A preliminary investigation of surface and groundwater exchange within tailwater recovery systems in the Mississippi Delta

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Abstract

Substantial withdrawals from the Mississippi Alluvial Aquifer for irrigation have resulted in a long-term trend of decreasing groundwater levels. Agricultural producers are adopting tailwater recovery systems, a best management practice for capturing surface water for re-use, but scientific data is lacking on the ability of these systems to mitigate aquifer depletion. One current area of interest is the potential for these systems to serve as a recharge mechanism. It is proposed that instrumenting tailwater recovery systems of varying age with piezometers, equipped with multiple loggers that measure temperature, atmospheric pressure, and depth, will provide data for a groundwater flow and heat transport model developed using VS2DH. Quantification of ground and surface water exchange indicated that over the observation period some influence from surface water was likely being exerted on groundwater stores. However, gradual changes in well temperature indicate low hydraulic flow rates between compartments. Additionally, gradual temperature changes were observed to change at a greater rate in the new (<1 year old) tailwater recovery system, indicating that age of the system does impact groundwater – surface water interaction. Surface water quality analysis resulted in low nutrient concentrations. Low flow rates and nutrient concentrations result in minimal concern for groundwater leaching from TWR/OFS systems.

Introduction

Irrigation accounts for the largest use (98%) of the Mississippi Alluvial Aquifer (Thornton, 2012), which is the primary groundwater source for agriculture in the Mississippi Delta. Substantial withdrawals from the Aquifer without equivalent recharge have resulted in a cone of depression in the central Mississippi Delta, and depletion of the Aquifer as a whole (Barlow and Clark, 2011). Producers in this region have been eligible for federal cost-share assistance through the US Department of Agriculture National Resource Conservation Service (NRCS) to implement tailwater recovery systems (TWR), with or without an additional on-farm storage reservoir (OFS). A TWR (with or without an OFS) is designed to capture surface runoff, reducing outflow of nutrients to receiving waters and simultaneously providing an alternative source for irrigation (Figure 1). This dual benefit is important because it addresses both quality and quantity of water, which are equally important in Mississippi and many other areas. As of August 2014, 184 TWR/OFS have been cost-shared under practice code 436 by NRCS in the State of Mississippi (Paul Rodrigue, NRCS, personal communication); over 50% of these systems are located within the cone of depression (Figure 2). Despite their prevalence on the landscape and their popularity with producers and government agencies, much research remains to be done to quantify the water quality and quantity benefits of TWR/OFS.

To accurately model levels within the Aquifer, it is necessary to determine the rate of ground and surface water exchange. Field observations at one research site reported water level losses due to leakage from a TWR and OFS between 0.5 to 3 feet per month over a six-month period (REACH, unpublished data). A primary hypothesis is that infiltration rates decrease over time as these systems compact and fill-in with silt due to head pressure from overlaying water, but the time required for systems to seal is unknown. During this time where water losses are high, a significant potential for groundwater – surface water exchange exists. The recharge potential for these systems must be quantified to assign additional value to continued investment in these systems. An additional factor of consideration is the potential of TWR to become a source for nutrient leaching as these systems accumulate and hold nutrient loads leaving agriculture fields. Thus it is important to examine groundwater – surface water exchange from a quantity *and* quality perspective. This information will be immediately useful to federal agencies that are under pressure to provide accurate accounting of the status of the Aquifer, agencies and producers making investment in these best management practices, and scientists working within the water quality and quantity arenas.

Barlow and Clark (2011) examined various conservation scenarios for the Mississippi Delta to determine their benefit on Mississippi Alluvial Aquifer levels. Scenarios investigated that specifically targeted the cone of depression resulted in the greatest improvements within the cone; however, Delta-wide scenarios resulted in greater broad area improvements in water level. Ultimately, it was the major conclusion of the authors that focusing conservation efforts within the cone of depression led to the greatest improvements in storage within the Aquifer. With the majority of TWR/OFS being implemented within the cone, it is imperative that their contribution to recharge be studied because this is the area with the most need, the area with the greatest density of TWR/OFS, the area where the most benefit Delta-wide is likely to be seen, and the area where the consequences of limited recharge will be felt first and most severely. The cost-benefit ratio of this project cannot be overstated. The data collection effort for this project is extremely straightforward, relatively simple to implement, and comparably low-cost; however, the results that these data will yield represent a major step forward in the understanding of the benefits of TWR and provide additional data for those tasked with estimating Aquifer levels. Ultimately this data will assist policymakers in designing strategies and guidelines to appropriately manage this vital resource

The objectives of the proposal are: 1) quantify the recharge contribution of TWR/OFS to the Mississippi Alluvial Aquifer; 2) quantify transport of nutrients between groundwater and surface water within TWR/OFS; and 3) determine if age of TWR/OFS impacts magnitude of groundwater – surface water exchange. Research priorities applicable to this research project include utilizing innovative approaches to estimate aquifer recharge via assessment of GWSW interactions within TWR/OFS using piezometers with pressure and temperature transducers to quantify TWR/OFS contribution to Aquifer recharge. Performance and effectiveness of innovative and established nutrient and sediment management methodologies via assessment of nutrient transport between groundwater underlying and surface water within TWR/OFS will be conducted. Prediction of future impacts from proposed infrastructure on water resources via quantification of quality and quantity benefits of TWR/OFS and additional model parameters related to system age as it relates to groundwater – surface water exchange. Methods, procedures, and facilities.

Materials and Methods

Potential recharge of the Mississippi Alluvial Aquifer from TWR/OFS was investigated at two sites within the Mississippi Delta region. Groundwater – surface water exchange was documented at two locations within each site using piezometers with loggers which measure and record real-time atmospheric pressure, water temperature and water level. Each site was instrumented with two piezometers as shown in Figure 3 and Figure 4; installation occurred between November 5, 2015 in System 1 and December 9, 2015 in System 2. Sites were equipped with additional temperature probes and an additional logger, located above the reach of surface water to provide a reference for barometric correction of the loggers within the piezometer. At each piezometer location, pressure and temperature were recorded from groundwater (at a 1 to 2 m depth), the sediment bed, and from surface water. Sediment and surface data was collected from August 22, 2015 to February 17, 2016. However, groundwater data was not collected from November 5, 2015 to February 17, 2016 due to constraints implementing piezometers in the systems. Figure 3 illustrates how these key data collection points are connected. Data was downloaded from loggers every other week from to ensure the loggers are working correctly and subsequent data loss. Data analysis required using a two-dimensional groundwater flow and heat transport model developed using VS2DH, a program developed by the U.S. Geological Survey. The VS2DH model quantifies groundwater – surface water exchange over the data collection period. Data from loggers is necessary to the successful development of the model within VS2DH, which requires daily groundwater levels and temperature values at identified collection points for model parameter specification.

Samples for water-quality analysis were collected every other week from surface water held within the TWR/OFS from September 9, 2015 to January 29, 2016, however, attempts at extracting groundwater samples from piezometers using Teflon tubing and a peristaltic pump, following nationally consistent sampling protocols (Koterba et al., 1995), were not successful. Personal communications with the landowner revealed that it is common for manually implemented shallow wells to become clogged due to clay particles. All surface water samples were handled, collected, and transported according to EPA quality assurance/quality control guidelines (USEPA, 2002). Water samples were transported (in coolers, on ice at ~4°C) from field sampling locations to the Mississippi State University Water Quality Laboratory for analysis. Samples were analyzed for total inorganic phosphorus, dissolved inorganic phosphorous, ammonia, nitrate, and nitrite. Quality-control data, including field blanks and field duplicates were collected along with routine samples to ensure that unintended contamination did not occur at any point in the sample collection and laboratory analysis. Field duplicate samples were collected for approximately 10% of all routine samples. Water quality data was intended to be used to determine the magnitude of nutrient leaching from TWR/OFS; in the absence of groundwater samples, water quality data was used to speculate potential groundwater leaching from surface concentrations.

Site selection was strategic and includes one TWR/OFS for which there is some preliminary data (REACH, unpublished data). System 1 is located in Coahoma County, MS and is approximately five-years old. System 2 is located in Sunflower County, MS and was less than one year old at the beginning of the project. Strategic site selection allows for comparisons of TWR/OFS based on age. Appropriate statistical methods for time series comparison will be employed to determine how age of TWR/OFS influences groundwater – surface water exchange over time, and will be based on comparison of the old system against the new system. As previously stated, a primary hypothesis is that infiltration rates decrease over time as these systems compact and fill-in with silt. By examining systems at two different ages, it is anticipated that the research will not only show the potential for groundwater recharge and nutrient leaching from these systems, but also an indication for the duration of these risks (i.e., the trend in recharge and leaching over time) so that any necessary management changes can be made to maximize water-use efficiencies or mitigate pollution risks.

Results and Discussion

Analysis of groundwater – surface water data via V2SDH models, proposed conducted a by USGS collaborator; was not completed at the time of reporting. Subsequent analysis of temperature patterns was conducted to address project objectives. Project objective 1 aimed to quantify the recharge contribution of TWR/OFS to the Mississippi Alluvial Aquifer. Temporal surface water, sediment, and within shallow wells (approximately 10 ft depth) temperature data from each sampling location were plotted together to identify patterns (Figures 5-8). At all locations variability in surface water and sediment followed changes in atmospheric temperature and displayed some instances diurnal cycling. However, well temperature remained fairly stable, showing gradual temperature decreases toward surface sediment and surface water temperatures over time. Given the lack of surface and sediment variability echoed in well temperature patterns (and vice a versa), data indicates that hydraulic flow rates through sediment are low, such that potential groundwater – surface water exchange would be occurring at a slow rate. Decreases in well temperature over the three month period toward sediment and surface water temperatures (while atmospheric temperature is rising) indicate that some surface water is influencing groundwater stores. However, low hydraulic flow indicates high potential for water treatment during movement through sediment.

Project objective 2 was to quantify transport of nutrients between groundwater and surface water within TWR/OFS. As attempts toward collecting groundwater samples failed, data only allowed for the forecasting of potential nutrient transport from measured surface water contributions. Water quality results revealed nutrient and sediment concentrations in TWR/OFS systems to be lower than previously reported runoff in the Mississippi Delta region (Littlejohn et al. 2014; Baker et al. 2016). Mean nutrient concentrations were found to be below 1 mg/L and total suspended sediment concentrations were found to be below 150 NTU. Given the low hydraulic flow rate indicated by temperature data and low observed surface water nutrient concentrations, concern for nutrient seepage to groundwater stores is minimal.

Project objective 3 was to determine if age of TWR/OFS impacts magnitude of groundwater – surface water exchange. Temperature differentials between well – sediment data at all sampling locations were plotted (Figure 9 (a-d)). Temporal temperature differences were plotted and linear trendlines with slope and r-squared equations were calculated to evaluate if these parameters differed between the two systems. Linear trendline slopes calculated for System 2 (<1 year old) were greater than System 1 (>5 years old), indicating a faster rate of change in temperature differences over the three month observation period. Results indicate that groundwater – surface water interactions were greater within system two, supporting the hypothesis that age of TWR/OFS impacts magnitude of groundwater – surface water exchange. These results, while notable, are not concerning bearing in mind that results supported low hydraulic flow rates at all locations. Furthermore, data from System 1, indicates that groundwater – surface water exchange will decline overtime.

Conclusion

Investigation of potential recharge of the Mississippi Alluvial Aquifer from TWR/OFS at two sites within the Mississippi Delta region yielded data indicating that any groundwater –

surface interactions are occurring at low hydraulic flow rates, such that daily or weekly interactions were not apparent and potential for significant groundwater recharge is minimal. Low hydraulic flows combined with low nutrient concentrations equate to minimal concern for nutrient leaching to groundwater stores. Decreasing trends in well temperature at all study locations over the study period do, however, indicate potential contribution of surface water to groundwater stores. This preliminary data should be interpreted with caution given the small observation period and number of replications. Future research is warranted to build a larger body of data toward project objectives.

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Student Training

One undergraduate student, Jonathon Rogers, received full-time experiential learning and research experience as a result of this funding. The student presented research at the Mississippi Water Resources Conference (below). Additionally, this student found immediate employment following May 2016 Graduation.

Presentations

Jonathon Rogers, ***Beth Baker****, Joby Czarnecki, and Jeannie Barlow. "Towards an understanding of surface and groundwater exchange through tailwater recovery systems." Mississippi Water Resources Conference. Jackson, MS. April 5-6, 2016.*

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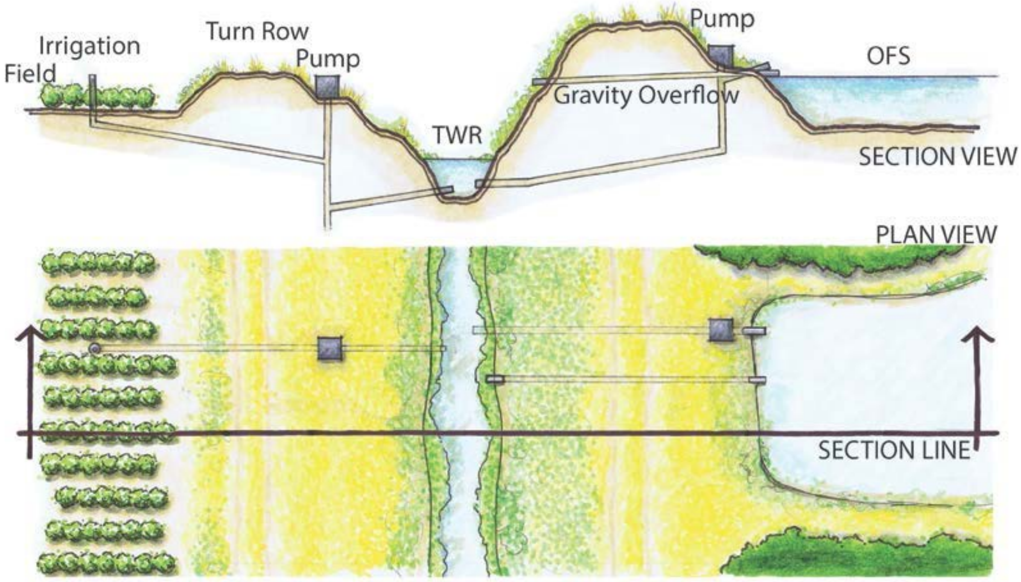

Figure 1. Schematic of a tailwater recovery system and on-farm storage reservoir in section and plane view.

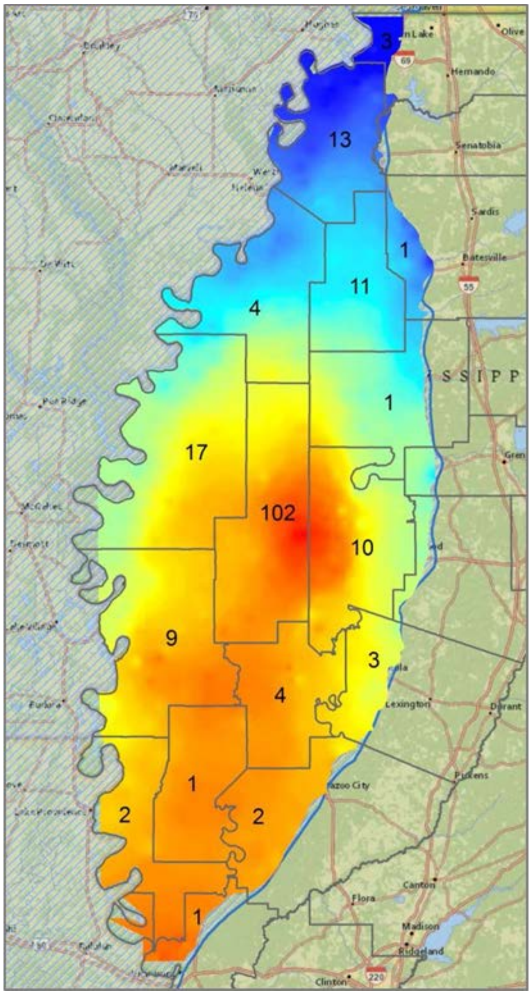

Figure 2. The Mississippi Delta counties with number of TWR/OFS cost-shared by NRCS within each county. Aquifer levels decrease from blue to red, with red representing the cone of depression. Aquifer levels based on data from Mr. Mark Stiles, Yazoo Mississippi Delta Joint Water Management District.

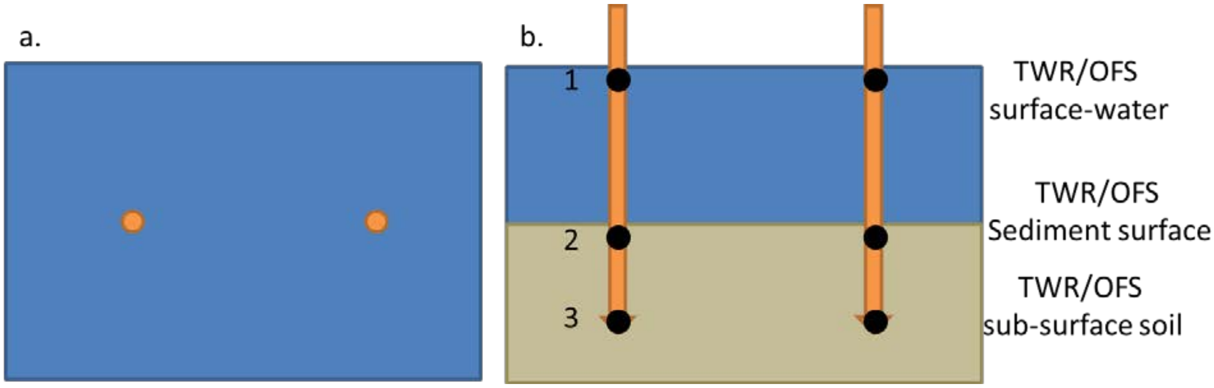

Figure 3. The image on the left (a) shows an aerial view of piezometer placement within the TWR/OFS. The image on the right (b) shows a transect of the horizontal plane to depict piezometer placement within the TWR/OFS extending from 1 to 2 m below the sediment surface to above the surface water level. Numbers 1, 2, and 3 indicate placement of respective data loggers, which will record pressure, water level, and temperature from surface water, from the sediment bed, and from groundwater, respectively.

Figure 4. Actual piezometer placed in TWR/OFS placed in System 1. Image A shows PVC pipe housing pressure gauge wiring and sample tubing along bank from the piezometer; Image B shows the PVC pipe where it connects to the piezometer and enters the sediment in System 1; Image C shows wiring and tubing housed in plastic bin on top of the TWR/OFS bank for accessible data downloading.

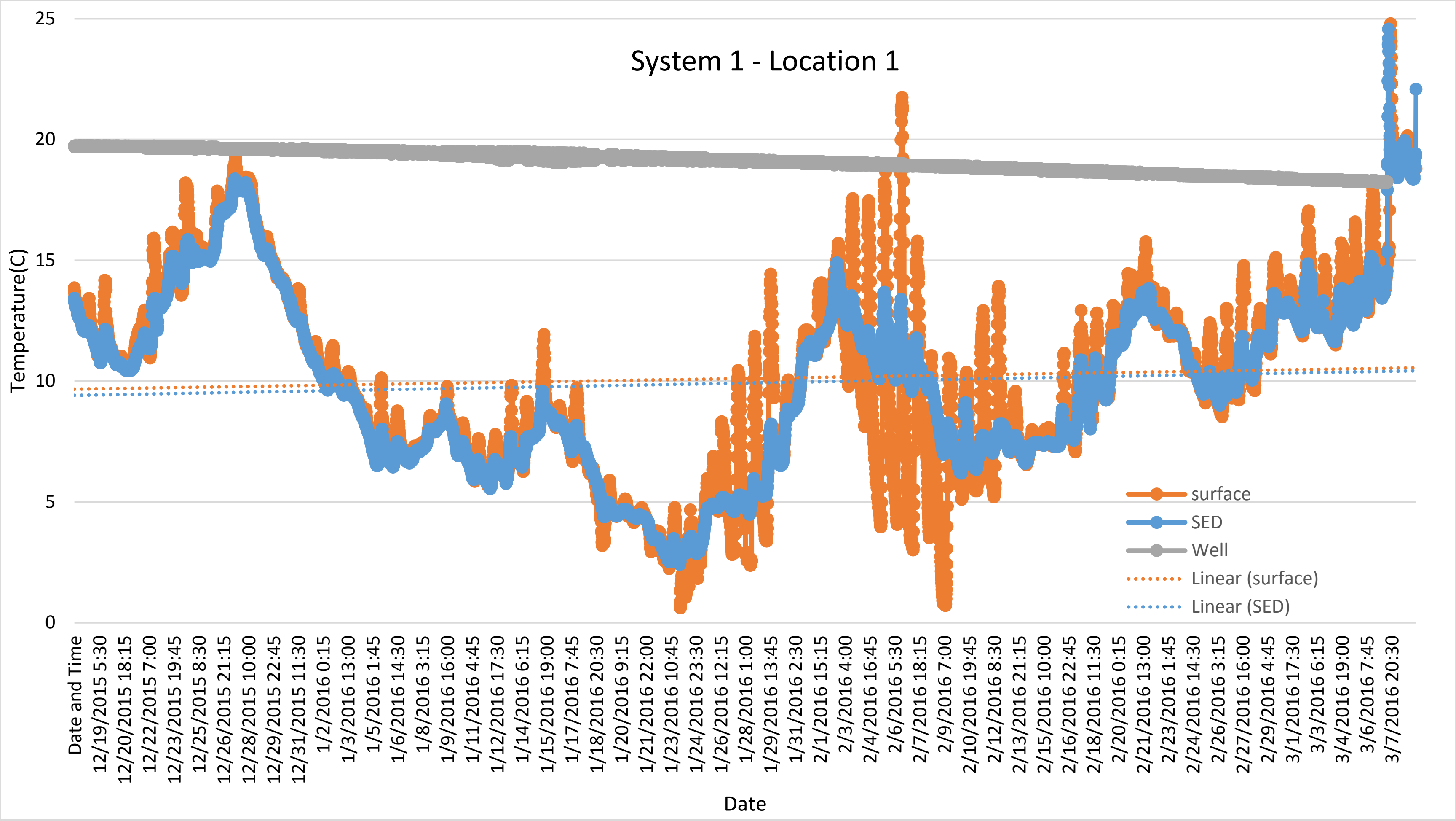

Figure 5. Temperature data collected from December 17, 2015 to March 7, 2016 at location 1 within TWR/OFS System 1 (>5 years old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

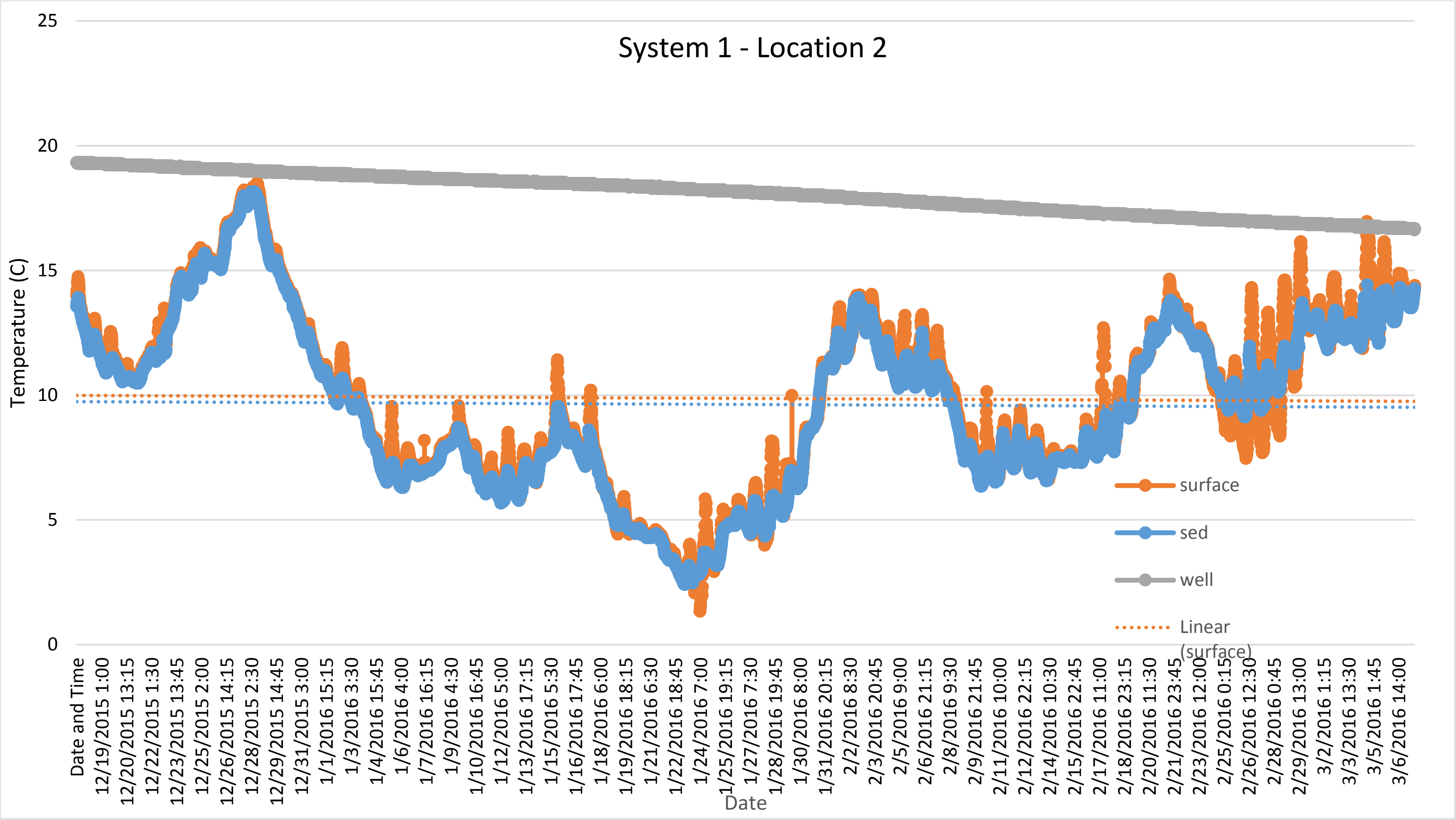

Figure 6. Temperature data collected from December 17, 2015 to March 7, 2016 at location 2 within TWR/OFS System 1 (>5 years old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

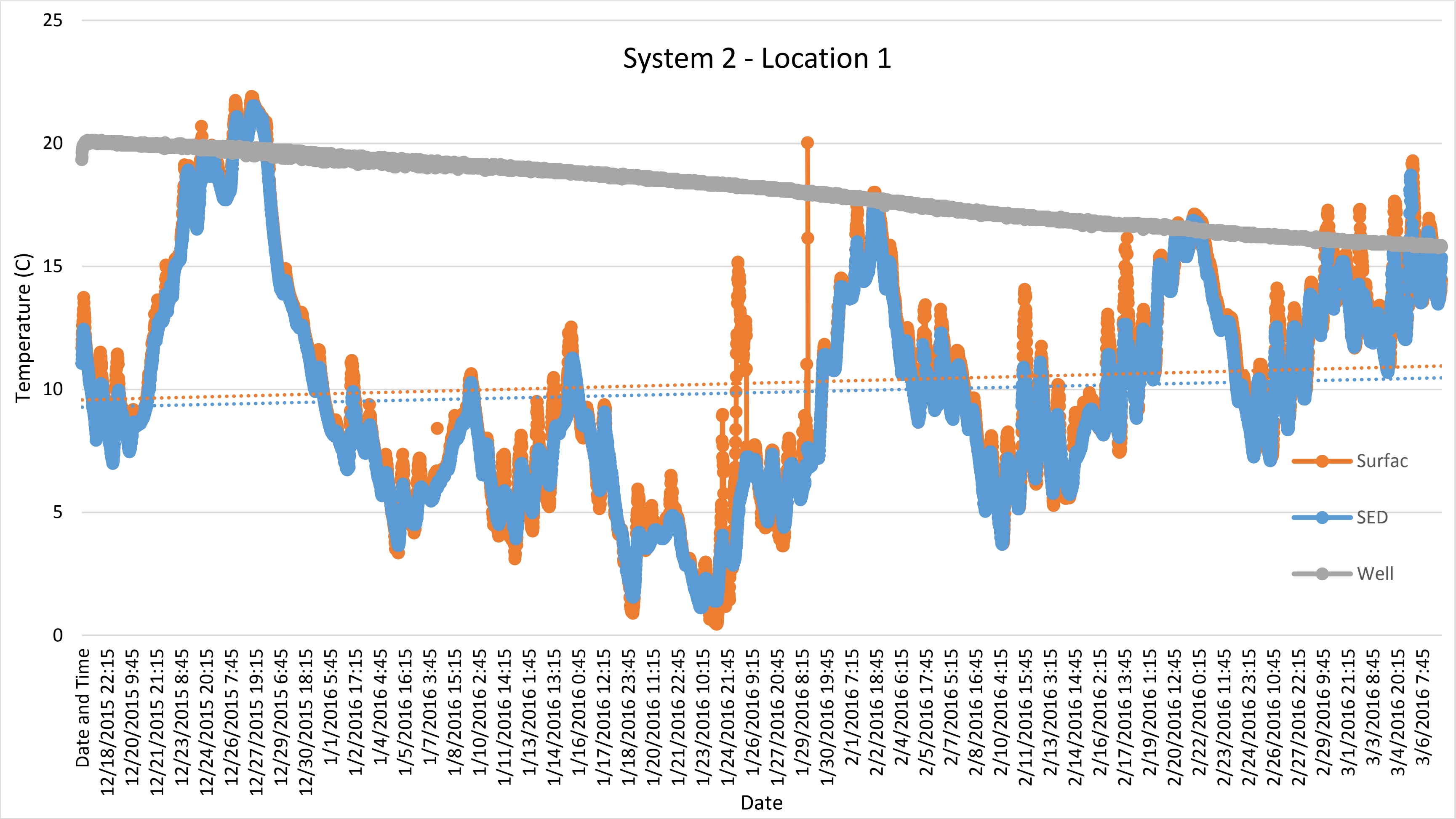

Figure 7. Temperature data collected from December 17, 2015 to March 7, 2016 at location 1 within TWR/OFS System 2 (<1 year old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

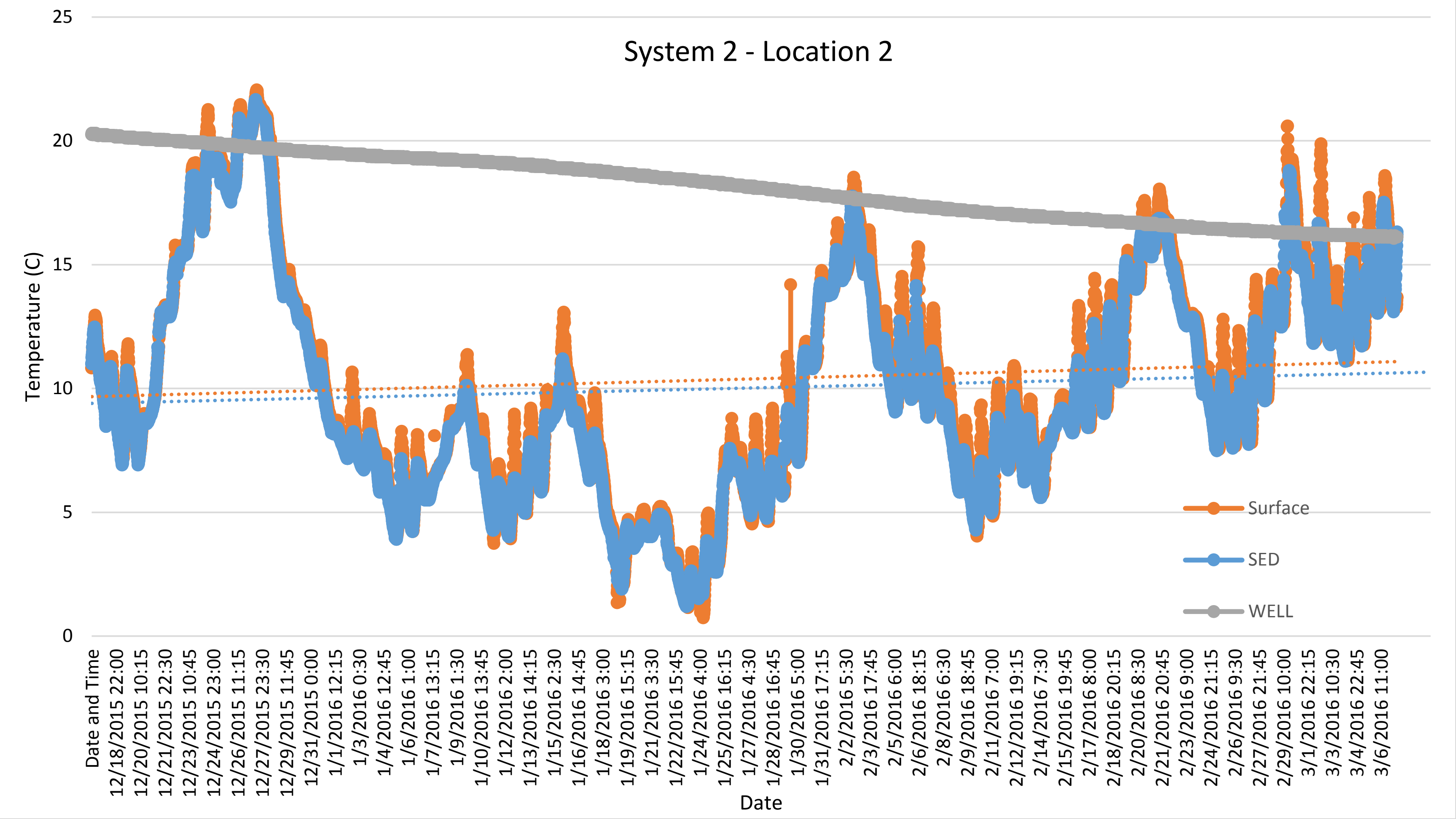

Figure 8. Temperature data collected from December 17, 2015 to March 7, 2016 at location 2 within TWR/OFS System 2 (<1 year old). Temperature data collected from surface water, sediment, and groundwater well are included, trend lines for surface water and sediment were added to better summarize trends over time in comparison to groundwater well data.

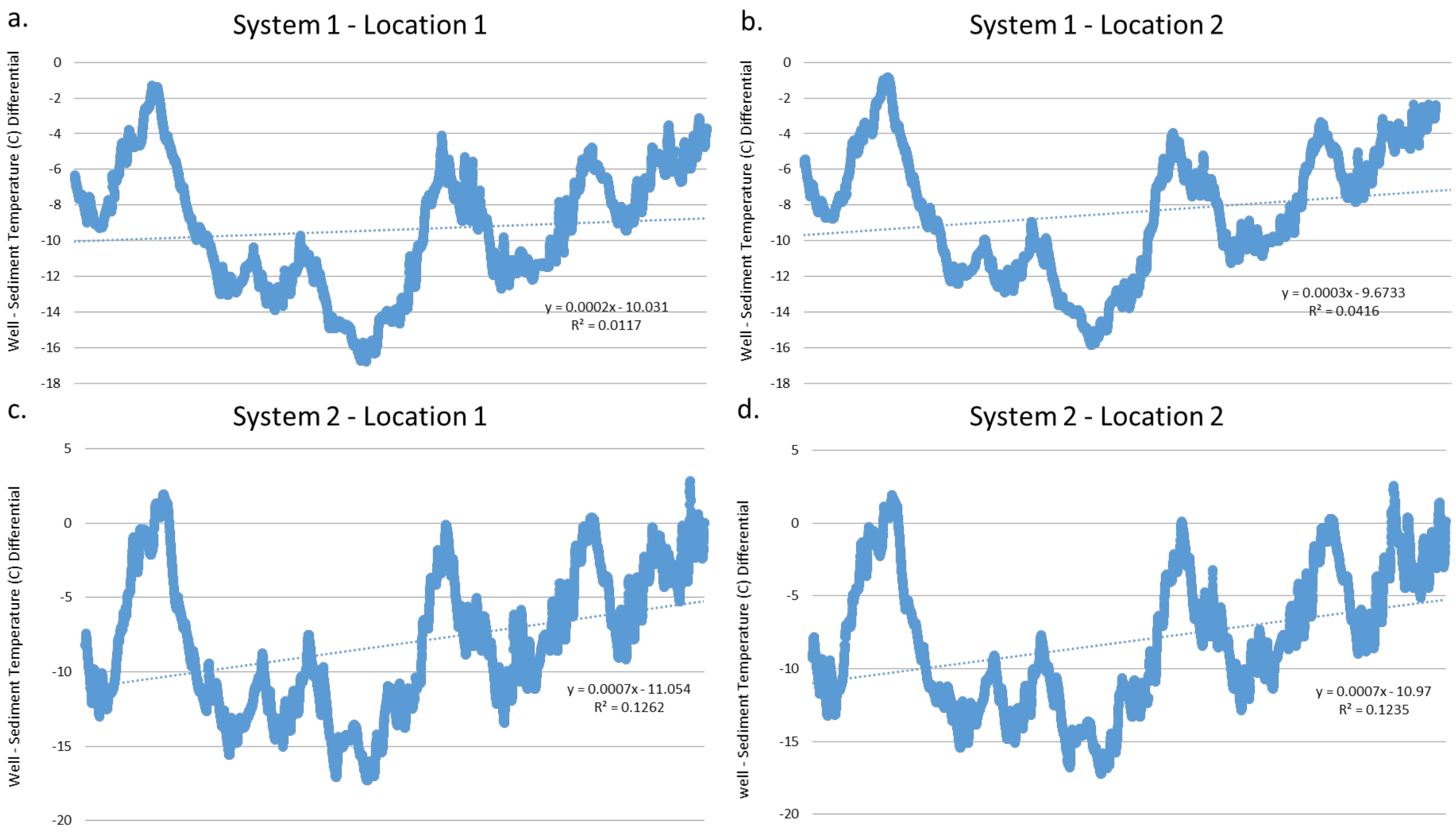

Figure 9. Well – Sediment temperature (C) differentials were calculated from temperature data over the observation period at System 1 – Location 1 (a) and 2 (b) and System 2 – location 1 (c) and 2 (d). Trend lines with associated slopes and r-squared values were calculated from well – sediment temperature differentials to compare rates of change within locations.

Table 1. Nutrient and sediment concentrations of surface water samples collected from both TWR/OFS systems. Minimum, maximum, mean, and median concentrations for samples. Samples that were measured below detection limits are reported as <BDL.

	System 1						System 2					
	NH3 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	TIP (mg/L)	Turbidity (NTU)	NH3 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	TIP (mg/L)	Turbidity (NTU)
Min	0.000	0.016	<BDL	0.004	0.01	30	0.025	0.006	<BDL	0.005	0.32	26
Max	0.467	0.411	<BDL	1.360	1.43	170	0.349	0.115	<BDL	0.150	1.78	528
Mean	0.118	0.077	<BDL	0.221	0.75	65	0.187	0.038	<BDL	0.046	0.90	154
Median	0.102	0.037	<BDL	0.100	0.78	53	0.195	0.031	<BDL	0.020	0.86	121