Irrigation Scheduling

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Why do we care?

Over application of water

- Leads to the waste of
  - water
  - energy
  - chemicals
  - money
  - may lead to the contamination of ground and surface waters.
  - leaching of fertilizers past the root zone
  - water logging
  - lower crop yields.

Under-application of water

- Leads to
  - crop water stress
  - Reduced crop yield
  - loss of revenue to the grower

How much money are we talking about?

	Relative Irrigation Applied						
	0.4	0.5	0.8	1.0	1.3	1.5	1.8
Cultivo*	**$ Lost / Cuerda**						
Gandules	47	32	10	0	12	35	69
Pepinillo	111	76	25	0	15	56	124
Repollo	256	174	57	0	21	103	247
Sandia	293	199	65	0	23	114	277
Platanos y Guineos, Plantilla	318	216	71	0	24	122	299
Calabaza	390	265	87	0	27	146	359
Cebolla	543	369	121	0	34	195	490
Pimiento	578	393	129	0	36	206	519
Barenjena	757	514	169	0	44	264	670
Platanos y Guineos, Reton~o	1,006	684	225	0	76	388	945
Melon, Cantaloupe y Honeydew	1,027	698	229	0	56	352	899
Raices y Tuberculos	1,041	707	232	0	57	356	911

*Based model budget data from the *Conjunto Tecnológico, UPR Experment Station*

Maintain soil water between θ_{FC} and θ_t

Gravimetric Soil Sampling

Time Domain Reflectometry

TDR

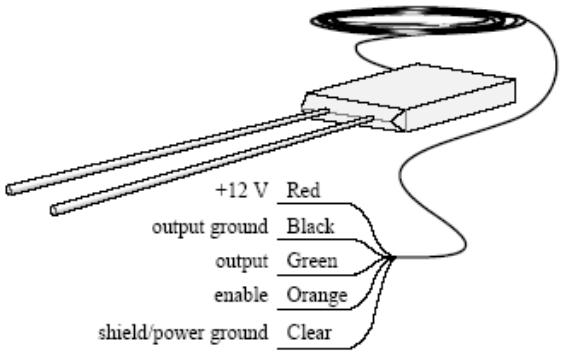
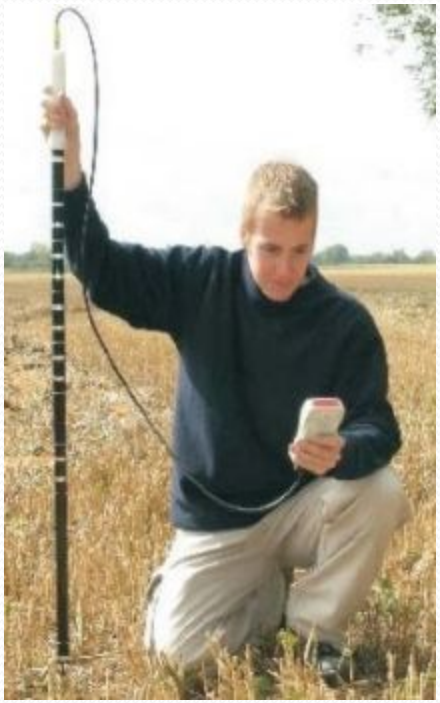
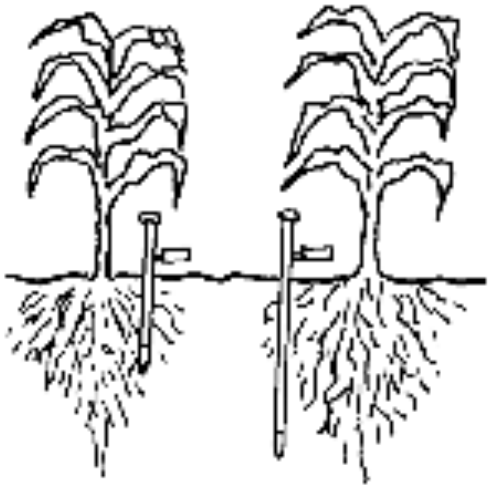


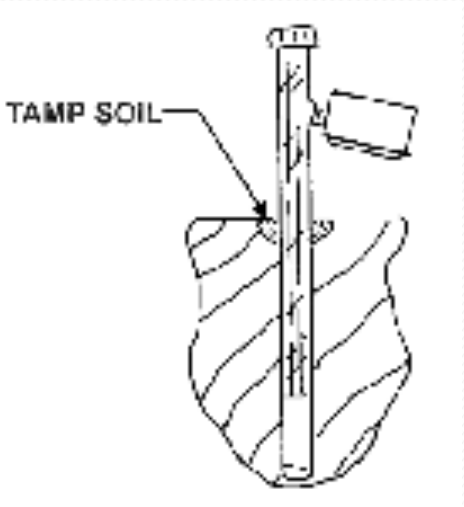
FIGURE 1. Water Content Reflectometer

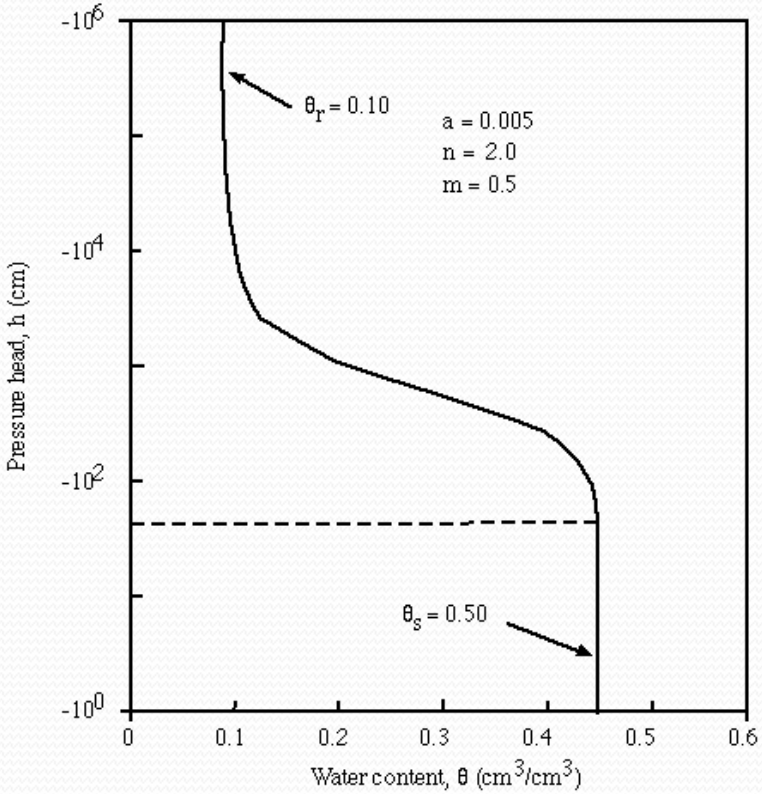
Capacitance Method



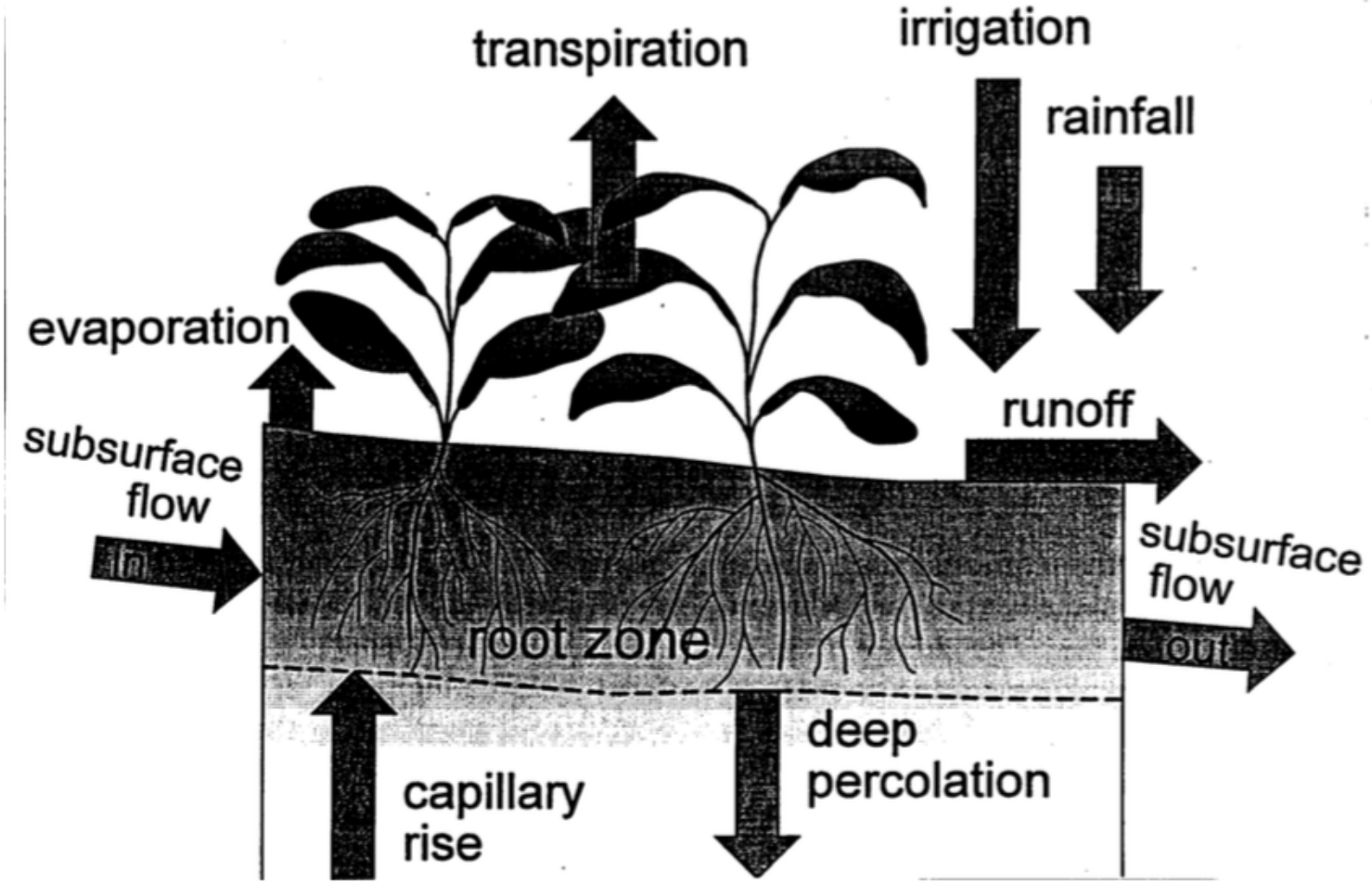
Tensiometers







Soil Water Balance



Water Balance Method

$$\theta_{t2} = R + Irr - RO - ET_{c\ adj} - PERC + \theta_{t1}$$

θ_{t2} = volumetric moisture content at time 2

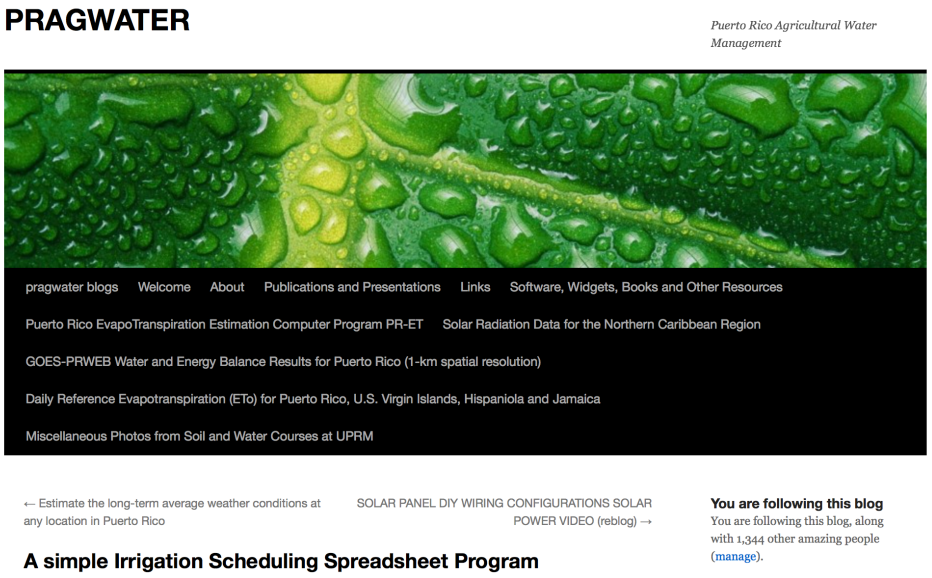
θ_{t1} = volumetric moisture content at time 1

R = effective rainfall

RO = runoff

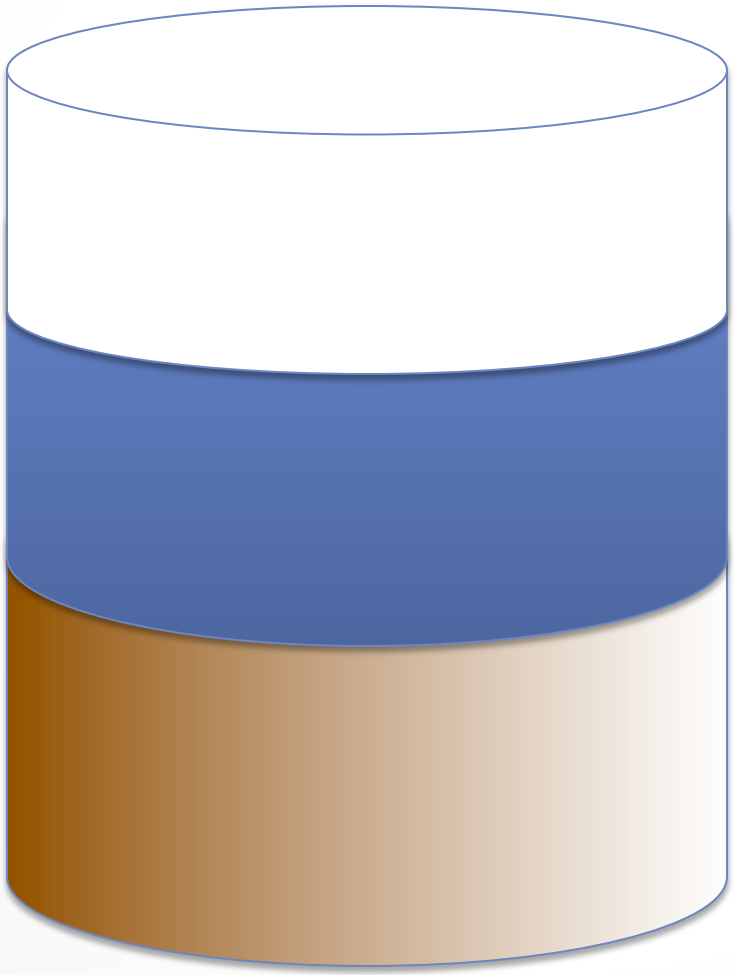
PERC = water that percolates past the root zone

A simple Irrigation Scheduling Spreadsheet Program

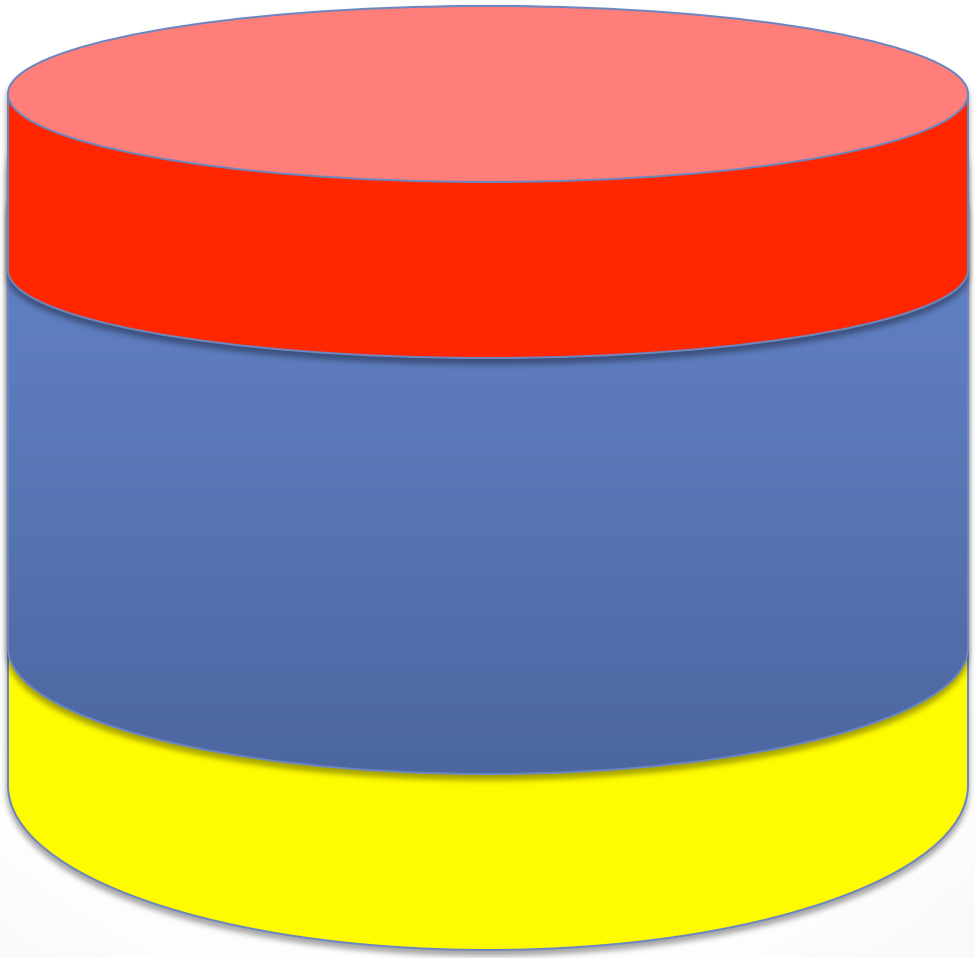


http://pragwater.com/2011/12/17/a-simple-irrigation-scheduling-spreadsheet-program/

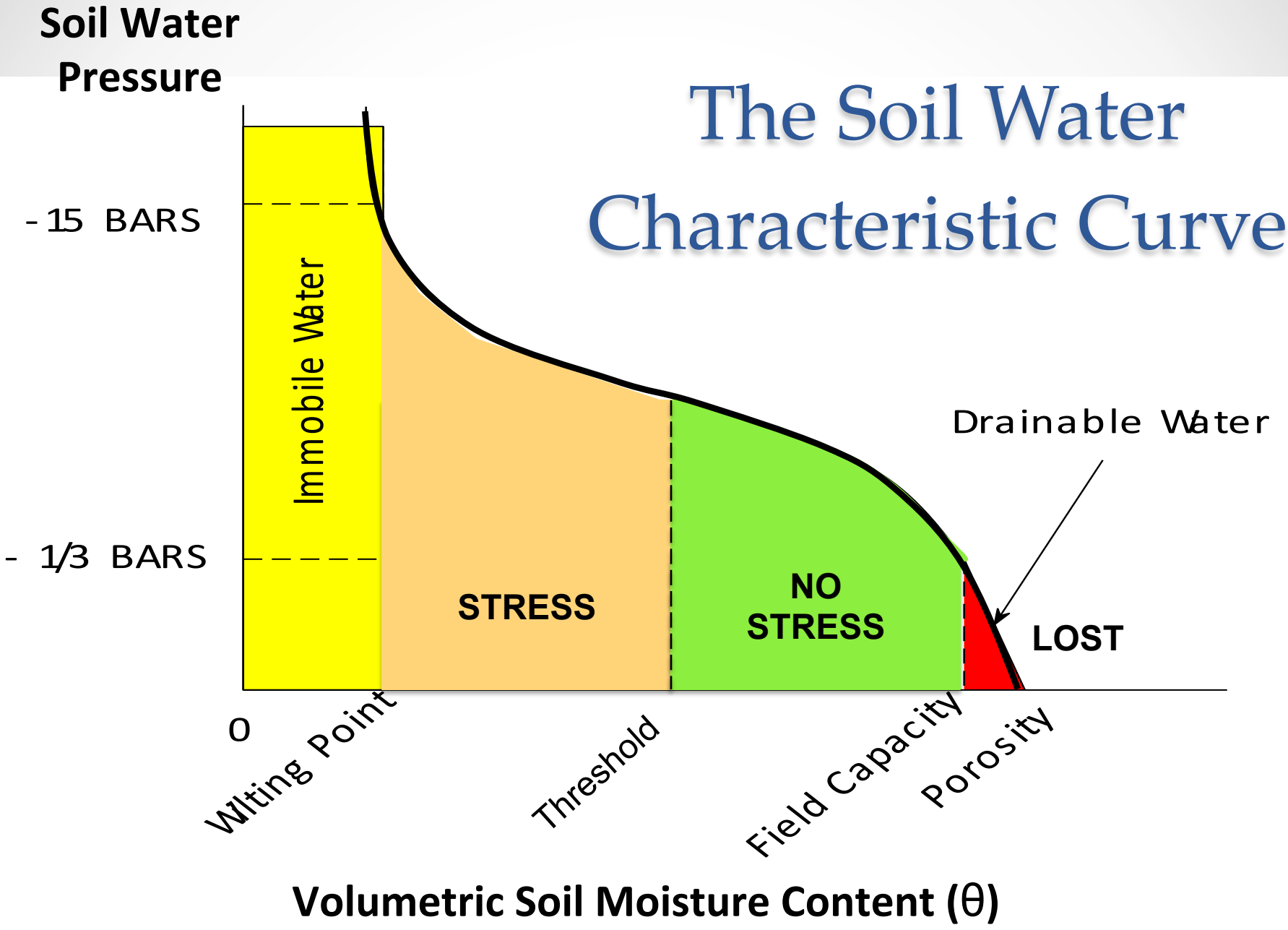
Soil Water Reservoir



Water Volume



The Soil Water Characteristic Curve



Goal of Irrigation Scheduling

Maintain soil water between θ_{FC} and θ_{t}

The Soil Water Reservoir

- Periodically filled by rainfall and/or irrigation
- Depleted slowly by ET
- Water applied in excess of the reservoir's capacity (soil water holding capacity) is wasted unless it is required for leaching.

$$TAW = (\theta_{FC} - \theta_{WP}) D_r/100$$

where

TAW = Total available water (mm)

θ_{FC} = Volumetric field capacity (%)

θ_{WP} = permanent wilting point (%)

D_r =depth of the root zone or depth of a layer of soil within the root zone.

The Soil Water Characteristic Curve

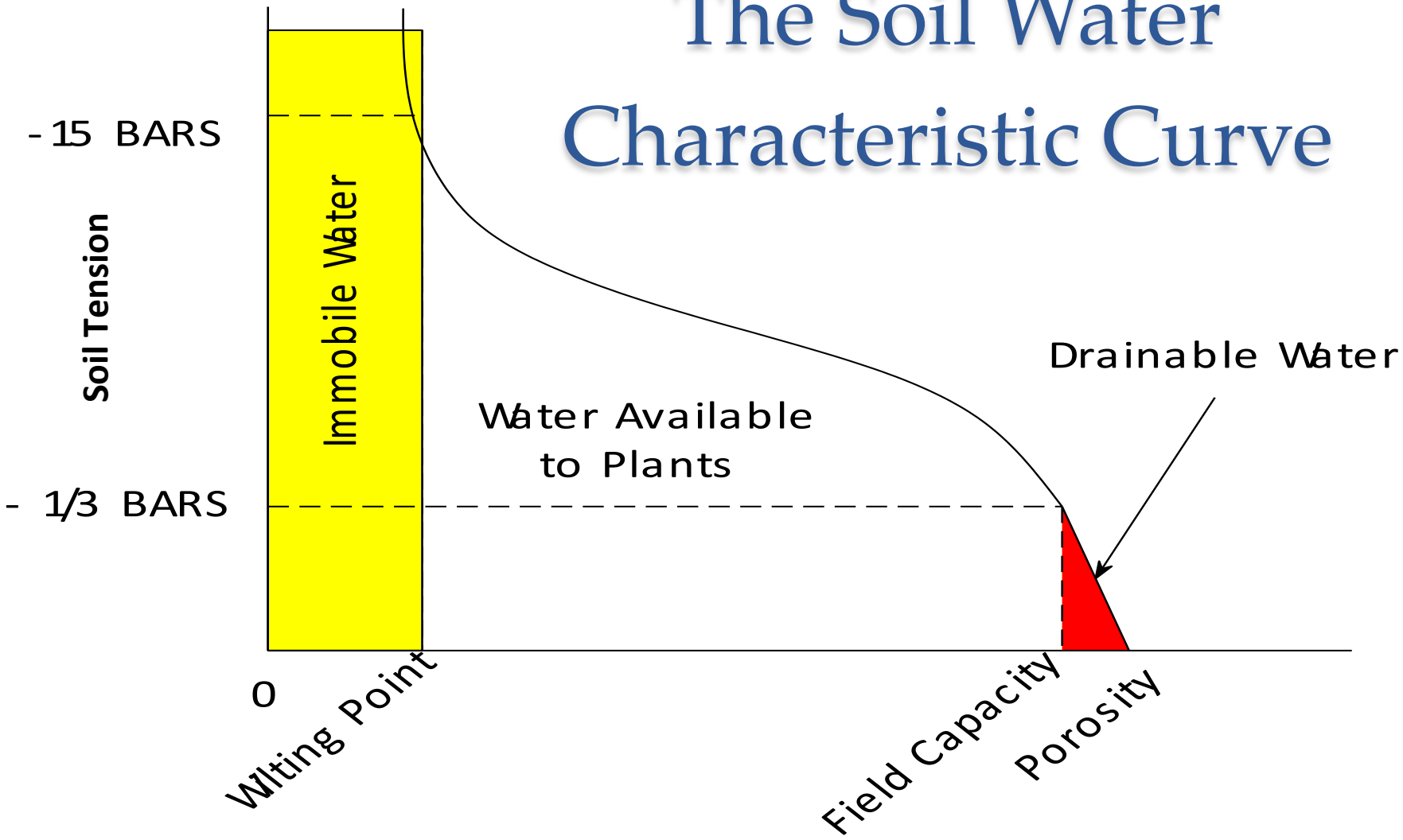


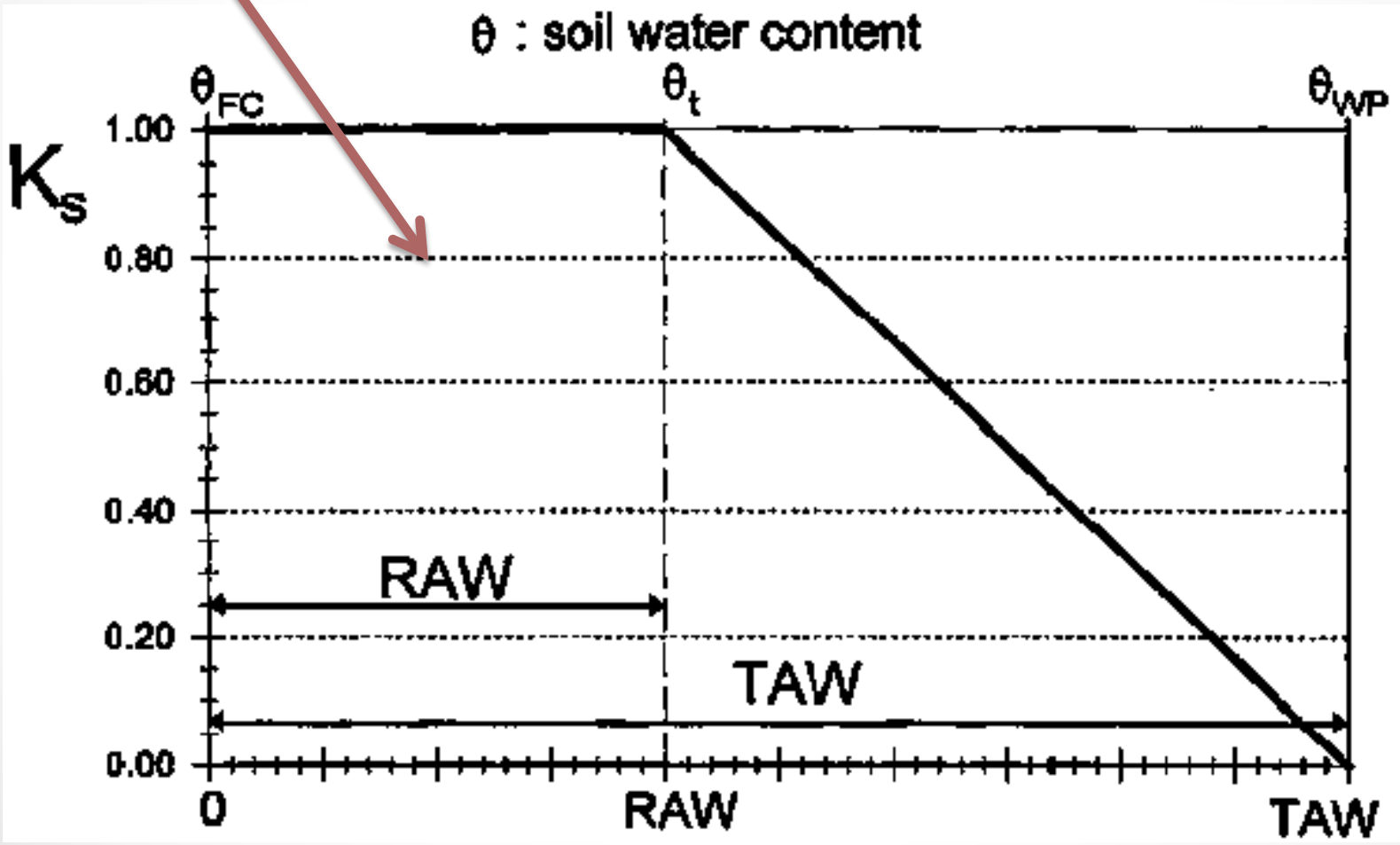
Table 15.2 Representative Physical Properties of Soils for Selected Soil Textures

Soil Texture	Total Pore Space (% by volume)	Apparent Specific Gravity (A_s)	Field Capacity, FC_v (% by volume)	Permanent Wilting PWP_v (% by volume)	Available Water (mm/m)
Sandy loam	39 (37 to 40)	1.58 (1.56 to 1.59)	16 (11 to 22)	7 (3 to 12)	80 (50 to 110)
Sandy clay loam	41 (38 to 42)	1.57 (1.53 to 1.60)	26 (20 to 32)	16 (13 to 19)	100 (70 to 120)
Loam	42 (40 to 43)	1.55 (1.50 to 1.58)	25 (18 to 31)	12 (7 to 16)	130 (110 to 150)
Silt loam	43 (40 to 46)	1.52 (1.44 to 1.59)	29 (16 to 36)	11 (3 to 16)	180 (130 to 230)
Silt	40 (39 to 42)	1.58 (1.55 to 1.61)	29 (25 to 32)	6 (4 to 8)	230 (210 to 250)
Silty clay loam	47 (45 to 50)	1.40 (1.33 to 1.47)	37 (34 to 40)	20 (17 to 22)	180 (160 to 200)
Clay loam	44 (42 to 47)	1.47 (1.41 to 1.53)	34 (30 to 37)	20 (17 to 22)	140 (130 to 160)
Clay	49 (44 to 56)	1.35 (1.19 to 1.44)	42 (36 to 47)	28 (23 to 33)	140 (130 to 150)

Note: Numbers are rounded; normal ranges are shown in parentheses.
Source: Saxton (2005).

Crop Stress Factor

This is where Your soil should be



Readily Available Water

- Plants can only remove a portion of the available water before growth and yield are affected. This portion is the "readily available water" (RAW).
- For most crops RAW is between 40% to 65%
- RAW is estimated from the following formula:

MAD = Management Allowed Deficit

$$RAW = (MAD)\ (TAW)$$

Table 15.4 Typical Management-Allowed Depletion Values, *MAD*, for Maintaining Maximum Evapotranspiration Rates of Crops Grouped According to Stress Sensitivity

Crop Group[a]	Maximum Evapotranspiration Rates (mm/day)								
	2	3	4	5	6	7	8	9	10
	MAD								
1	0.50	0.43	0.35	0.30	0.25	0.23	0.20	0.20	0.18
2	0.68	0.58	0.48	0.40	0.35	0.33	0.28	0.25	0.23
3	0.80	0.70	0.60	0.50	0.45	0.43	0.38	0.35	0.30
4	0.88	0.80	0.70	0.60	0.55	0.50	0.45	0.43	0.40

[a] Crop Group 1: Onion, pepper, potato.
Crop Group 2: Banana, cabbage, pea, tomato.
Crop Group 3: Alfalfa, bean, citrus, groundnut, pineapple, sunflower ,watermelon, wheat.
Crop Group 4: Cotton, sorghum, olive, grape, safflower, maize, soybean, sugar beet, tobacco.
Source: Doorenbos and Kassam (1979).

Example:
Assume Alfalfa, ETmax = 7 mm/day, 2m root depth and a Clay soil.
From the table: MAD=0.43. RAW=MAD*TAW = 0.43* 140 mm/m * 2 m = 120.4 mm
Assume a period during the season when ET= 7 mm/day
So the number of days required for the crop to use up the RAW is
120.4 mm / 7 mm/day = 17 days

Threshold Moisture Content, θ_t

- If the soil moisture content falls below θ_t, the crop will go into stress and you will loss crop yield!

$$\theta_t = \theta_{FC} - RAW$$

where

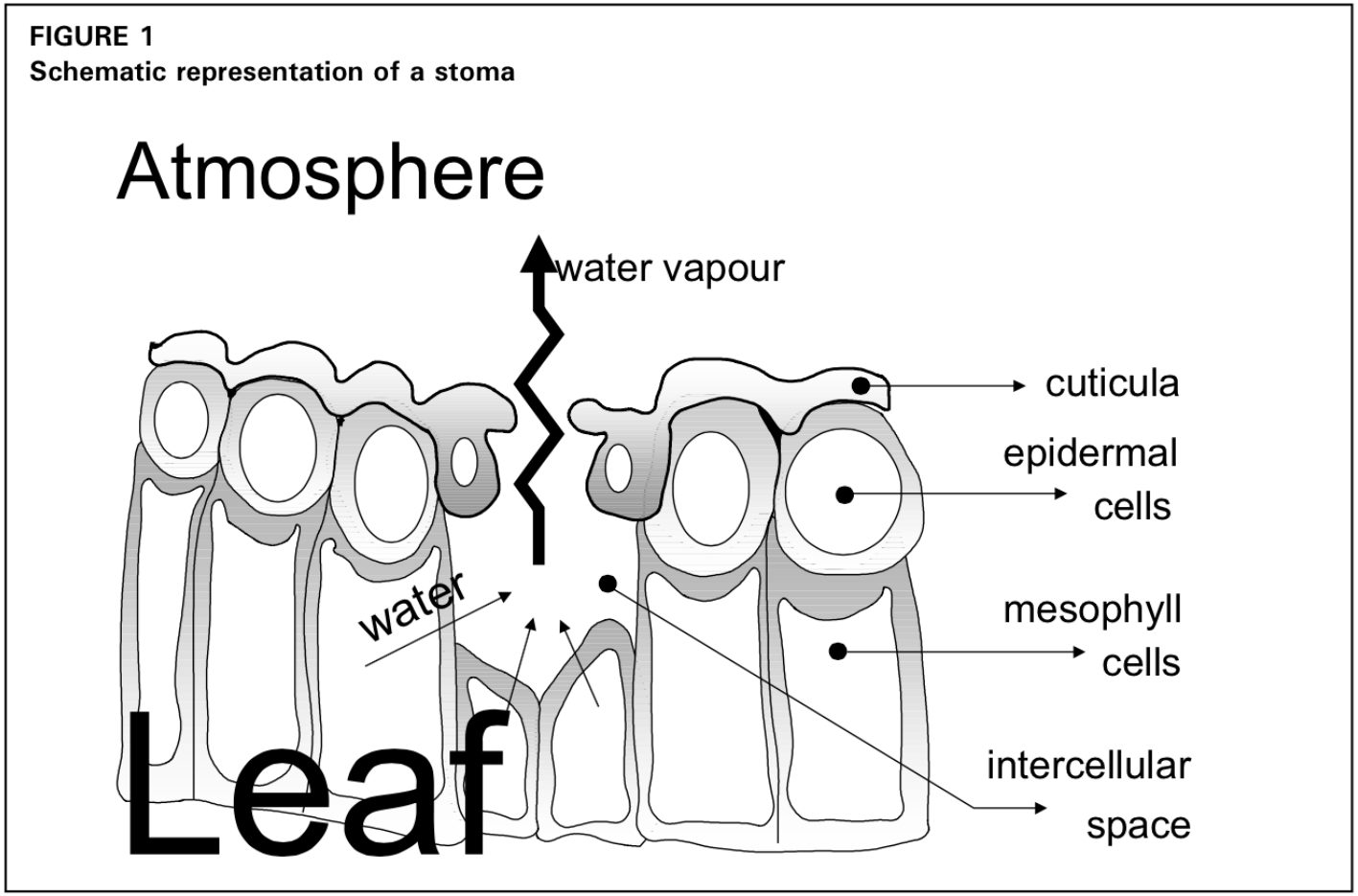
θ_t = threshold moisture content

θ_{FC} = field capacity moisture content

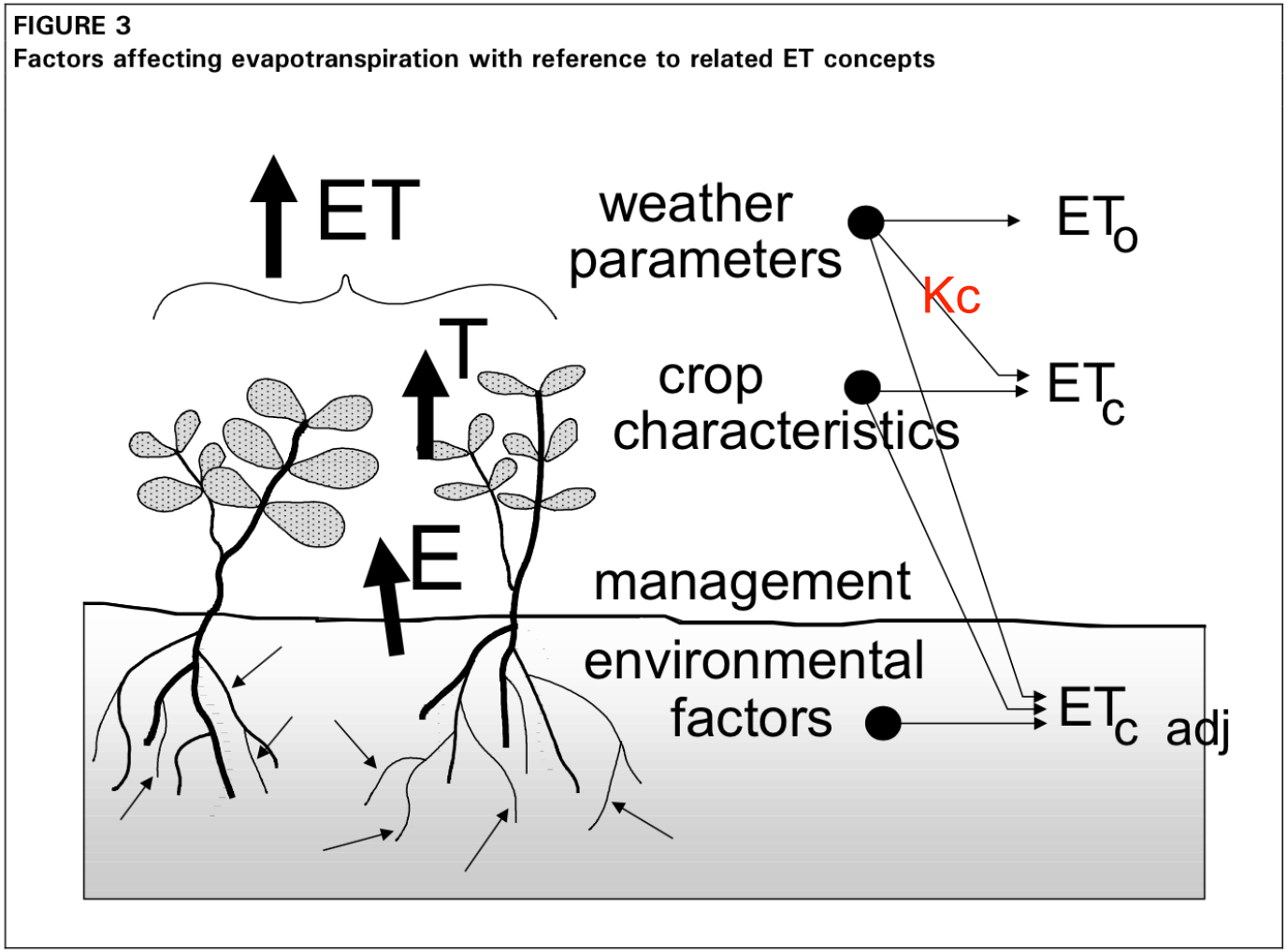
RAW = readily available water

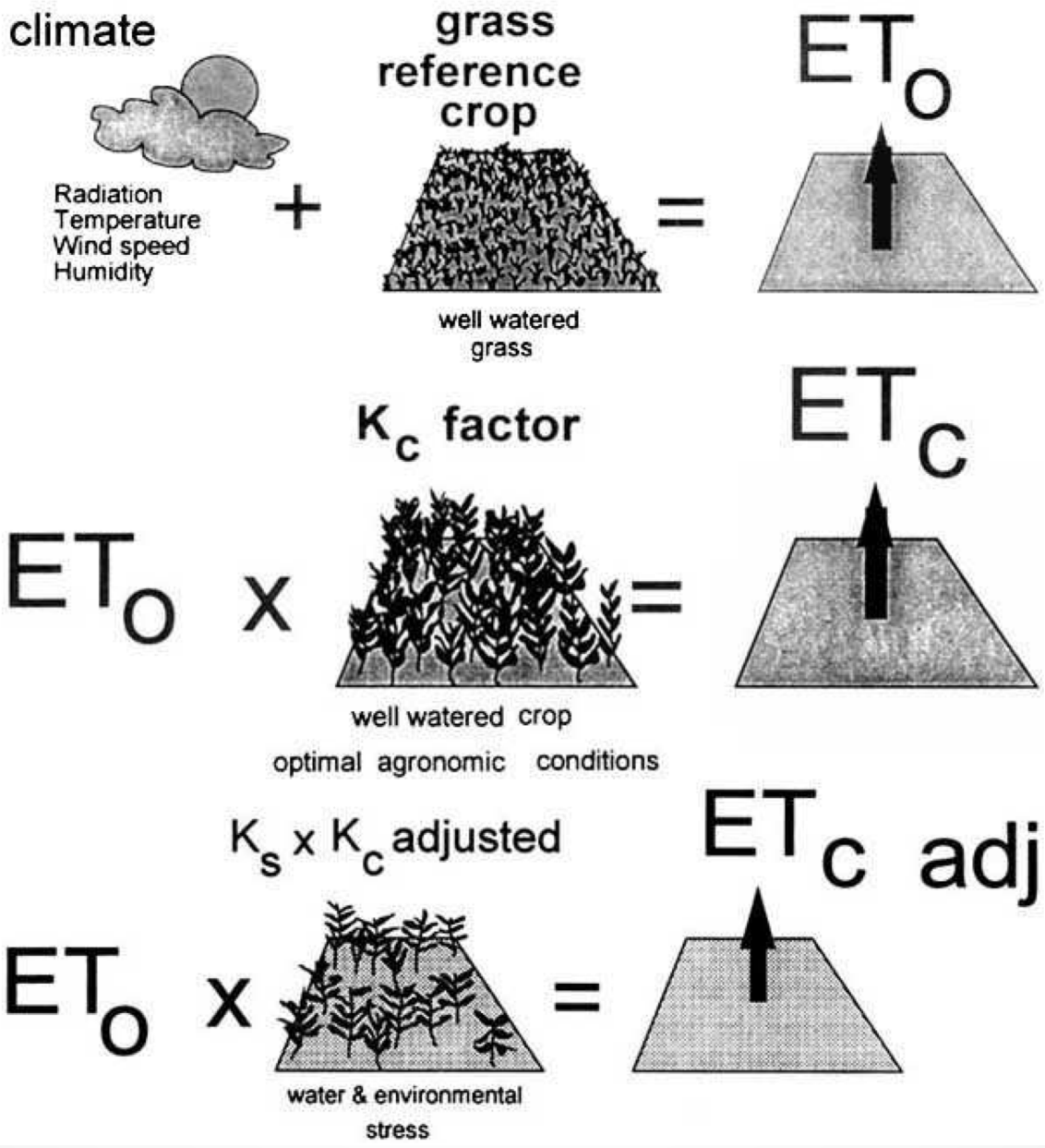
Estimate the Threshold Moisture Content (MCt) for the Alfalfa example.
Assume clay soil and 2m root depth.
FC = (42/100) * 2 m = 840 mm
MCt = FC- RAW = 840 - 120.4 = 720 mm
Convert MCt as a depth of water to percent volumetric moisture content:
=720 mm/ 2000 mm = 0.3581= 36%. (The root depth is 2000 mm)
Let's estimate the volume of water required assuming an area of 1 acre:
Volume= 120.4 mm * 1 acre = 129,000 gallons. (unit conversions were performed within WolfRam Alpha.)
Irrigation should start when the moisture content = 36% and should continue until 129,000 gallons has been applied or until the moisture content equals 42% (i.e., FC).

Transpiration



Evapotranspiration




climate
Radiation
Temperature
Wind speed
Humidity
+
grass
reference
crop
=
ET_O
well watered
grass
K_c factor
ET_O x
=
ET_C
well watered crop
optimal agronomic conditions
K_s x K_c adjusted
ET_O x
=
ET_c adj
water & environmental
stress

Crop Water Use (ET_{cadj})

- The rate of water use by the crops can be estimated as follows

$$ET_c = K_c\, ET_o$$

$$ET_{cadj} = K_s\, ET_c$$

Where

ET_o = Reference Evapotranspiration

K_c = Evapotranspiration Crop Coefficient

K_s = Crop Stress Factor

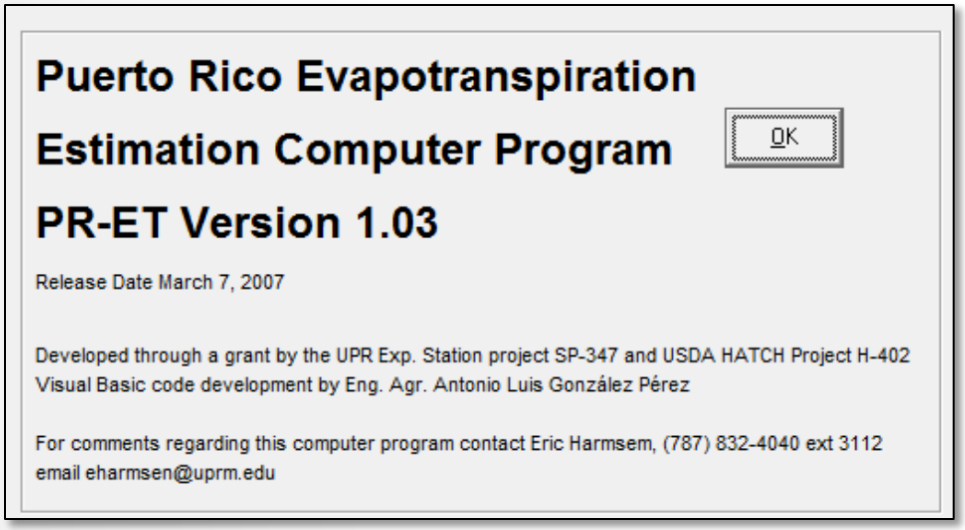
Spreadsheet

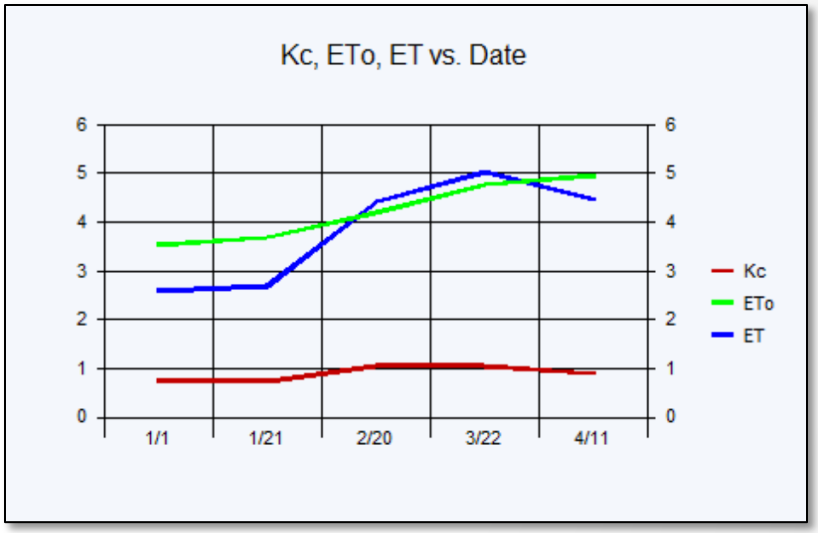
http://academic.uprm.edu/abe/PRAGWATER/

Date	Field Capacity	Wilting Point	Total Available Water	Root Depth	Management Allowed Deficit	Readily Available Moisture Content	Threshold Moisture Content	Moisture Content	Crop Stress Factor	Average Crop Evapotranspiration	Average Evapotranspiration Adjusted for Stress	Soil Water Deficit	Irrigation needed	Applied Irrigation or Rainfall	Did Stress Occur?
	FC	WP	TAW	RD	MAD	RAW	θ_t	θ	K_s	ET_c	$ET_{c\ adj}$				
	%	%	%	m	fraction	%	%	%		mm	mm	%	mm	mm	
3/14/2008	36	18	18	0.70	0.4	7.2	28.8	30.00	1.00	3.80	3.80	6.0	42	0	NO
3/15/2008	36	18	18	0.71	0.4	7.2	28.8	29.46	1.00	3.90	3.90	6.5	46	0	NO
3/16/2008	36	18	18	0.72	0.4	7.2	28.8	28.92	1.00	3.80	3.80	7.1	51	0	NO
3/17/2008	36	18	18	0.73	0.4	7.2	28.8	28.40	0.96	4.00	3.85	7.6	55	0	YES
3/18/2008	36	18	18	0.74	0.4	7.2	28.8	27.88	0.91	4.20	3.84	8.1	60	0	YES
3/19/2008	36	18	18	0.75	0.4	7.2	28.8	27.37	0.87	3.90	3.38	8.6	65	0	YES
3/20/2008	36	18	18	0.76	0.4	7.2	28.8	36.00	1.00	3.90	3.90	0.0	0	69	NO
3/21/2008	36	18	18	0.77	0.4	7.2	28.8	35.50	1.00	4.20	4.20	0.5	4	0	NO
3/22/2008	36	18	18	0.78	0.4	7.2	28.8	34.96	1.00	4.20	4.20	1.0	8	0	NO
3/23/2008	36	18	18	0.79	0.4	7.2	28.8	34.43	1.00	4.10	4.10	1.6	12	0	NO
3/24/2008	36	18	18	0.80	0.4	7.2	28.8	33.91	1.00	4.30	4.30	2.1	17	0	NO
3/25/2008	36	18	18	0.81	0.4	7.2	28.8	33.38	1.00	4.20	4.20	2.6	21	0	NO
3/26/2008	36	18	18	0.82	0.4	7.2	28.8	32.87	1.00	4.30	4.30	3.1	26	0	NO
3/27/2008	36	18	18	0.83	0.4	7.2	28.8	32.35	1.00	4.40	4.40	3.6	30	0	NO
3/28/2008	36	18	18	0.84	0.4	7.2	28.8	31.83	1.00	4.50	4.50	4.2	35	0	NO

User must enter the yellow spreadsheet cells

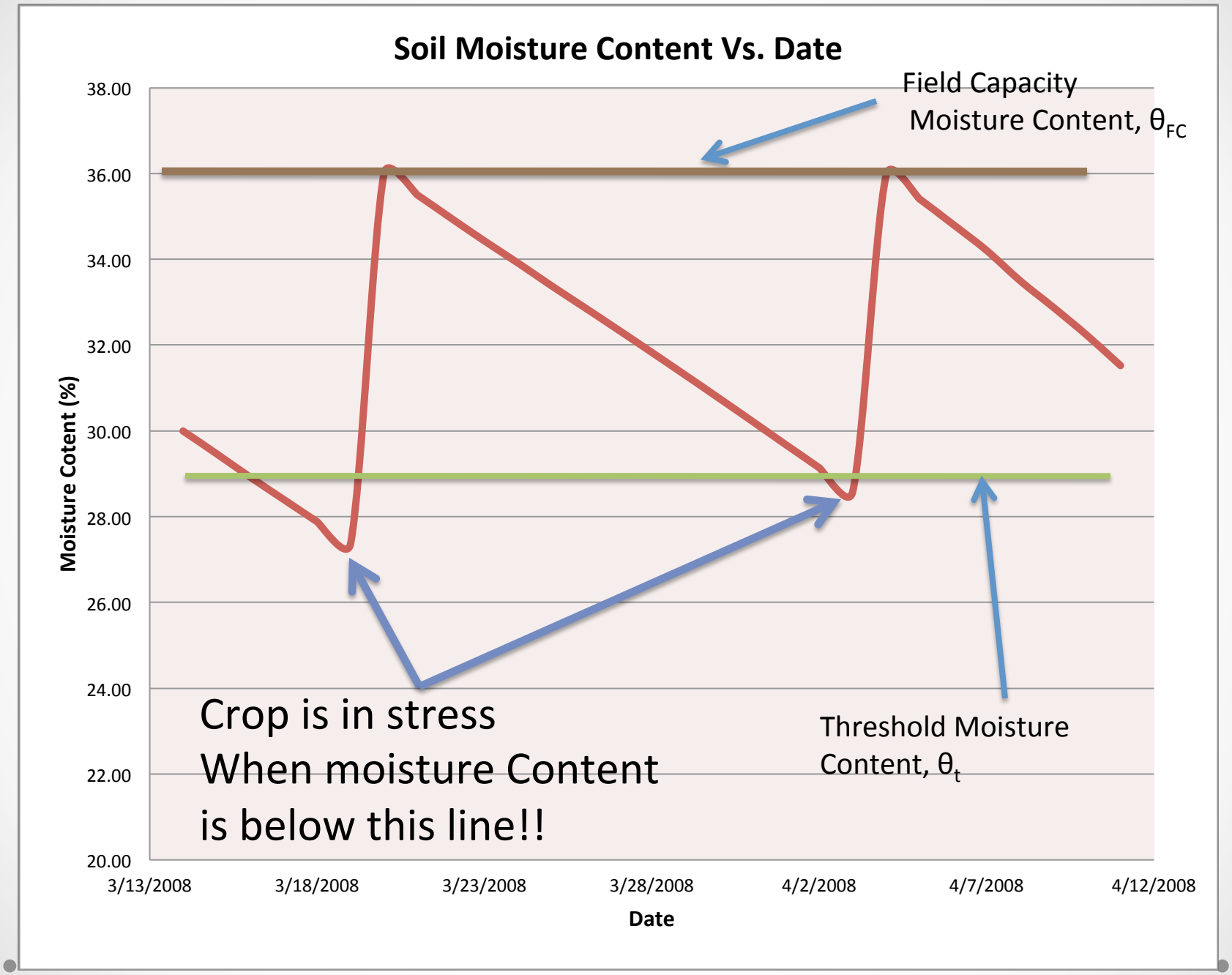
Evapotranspiration Computer Program



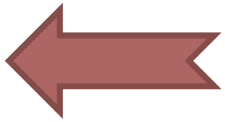


Based on climate parameter estimation procedure for Puerto Rico

- http://pragwater.com/crop-water-use/


Soil Moisture Content Vs. Date
Field Capacity Moisture Content, θ_{FC}
38.00
36.00
34.00
32.00
30.00
28.00
26.00
24.00
22.00
20.00
Moisture Cotent (%)
3/13/2008
3/18/2008
3/23/2008
3/28/2008
4/2/2008
4/7/2008
4/12/2008
Date
Crop is in stress
When moisture Content
is below this line!!
Threshold Moisture Content, θ_t

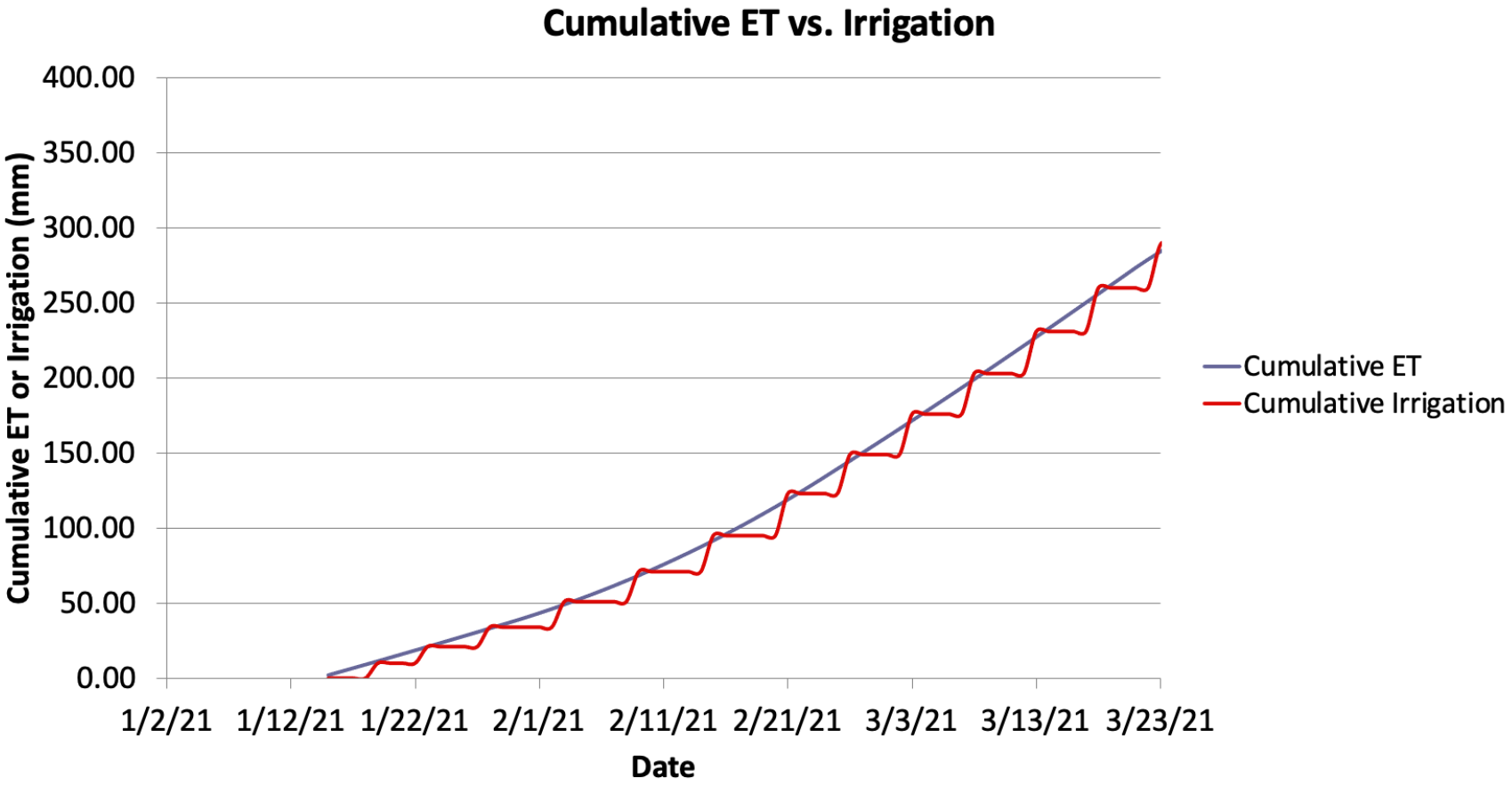
Soil Water Deficit	Irrigation needed	Applied Irrigation or Rainfall	Did Stress Occur?
%	mm	mm	
6.0	42	0	NO
6.5	46	0	NO
7.1	51	0	NO
7.6	55	0	YES
8.1	60	0	YES
8.6	65	0	YES
0.0	0	69	NO
0.5	4	0	NO
1.0	8	0	NO
1.6	12	0	NO
2.1	17	0	NO
2.6	21	0	NO
3.1	26	0	NO
3.6	30	0	NO



Crop Stress!

Irrigation Application Rate and Timing

Irrigation Needed	Field Area	Percent Wetted Area	Irrigation Efficiency	Volume of Water to Apply	Pump Manifold Flow Rate	Time to Apply Irrigation
mm	Acres	%	%	gallons	Gallons per Minute	Hours
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
69	5	50	90	204890	500	6.8
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0
0	5	50	90	0	500	0.0

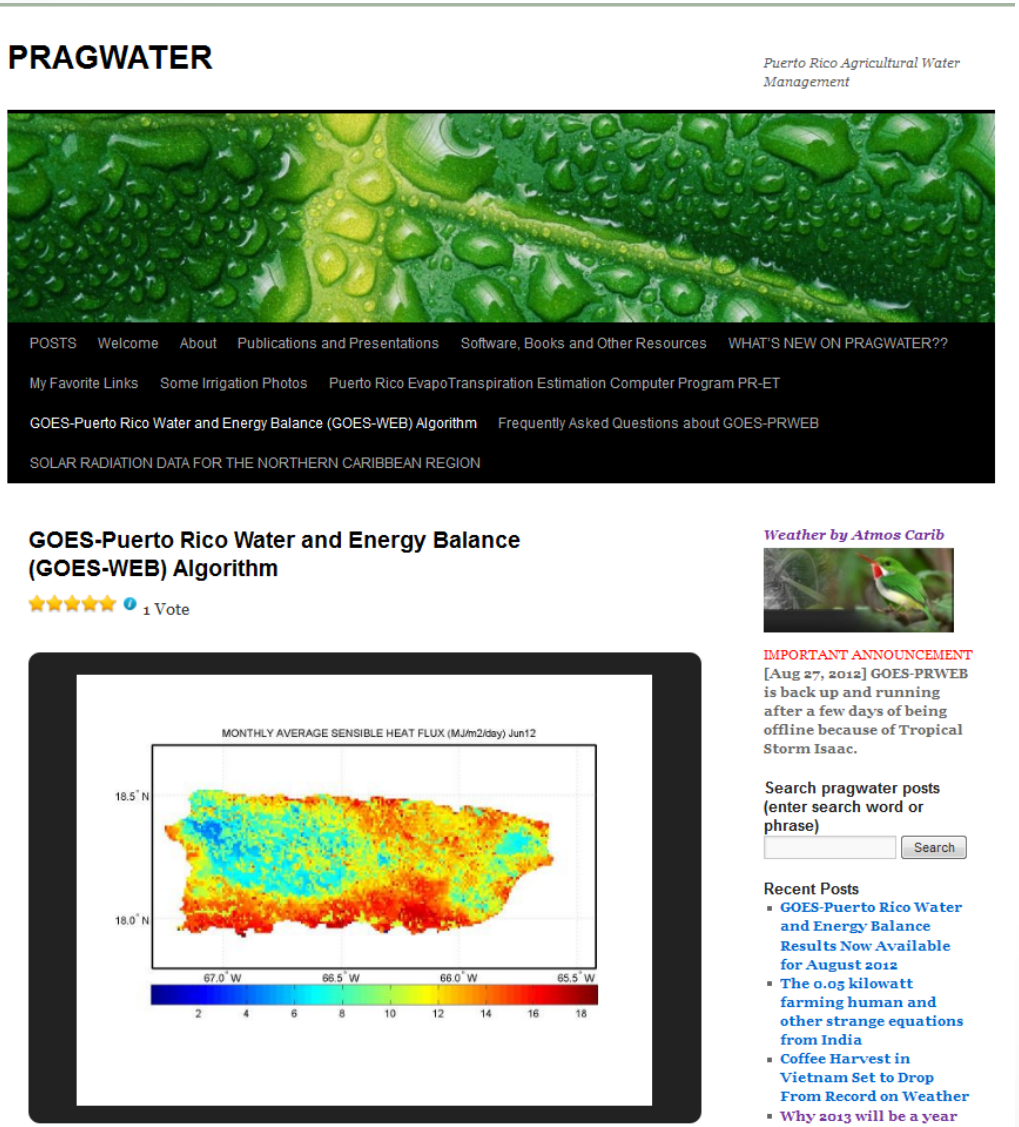

Cumulative ET vs. Irrigation
Cumulative ET or Irrigation (mm)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1/2/21
1/12/21
1/22/21
2/1/21
2/11/21
2/21/21
3/3/21
3/13/21
3/23/21
Date
Cumulative ET
Cumulative Irrigation

Conclusion

Maintain soil water between θ_{FC} and θ_{t}

GOES-PRWEB

http://pragwater.com

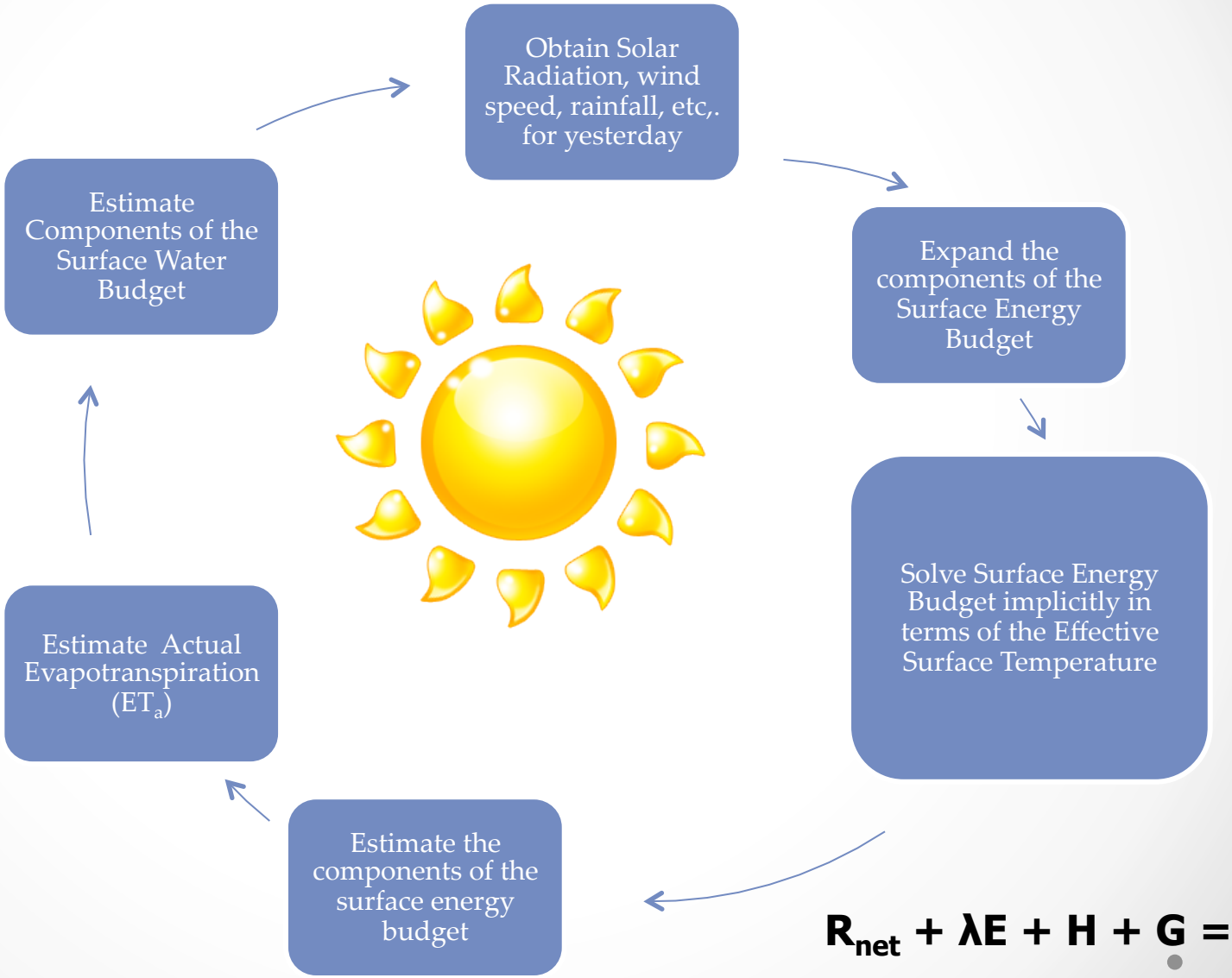


26 hydro-climate variables are produced each day at the website: pragwater.com.

Monthly and annual averages/totals are also available.

Algorithm Flow Chart

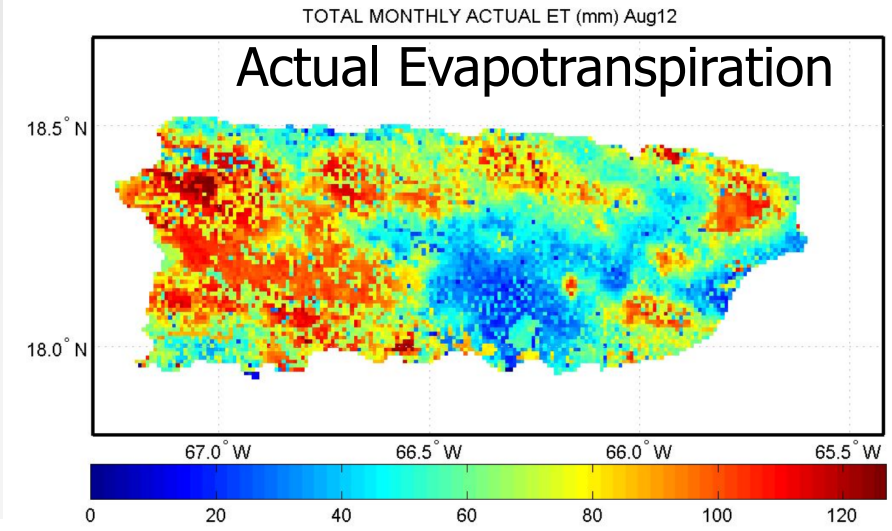
$$SM_2 = Precip - ET_a - RO - DP - SM_1$$

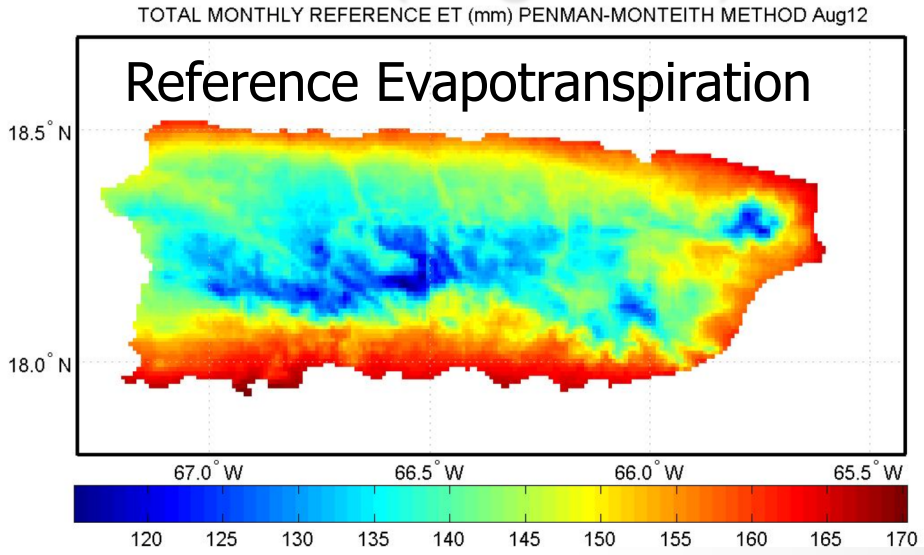


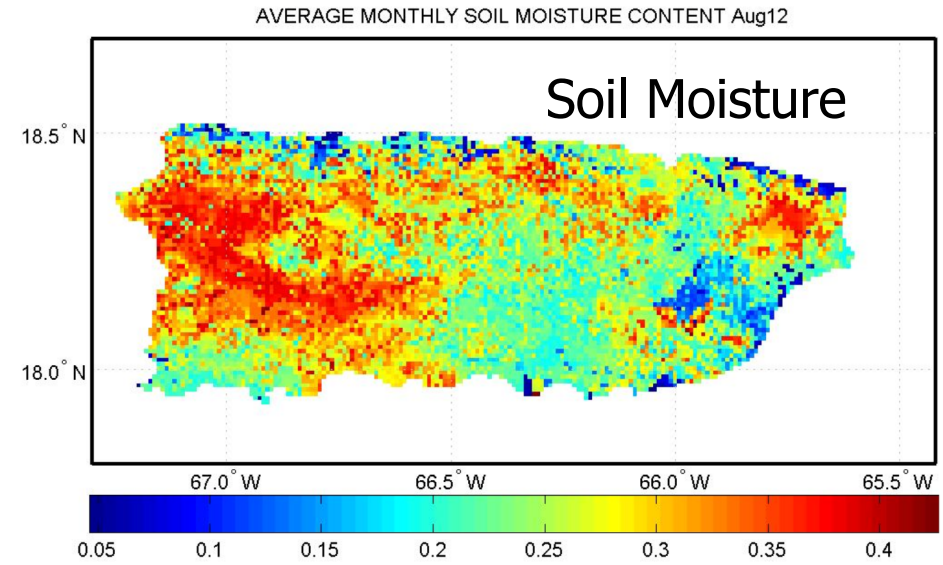
$$R_{net} + \lambda E + H + G = 0$$

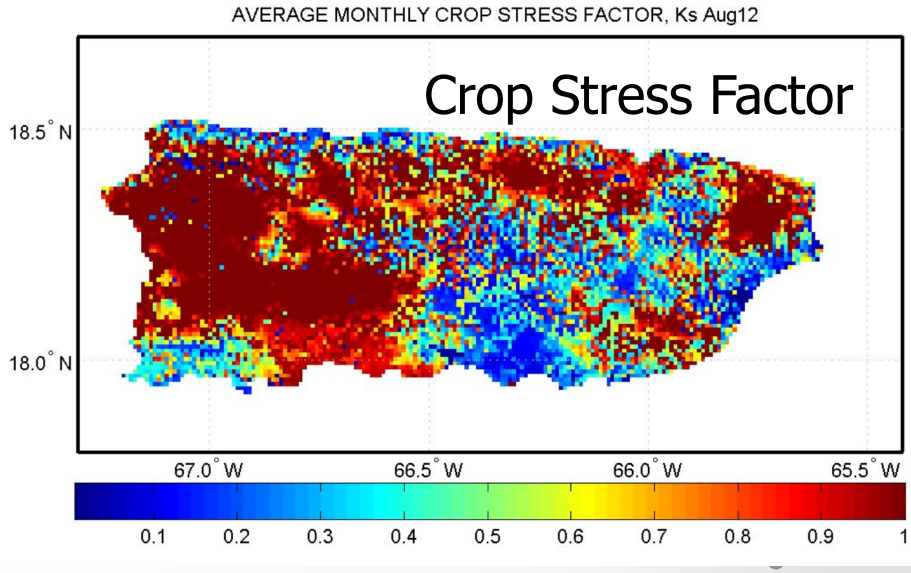
Monthly Average Actual and Reference Evapotranspiration,

Soil Moisture and Crop Stress Factor (Aug. 2012)

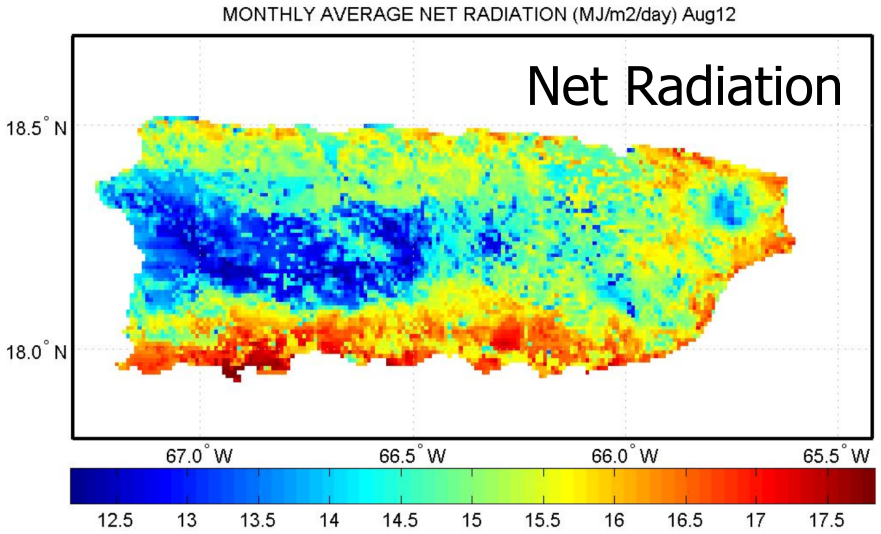


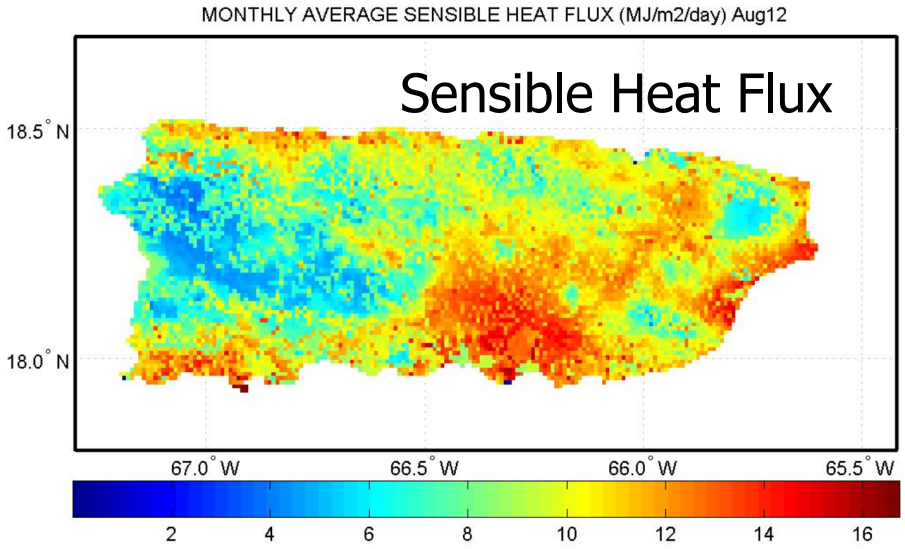


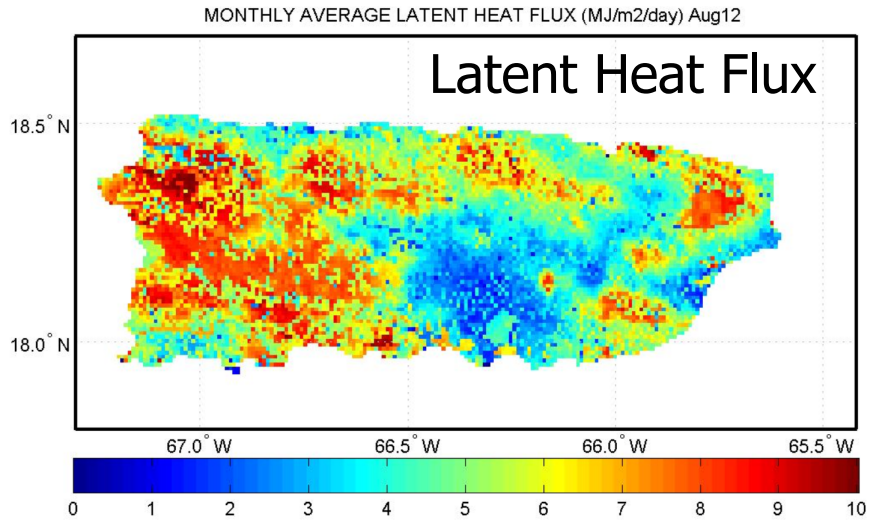


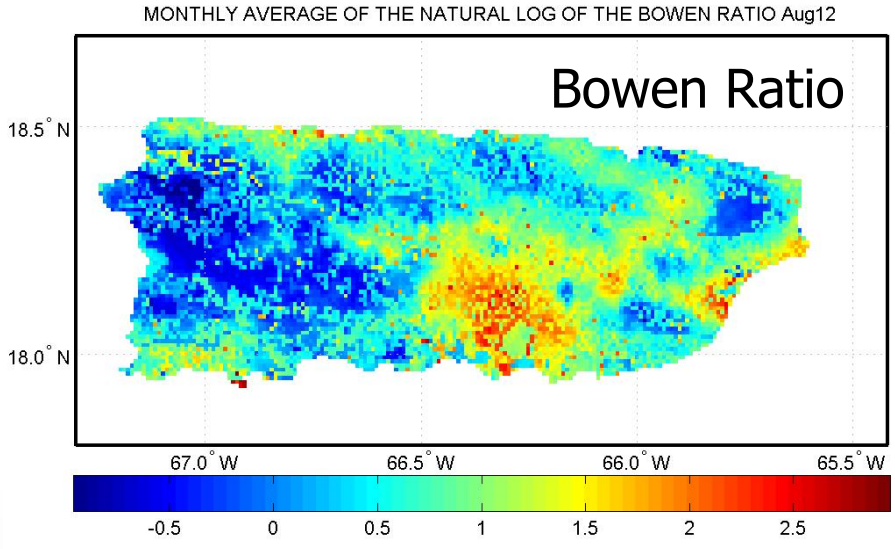


Monthly Average Net Radiation, Sensible Heat Flux, Latent Heat Flux and Bowen Ratio (Aug. 2012)

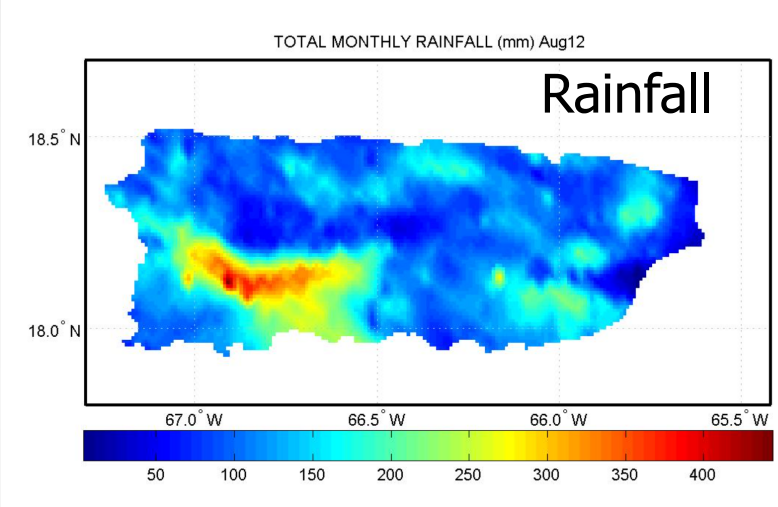


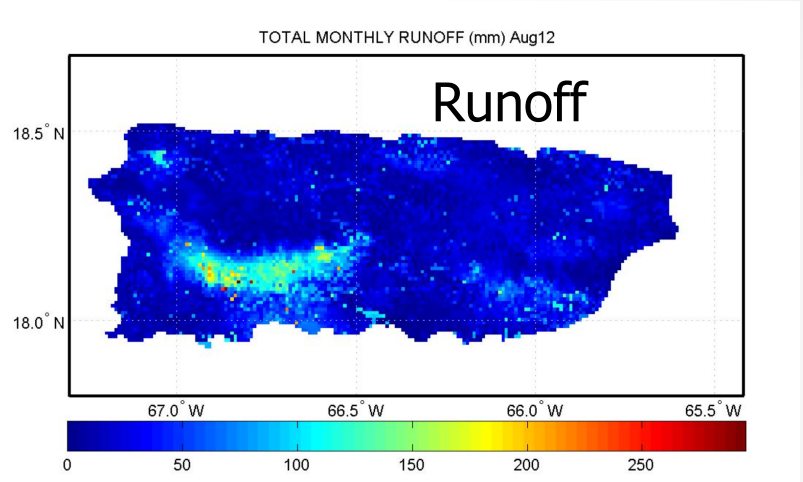


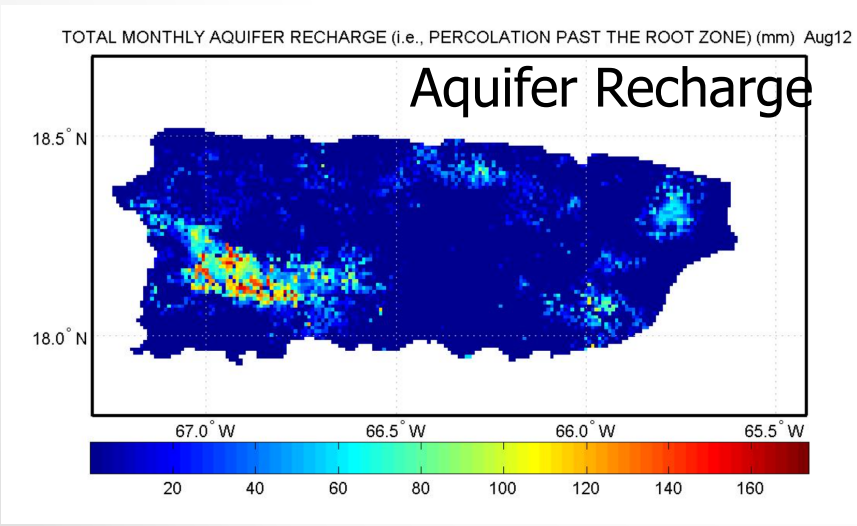


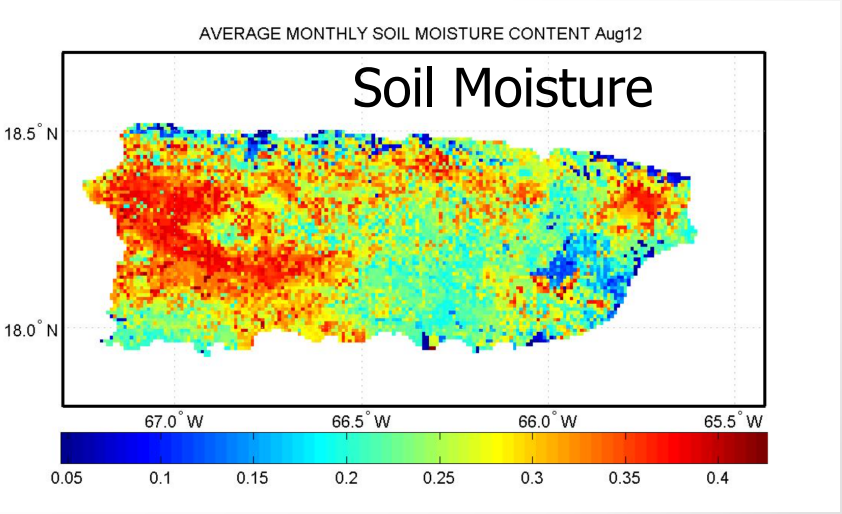


Monthly Average Rainfall, Runoff, Aquifer Recharge and Soil Moisture (Aug. 2012)

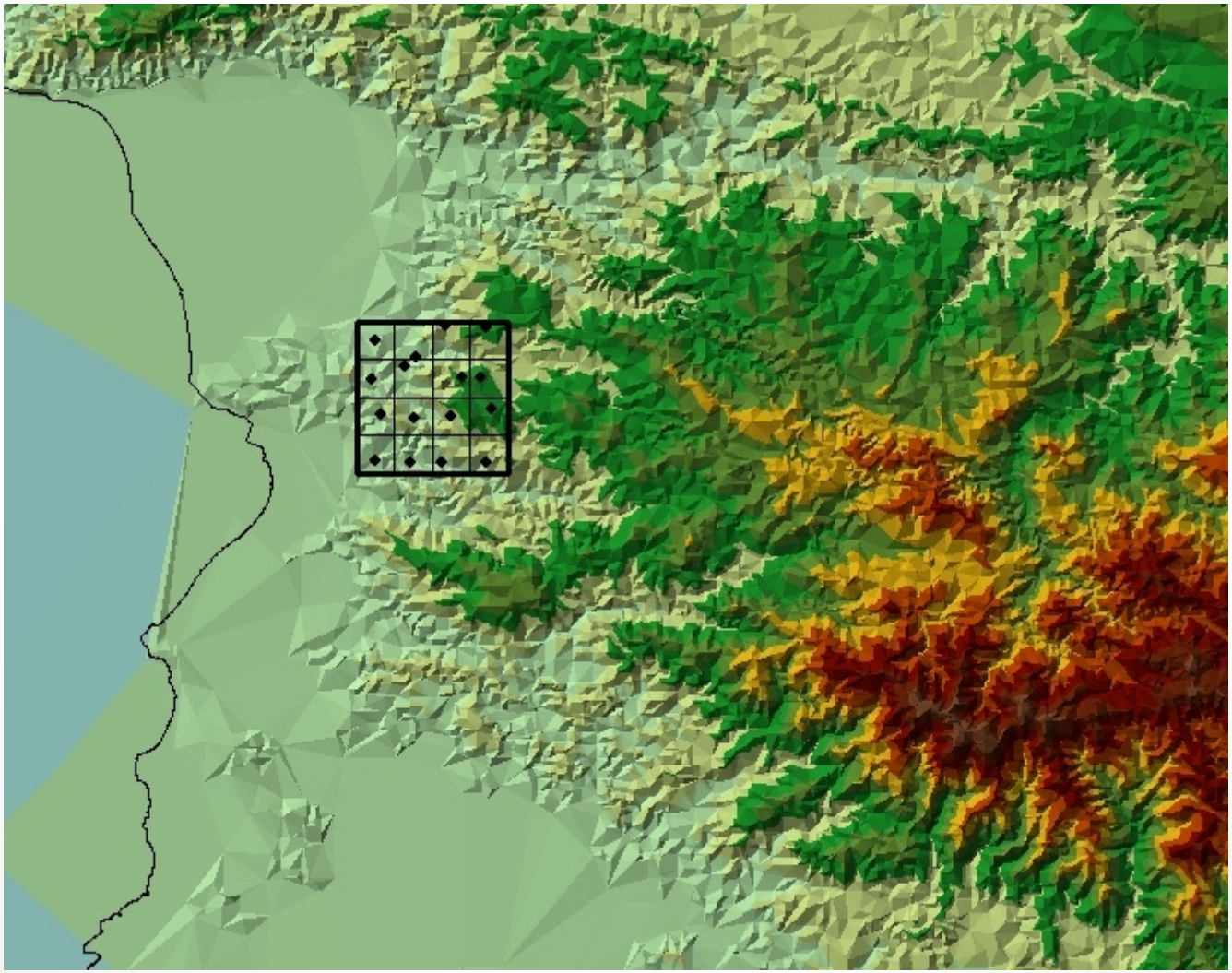


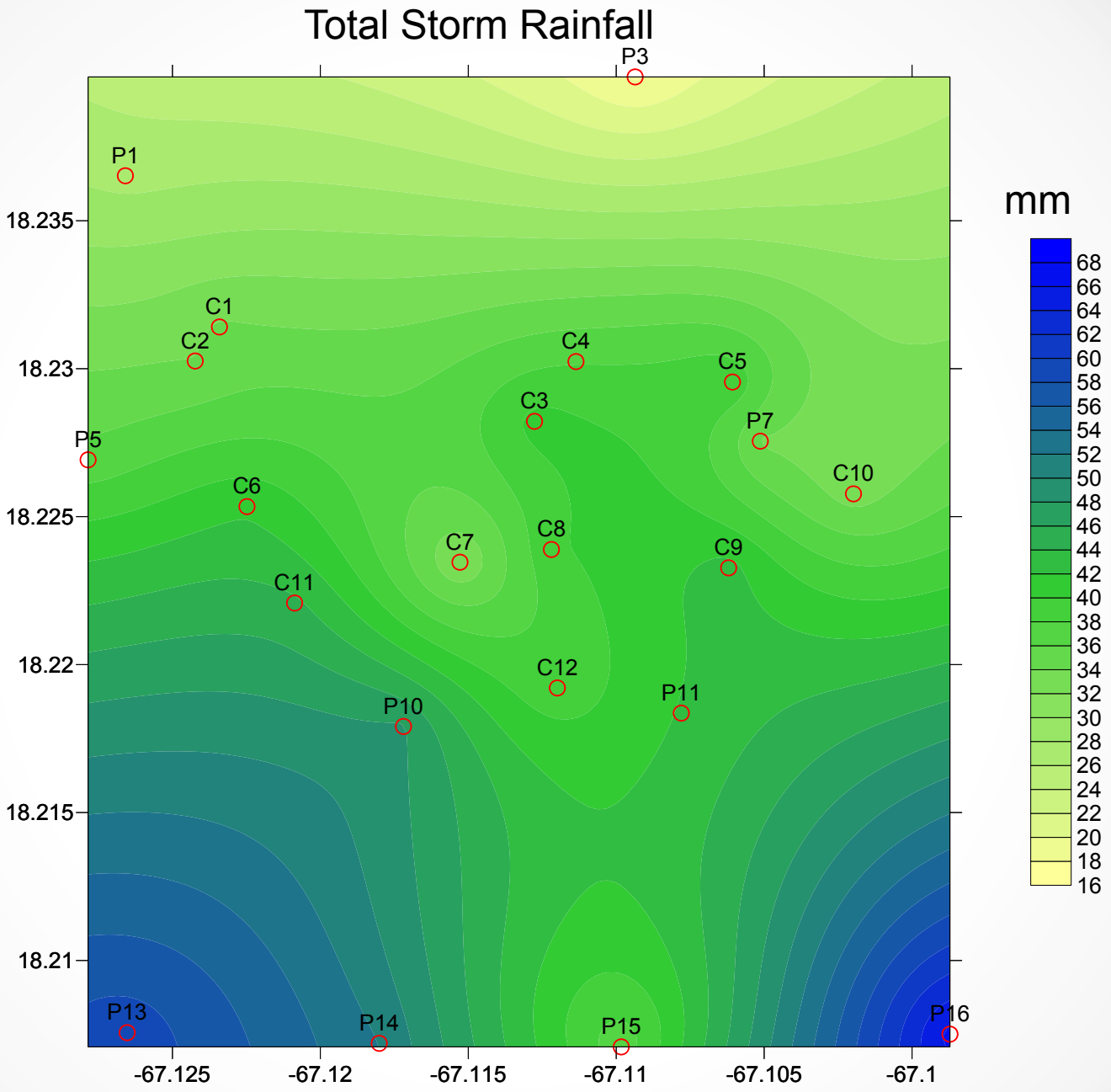






Rainfall Variability Study




Total Storm Rainfall
P3
P1
C1
C2
C4
C5
C3
P7
P5
C10
C6
C8
C7
C9
C11
C12
P11
P10
P13
P14
P15
P16
18.235
18.23
18.225
18.22
18.215
18.21
-67.125
-67.12
-67.115
-67.11
-67.105
-67.1
mm
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16

Many weather stations ($1,700 approx.) will calculate the daily reference evapotranspiration

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