Evapotranspiration and Irrigation Water Requirements for Washington State

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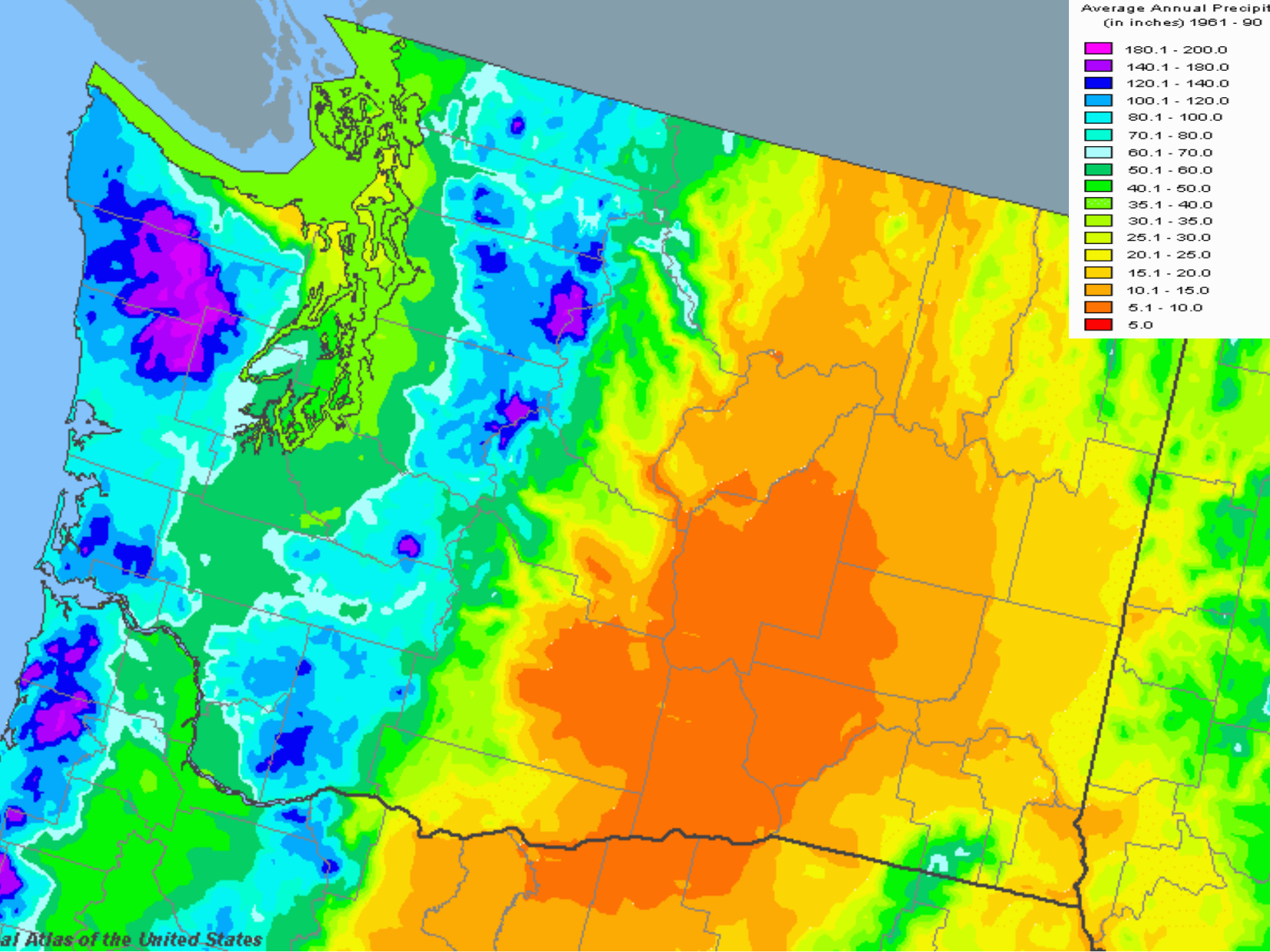

Average Annual Precipit
(in inches) 1961 - 90
180.1 - 200.0
140.1 - 180.0
120.1 - 140.0
100.1 - 120.0
80.1 - 100.0
70.1 - 80.0
60.1 - 70.0
50.1 - 60.0
40.1 - 50.0
35.1 - 40.0
30.1 - 35.0
25.1 - 30.0
20.1 - 25.0
15.1 - 20.0
10.1 - 15.0
5.1 - 10.0
5.0
al Atlas of the United States

Uses for Avg. ET Estimates

- Irrigation system design
  - Nozzle packages, pipe/pump sizing (in/day→gpm/acre)
- Rudimentary irrigation scheduling and simple irrigation scheduling guides (tools that get used)
- Evaporation pond/wetland design
- Water rights transfers
- Water litigation
- Hydrologic modeling
- River basin planning and management.
- Largest extension inquiry volume…
  - ”How much water does …. use?”

BELLINGHAM

BELLINGHAM 48.78 LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MEAN TEMPERATURE (F)	37.0	41.2	42.9	47.7	53.8	58.6	62.2	61.7	57.7	50.5	43.2	39.6	
TOTAL PRECIPITATION (IN)	4.69	3.49	2.97	2.58	2.08	1.74	1.15	1.45	2.18	3.47	4.61	5.05	35.46
EFFECTIVE PRECIP (IN)	.11	.63	1.31	1.68	1.47	1.26	.86	1.05	1.47	1.32	.32	.03	11.51

ALFALFA	BEG 5/14		END 11/13										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SEASON
MONTHLY NET IRRIG REQUIRE(IN)	.00	.00	.00	.00	.68	2.66	3.82	2.62	1.08	.00	.00	.00	10.87
AV. PAN FACTOR	.68	.68	.68	.68	.68	.68	.68	.68	.68	.68	.68	.68	

CLOVER	BEG 5/14		END 11/13										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SEASON
MONTHLY NET IRRIG REQUIRE(IN)	.00	.00	.00	.00	.99	3.35	4.65	3.27	1.53	.03	.00	.00	13.82
AV. PAN FACTOR	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	

PASTURE/TURF	BEG 5/14		END 11/13										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SEASON
MONTHLY NET IRRIG REQUIRE(IN)	.00	.00	.00	.00	.89	3.12	4.38	3.05	1.38	.00	.00	.00	12.82
AV. PAN FACTOR	.76	.76	.76	.76	.76	.76	.76	.76	.76	.76	.76	.76	

APPLES W/COVER	BEG 5/12		END 11/13										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SEASON
MONTHLY NET IRRIG REQUIRE(IN)	.00	.00	.00	.00	.54	3.81	5.75	4.13	1.98	.00	.00	.00	16.22
AV. PAN FACTOR	.40	.40	.40	.40	.60	.88	.96	.96	.92	.72	.40	.40	

APPLE W/O COVER	BEG 5/12		END 11/13										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SEASON
													10.52

Blaney-Criddle equation – Published 1985 – Last data 1982
Actual ET and crop coefficients hidden

Estimating Crop Water Use (Evapotranspiration)

Reference ET
(Weather and climate)
Water use of harvestable alfalfa

$$ET_c = K_c \times ET_r$$

Crop ET

Crop Coefficient
(Crop and growth stage)

Reference ET: From Weather

Standardized ASCE Penman-Monteith

$$ET_{ref} = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{C_n}{T+273}\,u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d\,u_2)}$$

Solar Radiation

Temperature

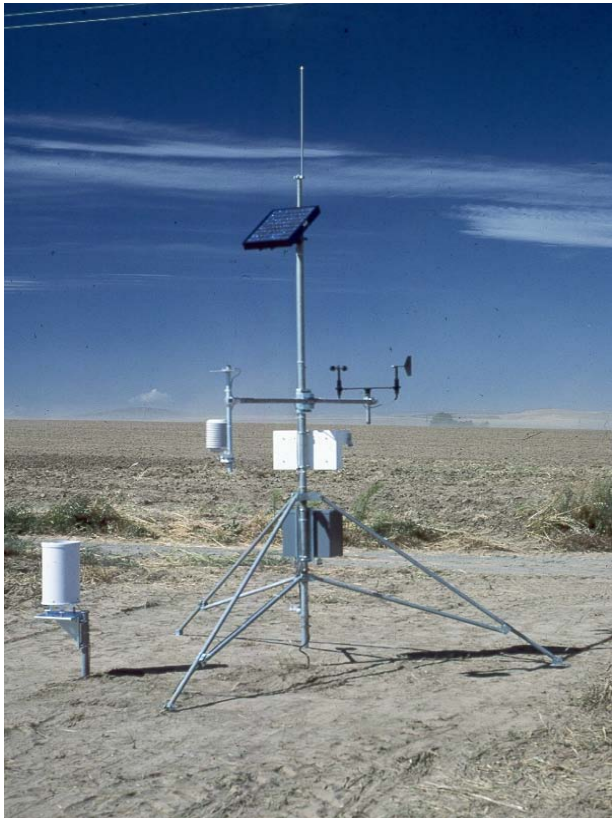
Wind Speed

Humidity

Credit: Richard Allen, University of I

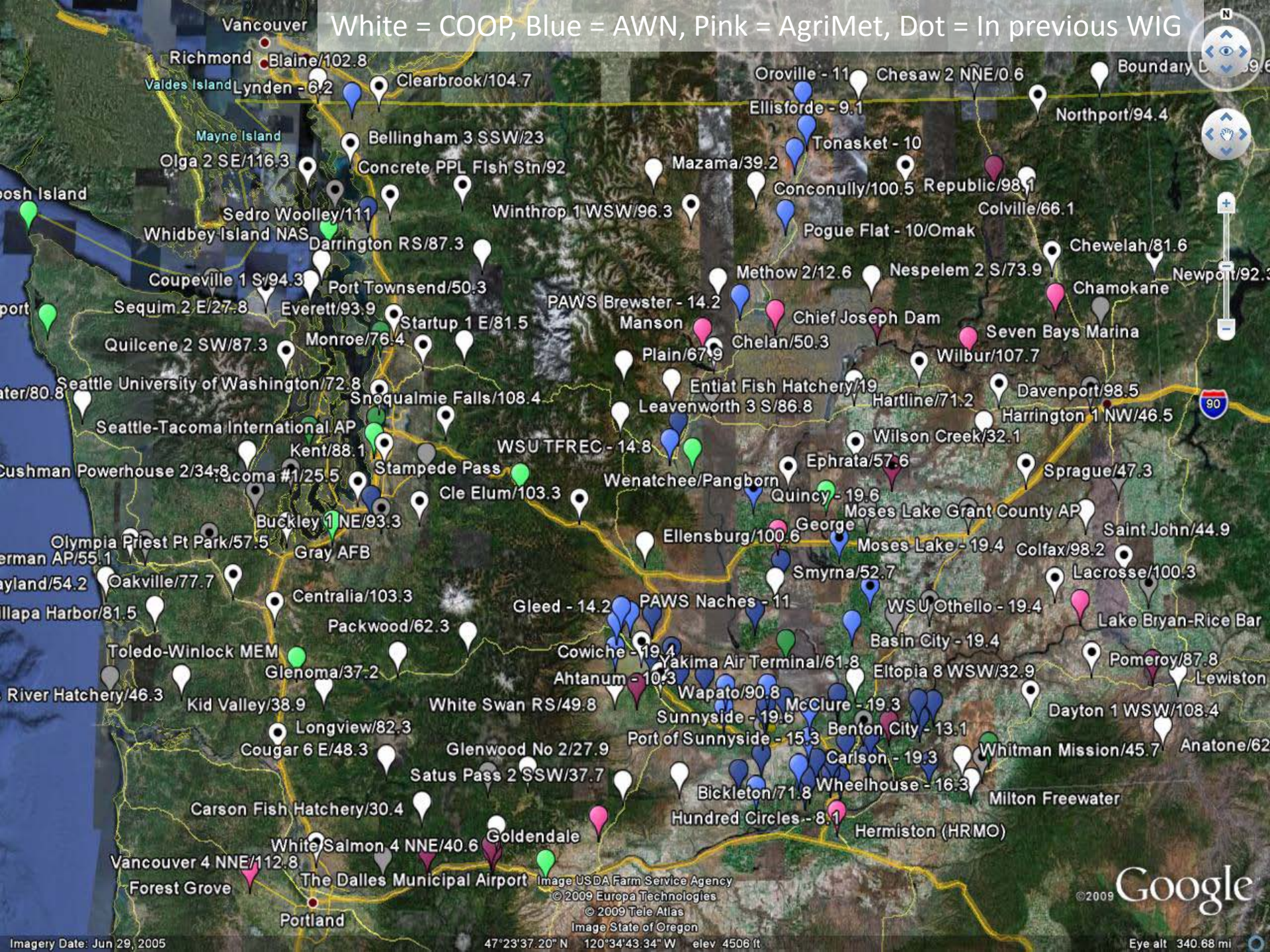
Weather Data Sources

- NCDC COOP Stations
  - Best coverage/Longest history (>100 yrs)
  - Temperature and precipitation only
- NCDC ASOS
  - Full data set
  - Airport Tarmacs – RH data only
- Agrimet
  - Full data set and good locations
  - Limited coverage
- Washington AgWeatherNet
  - Full data set and good locations
  - Growing coverage
  - Limited data history (5-20 yrs)



New Revision

- More recent and complete historical weather data
- Latest ETr estimation techniques (ASCE standardized Penman-Monteith equations)
- Take into account humidity, wind, and solar radiation, elevation, latitude as well as temperature.
- Expanded station coverage
- Inclusion of actual ET separate from IWR
- Inclusion of information on the variability (probability) of estimation


White = COOP, Blue = AWN, Pink = AgriMet, Dot = In previous WIG
Vancouver
Richmond
Blaine/102.8
Valdes Island
Lynden - 6.2
Clearbrook/104.7
Mayne Island
Bellingham 3 SSW/23
Olga 2 SE/116.3
Concrete PPL Fish Stn/92
Sedro Woolley/111
Whidbey Island NAS
Darrington RS/87.3
Coupeville 1 S/94.3
Port Townsend/50.3
Sequim 2 E/27.8
Everett/93.9
Startup 1 E/81.5
Quilcene 2 SW/87.3
Monroe/76.4
Seattle University of Washington/72.8
Snoqualmie Falls/108.4
Seattle-Tacoma International AP
Kent/88.1
Tacoma #1/25.5
Stampede Pass
Cle Elum/103.3
Buckley 1 NE/93.3
Olympia Priest Pt Park/57.5
Gray AFB
Oakville/77.7
Centralia/103.3
Packwood/62.3
Toledo-Winlock MEM
Glenoma/37.2
Kid Valley/38.9
Longview/82.3
Cougar 6 E/48.3
Carson Fish Hatchery/30.4
White Salmon 4 NNE/40.6
Vancouver 4 NNE/112.8
Forest Grove
Portland
The Dalles Municipal Airport
Goldendale
Satus Pass 2 SSW/37.7
Glenwood No 2/27.9
Cowiche - 19.4
Ahtanum - 10.3
White Swan RS/49.8
Yakima Air Terminal/61.8
Gleed - 14.2
PAWS Naches - 11
Wenatchee/Pangborn
WSU TFREC - 14.8
Leavenworth 3 S/86.8
Winthrop 1 WSW/96.3
Mazama/39.2
Oroville - 11
Ellisforde - 9.1
Tonasket - 10
Conconully/100.5
Pogue Flat - 10/Omak
Republic/98.1
Colville/66.1
Chesaw 2 NNE/0.6
Northport/94.4
Boundary D
Methow 2/12.6
PAWS Brewster - 14.2
Manson
Chief Joseph Dam
Chelan/50.3
Plain/67.9
Entiat Fish Hatchery/19
Nespelem 2 S/73.9
Chamokane
Chewelah/81.6
Seven Bays Marina
Wilbur/107.7
Davenport/98.5
Hartline/71.2
Harrington 1 NW/46.5
Wilson Creek/32.1
Ephrata/57.6
Sprague/47.3
Quincy - 19.6
Moses Lake Grant County AP
George
Ellensburg/100.6
Moses Lake - 19.4
Colfax/98.2
Saint John/44.9
Smyrna/52.7
Lacrosse/100.3
WSU Othello - 19.4
Lake Bryan-Rice Bar
Basin City - 19.4
Pomeroy/87.8
Eltopia 8 WSW/32.9
Lewiston
Wapato/90.8
McClure - 19.3
Sunnyside - 19.6
Port of Sunnyside - 15.3
Benton City - 13.1
Dayton 1 WSW/108.4
Anatone/62
Whitman Mission/45.7
Carlson - 19.3
Wheelhouse - 16.3
Bickleton/71.8
Hundred Circles - 8.1
Hermiston (HRMO)
Milton Freewater
Image USDA Farm Service Agency
© 2009 Europa Technologies
© 2009 Tele Atlas
Image State of Oregon
©2009 Google
Imagery Date: Jun 29, 2005
47°23'37.20" N 120°34'43.34" W elev 4506 ft
Eye alt 340.68 mi

AWN Data Cleaning

- Plotted and looked at:
  - Solar radiation plotted with calculated clear sky radiation
  - Wind speed was plotted – look for anomalies
  - T_{dew} plotted and compared with T_{min}
  - T_{max} and T_{min} plotted – look for anomalies
- Seasonal total rainfalls compared year to year.

Strategy

- Applied the ASCE Penman Monteith for COOP (temp and precip only) Stations.
  - Estimate missing Solar Radiation, using the Thornton-Running (1999)
  - Wind is from nearby station – using long-term historical monthly averages
  - Dew Point – Estimated from T_{min} with offsets as needed.
- Calculate for full year – not just growing season.

Data Corrections Manipulations

- “Missing” values in NCDC (COOP or MMTS) were treated as missing instead of 0.
- Out of bounds data was set to “missing”
  - Solar radiation visually compared to theoretical clear sky radiation
  - RH over 100% or less than 0%
  - Temperatures greater than 160 deg F or less than -60 deg F

Data Corrections Manipulations

- “Missing data was interpolated from stations within a 50 km radius. Weighted average based on distance. Everything except precip. Missing set to 0.
- Still missing values were generated by ClimGen.
- ASOS stations used only for avg dewpoint interpolations in stations that didn’t have RH data.

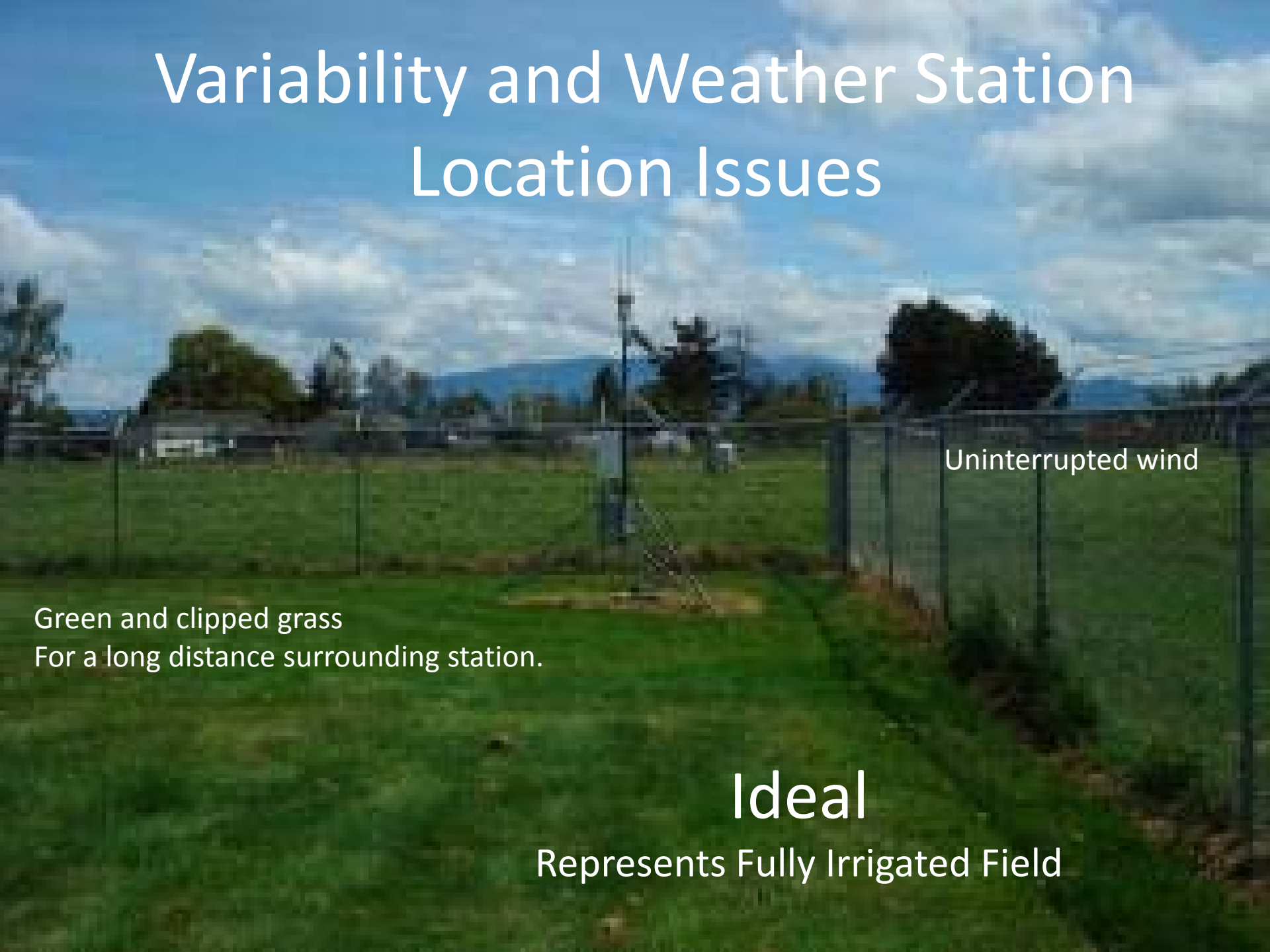
“Way Out There” Stations

- Many COOP (MMTS) stations weren’t close enough (50 km; 30 miles) to be comfortable with interpolating data from “full data” stations.
- Hargreaves equation (temp only) was calibrated using nearest “full data” stations.
- This calibrated Hargreaves equation used to make estimates for these stations.

Data Corrections Manipulations

- Over 20 different full iterations using various methods/assumptions etc. to troubleshoot (each takes 3-6hrs computation time).
- Final results plotted and reviewed with Leigh Nelson
- Specific stations were excluded. No “tweaking” just removal.
  - Removed stations are listed along with the reasons that they were excluded.
  - Best station of a close group was retained. (Eliminate redundancy)
    - Best = best data source, location, history, results or “believability”.

Variability and Weather Station Location Issues



Agrimet

AgWeatherNet

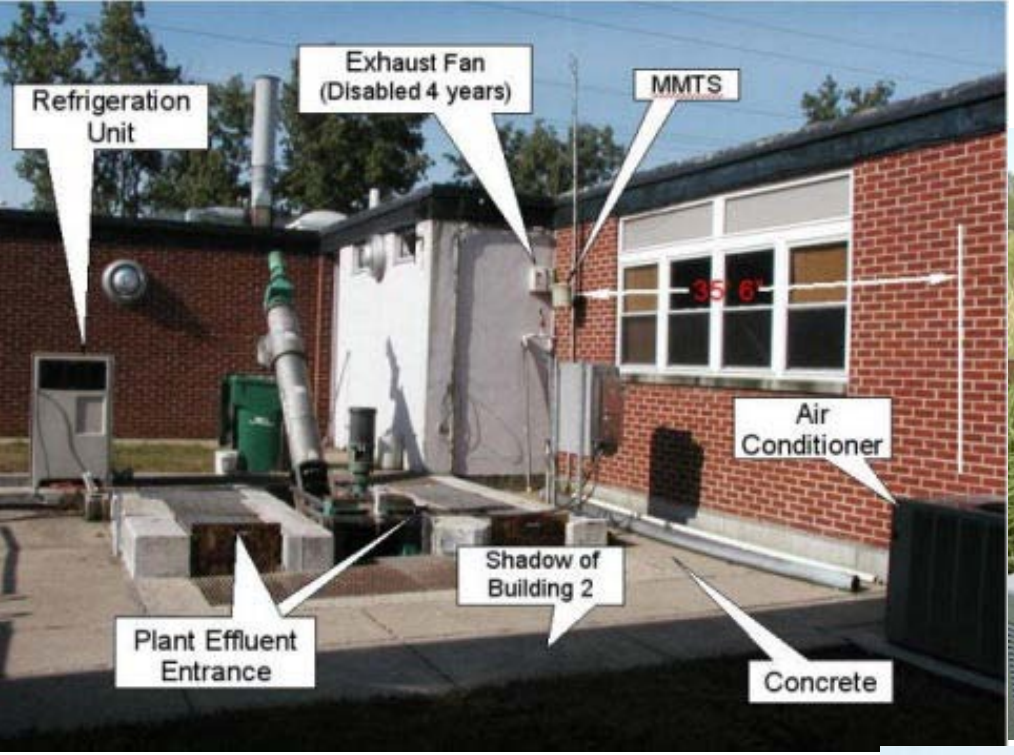
AgWeatherNet

COOP (MMTS)


U S WEATHER BUREAU
CO OPERATIVE STATION
GRANGER
UTAH
RAIN GAGE

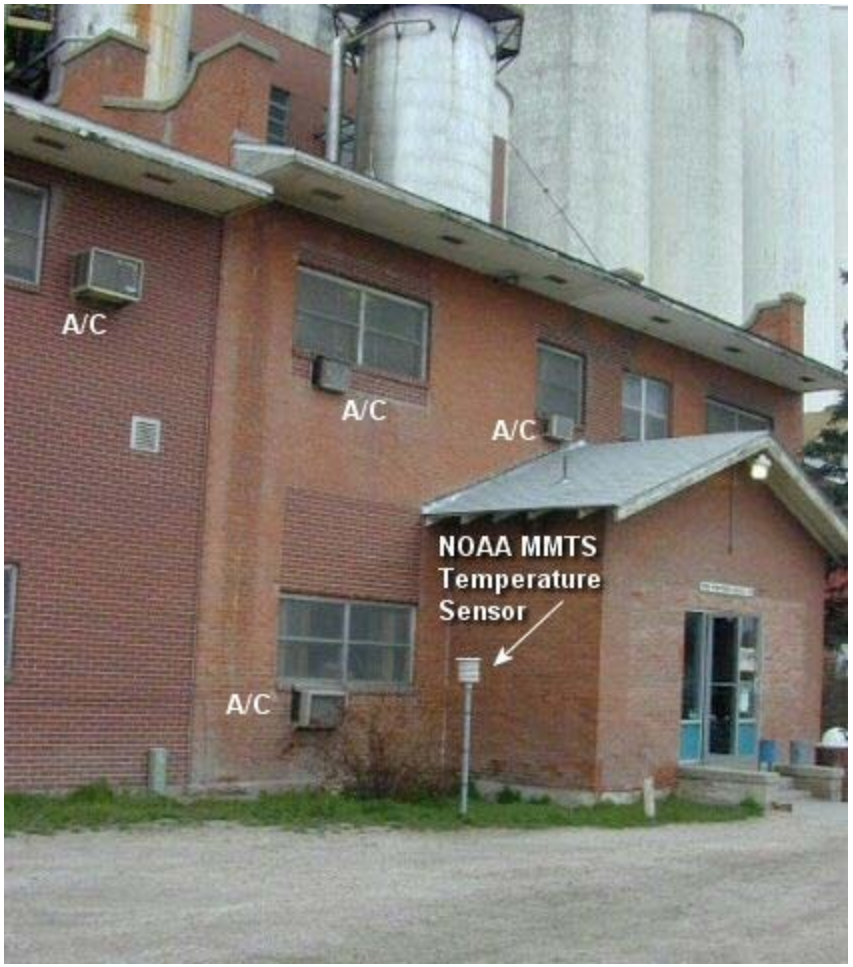

copyright 2006 Bruce B. Joh

COOP (MMTS)

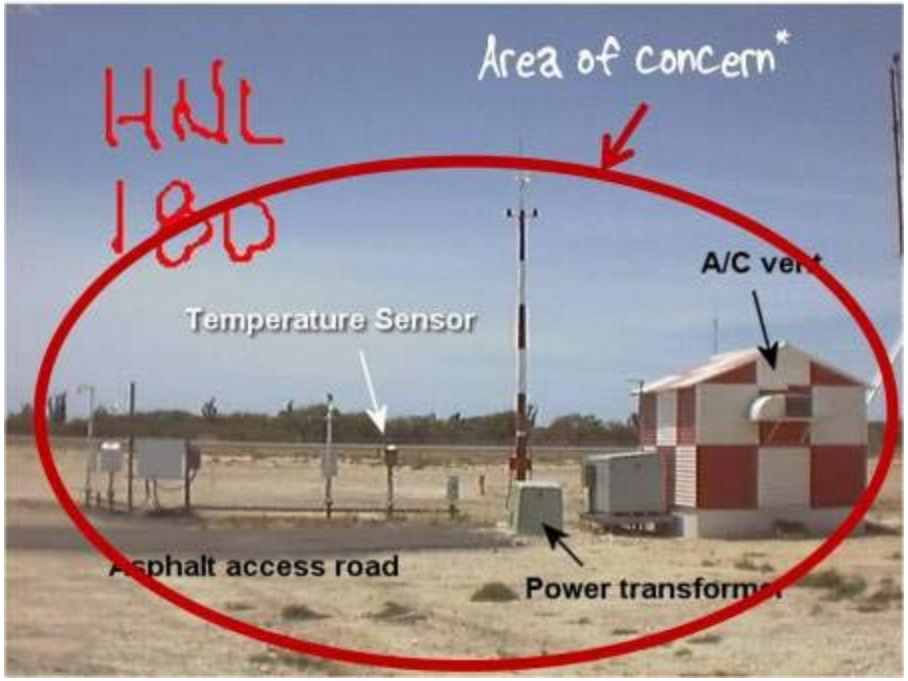

Refrigeration Unit
Exhaust Fan (Disabled 4 years)
MMTS
Air Conditioner
Shadow of Building 2
Plant Effluent Entrance
Concrete


STOP
A/C unit
MMTS Temp Sensor


NOAA MMTS
Temperature
Sensor
A/C
A/C
A/C
A/C
A/C
A/C


A/C
A/C
A/C
NOAA MMTS
Temperature
Sensor
A/C

ASOS Stations



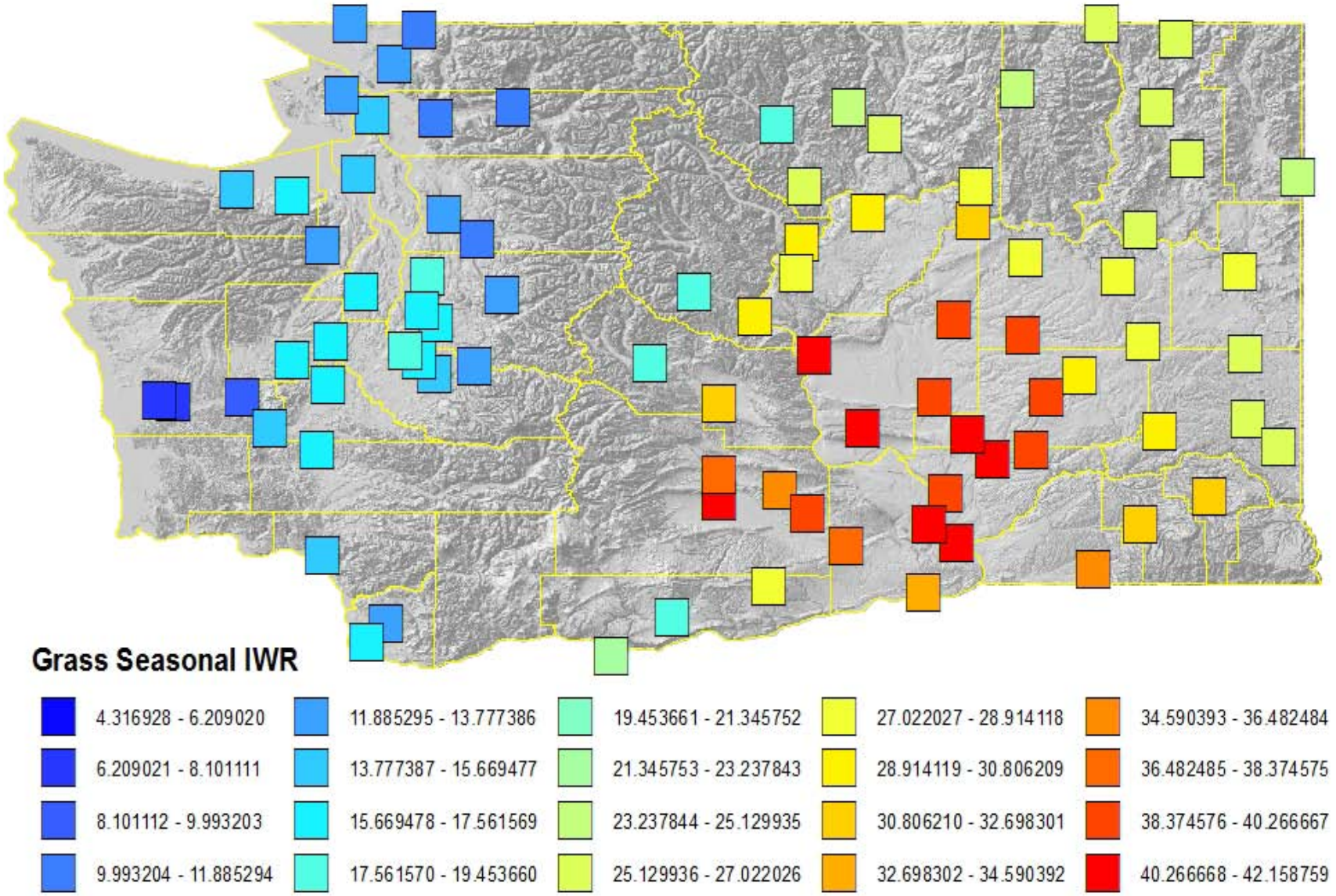
Comparison to Old WIG

- Both above and below old estimates in various locations, but in general 10 – 20% *lower*

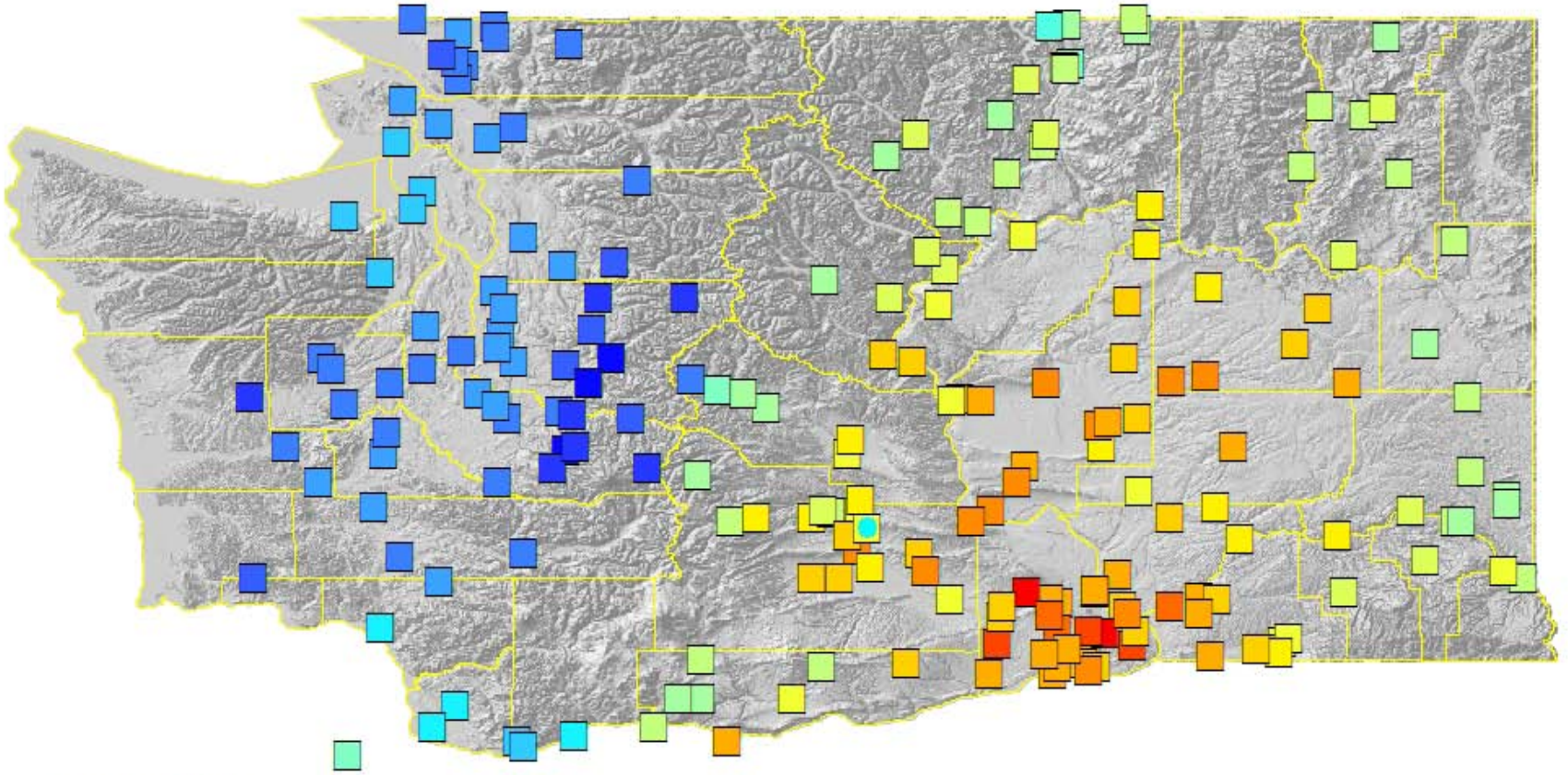
Accuracy

- Based on the variability between stations that “should have been the same”, we feel that the results are within 10-15% of actual. No way to test this.

Existing WIG



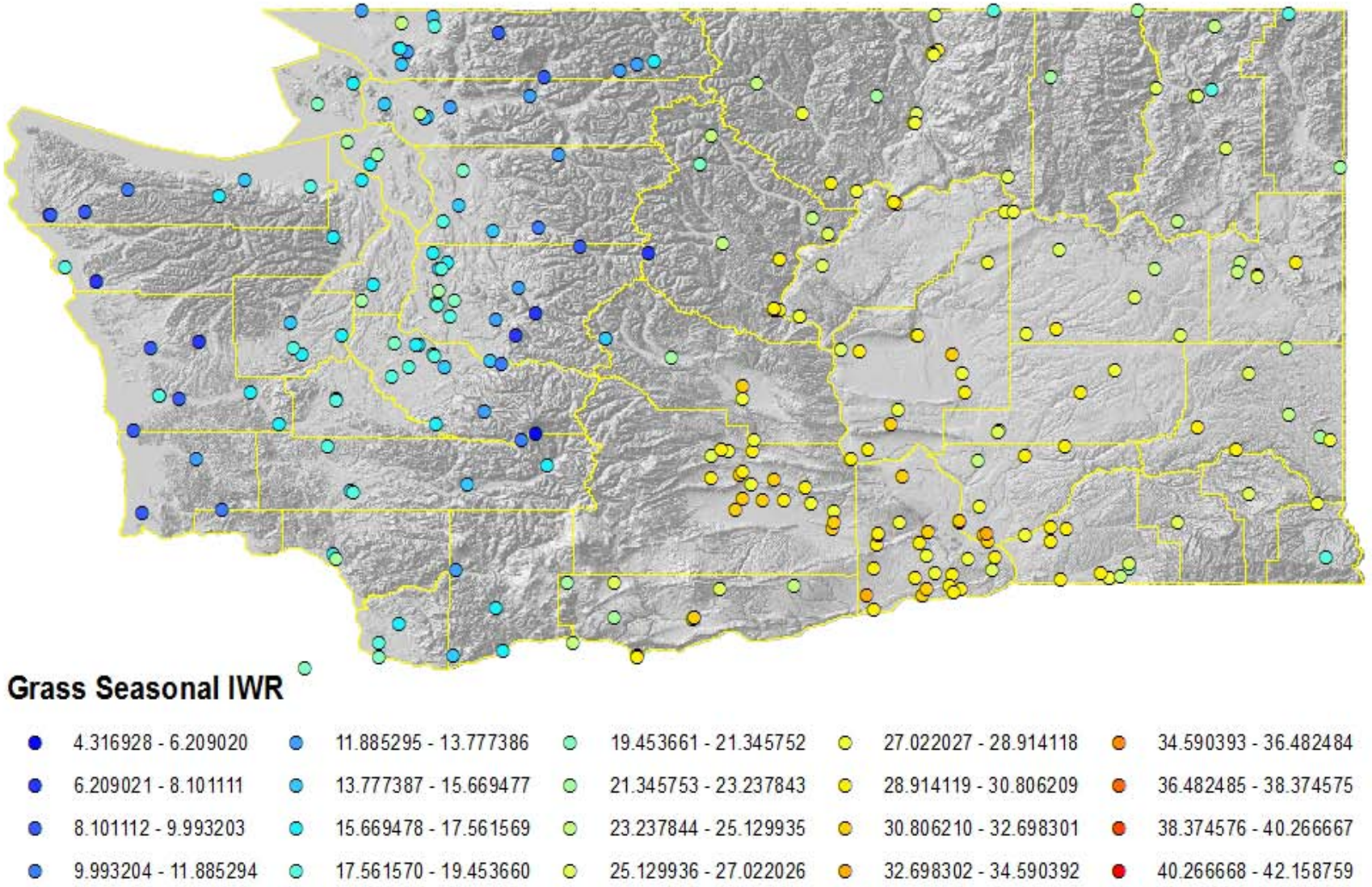
New Full Penman-Monteith



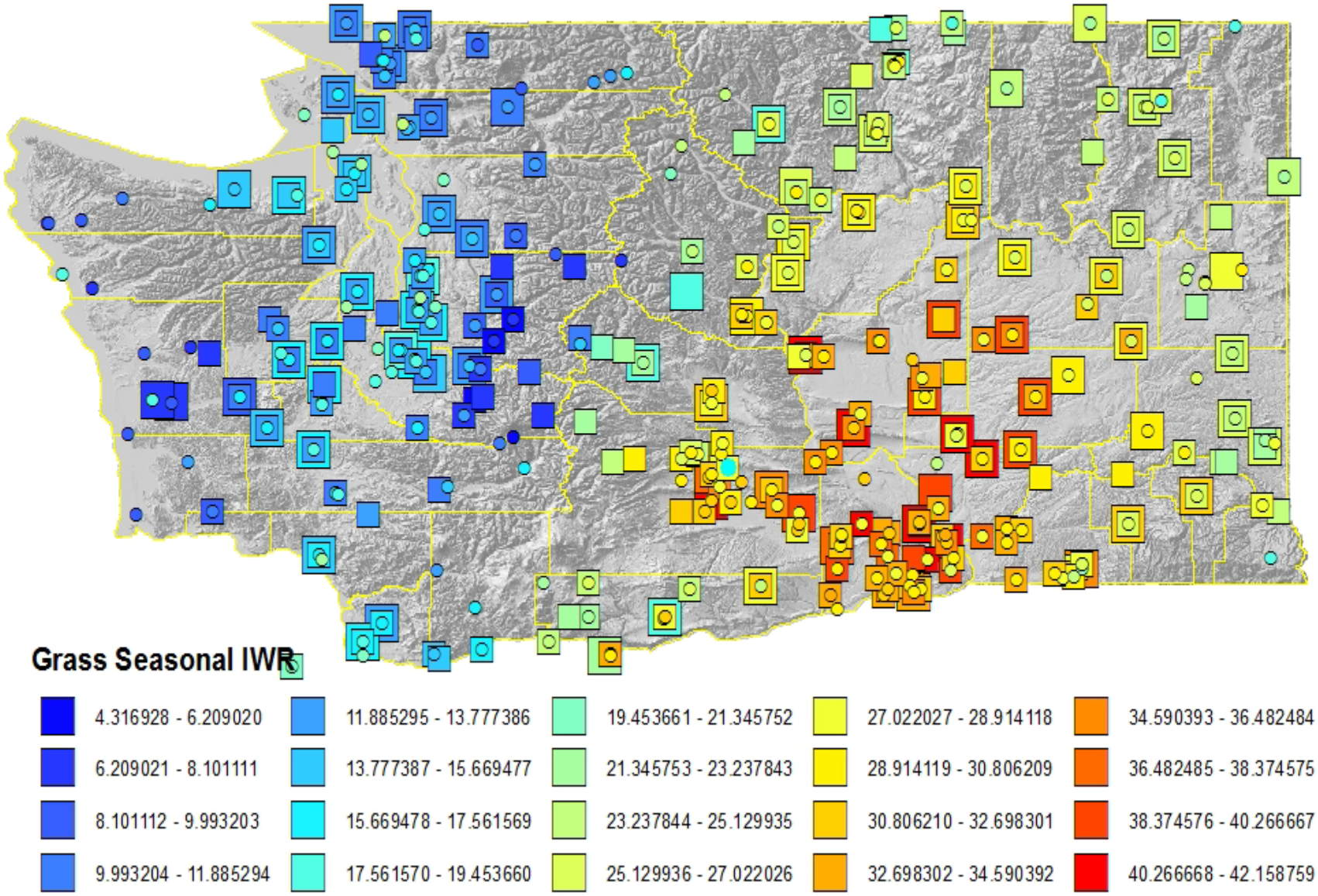
Grass Seasonal IWR

4.316928 - 6.209020	11.885295 - 13.777386	19.453661 - 21.345752	27.022027 - 28.914118	34.590393 - 36.482484
6.209021 - 8.101111	13.777387 - 15.669477	21.345753 - 23.237843	28.914119 - 30.806209	36.482485 - 38.374575
8.101112 - 9.993203	15.669478 - 17.561569	23.237844 - 25.129935	30.806210 - 32.698301	38.374576 - 40.266667
9.993204 - 11.885294	17.561570 - 19.453660	25.129936 - 27.022026	32.698302 - 34.590392	40.266668 - 42.158759

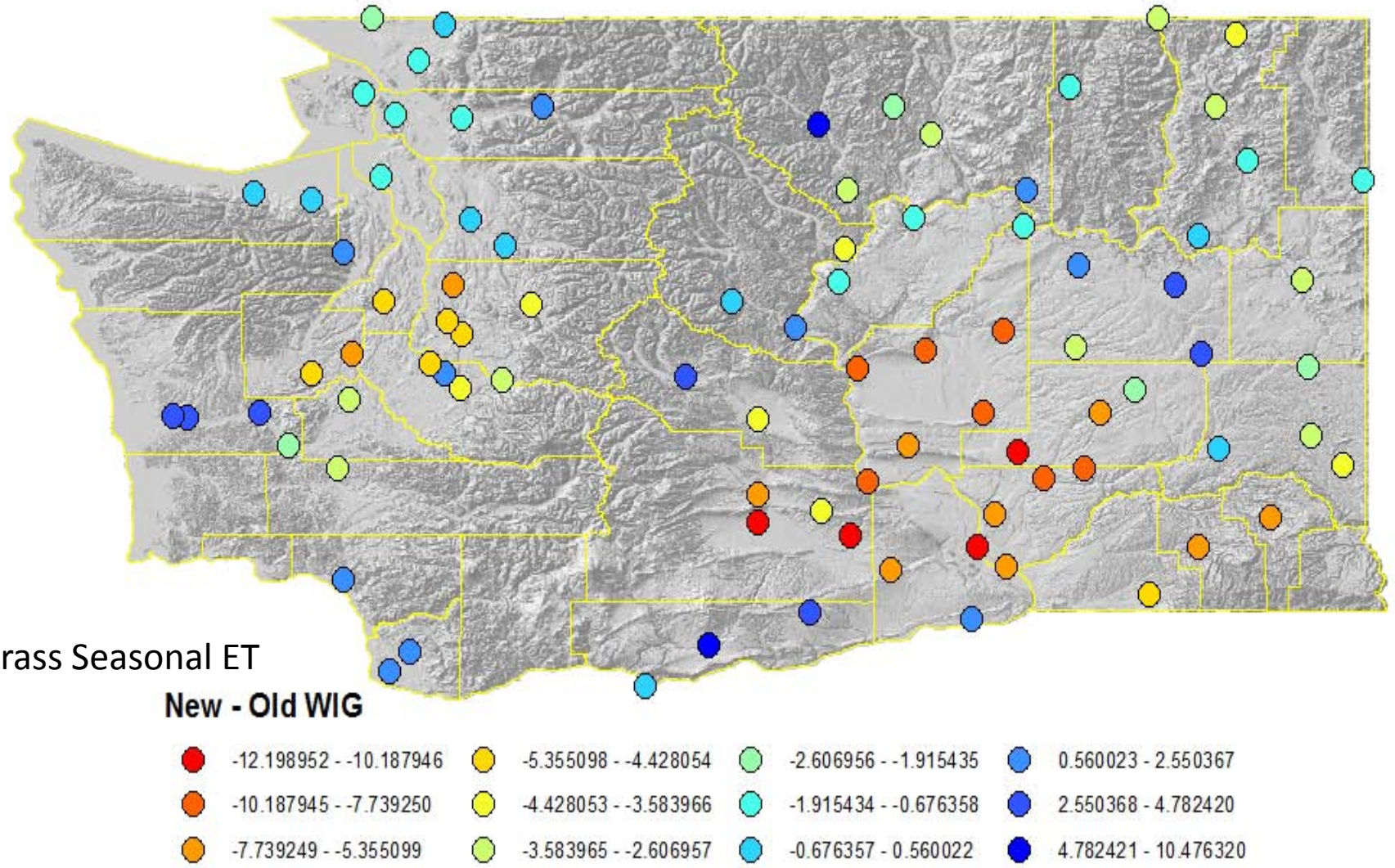
Calibrated Hargreaves



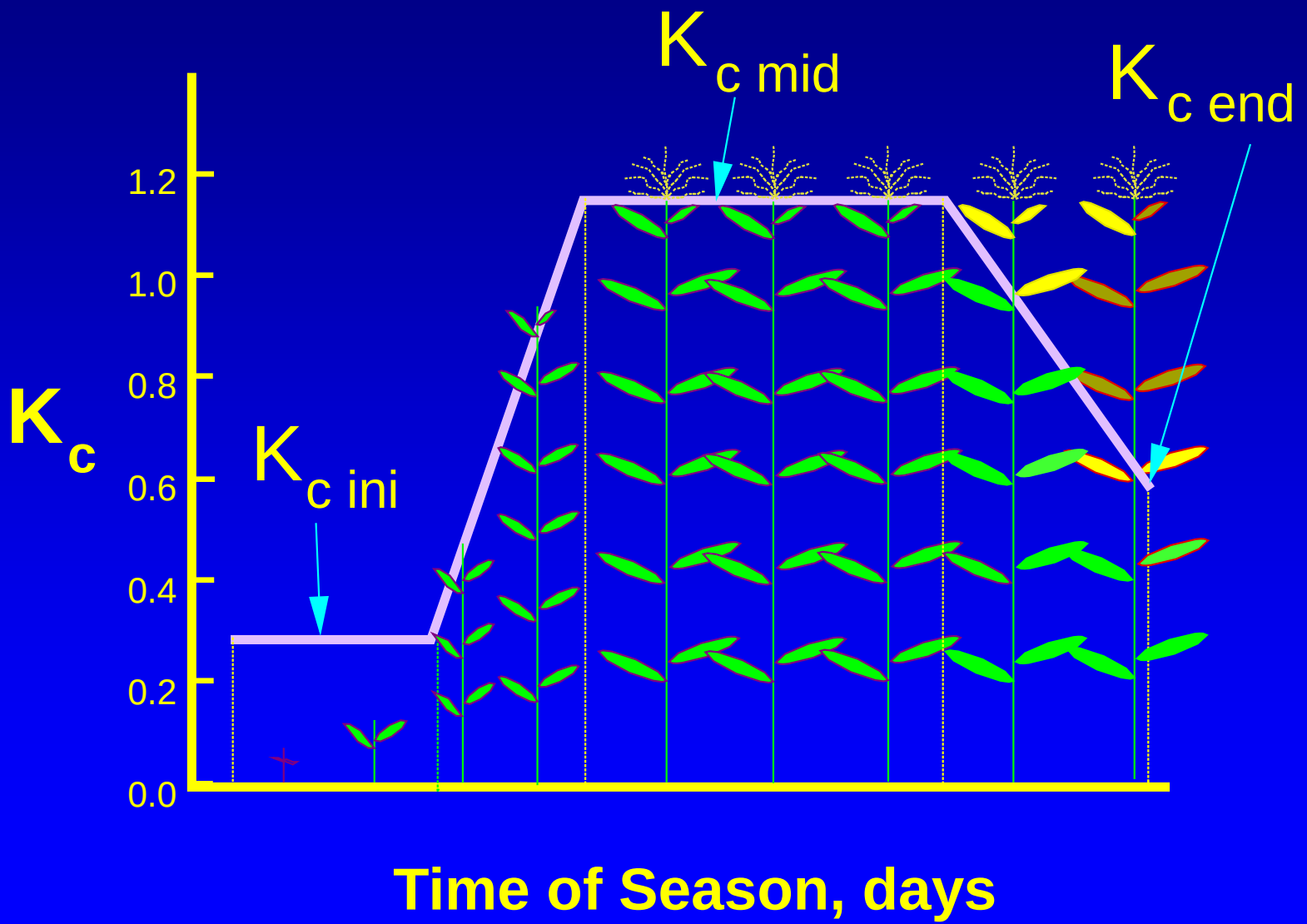
All Together



Differences from Existing WIG

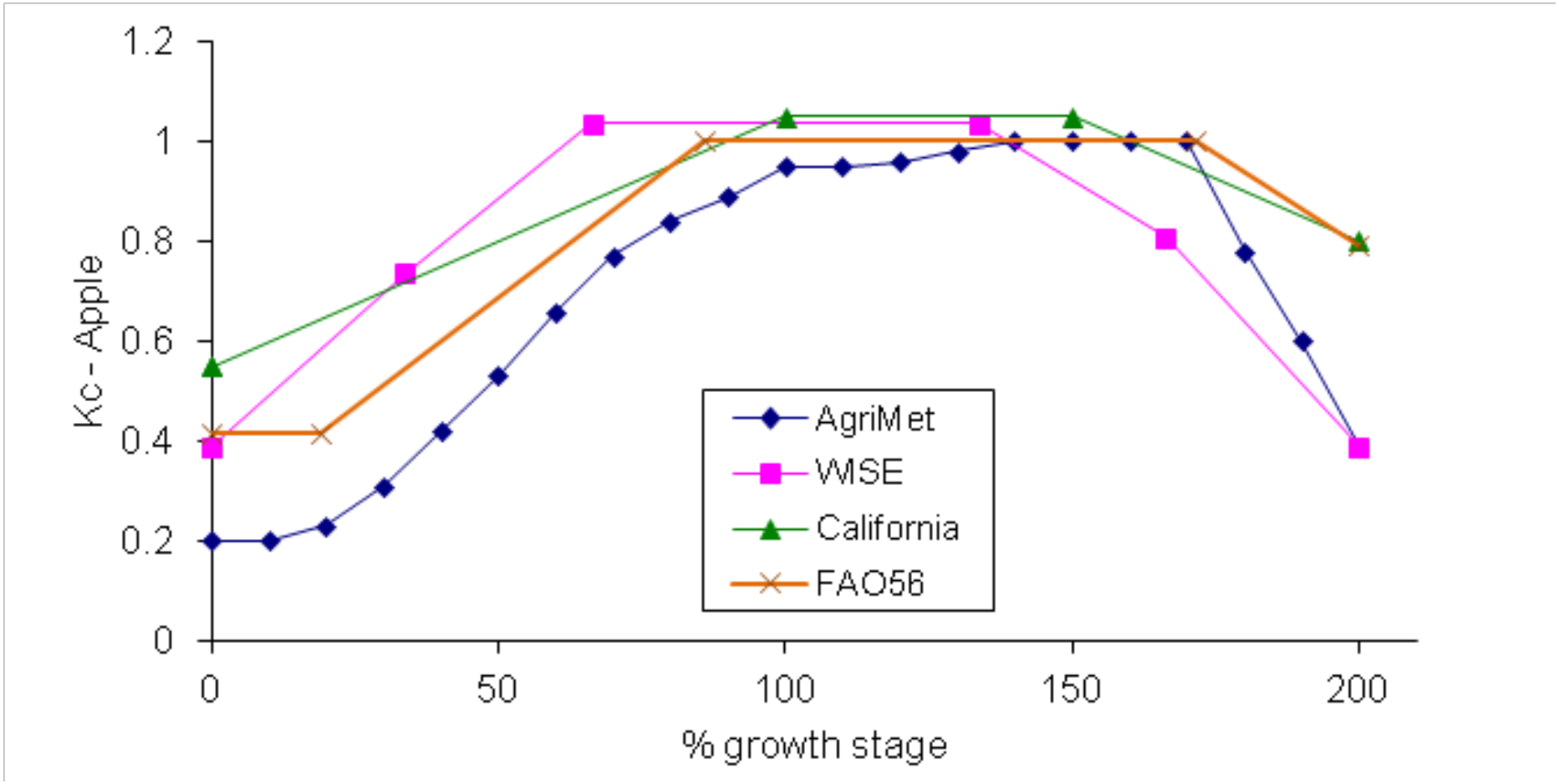


Crop Coefficient = ET/ET_{ref}



Credit: Richard Allen, UI

Crop Coefficients?



Crop Coefficients

- Thorough literature review:
- Started with Agrimet
  - Based on field research using lysimeters in Kimberly, ID
  - Similar climate to development area.
  - Well documented sources

Comparison of R (Kimberly/ASCE) across various climates

Use Average R

Crop Coefficients

- Converted for use with the ASCE Standardized Penman-Monteith
- Converted to be based on CGDD (crop specific) instead of DOY
- Missing crops filled in from FAO-56 and others as documented

Documentation

Num	Crop Name	Growth stage dates			Source
		Ave Initial	Ave Full cover	Ave End	
1	ALFALFA (MEAN)*	91	135	280	Agrimet, Curve developed by ARS research on lysimeter plots, Kimberly, Idaho 1969–75.
2	ALFALFA (PEAK)*	91	135	280	Agrimet, Curve developed by ARS research on lysimeter plots, Kimberly, Idaho 1969–75.
3	APPLES	110	149	278	Agrimet, (Modified per Soiltest input 1994), Curve developed by Soiltest, Inc., Moses Lake, Washington March 1994
4	APRICOTS	110	149	278	Agrimet, Cherry crop coefficients and planting date
5	ASPARAGUS	120	214	280	Agrimet, Pro Ag, Pasco, 1994

Apple					
% of growth stage	Kc From Agrimet Based On Kimberly	*R*	Converted Kc Based On ASCE	Average Planting Dates & CGDD In Eastern central WA	
				DOY	CGDD Tb=10
0	0.2	0.92	0.18	110	6
10	0.2	0.94	0.19	114	10
20	0.23	0.95	0.22	118	16
30	0.31	0.96	0.30	122	26
40	0.42	0.98	0.41	126	36
50	0.53	0.99	0.53	130	48
60	0.66	1.00	0.66	133	63
70	0.77	1.02	0.78	137	81
80	0.84	1.03	0.86	141	100
90	0.89	1.04	0.92	145	124
100	0.95	1.05	0.99	149	148
110	0.95	1.07	1.02	162	231
120	0.96	1.08	1.04	175	335
130	0.98	1.08	1.06	188	464
140	1	1.06	1.06	201	612
150	1	1.04	1.04	214	782
160	1	1.02	1.02	226	943
170	1	0.99	0.99	239	1080
180	0.78	0.96	0.75	252	1198
190	0.6	0.93	0.56	265	1281
200	0.39	0.89	0.35	278	1340

Crops	Select Stations (inches of ETc, precipitation not accounted for)						
	Chewelah	Cle Elum	Mount Vernon	Omak	Prosser	Quincy	Walla Walla
Apple	28.2	26.6	20.3	28.7	33.4	35.5	36.0
Apricot	31.0	29.3	22.7	30.9	36.0	38.2	38.7
Carrot	28.0	24.9	20.5	23.6	27.8	29.0	29.4
Cherry no cover	23.0	21.7	16.7	22.9	26.7	28.4	28.7
Cherry w cover	31.0	29.3	22.7	30.9	36.0	38.2	38.7
Clover	29.6	27.0	22.9	29.2	35.3	37.1	37.9
Concord Grape	27.1	21.1	16.7	24.9	29.0	30.9	31.5
Cucumber	16.7	13.3	9.2	16.3	19.3	20.7	21.1
Dry Bean	17.8	15.3	11.2	14.6	16.5	17.6	17.8
Hops	19.7	11.4	7.7	18.8	20.7	22.2	22.9
Mint	25.7	21.1	18.9	20.9	24.3	25.4	26.0
Onion	30.7	27.7	23.5	25.6	29.9	31.4	31.7
Pasture	27.4	22.1	18.8	23.9	28.5	30.1	30.5
Pea	15.1	14.6	12.4	13.2	15.3	16.1	15.8
Peach	31.0	29.3	22.7	30.9	36.0	38.2	38.7
Pear	30.1	28.3	21.7	30.3	35.1	37.3	37.9
Plum	28.2	26.6	20.3	28.7	33.4	35.5	36.0
Potato	20.9	16.8	15.2	17.5	20.3	21.3	22.0
Potato Shepody	26.4	23.4	19.8	23.3	27.0	28.2	28.9
Radish	3.4	3.4	2.9	3.3	3.6	3.8	3.7
Raspberry	32.4	29.1	24.7	30.8	36.8	38.6	39.5
Safflower	25.6	24.3	20.8	22.3	26.1	27.3	27.1
Spinach	21.1	19.8	15.8	18.3	21.4	22.6	22.1
Spring Grain	23.0	21.4	18.5	19.8	23.1	24.2	24.1
Strawberry	25.5	20.8	17.5	22.2	26.7	28.1	28.7
Sugar Beet	25.2	20.5	19.2	22.3	26.6	27.8	29.3
Tomato	21.1	17.2	12.1	17.7	19.8	21.2	21.5
Wine Grape	19.4	15.8	12.3	18.8	23.3	24.9	25.2
Winter Wheat	23.5	23.0	19.4	20.9	23.8	25.4	24.5