Trout Creek Ranch Water Use Measurement Report

Findings From a Two-Year Pilot Project

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Contents

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Photo Attributions

Cover photo and back cover photo: Trout Creek Ranch, May 2022. Photo by Claire Ruffing.

Acronyms

API	application programming interface
ET	evapotranspiration
FARMS	Farm and Ranch Management Support
NRCS	U.S. Natural Resources Conservation Service
OAR	Oregon Administrative Rules
OWRD	Oregon Water Resources Department
PoA	point of appropriation
PoD	point of diversion
PoU	place of use
SWMPA	Serious Water Management Problem Area
TCR	Trout Creek Ranch
TNC	The Nature Conservancy

Executive Summary

This report presents the findings from a two-year pilot project at Trout Creek Ranch (TCR) in Harney County, Oregon, aimed at evaluating water use measurement technologies for agricultural operations. In response to increasing pressure for water accountability and new regulatory designations like Serious Water Management Problem Areas (SWMPAs), The Nature Conservancy (TNC) and partners compared two on-farm flow meter technologies—propeller and electromagnetic meters—alongside satellite-based evapotranspiration (ET) estimates from the OpenET platform. This pilot explored the technical, economic, and operational considerations of each method to inform statewide water use measurement guidance.

Project Overview and Methods

Four center pivot irrigated fields at TCR were outfitted with both propeller (McCrometer McPropeller) and electromagnetic (Seametrics Ag90) meters, with telemetry installed on the latter. Over two irrigation seasons (2023–2024), field staff recorded meter data and collected anecdotal observations on irrigation operations, maintenance issues, and land management practices (e.g., grazing, haying). Simultaneously, OpenET data were used to estimate field-scale ET and compared to metered water use. The pilot also documented installation processes, infrastructure constraints, and funding mechanisms.

Findings and Key Insights

Meter Performance

The pilot revealed that propeller meters were easy to install and cost-effective but generally require in-person data collection. By comparison, electromagnetic meters offered more detailed data that could be telemetered but required technical expertise and were prone to installation or data access errors.

Telemetered systems (e.g., the electromagnetic meter coupled with the FieldNET platform) added value by allowing for remote monitoring, but they faced connectivity issues and installation challenges.

OpenET Data Use

We found that OpenET is a promising low-cost, low-maintenance option for estimating consumptive use. However, field conditions, such as grazing, infrastructure leaks, or subsurface flow, can skew ET readings, potentially under- or overestimating actual water use. Technical training is needed to use OpenET effectively.

Infrastructure and Practical Constraints

Many farms lack ideal infrastructure for accurate meter installation near points of diversion (PoDs). Funding programs should accommodate installation at the place of use (PoU) when necessary. Both metered and remote-sensing approaches become more complicated in cases where multiple pivots are connected to the same pump.

Recommendations

- Encourage the use of diverse measurement approaches to address site-specific obstacles as needed. Measuring water use consistently and accurately across fields proved to be more challenging than expected.
- Use OpenET technologies when field and infrastructure conditions allow or when installing meters would be infeasible. Where OpenET is not representative of consumptive use (e.g., significant subsurface flow), metering should be used.
- Allow meter installation at the PoU under certain configurations (e.g., a 1:1 pump-to-pivot ratio), with verification of system integrity by the Oregon Water Resources Department (OWRD).
- Promote training programs for meter installation and use, as well as OpenET data interpretation.
- Develop standardized logging tools or apps for producers to report water use.
- Continue testing hybrid approaches (meter + OpenET) for cross-validation and resilience in monitoring.

This project demonstrates that no single method will meet all measurement needs, but that careful alignment of technology, infrastructure, and user capacity can ensure accurate and cost-effective monitoring. With practical guidance and technical support, both metering and OpenET have the potential to help Oregon's communities respond to water scarcity with improved confidence and accountability. Table 1 provides a comparison of meter types and OpenET, summarizing the opportunities and challenges with each type of water use measurement.

Table 1. Comparison of OpenET and meter requirements for water use measurement.

Comparison category	Meter type		
	OpenET	**Propeller meter**	**Electromagnetic meter**
Measurement type	Estimates consumptive use (actual ET).	Measures diversion use via mechanical rotation.	Measures diversion use using electromagnetic sensors.
Infrastructure needs	No physical infrastructure required. Uses satellite and weather data.	Requires an exposed straight-run pipe section near the PoD or PoU.	Requires an exposed straight-run pipe section and power source if not battery-operated.
Special considerations			Meter may log in reverse if a precise interior diameter measurement is not entered into the meter interface at time of installation.
Installation requirement	None.	Should be installed by a professional irrigation contractor to ensure correct physical insertion into pipe (cutting/drilling may be required).	Should be installed by a professional irrigation contractor to ensure insertion with precise alignment and correct flow direction.
Cost	Minimal. OpenET data are free and publicly available.	Lower cost than electromagnetic (~$2000).	Higher cost than propeller (~$2100–$3500). *
Technical skill needed	Moderate: Spatial data interpretation and OpenET platform use.	Low to moderate: Periodic manual readings required.	High: Setup, calibration, maintenance, data interpretation, and troubleshooting required.
Data collection	Automatic data delivery via OpenET platform or application programming interface (API).	Manual readings. Optional analog or digital display.	Digital readings. Telemetry is available for real-time data access.
Maintenance	None.	Potential wear due to sediment. Requires occasional site visits.	Minimal wear. Regular checks needed of the power and telemetry system functions.
Connectivity needs	Internet access for data access, visualization, and downloads (optional).	None unless telemetry is added.	Cellular or satellite network required for telemetry. FieldNET compatibility.
Site accessibility	Not required.	Accessible location for meter installation and manual readings.	Accessible site for installation, with signal coverage for telemetry and power access if needed.

Comparison category	Meter type		
	OpenET	Propeller meter	Electromagnetic meter
Accuracy	Subject to variability based on field conditions and land management. **	Generally accurate. Can degrade over time with sediment exposure.	Highly accurate if properly configured and maintained.
Regulatory alignment	Supports consumptive-use reporting. May need validation.	Aligns with diversion-use reporting requirements.	Aligns with diversion-use reporting. Higher data resolution with telemetry.
Best use case	Low-cost, broadscale assessment. Remote or infrastructure-limited areas.	Smaller operations with limited budgets and simple system configurations.	Larger operations with technical capacity and a need for continuous, detailed data.

* If researchers do not use telemetry with the electromagnetic meter, capacity and funding costs will increase because either OWRD staff must travel to collect the data or the water user must collect, manage, and report the data. A higher risk of data errors will exist if the water user must complete these tasks.

** In certain situations, estimates of consumptive use derived from OpenET may require further information to ensure accuracy. For example, subsurface flow is likely to cause an overestimate of consumptive use within a field. When OpenET results in an overestimation of consumptive use, the water user may be at risk of regulatory action. In these cases, the water user has the right to appeal the regulation. On the other hand, OpenET data may result in underestimates of consumptive use, such as when there are leaks in the conveyance systems between the meter installed at the PoD and the PoU.

Introduction

Resource managers and water users must understand water use measurement to anticipate the impact of drought on communities and ensure resources are managed sustainably. Water use measurement can benefit agricultural producers by providing important information to improve water use efficiency, maximize crop productivity, and minimize costs related to water use. For example, precise estimates of applied water can help farmers account for crop water use without exceeding the field capacity of their soils, therefore allowing for the beneficial use of potential precipitation and avoiding runoff or other nonconsumptive losses.

Water use measurement is also foundational to implementing many voluntary actions for water management, including incentive programs and market-based solutions in Oregon (Warinner and Young 2021). As of 2019, less than 17% of all water rights have required any measurements (OWRD 2019). That proportion is likely to increase in the near future: recent changes to Oregon law offer new authority to state agencies to require the measurement and reporting of water use (House Bill 2010 in Oregon's 2023 Legislative Session). In addition, the new management designation of a Serious Water Management Problem Area (SWMPA) requires water users within the management area to measure their water use (Meinz and Gall 2023). To date, SWMPAs are being implemented in the Harney Basin, and other basins may be subject to this designation in the near future. However, no standardized or uniform guidance exists to advise communities on which devices to use or to explain when or if water use can be measured via satellite-based remote-sensing tools in lieu of water meters.

Oregon's lack of standardized guidance creates an information gap that hinders resource managers' ability to respond to water scarcity and understand the impacts of drought on water use. The pilot described in this report leveraged on-the-ground experiments at Trout Creek Ranch (TCR), a working ranch in southern Oregon, to compare different types of meters against each other and against satellite-based remote sensing (Figures 1A and 1B). We compared the cost, maintenance, and precision of mechanical flow meters (e.g., McCrometer propeller flow meters) with those of magnetic flow meters (e.g., Seametrics Magmeters). We also compared the benefits and costs of telemetry against the capacity needs of manual data collection. Finally, we compared the benefits of metering diversion water use at the well to the benefits of using newly available satellite-based remote-sensing technology (OpenET) to estimate the consumptive use of water on the fields.

This report provides recommendations to state agencies and communities on when using metered data is most appropriate (and which meters to use) and when satellite-based remote sensing is most appropriate (and associated data interpretation). This report enhances Oregon's ability to respond to drought and manage water resources effectively in the face of increasing drought frequency and magnitude. The water measurement guidance herein aims to assist communities throughout the state, especially following the implementation of future SWMPAs and new legislation enabling the measurement and reporting of water use by state water managers.

Agricultural Water Use

While agricultural water use may seem like a relatively straightforward concept, irrigators and water resource managers alike know that the reality is very complex. Inconsistencies are common in the terminology, disciplinary perspectives, and scales of measurement used to describe water use and irrigation practices (van der Kooij et al. 2013; Linstead 2018). This section provides an overview of common definitions (see Appendix A for all key terms and definitions).

Under Oregon water law, water users must possess a water right documenting the permitted requirements for the beneficial use of water. **Beneficial uses** include activities such as irrigation, domestic use, municipal use, hydropower generation, industrial use, mining, recreation, and ecological function. While some exempt uses of surface and groundwater exist, this report uses the term **water use** to refer to beneficial water use related to irrigation. Water right certificates document four pieces of information important to understanding water use. First, the certificate includes the amount of allowable water use

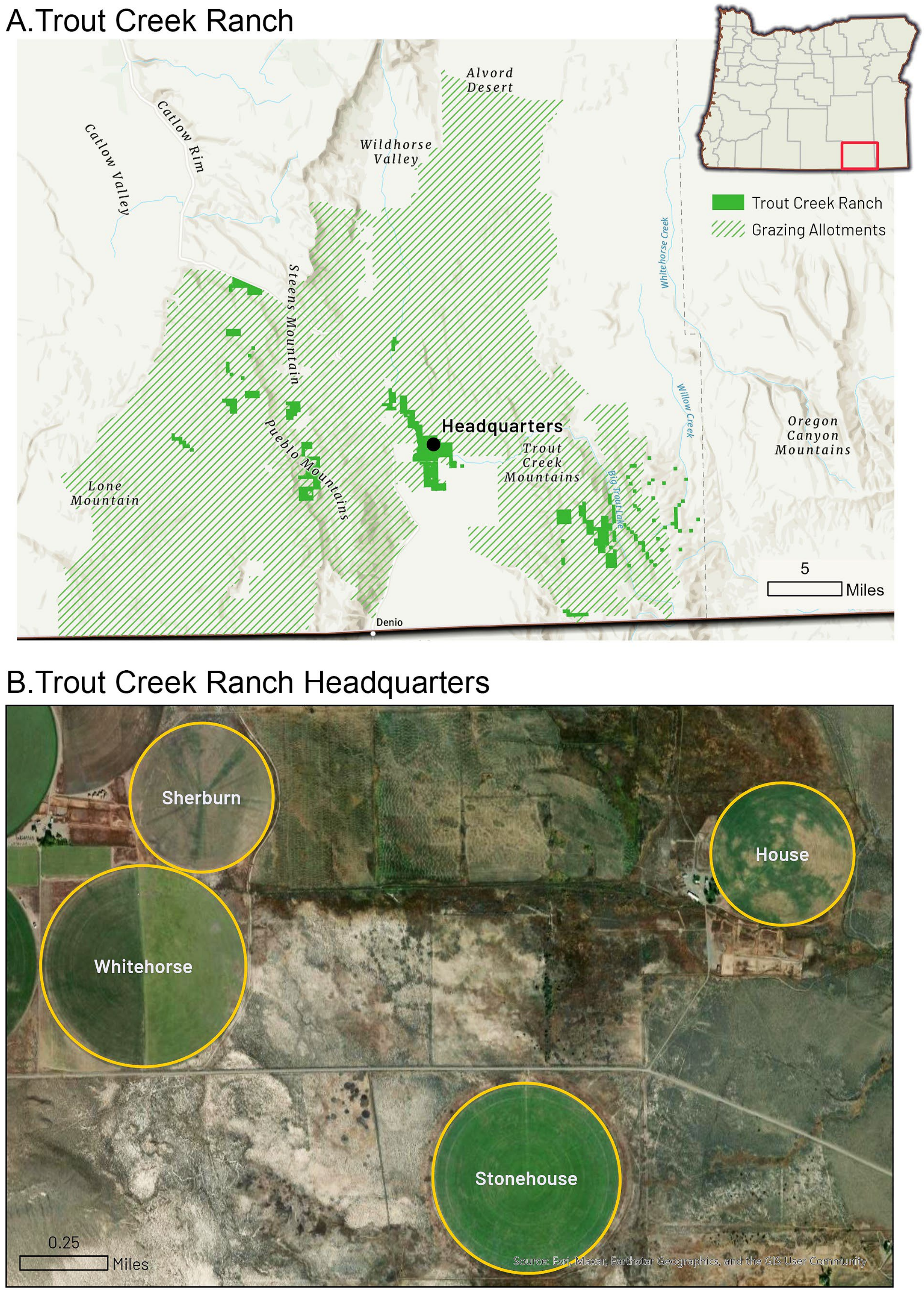

Figure 1. (A) Trout Creek Ranch property extent and headquarters. (B) Location of four monitored center pivot fields that were outfitted with both propeller (McCrometer) and electromagnetic (Seametrics) meters. OpenET data were used for these same fields to estimate evapotranspiration.

(also known as a **duty**) as an instantaneous rate and/or an annual volume that is allowed to be diverted (or pumped in the case of groundwater). The second key piece of information included is a time frame during which the water right can be applied. The third piece of information is the specific place where the diversion or well is located. This location is known as the **point of diversion** (PoD) for surface water rights and the **point of appropriation** (PoA) for groundwater rights. Fourth and finally, the certificate defines the **place of use** (PoU), which identifies where the beneficial use will occur.

In theory, water use measurement should confirm the permitted rate and/or duty stated on a water right. However, the reality of irrigation systems is complicated and measurements of "water use" vary depending on when and where they are measured (Figure 2). For example, **diversion use** refers to the amount of water withdrawn from an aquifer or diverted from a stream. In theory, diversion use should be equal to the duty associated with a given water right, assuming enough water is available to meet demand (Figure 2A). In the context of surface water rights, water diverted through a head gate or similar structure into an irrigation canal or pipeline can be directly measured by a weir or flow meter. Watermasters are typically responsible for regulating water use and ensuring compliance with diversion use provisions in irrigation districts. With respect to groundwater pumping, diversion use can be directly measured by attaching a meter at the pump, or it can be estimated by curating county-scale water use data, using process-based or deterministic models to predict groundwater withdrawals, or applying machine learning approaches to remote-sensing data to infer groundwater pumping patterns (Ott et al. 2024).

In some cases, it may be infeasible to measure water use at the PoD or PoA. It then becomes important to consider the irrigation system as a whole to understand the trade-offs. Typically, as water is moved from the PoD or PoA to the PoU, multiple opportunities arise for water to be "lost" (Figure 2B). This loss can occur as **nontarget consumption** (evaporation or transpiration from weeds or soils) or as **nonconsumptive uses** that are either **recoverable** (return flow to rivers or recharge to aquifers) or **non-recoverable** (no longer available due to the feasibility of access or legal restrictions). It is important to account for these losses when measuring water use in locations other than the PoD or PoA in order to accurately estimate water use.

For example, once water is diverted or extracted from an aquifer, it needs to be transported to a farm or field. This process, known as conveyance, typically occurs through irrigation canals or pipelines. The infrastructure materials and maintenance conditions determine how much water can be lost as return flow, groundwater recharge, or evaporation. Once the water reaches the field, the manner in which the water is applied can also contribute to losses. For example, wheel lines and pivots equipped with impact sprinklers are associated with nonconsumptive losses due to their high rates of evaporation and wind drift compared to mid- or low-elevation spray application systems.

To accurately measure water use as it is being conveyed or applied to a field, one must consider the water present as well as the amount of water lost up to that point. This issue is further exacerbated as a field is irrigated. Once water is applied to a field, measuring water use requires an understanding of soil moisture conditions and evapotranspiration (ET) requirements to distinguish the beneficial water use associated with crop production from nonconsumptive use. **Consumptive use** refers to water used for irrigation that is transpired by plants, has evaporated, or is otherwise removed from the hydrologic system without the possibility of return flow (Figure 2C). Therefore, using consumptive use as an estimate of water use does not account for water lost elsewhere in the irrigation system (Figure 2D).

Measuring Water Use With Meters

Direct Flow Measurement and Diversion Use

First and foremost, resource managers need to understand how much water is being removed from an aquifer, stream, or other natural water source to enable effective long-term management. As previously mentioned, this process—that of moving water from a natural source to an agricultural use or other human use—is called diversion use. Flow meters can provide the most direct measurement of diversion use if installed correctly.

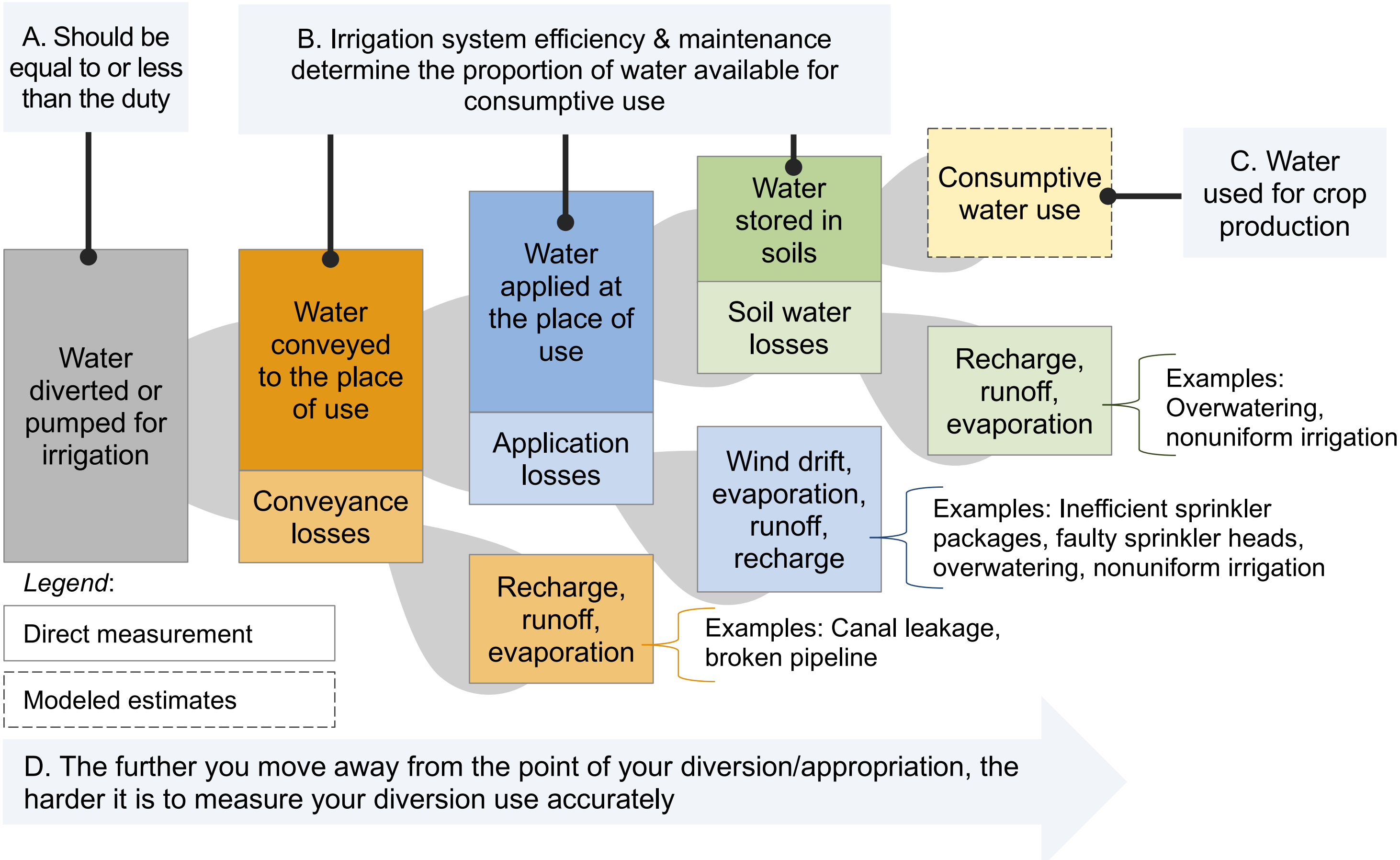

Figure 2. Conceptual diagram of a hypothetical irrigation system and the possible fate of water as it moves from the point of diversion or appropriation to satisfy crop water demand.

Meter Installation

In ideal circumstances, meters are placed as close as possible to the PoD to accurately measure diversion use (Figure 3A), as there may be conveyance losses between the PoD and PoU. For a center pivot irrigation system fed by groundwater, it is best to install the meter along a stretch of horizontal pipe near the pump that meets the minimum standards to achieve laminar flow (as defined in the meter specifications). When it is difficult to install a meter on the existing diversion infrastructure, other configurations may be used. One common arrangement is to install the meter on the pivot riser, with the meter directly measuring the volume of water available for field application (Figure 3B). When information is available about the amount of water being diverted, meters mounted on the pivot riser can be used to understand **conveyance efficiency**, which describes how effectively an irrigation system ensures that all water diverted or extracted from a water source is transmitted to a farm or field. Application and consumptive use ultimately depend on sprinkler packages, maintenance, etc. and cannot be inferred directly from the meters without additional information.

Meter Types

Two main categories of flow meters are available for agricultural water use measurement: propeller meters and electromagnetic meters, often referred to as "magmeters." Propeller meters detect the speed of a propeller placed inside a pipe that spins at varying speeds as water flows through the system. Electromagnetic meters function by measuring the voltage generated as water flows through the pipe. Unlike propeller meters, magmeters do not have any moving parts. Digital displays are standard for magmeters and are available as an option on some propeller meters. It is also possible to equip some magmeters with internal data loggers to record flow data over time.

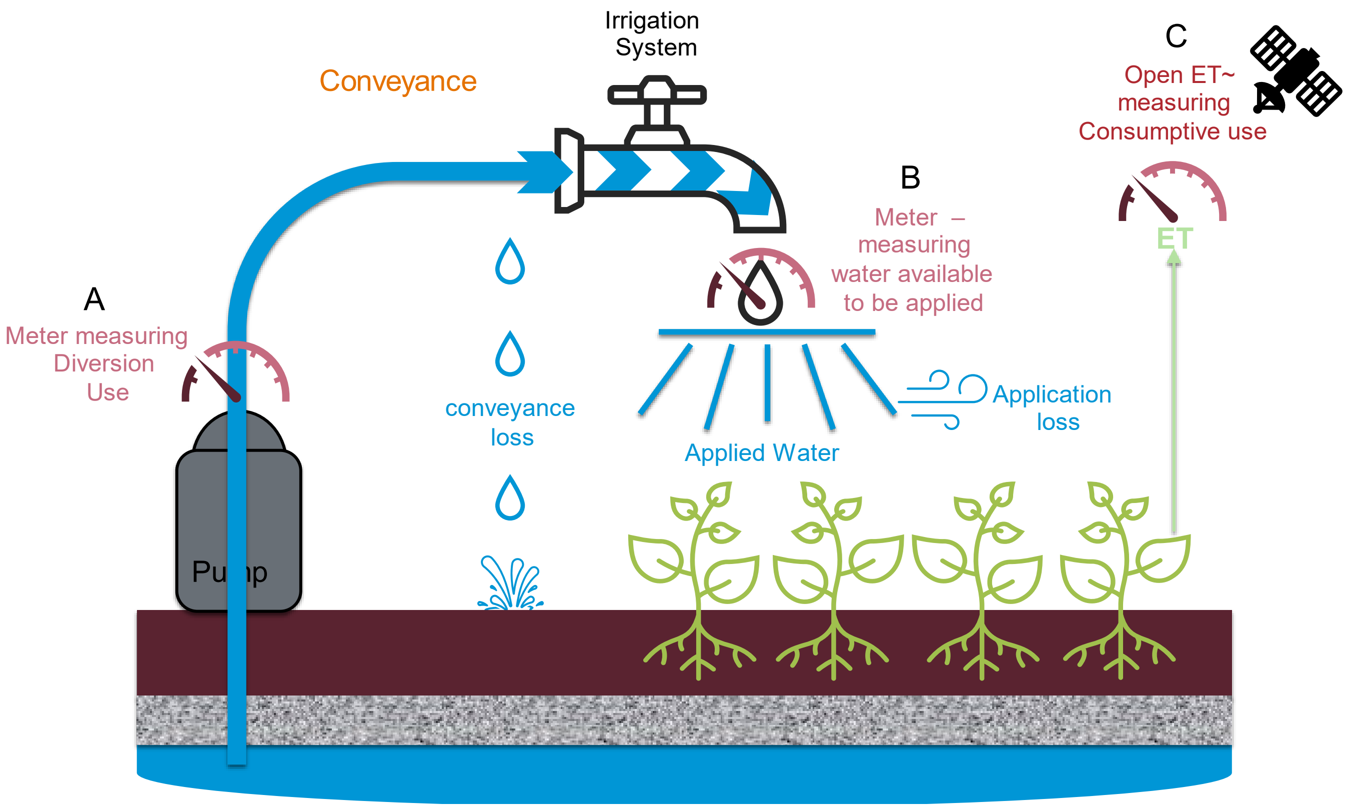

Figure 3. Conceptual diagram of locations where meters could be placed in a center pivot field: (A) near the irrigation pump to measure before conveyance and application losses, or (B) on the pivot riser to measure before application loss. Note that (C) remote-sensing technology can only measure consumptive use because it avoids neither conveyance nor application losses.

Propeller Meters

Several brands of propeller meters are currently on the market and can be classified into two main categories: in-line and insertion (Figure 4). In-line propeller meters are installed in line with the irrigation pipe and require either an existing flange connection or the installation of a new junction via cutting the pipe and welding on new flanges. Insertion meters are installed by drilling a hole in the pipe and inserting the propeller, then mounting the meter saddle onto the existing pipe.

There is anecdotal evidence that the propeller meters tend to become less accurate over time in alluvial aquifers due to sediment wearing down the propeller. The vertical position of the pump or the condition of the well casing or screen may allow for sediment to be introduced into the irrigation system. This deterioration could happen more readily in places where the well pumps sediment, wearing down the mechanical device and the pump over time.

Propeller meters often require in-person site visits to read the meter and record the information, though some newer propeller meters are available with digital displays and may include technology that allows for remote access to data using satellite or cellular networks, known as telemetry. Options also exist to retrofit non-telemetered propeller meters to enable this feature. These telemetry systems are battery-powered, with the option of a rechargeable solar-powered battery, and they require access to satellite or cellular networks. Telemetry technology for propeller meters was not tested in this pilot project.

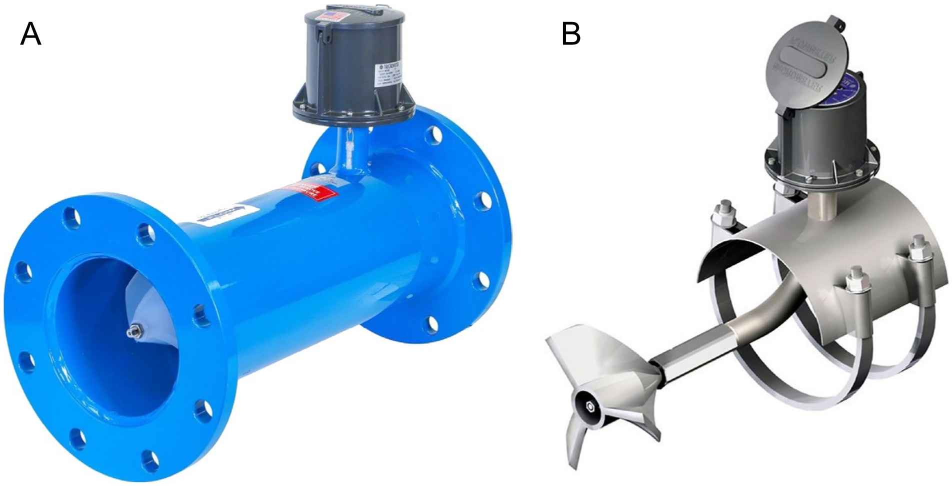

Figure 4. (A) In-line propeller meter with flanged connection. (B) Insertion propeller meter with saddle mount. A propeller meter is a physical meter with a turbine inserted into the pipe, which varies in speed with the rate of flow. The meter logs the total volume of water in acre-feet as well as the instantaneous rate of flow through the pipe (Table 2). From McCrometer (2024).

Table 2. Water measurement parameters for propeller meters.

Parameter	Definition
Total	Total volume withdrawn. Acre-feet x 0.001 = Total. Similar to an odometer in a car.
Rate	Instantaneous rate (analog) in gallons per minute.

Electromagnetic Meters

Several brands of electromagnetic flow meters are currently on the market and are available in both in-line and insertion models (Figure 5). The electromagnetic meter chosen for this project was the Ag90 Seametrics Magmeter. The AG90 is an insertion meter—meaning the sensor is inserted into the pipe and secured with a "saddle" mount to measure flow. The meter's inserted portion includes magnets and a sensor to measure flow rates using principles of electromagnetism. There are no moving parts. The battery-powered Ag90 has a battery life of roughly four years.

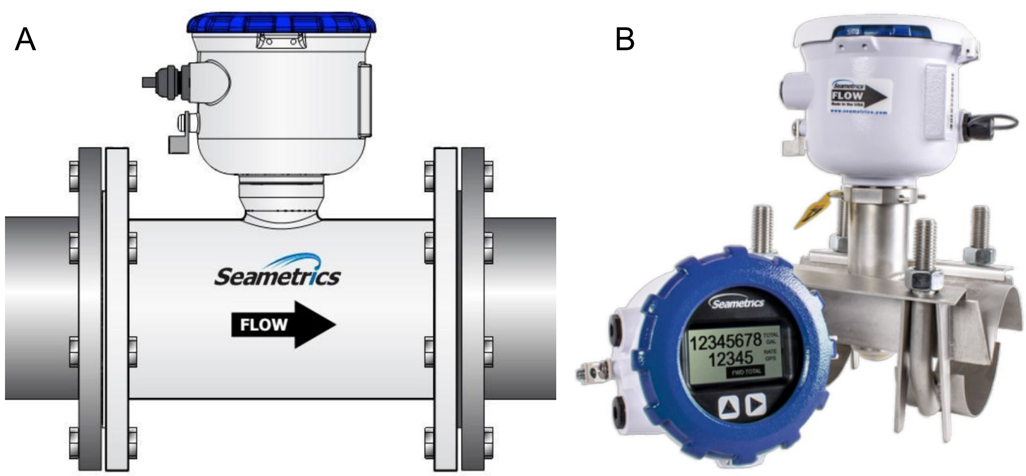

Figure 5. (A) In-line magmeter with flanged connection. (B) Insertion magmeter with saddle mount. Electromagnetic meters measure flow using a sensor inserted into the pipe that detects changes in velocity using principles of electromagnetism. From Seametrics (2021).

Electromagnetic meters have multiple measurement parameters that water users can assess (Table 3). The Batch Forward parameter is better for regulators or irrigators interested in understanding water application for specific time frames (this function is similar to the trip function on an odometer). In most cases, reverse flow is negligible but might be good for spotting issues. It is unlikely that backflow will be an issue if meters are installed at or near the pump due to backflow prevention.

Table 3. Water measurement parameters for electromagnetic meters.

Parameter	Definition
Forward Total	Total amount that does not account for any backflow. Forward Total includes cumulative flow from the date of installation. Similar to an odometer in a car.
Batch Forward Total	Total amount that does not account for any backflow during a specific time interval. Similar to a trip meter in a car. Batch Forward can be reset to zero manually.
Reverse Total	Total amount of cumulative backflow—i.e., water flowing backward when the pivot riser drains.
Batch Reverse Total	Total amount of backflow during a specific time interval. Similar to a trip meter in a car. Batch Reverse can be reset to zero manually.
Net Total	Total acre-feet. Batch Forward – Reverse Total = Net Total.
Rate	Instantaneous flow rate in gallons per minute or gallons per day.

Telemetry

Propeller and electromagnetic meters can optionally be telemetered using satellite or cellular networks. Telemetry can provide added value to irrigators by allowing them real-time access to measurement data and the ability to log data over custom time periods, thereby reducing the need for frequent in-person site visits compared to meters without telemetry.

Due to the remote location of the project site, we opted to test a telemetry system with pivot control functionality to facilitate data access and provide prospective operators with a review of system functionality and user experience. A Lindsay FieldNET Pivot Control system was installed on each pivot and connected to the Seametrics Ag90 Magmeters (Figure 6).

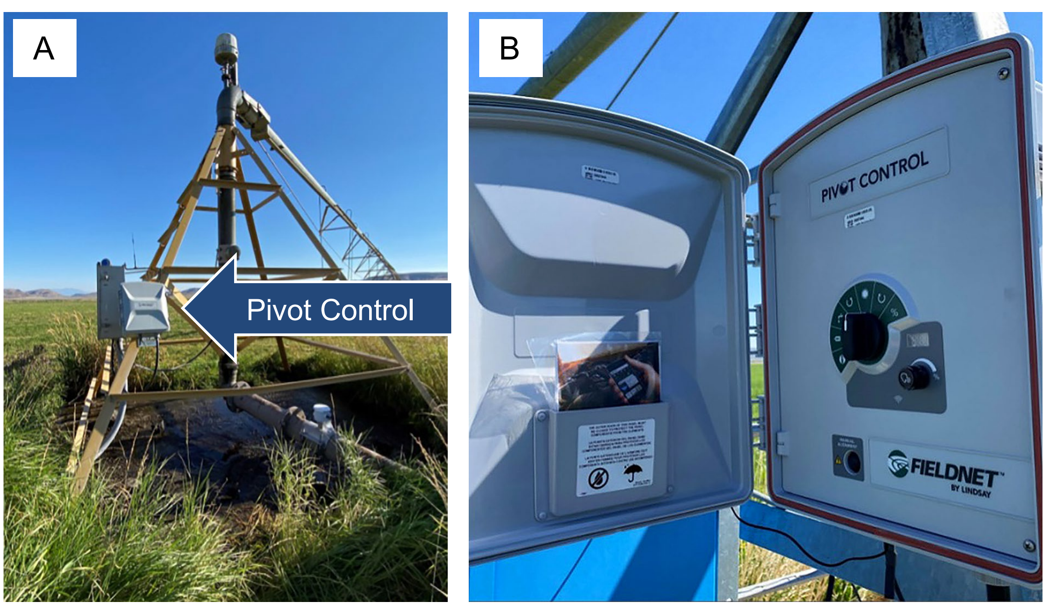

Figure 6. Photographs (A and B) of the pivot control installed at one of the fields in this project.

FieldNET is an online software platform with the potential to display real-time data for each pivot connected to the system. Data include rate (%), depth applied (in.), circle time (HH:MM), and pivot arm location (degrees). The rate is the percentage of time that the end tower is running, which controls the speed at which the pivot rotates. The speed of rotation is inversely related to the amount of water applied—if the pivot is rotating quickly (i.e., the end tower is rotating 100% of the time), less water will be applied. Circle time refers to the amount of time it takes to complete one revolution around the center pivot. The pivot arm location refers to the direction in which the pivot arm is pointing relative to due north (0 degrees).

In addition to providing remote access to flow information, this system allows agricultural operators to remotely control the pivot through an online software platform. Using this program, the operator can stop or start the pivot, change application rates, and set up notifications for system errors (e.g., alignment fault).

For telemetered systems, several additional requirements apply beyond those for a standard meter installation without telemetry:

1. cellular or satellite coverage;
2. access to power if the meters or telemetry system do not have an internal battery; and
3. an annual subscription to an online software platform.

Measuring Water Use With OpenET Data

The OpenET (etdata.org) project was conceived as a way to integrate advances in remote-sensing models of actual ET and to develop a publicly available platform for data processing and distribution in support of water resource management (Melton et al. 2022). The platform includes six different models and a model ensemble that estimate ET at daily, monthly, and annual timesteps at a fine spatial scale (30-meter pixels). The models' input datasets include LANDSAT imagery, weather station data, land cover, and other data necessary for the energy balance at the land's surface. The result is a unified approach for measuring ET that is applicable at various spatial and temporal scales and is publicly available to the water resource management community (Melton et al. 2022). The platform provides an interface to access public data in raw (i.e., raster) forms or as field-averaged data.

Quantifying ET can help local communities improve their water management. Agricultural producers have been able to use OpenET data to optimize their irrigation practices, improve crop yields, and reduce operating costs. In these cases, modeled ET values have been used as a proxy for consumptive water use. OpenET data have also been used in the context of conservation, where groundwater use is measured or the information is used to make more realistic water budgets. For example, OpenET data have been used in conjunction with climate and irrigation data to predict regional groundwater pumping, estimate irrigation efficiency, and validate available water use data from meters (Ott et al. 2024). The OpenET website includes more information on specific use cases (OpenET n.d.) where OpenET data have been used to manage water in agricultural landscapes.

Pilot Project

We piloted a demonstration project to highlight the challenges and opportunities with water use measurement in Oregon. The project's two objectives were to field-test multiple water use measurement devices and compare their performance against each other and against satellite-based remote sensing to identify trade-offs and propose statewide guidance. Multiple sets of propeller meters and electromagnetic flow meters were installed on center pivots on TCR, a working ranch in Harney County, Oregon, in preparation for this project. Our study was not intended to provide precise estimates of consumptive water use at TCR or investigate specific irrigation management practices.

To address our first objective, we compared propeller flow meters (McCrometer McPropeller) to electromagnetic flow meters (Seametrics Ag90 Magmeter) over two irrigation seasons to understand the installation process, familiarize ourselves with the technology, and test data collection and analysis protocols. Telemetry was installed for the electromagnetic meters at each pivot to improve access to the flow data and to ensure any performance issues were identified and addressed as quickly as possible. We chose not to install telemetry on the propeller meter to better replicate a common low-cost use case where the meter must be checked in person.

Our second objective was to compare the instrumented measurements of diversion water use with remotely sensed estimates of consumptive water use over the two irrigation seasons.

Project Location

TCR is a large conservation area located in Harney County, Oregon (Figure 1). The Oregon Desert Land Trust owns TCR and manages it in partnership with The Nature Conservancy (TNC). The entire property is 16,645 acres (67 km^2), with grazing permits on 500,000 acres (2023 km^2) of public land spanning the Pueblo and Trout Creek Mountains. The region is characterized by a semiarid climate, with average monthly temperatures ranging from 30 °F to 69 °F (−1 °C to 21 °C) and average annual precipitation of 8 to 12 in. (20 to 30 cm). Less than 4 in. (10 cm) of precipitation falls during the typical irrigation season (April–September; ODA 2020).

The TCR headquarters is located along Trout Creek and includes lodging and maintenance facilities, an AgriMet station and other infrastructure, and irrigated fields for forage production, predominantly of alfalfa and triticale. This project focused on four fields equipped with center pivot irrigation systems with mid-elevation spray application sprinkler packages (Figure 1; Table 4). The Stonehouse and House Pivots are each connected to a single well. Sherburn and Whitehorse Pivots are hydraulically connected and served by one well.

Table 4. Field sizes at Trout Creek Ranch.

Field	Size: ac (km^2)
House	82.7 (0.3)
Sherburn	86.3 (0.3)
Stonehouse	144.3 (0.6)
Whitehorse	167.1 (0.7)

Meter Selection and Installation

In spring 2023, a McCrometer M0308 Propeller Meter and a Seametrics Magmeter Ag90, both with an 8-in. (20.32 cm) diameter, were installed at each of the four pivots at TCR (Figure 7; see Appendix B for photos of the installation for each pivot). FieldNET Pivot Communication telemetry hardware was installed to accompany the magmeter at each pivot as well.

These meters were selected for the following reasons:

1. Existing irrigation infrastructure was most conducive to installing the insertion meter, which does not require the installation team to cut or weld irrigation pipe.
2. Ease of installation resulted in reduced associated labor costs when compared to labor estimates for in-line propeller meters.
3. Local familiarity and use of this product, due to its price point and availability, made it a logical choice for testing.

In many cases across Oregon, the configurations of groundwater pumps and water conveyance infrastructure do not allow for meter installation and measurement at the PoD without significant and costly upgrades. In this pilot project, all meters were installed on or near the center pivot risers due to a lack of access to aboveground pipes that met installation specifications. This configuration also allowed for a more accurate comparison between OpenET and metered water use at the PoU.

Meter Costs and Funding Considerations

The total cost of this project reflected the installation of two meters for each pivot (Table 5). The cost of meter use to a water user will vary depending on a few different factors:

- Type of meter chosen
- Availability of grants or other public funding sources
- Distance from an irrigation contractor to the installation site or PoU
- Existing infrastructure

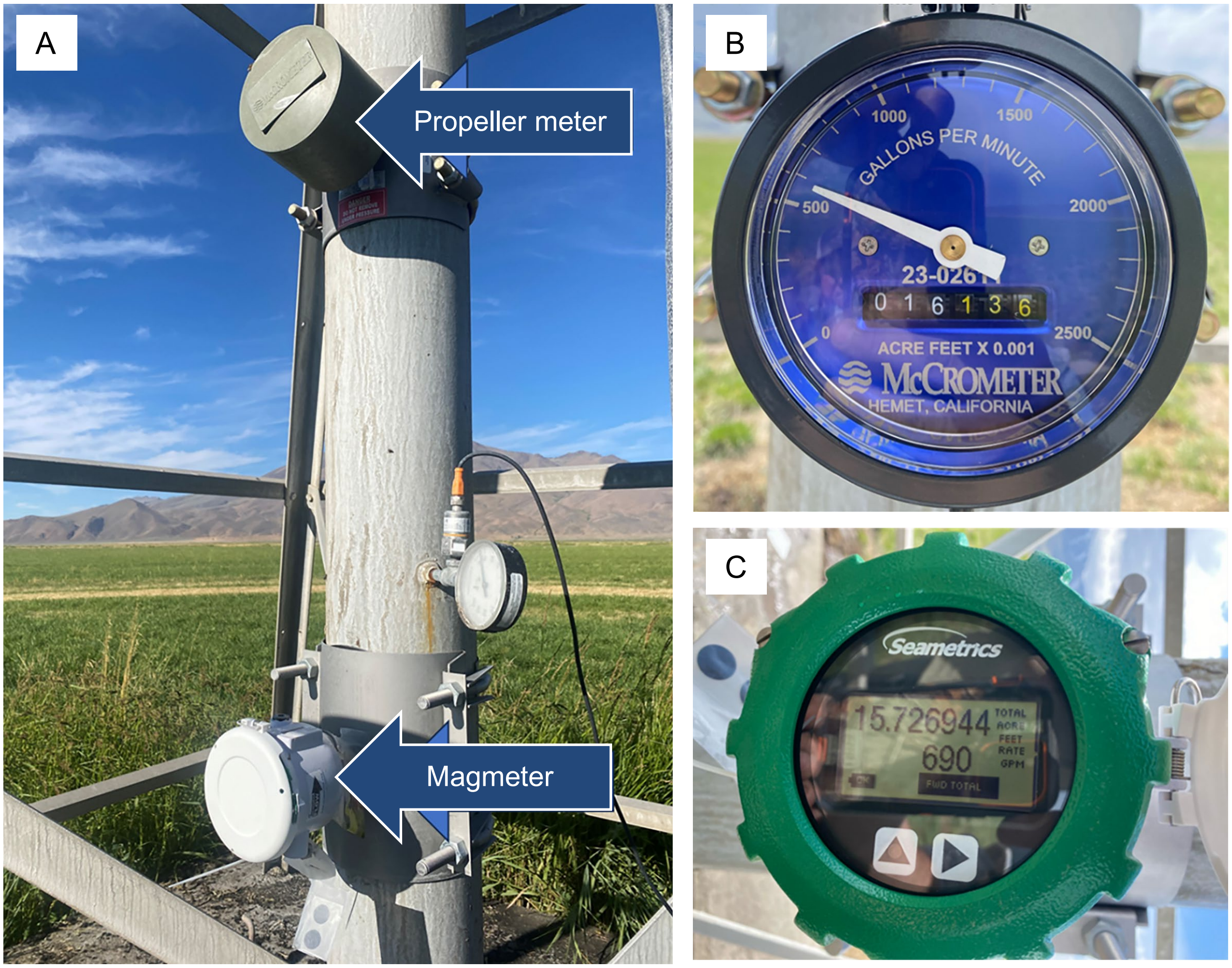

Figure 7. Photo A shows the meter installation schematic. The propeller meter (B) was installed above the electromagnetic meter (C) on all four pivots. See Appendix B for individual pivot setups.

Table 5. Pilot project budget. Dollar amounts reflect 2023 costs and are likely to change over time. The costs shown may not be representative of actual costs to water users in other geographies or with other irrigation systems.

Item	Cost per unit	Quantity	Total cost	**State cost** (reimbursement request)	**Water user cost** (user match)
Equipment					
McCrometer propeller meter	$2043.75	4	$8175.00	$4087.50	$4087.50
Seametrics electromagnetic meter	$2106.65	4	$8426.60	$4213.30	$4213.30
Telemetry equipment	$3500.00	4	$14,000.00	$7000.00	$7000.00
Subtotal			*$30,601.60*	*$15,300.80*	*$15,300.80*

Item	Cost per unit	Quantity	Total cost	State cost (reimbursement request)	Water user cost (user match)
Labor					
Meter installation	$125.00 ($/hour)	12	$1500.00	$750.00	$750.00
Subtotal (estimated)			*$1500.00*	*$750.00*	*$750.00*
In-kind contributions					
In-kind – water user	$50.00 ($/hour)	60	$3000.00		$3000.00
Telemetry subscription (annual)	$300.00	4	$1200.00		$1200.00
Subtotal			*$4200.00*		*$4200.00*
Totals					
Total			**$36,301.60**	**$16,050.80**	**$20,250.80**

Funding programs are available to facilitate the purchase and installation of water meters. TNC explored two main funding options for meter installation. Of the two, the Oregon Water Resources Department (OWRD) offered the most feasible method for funding this project via its Water Use Measurement Cost Share Program (OWRD n.d.; see Table 5 for the cost-share breakdown, water user vs. state reimbursement). This cost-share program is voluntary, and participating in the program implies consent for OWRD staff to access the flow meter. Participation in the cost-share program does not by itself require water use reporting. OWRD provides several helpful resources through this program, including the following:

- How to Select and Install a Suitable Flow Measuring Device: https://www.oregon.gov/owrd/WRDFormsPDF/How_to_Select_and_Install_a_Suitable_Measuring_Device.pdf
- Water Use Measurement and Reporting: https://www.oregon.gov/owrd/programs/WaterRights/Reporting/WUR/Documents/WURMemo.pdf
- Water Use Reporting Website: https://www.oregon.gov/OWRD/programs/WaterRights/Reporting/WUR/Pages/default.aspx

The other funding option that TNC explored was the EQIP WaterSMART Initiative (NRCS n.d.)—a collaboration between the U.S. Natural Resources Conservation Service (NRCS) and the U.S. Bureau of Reclamation in support of small-scale water use efficiency projects. Agricultural operators may want to consider this option for their needs; however, TNC did not pursue the EQIP grant because the focus of our pilot project was to explore the feasibility of water use measurement options and did not include water use efficiency improvements.

Methods

Field Methods

Field staff checked each meter array over the course of the 2023 and 2024 irrigation seasons to take a photo record of meter values, confirm whether the meters were working properly, and collect qualitative information on irrigation, field operations, and other notable events. Due to installation and maintenance challenges during the 2023 irrigation season, field staff increased the number of visits during the 2024 irrigation season.

Datasets and Analysis

Daily time series data describing actual ET for the 2023 and 2024 calendar years were downloaded through the OpenET application programming interface (API). Custom field boundaries for each field were manually delineated in ArcGIS Pro and used to extract field-based averages of actual ET. The ET estimates for this project were taken from the OpenET ensemble, which combines multi-model predictions. Research has demonstrated that these estimates perform well for the pilot project's region at the field scale (Ott et al. 2024).

The meter readings were corrected to get daily values so that we could compare the two types of meters. For propeller meters, the readings collected by photos were organized according to date. The difference in the total acre-feet value was calculated from each timestep, divided by the number of days between field visits, and then divided by the area of the appropriate field to determine the amount of irrigated water in feet per day. The magmeter data were treated the same way but using the Forward Total values. In addition, the measurement error was calculated between the two instruments as:

$$Error = \left| 1 - \left(\frac{M_{rate}}{P_{rate}} \right) \right| \times 100$$

where the percent error is calculated as the absolute value of 1 minus the ratio of the electromagnetic meter flow rate and the propeller meter flow rate, then multiplied by 100. Instantaneous flow measurements were not collected as part of this project, so the rates used reflect the difference between the volumetric measurements at two timesteps divided by days between measurements at those respective timesteps.

Limitations and Technical Issues

The project team worked closely with the landowner and land managers. Despite close collaboration, daily operational decisions—such as grazing, haying, and irrigation practices—shifted the study results. In addition, unanticipated technical challenges limited the sample size. Many of these impacts are detailed in the upcoming "Results" and "Considerations and Recommendations" sections. Several notable events are also listed here.

- *House Pivot*. At the House Pivot, the propeller meter did not register any change in water use during our field visits on May 20, May 29, and June 13, 2024, while the electromagnetic meter on the same pivot continued to log water use. One possibility for this anomaly—suggested by an ag producer that uses this type of meter—is that sediment in the system may have temporarily jammed the propeller. The electromagnetic meter was not logging during our field visits on August 9 and August 15, 2024. The House Pivot field was grazed for a portion of the 2024 irrigation season.
- *Sherburn Pivot & Whitehorse Pivot*. The Sherburn and Whitehorse Pivots are fed by the same groundwater pump. Due to required upgrades in the pump and conveyance system, the Sherburn and Whitehorse Pivots were not operational for the majority of the 2023 season. Only two recorded magmeter readings were taken for the Sherburn and Whitehorse Pivots during the 2023 irrigation season.
- *Sherburn Pivot*. The magmeter at the Sherburn field was installed incorrectly, and the contractor was not able to repair the issue until midway through the second irrigation season (2024). From the time of repair until the end of the irrigation season, the meter was logging from a deficit.
- *Stonehouse Pivot*. The Stonehouse field was grazed for a portion of the 2024 irrigation season. On July 23, 2024, the pivot at Stonehouse malfunctioned, and irrigation on the field ended for the remainder of the season.
- *Whitehorse Pivot*. The Whitehorse field was grazed for a portion of the 2024 irrigation season.

Results

Water Use Measurements From Meters

Propeller and electromagnetic meter readings (Figure 8) were collected six times in 2023 and 14 times in 2024. The propeller meter readings reflect a cumulative accounting of water applied to each field, and values are reported as acre-feet. The electromagnetic meter readings in Figure 8 are values for the Forward Total, which is most analogous to the propeller readings, and are also reported as acre-feet (see Table 3 for more details on electromagnetic meter parameters).

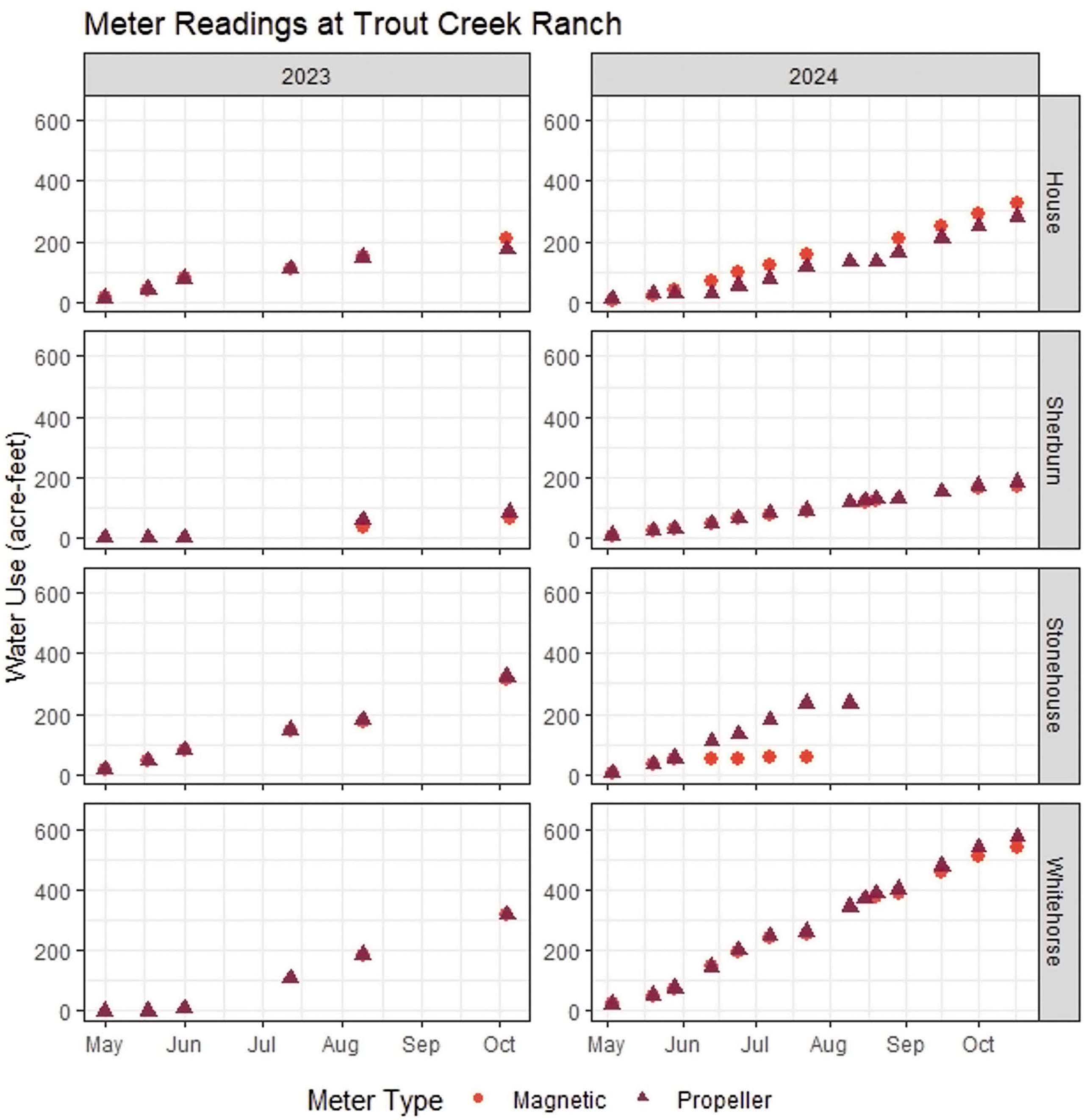

Figure 8. Readings collected from the propeller and electromagnetic meters installed at Trout Creek Ranch. The water use in acre-feet shows cumulative use throughout the irrigation season. The values for the Y-axis are different for each field to highlight the comparison in meter performance among sites. Readings for the 2024 season were corrected to show water use for the irrigation season without the influence of 2023.

The readings from each meter were compared with one another for each field to understand meter performance over the study period (Figure 9). No consistent trends appeared across all four meters; in some cases, the electromagnetic flow meter measured greater water use, while in others, the propeller meter measured greater water use. The measurement errors describing the difference in flow rates among the two pivots also varied through the season, as shown in Table 6. For the purpose of this analysis, error rates greater than 4% are bolded in the table since 4% corresponds to the propagated uncertainty threshold for instrument error alone described in the proposed rule OAR 690-512-0110(6)(a), which states that “A totalizing flow

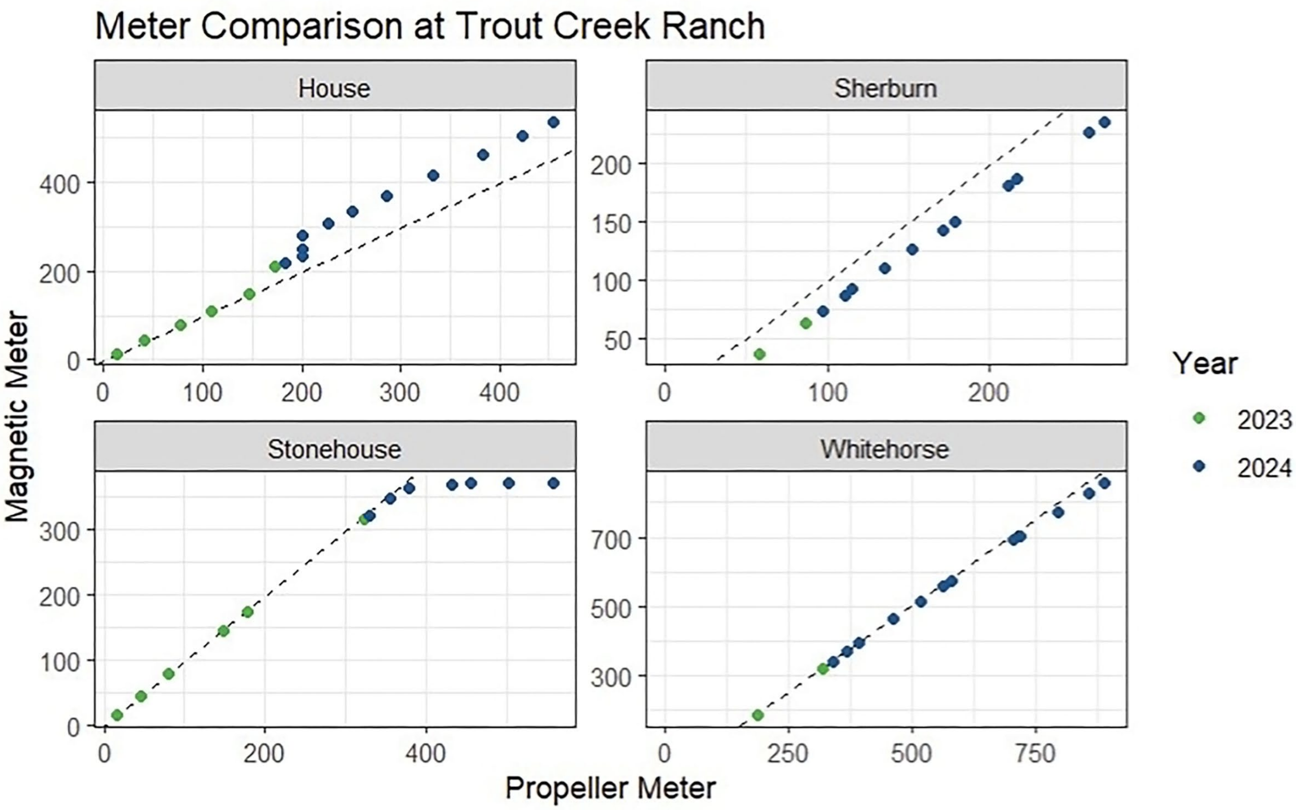

Figure 9. Comparison of readings for electromagnetic and propeller meters installed at each field over the study period. All units are in acre-feet. The dashed line represents the 1:1 relationship that would be evident if the readings for both were equal. The values for the Y-axis are different for each field to highlight the comparison in meter performance among sites.

meter shall have a rated accuracy of plus or minus 2% of actual flow for all flow rates for which the meter is expected to measure" (Amending and Adopting Division 512 Rules 2025). In other words, a relative percent error exceeding 4% indicates that the meter measurements diverge beyond the expectations of instrument error alone per state standards.

- *House Pivot*. At the House Pivot, the initial meter readings aligned well until fall 2023, when the reading for the electromagnetic meter began reading higher than the propeller meter. This issue was exacerbated in July 2024 when the propeller meter temporarily stopped logging (see the previous "Limitations and Technical Issues" section). Because of this issue, the magnetic readings for the June 24 sampling day were 82 acre-feet (101,145.00 m^3) higher than the propeller but decreased to 80 acre-feet (98,678.40 m^3) higher by the last sampling day in October. The average relative percent error was 33% over the course of the study. Four of the five days in 2023 and five of the 10 days in 2024 had relative percent errors of less than 4%. These results are attributable to the shift in meter performance in fall 2023, as well as the technical issues observed in June 2024.
- *Sherburn Pivot*. At the Sherburn Pivot, the propeller meter was consistently higher than the magmeter readings throughout the study. The difference ranged from 22 acre-feet (27,136.60 m^3) higher on the first sampling day (August 9, 2023) to 34 acre-feet (41,938.30 m^3) by the final day of sampling (October 17, 2024). The average relative percent error was 7% over the course of the study. One of the two days in 2023 and six of the 13 days in 2024 had relative percent errors of less than 4%. The largest error in measured flow rates occurred at the start of the study. However, the discrepancies in flow rates began to increase in fall 2024 as well.
- *Stonehouse Pivot*. At the Stonehouse field, the propeller meter registered 0.41 acre-feet (505.73

m³) higher than the electromagnetic meter on the first sampling day. This discrepancy increased to nearly 8 acre-feet (9867.84 m³) by May 20, 2024. By May 29, 2024, the propeller meter was reading 13 acre-feet (16,035.20 m³) higher than the electromagnetic meter, and this difference quickly grew to 187 acre-feet (230,661.00 m³) by July 22, 2024, before the pivot malfunctioned. It is possible that the power to the magmeter was intermittently off during this time frame, which may explain the discrepancy between the two meters. The average relative percent error was 35% over the course of the study. All five days in 2023 and two of the seven days in 2024 had relative percent errors of less than 4%. The high errors in measured flow rates during the remainder of the season further suggest that there was a technical issue with the magmeter.

- *Whitehorse Pivot*. Lastly, the propeller meter at the Whitehorse Pivot read 0.03 acre-feet (37.00 m³) higher than the electromagnetic meter at the start of the irrigation season. The difference continued to grow over the study period, reaching almost 34 acre-feet (41,938.30 m³) higher than the magmeter by the end of the study period. The average relative percent error was 6% over the course of the study. One of the two days in 2023 and four of the 14 days in 2024 had relative percent errors of less than 4%. Like Sherburn, the largest error in measured flow rates occurred at the start of the study and tapered off until the discrepancies in flow rates began to increase in August 2024.

Table 6. Error between the flow rate readings at each site's two meters over the course of the study. Numbers in bold indicate values that exceed the combined relative percent error threshold of 4%, which would correspond to expectations of instrument error alone. Volumes (acre-feet) were converted to rates (in./day) in accordance with proposed rule OAR 690-512-0110(6)(a) (Amending and Adopting Division 512 Rules 2025).

Field	Date	Magmeter (in./d)	Propeller meter (in./d)	Relative error (%) *	Mean relative error (%) *
House	5/18/2023	0.24	0.24	0.00	**39.66**
	6/1/2023	0.38	0.37	2.70	
	7/12/2023	0.12	0.11	**9.09**	
	8/9/2023	0.20	0.20	0.00	
	10/4/2023	0.15	0.07	**114.29**	
	5/20/2024	0.15	0.15	0.00	
	5/29/2024	0.21	0	NA	
	6/13/2024	0.32	0	NA	
	6/24/2024	0.37	0.11	**236.36**	
	7/7/2024	0.27	0.27	0.00	
	7/22/2024	0.34	0.34	0.00	
	8/29/2024	0.50	0.43	**16.28**	
	9/16/2024	0.36	0.40	**10.00**	
	10/1/2024	0.40	0.39	2.56	
	10/17/2024	0.29	0.28	3.57	
Sherburn	7/12/2023	0.07	0.10	**34.62**	**7.17**
	8/9/2023	0.06	0.06	3.37	
	10/4/2023	0.01	0.01	**6.96**	
	5/3/2024	0.10	0.10	0.44	
	5/20/2024	0.07	0.07	1.17	
	5/29/2024	0.15	0.16	**6.12**	
	6/13/2024	0.19	0.19	3.37	
	6/24/2024	0.16	0.18	**13.12**	

Field	Date	Magmeter (in./d)	Propeller meter (in./d)	Relative error (%) *	Mean relative error (%) *
	7/7/2024	0.06	0.06	4.00	
	8/9/2024	0.16	0.17	**6.55**	
	8/15/2024	0.14	0.14	1.93	
	8/29/2024	0.00	0.00	1.27	
	9/16/2024	0.15	0.16	**6.55**	
	10/1/2024	0.16	0.17	**9.08**	
	10/17/2024	0.07	0.08	**9.06**	
Stonehouse	5/18/2023	0.11	0.12	2.72	**35.40**
	6/1/2023	0.17	0.17	2.77	
	7/12/2023	0.11	0.11	2.24	
	8/9/2023	0.07	0.07	1.85	
	10/4/2023	0.17	0.18	2.16	
	5/3/2024	0.00	0.00	1.21	
	5/20/2024	0.10	0.10	1.65	
	5/29/2024	0.13	0.17	**24.01**	
	6/13/2024	0.02	0.24	**90.97**	
	6/24/2024	0.01	0.14	**96.44**	
	7/7/2024	0.00	0.24	**99.21**	
	7/22/2024	0.00	0.25	**99.54**	
Whitehorse	8/9/2023	0.13	0.20	**34.46**	**7.07**
	10/4/2023	0.17	0.17	0.34	
	5/3/2024	0.01	0.01	0.86	
	5/20/2024	0.12	0.12	0.24	
	5/29/2024	0.19	0.19	0.41	
	6/13/2024	0.34	0.34	0.77	
	6/24/2024	0.33	0.35	**6.41**	
	7/7/2024	0.24	0.26	**6.76**	
	7/22/2024	0.07	0.07	1.84	
	8/9/2024	0.31	0.32	**4.31**	
	8/15/2024	0.31	0.33	**5.75**	
	8/20/2024	0.30	0.27	**12.17**	
	8/29/2024	0.09	0.10	**9.11**	
	9/16/2024	0.27	0.30	**11.35**	
	10/1/2024	0.27	0.30	**11.28**	
	10/17/2024	0.13	0.20	**34.46**	

* Calculations for relative errors may appear incorrect due to rounding.

Water Use Measurements From OpenET

Daily estimates of actual ET from the OpenET ensemble model were compiled for each field for calendar years 2023 and 2024 (Figure 10). The high-resolution data clearly showed daily actual ET variability throughout the irrigation season, but understanding the specific mechanisms driving these dynamics would require additional data that were beyond the scope of this pilot project.

Weather

We were able to match precipitation and temperature from weather stations installed on the ranch, as well as key field observations, to highlight notable changes in ET (Figure 10). We recorded a substantial thunderstorm on May 23, 2023, before any weather stations were constructed, so the precipitation associated with the event is unknown. However, a rain gauge installed by Oregon Desert Land Trust recorded 0.97 in. (2.46 cm) of rain on August 21, 2023, and the AgriMet Weather Station (installed on December 29, 2023) in Fields, Oregon, recorded 0.87 in. (2.21 cm) of rain on September 16, 2024. These heavy rainfall events corresponded to a significant drop in ET that occurred across all study fields simultaneously. The AgriMet station also captured an unseasonably warm period in late September, during which the maximum daily air temperature reached 92.3 °F (33.5 °C) on September 28, 2024. This warm period corresponded to a dramatic and simultaneous spike in ET values across all study fields.

Field Management

Field management practices can also be gleaned from the daily time series of ET (Figure 10). Grazing was observed on the House and Stonehouse fields during our site visits on June 26, 2024, until July 22, 2024. The daily ET trends for those time periods appeared to be lower than ET in 2023 during the same time of year at the House field. It was harder to isolate the potential impacts of grazing on the Stonehouse field since the irrigation season abruptly ended on July 23, 2024. We also observed that the Sherburn and Whitehorse fields were hayed between our field visits on July 7 and July 22, 2024. There was a sharp decline in ET for both of those fields, which would be consistent with the impact of haying, given the AgriMet station recorded no precipitation during the month of July.

While daily variations in ET are interesting, understanding cumulative ET over the course of a year or irrigation season may be more useful in the context of water use measurement and reporting. Calculating cumulative ET is analogous to the way water is measured using propeller and electromagnetic meters. In this pilot project, cumulative ET increased slowly through April for all fields before increasing more dramatically until October, when the irrigation season ended (Figure 11). In 2023, cumulative ET increased at roughly the same rate for House, Stonehouse, and Whitehorse fields, while cumulative ET at Sherburn was lower throughout the season.

In 2024, this pattern continued early in the irrigation season, with cumulative ET ramping up a few weeks earlier than in 2023. By the end of the irrigation season, cumulative ET was similar for the Sherburn and House fields, but the Whitehorse field had a higher cumulative ET than in 2023. The cumulative ET curve for Stonehouse provides an interesting example of what cumulative ET looks like without any irrigation. In this field, cumulative ET increased at a similar rate to the other fields until July 22, 2024, when the irrigation ended. This cessation showed up clearly in the cumulative ET curve as the rate slowed and eventually lagged behind the other three fields.

Comparison Between Meters and OpenET

Crop water requirements are met through contributions from irrigation, precipitation, and subsurface flow or groundwater subsidies. In theory, aligning measured water use from the meters with the estimates of consumptive water use from OpenET should provide some indication of how effectively the water applied to each field is used to satisfy crop water demand, assuming precipitation and hydrologic subsidies can be accounted for. OpenET can indeed be used to estimate diversion use with the correct data on precipitation and applied water use, as well as rigorous assumptions about irrigation efficiency. However, this approach was infeasible for this study, given the observed differences in the irrigation patterns on the study fields and capacity limitations.

Figure 12 compares this pilot project's measurements from the propeller and electromagnetic meters with the pilot's OpenET estimates. In all cases, the contributions of precipitation and preceding soil moisture conditions were believed to be the sources of water driving ET before the start of the irrigation season, as evidenced by the increase in ET through April before water use was measured. Surface irrigations did not impact the fields in this pilot, and we know from our field observations, personal communications with ranch staff, and the available data from the region that

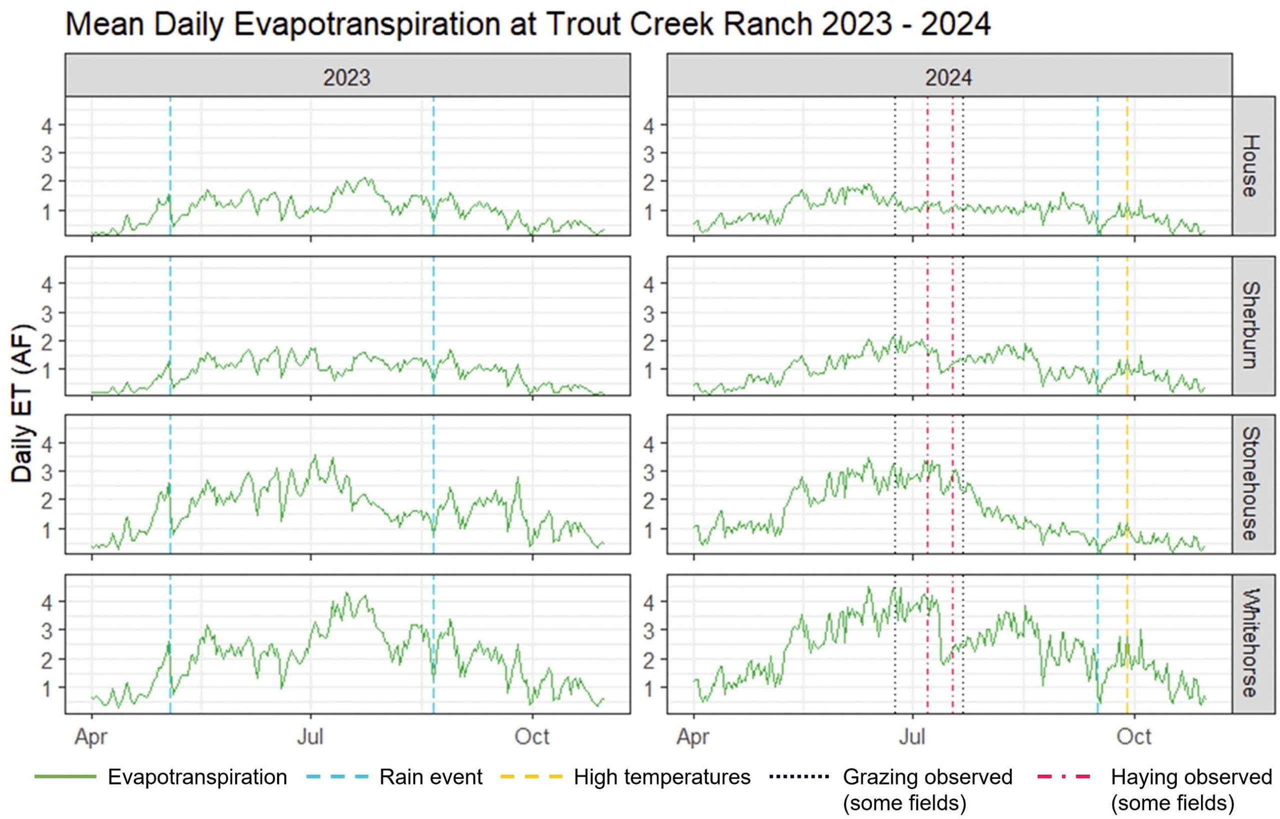

Figure 10. Daily estimates of actual evapotranspiration from the OpenET model ensemble. The black dashed line indicates grazing observed on the House and Stonehouse fields, and the red dashed line indicates observed haying on the Sherburn and Whitehorse fields. The data are limited to April 1 through October 31 for both years of this pilot project for clarity.

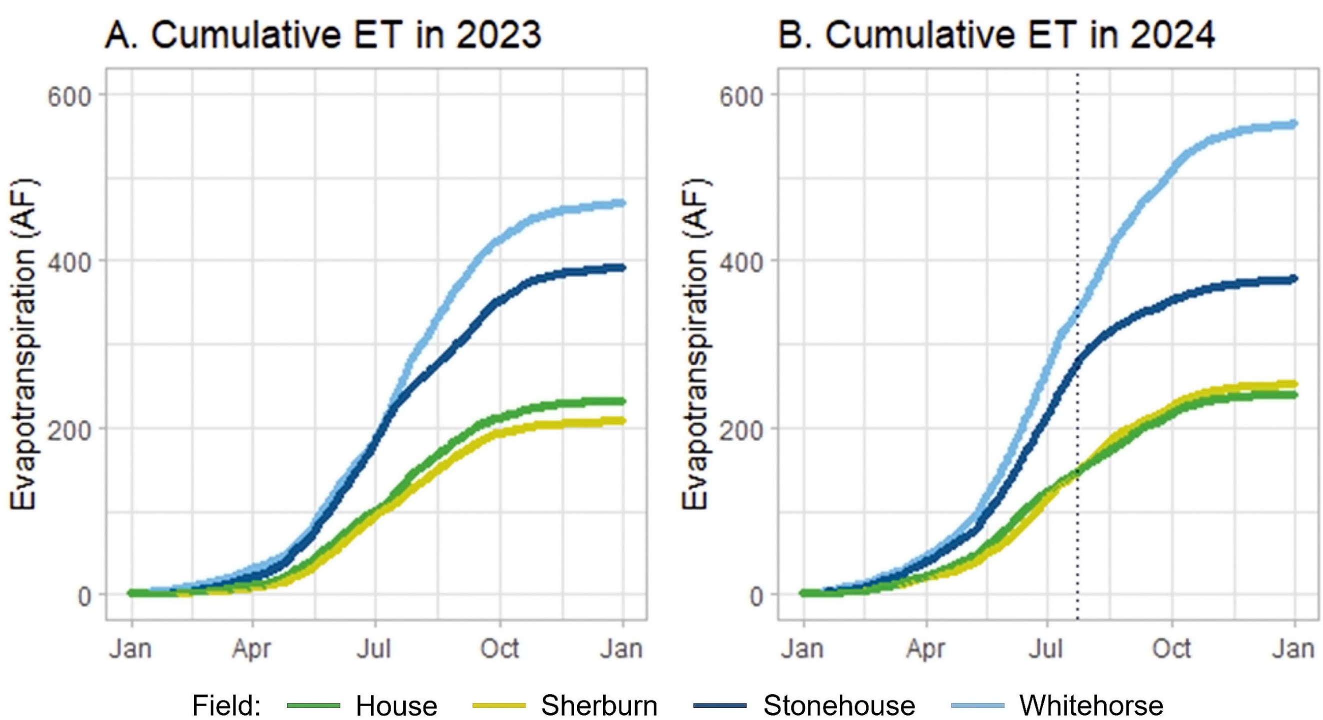

Figure 11. Cumulative evapotranspiration over the (A) 2023 and (B) 2024 irrigation seasons. The vertical dotted line in Plot B indicates the day the irrigation season ended on the Stonehouse field.

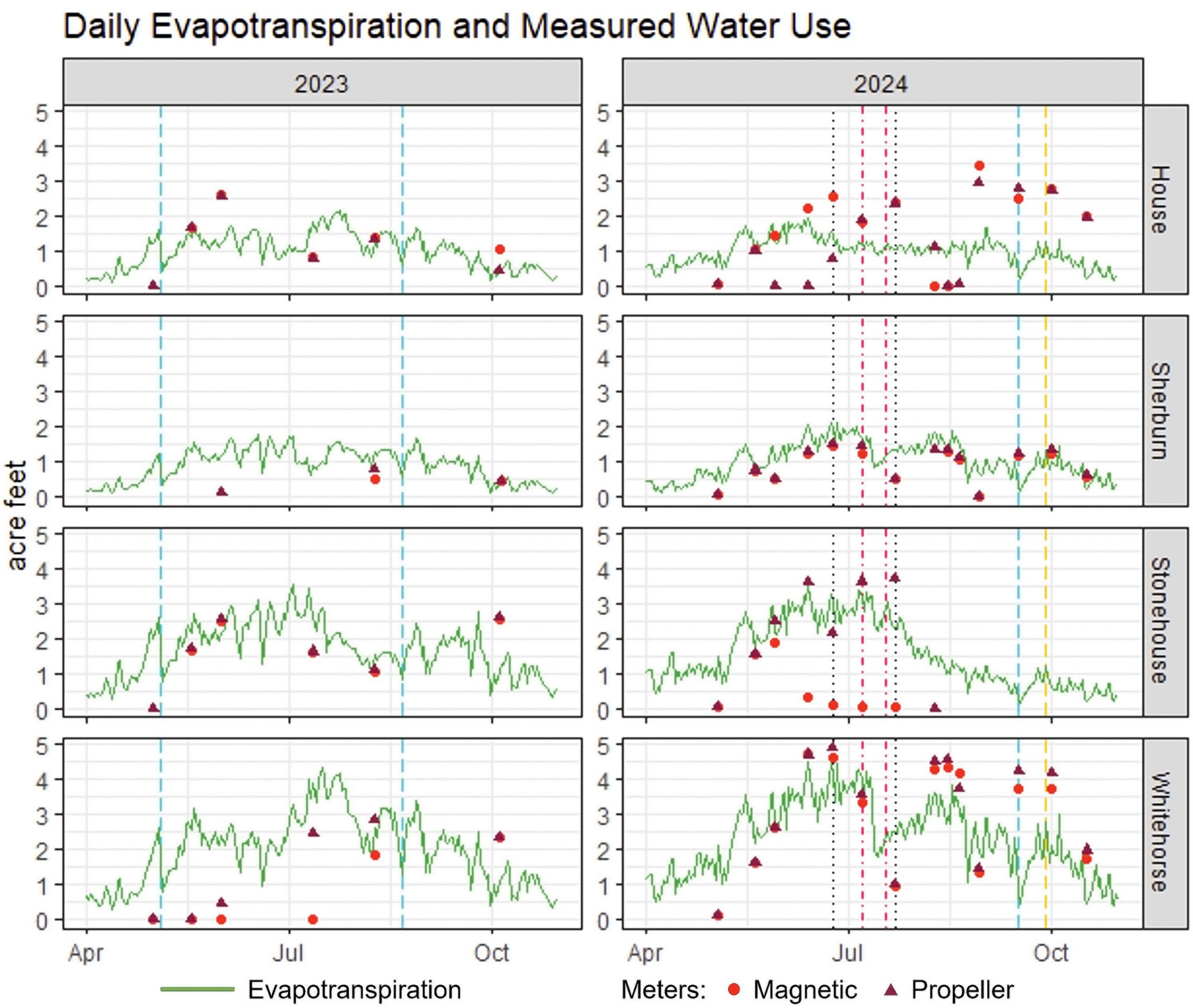

Figure 12. Daily water use measured by the meters and estimates of daily actual evapotranspiration from the OpenET model ensemble. The black dashed line indicates grazing observed on House and Stonehouse fields, and the red dashed line indicates observed haying on Sherburn and Whitehorse fields. The data are limited to April 1 through October 31 for both years of this pilot project for clarity.

precipitation during the irrigation season was relatively rare. However, the meter data were not at a fine enough temporal resolution to reconcile daily water use with the role of irrigation in daily ET patterns.

If OpenET data were as reliable and precise as metered data, they would need a relative error of +/- 2% of actual diverted water. In addition, the daily ET estimates are quite noisy, and it can be difficult to isolate signals unique to each field and explained by irrigation management or weather-based mechanisms. In Figure 12, we consider all measured water use values less than daily ET to be evidence of consumptive use, while measured water use values higher than daily ET indicate either nonconsumptive or consumptive losses.

- *House Pivot*. The corrected daily water use data collected from the meters were very close but exceeded the daily ET estimates during four of the six field visits in 2023. Also, anecdotal evidence showed that the House field received subsurface flow early in the 2023 irrigation season, but measuring this contribution was outside the scope of this study. In 2024, the corrected daily data for the magmeter data began exceeding the daily ET estimates in June, and the propeller meter data started exceeding ET in July. The difference between daily water use and ET was most striking for the House field in 2024, which is most likely due to the intensive grazing that occurred on the field throughout the irrigation season. Therefore, this field is an example in which using ET as a proxy for consumptive water use will result in a significant underestimate of actual water use in cases where irrigated fields are grazed. Consequently, the meters probably offer a more accurate representation of water use.

- *Sherburn Pivot*. The corrected daily water use data from the meters were well-aligned during both of the irrigation seasons. Daily measured water use remained close to or less than ET rates for all but two field visits, both of which occurred in fall 2024.
- *Stonehouse Pivot*. The daily water use at the Stonehouse field had a similar pattern to the House field in 2023 and remained close to or less than daily ET rates until the end of the irrigation season. In 2024, the propeller meter data suggested that daily water use was higher than the daily ET estimates (the magmeter was not operating properly during this time, as described earlier in this report). However, like the House field, grazing was observed on Stonehouse while irrigation was occurring, although at a much lower intensity than House. After the pivot malfunctioned in late July 2024, ET began to drop off.
- *Whitehorse Pivot*. In 2023, the daily measured water use at Whitehorse had a similar pattern to Sherburn, the next closest field, with water use staying below daily ET until the very end of the irrigation season. In 2024, measured daily water use increased during the beginning of the irrigation seasons and remained higher than ET for the duration of the season except for immediately before and after haying. Grazing did not occur on this field, to our knowledge, so the potential fates of the excess irrigation water could be evaporative losses from the sprinkler head or groundwater recharge.

Comparing cumulative patterns in water use and ET over the irrigation season is another potential approach for identifying trends in water use and irrigation practices (Figure 13).

- *House Pivot*. In 2023, cumulative water use tracked cumulative ET. In 2024, water use measured by the magmeter began to exceed cumulative ET in July; the propeller meter data began exceeding the cumulative ET a month or so later. Because we know the field was being intensively grazed, it is reasonable to assume ET was underestimating consumptive water use.
- *Sherburn Pivot*. Cumulative water use stayed below cumulative ET throughout both irrigation seasons. However, a substantial leak was observed upstream of the pivot during our field observations during the 2023 irrigation season. This conveyance loss was not reflected in the cumulative measured water use data.
- *Stonehouse Pivot*. In 2023, cumulative measured water use tracked cumulative ET. In 2024, the cumulative water use measured by the propeller meter indicated that the applied water was slightly less than ET. However, this is another instance where grazing likely resulted in an underestimate of consumptive water use, as reflected by ET.
- *Whitehorse Pivot*. Cumulative measured water use stayed below cumulative ET for both irrigation seasons.

Summary of Findings

Propeller Meters

Propeller meters appear to be cost-effective, easy to install and maintain, and user-friendly. Although anecdotal reports have stated that propeller meters may become less accurate over time due to the propeller wearing down, we did not find evidence to suggest a consistent, gradual decrease in accuracy over this limited, two-year period of operation.

Electromagnetic Meters, Pivot Control, and Telemetry

Electromagnetic meters offer a variety of data that could be useful to skilled operators who are technologically savvy. However, the technical manuals for these meters offer limited information on what each reading is measuring and how to interpret the data. Due to the advanced functionality potential of these devices, there are more opportunities for detailed data collection as well as opportunities for error.

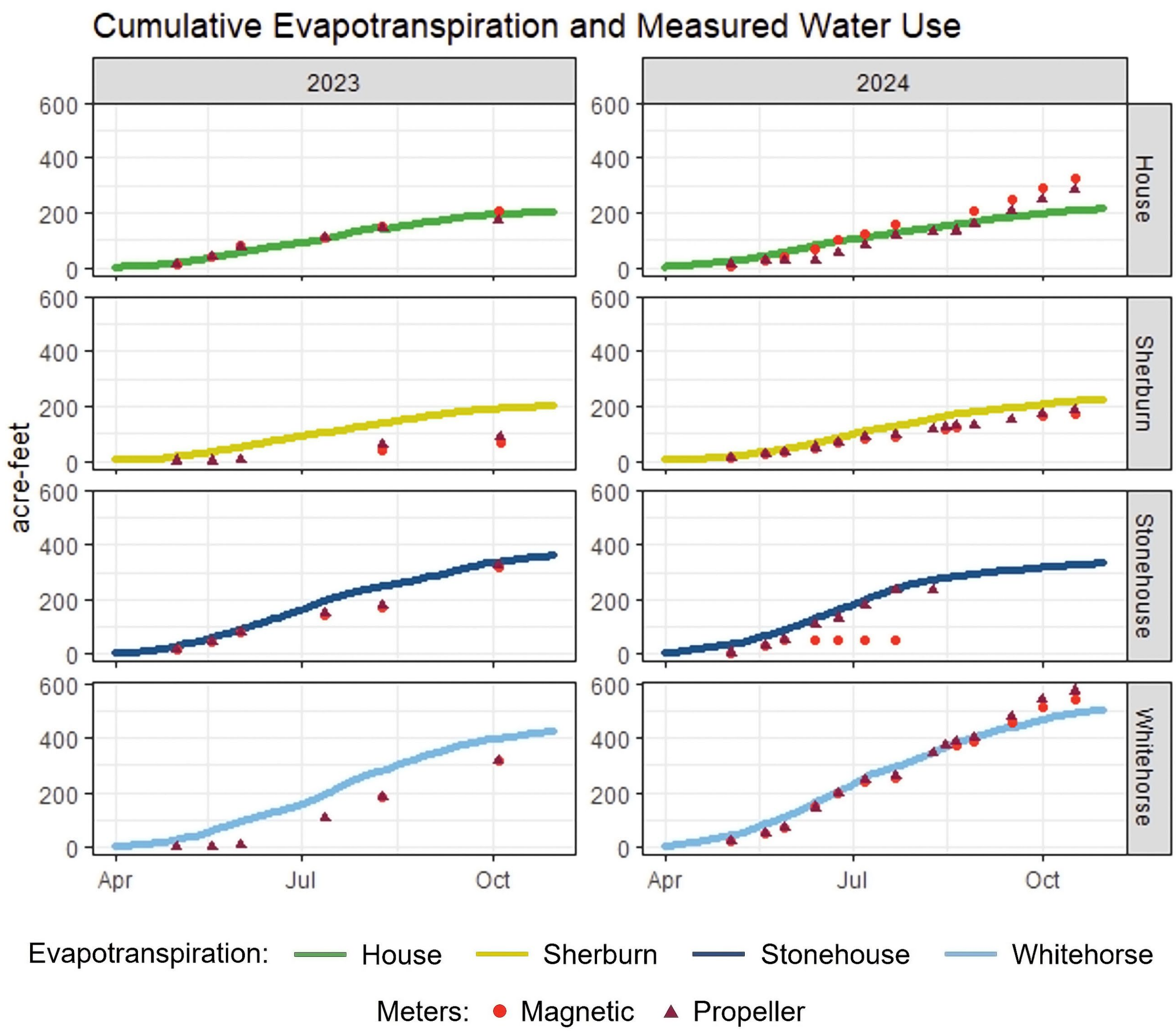

Figure 13. Cumulative water use from 2023 to 2024 measured by the meters and estimates of cumulative evapotranspiration from the OpenET model ensemble.

OpenET

OpenET requires no infrastructure purchase, installation, or maintenance, nor does it require the end user to collect, store, or transmit data, making it a cost-effective and low-maintenance option for measuring crop water use (i.e., consumptive use). The data are publicly available at the statewide extent, and reporting ET values from the OpenET platform requires minimal additional labor on the part of the agricultural producer. However, using ET as a proxy for diversion use requires assumptions regarding **irrigation efficiency** (i.e., how effectively an irrigation system delivers all the water necessary for crop production) and additional data describing precipitation application conditions. Securing this information in and accounting for field management practices may influence the accuracy of these calculations.

Table 7 compares the infrastructure needs for the three measurement technologies just described. This comparison focuses on existing infrastructure requirements; it does not consider upgrades a user may wish to make.

Table 7. Comparison of infrastructure measurement technology needs.

Measurement technology	Pump-to-pivot ratio	Access to pipes at the PoD that meet straight-run requirement	Location / accessibility
Propeller meter	1:1	required	Likely analog and physically accessed but can be equipped with telemetry. Compatible with data logger.
Magmeter	1:1	required	Likely digital and can be accessed via telemetry. Compatible with data logger.
OpenET	any	n/a	Site access only necessary for ground-truthing.

Considerations and Recommendations

The pilot project and in-depth outreach described in this report helped focus our understanding of the opportunities and challenges associated with water measurement and reporting from the landowner perspective. To complement this work, more research is needed into other aspects of water use measurement and reporting, including the implementation process, the responsible parties at each step in the process, government and market solutions for meter supply and installation, and the use of meters in irrigation configurations other than center pivot systems relying on groundwater supply. What follows are the primary reflections and suggested recommendations.

Irrigation Systems and Infrastructure

Given the issues encountered in our pilot project and the anecdotal evidence we collected from water users, we recommend the following: If OWRD requires meter installation, then funding mechanisms should allow for installation at the PoU if the system is configured where one pump provides water to one pivot. Furthermore, one of the conditions of accepting funding should be that OWRD has permission to inspect the system (in the field or through satellite technologies) for leaks between the PoD and the meter. The remainder of this section describes the issues that led us to this recommendation.

Working with the existing irrigation system presented three main challenges in this pilot project. First, the existing infrastructure for two of the fields had a complex hydraulic configuration. The Sherburn and Whitehorse Pivots were fed by a shared groundwater PoD (1 pump: 2 pivots), while the House and Stonehouse Pivots were each fed by their own groundwater PoD (1 pump: 1 pivot). This setup resulted in some delays during the first irrigation season. However, the larger issue here is the potential challenges for producers to accurately measure diversion use for a given PoD or estimate consumptive water use through OpenET data.

If we had been able to install the meters at the pump shared by the Sherburn and Whitehorse Pivots, we would have been able to more accurately measure diversion use for that PoD, but we would not have been able to parse differences in water use between the two fields. If a producer were to rely on OpenET data to meet measurement and reporting requirements, they would be able to report on the estimated consumptive water use for each PoU, but consumptive water use could differ from the actual diversion use. Advanced techniques allow a user to address the match between the PoD, meter readings, and PoU (Beamer and Hoskinson 2021; Ott et al. 2024), but it seems unrealistic for a producer to be responsible for such analytical requirements.

The second issue we encountered was finding a suitable location to install the meters. Meter installation requires a specific minimum straight-run length of irrigation pipe to ensure minimal turbulence to achieve meter accuracy. These lengths vary by meter type and pipe diameter. In this pilot project, there were no locations near the pumps with a minimum straight run of exposed pipe. Therefore, all meters were installed at the PoU, with seven of eight meters installed on the pivot risers and one meter installed on a horizontal stretch of pipe at the base of the pivot riser. Based on our field observations and outreach with other landowners and irrigators, we anticipate that, more often than not, it will be difficult to find locations of exposed irrigation pipe near the PoD that meet the minimum length requirements.

The third issue was the presence of significant leaks in the field plumbing at the pivot or upstream of the pivot. The existing funding mechanisms for water use measurement require meters to be installed at the PoD to avoid the issue of underestimating water use due to leaks in the pipes beyond the pump or irrigation systems. However, the reality is that irrigation systems, especially those with older infrastructure, can show signs of leakage. In this pilot project, we observed several significant leaks in the pivot systems. Some of these leaks occurred upstream of the meters. As such, we expect that the measured water use in this study was less than the diversion use at the PoD. In other cases, leaks were observed downstream of the meters at the top of the pivot riser or along the pivot arm.

Resolving estimates of consumptive use from OpenET with metered flow measurements is likely to be even more complicated when leaks are present, especially if that water is subject to groundwater recharge. In at least one of the situations we observed, a substantial leak was creating ponding water that—when combined with grazing—temporarily denuded the portions of the field that were impacted. Unfortunately, estimating the impact of such a significant field disturbance on ET estimates and consumptive use was beyond the scope of this study. However, it highlights the need for more work to understand the field and irrigation management assumptions inherent in using modeled ET data as a proxy for consumptive use at the field scale.

In some places, it may be necessary to modify or update irrigation systems to enable proper flow measurement and/or measure OpenET more accurately. If irrigation conveyance and application systems require repairs or upgrades, it will be important to identify or create pathways for funding these costly improvements.

Propeller Meters

Due to the simplicity of installation, setup, and data collection, we recommend using propeller meters in most smaller operations where meters are preferred over OpenET. These meters could be especially useful for small operations where the meters are regularly accessed and inspected for functionality. Because propeller meters have more moving parts than electromagnetic meters, they are more susceptible to wear and tear over time, especially in irrigation systems with sediment. Our study yielded insufficient data to indicate whether propeller meters become less accurate over time; however, to mitigate this potential challenge, we recommend periodically inspecting propeller meters and/or comparing a meter's data to OpenET. Avoid installing propeller meters in systems known to pump sediment.

The main limitation of using propeller meters is the need for in-person data collection unless telemetry is installed. Internal data loggers could be useful if higher-resolution data are desired (daily, weekly, monthly).

Electromagnetic Meters

Electromagnetic meters may be a good choice for larger operations where expertise, capacity, and funding can support this technology. Electromagnetic meters—especially when paired with telemetry and an online software platform—can be powerful tools for operating and managing agricultural fields. However, these meters require a higher level of expertise for correct installation, data collection, and interpretation. The meter interface is not intuitive, and there is ample opportunity for user error.

In this pilot project, the meter on the Sherburn Pivot was installed in a way that caused the meter to log in reverse. In 2024, the irrigation contractor corrected the installation issue. If this technology is desired at scale, it will be necessary to build capacity and technical expertise within the industry for proper installation, technical support, and maintenance. We recommend exploring and learning from other states (Nebraska and Kansas) about how water management entities approach installation, maintenance, data collection, and data interpretation when using electromagnetic meters, telemetry, and online water use tools. In addition, working with Oregon State University Extension to develop and administer training may be another pathway toward developing local knowledge within the community and industry.

Telemetry

Telemetry systems must be compatible with the meter type, and additional data cables may be required. If the data cables are not installed correctly, FieldNET—the online software platform we used—will not display all the data, nor will it have access to the data to generate reports on water use.

The pilot project's design did not include data loggers for each of the flow meters. The project team planned to collect more detailed flow data using the telemetered system paired with FieldNET. However, during installation, the data cables that carry information between the meter and the FieldNET pivot control system were not installed correctly. This error made the telemetry system for the electromagnetic meters inoperable throughout the entire study period despite several attempts to address the problem. Only limited data were available remotely; therefore, field visits were required to collect the flow and volume data.

For full functionality, it is also necessary for the FieldNET software to be configured in advance of data collection in order to generate water use reports. Because of this requirement, we were unable to collect a continuous time series for the electromagnetic meters installed at each field.

Similar to our recommendation for electromagnetic meters, it is essential to ensure the proper installation, technical support, and maintenance of telemetry systems if these systems are to become a common element in Oregon's water use measurement and reporting.

Pivot Control and Remote Data Access

The FieldNET pivot control system can generate a notification when an error occurs with the pivot (e.g., an alignment fault), immediately alerting the field managers of a problem. It also allows for remote control of the pivot's power, application rate, speed, and direction. These features could be very helpful, resulting in more efficient water use over time.

In our pilot project, the remote pivot control was very useful for property managers and farmers during daily operations. They were able to control the pivot function in this expansive, remote location and could address problems more quickly than they could with in-person inspections of the pivot fields alone.

Data Collection

While guidance on meter selection is important, the processes for data collection and reporting should also be given careful consideration to ensure water users have the resources they need to provide meaningful water use data. The meter data presented in this report were paired with copious field notes, which helped reconcile errors and outliers observed in the raw values. Also, we performed an additional step to transform the values into daily volumes to compare with OpenET. Altogether, this work involved an intermediate level of technical analysis, and it is likely unrealistic to expect water users to perform similar analyses.

We recommend creating a standardized log sheet or web application to enable water users with propeller or electromagnetic meters to submit their data easily. Such a log should capture the date of the reading, the cumulative volume of water use, and relevant information describing field management, irrigation system performance, and other details. If using the methods in this analysis, water users should be asked to report total volume if using propeller meters or Forward Total values if using a magmeter. Depending on the needs and preferences of the department, the specific parameters may vary. Additional guidance around error detection and allowable thresholds may also be necessary.

As demonstrated in this pilot project, the relative percent errors in measured flow rates fluctuated throughout the course of the irrigation season. On many days, the flow rates measured by the two meters at one or more of the study's four pivots were less than the threshold of 4% (see the "Water Use Measurements From Meters" section for details). However, all four pivots had average relative percent errors above 4% for each irrigation season. Although the relative percent error calculation does not determine which type of meter was more accurate, it does indicate that the mean uncertainty between the two types of meters exceeded the expectations of instrument error alone among all pivots. Therefore, differences between meter types likely exist. However, the lack of systemic direction in error in either direction suggests that the measurement difference between meter types is due to different causes of technical failure rather than different measurement approaches. Future studies would benefit from a greater understanding of the mechanical vulnerability and associated causes of meter failure during common field operations among different meter types.

OpenET

The OpenET platform provides a publicly available dataset that has been vetted as an acceptable proxy for consumptive water use in agricultural landscapes. Oregon has been at the forefront of efforts to ground-truth the modeled ET estimates and the ensemble estimates. Substantial progress has also been made in curating compatible water management data and building analytical frameworks for leveraging this resource (Beamer and Hoskinson 2021; Ott et al. 2024).

While OpenET clearly has an important role to play in water management, the pilot project revealed two primary lessons learned for water use measurement and reporting. First, ET patterns do not reflect field-scale water use practices—and therefore consumptive water use—in an intuitive way. This finding was highlighted by the differences in field management and infrastructure conditions among the fields, where observations of water applied and subsurface flow conditions were notable. For example, early in the 2023 irrigation season, the House field likely received substantial subsurface flow due to the flooding of nearby Trout Creek, which may have resulted in OpenET overestimating consumptive use. Then, during the 2024 irrigation season, the impact of grazing on the House field likely resulted in OpenET underestimating consumptive use. On the other hand, because of the early end of the 2024 irrigation season at the Stonehouse field, the consumptive use estimate may have overestimated actual water use (although it is worth noting that this field was also grazed).

The underlying data and analytical methods behind the OpenET models and ensemble have an inherent assumption that fields are being managed properly (e.g., limited weeds, no grazing). While quantifying the discrepancies between actual consumptive use and the modeled estimates was outside the scope of this project, our field observations make it clear that additional information on field management and more research investigating ways to parse out the hydrologic contributions of nearby water sources would improve this approach's estimates of water use.

The other issue encountered during the pilot project was the learning curve associated with using the OpenET platform. While the data were easy for project staff to download and manipulate, the platform required some degree of technical proficiency to navigate. This technical proficiency would be especially crucial if producers are required to perform tasks outside of the Data Viewer, such as accessing daily data or customizing field boundaries. At the time of this writing, the Farm and Ranch Management Support (FARMS) tool had been released to assist users with data visualization and report building. However, technical support from agencies like OWRD may be necessary to facilitate the broader use of OpenET for groundwater management.

Availability and Expertise of Irrigation Contractors

The availability of irrigation contractors is limited in rural locations across Oregon. For our pilot project, only two irrigation contractors were willing to serve the area, and they were both located two hours away from the ranch. Only one contractor was willing to install flow meters due to local politics and sociopolitical risk. Due to the limited capacity of local contractors, installation and maintenance service calls were delayed. If flow meters are required at scale, this challenge will be amplified.

In addition, the lack of water use measurement requirements in Oregon has led to limited experience and technical expertise in the purchasing, installation, use, and maintenance of flow meter and telemetry technologies. This barrier could be overcome by developing and implementing training programs for irrigation industry contractors as well as agricultural producers. We recommend that, where direct flow measurement is required in the future, there be programs in place to support program development. This capacity building is especially important in rural areas where long travel times can make installation and equipment repair times challenging.

This project demonstrates that no single method will meet all measurement needs but that careful alignment of technology, infrastructure, and user capacity can ensure accurate and cost-effective monitoring. With practical guidance and technical support, both metering and OpenET have the potential to help Oregon's communities respond to water scarcity with improved confidence and accountability.

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Appendix A: Key Terms and Definitions

Term	Definition
Water use	The deliberate application of water for a specified use. In this report, descriptive terms are used to specify the nature of water use where appropriate.
Diversion use	The amount of water withdrawn from an aquifer or diverted from a surface water source.
Beneficial use	"The reasonably efficient use of water without waste for a purpose consistent with the laws, rules and the best interests of the people of the state" (OAR 690-300-0010, 2024).
Duty	"The maximum flow of water in cubic feet per second or gallons per minute (instantaneous rate) and the total volume of water in acre-feet per acre per year that may be diverted for irrigation" (OAR 690-300-0010, 2024).
Place of use (PoU)	The location where the beneficial use that is authorized by a water right will occur.
Point of appropriation (PoA)	"A well or the pump location on a sump at which ground water is withdrawn from the ground for use under a ground water right" (OAR 690-380-0100, 2009).
Point of diversion (PoD)	"The place at which surface water is diverted from a surface water source as specified in the water right. It may be the head of a ditch, a pump suction line, the center line of a dam, or other point at which control is taken of surface water" (OAR 690-380-0100, 2009).
Consumptive use (or consumed fraction)	Water used for irrigation that is transpired by plants, evaporated, or otherwise removed from the hydrologic system without the possibility of return flow. This category includes target consumption and nontarget consumption.
Target consumption*	Water that is evaporated or transpired for its intended purpose, typically an irrigated crop.
Nontarget consumption*	Water that is evaporated or transpired for purposes other than the intended use, such as water transpired by weeds, water evaporated from wet or waterlogged soils, or water that supports riparian or groundwater-dependent ecosystems.
Nonconsumptive use (or non-consumed fraction)	The amount of water that is not used for evaporation or transpiration. This category includes recoverable and non-recoverable fractions.
Recoverable fraction	Water that can be captured and reused by other water users or is returned to the environment to satisfy ecological purposes, including flows returned to rivers and percolated into aquifers. From a water management perspective, this fraction can be thought of as water that returns to both the physical and legal pools of available water.

Term	Definition
Non-recoverable fraction	Water permanently lost to further use by irrigators, such as flows to saline groundwater sinks, flows to very deep aquifers not accessed for pumping, or flows directly to the ocean. From a water management perspective, the non-recoverable fraction of water returns to the physical pool of available water but is not accessible to irrigators due to feasibility or legal reasons (e.g., environmental flow protections where an instream water right with a senior priority date is in place).
Irrigation efficiency	In terms of the performance of a given irrigation system, irrigation efficiency describes how effective an irrigation system is at delivering all the water necessary for crop production. It is measured as a proportion by dividing the target consumption by the total volume of water conveyed to the farm or field.
Overall irrigation efficiency	The efficiency of the entire physical irrigation system. It is a percentage based on the ratio between a system's conveyance efficiency and application efficiency. Overall irrigation efficiency inherently includes operating decisions that influence the diversion, conveyance, and application of irrigation water.
Effective irrigation efficiency	This metric is derived from overall irrigation efficiency, but it is corrected for any water recovered, reused, or restored from runoff and deep percolation. Strategies for reducing these losses vary among a range of options depending on local irrigation approaches and local regulations dictating water use.
Conveyance efficiency	Conveyance efficiency describes how effective an irrigation system is in ensuring that all water diverted or extracted from a water source is transmitted to a farm or field. It is typically measured as the proportion of the total volume of water initially diverted that actually reaches the farm or field.

* The term "target" is meant to describe the intended (or unintended) use by the irrigator for crop production. However, the terms "beneficial consumption" and "non-beneficial consumption" are used extensively in the peer-reviewed and agricultural literature as synonyms for target and nontarget, respectively. The term "beneficial consumption" can be easily confused or conflated with the legal terms and definitions associated with the beneficial use doctrine that is a hallmark of water law in the Western United States. The term also conveys an inherent value biased toward agriculture. For example, it is not our intent to describe irrigation water supporting riparian ecosystems as being a use that is "not beneficial." It is also not our intent to address ways in which "beneficial uses" are or are not examples of consumptive use.

Appendix B: Meter Configurations

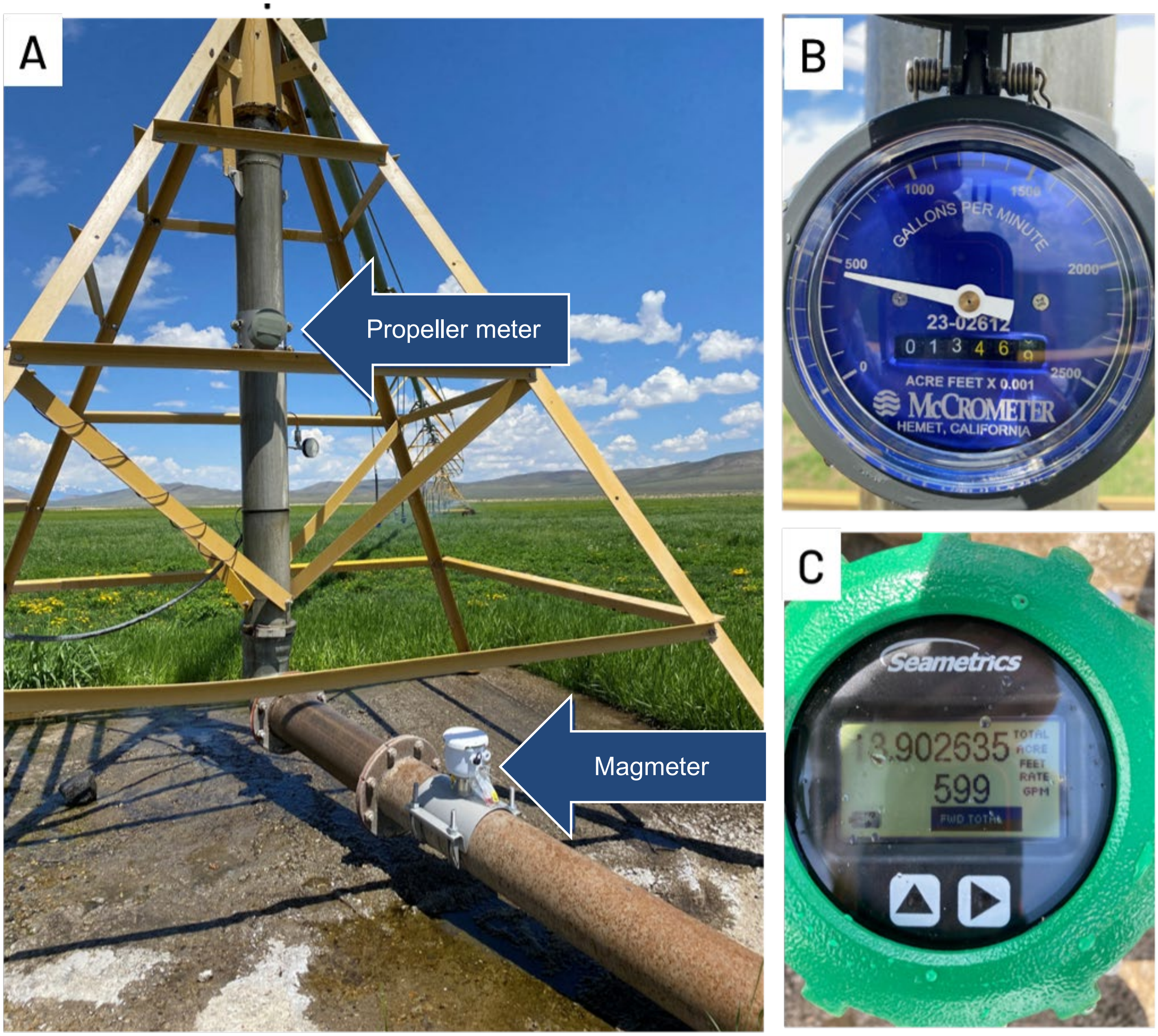

Figure B1. House Pivot configuration. Photo A shows the full meter installation schematic. The propeller meter (B) was installed above the electromagnetic meter (C).

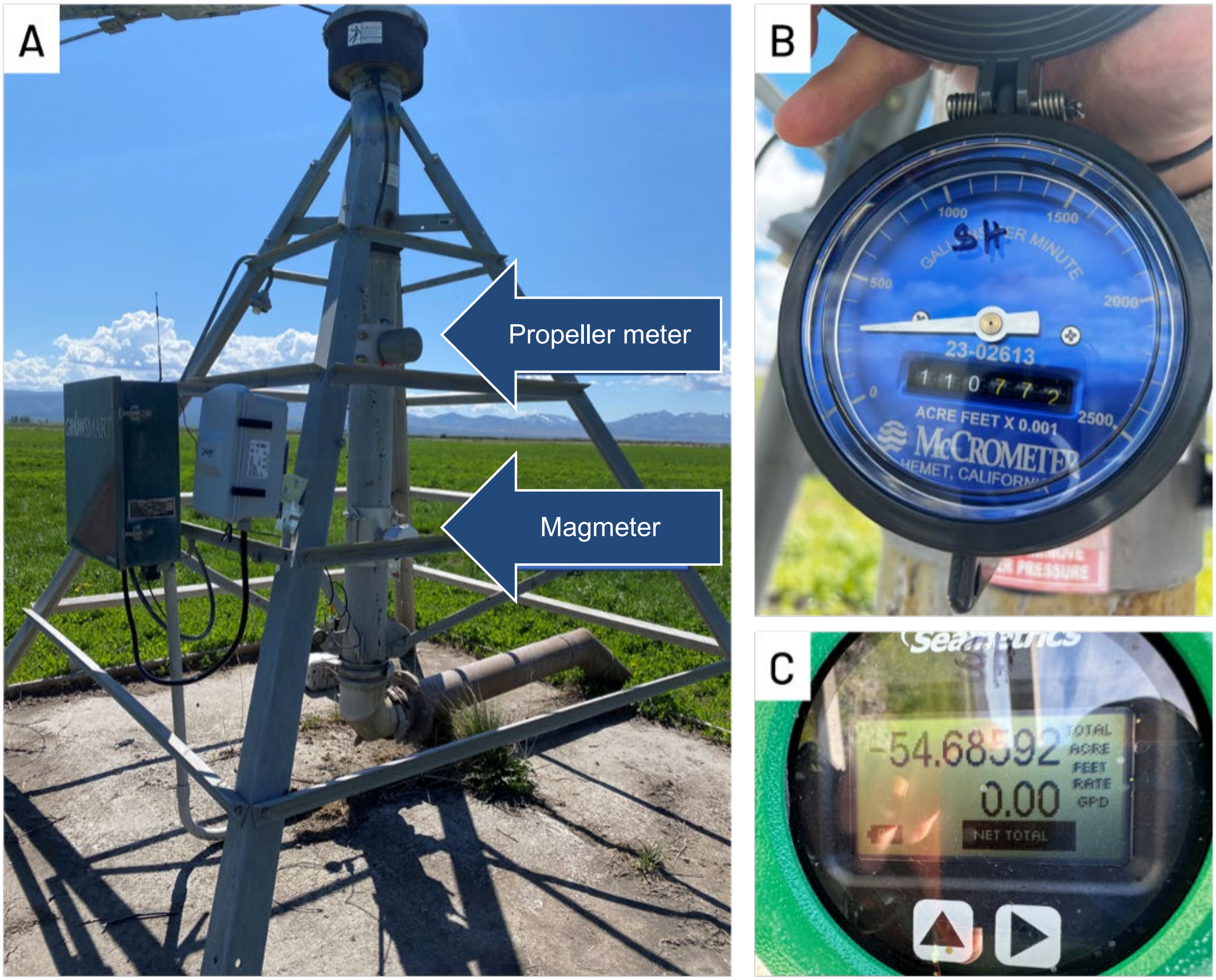

Figure B2. Sherburn Pivot configuration. Photo A shows the full meter installation schematic. The propeller meter (B) was installed above the electromagnetic meter (C).

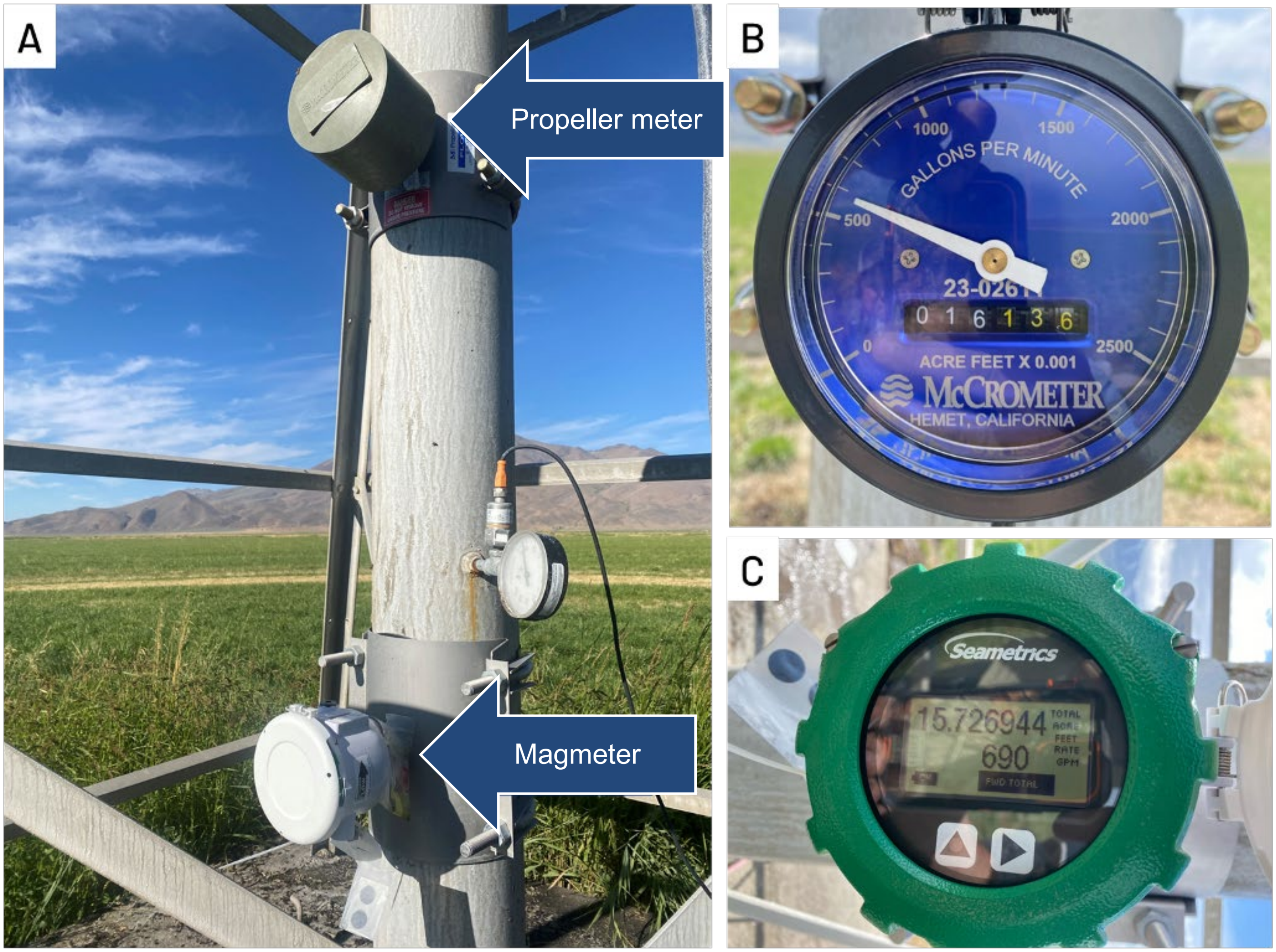

Figure B3. Stonehouse Pivot configuration. Photo A shows the full meter installation schematic. The propeller meter (B) was installed above the electromagnetic meter (C).

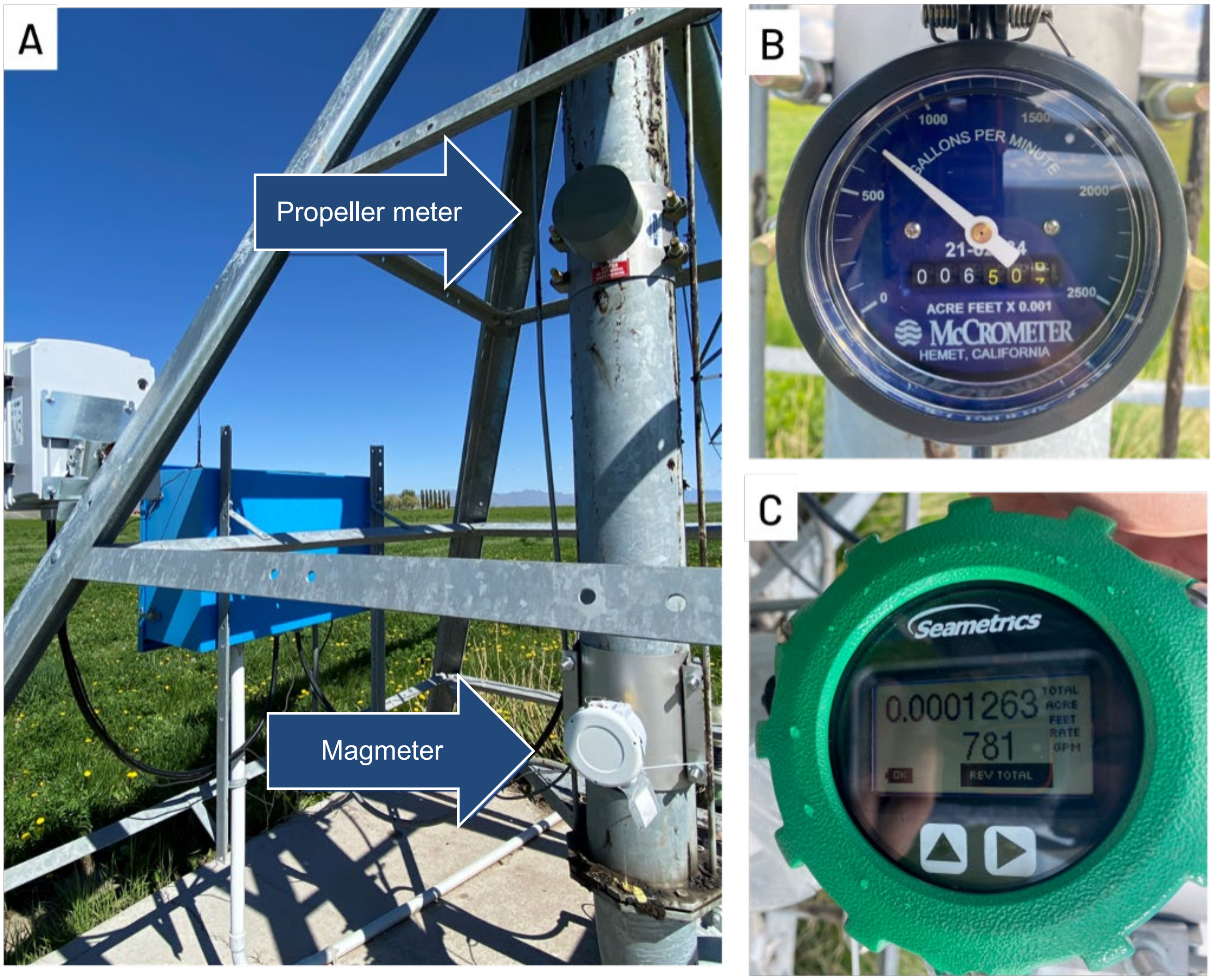

Figure B4. Whitehorse Pivot configuration. Photo A shows the full meter installation schematic. The propeller meter (B) was installed above the electromagnetic meter (C).

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