Characterizing evapotranspiration with remote sensing

A case study in the Smith River watershed of central Montana

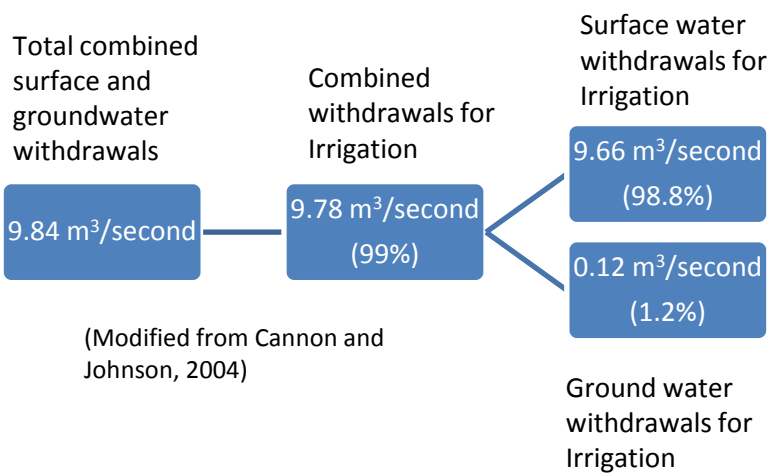
Roy Sando, Rod Caldwell, and Kyle Blasch
WY-MT Water Science Center

Outline

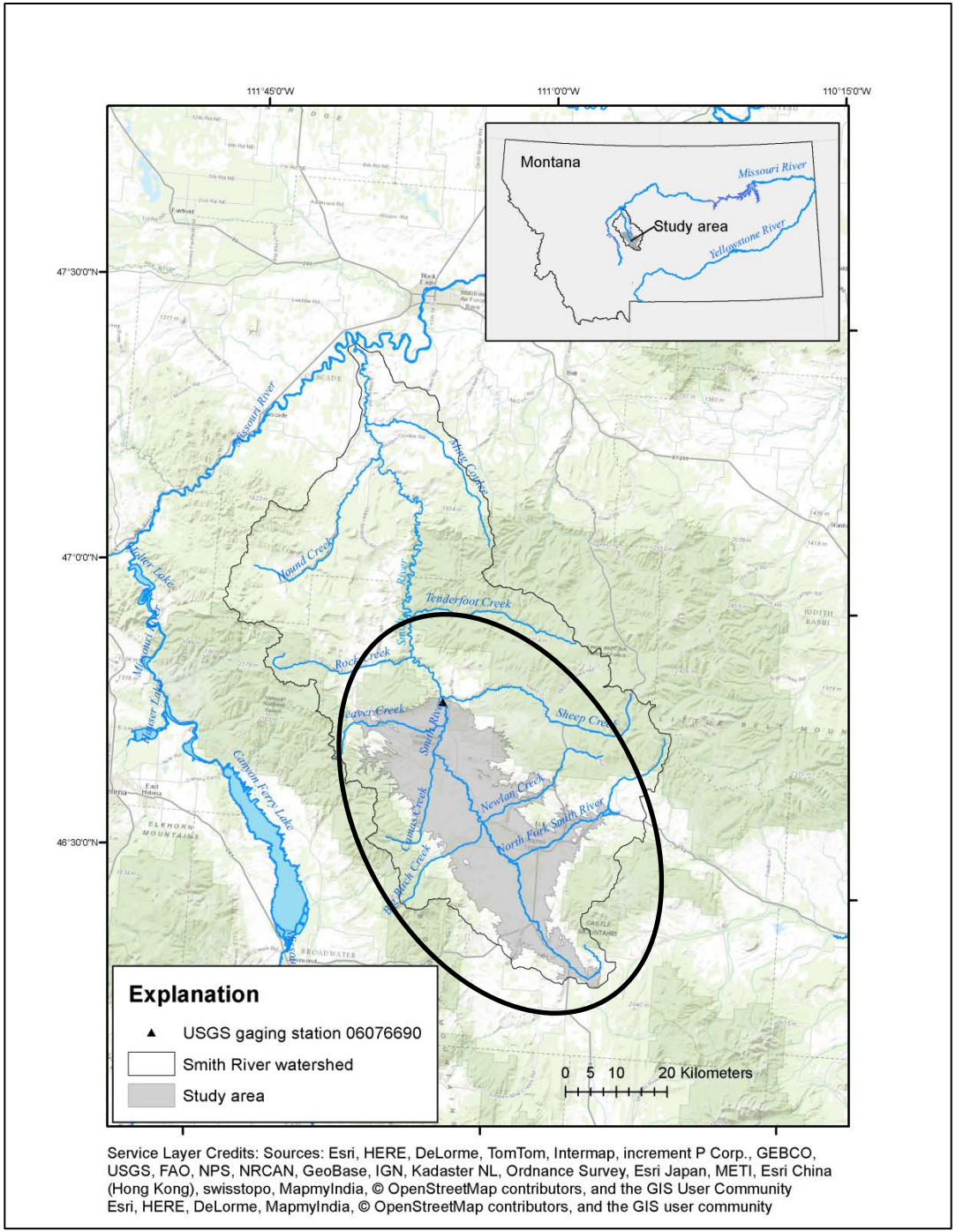
- Study area
- Image processing and data
- Limitations
- Results
  - Total seasonal ET
  - Within-field variability of ET
  - Impact of sprinkler irrigation on ET
- Conclusions

Study Area

- Located in the Smith River watershed
- 406 square miles
- Below 5,500 feet
- Contains approximately 85% of the agricultural lands in the Smith River Watershed
- Avg annual precip (1971-2000) ranges from < 12” to > 40”



(Modified from Cannon and Johnson, 2004)

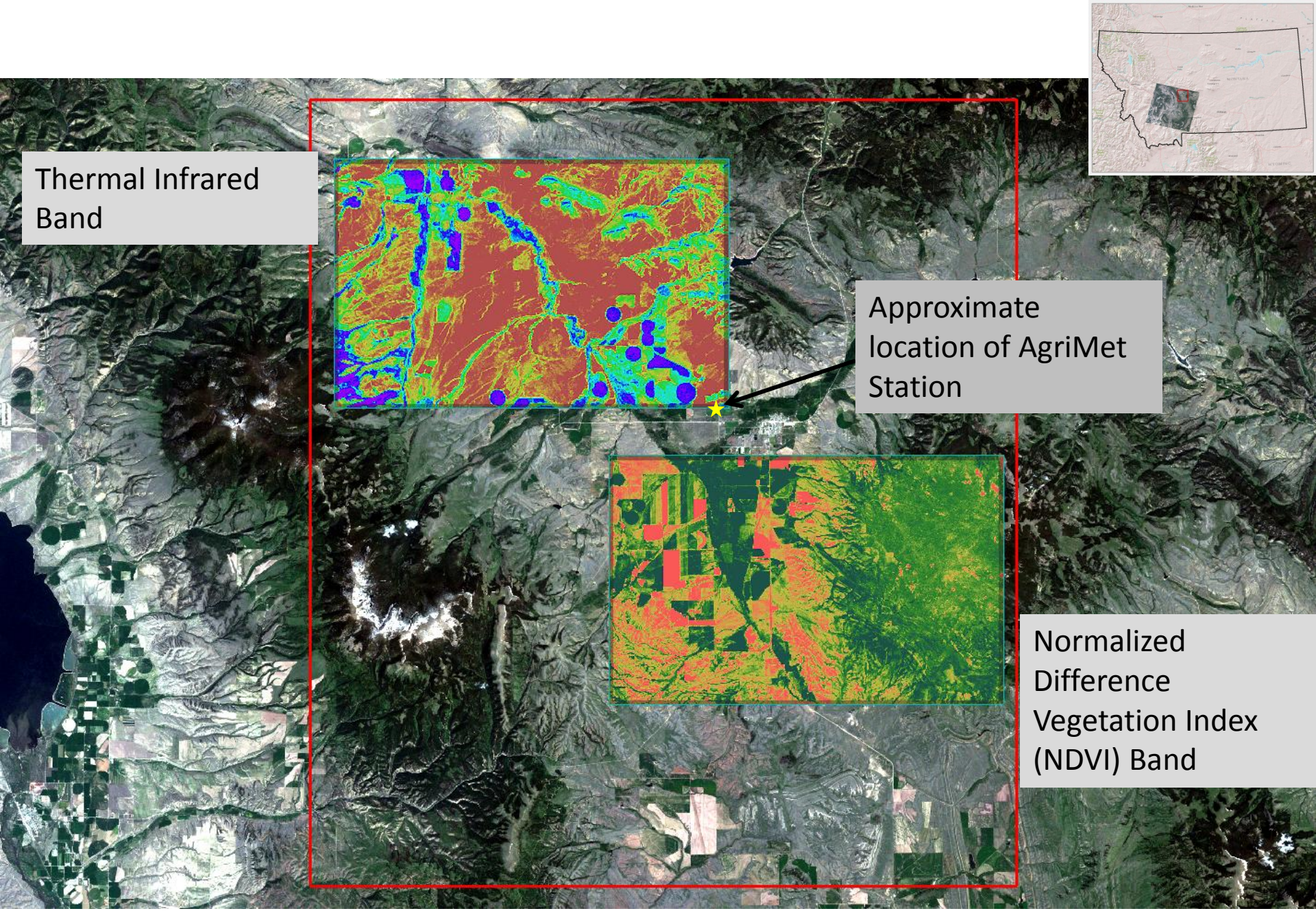


USGS
science for a changing world

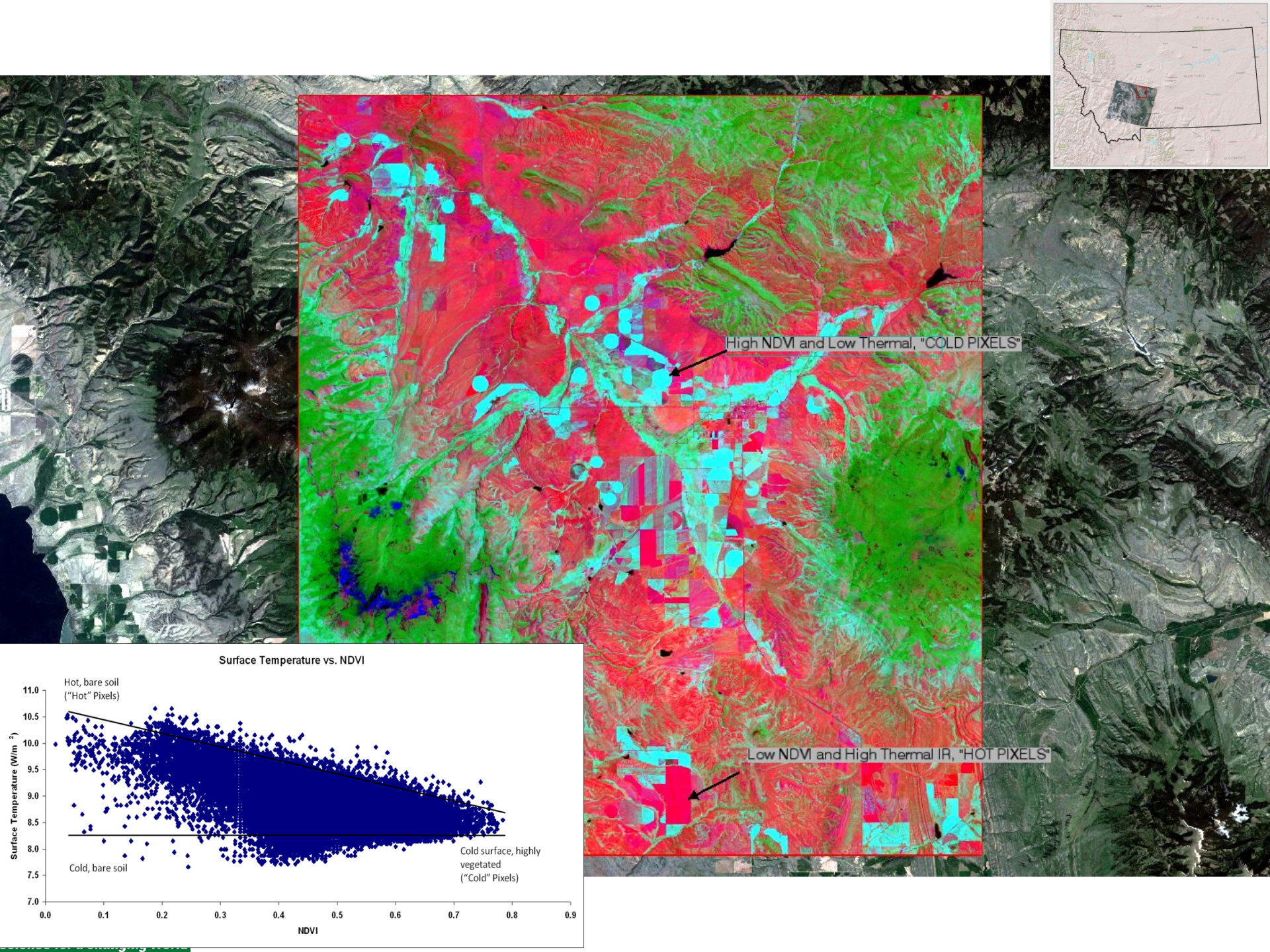
Image Processing

- Simplified Surface Energy Balance (SSEB)
  - Dry, bare soil = highest relative surface temp = lowest evapotranspiration (Fractional ET = 0)
  - Well-watered, dense vegetation = lowest relative surface temp = highest evapotranspiration (Fractional ET = 1)
  - Fractional ET times reference ET equals actual ET
  - Senay, G. B., M.E. Budde, J.P. Verdin, and A.M. Melesse, 2007, A coupled remote sensing and simplified surface energy balance approach to estimate actual evapotranspiration from irrigated fields, Sensors, vol. 7, p. 979-1000.
- Landsat 5 and 7 imagery for 7 dates in 2007 (March 12th – October 14th)
  - 2007 was an average precipitation year with the most cloud-free imagery available
- Reference ET
  - Alfalfa ET under optimum soil-water conditions
  - AgriMet station at White Sulphur Springs using Penmann-Montieth equation

USGS
science for a changing world



USGS
science for a changing world


High NDVI and Low Thermal, "COLD PIXELS"
Low NDVI and High Thermal IR, "HOT PIXELS"
Surface Temperature vs. NDVI
Hot, bare soil
("Hot" Pixels)
Cold, bare soil
Cold surface, highly
vegetated
("Cold" Pixels)
Surface Temperature (W/m 2)
NDVI
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Selection of “Hot” and “Cold” pixels

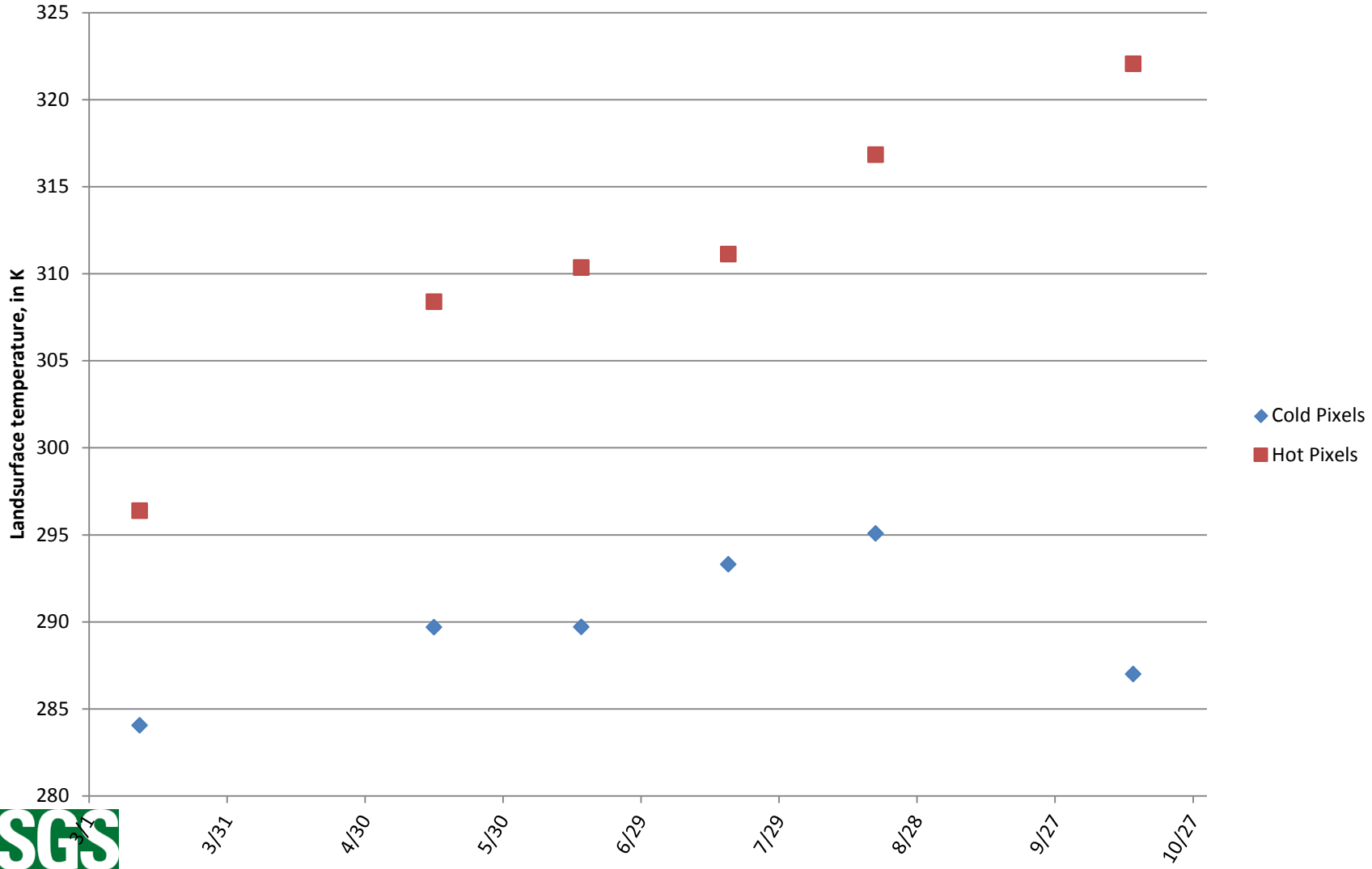
Cold pixels

- Normalized Difference Vegetation Index (NDVI)
- NDVI > 0.3 (3/12/2007)
- NDVI > 0.6 (10/14/2007)
- NDVI > 0.7 for all other dates

Hot pixels

- NDVI < 0.1

Selection of “Hot” and “Cold” pixels



USGS
science for a changing world

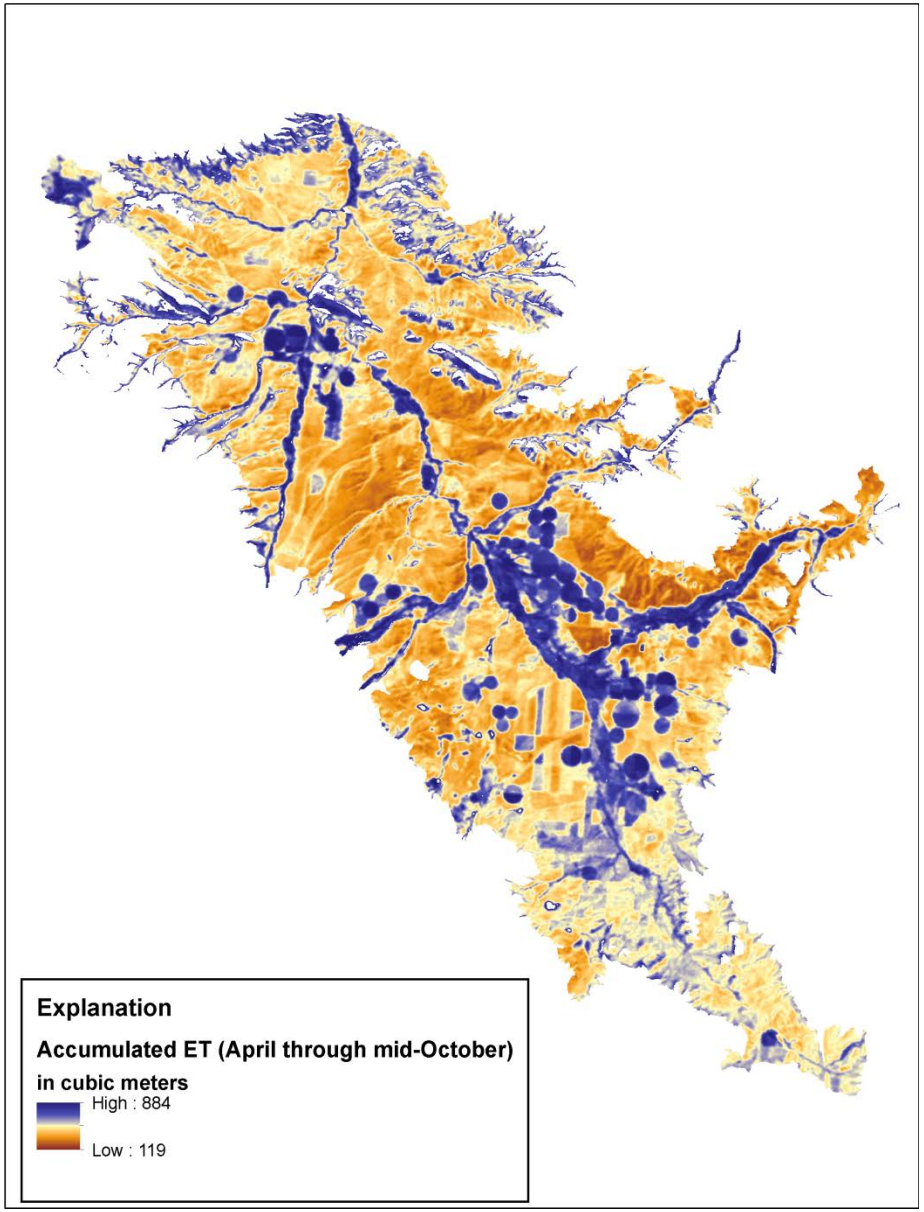
Limitations

- Elevation bias
- Cloud cover
- Riparian vs. flood-irrigated
- Tied to reference ET data
- Crop type/irrigation type associations
  - i.e. Alfalfa is rarely flood-irrigated; Grass less commonly sprinkler-irrigated
- Lack of ground-truthed data

Total accumulated ET (April through mid-October)

- Estimated total ET of 475 million m^3
- Approximately 28 m^3/second (989 cfs)

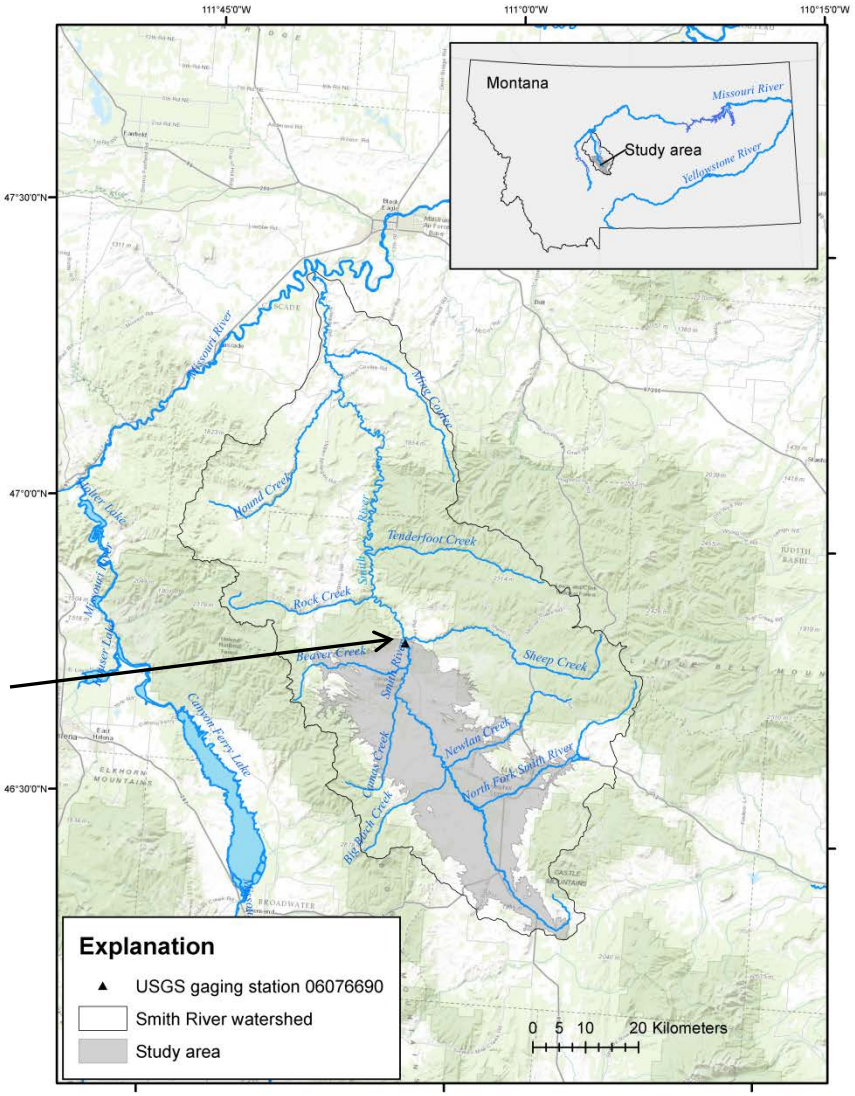
- METRIC estimated 569 million m^3 or 33 m^3/second (1180 cfs)



USGS
science for a changing world

Total accumulated ET (April through mid-October)

Smith River at Ft. Logan has a mean annual streamflow of 4.28 m^3/second (151 cfs)



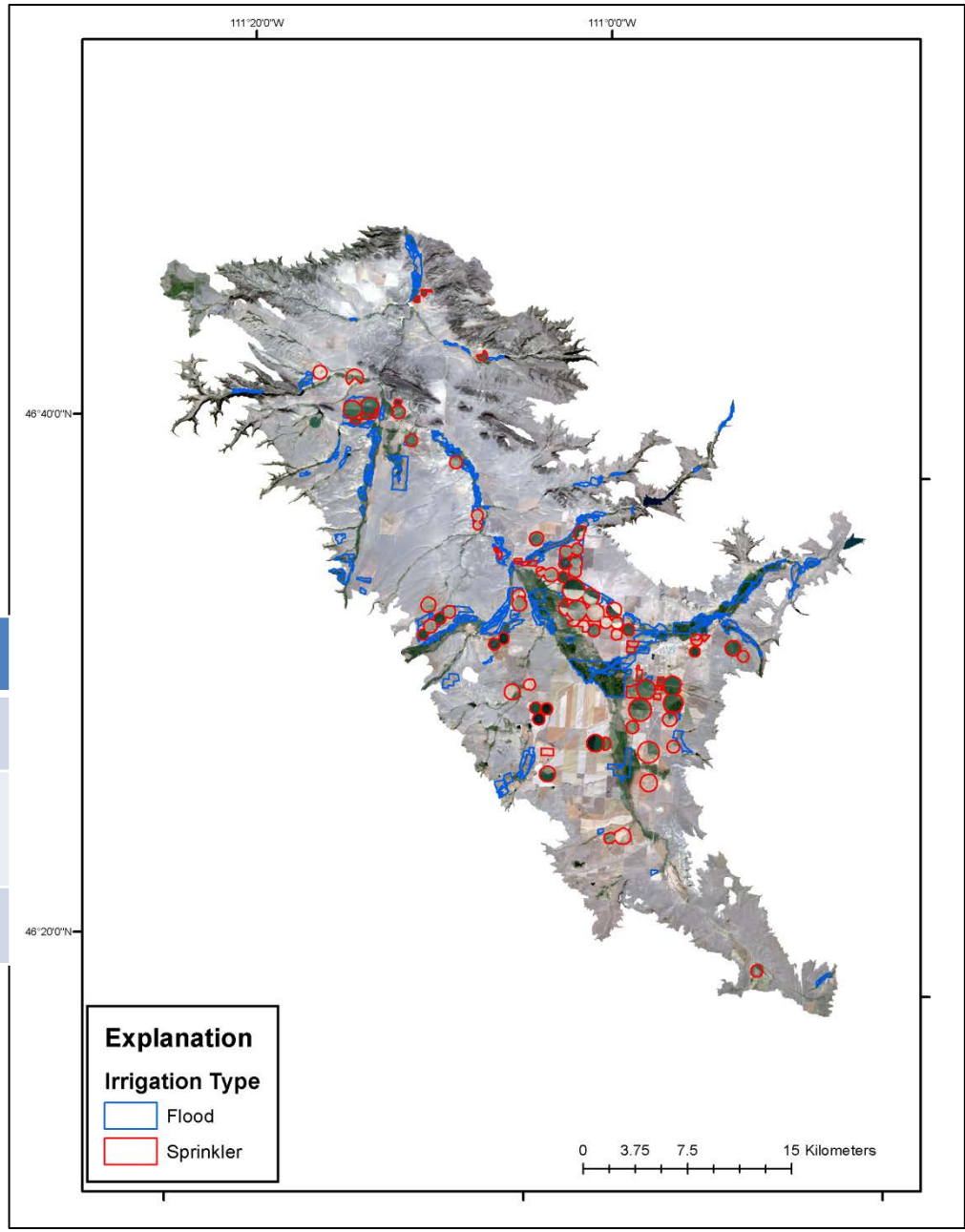
Service Layer Credits: Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

USGS
science for a changing world

Characterization of ET from irrigated fields

- Final land unit (FLU) classification dataset
- 4.6 percent of study area was flood-irrigated
- 5.3 percent of study area was sprinkler-irrigated

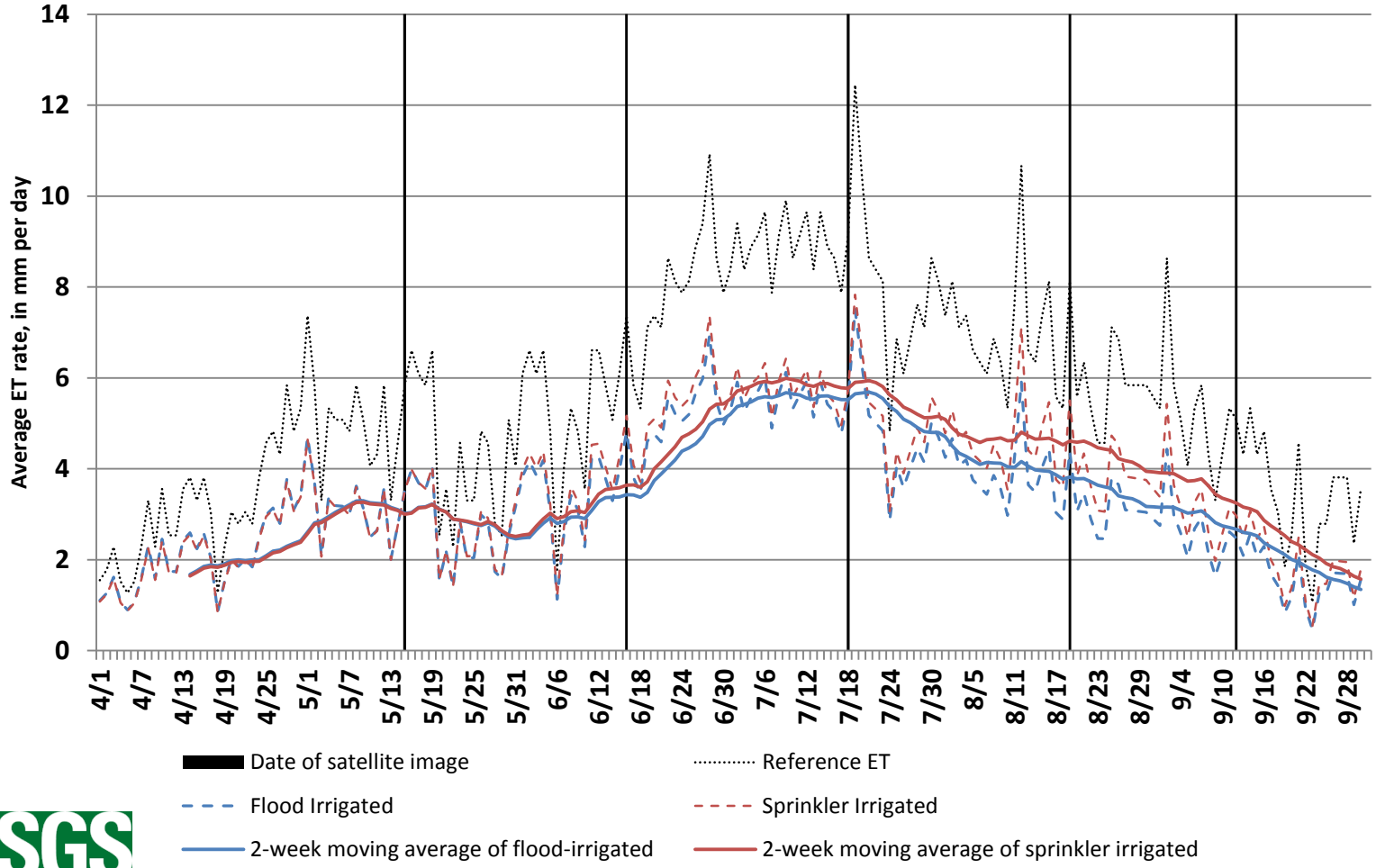
Irrigation Type	Miscellaneous Crops (NLCD)	Alfalfa (NLCD)	Grassland (NLCD)	Other (NLCD)
Flood Irrigated (48 km²)	2%	11%	67%	20%
Sprinkler Irrigated (56 km²)	18%	48%	29%	4%
Non-irrigated (947 km²)	0%	0%	77%	23%



USGS
science for a changing world

Characterization of ET from irrigated fields

- ET from sprinkler-irrigated fields is an average of 9% higher
- Maximum difference is approximately 20%, occurring in mid-August

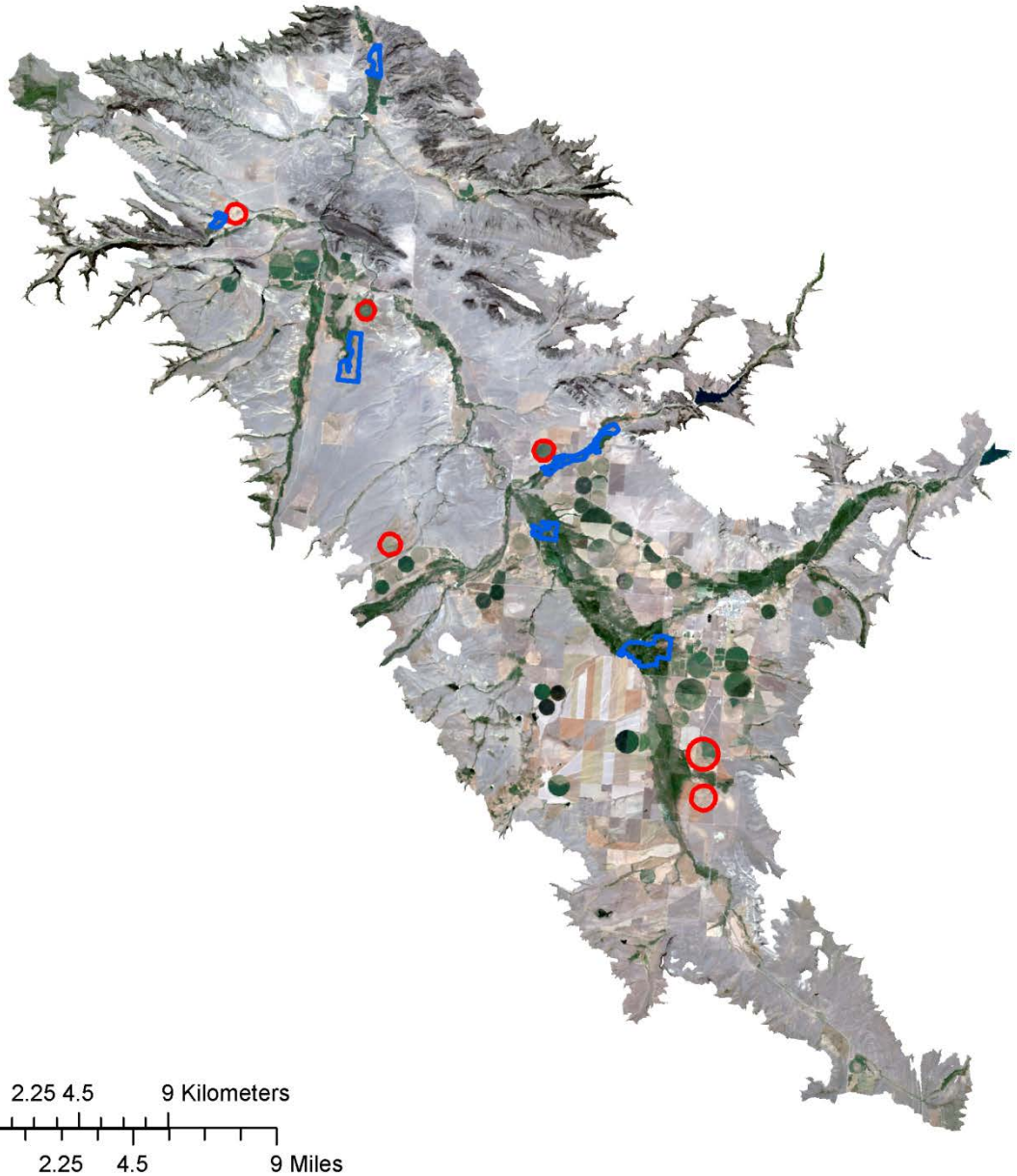


USGS
science for a changing world

Within-field variability of ET

Criteria for inclusion:

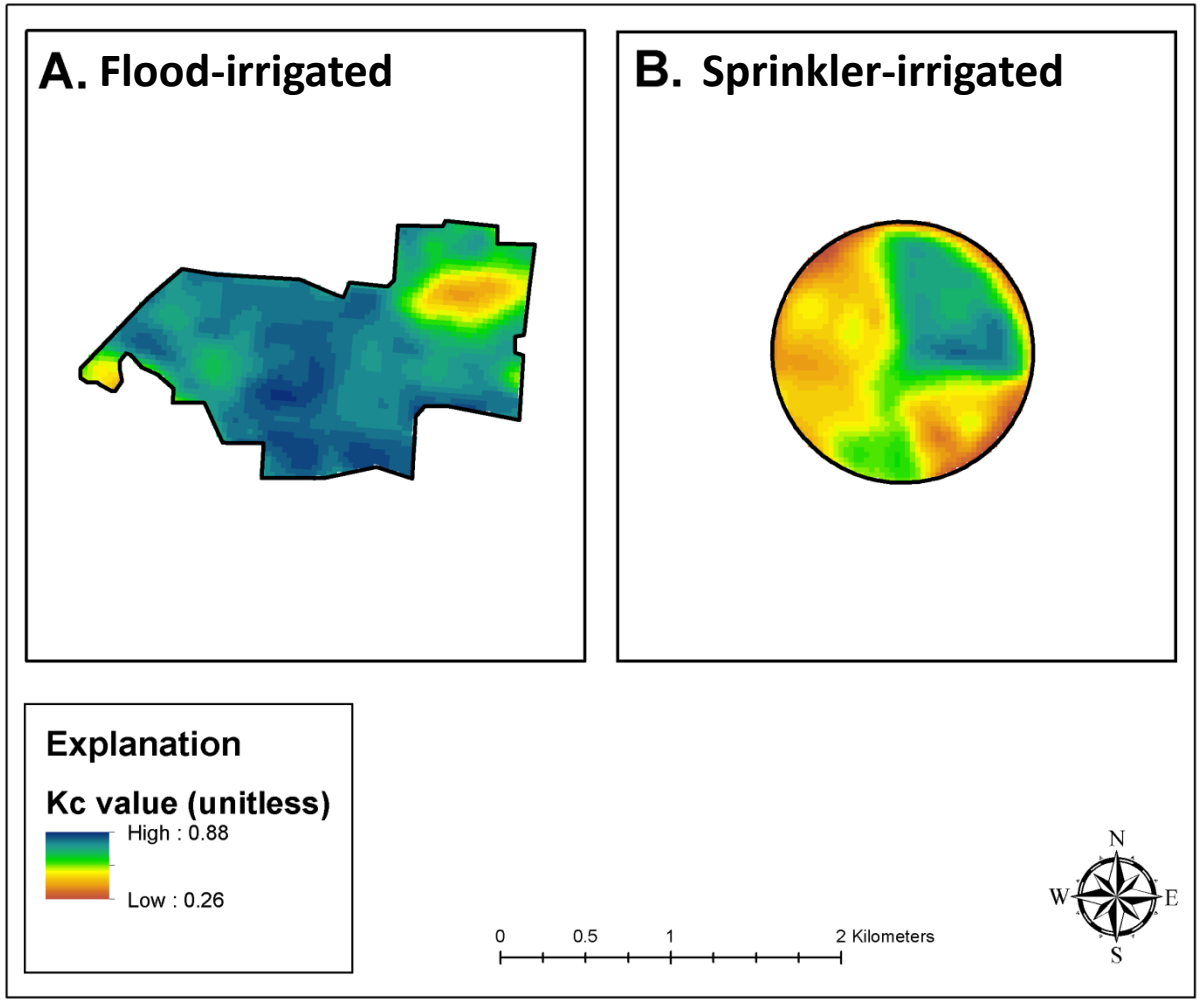
- Sprinkler- or flood-irrigated
- Identified as primarily alfalfa (sprinkler) or grass (flood)
- No cloud or snow adjustment
- Selected fields are distributed throughout the study area



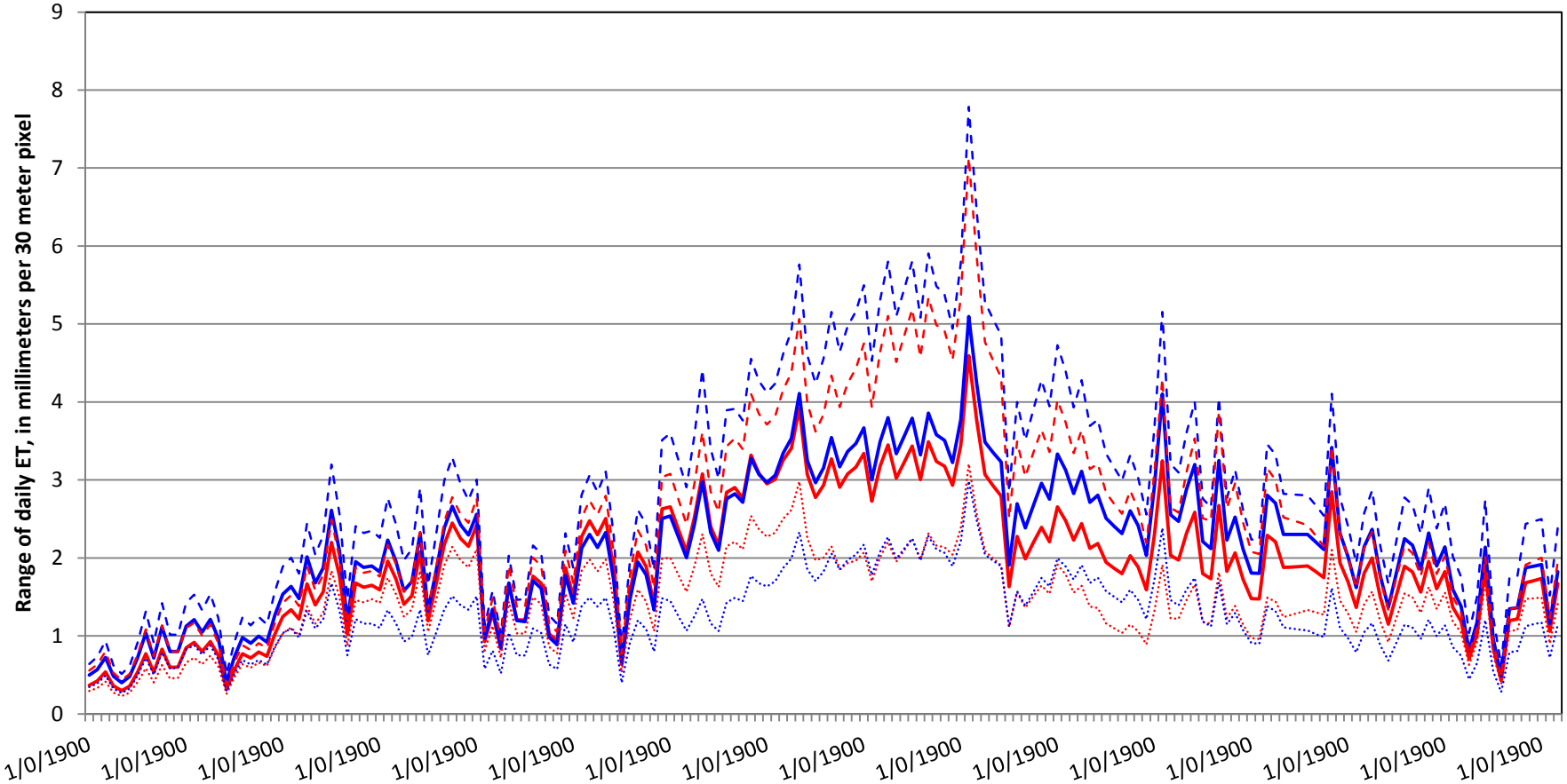
USGS
science for a changing world

Within-field variability of ET

July 18th, 2007



Within-field variability of ET

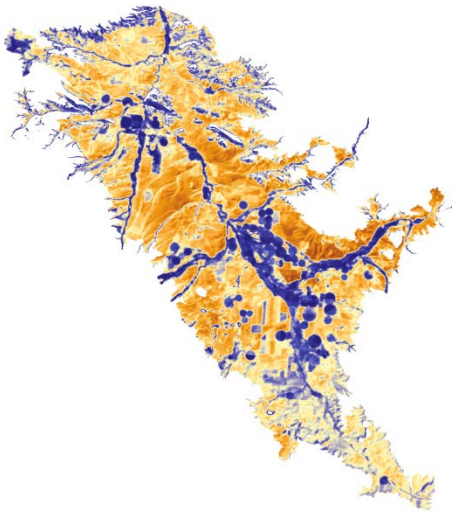


USGS
science for a changing world

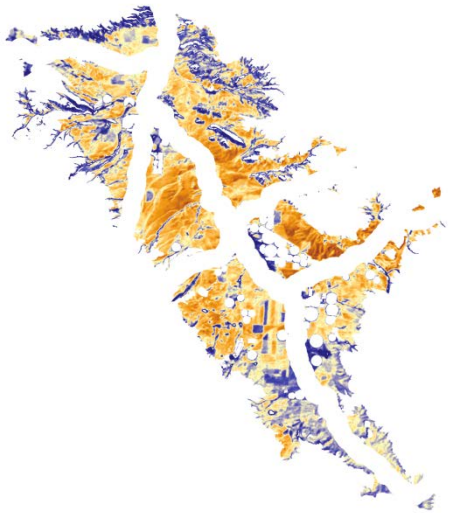
Estimated impact of sprinkler irrigation on ET

Average total ET from non-irrigated, non-riparian was 389 m^3

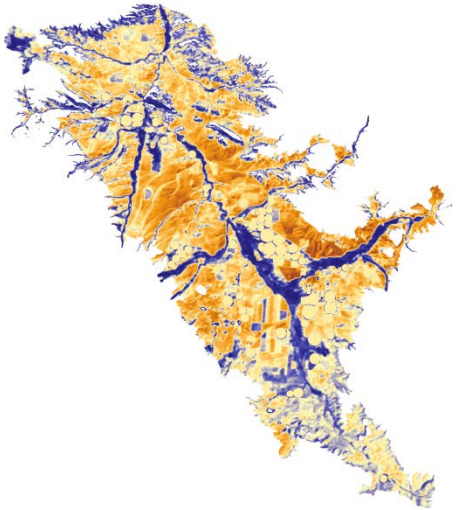
Resulting in a difference of approximately 14 million m^3 or 0.88 m^3/second (31 cfs)



Original



Non-irrigated, non-riparian pixels



Sprinkler-irrigated pixels replaced with non-irrigated, non-riparian average

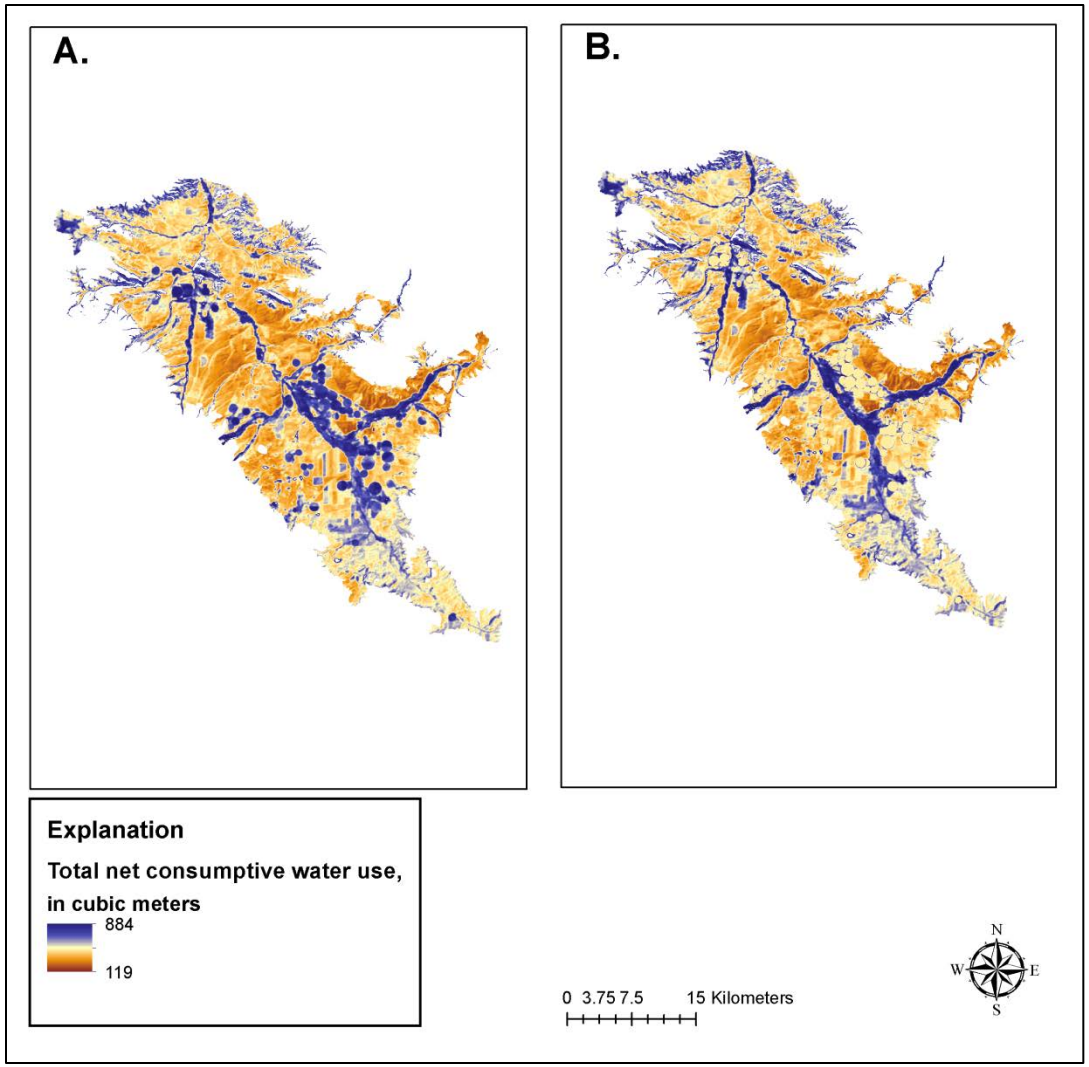
USGS
science for a changing world

Estimated impact of sprinkler irrigation on ET

- 3% increase in ET for the entire study area
(460 million m^3 to 475 million m^3)

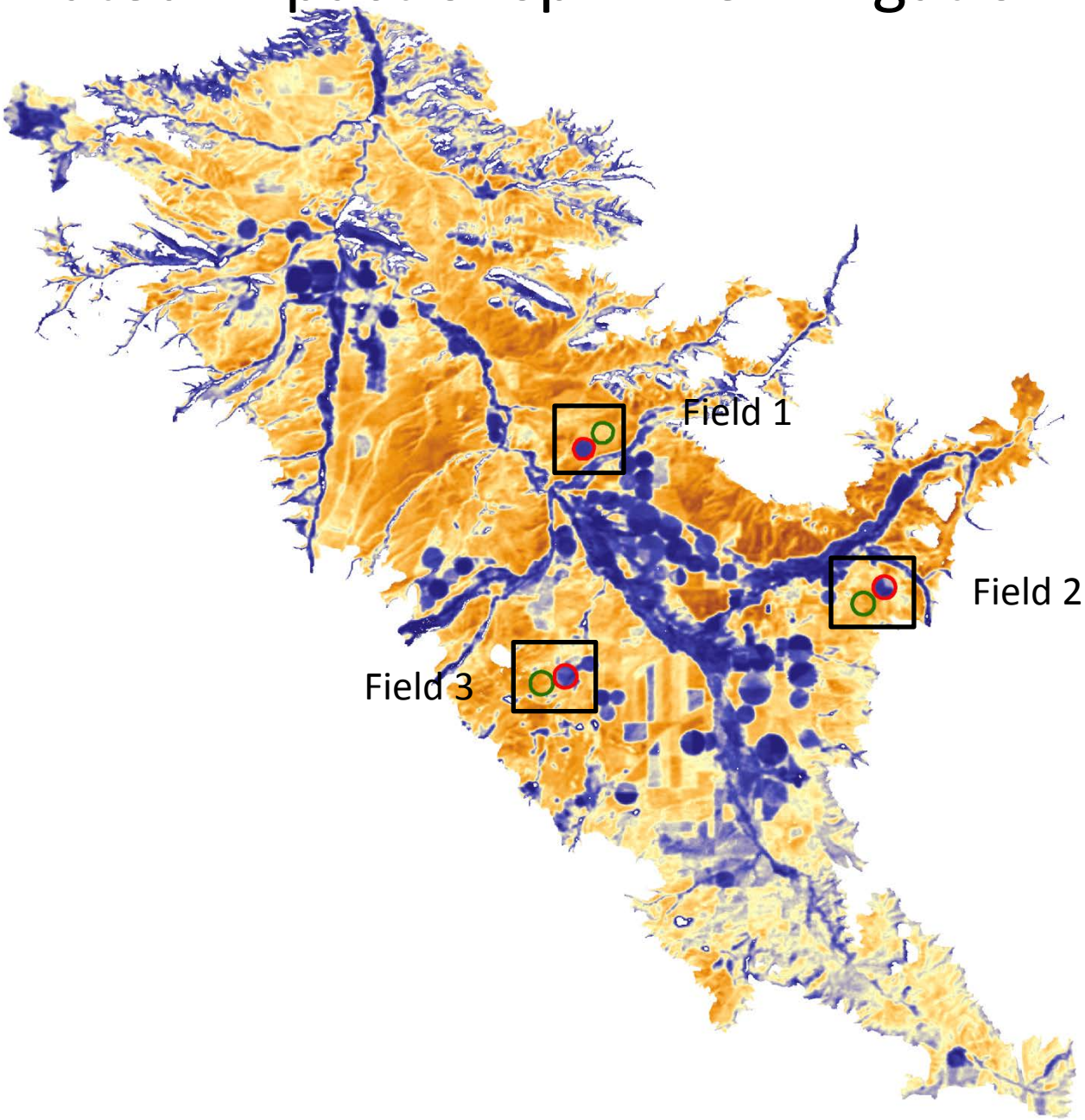
- 58% increase in ET for sprinkler-irrigated land
(24 million m^3 to 38 million m^3)

- Conservative, low-end estimate



USGS
science for a changing world

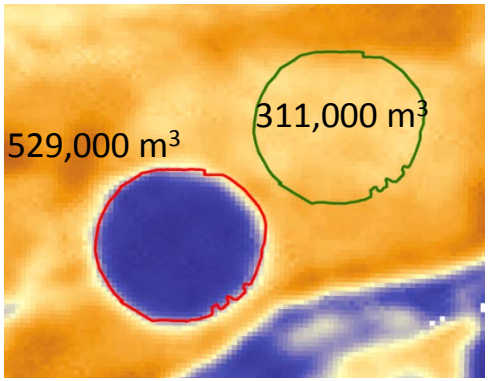
Estimated impact of sprinkler irrigation on ET



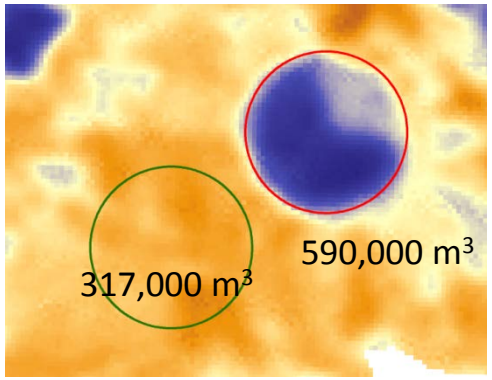
USG
science for a changin

Estimated impact of sprinkler irrigation on ET

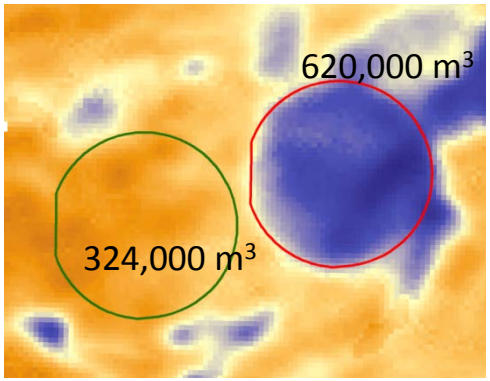
Field 1: 70% increase



Field 2: 86% increase



Field 3: 91% increase



- Average of 82% increase
- More liberal, high-end estimate
- Realistically, conversion from non-irrigated to sprinkler-irrigated will increase ET by between 58 and 82 percent

Conclusion

- On average, ET from sprinkler-irrigated fields was 9 percent higher than from flood-irrigated fields; Maximum difference was approximately 20 percent and occurred in mid-August.

- Maximum range (max-min) of ET within a single field was approximately eight millimeters per day and occurred in late July.

- The portion of ET in the study area that can be attributed to sprinkler irrigation is approximately 3 percent (14 million m^3 of 475 million m^3).

- On average, applying sprinkler irrigation to a parcel of land will:
  - Conservatively increase ET by 58% based on a conversion from an average non-riparian, non-irrigated
  - Increase ET by up to approximately 82% based on a conversion from exclusively non-irrigated grassland