	0.08	—	0.08	0.06	0.09	0.09	0.13
March	0.07	0.08	0.06	0.10	0.10	—	0.11	0.10	0.11	0.10	0.19
April	0.12	0.11	0.08	0.15	0.13	0.10	0.14	0.15	0.14	0.13	0.25
May	0.16	0.16	0.11	0.19	0.15	0.13	0.18	0.21	0.16	0.14	0.33
June	0.19	0.20	0.12	0.24	0.16	0.16	0.21	0.25	0.20	0.17	0.38
July	0.26	0.23	0.11	0.26	0.17	0.20	0.22	0.25	0.22	0.18	0.37
August	0.23	0.20	0.11	0.22	0.16	0.17	0.19	0.21	0.22	0.18	0.31
September	0.16	0.15	0.09	0.17	0.13	0.13	0.16	0.16	0.17	0.15	0.28
October	0.09	0.09	0.06	0.11	0.10	0.09	0.12	0.11	0.12	0.11	0.20
November	0.03	0.04	0.04	0.05	0.07	—	0.08	0.05	0.08	0.09	0.12
December	0.02	0.02	0.02	0.03	0.05	—	0.05	0.02	0.06	0.07	0.06
Totals:											
November-March	5.1	6.3	5.3	8.5	10.7	—	10.8	7.9	11.5	12.1	17.7
April-October	37.1	34.9	20.8	40.7	30.6	30.0	37.5	40.7	37.9	32.3	65.1
Annual	42.2	41.2	26.1	49.2	41.3	—	48.3	49.0	49.4	44.4	82.2

*From Dept. of Water Resources Bulletin 113-3, except for figures for Sierra (Tahoe Basin) which are UC observations for the growing season.

Other variables in the hypothesis should be practiced. Try the same site information for Winter - 151 days in this California example. Note the changes in ET Rate; Sprinkler Efficiency; Frequency etc. Consider that factors such as Ir, Pr, soil and system will stay the same as the example. **See results in Table 6.** Apply it to your local seasons, systems and applications. Compare older systems against new installations. Extend the hypothesis to show annual dollar-savings, man-hours, etc.

Of course, the hypothesis presumes that a system has been checked for hydraulic efficiency, pressure variables and other factors. Apply a pressure drop to an idealized system, note the effect. Ask "What If?".

By using these calculation methods together with real-time observation on site, an Automatic Sprinkler System Schedule may be tailored to the sites' unique properties.

Summary:

The Water Budget Method *of Irrigation considers known and predicted factors in the environment and balances them to the components of an automatic sprinkler system, producing an efficient schedule which satisfies crop water requirements and reduces water and man-hour waste.*

It is the understanding and application of these basic principles that leads to better Water Management and successful Design. We know of examples where its application to an existing system by Landscape Superintendents has resulted in man-hour and dollar savings as high as 43% in the first year! Other examples show that because this relatively simple method was applied by the System Designer, the result was remarkably low annual operating costs in new installations using **Toro** *advanced products.*

While it is applied here for turfgrass, the Method is equally valid without modification, where rooting depths and ET Rates are available, for most landscape crops, geographic areas and seasonal variations.

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Further information which may aid you in the understanding of the subjects discussed in this edition of "The Educator Series", or on how Toro products are applied to it, is obtainable at low cost from your local Toro Distributor. To get the name, address and phone number of your local Toro Distributor, call toll-free **1-800-FOR-TORO** in the Continental United States, or **1-800-255-TORO** in California.

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