Estrés hídrico con énfasis en sequía

Dr. Eric Harmsen
Professor, Dept. of Agricultural and Biosystems Eng.,
Univ. of Puerto Rico-Mayaguez

Isabela, Puerto Rico

Agenda

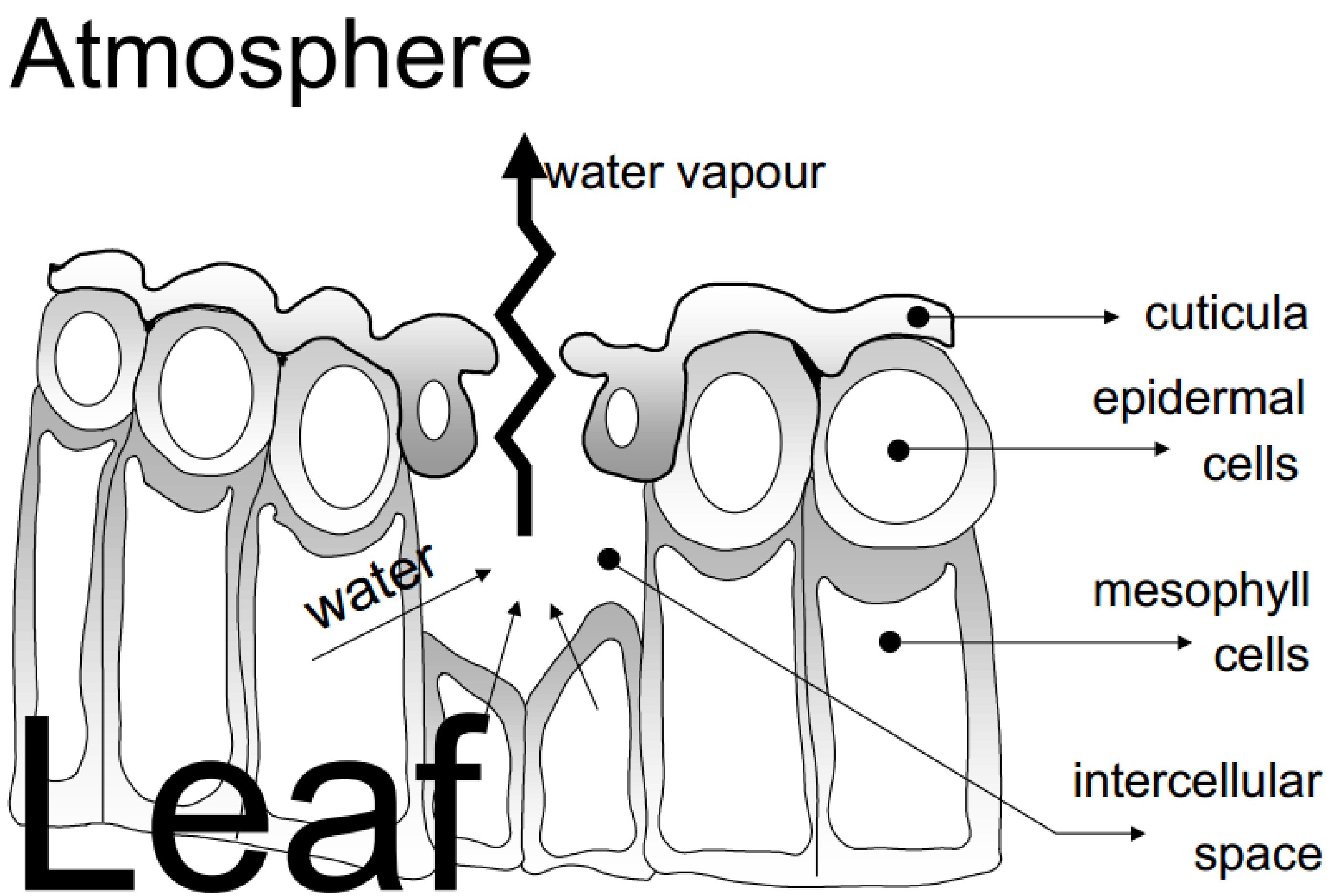
- What is crop water stress?
- What external factors cause crop water stress?
- How do we model crop water stress?
- PR drought of 2015
- How do we avoid crop water stress?

What is crop water stress?

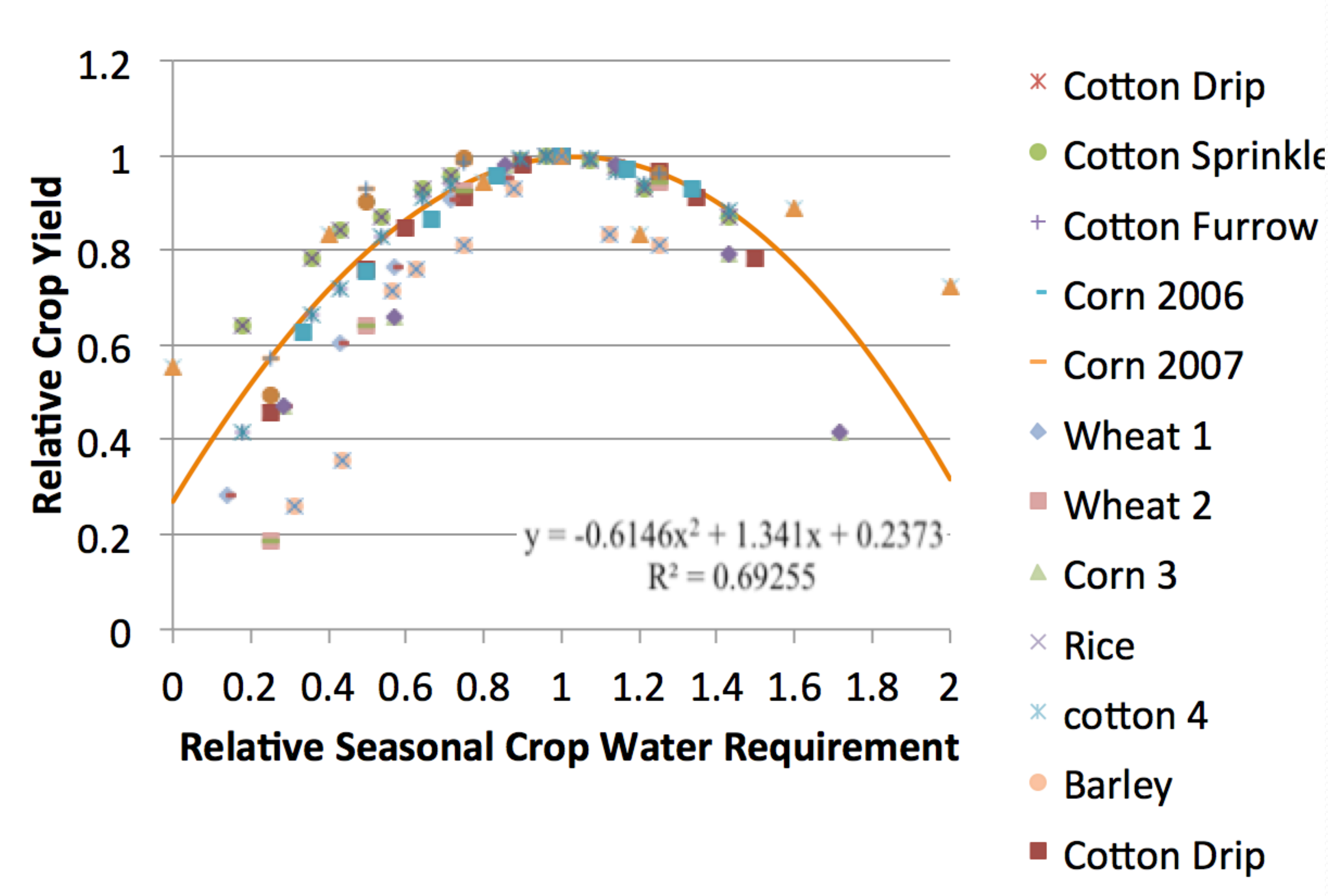
- "Plants experience water stress either when the water supply to their roots becomes limiting or when the transpiration rate becomes intense."
- "Plant growth under drought is influenced by altered photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and hormones."
- "Water stress is primarily caused by the water deficit, i.e. drought or high soil salinity. In case of high soil salinity and also in other conditions like flooding and low soil temperature, water exists in soil solution but plants cannot uptake it – a situation commonly known as 'physiological drought'."

Rahman W. and H Hasegawa, 2012. ***Water Stress***, InTech, Chapters published January 25, 2012 under CC BY 3.0

FIGURE 1
Schematic representation of a stoma



Relationship between relative crop yield and relative seasonal crop water requirement applied



How much money are we talking about?

	Percentage of Crop Water Requirement Applied						
	40	50	80	100	130	150	180
CROP*	**$ Lost / Acre**						
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*

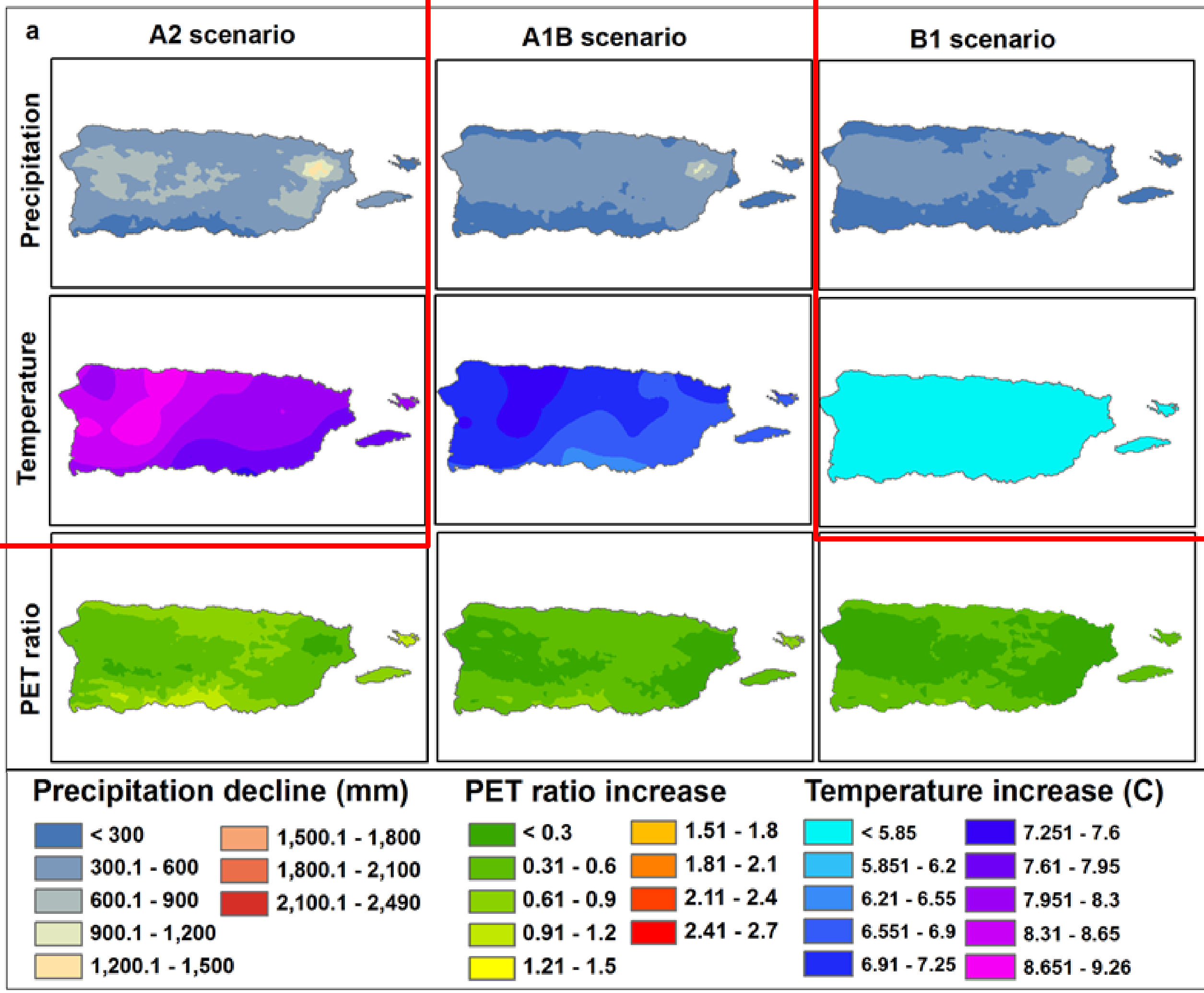
What external factors cause crop water stress?

- Drought
- Planting at the wrong time of year
- Poor irrigation system design
- Poor irrigation management
- Climate Change

The total changes in precipitation, mean temperature and PET ratio from the first time interval (1960 to 1990) to the last time interval (2071 to 2099) based on the multi-model average of all twelve models

30% Reduction in rainfall

8 ºC Increase in Average Temperature



20% Reduction in rainfall

4.5 ºC Increase in Average Temperature

Journal of Applied Metoeorology and Climatology
Authors: Azad Henareh Khalyani, Gould, Harmsen, Terando, Quinones and Callazo.

How do we model crop water stress?

Crop Water Stress Index (CWSI)

$$\mathrm{CWSI} = 1 - \frac{ET_a}{ET_p} = \frac{\gamma\left(0.81 + \frac{r_s}{r_{ah}}\right) - \gamma^*}{\delta + \gamma\left(0.81 + \frac{r_s}{r_{ah}}\right)}$$

$$\gamma^* = \gamma\left[0.81 + \left(\frac{r_s}{r_{ah}}\right)_p\right]$$

ET_a = Actual evapotranspiration
ET_p = Reference evapotranspiration
γ = Psychrometric constant
δ = Slope of the saturated vapor pressure-temperature curve
r_s = Resistance to water vapor transfer at leaf level
r_{ah} = Air resistance for heat diffusion

Jackson, R. D., S. B. Idso, R. J. Reginato, and P. J. Pinter Jr. 1981. Canopy temperature as a crop water stress indicator. Water Resources

Estimating CWSI is relatively complicated

The method involves canopy temperature, which is easy to obtain, but it also involves a lot of other measurements.

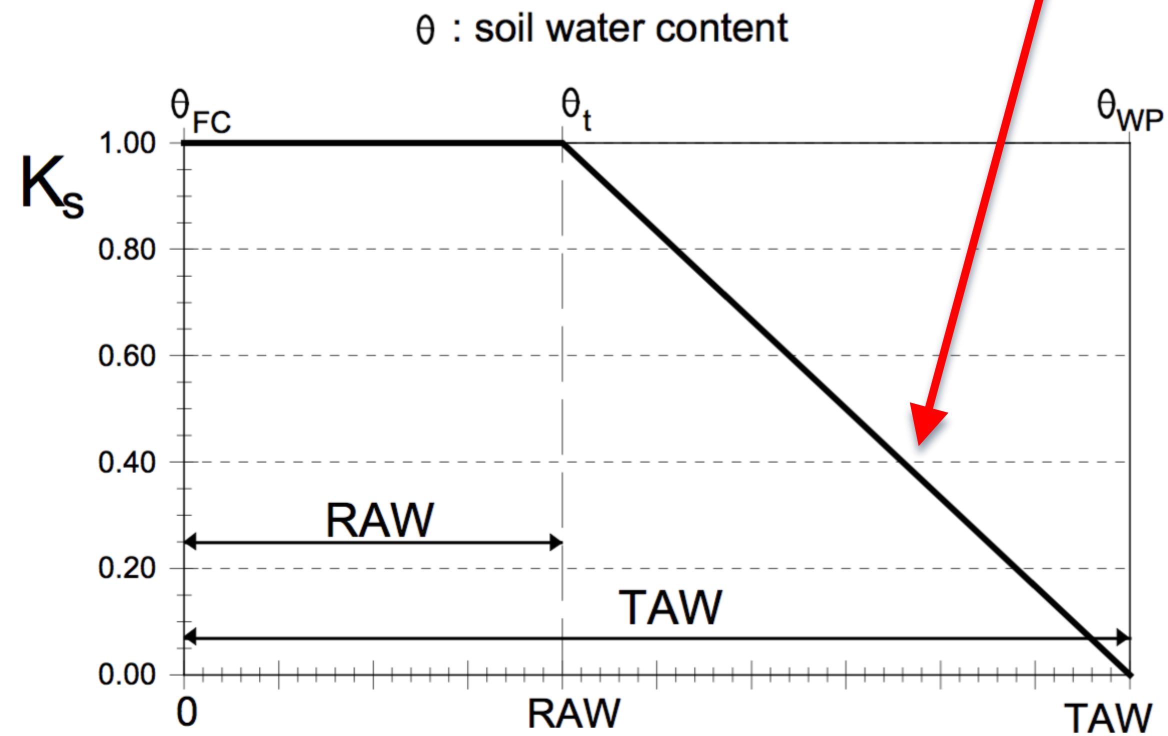
$$\frac{r_s}{r_{ah}} = \frac{\frac{0.81 Q_{RAD} r_{ah} \gamma}{2 LAI \rho C_p} - \left[(T_c - T_a)(0.81\gamma + \delta) \right] - \mathrm{VPD}}{\gamma \left[(T_c - T_a) - \frac{Q_{RAD} r_{ah}}{2 LAI \rho C_p} \right]}$$

FAO Paper No. 56

$$ET_{c\,adj} = K_s\,K_c\,ET_o$$

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)\,TAW}$$

FIGURE 42
Water stress coefficient, K_s



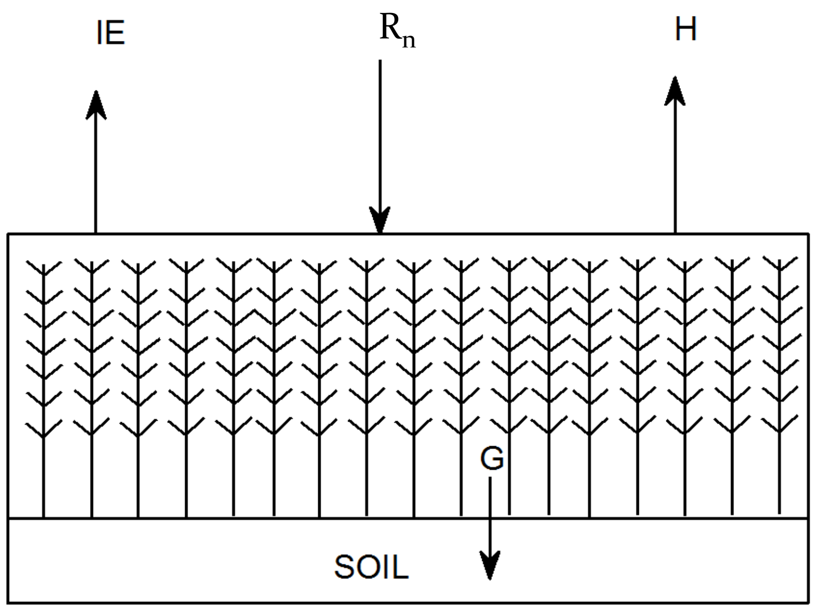
Relative Crop Yield (Y_a/Y_m)

$$\left(1 - \frac{Ya}{Y_m}\right) = K_y\left(1 - \frac{ET_{c\,adj}}{ET_c}\right)$$

where:

K_y	a yield response factor [-]
$ET_{c\,adj}$	adjusted (actual) crop evapotranspiration [mm d^{-1}]
ET_c	crop evapotranspiration for standard conditions (no water stress) [mm d^{-1}]

Canopy Energy Balance



$$R_n + lE + H + G + aA = 0$$

R_n = Net radiation
lE = Latent heat flux
H = Sensible heat flux.
G = Soil heat flux
aA = energy utilized in photosynthetic activity.

Bowen Ratio

$$\beta = \frac{H}{LE}$$

$$= \gamma \left(\frac{T_s - T_a}{e_s - e_a}\right)$$

Where *H* and *LE* are the sensible and latent heat flux, respectively,

T_s and T are the water surface and air temperatures respectively, in degrees Celsius,

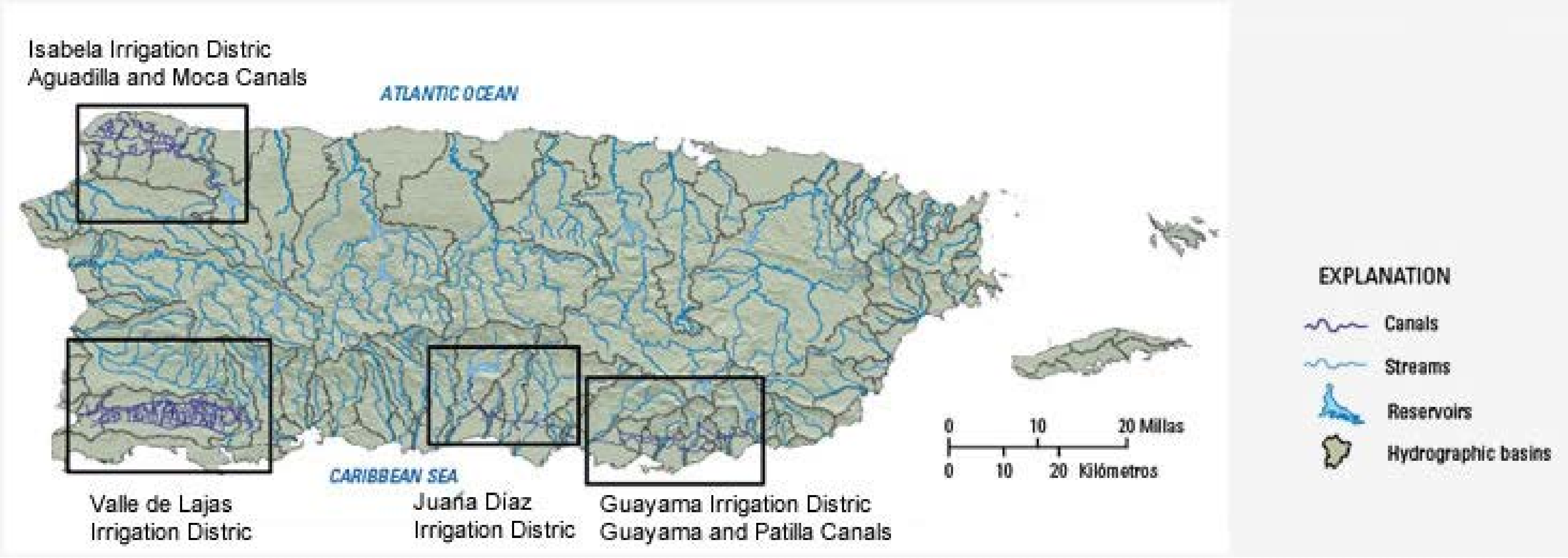
e_s and e_a are vapor pressures at the water surface and air, respectively, in kilopascals, and

γ is the psychometric constant, in kilopascals per degree Celsius.

The 2015 Drought

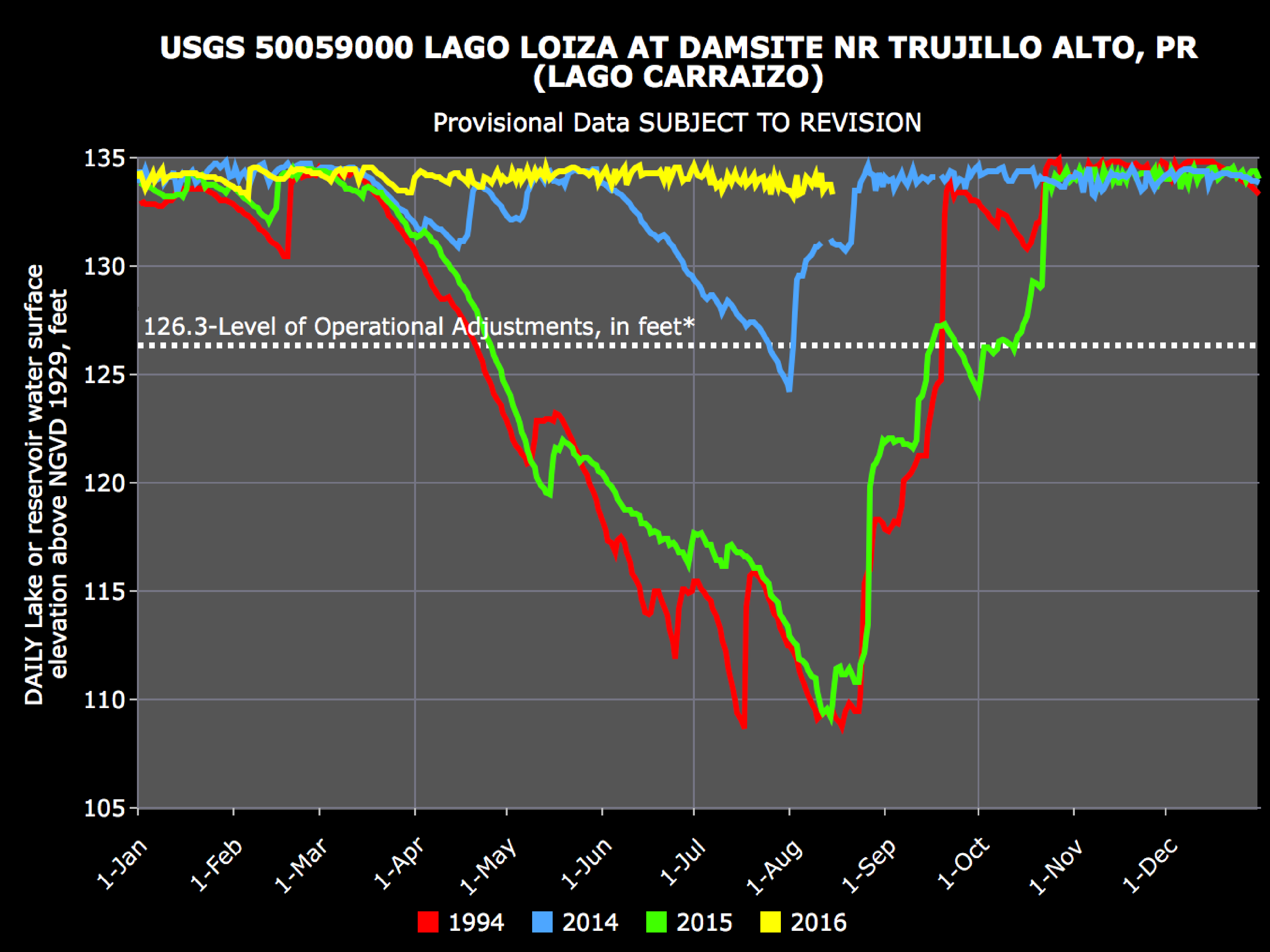
- Puerto Rico experience a prolonged drought during the months a April through September.
- Water

Irrigation Districts of PR



Irrigation Districts

- Agricultural water requirements are not well island
- Canals have limited spatial extent
- Canals are in disrepair in some areas, and water is lost from the system
- Water is essentially free to farmers


USGS 50059000 LAGO LOIZA AT DAMSITE NR TRUJILLO ALTO, PR
(LAGO CARRAIZO)
Provisional Data SUBJECT TO REVISION
DAILY Lake or reservoir water surface elevation above NGVD 1929, feet
135
130
125
120
115
110
105
126.3-Level of Operational Adjustments, in feet*
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1994
2014
2015
2016

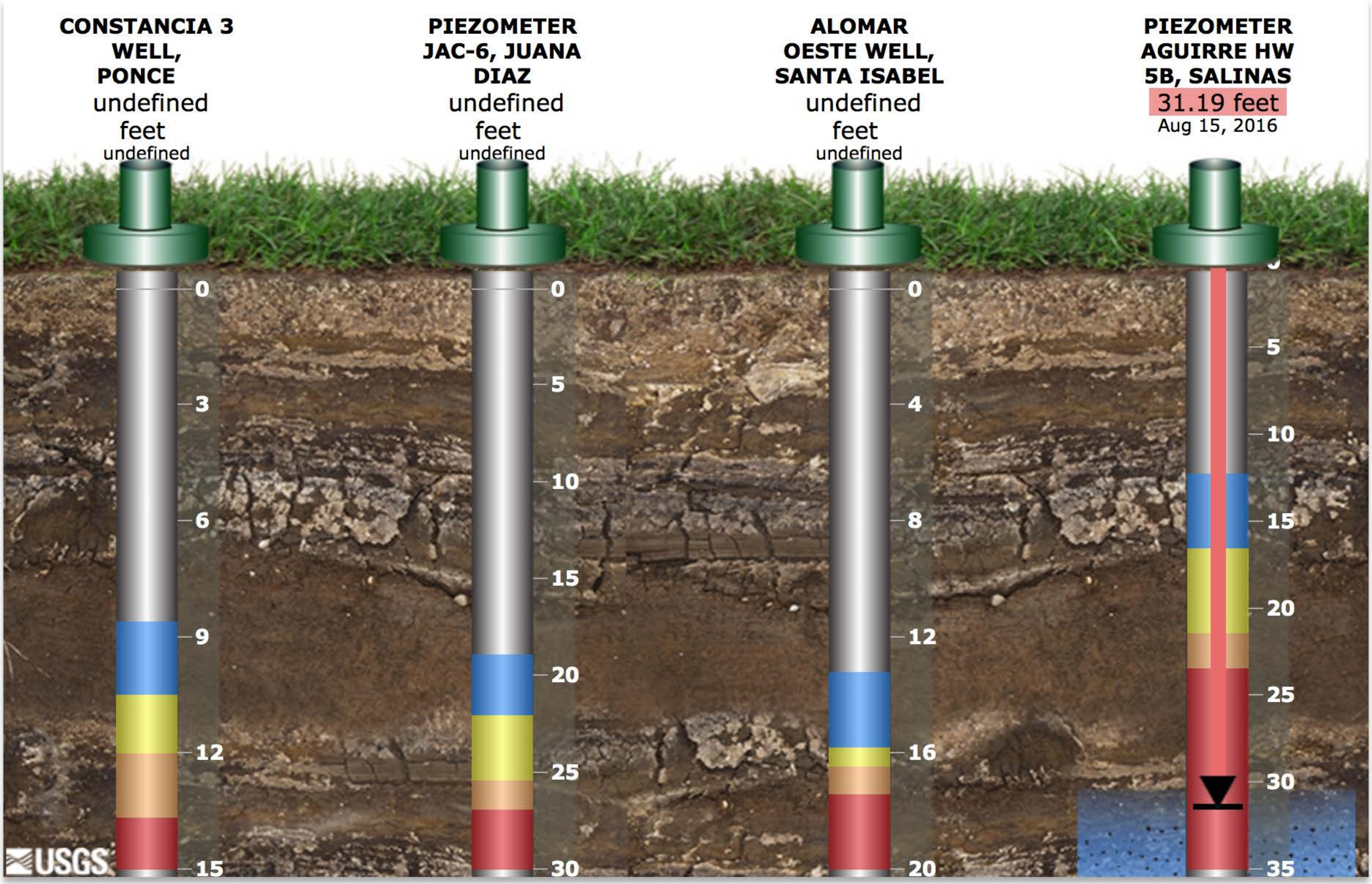
June 19, 2015, aerial photo shows the drought-affected lakeshore of La Plata reservoir in Toa Alta, Puerto Rico.

Water Conflicts

- Conflicts exist between the agriculture and non-agricultural sectors. For example, in the Guayama Irrigation District, 28% of the water is used for agriculture, 72% for domestic/industrial use.
- Expansion of agricultural production is being promoted, which will result in more competition for water resources.

Groundwater

- Salinity levels are increasing in some of the wells near the ocean.
- Induced aquifer recharge systems have been designed and are operational in Guanica and Juana Diaz areas.
- The interior of the island is characterized by relatively low permeable rock.



CONSTANCIA 3 WELL, PONCE
undefined feet
undefined
PIEZOMETER JAC-6, JUANA DIAZ
undefined feet
undefined
ALOMAR OESTE WELL, SANTA ISABEL
undefined feet
undefined
PIEZOMETER AGUIRRE HW 5B, SALINAS
31.19 feet
Aug 15, 2016
0
3
6
9
12
15
0
5
10
15
20
25
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0
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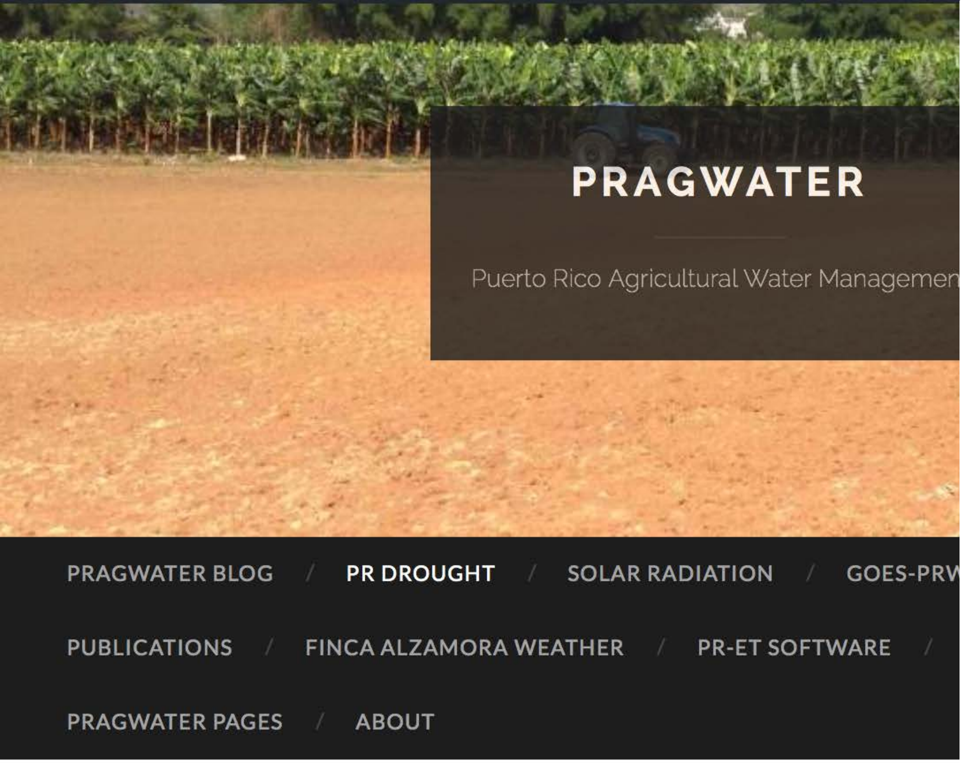
USGS



Progress of 2015 Puerto Rico Drought – Selected Soil and Water Parameters

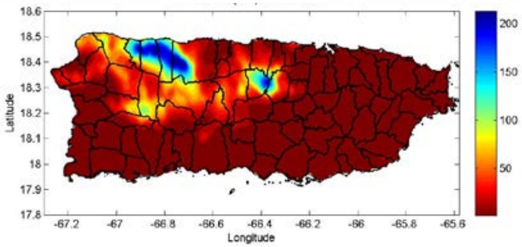
Weekly maps can be viewed by clicking on the following links:

Rainfall
Agricultural rainfall deficit
Agricultural rainfall deficit (negative values only)
Soil Moisture Saturation
Volumetric Soil Moisture Content
Crop Stress Coefficient
Reference (Potential)
Evapotranspiration Actual
Evapotranspiration Natural Log of the
Bowen Ratio

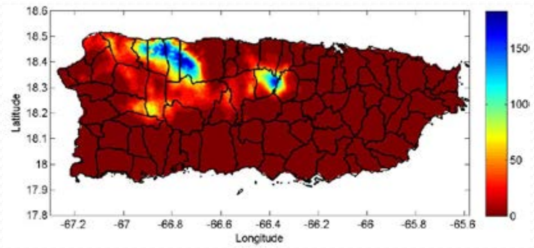
Monthly maps can be viewed by clicking on the following links:

Rainfall
Agricultural Rainfall Deficit
Soil Moisture Saturation
Volumetric Soil Moisture Content
Crop Stress Coefficient
Reference (Potential) Evapotranspiration
Actual Evapotranspiration
Natural Log of the Bowen Ratio

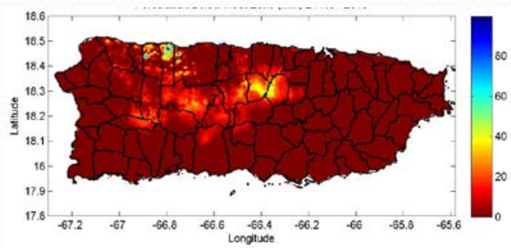
Water and Energy Balance
November 24, 2015



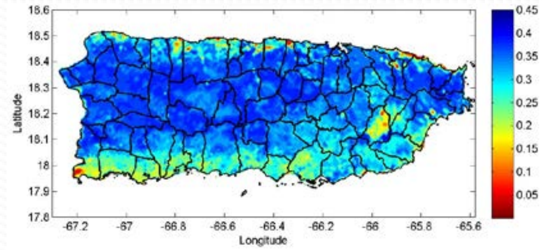
Rainfall



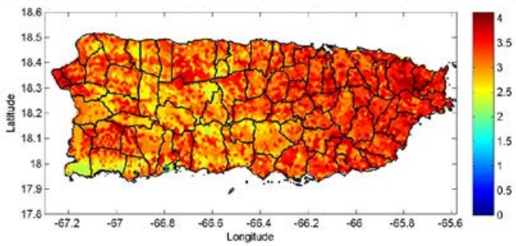
Runoff



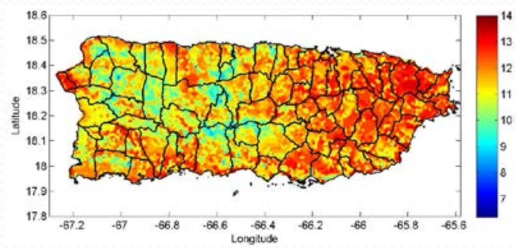
Aquifer Recharge



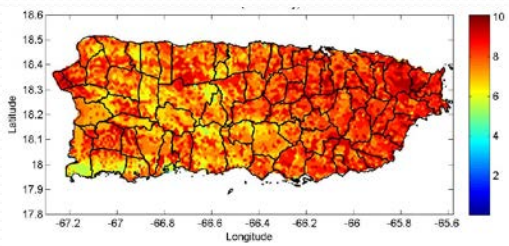
Soil Moisture



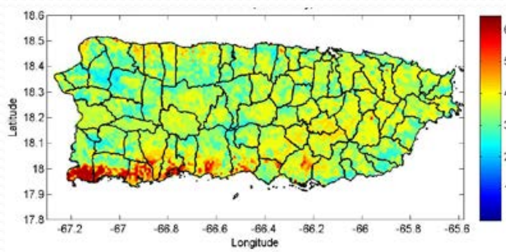
Actual ET



Net Radiation



Latent Heat Flux

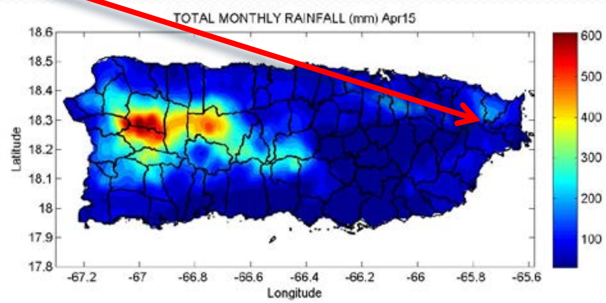


Sensible Heat Flux

RAINFALL (mm)

NOAA's Advanced Hydrologic Prediction Service

El Yunque Tropical Rain Forest



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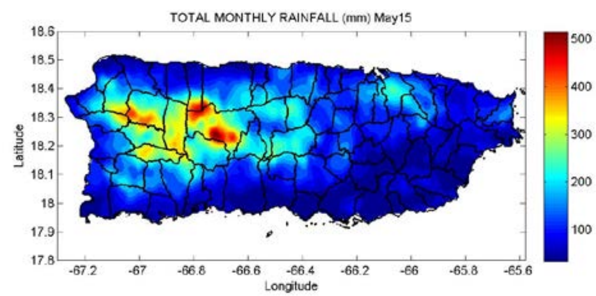

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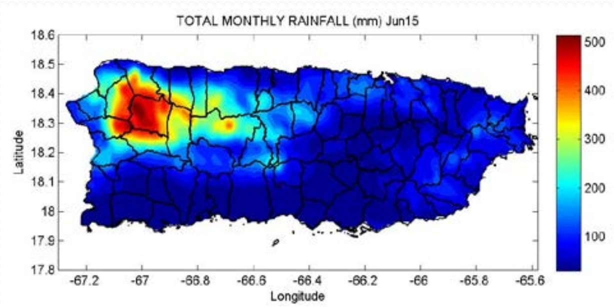

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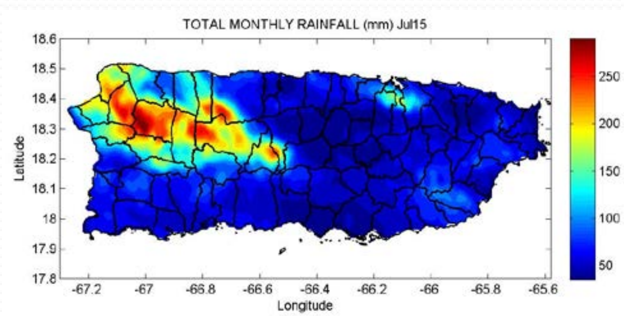

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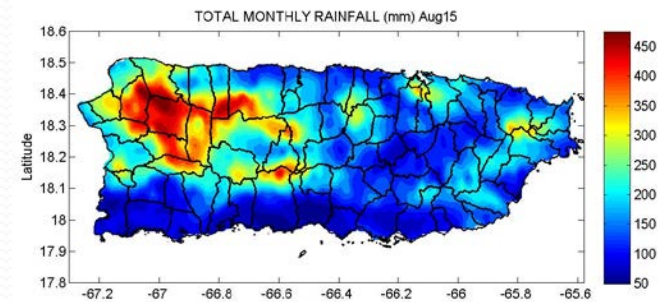

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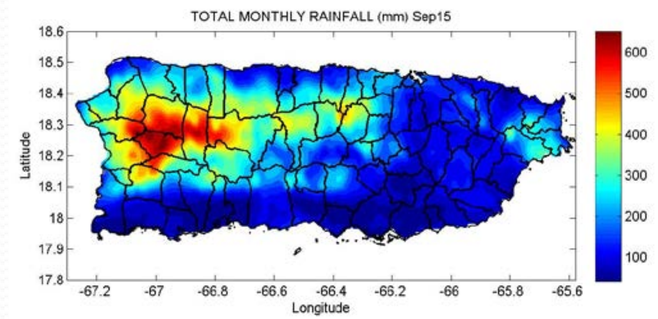

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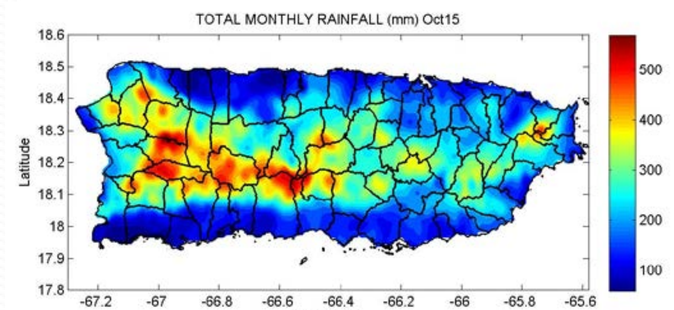

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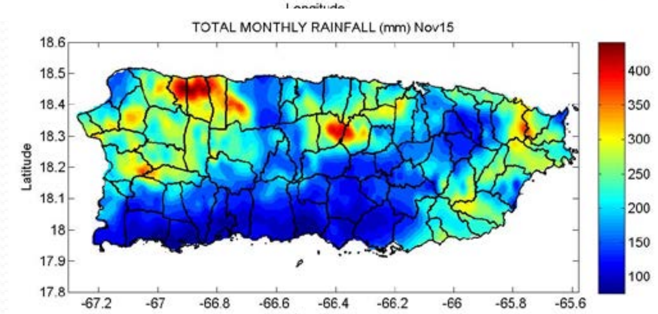

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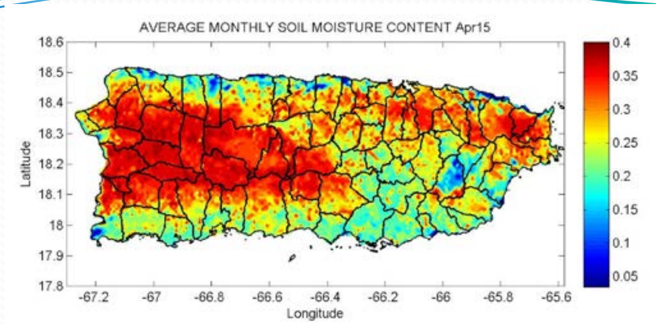
Volumetric Soil Moisture Content (cm³/cm³)



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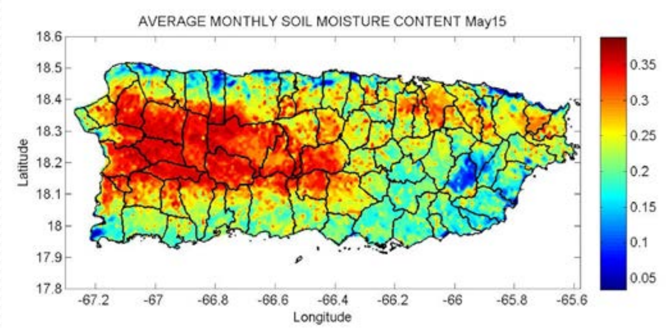

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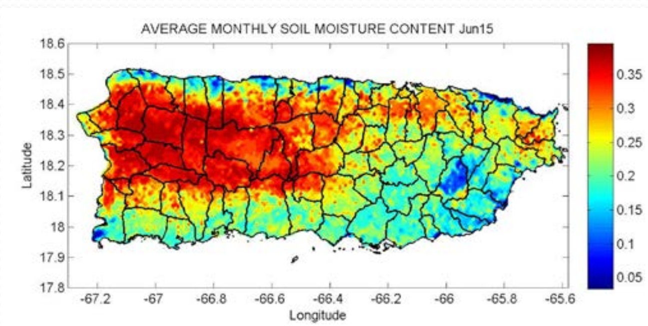

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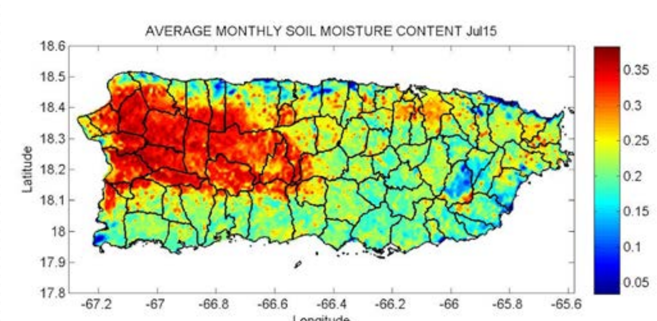

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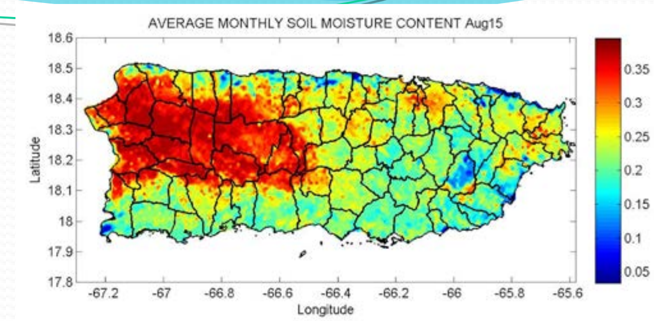

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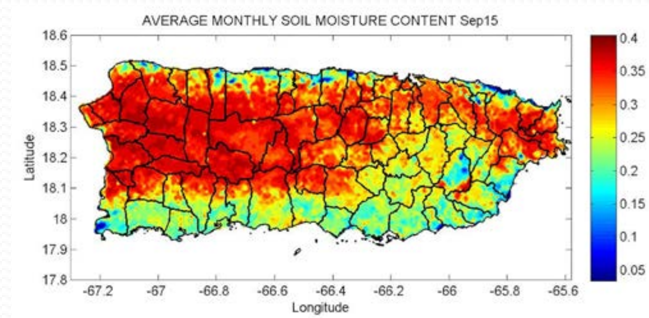

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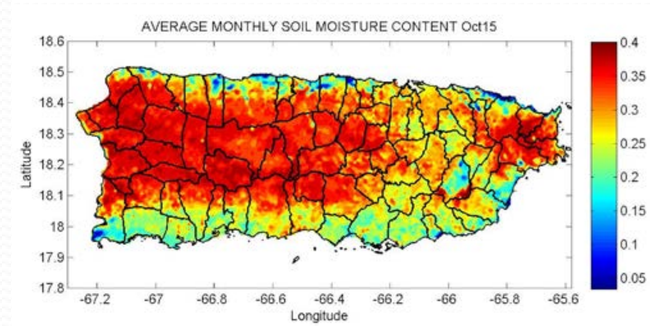

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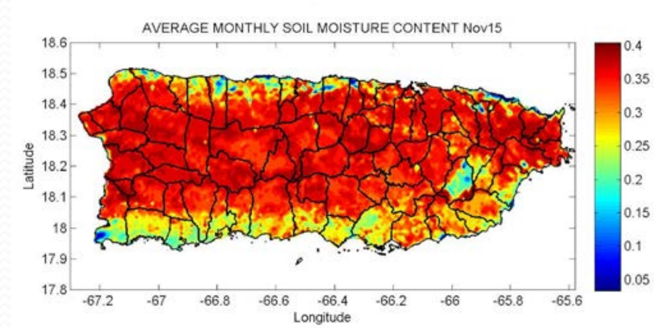

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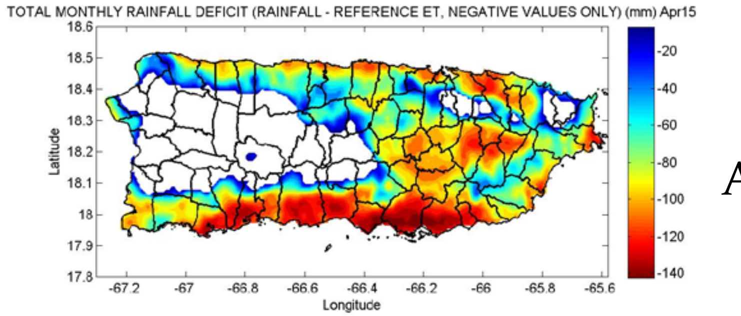
Rainfall Deficit (negative values only) (mm)

Rainfall – Reference Evapotranspiration



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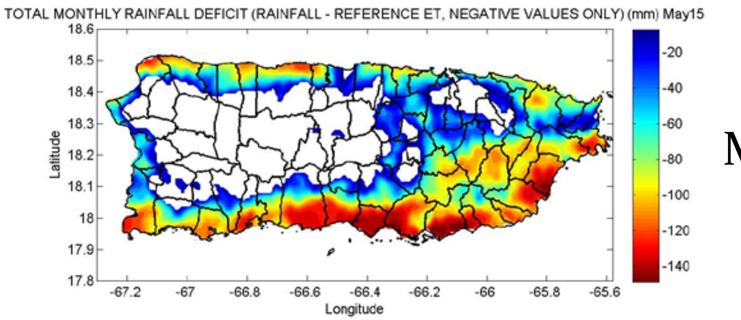

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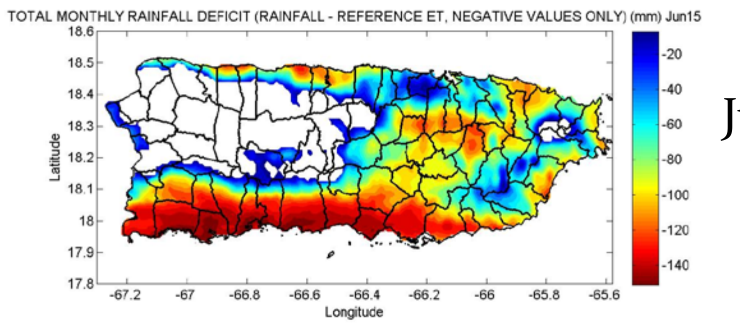

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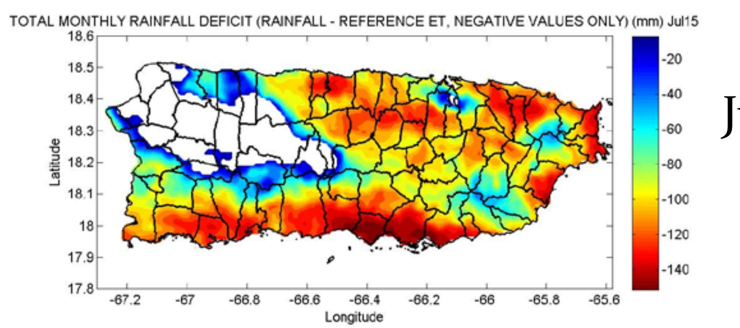

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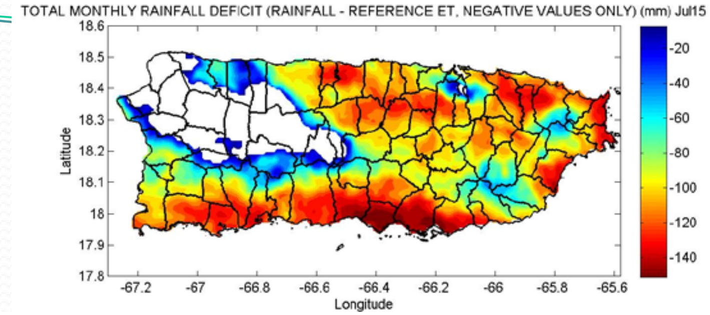

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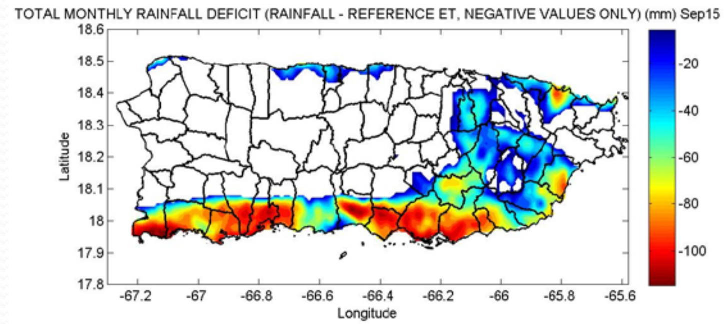

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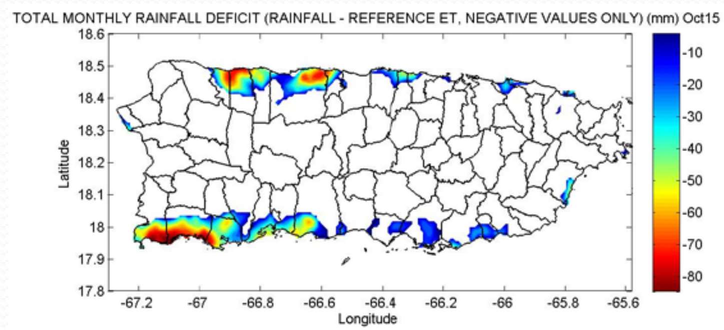

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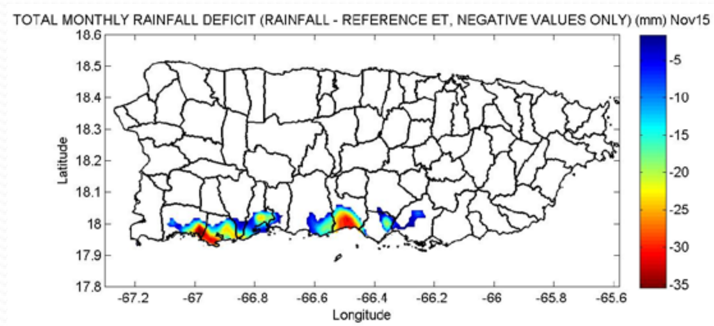

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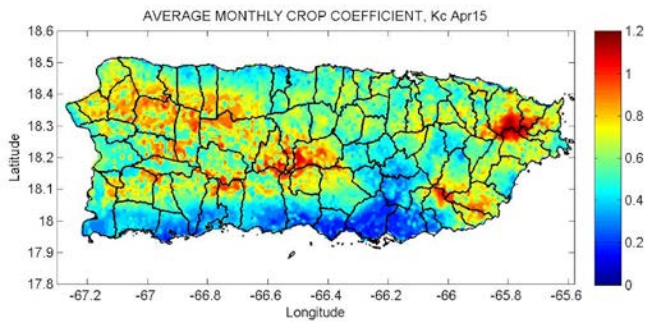
Effective Crop Coefficient



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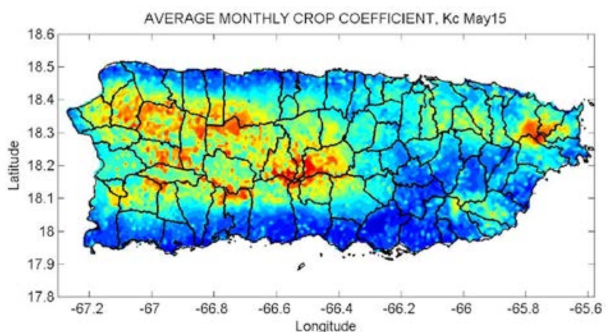

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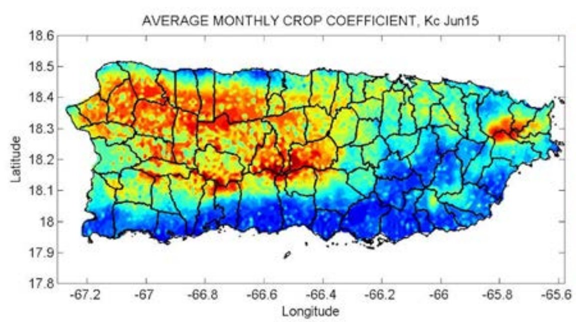

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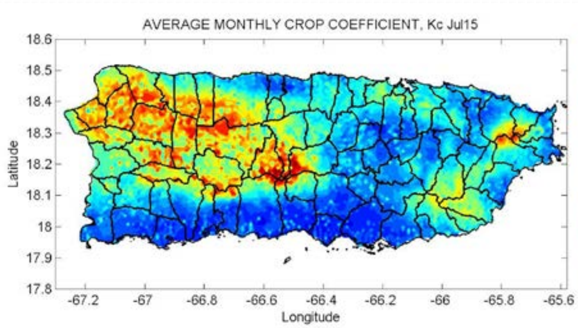

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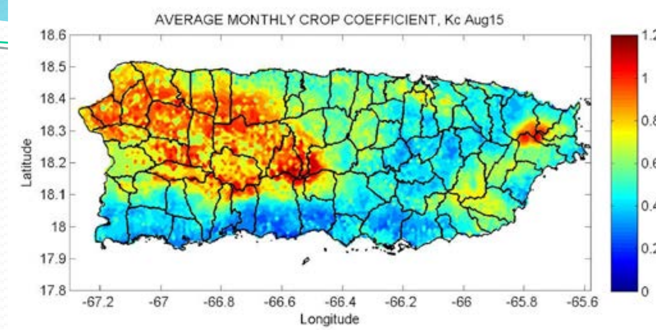

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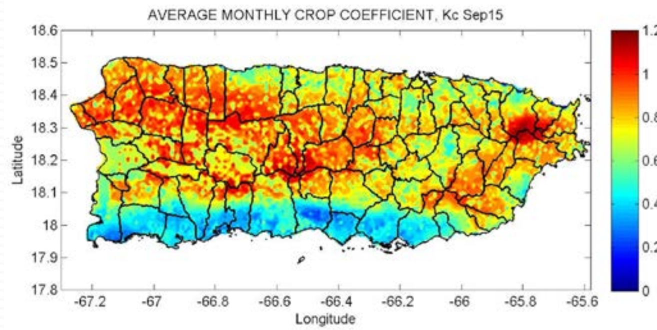

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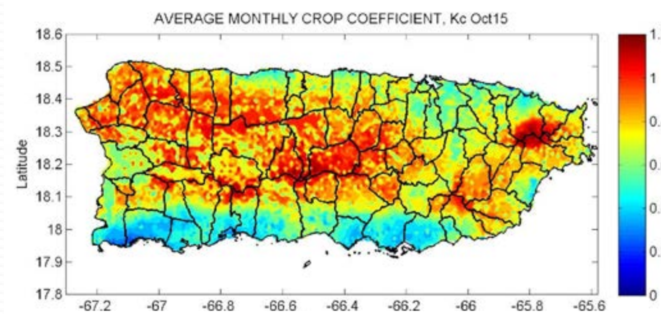

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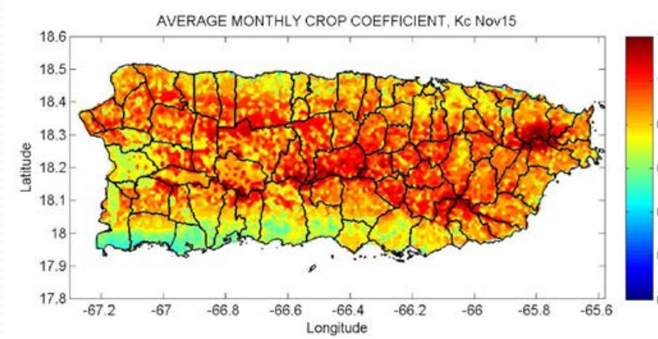

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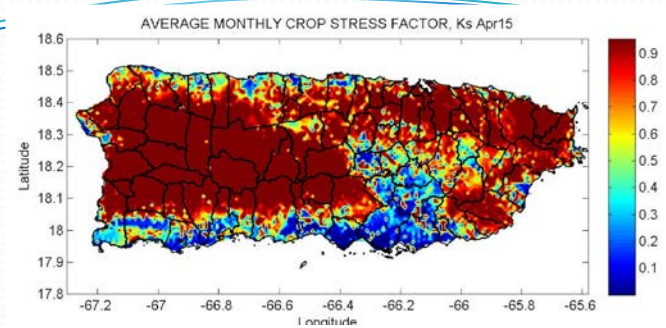
Water Stress Coefficient



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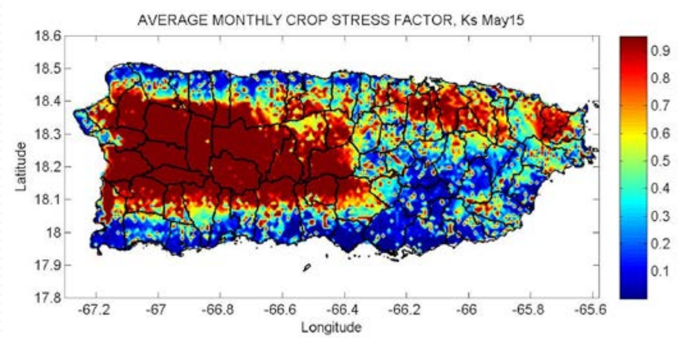

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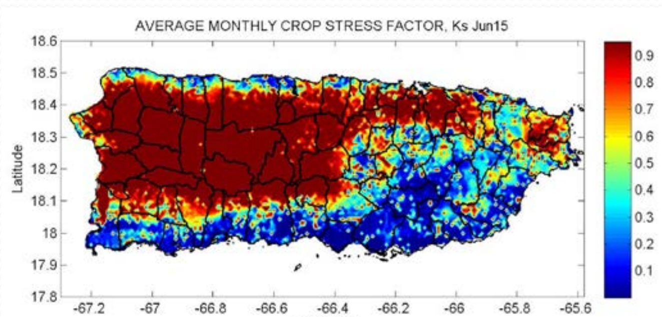
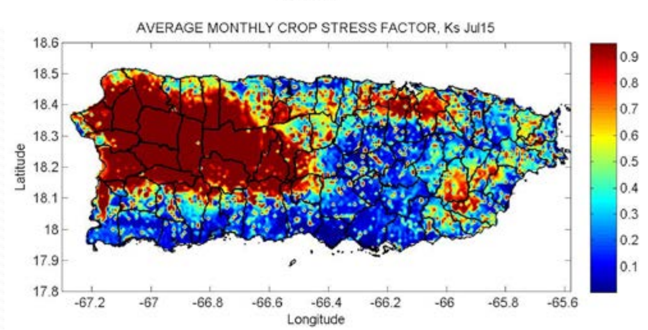


Jun



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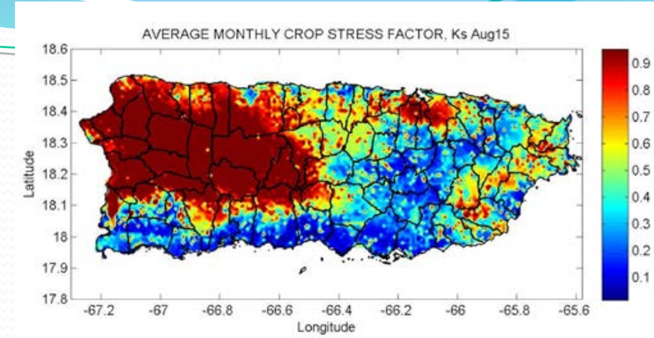

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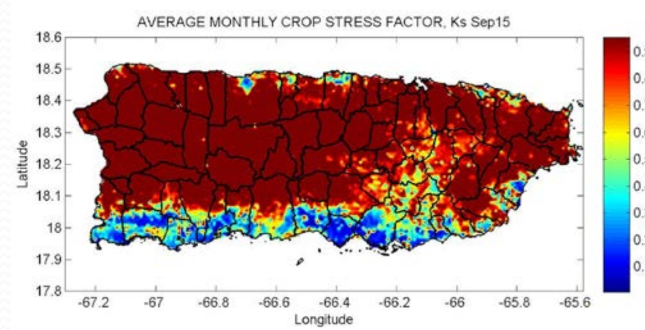

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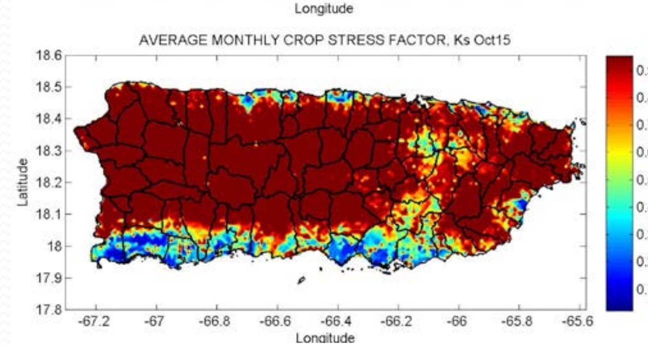

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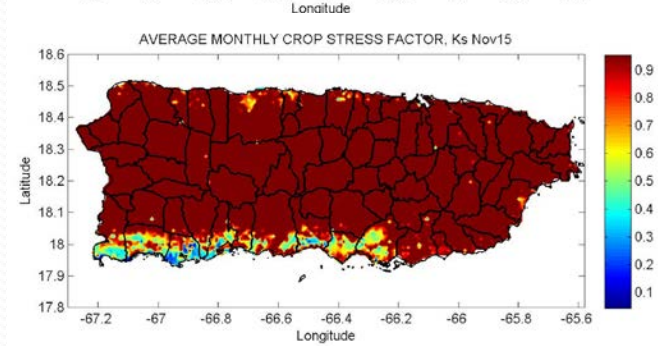
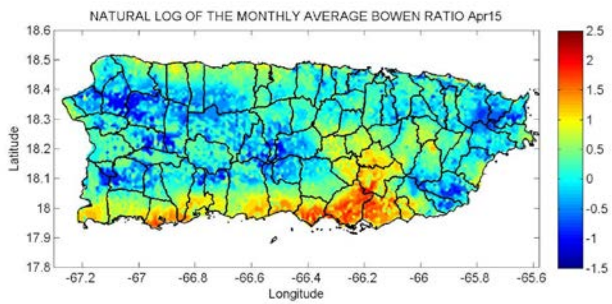


Nov

Log of the Bowen Ratio



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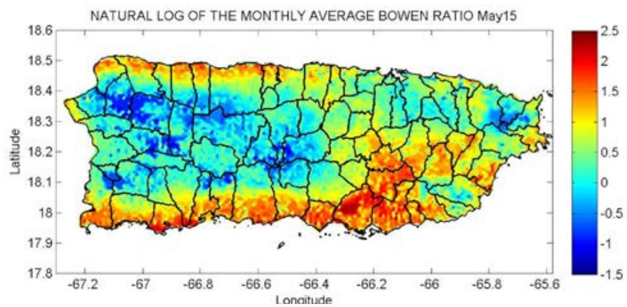

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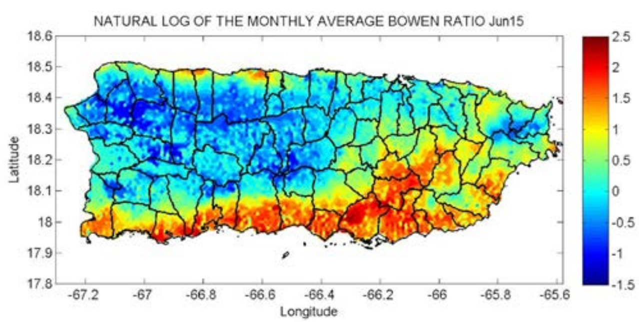

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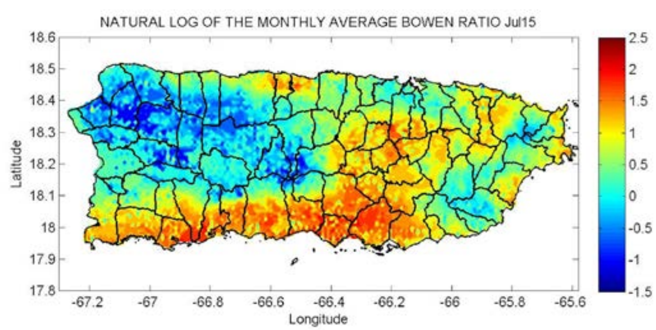

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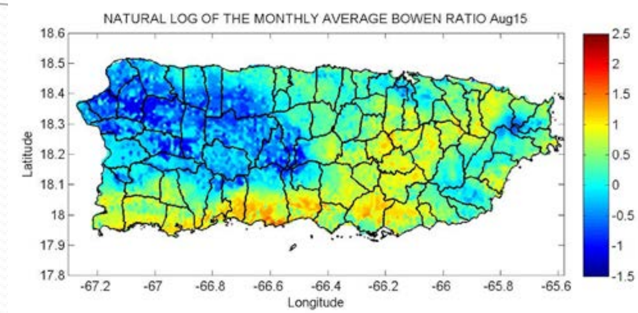

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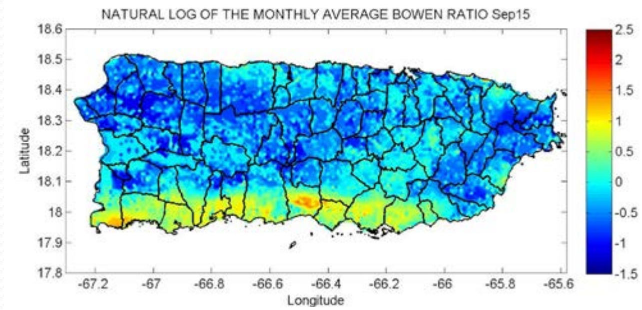

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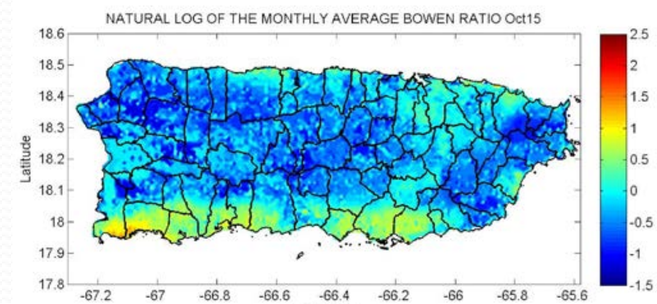

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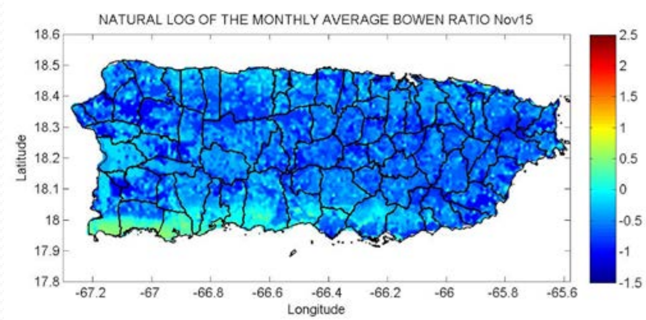
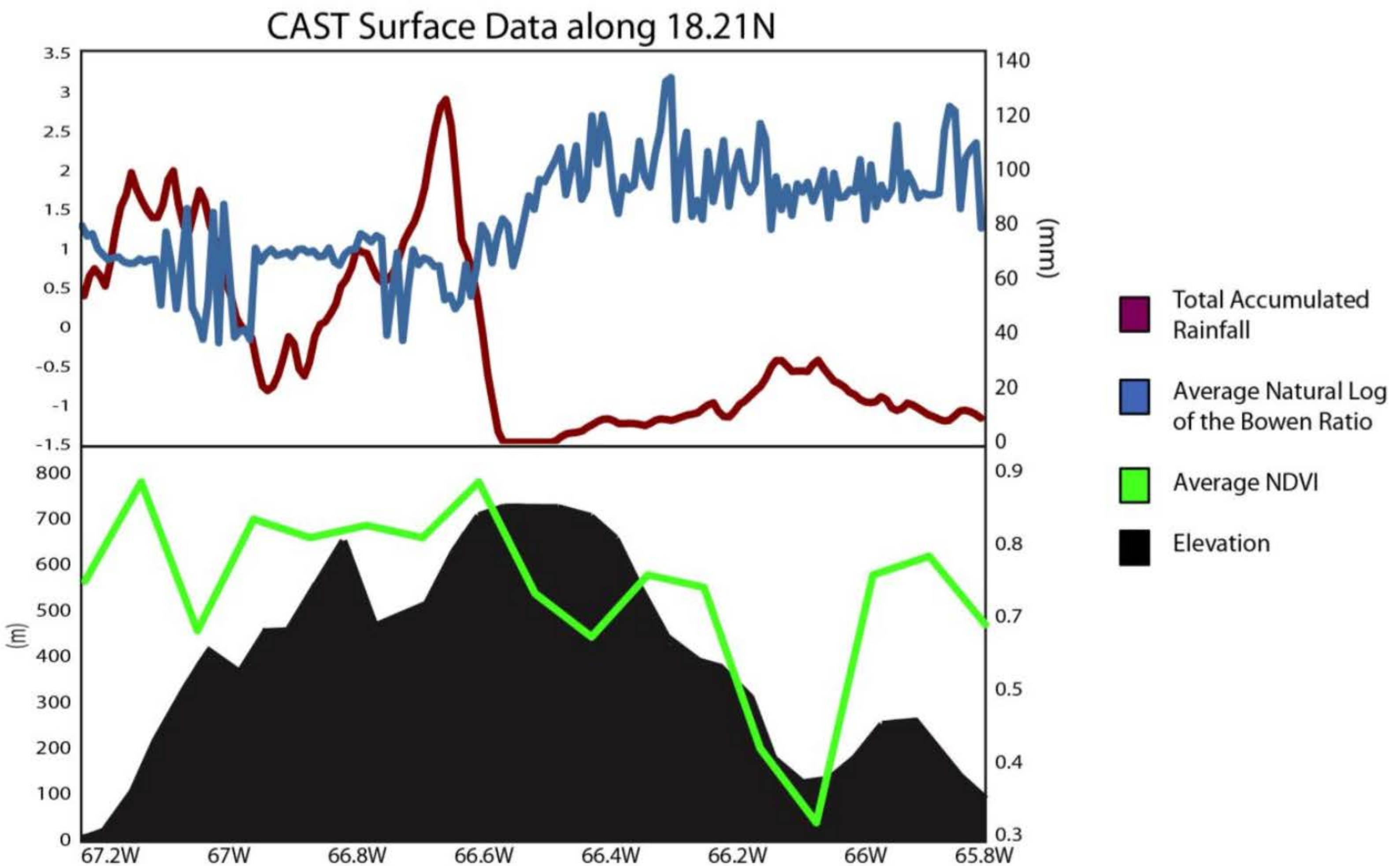


Nov

Natural Log of Bowen Ratio along Transect 18.21 N Latitude from Jun 20 to Jul 10.



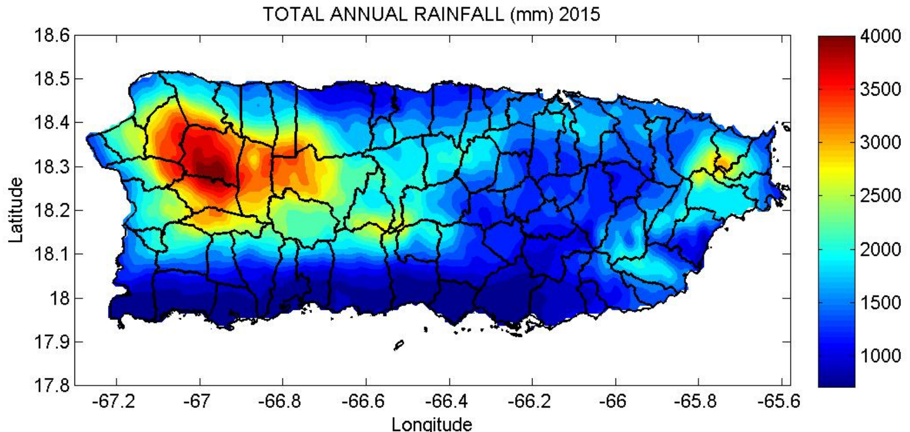
Comparisons of Rainfall in NW PR for drought and non-drought years

Weather Station	Avg. rain drought yrs.	Avg. rain non-drought yrs.
Coloso	72.88	77.48
Hacienda constanza	68.7	69.51
Maricao fish hatchery	81.92	98.62
Mayaguez city	62.31	67.44
Mayaguez airport	62.44	78.24
San sebastian 2 wnw	86.26	91.24

Compared average of:

17 Drought Years

94 Non-Drought Years



NOAA

weather.gov

National Weather Service Weather Forecast Office

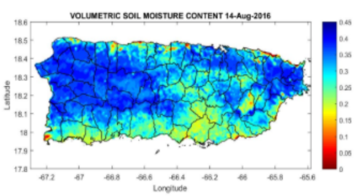
San Juan, PR

Climate & Drought Information

DISCLAIMER: Graphical display of observed rainfall is derived from a combination of USGS raingauge sensors and radar data retrieved by the Advanced Hydrologic Prediction Service (AHPS). Graphical display of Normal rainfall is derived from Puerto Rico 1981-2010 PRISM data. Please note, quality control is not performed on a daily basis.

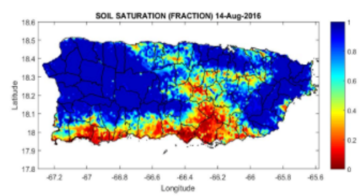
****Click here to access the PR & USVI Daily Precipitation & Deficits from AHPS****

Click to enlarge



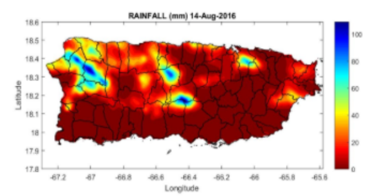
**PRAGWATER Soil Moisture

Click to enlarge



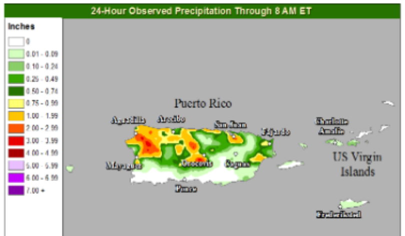
**PRAGWATER Soil Saturation

Click to enlarge



**PRAGWATER Yesterday Rainfall

Click to enlarge



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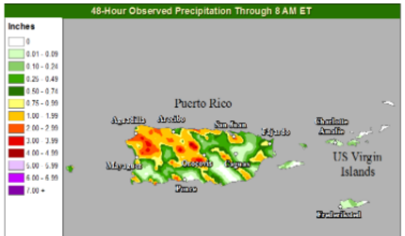

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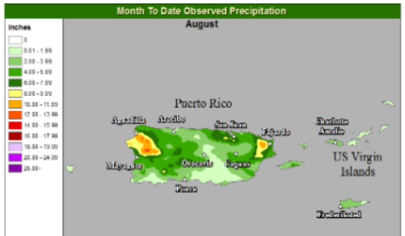
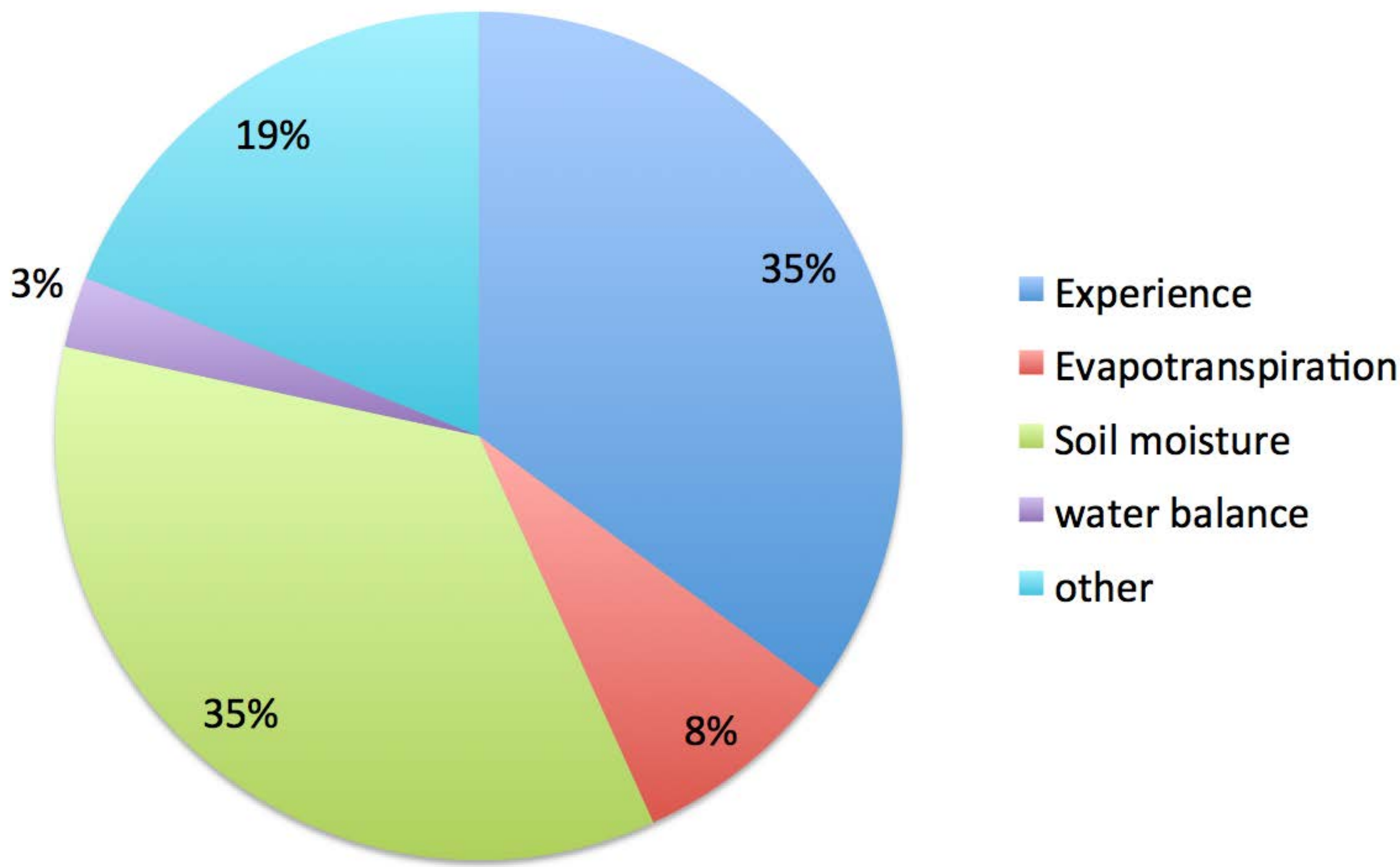


How do we avoid crop water stress?

Irrigation Scheduling

Irrigation Scheduling Methods used in Puerto Rico (preliminary data)



How much water should be applied?

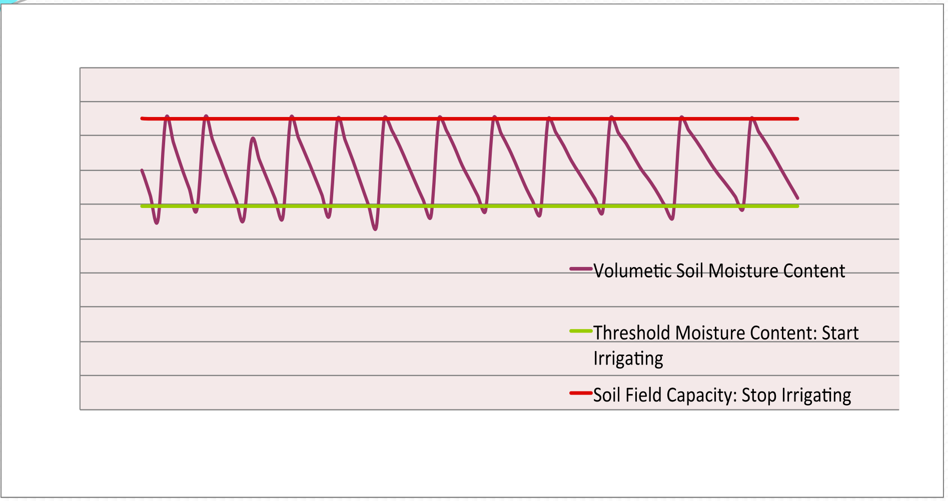
Plant Water Requirement

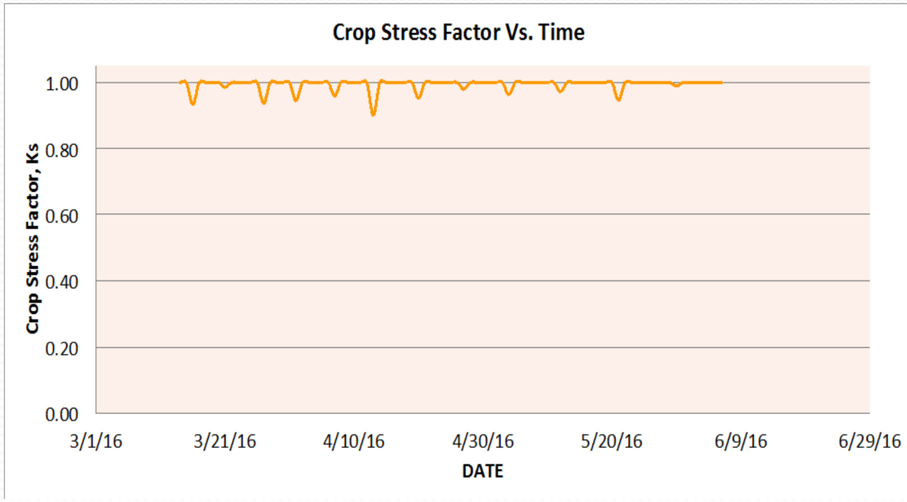
=

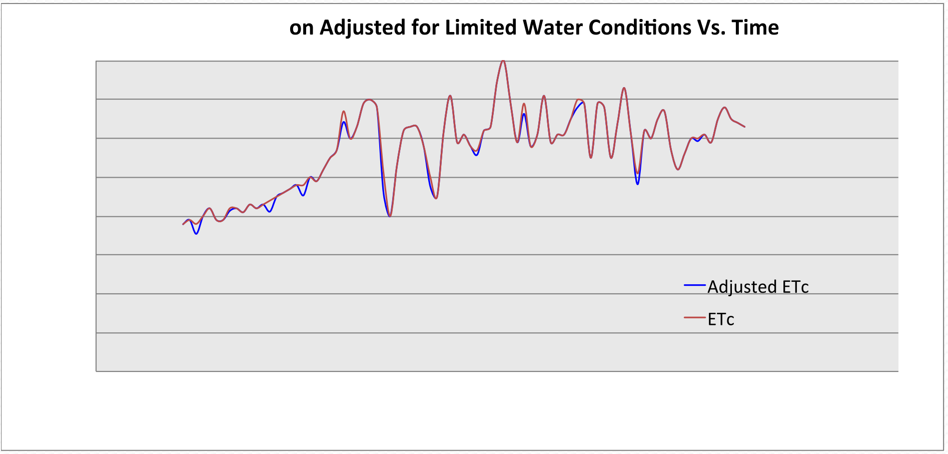
Crop Evapotranspiration

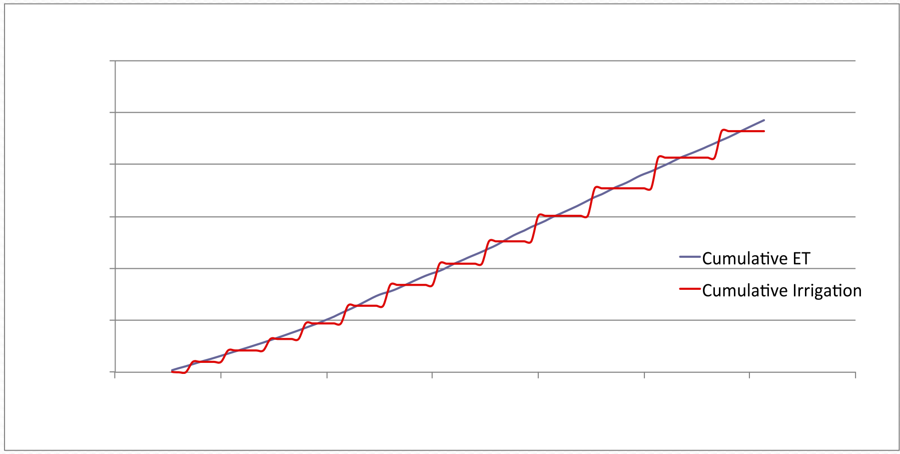
(under well-watered conditions)

OPTIMAL IRRIGATION

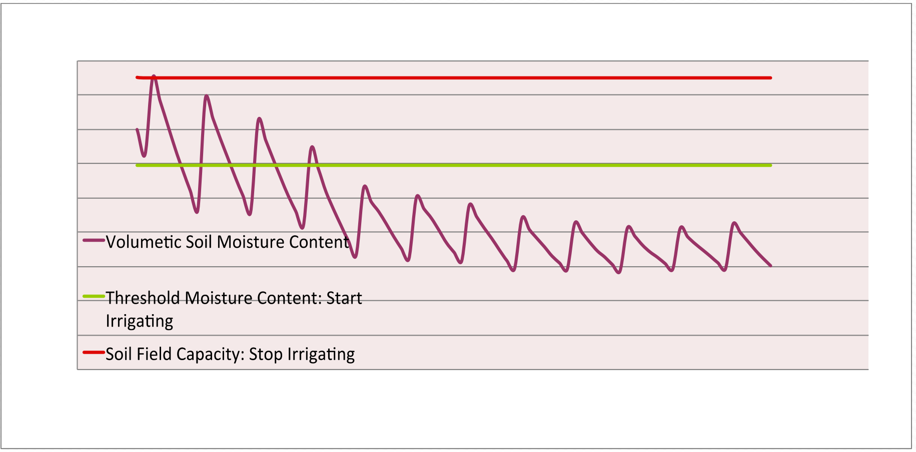


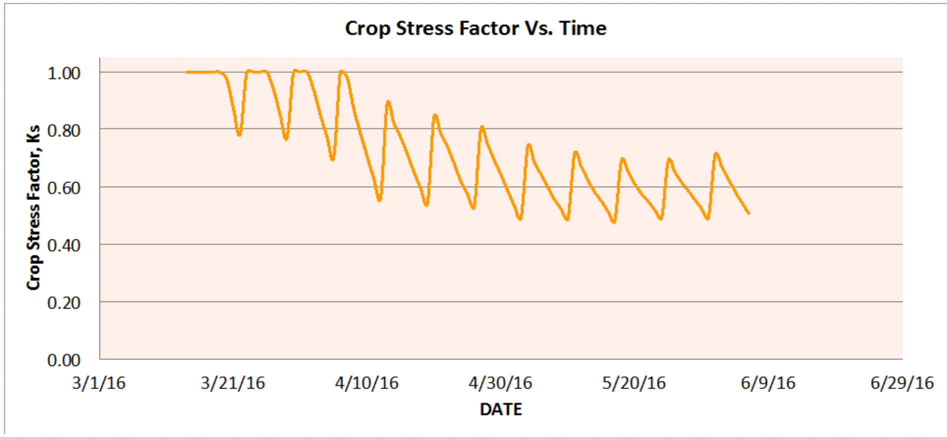


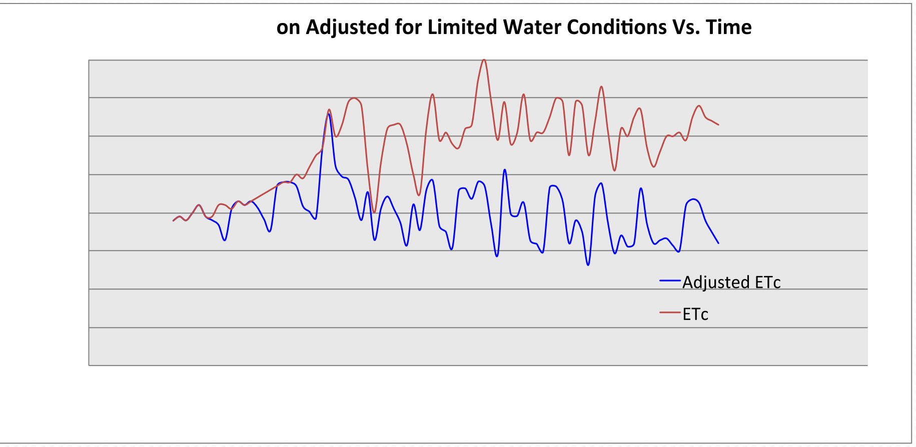


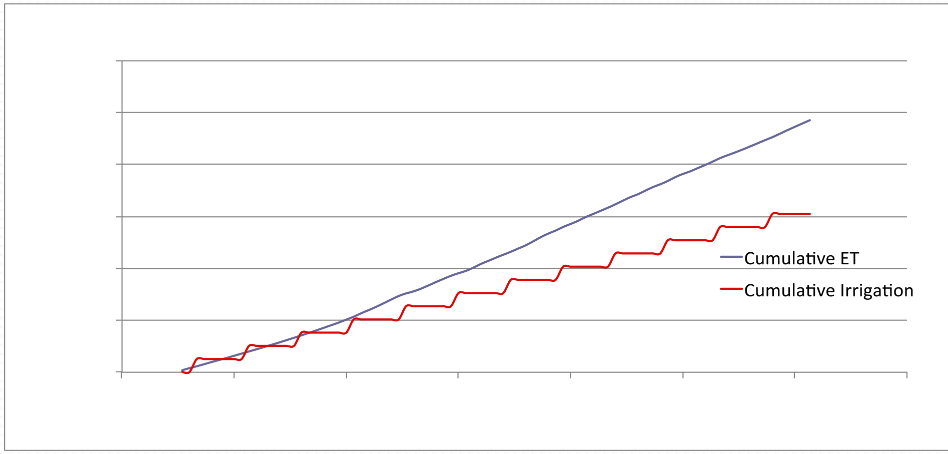


1-INCH PER WEEK IRRIGATION









The most commonly used method for determing the Crop Water Requirement

$$ET_c = K_c \, ET_o$$

where

ET_c = evapotranspiration under well-watered conditions = crop water requirement

K_c = Crop Coefficient (unique for every crop)

ET_o = Reference Evapotranspiration (function of climate)

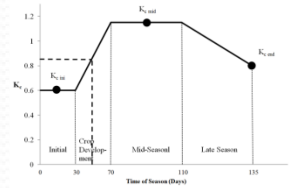
Many weather stations ($1,700 approx.) will calculate the daily reference evapotranspiration

What if a farmer doesn't have a weather station?

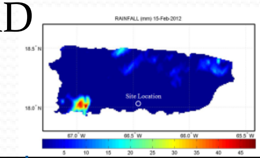
Here's a *relatively* simple web-based method for scheduling irrigation

Start → Define problem (location, farm size, crop, etc.)

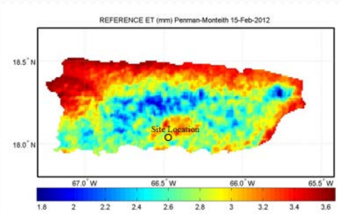
→ Determine average K_c for the time period



→ Determine rainfall from onsite gauge or NEXRAD



→ Determine ET_o



→ Estimate Crop Water Requirement

$$ET_c = K_c\, ET_o$$

→ Determine the number of hours to run the pump

$$T = 17.817 \times [D \times A]/[Q \times eff]$$

Harmsen E.W., 2012. TECHNICAL NOTE: A Simple Web-Based Method for Scheduling Irrigation in Puerto Rico J. Agric. Univ. P.R. 96 (3-4) 2012.

Detailed Example

- Determine the irrigation requirement for the 5 day period, February 15-19, 2012, for a tomato crop in Juana Diaz, Puerto Rico.

Required Hyperlinks

Length of Growth Stages (Table 11) and Crop Coefficients (Table 12)	http://www.fao.org/docrep/X0490E/x0490e00.htm
Daily Reference ET Results for Puerto Rico[4]	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/
Daily NEXRAD Rainfall For Puerto Rico	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall/

Step 1. Information used in example problem.

Location	Juana Diaz, Puerto Rico
Site Latitude	18.02 degrees N
Site Longitude	66.52 degrees W
Site Elevation above sea level	21 m
Crop	Tomato
Planting Date	1-Jan-12
Rainfall information	A rain gauge is not available on or near the farm
Type of irrigation	Drip
Irrigation system efficiency	85%
Field Size	10 acres
Pump capacity	300 gallons per minute

Step 2. Crop growth stage and crop coefficient data for example problem.

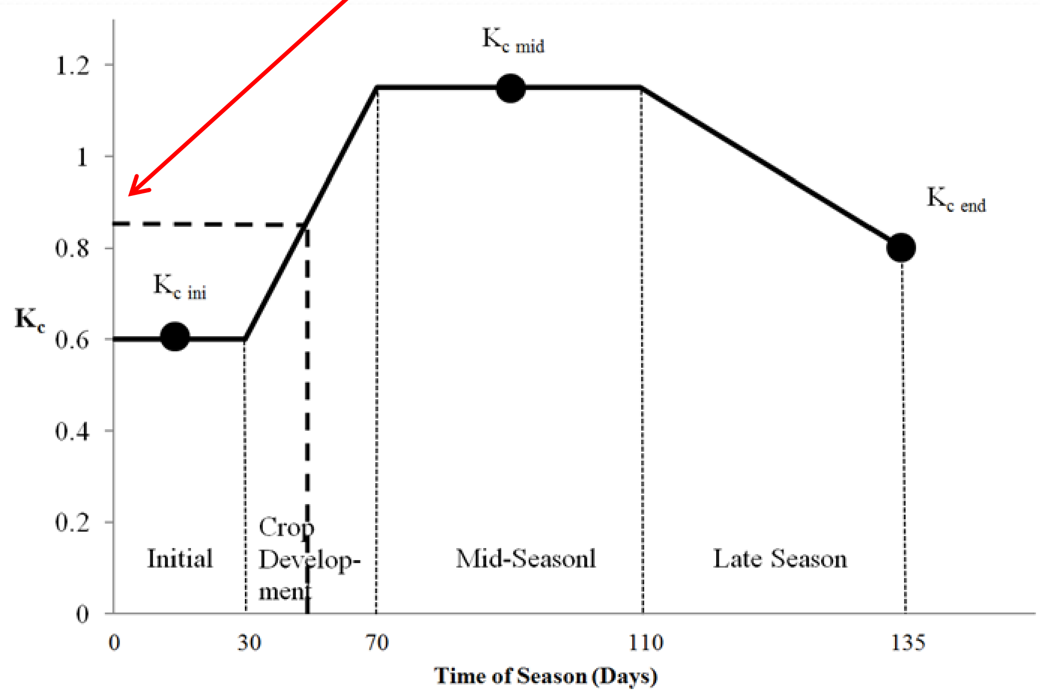
(http://www.fao.org/docrep/X0490E/x0490e00.htm)

Tomato Growth Stages and Crop Coefficients

Initial Crop Growth Stage	30 days
Crop Development Growth Stage	40 days
Mid-Season Growth Stage	40 days
Late-Season Growth Stage	25 days
Total Length of Season	135 days
$K_{c\ ini}$	0.6
$K_{c\ mid}$	1.15
$K_{c\ end}$	0.8

Crop Coefficient

- The averge K_c value of 0.85 for the five day period was obtained.

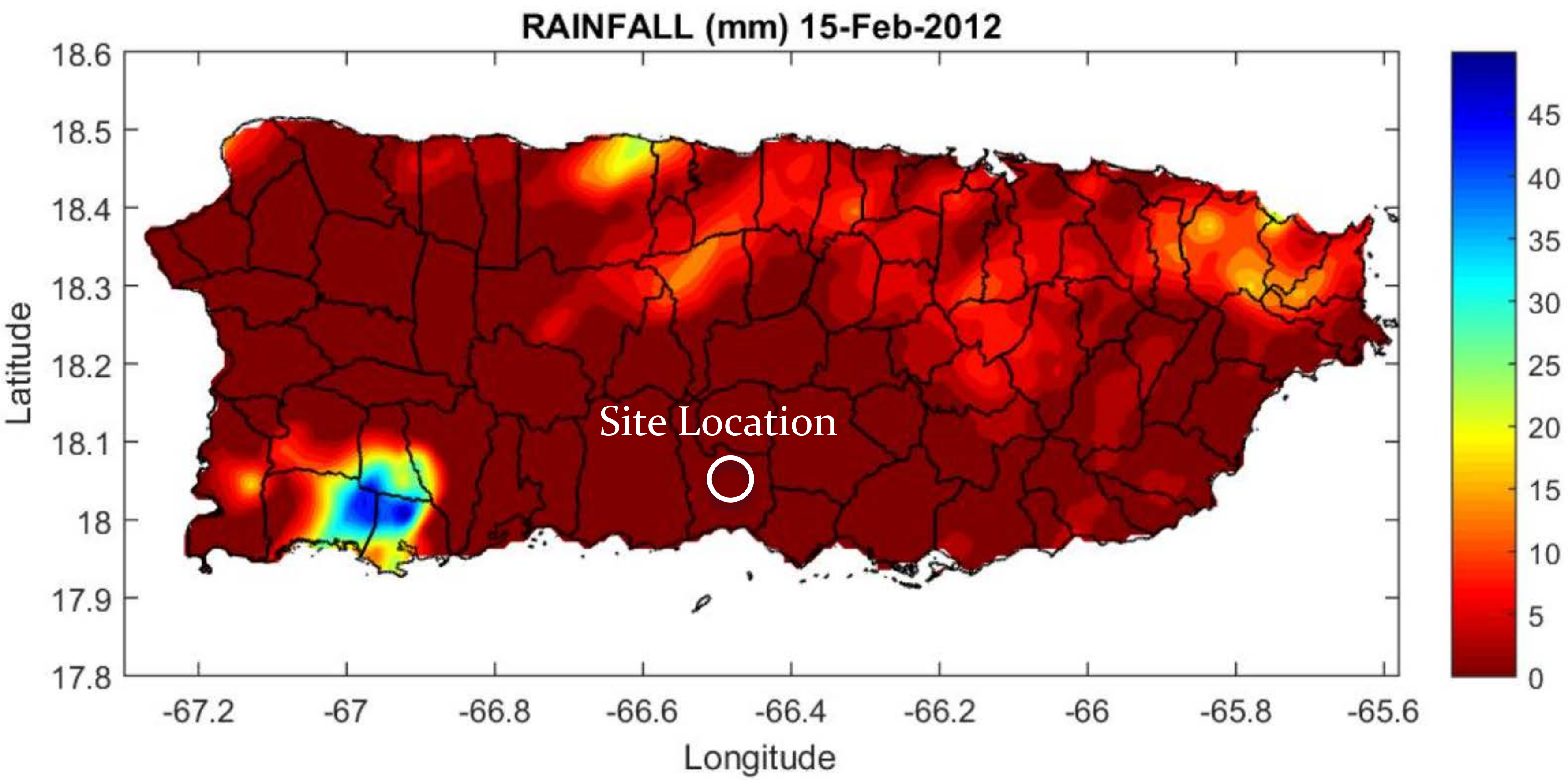


Crop coefficient curve for the example problem. The heavy dashed line applies to the example problem with day of season 46-50 (i.e., Feb 15-19) corresponding to an approximate crop coefficient of 0.85 (vertical axis).

Step 3. Rainfall

(http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall/)

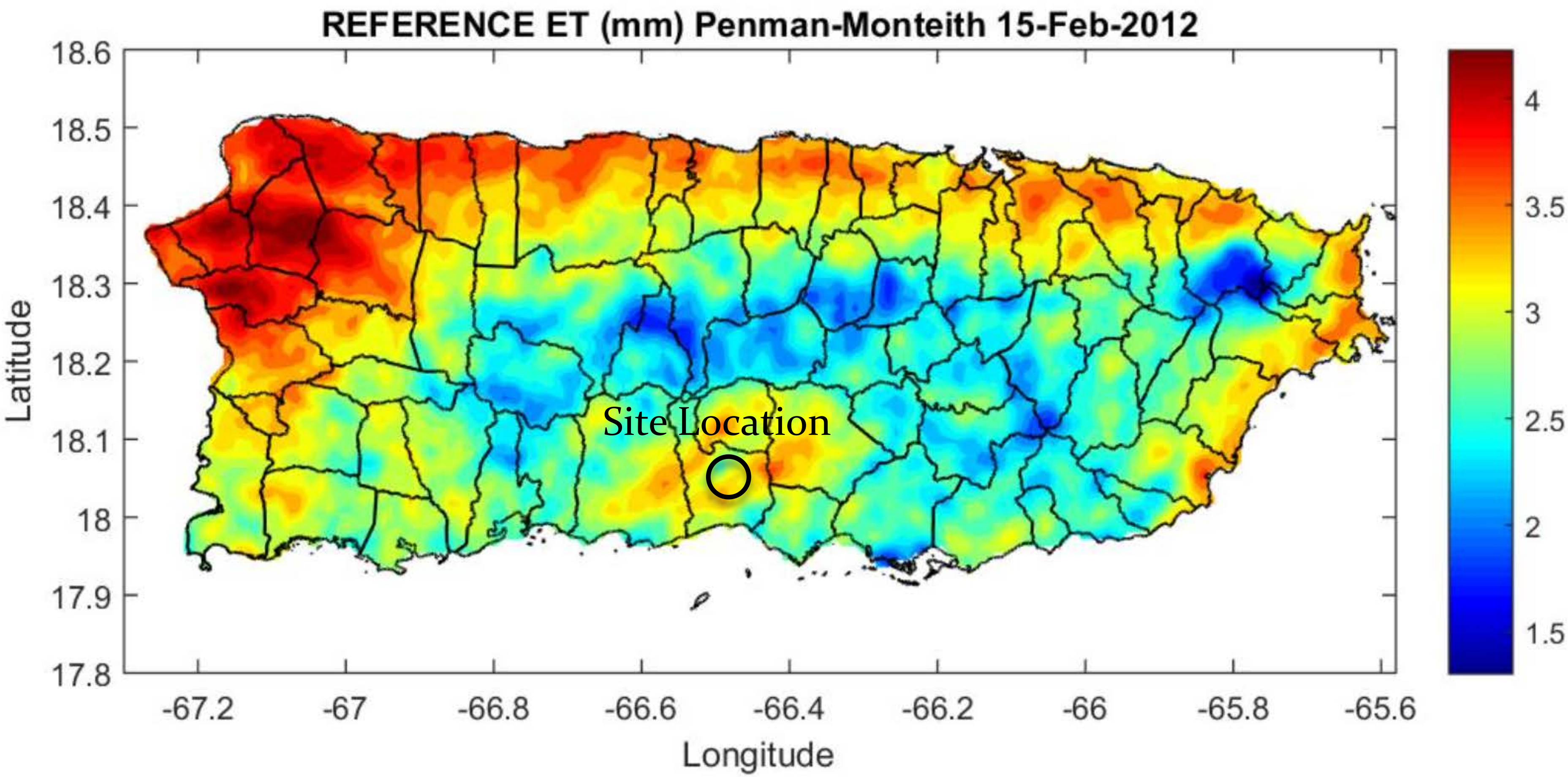
- Inspection of the rainfall maps at the URL provided indicates that there was no rainfall during the five day period.
- Therefore, all of the crop water requirement will have to be satisfied with irrigation.


RAINFALL (mm) 15-Feb-2012
Latitude
18.6
18.5
18.4
18.3
18.2
18.1
18
17.9
17.8
Longitude
-67.2
-67
-66.8
-66.6
-66.4
-66.2
-66
-65.8
-65.6
Site Location
45
40
35
30
25
20
15
10
5
0

Step 4. Reference Evapotranspiration (ET_o)

(http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/)

- Inspection of the ET_o maps at the URL provided above indicates that there was 16.1 mm of ET_o during the five day period.


REFERENCE ET (mm) Penman-Monteith 15-Feb-2012
Latitude
Longitude
18.6
18.5
18.4
18.3
18.2
18.1
18
17.9
17.8
-67.2
-67
-66.8
-66.6
-66.4
-66.2
-66
-65.8
-65.6
4
3.5
3
2.5
2
1.5
Site Location

Step 5. Crop Water Requirement

- The crop water requirement (ET_c) for the time period can now be estimated as follows:

$$ET_c = K_c\ ET_o = (0.85)(16.1\ \text{mm}) = 13.\ 7\ \text{mm}$$

Step 6. Number of hours to run the pump

- Pumping time is estimated from a form of the well-known irrigation equation (Fangmeier et al., 2005) can be used:

$$T = 17.817 \times [D \times A]/[Q \times eff]$$

- where T is time in hours, D is depth of irrigation water (=ET_c) in mm, A is effective field area in acres, Q is flow rate in gallons per minute and eff is irrigation system efficiency.

Number of hours to run the pump to satisfy the crop water requirement for the example problem.

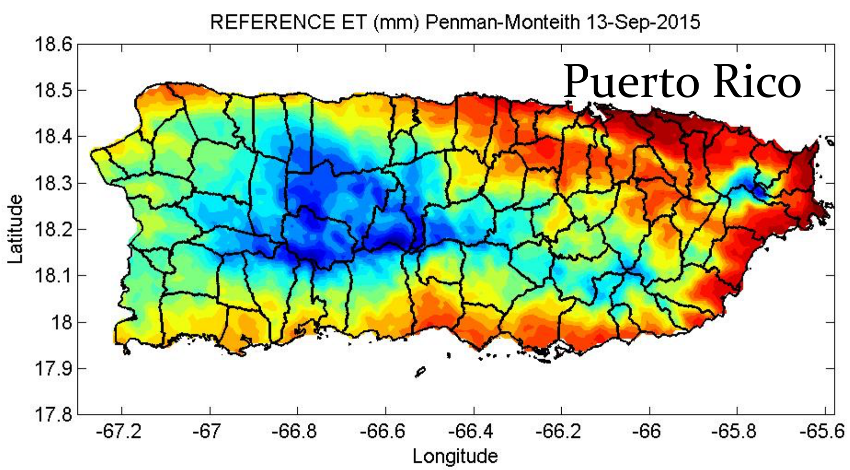
- Using $D = ET_c = 13.7$ mm
- $A = 10$ acres
- $Q = 300$ gallons per minute
- $eff = 0.85$, yields:

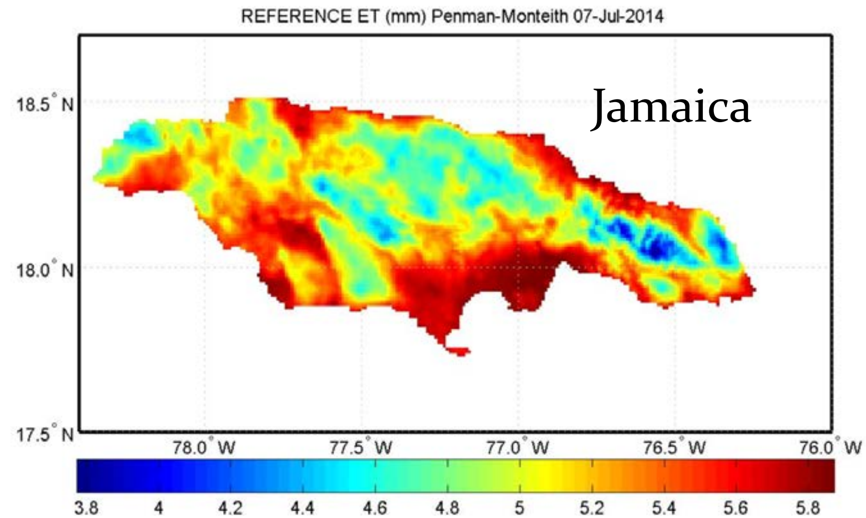
- T = 17.817 x [13.7 x 10] / [300 x 0.85]= **9.57 hours**.

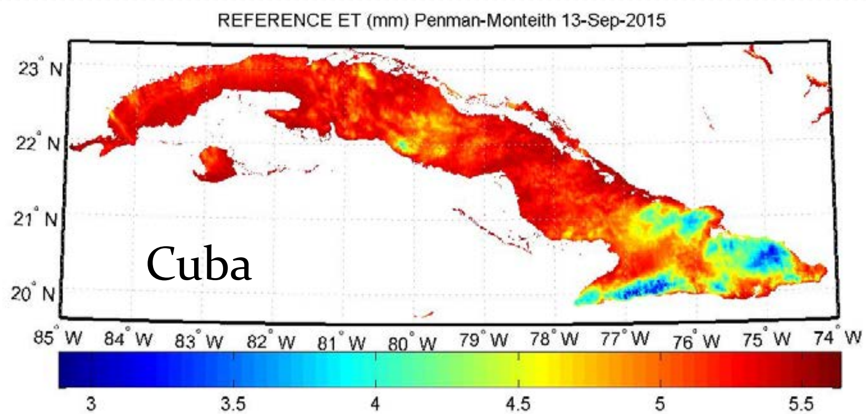
- Total volume = 172,300 gallons

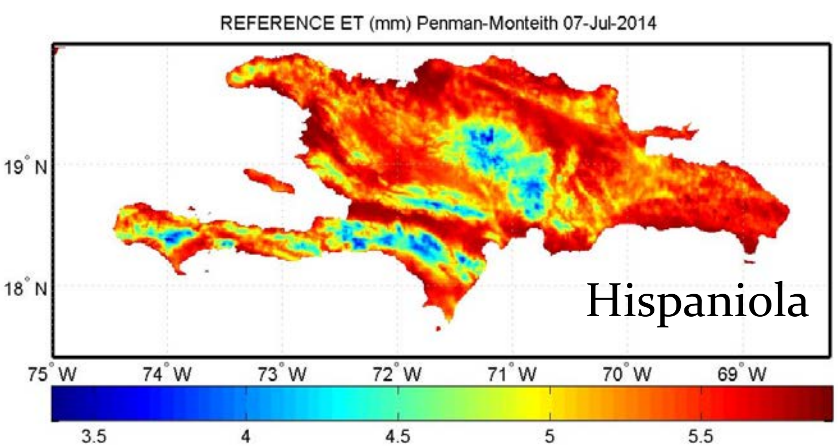
Reference ET for PR, USVI, Hispaniola, Jamaica and Cuba

pragwater.com



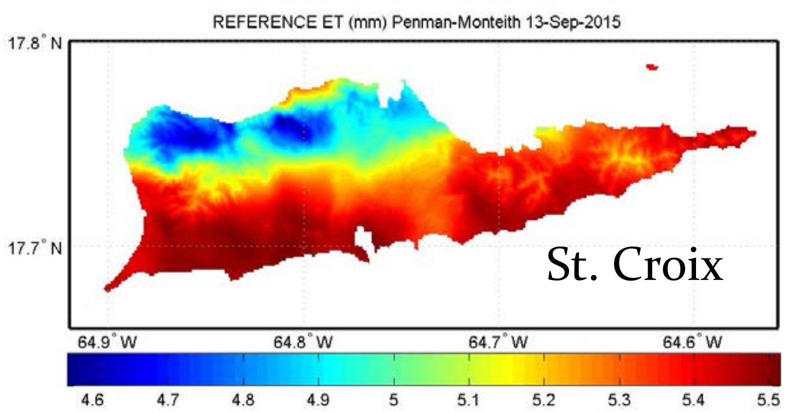


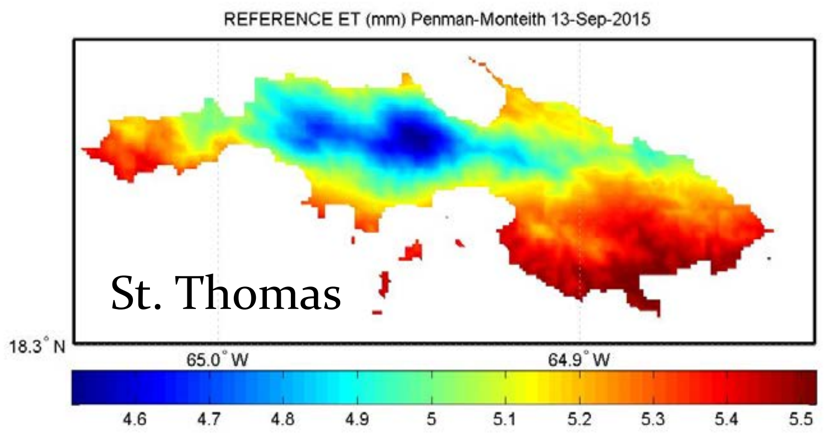


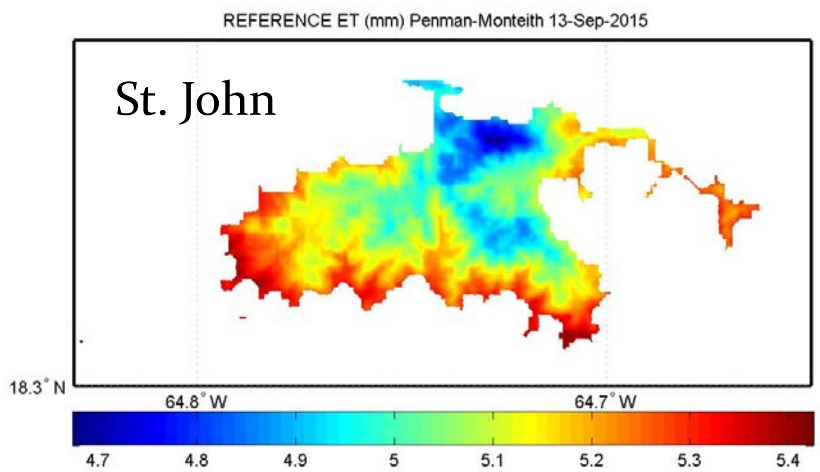


Reference ET for the U.S. Virgin Island

pragwater.com







Conclusions

- The 2015 drought has shown us how vulnerable our water supply system is in Puerto Rico.

- Reservoirs were overdrawn and the irrigation districts were operating at a fraction of their production potential.

- Daily values of soil moisture and crop stress-related parameters from an operational water and energy balance model for the period of the drought were presented.

- An example of irrigation scheduling was given that a farmer in the Caribbean Region can use to help avoid crop water stress.

ACKNOWLEDGEMENT

- Colegio de Ciencias Agrícolas, Universidad de Puerto Rico
- USDA Hatch Project (H-402)
- NOAA-CREST Project