City of Waitsburg Wastewater Treatment Plant Groundwater Study

Evaluation of Nutrient Loading to the Touchet River

April 2010

Publication No. 10-03-028

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and Contact Information

This report is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1003028.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search User Study ID, CHPI004.

Activity Tracker Code for this study is 09-547.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

o Headquarters, Olympia	(360) 407-6000
o Northwest Regional Office, Bellevue	(425) 649-7000
o Southwest Regional Office, Olympia	(360) 407-6300
o Central Regional Office, Yakima	(509) 575-2490
o Eastern Regional Office, Spokane	(509) 329-3400

This report was prepared by a licensed hydrogeologist. A signed and stamped copy of the report is available upon request.

Cover photo: *Touchet River above Coppei Creek, Waitsburg, Washington (Photo by C.F. Pitz)*

City of Waitsburg
Wastewater Treatment Plant
Groundwater Study

Evaluation of Nutrient Loading to the Touchet River

by
Charles F. Pitz, L.Hg. and Scott Tarbutton

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

Waterbody Number(s): WA-32-1020

This page is purposely left blank

Table of Contents

Page

List of Figures and Tables

Page

Figures

Tables

Glossary, Acronyms, Abbreviations, and Conversion Factors

Glossary

Anisotropy: A condition where one or more of the hydraulic properties of an aquifer vary according to the direction of water flow.

Anoxic: Depleted of oxygen.

Anthropogenic: Human-caused.

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Flux: The amount of fluid (or mass) that flows through a unit area per unit time.

Groundwater discharge: The movement of groundwater from the subsurface to the surface by advective flow.

Hydraulic conductivity: A coefficient that describes the rate at which water moves through a permeable medium such as sediments, or fractured rock.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Piezometer: A small-diameter, non-pumping well used during this study to (1) measure depth to groundwater, (2) measure streambed water temperatures, and (3) periodically collect groundwater quality samples.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Redox: Reduction/oxidation - all chemical reactions involving a change in oxidation state. Reduction is the gain of electrons or decrease in oxidation state by a molecule, atom or ion. Oxidation is the loss of electrons or increase in oxidation state by a molecule, atom, or ion.

Riparian: Relating to the banks along a natural course of water.

Specific conductance: A measure of water's ability to conduct an electrical current. Specific conductance is related to the concentration and charge of dissolved ions in water.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Acronyms and Abbreviations

BNA	base, neutral, acid semi-volatiles
CHIT	constant head injection test
DO	dissolved oxygen
DOC	dissolved organic carbon
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
Fe^{2+}	ferrous iron

MEL	Manchester Environmental Laboratory
MGD	millions of gallons per day
mg/L	milligrams per liter (equivalent to parts per million)
mV	millivolts
Na	sodium
NH_4-N	ammonium as N
NO_2-N	nitrite as N
NO_3-N	nitrate as N
NPDES	(See Glossary above)
OP	orthophosphate as P
Redox	reduction/oxidation
RM	river mile
RMS	root mean square
%RSD	percent relative standard deviation
SO_4	sulfate
SOP	standard operating procedures
TDS	total dissolved solids
TDP	total dissolved phosphorus as P
TMDL	(See Glossary above)
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WWTP	Wastewater treatment plant

Datums

Horizontal coordinates presented in this report are referenced to the North American Datum of 1983 High Accuracy Reference Network [NAD83(HARN)].

Vertical coordinates presented in this report are referenced to the North American Vertical Datum of 1988 (NAVD88). Elevation values represent the distance above or below the datum in feet.

Units of Measurement

°C	degrees centigrade
cm	centimeters
ft	feet
ft^3/sec	cubic feet per second
g	gram, a unit of mass
J/m^3°C	joules per cubic meter per
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/day	kilograms per day
km	kilometer
L/min	liters per minute
lb/day	pounds per day
m	meter

m/sec	meters per second
m^2/sec	square meters per second
m^3/sec	cubic meters per second
mg	milligrams
MGD	million gallons per day
mg/L	milligrams per liter (parts per million)
mV	millivolts
s.u.	standard units
µg/L	micrograms per liter (parts per billion)
µS/cm	microsiemens per centimeter, a unit of conductivity
Wm°C	watt per square meter per Kelvin per degrees centigrade

Conversion Factors

Units Conversion		
Multiply	By	To Obtain
Length		
centimeter (cm)	0.3937	inch (in)
meter (m)	3.2808	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square meter (m^2)	10.7639	square ft (ft^2)
acre	4046.9	square meter (m^2)
Volume		
cubic meter (m^3)	35.3147	cubic foot (ft^3)
liter (L)	0.0353	cubic foot (ft^3)
Mass		
kilogram (kg)	2.2046	pound (lb)
Flow		
cubic meter per second (m^3/sec)	35.3147	cubic foot per second (ft^3/sec)
Hydraulic Conductivity		
meter per day	3.2808	foot per day
Temperature Conversion		
degrees Celsius (°C)	(°C x 1.8) + 32	degrees Fahrenheit (°F)
degrees Fahrenheit (°F)	(°F – 32)/1.8	degrees Celsius (°C)

Abstract

The Touchet River, a tributary of the Walla Walla River, has been listed under Section 303(d) of the federal Clean Water Act for failing to meet standards for pH and dissolved oxygen conditions. In 2007, a Total Maximum Daily Load Study (TMDL) Water Quality Improvement Report was published to address these listings. The 2007 report recommended additional field investigation to determine if the Waitsburg, Washington municipal wastewater treatment plant (WWTP) is a possible source of excess nutrients to the river.

Treated effluent from the Waitsburg WWTP is released to an unlined infiltration wetland considered in hydraulic continuity with the Touchet River. If an excess nutrient load reaches the river from the infiltration system via groundwater transport, it could adversely impact pH and DO conditions. A focused groundwater study was conducted to determine if this is the case.

A variety of techniques were used to develop estimates of the groundwater discharge rate and nutrient mass load to the Touchet River adjacent to the Waitsburg WWTP. Study methods included installation and monitoring of instream piezometers, collection and evaluation of groundwater quality samples, and monitoring of streambed thermal profiles.

Highly elevated concentrations of dissolved nitrogen and phosphorus were observed in upwelling groundwater along a 150- to 200-meter-long portion of the site shoreline, primarily downgradient of the infiltration wetland. If these dissolved nutrients discharge to the river without further attenuation, daily baseflow-season inputs of between 2 to 28 kilograms of nitrogen (as ammonium-N) and 1 to 10 kilograms of phosphorus (as organic P) are estimated from this impacted area.

Biogeochemical processes active in the very uppermost portions of the streambed (just prior to groundwater discharge) may decrease the mass of dissolved nutrients actually reaching the water column.

Acknowledgements

The authors of this report would like to thank the following people for their contribution to this study:

- Dan Katsel, City of Waitsburg, for providing site access and facility background information.
- Mark Grandstaff, Washington State Department of Fish and Wildlife, and Stephen Donovan, Walla Walla County, for assistance with permitting study piezometers.
- Rich Sheibley, U.S. Geological Survey, for technical assistance.
- Washington State Department of Ecology staff:
    - Tighe Stuart for field support.
    - Brian Pickering for assistance with equipment fabrication.
    - Mitch Wallace for providing surface flow data.
    - Richard Koch and Kim Sherwood for field and project support and assistance with permitting study piezometers.
    - James Kardouni and Kirk Sinclair for assistance with thermal instrumentation and modeling.
    - Joe Joy for assistance with study design and data interpretation.
    - Nancy Rosenbower, Dean Momohara, Leon Weiks, Dickey Huntamer, and Stuart Magoon for laboratory support.
    - Martha Maggi, Bill Kammin, Richard Koch, Joe Joy, and Bob Raforth for providing review comments on project reports.
    - Donna Seegmueller for reference support.
    - Joan LeTourneau, Carol Norsen, and Jean Maust for assistance with preparing project documentation.

Introduction

In 2007 a Total Maximum Daily Load Study (TMDL) Water Quality Improvement Report was published for the Walla Walla watershed (Joy et al., 2007). The report described the findings and recommendations that resulted from an extensive field monitoring effort conducted within the basin during 2002 and 2003. The ultimate goal of the TMDL effort is to address federal Clean Water Act 303(d) listings for pH and dissolved oxygen non-attainment within the watershed.

The 2007 improvement report recommended additional field investigation in several key areas of concern within the watershed to help identify the specific source(s) of elevated nutrient concentrations observed in surface water.[1] This included a recommendation for further investigation of potential subsurface nutrient loading from the Waitsburg, Washington municipal wastewater treatment plant (WWTP) property (Joy et al., 2007) (Figure 1).

During the 2002-2003 TMDL monitoring period, increases in nitrogen, chloride, and alkalinity loads were observed in the Touchet River in the vicinity of the Waitsburg WWTP facility. These increases could not be explained by local tributary inputs alone (for example from nearby Coppei Creek).

Treated effluent from the Waitsburg WWTP is released to an unlined infiltration wetland in hydraulic continuity with the river (Ecology, 2005; Katsel, 2009). Based on this knowledge, Joy and his co-authors concluded that the facility could be delivering an excess nutrient load to the river via subsurface transport and discharge of groundwater.

An analysis of synoptic seepage data collected during an October 2007 follow-up effort supported the interpretation that a significant gain in stream discharge occurred along the reach immediately adjacent to the Waitsburg facility (Pitz, 2009a). These factors suggested the need for a more detailed study of groundwater status and behavior at the facility.

Project Goals and Objectives

The primary goal of this study was to characterize the nutrient load conveyed from the Waitsburg WWTP property to the Touchet River via groundwater transport. The information generated by this study will support further technical analysis and numerical modeling of water quality conditions and nutrient loading capacity for the Touchet River drainage.

During the summer and fall of 2009 a variety of field techniques were employed to meet two main technical objectives: 1) characterize local groundwater/surface water interaction patterns during the critical baseflow period, and 2) describe the quality of the groundwater downgradient of the WWTP facility, just prior to its discharge to the Touchet River.

The technical approach used to accomplish these objectives included the installation and monitoring of a network of near-shore streambed piezometers. A limited number of surface water stations were also monitored during the study to assist data interpretation. The effort described in this report was augmented by additional, larger-scale surface water monitoring and seepage evaluation work also conducted during 2009, as described by Tarbutton (2009).

Study Area Description

Physical Setting

The study site is located approximately 0.5 km (0.3 miles) west of downtown Waitsburg, Washington, in Walla Walla County (current population: ~1230; OFM, 2007) (Figure 1).

---

[1] An excess nutrient load can increase the rate of biological productivity in a river or stream, resulting in undesirable changes to pH and dissolved oxygen condition.

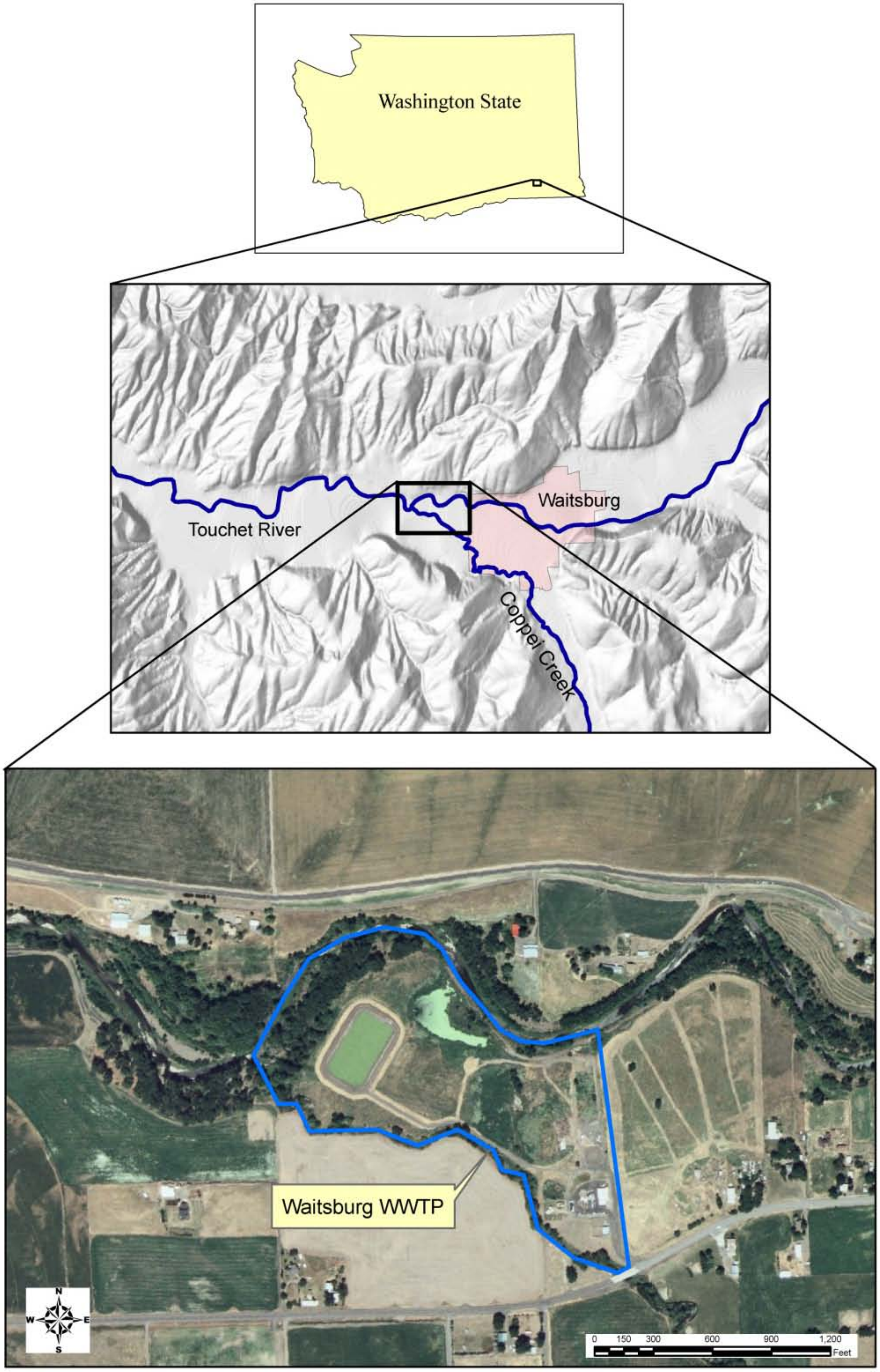


Figure 1. Study location map.

The city-owned treatment plant property, which occupies approximately 13 hectares (32 acres), is situated in the narrow, flat, east-west trending alluvial valley of the Touchet River, at a land surface elevation of approximately 373 m (1225 ft). The stream originates in the Blue Mountains southeast of Waitsburg then meanders west and then south to join the Walla Walla River ~50 km (31 miles) downstream of Waitsburg.

The river is bordered by a mixed-density riparian zone of willows, alders, and black cottonwood, and defines the northern boundary of the WWTP property (Stohr et al., 2007). Low-relief foothills rise abruptly from the valley bottom to the north and south.

Land Use

Land use immediately surrounding the treatment plant facility is comprised of low density rural development, and irrigated and non-irrigated agriculture (Figure 1). The foothills north and south of the Touchet River valley are dominated by dry-land agriculture, almost exclusively planted as wheat. Moderate density residential development surrounding the commercial center of Waitsburg is present approximately 0.5 km east of the facility.

This reach of the Touchet River drainage has limited fish-rearing capacity, but does serve as an important migration route to federally-designated critical spawning habitat for bull trout and steelhead salmon (both listed as threatened under the Endangered Species Act; Stohr et al., 2007).

Climate

The weather of the Walla Walla basin is characterized as a continental-type climate, with hot, dry summers, and generally cold, damp winters. Figure 2 presents the average minimum, mean, and maximum monthly temperature for the study area (National Climatic Data Center Cooperative Station 452030, Dayton, Washington; approximately 16 km east of the study site). July and August are typically the warmest months of the year; December and January are typically the coldest. Temperatures reported for the study period between July and October 2009 were near-normal (Figure 2).

Figure 3 presents the long-term (1893-2009) seasonal precipitation pattern for the area (Dayton co-op station). The annual precipitation total for the study area has averaged approximately 48 cm/year (19 in/year), mostly as rainfall (Western Regional Climate Center, 2009). The long-term average precipitation total for the July through October period is 9.09 cm (3.58 in). The precipitation total for the same four-month time frame was 8.51 cm (3.35 in) during 2009, indicating near-normal rainfall conditions during this study.

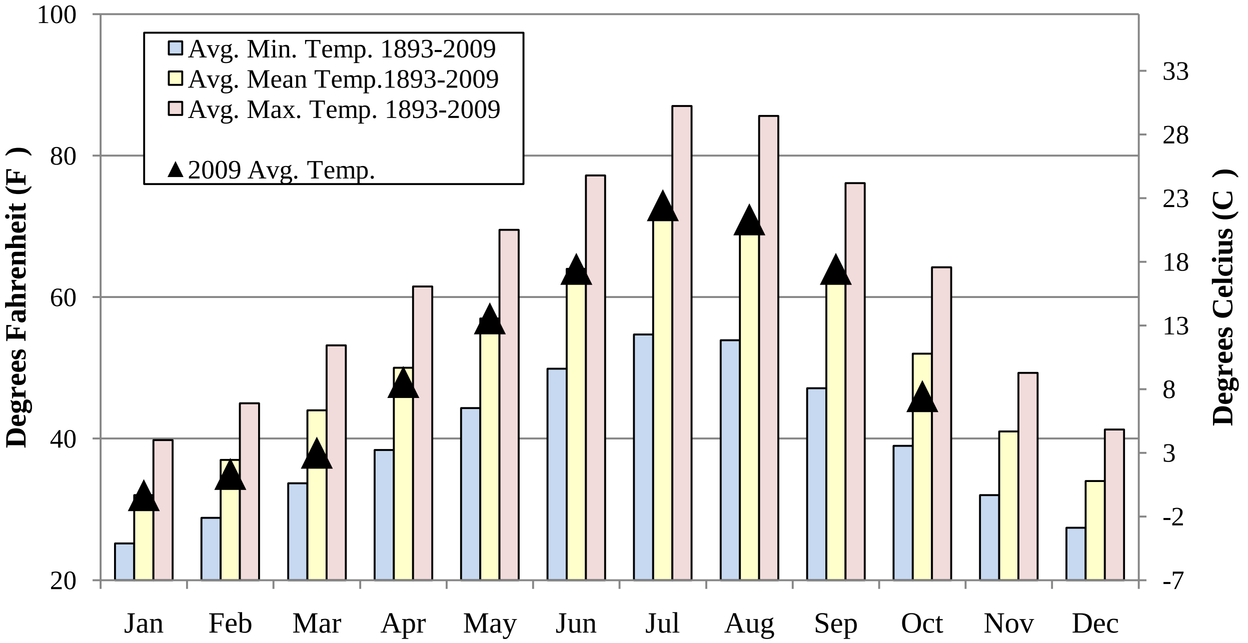


Figure 2. Long-term and recent monthly average minimum, maximum, and mean air temperatures, Dayton, Washington (Western Regional Climate Center, 2009).

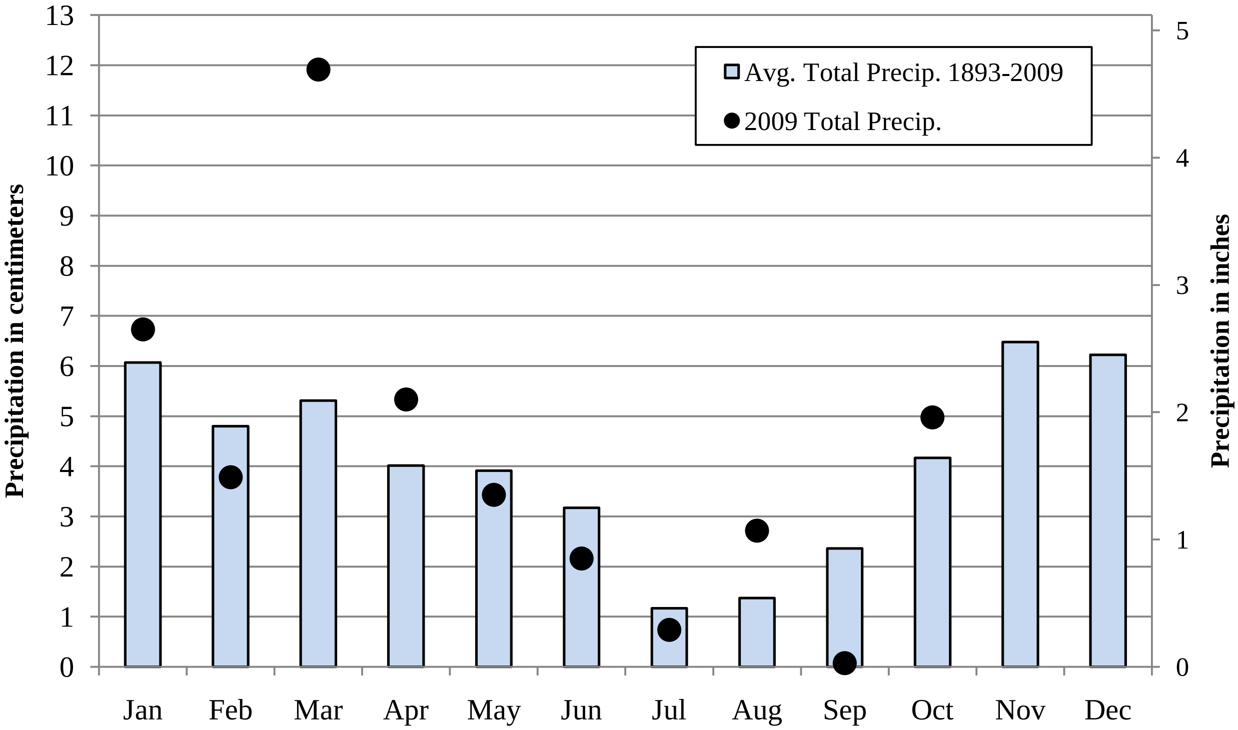


Figure 3. Long-term and recent monthly average precipitation totals, Dayton, Washington (Western Regional Climate Center, 2009).

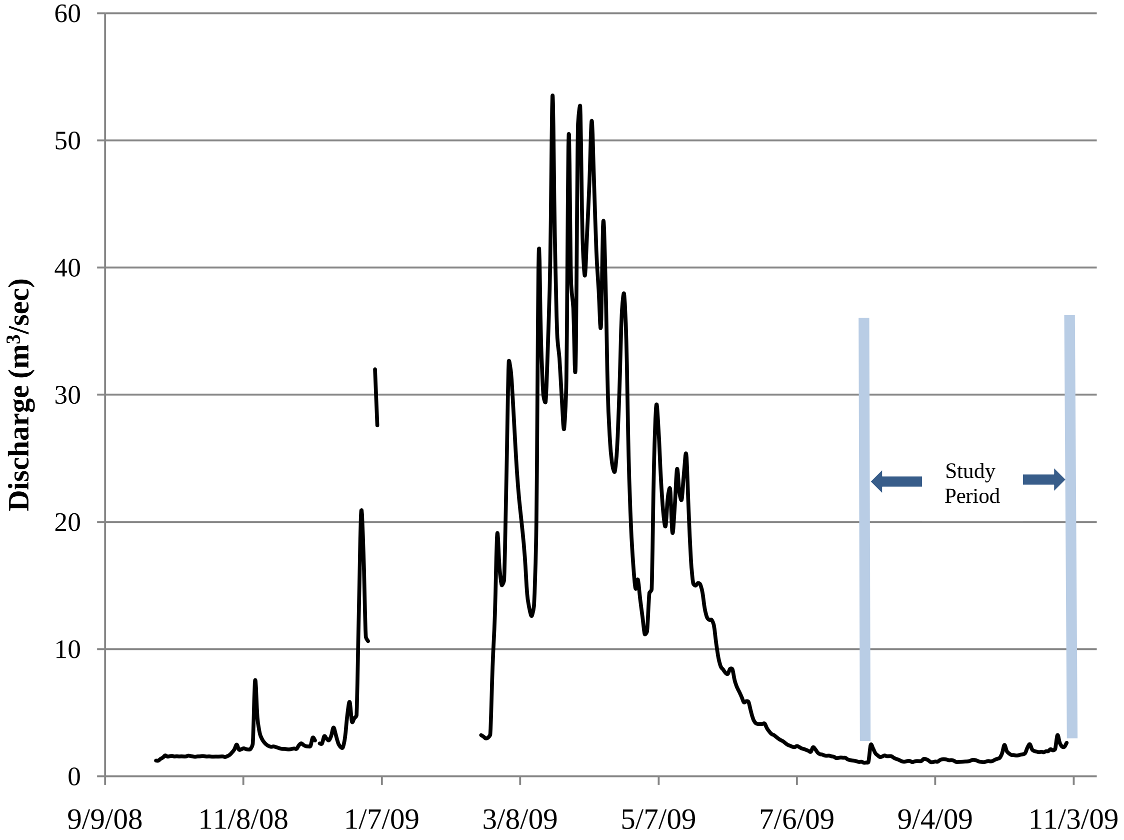


Figure 4. Stream discharge hydrograph - Touchet River at Bolles (provisional data, Ecology station 32B100).

Streamflow

Figure 4 presents a 2008-2009 stream discharge hydrograph for the Touchet River at the Bolles flow station, located approximately 5.2 km (3.2 miles) downstream of the study site (Ecology Stream Hydrology Unit Station 32B100). The baseflow season for the river, and the primary period of interest for nutrient loading, occurs between July and early November (Joy et al., 2007).

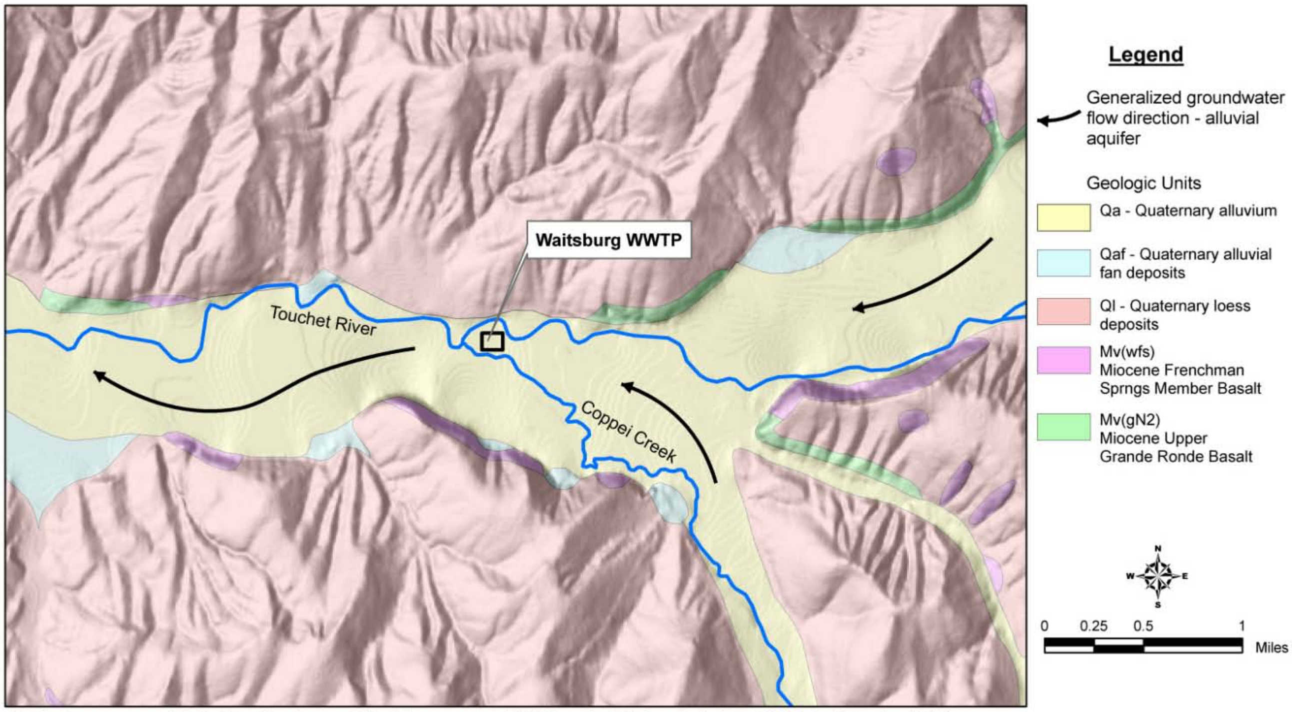
River discharge increases up to 20 fold during the later winter and early spring, driven by snowmelt-dominated runoff from the higher elevations of the drainage area. Discharge rates during the study period ranged between 1.05 to 3.23 m^3/sec (37 and 114 ft^3/sec), with an average discharge of approximately 1.53 m^3/sec (54 ft^3/sec).

Hydrogeologic Setting and Groundwater Occurrence

Regional Hydrogeologic Setting

The study site is located near the boundary between the Blue Mountains and Palouse Slope structural sub-regions, within the Columbia Plateau Regional Aquifer System (Kahle et al., 2009). The Waitsburg area is locally underlain by a thick sequence of Miocene-age flood basalt bedrock units (and associated sedimentary interbeds) which belong to the Columbia River Basalt Group (CRBG).

Two distinct units from the CRBG underlie the study area: basalts from the Frenchman Springs Member of the Wanapum Unit, and basalts from the Upper Grande Ronde Unit. In the vicinity



Geologic map source: Wash. Div. of Geology and Earth Resources; 1:100,000 scale digital geologic data, 2005 (after Schuster, 1994)
Base map topography source: 10m shaded relief DEM

Figure 5. Generalized surficial geology - Waitsburg, WA area.

of the study area, only limited surface exposures of the CRBG units are present, typically on eroded bluffs or cut banks bordering the alluvial plain (Figure 5). The majority of the basalt plateau surrounding the Touchet River valley is mantled by a thin unit of Quaternary-age eolian silt and fine sand loess deposits [typically ≤3 m (10 ft) thick].

The low-relief floodplain of the Touchet River is underlain by a sequence of recent and reworked, interbedded alluvial deposits of silt, sand, gravel, cobbles, and boulders. A review of local drilling logs (Ecology, 2010) indicates, on average, approximately 6-15 m (20-50 ft) of unconsolidated deposits overlie the basalt surface along the floodplain, thinning at the margins.

The basalt aquifer system serves the region as the principal source of water supply; most local water supply wells (including the City of Waitsburg municipal supply) are completed at a depth of ≥76 m (250 ft). A small number of private domestic supply wells are completed in the alluvial deposits. The static water level within the alluvial aquifer lies approximately 1.5-8 m (5-25 ft) below land surface, with the overall groundwater flow direction down-valley towards the west (Figure 5).

Regional Patterns of Groundwater/Surface Water Exchange

Existing information regarding patterns of groundwater/surface water exchange within the study area is very limited.

Marti (2005) presented the results of field investigations intended to characterize broad patterns of groundwater/surface water exchange within the Walla Walla watershed, in support of Ecology's 2002-2003 TMDL effort. A combination of seepage evaluations and instream piezometer monitoring was used to estimate groundwater loss and gain with the watershed's primary drainages, including the Touchet River.

Marti's evaluation of the seepage data indicated negligible net groundwater exchange along a 21.6 km long (13.4 mile) reach of the Touchet River that includes the Waitsburg facility. Measurements of vertical hydraulic gradient collected during the study showed a consistently gaining condition at an instream piezometer installed ~4.8 km (3 miles) upstream of the Waitsburg treatment plant, and a consistently losing condition at a piezometer ~4.8 km downstream.

Leek (2006) reported the results of a highly detailed characterization of groundwater/surface water exchange along two short sections of the Touchet River approximately 10 to 11 km (6-7 miles) upstream of the treatment plant. Consistent with the findings of other researchers (e.g., Conant, 2004), Leek found a high degree of heterogeneity in the location, direction, and amount of water exchange between the river and the alluvial deposits.

Site Conditions

The sediments observed in the riverbed within the study area are generally comprised of coarse gravels and cobbles, with boulders in higher-energy portions of the stream. In certain areas, very large blocks of rip rap material (concrete and basalt boulders; >0.5 m diameter) are present at the base of the river bank or within the stream channel.

Limited information is available regarding groundwater or lithologic conditions directly beneath the WWTP facility. Gray and Osborne (1981) and Heffner (1986) reported the results of studies conducted to evaluate site groundwater conditions. These reports summarized water level and water quality monitoring results collected from a network of shallow wells installed by excavation at the facility in the early 1980's.

The data collected during these studies indicated a water table position approximately 1.5-3 m (5-10 ft) below ground surface in coarse alluvial gravels (described as "river rock"). Several boring logs presented in the 1981 Gray and Osborne report indicate household garbage was encountered during the well excavation activities.

The groundwater flow direction across the site was estimated predominantly towards the north, although Heffner reported that changes in the hydraulic management of treatment plant discharge affected local groundwater flow directions through mounding. Heffner also suggested evidence of leakage from the lagoon and wetland system, raising a concern for local groundwater contamination and impact on the Touchet River.

Groundwater quality sampling results summarized by Heffner indicate groundwater beneath the site was, in areas, heavily impacted by anthropogenic activities. Chloride, fecal coliform, nitrogen, and phosphorus all showed significantly elevated concentrations, with nitrate levels reported as high as 180 mg/L in a well located in the far southeastern corner of the property (Figure 1).

A large flood event in 1996 destroyed all remaining wells in the facility monitoring network (Katsel, 2009).

Facility Information and Effluent Management Practices

Management of effluent generated by the Waitsburg WWTP has changed significantly over the past 30 years, as have the size and configuration of the features employed to handle that discharge.

The Waitsburg WWTP was constructed in 1952, to replace a large septic tank at the site (Gray and Osborne, 1981). Between 1952 and 1981, the treatment plant released its effluent directly to Coppei Creek.

In 1981, due to concerns about the water quality impact of the effluent on the creek, all plant discharge was redirected to a series of shallow, unlined, man- made surface trenches (referred to collectively as the "former lagoon"). Water pumped into the former lagoon was, in turn, drained to an unlined infiltration-wetland located

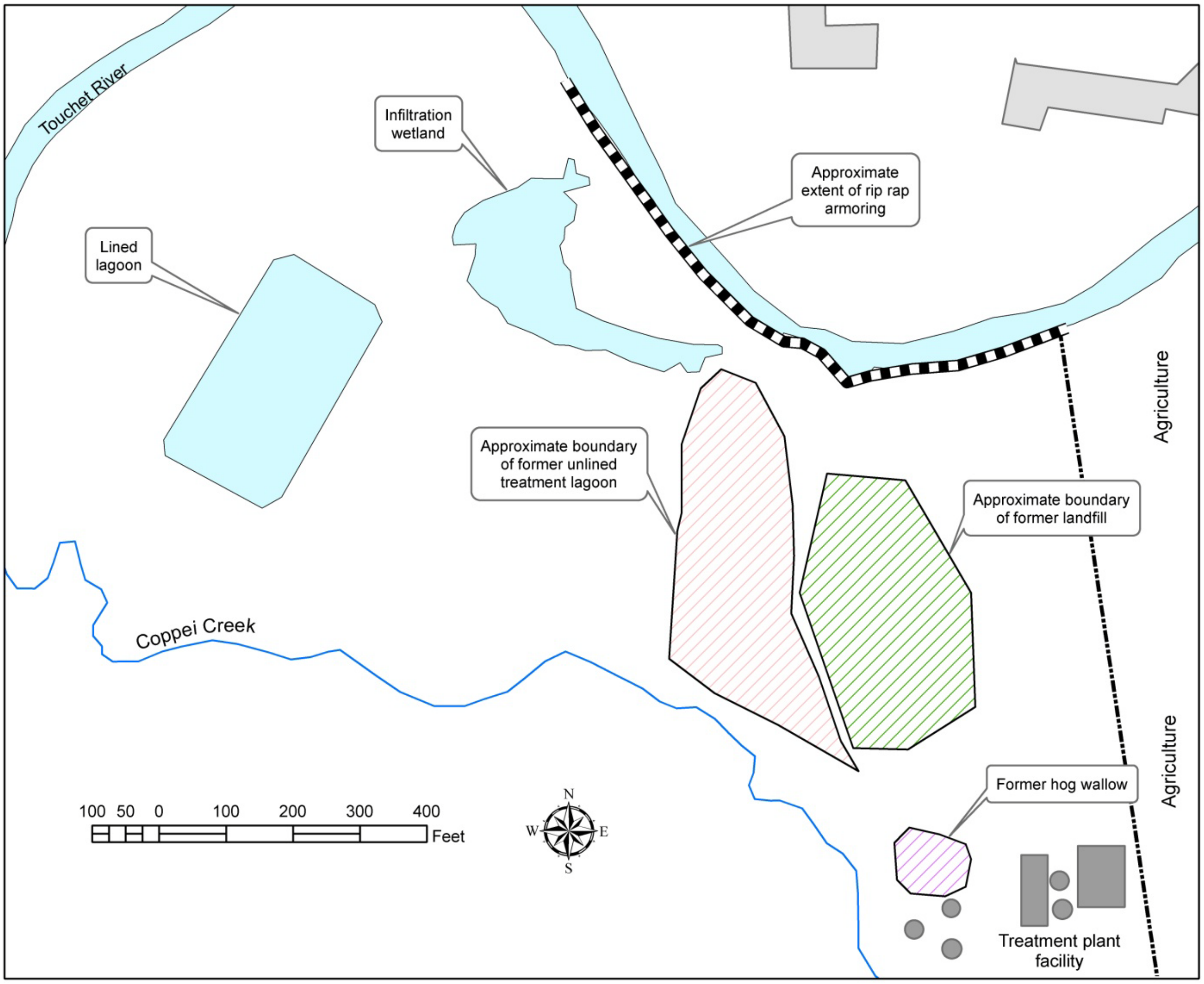


Figure 6. Waitsburg WWTP facility map.

adjacent to the river (Figure 6) (Heffner, 1986; Joy, 1986a, Koch, 2010; APA, 1999).

In 1990, the unlined lagoon system was abandoned, and a ~0.6 hectare (1.5 acre) lined lagoon was constructed in the western portion of the property to take its place. In 2003, coincident with additional treatment plant upgrades, use of this polishing lagoon for effluent management was abandoned entirely; all plant effluent has since been pumped directly to the infiltration wetland.

The lined lagoon is now used primarily as a storage facility for excess inflow under high flow conditions. A limited volume of water is now maintained in the lagoon throughout the year to suppress vegetation growth. Water held in the lined lagoon can still be released, as needed, directly to the wetland through an outlet weir (Katsel, 2009).

The former unlined lagoon is now backfilled level with the remainder of the site surface, and is used as a storage area for soil and construction materials.

While the change in the point of effluent release eliminated all direct discharge to surface water, the wetland is designated by the facility's NPDES permit to be in hydraulic continuity with the Touchet River (Ecology, 2005). The current NPDES permit limit for dry-season plant discharge to the wetland is 0.16 MGD (0.007 m^3/sec; 0.25 ft^3/sec).

The estimated plant discharge rates during the study period between August and October, 2009 were (WPLCS, 2010):

- 0.11 MGD (Aug.)
- 0.12 MGD (Sept.)
- 0.13 MGD (Oct.).

The water quality character of the plant effluent has also changed over time. Before 2003, wastewater received by the plant was treated using a clarifier/trickling filter system prior to release. In the spring of 2003, the plant was upgraded to an activated sludge/UV disinfection/ oxidation ditch system. This change resulted in a significant shift in the ratio of nitrogen species in the effluent ultimately released to the wetland (Table 1).

In 1996 a major flood event inundated the property. This flood, and the U.S. Army Corps of Engineers' (USACE) follow-up restoration efforts, reduced the surface area of the wetland by approximately one half (currently ~1 acre) (Katsel, 2009). An auto-level survey conducted during the current study determined that the water surface of the wetland was 1.65 m (5.4 ft) above the Touchet River stage in September 2009.

During their flood restoration and control project, the USACE diked and armored approximately 300 m (~1000 ft) of the left bank of the Touchet River adjacent to and upstream of the wetland (Figure 6). The rip rap used for armoring is, at the surface, a combination of very large boulders of concrete and basalt. A number of these boulders are now present within the river channel along the armored portion of the shoreline.

In contrast to other portions of the river shoreline, the armored area exhibits minimal deep-rooted riparian vegetation. Reed canary grass is currently the dominant plant species on the river bank throughout most of this area.

Additional sources of potential impact to site groundwater quality include: 1) an abandoned municipal landfill located to the east of the former lagoon, 2) a small, abandoned "hog wallow" located just north of the treatment plant, 3) direct leakage from the treatment facility, and 4) infiltration from agricultural fields on adjacent properties (Figure 6).

Table 1. Average monthly ammonia and nitrate effluent concentrations - Waitsburg WWTP.

Parameter (mg/L)	Oct 1995-Feb 2003	May 2003-Apr 2009
Total Ammonia as N	12	0.4
Total Nitrate as N	1	16

Data from WPLCS, 2010.

Limited documentation exists describing the true extent and history of use of the landfill and hog wallow. Gray and Osborne (1981) reported that the landfill received household garbage between 1969 and 1979. Material disposed in the landfill was reportedly placed in a series of shallow trenches (1-2 m deep) that, once full, were capped with a thin cover of compacted soil.

During the current study, old battery casings and numerous pieces of scrap metal were observed embedded in the river bank immediately down slope from the northern end of the landfill area (Figure 6). This suggests the possibility that the northern limit of the landfill reaches the near vicinity of the shoreline, possibly having been exposed by flood scour.

Study Methods

A variety of investigative techniques were used to evaluate groundwater/surface water exchange and water quality conditions at the study site. Monitoring of streambed piezometers was augmented by a reconnaissance thermal survey, modeling of streambed temperature profile data, and hydraulic testing of streambed sediments.

Water quality data and estimates of sediment hydraulic properties were ultimately integrated to develop estimates of groundwater-related nutrient loading to the Touchet River. General descriptions of the procedures employed during the study are presented below. Additional details about the study methods are described in Pitz (2009a) and other cited references.

Streambed Thermal Reconnaissance

A reconnaissance survey of streambed temperatures was conducted at the beginning of the study on the morning of August 3, 2009. The purpose of the survey was to rapidly identify locations of potential groundwater inflow to the river and to prioritize the placement of piezometers for longer-term monitoring.

The survey was accomplished by comparing surface water temperature immediately above the sediment surface to the porewater temperature ~5 to 10 cm below the sediment surface, just offshore of the left (southern) bank of the river (Figure 7). Temperature comparisons were made every 10 meters along an 880-meter reach encompassing the treatment plant property boundaries. Temperatures were collected using a calibrated, long-shaft, K-type temperature probe (Cole-Parmer®).

During the thermal reconnaissance, a strong temperature contrast between warmer surface water and cooler streambed porewater was observed along a continuous section of the left river bank, generally coincident with the extent of the infiltration wetland (Figure 7). In several cases, the porewater temperature was between 5° to 10°F cooler than the river temperature, implying significant groundwater inflow at these locations.

During inspection of the shoreline in this area, a small groundwater seep was identified flowing from the bankside (Figure 7). The seep emerges from the rip rap immediately down slope of the far eastern end of the wetland.

Discharge from the seep enters a small side channel that eventually joins the main channel of the Touchet River approximately 10 to 15 meters downstream of the seep. Abundant iron bacteria flocculate slime and algal growth was observed in the water in this channel throughout the study period (Figure 8). The seep discharge rate was estimated in the field at approximately 0.0006 m^3/sec (0.02 ft^3/sec).

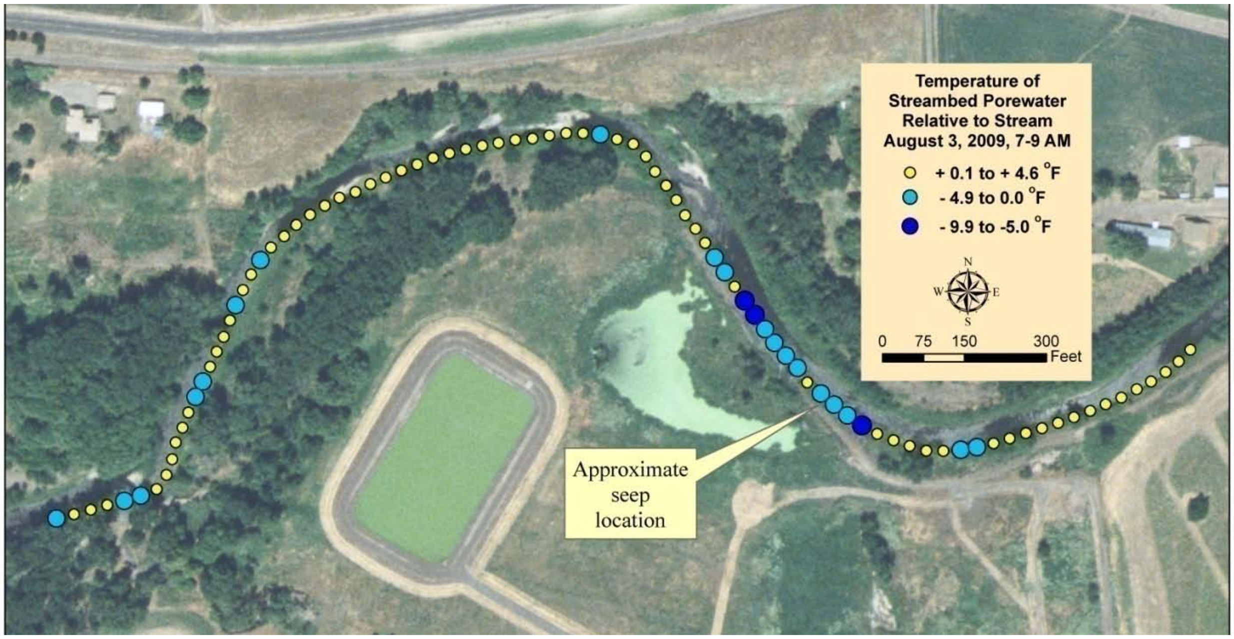


Figure 7. Streambed thermal reconnaissance results - August 3, 2009.

Figure 8. Iron bacteria slime and algal growth at seep.

Instream Piezometer Installation

Guided by the results of the thermal reconnaissance survey, a network of eleven galvanized-steel pipe piezometers was installed in early August 2009 in the streambed upstream, adjacent to, and downstream of the WWTP facility (Figure 9; Table A-1, Appendix A). Piezometers were constructed, installed, and developed following techniques described by Sinclair and Pitz (2009).

Each piezometer was constructed with a short, perforated open-interval at the base of the pipe. The average mid-point depth of the piezometer open intervals at the time of construction was 1.12 m (3.67 ft) below the sediment surface. Two piezometers (AGT413, AGT421) were installed in locations assumed to provide data on area-background conditions, including an opposite-bank station[2].

At the end of the development procedure for each piezometer, reconnaissance measurements of dissolved oxygen and nitrate-N concentrations were collected using a field photometer. This preliminary data helped to guide the placement of additional piezometers.

The location of all piezometers was recorded after installation using a Global Positioning System (GPS) receiver. These positions were later refined using geo-rectified digital orthophotography (Table A-1, Appendix A).

Hydraulic Conductivity Testing

To provide an estimate of the hydraulic conductivity of the streambed sediments, constant head injection tests (CHIT) were performed after installation on three of the study piezometers (AGT415, AGT423, and AGT424). Hydraulic testing procedures and assumptions followed guidance outlined by Cardenas and Zlotnik (2003) and Pitz (2006).

Each piezometer was lightly developed prior to testing to ensure an adequate hydraulic connection between the piezometer open interval and the adjacent sediments. The field test measurements were evaluated with an EAP-developed spreadsheet model using Equation 1:

$$K = \frac{Q}{2\pi L P y} \qquad (1)$$

where[3]:

K = the isotropic hydraulic conductivity of the sediments adjacent to the open interval (L/t)
Q = the net constant head injection rate (L^3/t)
L = the total length of the open interval of the piezometer (L)
P = well shape factor
y = the height of the constant head above the stream (L)

where: L = length, and t = time

Derivation of the well shape factor (P) is described in Cardenas and Zlotnik (2003).

---

[2] It is assumed that groundwater conditions observed in the opposite bank piezometer AGT421 represent groundwater inflow from the north, unassociated with the Waitsburg WWTP facility.

[3] See Figure B-1, Appendix B for illustration of terms.

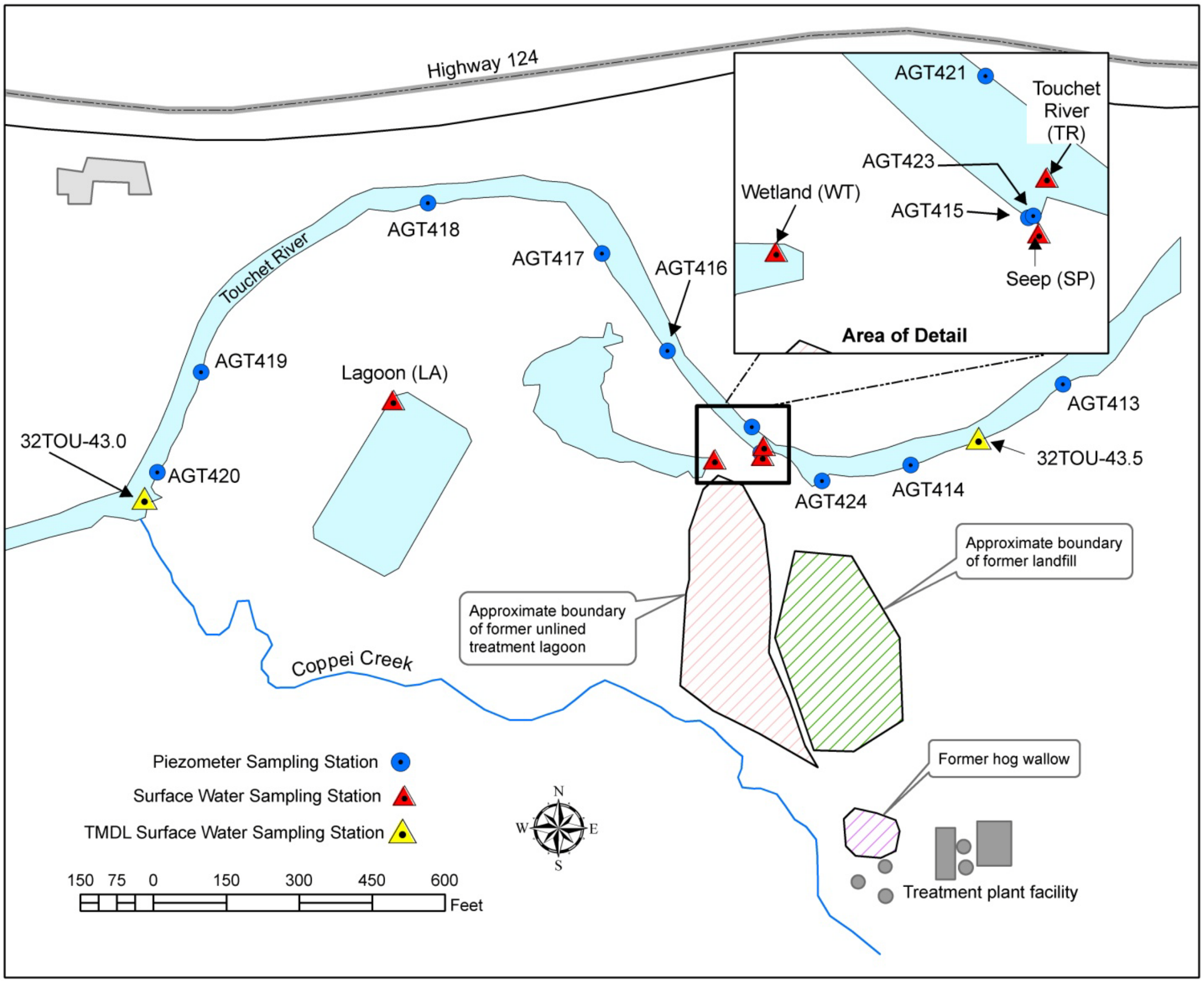


Figure 9. Monitoring station location map.

Hydraulic Head and Vertical Hydraulic Gradient Monitoring

Point measurements of hydraulic head for surface water and underlying groundwater were collected at all piezometer stations during early August, early September, late September, and late October. These head measurements were used to calculate the magnitude and direction of the vertical hydraulic gradient between the Touchet River and groundwater. The comparative hydraulic head measurements were collected following methods described by Sinclair and Pitz (2009).

These data were used to map gaining and losing sections of the river, and help estimate groundwater flux through the streambed. An e-tape and engineer's rule was used for head measurement during the first two monitoring events; a manometer board was used for measurement during the last two events. The manometer board estimates are considered the most accurate in cases of very small differences in head. Gradient estimates were geometrically corrected for piezometers that were installed off-vertical.

Differences in hydraulic head between a piezometer and adjacent surface water stage were used to assign the amount and direction of hydraulic potential using Equation 2 (Figure 10):

$$i_V = \frac{\Delta h}{\Delta l} \qquad (2)$$

where:

i_v = vertical hydraulic gradient (dimensionless)
Δh = difference in hydraulic head between the stream stage and the instream piezometer water level (L)
Δl = distance from the streambed surface to the mid-point of the piezometer open interval (L)

The hydraulic head measured inside a piezometer is the average head across the open interval. In cases where the piezometer hydraulic head is above the stream stage (recorded as a positive value), an upward gradient is indicated, suggesting the potential for groundwater inflow (gain) to the stream. The potential for the loss of water from the stream to the underlying sediments is implied when the stream stage is above the piezometer head (recorded as a negative value).

Thermal Monitoring

Automated monitoring and comparison of stream and underlying groundwater temperatures can provide a qualitative measure of the direction and timing of water exchange in a fluvial environment for continuous periods of record (Stonestrom and Constantz, 2003). These measurements can be used to confirm the point estimates of vertical hydraulic gradient described above, and as input for model simulations to estimate the hydraulic properties of streambed sediments.

During the study, two larger diameter piezometers in the network (AGT423, AGT424) were instrumented with recording thermistors to monitor spatial and temporal thermal patterns. Figure 10 illustrates a schematic of the thermistor array used to conduct the monitoring.

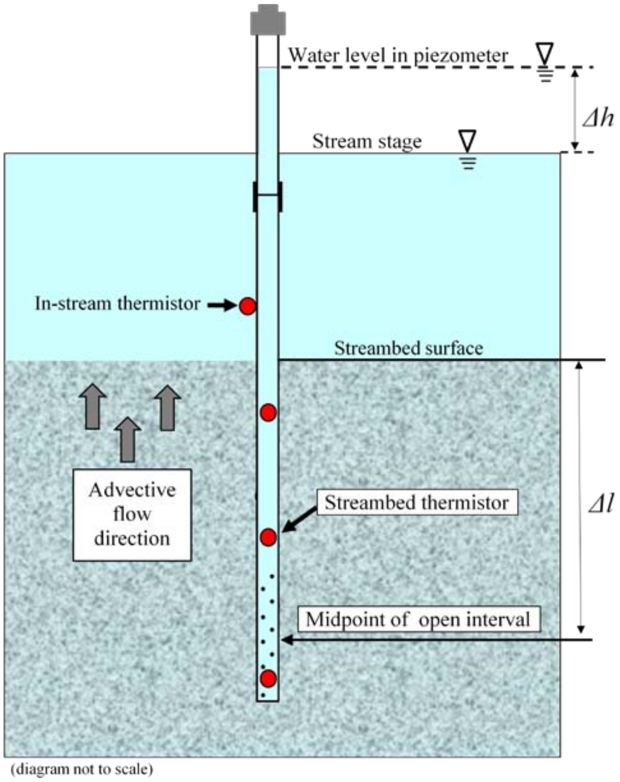


Figure 10. Schematic of instream piezometer and thermistor array (figure modified from K. Sinclair).

Recording thermistors (Onset Computer Corp. HOBO Pro™ v.1) were deployed at three distinct depths inside each monitored piezometer, with a fourth thermistor placed outside the piezometer casing to record the temperature of the lower portion of the stream water column (per procedures described by Sinclair and Pitz, 2009) (Table A-1, Appendix A). The thermistors, which were programmed to collect temperature data on a synchronized 30-minute cycle, were deployed from early August to late October 2009.

All thermistors were calibrated pre- and post-deployment to confirm accuracy and quantify drift (see Appendix C). HOBO Pro™ thermistors are accurate to approximately ± 0.2°C.

Thermal Modeling

The continuous temperature data obtained from piezometer AGT423 were integrated with periodic hydraulic head measurements to develop a one-dimensional, numerical simulation of transient groundwater flow and heat transport over the monitored portion of the sediment column.

Modeling was conducted using the U.S. Geological Survey's VS2DHI graphical user interface package (Hsieh et al., 2000). The VS2DH numerical model incorporated into the package (Healy and Ronan, 1996) solves a form of an energy transport equation for variably-saturated porous media (Equation 3) using a finite difference approximation method:

(3)

$$\frac{\partial}{\partial t}[\theta C_w + (1-\Phi)C_s]T = \nabla\cdot K_T(\theta)\nabla T + \nabla\cdot\theta\, C_w D_H \nabla T - \nabla\theta C_w\, vT + qC_w\, T^*$$

where:
t = time (seconds)
θ = volumetric moisture content
C_w = the heat capacity of water (J/m^3°C)
Φ = porosity of the porous media
C_s = the heat capacity of the dry solid (J/m^3°C)
T = temperature (°C)
K_T = the thermal conductivity of the water/solid matrix (W/m°C)
D_H = the hydrodynamic dispersion tensor (m^2/sec)
v = water velocity (m/s)
q = the rate of fluid source (1/sec)
T^* = temperature of the fluid source (°C)

The transport equation presented in Equation 3 accounts for changes in stored energy within a given volume of a porous media. Changes in energy occur due to advective transport of water of different temperature into the volume, and thermal conduction and energy dispersion into and out of the volume. Detailed discussions regarding the theoretical foundations for the VS2DH numerical model are presented in Healy and Ronan (1996), Healy (1990), and Lappala and others (1987).

Temperature distribution and transport in saturated sediments can be strongly dependent on the hydraulic conductivity of the porous media. Because of this sensitivity, the estimate of the vertical (or horizontal) hydraulic conductivity (K_V or K_H) of the sediment matrix is often the key calibration parameter for a vertically-oriented one-dimensional numerical energy transport model. Calibrated values for K_V and K_H can be compared against hydraulic conductivity estimates derived by alternative methods (e.g., CHIT), and can be used in Darcian calculations of groundwater discharge rates.

Modeling Assumptions

A number of simplifying assumptions were made during the development of the conceptual model of groundwater/surface water exchange offshore of the Waitsburg facility. These assumptions were then used to guide the construction of the numerical model:

- All groundwater flow within the uppermost portions of the sediment column (and therefore within the modeled domain) is assumed to be vertical – side boundaries of the model are established as no-flow/ no-energy flux boundaries.
- The thermal properties of the porous media through which flow occurs are assumed to be homogeneous and isotropic.
- The hydraulic properties of the porous media through which flow occurs are assumed to be homogeneous but anisotropic. The horizontal to vertical hydraulic conductivity ratio is assumed to be 5:1 to account for layering and orientation of stream-deposited sediment particles (Freeze and Cherry, 1979).
- The sediments within the model domain are assumed to be fully saturated.
- Changes in head condition at the top and bottom model boundaries (representing stream stage and hydraulic head at the piezometer open interval, respectively) are assumed to be linear between point measurements collected during baseflow conditions (August and September).
- Thermistor measurements collected inside of the piezometer are assumed to accurately reflect the thermal condition of the adjacent streambed sediments.

Model Structure and Input Parameters

The single-layer model domain established for the VS2DH flow simulations was 2 meters wide by 1.21 meters high, discretized vertically into 150 uniform grid cells. Simulations were run using a total of 500 one-hour stress time steps. Time-variable input temperatures for the upper model boundary (representing the temperature at the streambed surface) were drawn from the water column thermistor.

Input temperatures for the lower model boundary were drawn from the lowermost streambed thermistor. For model calibration, two observation points were positioned in the model domain coincident with the vertical placement of the middle and upper streambed thermistors. Variable heads for each time step were also established at the top and bottom boundaries through linear extrapolation of point measurements of head collected in the field.

Table 2 presents a summary of the sediment properties and heat constants used for the VS2DH simulations. Temperature-related parameter values were drawn from published literature and refined through model calibration (Stonestrom and Constantz, 2003; Healy and Ronan, 1996). Initial condition values for sediment hydraulic properties were drawn from field observations and the CHIT results. They were then also refined through calibration.

Table 2. Sediment property and heat constant assumptions - VS2DH simulations.

Property	Value
Porosity (Φ)	0.25
Heat Capacity of water (C_w)	$4.18x10^6$ J/m^3 °C
Heat capacity of dry solids (C_s)	$1.2x10^6$ J/m^3 °C
Thermal Conductivity (K_T)	1.8 W/m^3 °C
Thermal dispersivity constants	0.01 m
Anisotropy ratio (K_V/K_H)	0.2

Model Calibration and Verification

The VS2DH model was calibrated using an inverse trial and error method until a mathematical best-fit was realized between the modeled and measured temperatures for the two mid-depth observation points. Model calibration was conducted using a 20.8 day period of temperature record collected between 8/9/2009 and 8/29/2009. Best-fit was determined by calculating the root mean square (RMS) error between simulated and measured temperatures for the final 10.8 days (~260 hours) of the simulation run. Calibrating to the second half of the simulation time period minimized the potential for bias introduced by initial condition affects occurring during early time-step model iterations.

Once a best-fit simulation was obtained, the model was re-run (without further adjustment to the input parameters) using a 20.8 day period of temperature record collected later in the summer (8/29/2009 to 9/19/2009). This simulation served as a verification of the model using an independent data set. The RMS error for the two observation points was calculated using the final 10.8 days of the verification run.

Water Quality Sampling

In late August, approximately 3 weeks after installation (to allow equilibration), groundwater quality samples were collected from all piezometers that exhibited a positive vertical hydraulic gradient (i.e., gaining condition). A second sampling event was conducted in late September 2009.[4] Due to the similarity of the piezometer water quality results between the first and second sampling events, a third sampling event scheduled for late October was canceled to reduce project costs.

Prior to groundwater sample collection, surface water present adjacent to the entry-point of the piezometer into the streambed was pumped through a closed-atmosphere flow cell, using a

---

[4] Piezometer AGT423 was dropped as a sampling station during the late September monitoring event, due to the similarity of the first round water quality results with the co-located AGT415 piezometer. AGT415 and AGT423 were located approximately 1-2 meters apart, at a similar depth. AGT423 continued to be monitored for hydraulic gradient and thermal condition throughout the remainder of the study period.

peristaltic pump. Initial monitoring of surface water provided a benchmark water quality condition to assist in tracking annular leakage during the groundwater purge and sample process. The flow cell was instrumented with calibrated probes to measure pH, specific conductance (SC), dissolved oxygen (DO), and oxidation/reduction potential (ORP).[5]

After measurement of surface water field parameters, the sampling line was then suspended down the interior of the piezometer so that the intake was positioned adjacent to the mid-point of the open interval. The piezometer was then purged at a flow rate of ≤0.5 L/min.

Equilibration with subsurface conditions was assumed when field parameters stabilized in the flow cell, with a particular focus on the DO concentration. Confirmation measurements of field-sensitive parameters [ferrous iron (Fe^{2+}) and DO] were collected at the end of the purge period. These measurements were made by detaching the pump line from the flow cell and collecting a sub-sample for analysis using a zeroed field photometer operated following manufacturer's guidelines (Pitz, 2009a).

All groundwater samples were field filtered after completion of purge using a new, clean, 0.45 micron cartridge filter. The first 50 to 100 ml of filtrate was discarded to allow pre-soaking of the filter. Samples were collected in clean, laboratory supplied containers (pre-preserved as necessary), then placed on ice immediately after collection.

Sample coolers were transported to the Ecology Manchester Environmental Laboratory (MEL) via overnight shipment at the end of each sample day. All groundwater samples were submitted for analysis of chloride, total dissolved solids (TDS), dissolved organic carbon (DOC), sulfate (SO_4), sodium (Na), ammonium-N (NH_4-N)[6], nitrate-N (NO_3-N), nitrite-N (NO_2-N), orthophosphate-P (OP), and total dissolved phosphorus (TDP).

To aid data interpretation, and evaluate similarities in chemical profile between groundwater and surface water, four surface water stations were also sampled during both water quality events. These stations include samples from:

- the lined lagoon (LA),
- the far eastern corner of the wetland (WT),
- the bank seep located down slope of the wetland (SP), and
- the main channel of the Touchet River (TR) (Figure 9).

Samples collected from these stations were acquired using a peristaltic pump after measurement of field parameters in a flow cell. All surface water samples were also field filtered at 0.45 microns and submitted for analysis of all parameters listed above.

Plans to conduct higher-resolution vertical profiling of water quality conditions immediately below the groundwater/surface water interface (to characterize nutrient attenuation activity; Pitz 2009a, b) were not possible due to the large particle size of the streambed sediments in the area of interest.

In addition to the conventional water quality parameters described above, one-time samples were collected for analysis of 93 unique base/neutral/acid (BNA) semi-volatile organic compounds from four of the monitoring stations (the wetland, the seep, and piezometers AGT414 and AGT415; Figure 9).

---

[5] Temperature measurements collected during sampling are not reported due to the potential bias introduced by pump friction and atmospheric warming of the flow cell chamber. The thermistor data described elsewhere in this report provide the most accurate measure of groundwater and surface water temperatures for this study.

[6] Water quality results reported by the laboratory as ammonia-N are presented in the ionic form ammonium-N in this report. Ionized ammonium is the predominant inorganic nitrogen form under the observed groundwater pH and temperature conditions (Hem, 1992).

Analysis for BNA semi-volatiles was conducted to help evaluate water source correlations between monitoring stations, and to assess the transport of anthropogenic contaminants to the river. A fifth BNA semi-volatile sample from the AGT424 station was lost during shipment to the MEL. Target compounds for BNA analysis are listed in Pitz (2009a).

Additional details regarding field monitoring procedures (including quality assurance and instrument calibration steps) and laboratory analysis methods associated with water quality sampling are described in Pitz (2009a). Project quality assurance results are presented in Appendix C.

Results and Discussion

Hydraulic Conductivity Testing

Table B-1 and Figure B-1 (Appendix B) summarize the CHIT input parameters and resulting hydraulic conductivity estimates for the three tested piezometers. The hydraulic conductivity estimates range between 2.5×10^{-4} and 3.8×10^{-4} m/sec.

Although the test equations assume that the sediment hydraulic conductivity is isotropic, in layered alluvial deposits like those encountered in the Touchet River, it is likely that the test results most closely represent the horizontal permeability (K_H). The brief development of the piezometers prior to testing (resulting in the removal of fine particles in the near vicinity of the open interval) may have biased the K estimates somewhat high in comparison to in-situ conditions.

Vertical Hydraulic Gradient Estimates

Table B-2 (Appendix B) summarizes the estimates of the vertical hydraulic gradient at each piezometer. Two piezometers (AGT417, AGT420) showed consistently losing conditions throughout the monitoring period, while one piezometer (AGT419) was installed in sediments of such low permeability that reliable head comparisons were not possible (Figure 9). The remaining piezometers that showed gaining conditions had vertical hydraulic gradient values ranging between 0.001 and 0.061.[7]

Gradient conditions at each station were generally consistent between measurement rounds. While variable patterns of gain and loss through a streambed are common in complex fluvial environments, the large upward gradients observed in the AGT415 and AGT423 piezometers (0.03-0.06) are likely directly related to recharge from the wetland. In this case, it is assumed that the wetland acts as a permanent elevated reservoir that induces plug-like flow of groundwater to the river.

Thermal Monitoring

Figure 11 (AGT423) and Figure 12 (AGT424) illustrate the results of the thermal monitoring for the period between early August and late October. Both thermographs exhibit vertical temperature distributions throughout the monitoring period consistent with those expected for a gaining stream; i.e., temperatures in the lowermost portions of the streambed are highly dampened relative to significant diurnal and seasonal temperature variation in the overlying water column (see Stonestrom and Constantz, 2003, page 2).

This pattern, which is particularly strong in the AGT423 piezometer just offshore of the wetland, implies a significant rate of advective groundwater flow upward into the stream for the entire study period. The potential for groundwater inflow is further supported by the point estimates of the vertical hydraulic gradient also shown on the thermographs. These results are consistent with the stream/porewater temperature differences observed during the thermal reconnaissance (Figure 7).

---

[7] Field observations suggest that the hydraulic gradient values for the AGT416 piezometer may be biased due to annular leakage of surface water.

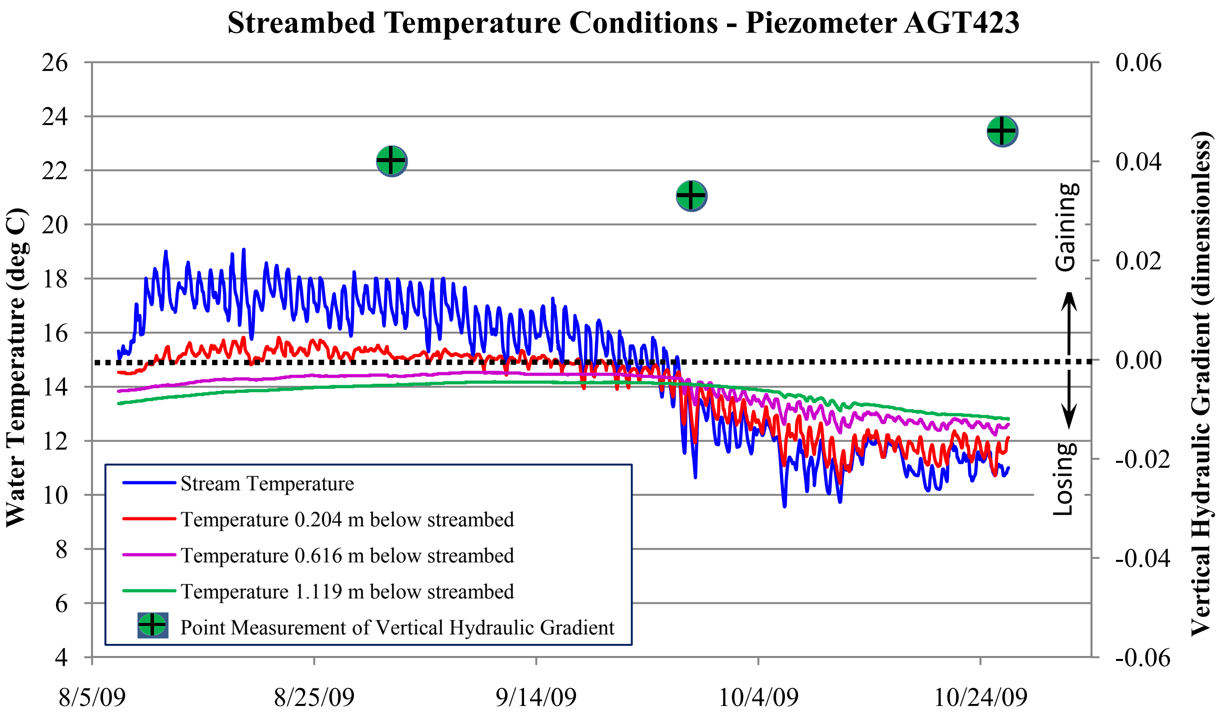


Figure 11. Streambed thermograph and hydraulic gradient measurements - Piezometer AGT423.

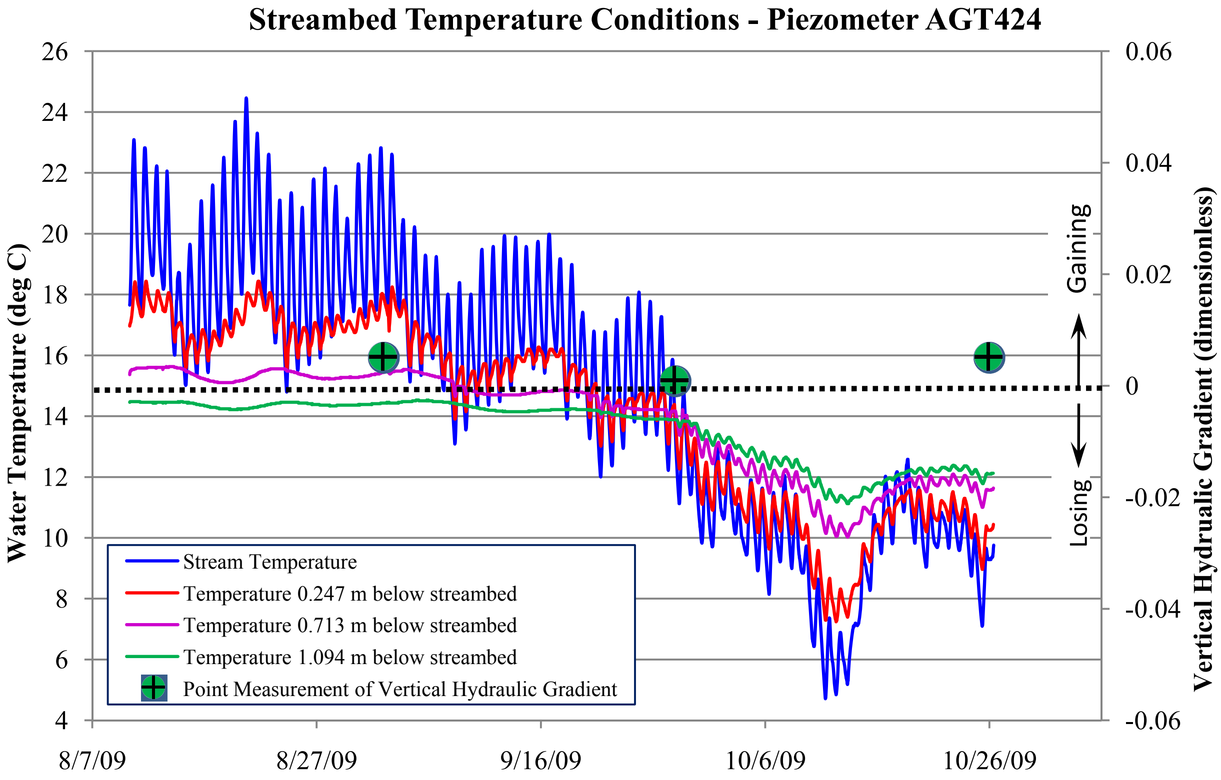


Figure 12. Streambed thermograph and hydraulic gradient measurements - Piezometer AGT424.

The thermistors at piezometer AGT423 showed a notably narrower overall temperature range in comparison to the AGT424 station. This is assumed to be related to the locations of the two piezometers with respect to the river channel. Piezometer AGT424 was located within the main river channel, while piezometer AGT423 was located in a side channel fed by the shoreline seep. Temperatures of the seep discharge and side channel are probably more closely related to groundwater temperatures and are less likely to exhibit the wide diurnal and seasonal fluctuations observed within the main river channel.

Streambed temperatures were cooler than water column temperatures throughout the late summer. This pattern reversed in late September as stream temperatures dropped with the change in season. The temperature record for the lowermost thermistor in piezometer AGT423 (Figure 11) shows an overall temperature decrease but maintains a minimal diurnal response after this transition.

In contrast, the streambed temperature record for the AGT424 piezometer (Figure 12) begins to exhibit a dampened diurnal signal after the transition. This suggests a reduction in the rate of advective flow in the AGT424 area during and after late September.

Since the vertical hydraulic gradient at the AGT424 station did not decrease during this period, this in turn suggests a temperature-related reduction in the hydraulic conductivity of the streambed due to an increase in dynamic water viscosity (Healy and Ronan, 1996; Ronan et al., 1998). The diurnal streambed thermal response during this period may also be related to an increase in the rate of thermal conduction relative to advective flow.

Thermal Modeling

Figure 13 presents the results of the best-fit VS2DH modeling simulation for the AGT423 temperature record. The model predicts a vertical hydraulic conductivity (K_V) value for the streambed sediments of 6.0x10^{-5} m/sec (K_H = 3.0x10^{-4} m/sec at a 5:1 K_H/K_V anisotropy ratio). The RMS errors between the simulated and measured temperatures for the two observation

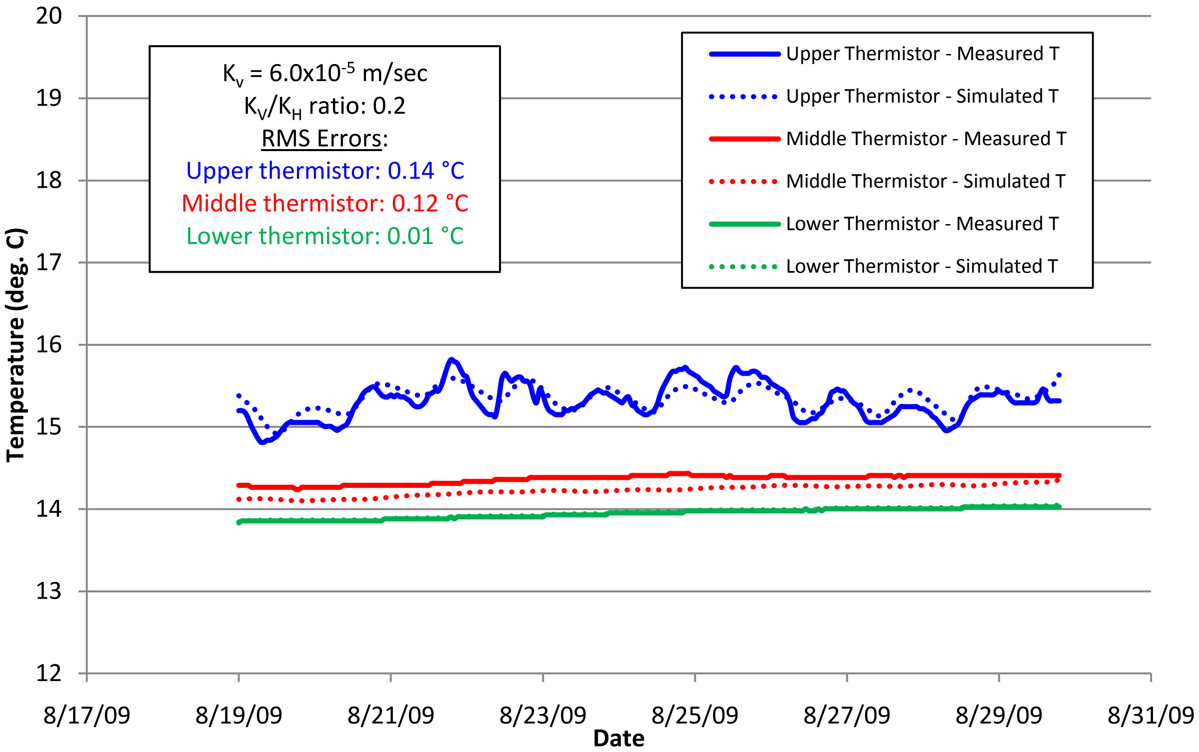


Figure 13. Best-fit measured vs. VS2DH model-simulated temperature - Piezometer AGT423.

points in the central portion of the model domain ranged between 0.12 and 0.14°C. These values are within the accuracy range of the thermistors used for measurement (±0.2°C).

Verification of the best-fit model simulation K_V estimate using an independent temperature record (8/29/09 to 9/19/09) resulted in RMS error values for the upper and middle streambed thermistors of 0.41 and 0.07°C, respectively.

The 3.0×10^{-4} m/sec K_H value estimated by thermal modeling falls within the conductivity estimate range derived from the CHIT (2.5×10^{-4} to 3.8×10^{-4} m/sec). The model estimated K_V value (6.0×10^{-5} m/sec) falls within the range of K_V estimates reported by Leek (2006) for sediment depths equivalent to the screen position for the AGT423 piezometer (1.9×10^{-5} to 2.2×10^{-3} m/sec, approximately 10-11 km upstream of the Waitsburg facility).

These results suggest the model estimates for vertical and horizontal hydraulic conductivity are reasonable values for use in groundwater flux calculations.

Water Quality

Table B-2 and Table B-3 (Appendix B) present the conventional-parameter water quality results for piezometer and surface water samples, respectively. Table B-4 presents the BNA semi-volatile detections for four selected stations.

Figures B-2 through B-14 (Appendix B) illustrate the relative concentration distribution for each of the study water quality parameters for the late September sampling event. Groundwater concentration results and spatial distribution between the first and second sampling events are closely similar; differences between the two rounds were typically within the target measurement quality objectives outlined in the project work plan (Pitz, 2009a). Results for the seep, wetland, and lagoon samples showed higher variability between rounds.

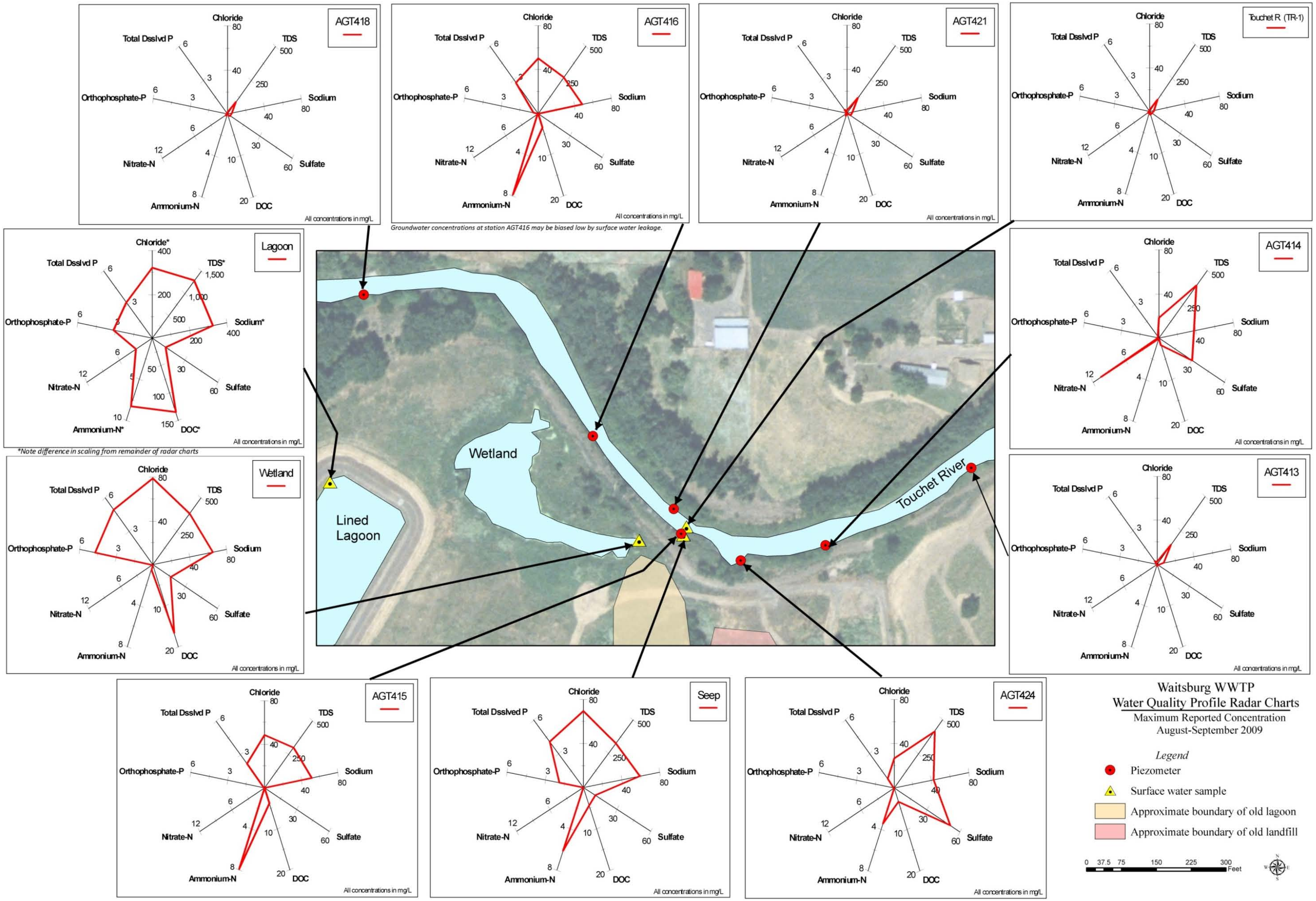
Figure 14 summarizes the water quality information for each sampled station in radar chart form to allow comparisons of overall chemical profile between stations.[8] Key observations about the water quality data results include:

- Piezometers located hydraulically *away from* the eastern portion of the property shoreline (AGT413, AGT418, and AGT421) show overall good to excellent water quality, indicative of uncontaminated regional or background condition. Groundwater in these areas tends to be suboxic to oxic, with low concentrations of general chemistry parameters (SC, chloride, TDS, Na, and SO_4). Nitrogen concentrations are typically low to non-detect at these stations; background TDP concentrations average ≤ 0.3 mg/L, mostly as organic P. Dissolved organic carbon is typically low to non-detect (Figure 14).
- Stations located along the portion of the shoreline adjacent to the landfill, the former lagoon, and the wetland (AGT415, AGT416[9], AGT424, and the shoreline seep 'SP') show very poor water quality, indicative of anthropogenic contamination. All general chemistry parameter concentrations at these stations are significantly elevated with respect to background. The redox condition at these stations is generally strongly anoxic, as indicated by elevated Fe^{2+}, low DO, large negative ORP values, and nitrogen occurring almost exclusively as NH_4-N. Dissolved

---

[8] Radar plots use the maximum concentration reported during the study for each parameter. Note that the radar chart scaling for the lagoon (LA) results on Figure 14 is different from all the remaining radars to accommodate the high values reported for this location.

[9] Field observations of streambed sediment character, hydraulic head relationships, and field parameter conditions during purge suggest that the groundwater concentrations reported for the AGT416 piezometer may be biased low due to possible annular leakage of surface water during sample collection.



Groundwater concentrations at station AGT416 may be biased low by surface water leakage.

*Note difference in scaling from remainder of radar charts

Figure 14. Waitsburg Groundwater Study water quality radar charts.

This page is purposely left blank

NH_4-N groundwater concentrations reach above 7 mg/L adjacent to the wetland; TDP concentrations reach over 4 mg/L, mostly as organic P. DOC concentrations reach 3-4 mg/L.

- There are strong similarities in the overall water quality profile between the seep and the AGT415 and AGT416 piezometers (Figure 14). The more conservatively transported general chemistry parameters for these stations (chloride, TDS, sodium) match closely to the wetland samples, supporting the interpretation of a direct hydraulic connection between these stations. The wetland water column samples, however, exhibited notable differences in nutrient conditions (higher DOC concentrations, significantly lower nitrogen, and phosphorus largely in the inorganic form as OP). This suggests significant changes in nutrient condition are occurring between the wetland water column and the point of groundwater discharge to the river.
- The large increase in NH_4-N concentration between the wetland sample and the shoreline suggests decomposition and mineralization (ammonification) of organic material accumulated on the bottom of the wetland, followed by infiltration of ammonium-enriched water to the underlying groundwater system. The strongly reduced conditions observed in the piezometers offshore of the wetland presumably extend inland and prevent nitrification of the ammonium.
- The anoxic conditions also likely mobilize dissolved phosphorus (also from decomposition of organic material accumulated in the wetland) for transport into the hyporheic zone. Reducing conditions present between the wetland and the shoreline would prevent sorption or co-precipitation reactions of P with iron or manganese oxyhydroxides.
- Piezometer AGT424, located immediately north of the former landfill, exhibits poor water quality (elevated general chemistry and nutrient concentrations) indicative of anthropogenic contamination. The water quality profile for this station, however, suggests the possibility of a separate (or additional) source of contamination besides the wetland recharge. The concentration of sulfate (SO_4) is notably higher at this station then all remaining stations. Elevated SO_4 concentrations are commonly observed in groundwater in the vicinity of municipal landfills (Lee and Jones, 1991).
- Piezometer AGT414 exhibits a water quality profile somewhat unique from all other stations. Elevated concentrations of a number of general chemistry parameters relative to the background condition indicate an anthropogenic influence on water quality similar to the AGT424 site. In contrast to other impacted stations, however, the AGT414 piezometer showed oxic conditions and inorganic nitrogen occurring over 10 mg/L as NO_3-N.
- The combination of elevated NO_3-N and SO_4 and low concentrations of dissolved phosphorus suggests the possibility of different contaminant sources influencing water quality at the AGT414 location (for example, influence from both the landfill and infiltration from upgradient agricultural land use east or south of the landfill.)
- No evidence exists that leakage from the lined lagoon in the western portion of the property is reaching the river via groundwater inflow. Although piezometer AGT418 is located in the most likely position for intercepting groundwater flow from the lagoon area, and the lagoon water is highly concentrated, the water quality signature at the station reflects ‘background’ conditions.
- No evidence exists for groundwater transport of significant concentrations of BNA semi-volatile organic compounds from the treatment plant facility to the river in the vicinity of the wetland (Table B-4).

Estimates of Nutrient Loading to the Touchet River

To develop estimates of groundwater-borne nitrogen and phosphorus loads to the Touchet River from the Waitsburg WWTP facility, water quality data from study piezometers were integrated with estimates of groundwater flux using Equation 4:

$$F_{nutrient} = Q * C_{nutrient} \qquad (4)$$

where:

$F_{nutrient}$ = the mass flux of dissolved nutrient to the river via groundwater inflow (m/t)
Q = the groundwater discharge rate to the river (L^3/t)
$C_{nutrient}$ = the dissolved groundwater nutrient concentration (m/L^3)

where: m = mass

Methods, assumptions, and shortcomings for the development of the Q and $C_{nutrient}$ values are discussed in the sections below.

Groundwater Volume Discharge Estimates

Darcian Flow Analysis

Estimates of groundwater volume flux to the Touchet River were developed using Darcy's law (Equation 5):

$$Q = -KiA \qquad (5)$$

where:

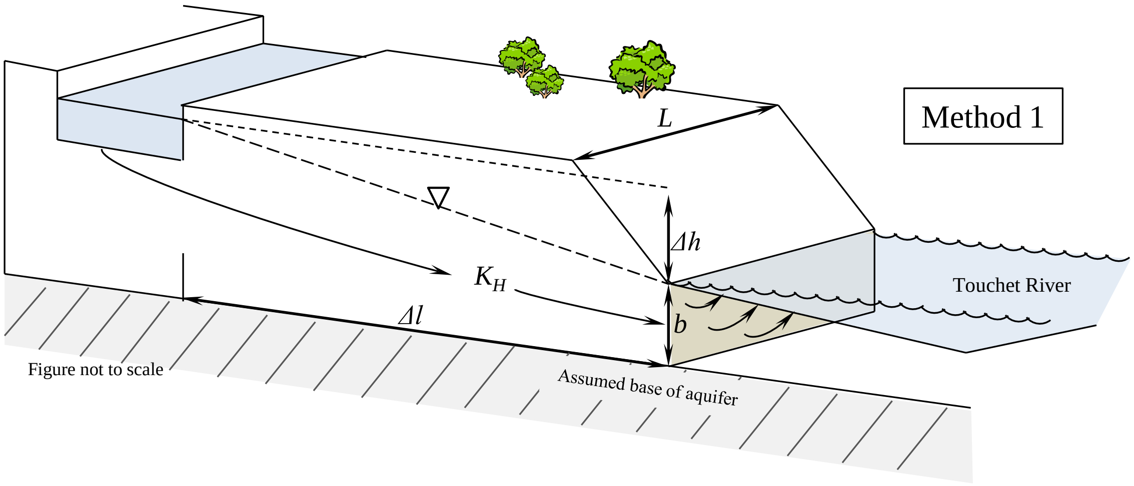
Q = the volumetric groundwater discharge rate to the river (L^3/t)
K = the estimated bulk hydraulic conductivity of the discharge zone sediments (L/t)
i = the estimated hydraulic gradient (dimensionless)
A = the estimated cross-sectional area of the groundwater discharge face (L^2)

Two independent conceptual models and methods were used to develop Darcian discharge estimates from the facility. Method 1 calculates the term Q_H for Equation 5 assuming horizontal groundwater flow through a vertical discharge cross-section located beneath the Touchet River shoreline. Method 2 calculates the term Q_V assuming vertical groundwater flow upward through a near-horizontal discharge cross-section positioned immediately offshore of the Touchet River shoreline. Figure 15 illustrates the conceptual models for each of these methods.

Both methods rely on simplified assumptions about aquifer geometry, sediment hydraulic properties, and groundwater discharge patterns. These assumptions include:

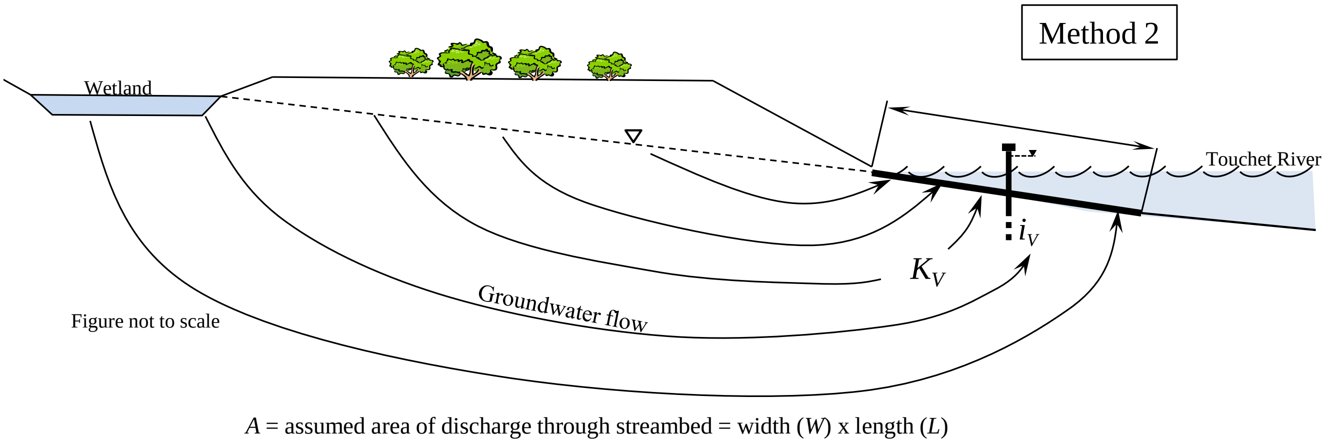
Method 1

- The bulk horizontal hydraulic conductivity of the groundwater discharge face is assumed to be equal to the model estimated K_H value derived from the thermal data collected from piezometer AGT415 (3.0×10^{-4} m/sec). This value is consistent with the results of the field hydraulic tests.
- Equation 2 is modified to solve for the horizontal hydraulic gradient (i_H). The Δl value is defined in this case as the average estimated horizontal separation between the wetland and the discharge face (estimated at 30.5 m). The Δh value is the measured elevation difference between the water surface of the wetland and the stage of the Touchet River at the AGT415 piezometer (Δ = 1.65 m) (Figure 15).
- The total length of the discharge face (L) used for calculating nutrient load to the Touchet River is assumed to be 168 m. This value is the approximate length of the shoreline extending from the northern corner of the wetland to the AGT424 piezometer.



Δh = elevation difference between wetland and river stage
Δl = average horizontal distance between wetland and river
i_H = horizontal hydraulic gradient = $\Delta h / \Delta l$
b = assumed aquifer thickness

L = assumed length of discharge zone
A = area of discharge = $b \times L$
K_H = average horizontal hydraulic conductivity
Q_H = groundwater discharge to river through discharge zone = $K_H \cdot i_H \cdot A$



A = assumed area of discharge through streambed = width (W) x length (L)
i_V = average measured vertical hydraulic gradient
K_V = estimated vertical hydraulic conductivity
Q_V = groundwater discharge through streambed = $K_V \cdot i_V \cdot A$

Figure 15. Conceptual models of groundwater flux and nutrient loading to the Touchet River.

This section is roughly coincident with both elevated dissolved nutrient conditions and a distinct streambed thermal signature that suggests focused groundwater upwelling associated with wetland infiltration (Figure 7; Figure 9). This river section is assumed to be the primary area for inflow of nutrient-enriched groundwater (the *impacted area*).

- The local groundwater system is assumed to be underlain by an impermeable base of bedrock. Due to the lack of subsurface geologic information, it is assumed that the saturated thickness of the aquifer at the plane of discharge (b) is 3 m.

Method 2

- The bulk vertical hydraulic conductivity of the groundwater discharge face is assumed to be equal to the K_V value derived from the thermal modeling ($6.0\text{x}10^{-5}$ m/sec). This value is consistent with K_V estimates reported from an extensive test effort conducted by Leek at a nearby location on the Touchet River (Leek, 2006).
- The average vertical hydraulic gradient across the discharge face (i_V) is assumed to equal 0.043 based on the average of field measurements collected from the AGT415 and AGT423 piezometers. The large variability in measured hydraulic gradient from piezometer to piezometer within the impacted area suggests that up-scaling these point measurements to the entire discharge face may be less accurate than the larger-scale gradient averaging approach used for Method 1.
- Large differences in vertical hydraulic gradient also suggest wide variations in sediment hydraulic conductivity along the shoreline. Sediments with significantly higher hydraulic conductivity are likely to exhibit a smaller pressure differential between upwelling groundwater and overlying surface water (i.e., there is less resistance to flow). On the basis of field observations of sediment character, this may be one explanation for the low vertical hydraulic gradients measured at piezometer AGT416.
- On the basis of the fact that groundwater discharge to surface water is typically focused near shore (Winter et al., 1998), the width of the groundwater discharge zone away from the river shoreline (W; Figure 15) is assumed to be 5 m. The length of the discharge face (L) is assumed to be the same as that described for Method 1 above.

Using the assumptions described above, the Darcian groundwater discharge rate to the Touchet River from the impacted area equals between $8.2\text{x}10^{-3}$ m^3/sec (Table 3, “base case” scenario) and $2.2\text{x}10^{-3}$ m^3/sec (Table 4, “base case” scenario).

For comparison, the facility effluent discharge rate to the wetland during the August-September 2009 period averaged approximately $5.0\text{x}10^{-3}$ m^3/sec (WPLCS, 2010), a value in close hydraulic balance to the estimated range of groundwater discharge.[10] Note that the groundwater discharge rate may account for both infiltration losses from the wetland and regional groundwater flow towards the river in this area.

Darcian Discharge Estimate Sensitivity Analysis

The greatest sources of uncertainty in the Darcian discharge estimates include the following factors:

- the assumed thickness of the saturated zone (b) in Method 1,

---

[10] Evaporative loss from the wetland during the summer is a negligible component of the volume balance. This assumes an average August pan evaporation rate of 0.006 m/day (Western Regional Climate Center Data – Whitman Mission station, Walla Walla, period of record 1962-2005; Class A pan evaporation value multiplied by a factor of 0.75 to accommodate for above-ground pan effects, per WRCC recommendations). Using an estimated wetland surface area of 4227 m^2, the average evaporation rate from the wetland is estimated at $2.7\text{x}10^{-4}$ m^3/sec.

Table 3. Waitsburg WWTP groundwater Darcian discharge estimates – Method 1.

	Elevation difference between wetland and river stage (m)	Average horizontal distance between wetland and river (m)	Horizontal hydraulic gradient (m/m)	Assumed aquifer thickness (m)	Assumed length of discharge zone (m)	Area of discharge (m^2)	Average horizontal hydraulic conductivity of discharge zone sediments (m/sec)	Groundwater discharge to river through discharge zone (m^3/sec)
	Δh	Δl	i_H	b	L	**A**	K_H	Q_H
Base case	1.65	30.5	0.054	3	168	504	3.0E-04	8.2E-03
Increase b by 3X				9		1512	3.0E-04	2.4E-02
Increase K_H by 5X				3		504	1.5E-03	4.1E-02

Refer to Figure 15 for explanation of terms.

Table 4. Waitsburg WWTP groundwater Darcian discharge estimates – Method 2.

	Assumed width of discharge zone (m)	Assumed length of discharge zone (m)	Area of discharge zone (m^2)	Average measured vertical hydraulic gradient (m/m)	Estimated vertical hydraulic conductivity of discharge zone sediments (m/sec)	Groundwater discharge to river through discharge zone (m^3/sec)
	W	L	**A**	i_V	K_V	Q_V
Base case	5	168	840	0.043	6.0E-05	2.2E-03
Increase K_V by 5X	5	168	840	0.043	3.0E-04	1.1E-02

Refer to Figure 15 for explanation of terms.

- the assumed bulk hydraulic conductivity of the discharge zone (K_H) in Method 1, and
- the assumed bulk hydraulic conductivity of the discharge zone (K_V) in Method 2.

To determine the sensitivity of the discharge estimates to these factors, the b, K_H, and K_V terms were increased by factors considered reasonable upper-limit uncertainty boundaries for these parameters (Table 3 and Table 4). The estimated groundwater discharge upper range predicted with these adjustments becomes $1.1\text{x}10^{-2}$ m^3/sec (Method 2) to $4.1\text{x}10^{-2}$ m^3/sec (Method 1).

Chloride Mass Balance Discharge Analysis

As a secondary check on the Darcian discharge estimates presented above, data collected during a concurrent surface water monitoring program (Tarbutton, 2009) were used to estimate groundwater discharge using a simple mass balance approach. During the summer of 2009, chloride concentrations and stream discharge rates were measured at two stations in the vicinity of the WWTP facility: 32TOU-43.5 (upstream) and 32TOU-43.0 (downstream) (Figure 9). These stations were monitored during both the morning and afternoon of 8/25/2009.

Assuming that chloride acts as a conservative tracer, Equation 6 can be used to calculate a mass balance between the upstream and downstream surface water stations:

$$Q_D C_D = Q_U C_U - Q_L C_L + Q_{GW} C_{GW} \qquad (6)$$

where:

Q_D = the stream discharge rate at the downstream station (L^3/t)
C_D = the chloride concentration at the downstream station (m/L^3)
Q_U = the stream discharge rate at the upstream station (L^3/t)
C_U = the chloride concentration at the upstream station (m/L^3)
Q_L = the rate of loss of surface water through the streambed (L^3/t)
C_L = the chloride concentration of the surface water lost through the streambed (m/L^3)
Q_{GW} = the rate of groundwater inflow between the upstream and downstream surface stations (L^3/t)
C_{GW} = the chloride concentration of the groundwater inflow (m/L^3)

Rearranging Equation 6 to solve for the rate of groundwater inflow between the two surface water stations yields Equation 7:

$$Q_{GW} = \frac{Q_D C_D - Q_U C_U + Q_L C_L}{C_{GW}} \qquad (7)$$

The Q_L and C_L terms are included to account for the loss of surface water, presumably through the streambed, in the case where: (Q_U-Q_D) is > 0 (otherwise Q_L is assumed = 0). The need for these terms is supported by hydraulic gradient measurements collected at several stations in the downstream half of the reach of interest that indicated a losing condition (AGT417 and AGT420). In cases where (Q_U-Q_D) > 0, the C_L term was assumed to be the average of the up- and downstream surface water chloride concentrations.

Two different scenarios were used for setting the average groundwater concentration of chloride entering the river (C_{GW}). In the first scenario, all of the groundwater inflow between the upstream and downstream station is assumed to enter from the impacted area. The C_{GW} in this case is assumed to be equal to 33 mg/L chloride, the average of the late August-early September chloride results from piezometers AGT415, AGT416, and AGT424.

In the second case, the C_{GW} term is assumed to be equal to the average chloride concentration reported for all gaining piezometers for the same time period (20 mg/L).

Table 5 summarizes the Q_{GW} values predicted by the mass balance analysis. The mass-balance-derived Q_{GW} estimates range between $5.6\text{x}10^{-3}$ to $1.5\text{x}10^{-2}$ m^3/sec. These values lie in the

Table 5. Groundwater inflow rate predicted by chloride mass balance (unpublished surface water data from Tarbutton, 2009).

	Q_U	C_U	Q_L	C_L	Q_D	C_D	C_{GW}	Predicted Q_{GW}
	m^3/sec	mg/L	m^3/sec	mg/L	m^3/sec	mg/L	mg/L	m^3/sec
8/25/09 AM	1.44	1.72	0.14	1.83	1.30	1.94	33	9.2E-03
8/25/09 AM	1.44	1.72	0.14	1.83	1.30	1.94	20	1.5E-02
8/25/09 PM	1.33	1.66	0.00	NA	1.33	1.80	33	5.6E-03
8/25/09 PM	1.33	1.66	0.00	NA	1.33	1.80	20	9.3E-03

See Equation 7 for explanation of terms

midrange of the discharge estimates predicted by Darcian techniques (2.3×10^{-3} to 4.1×10^{-2} m^3/sec).

Nutrient Loading Estimates

Using Equation 4, the lower- and upper-bound Darcian-predicted groundwater discharge rates presented in Table 3 and Table 4 were integrated with measured nutrient concentrations from the AGT415 and AGT416 piezometers (the piezometers immediately downgradient of the wetland). The maximum reported concentration for each of four target nutrient forms (NH_4-N, NO_3-N, TDP, and OP) were used as the $C_{nutrient}$ value in Equation 4 for the loading calculations.

Table 6 presents the range of nutrient loads estimated from the impacted area (“no attenuation” scenarios). The estimated daily dissolved inorganic nitrogen flux (as NH_4-N) from the impacted area ranges between ~2 and 28 kg/day. The estimated daily phosphorus flux (as TDP) ranges between ~1 and 10 kg/day.

For comparison, substituting the Darcian-derived Q values in Table 6 with the Q_{GW} values derived by the chloride mass balance (Table 5), the predicted daily nitrogen flux narrows to between ~4 to 10 kg/day (as NH_4-N) and the phosphorus load narrows to between ~1 to 4 kg/day (as TDP). It is interesting to note that the estimated average total inorganic nitrogen load to the wetland by treatment plant effluent discharge was approximately 5 kg/day for the August-September 2009 timeframe (as NO_3+NH_4)(WPLCS, 2010).

Integrating the maximum measured seep nutrient concentrations with the estimated seep discharge rate indicates the seep delivers a small additional daily mass of NH_4-N (0.3 kg/day) and TDP (0.2 kg/day) to the river.

Nutrient Attenuation

A complex suite of biogeochemical processes can be active in the sediments and porewater located immediately beneath the groundwater/surface water interface. These processes can produce strong vertical concentration gradients in upwelling groundwater over very short distances and, under the right conditions, can considerably alter the chemical character of groundwater discharging to surface water (Winter et al., 1998; Ford, 2005; Pitz, 2009b).

Relevant to the current study, dissolved nitrogen and phosphorus concentrations can be decreased or *attenuated* prior to discharge by a series of microbially-mediated redox reactions (Cox et al., 2005; Chambers and Odum, 1990; Jones and Mulholland, 2000; Duff et al., 1997; Bőhlke et al., 2006; Sheibley et al., 2003a, b). For example, Sheibley and his co-authors demonstrated that nitrogen concentrations in upwelling groundwater can be rapidly converted and reduced by coupled, temperature-sensitive, nitrification-denitrification processes active at the boundary between anoxic groundwater and oxic surface water.

Similar concentration reductions can occur for dissolved P as upwelling groundwater encounters an oxidizing environment. Iron and manganese oxyhydroxide precipitates formed at

Table 6. Waitsburg WWTP groundwater loading calculations.

	Groundwater discharge to river (m^3/sec))$^{(A)}$	Estimated nutrient concentration of groundwater discharge (mg/L $^{(B)}$	Estimated mass flux of nutrient discharged to the river via groundwater inflow (kg/day)	Estimated mass flux of nutrient discharged to the river via groundwater inflow (lb/day)
	Q	$C_{nutrient}$	$F_{nutrient}$	$F_{nutrient}$
Nitrogen (as NH_4)		C_{NH4}	F_{NH4}	F_{NH4}
Low Q – no attenuation	2.2E-03	7.91	1.5	3.3
Low Q – 50% attenuation	2.2E-03	3.96	0.7	1.6
High Q – no attenuation	4.1E-02	7.91	28.0	61.8
High Q - 50% attenuation	4.1E-02	3.96	14.0	30.9
Nitrogen (as NO_3)		C_{NO3}	F_{NO3}	F_{NO3}
Low Q – no attenuation	2.2E-03	0.044	0.0	0.0
Low Q – 50% attenuation	2.2E-03	0.022	0.0	0.0
High Q – no attenuation	4.1E-02	0.044	0.2	0.3
High Q - 50% attenuation	4.1E-02	0.022	0.1	0.2
Phosphorus (as TDP)		C_{TDP}	F_{TDP}	F_{TDP}
Low Q – no attenuation	2.2E-03	2.77	0.5	1.1
Low Q – 50% attenuation	2.2E-03	1.39	0.3	0.6
High Q – no attenuation	4.1E-02	2.77	9.8	21.6
High Q - 50% attenuation	4.1E-02	1.39	4.9	10.9
Phosphorus (as OP)		C_{OP}	F_{OP}	F_{OP}
Low Q – no attenuation	2.2E-03	0.37	0.1	0.2
Low Q – 50% attenuation	2.2E-03	0.19	0.0	0.1
High Q – no attenuation	4.1E-02	0.37	1.3	2.9
High Q - 50% attenuation	4.1E-02	0.19	0.7	1.5

(A)- Darcian-derived discharge values from Table 3 and Table 4.

(B) –maximum reported concentration

this boundary can rapidly scavenge dissolved phosphorus via sorption reactions prior to discharge (Pitz, 2009b).

Although the study piezometers located in the impacted area exhibited strongly reducing conditions within a meter of the point of discharge, the redox-sensitive conversion reactions and uptake processes described above can be most active in the final centimeters of the flowpath (i.e., vertically above the sampled horizon). Due to the very coarse-grained character of the streambed sediments present in the impacted area, the amount of nutrient processing actually occurring in the uppermost portion of the sediment column could not be quantified in the field.

To evaluate the potential sensitivity of the nutrient-loading estimates to hyporheic zone attenuation, the $C_{nutrient}$ concentrations used in Equation 4 were reduced by 50%, and the estimates were recalculated. Table 6 presents the resulting load predictions ("50% attenuation" scenarios).

Each percent reduction in assumed $C_{nutrient}$ concentration results in an equivalent percent reduction in load. If attenuation affects are incorporated into the estimates, the daily nitrogen load (as NH_4-N) decreases to between 0.8 to 14 kg/day, and the daily TDP load decreases to between 0.3 to 5 kg/day.

Several observations suggest that the actual attenuation capacity of the interface zone in the impacted area may be relatively limited:

- The large average grain-size observed at the sediment surface indicates the potential for higher than normal groundwater velocities and reduced particle-surface area in the uppermost portions of the sediment column. These factors can limit both residence time and available reaction sites necessary for attenuation processes to proceed fully (Puckett et al., 2008).
- The very high nutrient concentrations and high overall organic content of the discharging water may sustain anoxic conditions all the way to the point of discharge. This can prevent the redox-driven conversions or capture of dissolved nutrients observed in some environments. In fact, the seep discharge did not exhibit a significant level of reduction in dissolved nutrient concentration despite the fact that the seep samples were collected after contact with the atmosphere (i.e., after redox-driven attenuation reactions could initiate).
- Most published research on nutrient attenuation at the groundwater/surface water interface has described sites with upwelling groundwater nutrient concentrations significantly lower than those observed during this study. The elevated N and P concentrations measured in the piezometers at the Waitsburg facility may exceed or exhaust the attenuation capacity of the upper sediments, particularly after long-term loading.
- Similar to observations pertaining to streambed permeability, a number of authors have noted the very high spatial variability in hyporheic zone attenuation capacity (Puckett, et al., 2008). Some areas of the streambed offshore of the wetland may more completely convert or capture dissolved nutrients than others.

Summary and Conclusions

This study was undertaken to estimate the baseflow-season groundwater nutrient load delivered from the Waitsburg WWTP property to the Touchet River, via groundwater transport. Field measurements of groundwater quality just prior to discharge were integrated with estimates of groundwater flux to the river to approximate the daily loading rate for both nitrogen and phosphorus.

Background groundwater inflow to the river is of generally good quality, with low dissolved nutrient content. Water quality and thermal monitoring data indicate that an approximately 150-200 meter long section of the river offshore of the treatment plant property is, however, receiving elevated nutrient inputs by groundwater inflow.

The groundwater quality within this impacted area showed a significant degree of human-related contamination, probably influenced by a mixture of onshore sources that include the infiltration wetland, a buried former lagoon, and a buried landfill. One monitoring location closely upstream of the impacted area exhibited an elevated nitrate-N (NO_3-N) condition in discharging groundwater, but the extent of shoreline within the study area receiving elevated nitrate appears to be limited.

The estimated daily groundwater input to the river from the impacted area during the baseflow season ranges between 1 to 28 kg/day for dissolved inorganic nitrogen, largely as ammonium-N (NH_4-N). The estimated daily baseflow-season groundwater input for total dissolved phosphorus ranges between <1 to 10 kg/day, largely as organic phosphorus. These estimates were developed using a number of assumptions about aquifer geometry, sediment hydraulic properties, nutrient transport, and groundwater flow patterns in the vicinity of the wetland.

Recommendations

To determine if the estimated groundwater nutrient load entering the Touchet River from the Waitsburg WWTP facility is adversely impacting water quality and ecosystem function, the findings of this report will need to be integrated with the surface water information collected by Ecology during the summer 2009 (Tarbutton, 2009).

If more precise estimates of groundwater nutrient loading than provided in this report are determined to be critical to future TMDL modeling efforts, the following additional field investigations could help to narrow uncertainty in the estimated groundwater loading rates:

- Install monitoring wells between the wetland and the shoreline to determine the true saturated thickness of the aquifer and improve estimates of bulk hydraulic conductivity within the impacted area.
- Consider an alternative field method such as freeze-coring to collect higher resolution data on dissolved nutrient attenuation conditions in the uppermost portion of the hyporheic zone sediment column.

References

Anderson Perry and Associates (APA), 1999. City of Waitsburg Wastewater Facilities Plan – Final. December 1999.

Bilhimer, D., and Stohr, A., 2009. Standard Operating Procedures for continuous monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature. Washington State Department of Ecology Environmental Assessment Program SOP #EAP044, version 2.3; 30 p. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_044Cont_Temp_Monit_TMDL.pdf.

Bőhlke, J.K., Smith, R.L., and Miller, D.N., 2006. Ammonium transport and reaction in contaminated groundwater: application of isotope tracers and isotope fractionation studies, Water Resources Research, Vol. 42, W05411, 19 p.

Cardenas, M.B., and Zlotnik, V.A., 2003. A simple constant-head injection test for streambed hydraulic conductivity estimation. Ground Water, Vol. 41, No. 6, p. 867-871, *with erratum*: Ground Water, Vol. 45, No. 2, p. 125 (2007).

Chambers, R.M. and Odum, W.E., 1990. Porewater oxidation, dissolved phosphate and the iron curtain – Iron-phosphorus relations in tidal freshwater marshes. Biogeochemistry, v. 10, p. 37-52.

Conant, B. Jr., 2004. Delineating and quantifying ground water discharge zones using streambed temperatures. Ground Water, Vol. 42, No. 2, p. 243-257.

Cox, S.E., Simonds, F.W., Huffman, R.L., Doremus, L., Defawe, R.M., 2005. Ground water/ surface water interactions and quality of discharging ground-water in streams of the Lower Nooksack River Basin, Whatcom County, Washington. U.S. Geological Survey Scientific Investigations Report 2005-5255, 46 p. http://pubs.water.usgs.gov/sir2005-5255/.

Duff, J.H., Triska, F.J., Jackman, A.P., and LaBaugh, J.W., 1997. The influence of streambed sediments on the solute chemistry of ground-water discharge in the upper Shingobee River, in Hydrological and Biogeochemical Research in the Shingobee River Headwaters Area, North-central Minnesota, U.S. Geological Survey Water Resources Investigations Report 96-4215, p. 143-153.

Ecology, 2005. City of Waitsburg National Pollutant Discharge Elimination System Waste Discharge Permit No. WA-004555-1 and Fact Sheet Addendum. Issuance Date: March 24, 2005. Washington State Department of Ecology, Eastern Regional Office, Spokane, WA.

Ford, R.G., 2005. The Impact of Ground-water/Surface-water Interactions on Contaminant Transport with Application to an Arsenic Contaminated Site. U.S. EPA Environmental Research Brief, National Risk Management Research Laboratory, Ada, OK. EPA 600-S-05-002, 22 p. www.epa.gov/ada/download/briefs/epa_600_s05_002.pdf.

Freeze, R.A., and Cherry, J.A., 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 p.

Gray and Osborne, Inc., 1981. Waitsburg, Washington Wastewater Treatment Facilities Planning: Groundwater Study Report, Sept. 30, 1981. Project No. 73042. 39 p.

Healy, R. W., 1990. Simulation of solute transport in variably saturated porous media with supplemental information on modifications to the U.S. Geological Survey's computer program VS2D. U.S. Geological Survey Water-Resources Investigations Report 90-4025, 125 p.

Healy, R. W., and Ronan, A.D., 1996. Documentation of computer program VS2DH for simulation of energy transport in variably saturated porous media – modification of the U.S. Geological Survey's computer program VS2DT. U.S. Geological Survey Water Resources Investigations Report 96-4230, 36 p.

Heffner, M., 1986. Waitsburg Sewage Treatment Plant Class II Inspection, September 24-25, 1985. Washington State Department of Ecology, Publication No. 86-e14. 15 p. www.ecy.wa.gov/biblio/86e14.html.

Hem, J.D., 1992. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition. U.S. Geological Survey Water Supply Paper 2254, 272 p.

Hsieh, P.A., Wingle, W., and Healy, R.W., 2000. VS2DI – A graphical software package for simulating fluid flow and solute or energy transport in variably saturated porous media. U.S. Geological Survey Water Resources Investigation Report 9, 9-4130, 20 p. wwwbrr.cr.usgs.gov/projects/GW_Unsat/vs2di1.2/vs2di.pdf

Jones, J.B. and Mulholland, P.J., (Editors), 2000. Streams and Ground Waters, Academic Press. 425 p.

Joy, J., 1986a. Waitsburg Wastewater Treatment Plant Receiving Water Study. Memo to Carl Nuechterlein, Washington State Department of Ecology, Publication No. 86-e24. 28 p. www.ecy.wa.gov/biblio/86e24.html

Joy, J., Pelletier, G., and Baldwin, K., 2007. Walla Walla River Basin pH and Dissolved Oxygen Total Maximum Daily Load. Washington State Department of Ecology, Publication No. 07-03-010. www.ecy.wa.gov/biblio/0703010.html.

Kahle, S.C., Olsen, T.D., and Morgan, D.S., 2009, Geologic Setting and Hydrogeologic Units of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho: U.S. Geological Survey, Scientific Investigations Map 3088, 1 sheet. http://pubs.usgs.gov/sim/3088/

Katsel, D., 2009. Personal communication. City of Waitsburg Public Works Director, Waitsburg, WA.

Koch, R., 2010. Personal communication. Washington State Department of Ecology permit engineer, Spokane, WA.

Lappala, E.G., Healy, R.W., and Weeks, E.P., 1987. Documentation of computer program VS2D to solve the equations of fluid flow in variably saturated porous media. U.S. Geological Survey Water Resources Investigation Report 83-4099, 184 p.

Lee, G.F., and Jones, R.A., 1991. Groundwater pollution by municipal landfills: leachate composition, detection and its water quality significance. Proceedings of the Fifth National Outdoor Action Conference, National Groundwater Association, Las Vegas, Nevada, May 13-16, 1991, p. 257-271.

Leek, R., 2006. Heterogeneous characteristics of water movement through riverbed sediments of the Touchet River, southeastern Washington, USA. Master’s Thesis, Washington State University, Department of Biological Systems Engineering. 54 p.

Marti, P., 2005, Assessment of Surface Water and Groundwater Interchange in the Walla Walla River Watershed. Washington State Department of Ecology. Publication No. 05-03-020. 67 p. www.ecy.wa.gov/biblio/0503020.html.

MEL, 2006. Manchester Environmental Laboratory Quality Assurance Manual. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Office of Financial Management (OFM), State of Washington, 2007. Census 2000 results. www.ofm.wa.gov/census2000/default.asp.

Pitz, C.F., 2006. An Evaluation of a Piezometer-based Constant Head Injection Test (CHIT) for Use in Groundwater/Surface Water Interaction Studies. Washington State Department of Ecology. Publication No. 06-03-042. 31 p. www.ecy.wa.gov/biblio/0603042.html.

Pitz, C.F., 2009a. Quality Assurance Project Plan: Waitsburg Wastewater Treatment Plant Groundwater Study: Evaluation of Nutrient Loading to the Touchet River. Washington State Department of Ecology, Publication No. 09-03-119. 35 p. www.ecy.wa.gov/biblio/0903119.html.

Pitz, C. F., 2009b. High-resolution Porewater Sampling Near the Groundwater/Surface Water Interface. Washington State Department of Ecology, Publication No. 09-03-017. 41 p. www.ecy.wa.gov/programs/eap/quality.html.

Puckett, L.J., Zamora, C., Essaid, H., Wilson, J.T., Johnson, H.M., Brayton, M.J., and Vogel, J.R., 2008. Transport and Fate of Nitrate at the Ground-water/Surface-water Interface. Journal of Environmental Quality, Vol. 37, p. 1034-1050.

Ronan, A.D., Prudic, D.E., Thodal, C.E., and Constantz, J., 1998. Field study and simulation of diurnal temperature effects on infiltration and variably saturated flow beneath an ephemeral stream. Water Resources Research, Vol. 34, No. 9, p. 2137-2153.

Schuster, J.E. (compiler), 1994. Geologic map of the Walla Walla 1:100,000 quadrangle, Washington. Washington Division of Geology and Earth Resources Open File Report 94-3. 18 p., 1 plate.

Sheibley, R.W., Duff, J.H., Jackman, A.P., and Triska, F.J., 2003a. Inorganic nitrogen transformations in the bed of the Shingobee River, Minnesota: Integrating hydrologic and biological processes using sediment perfusion cores, Limnology and Oceanography, Vol. 48, no. 3, p. 1129-1140.

Sheibley, R.W., Jackman, A.P., Duff, J. H., and Triska, F.J., 2003b. Numerical modeling of coupled nitrification-denitrification in sediment perfusion cores from the hyporheic zone in the Shingobee River, MN. Advances in Water Resources, Volume 26, p. 977-987.

Sinclair, K. and Pitz, C.F., 2009. Standard Operating Procedure for installing, measuring, and decommissioning hand-driven in-water piezometers, Version 1.0. Washington State Department of Ecology. Environmental Assessment Program Standard Operating Procedure EAP061.

Stonestrom, D.A. and Constantz, J. (Editors), 2003. Heat as a tool for studying the movement of ground water near streams: U.S. Geological Survey, Circular 1260. 96 p. http://pubs.usgs.gov/circ/2003/circ1260/.

Stohr, A., LeMoine, M., and Pelletier, G., 2007. Walla Walla Tributaries Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Publication No. 07-03-014. 163 p. www.ecy.wa.gov/biblio/0703014.html.

Tarbutton, S., 2009. Quality Assurance Project Plan, Supplemental: Walla Walla River Basin Fecal Coliform Bacteria and pH Total Maximum Daily Load Study. Washington State Department of Ecology. Publication No. 09-03-114. 22 p. www.ecy.wa.gov/biblio/0903114.html.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998. Ground Water and Surface Water – A Single Resource. U.S. Geological Survey Circular 1139, 79 p. http://pubs.usgs.gov/circ/circ1139/.

WPLCS, 2010. Water Quality Permit Life Cycle System – Online Database. Washington State Department of Ecology. Waitsburg STP Discharge Monitoring Report data. Accessed January 11, 2010.

Appendix A. Monitoring Station Information

Table A-1. Monitoring station information.

Station ID	Station Description	Latitude	Longitude	Piezometer casing diameter	Piezometer open-interval length	Piezometer open-interval mid-point depth below streambed	Thermistor deployment depths within piezometer
		(decimal degrees)	(decimal degrees)	(cm)	(m)	(m)(1)	(m below streambed)(1)
AGT413	piezometer - south bank, far upstream background	46.27289	-118.16709	2.54	0.152	1.125	-
AGT414	piezometer - south bank, upstream background or downgradient of landfill?	46.27246	-118.16835	2.54	0.125	1.097	-
AGT415	piezometer - south bank, at seep	46.27255	-118.16958	2.54	0.158	1.109	-
AGT416	piezometer - south bank, east of wetland	46.27314	-118.17030	2.54	0.140	0.874	-
AGT417	piezometer - south bank, north of wetland	46.27371	-118.17081	2.54	0.152	1.113	-
AGT418	piezometer - south bank, north of lagoon	46.27402	-118.17221	2.54	0.152	1.286	-
AGT419	piezometer - south bank, west of lagoon	46.27310	-118.17410	2.54	0.158	1.113	-
AGT420	piezometer – south bank, west of lagoon Coppei Creek	46.27254	-118.17452	2.54	0.152	1.125	-
AGT421	piezometer – north bank, opposite wetland, background	46.27270	-118.16963	2.54	0.140	1.079	-
AGT423	piezometer – south bank, at seep	46.27255	-118.16957	3.81	0.143	1.183	0.204 0.616 1.119
AGT424	piezometer - south bank, north of landfill	46.27238	-118.16908	3.81	0.146	1.195	0.247 0.713 1.094
WTPGW-TR	surface water - Touchet River @ river mile ~43.4	46.27259	-118.16955	-	-	-	-
WTPGW-LA	surface water - northern corner of lined lagoon	46.27291	-118.17255	-	-	-	-
WTPGW-WT	surface water - far eastern end of discharge wetland	46.27253	-118.16995	-	-	-	-
WTPGW-SP	seep at base of bank below far east end of wetland	46.27254	-118.16956	-	-	-	-

(1) At time of construction.

Appendix B. Study Results

Table B-1. Constant head injection test results.

Piezometer ID	Test Number	Piezometer open interval length (m)	Assumed diameter (cm)	Piezometer penetration (m)	Assumed total saturated thickness (m)	Operating head (m)	Total volume of water injected during test (liters)	Time duration of test (min)	Net injection rate (L/min)	Estimated hydraulic conductivity (m/sec)	Average hydraulic conductivity (m/sec)
		L	*d*	*H*	*b*	*y*	V_{NET}	*t*	Q_{NET}	*K*	*K*
AGT415	1	0.158	2.54	1.19	3	1.36	13.25	0.9	14.72	3.5E-04	3.5E-04
	2	0.158	2.54	1.19	3	1.36	13.25	0.9	14.72	3.5E-04	
AGT423	1	0.143	3.81	1.26	3	0.67	12	2.0	6.0	2.5E-04	2.6E-04
	2	0.143	3.81	1.26	3	0.67	10	1.63	6.14	2.6E-04	
	3	0.143	3.81	1.26	3	0.67	10	1.62	6.17	2.6E-04	
AGT424	1	0.146	3.81	1.30	3	0.42	10	1.73	5.78	3.8E-04	3.8E-04
	2	0.146	3.81	1.30	3	0.42	12	2.07	5.80	3.8E-04	
	3	0.146	3.81	1.30	3	0.42	10	1.72	5.81	3.8E-04	

See Figure B-1 for explanation of terms.

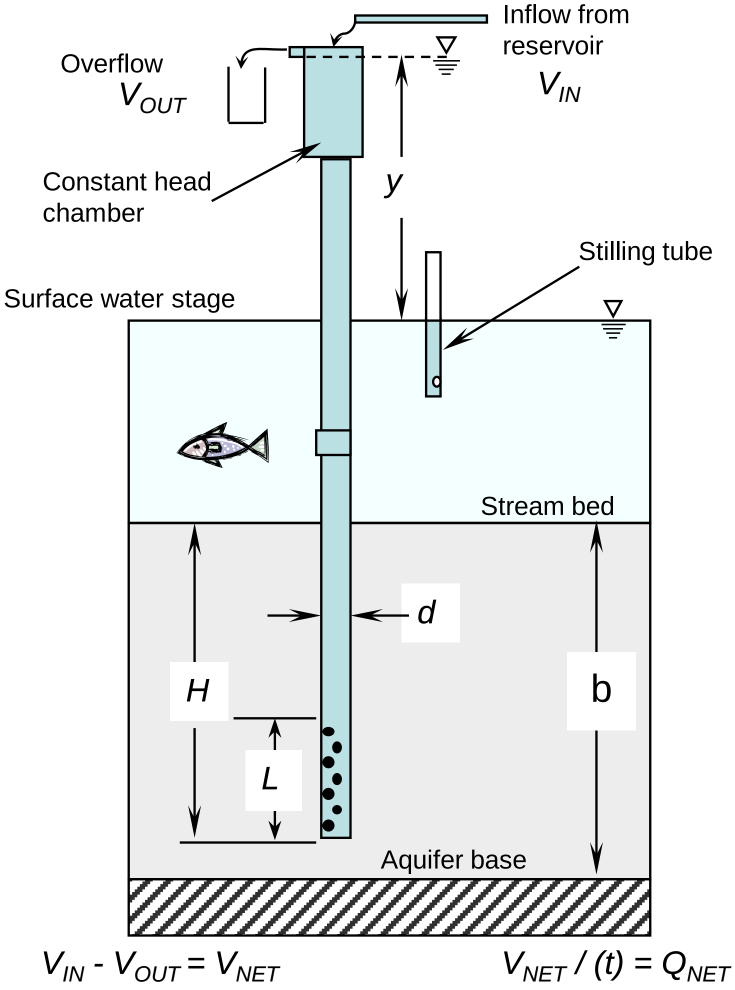


Figure B-1. Schematic of constant head injection test terms (after Cardenas and Zlotnik, 2003).

Table B-2. Monitoring results – piezometers.

	Date	Field Parameters						Laboratory Analytes									
		Vertical hydraulic gradient	pH	Specific conductance (SC)	Dissolved oxygen (DO)	Ferrous iron (Fe^{2+})	ORP	Chloride	Total dissolved solids (TDS)	Dissolved organic carbon (DOC)	Sulfate (SO_4)	Sodium (Na)	Ammonium-N (NH_4-N)	Nitrate-N (NO_3-N)	Nitrite-N (NO_2-N)	Ortho-phosphate-P (OP)	Total dissolved phosphorus (TDP)
		m/m	s.u.	µS/cm	mg/L	mg/L	mV	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
AGT413	8/3/09	+0.001	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/1/09	+0.001	6.69	182	0.99	3.35	-88	2.07	136	0.2 J	1.20	7.08	0.076	0.080	0.022 U	0.0254	0.217
	9/29/09	+0.001	6.72	184	0.75	3.57	-71	2.13	143 J	0.4 J	0.96	7.10	0.079	0.062	0.022 U	0.0277	0.270
	10/26/09	+0.001	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
AGT414	8/3/09	+0.022	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/1/09	+0.008	6.75	575	0.51	0.01	51	18.6	389	1.4 J	30.5	37.2	0.010 U	10.5	0.184	0.0610	0.0541
	9/29/09	+0.016	6.77	575	0.49	0.01 <	36	17.6	380	1.7 J	27.5	37.8	0.010 U	9.68	0.035	0.0647	0.0895
	10/26/09	+0.017	NM	NM	0.42	NM	NM	See Table B-4 for BNA semi-volatile organic results									
AGT415	8/5/09	+0.044	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	8/31/09	+0.047	6.90	552	0.37	6 >	-188	36.8	301	3.6 J	0.30 U	49.3	7.60	0.022 U	0.022 U	0.0607	1.84
	9/28/09	+0.031	6.88	573	0.47	6 >	-127	48.3	302	3.8 J	0.34	51.4	7.91	0.022 U	0.022 U	0.0532	2.19
	10/26/09	+0.040	NM	NM	NM	NM	NM	See Table B-4 for BNA semi-volatile organic results									
AGT416[(A)]	8/5/09	0.000	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/2/09	0.000	NM	500	0.74	6 >	-120	35.8 G	269 G	3.3 JG	0.30 G	47.5 G	7.66 G	0.034 G	0.022 UG	0.371 G	2.77 G
	9/29/09	+0.001	6.84	547	1.17	6 >	-79	50.1 G	256 G	3.4 JG	0.38 G	48.2 G	7.86 G	0.044 G	0.022 UG	0.207 G	2.54 G
	10/26/09	+0.005	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
AGT417	8/4/09	-0.282	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	9/2/09	-0.295	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	9/30/09	-0.323	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	10/26/09	-0.310	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
AGT418	8/4/09	0.000	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/2/09	0.000	NM	110	0.35	0.01 <	77	1.92	92	- R	2.29	4.97	0.010 U	0.214	0.022 U	0.0705	0.0664
	9/29/09	+0.003	6.81	116	1.53	0.01 <	30	1.62	80	- R	2.09	4.70	0.010 U	0.334	0.022 U	0.0609	0.0587
	10/27/09	+0.011	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
AGT419	8/4/09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	9/2/09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	9/29/09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	10/27/09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
AGT420	8/4/09	-0.016	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	9/2/09	-0.036	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	9/30/09	-0.033	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
	10/27/09	-0.043	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP
AGT421	8/5/09	+0.006	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/1/09	+0.005	6.66	128	0.87	2.65	-85	2.17	112	- R	3.39	6.00	0.219	0.167	0.022 U	0.0283	0.234
	9/29/09	+0.013	6.86	133	0.54	3.14	-15	2.01	101	- R	3.18	6.20	0.264	0.180	0.022 U	0.0225	0.300
	10/26/09	+0.015	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
AGT423	8/5/09	+0.061	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/1/09	+0.040	6.82	553	0.30	6 >	-157	36.6	306	3.8 J	2.21	47.2	7.39	0.022 U	0.022 U	0.0795	1.85
	9/28/09	+0.033	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	10/26/09	+0.046	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
AGT424	8/5/09	0.000	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/2/09	+0.005	6.79	722	0.42	6 >	-121	26.9	417	3.4 J	51.2	42.6	2.86	0.022 U	0.022 U	0.0121	0.711
	9/28/09	+0.001	6.8	700	1.99	6 >	-116	25.6	388	3.0 J	44.3	42.2	3.43	0.022 U	0.022 U	0.0036	0.792
	10/26/09	+0.004	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table B-2 Notes

(A) – Field observations of hydraulic head and water quality condition during purge suggest that the vertical hydraulic gradient and groundwater water quality values reported for the AGT416 station may be biased due to possible annular leakage of surface water.

Positive vertical hydraulic gradient values indicate upward potential flow; negative values indicate downward potential flow.

s.u. – standard units
µS/cm – microsiemens per centimeter
mV – millivolts
mg/L – milligrams per liter
NM – not measured
NS – not sampled
LP – losing piezometer, not monitored for water quality.
NP – non-producing piezometer, permeability too low for gradient measurement or water quality monitoring.
U – the analyte was not detected at or above the reported result.
J – the numerical result is an estimate.
R – the reported concentration was rejected due to field blank contamination.
G – the reported concentration may be biased low due to possible annular leakage of surface water.
> – the concentration is greater than the reported result.
< – the concentration is less than the reported result.

Table B-3. Monitoring results – surface water.

	Date	Field Parameters					Laboratory Analytes									
		pH	Specific conductance (SC)	Dissolved oxygen as O_2 (DO)	Ferrous iron (Fe^{2+})	ORP	Chloride	Total dissolved solids (TDS)	Dissolved organic carbon (DOC)	Sulfate (SO_4)	Sodium (Na)	Ammonium-N (NH_4-N)	Nitrate-N (NO_3-N)	Nitrite-N (NO_2-N)	Ortho-phosphate-P (OP)	Total dissolved phosphorus (TDP)
		s.u.	µS/cm	mg/L	mg/L	mV	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Touchet River (TR-1)	8/31/09	8.73	109	9.74	0.06	56	1.62	89	0.6 J	2.23	4.60	0.010 U	0.279	0.022 U	0.0604	0.0545
	9/28/09	8.34	106	9.86	0.06	NM	1.51	86	0.7 J	1.97	4.45	0.010 U	0.353	0.022 U	0.0539	0.0674
Wetland (WT)	8/31/09	6.58	558	3.67 J	0.20	-230	78.9	383	18.4	16.6	65.2 J	0.493	0.042	0.022 U	4.70	4.94
	9/28/09	6.52	387	1.09	0.33	-137	12.6	269	6.3	8.09	51.2	0.260	0.022 U	0.022 U	3.62	3.59
	See Table B-4 for BNA semi-volatile organic results															
Seep (SP)	8/31/09	7.04	541	3.83	6 >	-128	69.4	327	3.5 J	10.7	59.0	1.22	0.022 U	0.022 U	1.91	4.06
	9/28/09	6.95	598	1.41	6 >	-128	41.5	323	4.2 J	6.14	51.3	6.14	0.022 U	0.022 U	0.0047	1.47
	See Table B-4 for BNA semi-volatile organic results															
Lagoon (LA)	8/31/09	10.01	1792	15 >	0.01 <	-12	322	1290 J	137	3.73	324	0.150	0.022 U	0.022 U	0.796	0.670
	9/28/09	9.22	1230	19.7	0.40	-23	194	894	64.8	12.3	216	8.27	3.02	0.156	3.13	3.20
SW @ AGT413	9/1/09	7.50	113	7.97	NM	56	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	7.43	110	9.65	NM	116	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT414	9/1/09	7.18	113	8.78	NM	-17	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	7.88	106	9.80	NM	-69	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT415	8/31/09	NM	NM	12.60	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/28/09	6.90	598	1.73	NM	-118	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT416	9/2/09	NM	119	9.34	NM	-50	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	8.35	104	9.96	NM	-119	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT417	9/2/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/28/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT418	9/2/09	NM	114	9.69	0.01 <	143	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	8.56	102	10.18	NM	-139	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT419	9/2/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/28/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT420	9/2/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/28/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT421	9/1/09	8.39	107	7.82	NM	175	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	8.31	104	9.68	NM	-3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT423	9/1/09	6.78	539	1.40	NM	-131	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/29/09	NM	NM	NM	NM	NM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SW @ AGT424	9/2/09	7.83	119	8.89	NM	163	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	9/28/09	8.54	104	9.36	NM	-83	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NM – not measured
NS – not sampled
U – not detected at or above the reported result
J – the numerical result is an estimate
R – the reported concentration was rejected due to field blank contamination
> - the concentration is greater than the reported result
< - the concentration is less than the reported result

Table B-4. Base/neutral/acid (BNA) semi-volatile organic detections.

		3B-Coprostanol		4-Methyl-phenol		Benzoic Acid		Cholesterol		Ethanol, 2-Chloro-, Phosphate (3:1)		Pentachlorophenol		Phenol	
Station ID	Sample Date	µg/L		µg/L		µg/L		µg/L		µg/L		µg/L		µg/L	
Wetland(WT)	9/28/2009	**0.58**	J	**2.5**		**3.8**	J	**2.6**		**0.50**	J	0.25	U	**0.41**	J
Seep(SP)	9/28/2009	2.5	U	0.11	J	**2.8**	J	2.5	U	**0.11**	J	0.25	U	0.98	U
AGT415	9/28/2009	2.5	U	2.5	U	**2.6**	J	2.5	U	**0.14**	NJ	**0.31**	NJ	**0.09**	J
Field blank	9/28/2009	2.6	U	2.6	U	2.6	UJ	2.6	U	0.26	UJ	0.26	UJ	**0.15**	J
AGT414	10/26/2009	2.3	U	2.3	U	**2.7**	J	2.3	UJ	0.23	UJ	0.23	UJ	**0.15**	J
Field blank	10/26/2009	2.4	U	2.4	U	2.4	UJ	2.4	UJ	0.24	UJ	0.24	U	**1.0**	

Bold indicates detection

µg/L = micrograms per liter

U – not detected above the reported quantitation limit

J - the analyte was positively identified; the associated numerical value is the approximate concentration.

UJ – the analyte was not detected, however the reported quantitation limit is approximate.

NJ – the analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.

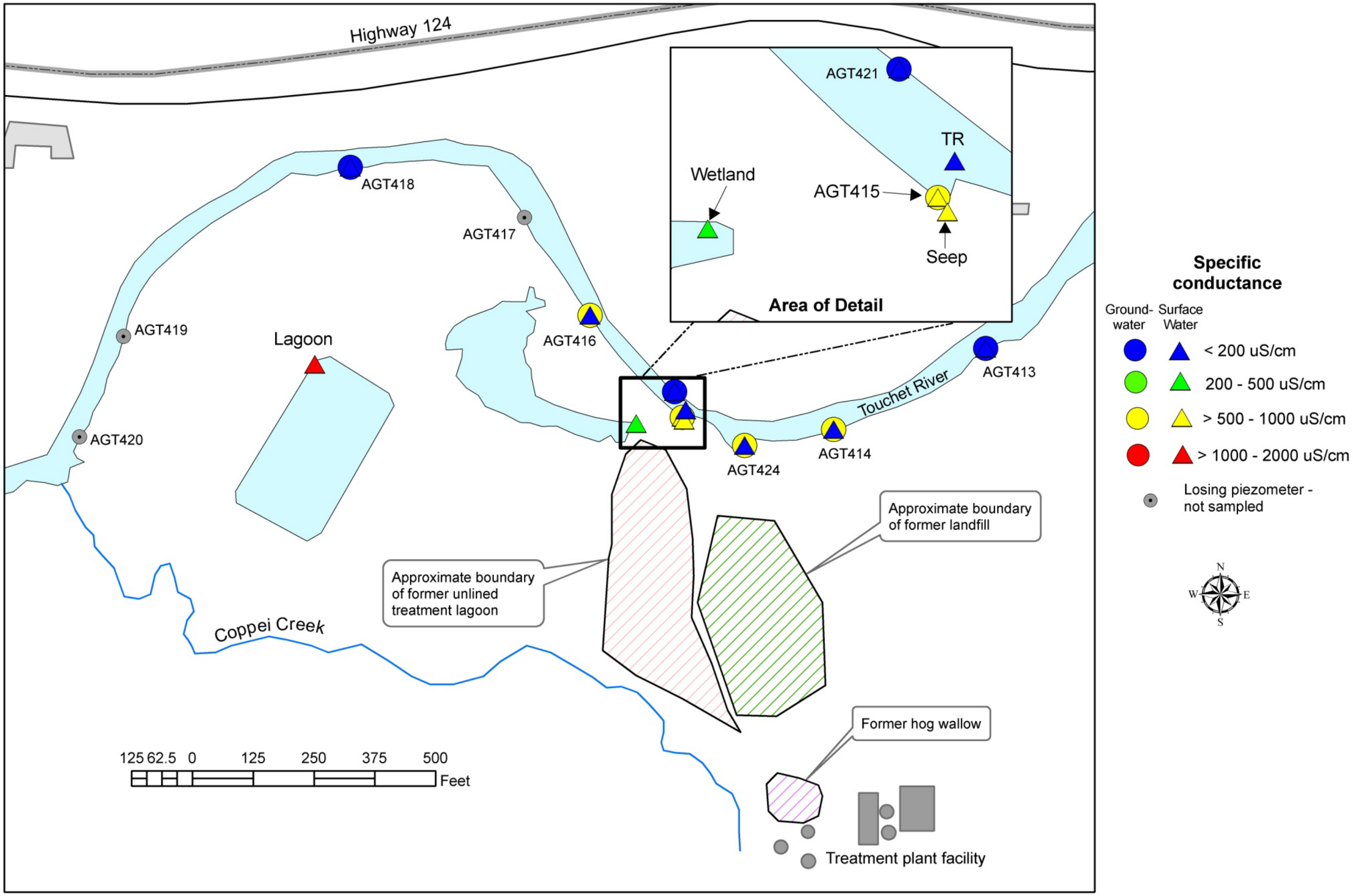


Figure B-2. Specific conductance condition in groundwater and surface water samples - Waitsburg WWTP, September 28-29, 2009.

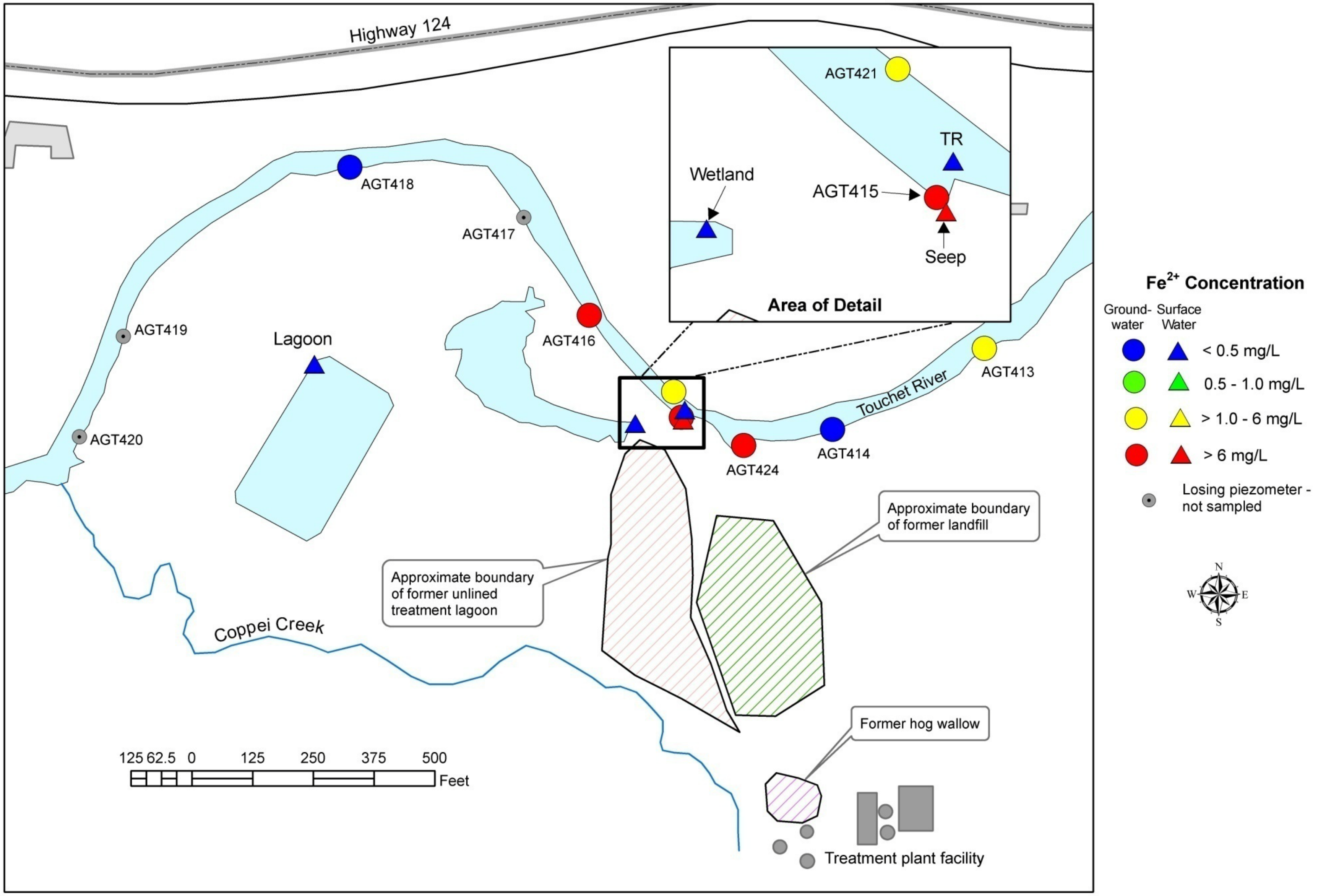


Figure B-3. Ferrous iron (Fe^{2+}) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

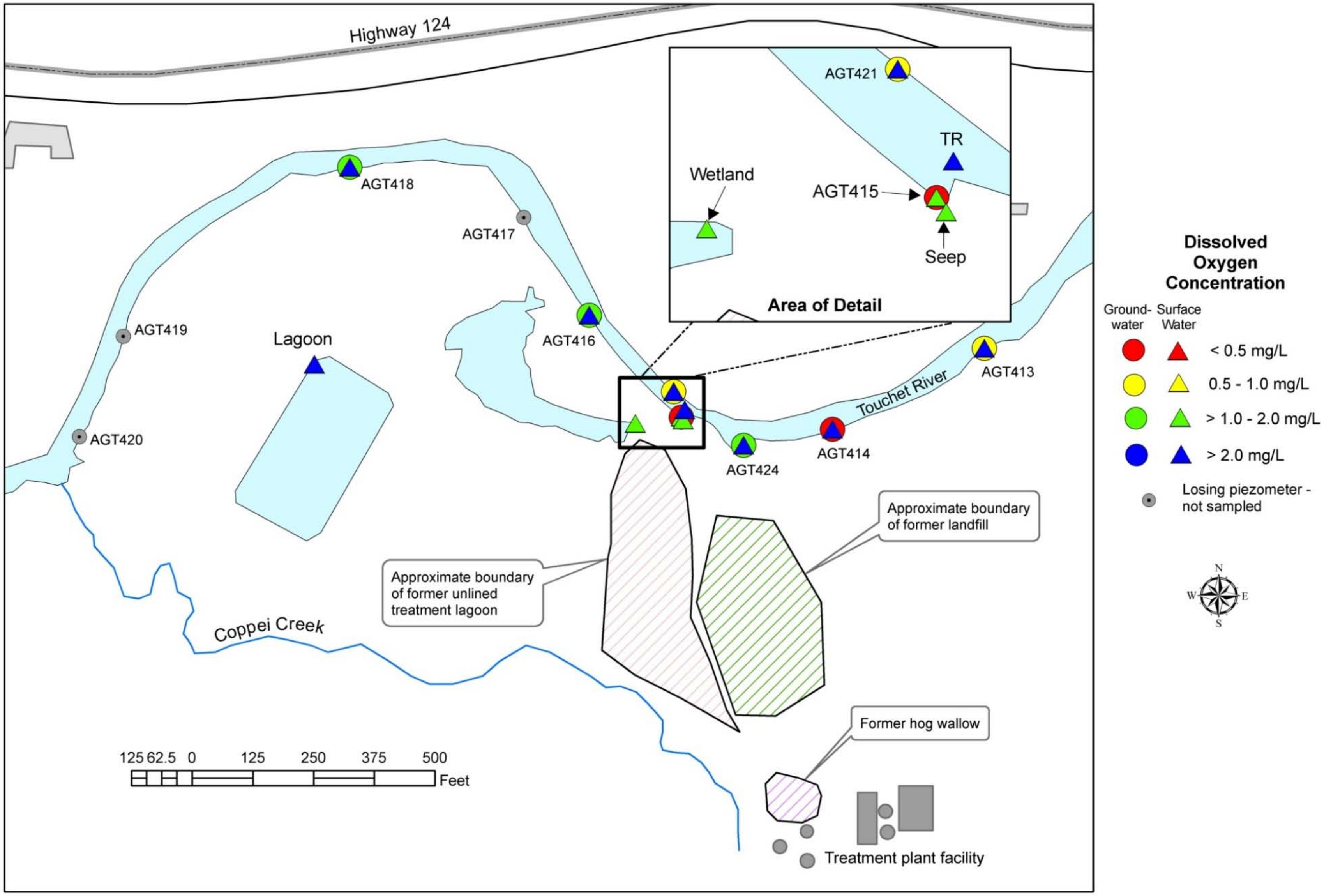


Figure B-4. Dissolved oxygen condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

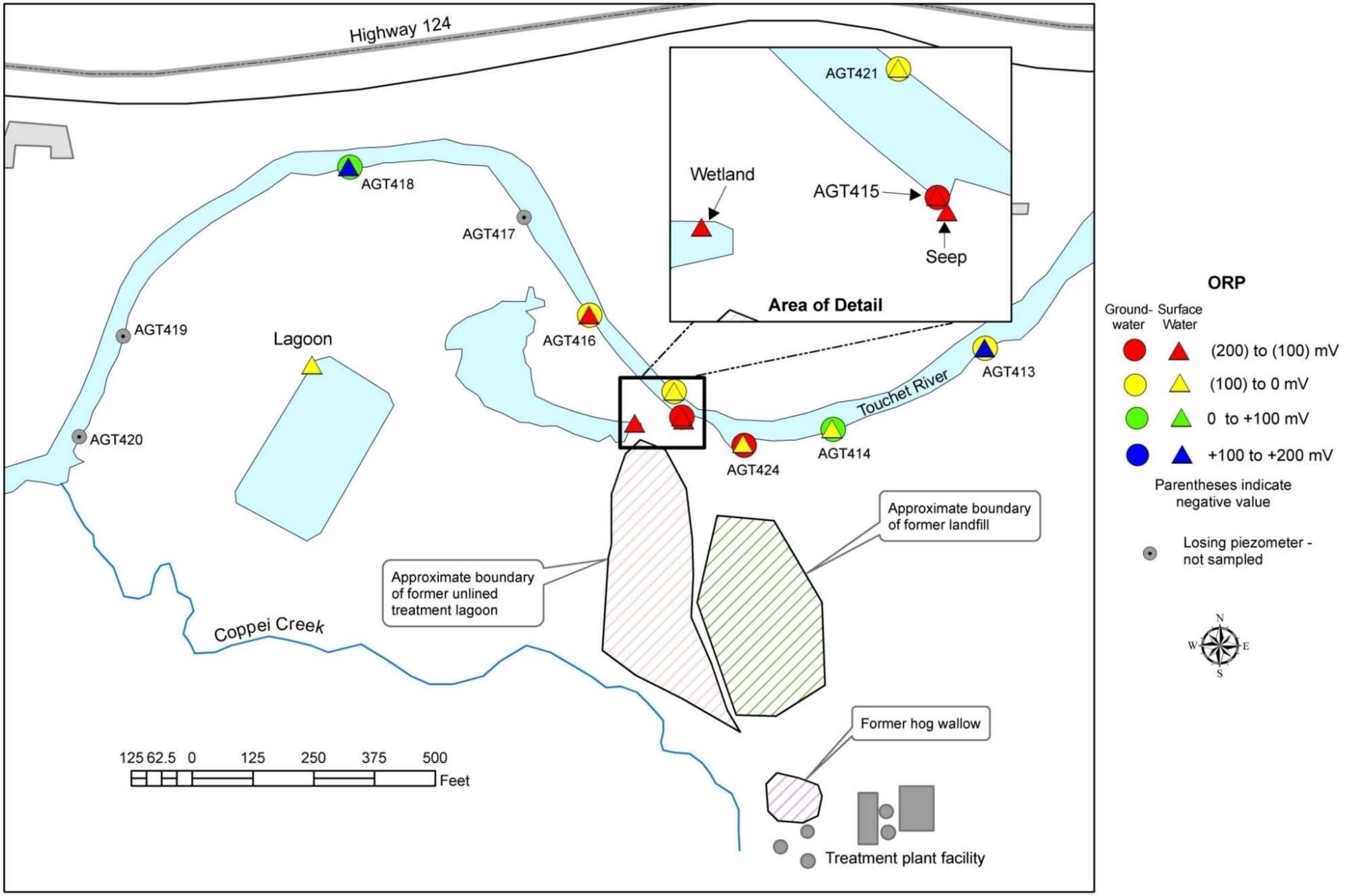


Figure B-5. Oxidation/reduction potential (ORP) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

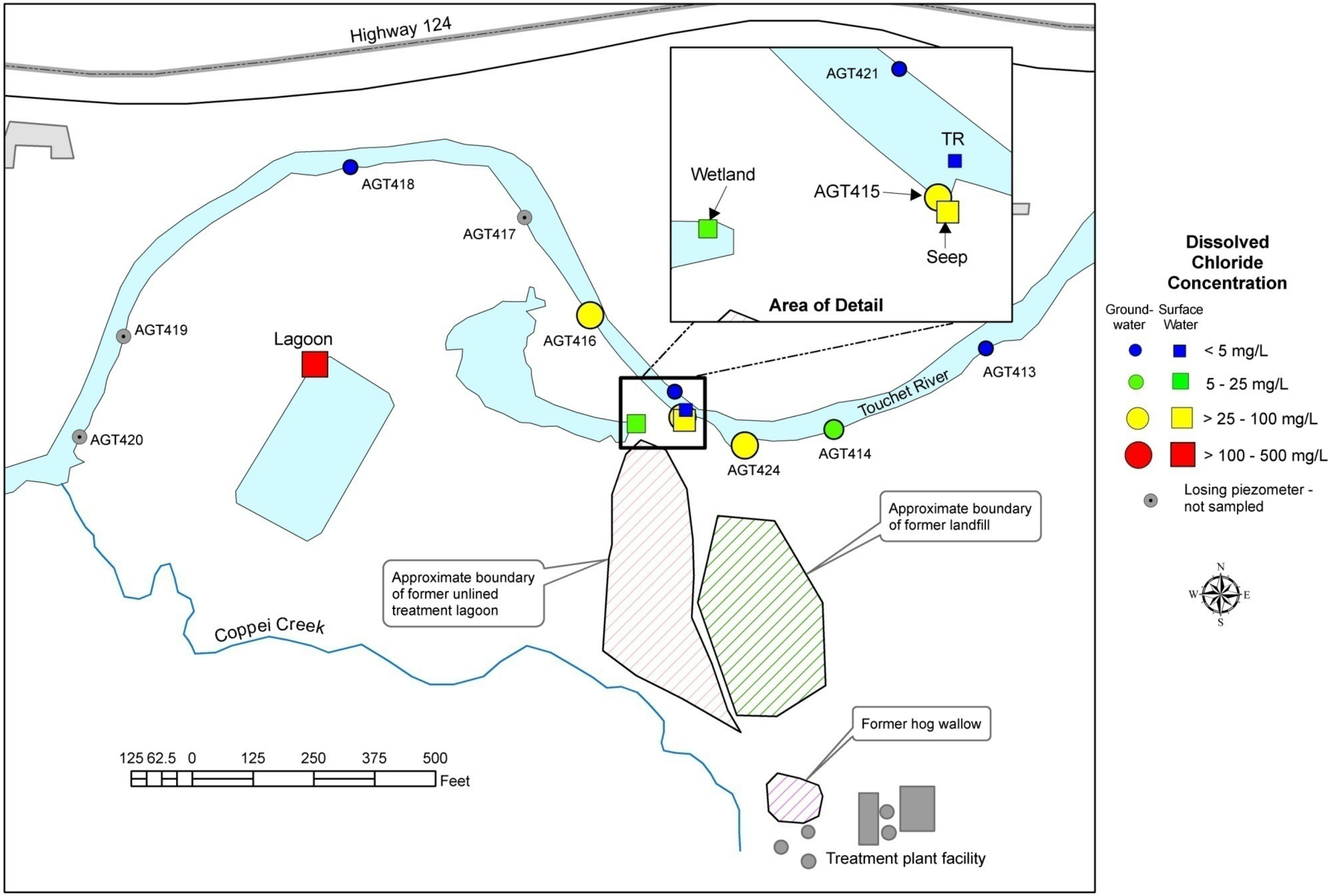


Figure B-6. Dissolved chloride condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

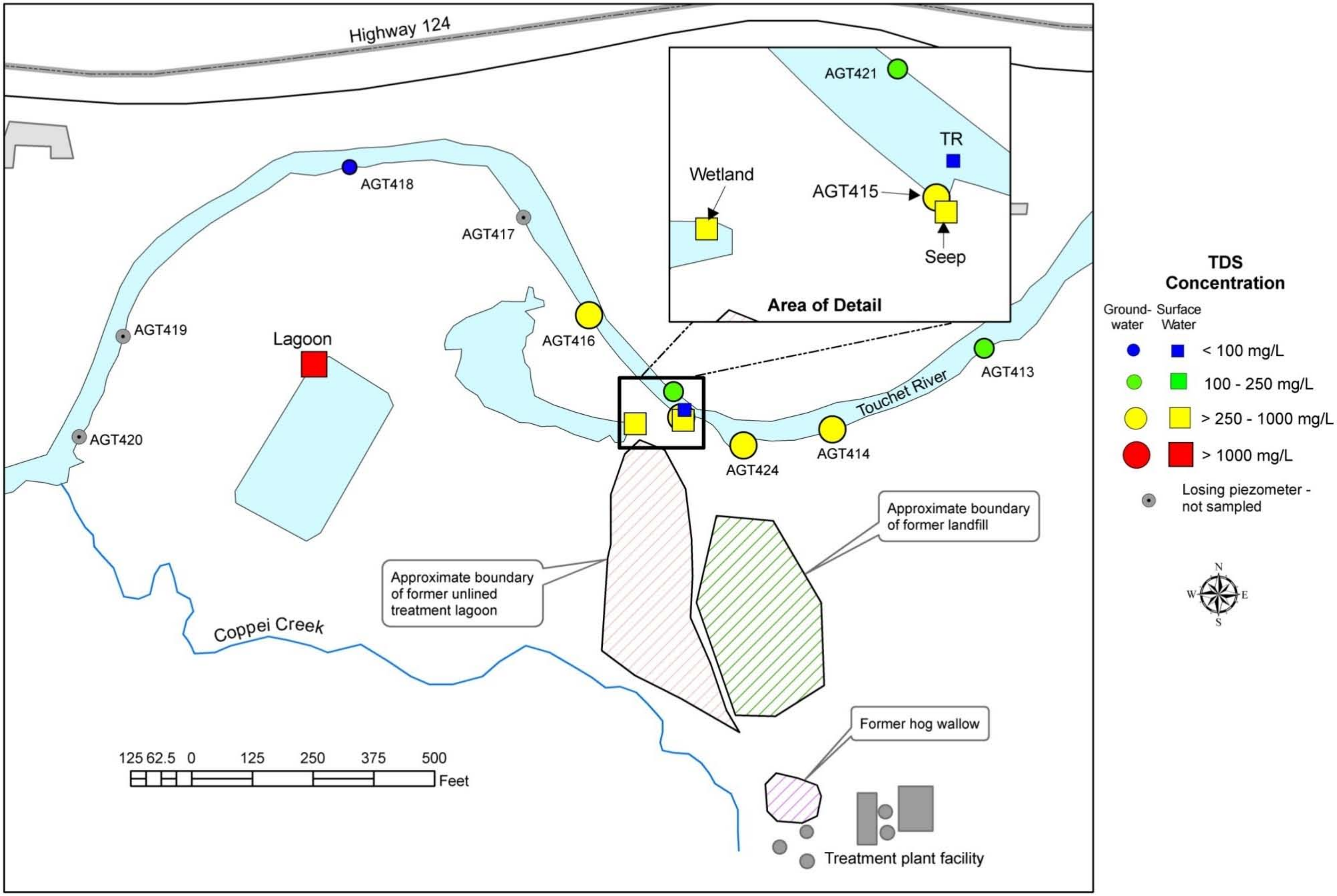


Figure B-7. Total dissolved solids (TDS) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

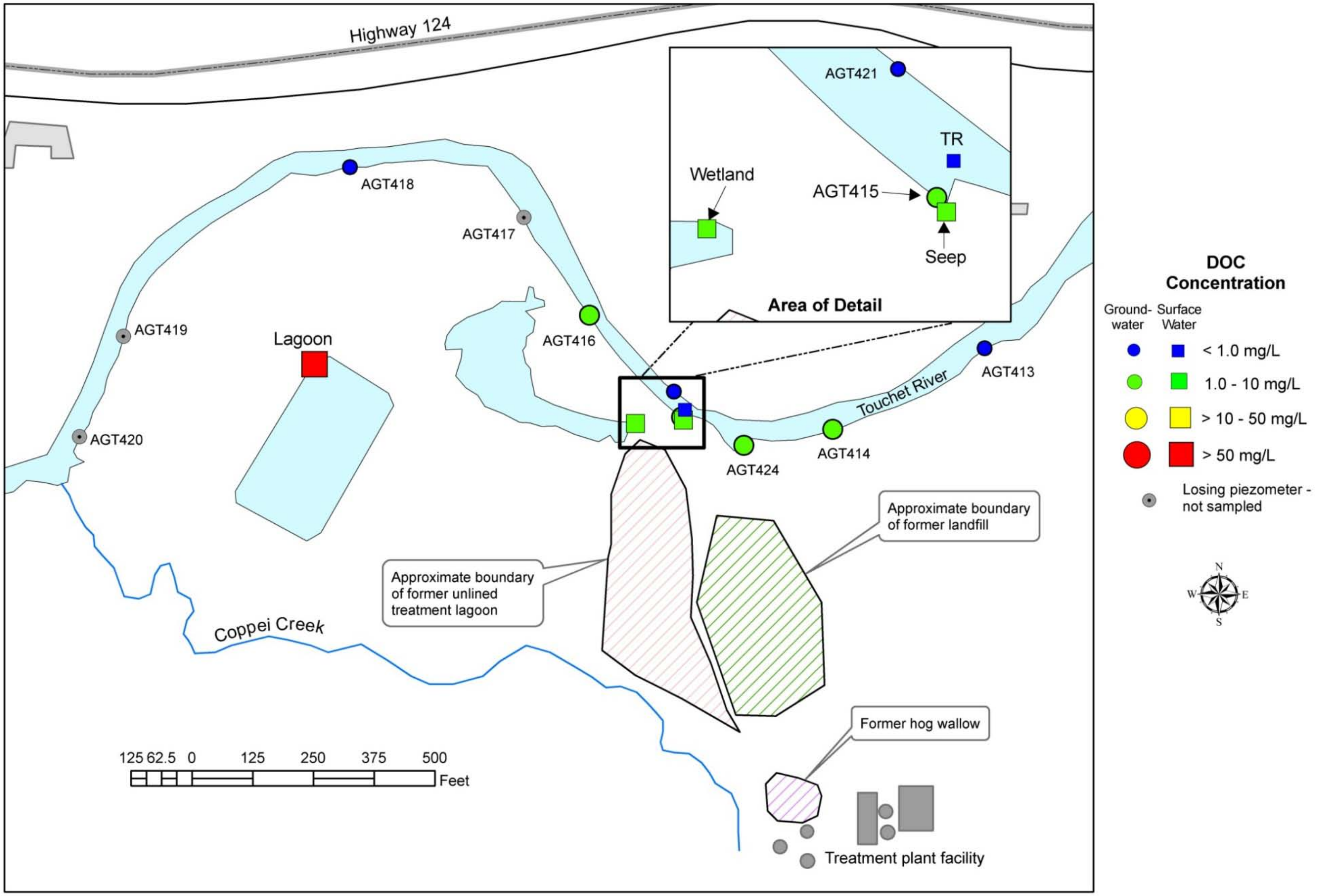


Figure B-8. Dissolved organic carbon (DOC) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

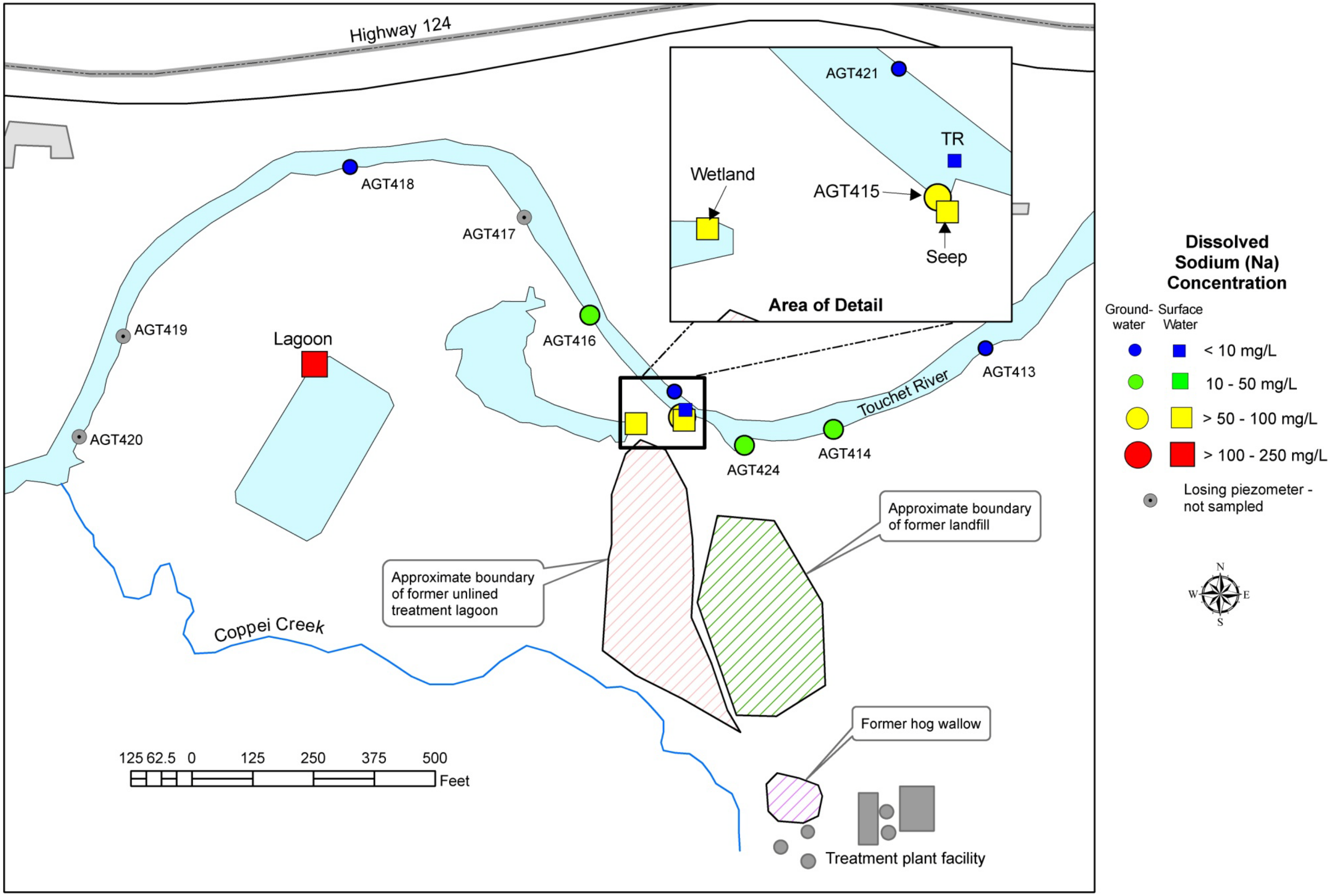


Figure B-9. Dissolved sodium (Na) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

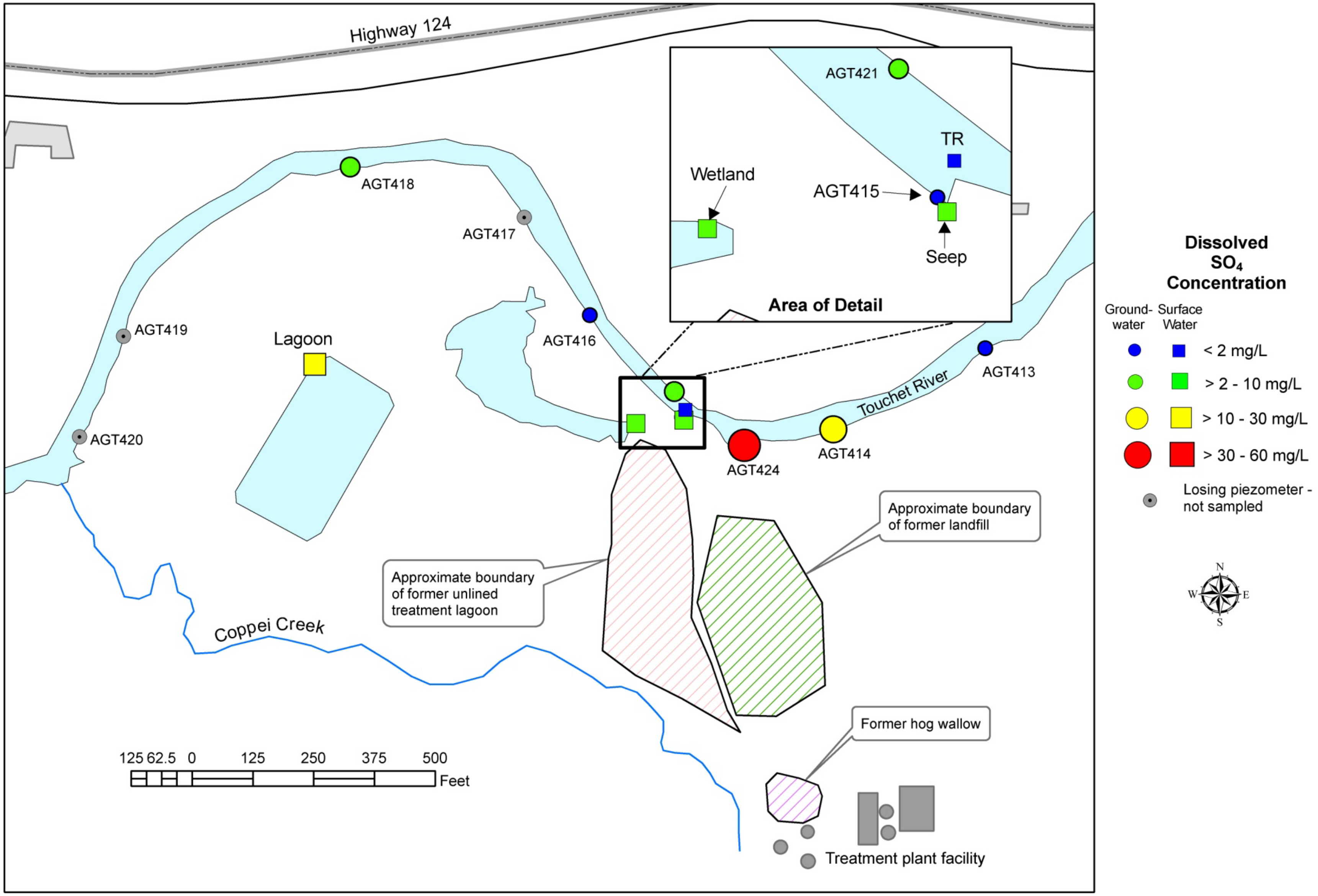


Figure B-10. Dissolved sulfate (SO_4) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

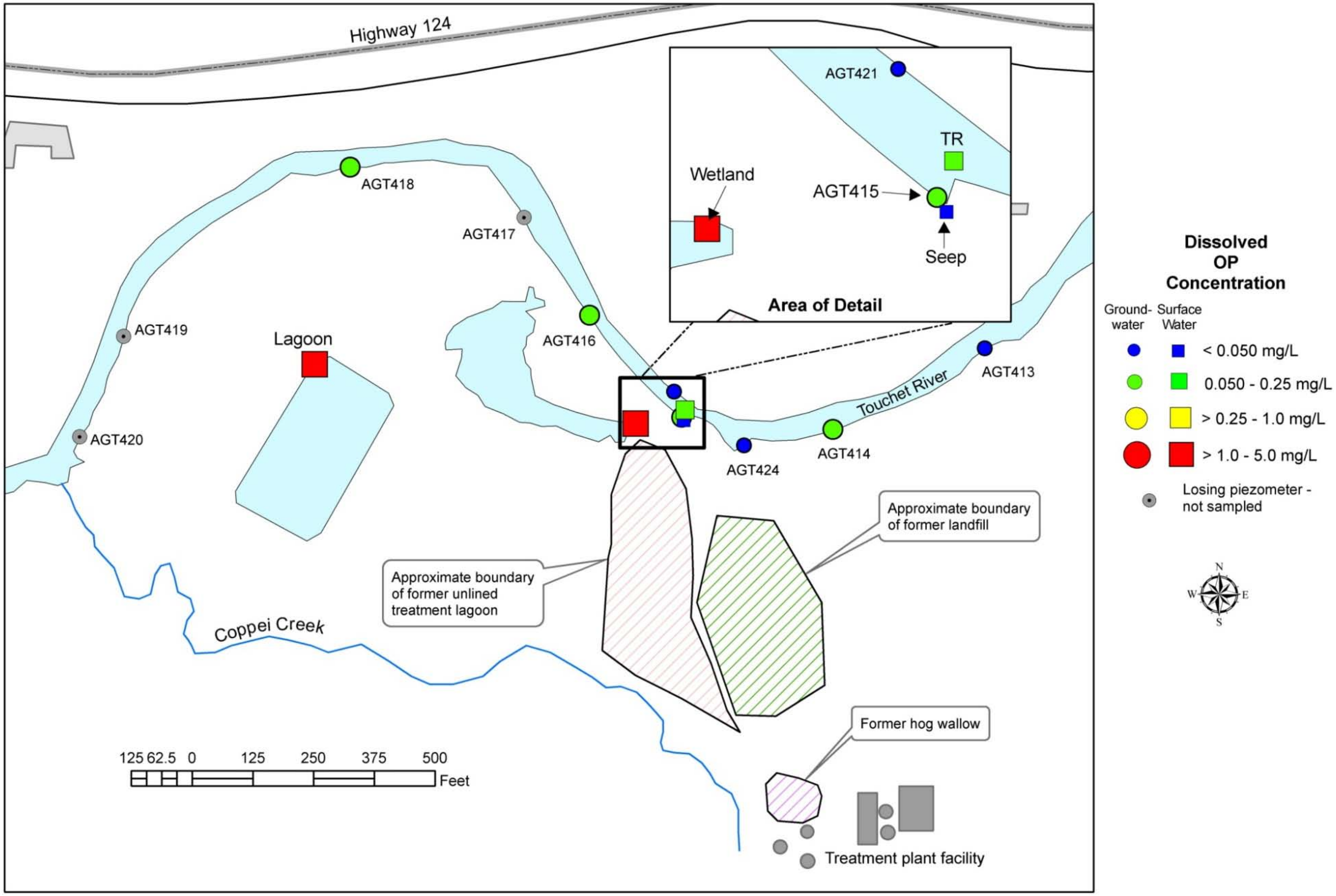


Figure B-11. Dissolved orthophosphate-P (OP) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

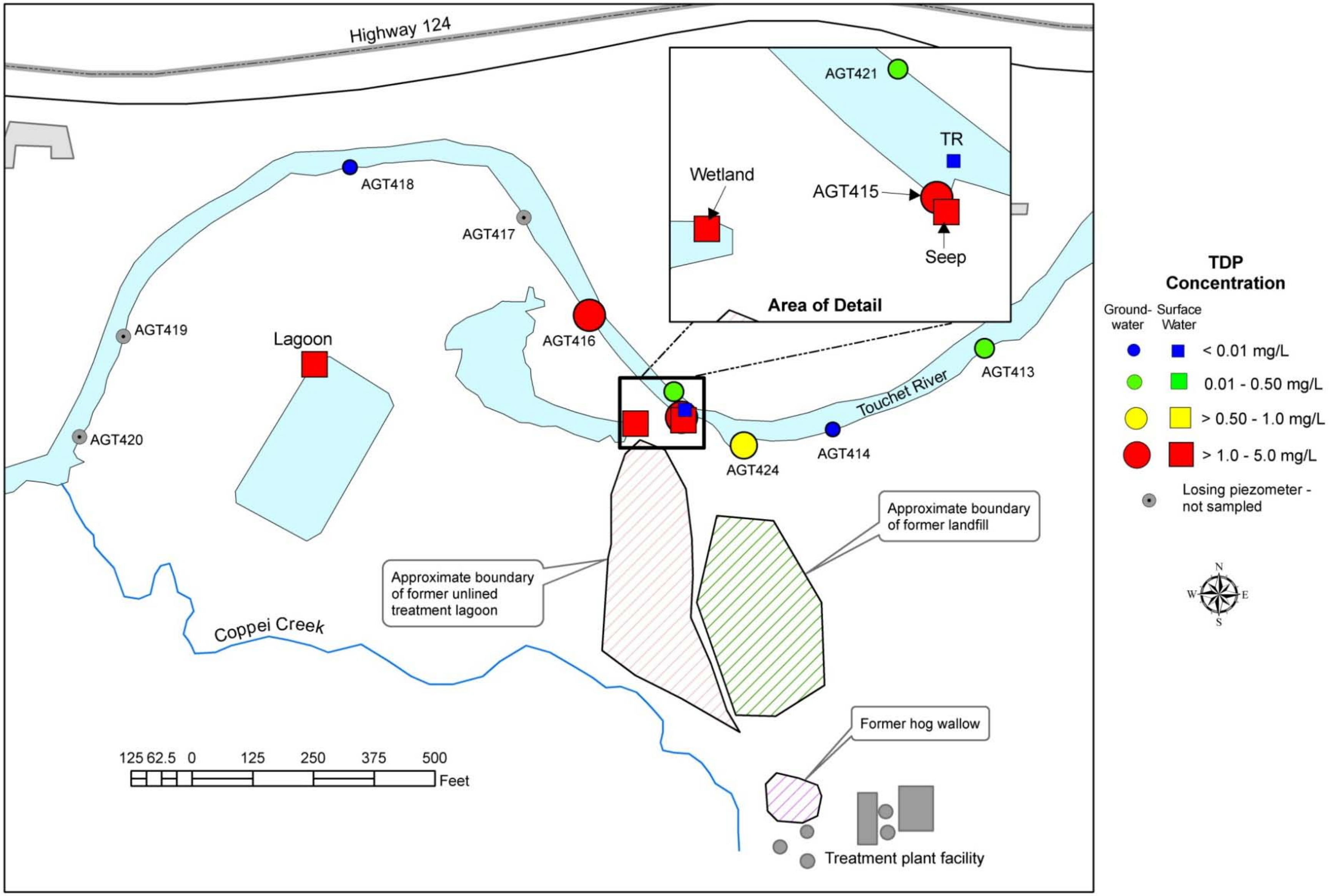


Figure B-12. Total dissolved phosphorus (TDP) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

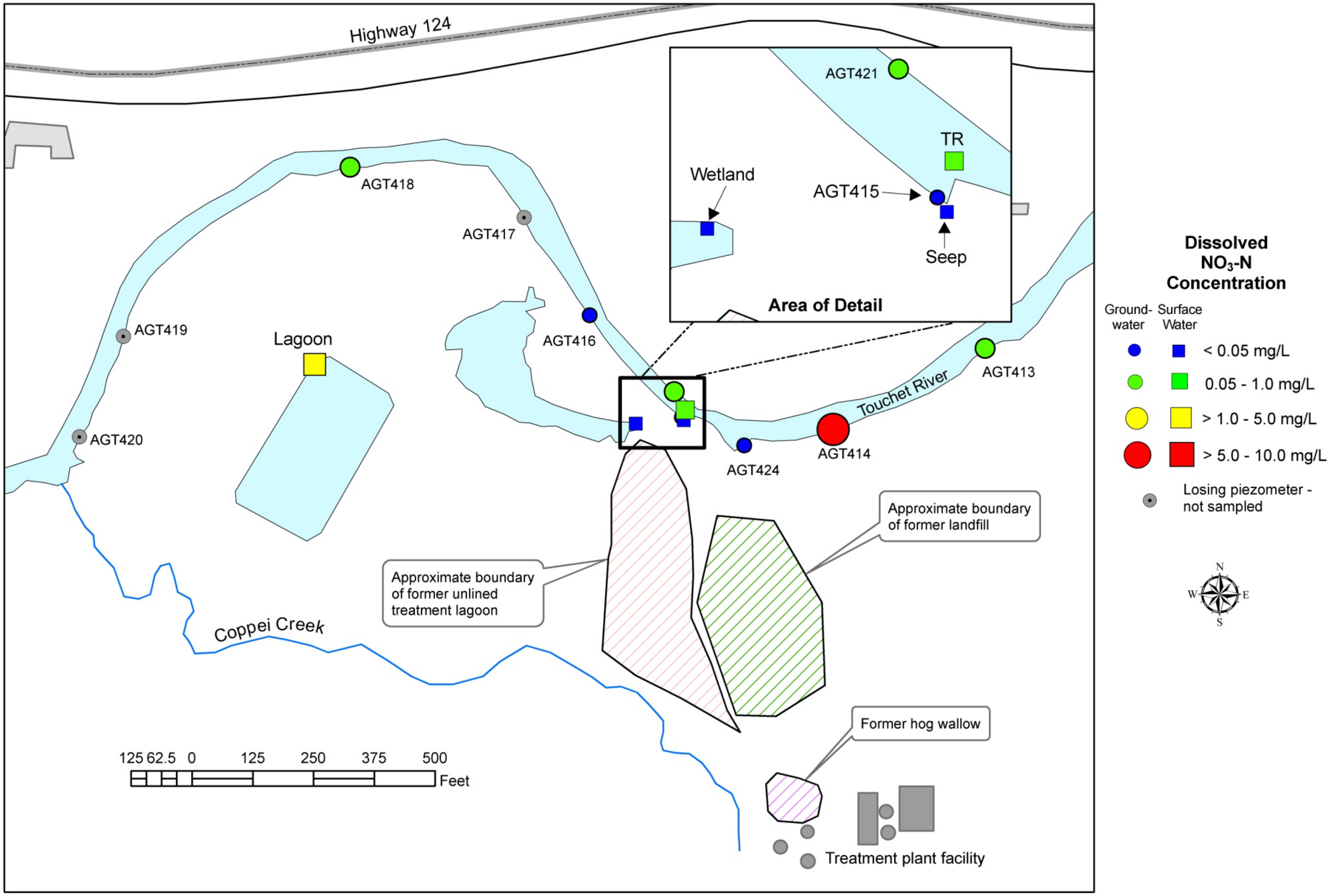


Figure B-13. Dissolved nitrate-N (NO_3-N) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

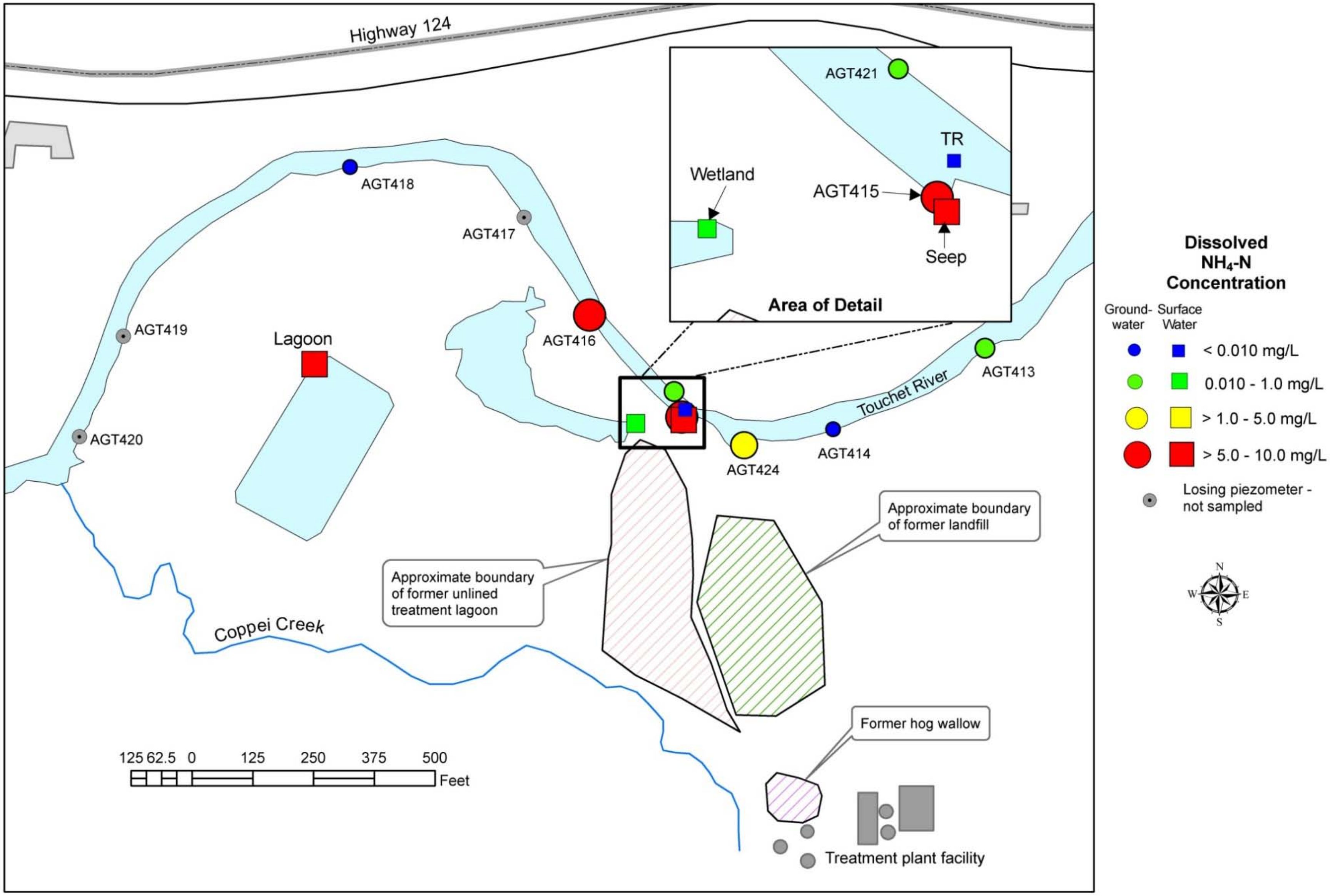


Figure B-14. Dissolved ammonium-N (NH_4-N) condition in groundwater and surface water samples – Waitsburg WWTP, September 28-29, 2009.

Appendix C. Data Quality

Thermal Data

Thermal monitoring devices used during this study were calibrated to a National Institute of Standards and Technology (NIST) reference thermometer prior to and after deployment. Calibration procedures followed guidelines outlined by Bilhimer and Stohr (2009). Calibration tests were intended to confirm that all thermistors were operating within the advertised vendor accuracy. A pre- and post-deployment calibration approach also allows assessment of instrument drift over time.

Figure C-1 presents the results of the calibration tests for the eight thermistors used during the study, pre- and post deployment. Each point on the graphs represents the mean of 10 separate measurements. The calibration test results indicate the accuracy of the thermistors was maintained within manufacturer's specifications (± 0.2°C) throughout the study period, with no discernible drift.

The long-shaft temperature probe used during the thermal reconnaissance was also tested during the thermistor calibration process. This probe was routinely within 0.5°C of the reference thermometer, in both warm and ice baths.

The thermal data generated during this study are judged to be of good quality and acceptable for use in support of the project goals.

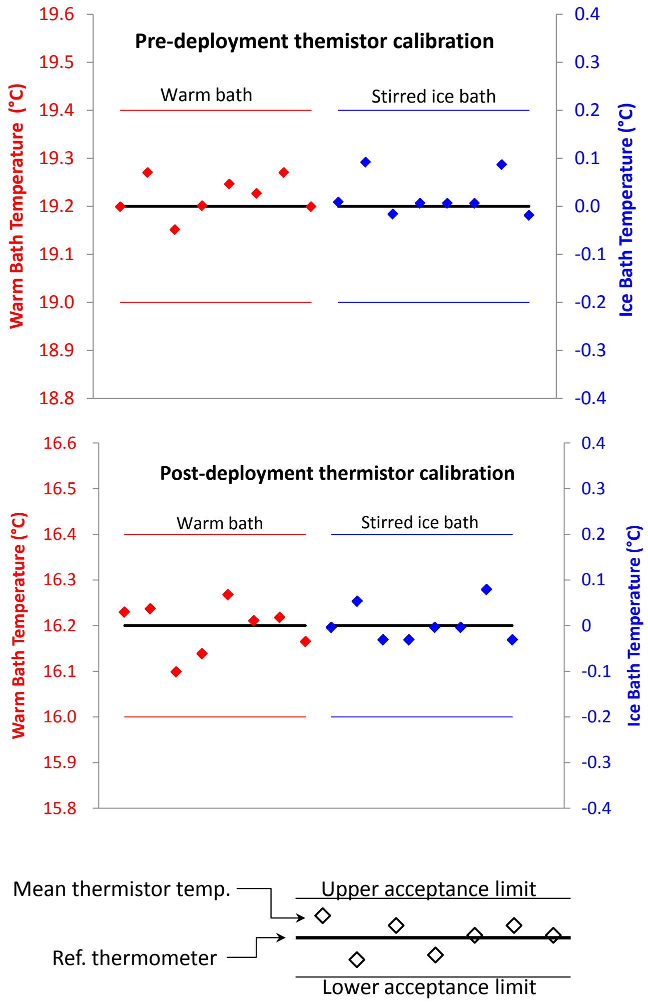


Figure C-1. Pre- and post-deployment thermistor calibration graphs.

Water Quality

Analytical Quality Assurance – Lab

The precision and accuracy of the project analytical results were estimated by the MEL chemists using laboratory quality control tests conducted for each batch of 20 or fewer samples. Laboratory quality control testing consisted of method blanks, lab duplicate samples, matrix spike samples, and control standards. Manchester Laboratory's quality control procedures are discussed in detail in MEL, 2006.

Quality assurance reviews of the analytical data were completed by MEL and forwarded to the authors for each round of sampling. The laboratory reviews revealed that the data were of generally good quality, meeting or exceeding the data quality objectives established in the project plan. The laboratory reviews indicated that the data may be used without qualification with the following exceptions:

- The 8/31/2009 TDS sample from the lagoon (LA) may have been contaminated during analysis. The result was therefore qualified as an estimate.
- The 8/31/2009 sodium sample from the wetland station (WT) was filtered upon receipt at the laboratory, not at the time of collection. The result was therefore qualified as an estimate.
- The 9/29/2009 TDS sample from piezometer AGT413 was analyzed outside the designated holding time. The result was therefore qualified as an estimate.
- Most of the BNA semi-volatile analysis results were qualified as estimates due to calibration values outside of established QA limits.

Six of 23 samples that were analyzed for both OP and TDP had a higher OP concentration than TDP concentration. The average %RSD for these six samples was 6%, indicating that the analysis results were within the analytical accuracy standard for the method. The TDP and OP results are therefore presented without qualification.

Analytical Quality Assurance – Field

Filter Blanks

Clean, laboratory-supplied de-ionized (DI) water was pumped through the sample collection and filtering system once per sampling round. Filter blanks were collected to determine if any component of the sampling system was contributing a positive bias to the analytical results. Filter blanks were submitted as blind samples to the laboratory and were analyzed for all study parameters. All tubing, filters, and fittings used to collect these blanks were factory new.

The analytical results for the project filter blank samples are presented in Table C-1. The results indicate that the sample collection and filtration system did not introduce significant bias into the study results for most of the parameters of interest. Significant positive bias for DOC was, however, observed in filter blank samples during both sampling rounds.

In cases where the DOC filter blank concentration was equal to or greater than the lab-reported station concentration, the result was rejected from further use. In cases where the station result was less than 4X the filter blank concentration, the blank value was subtracted from the lab-reported sample concentration and the resulting value was qualified as an estimate (Tables B-2 and B-3).

Field Duplicates

One blind field duplicate sample set was submitted to the MEL during each sampling round (Round 1 – station AGT415; Round 2 – station AGT424). Duplicates were analyzed for all parameters of interest. Duplicate samples were collected by splitting the pump discharge between two identical sets of sample bottles.

Field duplicates provide a measure of the overall sampling and analytical precision. Precision estimates are influenced not only by the random error introduced by collection and measurement procedures but are also a reflection of the natural variability of the concentrations in the media being sampled.

Table C-2 presents the reported concentration data for each of the duplicate pairs, grouped by parameter. The table also shows the percent relative standard deviation (%RSD) calculated for each pair. In all but one case, the %RSD was well within the precision objective established in the study project plan (Pitz, 2009a). The 9/28/2009 duplicate pair %RSD for orthophosphate-P was >40%, greater than the study precision objective.

This high value is assumed to be related to the low concentration of the sample; as a general rule, precision estimates are less representative of random error as measured values approach the analytical detection limit.

With the qualifications described above, the water quality data results generated during this study are judged to be of good quality and acceptable for use in support of the project goals.

Table C- 1. Field blank results.

Sample ID	Sample Date	Chloride	Total dissolved solids (TDS)	Sulfate (SO_4)	Sodium (Na)	Dissolved organic carbon (DOC)	Ammonium-N (NH_4-N)	Nitrite-N (NO_2-N)	Nitrate-N (NO_3-N)	Orthophosphate-P (OP)	Total dissolved phosphorus (TDP)
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
WTPGW-FB	8/31/09	<0.10	<10	<0.30	**0.345**	**1.8**	<0.010	<0.022	<0.022	<0.0030	<0.0050
WTPGW-FB	9/28/09	<0.10	<10	<0.30	**0.419**	**1.5**	<0.010	<0.022	<0.022	<0.0030	<0.0050

Bold indicates the analyte was detected in the sample.

Table C- 2. Field duplicate results (all concentrations in mg/L).

Station	Date	Concentration	Qual.	RSD%	Mean RSD%
Chloride					
AGT415	8/31/09	36.8			2.1
AGT415dup		36.3		1.0	
AGT424	9/28/09	25.6			
AGT424dup		26.8		3.2	
Total dissolved solids (TDS)					
AGT415	8/31/09	301			0.5
AGT415dup		303		0.5	
AGT424	9/28/09	388			
AGT424dup		385		0.5	
Sodium (Na)					
AGT415	8/31/09	49.6			8.8
AGT415dup		47.1		3.7	
AGT424	9/28/09	51.8			
AGT424dup		42.5		**13.9**	
Sulfate (SO_4)					
AGT415	8/31/09	0.30	U		0.1
AGT415dup		0.30	U	0.0	
AGT424	9/28/09	44.3			
AGT424dup		44.2		0.2	
Dissolved organic carbon (DOC)					
AGT415	8/31/09	5.4			1.4
AGT415dup		5.5		1.3	
AGT424	9/28/09	4.5			
AGT424dup		4.6		1.6	
Nitrite-N (NO_2-N)					
AGT415	8/31/09	0.022	U		0.0
AGT415dup		0.022	U	0.0	
AGT424	9/28/09	0.022	U		
AGT424dup		0.022	U	0.0	
Nitrate-N (NO_3-N)					
AGT415	8/31/09	0.022	U		0.0
AGT415dup		0.022	U	0.0	
AGT424	9/28/09	0.022	U		
AGT424dup		0.022	U	0.0	
Ammonium-N (NH_4-N)					
AGT415	8/31/09	7.60			5.3
AGT415dup		7.40		1.9	
AGT424	9/28/09	3.43			
AGT424dup		3.03		8.8	
Orthophosphate-P (OP)					
AGT415	8/31/09	0.0607			**24.3**
AGT415dup		0.0549		7.1	
AGT424	9/28/09	0.0036			
AGT424dup		0.0066		**41.6**	
Total dissolved phosphorus (TDP)					
AGT415	8/31/09	1.84			2.5
AGT415dup		1.96		4.5	
AGT424	9/28/09	0.792			
AGT424dup		0.799		0.6	

U – the analyte was not detected at or above the reported result.
Bold indicates a value above the measurement quality objective.