Toward Field Scale Groundwater Withdrawals in the Western U.S. using Remote Sensing and Climate Data

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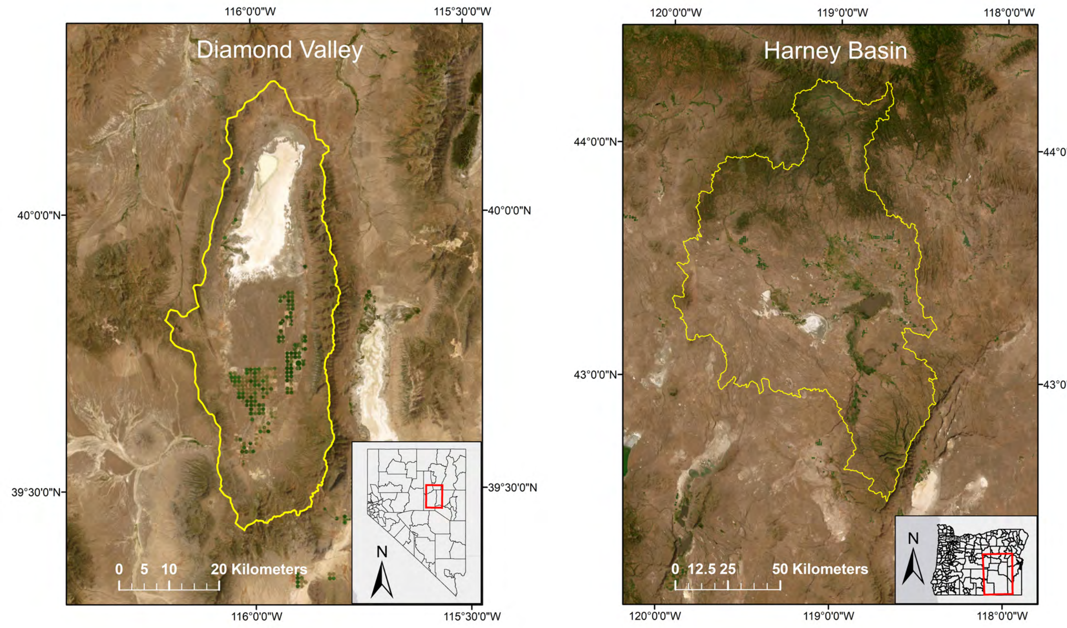
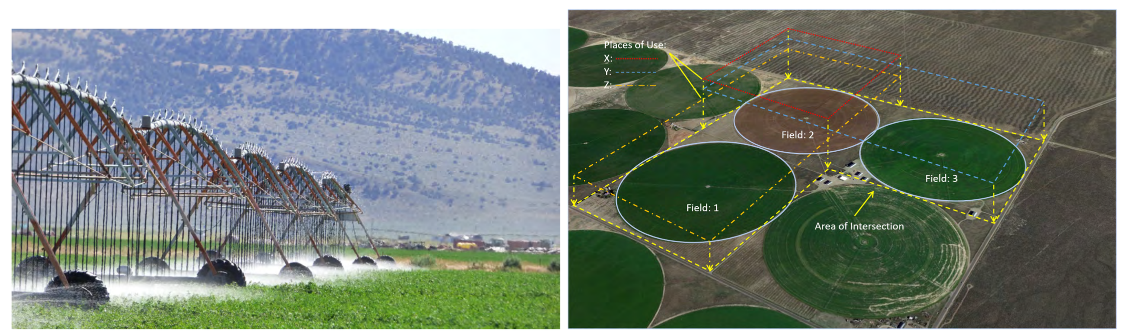
Introduction

- In the Western United States (U.S.), the combination of increased and projected droughts, rising irrigation water demands, and population growth is expected to **intensify groundwater consumption**, leading to adverse consequences like aquifer depletion and land subsidence [1, 2, 3].
- **New water management policies across the Western U.S. states have begun to include mandatory reporting of groundwater withdrawals or pumping.**
- Understanding how much water is being withdrawn from aquifers allows water managers to manage groundwater resources more effectively.
- Most GP in U.S. western states is used for **irrigated agriculture**, e.g., in Nevada, California, and Oregon, about 70% to 90% of groundwater is used for irrigation [4].
- The existing methods for estimating groundwater withdrawals are either costly and time-consuming, or they cannot generate dependable predictions at the scales required for effective local management.
- While our earlier works on **integrating remote sensing and machine learning techniques** to estimate gridded (1-5 km) groundwater use in Kansas [5], Arizona [6, 7], and the Mississippi Alluvial Plain [8] have been successful, field-scale estimation is still a challenge yet often required.





Research Goals and Objectives

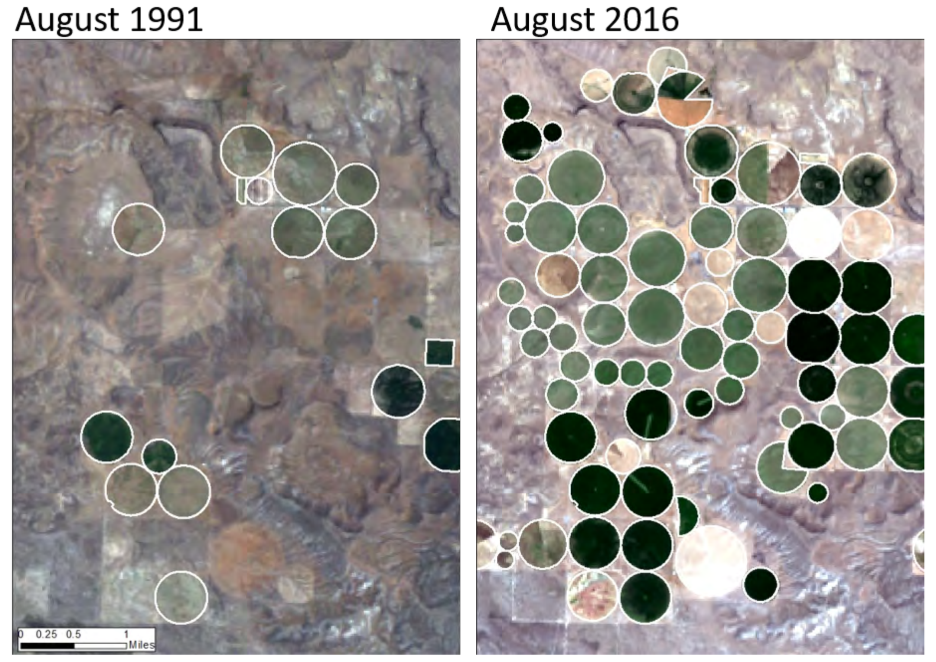
- We hypothesize that **satellite (Landsat)-based actual evapotranspiration (ET) estimates from OpenET [9] can be used to predict groundwater pumping (GP) or withdrawals and aid in QAQC of the reported GP data**.
- For this purpose, the objectives of this study are as follows:
  (a) to pair OpenET estimates of consumptive groundwater use (Net ET, i.e., actual ET less effective precipitation) and metered annual GP data from Diamond Valley (DV), Nevada, and Harney Basin (HB), Oregon;
  (b) to evaluate linear regression and ensemble machine learning (ML) models (e.g., Random Forests) to establish the GP vs Net ET relationship, and
  (c) to compare GP estimates at the field- and basin-scales.

Study Areas

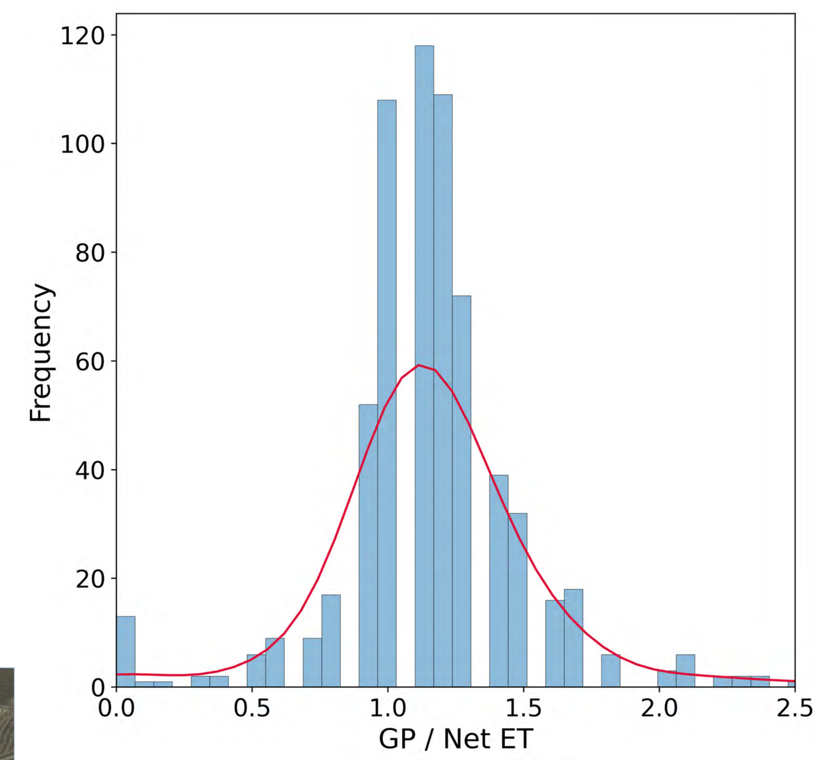
- **Diamond Valley (DV)** is located in Central Nevada and is a fully metered groundwater-dependent basin.
- **Harney Basn (HB)** is located in south-eastern Oregon, where irrigation is the primary user of groundwater, accounting for 95% of all groundwater use.
- DV is fully groundwater-dependent, and HB has mixed water rights, i.e., fields are irrigated with groundwater, surface water, or a combination of the two.
- **The primary crops irrigated in both these regions are alfalfa and grass hay.**

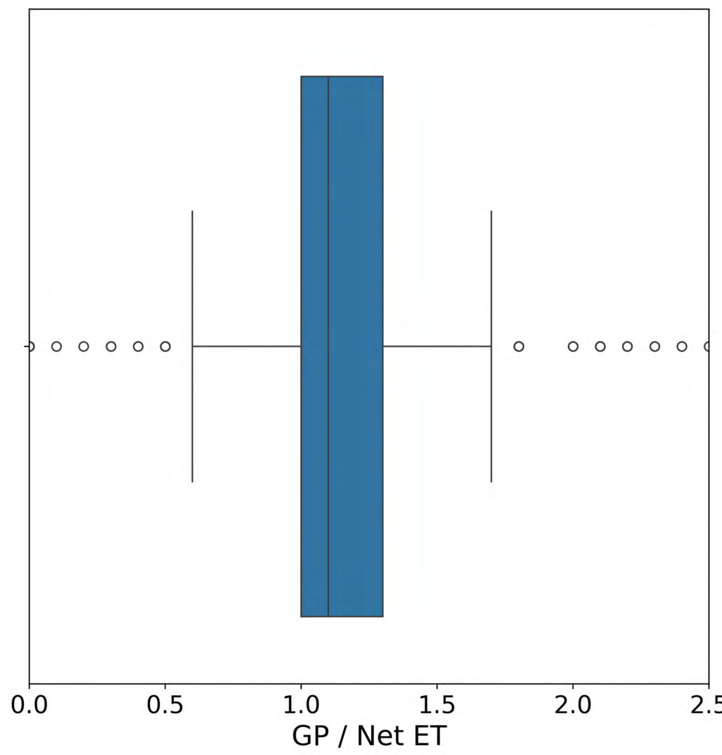
Methods and Datasets

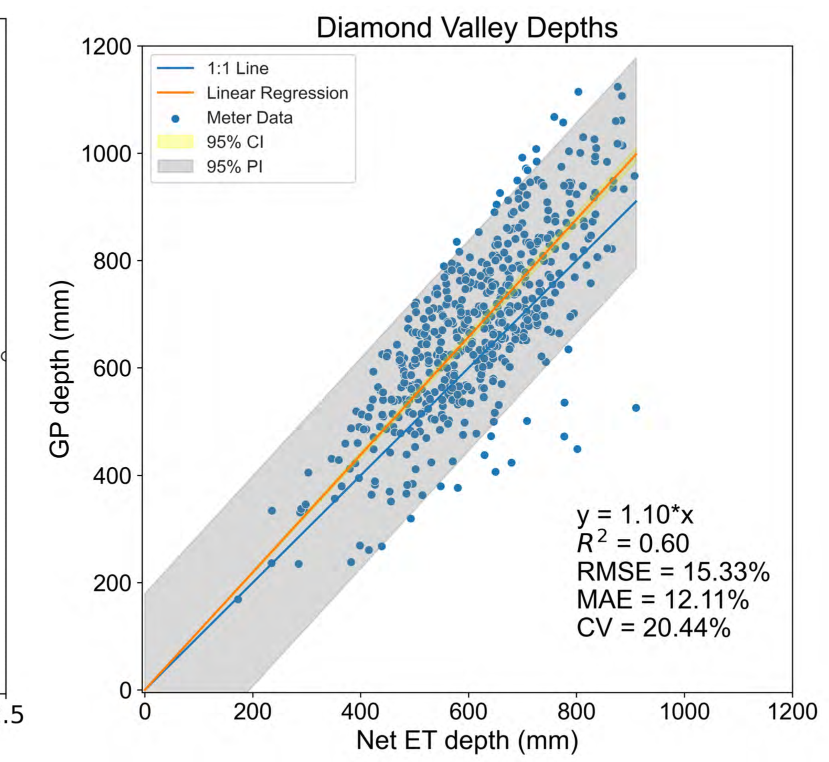
- **Net ET:** Consumptive groundwater use calculated as satellite-based actual ET from OpenET [9] minus effective precipitation from gridMET [10] and ET-Demands [11].
- **Irrigation Data:** Carefully attributed field boundaries as part of the OpenET project and water source type data [12].
- **Handling outliers:** Groundwater withdrawals (or pumping) and Net ET ratios to identify discrepancies in the metering data. We remove meter data which are 50% below or 150% above the consumptive use.
- **Linear Regression:** Building linear regression models with Net ET as the predictor in DV, Nevada, and HB, Oregon.
- **Machine Learning:** Comparing ensemble ML approaches, e.g., Random Forests (RF), Extremely Randomized Trees (ERT), and Gradient Boosting Trees (GBT) in DV, Nevada.
- **70-30%** train-test split with **5-Fold** cross-validation for assessing the ML models. The ML models have 28 predictors obtained from various remote sensing and climate data.

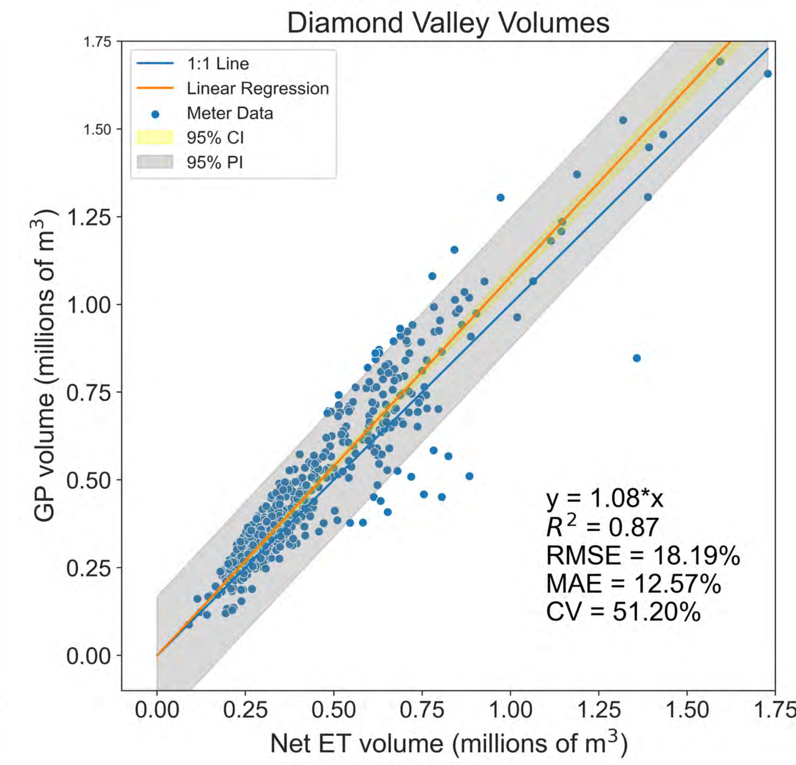


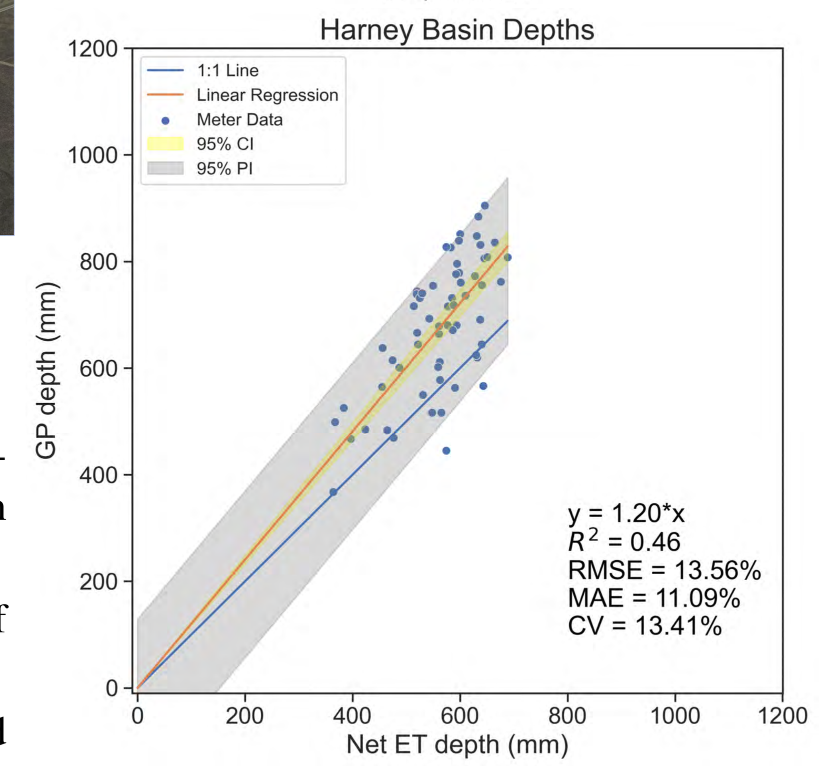
Results and Analysis

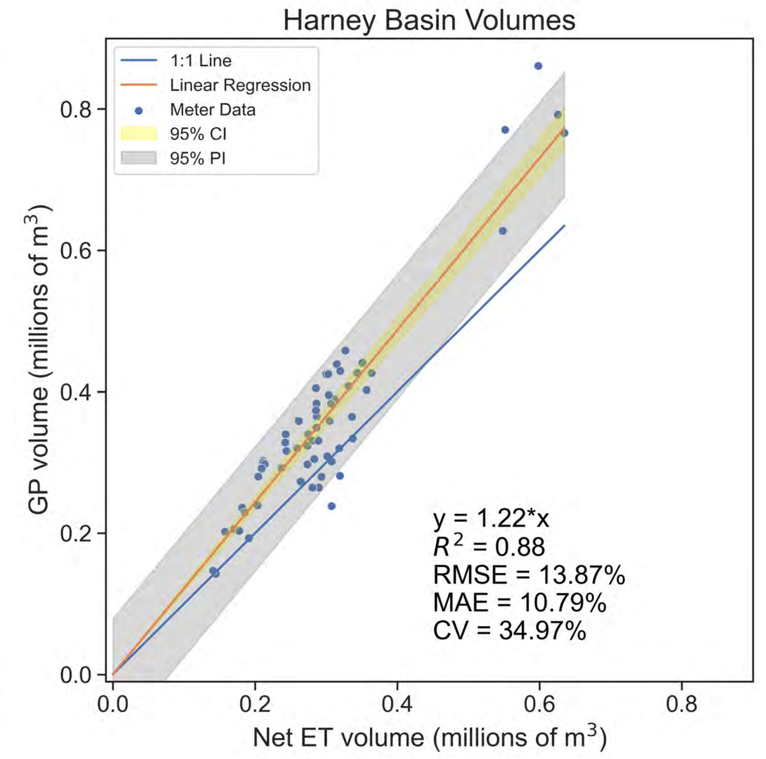


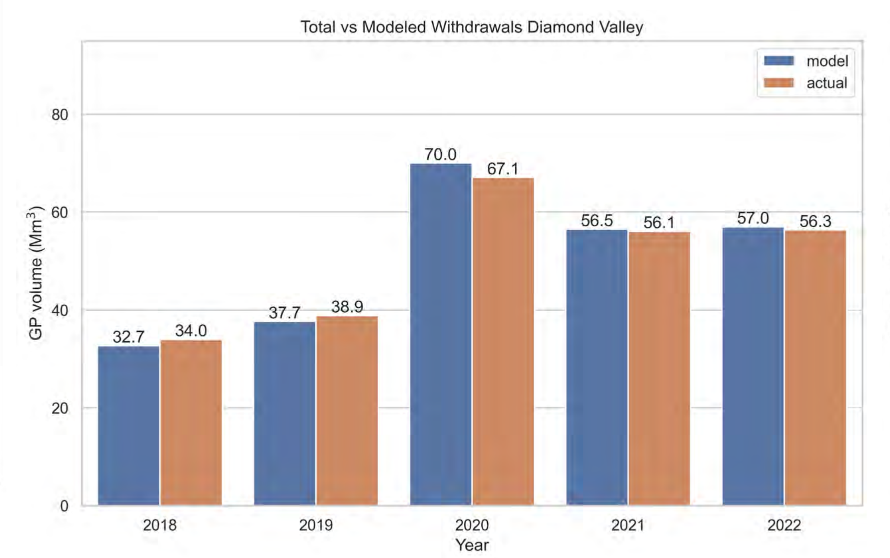


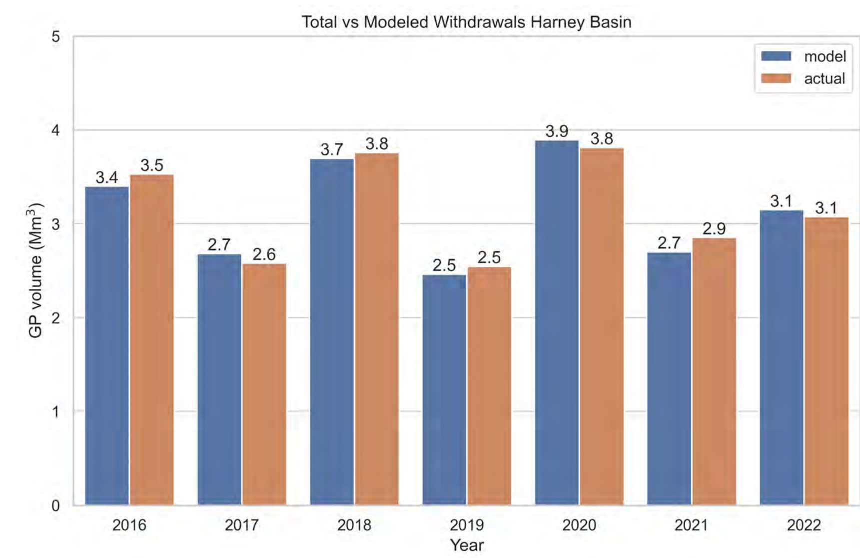












- The regression models, including the machine learning ones in Kansas [5] and Arizona [7], can explain 50%-80% variance in the pumping depths and ~90% variance in the pumping volumes.
- We find that the ERT model gives the best prediction performance with test R^2 = 0.63, RMSE = 14.82%, MAE = 11.46%, and CV = 17.43%, which is marginally better than the DV, Nevada linear regression model (R^2 = 0.6, RMSE = 15.33%, MAE = 12.11%, and CV = 20.44%).
- The estimated average irrigation efficiency of 88% (92% and 83% in DV and HB, respectively) aligns with known center pivot system efficiencies.

Conclusions

- Here, we employed statistical (linear regression and bootstrapping) and ensemble machine learning approaches to predict field-scale groundwater withdrawals in Diamond Valley, Nevada, and Harney Basin, Oregon.
- Our data-driven approaches provide a more systematic way of estimating groundwater withdrawals than conventional methods based on water right duties, potential crop ET, low-quality meter readings, or assumed values.
- We provide improved field-scale assessments of groundwater pumping, consumptive groundwater use, and irrigation efficiencies, thereby contributing to more efficient and sustainable water management solutions.
- We are currently compiling in-situ groundwater withdrawal measurements across multiple Western U.S. states and working toward ingesting newer remote sensing products, such as the downscaled SMAP soil moisture data [13].

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