DEPARTMENT OF NATURAL RESOURCES

Flow Meter Study

Double blind study of calculated and reported water use in the Little Rock Creek Area

3/4/2021

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Acknowledgements

Many DNR employees contributed time, services, and invaluable opinions. Erin Jenzen and Wyatt Naill performed quality control of the flow meters and 2018 data collection. A special thanks to the landowners of this study who graciously allowed access to their equipment and land.

Executive Summary

Minnesota Statute 103.G.265 requires the Department of Natural Resources (MNDNR) to manage water resources for sustainable use. Water uses in excess of 10,000 gallons per day or 1 million gallons per year require an appropriation permit. All permitted water users are required to measure monthly water use and submit the data to MNDNR annually. A reporting accuracy standard of ten percent is required according to Minnesota Rule 6115.0750 Subpart 3.B. but water use has never been verified in the Little Rock Creek area. Therefore, two-year study was conducted comparing reported and measured water use for irrigation from 2018 through 2019.

MNDNR partnered with eight appropriators to outfit nine center pivots with ultra-sonic flow meters to accurately measure volume of water pumped during the growing months. This was a double blind study where MNDNR used calibrated flow meters and the irrigators used several different methods (pumping rates, electricity usage and reporting equipment) to determine total water use. Volumes and pumping rates were compared after each growing season. The three variables compared were water use, pumping rate, and pumping time. This study found most irrigators overestimated pumping rates and water use compared to measured results, yet reported and measured pumping times were very close.

1. Introduction

How much water does an irrigation pump actually pump? This question is at the center of a collaborative effort by the Minnesota Department of Natural Resources (MNDNR) and eight landowners. Nine center pivot irrigation systems were fitted with temporary flow meters used to monitor the irrigation system (Figure 1). MNDNR purchased the meters, calibrated them and worked with local irrigators to install them on various irrigation systems. This was a two-year study after which, the DNR and landowners will use the information collected by these flow meters to compare to other more traditional methods. This project has several potential applications across the state to increase understanding of reported water use for crop irrigation.

1.1 Purpose

The goal of the flow meter project is to determine if there are differences between measured and reported volumes for the selected irrigation systems. Water appropriation permit holders (appropriators) are required to report monthly water use to MNDNR within 10% accuracy. Appropriators use a variety of methods to determine pumped volume including flow meters, known pump capacity and time in operation, electric usage and other methods. This study was developed to compare calibrated meter measured water volumes to other often-used methods. This study is a very small sample of irrigation systems so conclusions are limited to these specific systems. MNDNR works to determine potential impacts to surface water from groundwater pumping in the area and this study is another piece to help inform natural resource managers.

1.2 Study Area

The Little Rock Creek Watershed is located in Benton and Morrison Counties (Figure 1). The main stem of Little Rock Creek flows perennially and ultimately discharges into the Mississippi River. The tributaries of the stream are mostly intermittent and ditched but there is a general understanding that groundwater discharges into the stream. Since 1907 Little Rock Creek has been known to have a self-sustaining population of brown trout. However, in 2002 the Minnesota Pollution Control Agency added Little Rock Creek to the list of impaired waters for lack of cold water assemblage (Little Rock Creek).

This project observed irrigation of row crops including corn, beans, and potatoes, which accounts for nearly half the land use in the watershed. The wells in this study averaged a completed depth of 72’ set in a quaternary aquifer. The Little Rock area is known for sandy soils and groundwater surface water interactions.

2. Methods

This section describes the methods used to collect and process flow meter data.

2.1 Field methods

Nine ©Flexim FLUXUS Type F704 ultra sonic flow meters were purchased by MNDNR and calibrated at the Saint Anthony Falls Laboratory (an extension laboratory of the University of Minnesota) in Minneapolis. The meters were installed in the spring in 2018 and 2019 on the exterior of a horizontal pipe leading to a center pivot sprinkler. Ideally, the flow meters are installed in the spring before any crops are watered and removed in the fall when irrigators are finished watering. Two components clamped to the outside of the pipe comprise one meter (Figure 2). The up pipe component is a transmitter that sends out an acoustic signal through the pipe material reaching the fluid inside every five seconds. The second, down pipe component is the receiver, which collects the signal. Water velocity is measured by the time it takes the receiver to collect the transmitted signal.

The flow meters are attached by cable to a data logger powered by a battery, power regulator, and solar panel to continuously record the data from the flow meter (Figure 3). During installation, loggers were programmed according to the conditions of the pipe. Typical programming characteristics used for the flow meter loggers to calculate flow are:

1. Outside pipe diameter = 8”
2. Pipe material = Carbon steel
3. Pipe wall thickness = 0.063”
4. Median water temperature = 48.9˚F
5. Pipe roughness coefficient = 0.012 (*User manual* – Table C.2)

In 2018, the loggers recorded data every 5 minutes leading to the logger’s memory filling too quickly and some data was overwritten. In 2019, the loggers recorded every 15 minutes and no significant data was lost. Field staff visited every 4 weeks during the study to download data and perform maintenance on equipment, when necessary.

2.2 Data methods:

Data was downloaded to a laptop and then moved to a secure directory in the original format before creating new files for data processing. False flow data was removed from data sets by excluding data outside of accepted ranges of speed of sound, water velocity, and pump rate. Accurate, measured water use volumes were determined by data bounds shown in Table 1.

Unrealistic spikes or sporadic flow readings often represented an empty pipe, not actual watering periods. The temperature of the water influences the speed of sound and the pings meters send through the pipes. For example, the water pumped is cold groundwater and speed of sound increases with temperature. Higher speeds of sound were rejected because water in the pipe was interacting with warmer air temperatures and not flowing. Water velocity and pump rate bounds were set as a safe practice. Judgment was used to set these bounds (Table 1). The standard velocity of speed of sound in water is 1482 m/s at 20˚C (68˚F) and this rate drops with temperature. Speed of sound threshold differs slightly by each participant due to changing groundwater temperatures and instrument error.

Calculations

The results of the flow meters were compared to the following reported values:

1. Water use – Water use was compared by irrigator reported values against measured data from flow meter devices.
2. Pump flow rate – The meters measured water velocity through the pipe and physical pipe dimensions were measured during installation. Flow rate is reported as gallons per minute (GPM) (Equation 1).
3. Pumping time – The meters began collecting valid data when flowing water was present in the pipes. A back calculation was made to determine reported pumping hours (Equation 2).

$$Pump\ flow\ rate = water\ velocity\ x\ cross\ sectional\ area\ of\ pipe$$

Equation 1 – Volumetric discharge

$$Reported\ pumping\ time = \ (reported\ flow\ rate)^{-1} * reported\ water\ use$$

Equation 2 – Pumping time

Irrigators reported water use using several different methods (Table 2). An online database is used for irrigators to report pumping rates and monthly water use. Pumping rates are reported as a discrete number and does not change throughout the year.

3. Results

All participants watered crops in 2018 and 2019. Data was lost in both 2018 and 2019 and during periods of missing data reported and measured comparisons were not made. In 2018 flow meter data was lost from all meters ranging from June 30, 2018 to August 13, 2018. Therefore, this study did not use July 2018 for comparison at all sites and August 2018 at some sites. In 2019 flow meters did not capture the entire watering event at appropriator 5015 on May 14, 2019 because the meters were not installed yet so this study did not use May 2019 for comparison at that site. June was also omitted at appropriator 5015 because the meter ran out of battery for ten days. Table 3 shows the months used for comparison for both years of the study. Water use, pump flow rate and, pumping time were compared for all irrigators for both years.

1. Water use (Table 4) – With the exclusion of potential unmetered watering events, appropriator reported water use is likely greater than the measured volumes recorded by the flow meters. Values reported in Table 4 for 2018 are not comprehensive of all water withdraws for those center pivots because entire months were subtracted from the total in order to reasonably compare measured water use totals. Reported water use ranged from 4 MG to 35 MG and measured water use ranged from 6 MG to 25 MG in 2019. When only comparing complete months, water use was overestimated by 24% in 2018 and 25% in 2019.
2. Pump flow rate (Table 5) – Reported flow rates ranged from 300 GPM to 900 GPM in both 2018 and 2019. Measured flow rates ranged from 366 GPM to 864 GPM in 2018 and 386 GPM to 878 GPM in 2019. In 2018 the average flow rate reported and measured was 686 GPM and 560 GPM (23%

overestimated). In 2019 the average flow rate reported and measured was 691 GPM and 562 GPM (24% overestimated). Despite missing data in both years average pumping rate measured and reported can be compared since the reported pumping rate does not change throughout the year.

3. Pumping time (Table 6) – Like water use, pumping time cannot be compared when the meters are not collecting data so the values in Table 6 are not comprehensive. Reported values were calculated using Equation 2. In 2019 pump times the average reported and measured run times were 341 and 350 hours (2% underestimated). In 2018, pumping time was overestimated by 6%.

4. Discussion

It was difficult to compare water use for both years of the study due to the large data gap in 2018 during peak watering months. 2018 comparisons were limited to months with complete records. However, pump flow rate comparisons agree for both years of the study (Table 5). Data collected in 2019 does show discernable trends for pump flow rate, pump run time, and water use relationships. 2018 agrees with the trend directions in 2019 but this year is far less complete than 2019 (Table 2).

1. Water use – In aggregate, irrigators over report water use volume in both years. In 2018, water use was over reported by 24% (Table 4). Although this number is likely skewed due to some irrigators distributing their yearly total evenly each month, reporting their yearly total for the final month of the season, or using a different 30-day cycle rather than a calendar month. These nuances are clearer in sites that no not have complete yearly records. In 2019, water use was over reported by 25% (flow rate over reported by 24%, Tables 5 and 6).
2. Pump flow rate – Both years show average reported pumping rates are much higher than actual pump performance (23% overestimated in 2018 and 24% overestimated in 2019, Table 5).
3. Pumping time – Again, like water use this result is best analyzed with a complete season of data. Since measured flow in July was not completely collected in 2018 and some irrigators reported water use evenly by month, 2018 is not a representative year to compare pumping hours. For the purposes of this study, there was nearly a complete record for 2019. Overall, reported pumping time and measured pumping time were very similar (Table 6). On average, an irrigator’s pump ran 350 hours and was reported to run 341 hours. Therefore, appropriators on average underreported their pumping time by only 2%.

Irrigators are reporting total water use values to the best of their knowledge. Measured and reported pump run times are very similar meaning timing devices (Table 3) are accurate but flow rates are generally higher than measured leading to inflated reported water use.

5. Conclusion

This study was conducted to determine if there was a difference between irrigated volumes measured by a calibrated flow meter and standard methods used by appropriators. Flow meters measured water use, pumping rate, and pumping time on nine different center pivots in the Little Rock Creek area. Overall, water use was over reported by irrigators but measured and reported pump time ran matched closely in 2019. Every irrigator used pump rate in their water use calculation and on average pump rate was over estimated by 23% in 2018 and 24% in 2019. Water use was overestimated by 24% is 2018 and 25% in 2019.

This study is a small sample of irrigation pivots and methods used to determine water use. The appropriator partners for this study were volunteers and there was no effort to select certain types or ages of irrigation systems beyond setups that would allow for accurate measurements from the calibrated flow meters. Additional studies might determine if the age of the system or well along with any maintenance or development on the system or well would have an impact on calculated volumes. The general results of over reported use and pumping rate can be considered as MNDNR works to determine potential impacts to surface water from groundwater pumping in the area.

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Figures and Tables

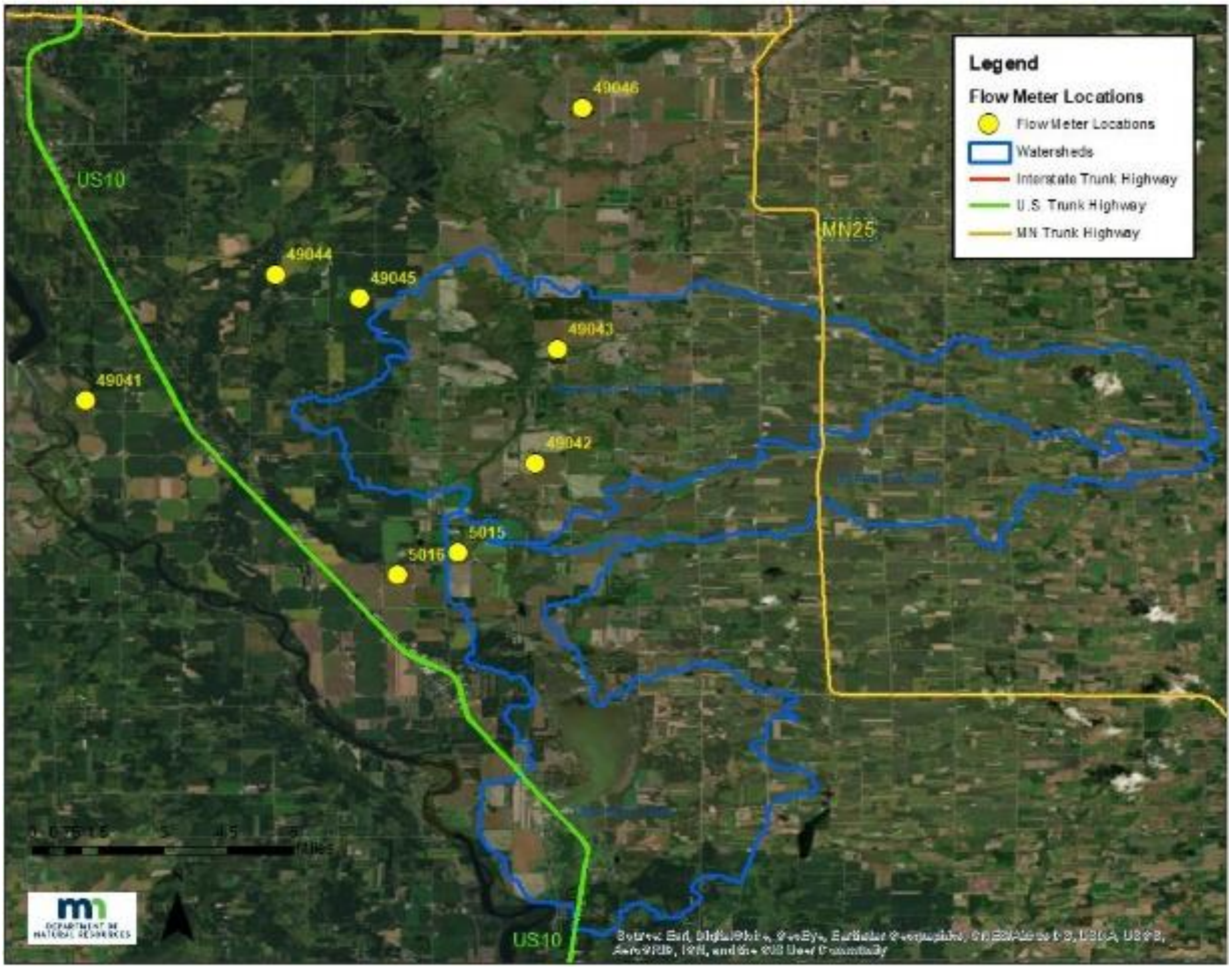

Figure 1 – Location of eight flow meters. The ninth flow meter (71043) is located off the map to the south.

Figure 2 – Flow meter clamped to exterior of pipe

Figure 3 – Flow meter gage house set up

Table 1 - Data bounds for filtering each center pivot.

Data bounds	Reject if…	Reject if…	Reject if…
Irrigator	Speed of sound range	Water velocity	Pump rate
5015	x>1458	7>x>10	x>950
5016	x>1400	x<3	x>800
49041	x>1381	3>x>10	x>600
49042	x>1468	x<3	x>700
49043	x>1382	2.5>x>10	x>600
49044	x>1485	x<2	x>400
49045	x>1401	x<2	x>450
49046	x>1475	x<3	x>650
71043	x>1453	2.5>x>6	x>700

Table 2 - Irrigator and associated method of reporting water use.

Irrigator	Method of reporting
5015	Hour meter on pivot x flow rate
5016	Hour meter on pivot x flow rate
49041	Kilowatt hours x horse power it takes to make 1 kilowatt hour x flow rate x efficiency factor
49042	Hour meter on pivot x flow rate
49043	Timing device with hour meter x flow rate
49044	Kilowatt hrs x horse power it take to make 1 kilowatt hour x flow rate
49045	Timing device with hour meter x flow rate
49046	Timing device with hour meter x flow rate
71043	Hour meter on pivot x flow rate

Table 3 – Months of flow meter data omitted from comparison due to missing values

Irrigator	Months Omitted in 2018	Months Omitted in 2019
5015	July	May and June
5016	July and August	None
49041	July	None
49042	July	None
49043	July and August	None
49044	July	None
49045	All months	None
49046	July and August	None
71043	July and August	None

Table 4 - Comparisons of study participants for reported and measured annual water use totals.

	2018				2019			
Irrigator	Measured Total (MG)	*Reported Total (MG)	% Diff	Volume Diff (MG)	Measured Total (MG)	*Reported Total (MG)	% Diff	Volume Diff (MG)
5015	22,103,908	23,149,800	5%	(1,045,892)	11,464,299	11,890,800	4%	(426,501)
5016	6,796,168	9,855,000	45%	(3,058,832)	24,782,169	35,199,900	42%	(10,417,731)
49041	10,850,796	14,134,500	30%	(3,283,704)	7,075,793	6,635,925	-6%	439,868
49042	8,855,526	13,261,500	50%	(4,405,974)	7,202,562	8,694,000	21%	(1,491,438)
49043	5,133,932	6,696,000	30%	(1,562,068)	19,233,869	25,020,000	30%	(5,786,131)
49044	5,774,722	6,094,340	6%	(319,618)	5,747,859	6,090,725	6%	(342,866)
49045	-	-	-	-	5,947,245	8,005,140	35%	(2,057,895)
49046	2,641,686	2,793,600	6%	(151,914)	5,549,362	4,134,100	-26%	1,415,262
71043	3,095,974	4,776,300	54%	(1,680,326)	15,783,680	23,185,500	47%	(7,401,820)
Total	65,252,712	80,761,040	24%	(15,508,328)	102,786,838	128,856,090	25%	(26,069,252)

*Indicates value was calculated

Table 5 - Comparisons of study participants for reported and measured annual average pump flow rates.

			2018	2019			
Irrigator	Measured GPM	Reported GPM	% Diff	Measured GPM	Reported GPM	% Diff	GPM Change
5015	864	900	4	878	900	3	NO
5016	650	900	38	644	900	40	NO
49041	512	900	76	525	900	71	NO
49042	632	700	11	644	700	9	NO
49043	473	600	27	475	650	37	YES
49044	366	300	-18	386	300	-22	NO
49045	429	550	28	405	550	36	NO
49046	617	600	-3	610	600	-2	NO
71043	503	725	44	494	725	47	NO
		Average	**23**		**Average**	**24**	

Table 6 - Comparisons of study participants for measured and calculated annual pumping times.

			2018	2019		
Irrigator	Measured Pumping Time (hours)	*Reported Pumping Time (hours)	% Diff	Measured Pumping Time (hours)	*Reported Pumping Time (hours)	% Diff
5015	426	429	1	226	220	-3
5016	174	183	5	657	652	-1
49041	353	262	-26	225	123	-45
49042	234	316	35	186	207	11
49043	179	186	4	679	642	-5
49044	263	339	29	251	338	35
49045	-	-	-	243	243	0
49046	71	78	9	152	115	-24
71043	101	110	9	531	533	0
Average	**225**	**238**	**6**	**350**	**341**	**-2**

*Indicates value was calculated