BUREAU OF RECLAMATION

Klamath River Basin Revised Natural Flow Study

November 2 – 3, 2022

Stakeholder Workshop

Evapotranspiration & Irrigation Demand Modeling

Presentation Overview

- Comparison of current study to previous
- Field boundaries
- Irrigation types and efficiencies
- Summary of models, input/output, etc.
- Crop evapotranspiration (ET) estimates from remote sensing eeMETRIC Model (Matt Bromley)
- Wetland and other phreatophyte ET estimates using remote sensing and in situ data method (Blake Minor)
- ET and effective precipitation estimates from ET Demands Model (Chris Pearson)

Previous & Current Irrigation Demand Analyses

2005 NFS:

- Crop and wetland ET estimates from obsolete Blaney-Criddle Model
- Crop ET estimates by sub-basin
- Riparian and upland phreatophyte ET not estimated
- Wetland ET estimates did not compare well to in situ measurements
- Effective precipitation estimated by empirical method at monthly time-step
- Irrigation and conveyance efficiencies not considered in irrigation demand estimates

Revised NFS:

- ET estimates from eeMETRIC Model and other remote sensing
- Crop ET estimates by field (>12,000)
- ET estimated for all phreatophyte areas
- Wetland ET estimates compare well to in situ measurements
- Effective precipitation estimated by soil moisture balance method at daily time-step using ET Demands Model
- Irrigation and conveyance efficiencies included in calculation of irrigation demand estimates

Irrigation Diversions to Estimate Natural Flow

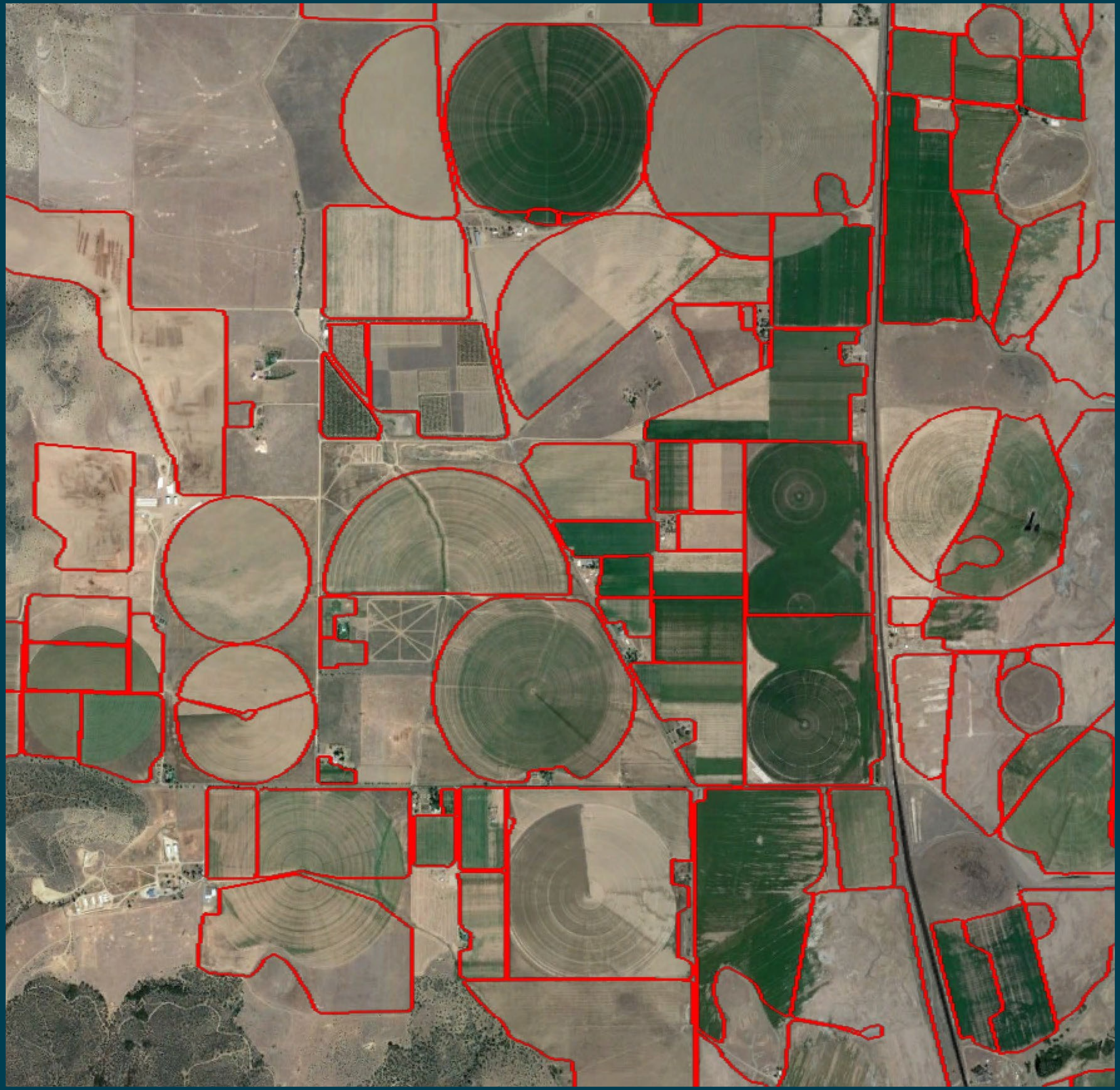
On-farm demands estimated as net ET (ET-EP) divided by irrigation efficiency

Diversion demands estimated as sum of on-farm demands divided by conveyance efficiency

Actual diversion data used for Project diversions

Field Boundaries

- Review and refinement of over 12,000 existing field boundaries
- CA boundaries developed by consultant required minor refinements to include maximum irrigation extent
- OR boundaries developed by OWRD/DRI for maximum irrigation extent, but needed refinements
- Boundary modifications made with digitizing in GIS by TSC/DRI at 1:2,500 scale

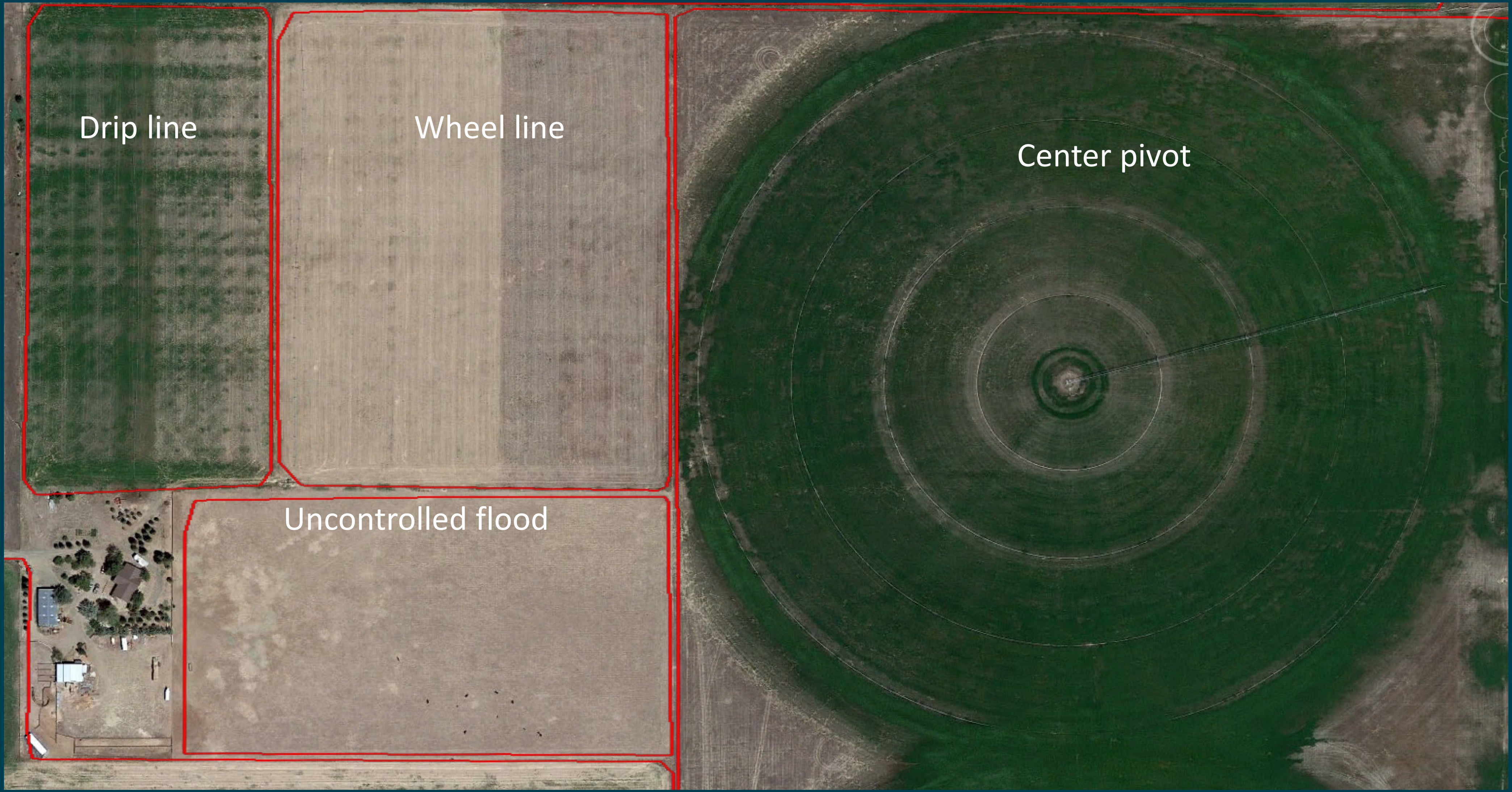


Irrigation Type ID and Efficiencies

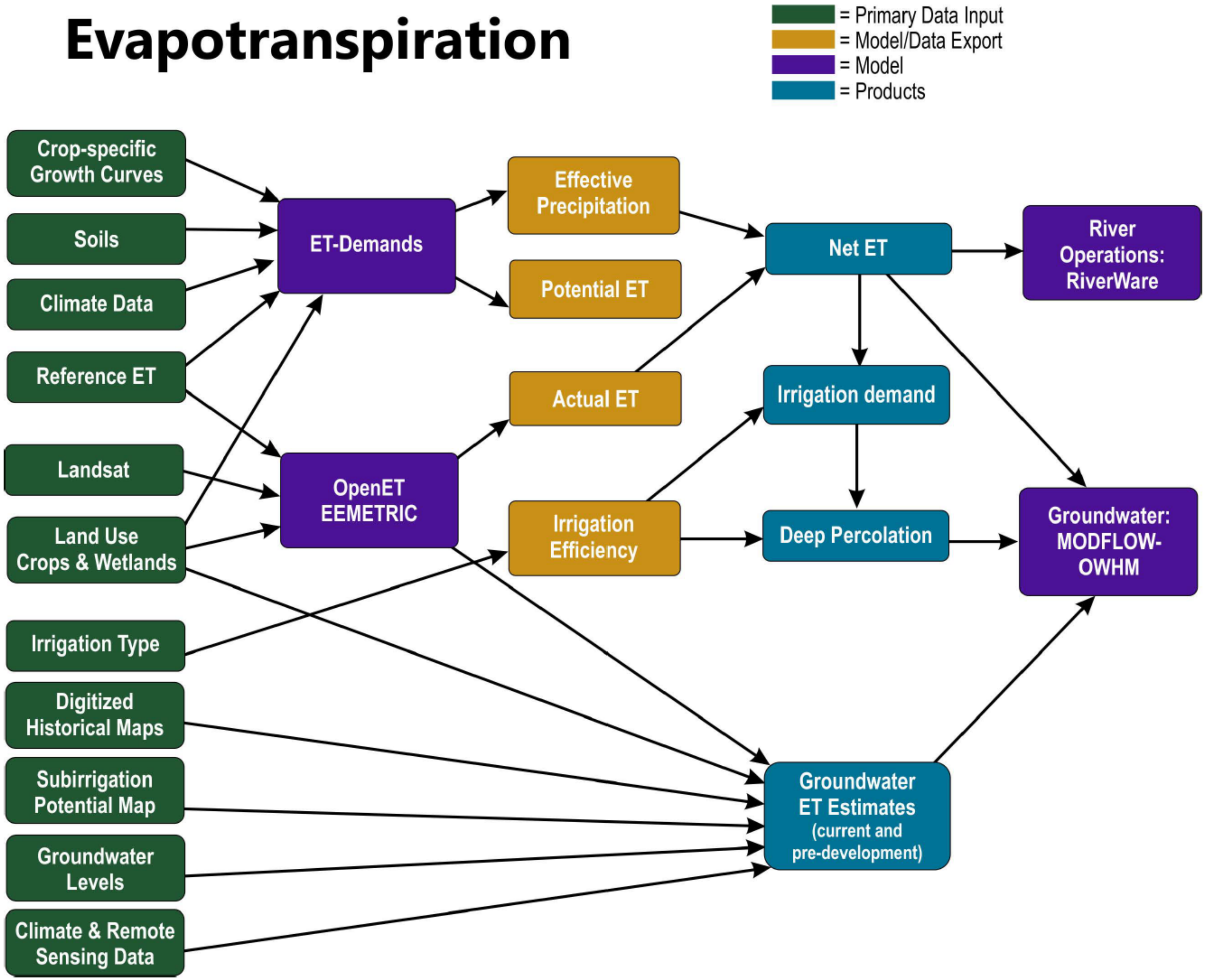
- Evaluation of one-meter resolution aerial photography from National Agricultural Imagery Program (NAIP)
- NAIP exists for 2003 - 2020
- Five irrigation types with varying irrigation efficiency rates
- 1980 – 2002 irrigation types assumed unchanged from 2003
- Analysis by TSC/DRI Team led by Bill Cronin

Irrigation Type	**Efficiency Rate**
Sprinkler pivot & linear	85%
Sprinkler other	75%
Flood controlled	65%
Flood uncontrolled	50%
Micro	85%

Irrigation Type Examples



Evapotranspiration




DRI
Impactful science, inspiring solutions.

ET Tasks

- Agricultural ET
- Groundwater ET
- ET Demands

ET for Agricultural Areas

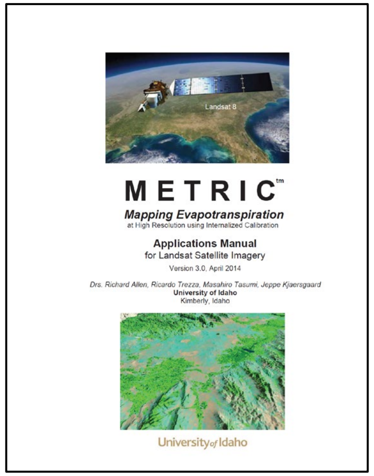
Matt Bromley

Outline

- Model
  - Selection
  - Input Data
  - Model Extent
  - Methodology
  - Calibration
- Natural Flow Representation
- Sensitivity & Uncertainty Analysis
- Summary

Model Selection

- eeMETRIC was selected for this study to estimate ET for agricultural areas
- METRIC has previously been used in the Klamath Basin (2004, 2006, 2010, 2013, and 2014)


Landsat 8

METRIC™

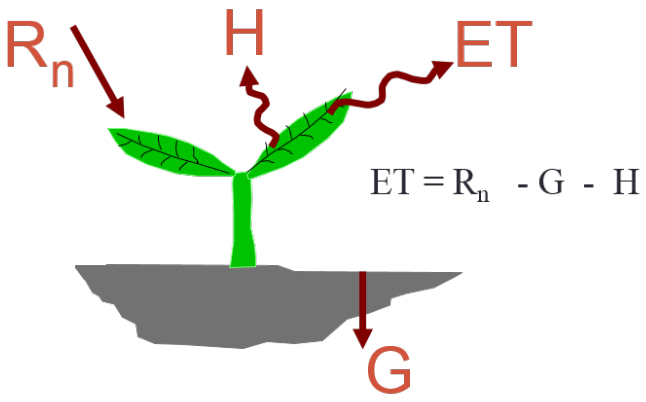
Mapping Evapotranspiration
at High Resolution using Internalized Calibration

Applications Manual
for Landsat Satellite Imagery

Version 3.0, April 2014

Drs. Richard Allen, Ricardo Trezza, Masahiro Tasumi, Jeppe Kjaersgaard
University of Idaho
Kimberly, Idaho

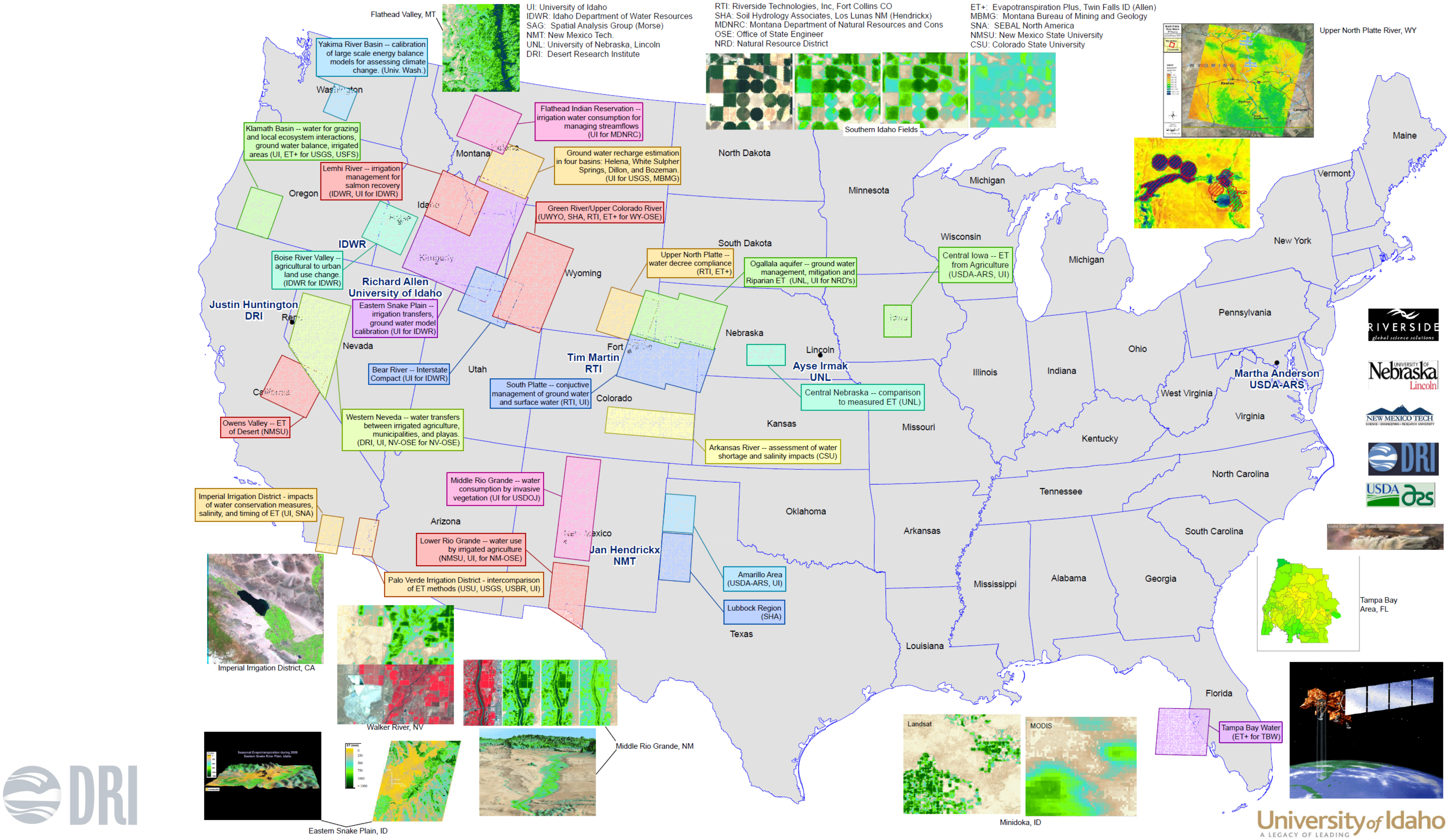
University of Idaho



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)

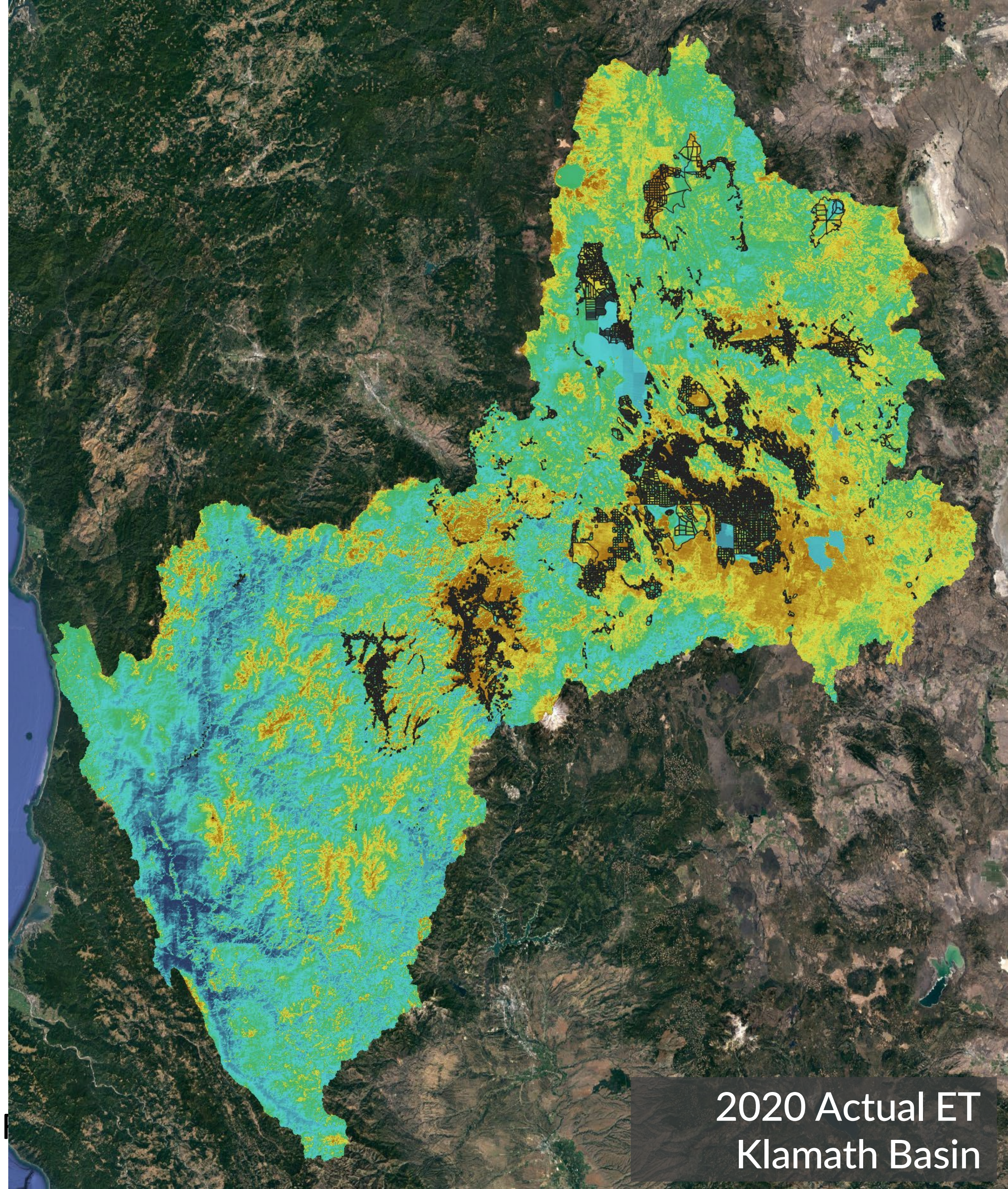


Input Data

- eeMETRIC uses
  - Optical and thermal data from Landsat satellites
  - Bias corrected GridMET for reference ET (atmospheric demand for water)
- ET data generated using Google Earth Engine

Model Extent

- Monthly actual ET for 1984-2020 at 30-meter resolution
- Model domain covers all areas within the KNFS boundary, with spatial summaries extracted for all fields
- Model extent covers the entire Klamath Basin



Modeling Methodology

Agriculture field boundaries attributed with crop type, irrigation status, etc.

Monthly ET rasters (1985-2020)

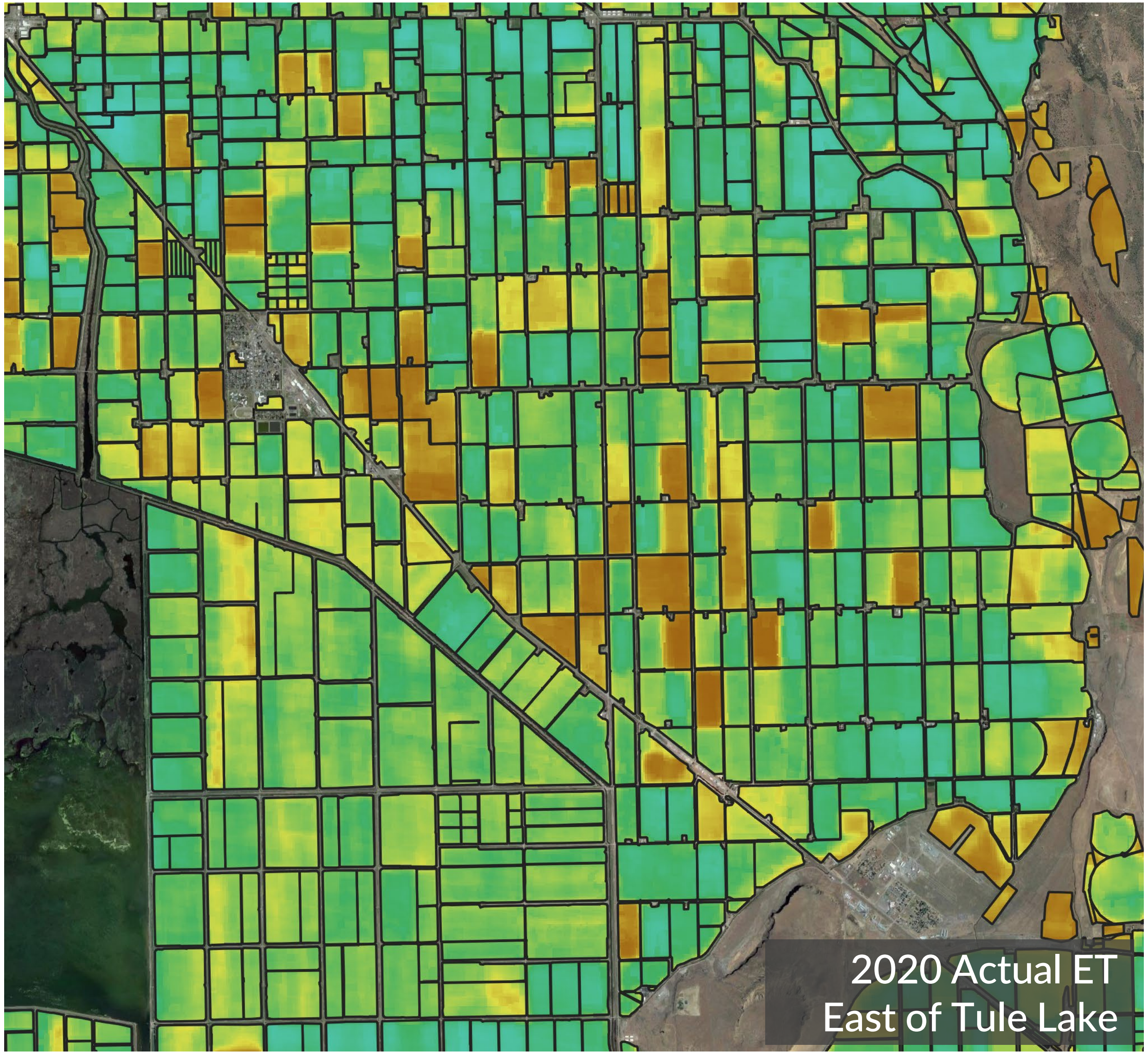
- Actual ET at 30-meter resolution

Spatial summaries

- Monthly time series for > 12,000 fields
- Analogous years used to populate 1980-1984 ET

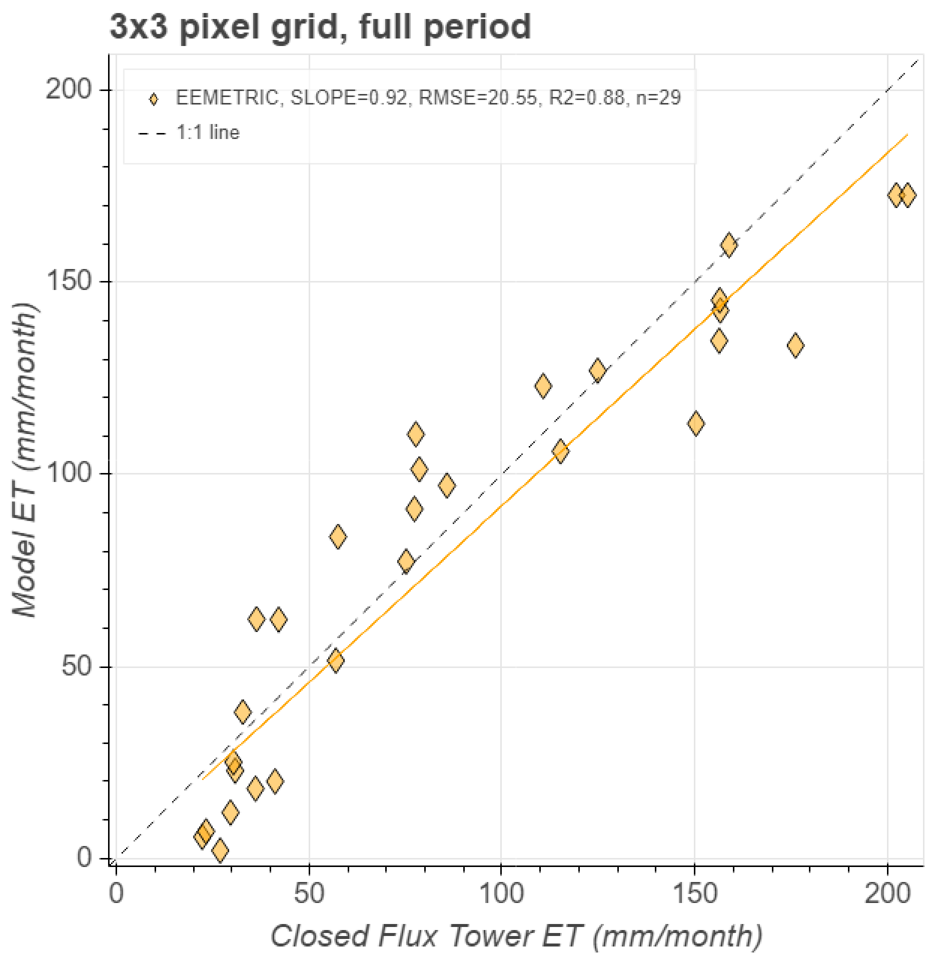
eeMETRIC summaries paired with ET Demands effective precipitation to estimate monthly Net ET

- Majority crop type 2008-2020 used for pre-2008 classifications



Model Calibration

- eeMETRIC is not calibrated specifically to station data
- eeMETRIC uses automated calibration which relies on normalized vegetation index, surface temperature, and albedo
- Validation at eddy-covariance sites (Stannard et al., 2013)
- Comparison with previous METRIC estimates in the region



Comparison to 2005 Natural Flow Study

- 2005 Approach
  - SCS Modified Blaney-Criddle Method
  - Diversion records, acreage
  - Approach assumed crop coefficient curves
- Current Approach
  - Satellite data to characterize land surface conditions
    - Irrigated areas
    - Water stressed areas
  - Energy balance model

2022 Growing Season Timelapse
Klamath Basin

Sensitivity & Uncertainty Analysis

- Intercomparison and accuracy assessment
- Percent error calculated from eddy-covariance station in region
- ET +/- percent error is reported to USBR/USGS for study

Summary

- eeMETRIC is used to calculate cropland ET
  - Datasets include ET data for entire study area, ET summarized by agricultural field boundaries
- Improved upon the 2005 Study by:
  - Uses actual crop conditions as observed by satellites
  - Does not rely on accuracy of crop classification, diversion records, surveys of crop yield/health, etc.
  - Makes use of long period of record from Landsat and GridMET
  - Uses best available science to calculate ET
- Natural flow represented by removing:
  - Water used to irrigate agriculture (surface and groundwater)
  - Consumptive use

Groundwater ET

Blake Minor

Outline

- Model Purpose
- Model Extent
- Input Data
- Methodology
- Model Output
- Sensitivity & Uncertainty Analysis
- Natural Flow Representation

Model Purpose

Beamer-Minor groundwater ET (Beamer et al., 2013; Minor, 2019)

- Transferable empirical approach that relates Landsat-derived vegetation indices to 54 site-years of flux tower measurements of ET
- Incorporates surface meteorological data (gridMET 4km) to account for variations in climate

Beamer-Minor provides estimates of annual groundwater ET from phreatophytes and wetlands, not irrigated agriculture

- Previous Applications:
    - Great Basin
        - Humboldt River Basin
        - Spring Valley, Red Rock Valley, White River Valley, Crescent Valley, Oasis Valley, and Dry Valley Hydrographic Areas

DRI

Model Extent

Model Set-up

- Spatially varying climate and vegetation vigor (greenness)
- Groundwater ET from 1984-2020 at 30-meter resolution
- Model domain covers all phreatophyte and wetland areas
- Extents based on contemporary and pre-project phreatophyte mapping effort in the upper Klamath Basin

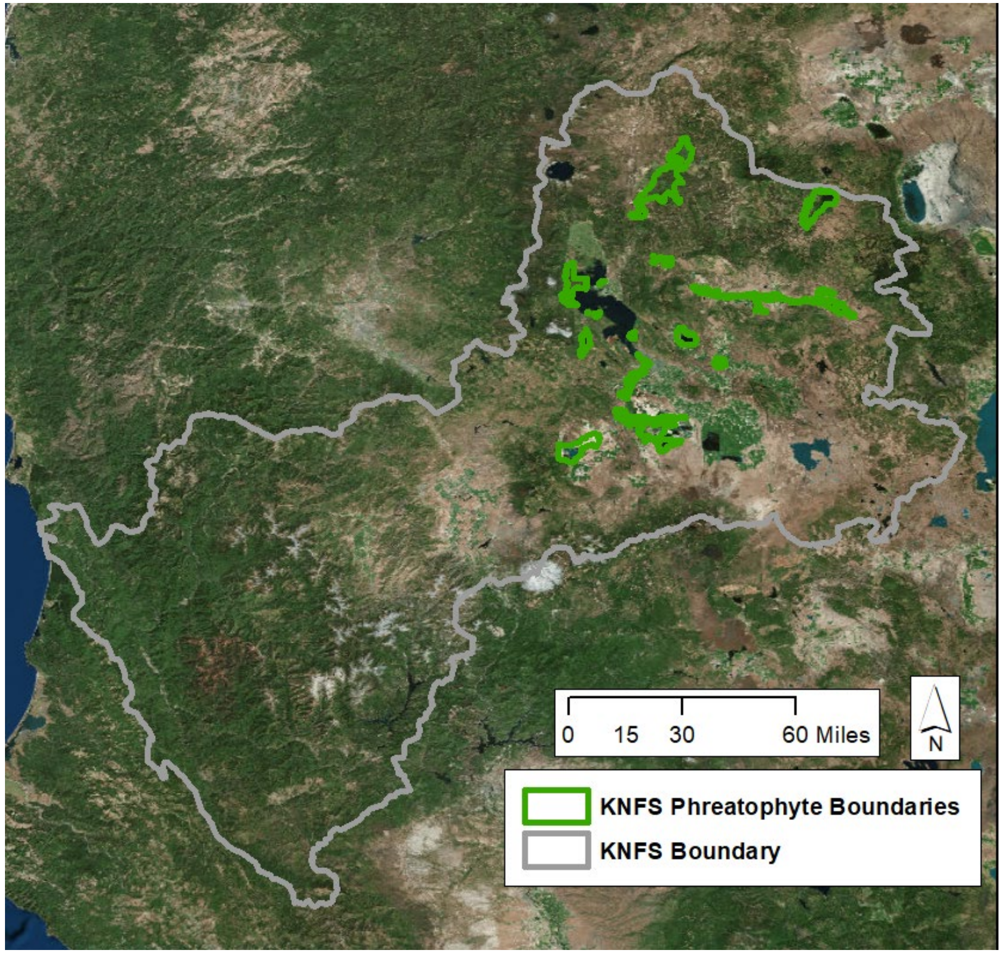


Figure: Map of upper Klamath NFS existing phreatophyte and wetland boundaries, or areas of potential groundwater discharge.

Beamer-Minor Model

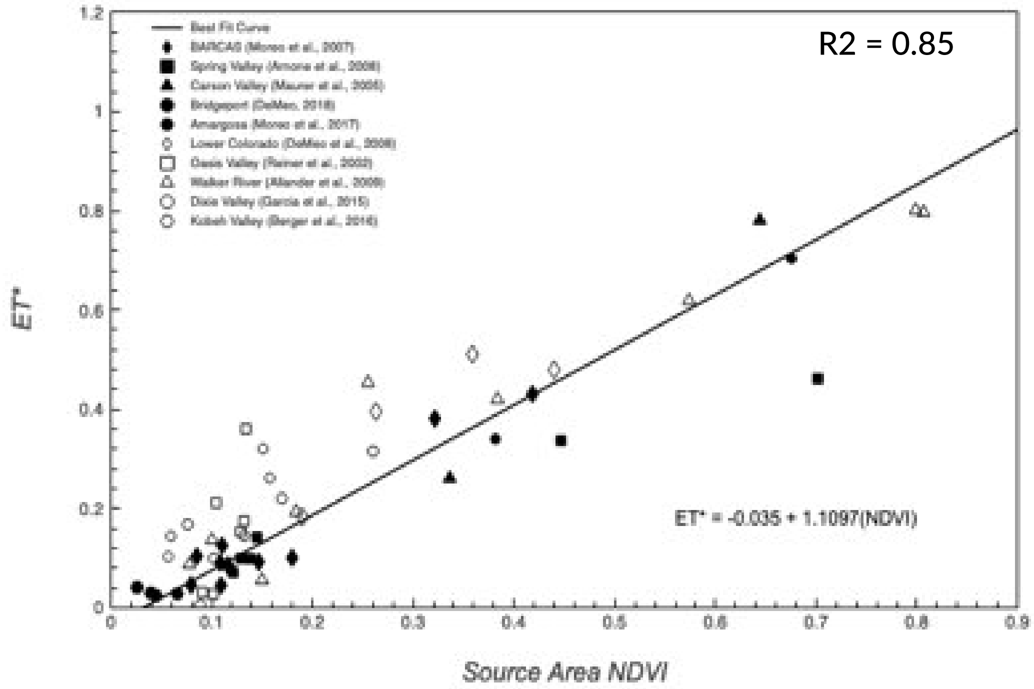
Annual Groundwater ET

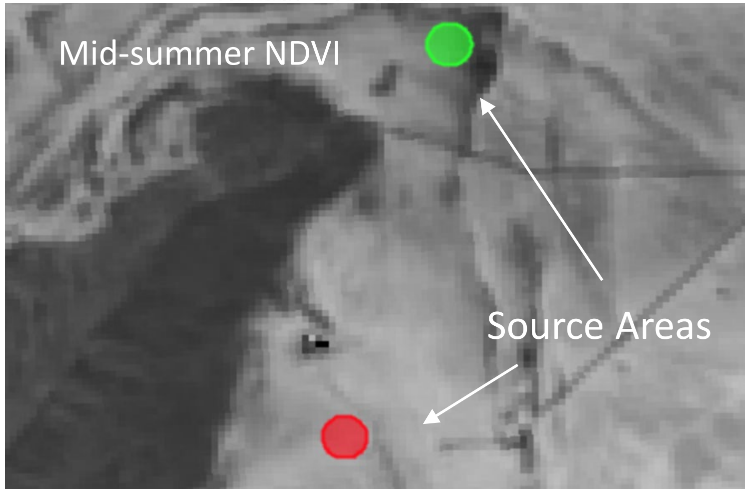
- Model that relates in-situ estimates of annual actual ET from phreatophytes to mid-summer Landsat source-area average NDVI
  - Energy balance corrected ET
  - Normalization to account for variations in climate

    ET* = (ETa - PPT) / (ETo - PPT)

- Mid-summer NDVI images (1984-2020) used to predict ET* from groundwater discharge areas

- Reference ET (ETo) and precipitation (PPT) used to then estimate actual ET (ETa) and groundwater ET (ETg)





DRI

Input Data

Areas of potential groundwater discharge

- Shapefile/polygons delineating contemporary wetland and phreatophyte extents

Remote Sensing

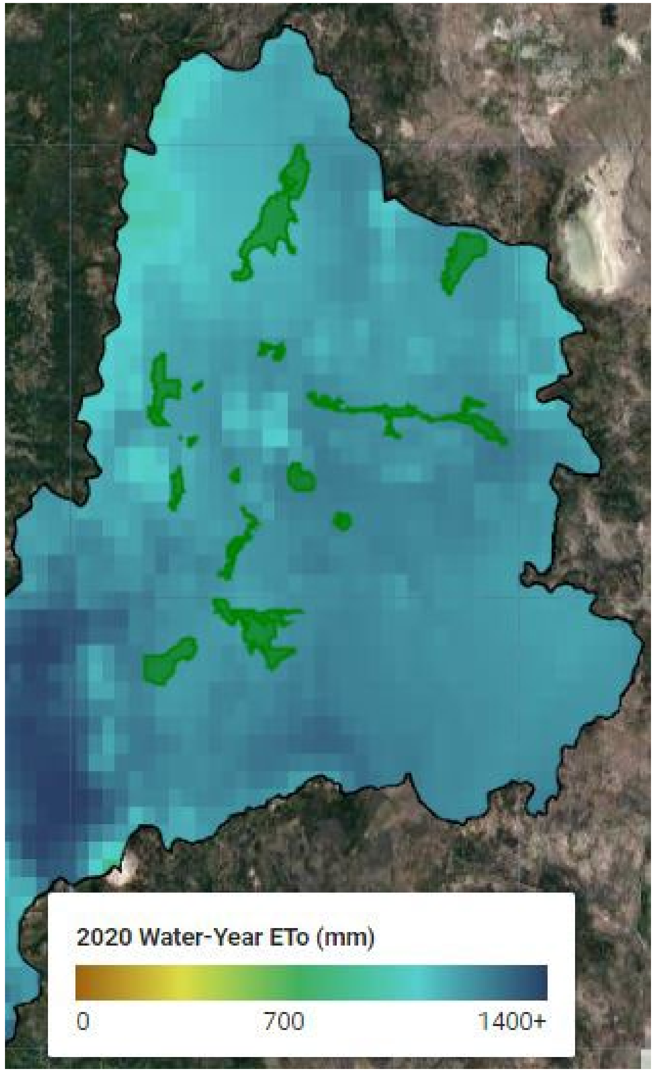
- Landsat Collection 2 Surface Reflectance
    - 30 m resolution NDVI (16-day return intervals)

Climate

- gridMET
    - Daily estimates at 4 km resolution
    - Tmin, Tmax, RH, Windspeed, Solar Radiation, Precipitation

ASCE Standardized PM Reference ET

- Grass Reference ET, ETo



Modeling Methodology

Google Earth Engine Python API

- Phreatophyte/wetland polygon shapefile used to define extent of pixel-based analysis
- Landsat archive processing (1984-2020)
  - June-Sept median NDVI
  - Apply Beamer-Minor regression to predict ET*

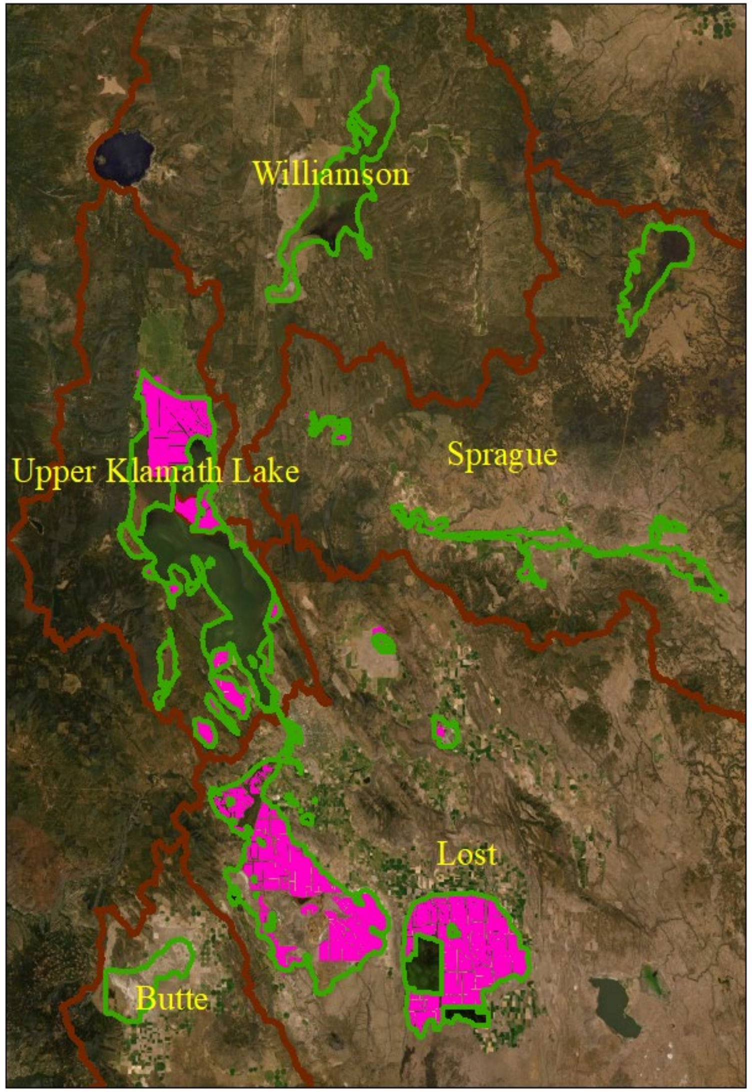
- Pair ET* with annual gridMET ETo and PPT to estimate annual ETg

$$ETg = (ETo - PPT)ET^*$$

ETg for irrigated fields within the groundwater discharge area estimated using rates from adjacent phreatophytes/wetlands

- Scaling factors can be used to reduce ETg for surface water flood-irrigated fields or irrigated pasture/grass-hay

Use contemporary ETg rates from phreatophytes/wetlands and pre-development extents to represent pre-development groundwater discharge



Model Output

Groundwater ET

- Annual output (1984-2020)
- Raster (30 m) and spatial summary table formats
- 90% confidence and prediction interval rasters

Disaggregation to seasonal

- Use water-year ETg/ETo ratios and apply to seasonal ETo
    - Quarterly ETg rasters for each water-year
        - Oct-Dec, Jan-Mar, Apr-Jun, Jul-Sep

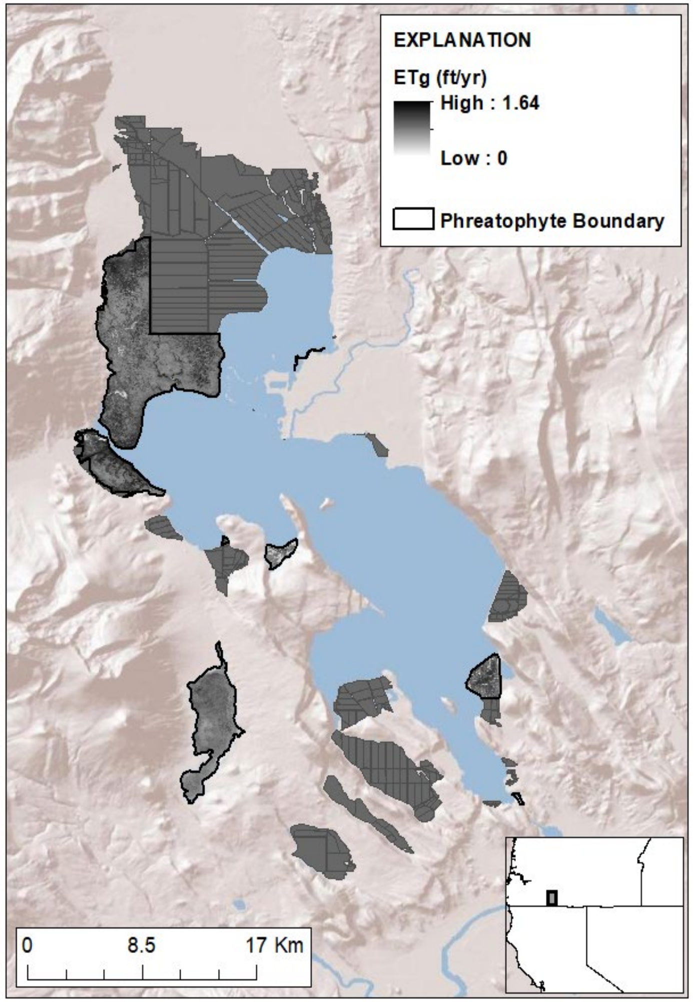


Figure: Map showing median annual groundwater ET for Upper Klamath Lake phreatophytes and wetlands.

DRI

Comparison to 2005 Natural Flow Study

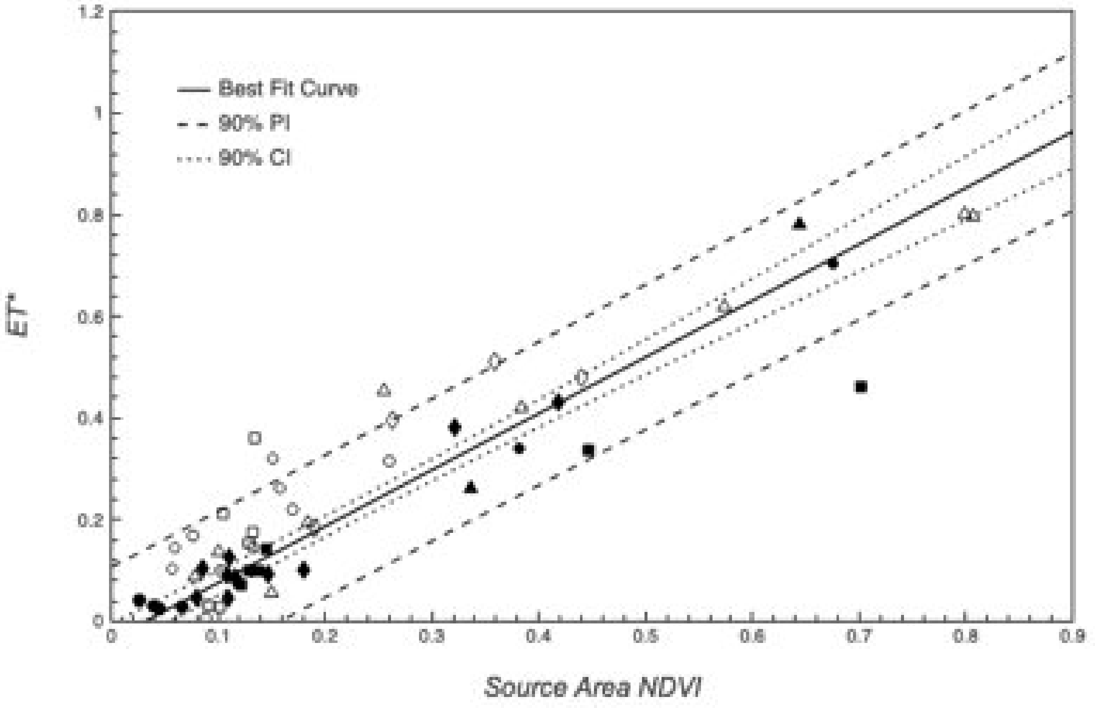
- 2005 Approach
  - USDA-SCS Modified Blaney-Criddle
    - Overly simplistic using monthly average air temperature
    - Estimates only for Upper Klamath Lake
    - No consideration of vegetation vigor variations
- Current Approach
  - Beamer-Minor empirical
    - Calibrated with in-situ measurements of actual ET
    - Accounts for variations in both climate and vegetation vigor
    - Automation and cloud computing enable rapid application
    - Provides uncertainty bounds

U Klamath Lake	Phreatophyte/Marshland Area (acres)	Median ETg/Avg. Net ET Rate (ft/yr)	Median ETg/Avg. Net ET Volume (acre-ft/yr)
Current Study	57,387	1.15	66,225
2005	52,200	1.21	63,000

90% confidence interval: 61,202 – 71,225 acre-ft per year
90% prediction interval: 47,345 – 82,573 acre-ft per year

Sensitivity & Uncertainty Analysis

- Beamer-Minor
  - Upper and lower 90% confidence and prediction interval estimates
    - CI shows range of values associated with some statistical parameter of the data, such as the population mean ET*
    - PI shows the range in which a future individual observation will fall
      - Must account for both the uncertainty in estimating the population mean, plus the random variation of the individual values



Summary

- Used the Beamer-Minor method to estimate annual/seasonal groundwater ET from phreatophytes and wetlands
  - Datasets include annual and seasonal groundwater ET rasters, uncertainty estimates, and spatial summary tables
  - Calibrated using 54 site-years of ET measurements from flux towers
- Improved upon the 2005 Study by:
  - Leveraging eddy covariance and Bowen ratio flux tower measurements of actual ET to develop the model
  - Using a robust, automated remote sensing approach that accounts for spatial and temporal variations in vegetation vigor and climate
  - Addressing uncertainty in estimates by providing 90% confidence and prediction bounds

Natural Flow Representation

- To simulate Natural Flow the following features are modified:
  - Use pre-project wetlands extent and estimates of pre-project wetland ET.
  - Remove ET and deep percolation recharge in irrigated areas (this will be accounted for in the groundwater model)

ET Demands

Chris Pearson

Outline

- Model Purpose
- Model Extent
- Input Data
- Methodology
- Model Calibration
- Model Output
- Comparison to 2005 Natural Flow Study

Model Purpose

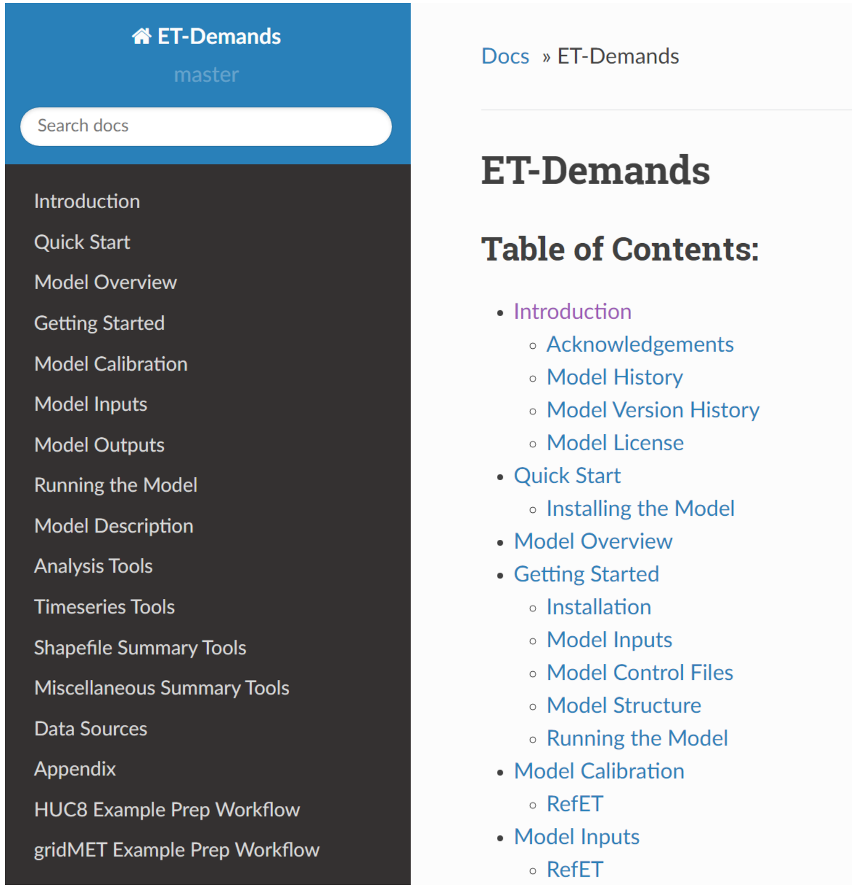
ET Demands Effective Precipitation

- The eeMETRIC model provides estimates of total ET
- Total ET = ETprecipitation + ETirrigation

Effective precipitation is defined as the amount of precipitation that is available for ET (Bos et al., 2009).

ET Demands provides estimates of daily Crop ET and Pe using a daily soil water balance approach

- Previous Applications:
    - Upper Colorado River Basin
    - Nevada
    - Idaho
    - West-wide Climate Risk Assessments



Model code and documentation: https://github.com/usbr/et-demands

Model Extent

Model Set-up

- Spatially varying climate and crop information
- Simulate Crop ET and Effective Precipitation from 1980-2020
  - 1979 initialization year
- Model domain covers all areas with irrigated agricultural
- Based on KNFS field boundary dataset

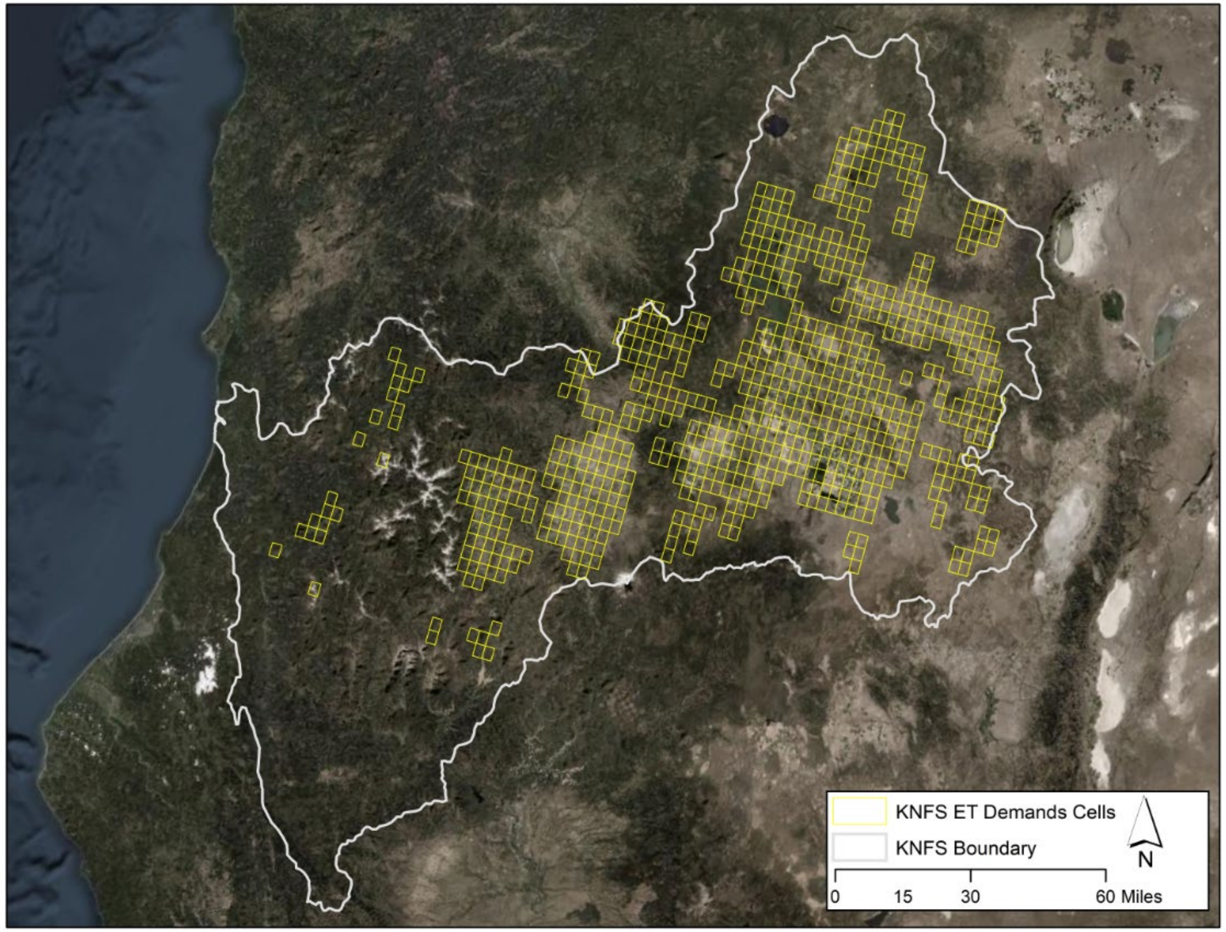


Figure: Map of Klamath NFS ET Demands Model domain. Crop ET simulations are made for each for each unique crop, grid cell combination.

ET Demands Model

Daily Crop ET and NIWR Estimates

- Crop ET
    - ASCE Standardized PM Reference ET
    - FAO-56 Dual Crop Coefficient Method
        - Kc = Kcb + Ke
- Daily Soil Water Balance
    - Effective Precipitation
        - P_rz = Amount of PPT available for both E and T
        - Pe = PPT - Runoff - Deep Percolation
    - Deep Percolation
        - Drainage below the crop root zone
        - Soil Water Content > Field Capacity
    - Runoff
        - USDA NRCS CN Approach
    - NIWR
        - ETc - Pe

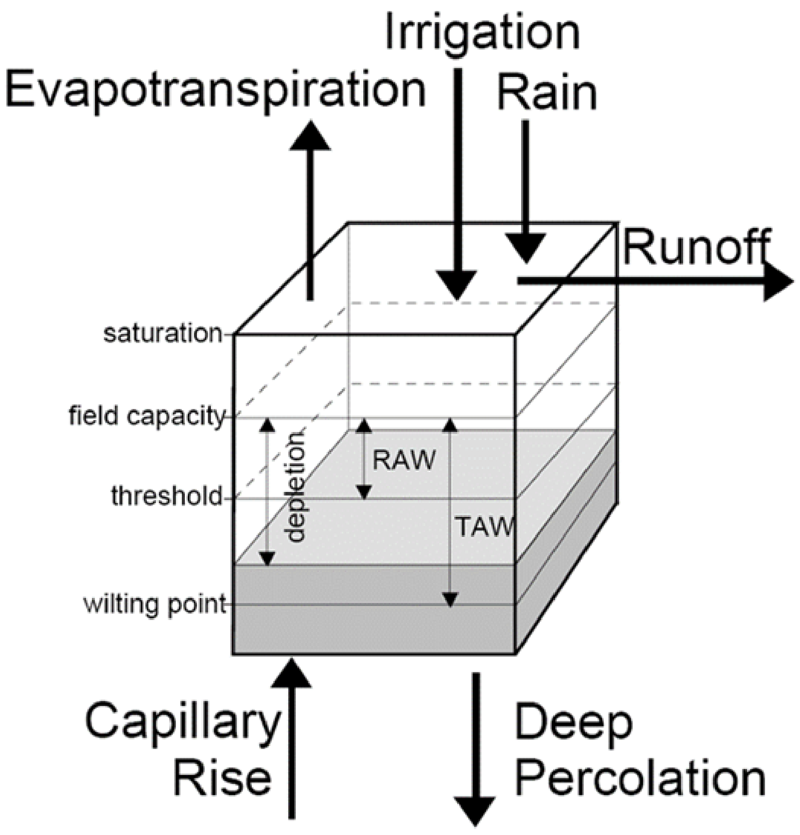


Figure: Conceptual diagram of the FAO-56 daily soil water balance utilized within ET Demands (modified from Allen et al., 2006).

DRI

Input Data

Climate
- gridMET
  - Daily estimates at 4 km resolution
  - Tmin, Tmax, RH, Windspeed, Solar Radiation, Precipitation

ASCE Standardized PM Reference ET
- Grass Reference ET, ETo
- Bias corrected to station data

Soil
- NRCS SSURGO/STATSGO2 Database
- Average 0-150cm available water capacity
- Hydrologic Group – A, B, C
- Sand, Silt, Clay Fraction

Crop Type
- USDA Cropland Data Layer (2008-2020)

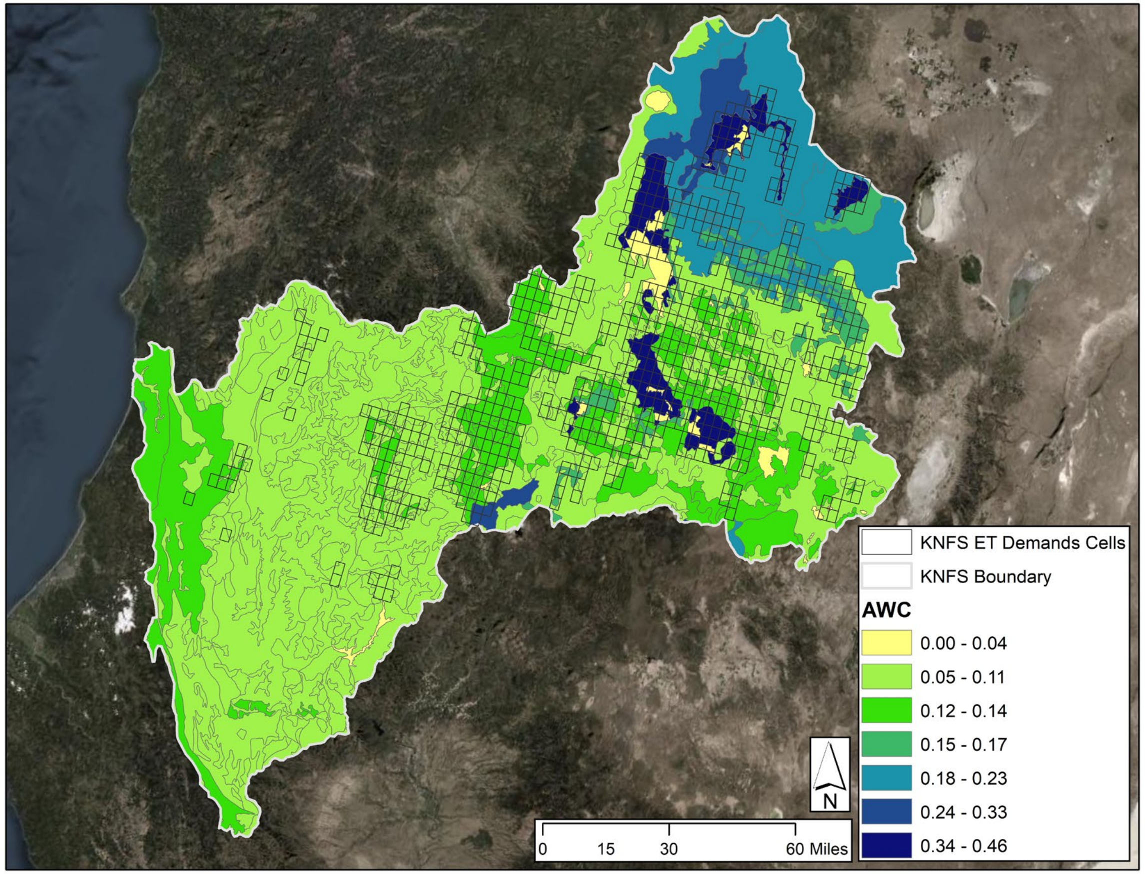


Figure: Map of Klamath Natural Flow study area soil available water capacity from SSURGO/STATSGO dataset.

Modeling Methodology

Crop Growth and ET Simulation

- Temperature-based model
- Green Up
  - T30 or CGDD
- Effective Full Cover
  - CGDD or Time
- Harvest/Killing Frost
  - CGDD, Time, KF

Irrigation Scheduling

- Maximum allowable depletion thresholds
- Irrigation occurs when MAD < Threshold
- For example, 50%

Each crop, grid cell combination is simulated separately. Daily time series output is aggregated to monthly for pairing with RSM ET.

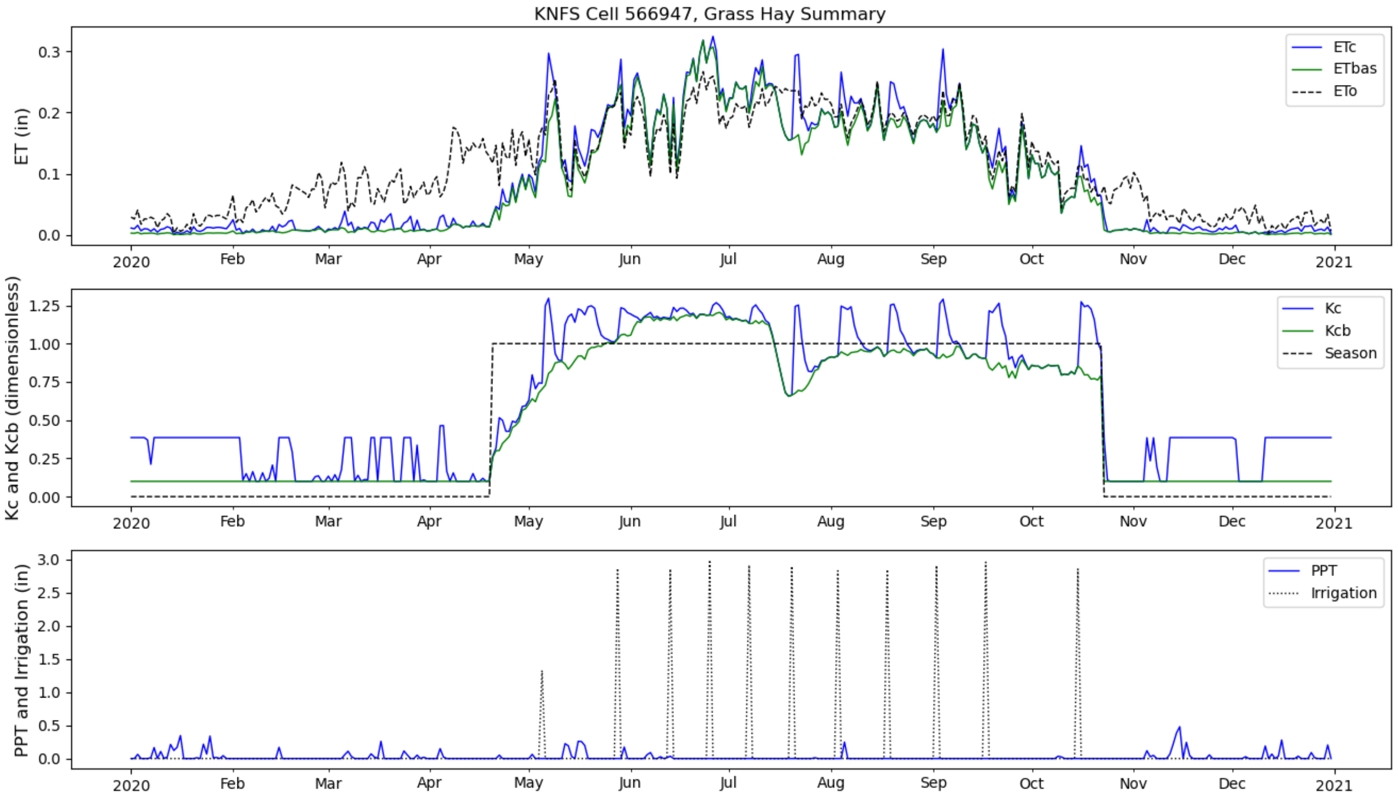


Figure: Example ET Demands output for Grass Hay Crop ET simulation.

Model Calibration

Calibration Sites

- Crop specific calibrations
- NDVI Comparisons
- Adjust Kc curve based on NDVI phenology
- Leverage typical growing season start and end dates

Goal is to capture average signal and interpolate throughout the entire study area.

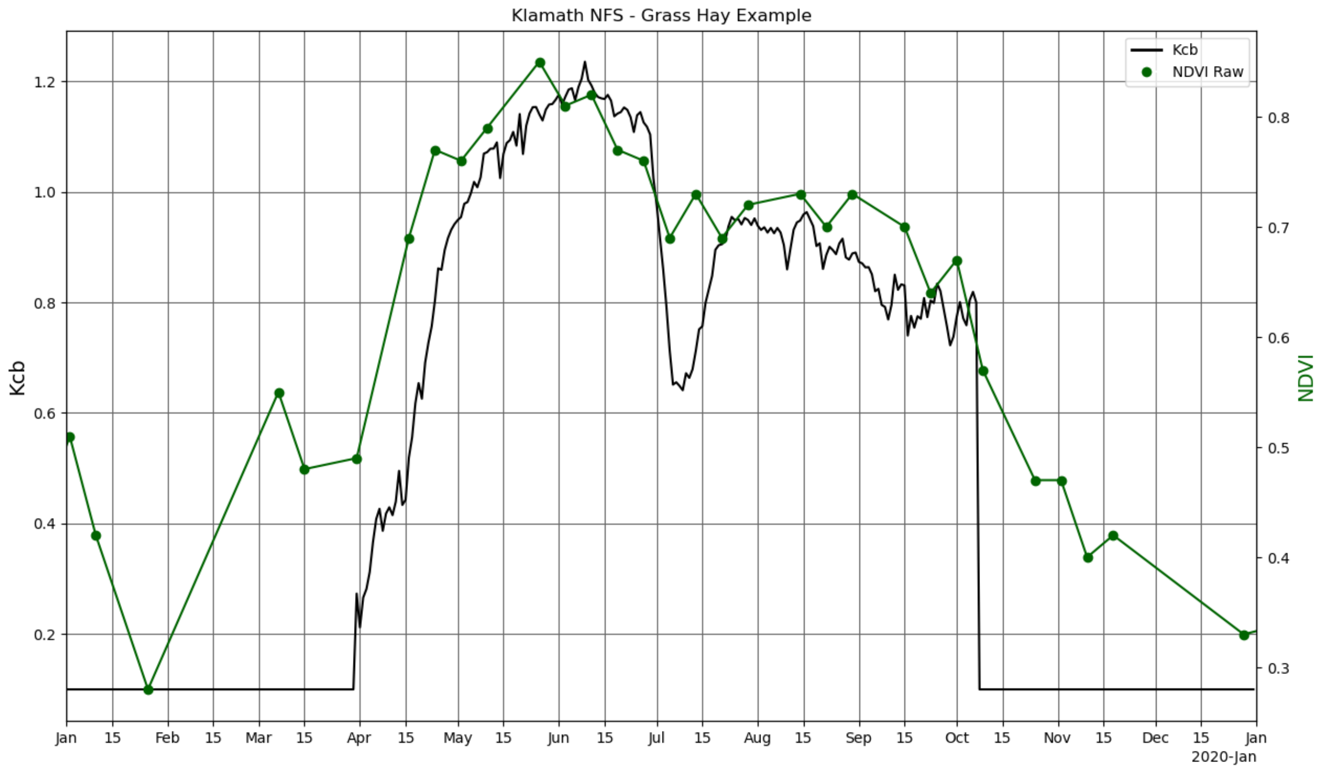


Figure: Time series comparison of Landsat derived NDVI and ET Demands simulated Kcb for grass hay crop in grid cell 564161 near Copoco Lake, CA.

Model Calibration Cont.

Each crop is calibrated independently

Alfalfa Example:
Cuttings:

- Timing of cuttings
- Total number of cuttings
    - Generally, 3-4 cuttings

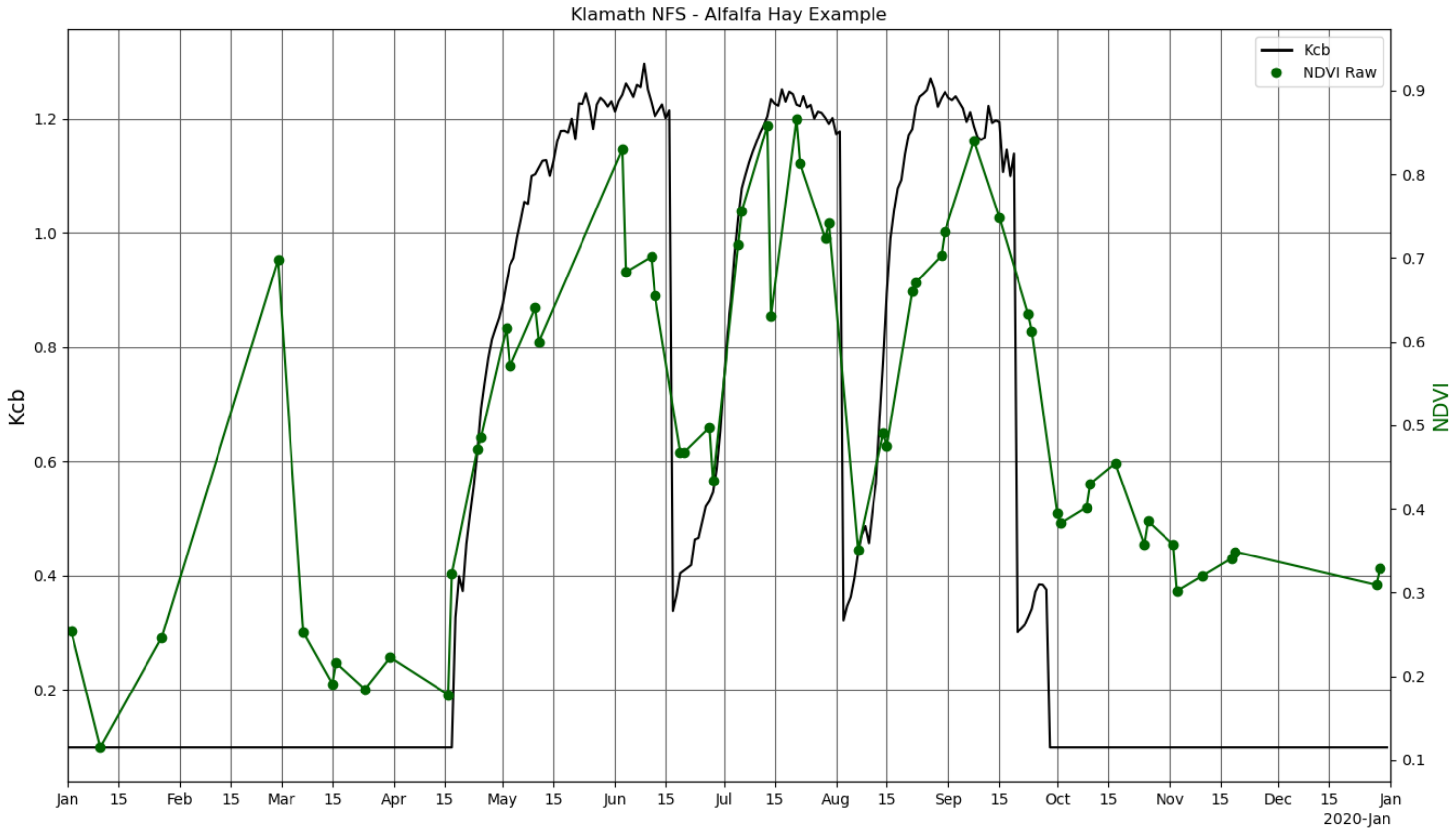


Figure: Time series comparison of Landsat derived NDVI and ET Demands simulated Kcb for alfalfa hay crop in grid cell 565566 outside of Merrill, OR.

Model Output

Effective Precipitation
- Monthly output (1980-2020)
- Crop specific pairing with field-level ET data from remote sensing

P_rz: Precipitation residing in the root zone that is available for both E and T

ET irrigation =
eeMETRIC ETa – ET Demands P_rz

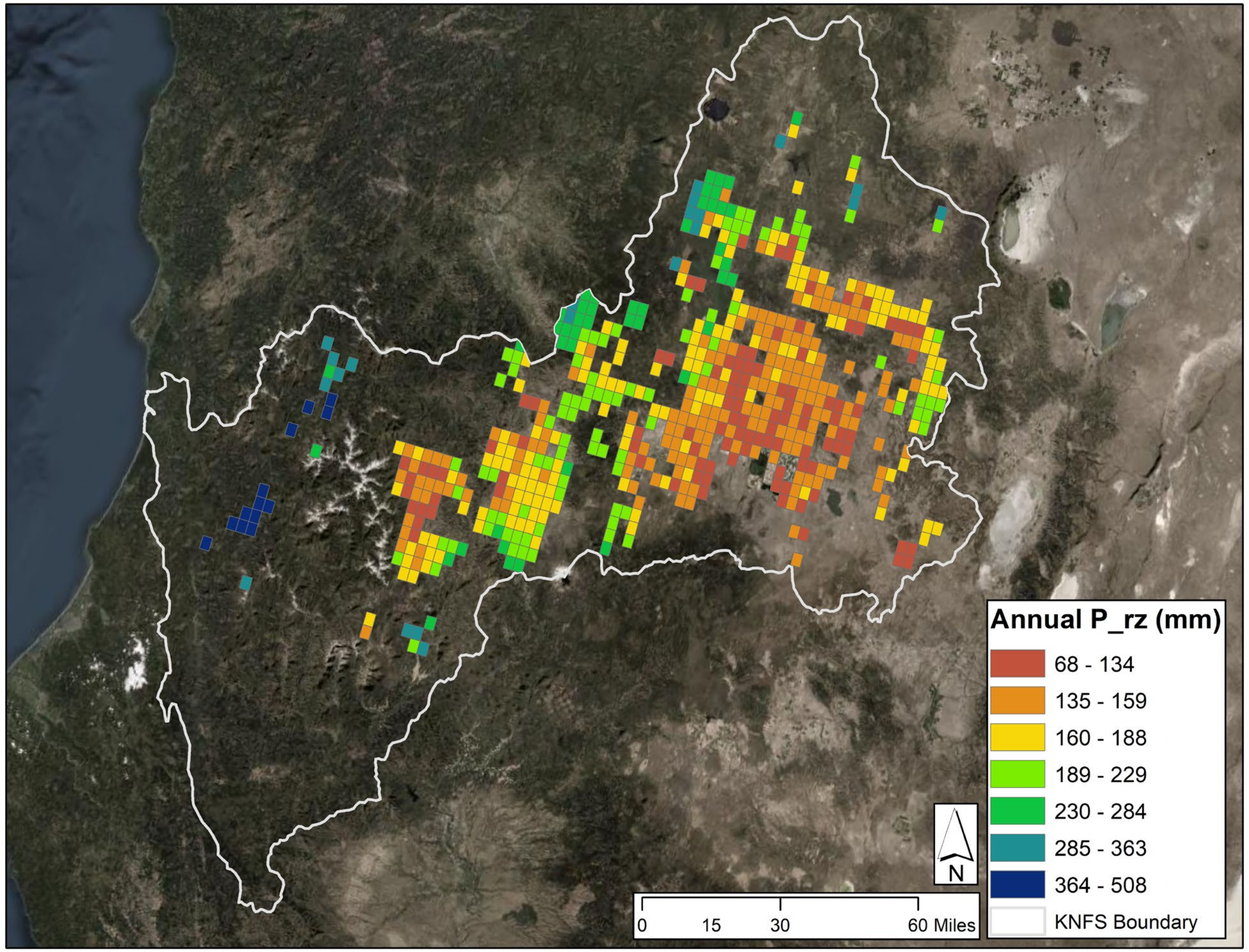


Figure: Map of ET Demands estimated effective precipitation for grass hay fields in 2020.

Comparison to 2005 Natural Flow Study

- 2005 Approach
  - USDA-SCS Method
    - Mean monthly EP
    - Upper limit is ET (no carry forward)
    - Combined with Blaney Criddle ET (CU) for ET irrigation
- Current Approach
  - ET Demands Daily Soil Water Balance
    - Considered the "most accurate method"[1]
    - Crop specific estimates
    - Considers both wintertime precipitation and carry forward soil moisture
    - Combined with eeMETRIC ETa for ET irrigation

[1]Patwardhan et al. (1990)

Questions &
Additional Discussion

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