Quantifying Effective Rain in Landscape Irrigation Water Management

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Abstract

Climatologically based control systems measure evapotranspiration, yet often fail to quantify effective rainfall. Many parts of the country receive more rain than ET. For control systems to effectively manage landscape irrigation, both ET_c and effective rainfall need to be quantified.

Effective rain is the amount of rain which is useful to the plant. Several factors must be considered to quantify effective rain. Rain that falls faster than the soil can absorb may run off. Soil moisture holding capacity is limited by soil type and root depth. Soil moisture holding capacity and current moisture content limit the amount of useful rain.

This report will identify each of the factors that limit the effectiveness of rain and will offer a method to quantify rain that will be useful to plants. By implementing this process, water managers can determine when irrigation should resume after it rains to more effectively eliminate wasteful over-watering.

Key Words

Effective Rain, Saturation Allowance, Water Management, Rain, Irrigation, Moisture Balance, Run-off, Saturation, Allowed Depletion, Check Book Method, Root Depth, Root Zone Capacity, Soil Type, ET, Evapotranspiration, Smart Controller, Climate, Root Zone Storage, Field Capacity, Permanent Wilt Point, Rain Gauge, Irrigation Amount, Efficiency, Maximum Hourly Rainfall Rate, Available Water.

Introduction

The landscape irrigation industry is responding to the need to use water efficiently on two fronts; improving distribution uniformity, and providing self-adjusting controllers. The most common “smart” controllers are climate-based, which utilize weather sensors to calculate evapotranspiration (ET); the loss of water to the atmosphere by evaporation from the soil and plants. If a Smart Controller knows how much water has evaporated from the landscape, then the controller knows how much to water needs to be replaced.

Many Smart controllers measure ET and then use a rain shut-off device. Smart controllers can be smarter by measuring both ET and rain. With both measurements, a Smart controller will not irrigate during rainfall and it will know when irrigation should resume after it rains. This is where rain shut-off devices fall short; too often watering resumes sooner than needed. The result is that plants get too much water and roots remain shallow, so water is wasted and plant health is compromised.

Much of the country receives more rain than ET, so irrigation supplements rain. Rain changes more dramatically than ET. During the growing season ET may range from 0.05″ to 0.40″ per day. A rain storm can easily deliver twice that amount, but is all rain effective?

There is good science to quantify effective rain to avoid wasteful overwatering. A close look at the process also exposes steps that can be taken to increase the effectiveness of rainfall.

Concept

The soil must be seen as a reservoir. Rain and irrigation fill the soil reservoir. Reservoirs have a capacity. The capacity of the soil reservoir is based on soil type and rooting depth. The amount of water in the reservoir changes; moisture is depleted from the soil by evaporation. Rain and irrigation refill it. When the reservoir is overfilled, water runs off or soaks below the roots. Effective Rain is rain that is useful to plants.

For decades soil moisture has been estimated using the Checkbook Method of irrigation scheduling. ET “withdraws” from the “account”; rain and irrigation make “deposits. By implementing the Checkbook method with hourly resolution, rainfall can be better accounted for. A Smart control system will know to stop irrigation when it rains and will also know when irrigation should resume.

To quantify effective rain there are four areas that need to be considered:

- Measuring Rain
- Percolation vs. Run-off
- Root Zone Storage
- Moisture Balance

Measuring Rain

A common method to measure rainfall is a "tipping bucket" gauge. Rain is funneled into a bucket or cup that tips when filled to a calibrated level, typically 0.01″ or 1mm. As the bucket tips, a magnet attached to the tipping mechanism actuates a switch. The momentary switch closure is counted and logged by circuitry in a datalogger or control system. Logging resolution typically ranges from 1 to 60 minutes.

Percolation vs. Run-off

Rain will be absorbed by the soil as fast as gravity, pore space and capillary action will allow. Soil type, compaction, and organic content all have a bearing on percolation rates. Rain that falls faster than the soil can absorb will accumulate on the surface of the soil. The slope of the surface will result in the water running away from the plant making it no longer useful to the plant.

Percolation rates and precipitation rates are typically expressed in inches per hour. By comparing the percolation rate to the rainfall rate, the amount of water that can soak into the soil is quantified. Rain in excess of percolation rates can be characterized as run-off.

Soil composition and compaction affect percolation rates. The following table offers accepted ranges of soil moisture intake rates:

Percolation Rate	
Soil Type	**Inches Per Hour**
Sand/Fine Sand	1.50-3.00
Loamy Sand	1.00-2.00
Sandy Loam	.80-1.20
Loam	.40-.60
Silty Loam	.25-.40
Silt	.30-.50
Sandy Clay Loam	.10-.30
Clay Loam	.07-.25
Silty Clay Loam	.05-.12
Sandy Clay	.08-.20
Silty Clay	.05-.15
Clay	.05-.10

USDA Agricultural Research Service

Organic content and compaction are the primary variables that influence the actual percolation rate. An onsite test or visual inspection can help refine the site's percolation rate.

Root Zone Storage

Once rain is absorbed by the soil, plant roots can access this water. An extended rainstorm may result in water percolating below the root zone or running off the surface. In either case the rain is no longer useful to the plant.

The soil is like a reservoir or tank that holds water. Soil reservoir capacity is limited by pore space in the soil and root depth.

Consider this example. Compare the soil reservoir to a glass of water. How much water can be drunk from the glass through a straw? It depends on how much ice is in the glass; ice represents soil particles. Particle size, shape and compaction affect the capacity of the remaining pore space. It also depends on how far the straw goes in the glass; a straw represents the roots. The reservoir capacity will increase as the roots go deeper.

Both the capacity and current soil moisture content must be considered to quantify how much rain will be held in the root zone. Before going any further, a review of the terms used to describe soil moisture content may be helpful.

> **Saturation** – All open pore space in the soil is filled with water. Gravity drains water from a saturated condition. Depending on soil type, drainage typically stops within 2-3 days after a saturating rain storm.

Field Capacity – The soil is considered to be at Field Capacity once the moisture held in soil after excess rain or irrigation stops draining. Visualize water draining from a sponge when pulled from a bucket, when the draining stops, there is still water held in the sponge. A significant amount of water is held in the soil by capillary force.

Permanent Wilt Point – The point where the plant can no longer draw water from the dried soil, the plant will either die or go into a dormant state.

Soil moisture holding capacities vary based on soil type, compaction and organic content. Available Water is defined as the amount of water in the soil between "Field Capacity" and Permanent Wilt Point. Soil charts express holding capacity as Available Water in inches of water per inch or per foot of soil. The following chart shows Available Water in inches per inch of soil.

Available Water	
Soil Type	**Inch / Inch ***
Sand	.03--.07
Loamy Sand	.06--.08
Sandy Loam	.11--.13
Loam	.16--.18
Silty Loam	.19--.21
Silt	.16--.18
Sandy Clay Loam	.14--.16
Clay Loam	.19--.21
Silty Clay Loam	.19--.21
Sandy Clay	.15--.17
Silty Clay	.15--.17
Clay	.14--.16

* National Engineering Handbook, Part 652 Irrigation Guide

To determine the Root Zone Storage capacity, a core sample should be pulled to examine the length of the roots. When doing this inspection, remember roots are very fragile and very small, give the roots the benefit of the doubt, roots are often deeper than perceived with a simple visual inspection.

Root Zone Storage capacity can be estimated by taking Available Water (inch/inch) x Root Depth. For example if we assume the mid-range of the Available Water in a Sandy Clay Loam Soil (0.15" per inch) and turf with a 6" root depth the Root Zone Storage is 0.90". (6 x 0.15 = 0.90)

In addition to the storage identified by using the Available Water table, there is short term "storage" when the soil becomes saturated. Once a storm is over, water in a saturated condition will begin to drain and evaporate until it reaches Field Capacity.

Drainage may take several days. During this time this water is available to the plants and will evaporate from the soil.

The following chart demonstrates the amount of additional water that can saturate a soil beyond Field Capacity.

Mosisture as % of Volume		
Soil Type	**Field Capcity**	**Saturation**
Sand/Fine Sand	14%	37%
Loamy Sand	15%	38%
Sandy Loam	20%	42%
Loam	27%	46%
Silty Loam	28%	46%
Silt	30%	44%
Sandy Clay Loam	29%	44%
Clay Loam	32%	50%
Silty Clay Loam	35%	52%
Sandy Clay	32%	50%
Silty Clay	43%	54%
Clay	45%	54%

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Soil conditions and root depth can be used to quantify a Saturation Allowance or the amount of extra water the soil can hold beyond Field Capacity. The concept of a Saturation Allowance is not commonly recognized. There is no disagreement regarding the difference between Field Capacity and Saturation. The above sited USDA table provides a means to quantity this value. This value can be estimated based on the Available Water at Field Capacity and Moisture as a % of Volume. The following table combines Moisture as a percent of Volume data with Available Water at Field Capacity to provide an estimate of Maximum Saturation Allowance.

Soil Type	Average Available Water at Field Capacity - Inch / Inch	Mosisture as % of Volume (PER USDA)		Total Water at Saturation - Inch / Inch	Maximum Saturation Allowance	
		Field Capcity	Saturation		Inch / Inch	Percent of Available Water
Sand	0.05	14%	37%	0.13	0.08	164%
Loamy Sand	0.07	15%	38%	0.18	0.11	153%
Sandy Loam	0.11	20%	42%	0.23	0.12	110%
Loam	0.16	27%	46%	0.27	0.11	70%
Silty Loam	0.2	28%	46%	0.33	0.13	64%
Silt	0.2	30%	44%	0.29	0.09	47%
Sandy Clay Loam	0.15	29%	44%	0.23	0.08	52%
Clay Loam	0.16	32%	50%	0.25	0.09	56%
Silty Clay Loam	0.18	35%	52%	0.27	0.09	49%
Sandy Clay	0.12	32%	50%	0.19	0.07	56%
Silty Clay	0.15	43%	54%	0.19	0.04	26%
Clay	0.14	45%	54%	0.17	0.03	20%

However, this table does NOT consider the time it takes for water to drain from a saturated condition. I have not found any research that provides a means to definitively quantity a practical means to quantify a Saturation Allowance. Research has shown drainage time ranges from 1 to 3 days depending on soil conditions. In recognizing this condition exists, for the last several years I have been advising water managers to apply a Saturation Allowance when implementing a Moisture Balance. I have recommended and used 25% of Available Water as a means to estimate a Saturation Allowance. Limiting the value to 25% of Available Water provides a generous allowance for drainage time. Water managers may change the Saturation Allowance after observing site conditions after it rains. Feedback from projects with automated water management, using a 25% Saturation Allowance, has been very positive. All indications are this value has resulted in effectively delaying watering after it rains.

There should be no question there is a difference in soil moisture content between Field Capacity and Saturation. Water held in this state is available to the plant and can evaporate. Current methodology suggests any moisture beyond Field Capacity should be characterized as run-off. This approach results in premature resumption of irrigation. Implementing a Saturation Allowance in the Checkbook method of irrigation management will increase the effectiveness of rain.

Moisture Balance

The storm is over, the sun comes out and the landscape begins to dry because of evaporation and transpiration. The question is; when should irrigation resume after it rains? - Once soil moisture is depleted by ET to an allowable level.

The goal of an effective water manager is to irrigate once the soil dries out to a manageable level, and return it to Field Capacity; not irrigate to keep the soil saturated. When a soil is saturated, oxygen is replaced with water; all the pore space is filled. Plant roots need air; too much water forces roots to remain shallow in order to breathe.

The irrigation industry teaches the principle of Allowed Depletion. The soil should dry out to an allowable level between irrigation cycles. Using the Allowed Depletion method provides an accurate process to determine irrigation frequency and when irrigation should resume after it rains.

The most effective way to implement the principle of Allowed Depletion is by using the Checkbook Method of Irrigation Scheduling. This method has been used for decades as a means of determining irrigation frequency and amount. The process compares ET to a “withdrawal” from the “Checking Account” and irrigation and rain as a “deposit”. Once the balance reaches Allowed Depletion irrigation is needed.

Traditionally the Checkbook is implemented with daily calculations. ASCE recommends hourly ET calculations. When the moisture balance is calculated hourly, using

Checkbook method, Effective Rain can be easily accounted for. The math is simple, each hour ET is subtracted from the "balance," effective rain and irrigation is added. The Checkbook must be calculated respecting site specific limits. Site conditions such as soil type and root depth need to be used to define the limits of the "account" or soil reservoir. There are a number of variables that affect these limits.

Maximum Hourly Rain – Soil conditions affect percolation rates. Soil tables are a beginning point to determine the maximum amount of rain the soil can absorb.

Root Zone Capacity - Soil type and root depth give us enough information to estimate the Root Zone Capacity, also referred to as Available Water. (See Available Water chart).

Allowed Depletion - Horticulturists have indicated the best management practice is to deplete soil moisture to an allowed depletion level of 30% to 60% of Available Water. A 50% Managed Allowed Depletion is a well accepted standard. In other words, soil moisture should be depleted to half of the available water before irrigation should occur.

Optimum Irrigation Amount - The purpose of irrigation is to refill the soil reservoir to Field Capacity. In a perfect world the optimum irrigation amount is equal to the amount of Allowed Depletion. The actual irrigation amount may vary based on when watering occurs and the availability of water.

Moisture Balance Reference – The Checkbook needs to be referenced to the soil moisture content. Using a value of zero as equal to the point of Allowed Depletion provides a logical reference. Once soil moisture is depleted to "0" then it is time to irrigate. Using a reference of zero may imply the soil is bone dry, which is not true; it does suggest irrigation is needed. The soil offers its own "overdraft protection," if zero is equal to the point of Allowed Depletion there is still additional moisture in the soil. Remember, when using a 50% Managed Allowed Depletion only half of the Available Water has been depleted.

Accepting a value of 0 as equal to a depleted soil moisture level means that when the soil has reach Field Capacity the moisture balance is equal to Allowed Depletion.

Moisture Balance Limits – The Checkbook needs maximum and minimum limits referenced to soil moisture conditions.

A minimum limit to a moisture balance is Permanent Wilt Point which equates to 0 minus Allowed Depletion.

The maximum limit of a soil moisture balance is Saturation. Once the soil is saturated, water will accumulate on the surface and may run off. A Saturation Allowance provides a water manager the means to account for additional water that will soak in and saturate the soil. A maximum limit to the moisture level would be equal to the Allowed Depletion value plus a Saturation Allowance.

With capacities and constraints set within the Checkbook and moisture balance limits defined, data can now be applied to a mathematical model of soil moisture content.

There are three inputs to the Checkbook; rain and irrigation make “deposits,” and “withdrawals” come as a result of ET. ET is a measurement of the amount of water lost to the atmosphere as a result of evaporation and transpiration. A measurement of climate conditions including, solar radiation, temperature, wind and humidity are used to calculate a reference ET value, referred to as ET_o. The ET formula is based on a reference crop. By multiplying a crop coefficient (K_c) to ET_o, a more exact estimate of plant evaporation may be applied to the Checkbook ($ET_o \times K_c = ET_c$).

In summary these are the formulas that have been described:

Root Zone Capacity (RZC)

RZC = AW x RD

Where:

AW = Available water in inches per inch of soil
RD = Root Zone Depth in Inches

Allowed Depletion (AD)

AD = RZC x MAD%

Where:

RZC = Root Zone Capacity (inches)
MAD% = Management Allowed Depletion Percent (decimal value)

Maximum Moisture Balance (MAX)

MAX = AD + SA

Where:

AD = Allowed Depletion
SA = Saturation Allowance

Minimum Moisture Balance (MIN)

MIN = 0 - (RZC x (1 - MAD%))

Where:

RZC = Root Zone Capacity (inches)
MAD% = Management Allowed Depletion Percent (decimal value)

The following is an example of an implementation of the Checkbook method of modeling soil moisture with a set of variables:

Variables

Soil Type	Sandy Clay Loam
Available Water in/in	0.11
Root Depth - Inches	8.00
Managed Allowed Depletion	50%
Saturation Allowance	0.22
Maximum Hourly Rain	0.35

Resulting Limits

Root Zone Capactity	0.88
Allowed Depletion	0.44
Optimum Irrigation Amount	0.44
Moisture Balance Limit	0.66

Date	ETc	Total Rain	Rain Limited by Max Hourly	Effective Rain	Irrigation	Moisture Balance
7/1/2006 3:00:00 AM	0.005	0.00	0.00	0.00	0.00	0.01
7/1/2006 4:00:00 AM	0.005	0.00	0.00	0.00	0.44	0.44
7/1/2006 5:00:00 AM	0.000	0.00	0.00	0.00	0.00	0.44
7/1/2006 6:00:00 AM	0.000	0.00	0.00	0.00	0.00	0.44
7/1/2006 7:00:00 AM	0.001	0.00	0.00	0.00	0.00	0.44
7/1/2006 8:00:00 AM	0.003	0.00	0.00	0.00	0.00	0.44
7/1/2006 9:00:00 AM	0.005	0.00	0.00	0.00	0.00	0.43
7/1/2006 10:00:00 AM	0.006	0.00	0.00	0.00	0.00	0.42
7/1/2006 11:00:00 AM	0.013	0.00	0.00	0.00	0.00	0.41
7/1/2006 12:00:00 PM	0.016	0.00	0.00	0.00	0.00	0.40
7/1/2006 1:00:00 PM	0.008	0.00	0.00	0.00	0.00	0.39
7/1/2006 2:00:00 PM	0.002	0.00	0.00	0.00	0.00	0.39
7/1/2006 3:00:00 PM	0.002	0.00	0.00	0.00	0.00	0.38
7/1/2006 4:00:00 PM	0.002	0.02	0.02	0.02	0.00	0.40
7/1/2006 5:00:00 PM	0.003	0.03	0.03	0.03	0.00	0.43
7/1/2006 6:00:00 PM	0.003	0.41	0.35	0.23	0.00	0.66
7/1/2006 7:00:00 PM	0.001	0.01	0.01	0.00	0.00	0.66
7/1/2006 8:00:00 PM	0.001	0.00	0.00	0.00	0.00	0.66
7/1/2006 9:00:00 PM	0.000	0.00	0.00	0.00	0.00	0.66
		0.47		0.29		
				61%		

There are several lessons that can be learned from this example. Notice irrigation occurred at 4:00 in the morning. Soil moisture was returned to Field Capacity. Rain began later in the afternoon. Two factors limited the amount of Effective Rain. 1) The rainfall rate at 6:00 PM exceeded the soil intake rate, so only 0.35″ of rain was accepted. 2) Also note that the soil reservoir was nearly full. The rain at 6:00 PM saturated the soil. The total rainfall was 0.47″ but Effective Rain was only 0.29″ or 61%.

Examples

The next four pages are reports calculated by implementing the Checkbook method of irrigation scheduling with hourly data for a 30 day period. The data is actual recorded data from the locations noted. Changes were made to site variables to demonstrate the effects. To make it easier to see the results, the calculations have been compiled into a daily summary. A graph of the hourly Moisture Balance is included to provide another method of examining the results.

Rain storms can come with different intensities and durations. Example 1 provides an example of a wet cycle followed by a dry period. ET rates during the rain are much lower because of cloud cover, higher humidity and cooler temperatures. Notice in example 1 irrigation was delayed for nearly a week after the bulk of the storm passed. During that time it was cool, overcast and very light rain fell on several days.

Example 2 shows what can happen with much heavier rains. The percent of Effective Rain is much less than in Example 1. In this mid-summer example it rained 14 days. There were only 5 days when irrigation was needed during the entire month; the Checkbook Method correctly identified the appropriate 5 days.

Look closely at Example 3 and 4, the only one change was made to the setup. Example 3 has a 3” root depth, which limits Allowed Depletion and the Saturation Allowance. Example 4 has a 6” root depth, which results in an increased Allowed Depletion and Saturation Allowance. Notice how the watering frequency and Effective Rain are affected by this one change.

Example 1 Aurora, CO

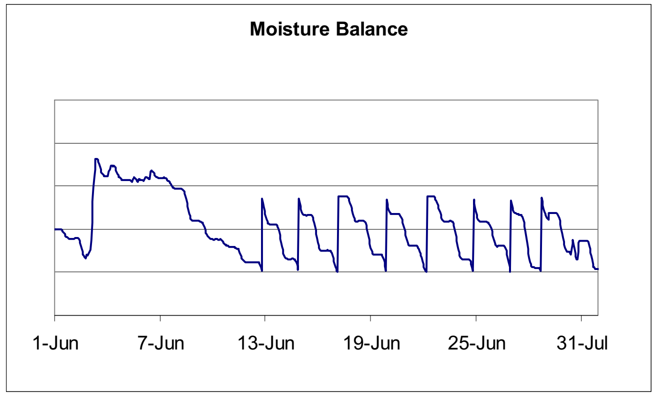
Rain Fall Efficiency: 99%

Variables

Soil Type	Sandy Clay Loam
Available Water in/in	0.11
Root Depth - Inches	8.00
Managed Allowed Depletion	50%
Saturation Allowance	0.22
Maximum Hourly Rain	0.35

Resulting Limits

Root Zone Capactity	0.88
Allowed Depletion	0.44
Optimum Irrigation Amount	0.44
Moisture Balance Limit	0.66



Moisture Balance

Date	ET	Total Rain	Effective Rain	Irrigation	Moisture Balance
6/1/2008	0.06	0.00	0.00	0.00	0.19
6/2/2008	0.12	0.04	0.04	0.00	0.11
6/3/2008	0.12	0.58	0.57	0.00	0.56
6/4/2008	0.09	0.07	0.07	0.00	0.54
6/5/2008	0.06	0.06	0.06	0.00	0.53
6/6/2008	0.07	0.08	0.08	0.00	0.55
6/7/2008	0.07	0.01	0.01	0.00	0.48
6/8/2008	0.19	0.00	0.00	0.00	0.30
6/9/2008	0.11	0.00	0.00	0.00	0.19
6/10/2008	0.06	0.02	0.02	0.00	0.15
6/11/2008	0.10	0.01	0.01	0.00	0.06
6/12/2008	0.14	0.00	0.00	0.44	0.36
6/13/2008	0.21	0.00	0.00	0.00	0.15
6/14/2008	0.19	0.00	0.00	0.44	0.40
6/15/2008	0.21	0.00	0.00	0.00	0.20
6/16/2008	0.15	0.00	0.00	0.00	0.05
6/17/2008	0.13	0.00	0.00	0.44	0.36
6/18/2008	0.20	0.00	0.00	0.00	0.16
6/19/2008	0.21	0.00	0.00	0.44	0.40
6/20/2008	0.16	0.00	0.00	0.00	0.24
6/21/2008	0.17	0.00	0.00	0.00	0.07
6/22/2008	0.16	0.00	0.00	0.44	0.35
6/23/2008	0.19	0.00	0.00	0.00	0.16
6/24/2008	0.22	0.00	0.00	0.44	0.37
6/25/2008	0.16	0.00	0.00	0.00	0.22
6/26/2008	0.21	0.00	0.00	0.00	0.00
6/27/2008	0.30	0.00	0.00	0.44	0.14
6/28/2008	0.24	0.00	0.00	0.44	0.34
6/29/2008	0.18	0.04	0.04	0.00	0.20
6/30/2008	0.28	0.26	0.26	0.00	0.18
Total	4.74	1.17	1.16	3.52	
			99%	8 Water Days	

Example 2 Houston, TX

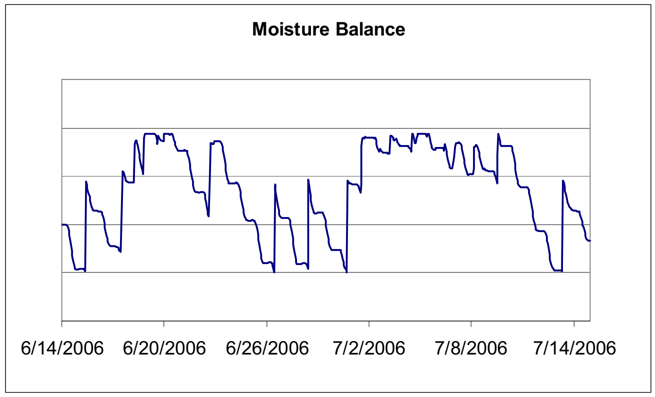
Rain Fall Efficiency: 36%

Variables

Soil Type	Clay Loam
Available Water in/in	0.16
Root Depth - Inches	6.00
Managed Allowed Depletion	50%
Saturation Allowance	0.24
Maximum Hourly Rain	0.20

Resulting Limits

Root Zone Capactity	0.96
Allowed Depletion	0.48
Optimum Irrigation Amount	0.48
Moisture Balance Limit	0.72



Moisture Balance

Date	ET	Total Rain	Effective Rain	Irrigation	Moisture Balance
6/14/2006	0.23	0.00	0.00	0.00	0.02
6/15/2006	0.18	0.00	0.00	0.48	0.32
6/16/2006	0.18	0.00	0.00	0.00	0.14
6/17/2006	0.09	1.13	0.42	0.00	0.47
6/18/2006	0.18	0.48	0.43	0.00	0.72
6/19/2006	0.10	0.94	0.06	0.00	0.68
6/20/2006	0.11	0.40	0.06	0.00	0.63
6/21/2006	0.22	0.00	0.00	0.00	0.42
6/22/2006	0.14	0.60	0.40	0.00	0.68
6/23/2006	0.22	0.00	0.00	0.00	0.46
6/24/2006	0.19	0.00	0.00	0.00	0.27
6/25/2006	0.22	0.00	0.00	0.00	0.05
6/26/2006	0.25	0.00	0.00	0.48	0.28
6/27/2006	0.24	0.00	0.00	0.00	0.05
6/28/2006	0.22	0.00	0.00	0.48	0.31
6/29/2006	0.19	0.00	0.00	0.00	0.12
6/30/2006	0.14	0.00	0.00	0.48	0.46
7/1/2006	0.07	0.55	0.31	0.00	0.70
7/2/2006	0.11	0.03	0.03	0.00	0.62
7/3/2006	0.08	0.11	0.11	0.00	0.65
7/4/2006	0.09	0.59	0.16	0.00	0.72
7/5/2006	0.11	1.34	0.04	0.00	0.65
7/6/2006	0.15	0.07	0.07	0.00	0.57
7/7/2006	0.16	0.10	0.10	0.00	0.51
7/8/2006	0.14	0.16	0.16	0.00	0.53
7/9/2006	0.14	0.68	0.26	0.00	0.66
7/10/2006	0.21	0.00	0.00	0.00	0.44
7/11/2006	0.23	0.00	0.00	0.00	0.22
7/12/2006	0.20	0.00	0.00	0.00	0.01
7/13/2006	0.17	0.00	0.00	0.48	0.32
7/14/2006	0.16	0.00	0.00	0.00	0.16
Total	5.09	7.18	2.61	2.40	
			36%	5	Water Days

Example 3   Logan, UT

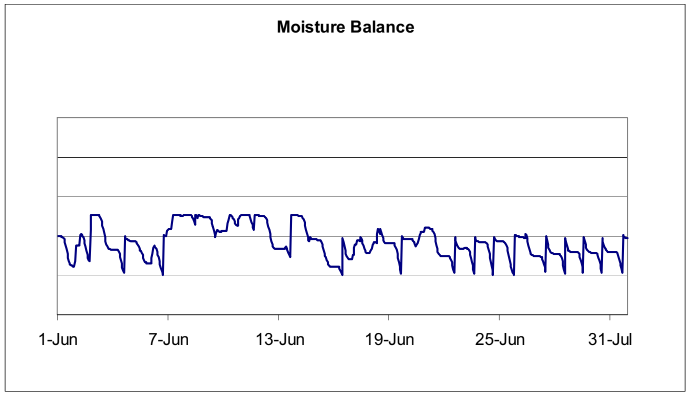
Rain Fall Efficiency: 45%

Variables

Soil Type	Silty Clay Loam
Available Water in/in	0.17
Root Depth - Inches	3.00
Managed Allowed Depletion	50%
Saturation Allowance	0.13
Maximum Hourly Rain	0.35

Resulting Limits

Root Zone Capactity	0.51
Allowed Depletion	0.26
Optimum Irrigation Amount	0.26
Moisture Balance Limit	0.38



Moisture Balance

Date	ET	Total Rain	Effective Rain	Irrigation	Moisture Balance
6/1/2009	0.19	0.03	0.03	0.00	0.09
6/2/2009	0.18	1.37	0.47	0.00	0.38
6/3/2009	0.22	0.00	0.00	0.00	0.16
6/4/2009	0.20	0.00	0.00	0.26	0.22
6/5/2009	0.15	0.01	0.01	0.00	0.08
6/6/2009	0.19	0.14	0.14	0.26	0.28
6/7/2009	0.06	0.97	0.16	0.00	0.38
6/8/2009	0.13	0.55	0.12	0.00	0.37
6/9/2009	0.15	0.06	0.06	0.00	0.28
6/10/2009	0.08	0.38	0.18	0.00	0.38
6/11/2009	0.11	0.39	0.11	0.00	0.38
6/12/2009	0.21	0.00	0.00	0.00	0.17
6/13/2009	0.09	0.33	0.30	0.00	0.38
6/14/2009	0.18	0.03	0.03	0.00	0.23
6/15/2009	0.17	0.00	0.00	0.00	0.06
6/16/2009	0.21	0.00	0.00	0.26	0.10
6/17/2009	0.13	0.17	0.17	0.00	0.15
6/18/2009	0.14	0.20	0.20	0.00	0.20
6/19/2009	0.23	0.00	0.00	0.26	0.23
6/20/2009	0.07	0.15	0.15	0.00	0.30
6/21/2009	0.18	0.00	0.00	0.00	0.12
6/22/2009	0.20	0.00	0.00	0.26	0.17
6/23/2009	0.22	0.00	0.00	0.26	0.21
6/24/2009	0.25	0.00	0.00	0.26	0.21
6/25/2009	0.22	0.00	0.00	0.26	0.25
6/26/2009	0.17	0.04	0.04	0.00	0.12
6/27/2009	0.24	0.00	0.00	0.26	0.14
6/28/2009	0.24	0.00	0.00	0.26	0.15
6/29/2009	0.26	0.00	0.00	0.26	0.14
6/30/2009	0.25	0.00	0.00	0.26	0.15
7/31/2009	0.17	0.00	0.00	0.26	0.24
Total	5.49	4.82	2.17	3.32	
			45%	13 Water Days	

Example 4 Logan, UT

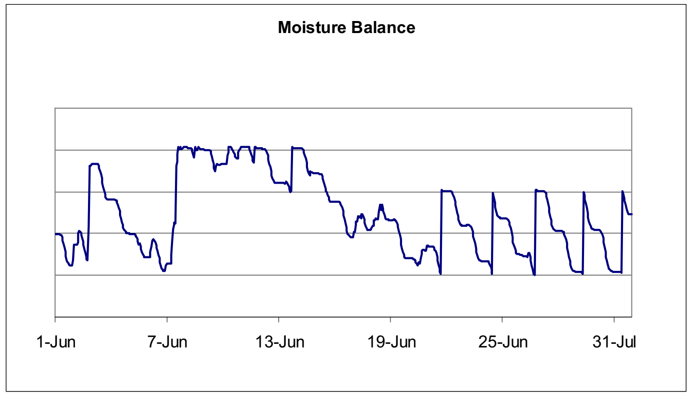
Rain Fall Efficiency: 63%

Variables

Soil Type	Silty Clay Loam
Available Water in/in	0.17
Root Depth - Inches	6.00
Managed Allowed Depletion	50%
Saturation Allowance	0.26
Maximum Hourly Rain	0.35

Resulting Limits

Root Zone Capactity	1.02
Allowed Depletion	0.51
Optimum Irrigation Amount	0.51
Moisture Balance Limit	0.77



Moisture Balance

Date	ET	Total Rain	Effective Rain	Irrigation	Moisture Balance
6/1/2009	0.19	0.03	0.03	0.00	0.09
6/2/2009	0.18	1.37	0.76	0.00	0.67
6/3/2009	0.22	0.00	0.00	0.00	0.45
6/4/2009	0.20	0.00	0.00	0.00	0.25
6/5/2009	0.15	0.01	0.01	0.00	0.11
6/6/2009	0.19	0.14	0.14	0.00	0.06
6/7/2009	0.06	0.97	0.77	0.00	0.77
6/8/2009	0.13	0.55	0.12	0.00	0.75
6/9/2009	0.15	0.06	0.06	0.00	0.67
6/10/2009	0.08	0.38	0.18	0.00	0.77
6/11/2009	0.11	0.39	0.11	0.00	0.76
6/12/2009	0.21	0.00	0.00	0.00	0.55
6/13/2009	0.09	0.33	0.30	0.00	0.76
6/14/2009	0.18	0.03	0.03	0.00	0.61
6/15/2009	0.17	0.00	0.00	0.00	0.44
6/16/2009	0.21	0.00	0.00	0.00	0.23
6/17/2009	0.13	0.17	0.17	0.00	0.27
6/18/2009	0.14	0.20	0.20	0.00	0.33
6/19/2009	0.23	0.00	0.00	0.00	0.10
6/20/2009	0.07	0.15	0.15	0.00	0.18
6/21/2009	0.18	0.00	0.00	0.51	0.50
6/22/2009	0.20	0.00	0.00	0.00	0.30
6/23/2009	0.22	0.00	0.00	0.00	0.08
6/24/2009	0.25	0.00	0.00	0.51	0.34
6/25/2009	0.22	0.00	0.00	0.00	0.12
6/26/2009	0.17	0.04	0.04	0.51	0.51
6/27/2009	0.24	0.00	0.00	0.00	0.26
6/28/2009	0.24	0.00	0.00	0.00	0.02
6/29/2009	0.26	0.00	0.00	0.51	0.27
6/30/2009	0.25	0.00	0.00	0.00	0.02
7/31/2009	0.17	0.00	0.00	0.51	0.37
Total	5.49	4.82	3.06	2.55	
			63%		5 Water Days

Observations

There are a number of lessons that can be learned and conclusions drawn from these four examples.

Rain fall amounts are sporadic; in these examples daily rainfall amounts range from 0 to 1.37″. During the same period ET ranges from only 0.06″ to 0.26″. Rain can be a higher variable and needs to be properly accounted for to effectively manage irrigation. What matters to the plant is the actual water that is available to it.

A simple percentage applied to total rainfall is not an accurate method for quantifying Effective Rain. Example 1 and 2 clearly demonstrate the percent of Effective Rain varies. Rainfall rate, soil conditions, root zone capacity, and soil moisture content when it begins to rain all affect how much rain is useful to plants.

The single most important factor that affects how much rain becomes effective is the Root Zone Storage Capacity. This is apparent when comparing example 3 and 4. Both examples use the same ET and rain. The only change to example 4 was root depth. Changing the root depth increased the capacity of the root zone storage; 23% less water was needed for irrigation because the soil could hold more rain.

A close look at the moisture balance prior to a rain storm reveals another factor that affects the amount of effective rain. When the moisture balance is near allowed depletion then there is more room in the soil to hold the water. The opposite is also true, if irrigation had just occurred prior to the rain; the soil reservoir is already full, not leaving much room for rain.

In looking at the data from these examples most rainfall rates did not exceed soil intake rates. But, occasionally a heavy storm did occur, demonstrating the importance of ignoring rainfall values that exceed soil intake rates.

Increasing Effective Rain

Rain must have a place to go. If the soil reservoir was recently filled by irrigation or rain, there may not be much room left in the reservoir to hold the rain. Soil moisture content when a storm begins limits the amount of Effective Rain. If rain is in the forecast, turning irrigation off will leave room in the soil reservoir for a coming storm.

Irrigation and horticultural management practices can promote a deeper root system which increases the soil reservoir capacity. More rain is effective because it can be stored in the root zone. Deep, less frequent watering will promote deeper roots. Better soil preparation and aeration can also increase root depth.

Rain shut-off devices do not measure rain. After a heavy rain, a shut-off device allows irrigation to resume sooner than needed. Automated control systems should measure rain and maintain a soil moisture balance using the Checkbook method of irrigation management.

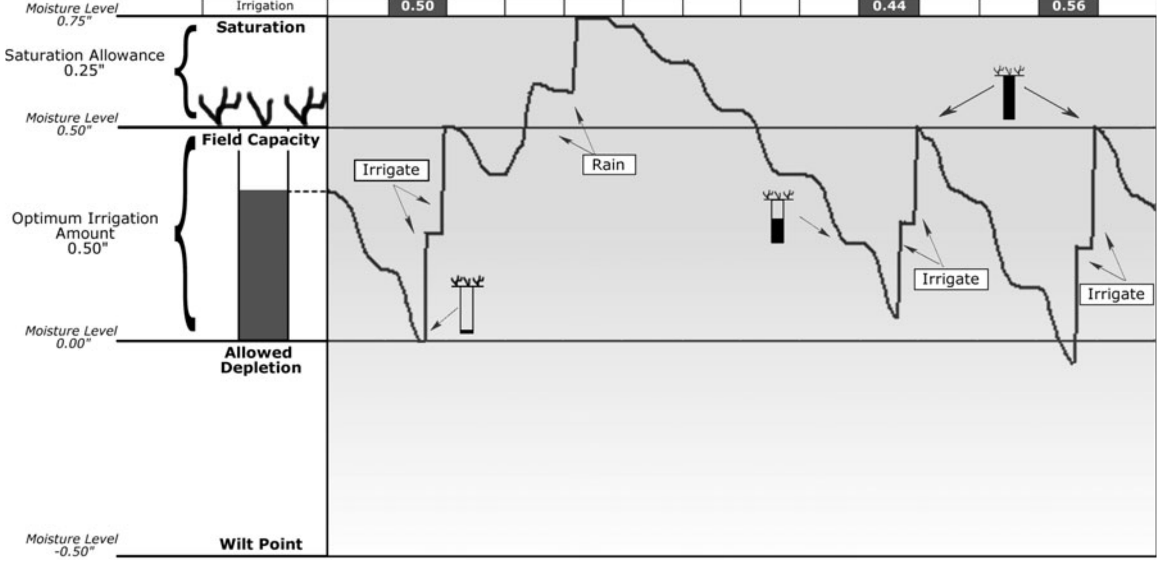
When tight soil conditions limit soil intake rates, adding mulch, cultivating and aerating the soil or adding soil amendments can loosen the soil to improve permeability.

Summary

This example demonstrates the affects of implementing the presented principles. Site specific soil reservoir capacities were defined. Soil moisture is modeled using the Checkbook Method. Two days of rain resulted in a delay in irrigation for six days.

Irrigation Moisture Balance

	Day 1		Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Evaporation (ET)	0.18	0.17	0.11	0.08	0.09	0.08	0.11	0.15	0.16	0.17	0.17	0.20	0.19	0.18
Rain				0.28	1.28									
Irrigation		0.50								0.44			0.56	



Hourly ET_c and rainfall measurements implemented in the Checkbook method of irrigation management and the application of a Saturation Allowance provide the means to improve automated water management. Rain is more accurately accounted for, which reduces the amount of water needed for irrigation.

Conclusions

- In a majority of the country measuring rain is as important as measuring ET.
- Effective rain cannot be determined by taking a percentage of total rain.
- Effective rain can be quantified by measuring rain and implementing an hourly moisture balance model using the Checkbook method of irrigation management.
- By quantifying Effective Rain, a control system can delay irrigation after it rains to avoid unnecessary watering.
- With proper management rainfall effectiveness can be improved.
- Roots need a balance of both air and water. When watering is delayed until soil moisture reach allowed depletion, air is drawn into the root zone. Landscapes health improves when soil moisture is managed properly.
- Water and money can be saved with improved irrigation control that considers Effective Rain to reduce wasteful overwatering.

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