

Landsat-based (Field-Scale) Evapotranspiration Estimates - METRIC Overview and Applications



Landsat 8 - launched Feb. 2013

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Who Cares about ET?

- ◆ Departments of Water Resources
- ◆ US Bureau of Reclamation
- ◆ US Geological Survey
- ◆ Environment
- ◆ Irrigators
- ◆ Courts



Applications in the West

Water Planning

Aquifer Depletions

Hydrologic Modeling

Endangered Species

Agricultural Water Use

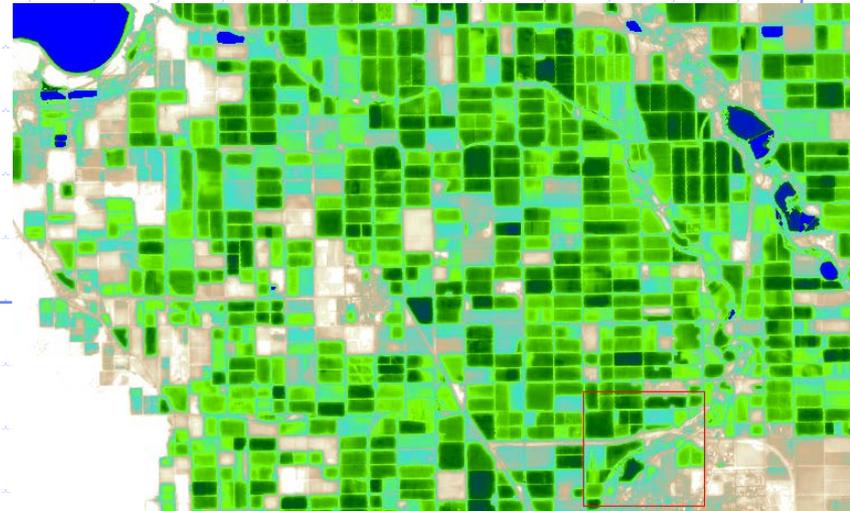
Legal Finding-of-Fact

Water Rights Buy-Back

Water Rights Compliance

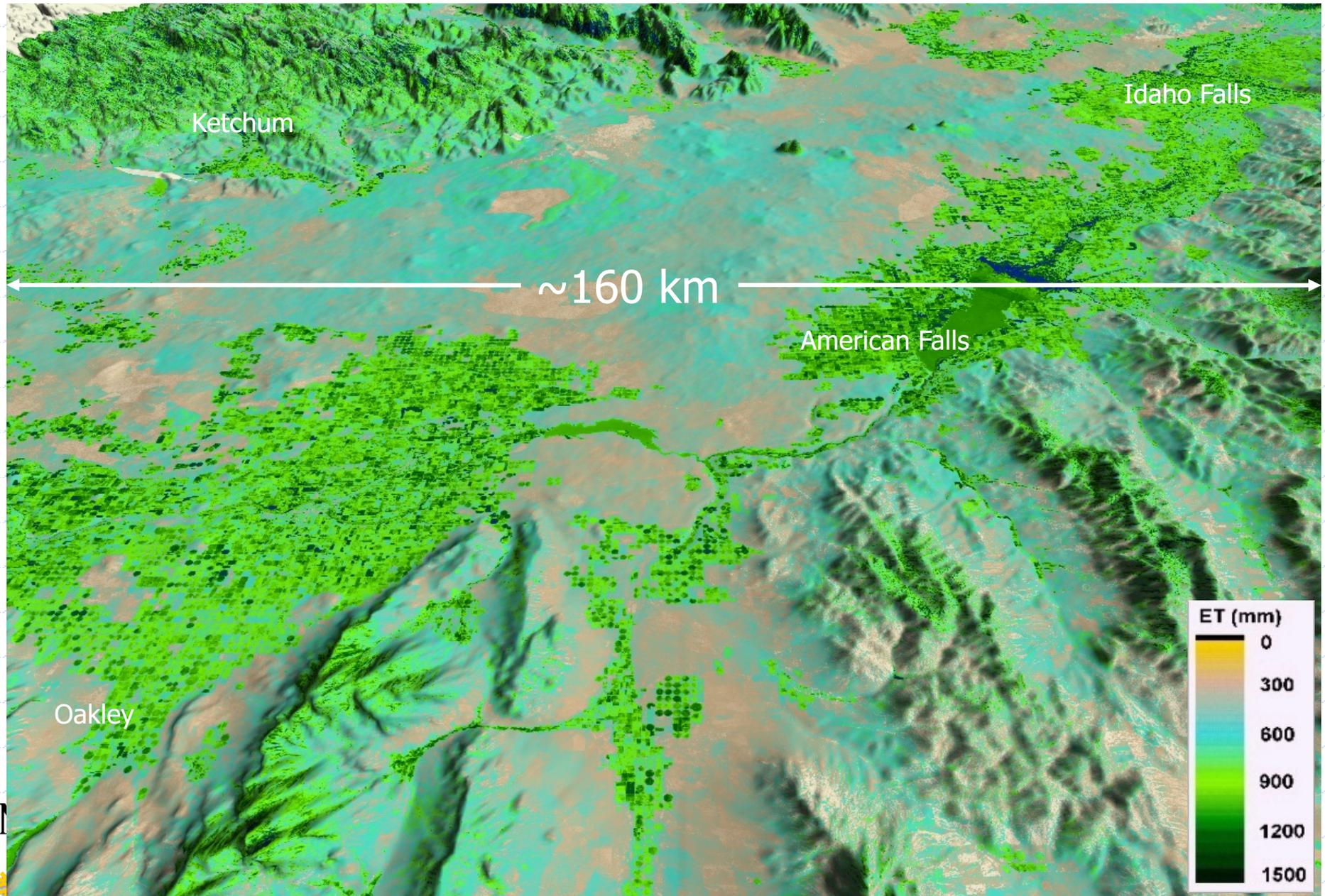
In-Season Water Demand

Tribal Water Rights Negotiations



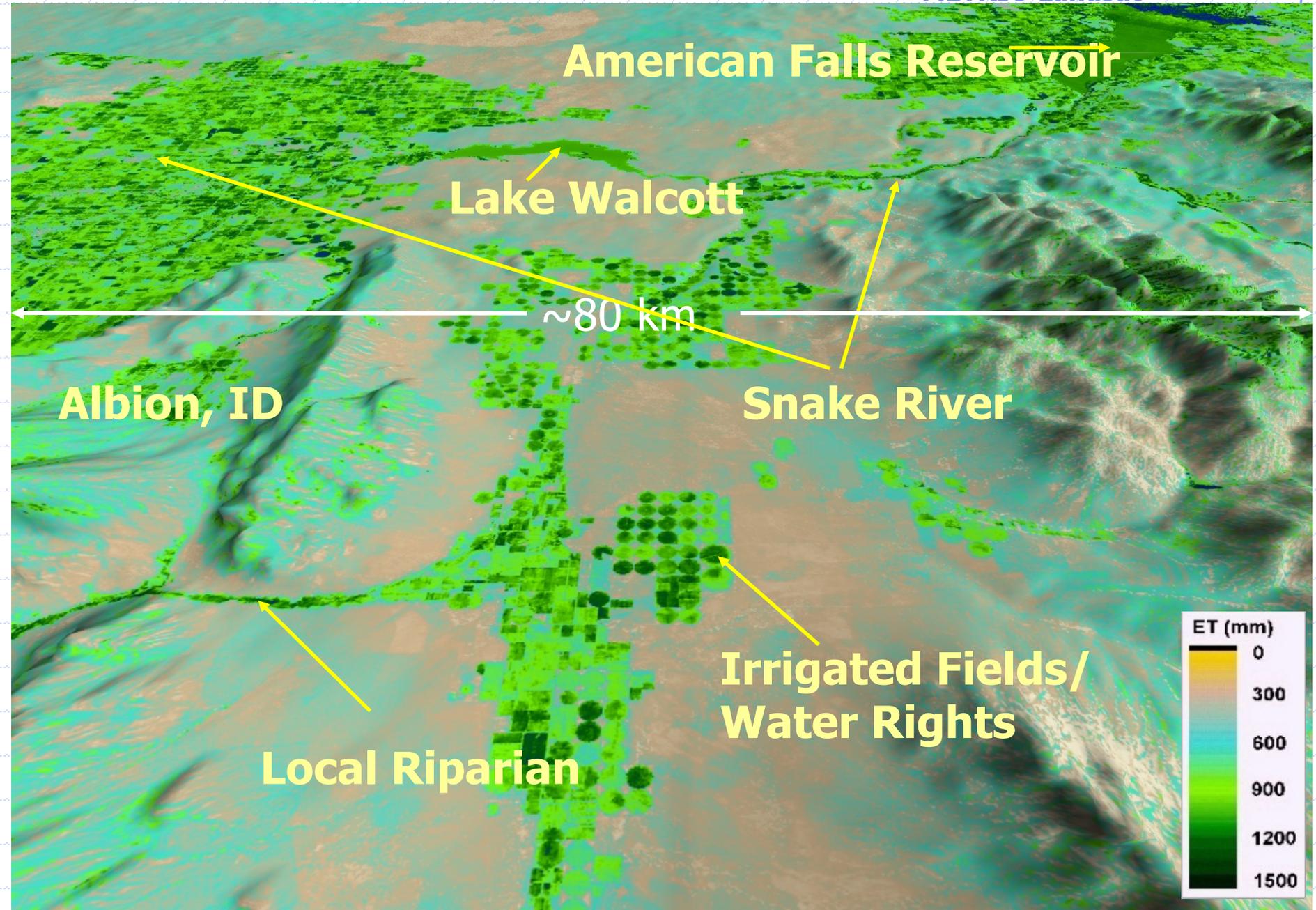
Does ET vary in Space? (Yes!) -- Monthly and Seasonal ET at 30 m resolution for the Eastern Snake Plain of Idaho

April – October, 2006 ET



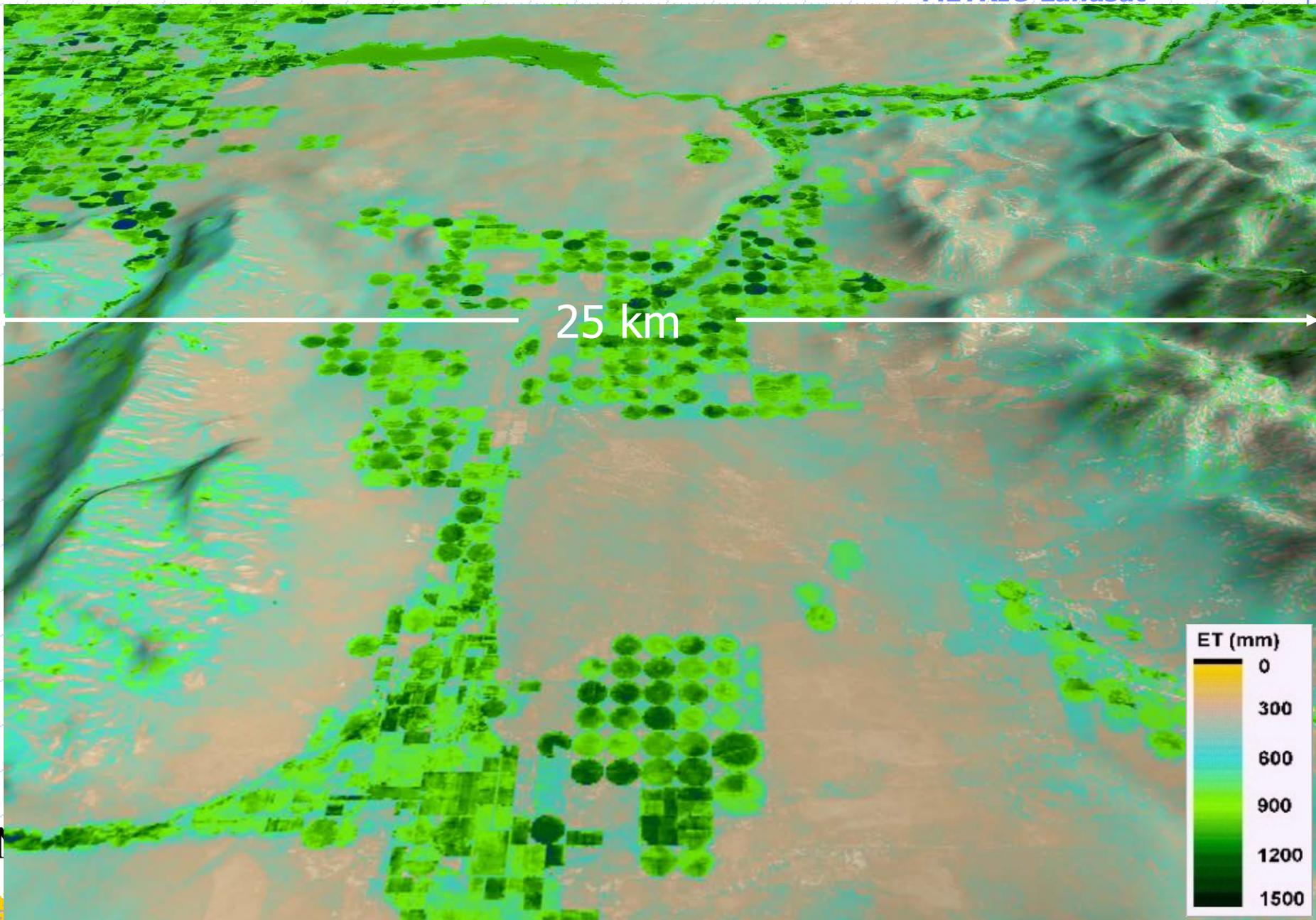
ET features at 30 m resolution

April – October, 2006 ET from METRIC-Landsat



ET features at 30 m resolution

April – October, 2006 ET from METRIC-Landsat



When Energy Balance Matters

◆ Energy Balance

- Remember: ET is the water that changes from liquid to water vapor
- Liquid to vapor conversion requires energy
- We 'look' for the energy used to produce the evaporation
- **EB components can be derived from the temperature of the surface**

Why use an “Energy balance”?

- ◆ ET is calculated as a “residual” of the energy balance

R_n (radiation from sun and sky)

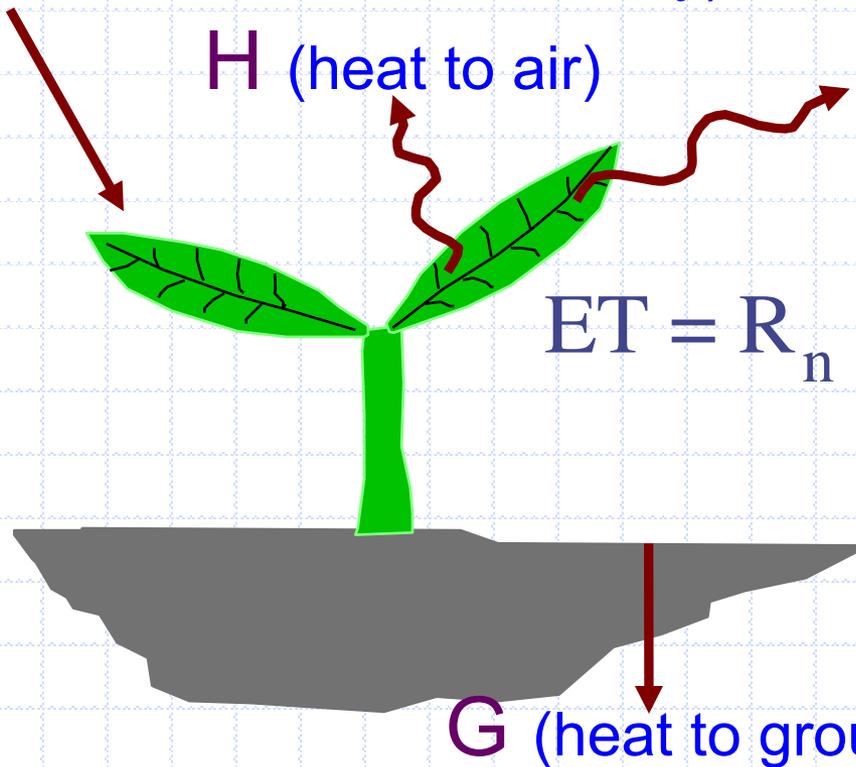
H (heat to air)

ET

$$ET = R_n - G - H$$

Basic Truth:

Evaporation
consumes
Energy



Energy balance gives us “actual” ET

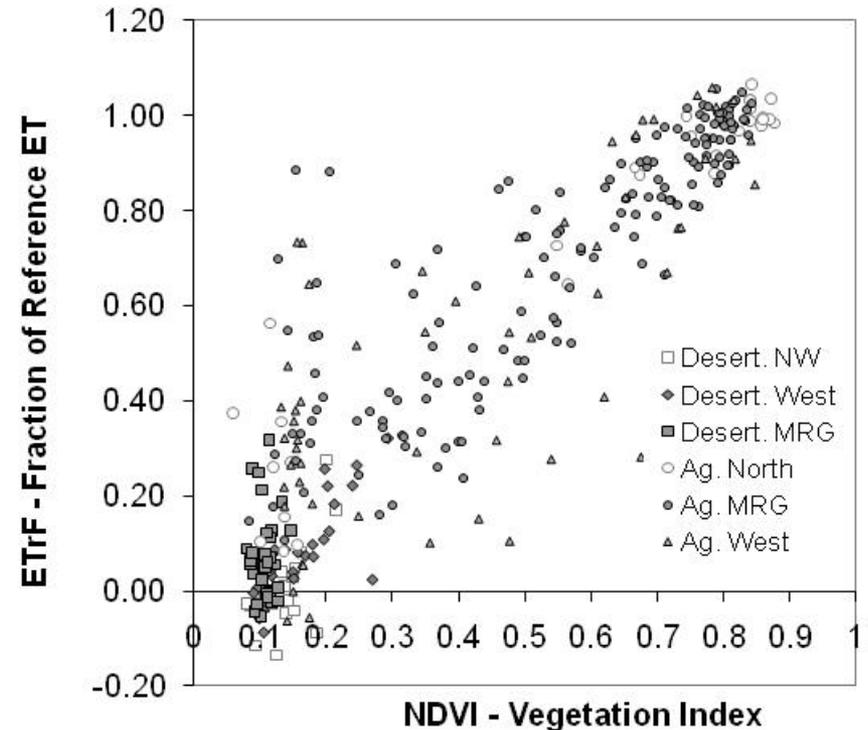
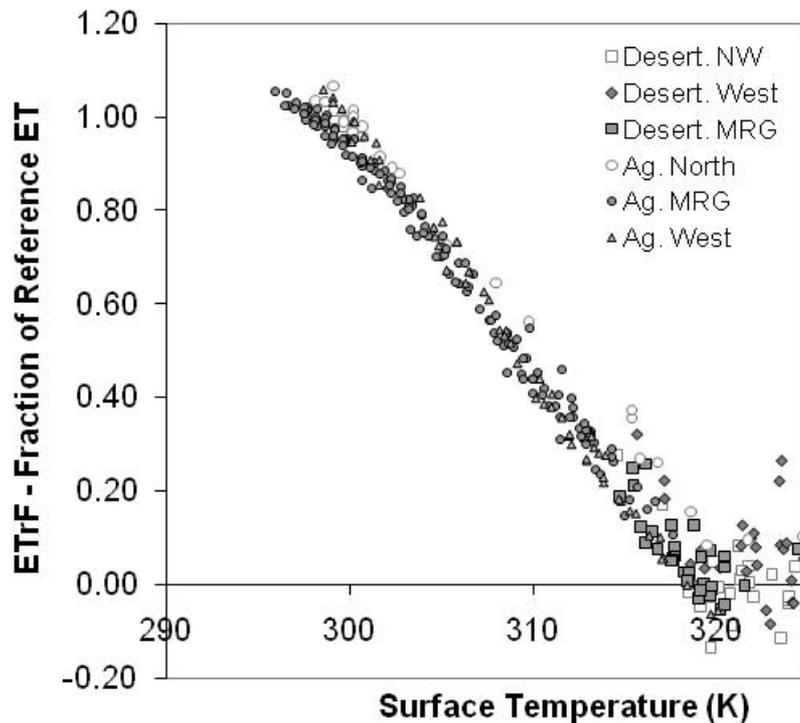
Energy Balance can ‘see’ impacts on ET caused by:

- ◆ **water shortage**
- ◆ disease
- ◆ crop variety
- ◆ planting density
- ◆ cropping dates
- ◆ salinity
- ◆ management

◆ *(these effects can cause the ratio $ET / \text{amount of vegetation}$ to vary widely, thus the need to compute ET as a residual of the energy balance)*



ET is influenced more by (and correlated with) Surface Temperature, rather than with Vegetation Amount

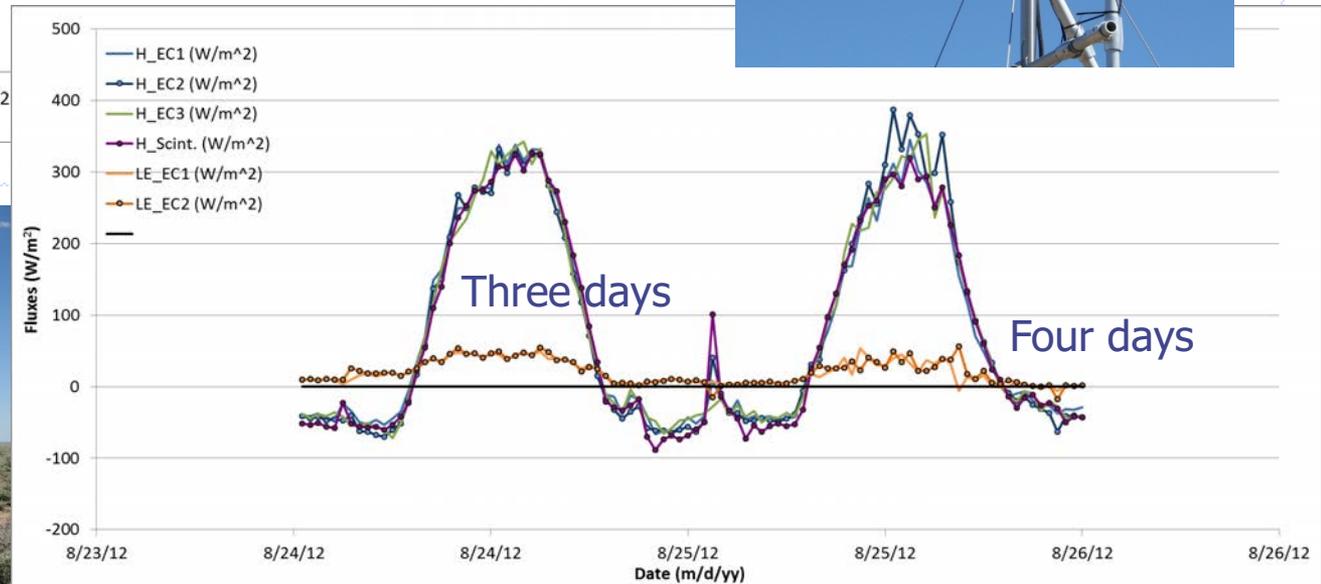
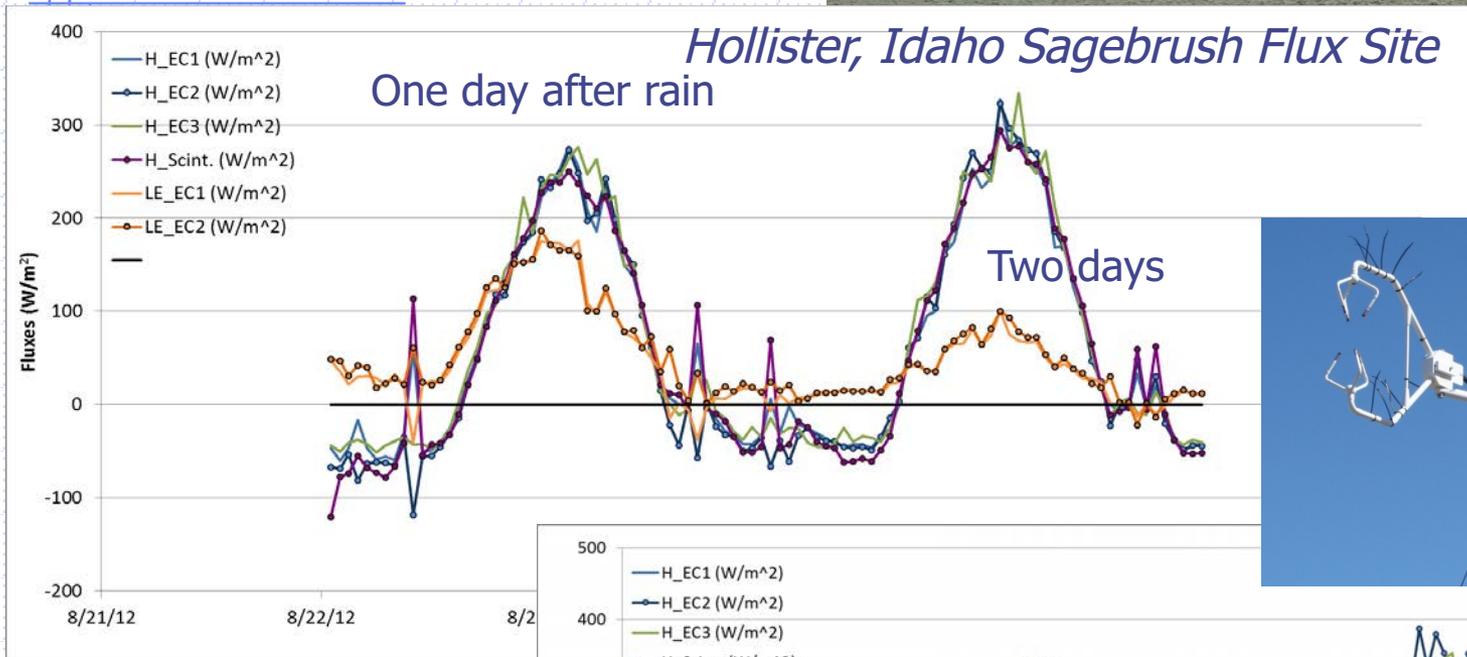


Middle Rio Grande, New Mexico, 2002

ET_{rF} = fraction of Reference ET.

$$ET_rF = ET_{actual} / ET_{ref}$$

Low levels of ET require high quality surface energy balance (EB)



General EB Components in METRIC

(Mapping ET at high Resolution using Inverse Calibration)

◆ Net Radiation (R_n)

- Reflected shortwave from satellite
- Incoming shortwave from theory
- Emitted longwave from satellite
- Incoming longwave from emitted and atmospheric transmissivity

◆ Sensible Heat Flux (H)

- Near surface vertical air temperature gradient (dT) keyed from surface temperature (T_s) – calibrated to each image date ($dT = a + b T_s$)
- Aerodynamic resistance from
 - ◆ Wind speed at blending height (from gridded or local weather)
 - ◆ Aerodynamic roughness from vegetation indices and land use type
 - ◆ Buoyancy effects from iterative solutions

◆ Soil Heat Flux (G)

- Function of H for nearly bare soil and function of R_n for vegetation

◆ $\lambda E = R_n - G - H$

Sensible Heat Flux (H)

– METRIC model

Advantage:
 r_{ah} 'floats' above the surface and is 'free' of z_{oh} and some limitations of a single source approach

$$H = (\rho \times c_p \times dT) / r_{ah}$$

Advantage:
 dT is inverse calibrated (simulated) (free of T_{rad} vs. T_{aero} vs. T_{air})

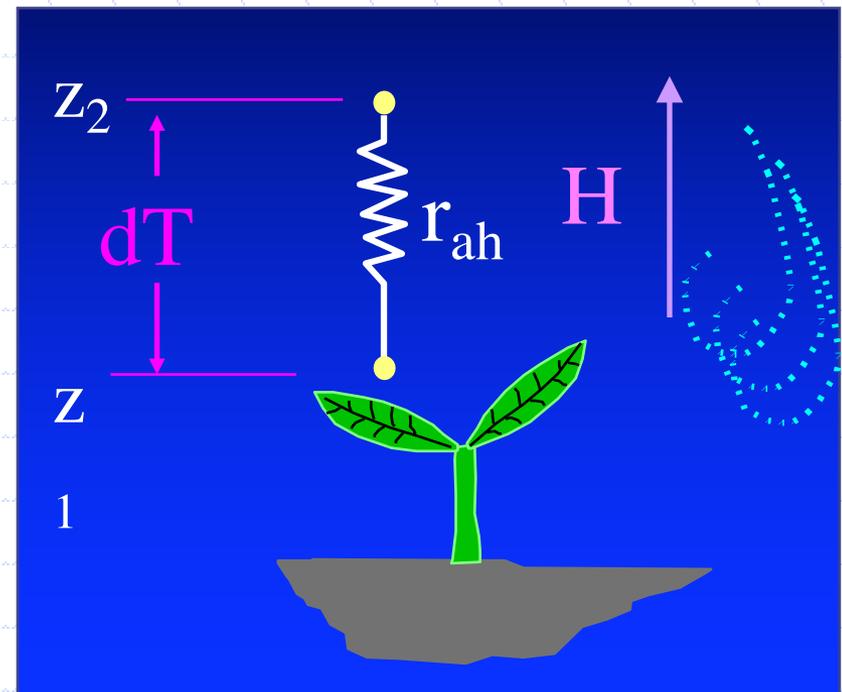
dT = "floating" near surface temperature difference (K)

r_{ah} = the aerodynamic resistance from z_1 to z_2

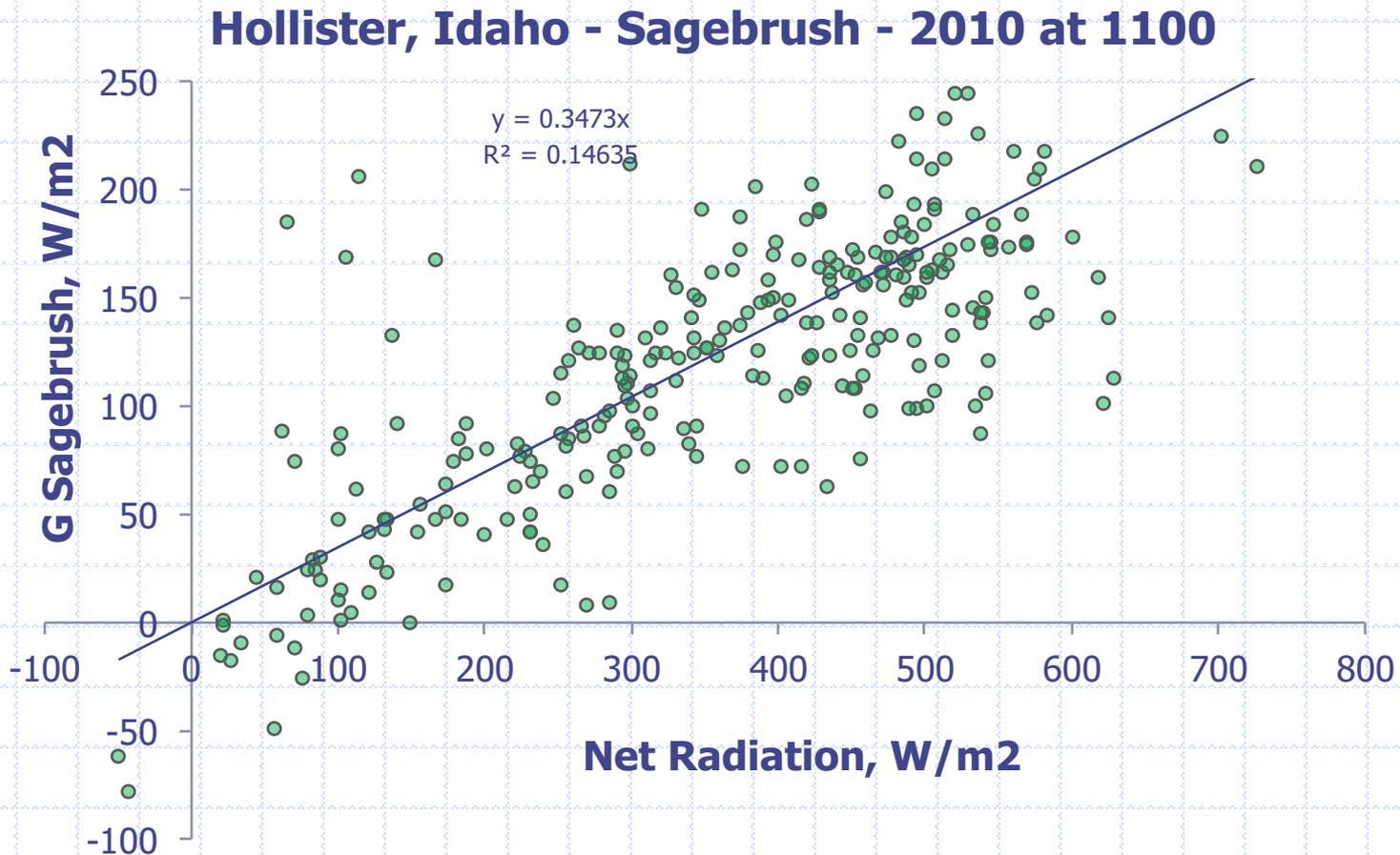
$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k}$$

u_* = friction velocity

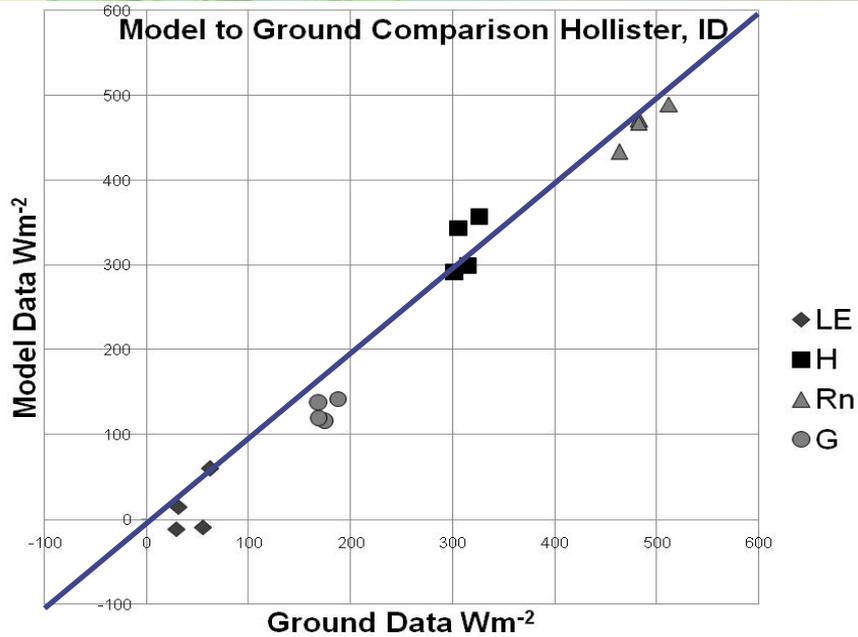
k = von karmon constant (0.41)



G for water stressed systems can be large and needs to be accounted for



Idaho NSF EPSCoR Flux Sites – Desert Systems



Four Landsat Dates during 2010 – Sagebrush

April – September ET from METRIC

➤ Comparison of satellite-based surface energy balance (METRIC) with Eddy Covariance for very low ET signal

Hydroclimate

Nebi

Calibration of METRIC/SEBAL:

$$\text{bias}_{R_n-G} \rightarrow \text{bias}_{H-\text{cal}} \rightarrow \text{bias}_{dT} \rightarrow \text{bias}_{H-\text{pixel}} \not\rightarrow \text{LE}$$

unbiased

The Sensible Heat (H) Function calibrates around Biases in many of the Energy balance components:

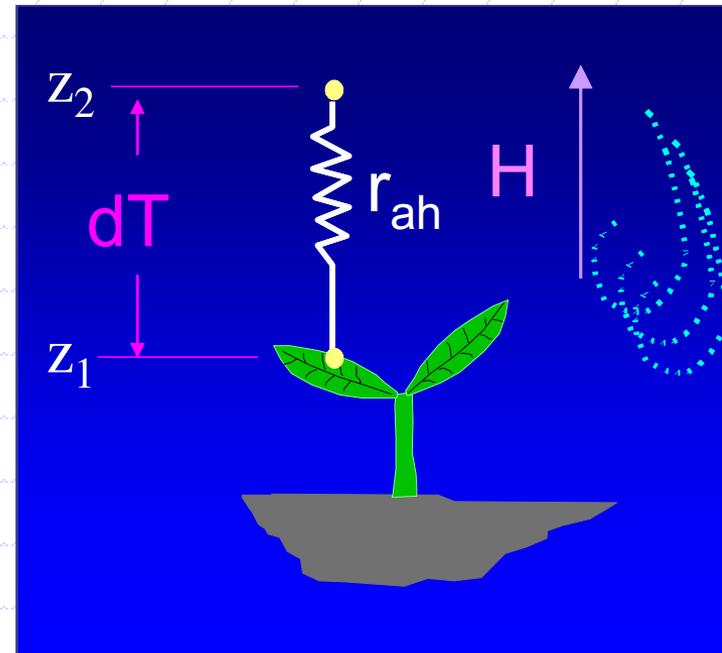
(Biases exist in: net radiation, soil heat flux, aerodynamic stability, aerodynamic roughness, absolute surface temperature, atmospheric correction)

$$H = R_n - G - \text{LE} \quad (\text{for calibration})$$

any biases

$$\text{LE} = R_n - G - H \quad (\text{during application})$$

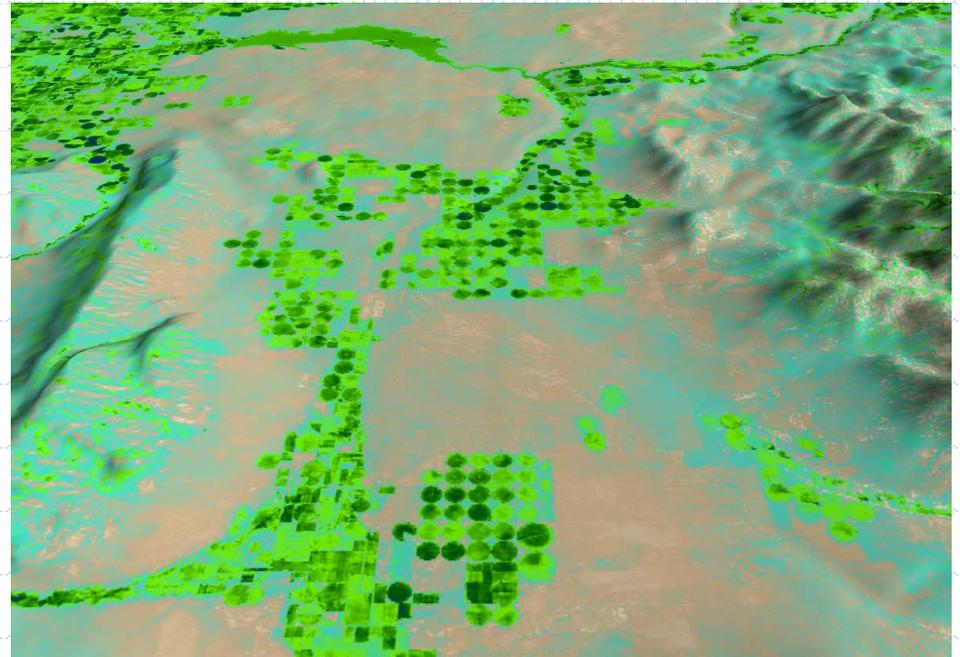
Biases cancel out



METRIC is an 'engineering' model aimed at field-scale ET with local (~ 200 km x 200 km) focus

A formula for quantifying spatially and time-variable processes:

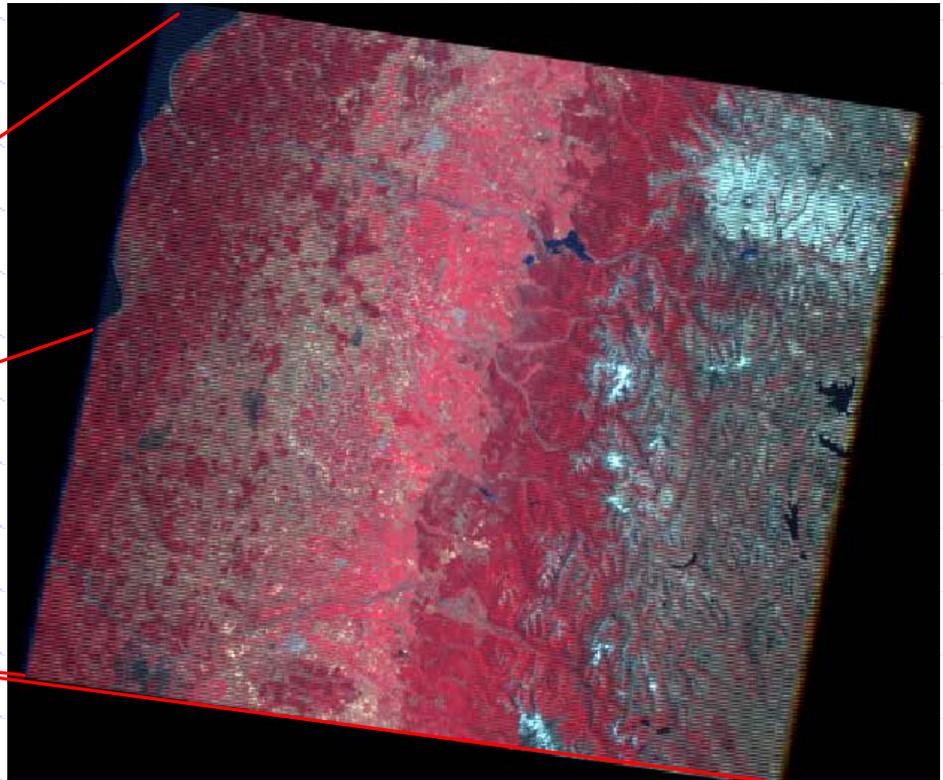
*Accuracy =
physics x human effort
+ human review and
intervention*



Fine-tuning adjustments in METRIC

- ◆ Soil heat flux of freezing soils
- ◆ Soil heat flux under organic mulch
- ◆ Soil heat flux optimization using EB inversion
- ◆ Excess aerodynamic resistance in sparse brush
- ◆ Nadir-based albedo adjustment for deep canopies
- ◆ Aerodynamic-based estimation of evaporation from water
- ◆ Radiation and Aerodynamic Algorithms in METRIC Level 3 for Complex Terrain (Mountains)

Olives in Chile

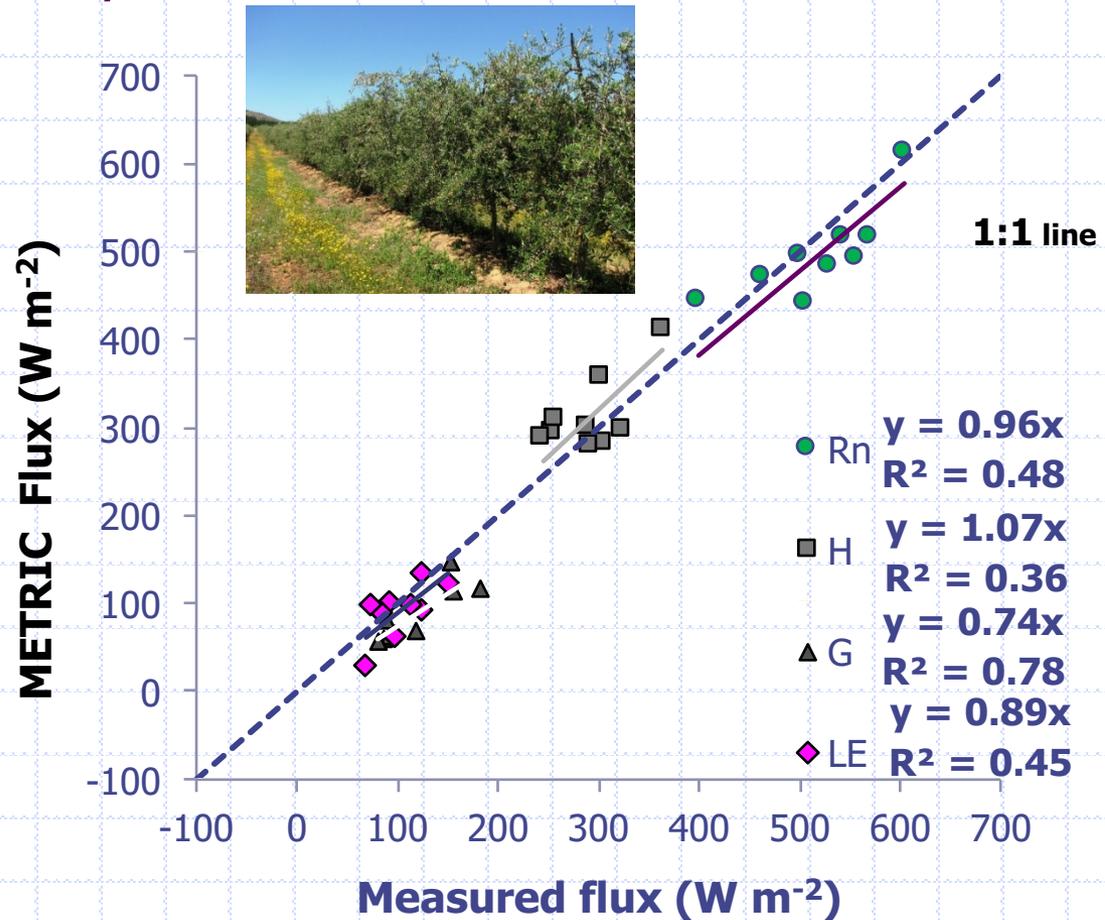


Study area is in the center of Chile
Path 233, Row 85, Landsat 7 processing
(2011 & 2012)

Chile

*Data by Dr. Samuel Ortega, Univ. Talca, Chile,
collaboration with Dr. A. Kilic, Univ. Nebraska*

METRIC vs. Ground Measurements – Olive Orchard near Talca, Chile



New olive production in central Chile with relatively dense tree spacing.

ET fluxes measured using an eddy covariance system mounted above the crop.

Analyses by Samuel Orlando Ortega Salazar, with with A. Kilic, Univ. Nebraska

Computing ET for Long (Monthly) Periods

- ◆ Utilize Relative ET from Landsat Snapshots
- ◆ Use “Fraction of Reference ET” ($ET_r F$) concept to extend Snapshots over time
- ◆ Use “Reference ET” (ET_r) as the daily Scaler that incorporates day-to-day weather impacts on ET

Reference ET: A Living Evaporation Index

30 s m^{-1}
(daytime
hourly)

45 s m^{-1}
(24-hr)
for alfalfa

ASCE Penman-Monteith

$$ET = \left(\frac{\Delta(R_n - G) + K_{time} \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a} \right)} \right) / \lambda$$

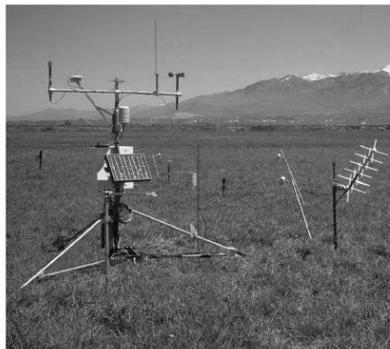
Standardized ASCE Penman-Monteith

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

f (Solar Radiation) points to $\Delta(R_n - G)$
 f (Temperature) points to $T + 273$
 Wind Speed points to u_2
 f (Humidity) points to $(e_s - e_a)$
 C_n and C_d are constants

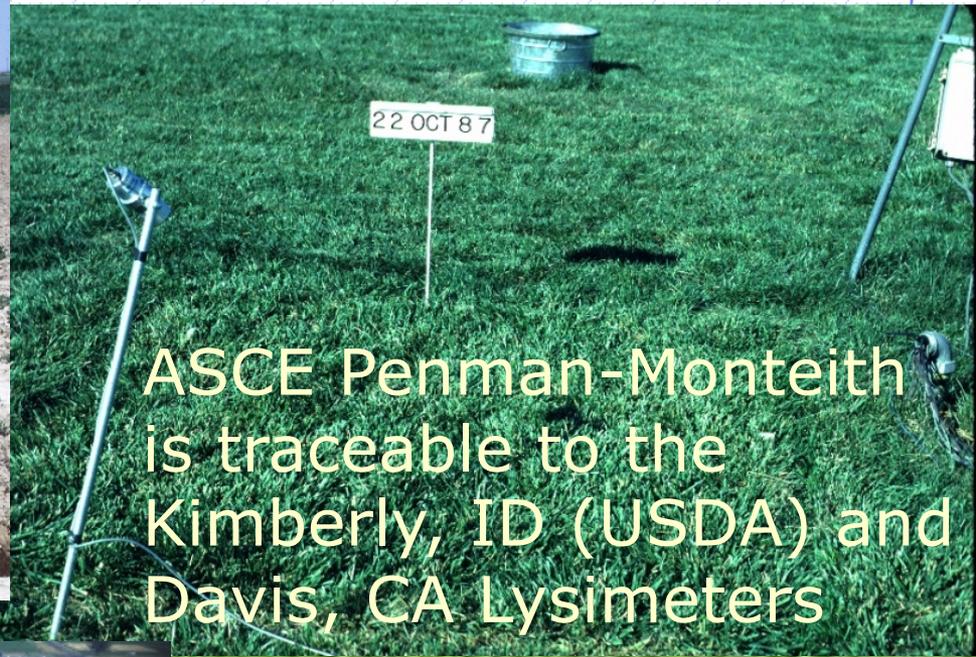
The ASCE Standardized Reference
Evapotranspiration
Equation

Edited by
Richard G. Allen
Igor A. Walter
Ronald Elliott
Terry Howell
David Jeppia
Marvin Jensen



ASCE



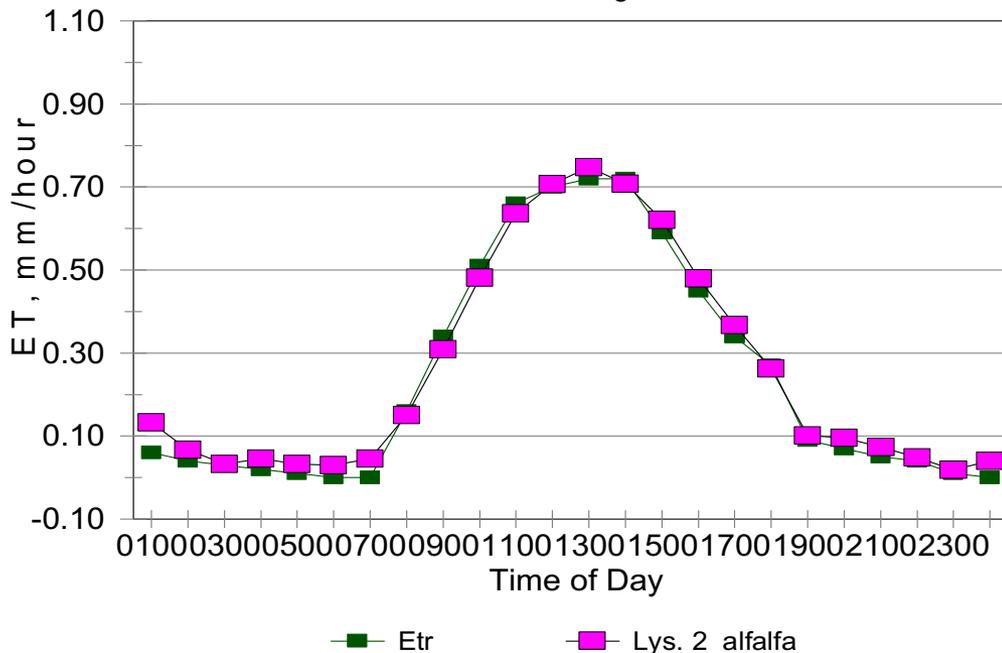


ASCE Penman-Monteith
is traceable to the
Kimberly, ID (USDA) and
Davis, CA Lysimeters



Kimberly Lysimeters - September 4, 1990

Data from Dr. J.L Wright

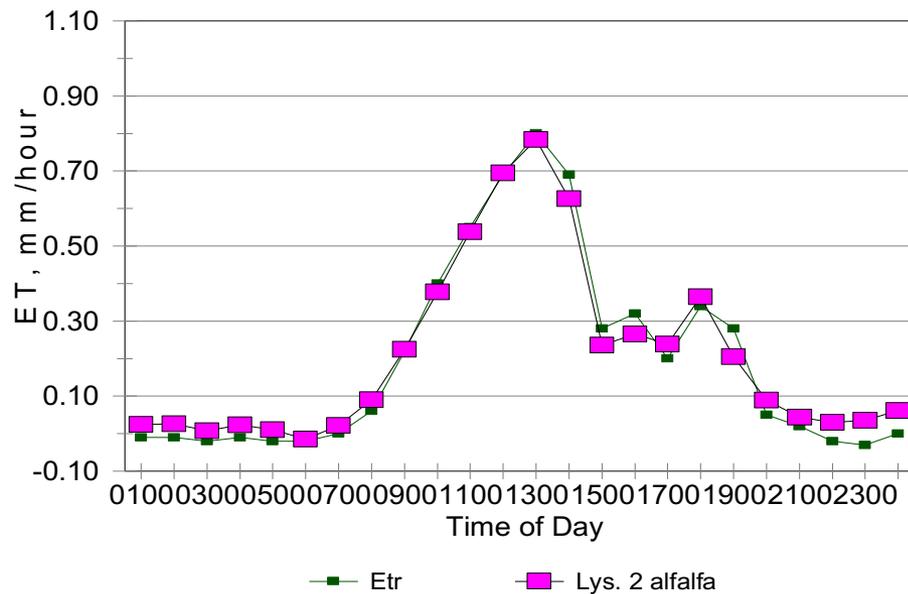


ASCE Standardized
Penman-Monteith
(alfalfa reference)
at Kimberly, Idaho

- hourly time step

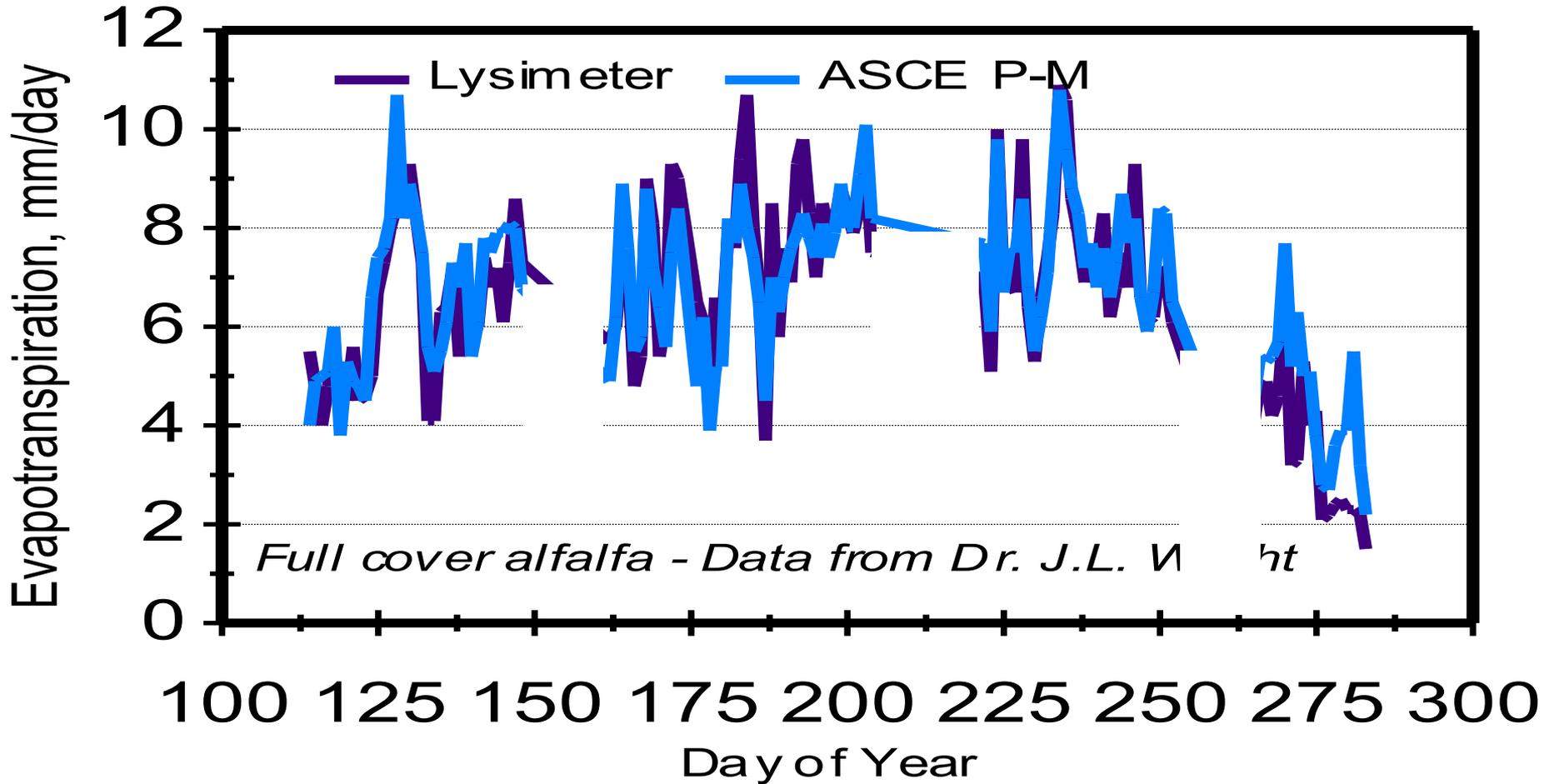


Kimberly Lysimeters - September 7, 1990

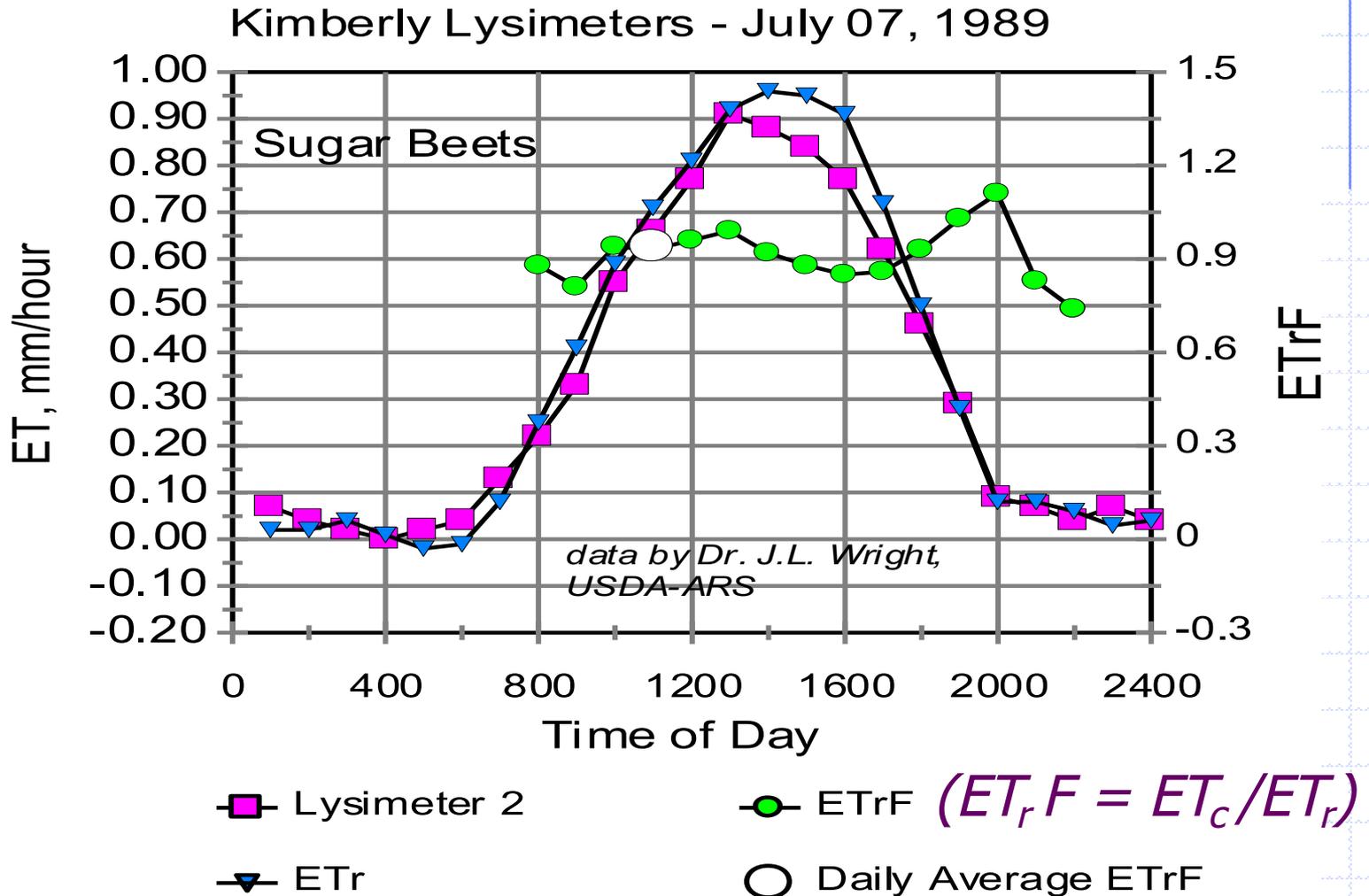


Good day to day correspondance with lysimeter

Kimberly, Idaho 1969



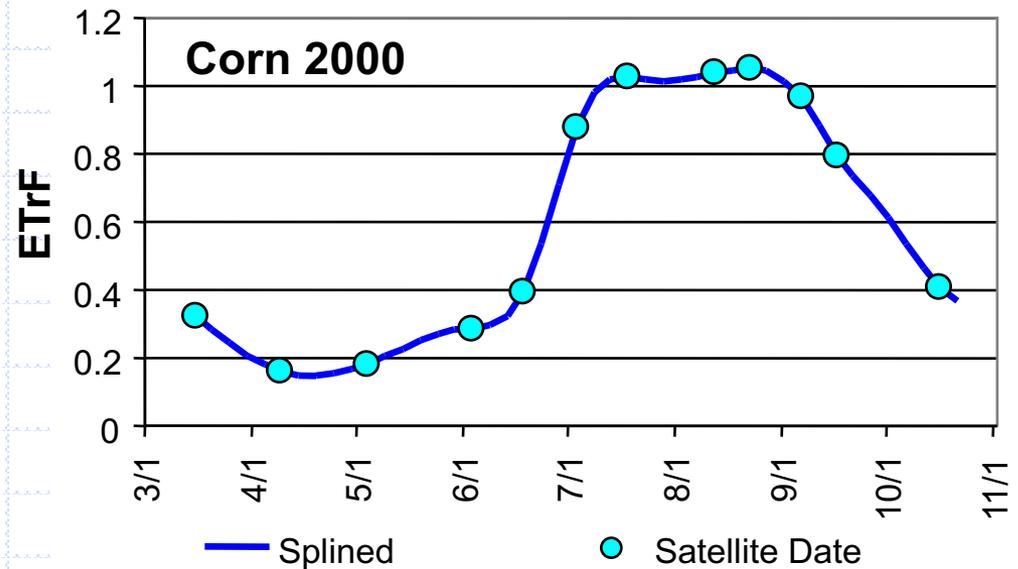
$ET_r F = \text{Fraction of } ET_r = K_c$
 $ET_r F$ is consistent through the day



Interpolation/Integration for Monthly or Seasonal ET

$ET_r F$ = fraction of reference
(potential) ET

-- interpolated day-to-day
using a cubic spline



$$ET_{period} = \int ET_r F_t \times ET_{r24t} dt$$

Use ET_r to account for daily weather effects

Weighing Lysimeter System at Kimberly, Idaho

Dr. James L. Wright, USDA-ARS

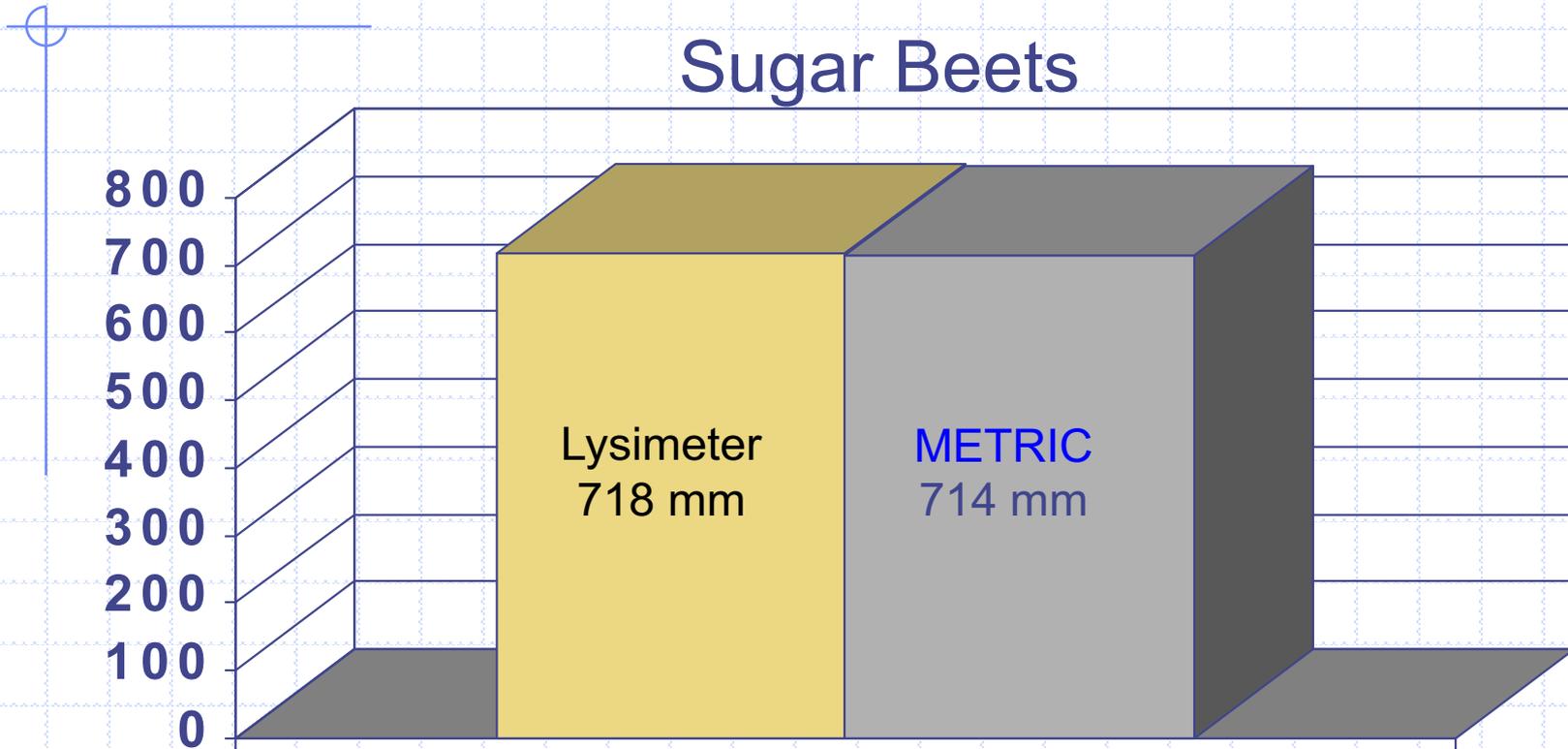


photos courtesy of Dr. J.Wright, USDA-ARS (ret)

Comparison of Seasonal ET by METRICtm with Lysimeter

ET (mm) - April-Sept., *Kimberly, 1989*

Sugar Beets



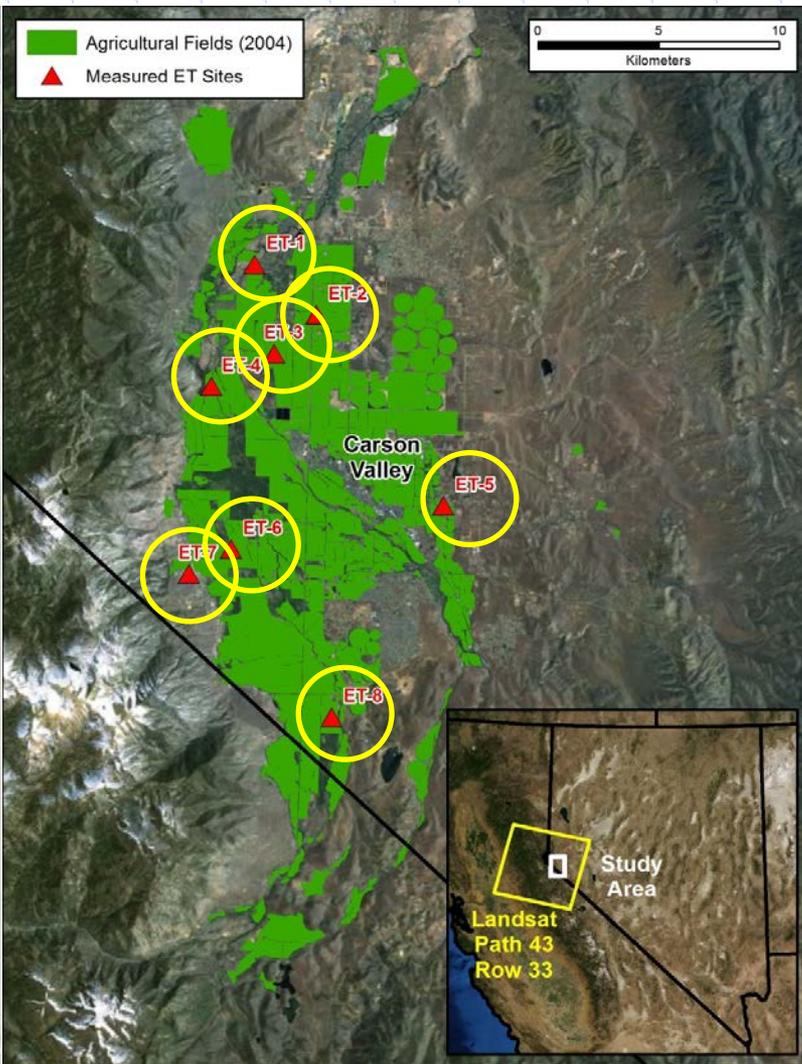
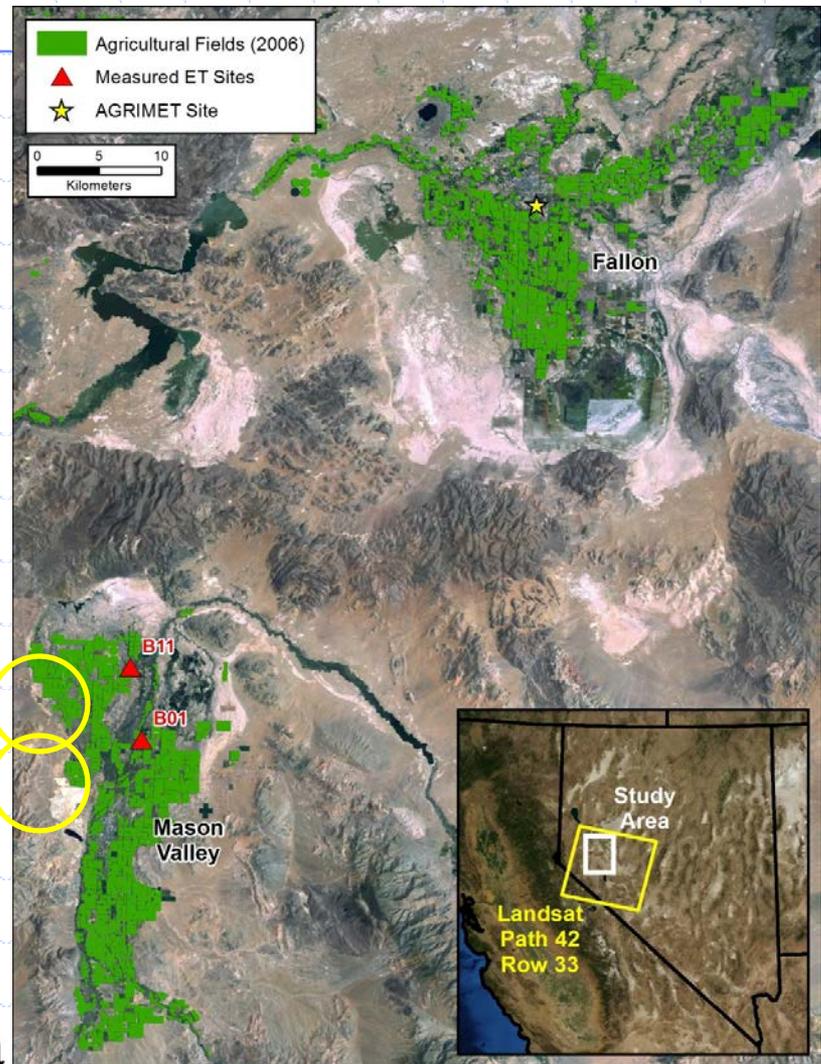
Total

■ Lysimeter ■ METRIC

Nevada

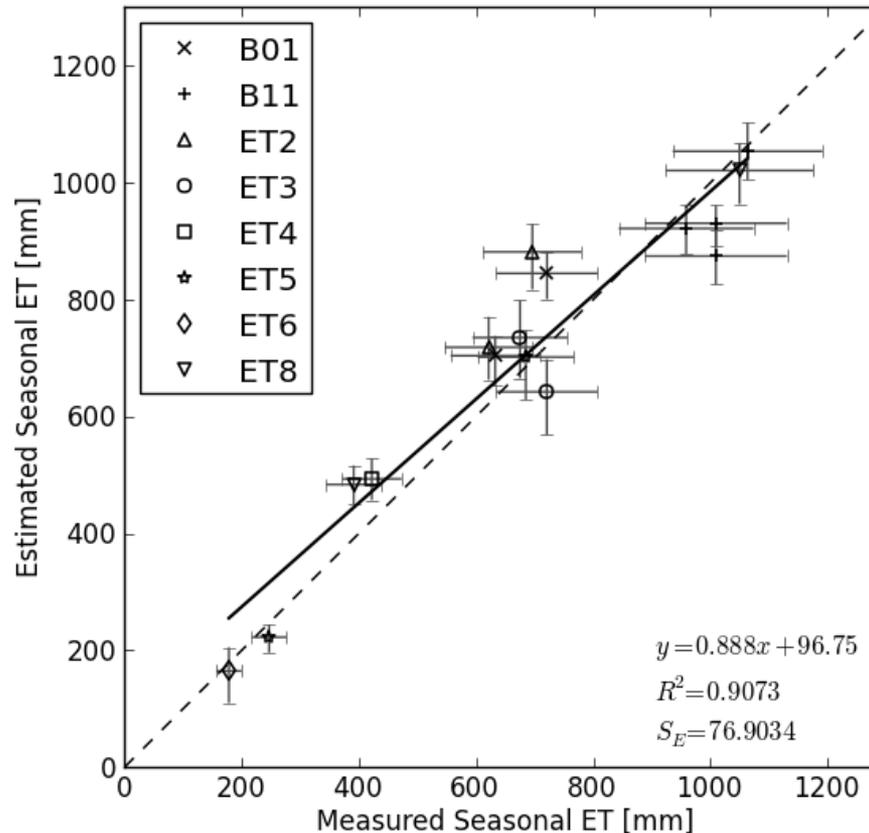
compiled by Dr. Justin Huntington, DRI

Blind Comparison of METRIC Seasonal ET to Measured ET – Desert Research Institute



Nevada

Blind Comparison of METRIC Seasonal ET to Measured ET



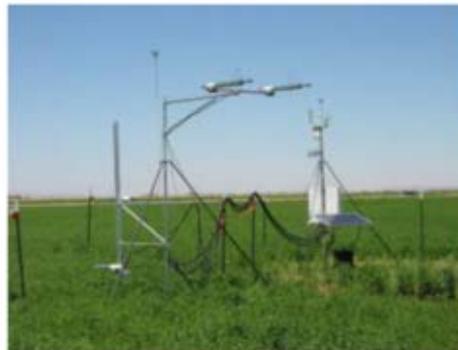
- ◆ Whiskers on X = +/- 12% USGS estimated uncertainty in measured Bowen ratio/eddy ET
- ◆ Whiskers on Y = +/- 95% confidence interval of 100 Monte Carlo METRIC ET estimates

“Blind” Intercomparison of Leading ET models – 2014 – SE California

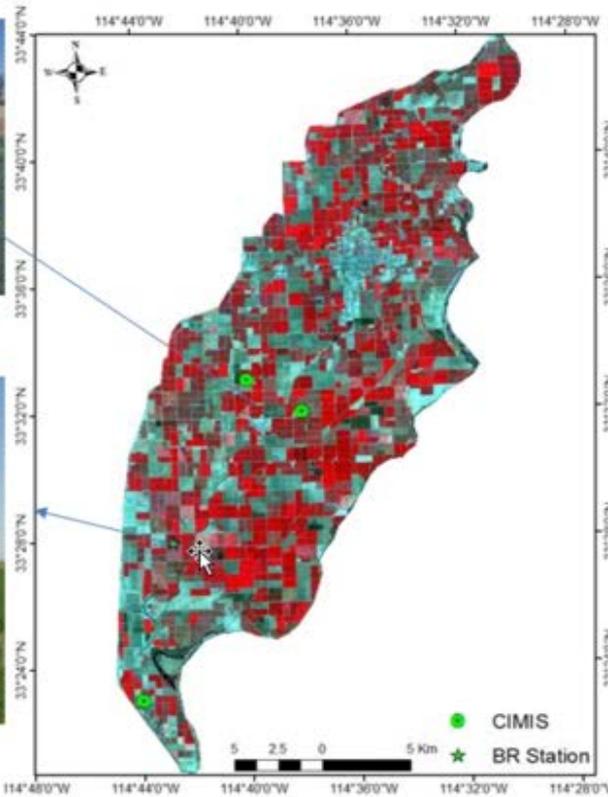
Site 1: Palo Verde Irrigation District (PVID)



CIMIS Weather Station , Blythe NE # 135



Full surface energy balance flux measurements based on Bowen Ratio Station



List of Landsat 5 scenes used

No.	Date (2008)	DOY (2008)	Path	Raw
1	19-Jan	19	38	37
2	11-Feb	42	39	37
3	27-Feb	58	39	37
4	07-Mar	67	38	37
5	23-Mar	83	38	37
6	08-Apr	99	38	37
7	24-Apr	115	38	37
8	10-May	131	38	37
9	17-May	138	39	37
10	26-May	147	38	37
11	11-Jun	163	38	37
12	18-Jun	170	39	37
13	13-Jul	195	38	37
14	29-Jul	211	38	37
15	05-Aug	218	39	37
16	21-Aug	234	39	37
17	15-Sep	259	38	37
18	01-Oct	275	38	37
19	17-Oct	291	38	37
20	09-Nov	314	39	37
21	18-Nov	323	38	37

“Blind” Intercomparison of Leading ET models – 2014 – SE California

Summary of

Individual O
– vs. Ground Fl

	RMSE	BIAS	BIAS (%)
Measured			
	1.5	-0.2	-7.2%
	2.7	-2.5	-42.0%
METRIC	0.9	-0.1	1.6%
	1.3	-0.8	-9.8%
	2.1	-1.7	-22.9%

Seasonal Water Balance

Water balance Component	Depth (mm/year)			METRIC			
Precipitation	71	71	71	71	71	71	71
Inflow Main Canal	2479	2479	2479	2479	2479	2479	2479
Total Inflow	2550	2550	2550	2550	2550	2550	2550
Canal Spills	284	284	284	284	284	284	284
Drainage	998	998	998	998	998	998	998
ET	(1000)		956	1223	952	X	
Total Outflow	(2282)		2238	2505	2234	X	
Inflow- Outflow	(268)		312 (-12.2%)	34 (-1.8%)	316 (-12.4%)	X	



Estimates by METRIC were < 2% for both individual field and entire district



Comparison with Lysimeter Measurements:



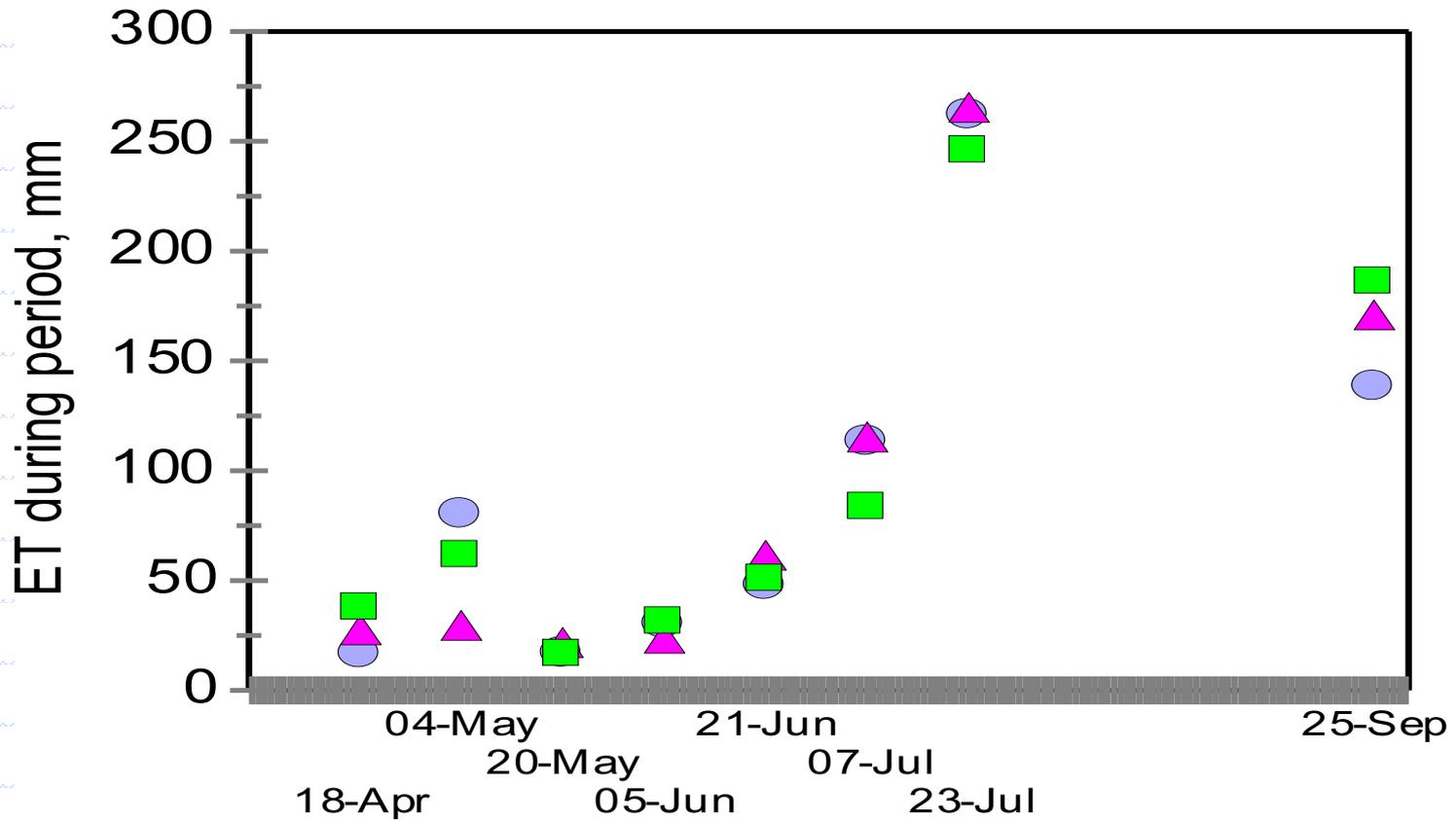
1968-1991

Lysimeter at Kimberly (Wright)



Kimberly, Idaho – Periods between Satellites

Impact of using Kc from a single day to represent a period: Kimberly 1989



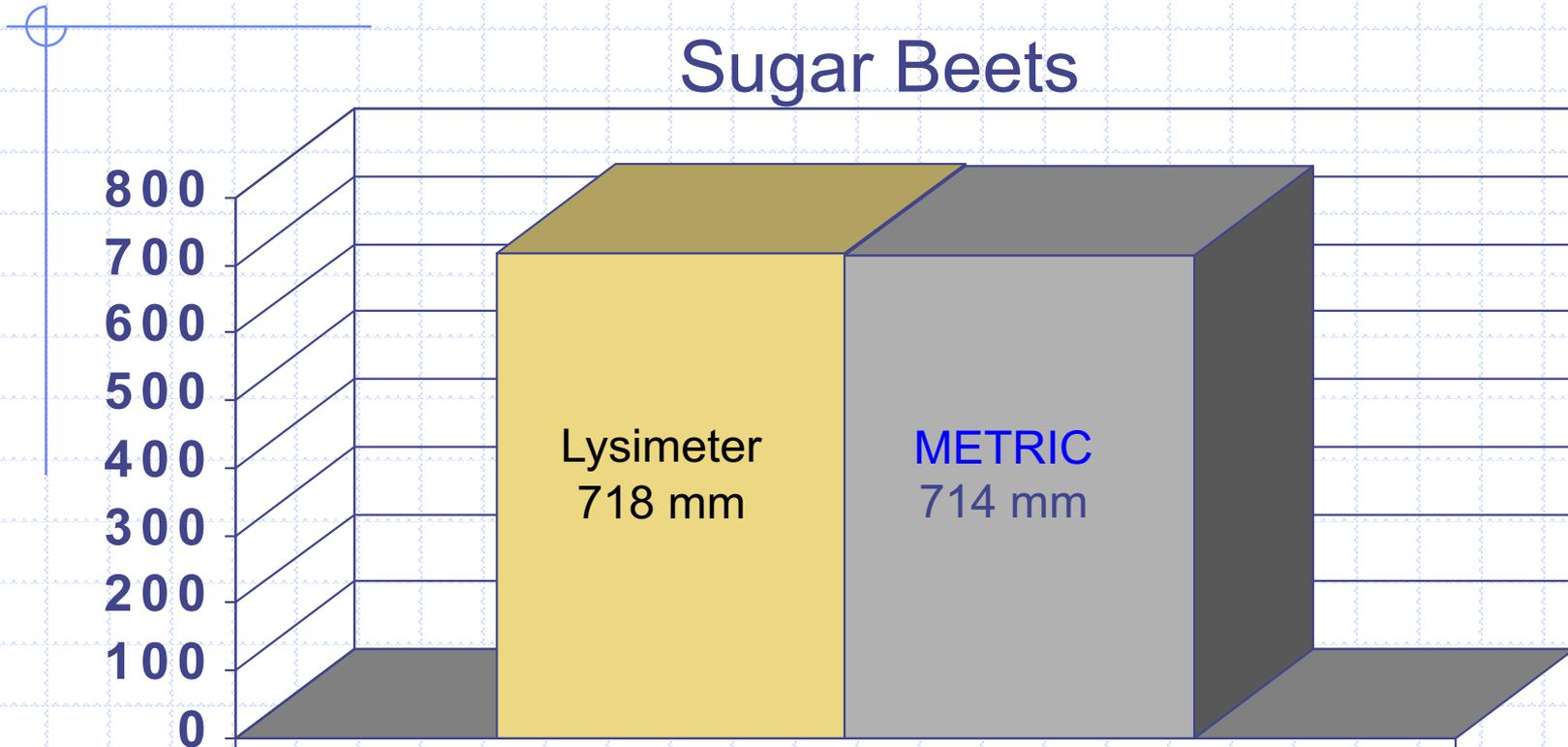
● Lys. Kc on Sat. date x sum ETr
 ▲ Sum. all lysimeter meas. (Truth)

■ METRIC ET for period

Comparison of Seasonal ET by METRICtm with Lysimeter

ET (mm) - April-Sept., *Kimberly, 1989*

Sugar Beets



Total

■ Lysimeter ■ METRIC



Applications where effort and accuracy matters

Snake River Plain and Aquifer
Yellow "dots" are ground-water wells
(> 4000)

"Junior" Irrigators from Aquifer
~1960

"Senior"
Aquiculture
from
Springs
~1950

Junior consumption from Aquifer
"Injures" Senior River and Spring
Rights

"Senior" Irrigators from River ~1900

Idaho

Eastern Snake Plain Aquifer Model

METRIC ET data:

- ◆ Have provided more accurate calibration of the groundwater model
- ◆ Improved accuracy of depletions and recharge estimates
- ◆ Shows long term trends and annual variation in ET

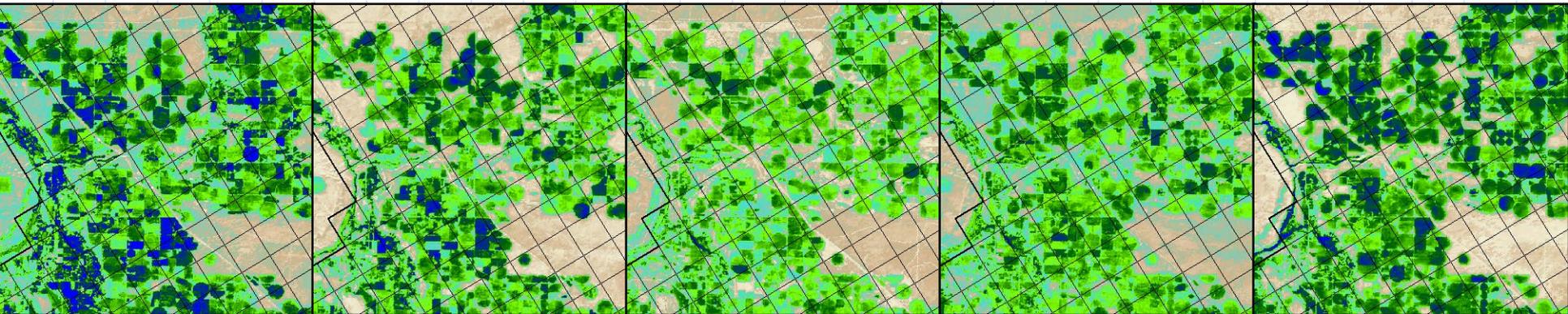
1996

2000

2002

2006

2008



Idaho Clear Springs Foods Water Call

Idaho *Business News*

Water curtailment ordered in Magic Valley

POSTED: 11:13 MDT Thursday, July 23, 2009

by IBR Staff

Idaho Department of Water Resources Interim Director Gary Spackman on July 22 issued a **curtailment order** to about 250 holders of 315 junior water rights in south central Idaho's Magic Valley. The curtailment order is part of a continuing response to a water delivery call made in 2005 by senior water right holder Clear Springs Foods.

State goes ahead with first large-scale well closure of more than 300 water rights in M.V.

Water districts have limited options, could file a stay

7/31/2009

By Nate Poppino

Times-News writer

The Idaho Department of Water Resources will go forward this morning with a plan to shut off more than 300 water rights irrigating just less than 9,000 acres of Magic Valley farmland, the first wide-scale well curtailment to actually be carried out by the state.

Water watch begins

8/1/2009

Unprecedented well shut-off goes into effect in valley

By Nate Poppino and Jared Hopkins

WENDELL - Employees of Idaho's state water agency quietly fanned out across the Magic Valley Friday morning, to see if nearly 250 water-right holders have complied with an order to stop using some groundwater rights.

It was the first time that the Idaho Department of Water Resources actually enforced widespread well closures to provide water to another entity.

Talks fail to find well shutoff solutions

State continues curtailment enforcement

By Nate Poppino

Times-News writer

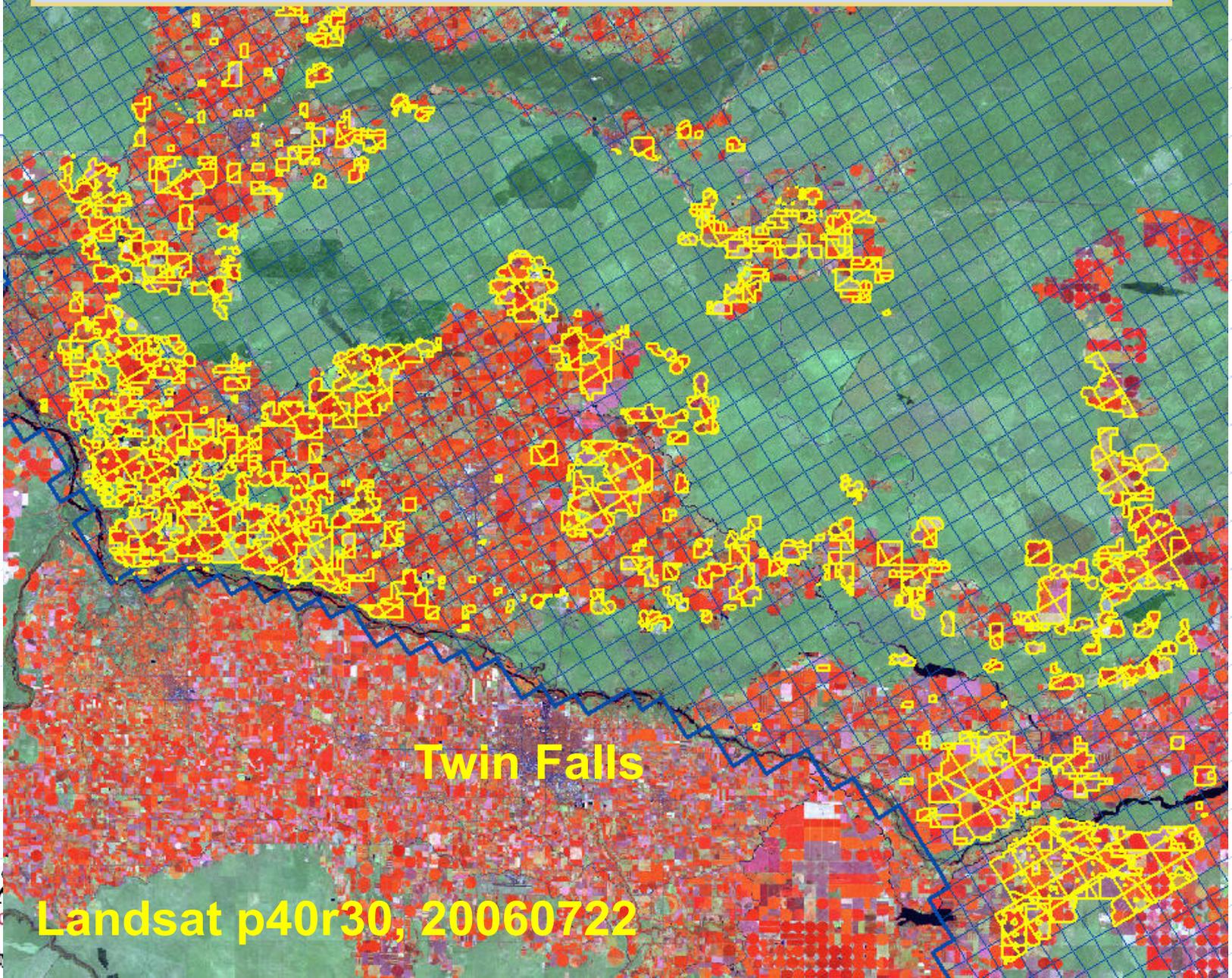
8/11/2009

Officials with two Magic Valley groundwater districts have not been able to reach an arrangement with a Buhl-area fish company, a setback in efforts to lift wide-scale well closures in the region.

Representatives of the North Snake and Magic Valley groundwater districts were attempting to reach an agreement to end curtailment of about 150 water rights affecting businesses, towns and about 4,150 acres of irrigated land. But Lynn Carlquist, chairman of the North Snake Ground Water District, said Monday afternoon that the districts will not be able to agree to requirements Clear Springs Foods listed as necessary for the company to consider a plan submitted last week acceptable.

The water rights were ordered shut down on July 31 by Idaho Department of Water Resources Interim Director Gary Spackman after he concluded the districts were not following through on a portion of an agreement aimed at providing more water for the springs Clear Springs relies on. Spackman's predecessor, Dave Tuthill, ruled last year that groundwater pumpers were depriving the company of part of its water.

GW Model Cells and Junior Water Rights



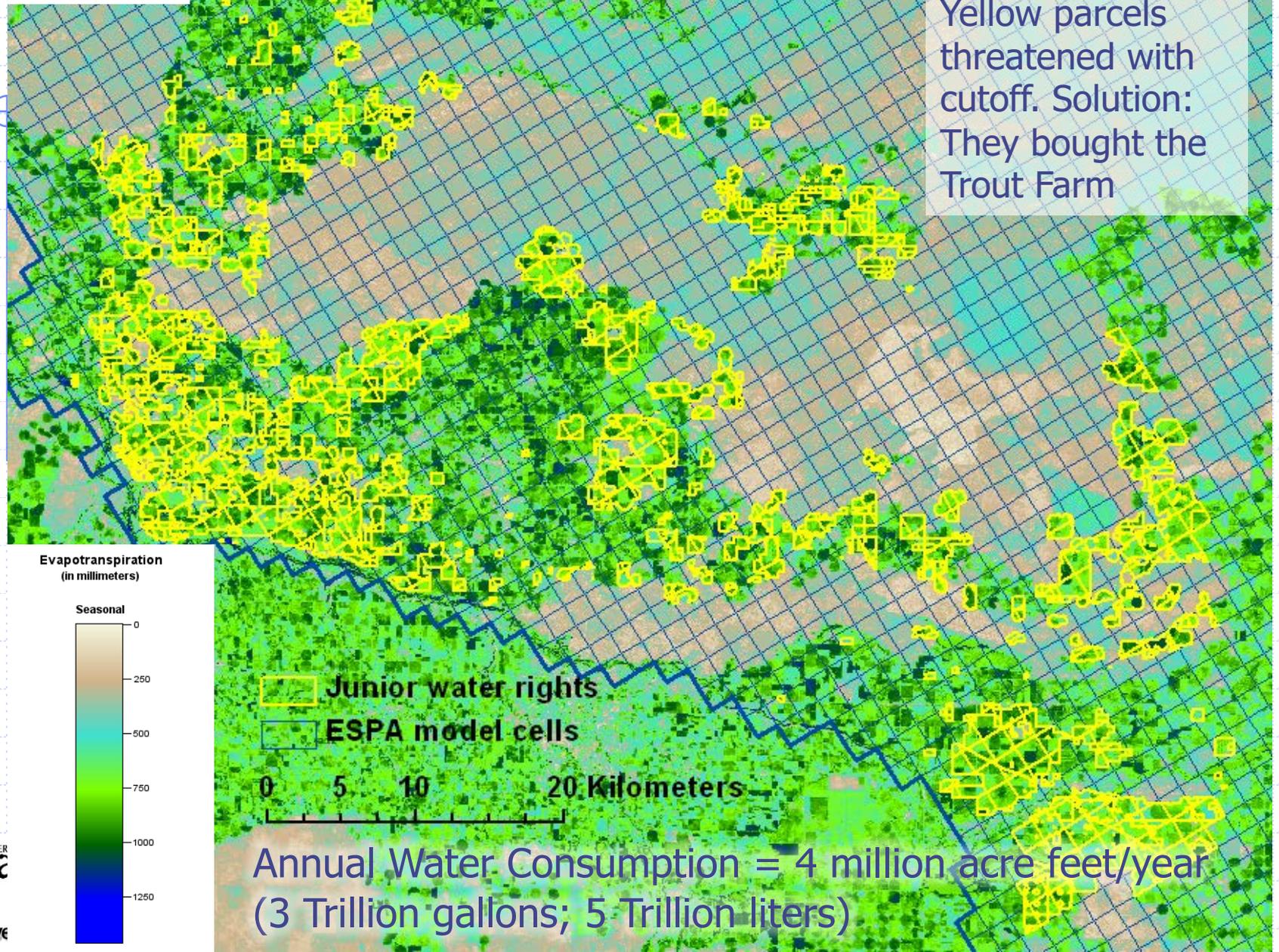
Twin Falls

Landsat p40r30, 20060722

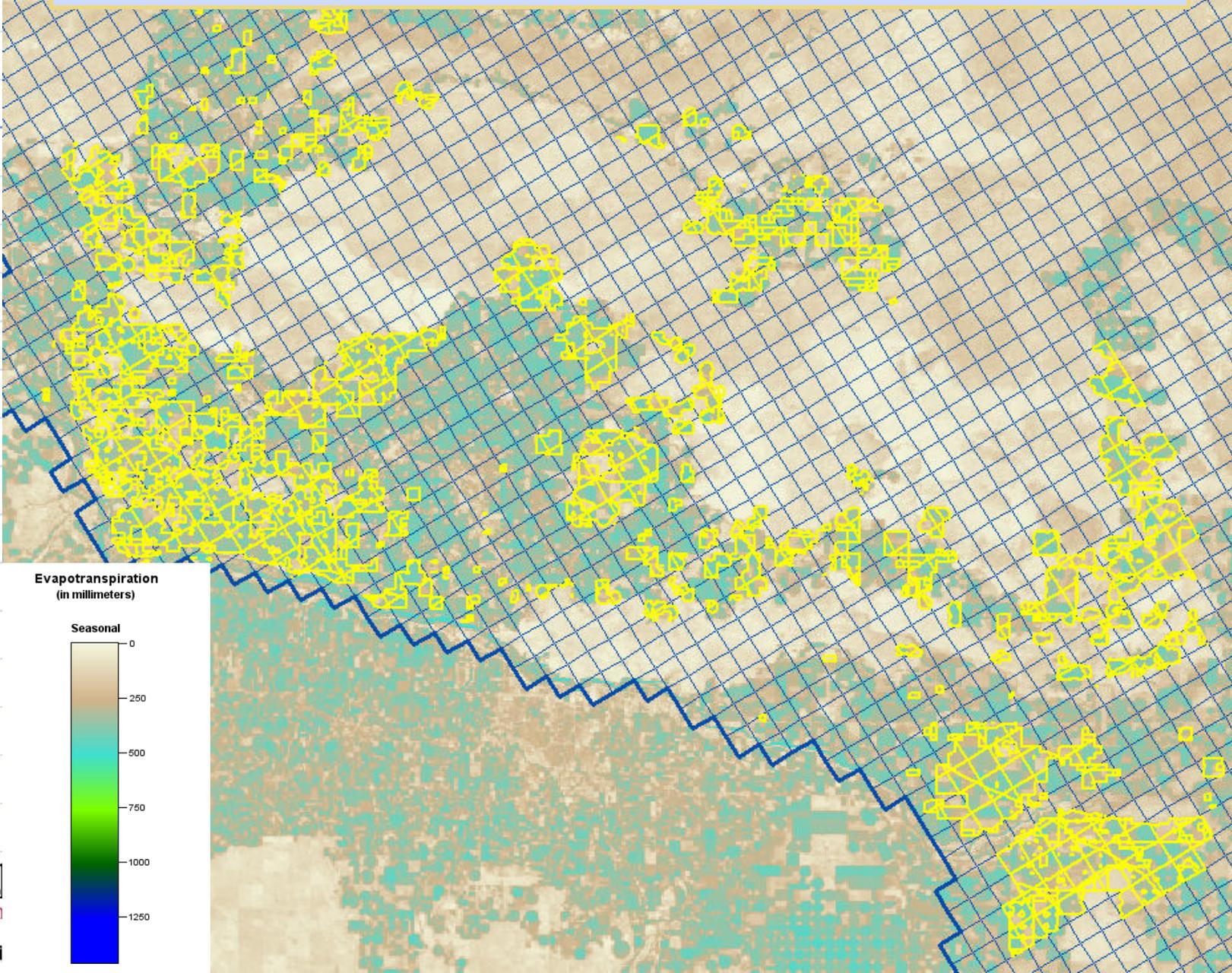
Idaho

METRIC ET 2006 April to October

Yellow parcels threatened with cutoff. Solution: They bought the Trout Farm

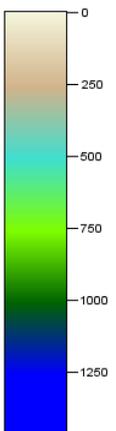


METRIC ET 2006 August to October



Evapotranspiration
(in millimeters)

Seasonal



Example 2: Water Rights Buy-Back

Issue:

Maintain minimum Snake River Flows

Endangered species

Hydro power rights

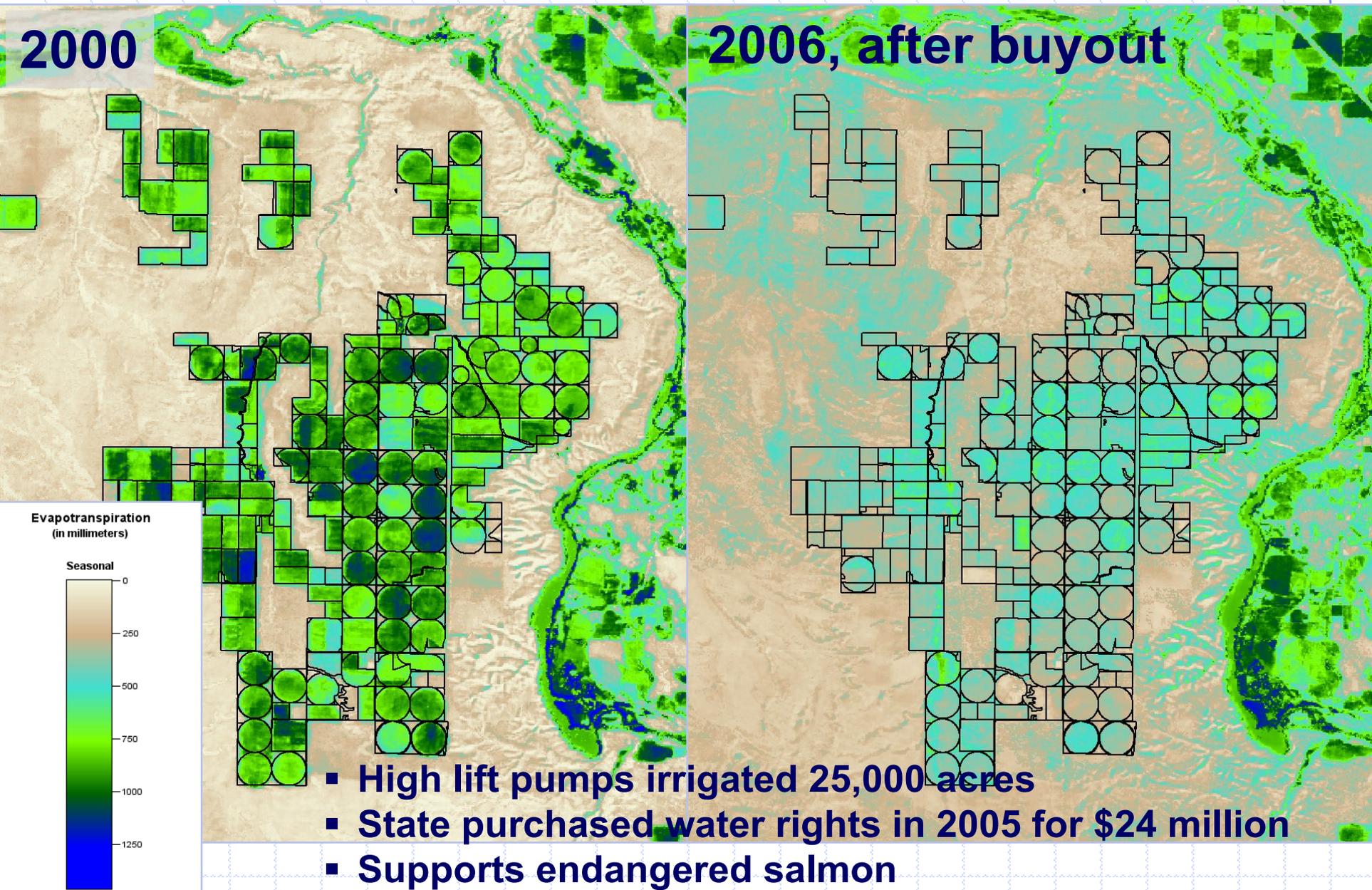
Method: Buy out marginal water rights

Negotiation

Farmer's position: buy full water right

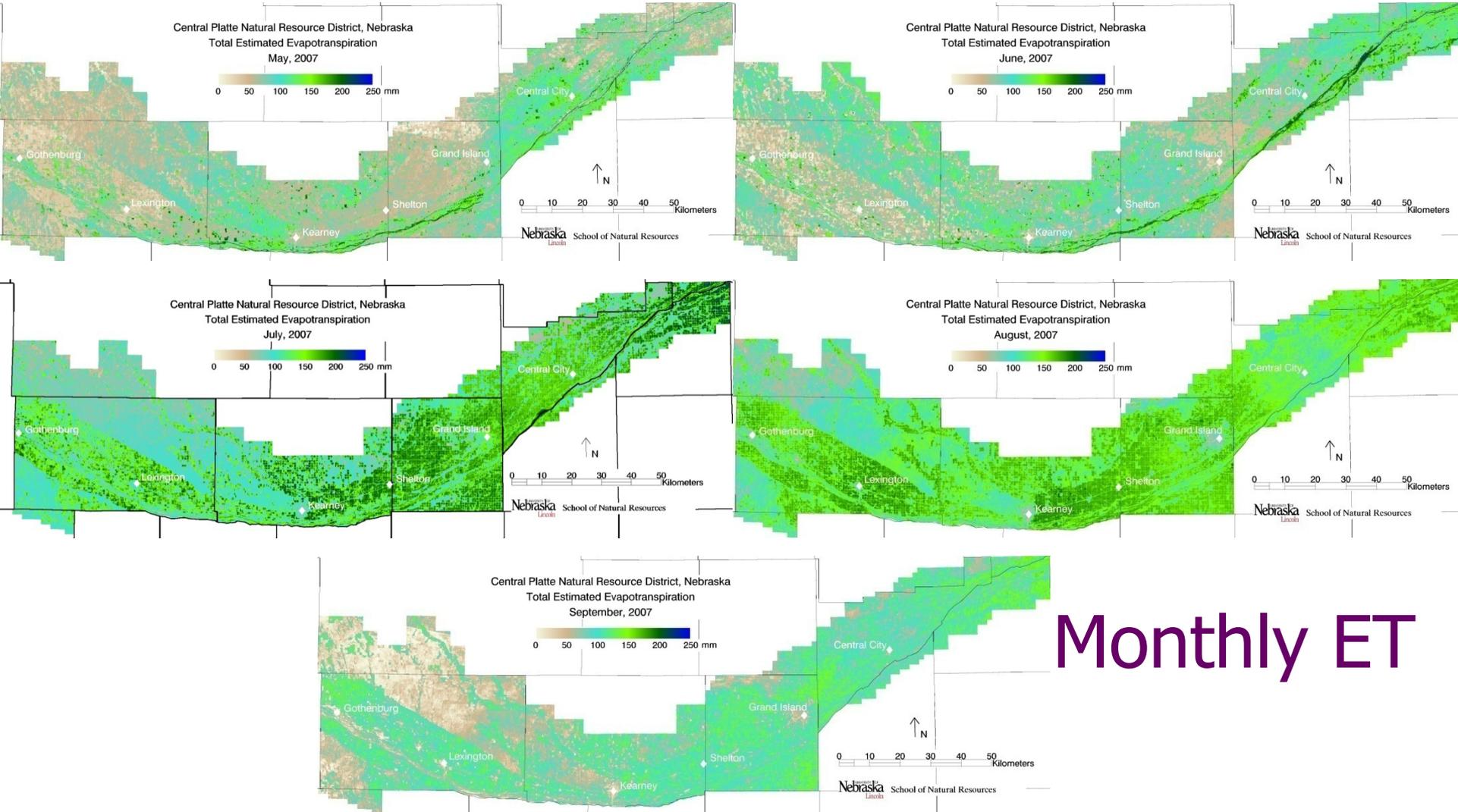
IDWR's position: buy wet water

Idaho Bell Rapids Irrigation Project, Idaho: Seasonal ET



Nebraska

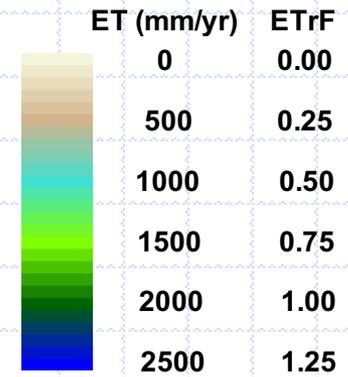
Central Platte Natural Resource District --- Management of the Ogallala Aquifer



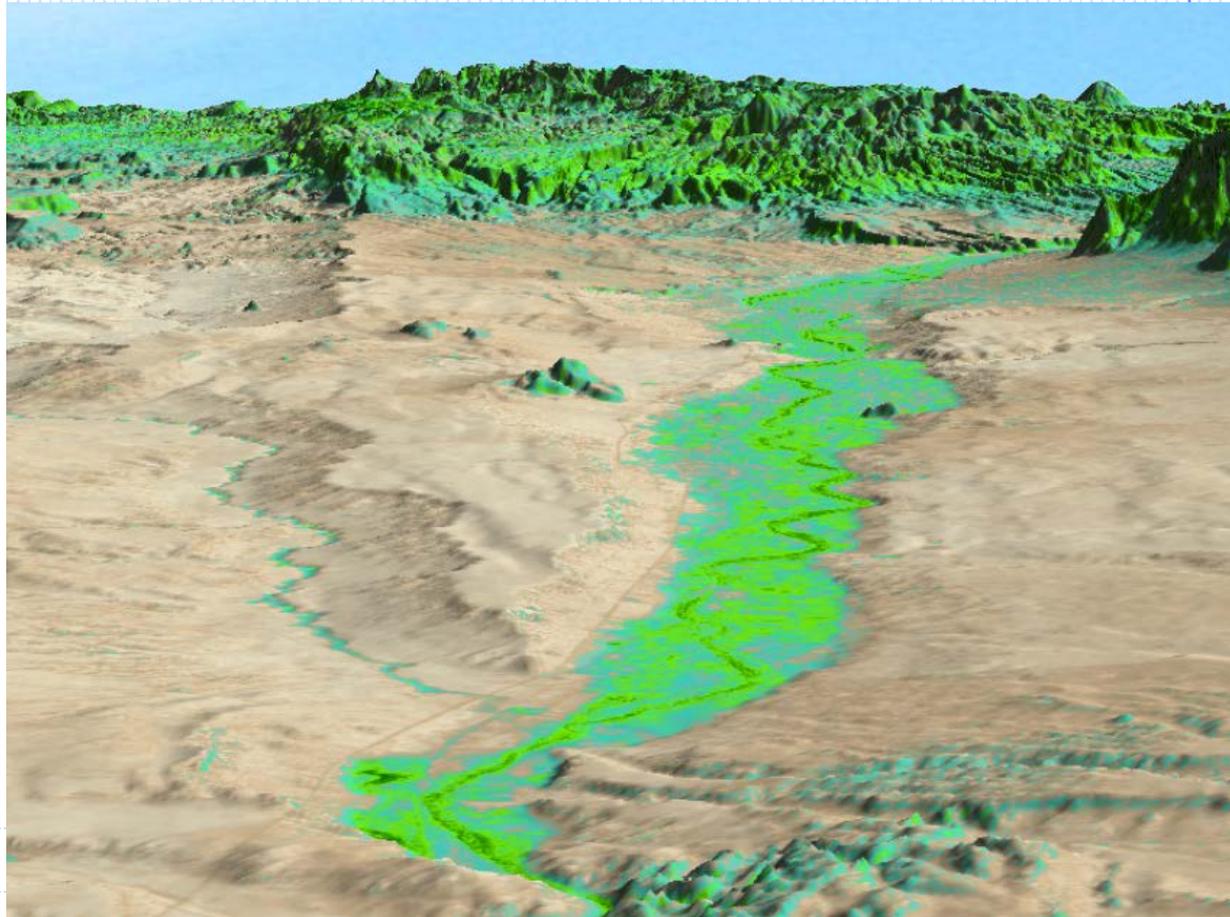
Monthly ET

New Mexico

Rio Grande of New Mexico



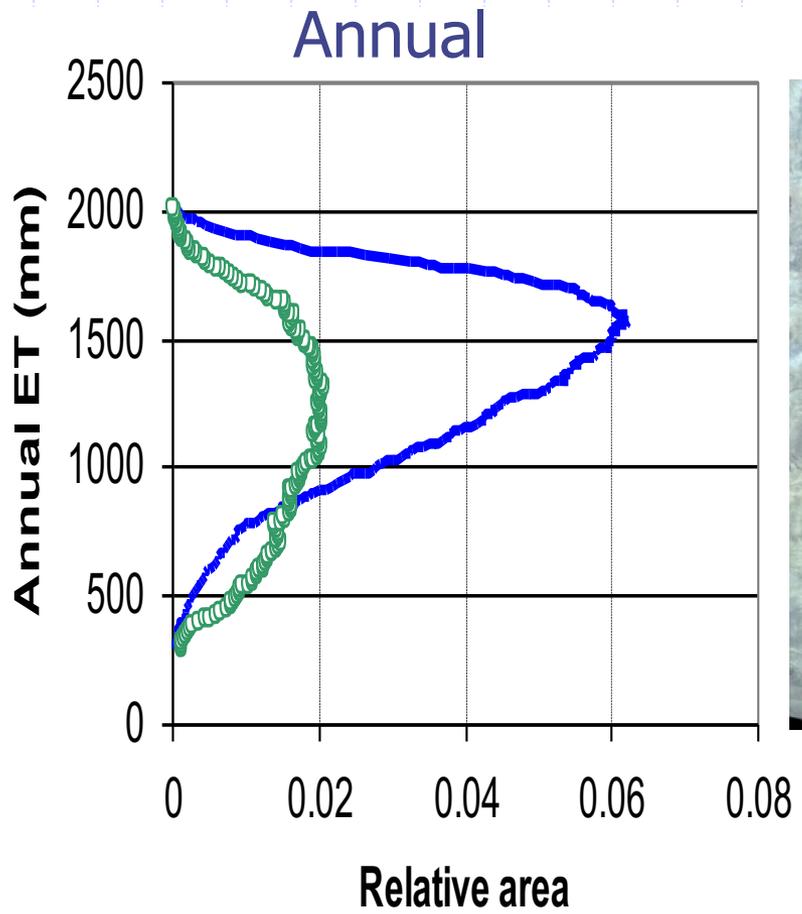
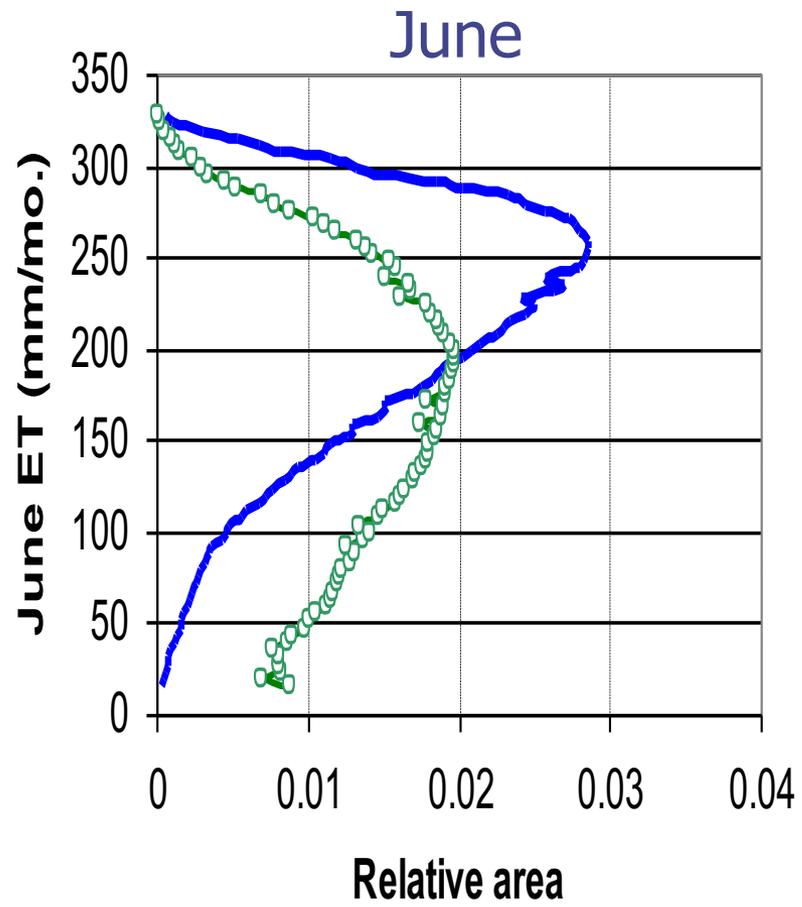
- Pueblo (*native American*) water rights dating to Coronado in 1500's
- Invasion of salt cedar
- Does increased pecan production increase ET from irrigated agriculture?



New Mexico

Frequency Distribution of ET

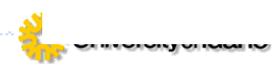
15,000 acres of cottonwood and salt cedar



— Cottonwoods —○ Saltcedar

— Cottonwoods —○ Saltcedar

Tasumi and Allen, 2006



*Estimated water consumption by class of riparian vegetation within the riparian area between San Acacia and Cochiti, NM during 2002**

	Total area (acres)	Annual ET_rF (K_c)	Annual ET (mm)	Annual Water Consumption (AF)
Cottonwood	10,800	.67	1380	49,000
Salt Cedar	4,550	.54	1110	17,000
Willow	630	.71	1440	3000
R. Olive	90	.63	1280	400



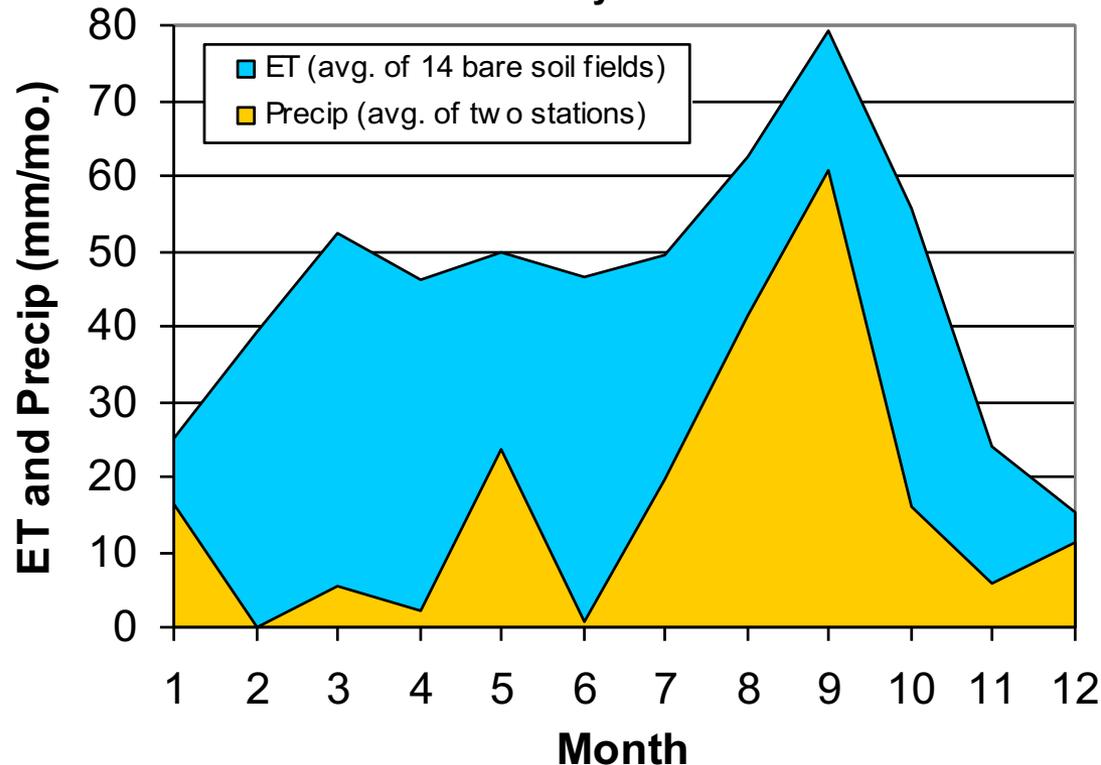
*Assumes constant ET_rF (i.e., ET/ET_r) during the day

From report by University of Idaho (Allen et al., 2004) to Keller-Bliesner Engineering, Logan, UT for U.S. Department of Justice

High Resolution Classification courtesy of Dr. Christopher Neale Utah State University

With Thermal Imaging, we can see important evaporation from wet soil – for example from high water tables

Monthly bare soil ET and precipitation in MRG valley



*Evaporation during 2002 from continuously bare areas along the **Middle Rio Grande** of NM contrasted with precipitation*

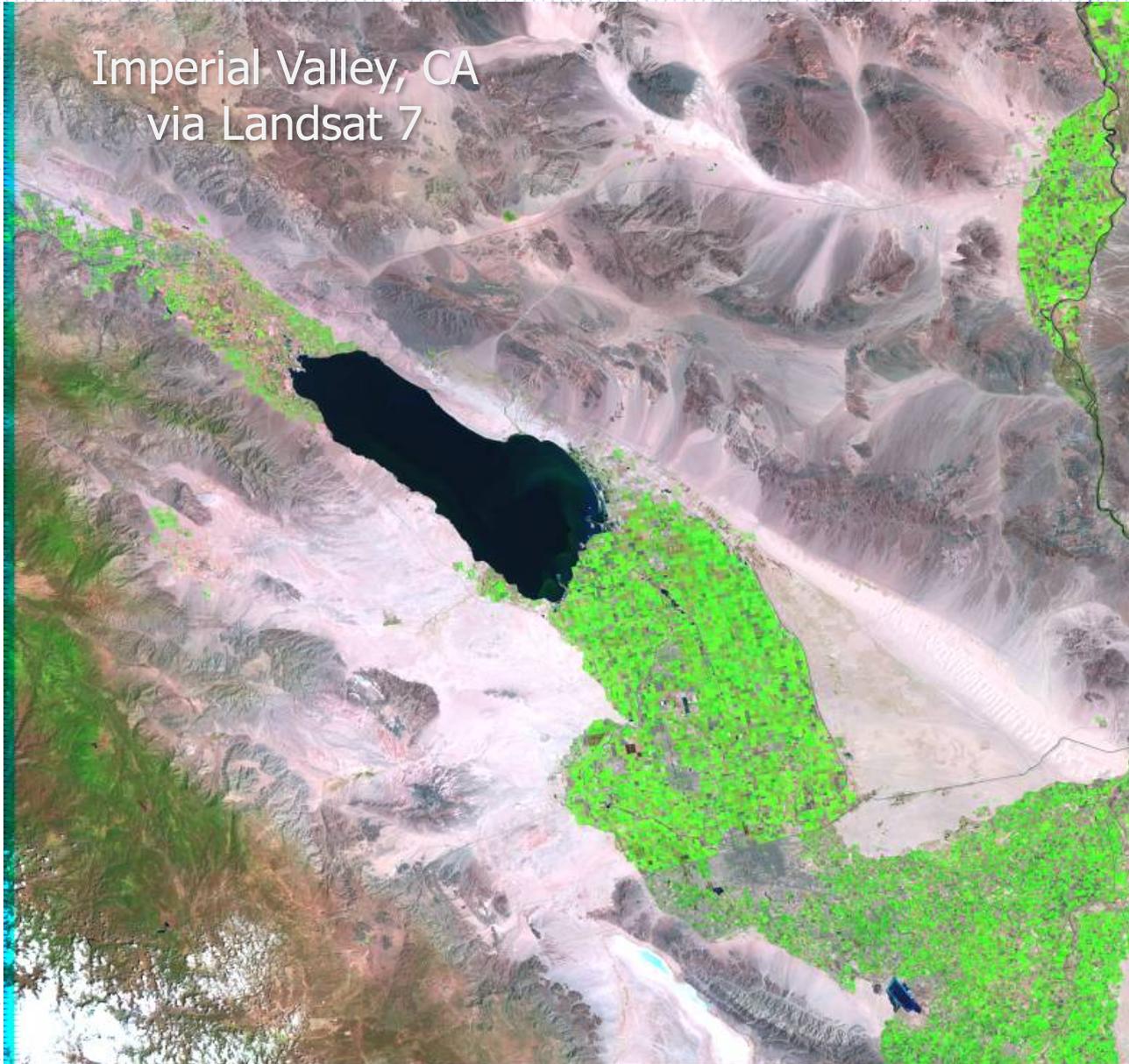
California

Imperial Valley



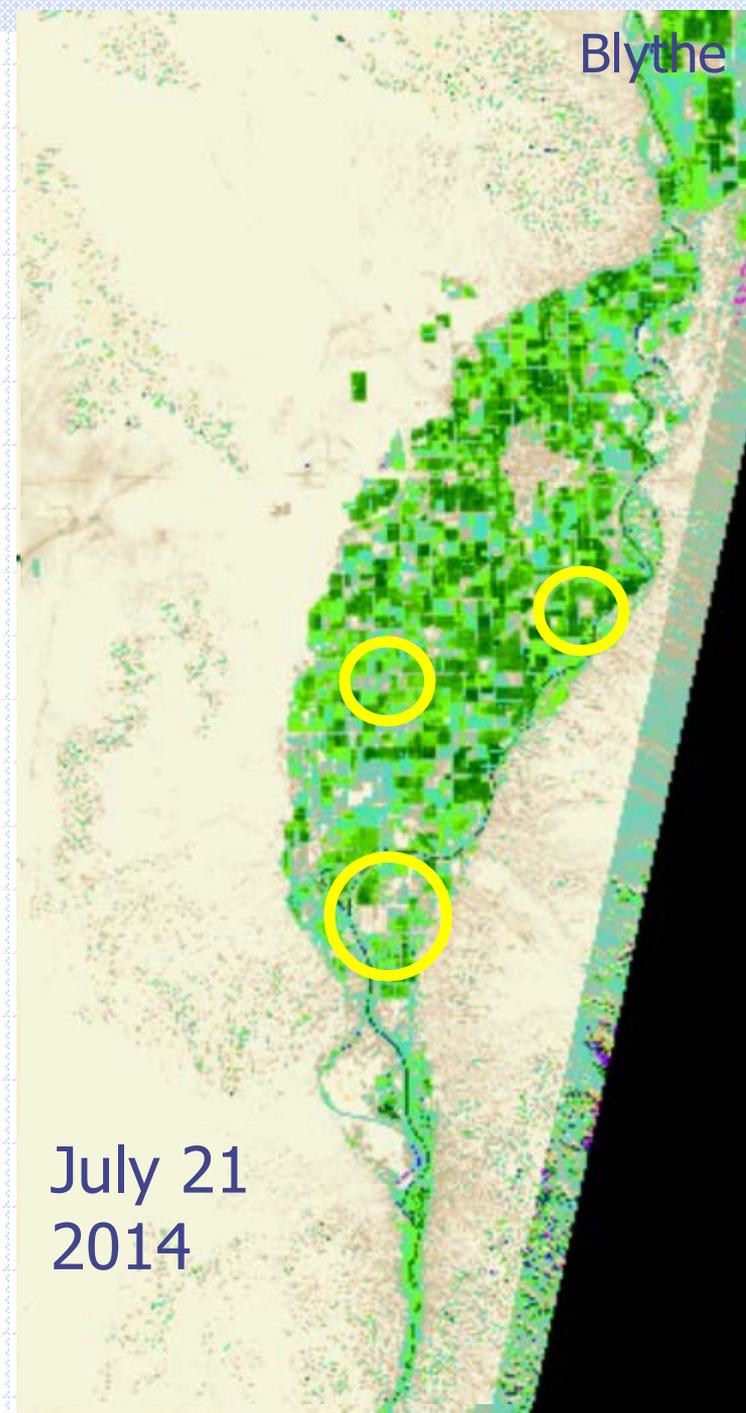
- ~15% of traditional water supply to agriculture will now flow to San Diego/ Los Angeles
- What is the impact on agriculture, water consumption and on the Salton Sea?

Imperial Valley, CA
via Landsat 7



Fallowed Fields in 2014

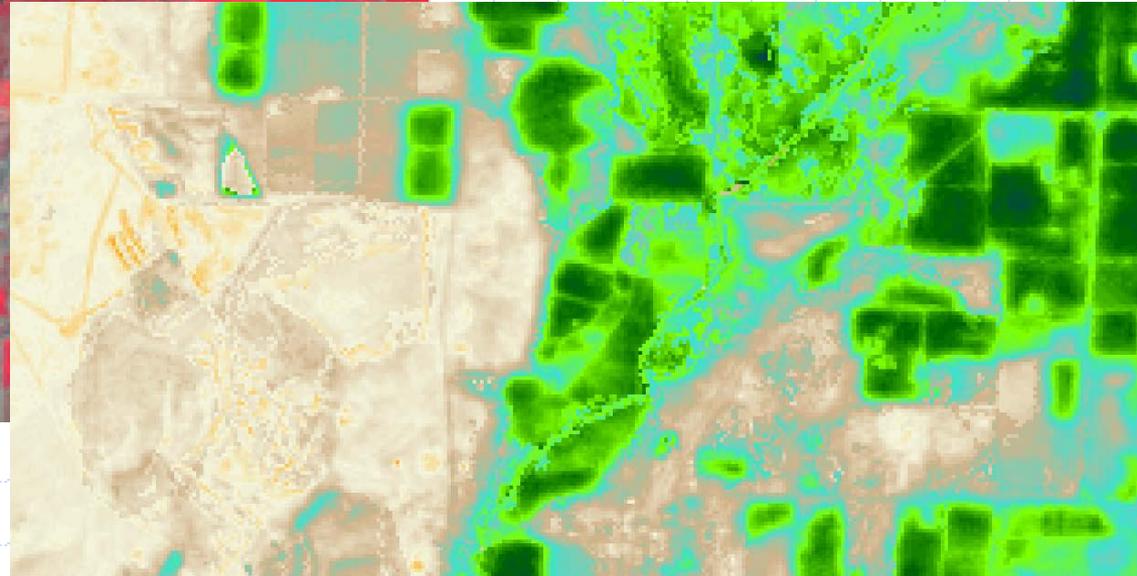
- Reduction of ET 'should' reduce to nearly zero (if little rainfall)
- Transition of alfalfa fields is notable
- Cities are able to document reduction of agricultural ET and compliance with Colorado River Compact



Nevada

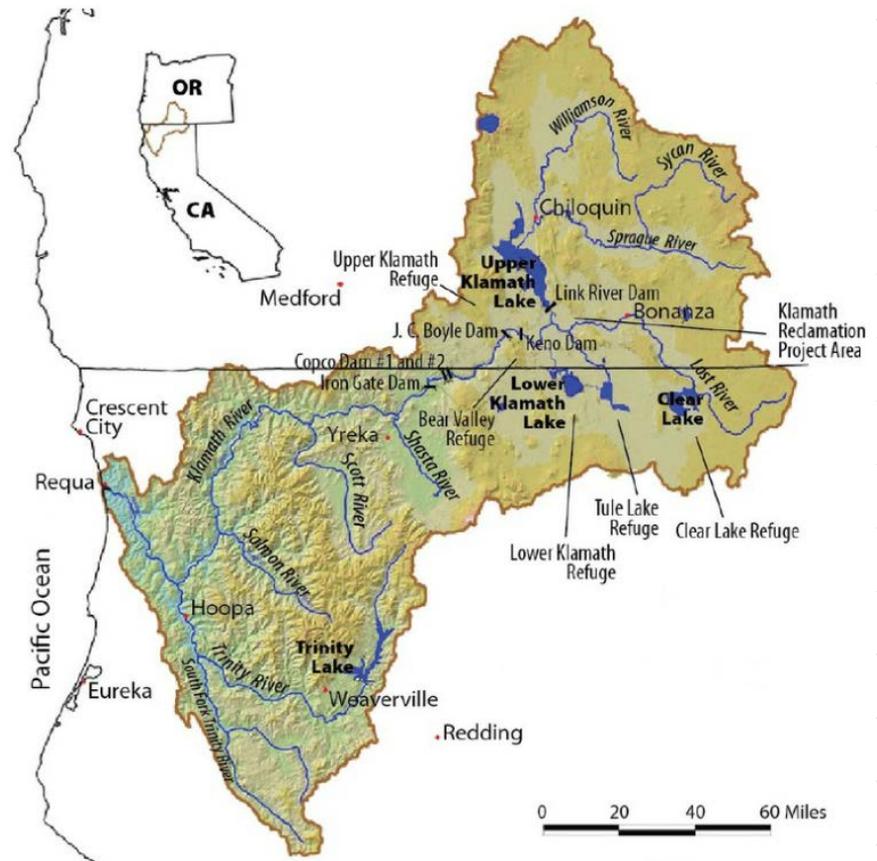
◆ Desert Research Institute / Nevada Office State Engr.

- Water transfers from Irrigated Ag. to Reno/Las Vegas
- Water transfers from phreatophytes and playa to Las Vegas
- *Need High Resolution thermal for narrow irrigation corridors and sometimes narrow phreatophytic systems*

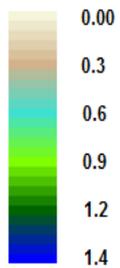


The Klamath River Basin

- ◆ Home to many diverse species of wildlife
- ◆ Economically and culturally diverse rural communities
- ◆ The Karuk, Yurok, and Klamath Tribes harvest salmon and c'wam from the river for cultural and subsistence purposes
- ◆ Coastal commercial fishing families depend on Klamath salmon for their living
- ◆ Family farmers and ranchers use the river for irrigation of diverse crops
- ◆ Bitter conflicts have emerged between Tribal, agricultural, and commercial fishing communities
- ◆ Klamath Tribes were granted senior water rights (may 2013) for large portions of the Upper Basin
- ◆ **This led to large scale water retirement for some irrigated areas - Requires Monitoring and Confirmation of Reduction in ET following Water Retirement**



Relative ET (ET_rF)



$$(ET_rF = ET_{act} / ET_{ref})$$

Crater Lake



Wood River Valley

Klamath Lake

October 19

N



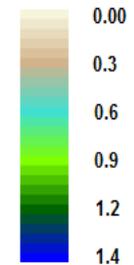
Work funded by the USGS

October 19

Conclusion: Some areas did not dry because of high GW table or proximity to a wetland

Wood River Valley

Relative ET (ET_rF)



$$(ET_rF = ET_{act} / ET_{ref})$$

Agency Lake

Conclusion: Some areas had substantial reductions in ET. Landsat-based monitoring was essential to quantify reductions and to support adaptive water management in the basin.

US Supreme Court Introduction

◆ Montana vs. Wyoming on Tongue River

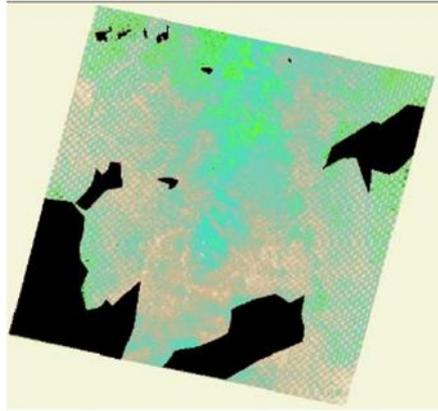
- US Supreme Court case
- Upstream vs. downstream water rights and Depletion by upstream state
- Interstate Compact
- High resolution ET used to aggregate water use across irrigated fields surrounded by desert
- METRIC ET used to investigate expansion of irrigated acreage in Wyoming
- Change in ET between dry and wet years
- Testimony by Allen

Challenges in using High Resolution 'Snapshot' Satellite Images to Quantify Seasonal Water Consumption

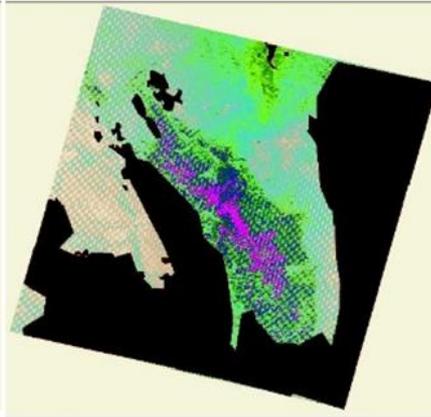
- ◆ Landsat passes over each 16 days
- ◆ Parts of the image area are often cloudy
- ◆ Landsat 'snapshot' may miss the evaporation from rain events in between satellite dates

Images can be plagued with Clouds

04-16-04

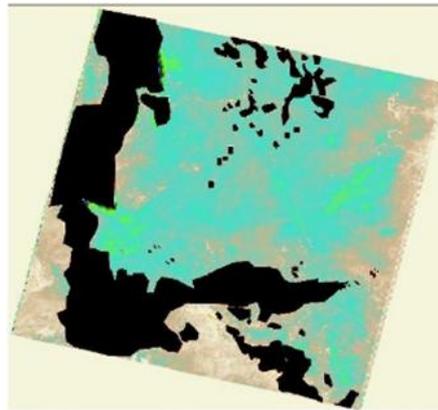


04-23-04

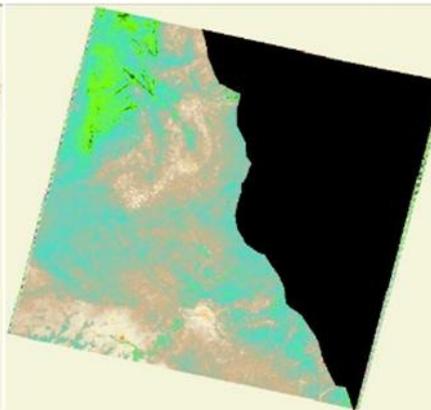


north-
central
Wyoming

04-24-04



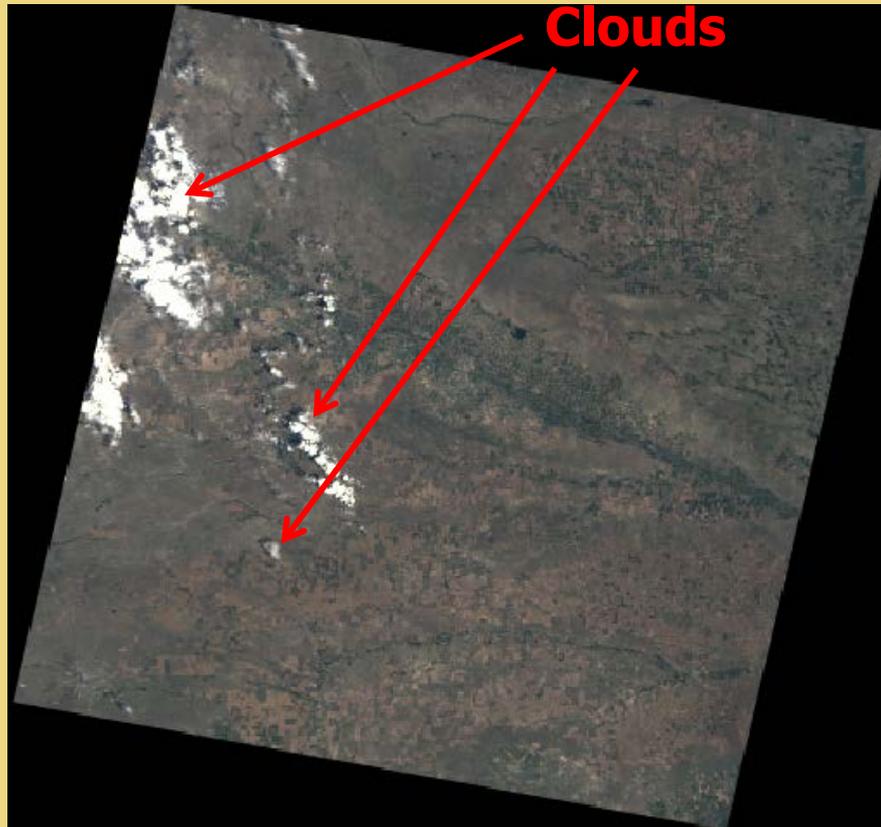
05-10-04



Cloud Mitigation

ET can not be estimated for areas covered by clouds.

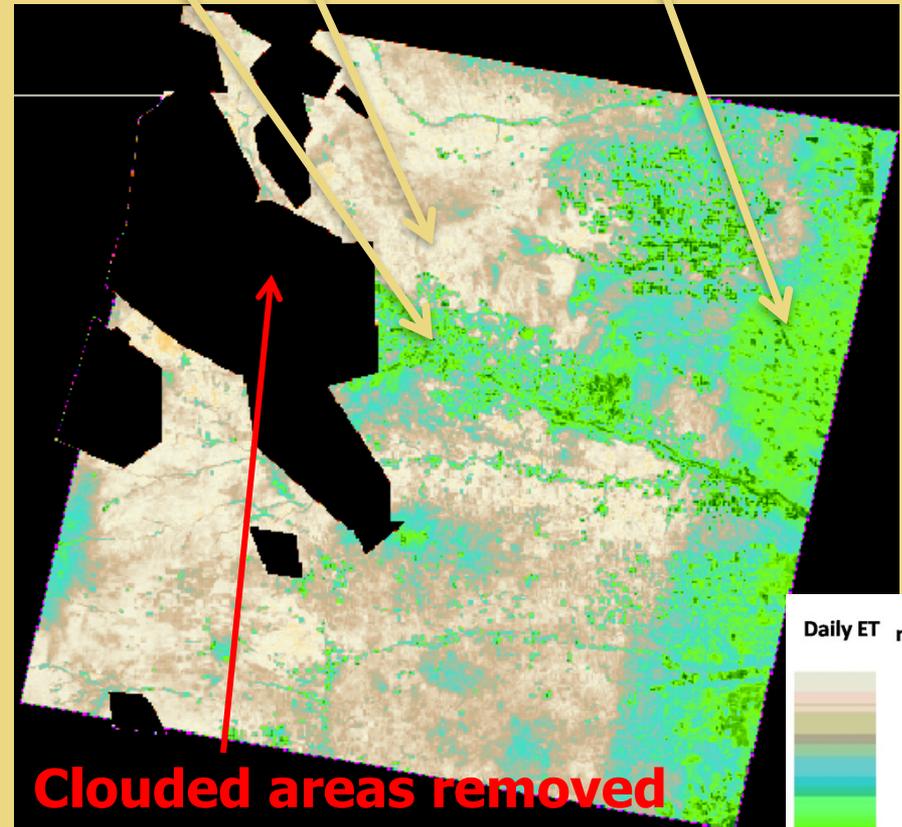
Areas with cloud cover must be 'masked' out



Landsat image 07/12-1997

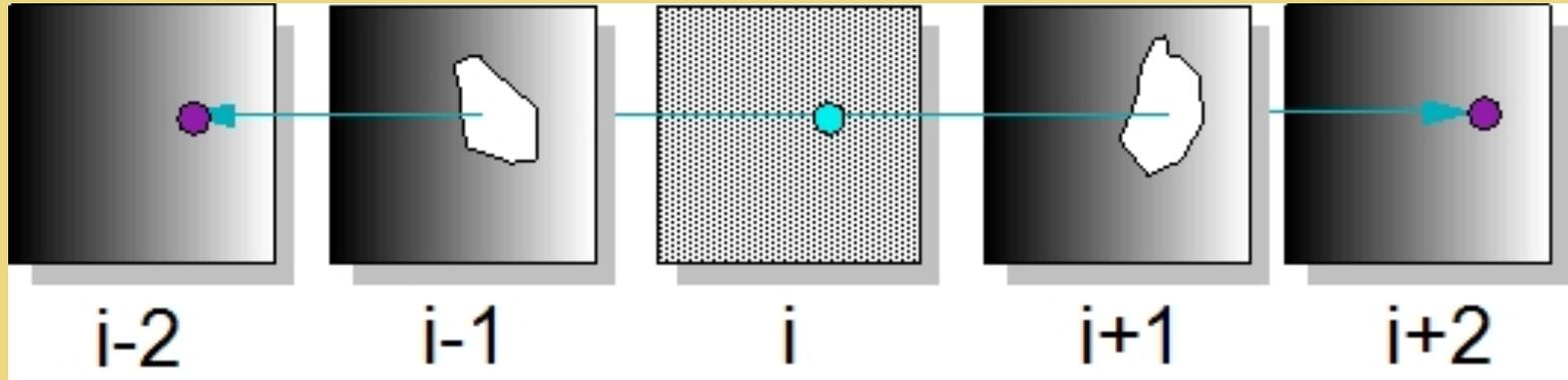
Nebraska Panhandle - 1997

Dry soil (low ET)
Irrig. Ag. Recent rain in this area increases ET



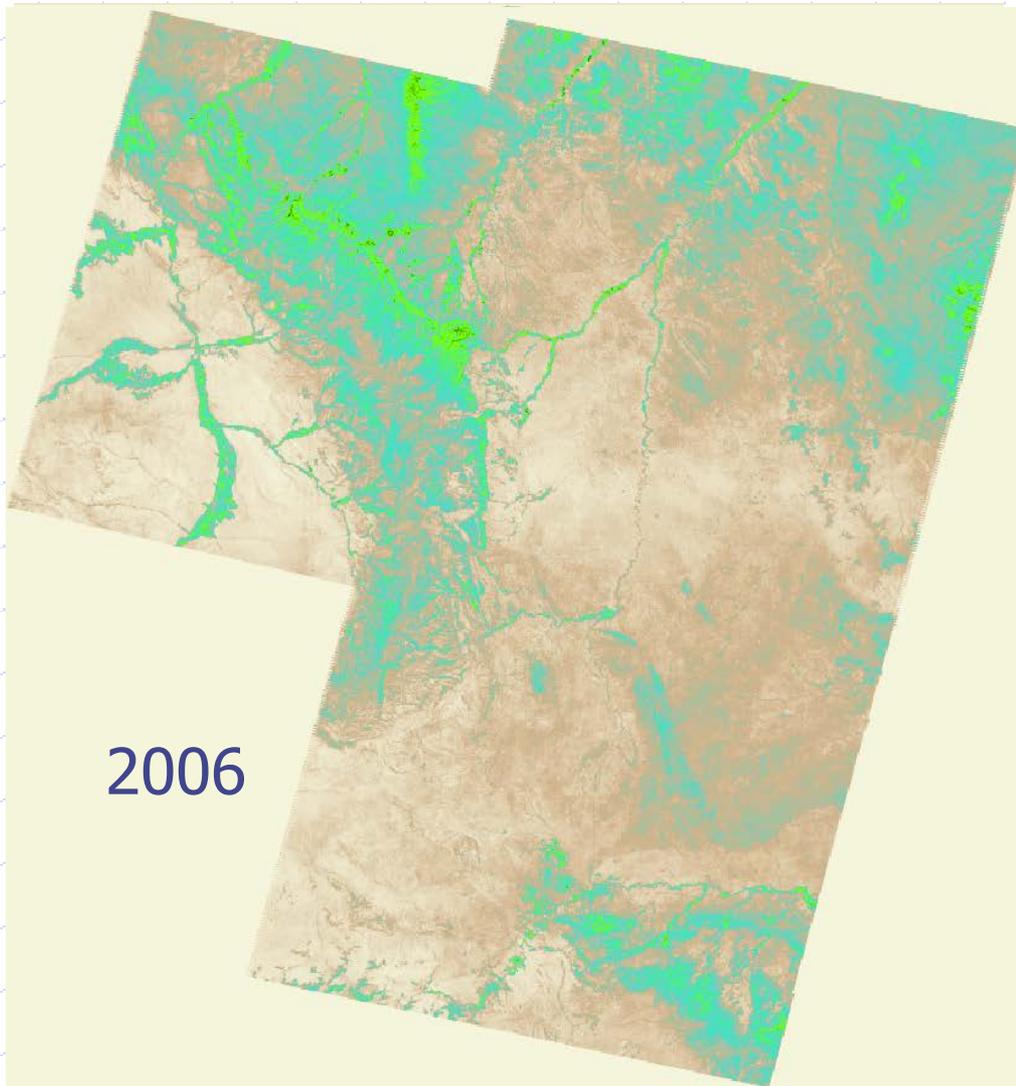
ET on 07/12-1997.
Clouds have been masked out.

Procedure for cloud gap filling

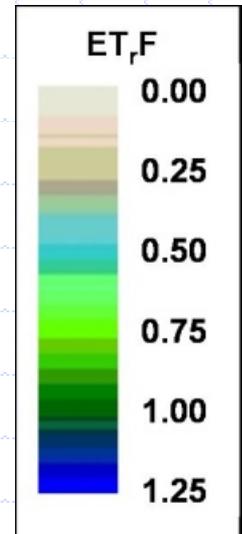


Borrow 'relative ET' information from adjacent images (in time)

ET from the north Wyoming Region for Years 2004 and 2006 following Time Integration between Landsat images and Mitigation for Clouds



Accurate seasonal ET does not come easy due to the lack of Landsats



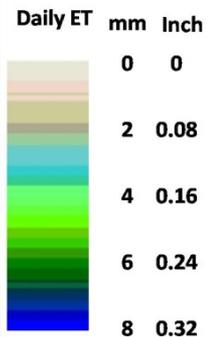
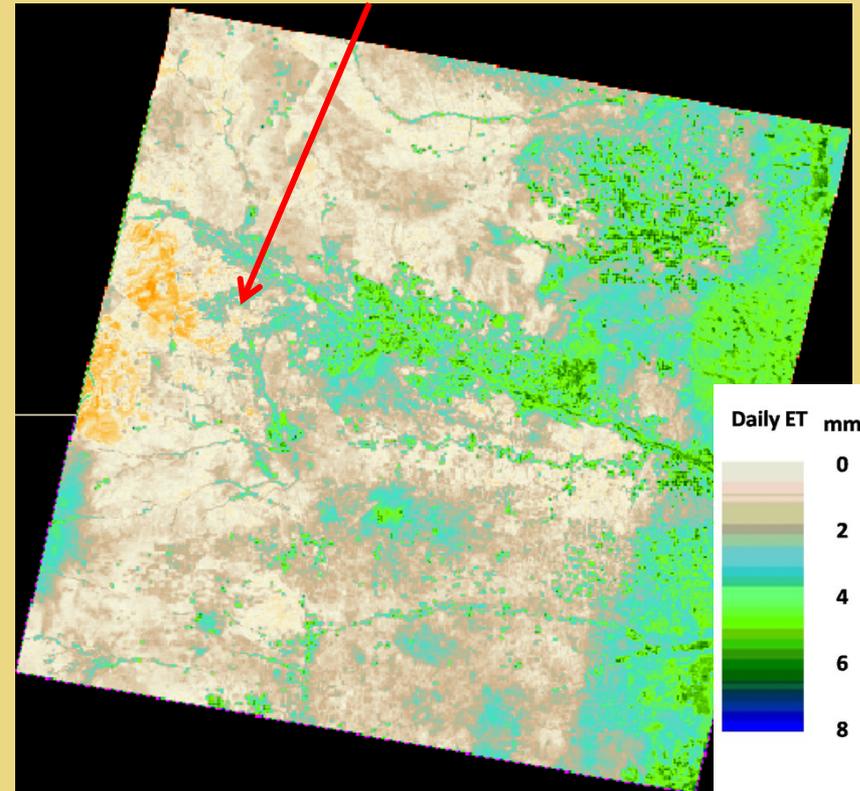
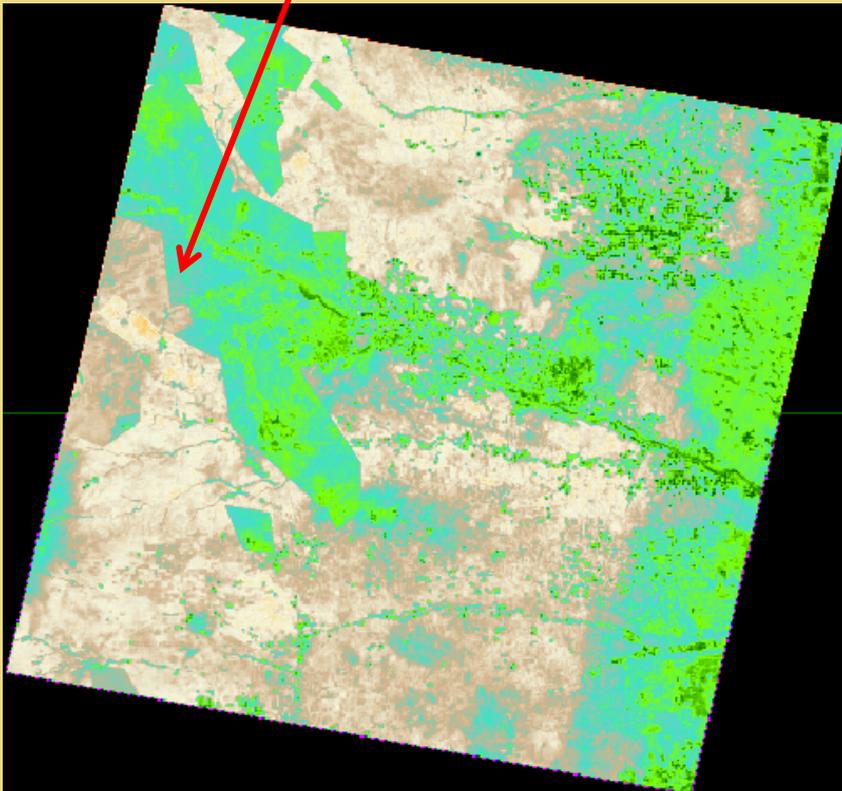
2006

Kelly and Allen, 2009

Step 2: Adjust for changes in Evaporation due to Rainfall

Filled areas are too high for bare soil

Better matching



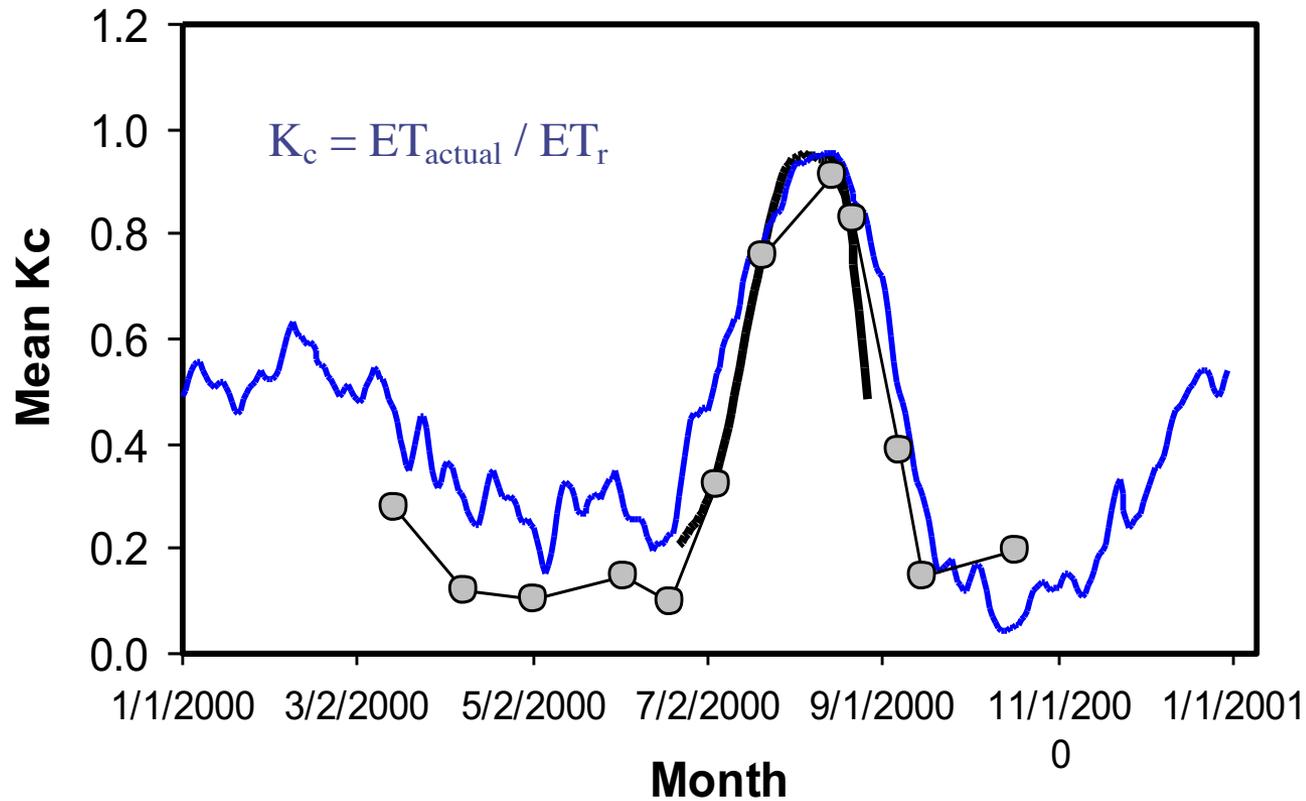
Filled with no adj.

Filled with adj. for Evap.

07/12-1997

Congruency of K_c from METRIC and K_c based Methods

Dry Beans Twin Falls, ID 2000



— Agrimet for 2000 — Allen-Robison - 14 yr ave. —○— METRIC for 2000

Recent or Current users of METRIC

Public

- ◆ Idaho Dept. Water Resources --see previous slides
- ◆ USGS – Klamath River Basin, Montana GW modeling
- ◆ Metropolitan Water District – fallowing in Palo Verde
- ◆ New Mexico Office of the State Engineer (OSE)
- ◆ Wyoming Office of the State Engineer – Green River Basin – part of Colorado Compact
- ◆ Nevada Office of the State Engineer – water transfers from agriculture or from phreatophytic areas to cities
- ◆ California Water Resources Control Board – water consumption in the California Bay-Delta (just starting); - monitoring and intervention in Groundwater Sustainability Requirements throughout California (will use Satellite-based ET)

Recent or Current users of METRIC

Public

- ◆ Central Platte Natural Resources District, Nebraska – Conjunctive management of GW and SW
- ◆ Univ. Texas – State wide explorations in ET mapping and intercomparisons of models
- ◆ North Dakota State Univ. – rainfed agriculture, wetlands
- ◆ Oregon Water Resources Dept. – ET from irrigation (Univ. Idaho); Impacts of Climate Change (ET+/HH)
- ◆ Montana Department of Natural Resources – ET depletions from irrigation, ET from tribal lands
- ◆ Department of Justice – Middle Rio Grande ET depletions

Recent or Current users of METRIC

Commercial

- ◆ Soil Hydrology Associates, Las Lunas, NM – ET in hydrological models – CA, TX, NM, AZ
- ◆ Davids Engineering – multiple uses
- ◆ Riverside Technology Inc. – North Platte River (compact), South Platte River (Univ. Idaho), Morocco
- ◆ ET+ -- Klamath Basin, Palo Verde area
- ◆ Gallo, Inc. – management of ET and soil water to improve wine quality
- ◆ Intera, Inc. – ET of surface water and ground water in Pecos River Basin
- ◆ CalPoly / DRI – ET in the Central Valley of California
- ◆ State of Nevada / DRI – ET of water transfers from agriculture or playas to cities

Recent or Current users of METRIC

International

- ◆ Andalusia State of Spain – ET from irrigated vs. rainfed olives
- ◆ Univ. Talca, Chile – ET from irrigated olives, wine grapes, orchards, including UAV-based systems
- ◆ Ciera, Brasil – ET for hydrologic models and irrigation depletions
- ◆ Morocco – Riverside Technology, Inc. – equity in water allocation

Access to METRIC

◆ Annual Training Courses on METRIC

- Access to Level 1/2 METRIC Code
- Access to METRIC Applications Manual
- Four-day Training

◆ METRIC is coded into:

- ERDAS Imagine with scripted mode
- ArcGIS – ArcPy
- Some segments in Python-GDAL



CURRENT VENTURE:

EVAPOTRANSPIRATION MODELING TOOL AT LANDSAT RESOLUTION ON GOOGLE EARTH ENGINE --- **EEFLUX**

EEFlux Development Team

Ayse Kilic – University of Nebraska -- Professor and
Presenter, *Member of Landsat Science Team*

Justin Huntington – Desert Research Institute –
Professor, *Member Landsat Science Team*

Rick Allen -- University of Idaho – Professor, *Member
of Landsat Science Team*

**Doruk Ozturk, Samuel Ortega, Babu Kamble,
Ian Ratcliffe** – University of Nebraska – Developers

Charles Morton – Desert Research Institute –



Developer

Clarence Robison – Univ. Idaho – GIS technician

Ricardo Trezza – University of Idaho – Professor

David Thau, Google, Inc. – Earth Engine Advocate

Tyler Erickson, Google, Inc. – Earth Engine
Advocate

Rebecca Moore, Google, Inc. – Manager, Earth
Engine / *Visionary*

Why an Evapotranspiration Tool on Google Earth Engine?

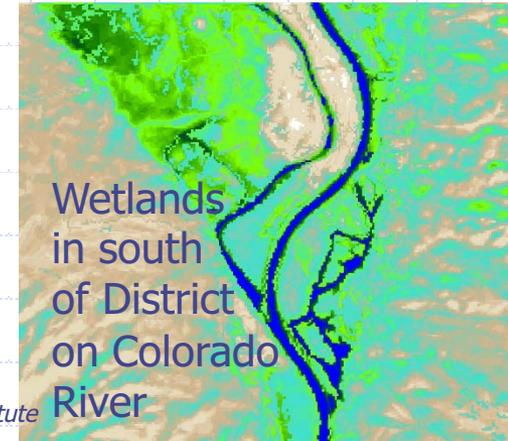
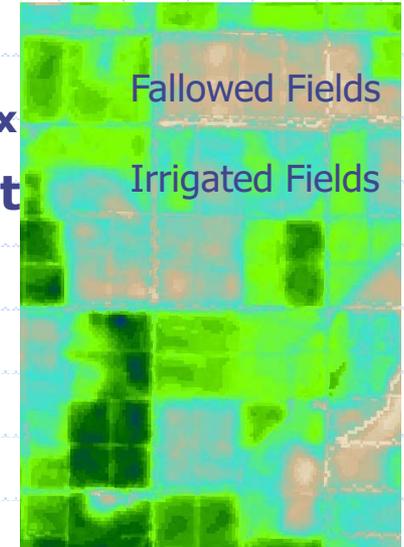
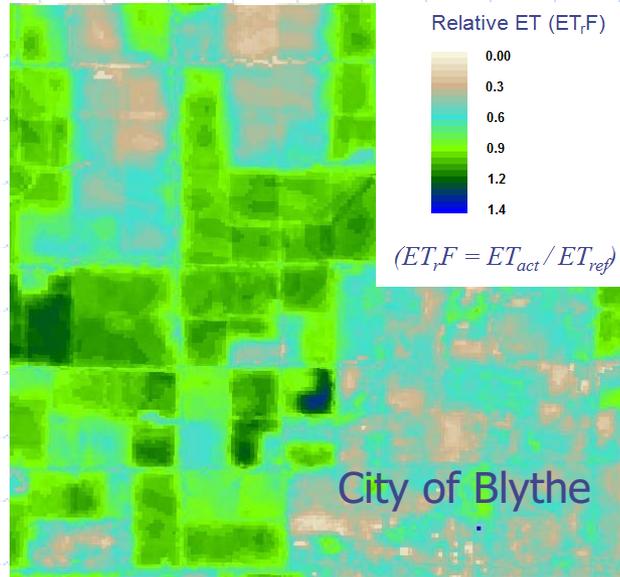
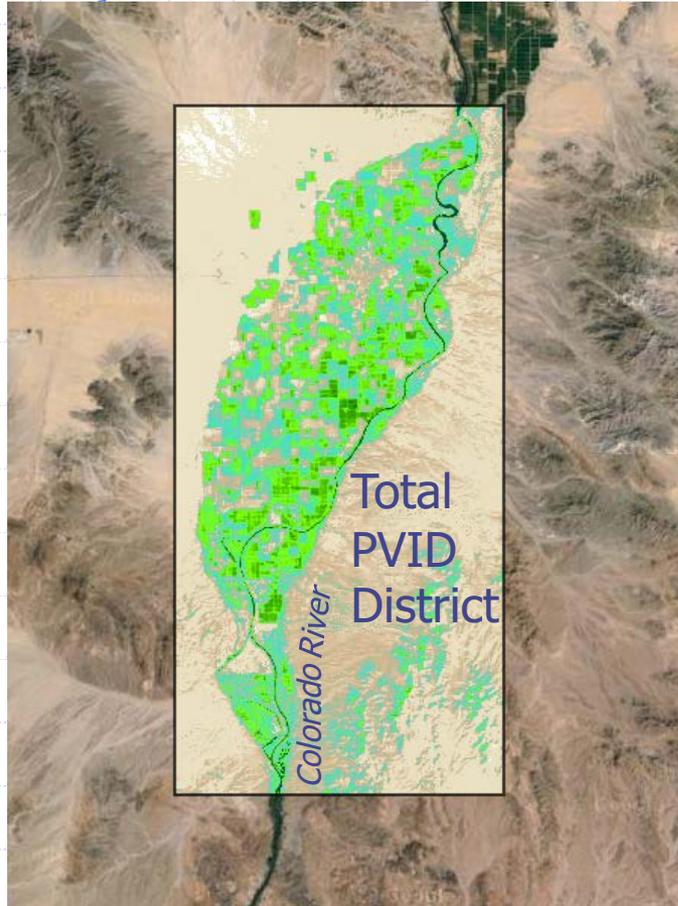
- Earth Engine (EE) has enormous computing and storage power
- EE has essentially free access
- EE holds the entire Landsat archive and NLDAS/CFSV2 gridded weather
- EE has strong developer support
- ET information is needed across the Global spectrum
- Google supports and encourages developers to 'change the world' regarding access to spatial information on the environment, natural resources, conservation and climate change

Google Earth Engine App --- **EEFlux**

Earth Engine Evapotranspiration Flux Palo Verde Irrigation District

Blythe, California – Jan. – Dec. 2008

-- Landsat 5 imagery Dec.

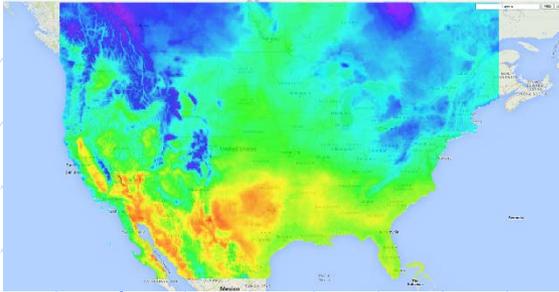


Univ. Nebraska-Lincoln, Univ. Idaho, Desert Research Institute

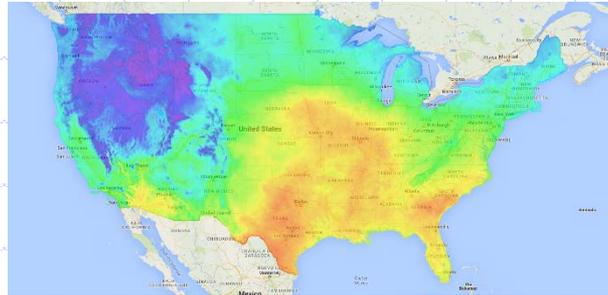
Computations are based on a complete surface energy balance (**METRIC**)

Data Resources Used by EFlux

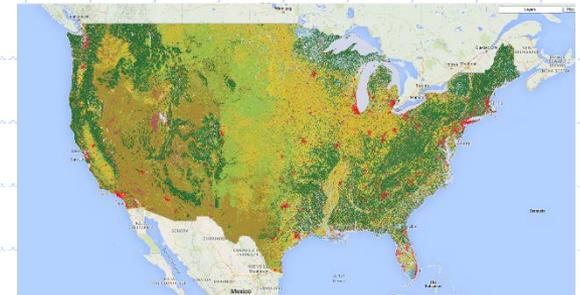
NLDAS-Jan 1, 1979 - Current



GRIDMET-Jan 1, 1979 - Current



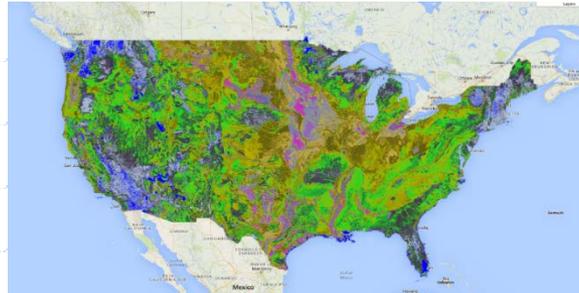
NLCD Landuse



DEM



Soil Data Layers

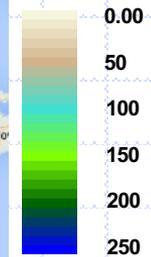


- Landsat 5/7/8 and MODIS
- Weather Data
 - Hourly Weather Data (NLDAS)--CONUS
 - Daily Weather Data (GRIDMET)--CONUS
 - Climate Forecast System Version 2, 6-hourly Products (CFSV2)--nonCONUS
- Landuse and Digital Elevation Maps
- Soil Data Layers (STATSGO--CONUS and FAO)

Reference ET on the Google Earth Engine EFlux App.



Reference ET (mm/mo)

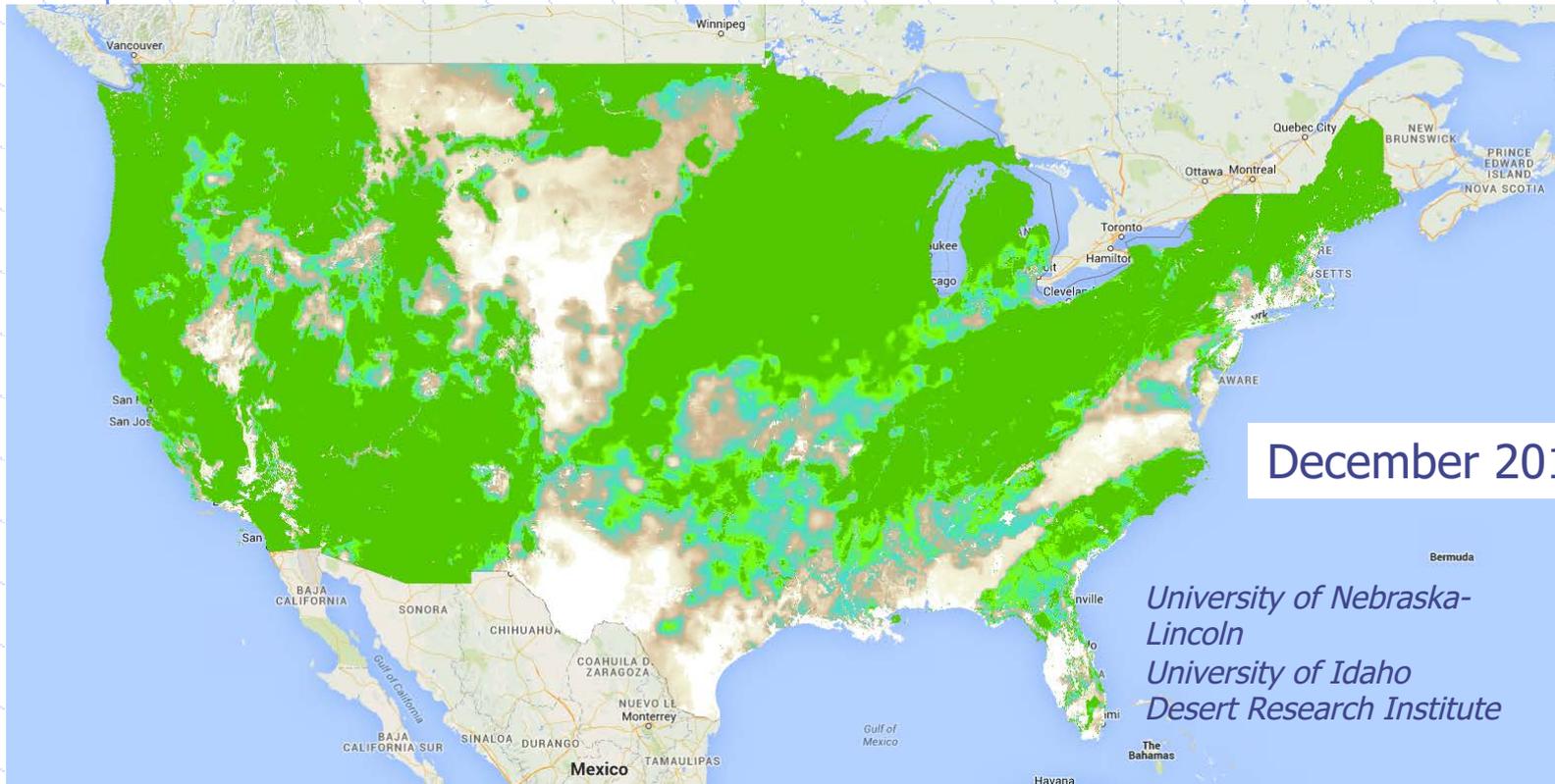


Reference ET
calculated using
the ASCE
Standardized
Penman-
Monteith
Equation for the
Tall Reference
(Alfalfa)

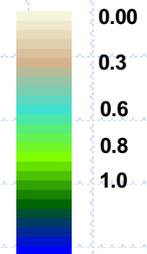
--computed from
the GridMET
data set of
Abatzoglou
(2012)

The Soil Surface Evaporation Component of the Google Earth Engine EEFlux App.

--- Evaporation from Bare Soil --- used to calibrate the EEFlux Evapotranspiration Surface Energy Balance to account for Precipitation Effects on ET



Evap. Coef. (K_e)



$$(K_e = E_{act} / ET_{ref})$$

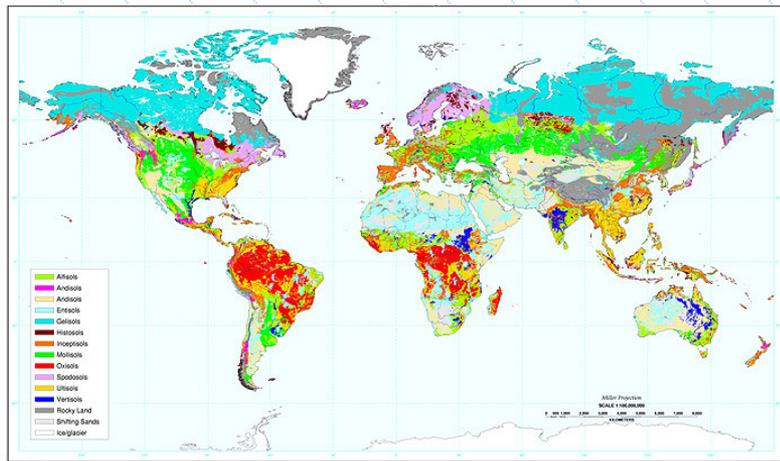
December 2012

University of Nebraska-Lincoln
University of Idaho
Desert Research Institute

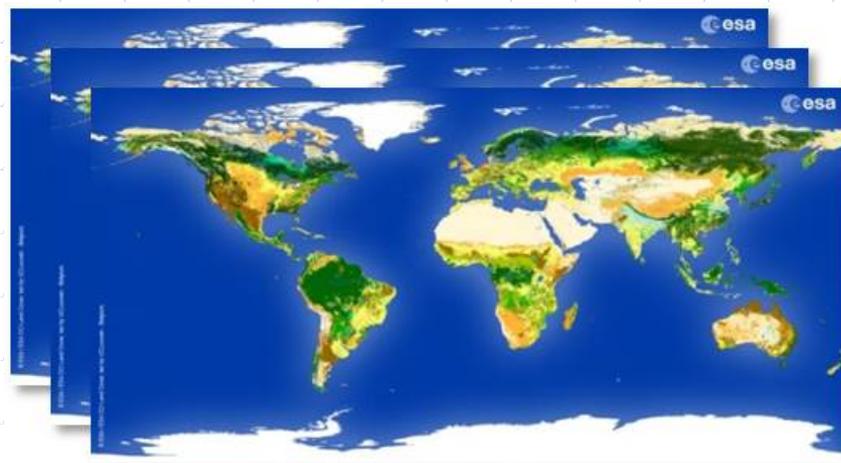
--computed from the GridMET weather data set of Abatzoglou (2012)
-- GridMET is traceable to NLDAS and PRISM data sets

EEFlux -- IT IS RUNNING GLOBALLY

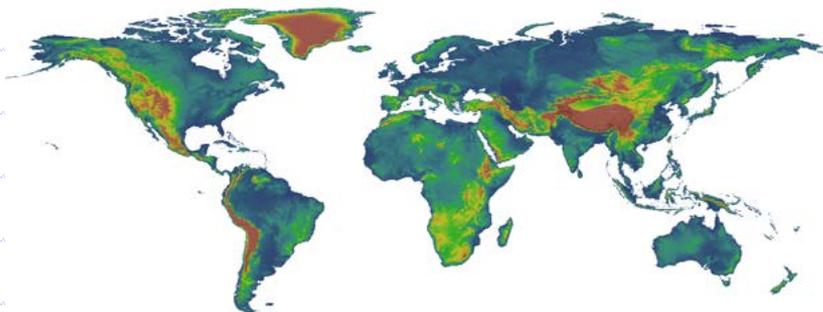
GLOBAL SOIL



LANDUSE-ESA



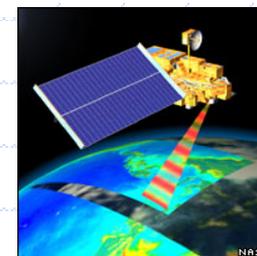
DIGITAL ELEVATION DATABASE-SRTM



LANDSAT 5/7/8



MODIS



These data products are loaded and are functional on Earth Engine

Development Steps

Development of Web Access

<http://2.eeflux-level2-single-hotcold.appspot.com/>

Development of a User Console

- to save project information (*coming*)
- free access to EEFlux API's (level 1)
- level 2 means to permit some degree of tuning

National and Global application (Seamless)

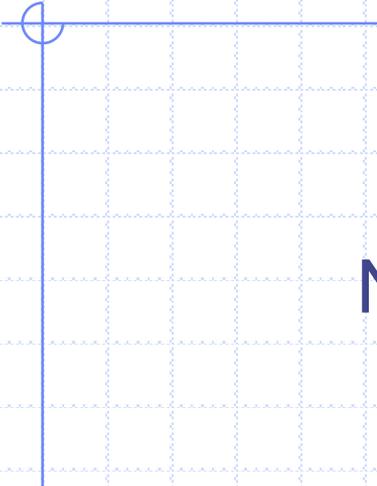
Automation of:

- Cloud detection and mitigation (*coming*)
- Calibration of EEFlux energy balance for highest accuracy
- Time integration to produce monthly and annual ET volumes (*coming*)
- Mosaicking paths (*coming*)

Demo of EEFlux

<http://eeflux-level1.appspot.com/>

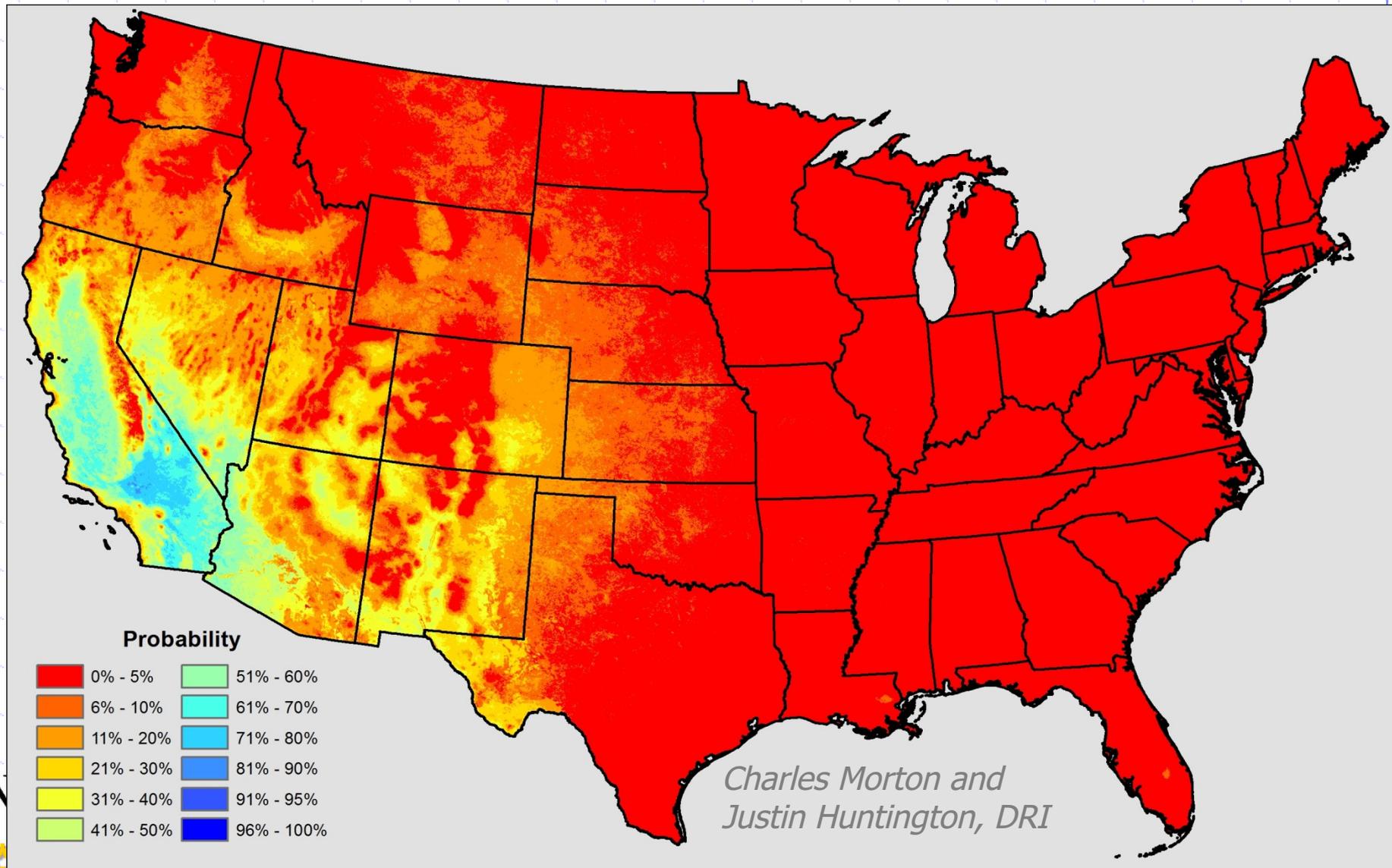
<http://2.eeflux-level2-single-hotcold.appspot.com/>



Need for Shorter Revisit Time for Landsat-type Satellites (with Thermal Imaging) to Mitigate for Clouds

1 Satellite (image each 16 days)

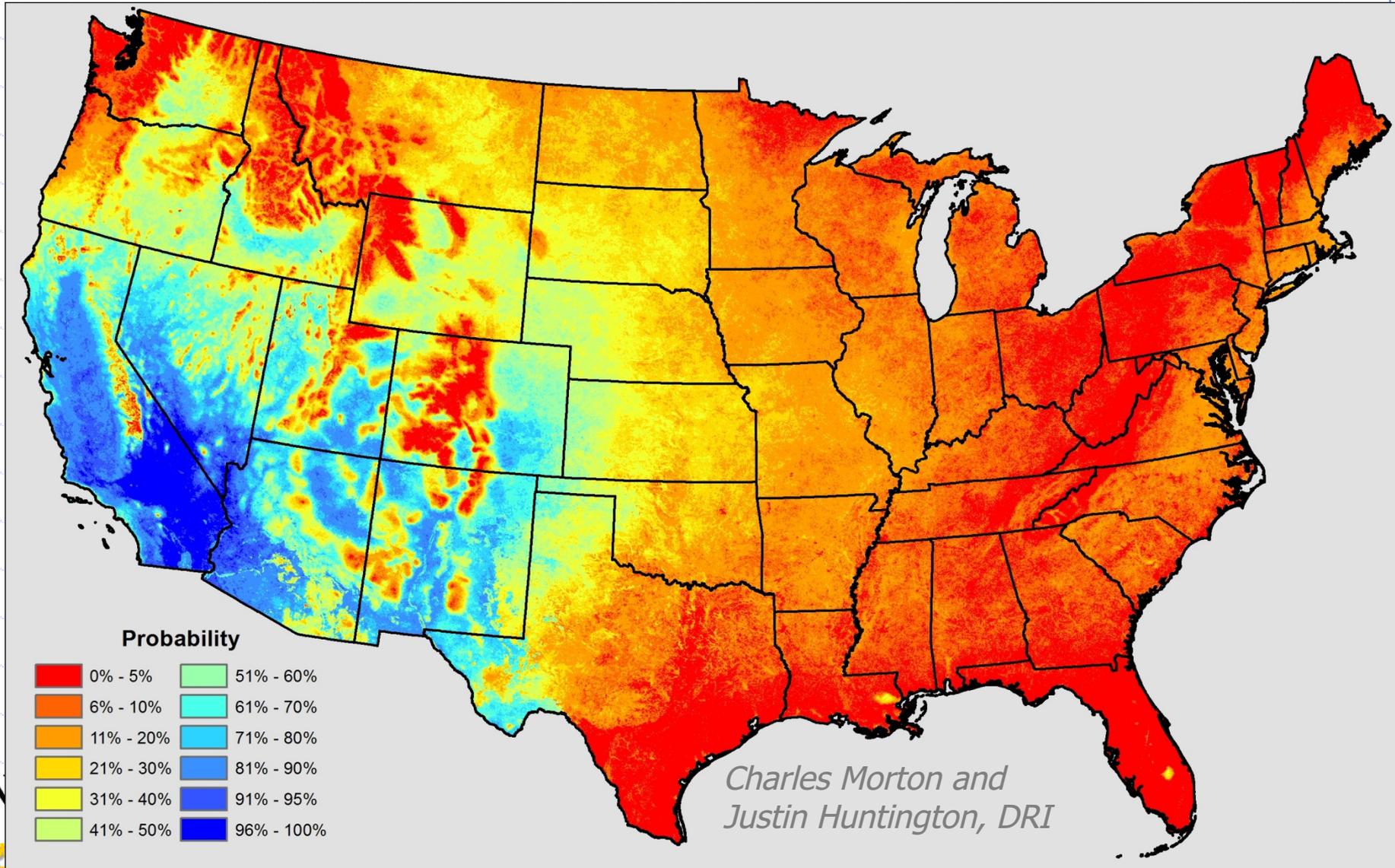
Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



2 Satellites (image each 8 days)

Probability of producing a good estimate of Water

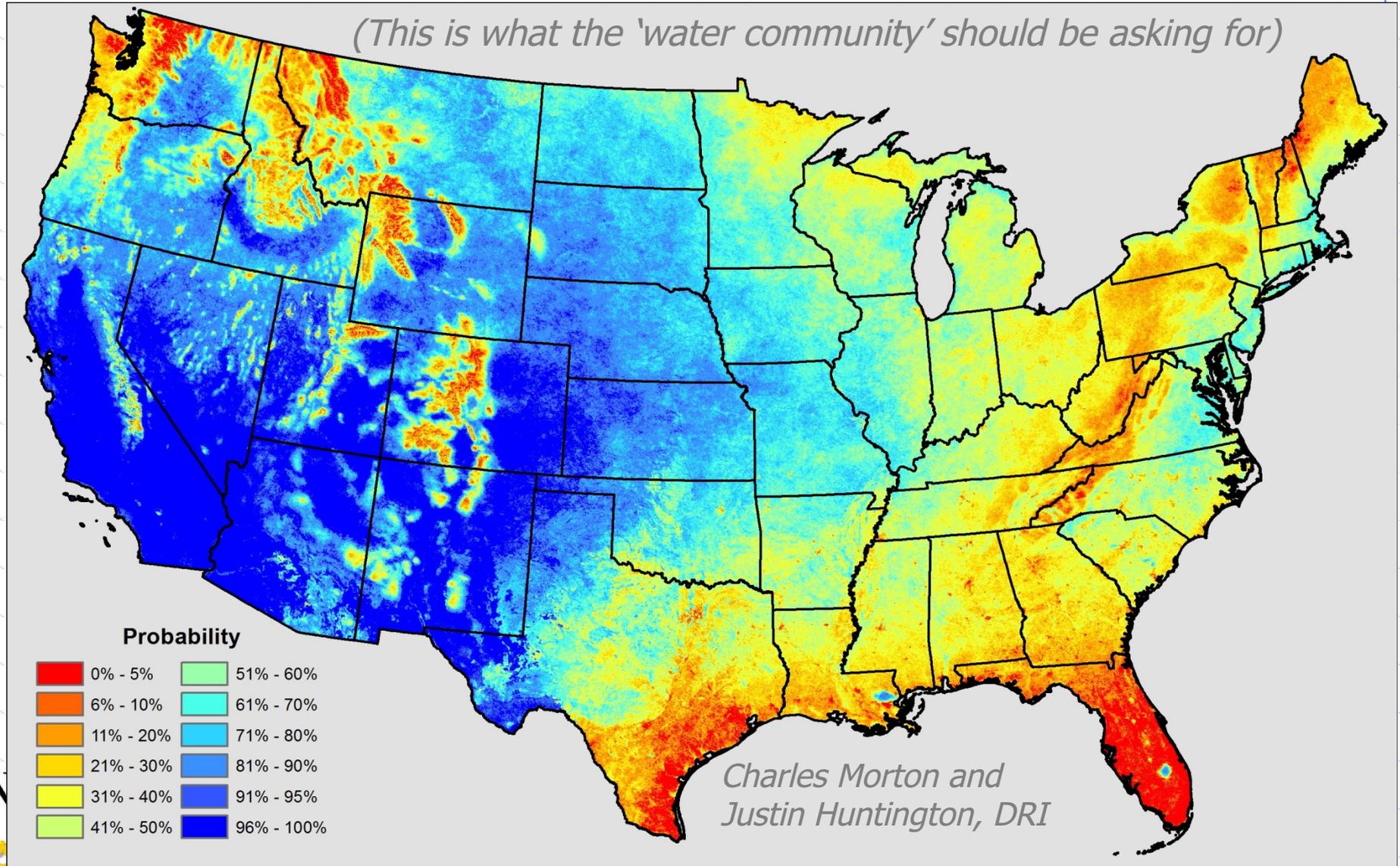
Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)



4 Satellites (image each 4 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)

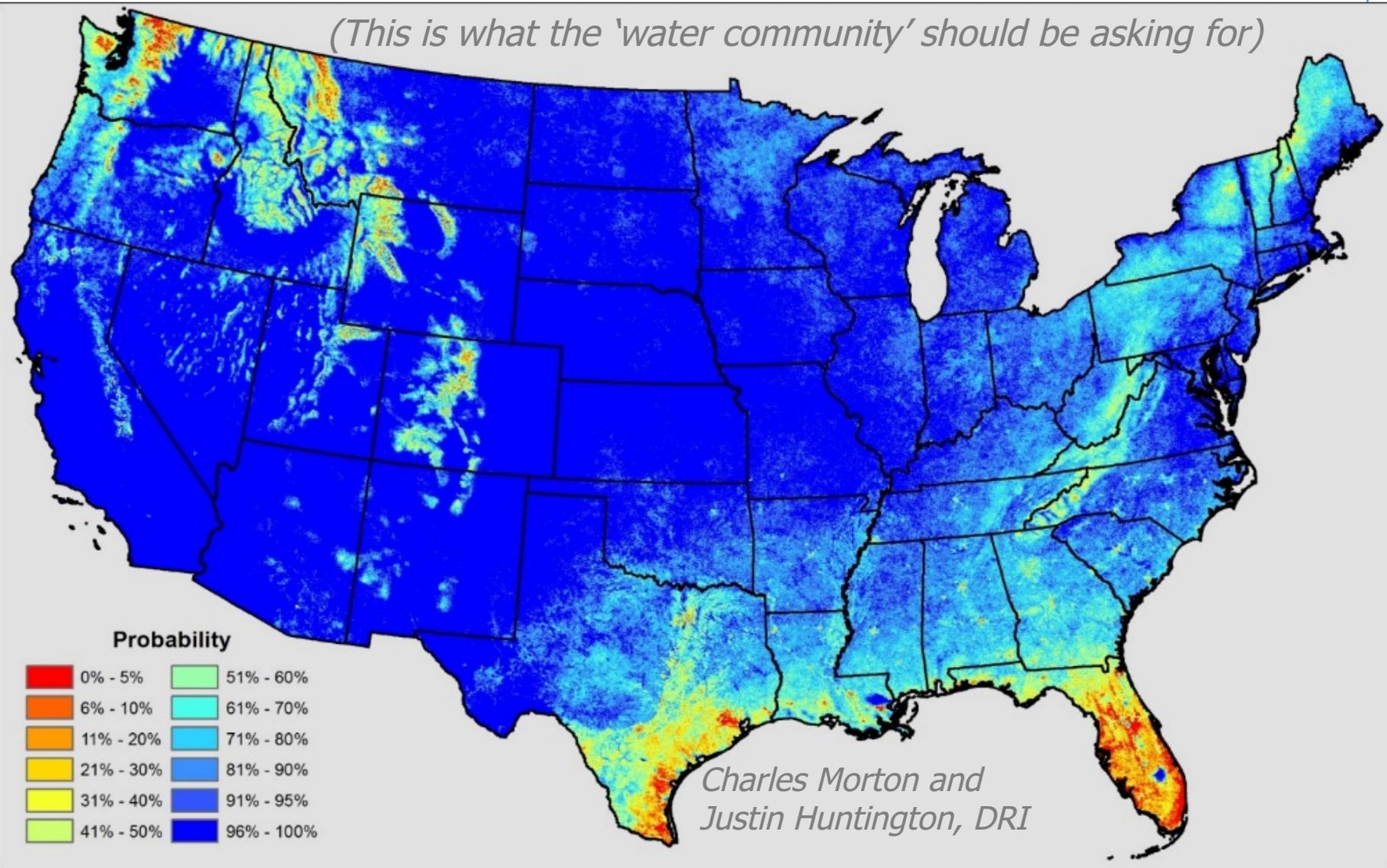
(This is what the 'water community' should be asking for)



8 Satellites (image each 2 days)

Probability of producing a good estimate of Water Consumption over any given year (having a Cloud-free Image at least every 32 days during the growing season)

(This is what the 'water community' should be asking for)



A Landsat-based "Earth-Selfie" concept

- ◆ Cost: Less than 3 coffee-latte's per American per year
- ◆ Support SIXTEEN Landsats in orbit
- ◆ DAILY Earth-Selfie's
- ◆ Consider:

- *99% of all Americans spend at least \$10 per week on superfluous things: cafe-lattes; bottled water; movies; gasoline to motor three blocks to the market-place or across town to look for designer jeans.*
- *However, we don't want to spend the <\$0.50 PER YEAR per American needed to launch and operate Landsats or similar that take field-scale 'selfies' of our Nation.*
- *Less than \$6 per American PER YEAR would place SIXTEEN Landsats into orbit, giving us DAILY Selfies of the entire Nation.*

$$\begin{aligned} & \$800 \text{ million/LS} \\ & \div 8 \text{ years} \\ & \times 16 \text{ LS} \\ & \div 300 \text{ million Americans} \\ & = \$5.30 \text{ per American per year} \end{aligned}$$



Can you imagine what that would be like? A Landsat 'Selfie' EVERY DAY???

Thank You

<http://2.eeflux-level2-single-hotcold.appspot.com/>

Extra/Supplementary Material

Sensible Heat Flux (H)

– METRIC model

Advantage:
 r_{ah} 'floats' above the surface and is 'free' of z_{oh} and some limitations of a single source approach

$$H = (\rho \times c_p \times dT) / r_{ah}$$

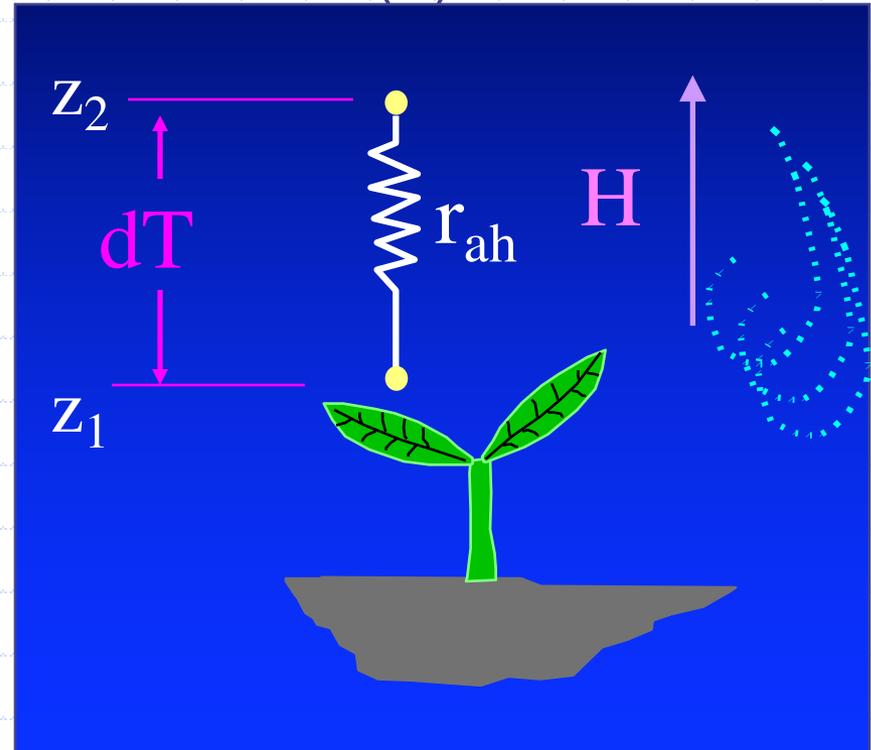
Advantage:
 dT is inverse calibrated (simulated) (free of T_{rad} vs. T_{aero} vs. T_{air})

dT = "floating" near surface temperature difference (K)

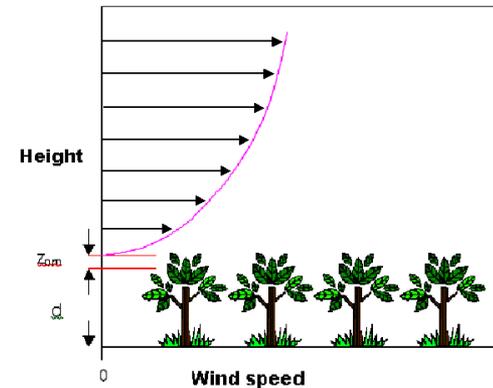
r_{ah} = the aerodynamic resistance from z_1 to z_2

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k}$$

u_* = friction velocity
 k = von karmon constant (0.41)



Sensible Heat Flux (H) – “Traditional Approach”



$$H = \rho c_p (T_{aero} - T_{air}) / r_{ah}$$

Challenge (BIAS):
Up to 2 K different from T_{rad}

(satellite)
 T_{aero} = aerodynamic temperature

Challenge (BIAS):
Unknown Spatial Distrib. of T_{air}
(feedback between H , T_{rad} , T_{air})

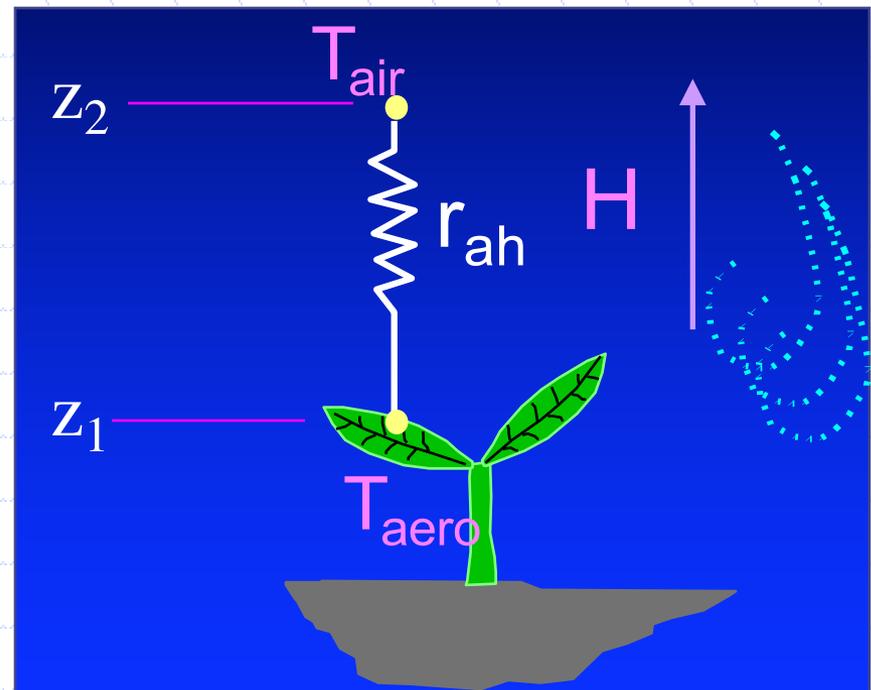
r_{ah} = the aerodynamic resistance

$$r_{ah} = \frac{\ln\left(\frac{z_2 - d}{z_{oh}}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* k}$$

u_* = friction velocity

k = von karmon constant (0.41)

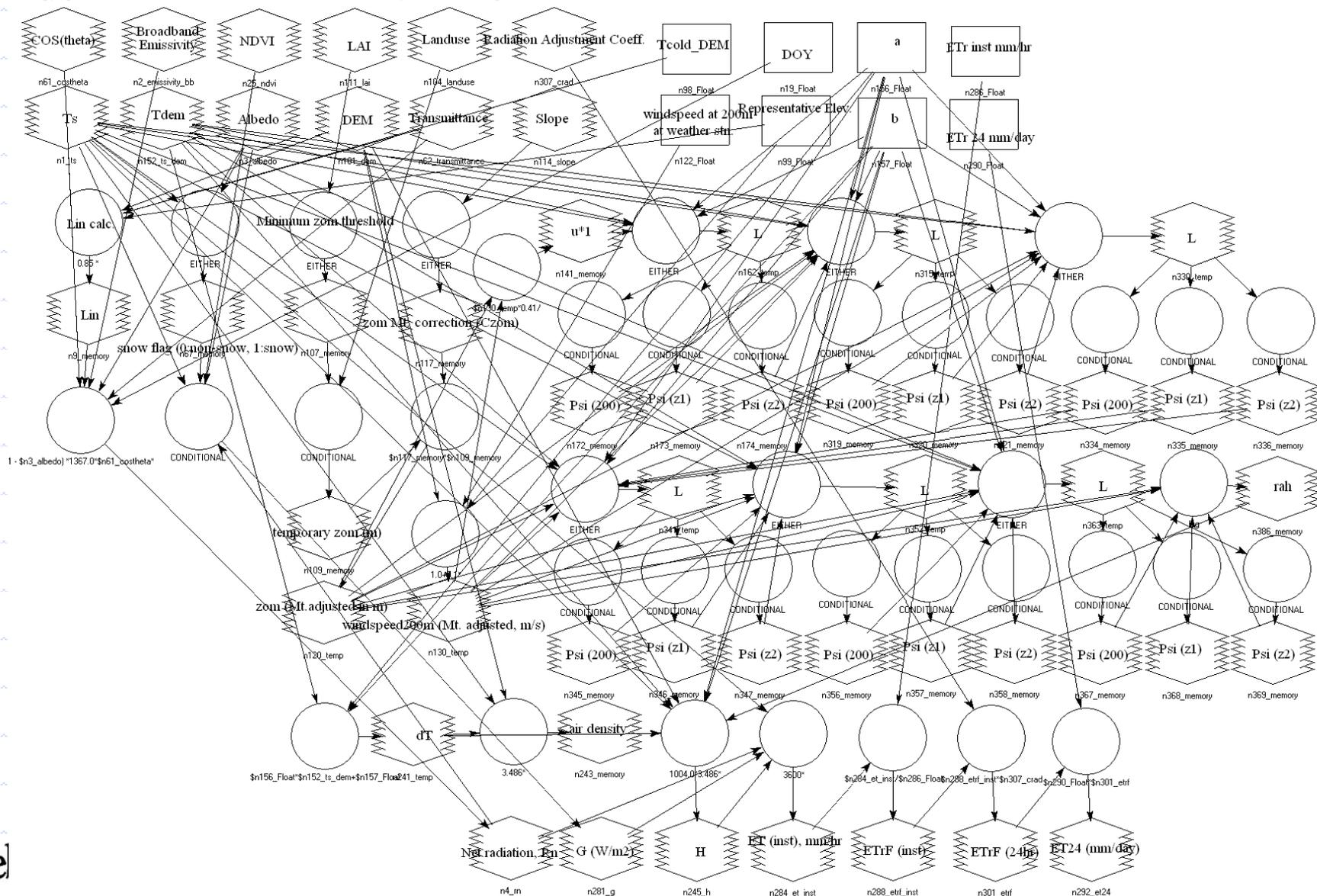
Ψ_h = buoyancy-instability correction
= $f(H)$

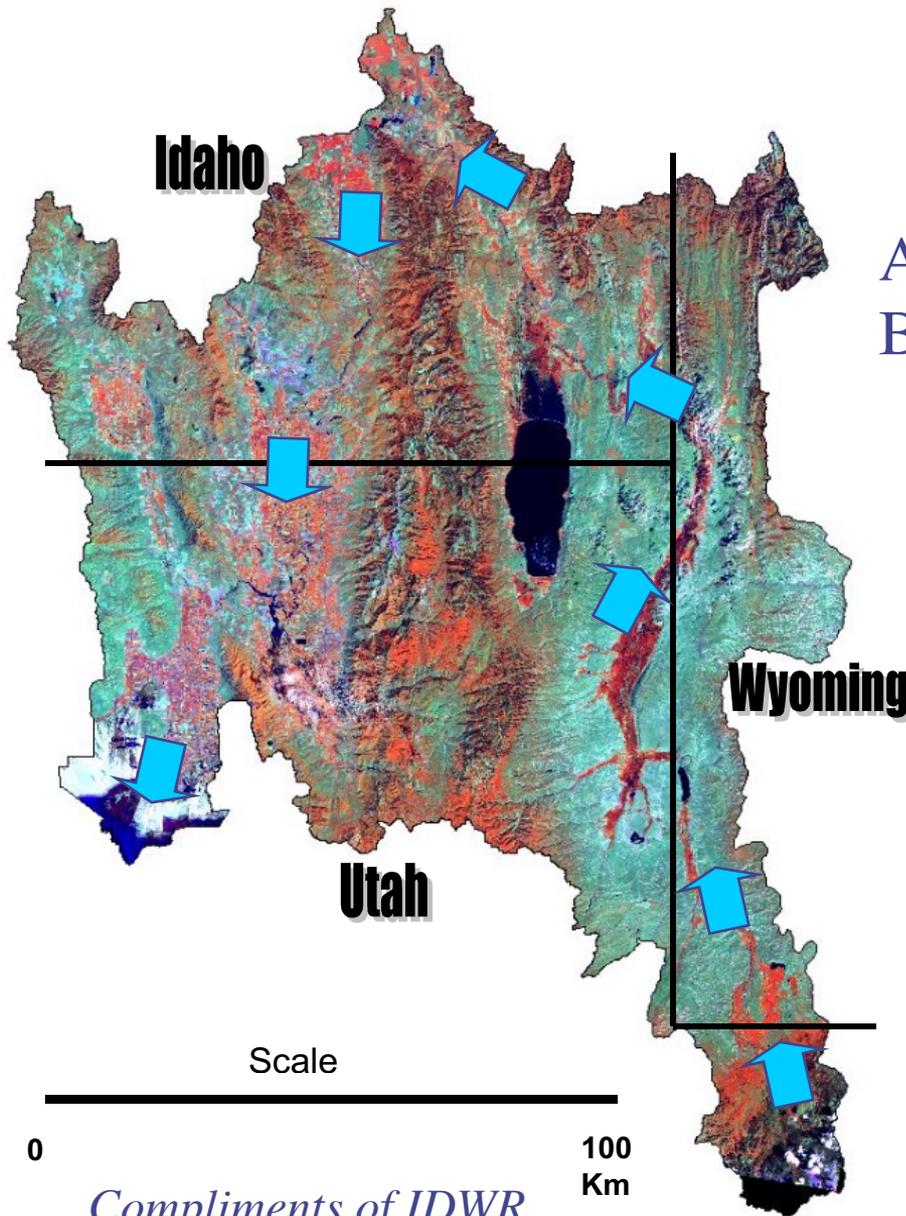


METRICtm-ERDAS submodel for sensible heat and ETrF

M02, Main energy balance model for SEBAL-ID: Sensible heat flux, Net radiation, Ground heat flux, Reference ET fraction and ET

Copyright (C) 2003 R.G.Allen, M.Tasumi, R.Trezza and University of Idaho. All rights reserved.





Application to the Bear River Basin

Bear River Compact

Three USA States

Need ET maps for:

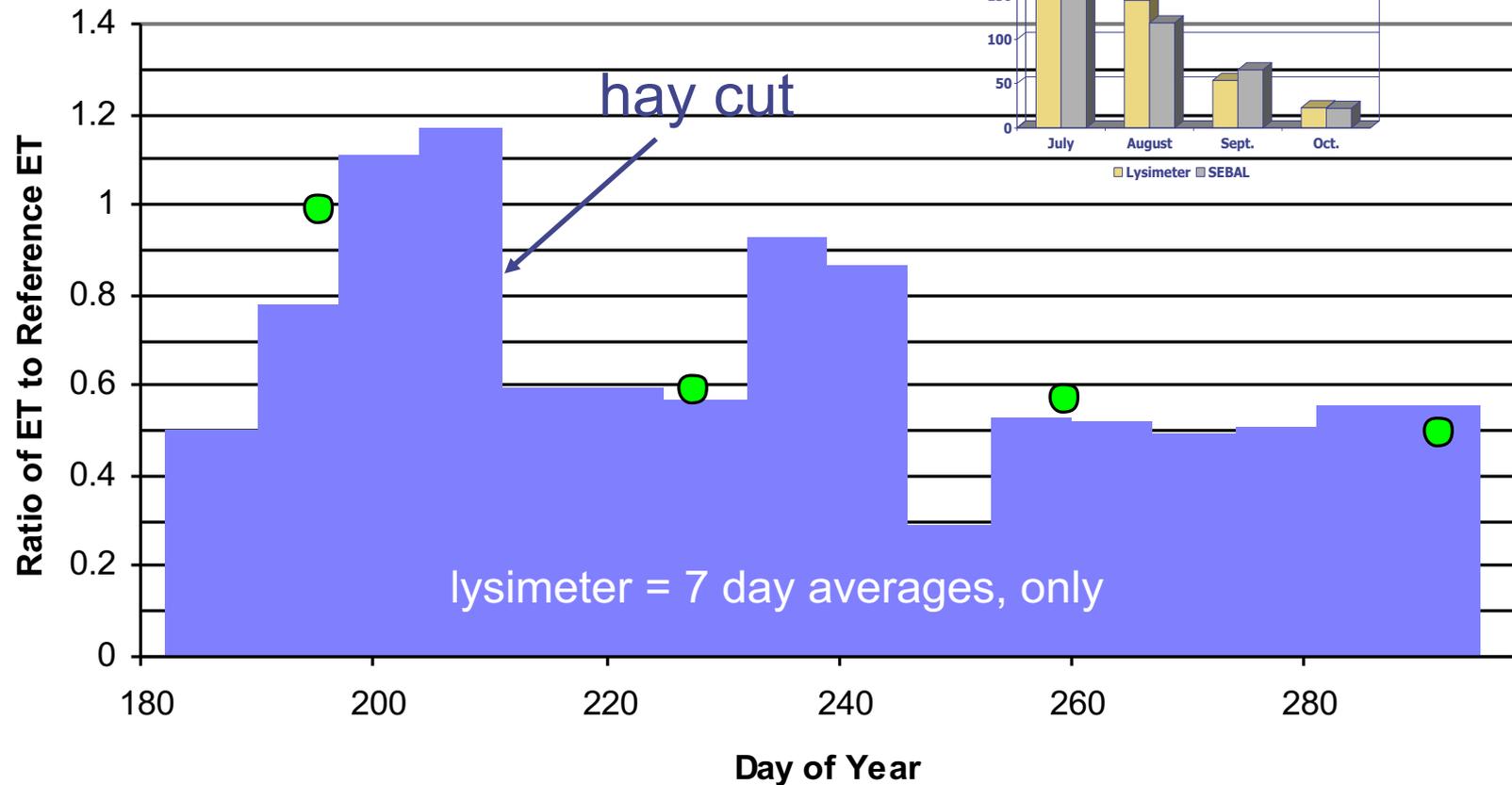
Total “depletion” by
each state

Total hectares of
development

Monitoring

Validation in the Bear River Basin

ET by Lysimeters and SEBAL Montpelier, Idaho 1985

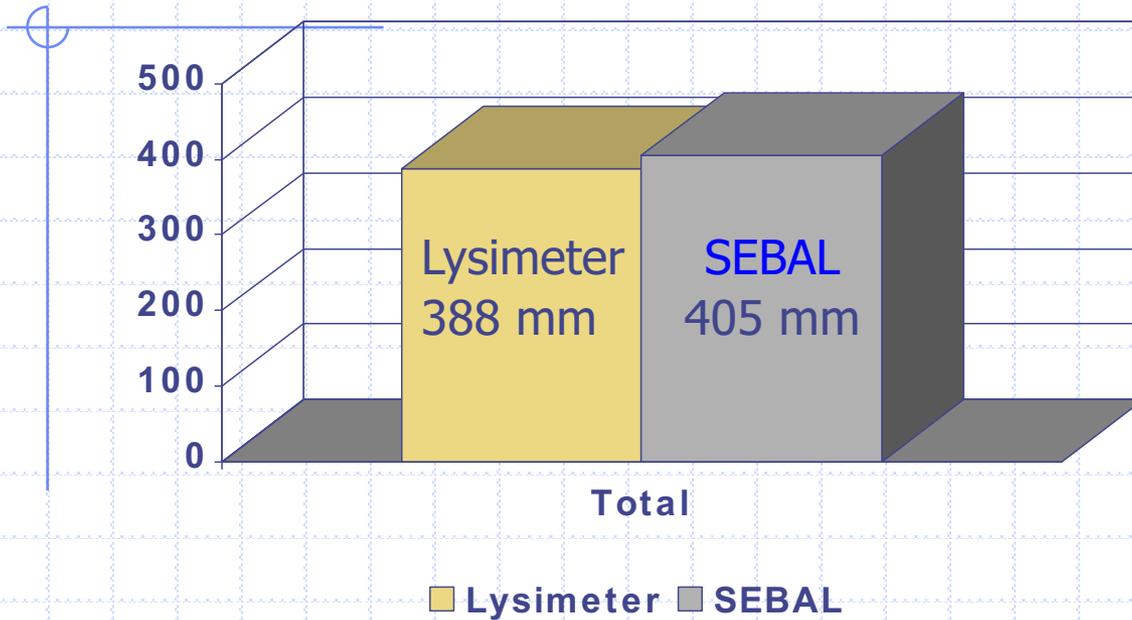


■ Avg. Etc/Etr by lysimeter

● Ratio of Etc to Etr by SEBAL

Comparison of Seasonal ET by SEBAL₂₀₀₀ with Lysimeter

ET (mm) - July-Oct., *Montpelier, ID 1985*



Example 2: Legal Finding of Fact

Water 'Call' 12/2007 by A&B Irrigation District (surface + senior ground-water)

Water Call

Claim of injury due to water shortage in 2006

- caused by lowering of aquifer by junior pumpers

Demand for curtailment order to junior GW irrigators

A Curtailment Order

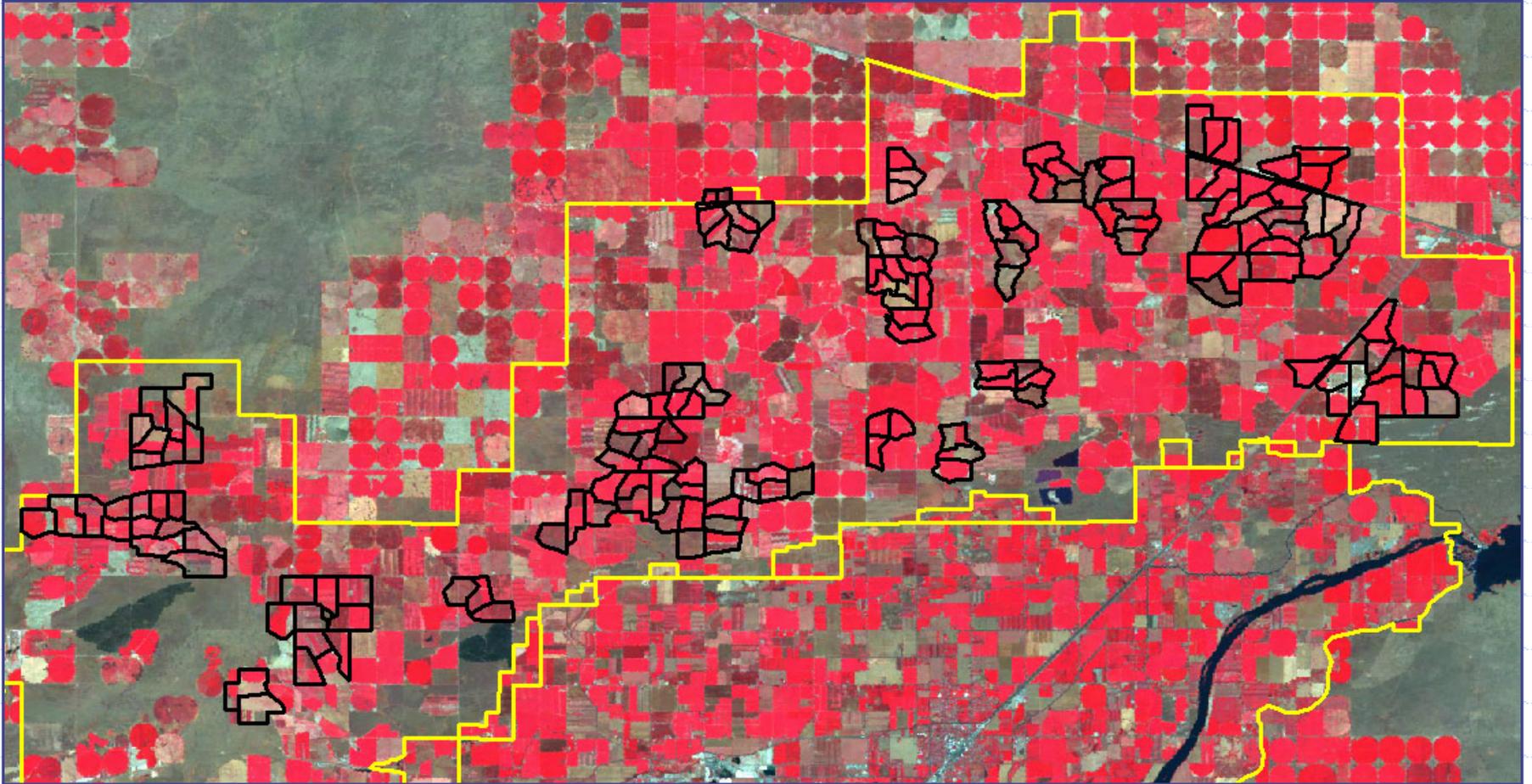
Issued by IDWR

Has the force of law

Built on Finding of Fact

At stake: >1,000 farmers' livelihoods.

Legal Finding of Fact



Polygons of fields claimed to be water-short in 2006.

The Crux of the Issue

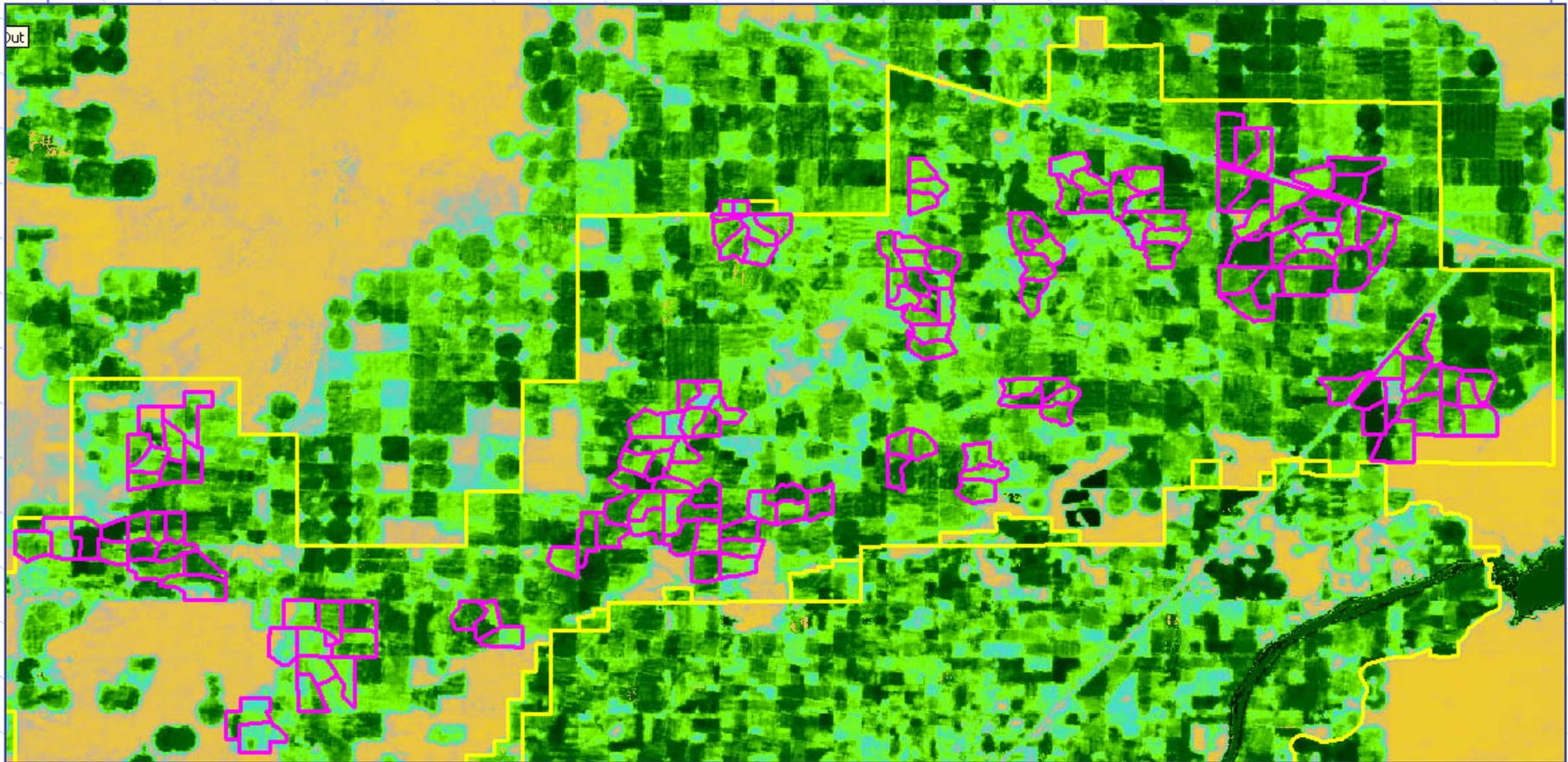
Was there enough water in 2006?

How do you assess that 2 years later?

How do you evaluate individual fields?

The Answer

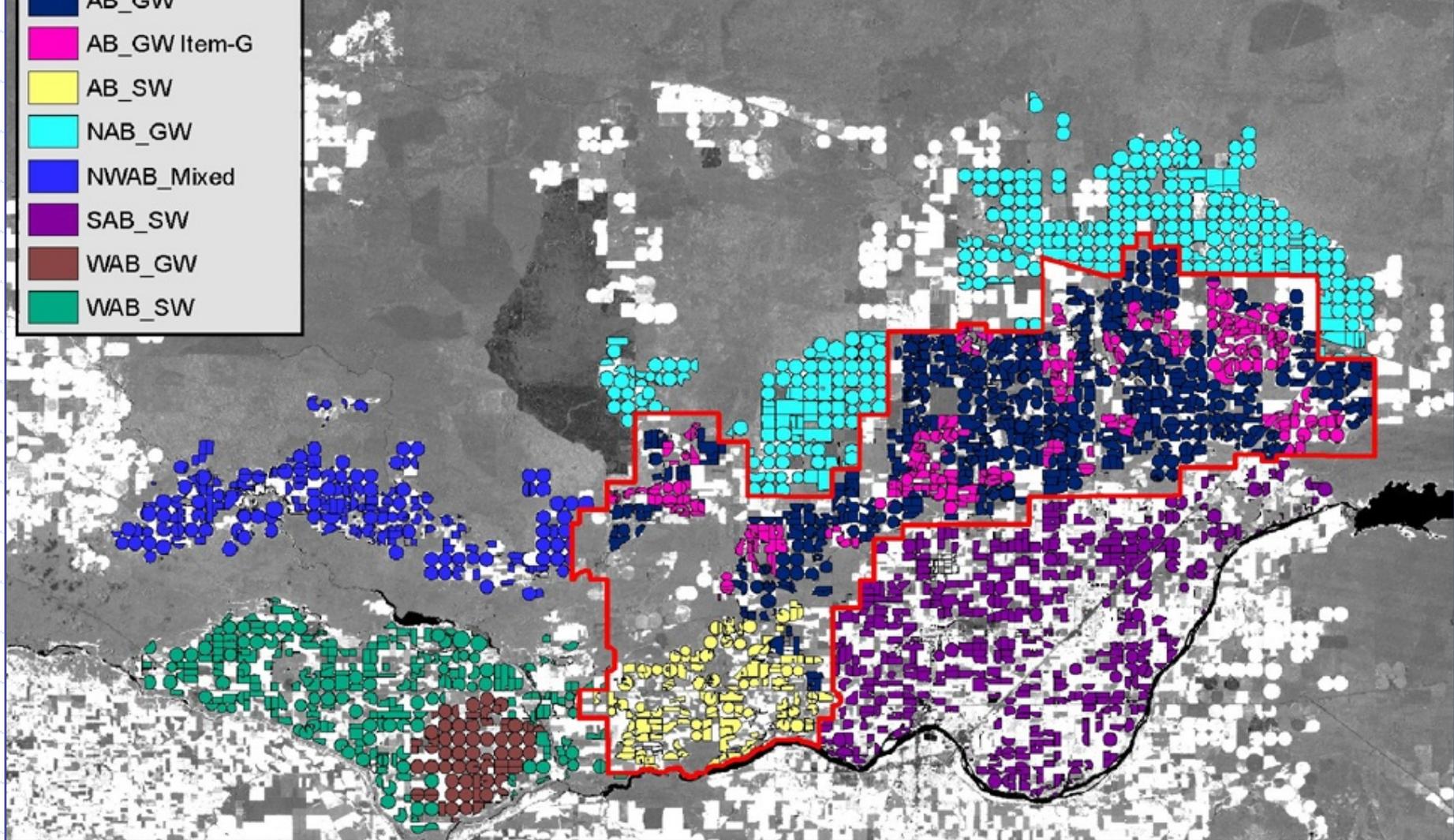
Use Landsat to map 2006 evapotranspiration



Purple polygons are fields claimed to be water-short in 2006

A&B Irrigation District and adjacent land

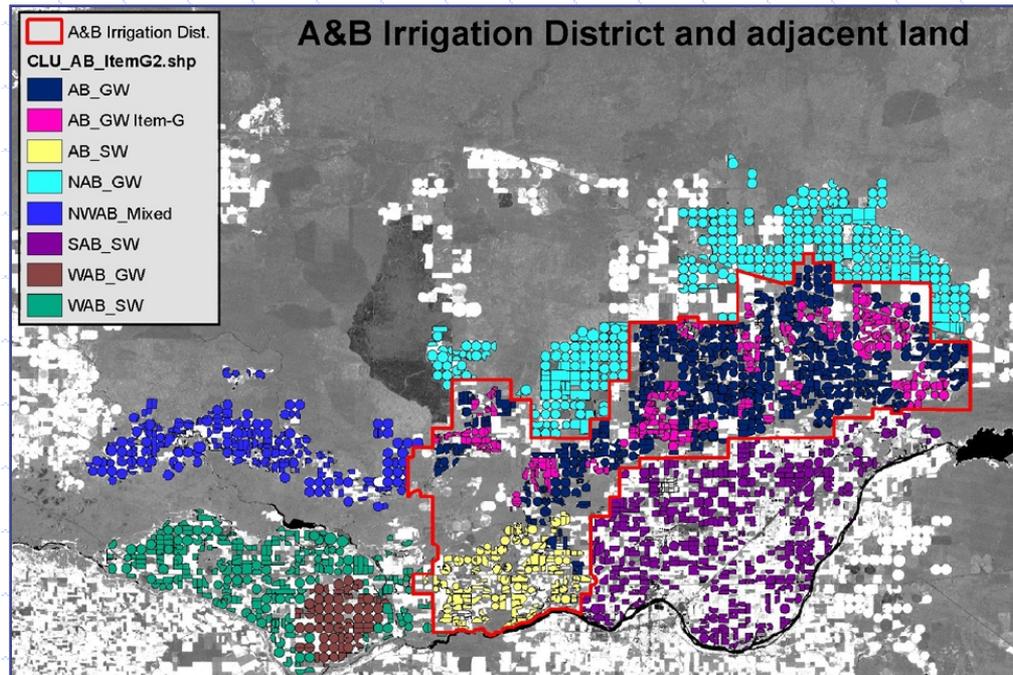
- A&B Irrigation Dist.
- CLU_AB_ItemG2.shp
- AB_GW
- AB_GW Item-G
- AB_SW
- NAB_GW
- NWAB_Mixed
- SAB_SW
- WAB_GW
- WAB_SW



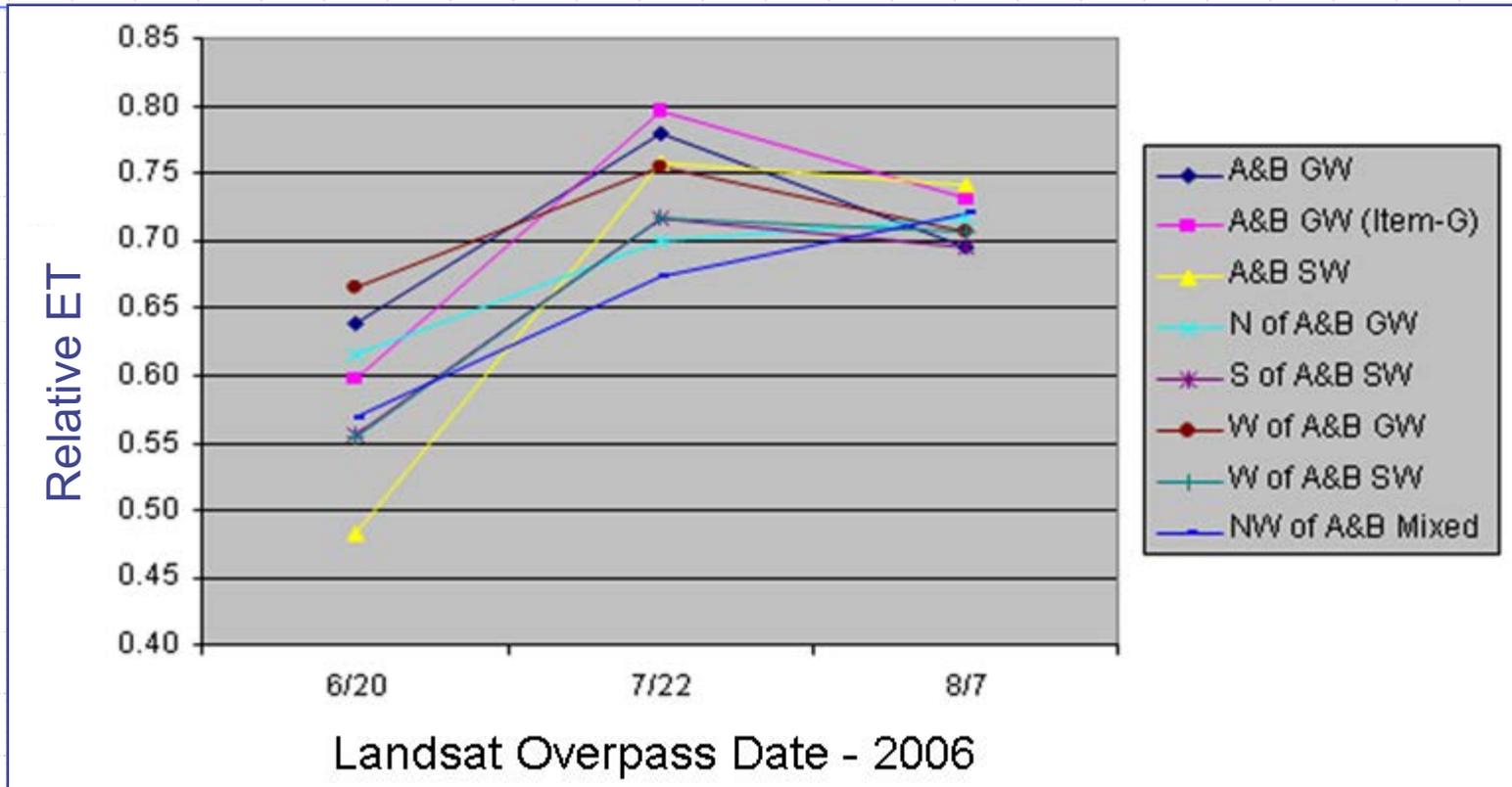
Water-short polygons and 'other' irrigation entities to be compared against

The Analysis

METRIC ET Images for 6/20, 7/22, 8/7
Compared mean 24-hour ET
Compared mean Vegetation indices (NDVI)
Compared mean ratio ET / NDVI.

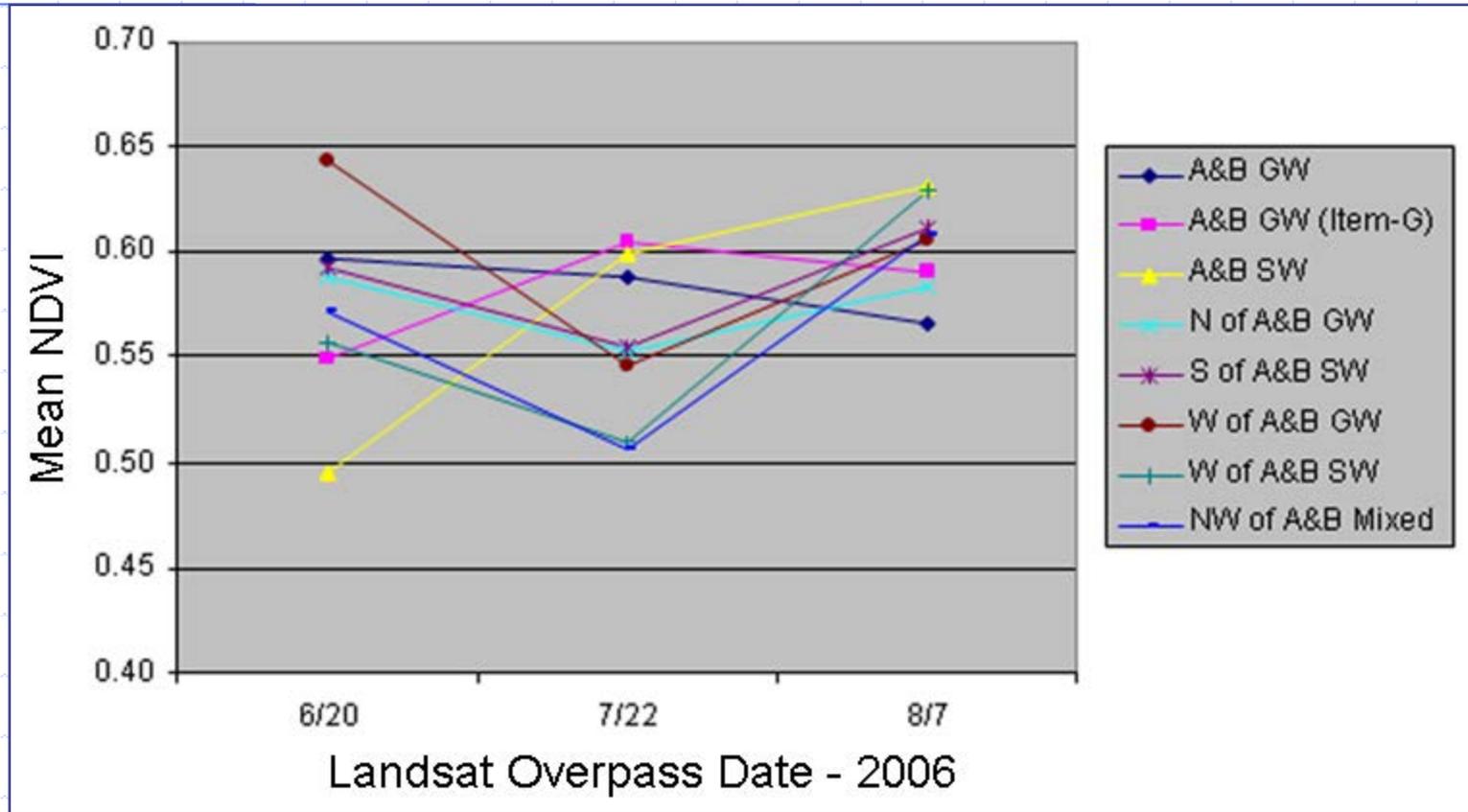


Relative ET



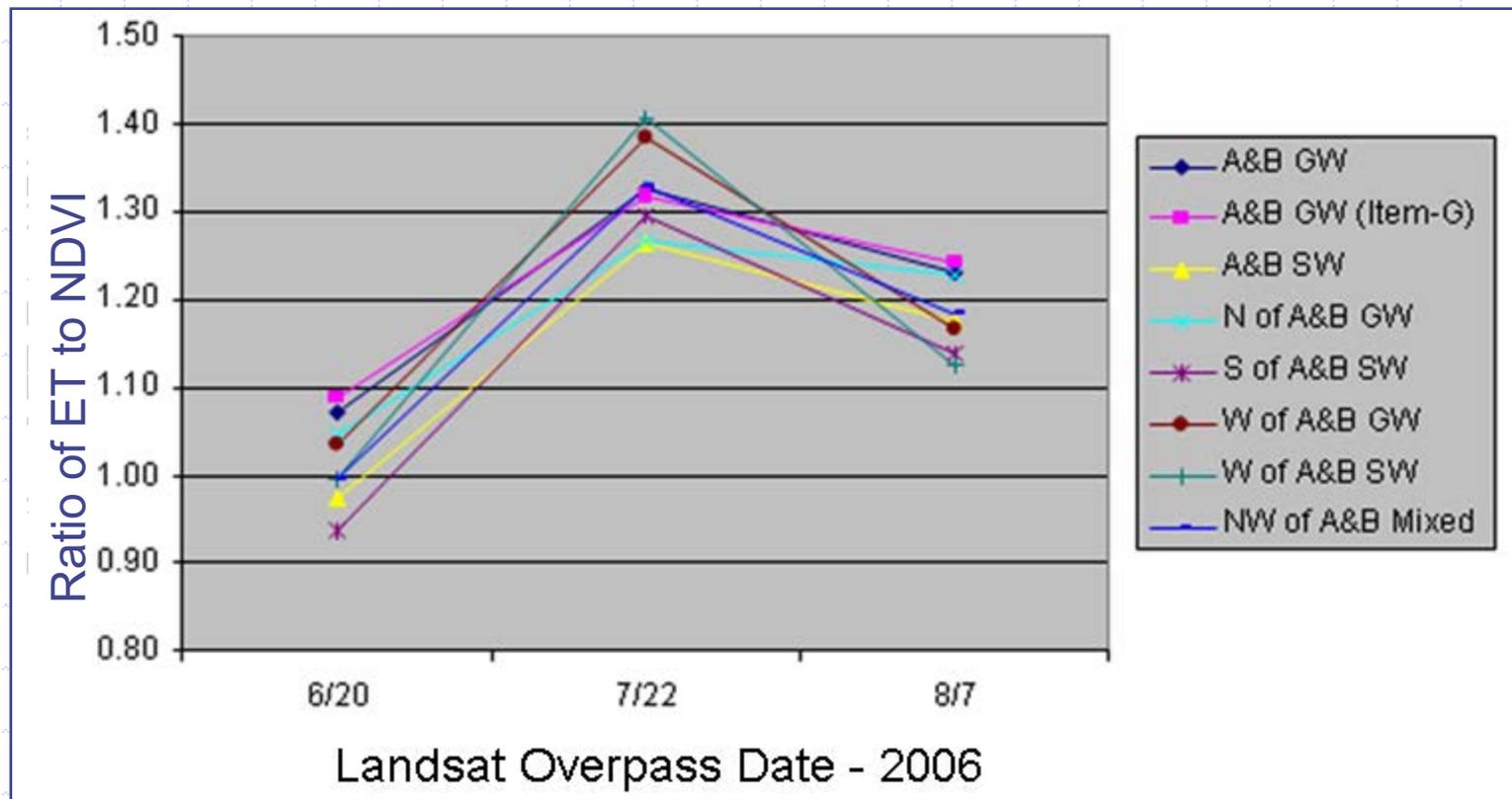
How much evapotranspiration? (*A&B did not appear to suffer*)

Mean NDVI



How much vegetation? (A&B did not appear to have lower VI)

ET / NDVI



How much evapotranspiration per amount of vegetation?

(A&B did not appear to suffer)

Result

IDWR denied the call

A&B appealed (and lost)

Analysis based on

Unbiased data sets

Single data source

Field-level data

Archive data

Landsat resolution (30 m)
enabled the analysis

BEFORE THE DEPARTMENT OF WATER RESOURCES

OF THE STATE OF IDAHO

IN THE MATTER OF THE PETITION FOR)
DELIVERY CALL OF A&B IRRIGATION)
DISTRICT FOR THE DELIVERY OF GROUND) **ORDER**
WATER AND FOR THE CREATION OF A)
GROUND WATER MANAGEMENT AREA)

This matter originally came before the Director of the Department of Water Resources ("Director" or "Department") on July 26, 1994 when the A&B Irrigation District ("A&B" or "District") filed a petition for delivery call, which sought administration of junior priority ground water rights diverting from the Eastern Snake Plain Aquifer ("ESPA"), as well as the designation of the ESPA as a ground water management area.

On May 1, 1995, A&B, the Department, and other participants entered into an agreement that stayed the petition for delivery call until such time as a motion to proceed was filed with the Director. On March 16, 2007, A&B filed a motion to proceed seeking the administration of junior priority ground water rights, as well as the designation of the ESPA as a ground water management area.

Based upon the Director's consideration of the available information and documents filed herein, the Director enters the following Findings of Fact, Conclusions of Law, and Order.

FINDINGS OF FACT

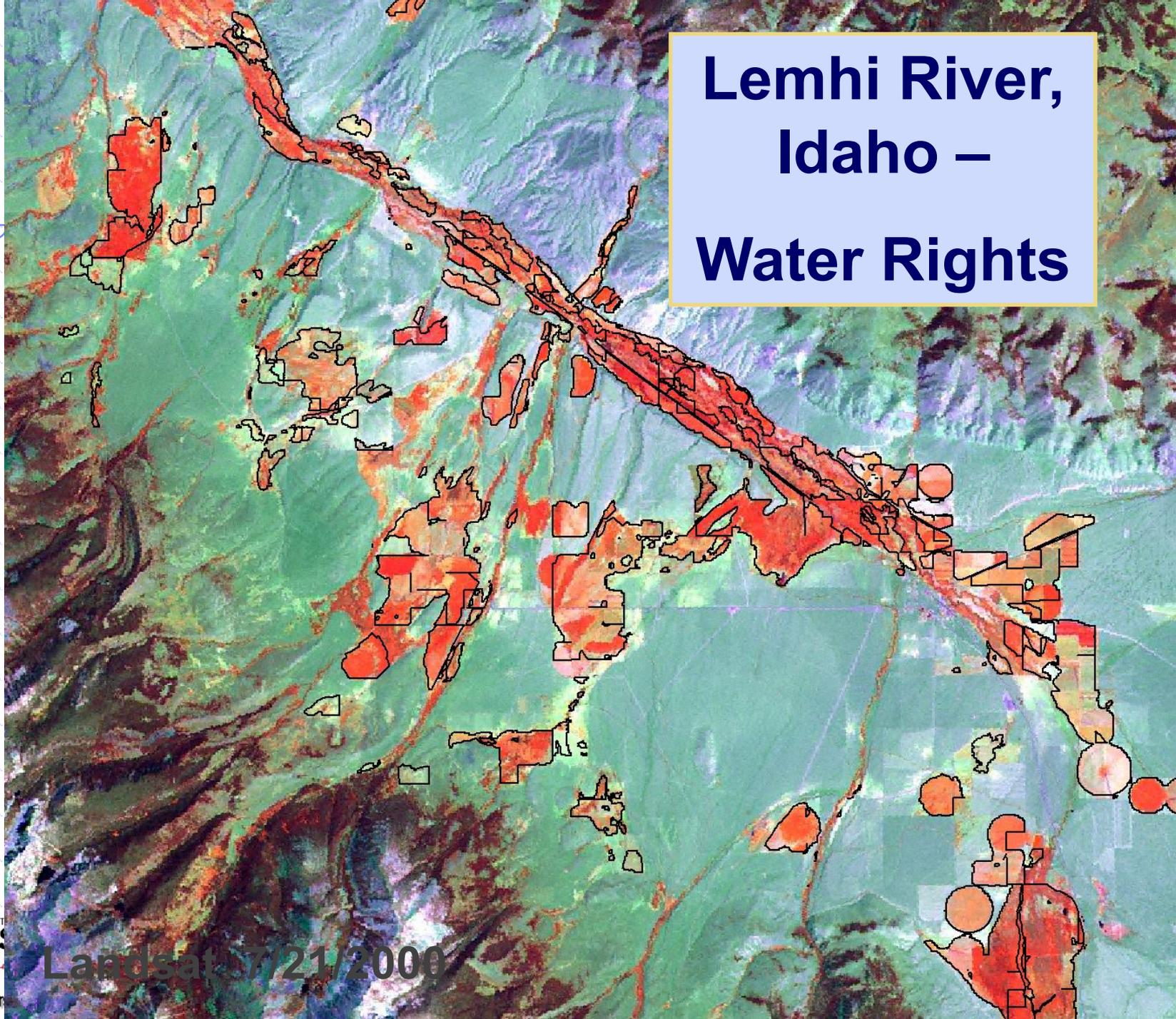
Procedural History

1. On July 26, 1994, A&B filed a Petition for Delivery Call ("Petition") with the Department. The boundary of the A&B Irrigation District is depicted in Attachment A. According to the Petition, A&B "is the beneficial owner of Water License No. 20736, now known as A-36-02080, which entitles the Irrigation District to divert eleven hundred (1100) cfs from one hundred seventy-seven (177) wells for the irrigation of sixty-two thousand six hundred four and three tenths (62,604.3) acres within the irrigation district, with a priority of September 9, 1948." *Petition* at 1, ¶ 2. "That said water right is held in trust by the United States, for the benefit of the owners of said 62,604.3 acres, all of whom are landowners within and are included within A&B Irrigation District." *Id.* at 1, ¶ 3. Additionally, the Petition stated that due to diversions from the ESPA by junior priority ground water users, A&B "is suffering material injury as a result of the lowering of the ground water pumping level within the E[SPA] by an

Example 3: Water Planning for Endangered Species

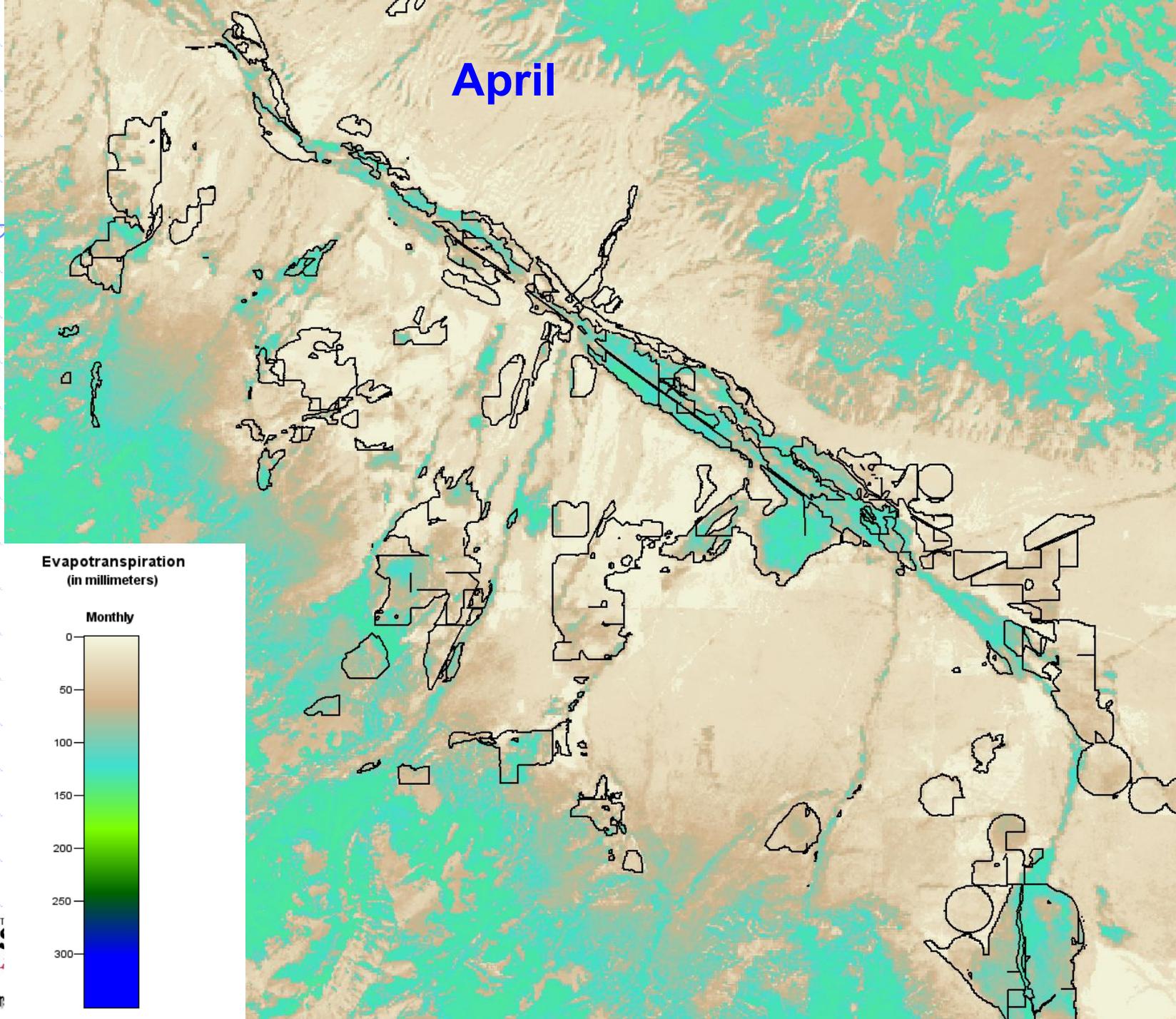
- Landsat-based ET estimates
- overlay irrigated areas to calculate volumes of water used for irrigation of specific water rights
- Consumptive portion compared to diversions to help producers reduce diversions and sustain streamflows during summer for Salmon

Lemhi River, Idaho – Water Rights



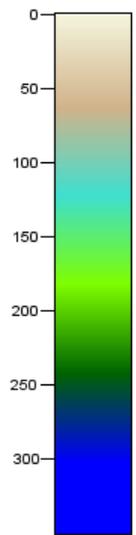
Landsat 7/21/2000

April

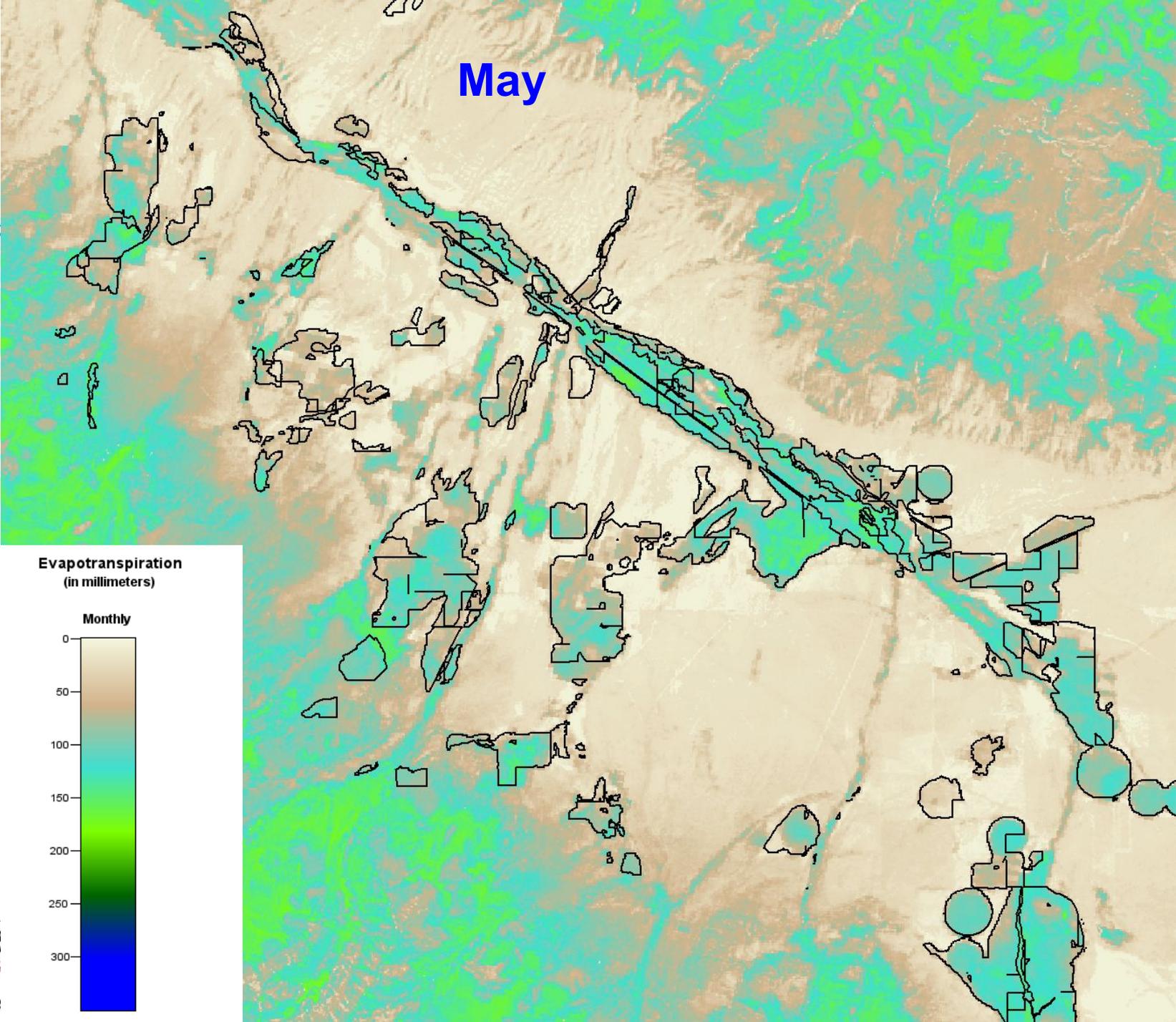


Evapotranspiration
(in millimeters)

Monthly

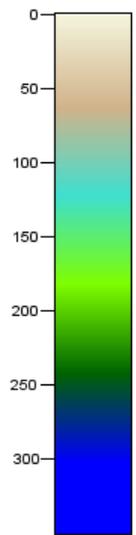


May

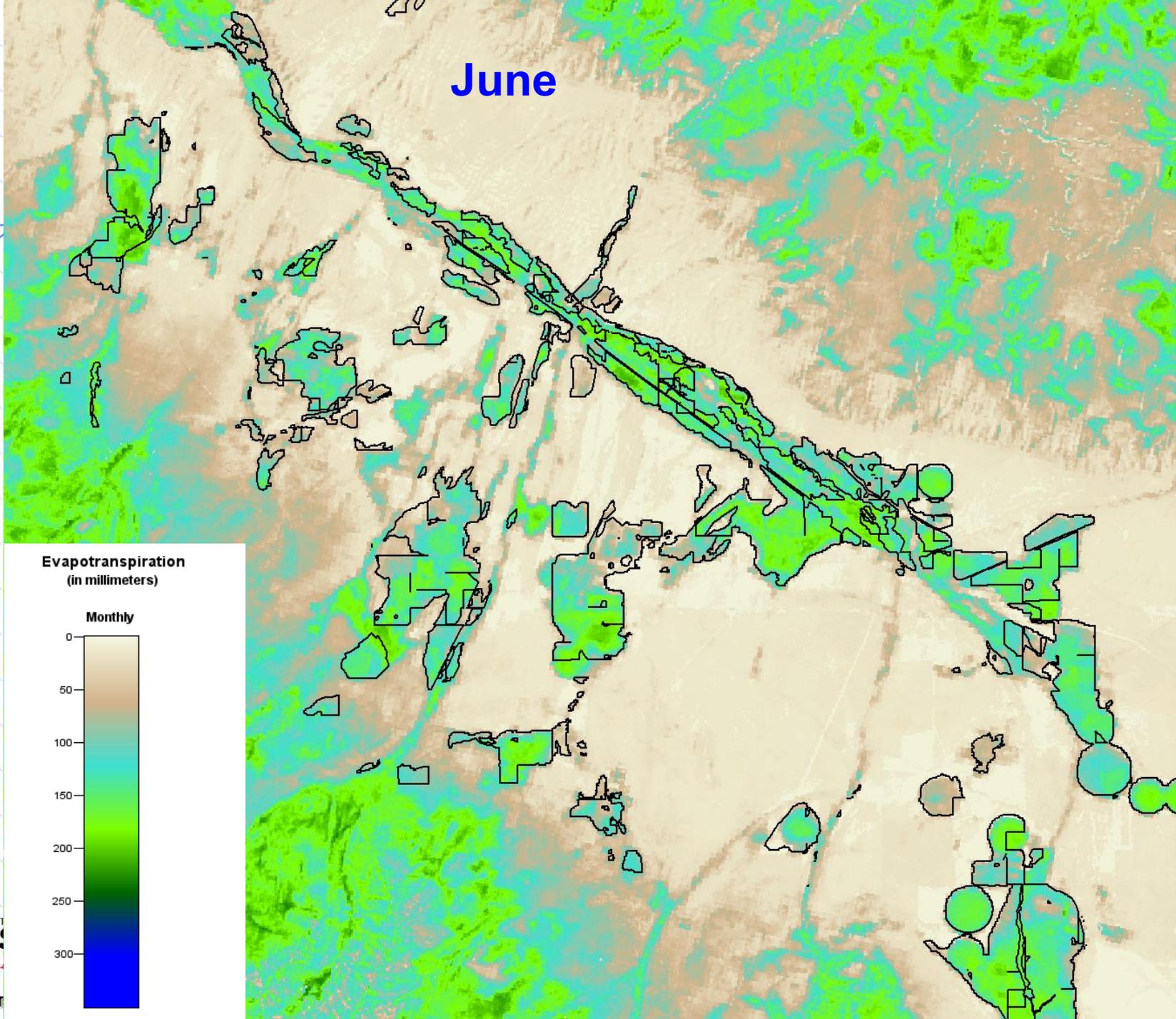


Evapotranspiration
(in millimeters)

Monthly

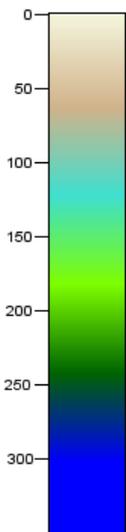


June

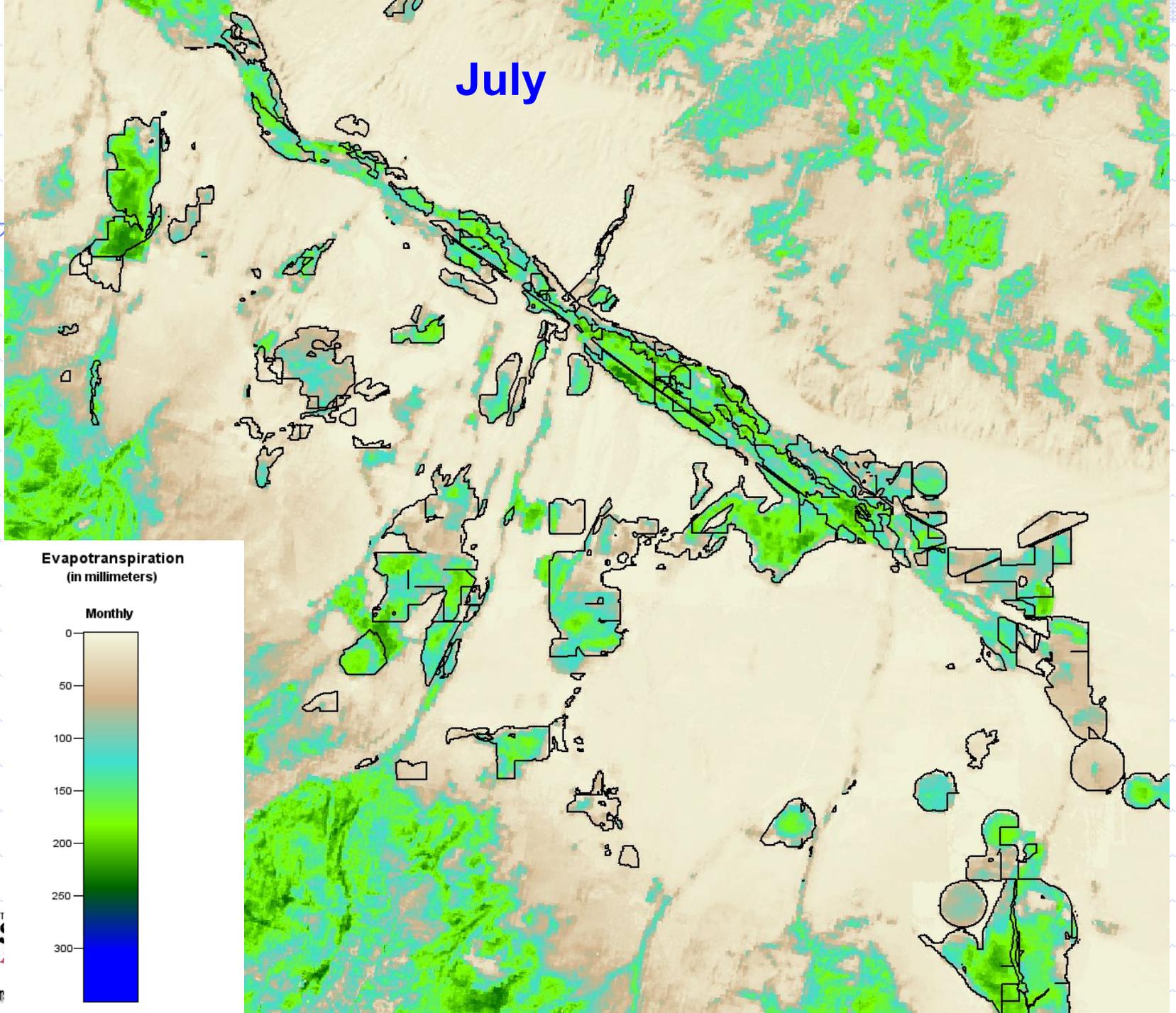


Evapotranspiration
(in millimeters)

Monthly

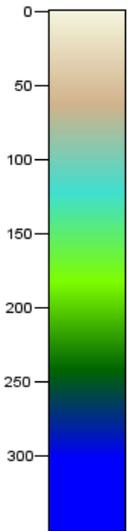


July

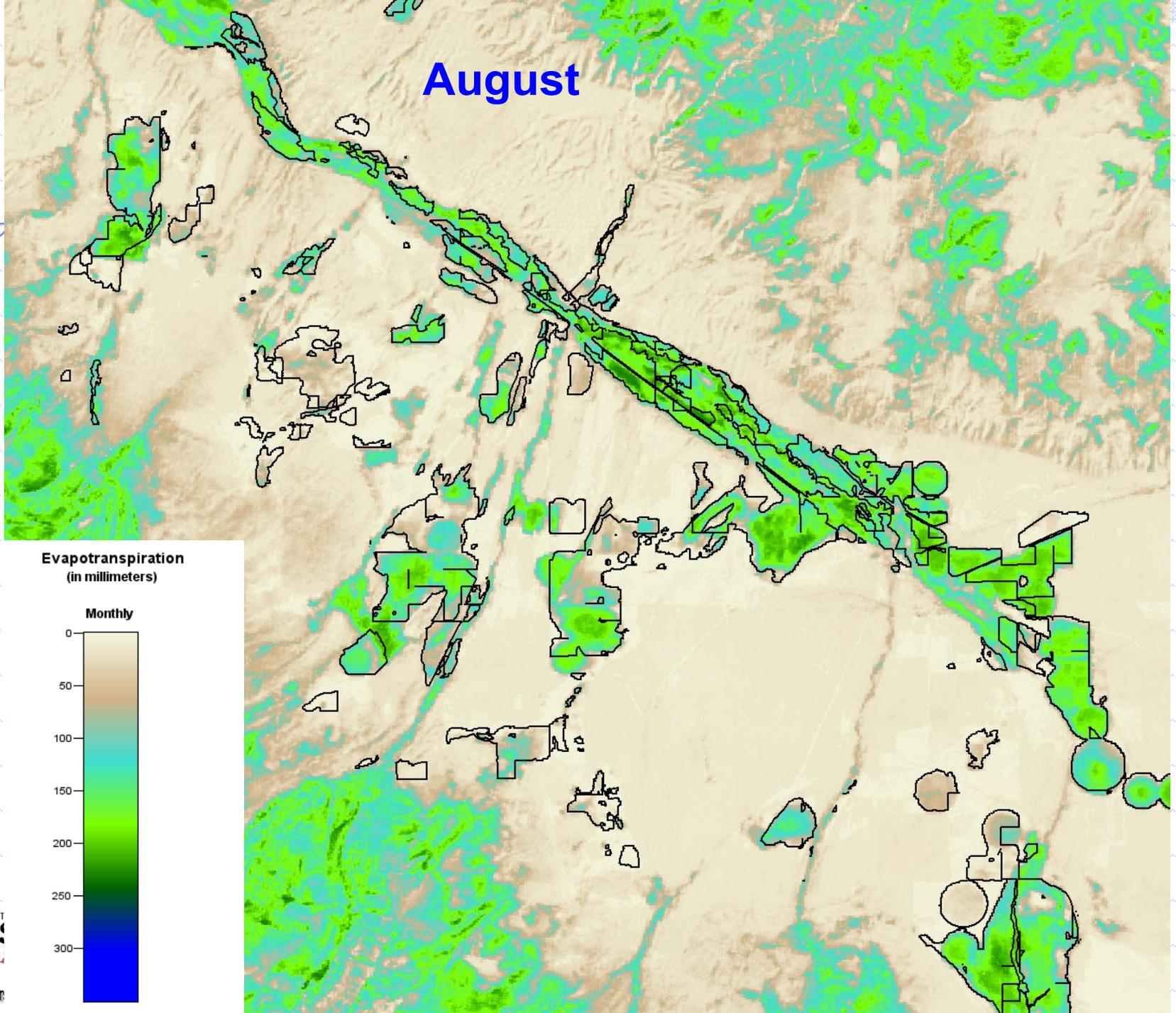


Evapotranspiration
(in millimeters)

Monthly

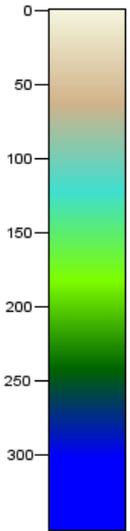


August

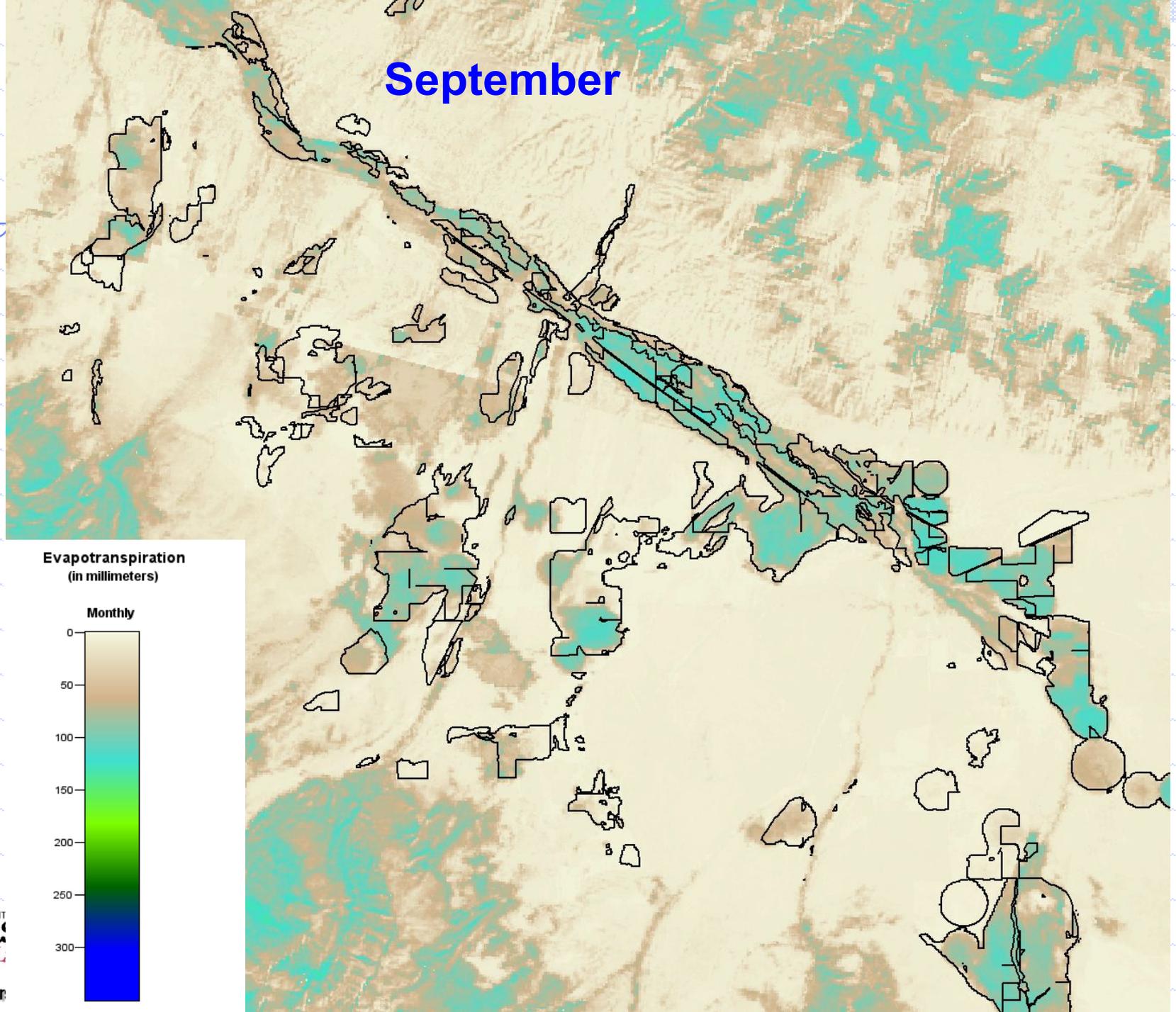


Evapotranspiration
(in millimeters)

Monthly

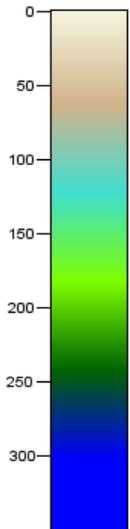


September

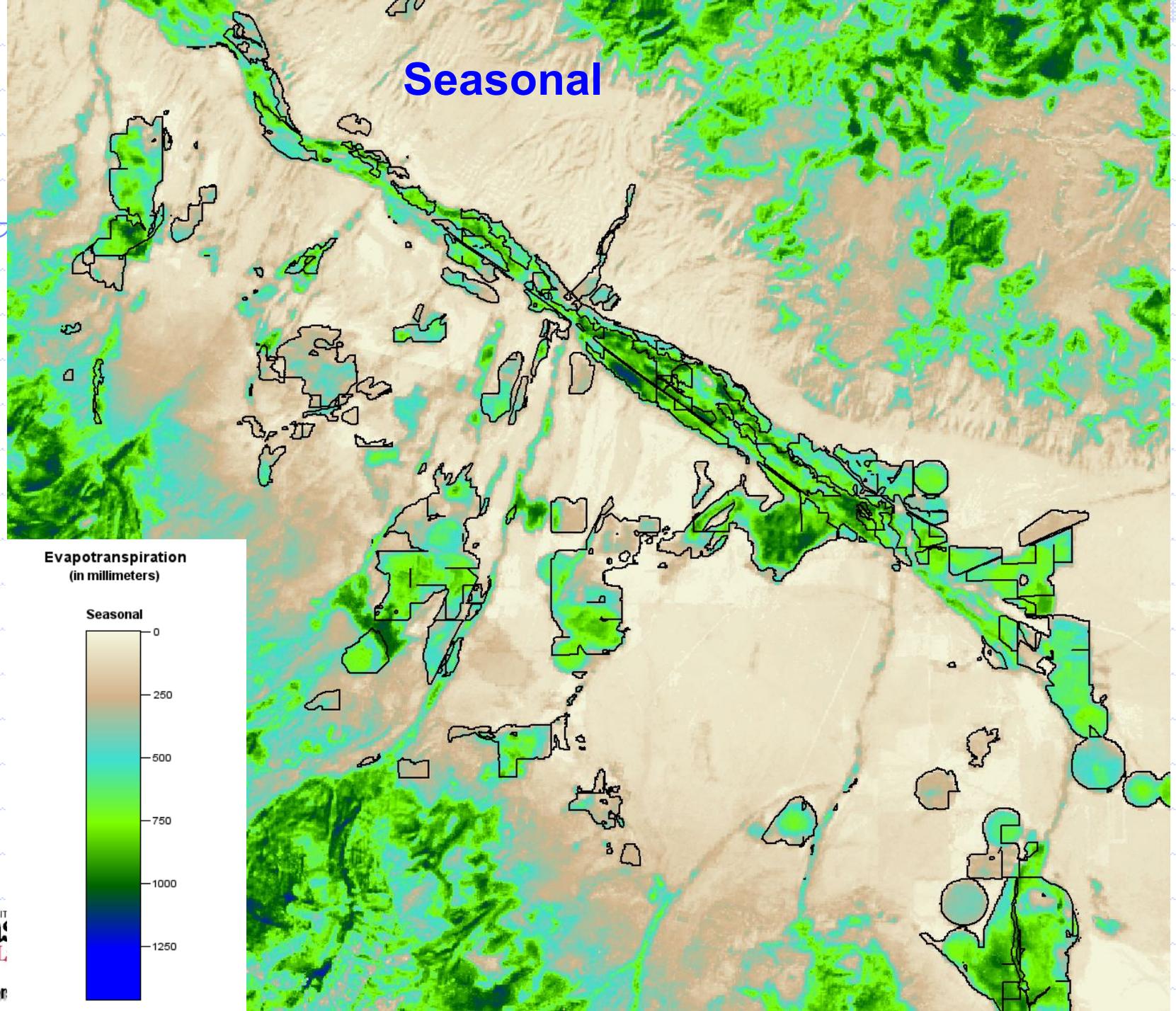


Evapotranspiration
(in millimeters)

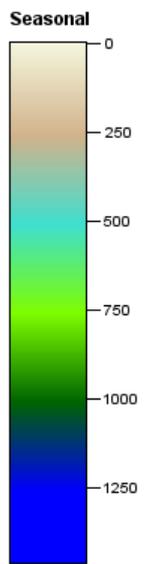
Monthly



Seasonal



Evapotranspiration
(in millimeters)



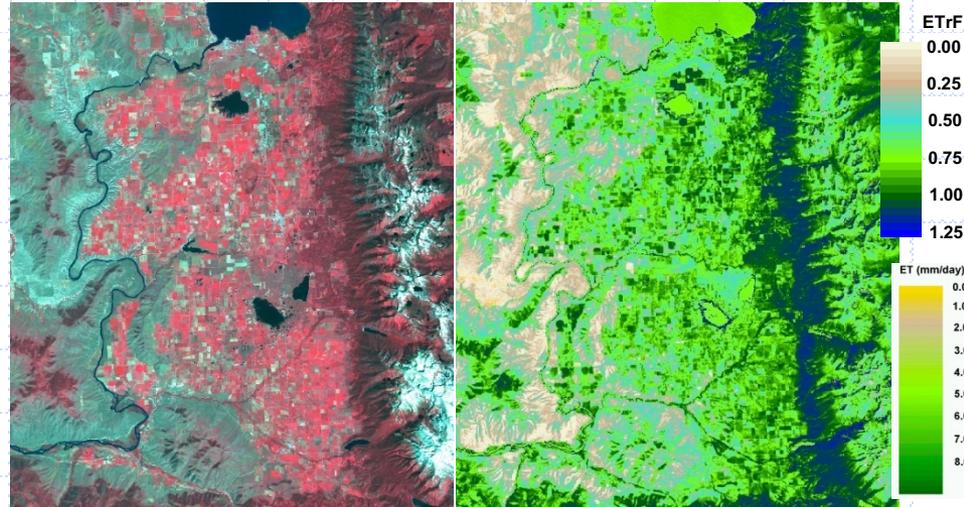
Other METRIC Applications in Western Water Management

◆ Colorado

- Conjunctive management of ground-water and surface water by State Engineer along the South Platte (Riverside Technology-UI)
- Assessment of water shortage and salinity impacts along the Arkansas River (an independent application by CSU)

◆ Montana

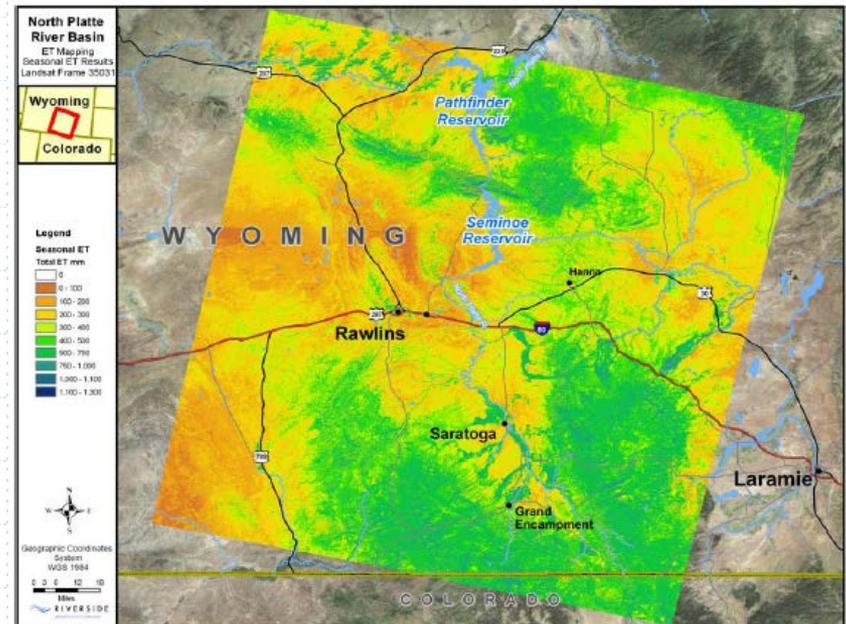
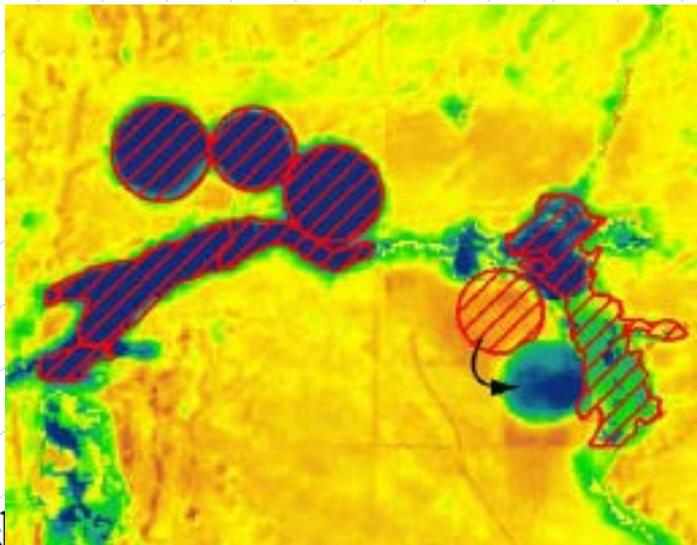
- Flathead Indian Reservation
 - ◆ Balancing Irrigation Depletions with instream flow needs



Other METRIC Applications in Western Water Management

◆ North Platte Water Decree

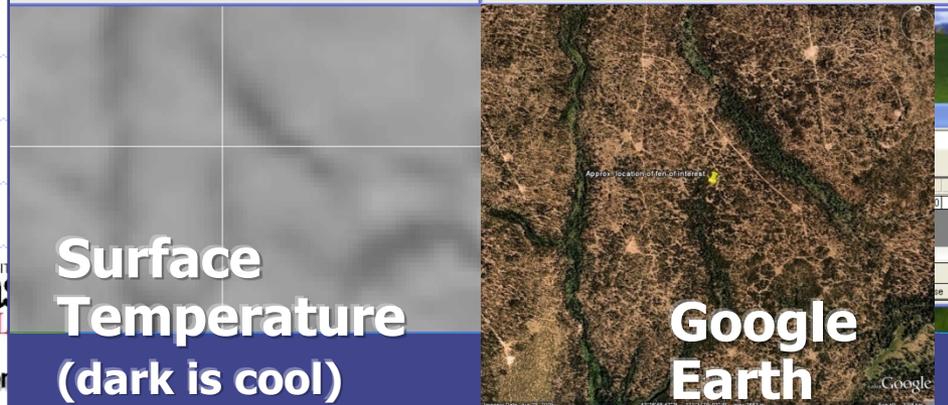
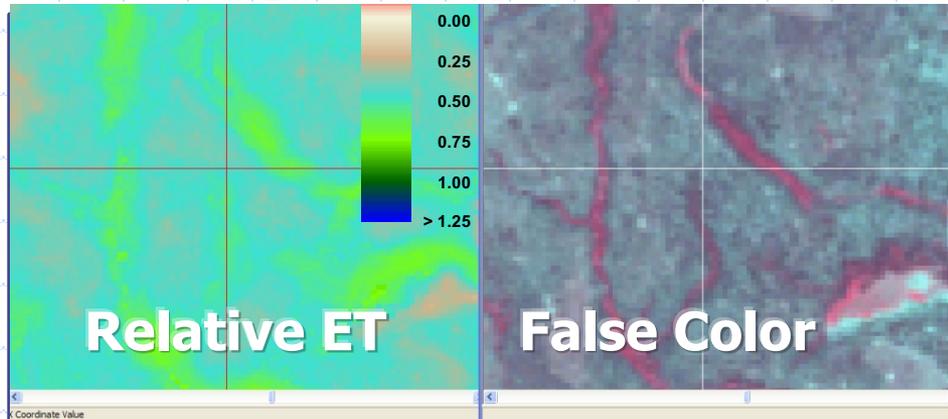
- Nebraska / Wyoming / Colorado settlement in 2001
- States proportion ET among themselves
- High resolution monitoring is needed due to narrow irrigation corridors along streams



Other METRIC Applications in Western Water Management

◆ Oregon

- “Fen” areas north of Klamath Basin where Stock Water Supplies for Grazing compete with local Ecosystems supplied by Springs (USFS) - narrow systems require hi-res. thermal of Landsat
- Irrigation Depletions in the Klamath Basin



Other METRIC Applications in Western Water Management

◆ Central Montana

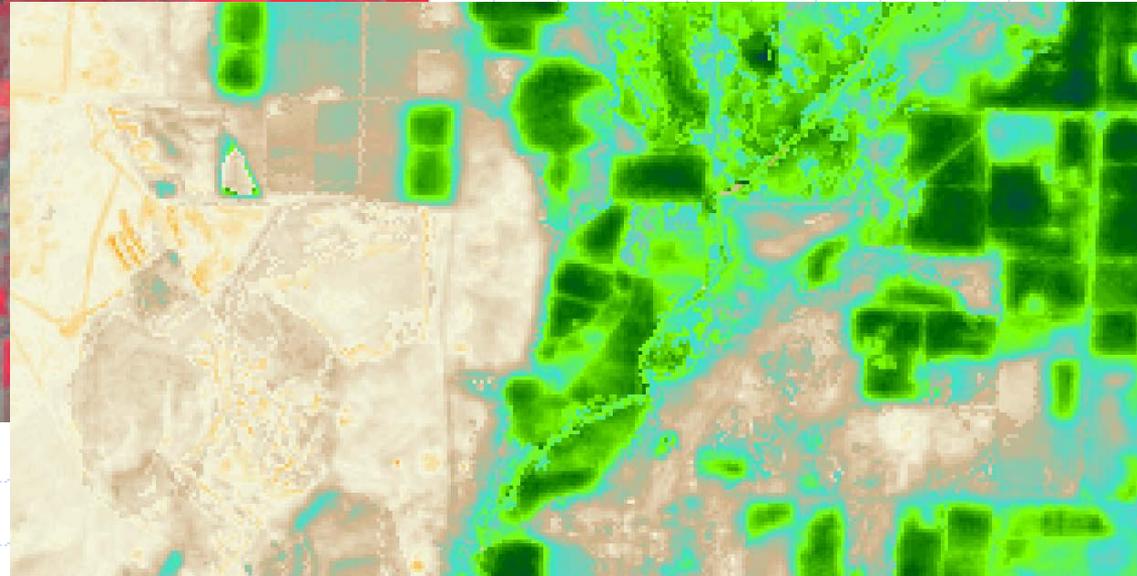
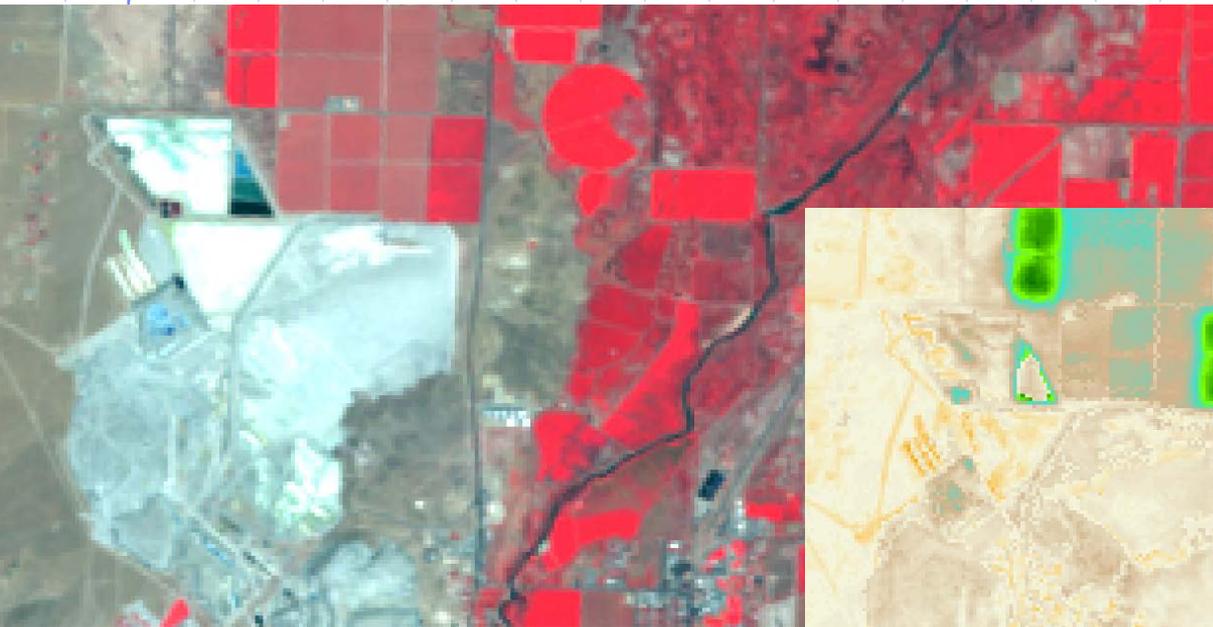
- Ground-water Recharge estimation in four different basins in a single path!
- Customer: USGS and Montana Bureau of Mining and Geology
- Recharge \approx Precipitation – Evapotranspiration
- *High resolution is needed due to narrow domains of irrigation*



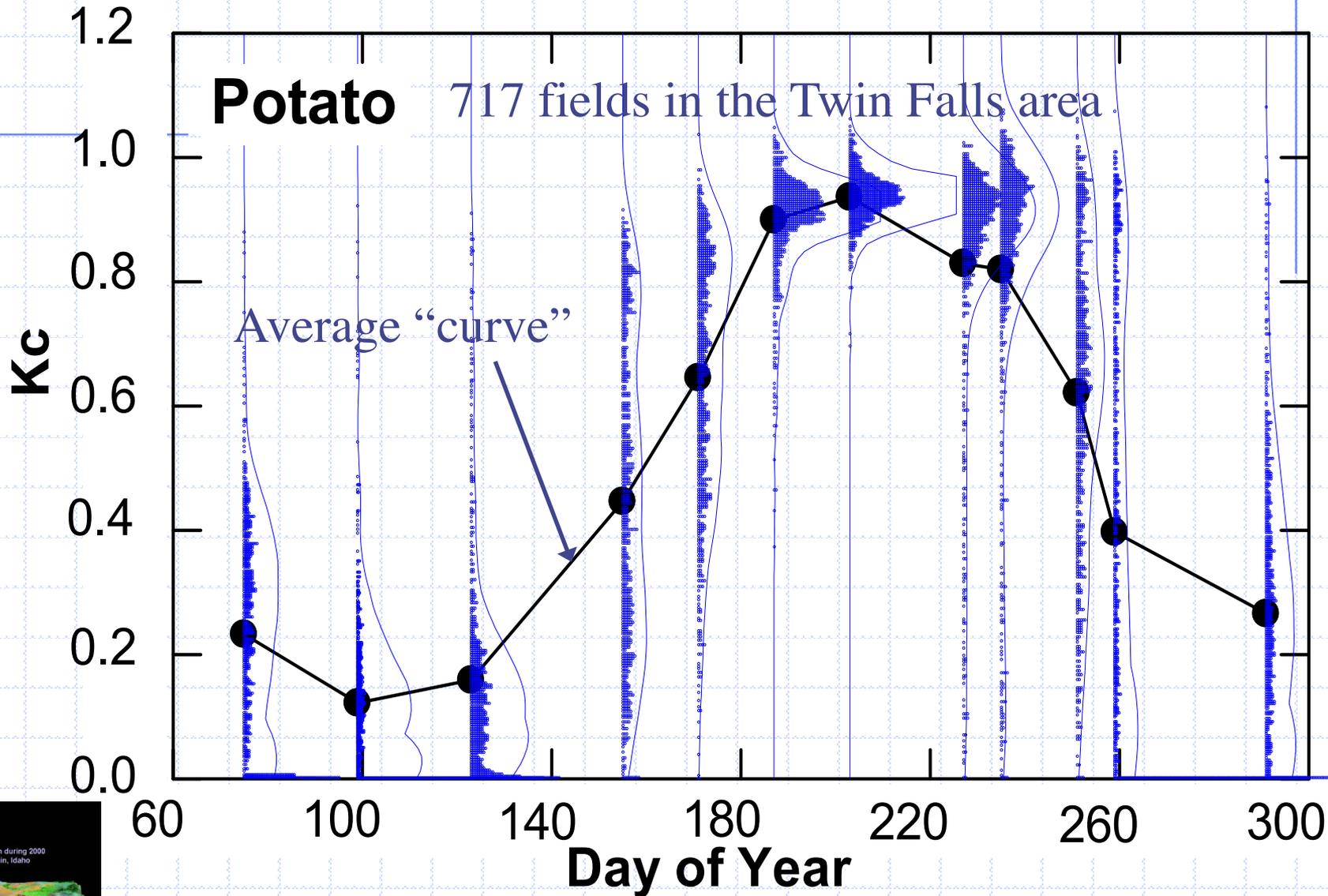
Other METRIC Applications in Western Water Management

◆ Nevada – UI partnership with DRI

- Water transfers from Irrigated Ag. to Reno/Las Vegas
- Water transfers from phreatophytes and playa to Las Vegas
- *Need High Resolution thermal for narrow irrigation corridors and sometimes narrow phreatophytic systems*

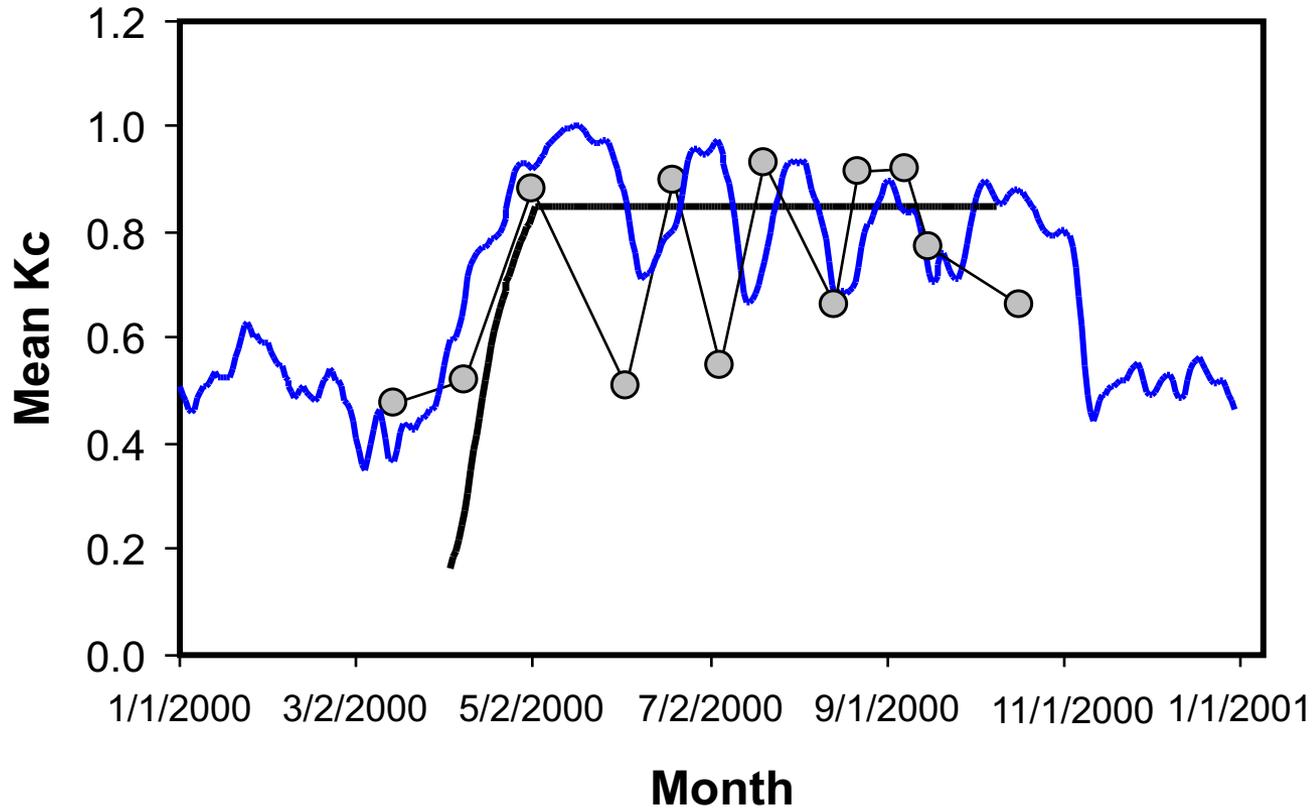


Use to Refine Local ET and Kc Information



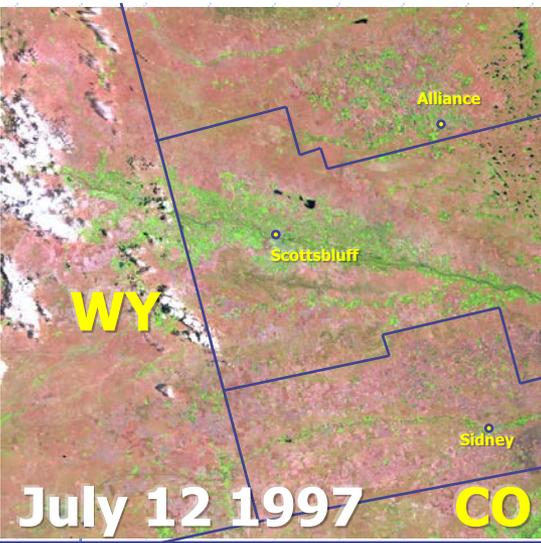
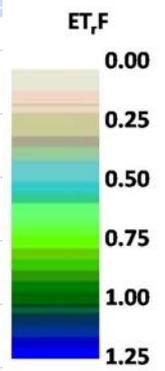
Comparison with K_c from METRIC and K_c based Methods

Alfalfa - Dairy hay Twin Falls, ID 2000

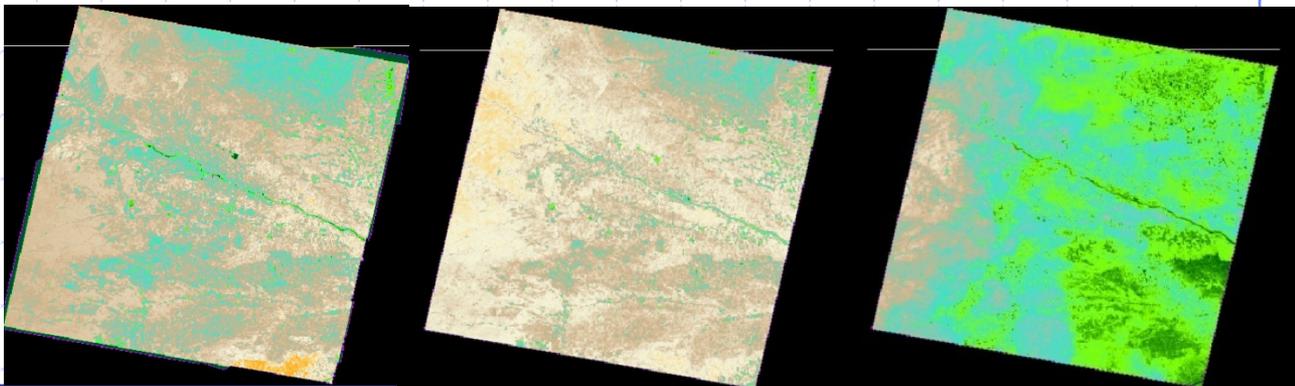


— Agrimet for 2000 — Allen-Robison - 14 yr ave. —○— METRIC for 2000

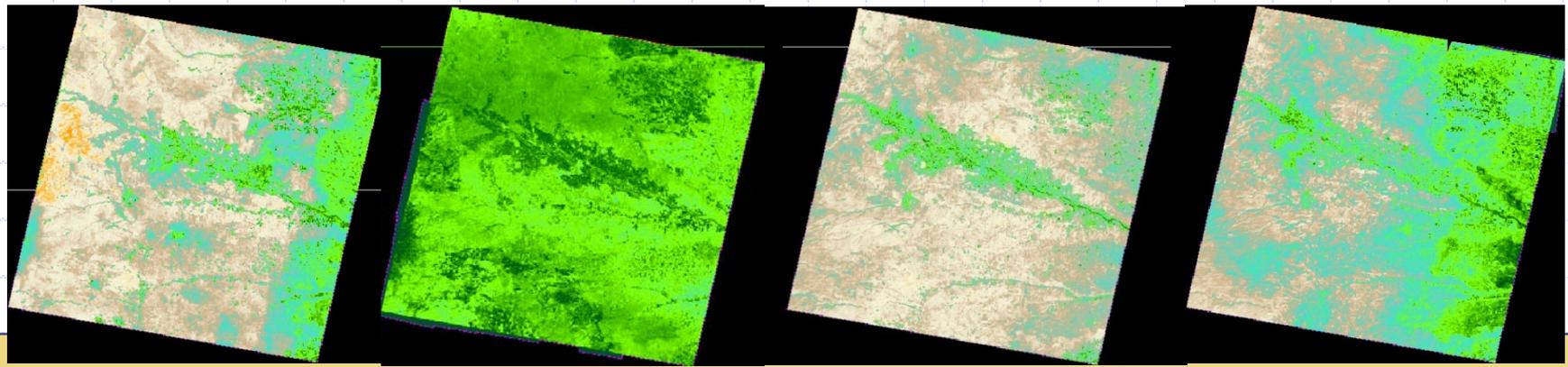
Relative ET during the growing season showing impacts of wetting events – This can bias the seasonal estimate – *need to 'adjust' images*



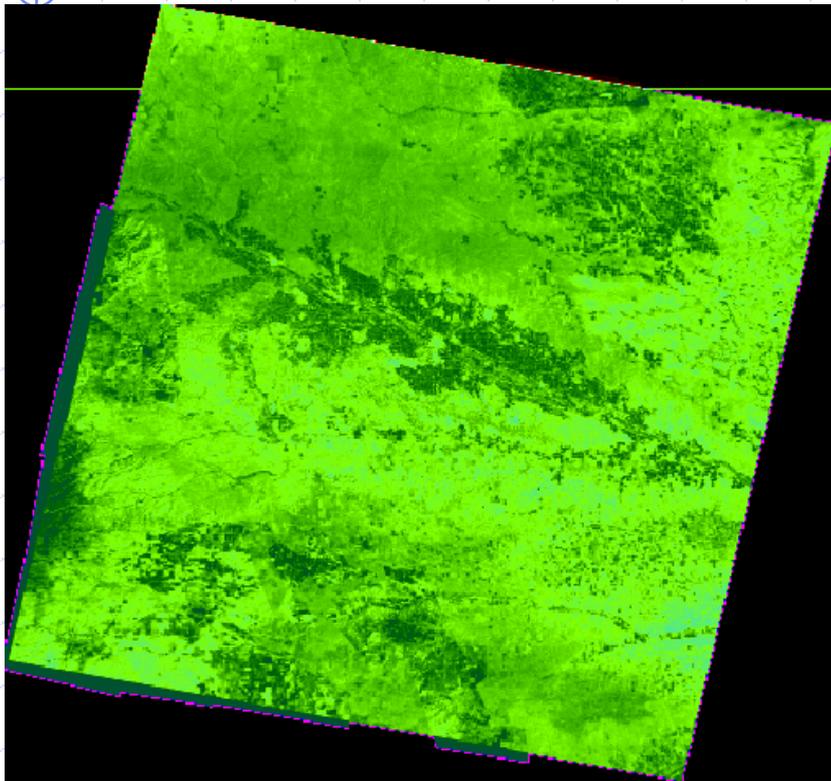
1997 image date relative ET estimates



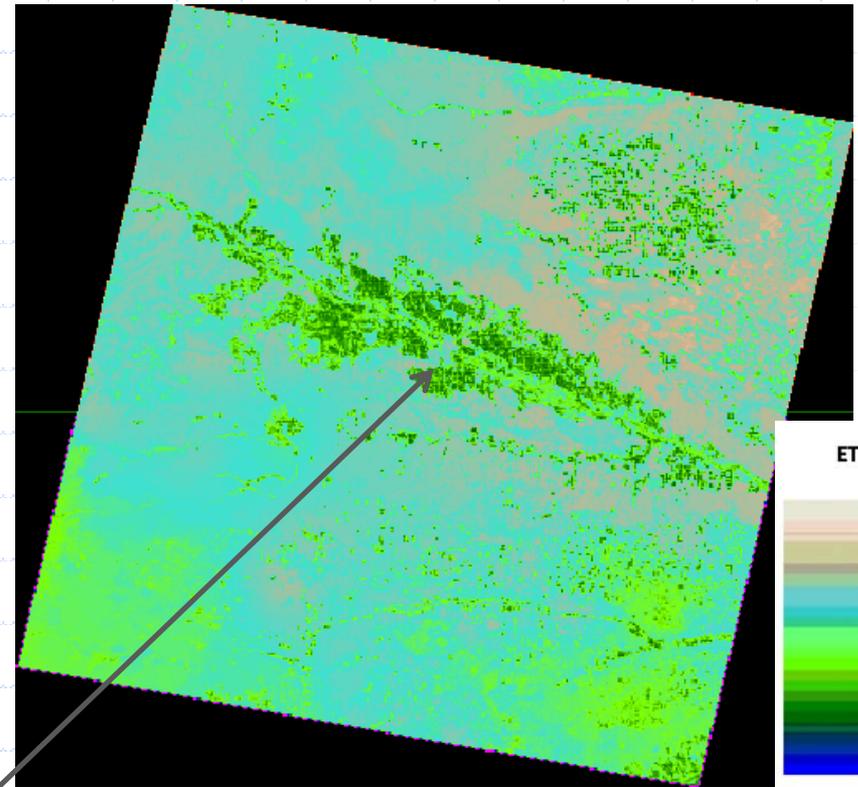
Landsat true color



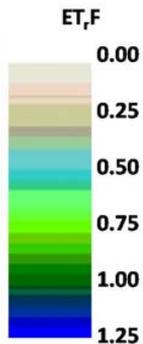
Adjusting for background evaporation from day of image to monthly period (*using a gridded daily evaporation process model*)



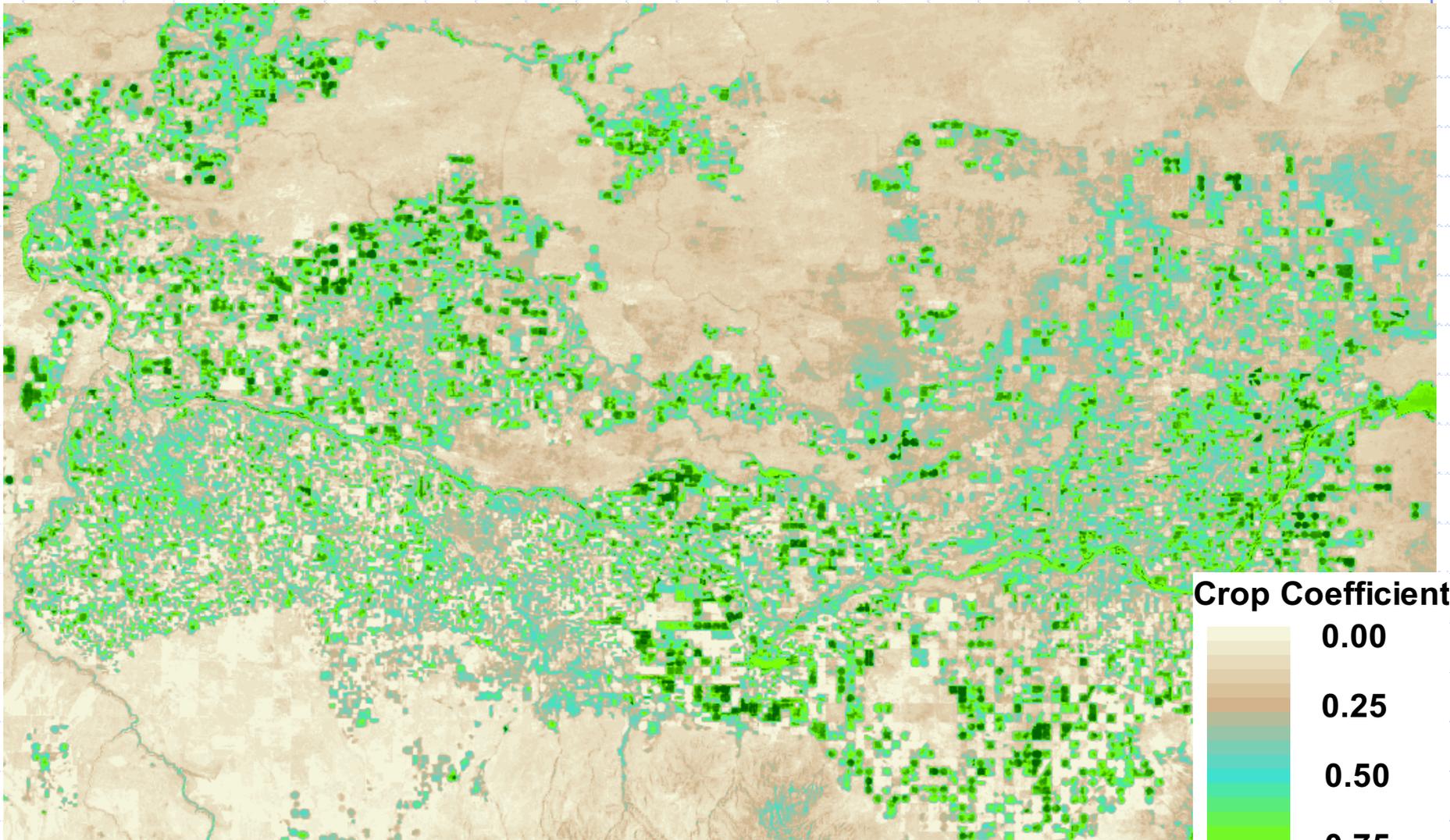
ET from August 13 1997
before adjustment



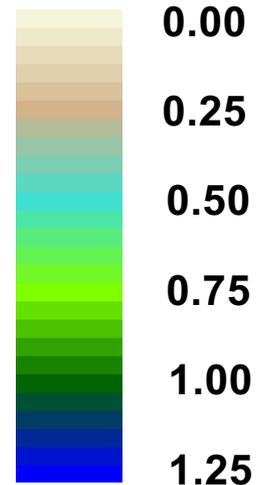
ET from August 13 1997
adjusted to represent
August



Irrigated Agriculture



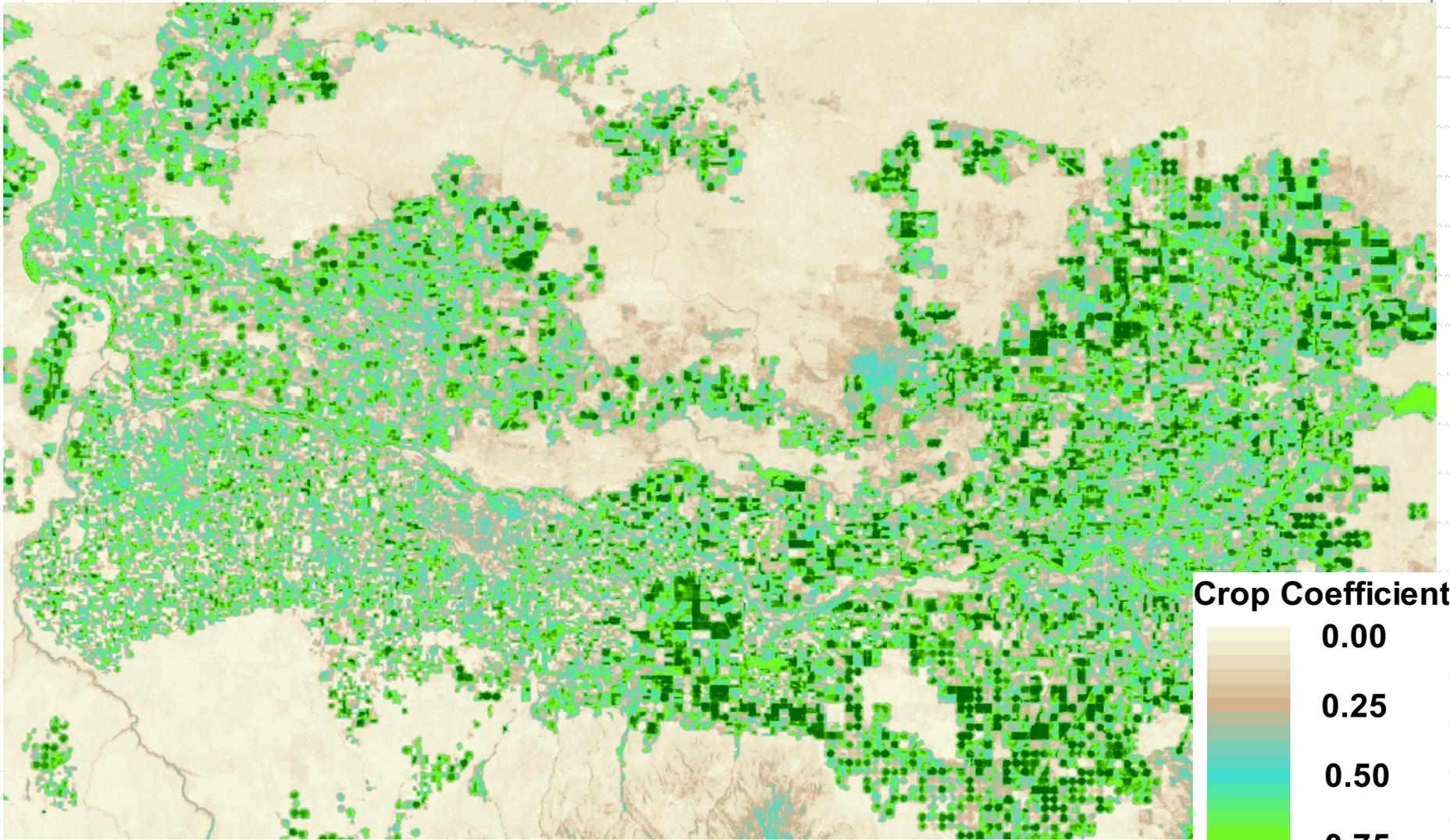
Crop Coefficient



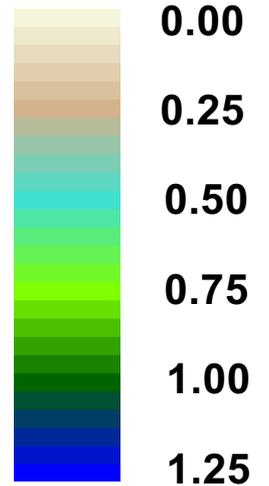
5/2/2000

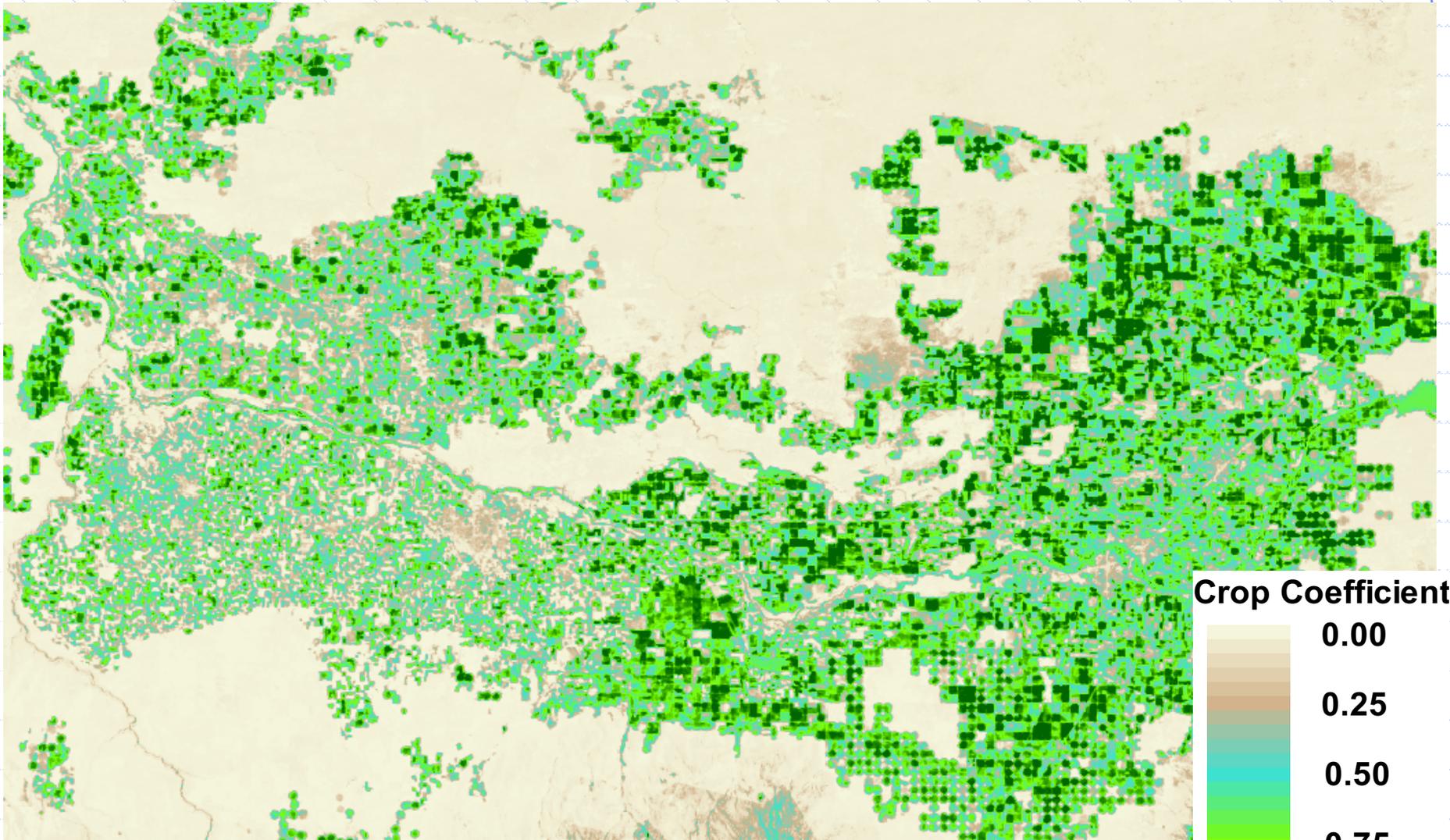
9/22/16

ASAB

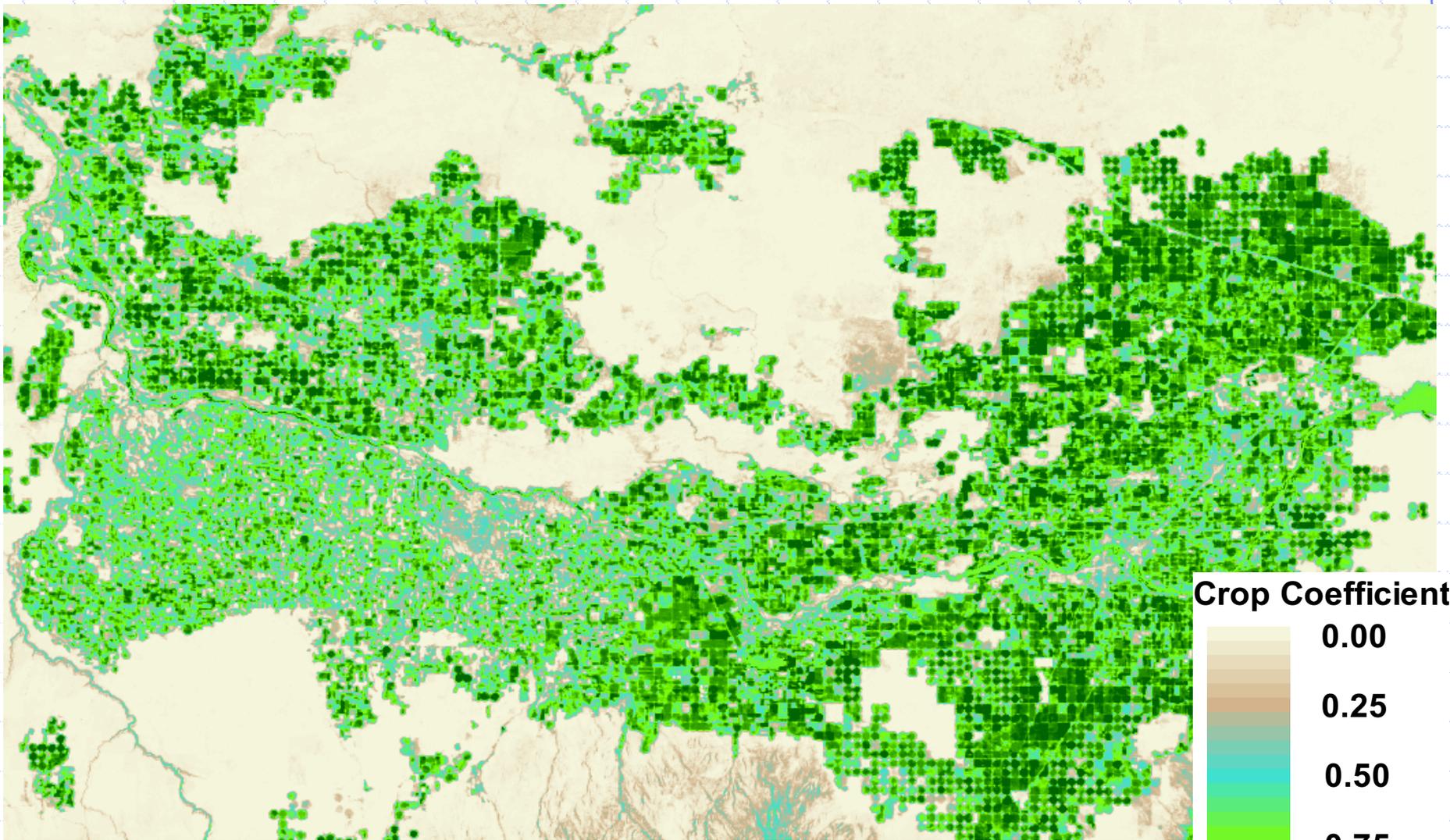


Crop Coefficient





6/19/2000



Crop Coefficient



0.00
0.25
0.50
0.75
1.00
1.25

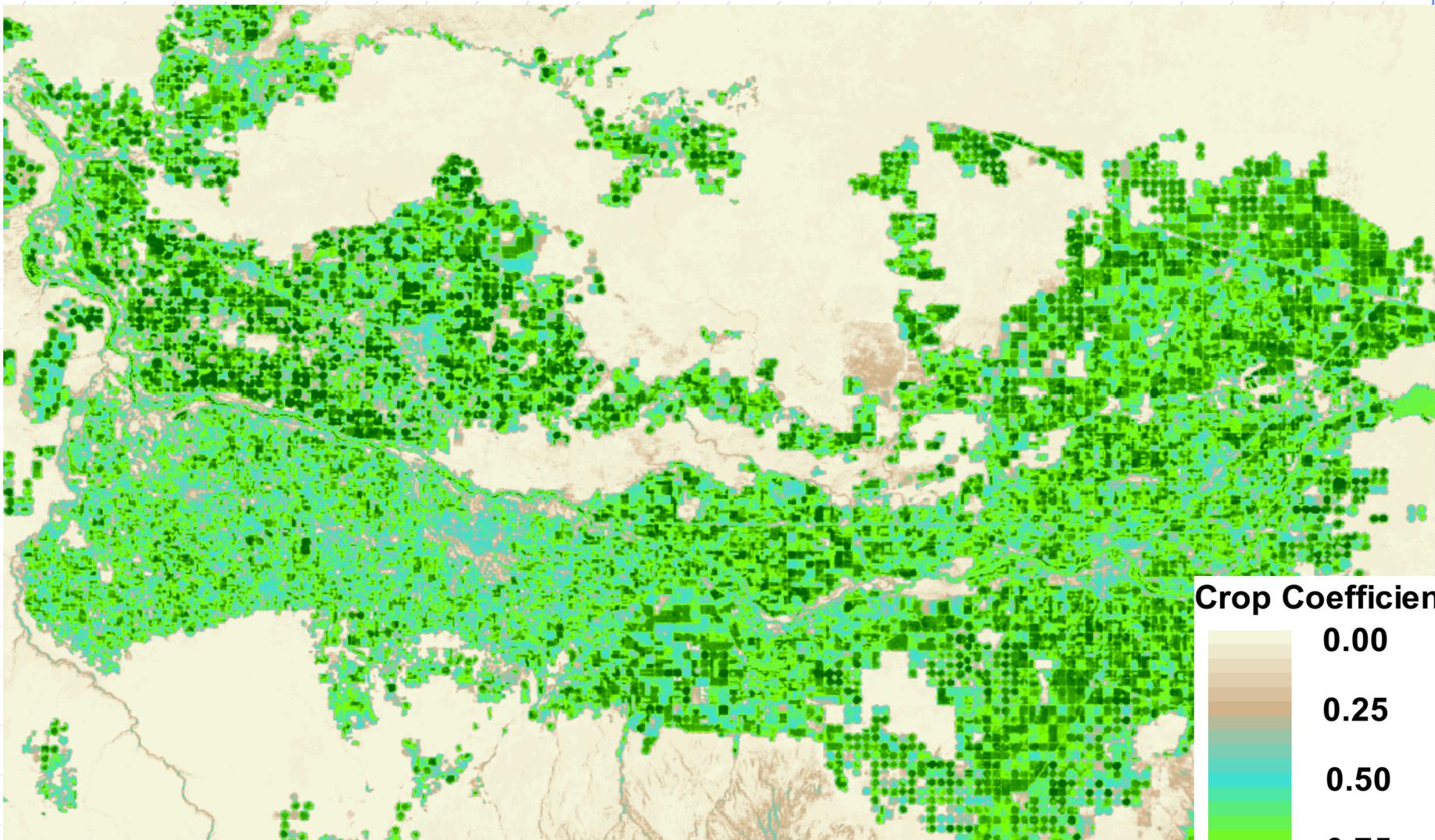
7/5/2000

UNIVERSITY OF
Nebraska
Lincoln

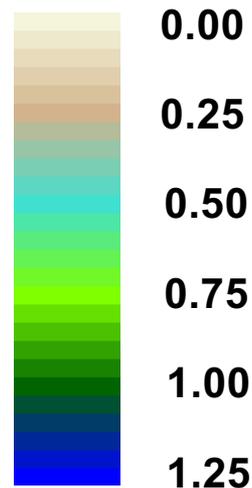
9/22/16

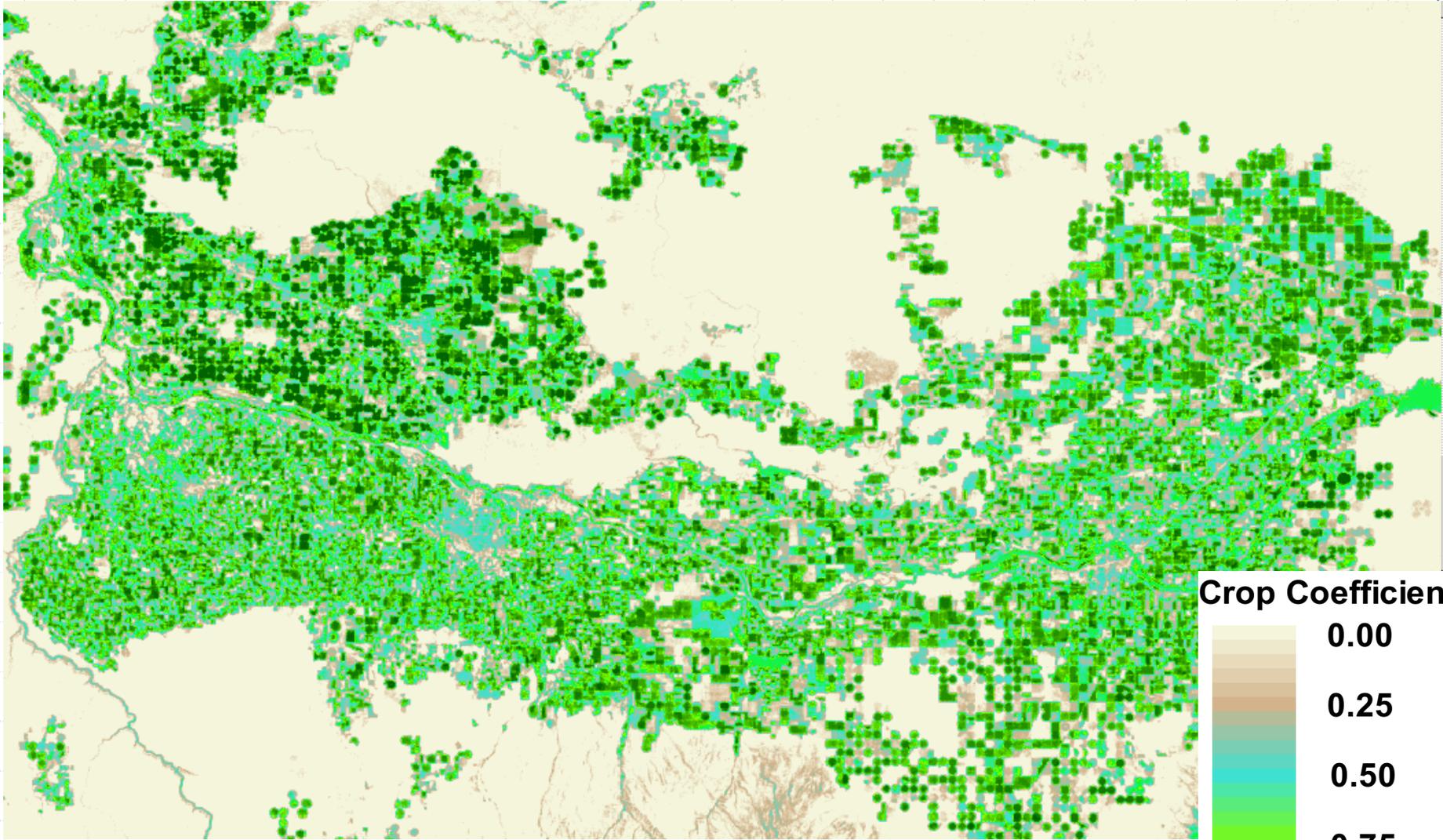
ASAB

 University of Idaho



Crop Coefficient





Crop Coefficient



0.00

0.25

0.50

0.75

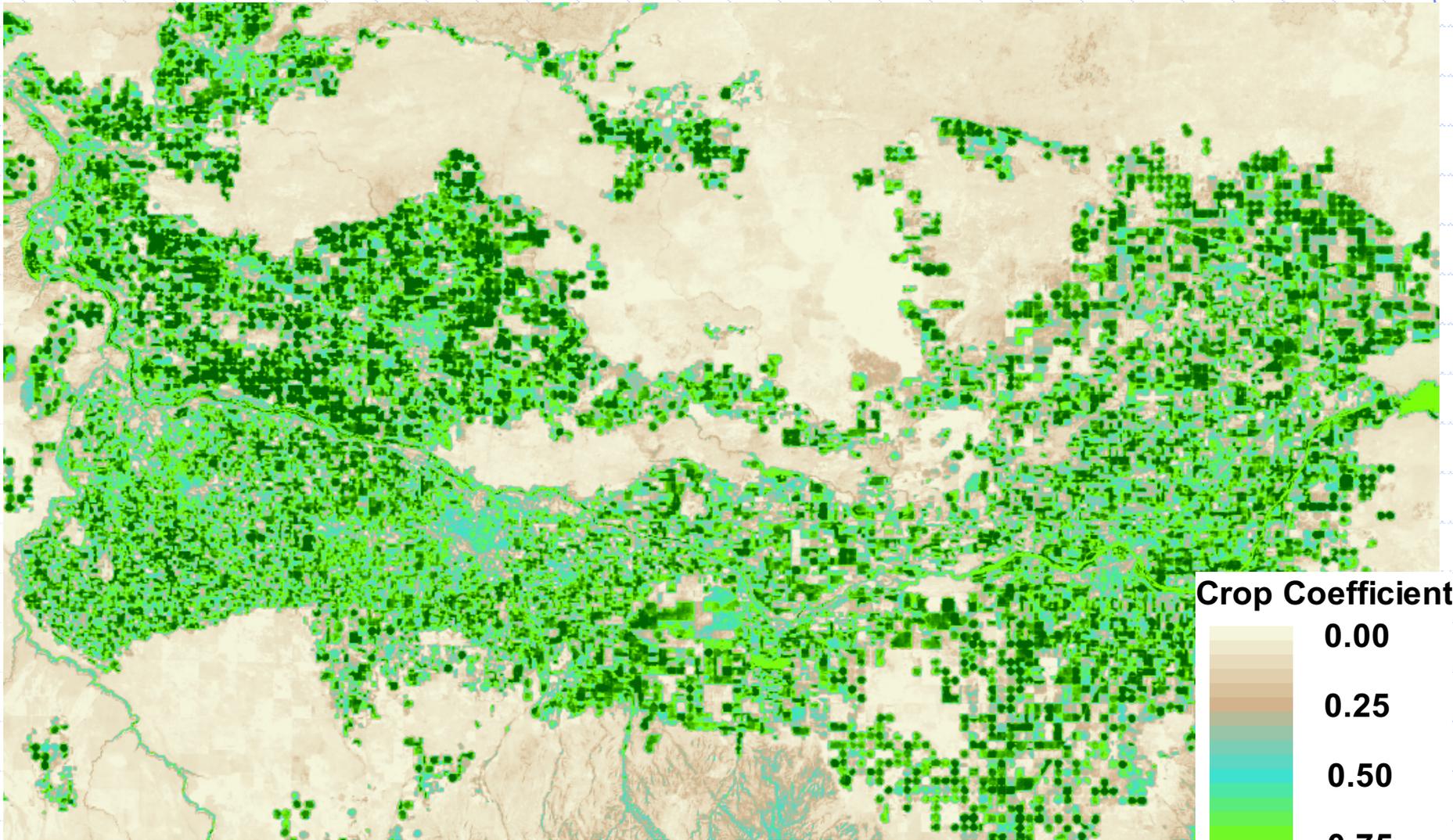
1.00

1.25

8/14/2000

ASAB

9/22/16



Crop Coefficient



0.00

0.25

0.50

0.75

1.00

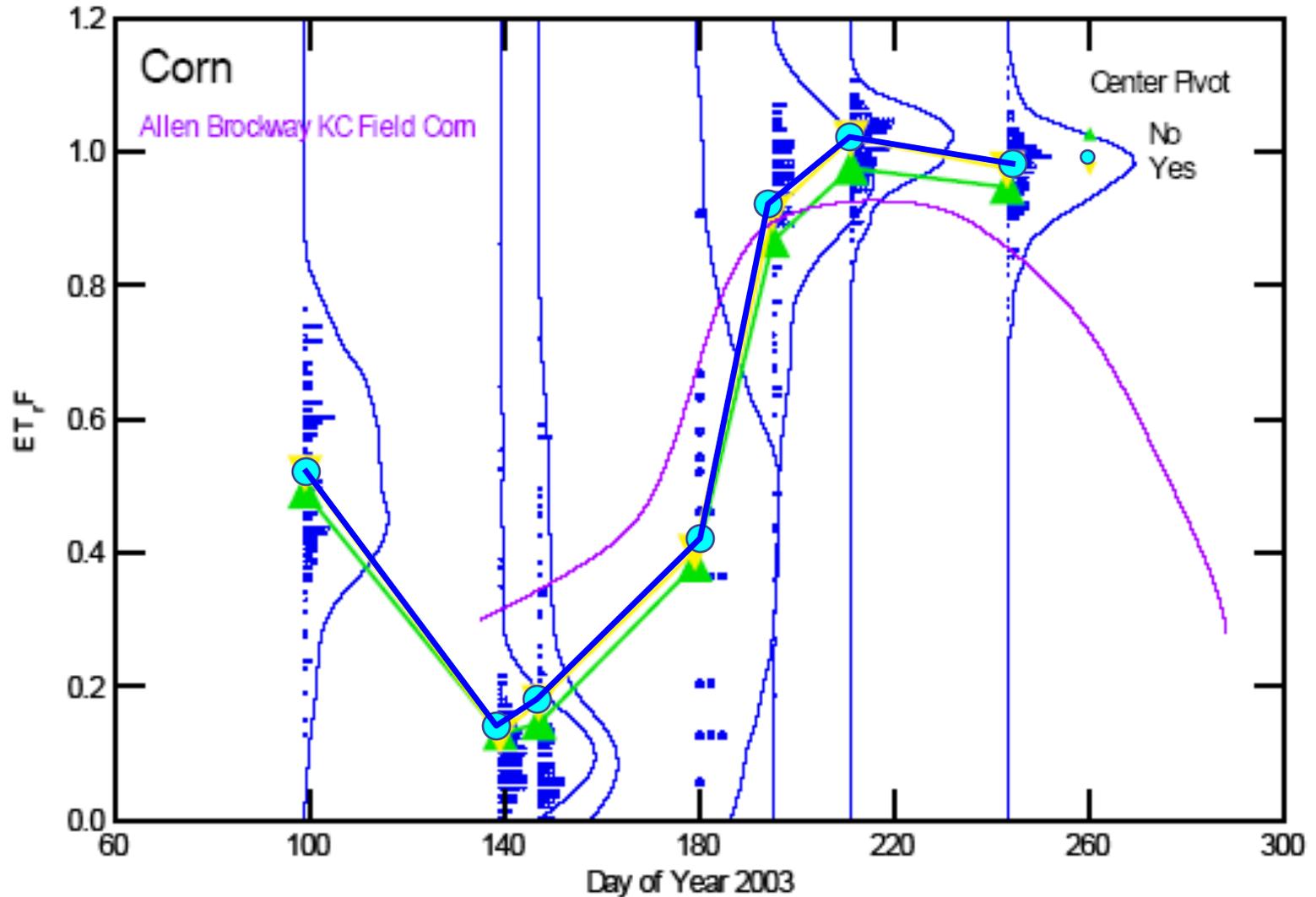
1.25

8/22/2000

9/22/16

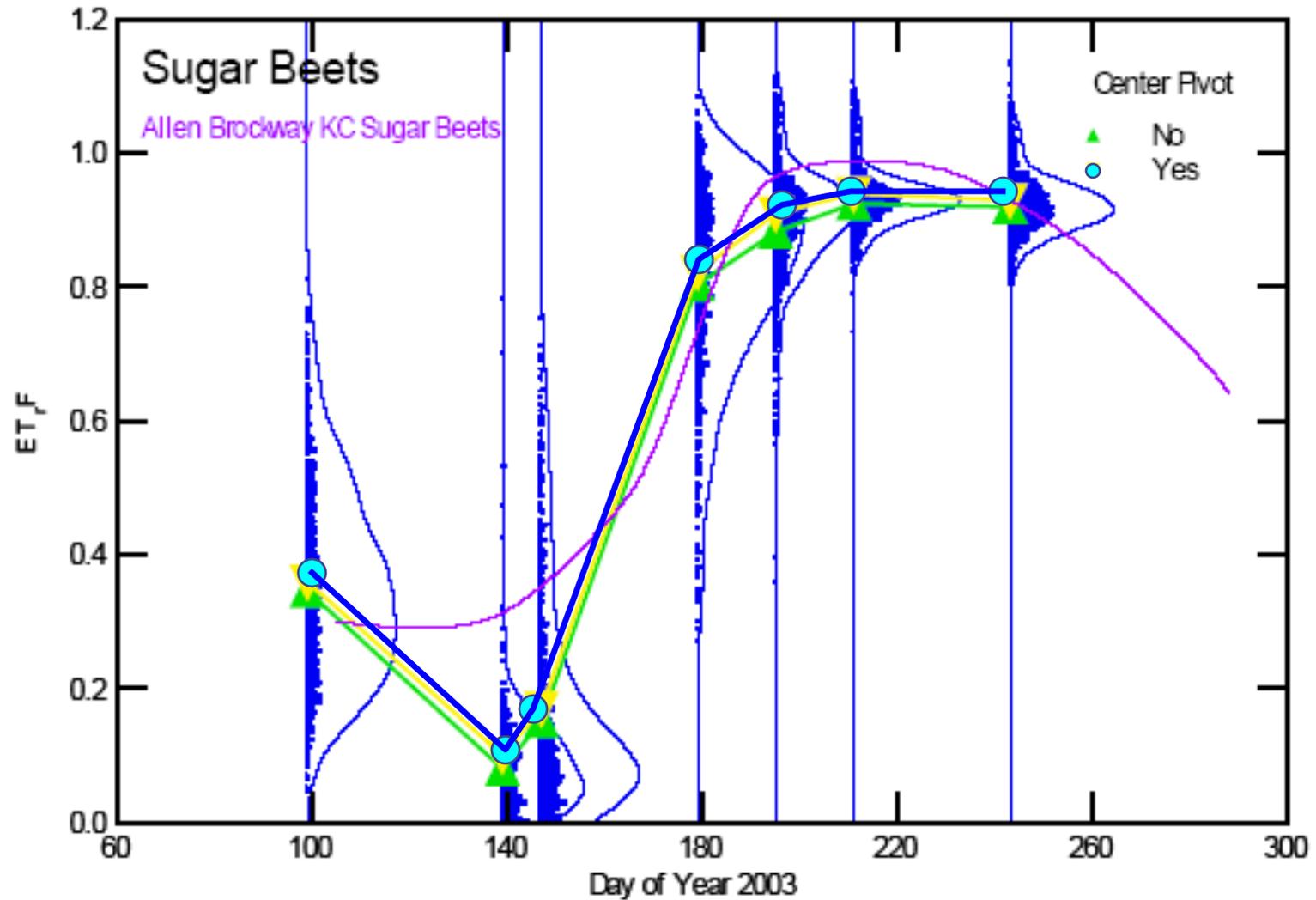
ASAB

Impact of Irrigation System Type



EACH BLUE DOT IS ONE FIELD.

Impact of Irrigation System Type



Impact of Irrigation System Type

