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Pathogen Risk to Human Health in Potable Water Related to Nonpoint Sources of Contamination:

Colorado River Alluvium Case Study, River Segment 1428
Phase II Final Report

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make every drop count

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Contents

Acronyms

CWA- Clean Water Act
DQO- Data Quality Objectives
GRTS- Grant Reporting and Tracking System
OSSF- Onsite Sewage Facility
QAPP- Quality Assurance Protection Plan
QPR- Quarterly Progress Reports
SCSC- Soil and Crop Sciences Department
TCEQ- Texas Commission on Environmental Quality
TWQI- Texas Water Quality Inventory
TWRI- Texas Water Resources Institute
UT-BEG- University of Texas at Austin Bureau of Economic Geology
WQMP- Water Quality Management Plan

Executive Summary

Public and private wells that use alluvial aquifers as a drinking water source have an increased risk of contamination from pathogens. This reconnaissance study, conducted by the Texas Water Resources Institute (TWRI) and subcontractors, focused on Segment 1428 of the Colorado River as a site of highest contamination risk based on (1) density of OSSFs, (2) groundwater chemistry, and (3) areas Texas Commission on Environmental Quality (TCEQ) Water Supply Division has previously identified as either having fecal coliform positive samples in raw well samples or when 1 micron filtration samples are indicative of "Groundwater under the influence of Surface Water."

Groundwater (and adjacent surface water) sampling was conducted following dam releases from Tom Miller Dam and transmitted through Longhorn Dam. Water chemistry data (pH, specific conductance, dissolved oxygen, temperature) was evaluated to determine the effects of the mixing of surface water and groundwater. A transect of wells at different distances from the river was sampled to determine to what degree distance from the river controls the level of pathogens. Transects were sampled at one location along the river. Water samples were analyzed for bacteria. Polymerase chain reaction (PCR) for *Cryptosporidium* and for selected viruses was conducted on selected samples (minimum of 3). This final report provides an account of activities conducted under this scope of work as well as work from a companion Clean Water Act (CWA) 604(b) grant project titled "Pathogen Risk to Human Health in Potable Water Related to Nonpoint Sources of Contamination: Colorado River Alluvium Case Study, River Segment 1428."

Introduction

Groundwater in alluvium adjacent to rivers is a potential source of pathogen contamination resulting from river water flowing into adjacent alluvial aquifers as well as infiltration from surface or subsurface sources. However, quantifying the extent of pathogens in riparian alluvial aquifers as a result of river water quality is limited. There are multiple ways that surface water/groundwater interactions can potentially increase the risk of pathogens: (1) in alluvial aquifers adjacent to rivers and (2) in wells that pump water from alluvium. In the first, high instream flow events may cause bank overflows, which raise the water table, resulting in infiltration of water and pollutants to the alluvial aquifer. In the second, a well's cone of depression may pull surface water to the well pump if the well is in close proximity to the surface water.

In addition, a recent study conducted on Segment 1428 by researchers at the University of Texas (Sawyer et al., 2009) indicates that hydrologic connectivity between a river and its adjacent alluvial aquifer is very sensitive to surface water flows, especially as it relates to water releases from dams. The study investigates the impact of dam operations on lateral hyporheic exchange in riparian zones and indicated that stage fluctuations force river water into and out of the surrounding banks. While this study demonstrates that dam operations alter the hydrological dynamics of riparian aquifers, the impacts on the interactions of pollutants between surface water and groundwater is largely unknown.

This reconnaissance study investigated pathogen risk to human health, using alluvial aquifers adjacent to Segment 1428, Colorado River below Town Lake, as a case study. Segment 148 is listed as having concerns for bacterial contamination and represents an appropriate segment for study. The findings from this study will be transferable to similar river segments throughout the state. Potential anthropogenic pathogens include viruses, protozoa (e.g. *Cryptosporidium*, *Giardia*) and bacteria. Potential sources of pathogens in surface water include discharge of untreated waste water or combined sewer overflows from municipalities, direct sewage discharge into streams, onsite sewage facilities (OSSFs) such as septic tanks and drain fields and leaking waste water collection systems. Other sources might also include wildlife and livestock.

This project was the assessment component of a two-part study. The initial phase was conducted under section 604(b) of the CWA and was designed to gather the necessary studies and resources in order to initiate water quality monitoring part of the proposed study. As part of the Phase 1 CWA 604(b) project, a communication plan, groundwater-surface water interactions, and draft Data Quality Objectives (DQO) and a Water Quality Monitoring Plan (WQMP) for the Quality Assurance Protection Plan (QAPP) were developed. All of these items were designed to be utilized in this project.

Project Significance and Background

A survey of technical literature in the Phase I Project found numerous instances where groundwater quality has been degraded by impacted surface water sources. Microbial residence time, survivability, pathogenicity, rate of transport and methods of transport through the unsaturated zone are less well understood. It remains largely unknown what circumstances allow pathogens to survive transport through the soil zone, into and through the alluvium and into the production zone of water supply wells.

The TCEQ *2008 Texas Water Quality Inventory (TWQI) and 303(d) List* identified numerous stream segments that are impacted by biological contaminants, some related to unrestricted grazing access as an example, and others impacted by the discharge of municipal waste users, surface runoff and OSSFs. The 2008 TWQI identified high bacteria counts, reduced dissolved oxygen, excessive nitrates and contaminated sediments all in direct contact with alluvial aquifers supplying water for both public and private use. Whether or not pathogens are adversely impacting the water supply wells adjacent to these river segments is not well known or documented.

Project Studies and Coordination Activities

This project was administrated by TWRI, the Texas A&M AgriLife Research Soil and Crop Sciences Department (SCSC) and the University of Texas at Austin Bureau of Economic Geology (UT-BEG) in conjunction with the companion Phase I 604(b) project. TWRI provided technical and fiscal oversight of the project staff and subcontractors to ensure tasks and deliverables were acceptable, and were completed as scheduled and within budget. With the TCEQ Project Manager's authorization, project oversight status was provided to the TCEQ with the Quarterly Progress Reports (QPRs).

TWRI, with the assistance from the Project Team, submitted QPRs to the TCEQ by the 15th of the month, for the previous three months for incorporation into the Grant Reporting and Tracking System (GRTS). These progress reports contained documentation of activities that occurred under each task the previous three months, while also containing a comprehensive tracking of deliverable status under each task. These QPRs can be found at: http://waterinteractions.tamu.edu/reports/. Additionally, reimbursement forms were submitted to the TCEQ at the end of the month following the end of each state fiscal quarter.

TWRI, with assistance from the Project Team, coordinated with state and local officials and ongoing outreach programs to inform and educate the stakeholders about project goals, solicit their input on the studies and outreach materials, and to present the project results. In addition, the results of this study were used by TWRI and the Project Team to develop educational materials for private well owners to allow them to assess vulnerability to contamination from pathogens and what practices might be used to mitigate such problems. At project completion, a two-page project fact sheet summary was developed that illustrates the study process and results related to developing best management practices for the protection of groundwater quality and the protection and improvement of surface water quality related to nonpoint source (NPS) pollution. Educational materials were provided for inclusion on the TCEQ web site and the Project Team's websites.

TWRI, with assistance from the Project Team, implemented the communication plan developed through the companion CWA 604(b) project, informing and educating the public and government officials about the project goals, results, conclusions and implications for other stream and river segments. The process was used to enhance partnerships with stakeholders and foster an understanding of project goals and objectives, along with results and implications for other comparable stream and river segments in the state. The process also helped achieve a better understanding of land use activities and their impact on water quality.

After data analysis had been conducted, the participating landowner was informed by TWRI and the Project Team of water quality results of samples collected on its property. The results of the project are also available on the TWRI web page, which was continually updated as new materials became available.

Methods

Prior to sampling, TWRI along with the Project Team developed a QAPP that was submitted to the TCEQ and contained project specific data quality objectives consistent with the US Environmental Protection Agency (EPA) Requirements for Quality Assurance Project Plans (QA/R5) format and the TCEQ NPS Shell. All monitoring procedures and methods prescribed in the QAPP were consistent with the guidelines detailed in the TCEQ Surface Water Quality Monitoring Procedures, Volume 1 and 2, to the extent that these guidelines were applicable. The QAPP was developed with assistance from the TCEQ Project Manager, Quality Assurance Staff, technical staff and management. The QAPP was submitted for approval by the TCEQ and was approved by TCEQ before any data collection began.

Throughout the project period, TWRI, with assistance from the Project Team, provided input to TCEQ to develop annual QAPP revisions. Also, changes in the sampling occurred; therefore, the Project Team revised the QAPP in an amendment to reflect the needed changes.

UT-BEG served as the primary point of contact with the City of Austin (the landowner for the sampling site) and secured a written landowner agreement, which was provided to TCEQ. Upon landowner agreement, the UT-BEG installed four wells adjacent to the Lower Colorado River along a river transect (a line perpendicular to river flow) at 5, 10, 15 and 20 feet from the edge of the river. After the installation of wells, Texas A&M AgriLife Research staff collected samples during three different sampling events, each of which spanned across 24 hours. Field parameters were taken along with surface water and groundwater samples every four hours. Water samples were taken to the Lower Colorado River Authority Environmental Services Laboratory for *E. coli* analysis and to the Texas A&M Soil and Aquatic Microbiology Laboratory for pathogen (*cryptosporidium* and enterovirus) analysis. All surface water data was formatted by TWRI for Surface Water Quality Monitoring Information System (SWQMIS) and submitted to TCEQ together with all data (surface and groundwater) in spreadsheet format. Finally, Texas A&M AgriLife Research has developed a "Data Analysis and Pathogen Risk to Human Health in Potable Water Case Study Report" which can be found in Appendix A.

Results and Observations

During 24-hour sampling periods, dam releases only produced about half a foot of change in river height. Little fluctuation in field parameters and bacteria concentrations in groundwater was found with increasing river levels. Water temperatures in the river were generally higher in the late afternoon and correlated most closely with air temperature. Groundwater samples remained fairly consistent throughout. For all samples, pH ranged between 7.4 and 8.0 with peak values occurring from evening to night and lowest values occurring in the morning. Specific conductivity data indicated little to no mixing of river water and groundwater in the surrounding alluvium during the project period. Dissolved oxygen ranged from 3.3 to 7.0 mg/l and correlated strongly with water temperatures. Finally, most bacteria samples remained under the regulatory standard of 126 MPN for *E. coli*; however, one sample did exceed the regulatory standard. *E. coli* levels were higher in river samples than in groundwater samples and fecal coliform samples followed similar trends. For all parameters, detailed results can be found in Appendix A.

Summary

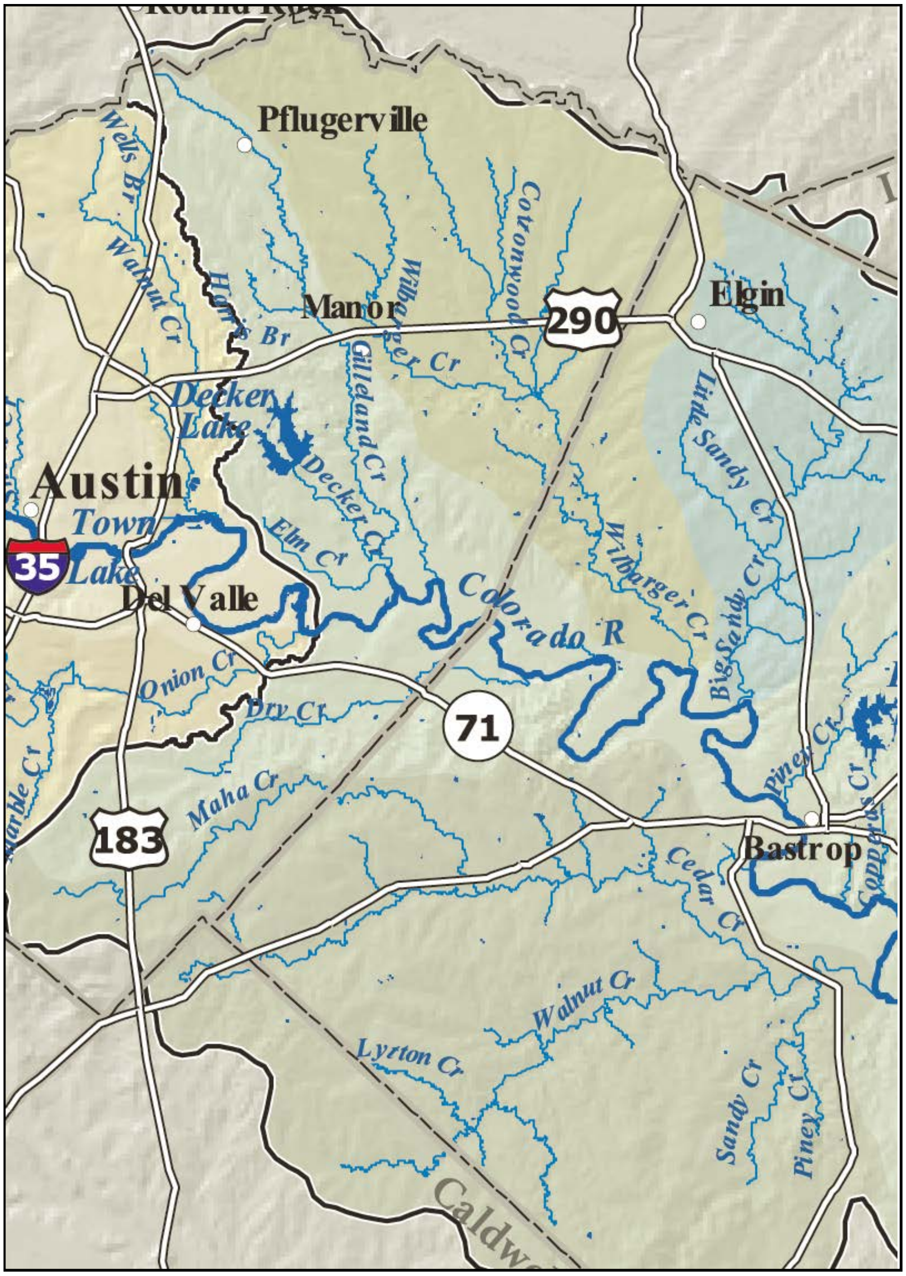
In comparison to river samples, the lack of fluctuations in groundwater bacterial and field parameter results indicate that there was little-to-no mixing of river and groundwater due to elevated river levels from daily dam releases during the sampling times in this study. With the exception of two samples, river *E.coli* levels were below regulatory limits; however, higher potential risks may be present if dam releases increase in magnitude.

References

Sawyer, A.H., M.B. Cardenas, A. Bomar, and M. Mackey. 2009. Impact of dam operations on hyporheic exchange in the riparian zone of a regulated river. Hydrol. Process. 23:2129-2137.

Appendix A

Colorado River Alluvium Segment 1428 Case Study: Assessment of Pathogen Risk to Human Health in Potable Water Related to Nonpoint Sources of Contamination



Pathogen Risk Final Report

This project was funded by the U.S. Environmental Protection Agency through the Texas Commission on Environmental Quality under Section 604(b) of the Clean Water Act. The Project examines how surface water contaminants such as pathogens, chemicals and other pollutants affect groundwater and the potential for movement of pathogens between surface and groundwater. Led by the Texas Water Resources Institute, the project team consists of personnel from the Texas A&M AgriLife Research, Texas A&M University, and the University of Texas at Austin, Bureau of Economic Geology. The primary authors of this report are Terry Gentry, Christina Barrera, T. Allen

Berthold, and Brad Wolaver of Texas A&M AgriLife Research, Texas A&M University, Texas Water Resources Institute, and University of Texas at Austin, Bureau of Economic Geology, respectively. Bill Carter served as Project Manager for the Texas Commission on Environmental Quality.

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Executive Summary

A study was conducted in Segment 1428 of the Colorado River below Lady Bird Lake in Austin, TX to characterize the impact of dam releases on levels of microbial indicators and the presence of selected pathogens in the river and surrounding riparian aquifer. Flow and river stage within this segment of the river is predominantly controlled by releases from Longhorn Dam, and previous studies have indicated a potential for dam releases to result in mixing of surface water with groundwater in the surrounding alluvium (Sawyer et al., 2009).

A transect of four wells were installed at the site every five feet (5, 10 15, and 20 feet from the river's edge at the time of well installation) along a transect perpendicular to river. Three rounds of sampling occurred, during which samples were collected every 4 hours for 24-hr periods to encompass river levels before, during, and after a dam release. Field parameters (water temperature, specific conductivity, pH and dissolved oxygen concentration) were measured along with *E. coli*, fecal coliforms, and total coliforms. A subset of samples was analyzed for the presence of *Cryptosporidium* and enterovirus.

In comparison to river samples, the groundwater samples showed a lack of daily fluctuations in bacterial and field parameter results thus indicating that there was little-to-no mixing of river and groundwater following elevated river levels from daily dam releases. This is in contrast to previous work at the site, and is likely due to the relatively small daily releases currently occurring from the upstream dams as a result of the ongoing drought in the region. Except for two samples, river *E. coli* levels were below regulatory limits, which is consistent with the recent history of nearby sampling stations. It is notable that river *E. coli* levels rose with river height and peaked shortly after the river level began to fall. One possible explanation is that rising river levels collected additional *E. coli* from the surrounding riparian area and the bacteria were concentrated into the river as it receded. Regardless of the cause, these results suggest that the temporal impacts of dam releases on river *E. coli* levels should be taken into consideration when designing routine monitoring schedules. None of the water samples tested positive for *Cryptosporidium* or enterovirus.

Overall, the combination of low levels of fecal indicator microorganisms and pathogens observed in the river samples collected in this study combined with little evidence of surface water mixing into the surrounding riparian aquifer suggests that that there is a low probability of significant increases in pathogen risk to the surrounding alluvium at the study site under current dam release conditions. However, the potential risk may

change if dam releases increase to historical levels and/or the fecal indicator levels in the river increase due to future impairments.

Project Significance, Background and Relevance to TCEQ Goals

Drinking water supplies derived from wells have generally been assumed to be relatively safe from pathogen contamination because of the filtration capacity of surface soils and the unsaturated zone above the water table along with the ability of aquifers, as porous media, to filter out biological contaminants. Where concerns of adverse impact of surface sources of pathogens on groundwater have arisen, the solution has often been to simply ensure that surface casings for wells are adequately sealed and of sufficient length to isolate the production zone of the well from direct infiltration of surface water. Regulations governing the required distance of septic tanks and drain fields from water supply wells are an example of this approach. However, there is growing concern that public and private wells that use alluvial aquifers as a drinking water source are at increased risk of contamination from pathogens due to elevated pathogen levels in hydrologically connected surface waters.

This project is the assessment component of a two-part study. Phase I was conducted under section 604(b) of the Clean Water Act (CWA) and was designed to gather the necessary studies and resources in order to initiate the water quality monitoring part of the Phase II study. In Phase I, a survey of technical literature found numerous instances where groundwater quality has been degraded by impacted surface water sources (Cutright et al., 2011). This literature review focused only on the impact of pathogens in groundwater and did not address the impact of chemical contamination of groundwater by surface sources as that process is well documented. Residence time, survivability, pathogenicity, rate of transport and methods of transport through the unsaturated zone of viruses, bacteria and protozoa are less understood. The soil zone represents a relatively hostile environment to nonresident microbes because of pH changes, aggressive soil microbes, dehydration and lack of nutrients, but conversely, many types of microbes survive and prosper in this environment through adaptation. There remain many uncertainties regarding what circumstances allow pathogens to survive transport through the soil zone, into and through the alluvium and into the production zone of water supply wells.

This study, focused on Segment 1428 of the Colorado River as a site of highest risk based on (1) density of OSSFs, (2) groundwater chemistry, and (3) areas TCEQ Water Supply Division has previously identified as either having fecal coliform positive samples in raw well samples or when 1 micron filtration samples are indicative of “Groundwater under the influence of Surface Water.”

Additionally, a recent study conducted on Segment 1428 by researchers at the University of Texas (Sawyer et al., 2009) indicates that hydrologic connectivity between the Colorado River and its adjacent alluvial aquifer is very sensitive to surface water flows, especially as it relates to water releases from dams. Natural exchange between surface and groundwater fluctuates depending on the hydraulic gradient of the area. In the situation of a normally gaining stream, low flow river conditions mean that the river is receiving water from the natural groundwater. At times of high river stage, the hydraulic gradient may be reversed and surface water would be forced into the surrounding alluvium (Fig. 1). Sawyer et al. (2009) investigated the impact of dam operations on lateral hyporheic exchange in riparian zones and indicated that stage fluctuations (Fig. 2) force river water into and out of the surrounding banks (Fig. 3). Thus, groundwater in alluvium adjacent to the river may be a potential source of pathogens resulting from river water flowing into adjacent alluvial aquifers as well as infiltration from surface or subsurface sources. However, impacts of dam releases on the interactions of microbial pollutants between surface water and groundwater is largely unknown.

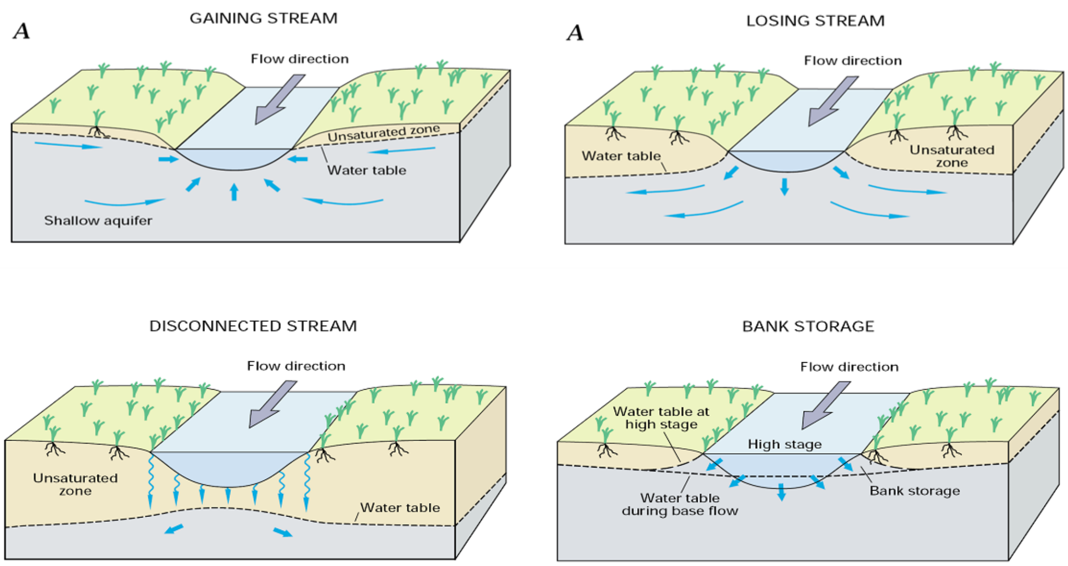

Figure 1. Groundwater and Surface Water Relationships (Winter et al., 1998).

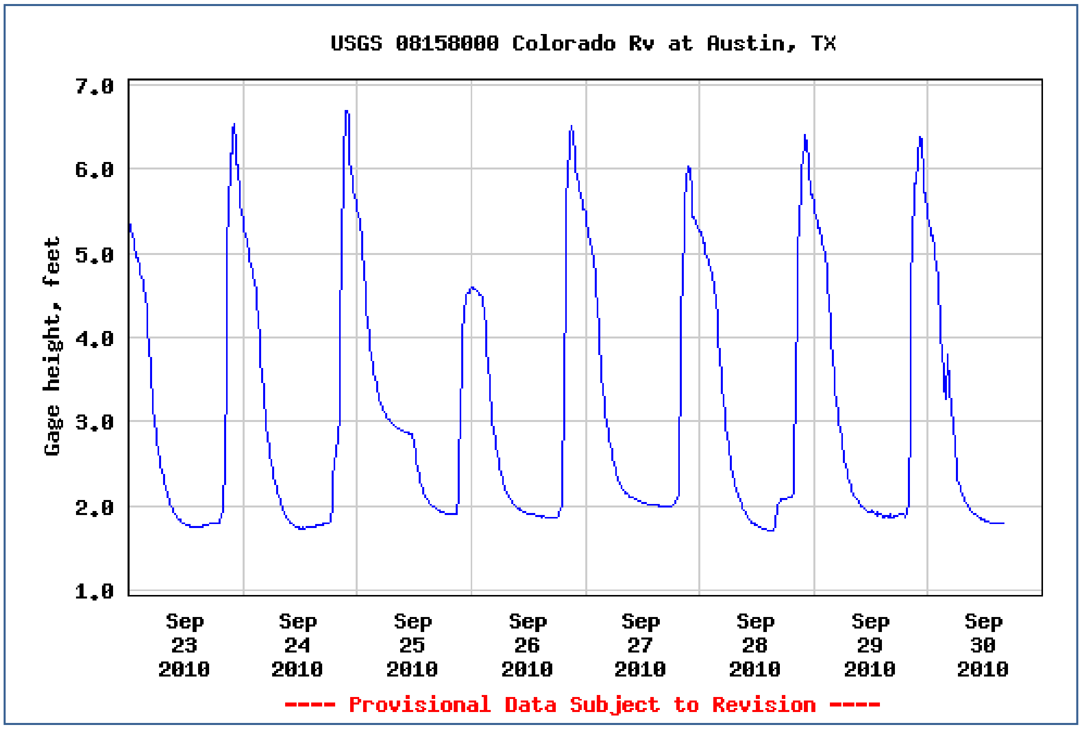

Figure 3. Daily fluctuations in stage height as a result of releases from dam operations.

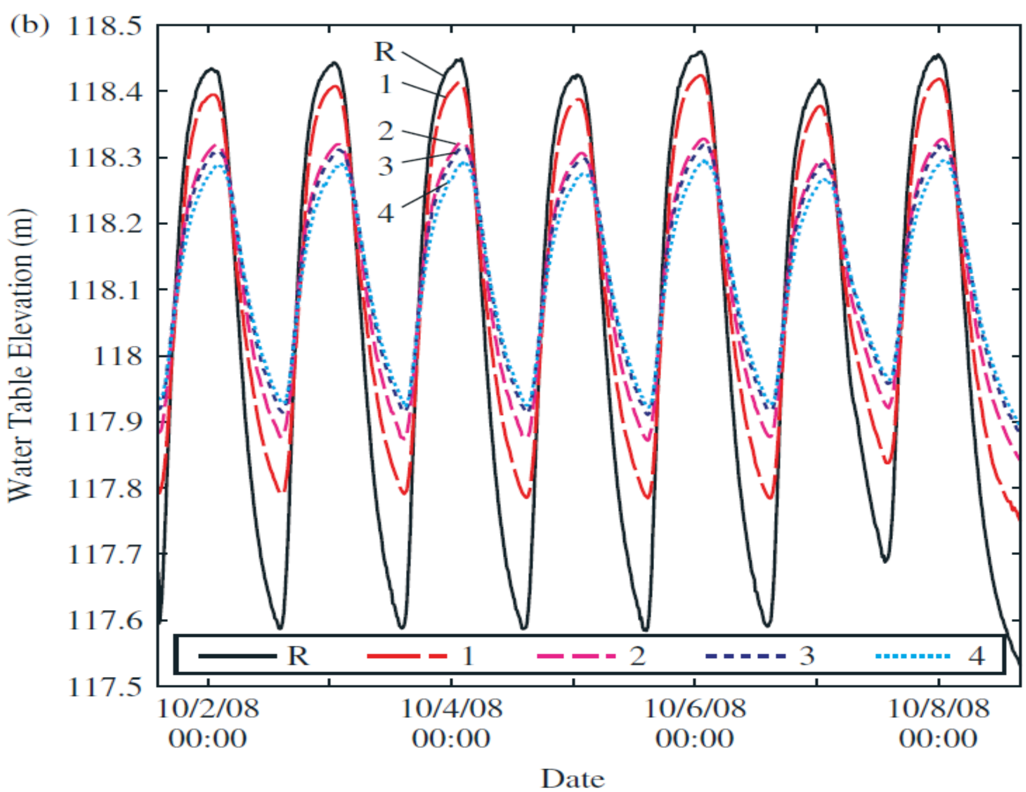

Figure 2. Relationship of daily river fluctuations (R) from dam releases to shallow groundwater levels (1-4) (Sawyer et al., 2009).

Therefore, the primary purpose of this study was to characterize the impact of dam releases on levels of microbial indicators and the presence of selected pathogens in the alluvial aquifer adjacent to Segment 1428 of the Colorado River below Lady Bird Lake. Segment 1428 has been listed, in the past, as having concerns for bacterial contamination (Fig. 4) and represents an appropriate segment for study. Flow and river stage within this segment of the river is predominantly affected by releases from Tom Miller Dam that are passively transmitted through Longhorn Dam (Fig. 2) at the upper end of Segment 1428. Longhorn Dam is managed by Austin Energy but is also coordinated with the LCRA's Tom Miller Dam, upstream from the Longhorn Dam. The impact of releases from the dam is more pronounced in the upstream segment than further downstream, near Bastrop. Ultimately, however, river stage and groundwater levels are controlled by rainfall, runoff and precipitation. They are also modified by antecedent conditions, rainfall event characteristics and land use factors. Findings from this study can be used to target groundwater wells around this segment for additional testing and will be transferable to similar river segments throughout the state.

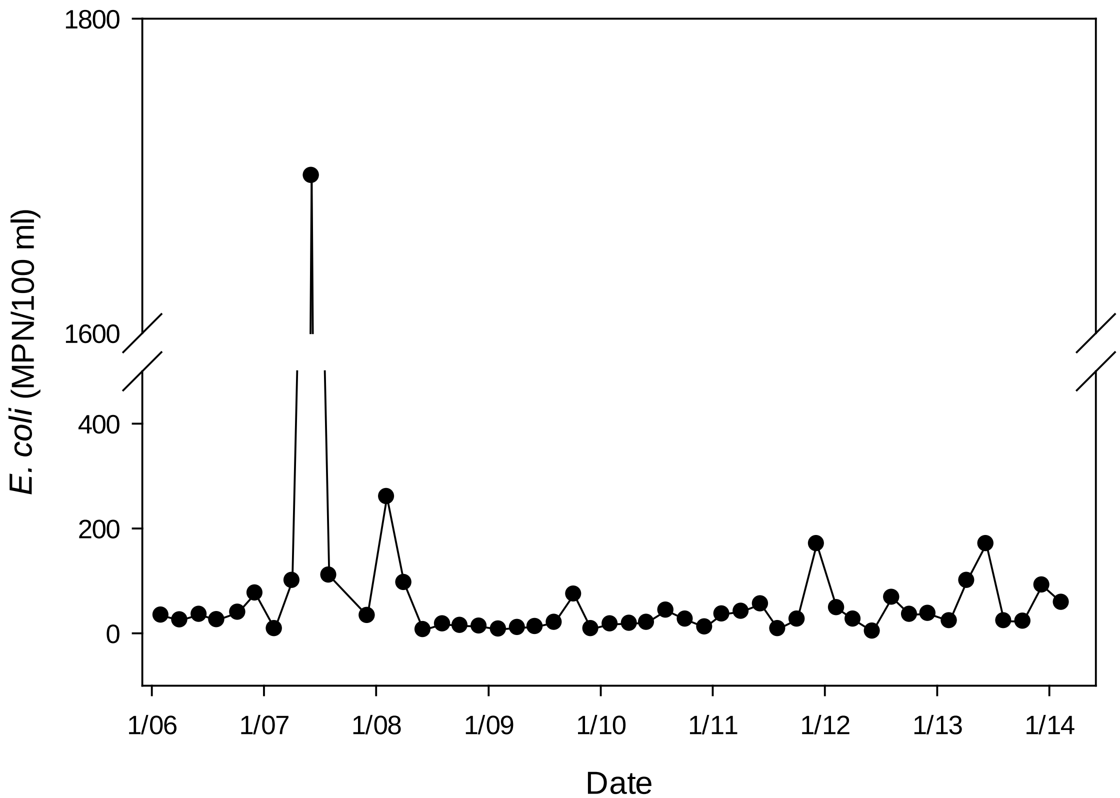

Figure 4. *E. coli* concentrations in Colorado River Segment 1428 (TCEQ Station 12469) from February 2006 through February 2014.

Project Site and Methods

Study Site

This study focuses on a representative segment of the Colorado River in Travis and Bastrop counties designated as Colorado River Segment No. 1428 (Fig. 5-7). The river segment extends from the downstream face of Longhorn Dam in Travis County, downstream a distance of 41 river miles to a point 330 feet upstream of State Highway FM-969. Segment 1428 is immediately downstream from a major urban area, the City of Austin, but also flows through a region that transitions from urban to rural agricultural.

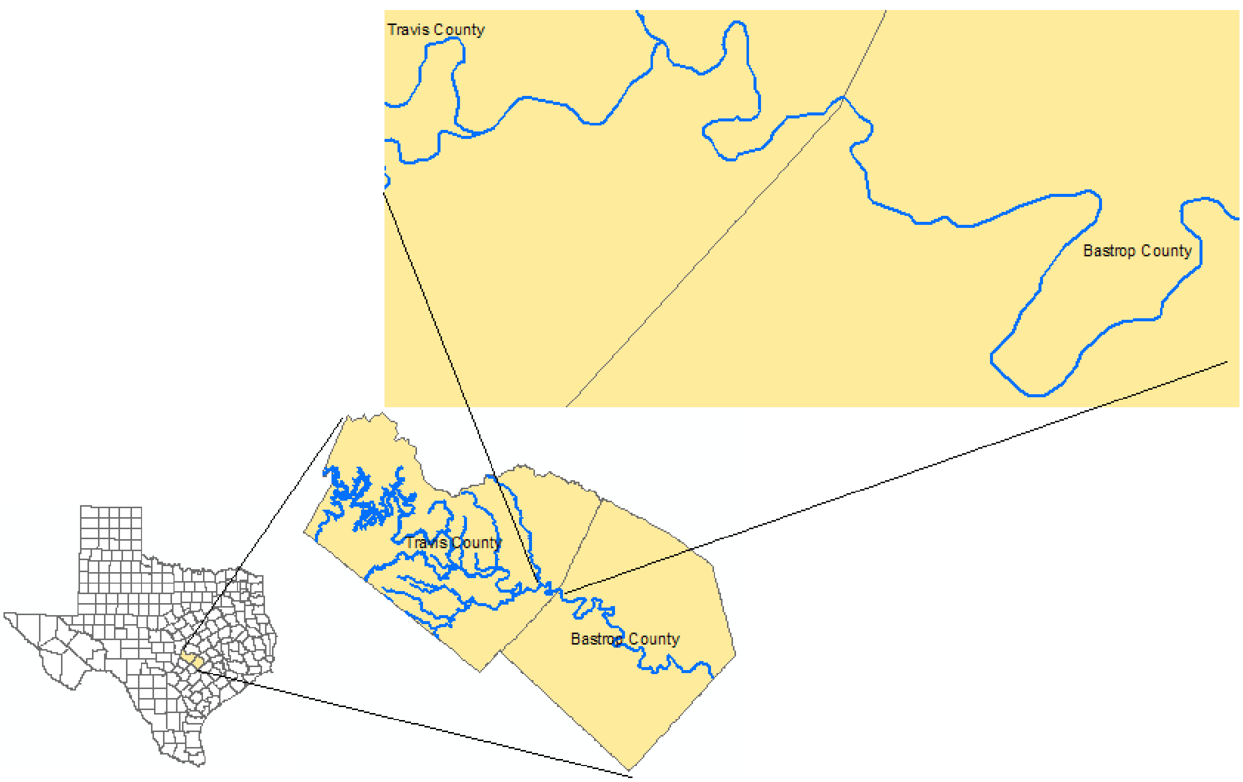

Figure 5. Colorado River below Town Lake, Segment 1428.

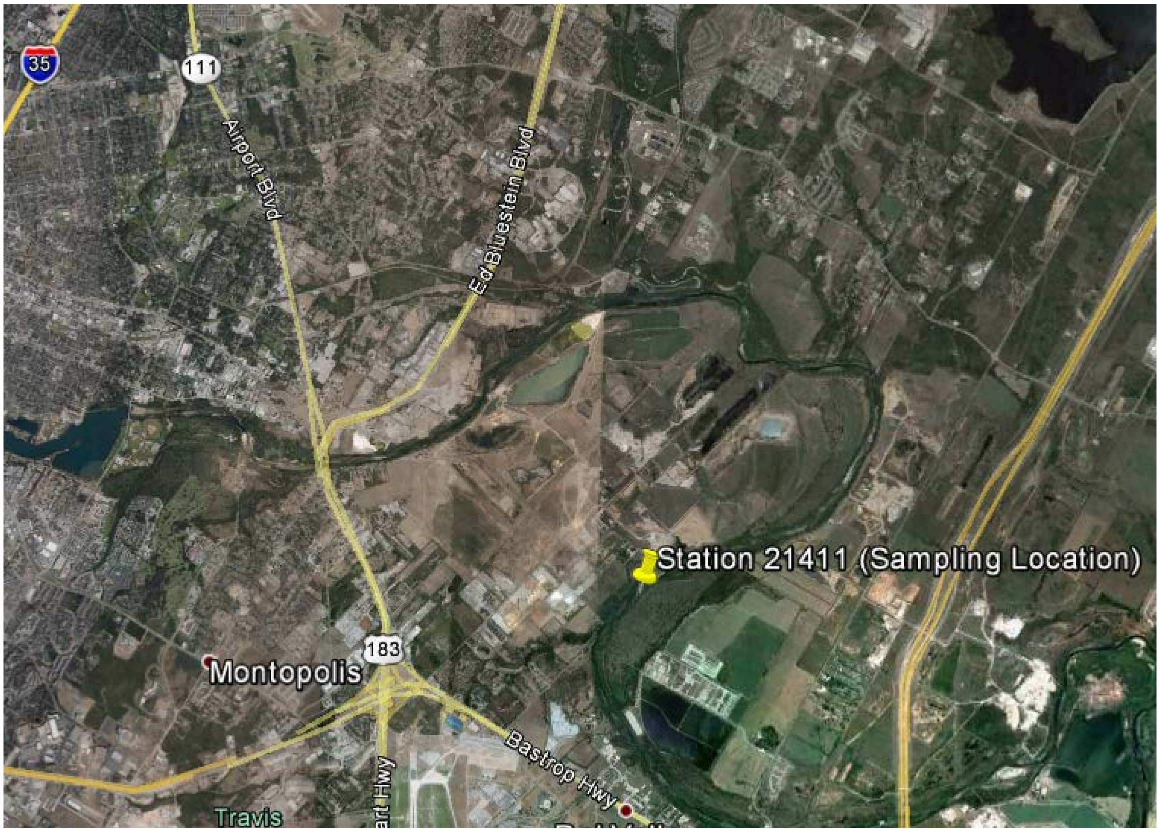

Figure 6. Aerial view of Colorado River below Town Lake, including study site at TCEQ Station 21411.

Figure 7. Aerial view of study site (TCEQ Station 21411) on Colorado River below Town Lake.

Monitoring Wells

A transect of four wells was installed at TCEQ Station 21411 along the Colorado River Segment 1428 in Austin, Texas (Figures 5-7). The well site is located at Hornsby Bend and the Center for Environmental Research. The four wells were installed using a Geoprobe every five feet (5, 10 15, and 20 feet from the river's edge at the time of well installation) along a transect perpendicular to river to a depth of approximately 10 feet. Wells were screened across the entire water table (Fig. 8).

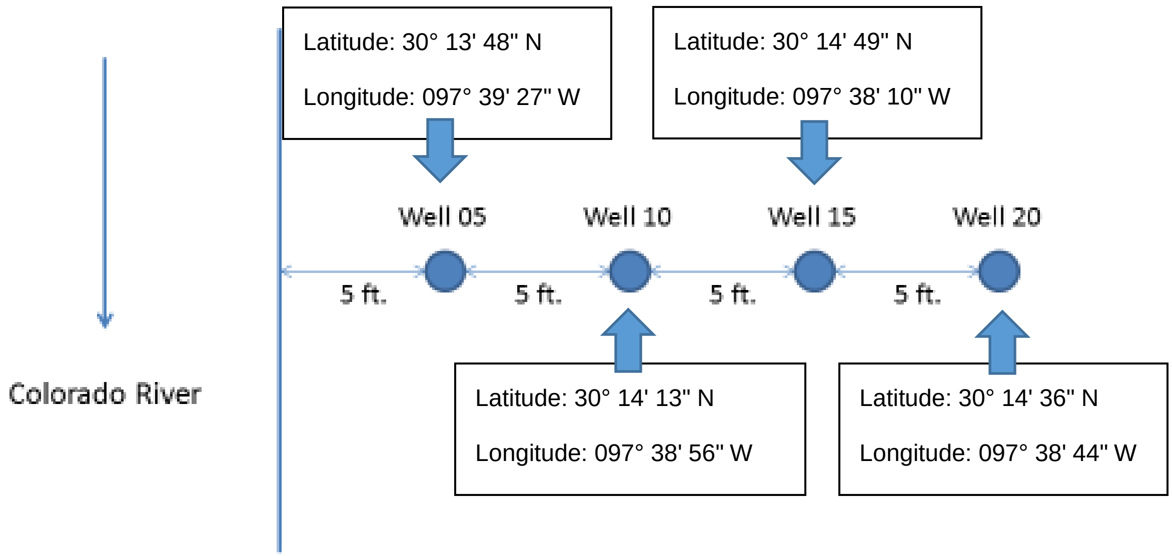

Figure 8. Schematic of well transect installed at TCEQ Station 21411 along the Colorado River at Hornsby Bend.

Sample Collection

Three rounds of sampling occurred on October 2-3, 2013; June 8-9, 2014; and June 16-17, 2014. During each round, samples were collected every 4 hours for a 24-hr period to encompass the river levels before, during, and after a dam release. Samples were collected at least 3 days after the most recent rainfall event in order to avoid stormwater influences. Prior to each round of sampling, the pumps and tubing were disinfected by pumping a chlorine solution through the pumps followed by reverse osmosis water to remove any residual chlorine. Chlorine removal was confirmed with a commercial chlorine test kit (Hach®, Loveland, CO). Before each groundwater sample was collected, three well-volumes of water were purged from each well (Boghici, 2003). Grab samples were collected for surface water analysis (TCEQ, 2012). Water flow and river height were determined from USGS Gauge 08158000.

Field Parameters

Field parameters (water temperature, specific conductivity, pH and dissolved oxygen concentration) were measured using a multiparameter sonde (TCEQ, 2012; YSI Inc., Yellow Springs, OH). During the second round of sampling (June 8-9, 2014), the YSI pH probe malfunctioned; therefore, the pH for these water samples was measured in the laboratory by Lower Colorado River Authority-Environmental Laboratory Services (LCRA-ELS).

Bacterial Analyses

After collection, water samples were stored on ice (~4°C) until delivery to the LCRA-ELS for analysis. *E. coli* concentrations were measured via a most-probable-number (MPN) methodology (IDEXX, Westbrook, ME) using Standard Method 9223 (APHA, 1999). Total and fecal coliforms were measured as colony-forming-units (CFU) via membrane filtration methodologies following Standard Method 9222 (APHA, 1999).

Cryptosporidium and Enterovirus Analyses

Water samples for *Cryptosporidium* and enterovirus analysis were collected on June 11, 2014. Groundwater wells were purged and pumps disinfected as described for the 24-hr sampling rounds above. For *Cryptosporidium*, water was passed through Envirochek HV Sampling Capsules (Pall, Cortland, NY) following USEPA Method 1623.1 (USEPA, 2010) to collect the organisms. For enteroviruses, water was passed through NanoCeram® filter cartridges (Argonide, Sanford, FL) following USEPA method 1615 (Fout et al., 2010) to collect the viruses. Sampling capsules/cartridges were maintained on ice during transport to the laboratory. Collected *Cryptosporidium* were eluted off of the sampling capsules and concentrated (USEPA Method 1623.1). DNA was extracted from each sample and assayed for the presence or absence of *Cryptosporidium* spp. by polymerase chain reaction (PCR) (Di Giovanni et al., 2010; ceeramTOOLS®, France). Collected enteroviruses were eluted off of filters and concentrated (Fout et al., 2010). RNA was extracted from each sample and assayed for the presence or absence of enteroviruses by reverse transcriptase-PCR (RT-PCR) (Fout et al., 2010; ceeramTOOLS®, France).

Results and Observations

River Height

For all three sampling rounds, upstream dam releases produced peak river levels at USGS Gauge 08158000 between midnight and 2:00 AM. For round 1, river height increased from 12.4 ft to 12.8 ft and then dropped to 12.6 ft during the 24-hr sampling period (Fig. 9). For round 2, the river height began at 13.4 ft, increased to a maximum of 13.8 ft and then decreased to 13.6 ft (Fig. 10). For round 3, the river height began at 13.3 ft, increased to a maximum of 13.9 ft and then decreased to 13.6 ft (Fig. 11). River height is plotted in all subsequent graphs for comparison of data to changing river heights before, during, and after the dam releases.

It should be noted that the change in river height during the 24-hr sampling periods was only ~0.5 ft. This is much less than the changes that occurred in the years preceding this study, often 3 feet or more, when a larger volume of water was being released from the upstream dam (Fig. 2).

Field Parameters

Water temperatures for river samples ranged from 27 to 31°C and were generally highest in late afternoon and lowest in the early morning hours (Fig. 9-11). The overall

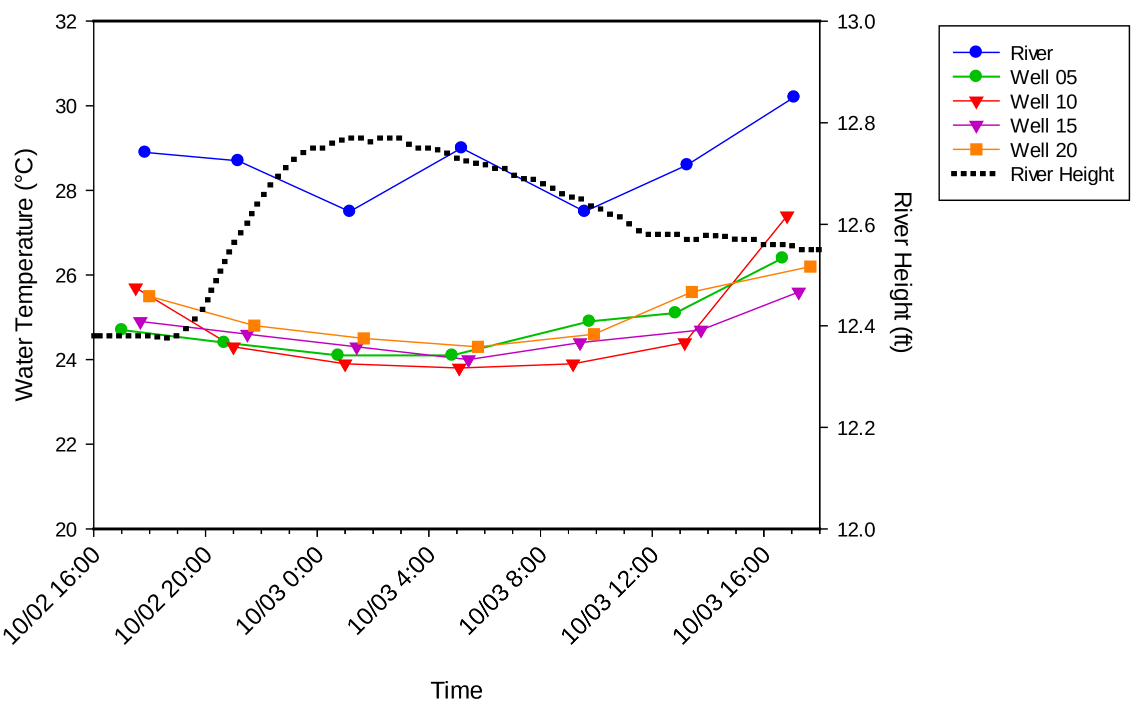

Figure 9. Temperature of water samples collected during October 2-3, 2013 sampling event (TCEQ Station ID 21411).

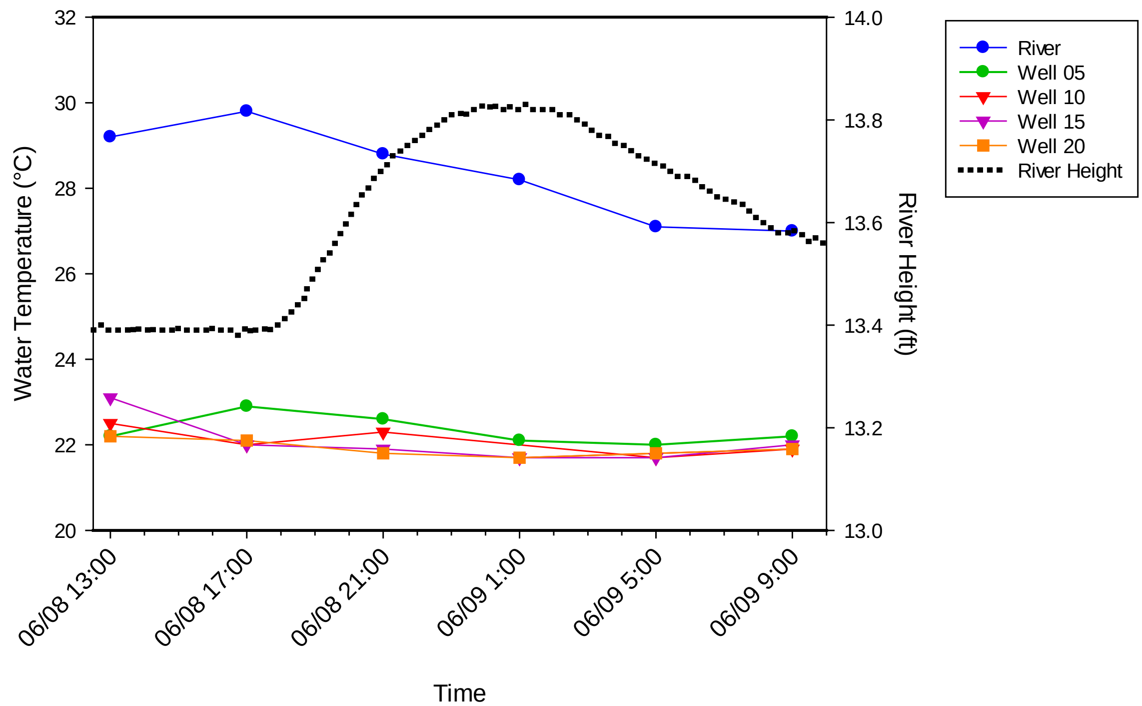

Figure 10. Temperature of water samples collected during the June 8-9, 2014 sampling event (TCEQ Station 21411).

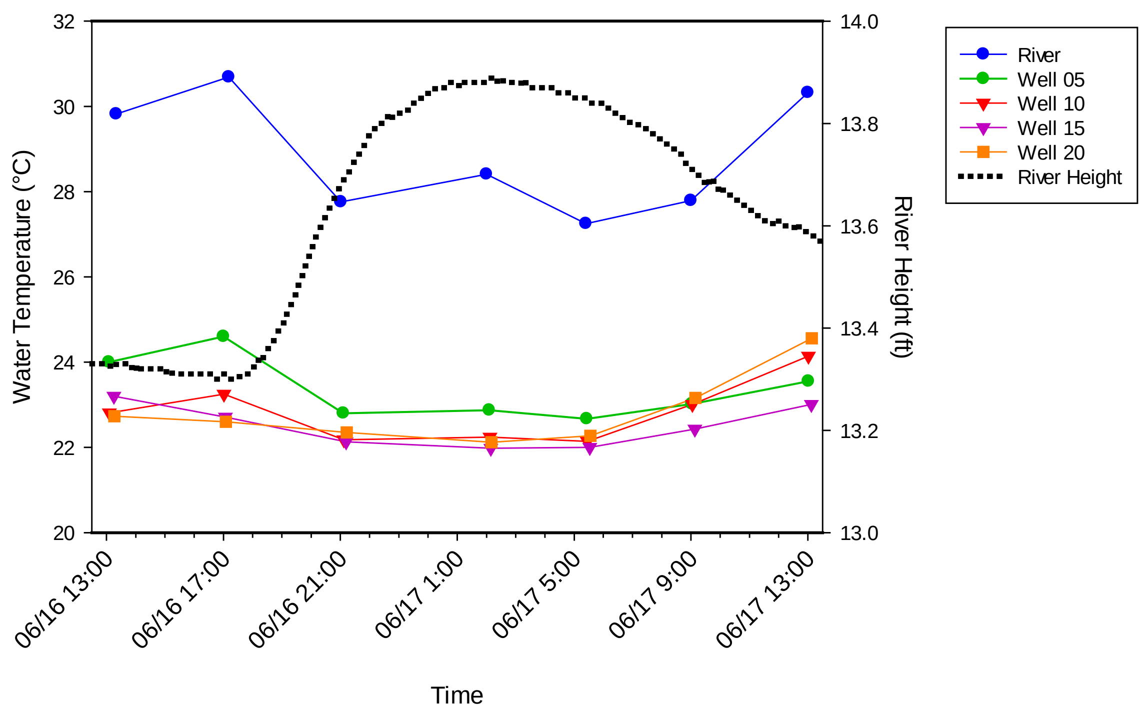

Figure 11. Temperature of water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

trends in river temperature fluctuation appeared to depend most heavily on the time of day, and not on any fluctuation in the height of the river. Groundwater samples were lower and generally less variable within a sampling round, ranging from 22 to 27°C.

For sampling rounds 1 and 3, the river water pH ranged between 7.4 and 8.0 with peak values reached in the evening to night and lowest values observed in the morning (Fig. 12 & 14). Groundwater pH values were generally lower and less variable during each sampling round with no consistent trends. The pH values for the second round of sampling (Fig. 13) were slightly higher than those for rounds 1 and 3, but this may have been an artifact of the samples being stored for a few hours before analysis by the LCRA-ELS as opposed to being immediately measured in the field as in rounds 1 and 3.

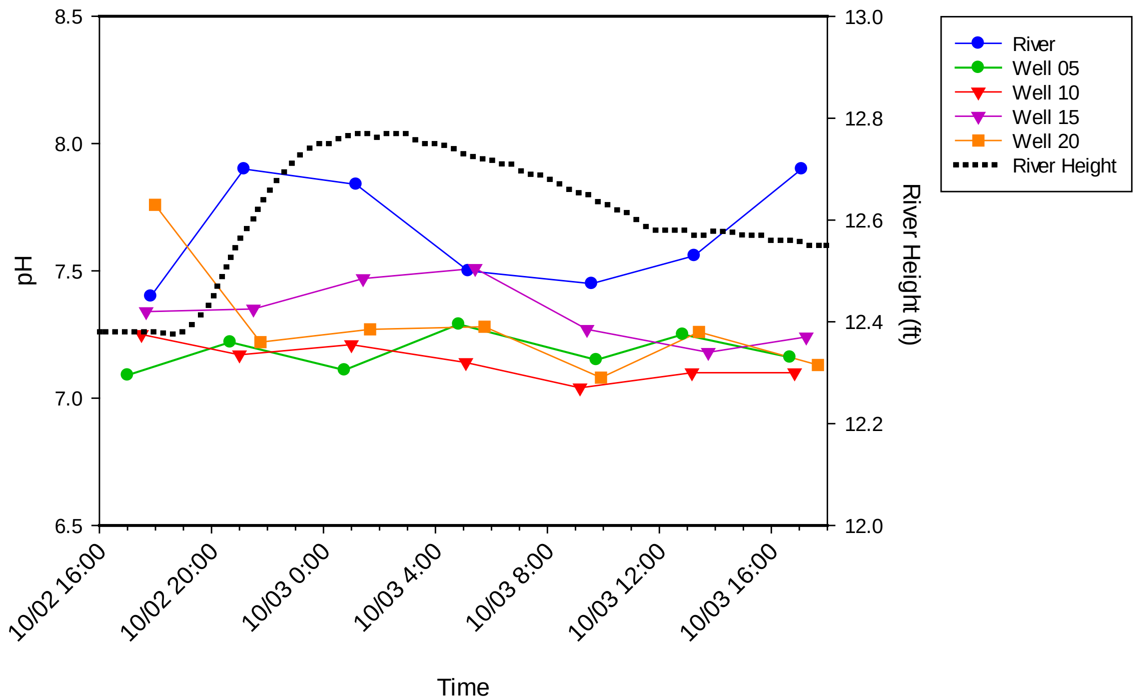

Figure 12. pH of water samples collected during October 2-3, 2013 sampling event (TCEQ Station ID 21411).

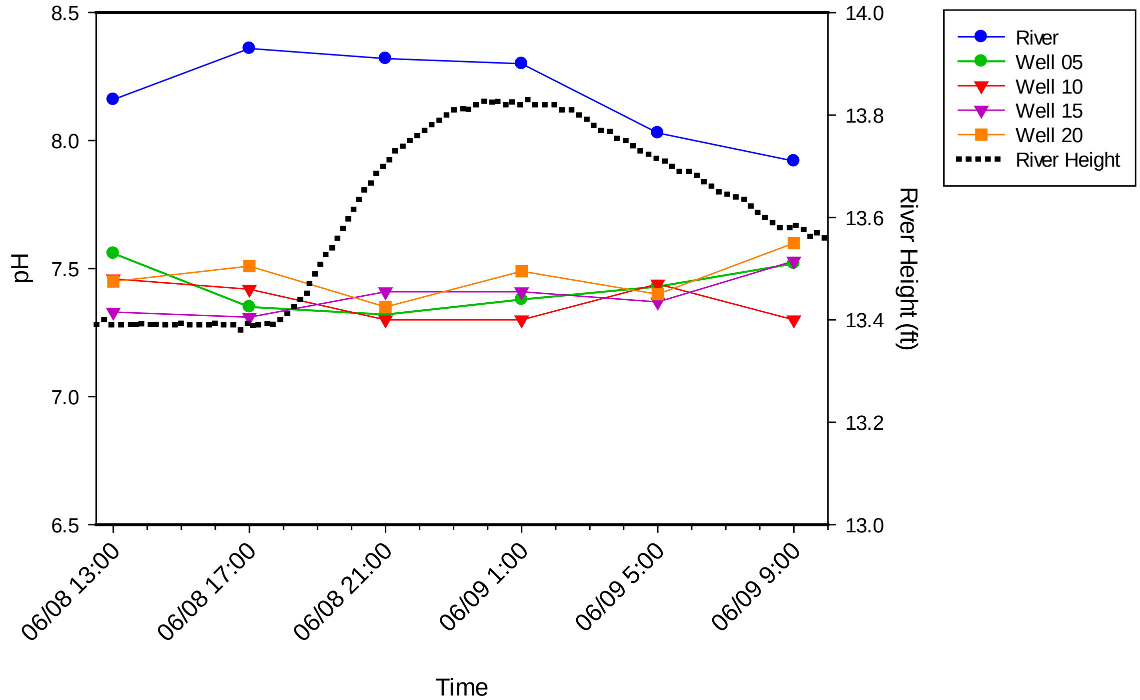

Figure 13. pH of water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).

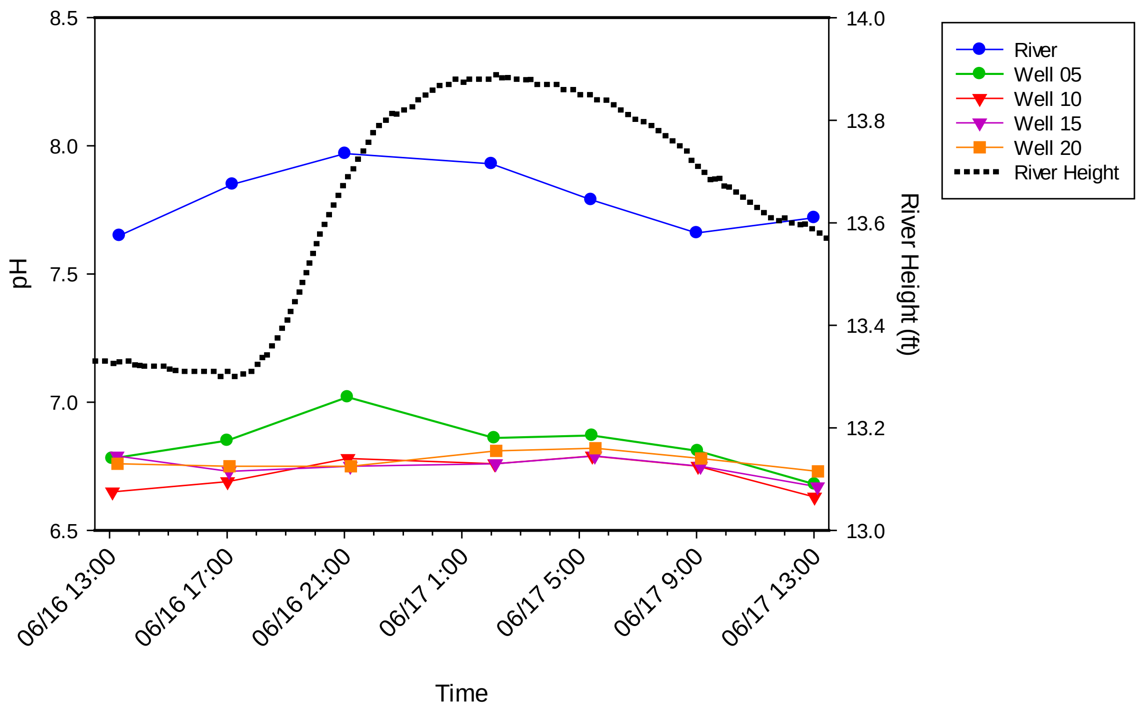

Figure 14. pH of samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

As normally found, specific conductivity of the river water was lower than that of the groundwater samples for all sampling rounds (Fig. 15-17). It is notable that there was no change in specific conductivity of the groundwater samples during sampling rounds 2 and 3 (Fig. 16 & 17). This is strong indication that there was little-to-no mixing of river water with groundwater in the surrounding alluvium during the sampling period. For sampling round 1 (Fig. 15), there was an increase in specific conductivity as the river height decreased, but this occurred for both the surface water and all groundwater samples indicating that it was unlikely due to mixing of surface water with groundwater in the surrounding alluvium.

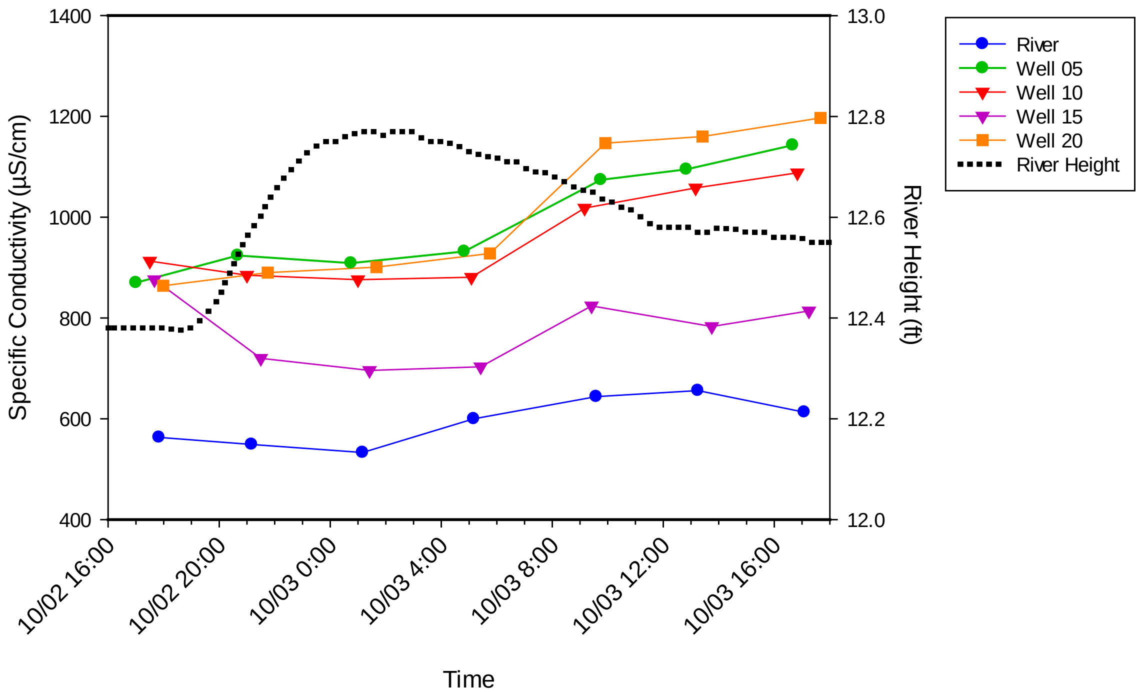

Figure 15. Specific conductivity of water samples collected during October 2-3, 2013 sampling event (TCEQ Station ID 21411).

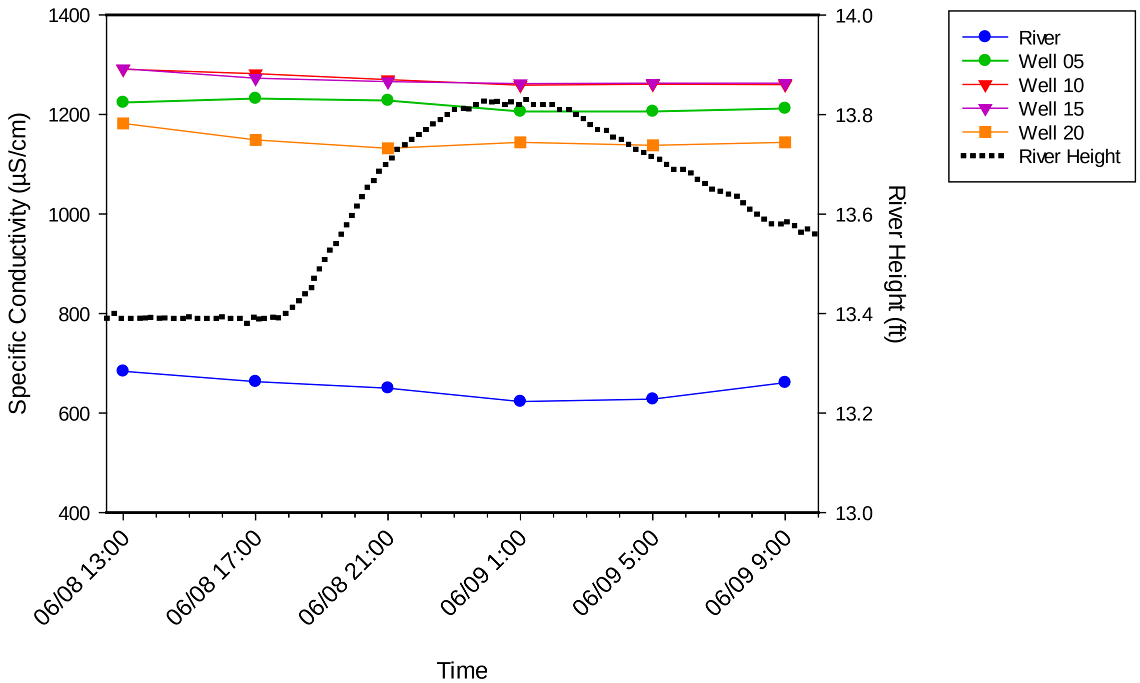

Figure 16. Specific conductivity of water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).

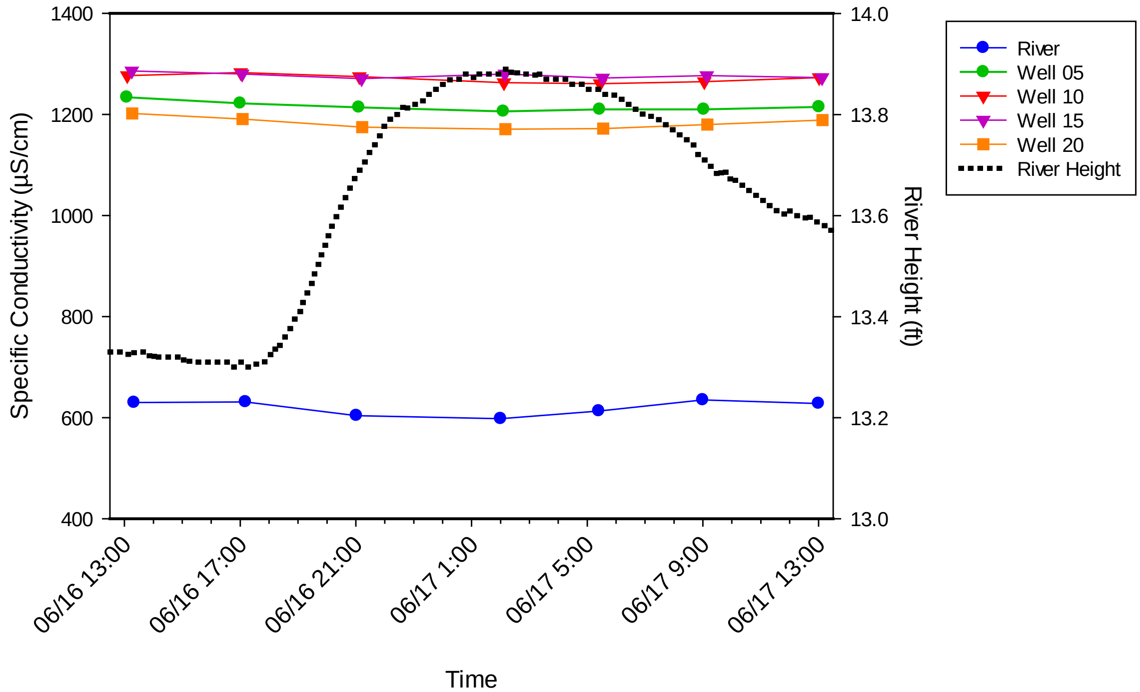

Figure 17. Specific conductivity of water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

For all sampling rounds, dissolved oxygen (DO) concentrations in the river samples ranged from 3.3 to 7.0 mg/l and paralleled changes in water temperature with peak values in afternoon and minimum values in early morning (Fig. 18-20). For sampling round 1, the groundwater DO concentrations remained constant (3.3-4.8 mg/l) after the initial samples were collected (Fig. 18). For sampling rounds 2 and 3, groundwater DO values were generally constant across the sampling period and lower than found in the river water, ranging from 1.2-4.6 mg/l (Fig. 19 & 20).

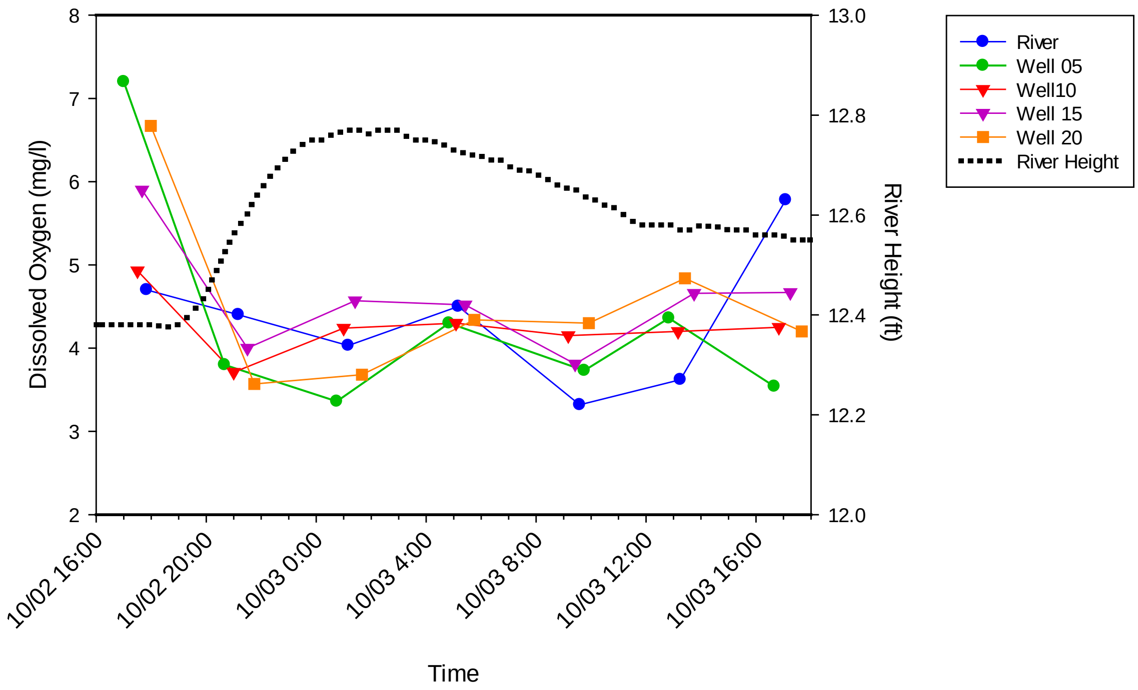

Figure 18. Dissolved oxygen concentrations in water samples collected during October 2-3, 2013 sampling event (TCEQ Station ID 21411).

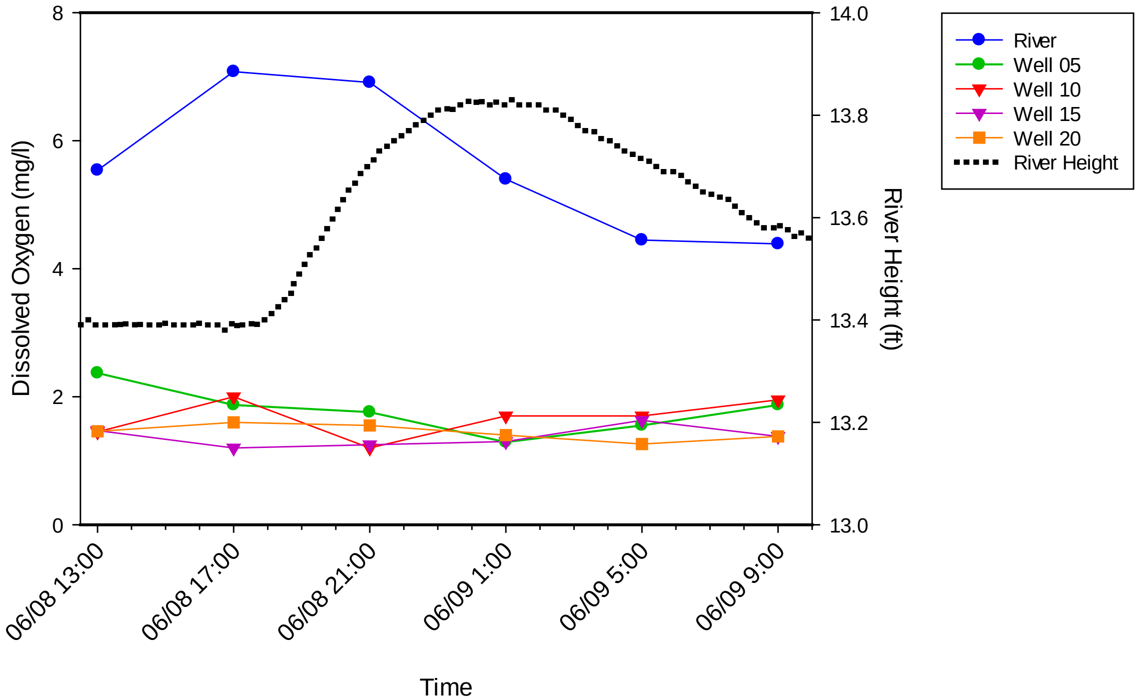

Figure 19. Dissolved oxygen concentrations in water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).

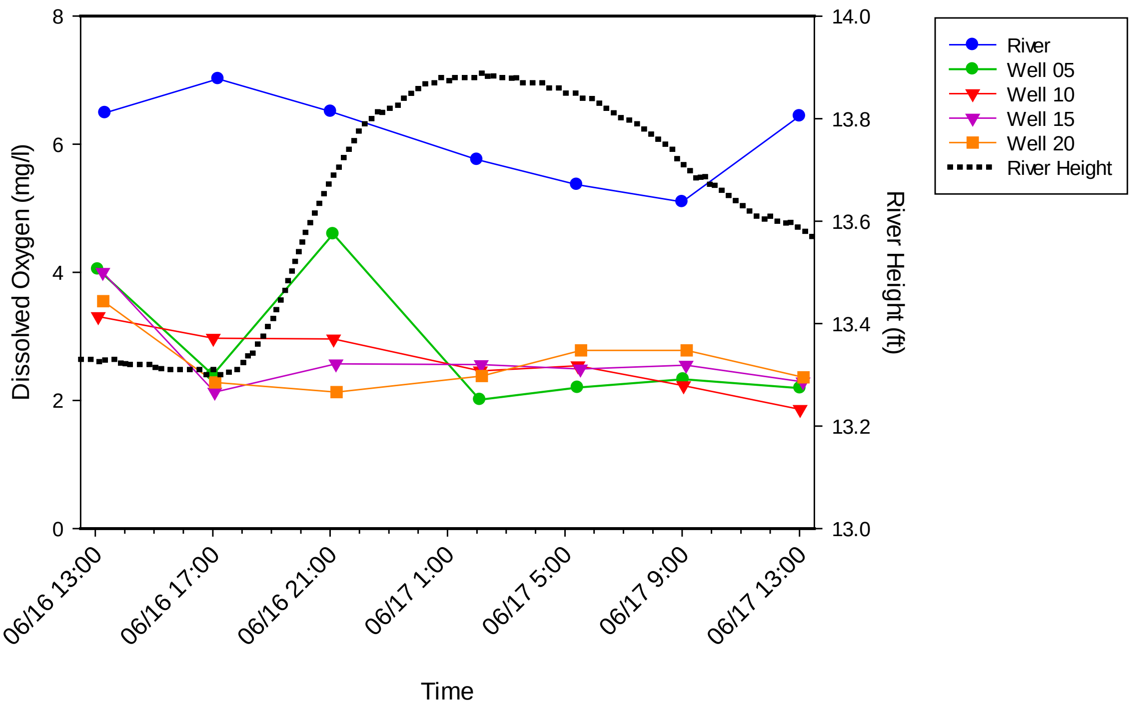

Figure 20. Dissolved oxygen concentrations in water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

Bacterial Analyses

For all sampling rounds, *E. coli* concentrations in the river samples increased with river height, peaking shortly after the river height began to decrease (Fig. 21-23). However, the *E. coli* concentrations were generally low. For round 1, *E. coli* levels ranged from 58 to 416 MPN/100 ml with only two values (260 & 416 MPN/100 ml) exceeding 126 MPN/100 ml (Fig. 21). For sampling rounds 2 and 3, none of the *E. coli* concentrations exceeded 67 MPN/100 ml (Fig. 22 & 23). Groundwater *E. coli* concentrations were much lower than in the river samples for all sampling rounds (<1 to 29 MPN/100 ml) and were generally constant across each 24-hr sampling period.

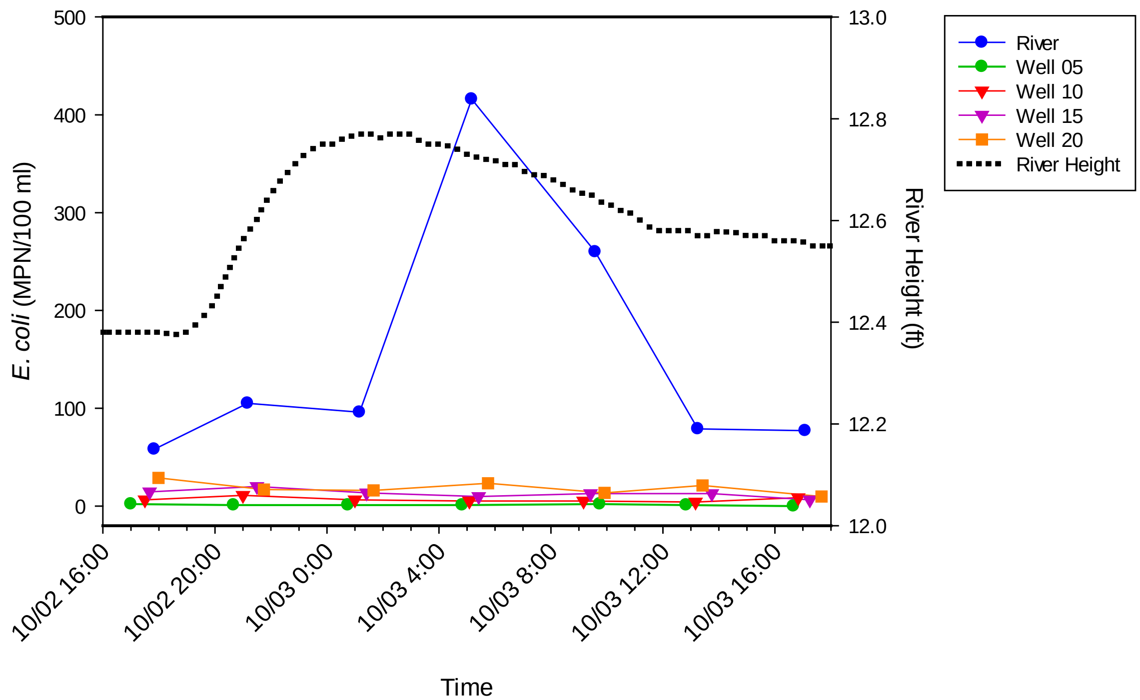

Figure 21. *E. coli* concentrations in water samples collected during the October 2-3, 2013 sampling event (TCEQ Station ID 21411).

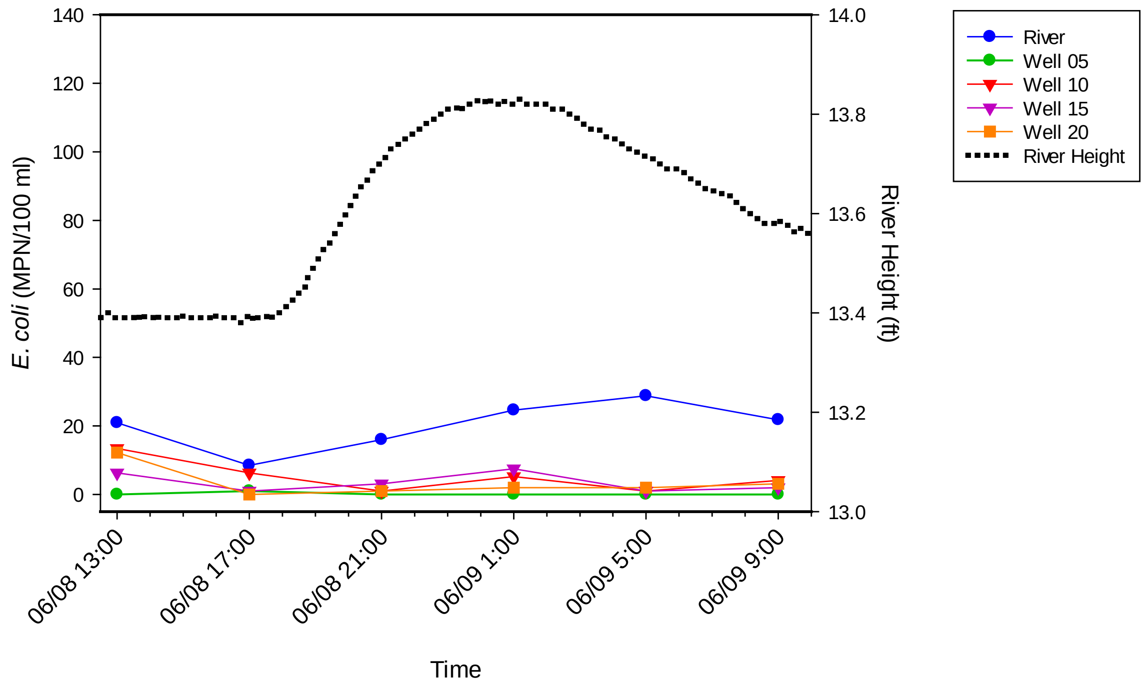

Figure 22. ***E. coli*** **concentrations in water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).**

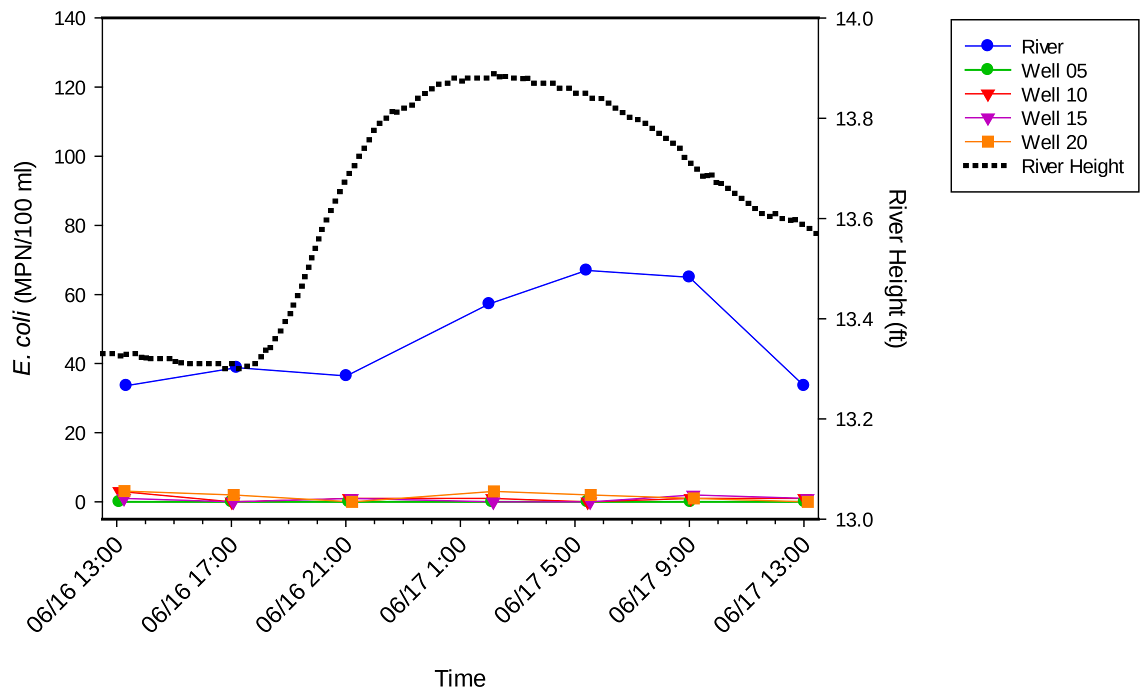

Figure 23. ***E. coli*** **concentrations in water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).**

For all sampling rounds, fecal coliform levels in the river samples followed trends similar to *E. coli*, increasing with river height and peaking shortly after the river height began to decrease (Fig. 24-26). As for *E. coli*, fecal coliform concentrations were much lower in the groundwater samples (<1 to 59 CFU/100 ml) and were generally constant across each 24-hr sampling period.

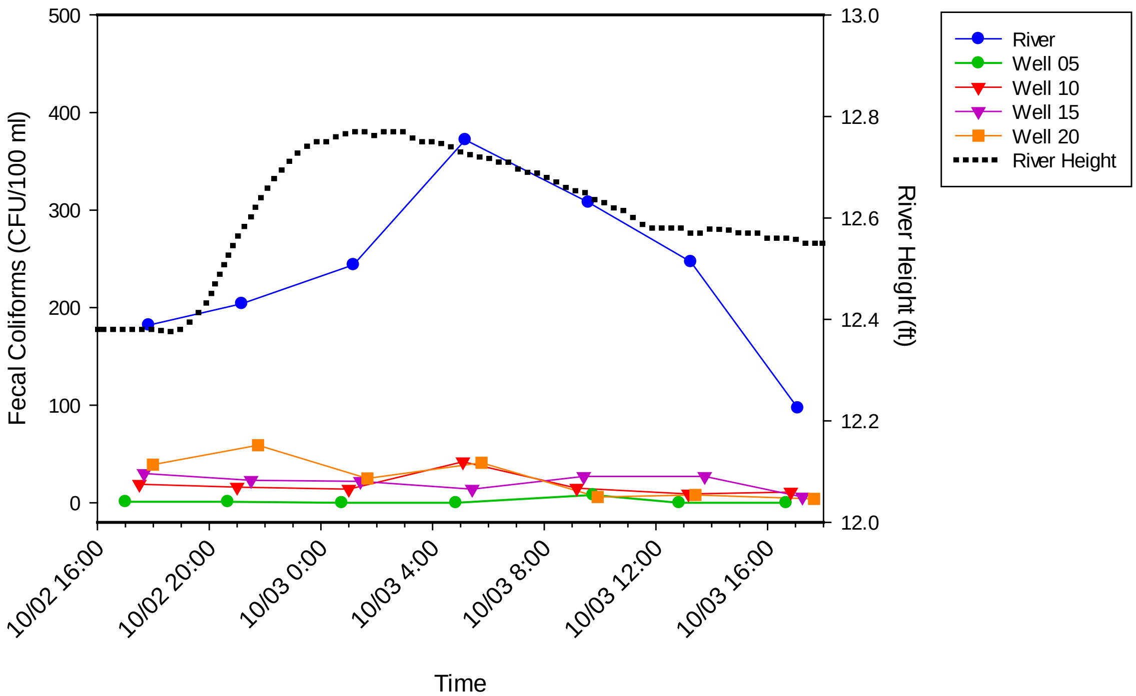

Figure 24. Fecal coliform concentrations in water samples collected during the October 2-3, 2013 sampling event (TCEQ Station ID 21411).

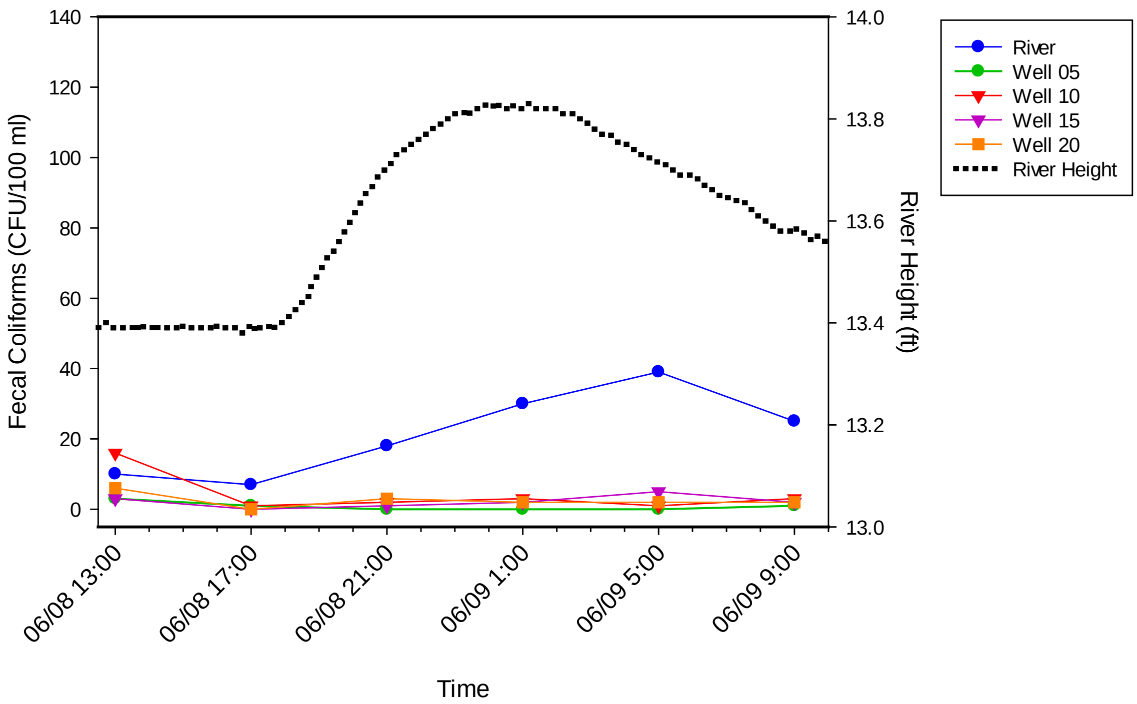

Figure 25. Fecal coliform concentrations in water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).

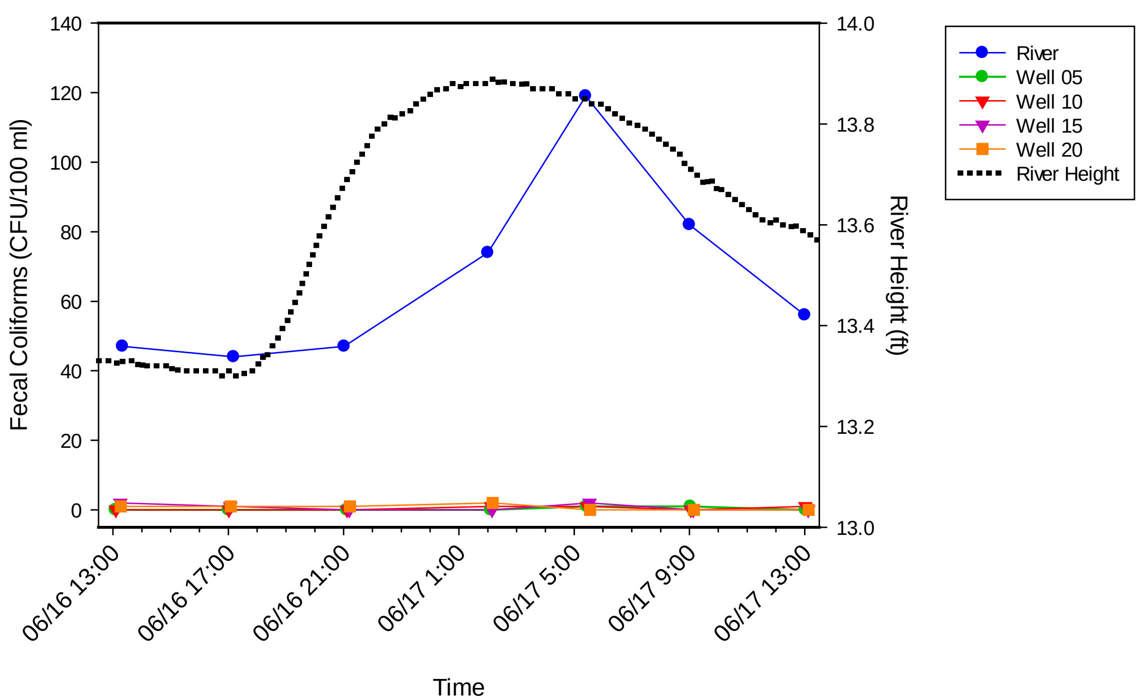

Figure 26. Fecal coliform concentrations in water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

For all sampling rounds, total coliform levels in the river samples generally followed trends similar to *E. coli* and fecal coliforms, increasing with river height and peaking shortly after the river height began to decrease (Fig. 27-29). This was especially notable for the first round of sampling (Fig. 27) due to relatively high total coliform levels (176-492 CFU/100 ml). This was less observable for sampling rounds 2 and 3 due to much lower total coliform counts (<15 CFU/100 ml) (Fig. 28 & 29). Total coliform concentrations were generally lower in the groundwater samples with no consistent trend in changes over time.

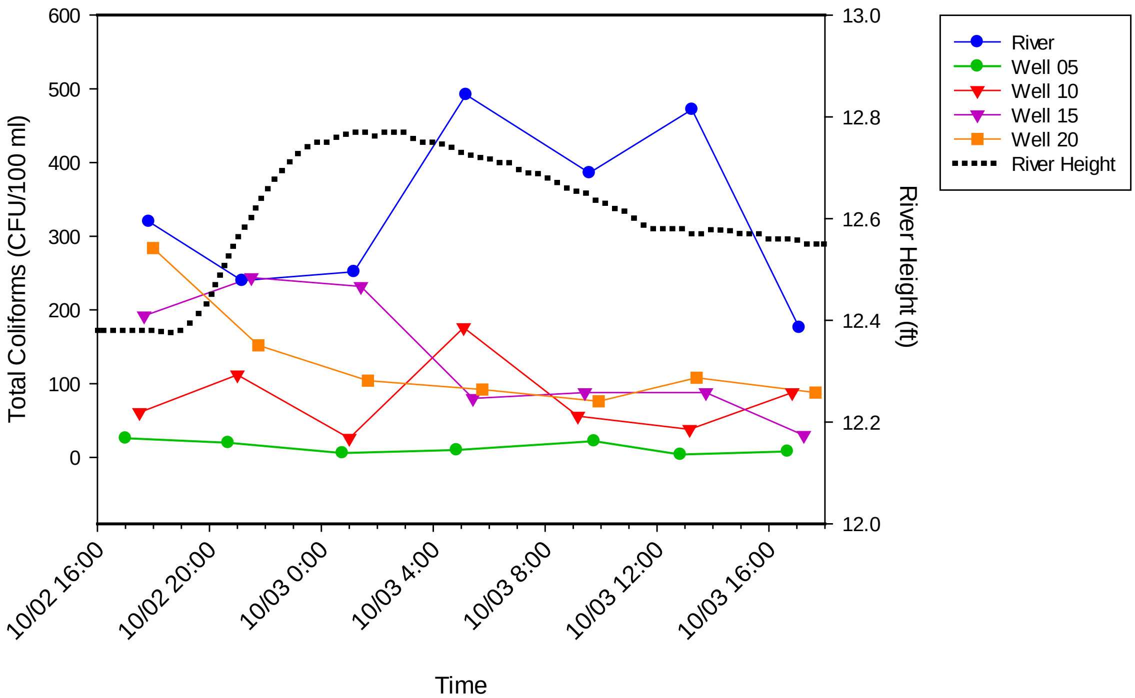

Figure 27. Total coliform concentrations in water samples collected during the October 2-3, 2013 sampling event (TCEQ Station ID 21411).

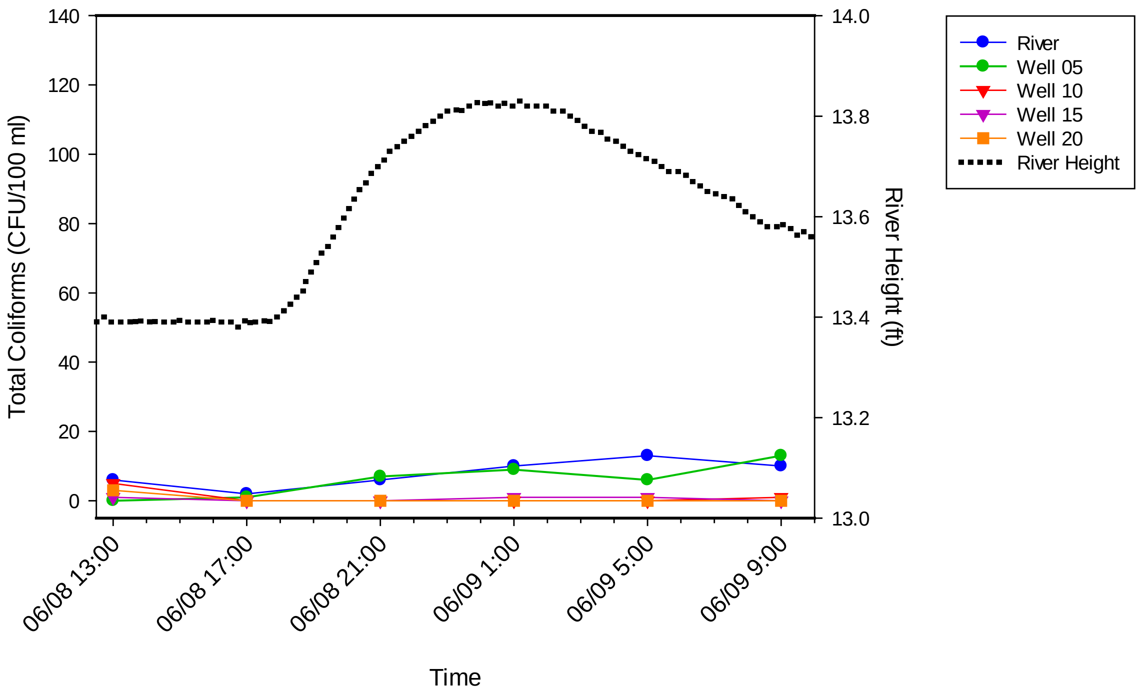

Figure 28. Total coliform concentrations in water samples collected during the June 8-9, 2014 sampling event (TCEQ Station ID 21411).

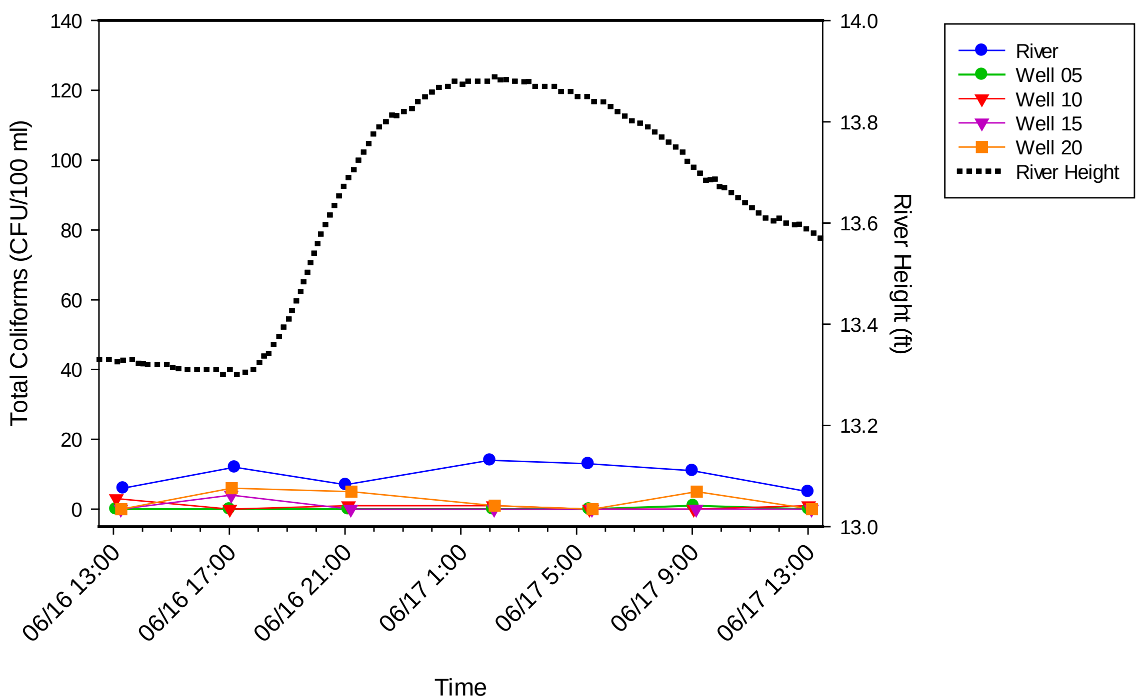

Figure 29. Total coliform concentrations in water samples collected during the June 16-17, 2014 sampling event (TCEQ Station ID 21411).

Cryptosporidium and Enterovirus Analyses

A water sample from the river and one from each groundwater well were collected on June 11, 2014 and assayed by PCR and RT-PCR for the presence of *Cryptosporidium* spp. and/or enterovirus, respectively. None of the water samples tested positive for either.

Conclusions

In comparison to the river samples, the lack of daily fluctuations in groundwater bacterial and field parameter results provide virtually no evidence of mixing of river and groundwater due to elevated river levels from daily dam releases during the sampling times in this study. This is in contrast to the study by Sawyer et al. (2009) who found daily changes in the river level, at an adjacent site on the Colorado River, to impact water-table fluctuations 30 m into the surrounding aquifer and result in a hyporheic zone approximately 1-5 m into the riparian aquifer. However, daily dam releases to the river were much larger during their study, producing changes in river levels of 8.2 ft as compared to 0.5 ft during our study.

Except for two samples, river *E. coli* levels were below regulatory limits (126 MPN/100 ml). This is consistent with the recent history of the river at a nearby site (TCEQ Station 12469 from February 2006 through February 2014) for which only 4 out of 48 samples exceeded 126 MPN/100 ml. It is interesting that river *E. coli* levels rose with river height and peaked shortly after the river level began to fall. One possible explanation is that rising river levels collected additional *E. coli* from the surrounding riparian area and that this was concentrated into the river as it receded. Regardless of the cause, these results suggest that the temporal impacts of dam releases on river *E. coli* levels should be taken into consideration when designing routine monitoring schedules. In the case of this study area, peak river height and *E. coli* levels both occurred at night and early morning hours, with lower levels later in the day.

Overall, the combination of low levels of fecal indicator microorganisms and pathogens in the river samples combined with little evidence of surface water mixing into the surrounding riparian aquifer suggests that there is not a large increase in pathogen risk from groundwater in the surrounding alluvium under recent dam release conditions. However, the potential risk may change if dam releases increase to historical levels and/or the fecal indicator levels in the river increase due to future impairments.

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