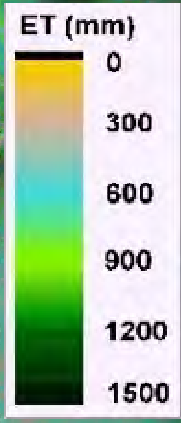
Mapping Evapotranspiration in Idaho with Landsat

Richard G. Allen, University of Idaho
William J. Kramber, Idaho Dept. of Water Resources
Anthony Morse, Spatial Analysis Group



Partners and Collaborators: Dr. Ricardo Trezza, Univ. Idaho; Dr. M. Tasumi, Univ. Miyazaki, Japan; Dr. Justin Huntington, Desert Research Institute; Dr. Jan Hendrickx, NMT; Dr. Ayse Kilic, Univ. Nebraska; Dr. Jeppe Kjaersgaard, South Dakota State Univ.; Clarence Robison, Univ. Idaho; Carlos Kelly, Univ. Idaho; Dr. Magali Garcia, Univ. LaPaz, Bolivia; Dr. Wim Bastiaanssen, WaterWatch, Netherlands; Dr. J. Wright, USDA-ARS; Dr. Allan Wylie, IDWR.

EDF / NASA / CWF / WEF Remote Sensing Workshop, San Diego, CA, Sept. 27-28, 2012

University of Idaho

INNOVATIONS IN AMERICAN GOVERNMENT AWARD WINNER

Idaho Department of Water Resources

Why is mapping Evapotranspiration (ET) important?

- ET is the water **consumed** by irrigated agriculture
- Essential to administration, management, and planning of **water resources**
- In Idaho -- Irrigated Agriculture:
  - covers 3.4 million acres
  - Accounts for over 90% of the water consumed
- In the US – Irrigated Agriculture:
  - covers 50 million acres
  - Accounts for over 80% of the water consumed
- Idaho needs **Serious** Estimates of Water Consumption

Why Energy Balance and Thermal?

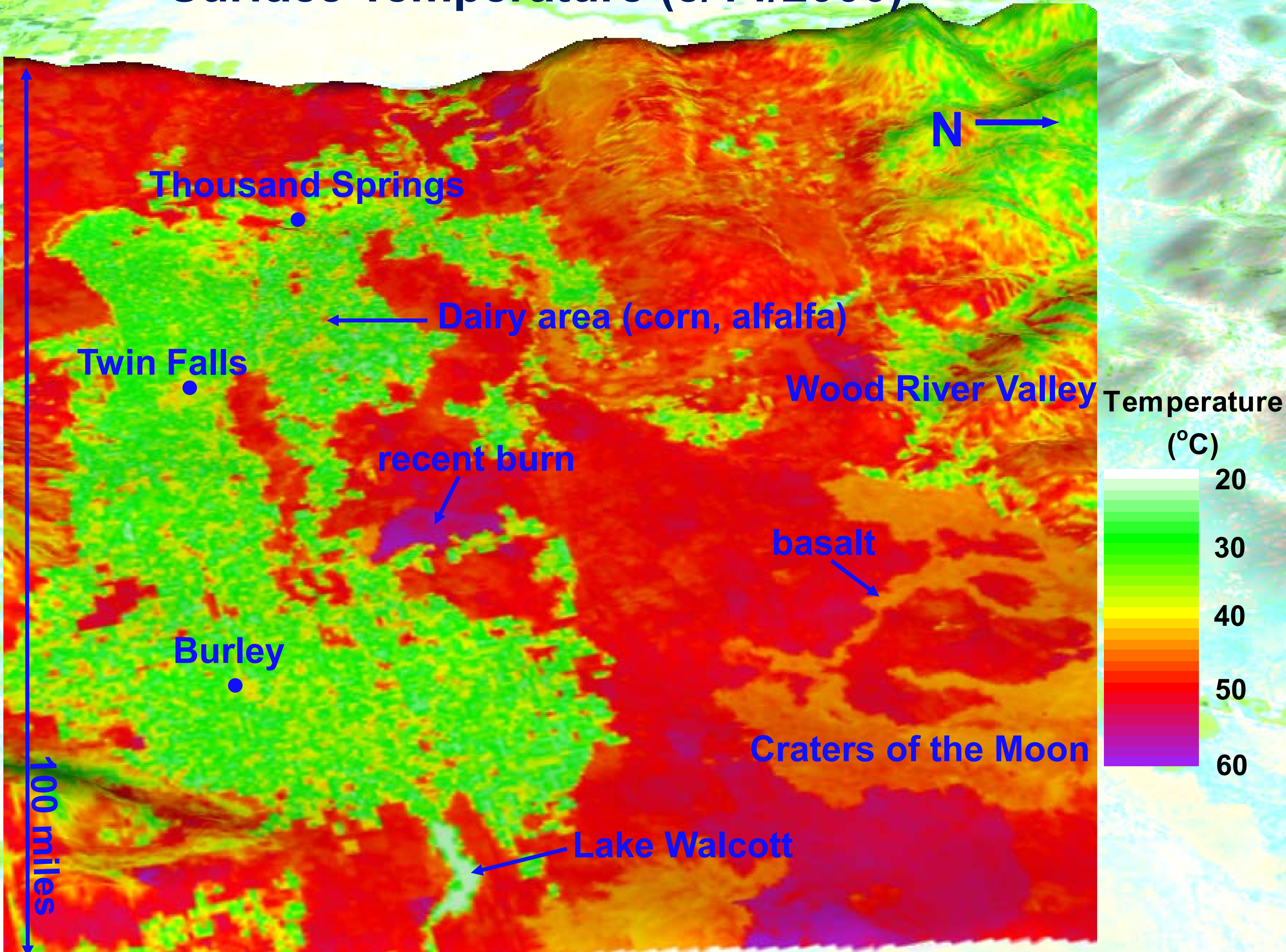
Energy balance computes “actual” ET

We can ‘see’ impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management
- wet soil

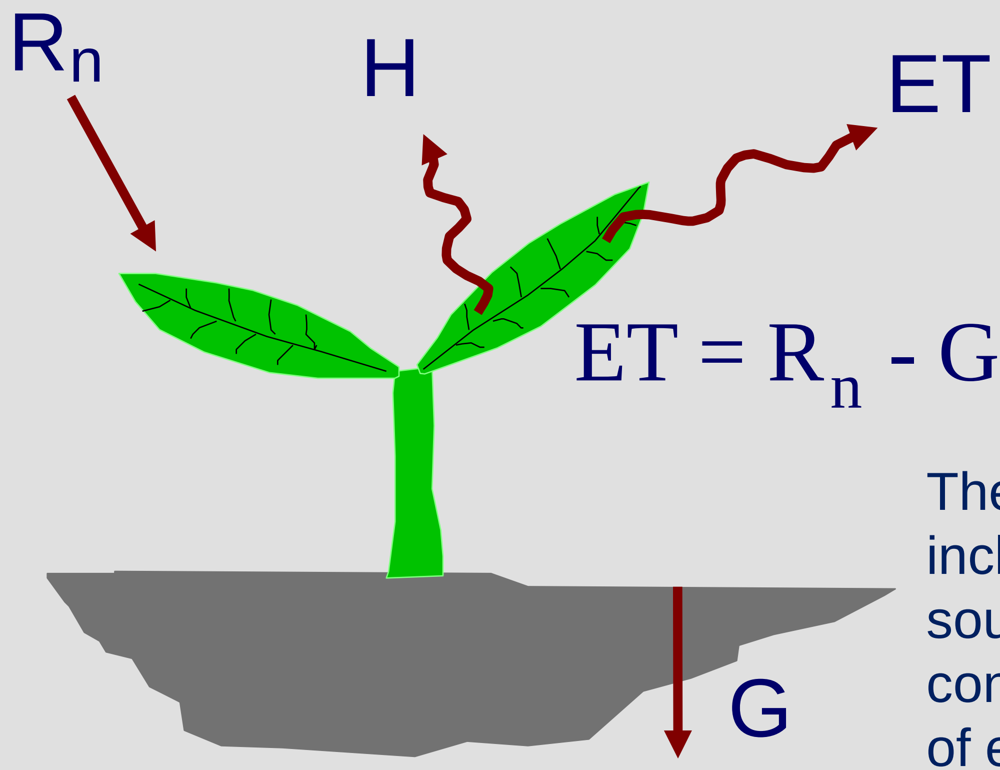
$$ET_{crop\text{-}actual} \leq ET_{crop\text{-}potential}$$

Surface Temperature (8/14/2000)



Energy Balance for ET

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

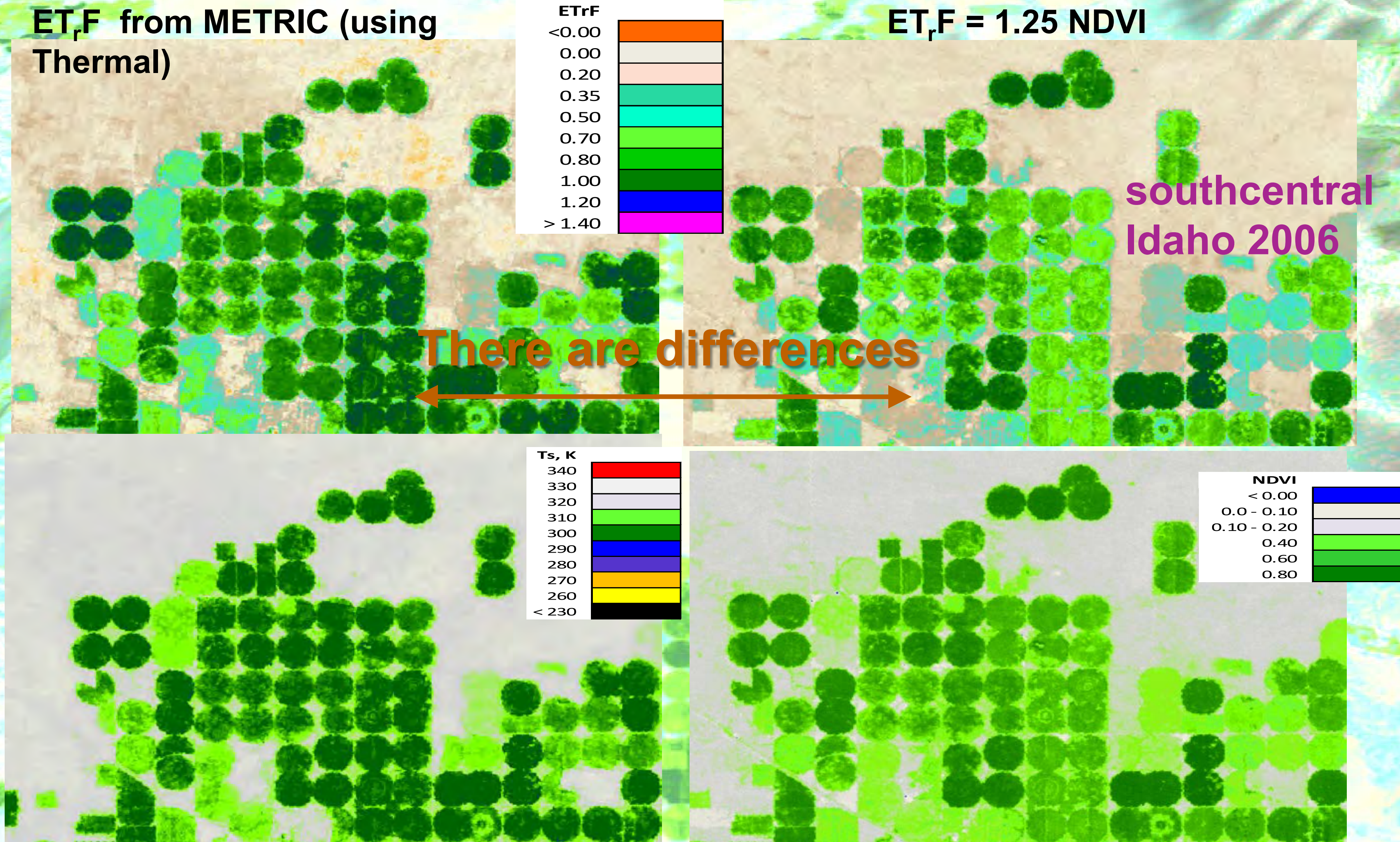


$$ET = R_n - G - H$$

The energy balance includes all major sources (R_n) and consumers (ET, G, H) of energy

Contrast between ET from Energy Balance (left) and ET from NDVI (right)

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

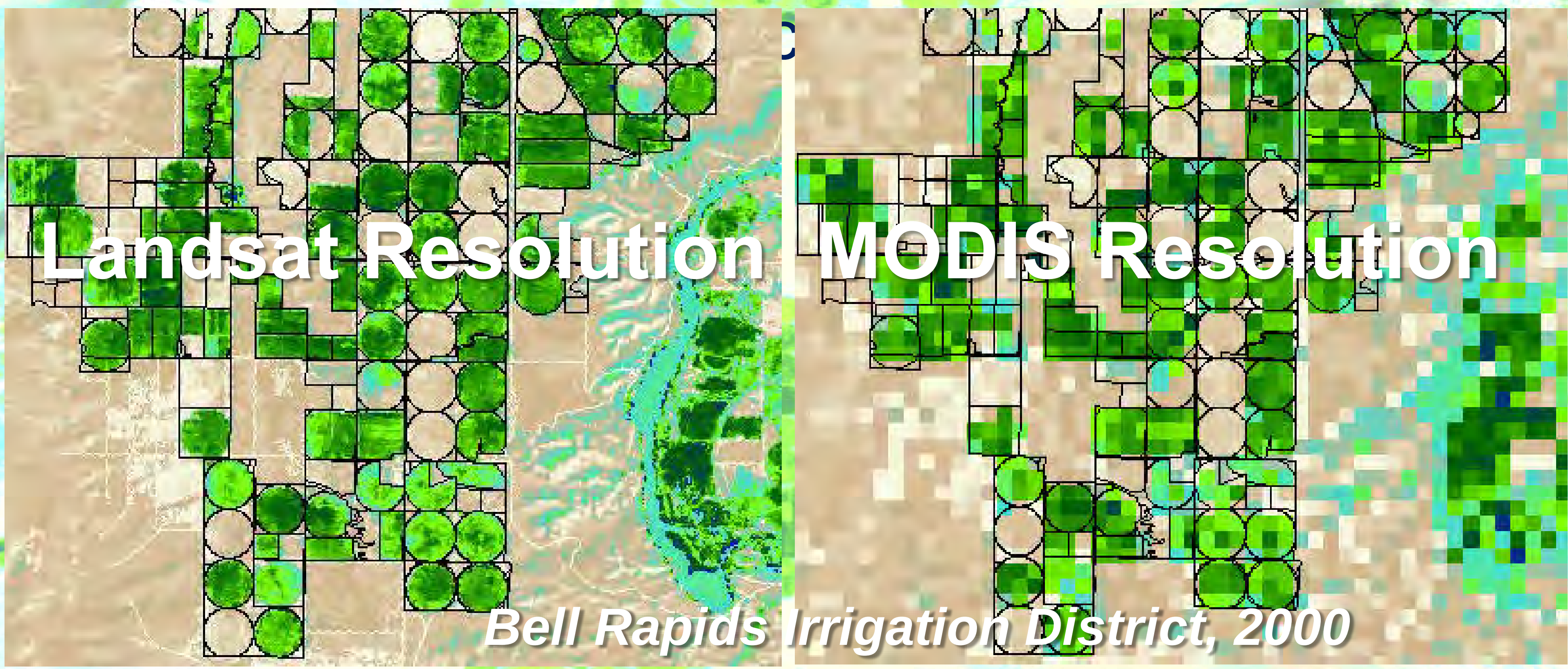


Surface Temperature

NDVI

Why (Moderately) High Resolution?

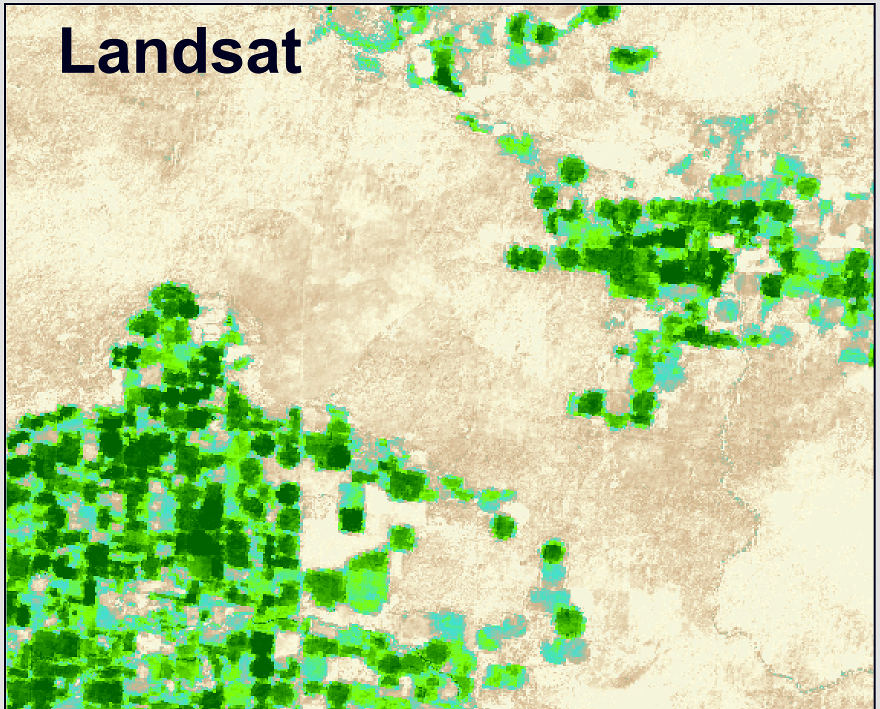
- Water Rights Management
- Field Histories
- Riparian Systems

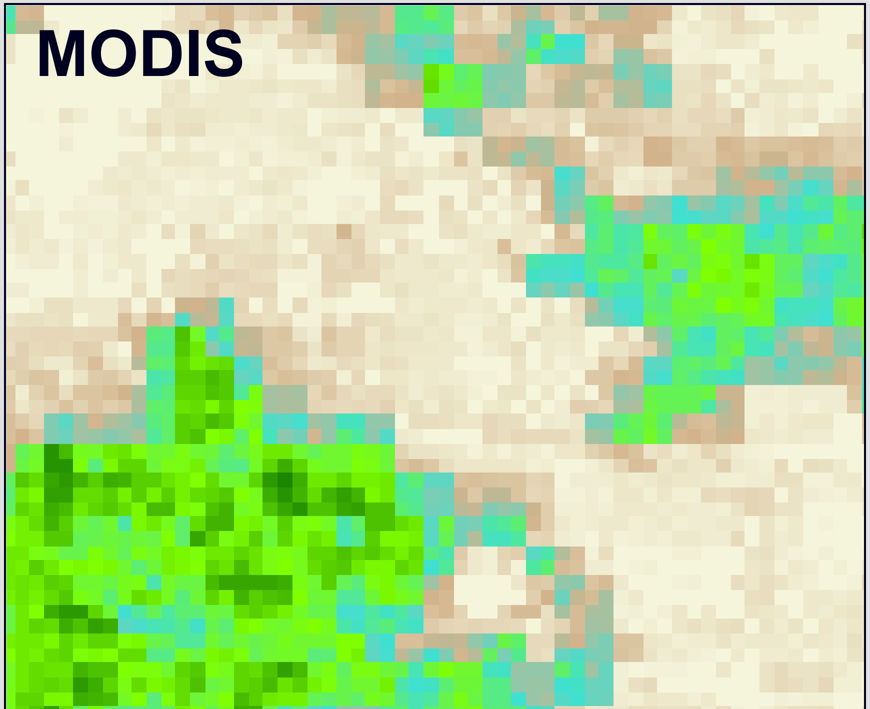


Bell Rapids Irrigation District, 2000

Why not use other satellites

- MODIS: 500 meter pixels
- AVHRR: 1000 meter pixels
- SPOT: no thermal band
- IRS AWiFS: no thermal band
- Aster: too infrequent





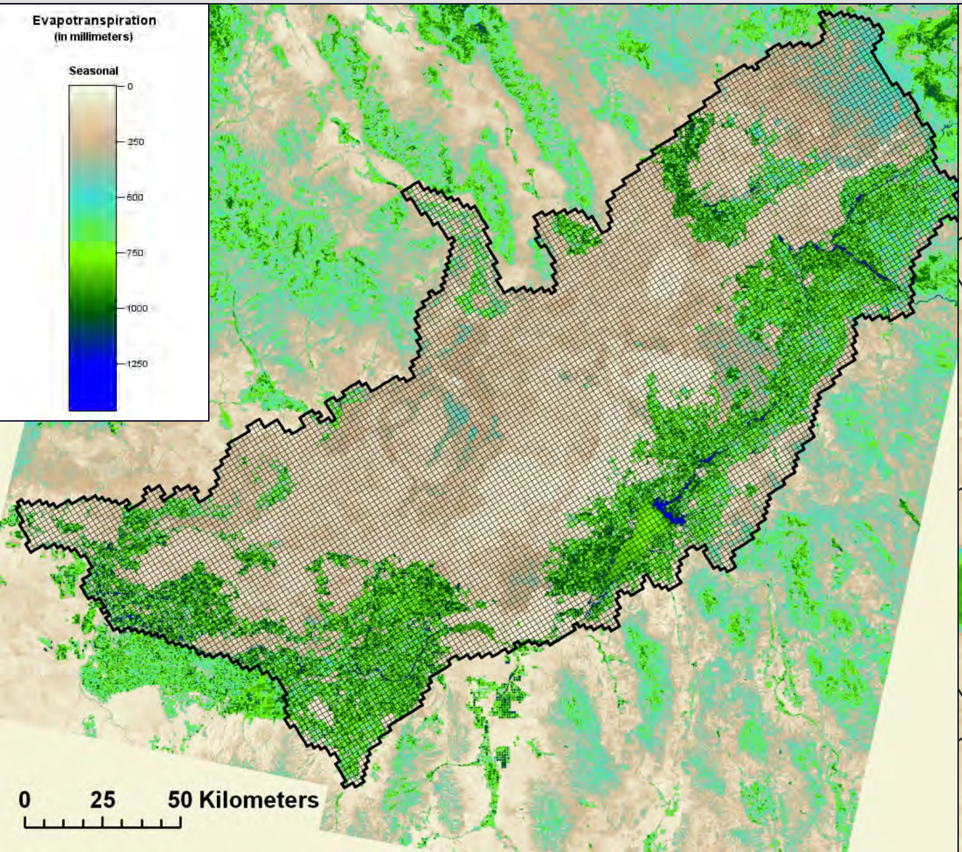
Applications in Idaho

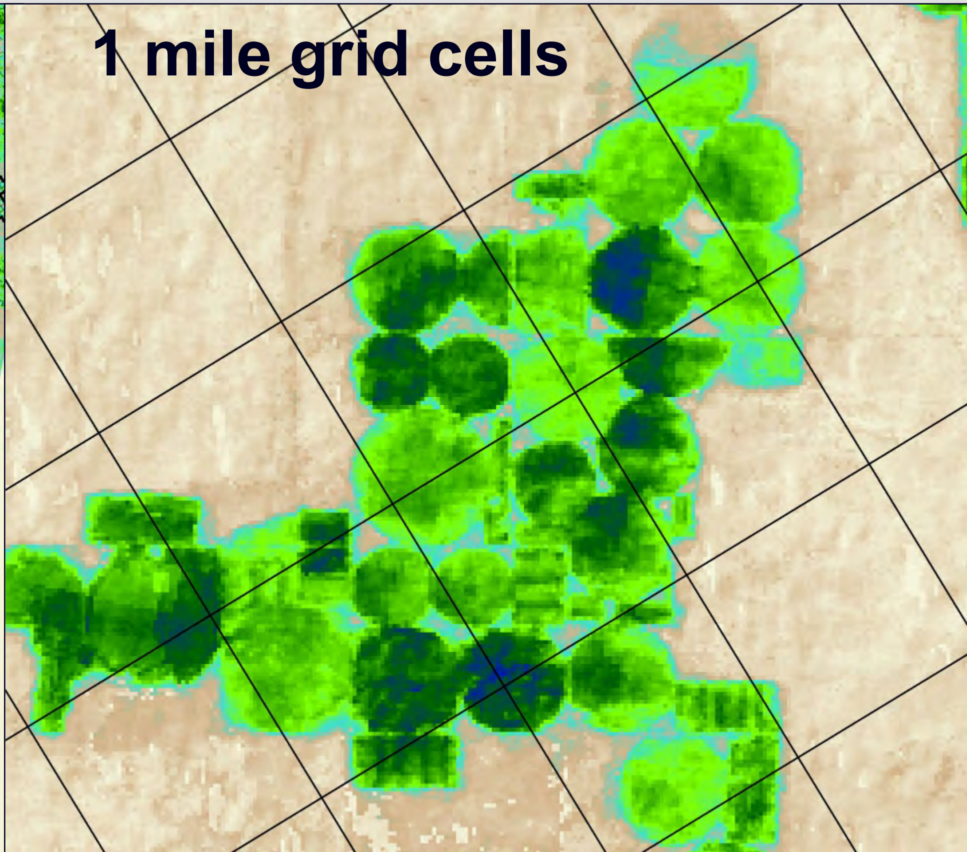
- Hydrologic modeling
- Water planning
- Water administration

Hydrologic Modeling

Eastern Snake Plain Aquifer Model

ET data founded on METRIC-Landsat from 1986 to present



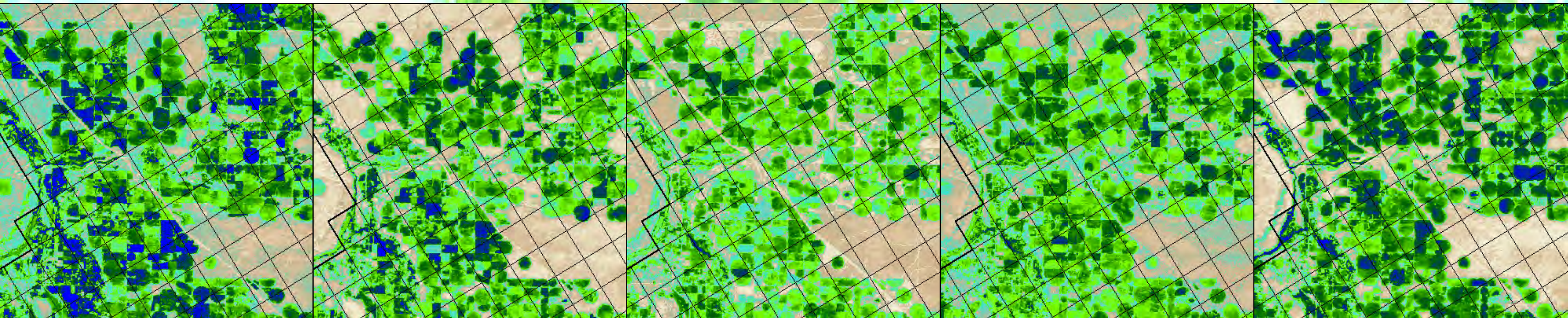


Eastern Snake Plain Aquifer Model

METRIC ET data

- More accurately calibrates the groundwater model
- Improved accuracy of depletions and recharge estimates
- Shows long term trends in ET

1996 2000 2002 2006 2008

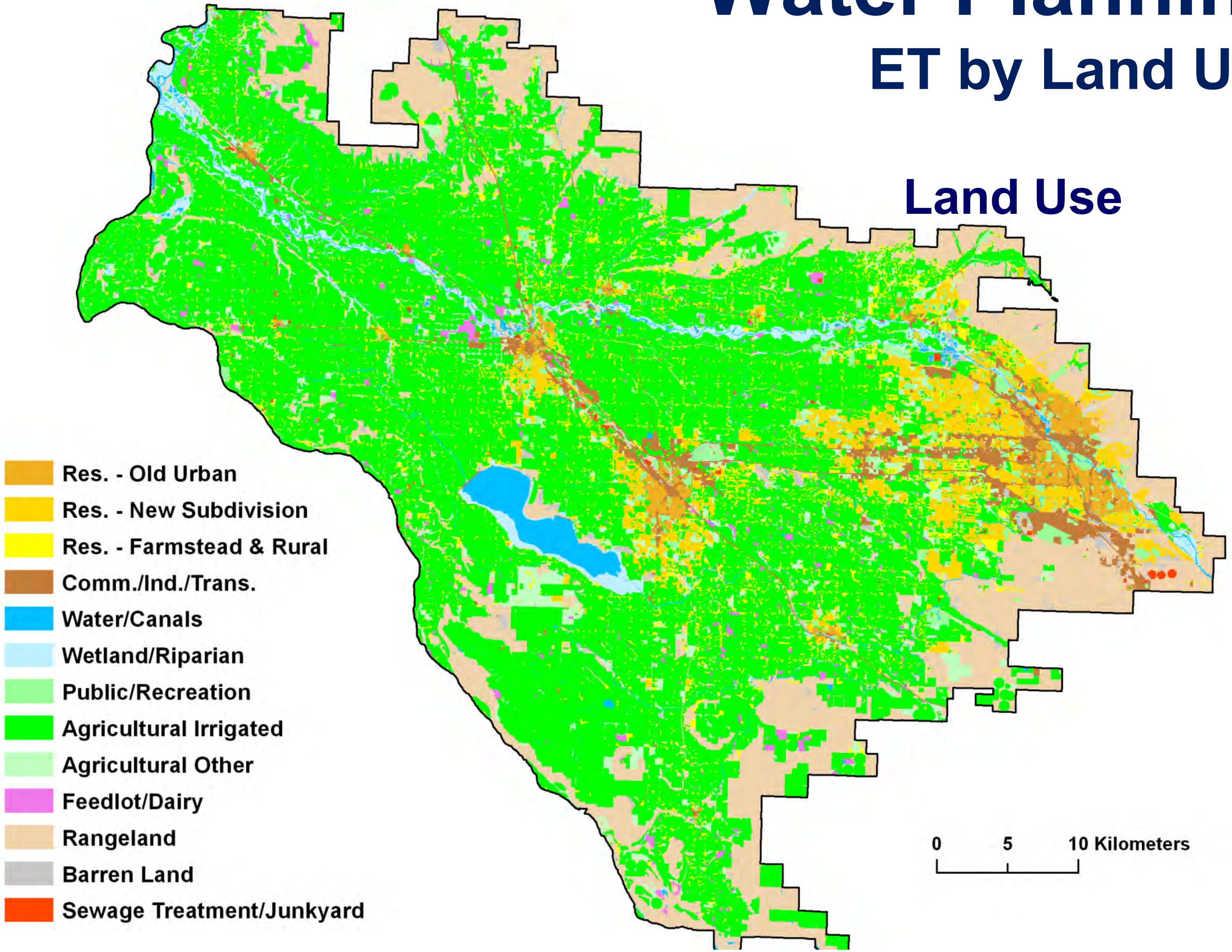


Potential METRIC Processing for the Eastern Snake Plain Aquifer

1984 - too sparse
1985 - too sparse
1986 - yes (METRIC **in Progress**)
1987 – cloudy, not as populated as 1986, but possible for METRIC
1988 - clouded April-May for METRIC on path 40
1989 - clouded Sept-Oct for METRIC on path 40, poor on path 39
1990 - possible METRIC on 40, clouded on 39
1991 – no – too clouded
1992 - possible METRIC for 40 and 39
1993 - possible for METRIC, clouded April-May on 39
1994 - clouded May-June for METRIC path 40
1995 - no - too clouded
1996 - yes (METRIC **DONE**)
1997 - yes, iffy METRIC for June-July on 39
1998 - clouded May for METRIC on 40 and 39
1999 - clouded for METRIC in spring
2000 - yes (METRIC **DONE**)
2001 - yes for METRIC on both paths
2002 - yes (METRIC **DONE**)
2003 - iffy for METRIC for both paths (path 40 **DONE** through August (cloudy after that))
2004 - yes for METRIC on both paths
2005 - iffy for METRIC
2006 - yes (METRIC **DONE**)
2007 - possible, but challenging for METRIC on path 40
2008 - yes (METRIC **DONE**)
2009 - yes (METRIC **in Progress**)
2010 - yes (METRIC **in Progress**)
2011 - yes for METRIC on both paths (**in Progress**)

Water Planning

ET by Land Use

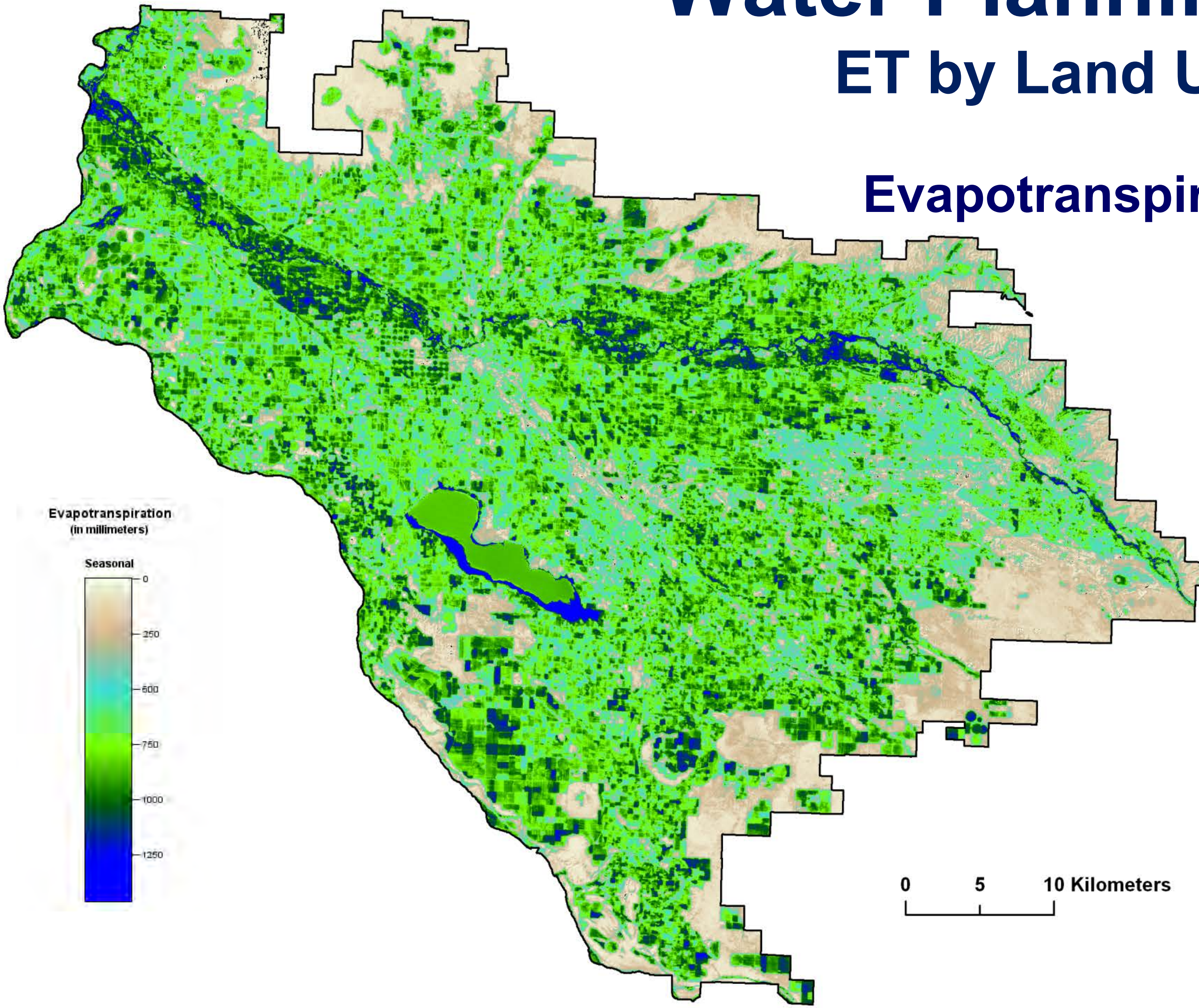


Boise Valley 2000

Water Planning

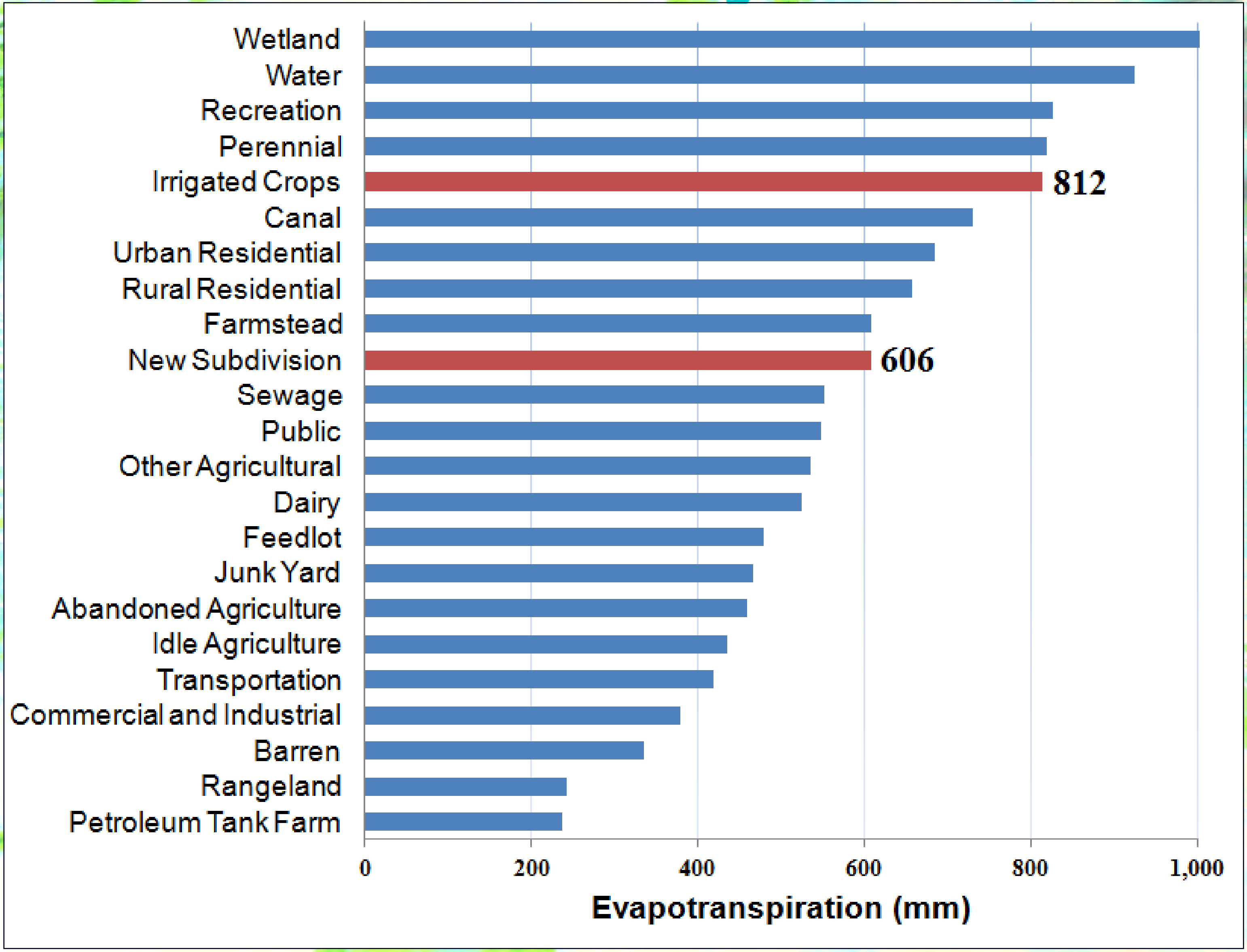
ET by Land Use

Evapotranspiration



Boise Valley 2000

Seasonal ET by land use



Water Administration in Idaho

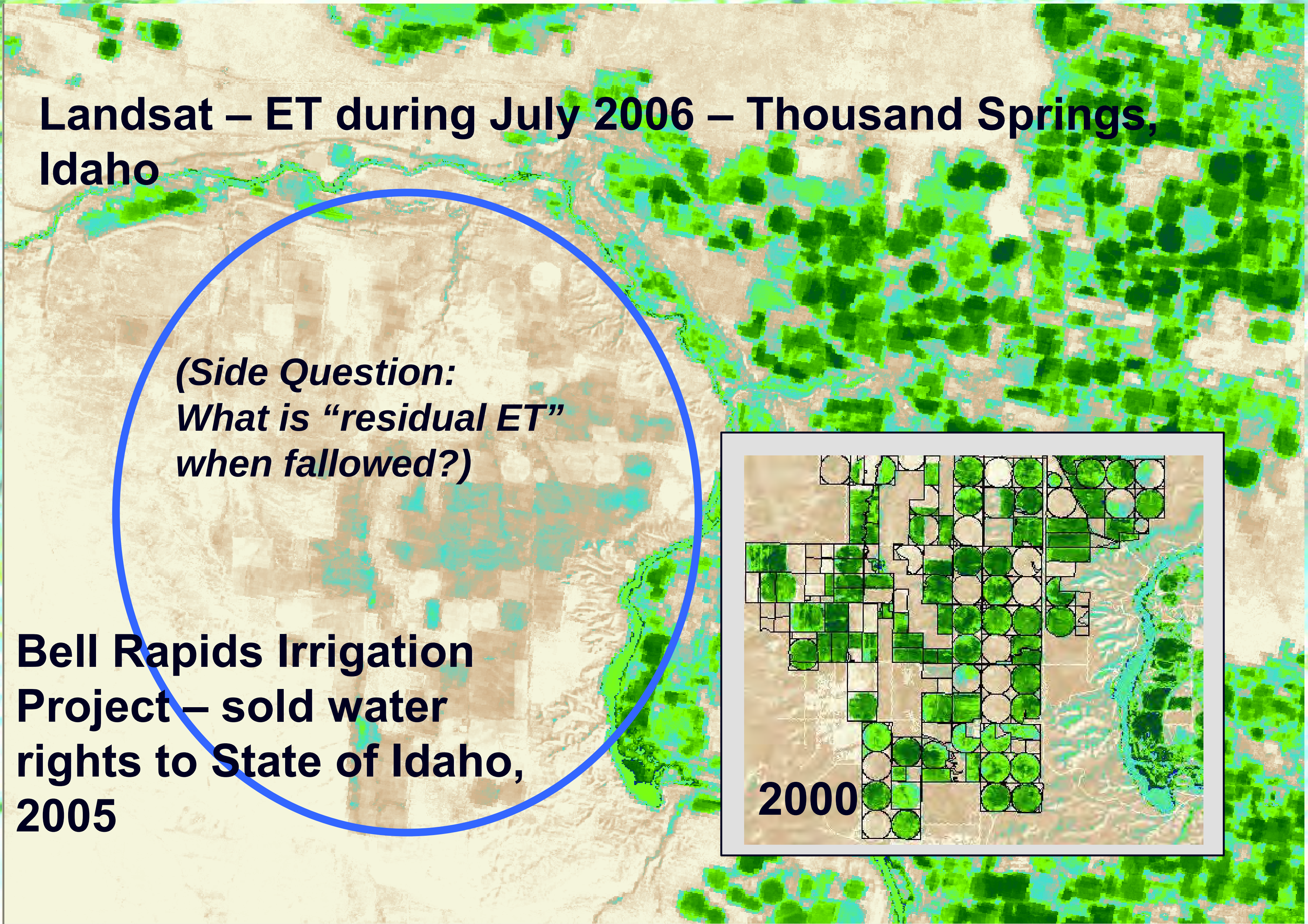
Mitigation

- Bell Rapids Irrigation Company
  - Water Rights "Buy Back"

Litigation

- A&B Irrigation District water call
- Clear Springs Foods water call

Water Rights "Buy Back"

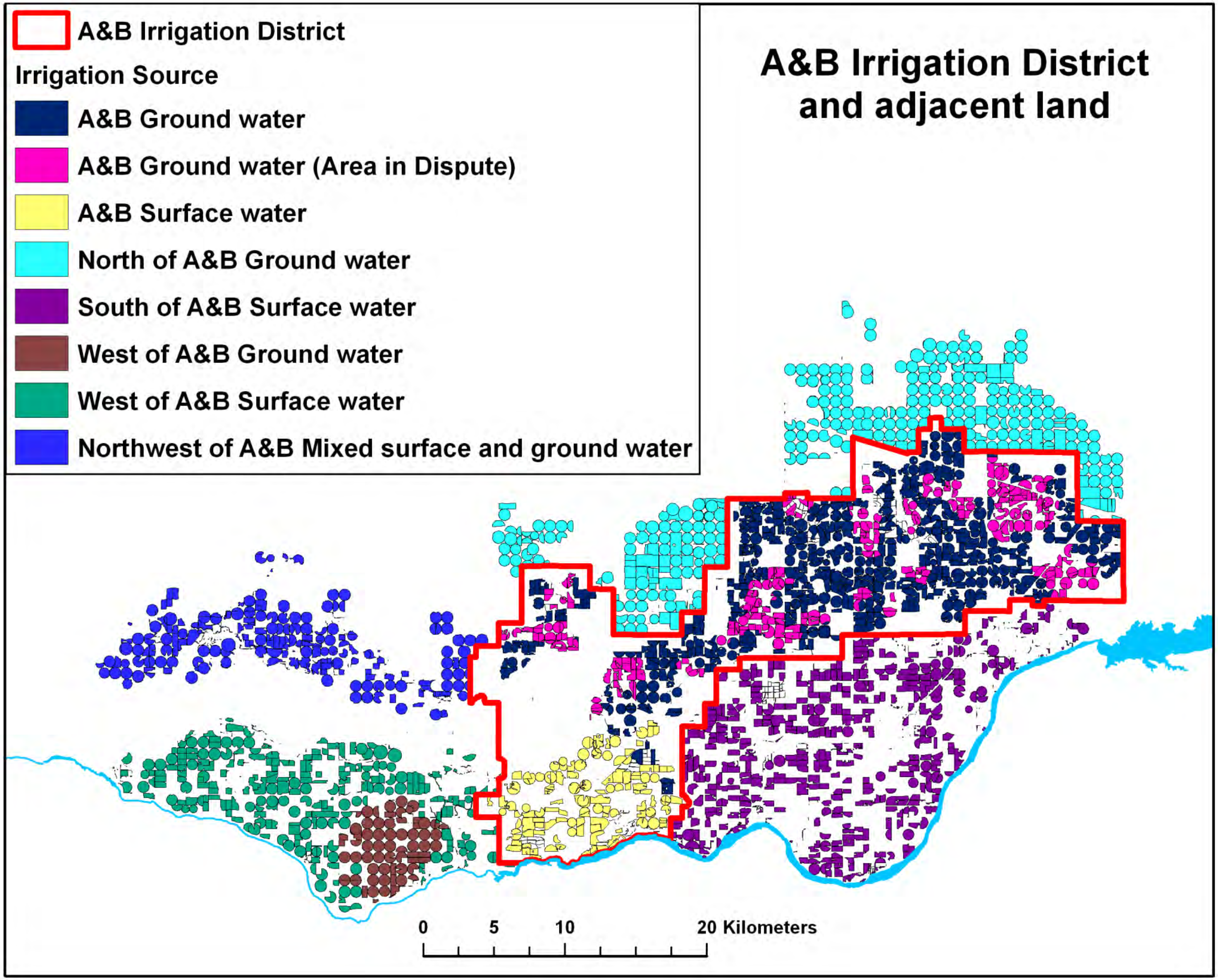


Water Law Terms

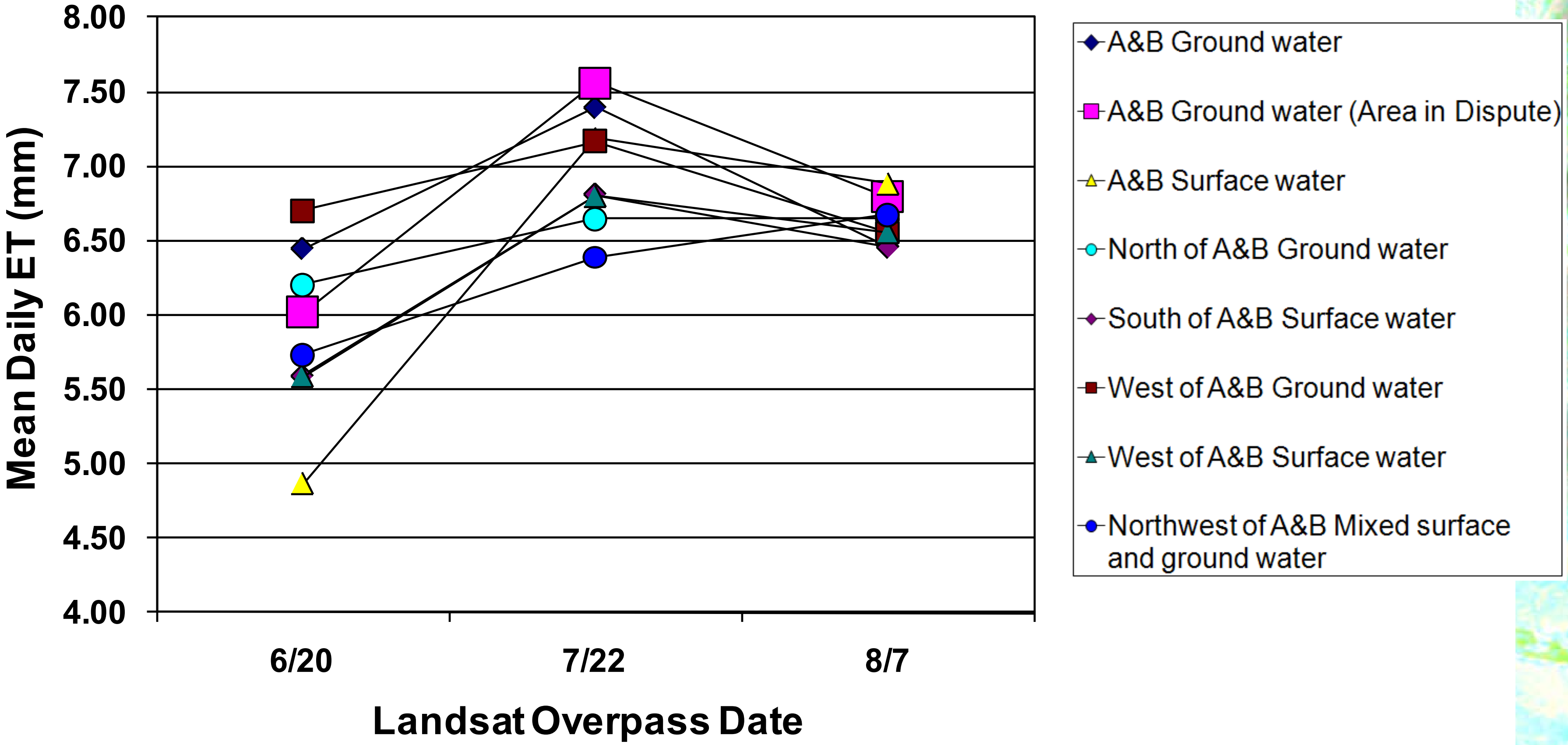
- Water Right
  - Authorization to use water
  - Includes priority date and rate of flow/volume
- Call
  - When a senior water right holder experiences a water shortage they may place a call
- Curtailment Order
  - Defines how the state directs junior water right holders to stop diverting water in response to a call
- Mitigation Plan
  - Junior users response to a curtailment order

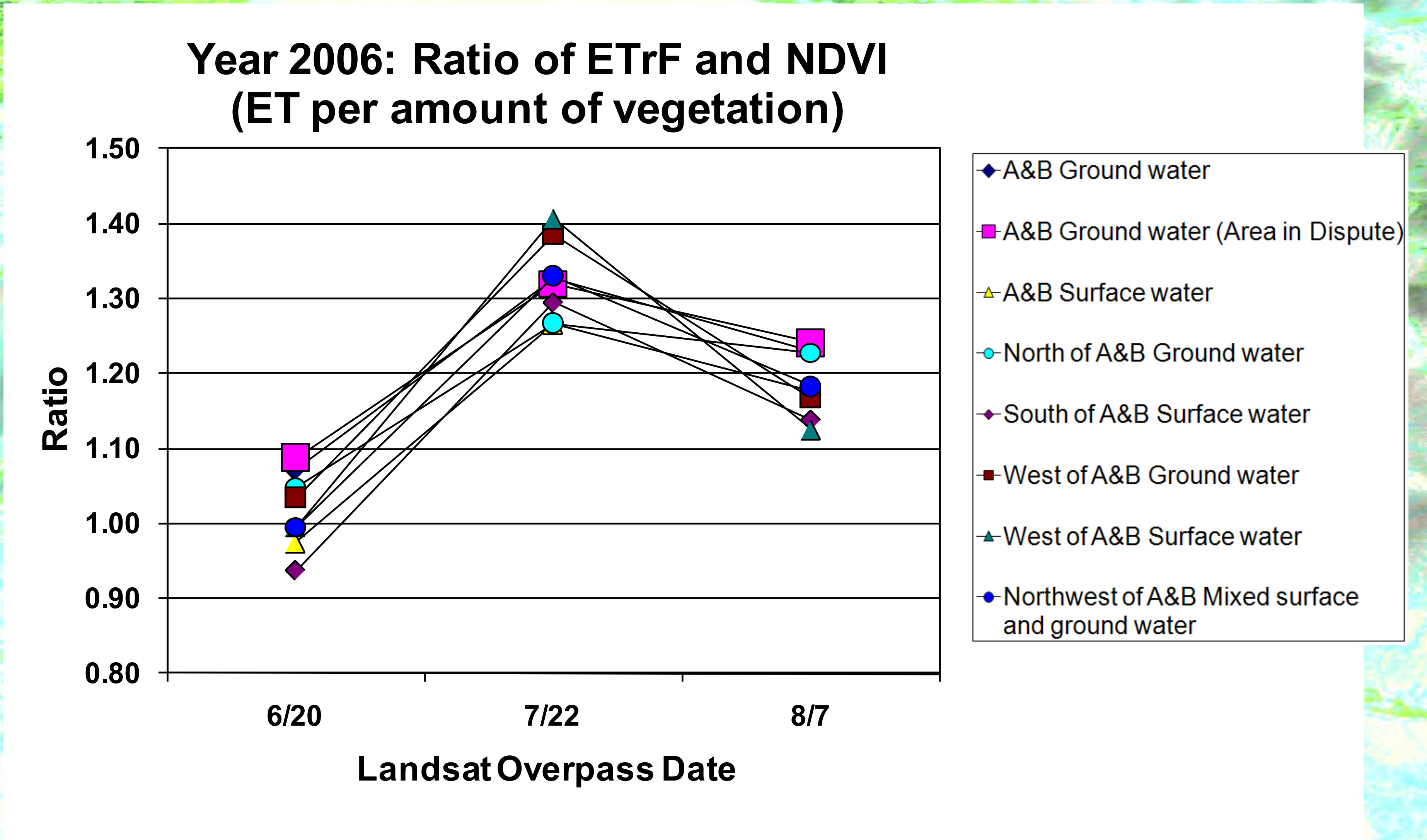
A&B Irrigation District Water Call

- A&B claimed that certain fields were short of water in 2006 due to diversions from junior ground water users
- METRIC ET showed that the fields had ET rates as high as surrounding fields that were not identified as water short


A&B Irrigation District
Irrigation Source
A&B Ground water
A&B Ground water (Area in Dispute)
A&B Surface water
North of A&B Ground water
South of A&B Surface water
West of A&B Ground water
West of A&B Surface water
Northwest of A&B Mixed surface and ground water
A&B Irrigation District and adjacent land
0
5
10
20 Kilometers

Year 2006: Mean Daily Evapotranspiration (ET)




Year 2006: Ratio of ETrF and NDVI
(ET per amount of vegetation)
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
Ratio
6/20
7/22
8/7
Landsat Overpass Date
A&B Ground water
A&B Ground water (Area in Dispute)
A&B Surface water
North of A&B Ground water
South of A&B Surface water
West of A&B Ground water
West of A&B Surface water
Northwest of A&B Mixed surface and ground water

A&B Irrigation District Water Call

Summary

- Director issued order denying the call
- Hearing Officer agreed with the Director's decision
- District Court affirmed the Director's decision
- Idaho Supreme Court
  - Argued on February 28, 2012
  - September, 2012 – remanded back to District Court due to 'timing issues' by IDWR

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.

7/31/2009

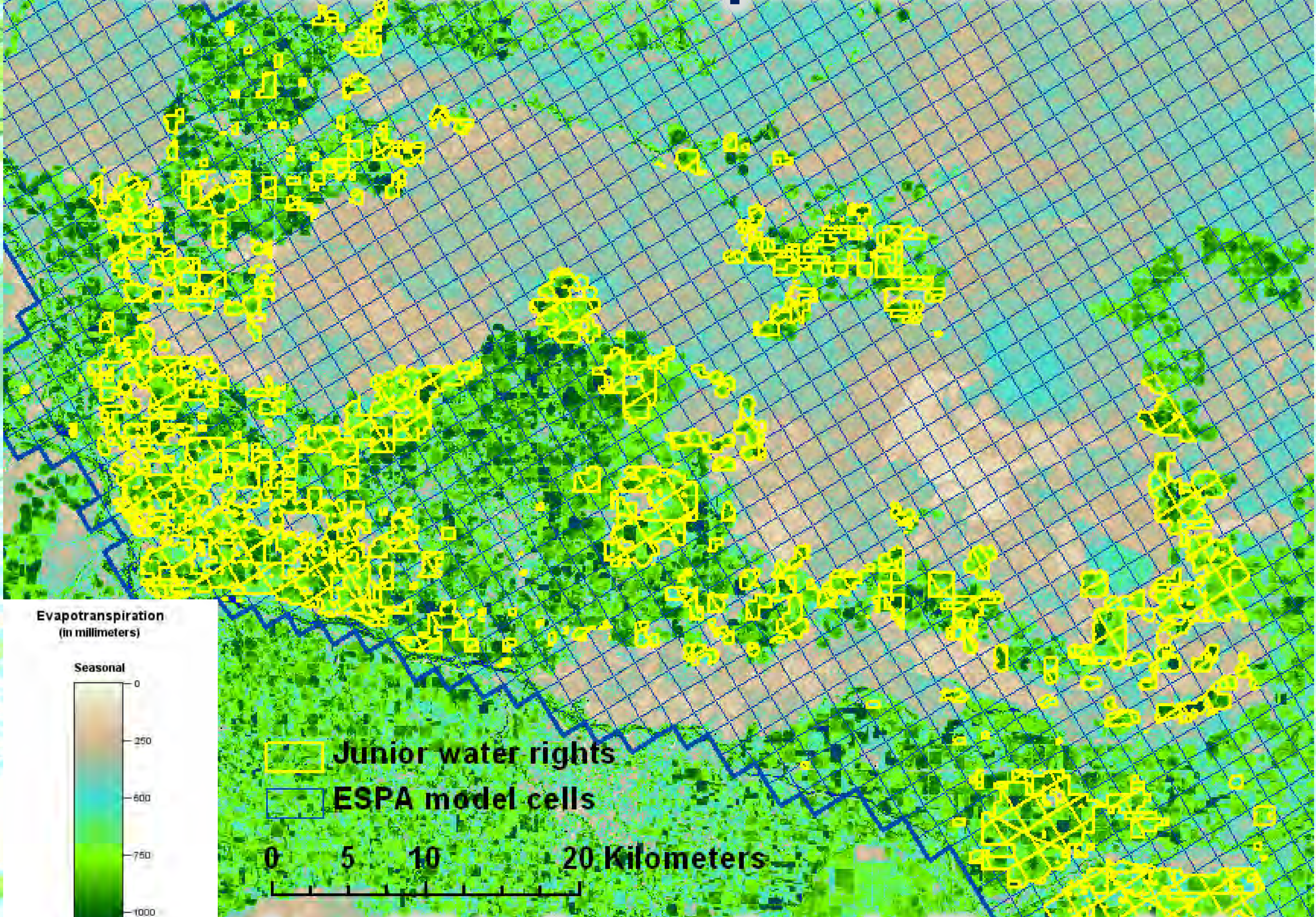
Water districts have limited options, could file a stay

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.

Clear Springs Foods, Inc.

METRIC ET 2006 April to October



Annual Water Consumption = 4 million acre feet/year
(3 Trillion gallons; 5 Trillion liters)

Clear Springs Foods Water Call

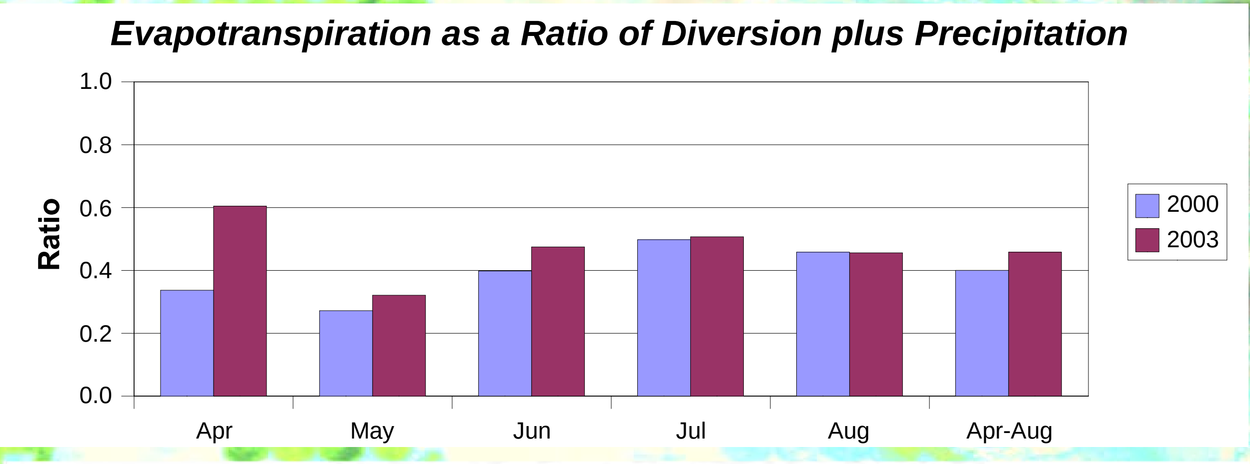
Summary

- ESPA GW model used METRIC ET data
  - For model calibration
  - **To select water rights to curtail**

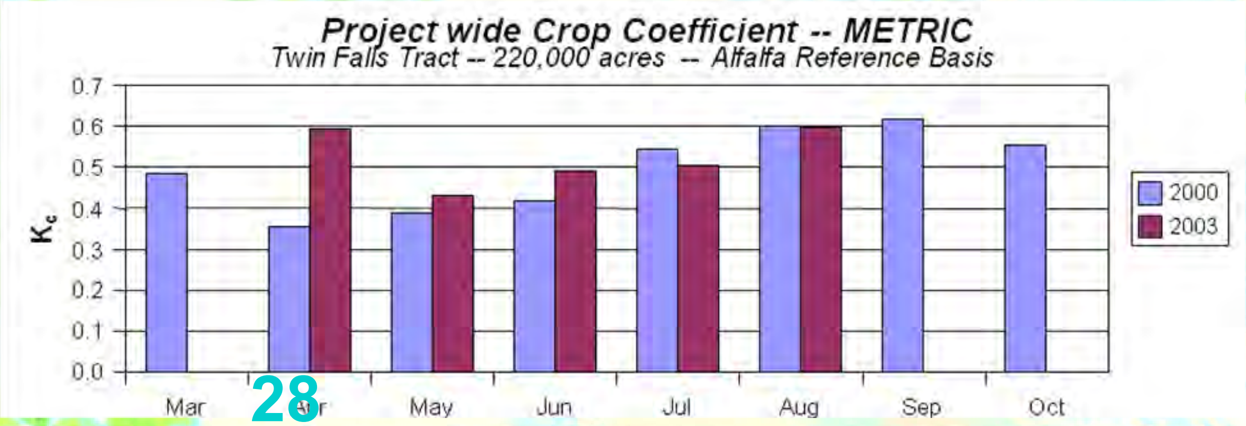
- No complaints from junior users about GW model or METRIC ET data

Performance of Irrigation Entities – Twin Falls Canal Company, Idaho

Right: ET as a fraction of total water supply (Diversions + Rainfall)



Right: The average K_c over the 220,000 acre service area.



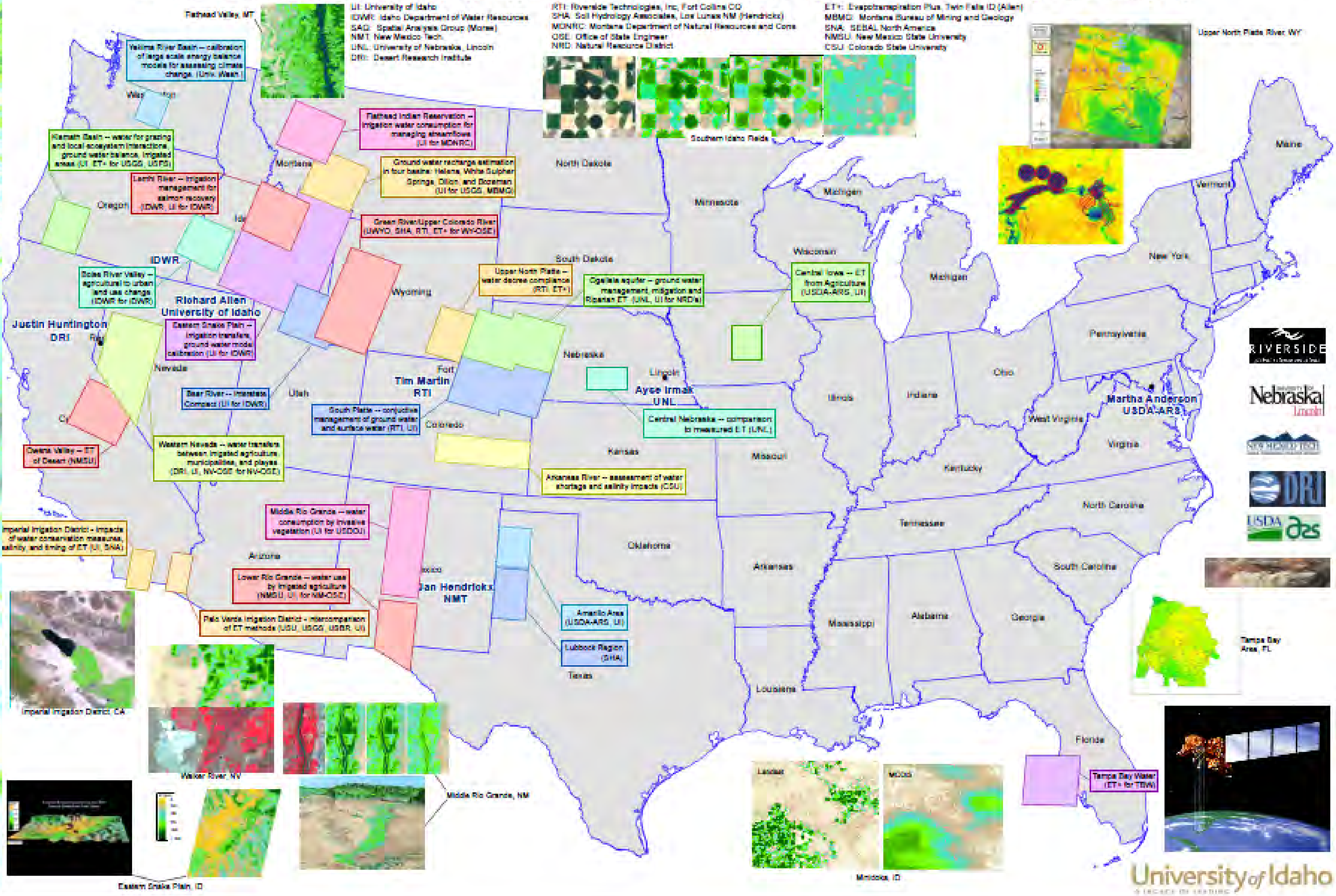
Other states using METRIC

- Nevada
  - Water transfers to Reno and Las Vegas
- Nebraska
  - Over pumping of the Ogallala Aquifer
- Colorado
  - Kansas vs. Colorado over Arkansas River
  - Nebraska vs. Colorado over S. Platte River
- Wyoming
  - Nebraska vs. Wyoming over N. Platte River
  - Depletions along the Upper Colorado Basin (in progress)
- Oregon
  - Klamath Basin water shortages
- California
  - Imperial Irrigation District: water consumption by irrigation
- New Mexico
  - Middle Rio Grande: water consumption by agriculture and riparian systems
- Montana
  - Flathead Indian Reservation and ground water areas east of Helena: for improved irrigation water management and management of total depletion

ET Investigations involving METRIC/Landsat – Applications for Water Management

University of Idaho and Associates/Partners

Richard Allen (UI), Ricardo Trezza (UI), Bill Kramber (IDWR), Tony Morse (SAG), Jan Hendrickx (NMT), Ayse Irmak (UNL), Justin Huntington (DRI), Clarence Robison (UI), Carlos Kelly (UI), Jeppe Kjaersgaard (UI), Jeremy Greth (UI), Masahiro Tasumi (UI), Tim Martin (RTI)



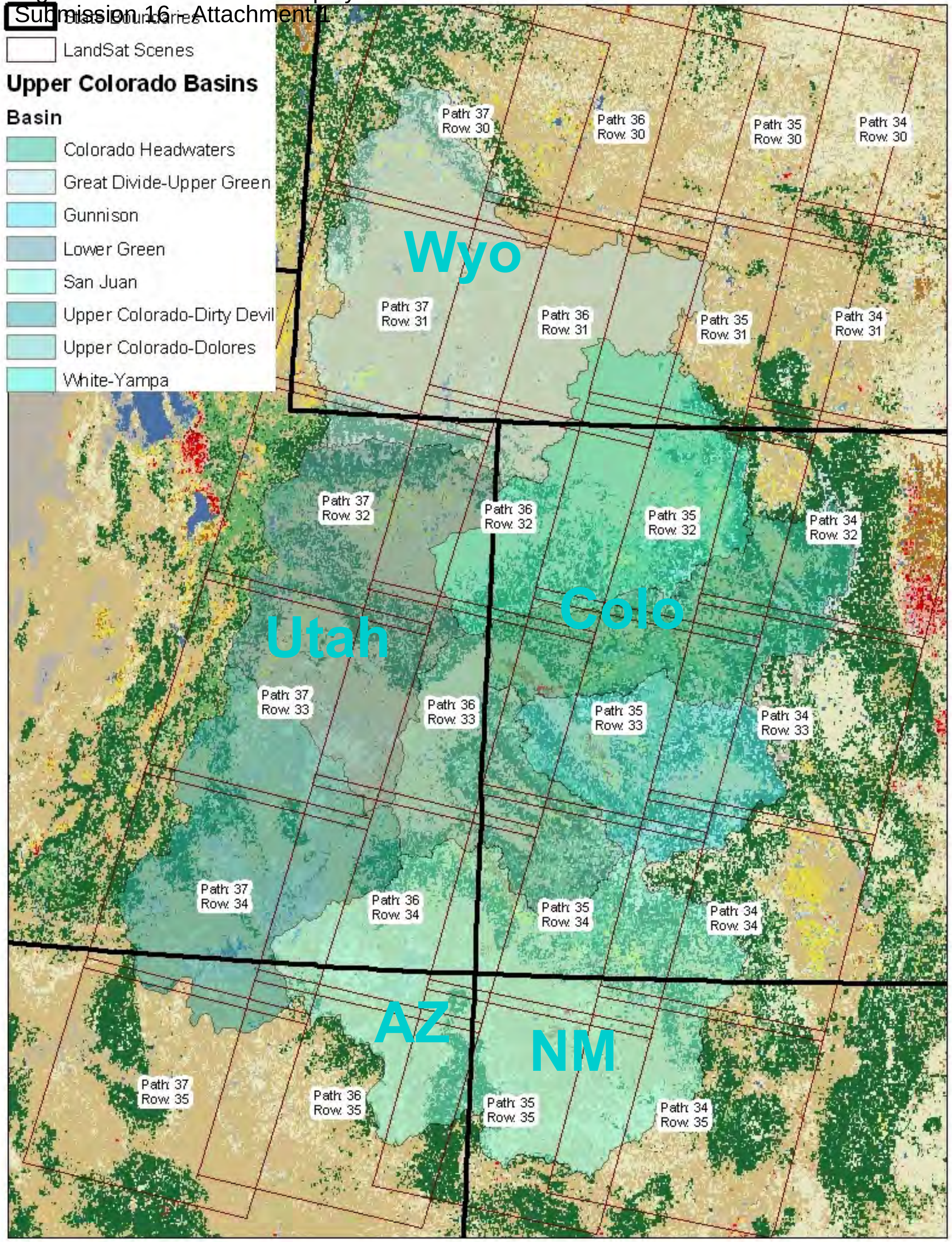
Overlays of Landsat paths and rows over the Upper Colorado Basin

(100 x 100 miles per path/row)

24 total path/rows

METRIC ~ $0.5 – 1.0 mill/yr?

NDVI –basis ~ $400,000/yr?

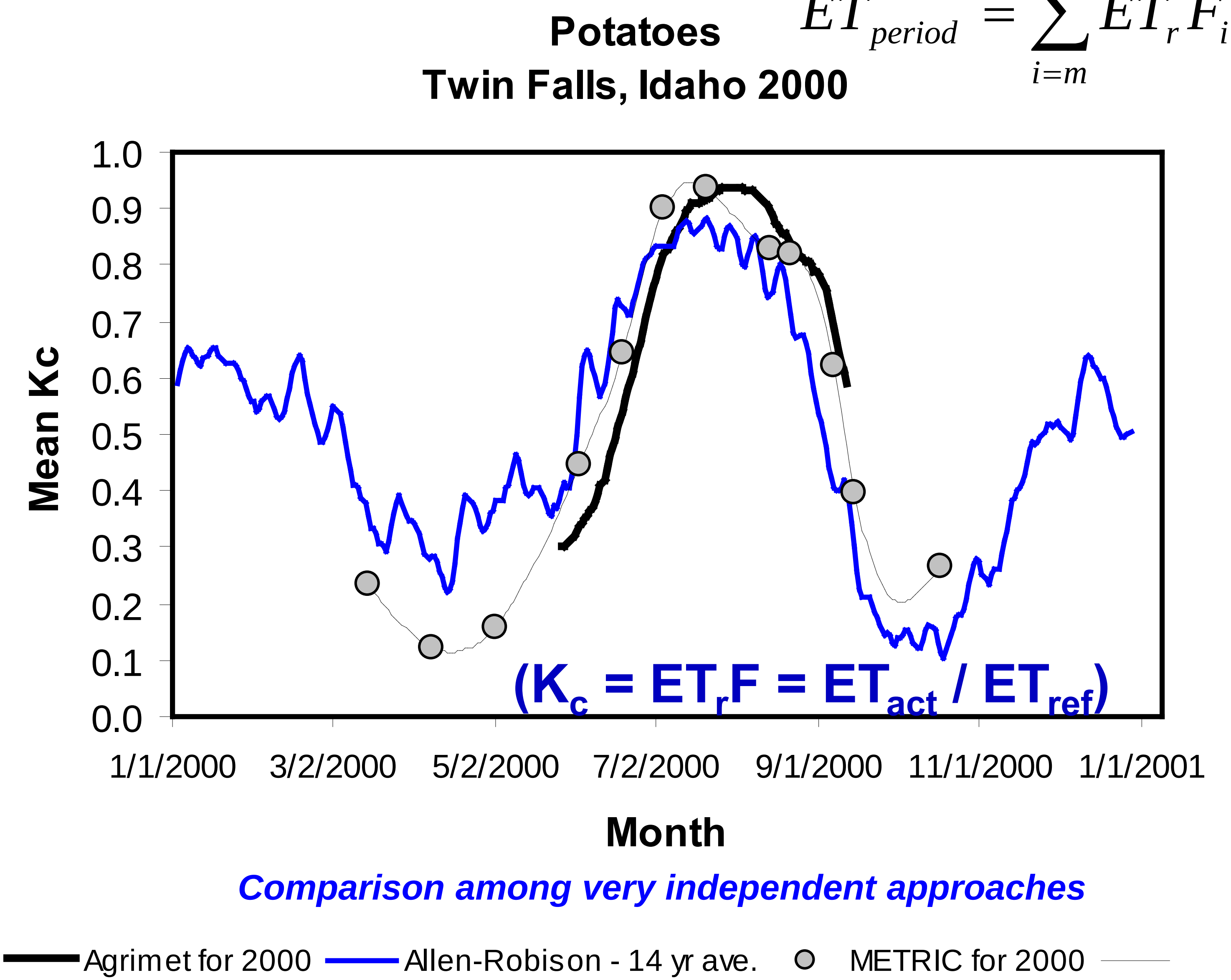


Concern about Landsat's future

- Landsat 5 was **27 years old** at failure
  - Imaging halted November 2011 due to electronic component problem
- Landsat 7 is **13 years old**
  - Scan line corrector failed March 2003
  - About 22% of each image is missing
  - Missing areas are filled in using ArcGIS tools
- Landsat 8 scheduled to launch February 2013
- Funding for Landsat 9 **is uncertain**

Estimates of Consumption require Integration over Time

$$ET_{period} = \sum_{i=m}^{n} ET_r F_i \; x \; ET_{r24i}$$

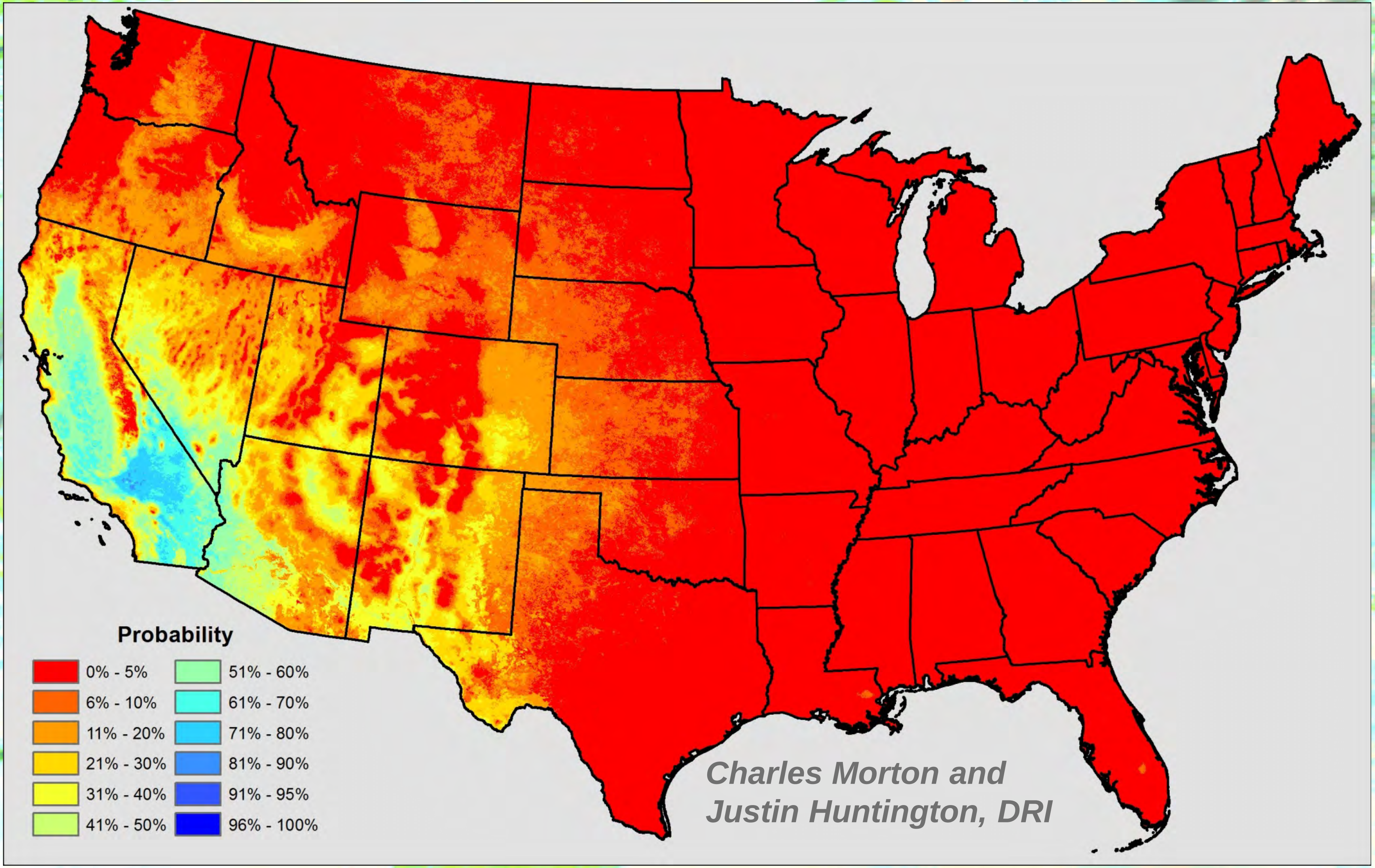


Comparison among very independent approaches

We would 'like' one 'point' (image) each 32 days (minimum)

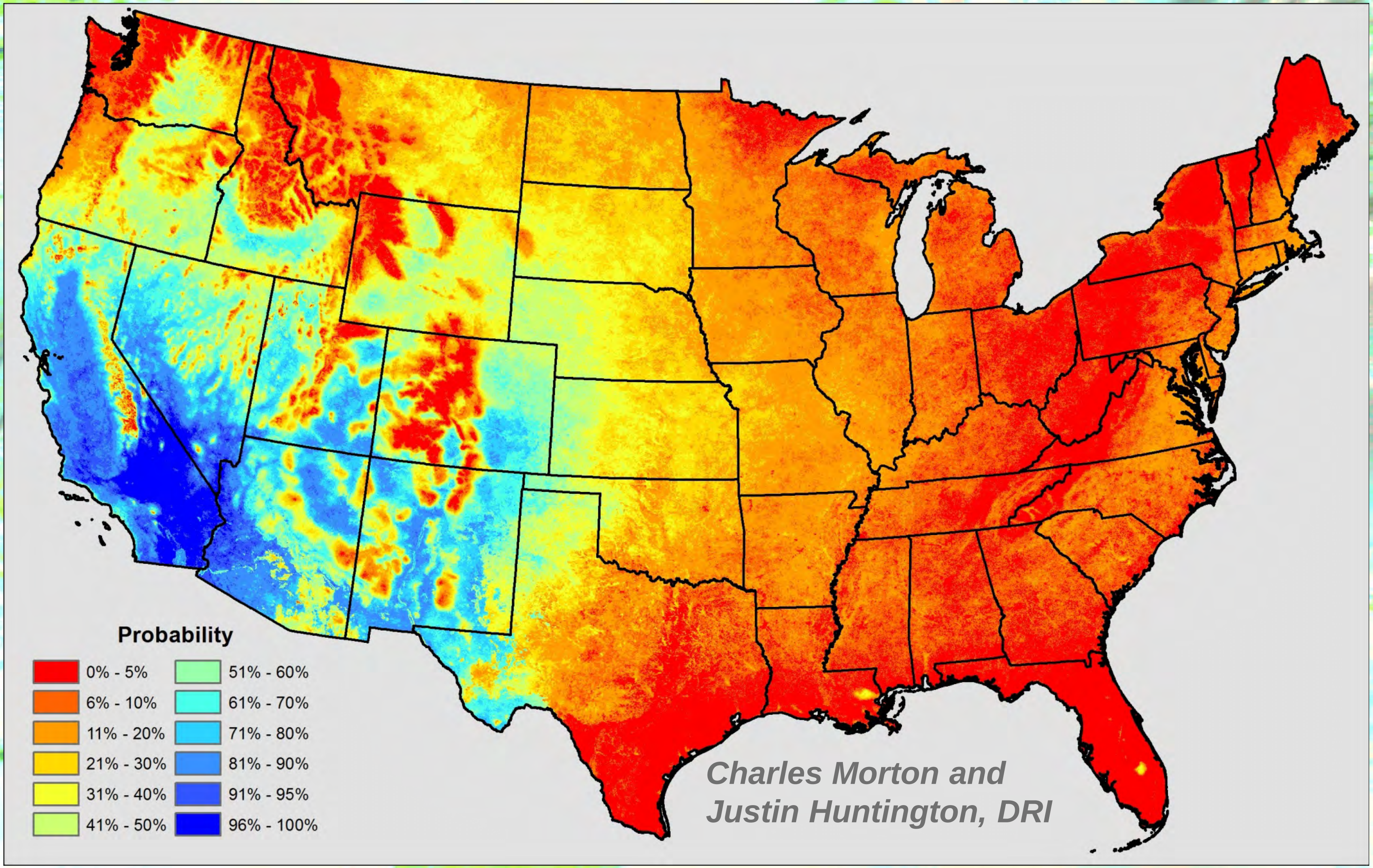
1 Satellite (each 16 days)

Probability of a Cloud-free Pixel at least every 32 days



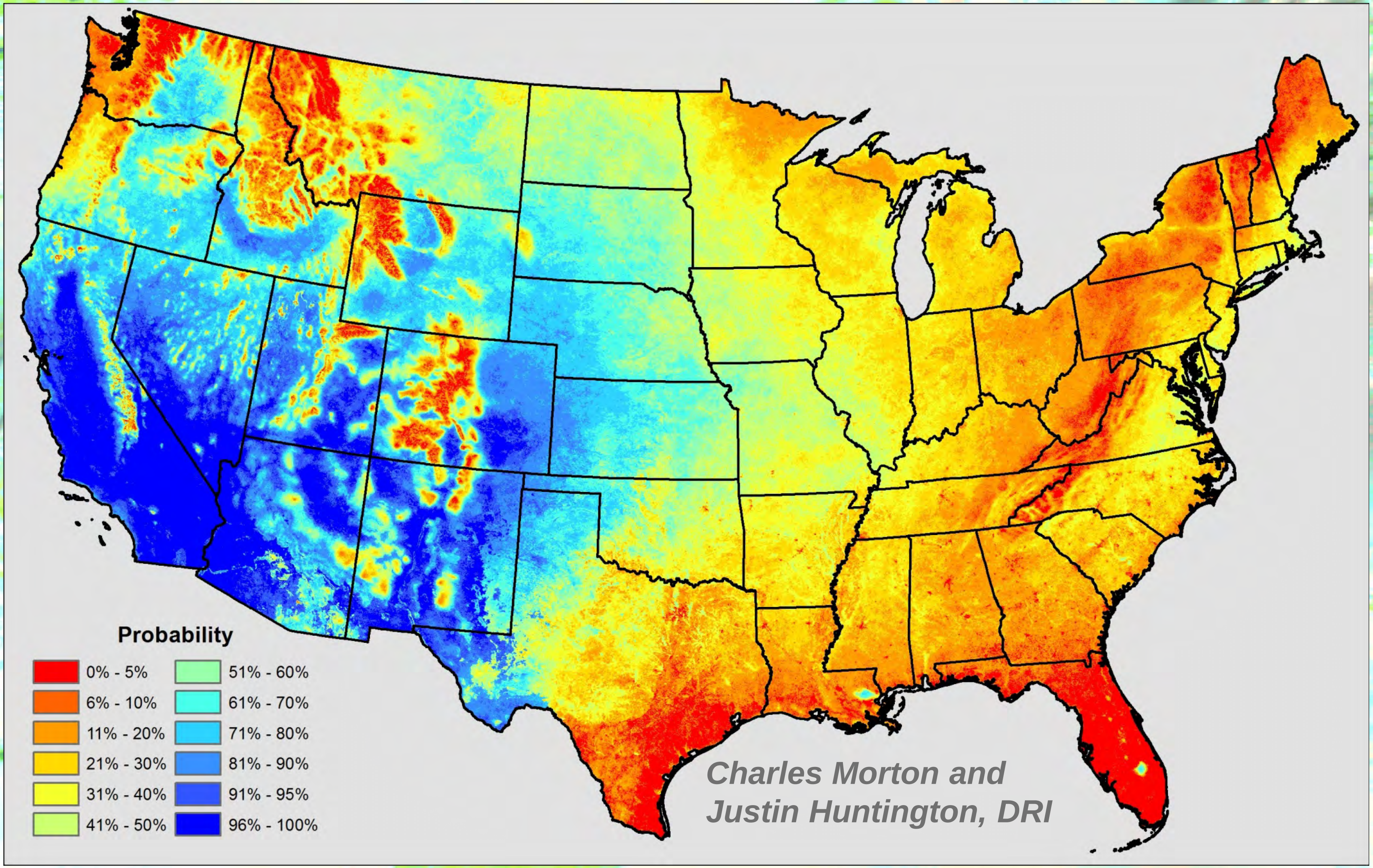
2 Satellites (image each 8 days)

Probability of a Cloud-free Pixel at least every 32 days



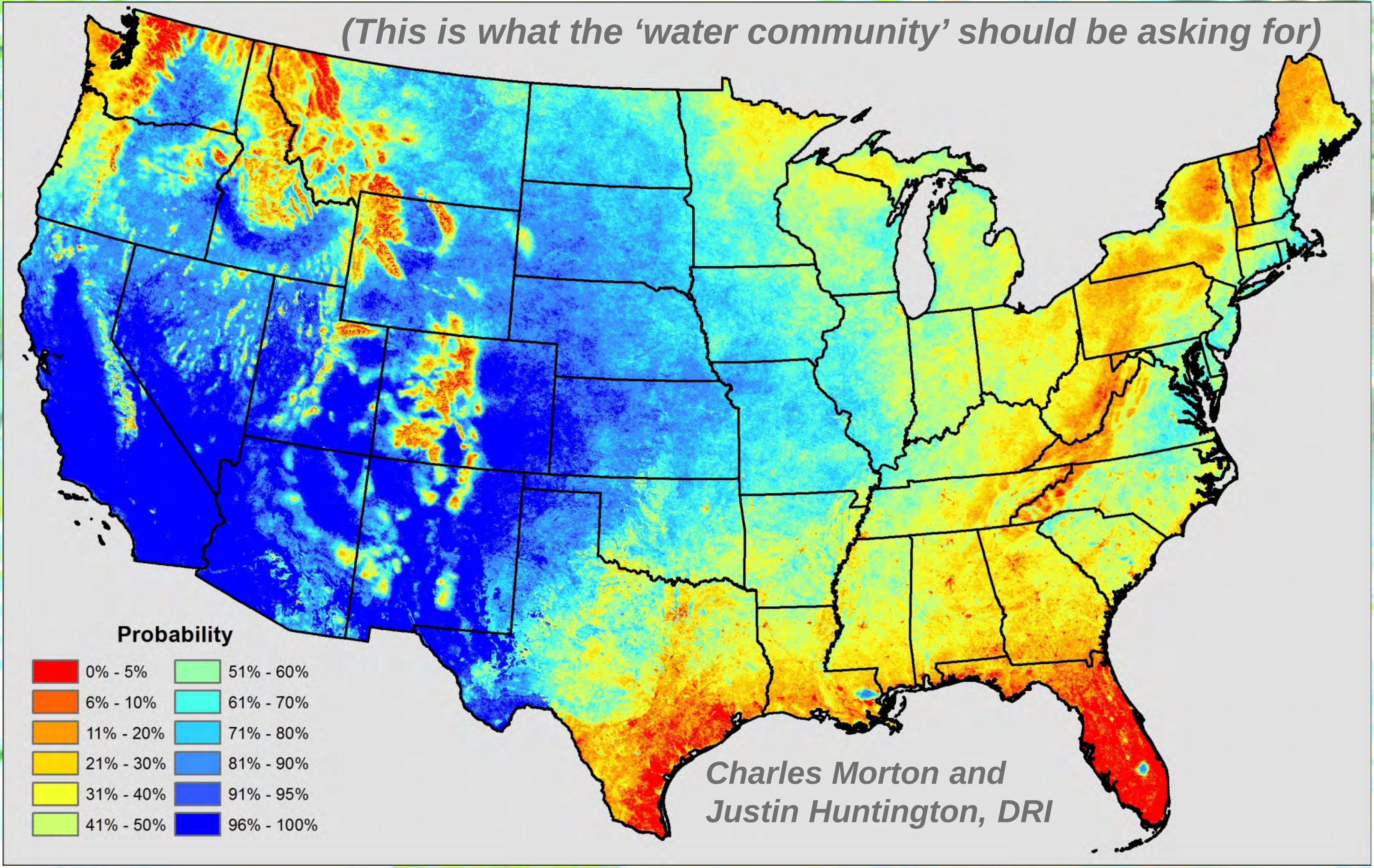
3 Satellites (image each ~5 days)

Probability of a Cloud-free Pixel at least every 32 days



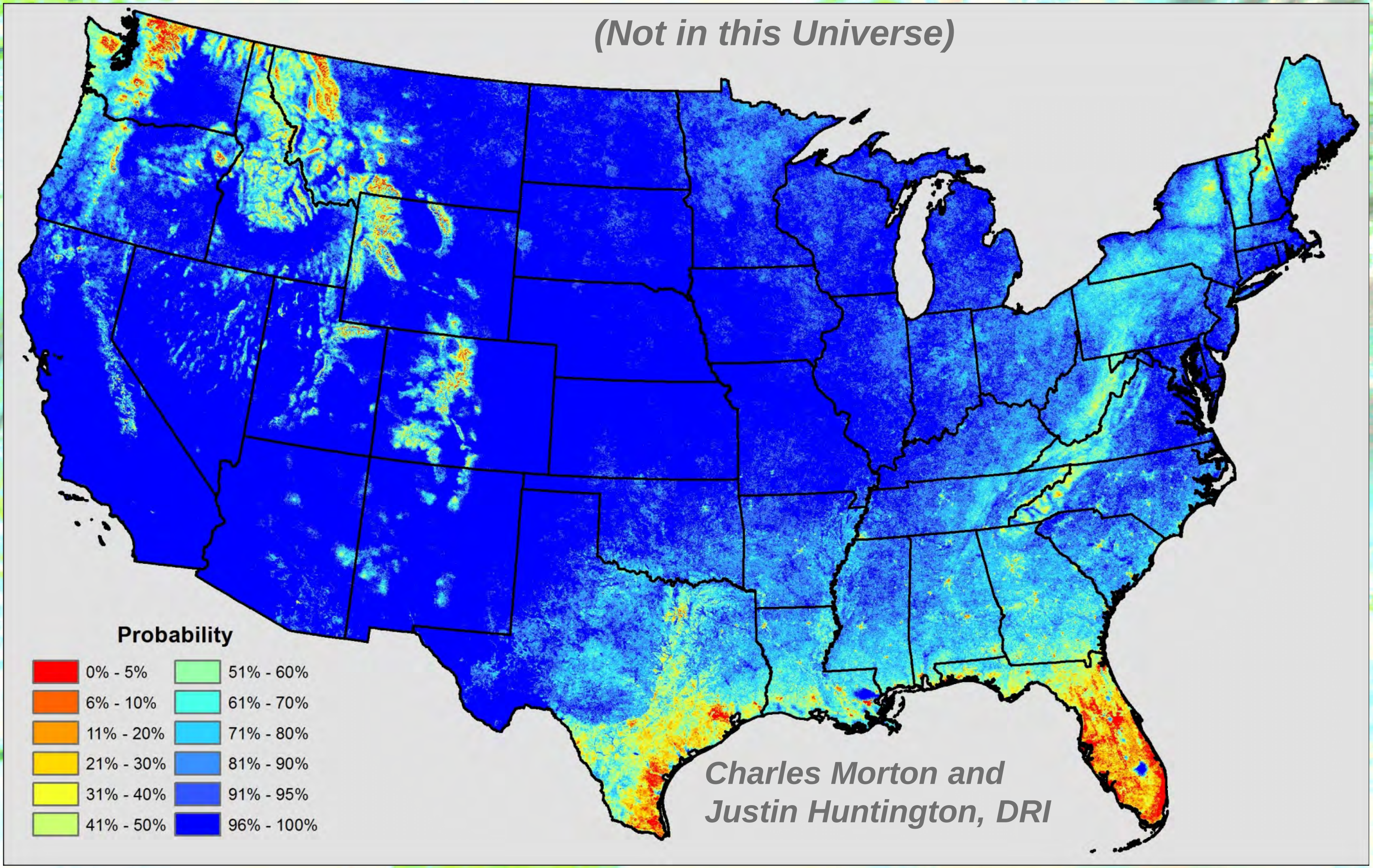
4 Satellites (image each 4 days)

Probability of a Cloud-free Pixel at least every 32 days



8 Satellites (image each 2 days)

Probability of a Cloud-free Pixel at least every 32 days



Support Landsat!!

The Landsat Program and Water Resources Information Needs in the United States

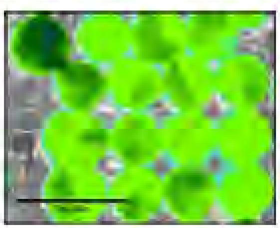
Western States Water Council

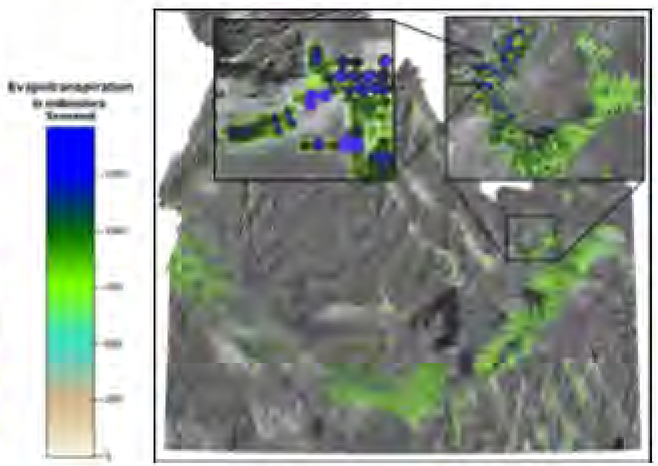
The water resources of the United States are a $200 billion per year economic engine that supports hundreds of thousands of jobs. However, in the West and the Nation water is in short supply, requiring reductions in consumptive uses. Water and water rights are increasingly valuable commodities being bought and sold. Remotely sensed imagery collected by Landsat is essential for determining past and present water use and evapotranspiration (ET) at scales that reveal patterns of land management and water consumption. ET maps derived from Landsat thermal imagery are used operationally by water managers to monitor and manage agricultural and urban water use, administer water rights, evaluate market transfers, negotiate and monitor interstate compacts, estimate water-use by invasive species, and assess and monitor water and food security and sustainability. Landsat is the only operational satellite that combines thermal data with short-wave data at the spatial resolution needed to administer water use and water rights, which is often at the level of the individual agricultural field.

Water Resources Management Needs in the United States for the Landsat program:

1) Establish an Operational Land Observation program having spatial resolution at land and water management scales to build on the 30-year global archive of Landsat data
2) Maintain continuity of Landsat resolution data in visible, near infrared, short-wave infrared and thermal bands
3) Spatial resolution sufficient to observe land and water at field scale: 30 to 60 meter pixels
4) An ideal image procurement process with satellite passes each 4 days (*4-day return cycle*), 16 days maximum.
5) Continuous Scene Acquisition around the globe with no data gaps in any future year
6) A policy of and funding for building multiple satellites under a long term program to assure no future data gaps
7) Continuation of the existing policy of no-cost data access for all archived and future scenes
8) Absolute radiometric uncertainty < 5%, 1-sigma, for VNIR/SWIR bands and < 2%, 1-sigma, for the thermal band.
9) Necessary Federal funding:

   1) $ 40 million in FY 2012
   2) $125 million in FY 2013
   3) $250 million in FY 2014
   4) $250 million in FY 2015
   5) $265 million in FY 2016
   6) $250 million in FY 2017
   7) $200 million in FY 2018





ET maps showing depths of water evaporated from irrigated fields of Idaho during the April - October growing season-- derived from Landsat.

For more information: *Mr. Tony Willardson, Executive Director, Western States Water Council, 5296 Commerce Drive, Suite 202, Murray, UT 84107, (801) 685-2555 http://www.westgov.org/wswc/* twillardson@wswc.utah.gov

http://www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm and http://www.kimberly.uidaho.edu/water/metric/index.html
http://www.westernstatesetworkshop.com/past-events/boise-2011/ and http://wmp.gsfc.nasa.gov/workshops/ET_workshop.php
April 6, 2012.

Why Landsat is an Essential Earth Imaging Program and Why it Requires Federal Support

olution of Landsat -- 30 m reflected data and coincident 60-120 m thermal data
onitoring land use change and water consumption of human-related features --
ls, riparian systems, forest clearings, vegetation disease outbreaks, etc..

critical niche between the high resolution commercial satellites and the 'daily'
atellites like MODIS, NPOESS-VIIRS and AVHRR , which cannot resolve most
land features.

a 16 day return time (8 days with 2 Landsats) that provides the high-frequency
ed to monitor the dynamic evolution of vegetation and water consumption.
, sub-meter systems can not cover the US every 8 or 16 days.

w angle of less than 8 degrees assures high data-accuracy and fidelity.

are optimal for operational natural-resource models. The models are
promoting economic growth and efficiency, food production and security, and
es management, planning and projection. Imagery from low-resolution satellites
is generally too coarse to be used exclusively, while imagery from high
ms (IKONOS, QuickBird, etc.) is too infrequent[1]. Small-sat systems may not
spectral bands and coverage and are currently not capable of carrying thermal
Landsat-type coverage and accuracy.

y 80% of Landsat data are used in natural-resource applications. A majority of
sers work in government and do not have the budgets to support high prices for
ence has shown that the 30 m Landsat pixel, while ideal for natural resources,
command the high prices afforded high-resolution imagery. As a consequence,
emain publically financed. America's investment in Landsat reduces costs for
rces management products from low-cost or no-cost Landsat imagery.

ntinuous archive of Landsat imagery dating from 1972 for short-wave and from
l data provides a time machine for viewing land surface temperature and
the entire US. Western water-resource applications depend on the Landsat
chive to map and quantify historical water use. No other satellite system comes
rmanent heritage of data.

be interpolated to cumulative monthly and growing season estimates by
ages from Landsat with weather-based measurements of potential ET. This
ontinue to increase as gridded weather data systems evolve.

s advances in the use of Landsat data for natural resources management,
have come because Landsat data are free to users. The user community will
elop valuable Landsat-based applications as long as Landsat data are provided
minimal cost.

by Richard G. Allen, Univ. Idaho and Tony Morse, Spatial Analysis Group, April 9, 2012.

[1] eoEye, for example, can cover every point of the US approximately only every 160 days and
0 days.

More Information

www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm

www.kimberly.uidaho.edu/water/metric

www.idwr.idaho.gov/geographicinfo/landsat/Landsat Concerns.htm

www.westernstatesetworkshop.com

http://www.facebook.com/NASA.Landsat

http://www.facebook.com/LandsatAdvocates

Seasonal METRIC ET for 2000

0 25 50 100 Kilometers