USING NET GROUNDWATER EXTRACTIONS FOR FARM LEVEL GROUNDWATER SUSTAINABILITY MONITORING

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ABSTRACT

The Cal Poly Irrigation Training and Research Center (ITRC) has developed a method for computing net groundwater extraction and recharge at the farm level for district management and regulation of sustainable/safe yields. This method is called Net To/From Groundwater (NTFGW). Net groundwater extraction is preferred for assessing sustainable yield in unconfined aquifer systems over direct metering of gross groundwater pumping. A recent pilot project with the Lower Tule River and Pixley Irrigation Districts' Groundwater Sustainability Agencies (GSAs) compared actual metered groundwater pumping, surface deliveries, and evapotranspiration to the NTFGW outputs on 19 farms within the GSAs over a 3-year period (2014-2016). In nearly all cases gross metered pumping was greater than net groundwater use, as it should be. In the few instances where this was not the case, intensive investigations identified the issues, which will be presented. The average difference between gross and net groundwater extractions was approximately 14". The variation of this difference was substantial between farms, indicating the difficulty in using gross pumping from flow/volume metering of actual pumping for sustainability. The NTFGW can incorporate seepage and recharge basin operation on a GSA level. It is also capable of tracking banked groundwater supplies on a farm level.

INTRODUCTION

The Sustainable Groundwater Management Act (SGMA) signed by Governor Jerry Brown in September of 2014 will likely have the most significant impact on California agriculture since the Central Valley and State Water Projects. At a very basic level, SGMA mandates that groundwater basins must balance groundwater use and recharge by the year 2040 for high-priority critically over-drafted basins and by 2042 for medium-priority basins in California. These basins cover nearly all irrigated agriculture in California, with the exception of Imperial Valley. Besides eliminating long-term overdraft, SGMA also addresses issues like land subsidence.

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Under SGMA, local management and implementation are encouraged through GSAs within each subbasin. Each GSA must provide a Groundwater Sustainability Plan (GSP) by 2020 and 2022 for high and medium priority basins, respectively. Plans from GSAs within each subbasin must have a technical agreement (same data and methodologies to develop the plan), which will be accomplished through a coordination agreement, sometimes referred to as Memorandum of Understanding (MOU), among a group made up of all GSAs within each subbasin. However, each GSA can have a different strategy to accomplish "sustainable groundwater management."

A methodology to assist in developing GSPs and enhance groundwater modeling was developed by the primary author and others (Howes et al. 2014). This technique is called Net To/From Groundwater (NTFGW) and provides monthly and annual net groundwater use and recharge spatially throughout a GSA. The resolution (farm/field, district, GSA) of this approach varies based on input data. It relies heavily on the ITRC-METRIC output of actual evapotranspiration (actual ETc) developed from remote sensing and ground-based weather data (Howes et al. 2012a, Howes et al. 2012b). It also relies on surface water applications or diversions minus spills/drainage with a GSA. A more general description of the process and need for net groundwater use for groundwater management was provided by Burt (2016).

Location

The study was conducted with the cooperation and support of Lower Tule River Irrigation District (LTRID) and Pixley Irrigation District (PID). Each district is its own GSA. Both districts are managed by the same district staff (General Manager, etc.) from a single office, although each have their own Board of Directors. The combined district and GSA management is called Lower Tule River and Pixley Irrigation Districts (LTRPID). The study was conducted over both GSAs/irrigation districts.

The GSAs are located on the eastern side of the Southern San Joaquin Valley, around Tipton and Pixley, California. This is between Fresno and Bakersfield, CA approximately 15 miles south of Tulare, CA. Lower Tule River ID is a Central Valley Project contractor receiving class 1 and 2 water from the Friant Kern Canal. LTRID also receives water from the Tule River with storage in Lake Success. Pixley Irrigation District receives excess water when available through purchases; however, growers mainly rely on groundwater. LTRID and PID have boundary areas of approximately 103,000 acres (41,680 hectares) and 70,000 acres (28,330 hectares), respectively. Major crops in the area are alfalfa, corn, winter small grains, almonds, and pistachios. This is a major dairy region in the state.

Objectives

The objective of this study was to compare the NTFGW approach using ITRC-METRIC with a pilot project that had detailed records of applied water (ground and surface) on multiple fields with various crops, irrigation types, and farm management. While this type of comparison (net vs. gross) has limitations, there are several important aspects that can be gained from such an analysis. The first is an understanding of the differences between applied and consumed water in a particular region. The second is quality control of ITRC-METRIC and applied water measurements. Net groundwater use should be less than gross groundwater pumping. If this is not the case, errors must exist in one or more analysis inputs.

METHODOLOGY

LTRPID started a pilot program in 2014 on specific farms (11 to 19 depending on the year) within the districts (shown in Figure 1) collecting well pumping volumes in addition to the surface water inflows already measured. The pilot project started before ITRC began working on the NTFGW for the GSAs. The continuous records from the pilot project farms provided an excellent comparison tool to test the potential for using the NTFGW approach as an alternative to groundwater metering at a farm level.

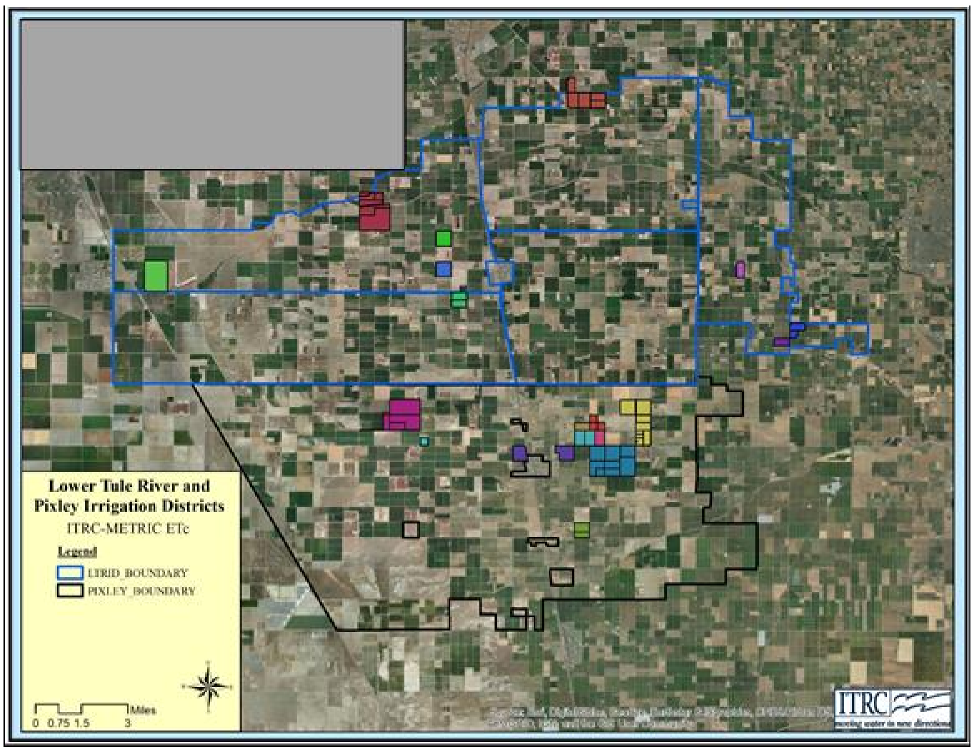

Figure 1. Pilot projects in LTRID and PID

Farmers volunteered sites for the pilot project, and the sites used were selected based on whether the applied water (surface and ground) could be utilized under a distinct set of criteria. In many cases, on-farm distribution systems allow for movement of multiple water sources to various fields to such an extent that it would make it nearly impossible to conduct this type of evaluation. The pilot project allowed multiple fields to be used for the evaluation, because it is rare to have one supply for one field, but the on-farm distribution system had to be closed so that all water was metered and only applied to the reported fields. It was not possible to determine when and how much water was applied to specific fields within a farm. In these situations, the fields were combined into a farm and the total applied water, precipitation, and ETc was compared over the aggregated area (termed "farm").

There were two evaluations conducted in this study. The first was a simple annual water balance, comparing irrigation applied plus precipitation with ITRC-METRIC actual ETc. The second compared NTFGW with applied groundwater within each pilot project farm on a monthly basis.

Simple Water Balance

The initial evaluation on the pilot project farms utilizing a farm water balance was conducted using the pilot project data. The goal was to examine the relationship between total applied water (surface, groundwater, and precipitation) and actual evapotranspiration. In general, over a 12-month period, the ETc should be less than the total applied water assuming the change in soil moisture storage over the period was nominal. The following equation was used in this analysis:

$$Closure = TAW + P - ETc \quad (1)$$

Where,

Total Applied Irrigation Water (TAW): Taken from district meter readout sheets, this refers to the total volume, including pumped groundwater and irrigation district supplied surface water applied to the pilot project fields. All values were recorded as a volume by the district, and were converted to a depth for each set of fields based on parcel acreages. Note that there were no surface irrigation water deliveries made by the district in 2014 or 2015. After March of 2016, the district began recording groundwater meter readings every three months instead of every month. Therefore, total irrigation applied water is a three-month average, and may not reflect the actual month water was applied.

Precipitation (P): Total precipitation, as a depth. Spatial precipitation estimates were obtained from the PRISM program at Oregon State University. PRISM datasets are based on ground-measured precipitation at numerous stations throughout the U.S. The monthly precipitation records are used to interpolate the precipitation between stations based on topography and other factors. Raster images were taken from PRISM monthly precipitation data, and were trimmed to fit the approximate project area. Pixel cell size of these images was adjusted to 30 meters by 30 meters using the bilinear interpolation method. Precipitation depths for each field were extracted from these images, and mean precipitation depth for each field was used.

ETc: Total evapotranspiration, taken from ITRC-METRIC raster images for 2014-2016.

There are uncertainties in the data provided, as will be discussed. Through the data gathering process, there were issues that arose related to how applied data was presented or organized. Even with just 19 farms, understanding and correcting the data took several meetings with district staff and visits to the fields to reconcile issues. This highlights the challenge of implementing a district-wide metering program.

NTFGW

The NTFGW was utilized on all areas of both GSAs, and pilot project fields were extracted for comparison. The total NTFGW evaluation was conducted from 2008-2016 (excluding 2012). The pilot project analysis data contained in this study was from 2014-2016. Figure 2 shows a simple schematic of the individual components for estimating the *Net To and From Groundwater* (*NTFGW*).

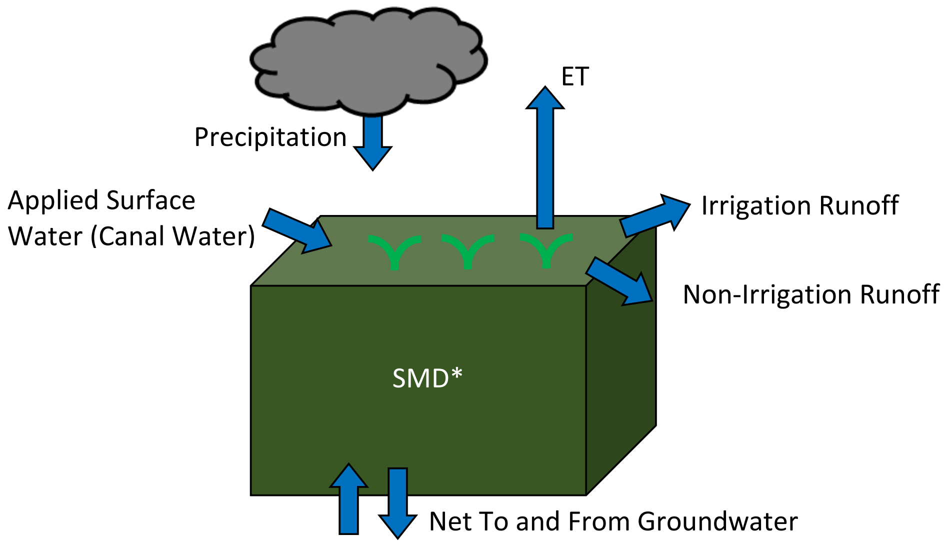

Figure 2. Schematic showing the components for computing the net to and from groundwater

The main components of NTFGW shown in Figure 2 include:

1. Applied surface water (canal water)
2. Precipitation
3. ITRC-METRIC actual evapotranspiration (ET)
4. Irrigation runoff
5. Non-irrigation runoff (precipitation runoff)
6. Surface water and precipitation soil moisture depletion (SMD*) to account for carryover

The *NTFGW* was computed monthly using the following equation:

$$NTFGW = Applied\ Surface\ Water + Precipitation - ET - Irrigation\ Runoff - Non\text{-}Irrigation\ Runoff \quad (2)$$

In this region there is no surface drainage to remove on-farm runoff. Most surface-irrigated fields have a tailwater return pond or do not use tailwater. Both irrigation and non-irrigation runoff were zero in this analysis. Precipitation from the Oregon State PRISM program was used as it provides spatially varied precipitation over the region. Applied surface water was provided by the districts through monthly database records for each turnout in the project area. The turnouts were tied to the parcels/fields where that water would be utilized.

On a monthly time step, this equation must include the soil moisture depletion (SMD) at the beginning of the month. In order to determine SMD, the soil type and general crop type are needed to determine the soil's available water holding capacity in the crop's root zone. The initial SMD is estimated based on prior months' (November and December) precipitation amounts. The evaluation of monthly NTFGW requires several checks on Equation 2 based on the SMD to account for carryover of precipitation and applied water from month to month.

Note that groundwater pumping is not an input into NTFGW. Instead, the net groundwater use or recharge is the remainder or closer to the equation.

RESULTS AND DISCUSSION

Results from the simple farm water balance are shown in Table 1 for the three analysis years. These annual results are based on calendar year totals shown as a depth (inches). The farm code is the anonymous code indicating different farmers/owners. The crop types and irrigation methods are shown. Irrigation (IRR) is identified as "S" for surface irrigation and "DM" for drip/microspray. ET is the actual evapotranspiration over the 12-month period. Total precipitation is used rather than effective precipitation, because the annual total ETc includes precipitation evaporation and plant transpiration.

The simplified evaluation shows that several farms had higher ET than applied water plus precipitation. Fields 4 and 16 showed a negative closure in both 2014 and 2015. Field 6 had a negative closure in 2015 only. Fields 9 and 14 indicated higher ET than applied water in 2016. There are several likely causes for these. One is that the simple balance does not account for carryover soil moisture storage from year to year. The NTFGW evaluation accounts for this carryover and will be examined next.

Table 1. Simplified annual water balance results with results in inches

FARM CODE	CROP*	IRR	2014				2015				2016			
			ET (IN)	P (IN)	TAW (IN)	CLOSURE (IN)	ET (IN)	P (IN)	TAW (IN)	CLOSURE (IN)	ET (IN)	P (IN)	TAW (IN)	CLOSURE (IN)
1	DAIRY	S					37.1	5.7	48.3	16.8	35.5	7.8	52.2	24.5
2	PISTACHIOS	DM					17.4	5.7	27.8	16.1	19.8	7.5	46.6	34.3
3	DAIRY	S	33.5	6.2	45.2	17.8	37.3	6.2	41.2	10.2	30.1	8.4	40.5	18.8
4	ALMONDS	DM	48.8	6.9	36.8	(5.0)	43.8	7.5	35.5	(0.7)	54.2	9.6	50.2	5.6
5	DAIRY	S	37.6	6.1	47.8	16.4	38.3	5.8	39.8	7.2	33.6	8.1	34.8	9.3
6	PISTACHIOS	DM	43.5	6.3	37.5	0.3	34.5	6.1	26.6	(1.7)	39.0	8.3	41.1	10.4
7	WALNUTS	DM	34.8	6.9	37.3	9.4	30.2	7.4	34.7	11.8				
8	ALMONDS	DM					36.8	6.2	36.0	5.4	46.1	8.3	42.1	4.3
9	ALMONDS	DM	43.7	6.3	42.5	5.0	41.3	6.1	39.6	4.5	49.9	8.3	39.1	(2.4)
10	WALNUTS	DM	47.6	7.1	43.0	2.6	40.7	7.6	34.8	1.7	47.9	9.9	46.7	8.7
11	GRAPES	DM	41.0	5.8	37.4	2.2	34.7	5.7	34.6	5.6	44.9	7.8	38.9	1.8
12	TOMATOES	DM					23.1	6.2	19.6	2.7	26.5	8.4	25.4	7.4
13	DAIRY	S					35.4	7.4	51.4	23.4	33.2	9.6	67.8	44.2
14	ALMONDS	DM	31.1	5.9	32.1	6.9	34.4	5.9	36.7	8.2	44.1	8.0	35.0	(1.0)
15	DAIRY	S	27.3	6.5	53.1	32.4	28.7	6.6	44.6	22.6	24.8	8.9	47.7	31.9
16	WHT/CORN	DM	45.3	5.8	37.9	(1.6)	48.1	5.6	36.6	(5.9)	38.4	7.7	32.9	2.2
17	PISTACHIOS	DM					4.0	6.2	6.7	9.0	6.2	8.4	12.6	14.9
18	ALMONDS	DM					35.9	6.3	36.5	6.8	42.8	8.5	40.2	5.8
19	PISTACHIOS	DM					30.5	6.1	36.4	12.0	34.8	8.3	36.5	9.9
WEIGHTED AVERAGE			35.3	6.26	44.55	15.51	33.3	6.22	39.24	12.17	32.9	8.36	43.68	19.12

**Dairy includes multiple fields that could be alfalfa, corn, sorghum, and winter grain hay. Some fields may be double cropped.*
Information on perennial crop age is shown in the Farm Information and Observations.
Blank cells indicate the farms were not in the program that year.

The results from the NTFGW evaluation are shown in Table 2. NTFGW can be either a positive (net recharge to groundwater) or negative (net groundwater use). The Applied from GW is shown as a positive, and should therefore be compared to the absolute value of the NTFGW. It is not expected that the two values used for comparison will be equal. Applied from Groundwater (GW) is a total gross pumping value while NTFGW is a net. The absolute value of NTFGW should be less than the Applied GW.

The evaluation shows that two fields in 2014, and one of the fields in 2015, has NTFGW greater than the gross applied groundwater. Fields 4 and 16 also show higher ETc than applied water in Table 1 in 2014. Field 4 in 2015 did not show greater NTFGW than applied water. It can be concluded that carryover storage from previous years was the cause for higher ETc than applied water from the simplified water balance. The monthly, continuous analysis used for NTFGW is a better evaluation tool to track actual groundwater consumption.

Table 2. Comparison of water applied from Groundwater and NTFGW analysis results. Values in red indicate applied water lower than NTFGW result. Negative values for NTFGW indicate water taken from groundwater. Units are in inches.

FARM CODE	*ACRES*	2014[1]		2015		2016	
		APPLIED FROM GW	NTFGW RESULT	APPLIED FROM GW	NTFGW RESULT	APPLIED FROM GW	NTFGW RESULT
1	*717.1*			48.3	-30.6	51.0	-25.7
2	*484.1*			27.8	-9.1	36.8	-2.8
3	*935.4*	45.2	-27.9	41.2	-29.1	40.5	-20.5
4	*115.1*	36.8	-42.2	35.5	-34.1	50.2	-39.6
5	*717.3*	47.8	-28.3	39.8	-29.7	31.0	-21.7
6	*156.4*	37.5	-36.8	26.6	-26.1	33.6	-21.7
7	*78.8*	37.3	-29.7	34.7	-22.7		
8	*77.9*			36.0	-29.4	42.1	-37.0
9	*157.0*	42.5	-38.1	39.6	-32.9	39.1	-32.7
10	*77.6*	43.0	-42.4	34.8	-32.2	29.5	-22.9
11	*153.2*	37.4	-36.4	34.6	-27.3	38.9	-34.7
12	*157.8*			19.6	-15.9	25.4	-11.8
13	*469.9*			51.4	-26.5	57.7	-12.5
14[2]	*312.2*	32.1	-30.0	36.7	-26.9	35.0	-35.0
15	*616.5*	53.1	-22.5	44.6	-21.7	47.7	-15.3
16	*38.3*	37.9	-41.5	36.6	-40.9	32.9	-29.9
17	*102.7*			6.7	1.1	12.6	3.0
18	*118.0*			36.5	-28.6	40.2	-35.8
19	*206.3*			36.4	-23.1	36.5	-27.5
WEIGHTED AVERAGE		**44.5**	**-25.4**	**39.2**	**-23.4**	**40.9**	**-17.6**

[1]Blank cells indicate that the field was not in the program that year.
[2]Participant 14 only had 1 of the 2 fields in the program in 2014 (139 acres). Both fields were in the program in 2015 and 2016.

Evaluation of Fields with Higher ET than Applied Water

ITRC went to each field that had higher ET than applied water identified in Table 1 in an attempt to determine what might cause this issue. Additionally, ITRC-METRIC was examined as part of this evaluation. These investigations were conducted prior to the completion of the full NTFGW processing, which reconciled the majority of the issues. Issues were found with Farms 4 and 16 that will be discussed.

Participant 4

During visits to this field in 2017, it was observed that the flow meter (propeller meter) had significant instability in the flow rate reading. While flow rate indicators (needle) traditionally vary (bounce between flows) this particular meter's flow rate indicator varied by nearly 50% of the flow, bouncing regularly from 550 to 1000 GPM (2,000 to 3,785 LPM) as shown in Figure 3. In good installations, the normal variance is not an issue because the totalizer (volume readout) buffers the variance out. However, the large variance seen at the Participant 4 field is not typical and is likely an issue that will impact the volume totalizer as well.

Figure 3. Participant 4's flow meter reading fluctuated continuously from low (left) to high (right) values as the photos were being taken

An examination of the flow measurement location and overall pump, filter, and meter installation indicated that the likely problem is with air in the pipeline. Participant 4 uses a gravity overflow screen upstream of the booster pump that supplies pressure to the microsprayers' irrigation system. The flow meter is located downstream of the booster pump (Figure 4), approximately 10 pipe diameters from any upstream obstructions. The likely problem is the lack of a continuous acting air vent (or any air vent) between the pump and the flow meter. Entrained air from the gravity overflow screen, traveling through the pipe likely cause the flow measurement indicator to vary wildly and leads to volumetric measurement errors.

The solution to this problem is to add a dual purpose, large, continuous acting air vent to the top of the pump discharge pipe just after the 90 degree bend. Another of these dual purpose air vents should be installed downstream of the flow meter as the pipe bends 90 degrees down prior to going underground.

Figure 4. Filter station at Participant 4 (left) and flow meter location (right)

Participant 16

Participant 16's field is a subsurface drip system for row/field crops. This site is typically double cropped with a winter small grain harvested for hay or silage and a summer corn harvested for silage. The discrepancy in this field is most likely caused by one or a combination of two factors. One possibility is that an inaccurate meter shows less total volume than was actually applied to the field. The second potential issue is related to the ETc for the field. Since seasonal crops are grown in this field, the LandSAT imagery used in ITRC-METRIC modeling captured an image on a date close to the harvest of the crop. As a result, when interpolating between image dates, the ITRC-METRIC model would assume that a crop was in the field longer than it was, and ET would be high.

An analysis of LandSAT images in fall of 2015 showed that the large discrepancy between ET and applied water for this year is likely caused by an error in ITRC-METRIC interpolation between these images. LandSAT images used in the modeling were captured on 8/14/2015 and 9/23/2015. Between these image dates, a LandSAT 7 image taken on 8/22/2015 (not used in the METRIC analysis) was examined and this field appears to have been harvested. Considering that the field was harvested between August 14 and August 22, and that the next image date used in the ITRC-METRIC model was captured September 23, the model would have over-estimated the amount of time that a crop was in the field. This would lead to an overestimation of the ET for the months of August and September. In the future, ITRC will utilize images as frequently as possible, especially during the planting and harvest periods, to minimize this issue.

Other items of note include:

- The flow meter is not located at an ideal location in the pipeline. The propeller meter in Figure 5 is only about three or four diameters downstream of the screen filter, which is considered a significant obstruction. The district installed an insert magnetic meter for this project, just upstream of the filter and directly downstream of a check valve and bend. This is a very poor location for a flow meter. It is important to have a proper velocity profile and minimal turbulence with propeller meters. This cannot be guaranteed in this installation at either meter.
- While the farmer states that the surface irrigation system fed by the standpipe shown in Figure 6 is not used, groundwater applications could be missed because there is no flow meter between the standpipe and the well.
- There is a continuous acting air vent on the section of pipe feeding the standpipe, which should eliminate any entrained air during operation. It may be appropriate to install a dual purpose, large, continuous acting air vent upstream of the check valve shown.

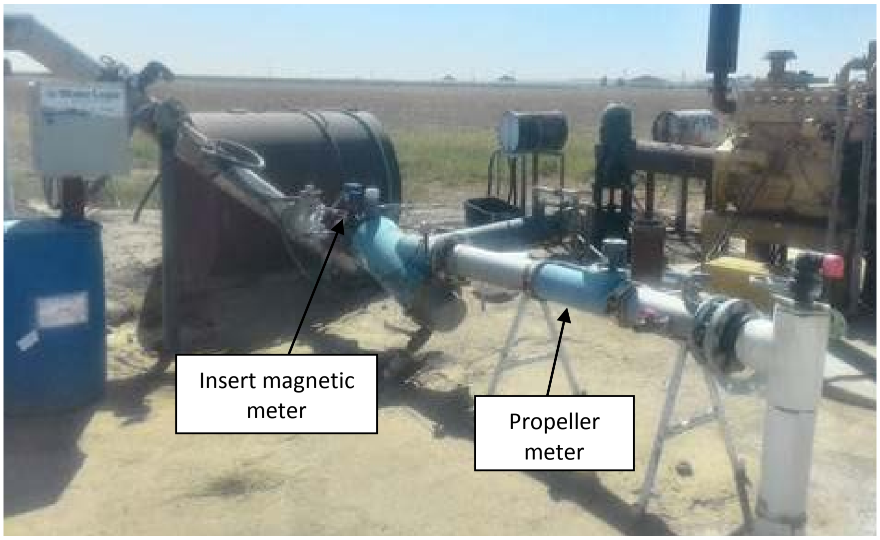

Figure 5. Filter and pump station at Participant 16

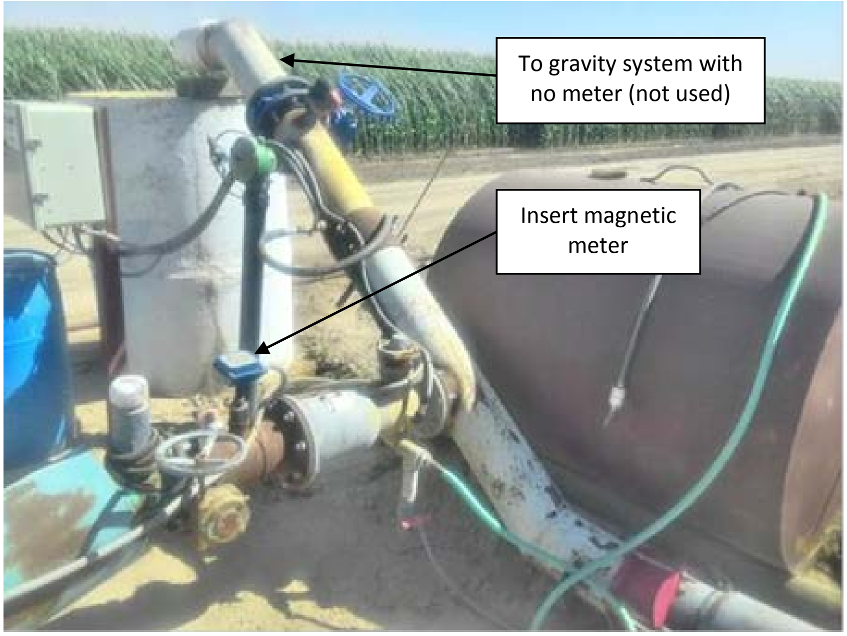

Figure 6. Pipe leading from pump into standpipe at Participant 16

CONCLUSION

The pilot project conducted by LTRPID showed several key details regarding groundwater management. As work began initially, there were significant issues related to where water was being delivered and metered that needed resolution. Significant time was spent with staff determining water accounting. In general, if a groundwater metering program (using individual well meters) were to be in place, the GSA/District staff will need to spend significant amounts of time understanding individual farm groundwater/surface water place-of-use. The cost and effort would be tremendous.

Several fields showed higher crop water use (ETc) than applied water in some years. Most of these have been explained or likely issues have been found. Most of the discrepancies found are minor compared to the overall consumption.

A key point found in this analysis is that overall the groundwater pumped is greater than the net groundwater use. This varies by field but was the general trend. This is to be expected since applied water must account for inefficiencies in the irrigation system. The NTFGW analysis is more accurate than a simple water balance because it accounts for monthly and annual soil moisture carryover.

Implementation of Net To/From Groundwater (NTFGW)

ITRC has developed a process to examine net groundwater use without the need to monitor groundwater pumping. This process has been described in this report and elsewhere and can be conducted at various scales from the farm/field, GSA, and basin depending on client needs and input data resolution. NTFGW incorporates surface water diversions, turnout deliveries (for farm/field scale), surface outflows, and precipitation with the monthly ETc to determine net groundwater use. Basically, if precipitation and surface water deliveries exceed ETc, the excess water would be stored in the root zone or moves to the groundwater (net to groundwater). If ETc exceed surface supplies, there is a net extraction from the groundwater to make up the difference. Results are provided spatially at the 30 meter pixel resolution. NTFGW is being used for two purposes:

1. Using historical data, to assist in calibration/verification of groundwater models. Equally important, the results provide a directly computation of the future ETc with net zero extraction.
2. For future management and regulation of groundwater use within the GSA. Monthly results will be provided to each GSA participant in near real-time (approximately 15 days after surface delivery information is provided to ITRC). Some GSAs are planning on providing this to farmers via a web mapping portal.

Benefits of NTFGW:

- No groundwater metering program with meters at each well is needed. DWR has approved the method as a best available science alternative.
- No estimates on irrigation efficiency are needed. Irrigation efficiency estimates have a high level of uncertainty, vary from field to field, and will change over time. NTFGW simplifies the evaluation of sustainable yield because inherently sustainable yield is a net value of how much groundwater can be consumed in a GSA. There is no need to estimate leaching requirements or other non-consumptive uses of groundwater. Comparing net values eliminates many uncertainties.
- It provides the ability to track net canal seepage and net recharge basin recharge by basin.
- It provides the ability to continuously track banked or over-drafted groundwater on a farm, district, and GSA level.
- It is cost-effective: the anticipated cost will be $30,000-$50,000 per year per district/GSA. Actual cost will depend on the district/GSA size and the level of evaluation.

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