RIVERBANK FILTRATION ALONG THE WABASH RIVER IN TIPPECANOE COUNTY

STREAM-AQUIFER CHARACTERIZATION
AND YIELD ESTIMATES
TEST WELL SITES 1 AND 2

Prepared for:
State of Indiana

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1.0 INTRODUCTION

The State of Indiana has identified the need to assess the feasibility of developing a large-scale water supply in Central Indiana. The area identified for investigation is along the Wabash River where it crosses an unconsolidated aquifer in the shallow subsurface. The analysis focuses on evaluating the potential for water production from a series of radial collector wells (collector wells) located along the Wabash River downstream of West Lafayette.

This document presents the results of exploration and testing at the first two potential collector well sites (Sites 1 and 2), conducted on a single 70-acre parcel (Parcel 1) on the south bank of the river downstream of West Lafayette (Figure 1). The exploration and testing program at Parcel 1 was conducted to characterize the hydrogeologic setting and determine critical aquifer properties used for predictive modeling. Results from the field investigation were incorporated into a previously developed regional groundwater flow model (INTERA, 2023) to estimate the potential yield by simulating collector wells located on Parcel 1.

A collector well consists of a circular central caisson sunk into the ground with horizontal screens (laterals) at the bottom of the caisson that are hydraulically jacked into the aquifer sediments. The planned collector wells along the river will be located adjacent to the river and will utilize riverbank filtration (RBF) to sustain high yields and provide quality source water. By design, an RBF well induces recharge of river water through the riverbed sediments.

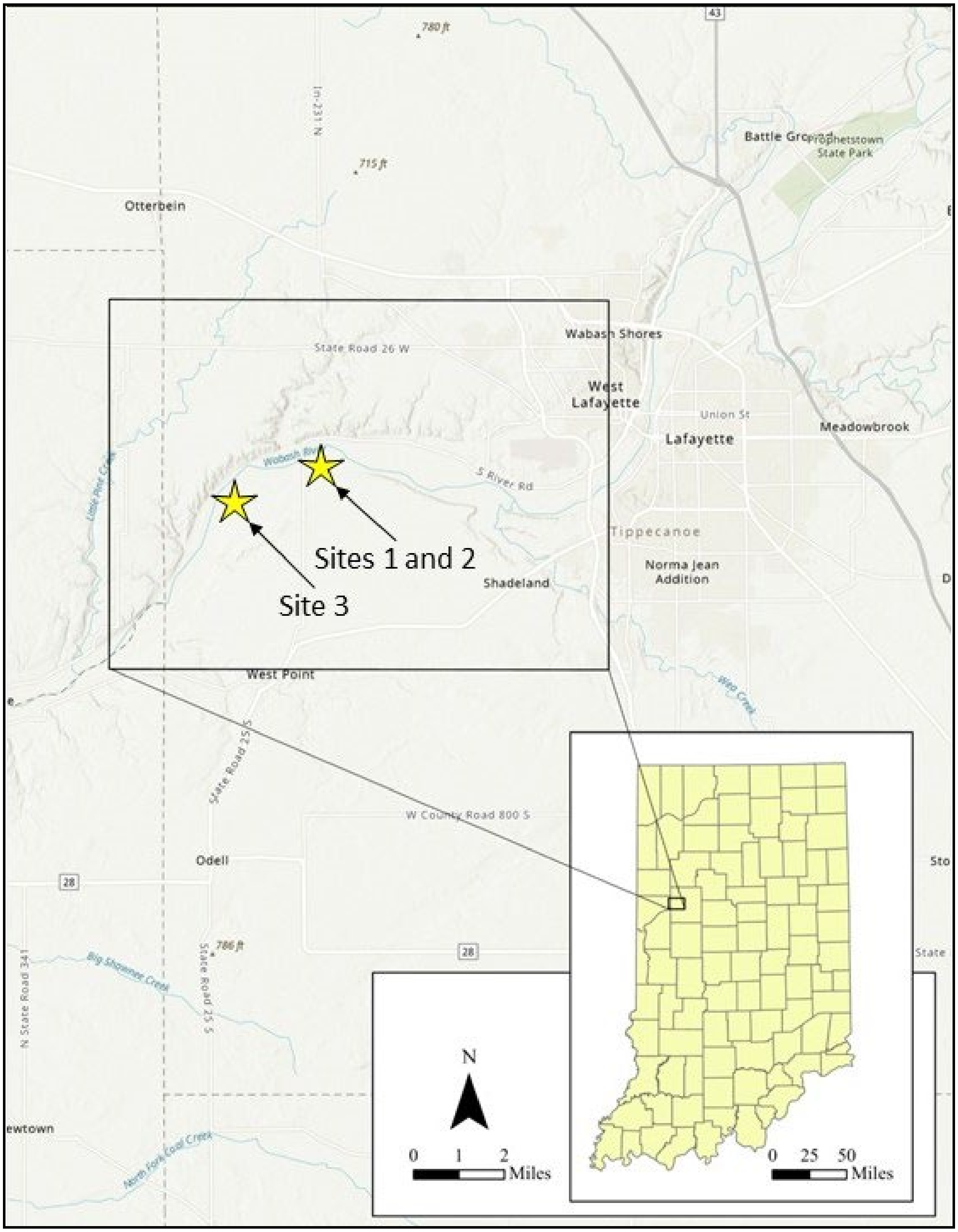


Figure 1. Location of target area and Test Well Sites 1, 2, and 3 along the Wabash River in Tippecanoe County.

2.0 PROCESS FOR PRELIMINARY DESIGN OF HORIZONTAL COLLECTOR WELLS AND YIELD ESTIMATES

Producing an estimate of the yield of a collector well prior to construction requires expert knowledge of groundwater mechanics (groundwater-surface water interactions in particular), field testing and analysis, and collector well design, construction, and operation.

The process followed for evaluating yield includes geologic exploration, aquifer testing, analysis of aquifer test data to evaluate best-fit hydraulic parameters, a conservative collector well design, seasonal yield evaluation, and a predictive uncertainty analysis. This process is illustrated in Figure 2. Details and results of each step are summarized below and expanded upon in the report.

2.1 Geologic Exploration

Extensive local and regional exploration was conducted.

- A regional, conceptual geologic model was constructed using existing geologic coverages from the Indiana Geological and Water Survey and private well logs in the region available from the Indiana Department of Natural Resources.

- At Parcel 1, seventeen borings were logged and analyzed.

- Finally, a regional AEM geophysical survey of the area was conducted (Abraham and other, 2023), and the results incorporated into the geologic model.

Conclusions from the exploration is that there is a thick regional sand and gravel aquifer adjacent to the Wabash River in the target area. Near the river, there is an 80 to 90 foot thick sand and gravel aquifer overlying bedrock or a basal clay layer. Local borings show the aquifer to be very homogeneous at each site.

2.2 Aquifer Testing

Aquifer testing was conducted to evaluate the critical hydraulic design parameters needed for the preliminary collector well design and yield analysis.

- Lithologic borings were converted to monitoring wells and equipped with pressure transducers to monitor groundwater levels. Shallow piezometers were installed near the river and equipped with pressure transducers to measure groundwater levels near the river. Stilling basins were installed in the river and instrumented with pressure transducers to monitor river stages.

- A long record of ambient monitoring was collected prior to site testing.
- A test production well (test well) was drilled, constructed, and developed at each of the three test sites.
- 72-hour, constant rate tests were performed at three test sites. During testing at each site, water levels in multiple monitoring wells and piezometers were recorded, and river stages were recorded in stilling wells. 24 hours of recovery data was collected at the conclusion of pumping.
- A GPS survey was conducted by American Structurepoint at all three well sites to tie the test wells and monitoring points to a common horizontal and vertical datum.

Results from the testing include time series records of both water elevation and drawdown prior to pumping, during pumping, and during recovery at all monitoring wells, piezometers, and stilling wells.

2.3 Analysis of Aquifer Test Data

All test data were analyzed to evaluate the hydraulic properties of the aquifer, including the aquifer transmissivity and streambed resistance of the Wabash River.

- Initial estimates of transmissivity and streambed resistance were made using standard, approximate methods (Rorabaugh, 1956) to provide an initial range of property values.
- Transient models of the pumping tests were developed using TTim software (Bakker, 2013; Bakker, 2023). The models were calibrated to drawdown records at the monitoring wells and river. Results of the analysis include multiple combinations of transmissivity and resistance (multiple realizations) that produce similar calibration attributes.
- Additional information was incorporated into the analysis to narrow the range of potential streambed resistance values. Steady-state groundwater models were developed for each test site. The models were calibrated to: static conditions prior to

pumping, near-static conditions during pumping, and drawdown. The static site conditions, particularly the elevation of the river relative to water elevations in the monitoring wells, provides information about the resistance of the streambed. The steady-state models were used to identify the best fit set of hydraulic parameters within the multiple realizations obtained from the transient analysis.

- This stepwise approach to evaluating the hydraulic parameters was followed to minimize the uncertainty of the individual hydraulic parameters.

Conclusions of the aquifer test analysis include the best-fit hydraulic parameters at each site, and multiple realizations of parameters from the transient analysis. Water level data obtained from the monitoring wells during testing indicates a very homogeneous aquifer at all test sites, with high transmissivity and good connection to the river, which are conducive to high collector well yields. The uncertainty of the hydraulic properties was significantly reduced through the extensive testing and analysis performed.

2.4 Preliminary Collector Well Design and Yield Estimate

Steps taken to develop a conservative yield estimate for collector wells constructed at the sites are presented below.

- Conservative values were chosen to be used as design parameters based on the best-fit hydraulic parameters.
- Seasonal stage-frequency curves for the Wabash River were developed for each test site. The curves provide seasonal low flow and low stage water levels to be used as boundary conditions in the yield model.
- A standard collector well design was chosen for each site, including: a minimum 200-foot setback from the riverbank, six evenly spaced 200-foot screened laterals, and a 20-foot diameter central caisson. The laterals are placed 17 feet above the aquifer base, and minimum pumping level in the caisson is set at 15 feet above the laterals. This allows for 10 additional feet of drawdown in the caisson to increase yield if construction difficulties are encountered.
- The construction process introduces the largest parameter uncertainty associated with yield estimates. During installation of the lateral screens in the collector well, a skin

resistance develops around the screens due to the natural formation collapsing around the screen. That skin resistance is unknown prior to construction and performance testing of the well. An average and a high skin resistance were specified to provide a range of possible well yields.

- Regional flow was not included in the yield model. Within the model, the river is assumed to be the source of all groundwater discharging to the well. This is a conservative assumption for the purpose of estimating yield.

- A seasonal yield analysis was conducted using seasonal low and average river stages, and the design hydraulic parameters from the aquifer testing and analysis. The yields are evaluated using GFLOW groundwater modeling software. Winter yields estimated with GFLOW were reduced 30% to account for the higher viscosity of the cold river water entering the aquifer.

2.5 Analysis of Predictive Uncertainty

The uncertainty of the hydraulic parameters was minimized by extensive testing and analysis programs. The effects of the remaining uncertainty on the predicted yield of the collector wells were then investigated, including a worst-case lower bound that assumes the river is in direct connection with the aquifer.

- Results of the yield model with design parameters based on the best parameter fit to all data, with average and high lateral resistances are reported.

- Yields for alternate realizations of parameters are evaluated to show the likely range of uncertainty in the best fit yield estimate. Note that the alternate realizations are calibrated to drawdowns only – they do not include calibration to static and pumping water elevations.

- A yield model was developed for the extreme case of the river in direct connection with the aquifer and low aquifer hydraulic conductivity for the lowest feasible bound on yield. This is the lowest yield case as the collector well yield is sensitive to lateral arm resistance and low hydraulic conductivity translates to the high lateral arm resistance.

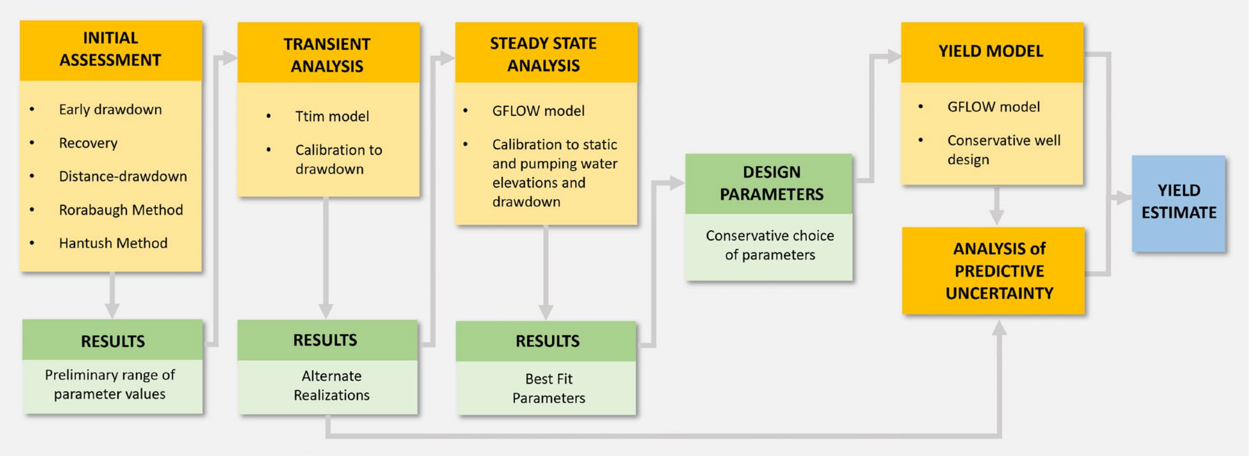


Figure 2. The process of preliminary design of a horizontal collector well: assessment of aquifer testing data through preliminary design and yield estimate.

3.0 SITE 1 AND 2 DRILLING

The field program at Parcel 1 included: drilling sonic test borings, logging geologic sediments from the borings, installation of seventeen monitoring wells, installation of two test production wells (test wells), two aquifer tests, and water-quality sampling. In addition, a geophysical survey was completed throughout the region. The survey was conducted by Aqua Geo Frameworks using an aerial electro-magnetic (AEM) method to fill in data gaps between existing well log information (Abraham and others, 2023). Results from the field program were integrated into a predictive modeling analysis (Section 6.0).

3.1 Test Borings

Seventeen exploratory test boreholes were drilled on Parcel 1 to characterize the lithology of the unconsolidated material (Figure 3). All test borings were advanced to bedrock with a sonic drill rig to depths ranging between 96 - 146 feet below ground surface (bgs). Continuous cores were collected with a 6-inch diameter core barrel. All test borings were completed as monitoring wells to support data collection during aquifer testing. Lithologic descriptions and well construction logs are included in Appendix A.

To begin the investigation, seven borings were drilled parallel to the river (MW-1 – MW-7), with an additional two on the south side (MW-8 and MW-9) and one on the west side of Parcel 1 (MW-10). The first test well (TW-1) was drilled just south of MW-5 and the second (TW-2) was drilled between MW-1 and MW-2 (Figure 3). The locations of these wells were selected based on results from the test borings which indicated the potential for Parcel 1 to support two collector wells. Additional monitoring wells were installed at the south side of the parcel (MW-11), along the river (MW-12, MW-13, and MW-14), along the eastern tree line (MW-15 and MW-16), and in the middle of the parcel (MW-17) (Figure 3). The additional monitoring wells were installed to gather more comprehensive geologic samples and to support data collection during aquifer testing.

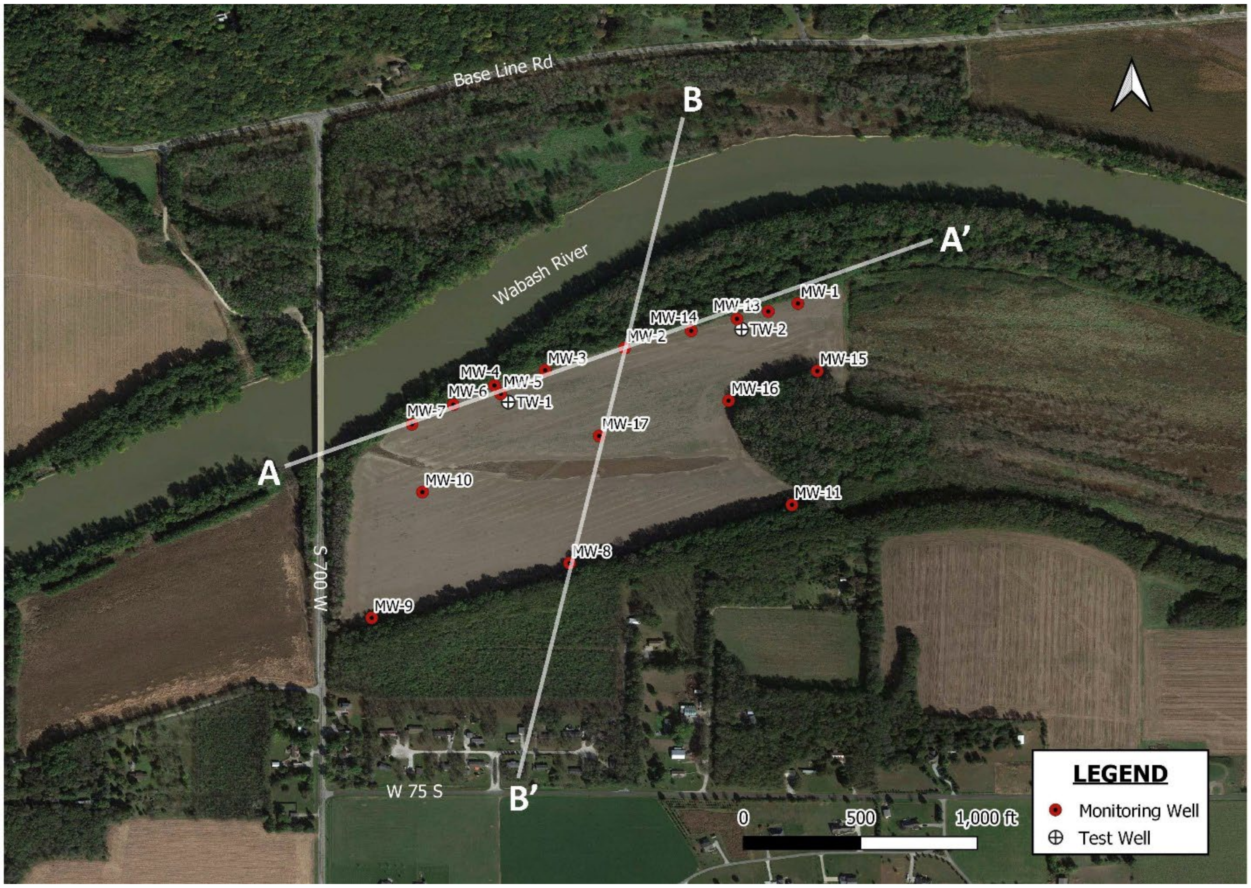


Figure 3. Location of monitoring wells (MW) and test wells (TW) installed at Sites 1 and 2. Also shown is the location of geologic cross-sections A-A' and B-B'.

3.2 Conceptual Geologic Model

The lithologic information gathered during drilling and AEM results were used to refine a three-dimensional (3D) conceptual geologic model (CGM) of the aquifer system, described in INTERA (2023). The 3D CGM illustrates the aquifer system and surrounding area and was used as input for the conceptual aquifer model.

The aquifer system in the area consists of large bodies of highly permeable unconsolidated sand and gravel which were deposited as glacial outwash or alluvial valley fill (Fenelon and Bobay, 1994). These permeable sediments fill both the recent alluvial valleys as well as the ancient valleys eroded into the bedrock by pre-glacial drainage. The bedrock topography reflects the regional, pre-glacial drainage system that converged into a trunk valley near Lafayette, called the Lafayette Bedrock Valley (historically referred to as the Teays-Mahomet Bedrock Valley) (McBeth, 1901; Bleuer, 1991; Wayne, 1956).

Glacial advances that shaped the bedrock surface also deposited sediments including clay, silt, sand, gravel, and cobbles with various sorting and layering. Unconsolidated deposits in the area range from thick sections of hydrologically unproductive glacial till with high contents of clay and silt to thick sections of outwash and alluvium consisting of highly productive sands and gravels. The physical characteristics of these sediments play a role in determining the capacity of the aquifer system.

3.3 Geologic Cross Sections

Results of the test drilling show that the underlying stratigraphy at the site is consistent with the regional setting. Transect locations for two geologic cross sections are shown on Figure 3. Cross section A-A’ includes the ten borings along the river (Exhibit A), and cross-section B-B’ runs perpendicular to the river, through the center of Parcel 1 and includes MW-2, MW-17, and MW-8 (Exhibit B).

In general, there is approximately 10 to 15 feet of clay and fine sand at the surface that overlies a laterally continuous zone of sand and gravel that has an average thickness of 90 feet (Exhibit A). The permeable zone of sand and gravel is comprised of multiple distinct layers of sands and gravels. At the top of this sand and gravel formation, there is a 20 to 30 feet thick upper sand layer which lies above about 5 feet of gravel. Beneath the gravel layer is a middle sand zone about 10 to 25 feet thick overlying 40 to 48 feet of lower sand. Within the lower sand are intermittent layers of silty sand and gravel varying in thickness from 3 to 13 feet. Underlying the lower sand is a continuous layer of basal silt and clay approximately 20 to 35 feet thick. Shale bedrock lies beneath the silt and clay confining unit starting at 115 to 136 feet below ground surface (bgs). Borings located perpendicular to the river show similar results, with 10 – 15 feet surficial clay and soil layer that lies above a sand and gravel zone about 90 feet thick (Exhibit B).

4.0 AQUIFER TESTING

Two separate aquifer tests were conducted at Parcel 1. Each test well was pumped at a constant rate of approximately 2 million gallons per day (MGD) for a standard length of 72 hours. Each test was performed by pumping one well at a constant rate and continuously measuring the response in water levels in each monitoring well on Parcel 1. The two aquifer tests were conducted between June 25 and July 16, 2023. The primary objective of the testing was to determine the hydraulic properties of the water-bearing zone and the degree of hydraulic connection to the river.

4.1 Test Set-up

Two 12-inch diameter test wells (TW-1 and TW-2) were drilled and constructed on opposite sides of Parcel 1 (Figure 3). The test wells were drilled with a mud rotary drill rig and constructed with 30 feet of hi-flow, stainless steel, 0.050-inch slotted screen manufactured by Alloy Machine Works. An artificial gravel pack sized for the screen slot size was installed around the screen (GP#3, Southern Products and Silica Company). The test wells were developed using airlifting and pump and surge techniques. Construction logs for the two test wells are included in Appendix A.

Each monitoring well was constructed with 2-inch PVC casing with 20 or 30 feet of 0.01-inch slot screen and equipped at the surface with a protective cover. Three well points were also installed to act as piezometers in locations inaccessible to the sonic drill rig (Figure 4). The piezometers were constructed using 3 feet long, 1.25-inch diameter, stainless steel drive point well screens. The screens were attached to 1.25 stainless steel pipe and advanced into the ground using a gas-powered posthole hammer.

A stilling well (SW) was constructed to continuously track changes in the stage (water level) of the river adjacent to Parcel 1 (Figure 4). The river stage was relatively stable over the duration of the testing period, varying by approximately 4 feet (Figure 5).

The location and elevation of each measuring point was surveyed by American Structurepoint. The location and construction information for the test wells, monitoring wells, piezometers, and stilling well are presented in Table 1.

Table 1. Characteristics of measuring points.

ID	Northing	Easting	Latitude	Longitude	Total Depth [FT]	Ground Elevation [FT]	TOC Elevation [FT]	TW-1 Distance [FT]	TW-2 Distance [FT]
MW-1	1881369	2967925	40.41359347°	-87.02883806°	126	511.68	514.26	1356	280
MW-2	1881119	2967184	40.41290819°	-87.03149794°	106	509.69	512.79	583	512
MW-3	1880995	2966844	40.41256822°	-87.03271911°	106	508.7	511.94	238	872
MW-4	1880909	2966627	40.41233375°	-87.03349853°	106	509.02	512.29	110	1104
MW-5	1880862	2966654	40.41220558°	-87.03340283°	96	510.41	513.27	56	1093
MW-6	1880802	2966452	40.41203961°	-87.03412656°	126	509.92	512.66	234	1303
MW-7	1880692	2966276	40.41173783°	-87.03476058°	146	509.95	512.84	429	1506
MW-8	1879916	2966949	40.40960806°	-87.03234294°	116	512.25	515.4	938	1500
MW-9	1879610	2966104	40.40876833°	-87.03538078°	109	513.63	516.39	1339	2260
MW-10	1880314	2966320	40.41070092°	-87.03460072°	106	510.52	513.84	621	1640
MW-11	1880244	2967900	40.41050594°	-87.02893008°	126	511.29	514.23	1342	1003
MW-12	1881325	2967799	40.41347214°	-87.02928931°	110	511.91	514.76	1224	152
MW-13	1881282	2967665	40.41335642°	-87.02976925°	112	511.79	514.66	1085	61
MW-14	1881216	2967469	40.41317439°	-87.03047425°	106	510.36	513.58	879	216
MW-15	1880991	2968008	40.41255617°	-87.02854°	116	509.93	512.83	1333	398
MW-16	1880825	2967629	40.41210211°	-87.02989908°	114	512.89	516.16	944	403
MW-17	1880627	2967076	40.41155839°	-87.03188753°	106	512.17	515.44	433	853
P-1	1880983	2966590	40.41253744°	-87.03363275°	15	512.44	516.21	193	1121
P-2	1881434	2967629	40.41377192°	-87.02989864°	25	508.74	514.27	1127	217
P-3	1881564	2967631	40.41413039°	-87.02989114°	25	510.2	514.88	1205	344
TW-1	1880816	2966686	40.41207856°	-87.03328736°	86	510.97	513.55	--	1079
TW-2	1881224	2967685	40.41319656°	-87.02969894°	94	510.85	513.93	1079	--

Notes: Nothing/easting projection in State Plane Indiana West (1302) NAD83 (CORS96); TOC = top of casing; '-' = Not Applicable

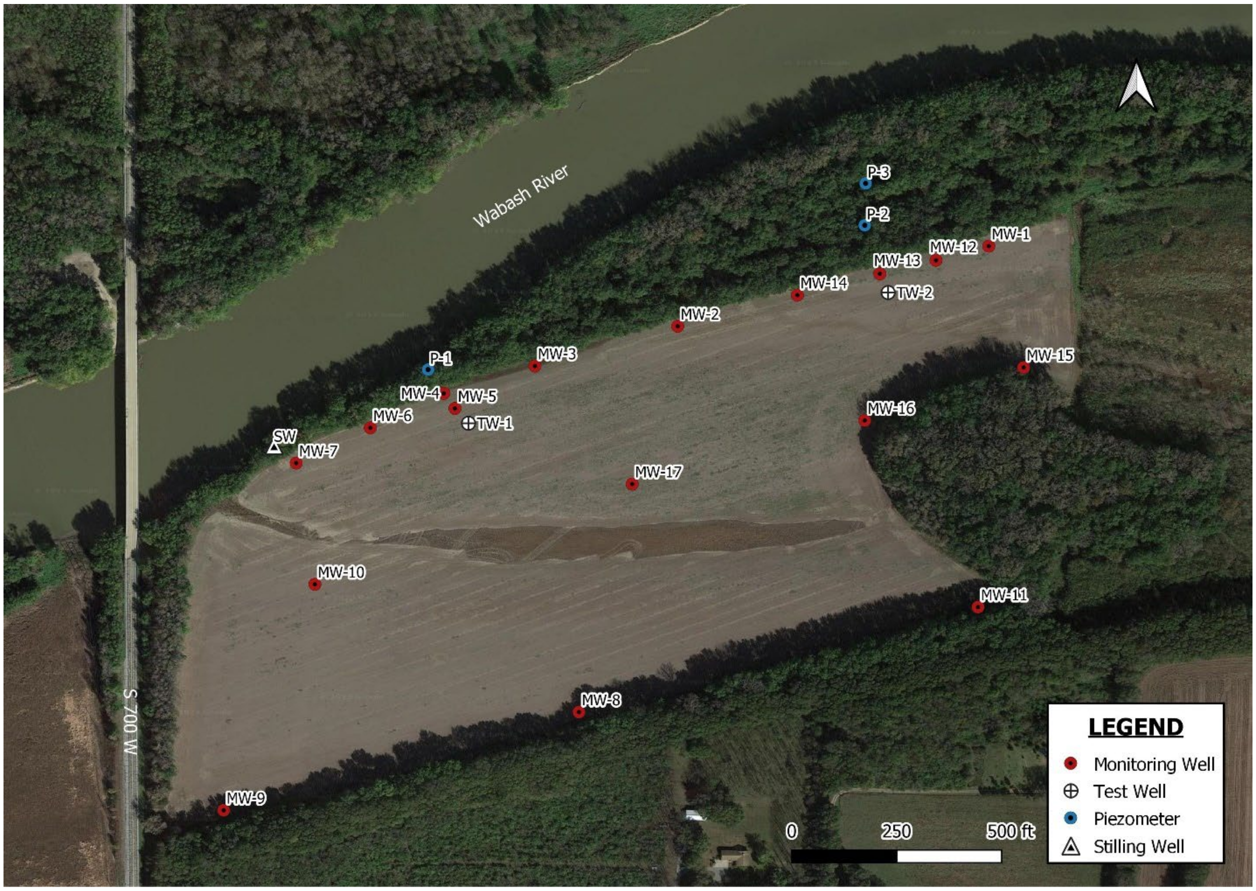


Figure 4. Layout of measuring points.

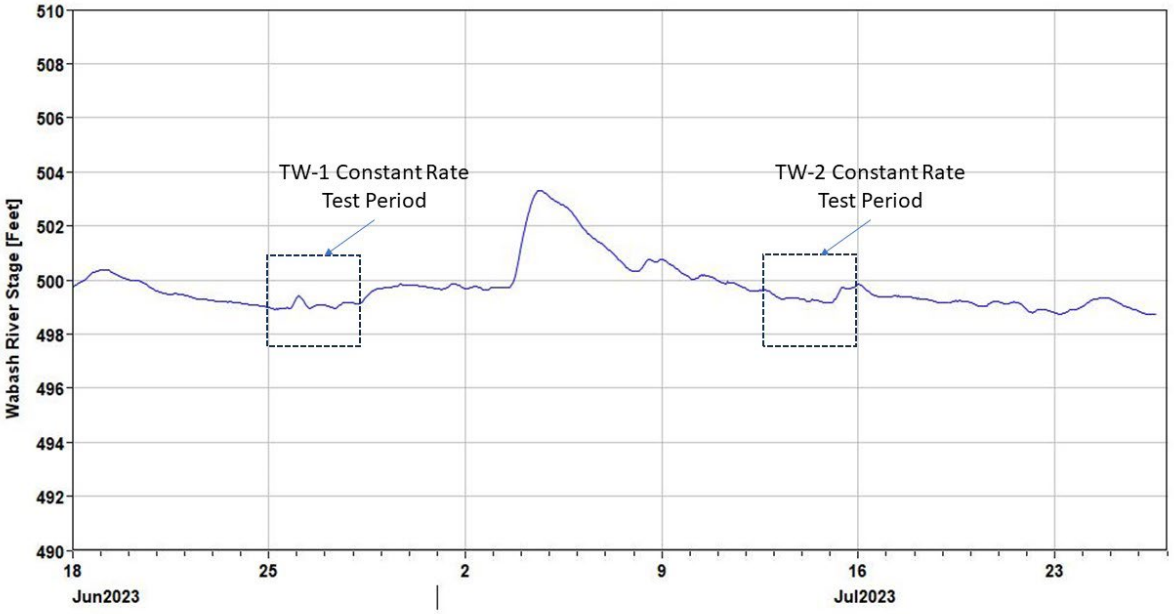


Figure 5. Wabash River stage recorded in stilling well over the testing period.

Each test well was equipped with a submersible pump connected to an 8-inch diameter temporary pipe discharging directly to the river. The pipe was equipped with an electronic flow meter to monitor the pumping rate. A step-drawdown test was completed at each test well to determine a pump rate that could be sustained for the duration of each constant-rate test.

During aquifer testing, water levels in the monitoring wells, piezometers, and stilling well were continuously monitored and recorded using remote pressure transducers designed to collect and store water level data at predetermined time intervals. Water levels were verified with manual measurements gathered using an electric water-level indicator. Water-quality samples were collected from the test wells during pumping and submitted to an independent laboratory for analysis.

4.2 Aquifer Tests

Two aquifer tests were conducted between June 25 and July 16, 2023. The primary objective of the testing was to determine the hydraulic properties of the water-bearing zone and the degree of hydraulic connection to the river.

4.2.1 Aquifer Testing at Test Well 1

Test Well 1 (TW-1), installed on the western side of Parcel 1 (Figure 4), was constructed with 30 feet of screen set at 54 to 84 feet bgs. A submersible pump was installed in the well with the intake location at 52 feet bgs.

A four-hour multiple rate step test was conducted on June 24, 2023 to select a pumping rate for the constant-rate test. During the step test, the well was pumped for one hour each at rates of 1040, 1330, 1430, and 1470 gpm. A rate of approximately 1430 gpm was selected for the constant-rate test based on results from the step test.

The constant-rate test was conducted between June 25 and June 28, 2023. The constant rate pumping started on June 25 at 9:30 AM and was terminated June 28 at 1:00 PM. With an average pumping rate of 1420 gpm, the total volume of water pumped during the test was approximately 6,425,780 gallons (19.72 acre-feet).

There was some precipitation in the area within 24 hours after the start of the test. The stage of the river was 498.9 feet NAVD 88 prior to the start of the test. The stage fluctuated throughout the test, varying from approximately 498.9 to 499.5 feet NAVD 88 (Figure 5).

Water samples were collected from TW-1 at 70 hours into the test. Drawdown observed in TW-1 after 72 hours of pumping was approximately 37.7 feet, indicating a specific capacity of 37.6 gpm/ft.

Water levels recorded in the measuring points responded accordingly to pumping and stage changes in the river (Figure 6). The maximum drawdown in nearby monitoring wells ranged from 0.32 feet at MW-9 to 3.2 feet at MW-5.

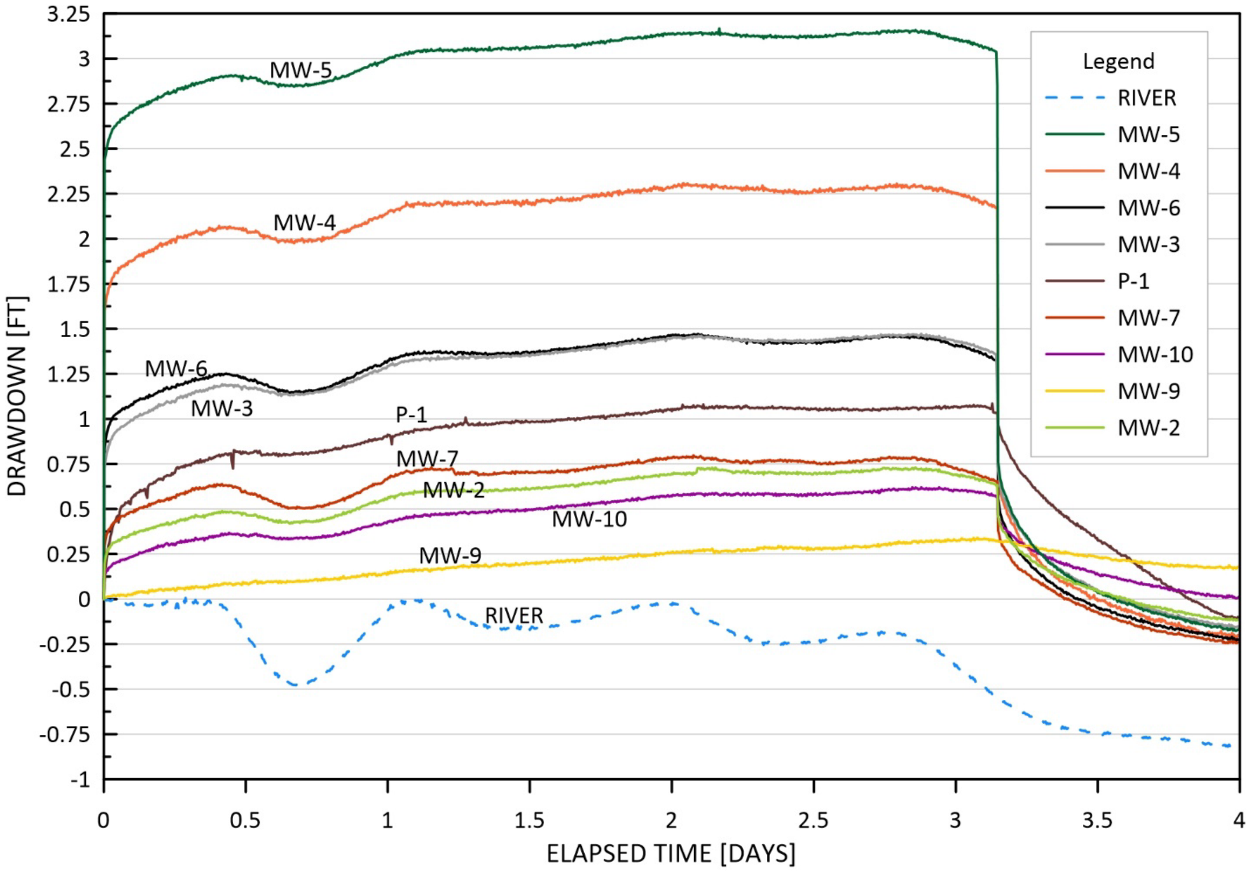


Figure 6: Drawdown results for TW-1 aquifer test.

4.2.2 Aquifer Testing at Test Well 2

Test Well (TW-2), installed on the eastern side of the parcel (Figure 4), was constructed with 30 feet of screen that was set between 63 and 93 feet bgs. A submersible pump was installed in the well with the intake located at 70 feet bgs.

A four-hour multiple rate step test was conducted at the TW-2 on July 12, 2023, to determine a specific capacity of the well and select a pump rate for the constant rate test. During the step test TW-2 was pumped for one hour each at rates of 1020, 1240, 1350, and 1380 gpm. A rate of 1350 gpm was selected for the constant-rate test based on results from the step test.

The constant-rate pumping test for TW-2 was conducted between July 13 and July 16, 2023. The test started on July 13 at 9:00 AM and was terminated July 16 at 9:12 AM. The pumping rate for the test was 1350 gpm, and the total volume of water pumped during the test was approximately 5,829,473 gallons (17.89 acre-feet). Water samples were collected from the test well at 26 hours into the test. Drawdown observed in TW-2 after 72 hours of pumping was approximately 43.1 feet, for an observed specific capacity of 31.3 gpm/ft.

There was some precipitation in the area during the TW-2 test period, about 48 hours after the start of the test. The water elevation in the river was approximately 499.3 feet NAVD 88 prior to the start of the test. The river fluctuated throughout the test, varying between 499.1 and 499.8 feet NAVD 88 (Figure 5).

Water levels in each monitoring well responded to pumping and river stage changes (Figure 7). The final drawdown in the nearby wells ranged from 0.5 feet at MW-11 to approximately 3 feet at MW-13.

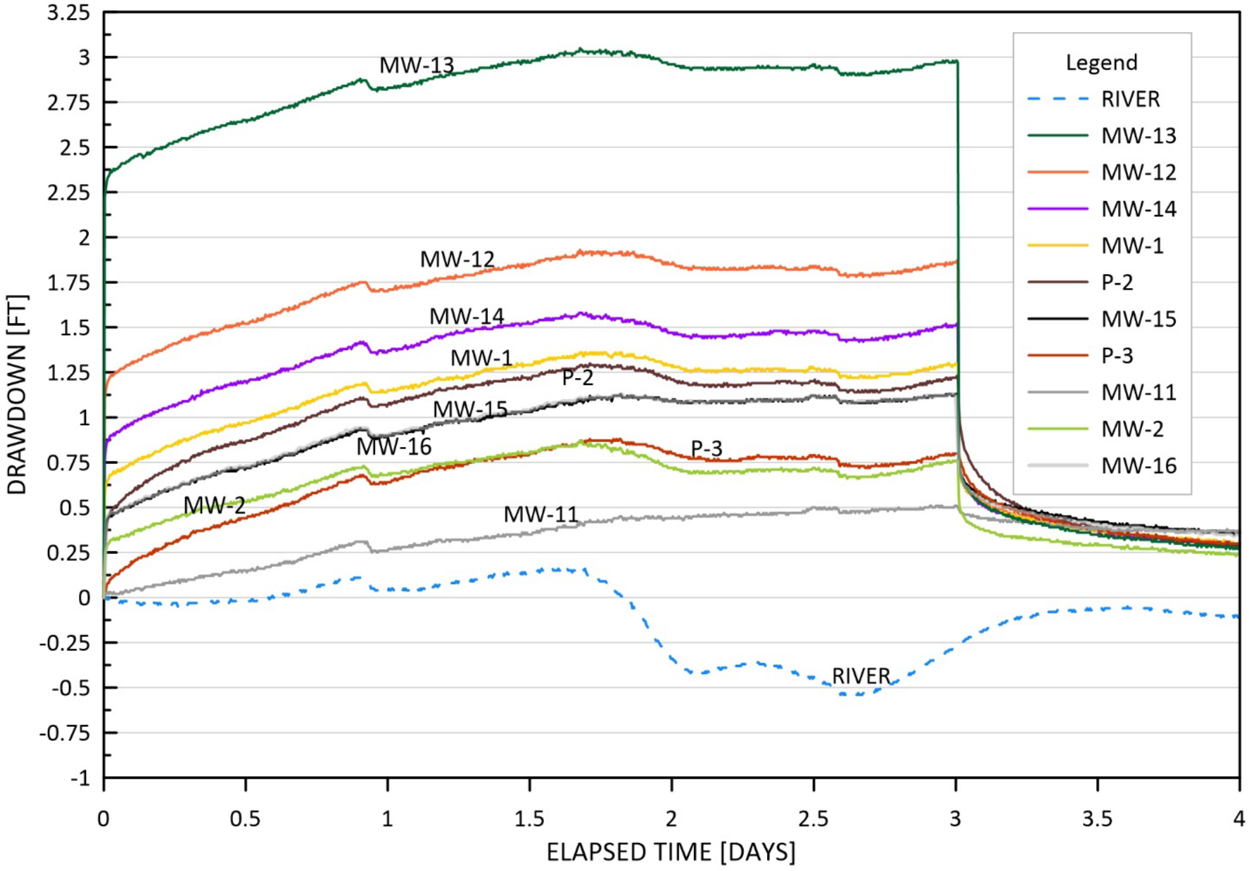


Figure 7: Drawdown results for TW-2 aquifer test.

5.0 AQUIFER TEST ANALYSIS

The aquifer test results from TW-1 and TW-2 were analyzed to estimate hydraulic conductivity of the aquifer and the hydraulic resistance between the bed of the river and the aquifer. Results from the tests were incorporated into the groundwater flow model analysis.

5.1 TTim Software

Specialized hydraulic software called TTim (version 0.5) was used to analyze the aquifer test results (Bakker, 2013; Bakker, 2023). The software, based on analytic elements, is designed for modeling transient, multi-layer flow and is better suited for analyzing RBF aquifer tests compared to traditional methods:

1. Flexibility in measuring point layout: TTim's approach eliminates the dependency on a predetermined design layout for monitoring wells. In contrast, traditional methods mandate that monitoring wells be precisely situated in lines perpendicular and parallel to the river, which can be restrictive or impractical in real-world scenarios, as was the case at TW-1 and TW-2.

2. Incorporation of river geometry: TTim empowers the user to explicitly integrate the river's actual geometry into their analysis. Traditional methods, on the other hand, often make the simplifying assumption that the river is a straight line within the section affecting an RBF system.

3. Dynamic river stage consideration: TTim enables the direct inclusion of changes in river stage in the analysis. In contrast, traditional methods necessitate data filtering based on an estimated or assumed loading efficiency for each measuring point, which can introduce needless uncertainty and complexity.

4. Hydraulic property integration: TTim's analytic element models facilitate the explicit derivation of the hydraulic property governing the connection between the river and the aquifer used in the predictive GFLOW model. This obviates the need for translating this parameter between models, as is common in traditional approaches.

In summary, TTim's use of analytic elements for RBF aquifer test analysis offers a flexible, accurate, and practical alternative to traditional methods, addressing limitations related to monitoring well layout, river geometry, river stage changes, and hydraulic property integration, ultimately leading to more robust results and a deeper understanding of the aquifer system.

5.2 Approach

The aquifer was modeled with TTim as a single, 75-foot thick layer of homogeneous, saturated material with a phreatic surface. The TTim model layout is shown in Figure 8. The river is represented by parallel sets of linesink strings as proscribed in Haitjema (2005). River stage changes observed during each test (Figure 6 and Figure 7) were incorporated as model input.

The primary objective was to optimize the performance of each test model by matching the modeled and observed response to pumping and stage changes recorded at select monitoring wells. The matching was achieved by manual adjustment of three key parameters:

- the horizontal hydraulic conductivity of the aquifer (Kh),
- the riverbed resistance to vertical flow (c),
- and the specific yield (Sy).

This iterative process aimed to achieve the best-fit representation of the aquifer's behavior and responses to various conditions based on the root mean square error (RMSE). The RMSE is an indication of average delta between predicted values from the TTim model and the observed response at select monitoring wells. For TW-1, this included the following eight monitoring wells: MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-9, and MW-10. For TW-2, this included: MW-1, MW-2, MW-11, MW-12, MW-13, MW-14, MW-15, and MW-16.

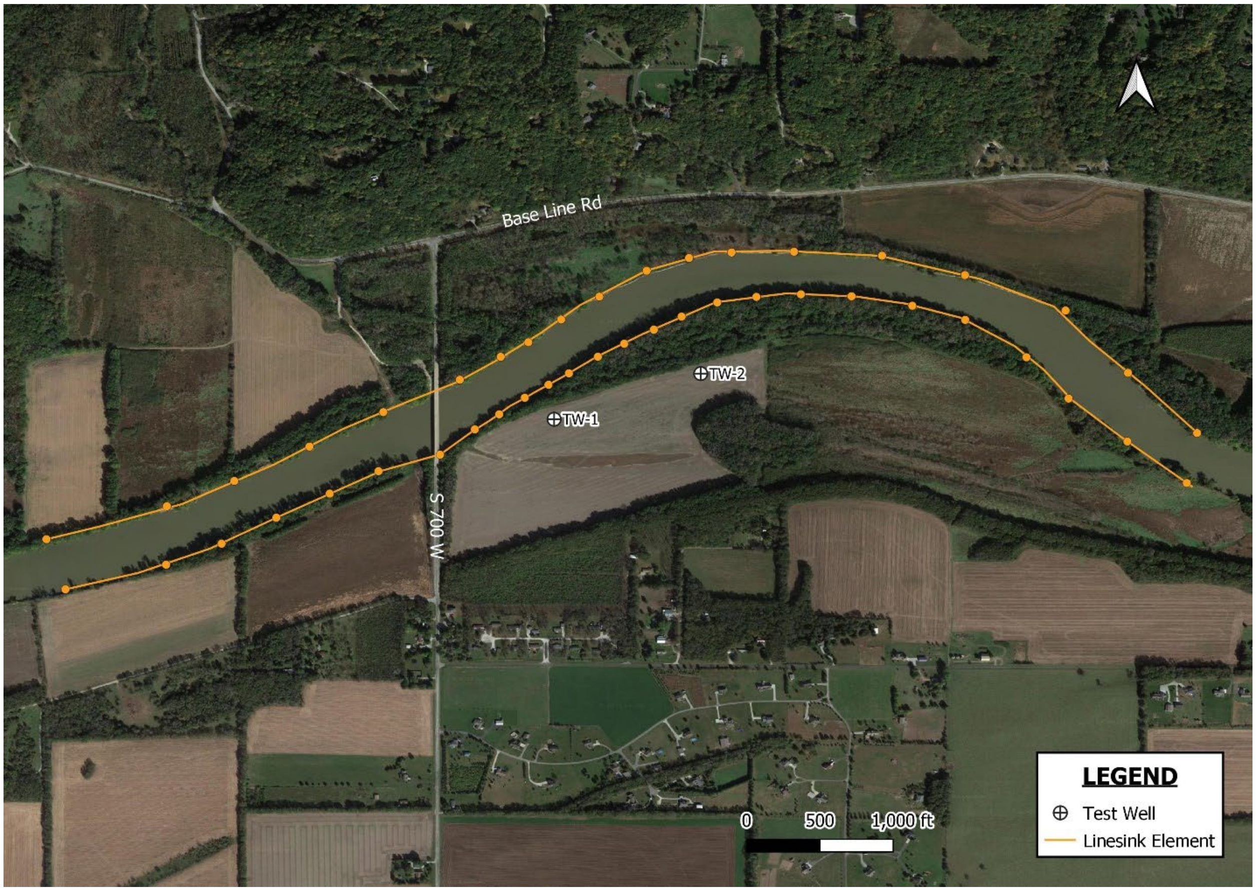


Figure 8. Layout of analytic elements used in TTim modeling analysis.

5.3 Results

Table 2 presents various best-fit parameter combinations from the TTim analysis for both TW-1 and TW-2 results. For TW-1, a specific yield of 0.04 resulted in the best fit to stage fluctuations with Kh=425-500 ft/day and c=0.75-2.5 days resulting in a good fit to water level changes. For TW-2, a specific yield of 0.08 resulted in the best fit to stage fluctuations with Kh=450-550 ft/day and c=0.1-1.5 days resulting in a good fit to water level changes.

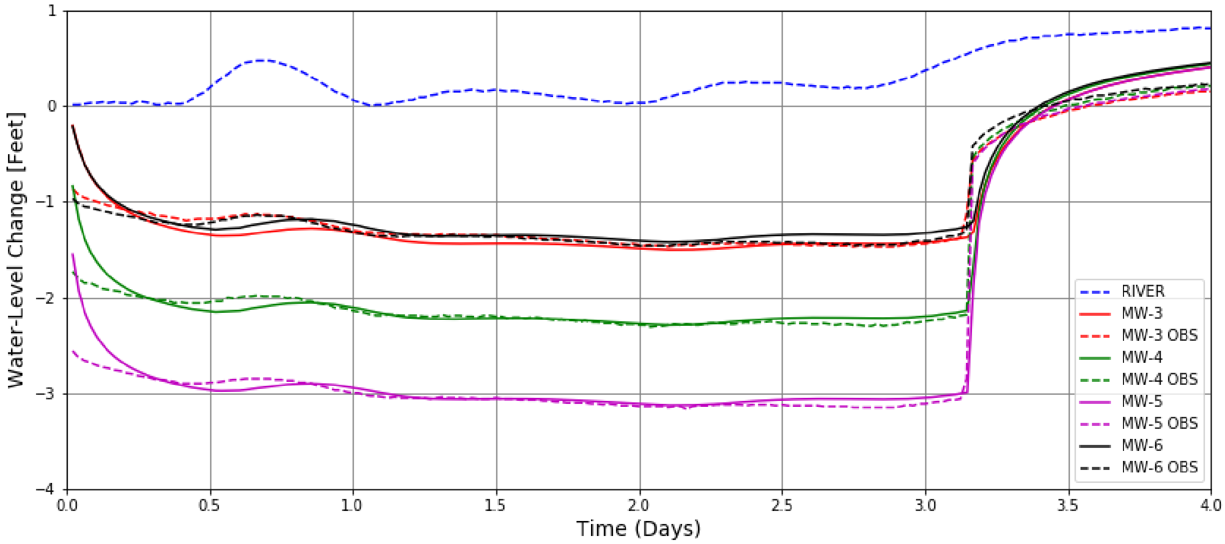
The range of RMSE values for both tests (0.161-0210 ft) represents approximately 5-7% of the observed range of drawdown, indicating a good fit between simulated and observed drawdowns. Simulated vs observed water-level changes are presented for the model run with the lowest RMSE for each test. For TW-1, this is the model run with values of Kh=500 ft/day and c=1.5 day (Figure 9). For TW-2, this is the model run with values of Kh=500 ft/day and a c=0.5 day (Figure 10).

The range of results from the both tests suggests that the value of Kh may be slightly higher and the value of c slightly lower at the TW-2 site compared to TW-1 (Table 2). However, in general the results are very similar, suggesting that the river-aquifer system exhibits homogeneity across the parcel. This consistency aligns with the conceptual aquifer model, reinforcing the validity and reliability of the model's representation of the system's behavior.

Results derived from a traditional technique to analyze RBF tests are in general agreement with the range of parameters derived from the TTim analysis. Using the results from MW-5 and MW-4 from the TW-1 test, the river-line method prescribed by Rorabough (1956) estimates a Kh=540 ft/day and a distance to the line source (a-distance) of 460 ft, which can be translated to c value of 0.75 days. Similarly, the results from MW-13 and P-2 from the TW-2 test estimates a Kh=480 ft/day and an a-distance of 475 ft, which can be translated to c value of 0.75 days.

Table 2. TTim model results for various parameter combinations resulting in a good fit to observed data for TW-1 and TW-2 tests.

Kh [ft/day]	c [days]	Sy -	RMSE [ft]
TW-1			
425	0.75	0.04	0.193
450	1	0.04	0.169
500	1.5	0.04	0.161
500	2	0.04	0.165
500	2.5	0.04	0.210
TW-2			
450	0.1	0.08	0.170
475	0.25	0.08	0.162
500	0.5	0.08	0.161
500	0.75	0.08	0.163
550	1.5	0.08	0.174



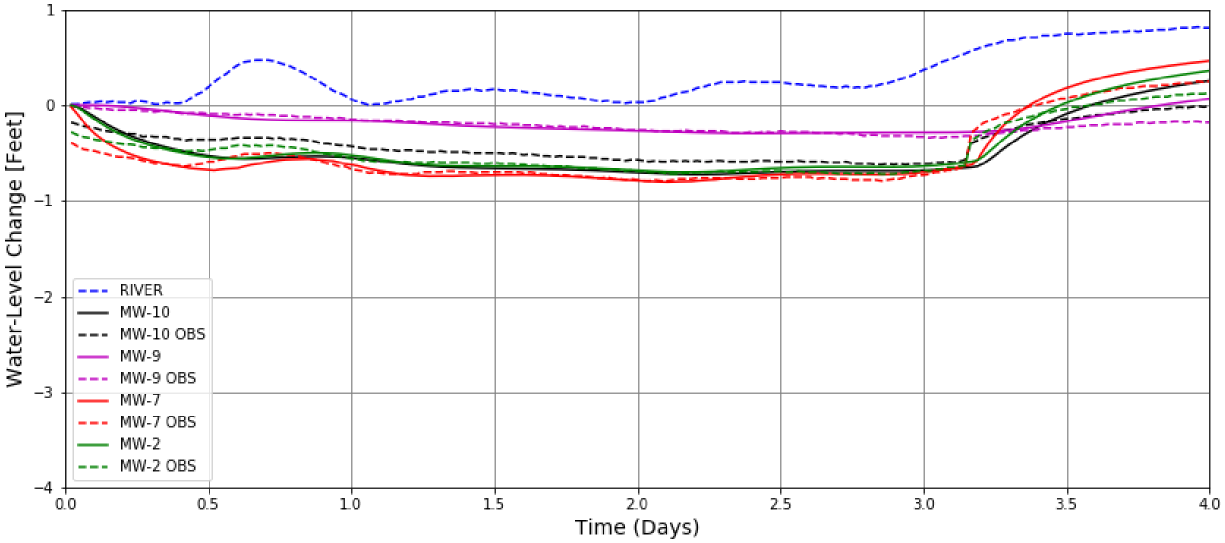


Figure 9. Simulated and observed water-level change for local monitoring wells (*top*) and other monitoring wells (*bottom*) during TW-1 test (Kh=500 ft/d, c=1.5 d, Sy=0.04).

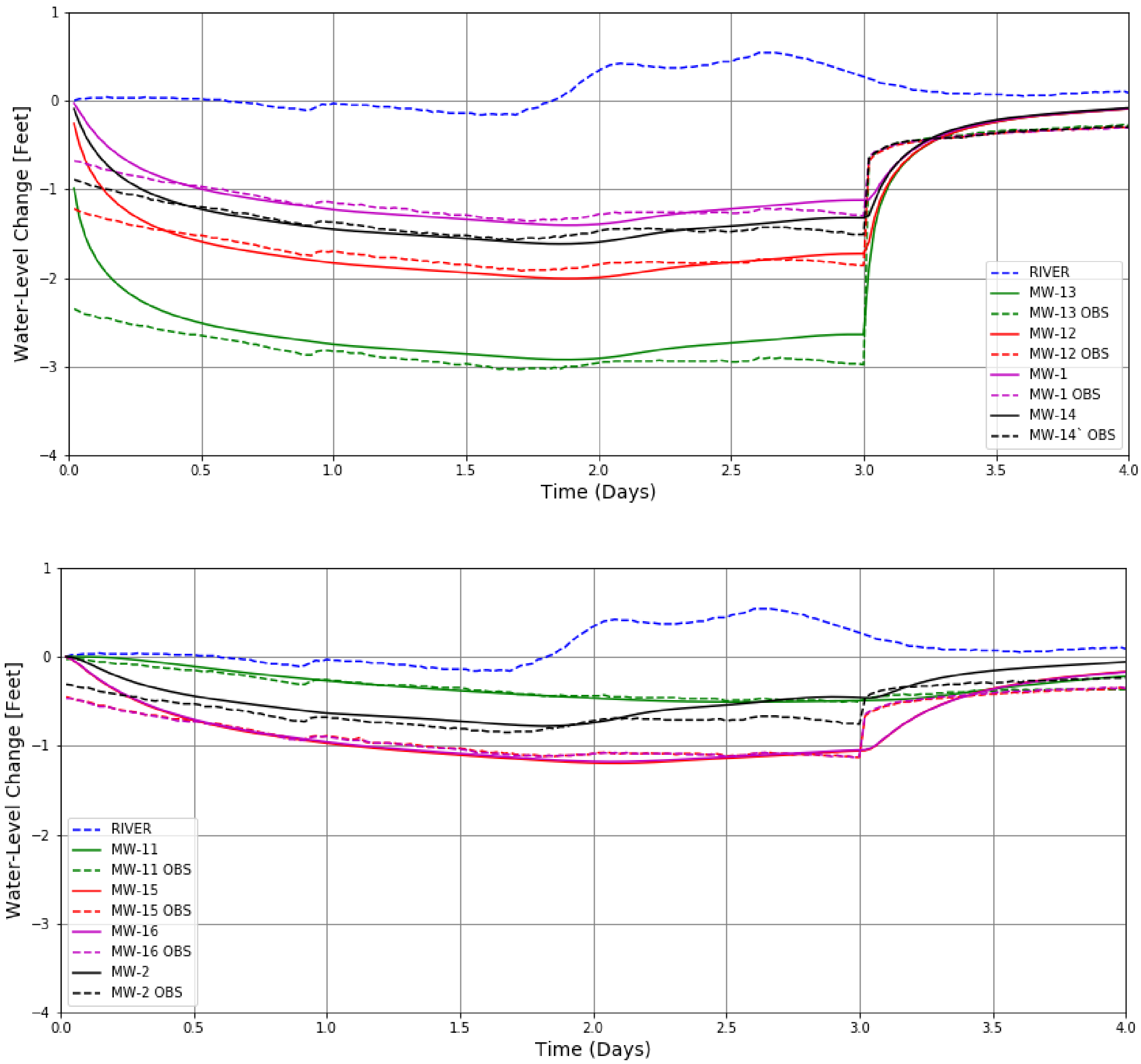


Figure 10. Simulated and observed water-level change for local monitoring wells (*top*) and other monitoring wells (*bottom*) during TW-2 test (Kh=500 ft/d, c=0.5 d, Sy=0.08).

6.0 PREDICTIVE MODELING ANALYSIS

Estimating the yield of a collector well requires knowledge of the hydraulic properties of the aquifer and river, regional groundwater flow conditions, and historic records of river stage and discharge. This information was obtained with high certainty by an extensive analysis of aquifer monitoring and testing data, as well as records of the daily stage and discharge of the Wabash River maintained by the USGS.

The properties of the collector well—which cannot be evaluated by field testing until the well is constructed—are as important as the aquifer and river properties in estimating the potential yield. These properties are greatly affected by construction methods and conditions encountered during construction, which may require design modifications to the well. These properties include the caisson depth and the elevation of the laterals (which can limit the drawdown in the caisson and can directly impact yield) and the length and alignment of the laterals which are often dictated by conditions encountered during construction. Finally, a skin resistance can form around the lateral screens caused both by hydraulically jacking pipes into the formation, and after inserting the screen, pulling the piping back out which causes the formation to collapse around the screen. These parameters related to the collector well are highly uncertain prior to well construction.

To deal with the uncertainty of the collector well properties, we used engineering judgement based on experience designing and constructing collector wells in similar settings, and by conservatively setting both well elevations and lateral lengths in the yield analysis. The skin resistance is based on post-construction well testing at hydrologically similar sites, followed by post-testing calibration of a yield model. This provides a range of potential lateral skin resistances that can be analyzed based on measured values at multiple sites. Note that these calibrated skin resistances include the effects of anisotropy that may be present at the collector well sites. Overall, during preliminary design, the objective was to provide a conservative, lower bound on the yield of each collector well design.

6.1 Approach

The previously developed regional GFLOW model was used to develop a collector well yield model. First, the model boundaries were refined based on the AEM survey (Abraham and other, 2023) and the 3D geologic model. Results from the two pumping tests were used to calibrate a steady-state model to match both observed static and pumping water levels in the aquifer, and drawdown at monitoring wells. This calibration was done to provide a final check on the results of the transient aquifer test analysis conducted with TTim software. In particular, the elevation of the groundwater relative to the river elevation provides additional information about the resistance of the streambed, not used in the transient analysis of drawdowns.

Then, a typical collector well design is represented in the model to assess potential yields. A range of collector well properties was investigated within the model including pumping levels in the caisson, seasonal water levels in the river, and the potential skin resistance along the laterals created by the collapse of the formation over the screens during construction.

Geometric parameters related to the aquifer and the river that are fixed in the model are summarized in Table 3 along with a description of the source of the data. The lateral extent of the model is defined by a combination of impermeable boundaries where the bedrock rises above the water table, and linesinks of specified discharge which provide the regional flow. Regional flow was calibrated based on matching the observed groundwater gradient across the site.

Table 3. Fixed geometric features specified in the yield model.

Feature	Units	Value	Source
Aquifer base elevation	ft, NAVD 88	410	Site borings
Aquifer top elevation	ft, NAVD 88	505	Site borings
Riverbed elevation	ft, NAVD 88	493	FIS river profile

6.2 Model Calibration with Aquifer Test Data

River stage and elevation, and groundwater levels at many monitoring wells at the site were monitored prior to, during, and after aquifer testing. A summary of the observed conditions prior to testing and conditions late in the aquifer testing are summarized in Table 4. These data were used as calibration points for the yield model. The model was calibrated to all three sets of observations (static, pumping, and drawdown) for both aquifer tests.

Table 4. Calibration data set for static and pumping elevations (feet, NAVD88) and drawdown (feet) for both aquifer tests.

	Static		Pumping		Drawdown	
Label	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**
MW-1	500.73	501.06	500.51	499.71	0.22	1.35
MW-2	500.84	501.12	500.14	500.4	0.70	0.72
MW-3	500.67	500.99	499.22	500.61	1.45	0.38
MW-4	500.55	500.88	498.29	500.67	2.26	0.21
MW-5	500.52	500.84	497.37	500.59	3.15	0.25
MW-6	500.38	500.70	498.94	500.55	1.44	0.15
MW-7	500.47	500.78	499.69	500.7	0.78	0.08
MW-9	502.22	502.34	501.96	502.12	0.26	0.22
MW-10	501.28	501.51	500.70	501.3	0.58	0.21
MW-11	502.30	502.48	502.01	501.95	0.29	0.53
MW-12	500.91	501.23	500.64	500.21	0.27	1.02
MW-13	501.14	501.46	500.86	498.44	0.28	3.02
MW-14	500.78	501.1	500.39	499.53	0.39	1.57
MW-16	501.16	501.44	500.71	500.26	0.45	1.18
TW-1	--	500.91	--	500.60	--	0.31
TW-2	500.83	--	500.53	--	0.30	--

The best-fit parameters obtained by model calibration are presented in Table 5, with a calibrated value for hydraulic conductivity of 500 ft/day for Test 1 and 550 ft/day for Test 2. A riverbed resistance of 2 days was obtained for both aquifer tests. Regional flow was estimated to be 200 to 300 ft^2/day; the value was evaluated by matching the observed static water levels across the parcel. These parameter values match closely the ranges obtained from the transient analysis of the test data. Values of 500 ft/day conductivity and 2 days riverbed resistance were chosen to represent aquifer and river conditions in the collector well yield model.

Table 5. Calibrated values of hydraulic parameters for aquifer tests 1 and 2.

Test	Property	Units	Calibrated Values
1	Aquifer hydraulic conductivity	ft/day	500
	Riverbed resistance	days	2
2	Aquifer hydraulic conductivity	ft/day	550
	Riverbed resistance	days	2
1, 2	Regional flow	ft^2/day	200-300

A cross plot of the observed and modeled water levels representing static and pumping conditions for both aquifer tests is shown in Figure 11. Figure 12 shows a cross plot for the aquifer drawdown. The RMSE for the residuals in Figure 11 is 0.22, which is 4.3% of the total observed range in water levels, indicating a good fit between observations and model results. The root mean square error of the drawdown residuals is 0.24, which is 7.9% of the observed range of drawdowns. In general, the model over-predicts the drawdown in the aquifer indicating the calibrated parameters will provide a conservative estimate of the aquifer yield.

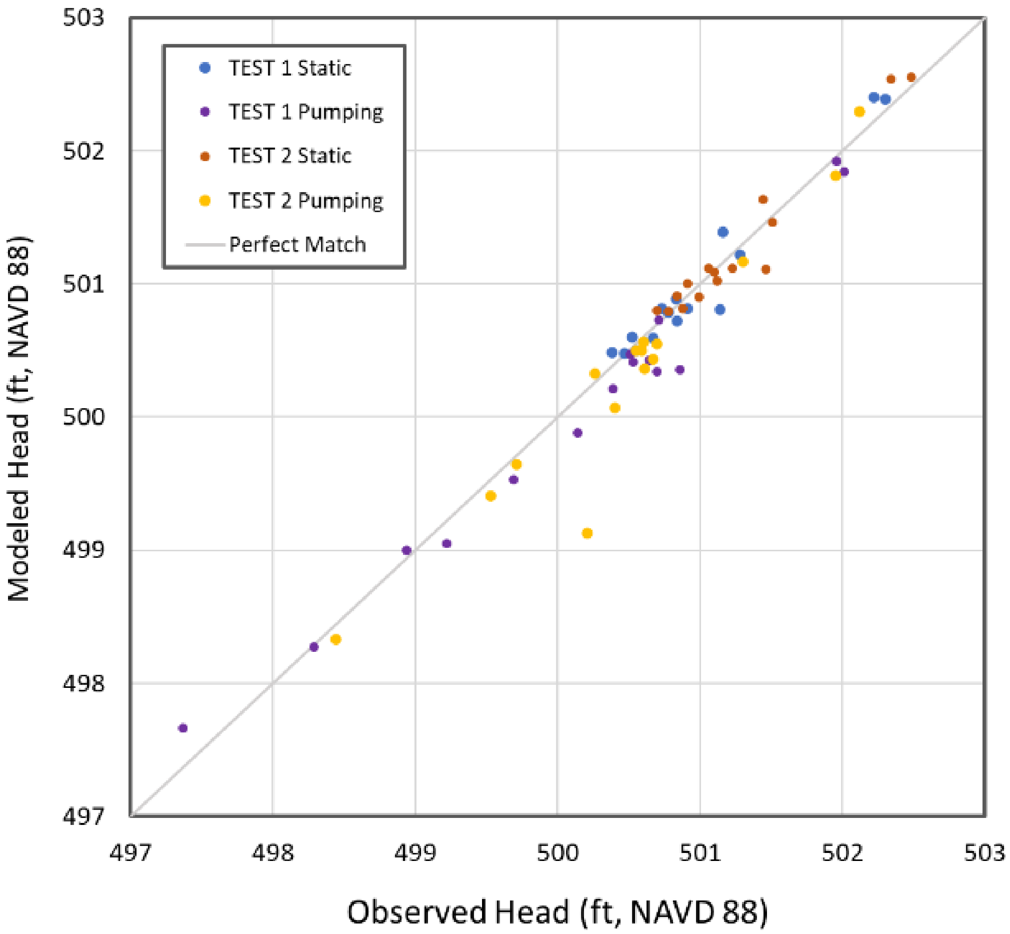


Figure 11. Cross plots of observed and modeled pumping and static water levels during TW-1 and TW-2 aquifer tests.

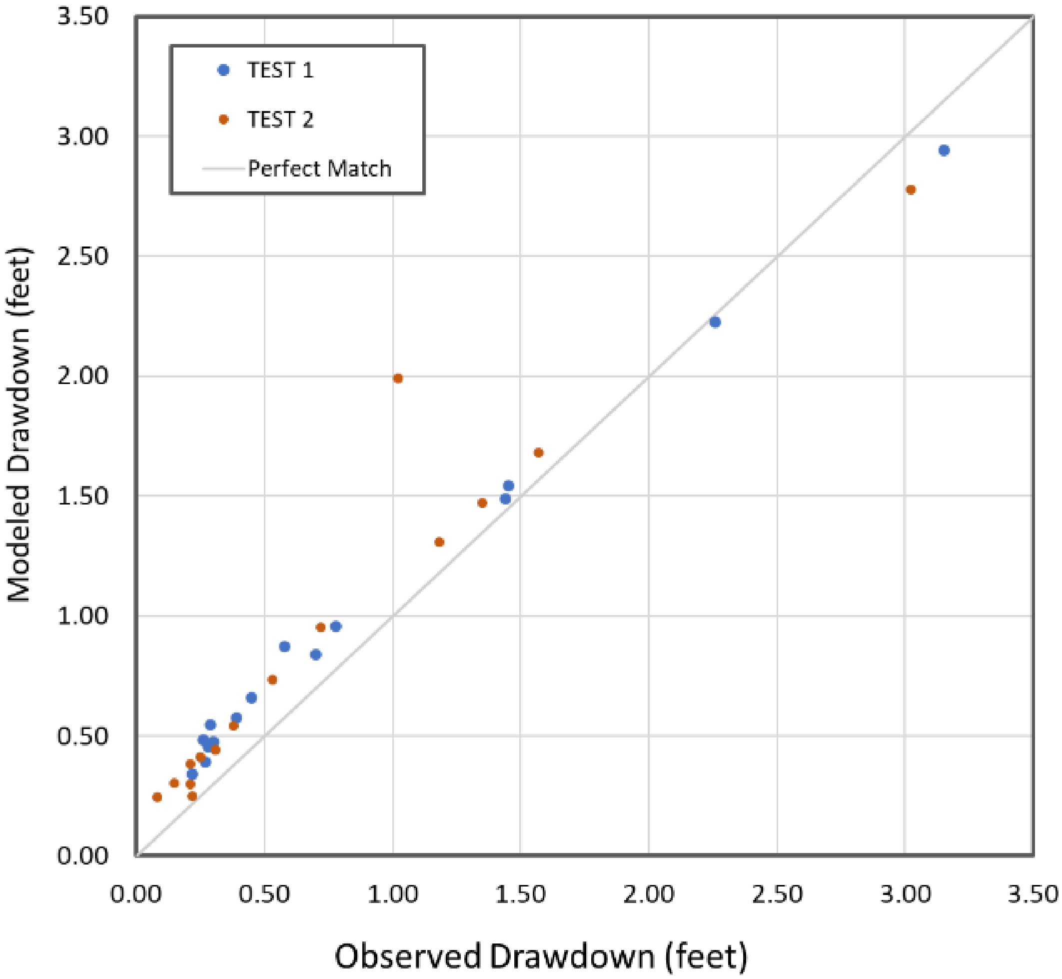


Figure 12. Cross plot of observed and modeled drawdown at monitoring wells for TW-1 and TW-2 aquifer tests.

6.3 Preliminary Collector Well Design and Model Parameters

A typical collector well design consisting of a 20-foot diameter caisson with 6 evenly spaced laterals, each with 10 feet of blank casing adjacent to the caisson and 200 feet of screen is represented in the model to assess potential yields. The lateral closest to the bank of the river was maintained at a minimum distance of 200 feet from the river.

Pertinent elevations are illustrated on Figure 13, including the centerline of laterals at 427 feet, and the minimum allowable water level in the caisson at an elevation of 442 feet. This provides a minimum of 15 feet of head over the laterals at maximum pumping rate, which is conservative, where collector wells often operate with as little as 5 feet of head on the laterals. This minimum water level allows for flexibility during construction if, for example, the caisson cannot be sunk to the full depth and the laterals elevations must be increased. Alternatively, it also allows for a second tier of laterals at centerline elevation of 434 feet if formation gradations require small screen openings resulting in high entry velocities.

The skin resistance of the laterals is specified to range from 0.01 days/foot to 0.02 days per foot. This range is based on post construction yield modeling of collector wells in similar geologic settings; the low value represents a typical average value for an individual lateral and the high value represents a low efficiency lateral for formations with hydraulic conductivity of 500 ft/day.

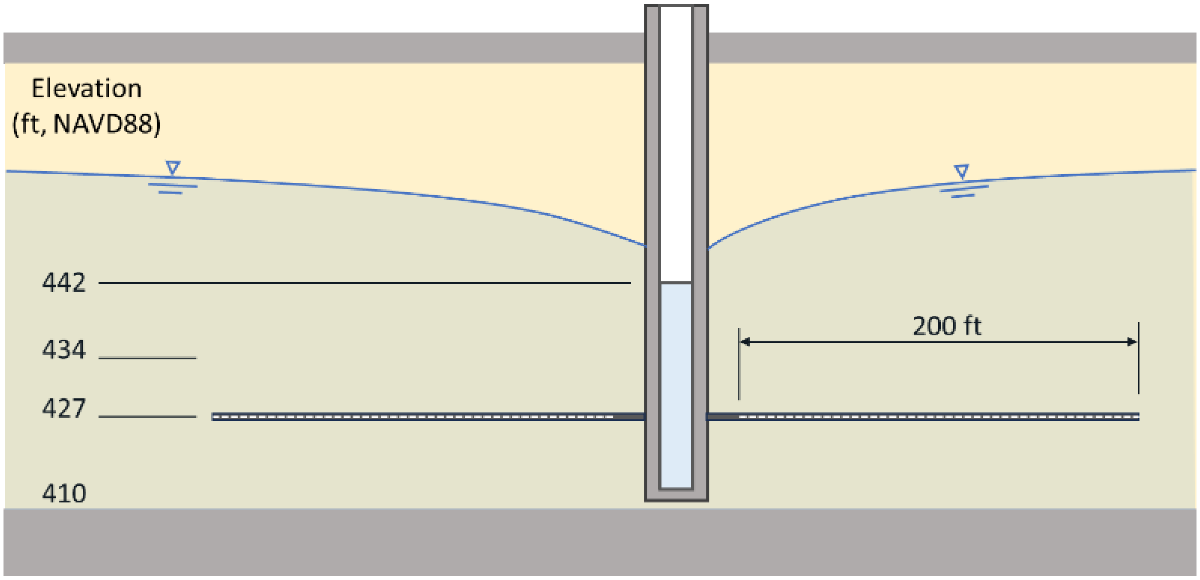


Figure 13. Conceptual design of the collector well showing the minimum allowable water level in the caisson.

6.4 Seasonal Variation in River Levels and Bed Resistance

Water levels in the Wabash River at the project site were monitored for several months and tied to NAVD88 elevation. The water elevations in the river ranged from 498.9 feet to 503.3 feet during monitoring. Daily river stage and elevation records are maintained by the USGS upstream at Station 03335500, Wabash River at Lafayette, with records beginning in 2007. That data was correlated with the site data to produce a river elevation record at the project site for the period 2007 to current. The correlation is only valid for river stages encountered on site while monitoring. The results are used to produce an approximate low- flow elevation duration curve for the Wabash River at Parcel 1.

The results are presented in Figure 14, which includes both an annual curve and seasonal curves. A summary of seasonal river elevations used in the yield model is provided in Table 6.

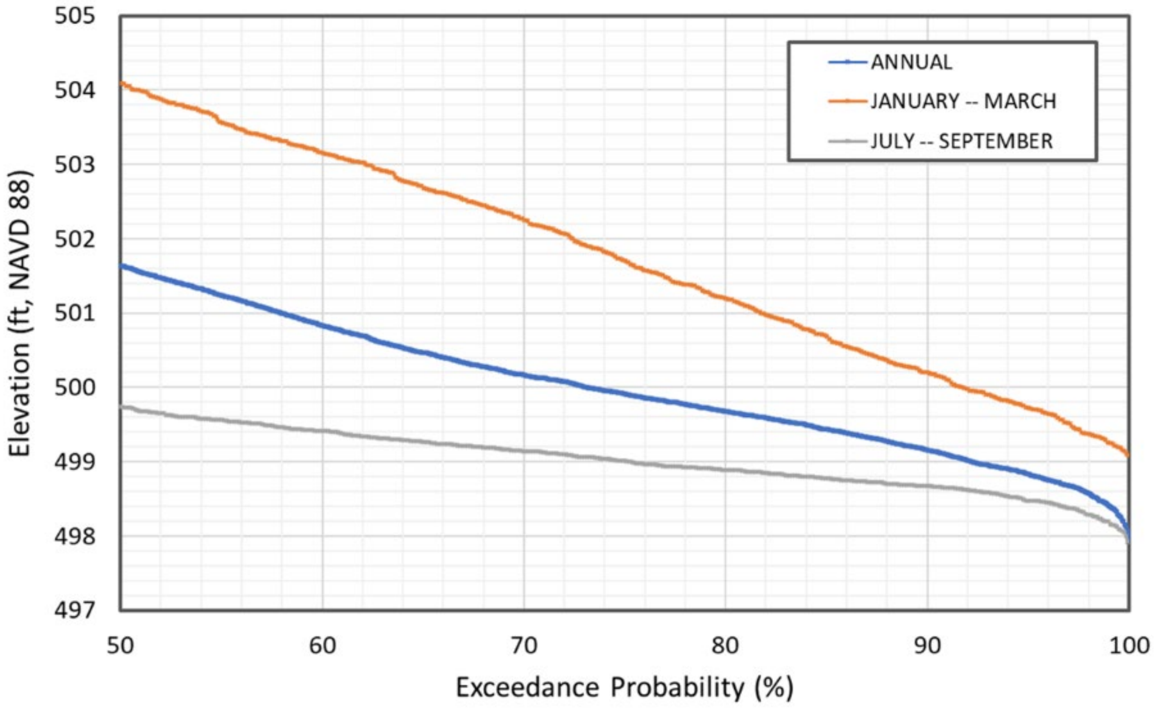


Figure 14. Approximate, low-flow elevation-duration curve for the Wabash River at the Parcel 1.

Table 6. Summary of seasonal river stages used in the yield scenarios.

Season	Condition	Elevation (ft, NAVD88)
Summer	Low Stage	498.0
	Median Stage	499.8
Winter	Low Stage	499.0
	Median Stage	504.0
Annual	Median Stage	501.6

6.5 Yield Scenarios and Results

Several scenarios were investigated to test the potential yield of one and two collector wells on Parcel 1 under a range of conditions. The scenarios include differing river stages, and both low and high skin resistance values on the lateral screens. A summary of results is presented in Table 7.

The winter yields of collector wells are often lower than summer yields due to the increase in viscosity of cold water compared to warm water. The increased viscosity also increases the resistance of the riverbed and potentially decrease the hydraulic conductivity of the aquifer adjacent to the river. The potential reduction in yield depends on several factors, including the percentage of groundwater captured by the well that originates from the river with a travel time less than 3 months, versus the percent of water captured from regional flow that will have a higher ambient temperature than the river water. Based on observations of the winter operation of collector wells by the Kansas City BPU (personal communication with Jeff Henson, Black and Veatch), the winter yield predicted with the model were reduced by 30% to account for the cold-water conditions.

Table 7. Summary of scenarios and yield results.

			Summer		Winter*	
	Property	**Units**	Low Stage	Median Stage	Low Stage	Median Stage
River Properties	Elevation	ft, NAVD88	498.0	499.8	499.0	504.0
	Depth	feet	5	7	6	11
	Bed resistance	days	2.0	2.0	2.0	2.0
Aquifer Properties	Hydraulic conductivity	ft/day	500	500	500	500
	Regional flow	ft^2/day	0	0	0	0
Collector Well Properties	Caisson water level	ft, NAVD88	442	442	442	442
	Arm resistance/width	days/ft	0.02-0.01	0.02-0.01	0.02-0.01	0.02-0.01
	Yield, 1 well	**MGD**	**15-21**	**16-23**	**11-15***	**12-17***
	Yield, 2 well	**MGD**	**29-39**	**31-42**	**20-27***	**23-31***

*Note: Winter yields reduced by 30% to account for the decreased viscosity of water at 32 degrees F.

Based on the modeling scenarios, a lower bound on the yield of a single collector well was set at 11 MGD, and two collector wells at 20 MGD. These estimates are conservative and based on low river-stage conditions, high skin resistance along the lateral screens, no contribution to yield from regional flow, and a 30% reduction in yield for cold-water conditions.

6.6 Analysis of Predictive Uncertainty

To assess the effects of parameter uncertainty on the collector well yield, the yield model was used with alternate realizations of hydraulic conductivity and streambed resistance identified during the transient pumping test analysis. The analysis used the model of summer low flow conditions, streambed resistances adjusted for summer viscosity, and the range of lateral resistance as defined by the dimensionless relationship,

$$5 \leq ck/w \leq 10$$

where c/w s the resistance per width of the lateral, and k is the hydraulic conductivity of the aquifer. The alternate realizations of parameters are summarized in Table 8.

The results of the analysis are presented in Figure 15. The x-axis is the hydraulic conductivity, with the associated streambed resistance noted above the axis, and the y-axis is the total yield in million gallons per day for collector wells at Sites 1 and 2. The lowest value of the hydraulic conductivity presented is 350 ft/day, which represents the alternate realization when the river is in direct contact with the aquifer; this represents the lowest possible hydraulic conductivity of the aquifer. The upper value of 600 feet per day represents the limit where higher values can no longer be well calibrated to drawdown data.

A comparison of yields for the alternate realizations of parameters with the design yield of the collector wells shows that the upper bound of the design yield is conservative in all cases with hydraulic conductivity greater than 475 ft/day. For the limiting case of 350 ft/day, the upper and lower bounds are about 7 MGD below the design yield.

Note that the alternate realizations of parameters are obtained by calibration to observed drawdown only; the river and groundwater elevations are not considered, and therefore the best-fit parameters presented earlier make use of additional information not considered in the alternate realizations. The water level conditions at Test Sites 1 and 2 suggest a high streambed resistance of 2 days. This is illustrated in Figure 16 and Figure 17 which show cross plots of simulated and observed heads for the best fit parameters at Site 1, and the bounding alternate realization, k=350 ft/day and c=0.05 days. Both cases fit the observed site gradients, but without a higher streambed resistance the case of low hydraulic conductivity cannot accurately represent the observed heads.

Table 8. Alternate realizations of parameters used in the predictive uncertainty analysis. Realization 1 represents the streambed in direct connection with the top of the aquifer.

Realization	Hydraulic Conductivity (ft/day)	Riverbed Resistance (days)
1	350	0.05
2	400	0.5
2	450	1.0
3	500	1.5
4	550	2.0
5	600	3.0

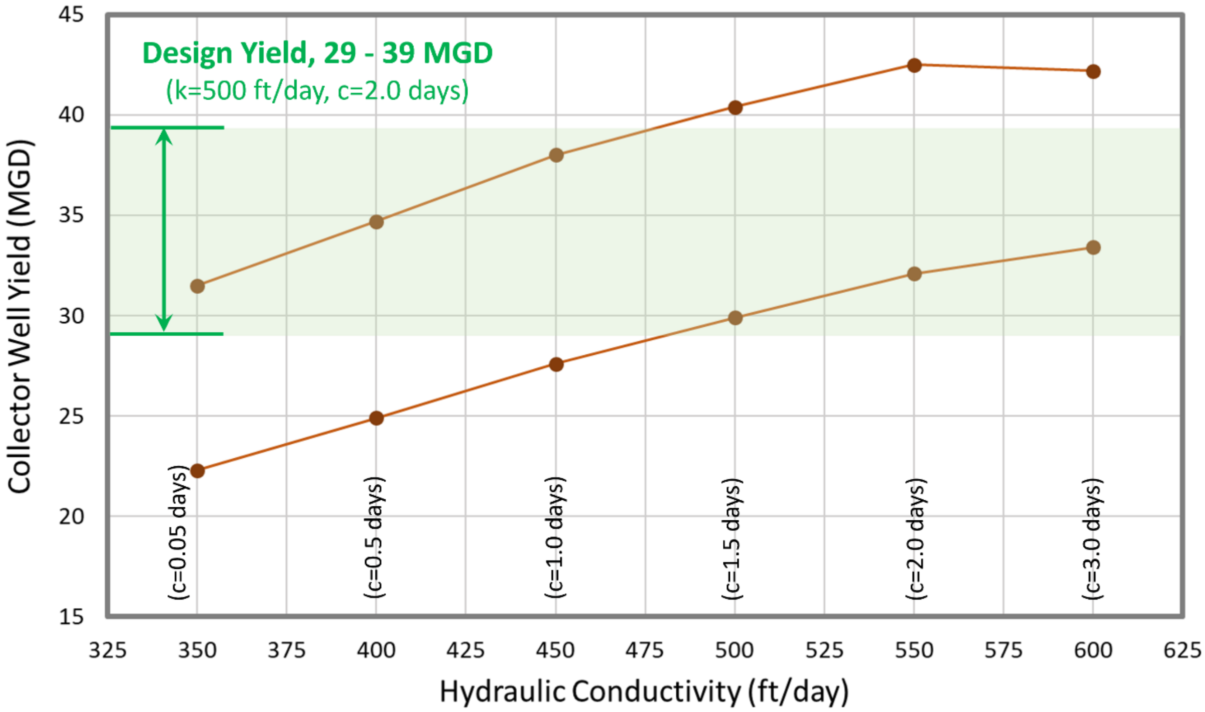


Figure 15. Results from the Predictive Uncertainty Analysis. The design yield range is highlighted in green. Yields based on alternate realizations of hydraulic conductivity and riverbed resistance are indicated by the brown lines.

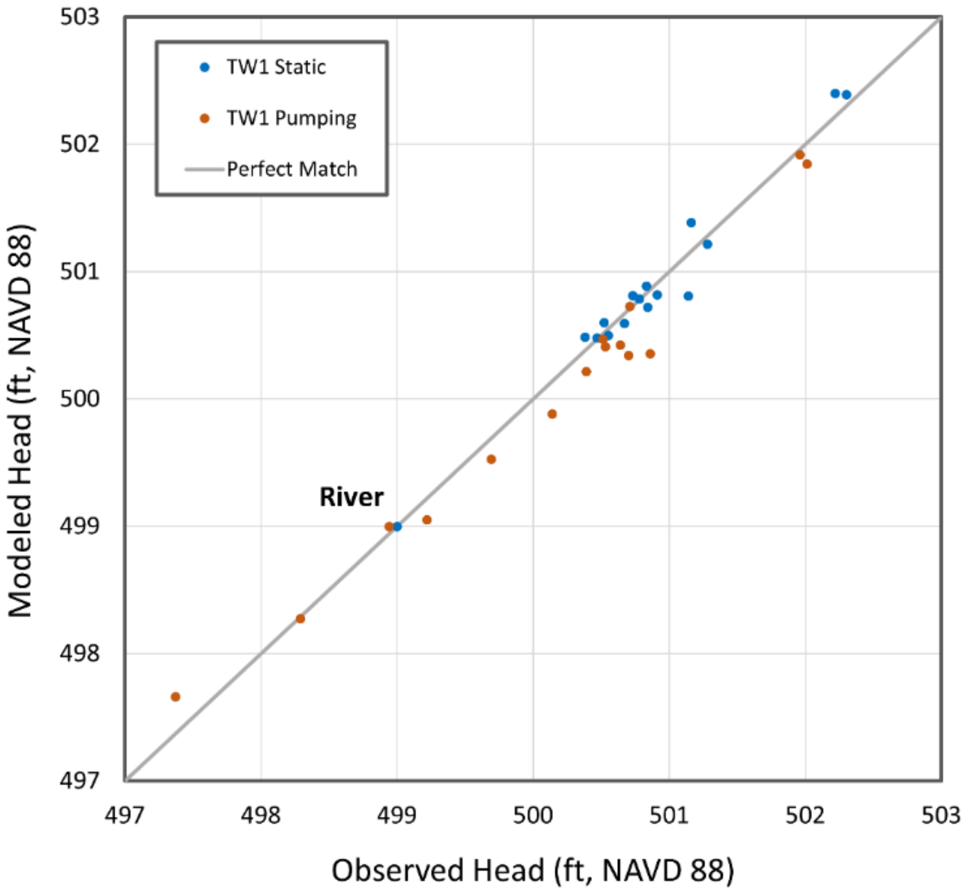


Figure 16. Calibration results for the best-fit parameters at Site 1 (k=500 feet/day, c=2 days).

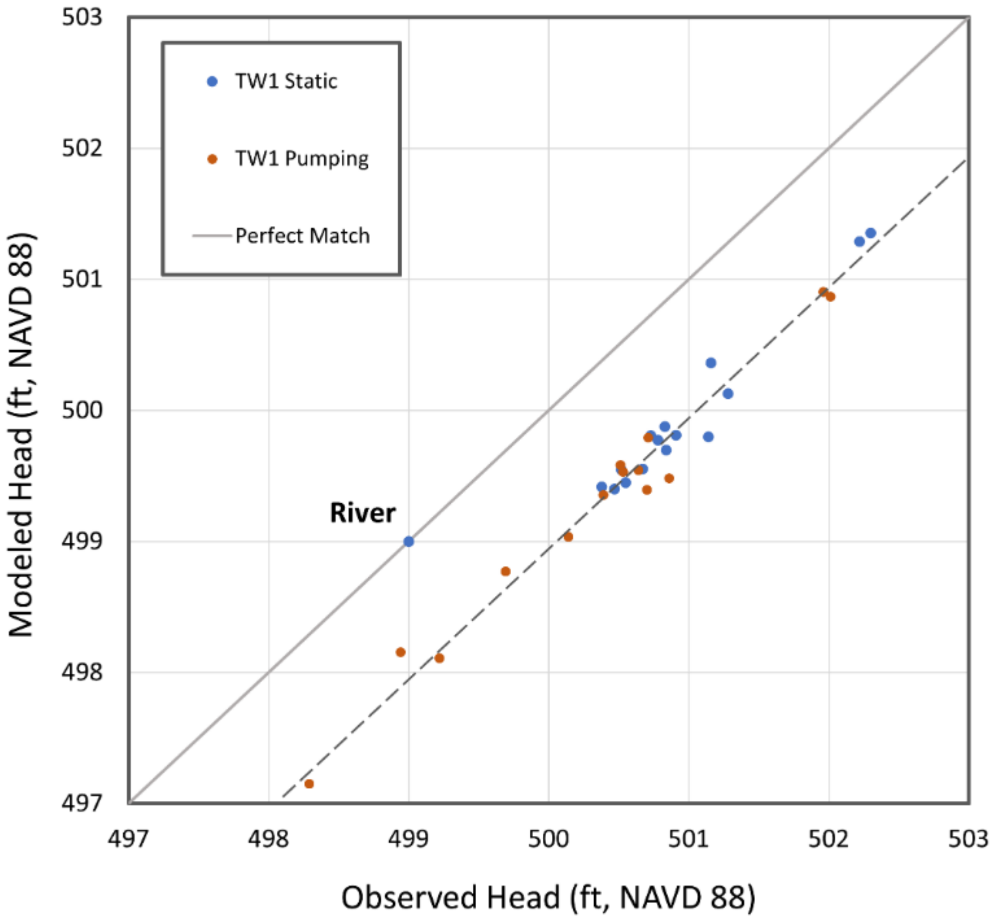


Figure 17. Calibration results for the alternate realization (k=350 feet/day, c=0.05 days).

6.7 Dewatering at Well

In general, dewatering should not exceed 50% of the static saturated thickness. A summary of the predicted aquifer dewatering under the critical summer low river stage and winter low river stage scenarios for a collector well at both Sites 1 and 2 is presented in Table 9, for a minimum water elevation in the caisson of 442 feet NAVD 88; for the scenarios shown, the water elevation in the aquifer outside the caisson is dependent on the lateral resistance and in all cases is significantly higher than 442 feet. As summarized in the table the maximum aquifer dewatering is 44% of the static saturated thickness. Only results for the aquifer drawdown near the collector well at Site 1 is presented. The aquifer drawdown at a collector well at Site 2 is slightly less than at Site 1.

Table 9. Summary of aquifer dewatering for Summer and Winter Low Stage Scenarios at Site 1.

	Units	Summer Low Stage		Winter Low Stage	
Lateral Resistance/Width	days/ft	0.01	0.02	0.01	0.02
River Elevation	ft, NAVD 88	498	498	499	499
Aquifer Base Elevation	ft, NAVD 88	410	410	410	410
Aquifer Saturated Thickness	feet	88	88	89	89
Min. Aquifer Elevation	ft, NAVD 88	459.9	472.1	459.5	471.9
Max. Aquifer Drawdown	feet	38.1	25.9	39.5	27.1
Aquifer Dewatering	%	43	29	44	30

7.0 WATER QUALITY

INTERA collected raw-water samples from each test well during their respective aquifer tests. The samples were collected according to a sampling and analysis plan (SAP) developed by Black and Veatch (Black and Veatch, 2023). The objectives of the sampling effort were to:

1) characterize the groundwater component of the source water and inform assumptions related to treatment process strategies, and
2) identify any contamination that might be present near the proposed collector well locations.

The water samples were submitted to Eurofins Environmental Testing Laboratory for analysis of a broad suite of analytes, including the United States Environmental Protection Agency's (USEPA's) primary and secondary drinking-water contaminants and additional water-quality parameters. All analytes are provided in Table B-1 in Appendix B.

Also sampled and analyzed were analytes included in the USEPA Unregulated Contaminant Monitoring Rule (UCMR). The UCMR program is part of the Safe Drinking Water Act. It requires public water systems to monitor and test for the presence of certain unregulated contaminants in drinking water. Unregulated contaminants are substances that are not currently subject to regulatory standards, but the USEPA wants to gather data about their occurrence and potential health effects. The UCMR analytes that were tested include the UCMR 5 list of PFAS compounds as well as select compounds from UCMR 1-4.

7.1 Sampling Approach

Prior to sample collection, field parameters were monitored using a Horiba multi-sonde and a flow-through device. The unit was outfitted with sondes for measuring temperature, pH, specific conductance, turbidity, dissolved oxygen, oxidation-reduction potential (ORP), and total dissolved solids (TDS) (Table 10).

After the field parameters had stabilized, water samples were collected from a spigot installed on the pump discharge piping at each test well. Water samples were collected from TW-1 on 6/28/23 at 70 hours into the test, just prior to cessation of pumping. A total of approximately 6 million gallons (MG) of water had been pumped from the TW-1 prior to sample collection.

Due to schedule and holding time constraints, water samples were collected from TW-2 on 7/14/23, the second day of the test, well before the cessation of pumping. Specifically, the TW-2 samples were collected at 26 hours into the test, after a total of approximately 2 MG had been pumped from the well.

All samples were packed in coolers of ice and delivered in person to the Eurofins Laboratory in South Bend, Indiana on the same day as sample collection.

7.2 Results

Water-quality results are summarized in three tables. Table 8 presents the field parameters observed prior to sample collection. Detections above respective reporting limits for inorganic analytes are summarized in Table 9. Detections above respective reporting limits for physical parameters, nutrients, organics, and microbes are summarized in Table 10. Where applicable, the USEPA maximum contaminant level (MCL) and secondary maximum contaminant level (SMCL) are shown. Full lab reports are included in Appendix B.

Some of the results from TW-1 suggest that the well may not have been sufficiently developed prior to sampling, as indicated by a relatively high turbidity (Table 10) and color result (Table 12).

A piper plot like the one shown in Figure 18 is a tri-linear diagram that summarizes and illustrates the major inorganic species in a water sample and can be used to compare different water samples and determine water type. The clustering of the data points on the plot indicates that the source water from the two test wells is similar in type and can be classified as calcium-bicarbonate type water, which is typical for groundwater in Indiana (Figure 18).

The testing results indicate that the water meets necessary criteria and is safe for use as a drinking water source. No VOC, SVOC, or pesticide was detected above a respective reporting limit. No primary USEPA standard was exceeded.

No analyte associated with the UCMR was detected except for perchlorate in TW-1 (Table 11). Perchlorate in groundwater primarily originates from human activities and industrial processes. Perchlorate is not commonly found in significant concentrations in natural groundwater but has become a concern due to its widespread use in various applications, including manufacturing and industrial processes, and fertilizers and agricultural runoff.

The observed iron and manganese concentrations in the test wells were above the respective SMCL, with iron ranging from 1.4 to 1.5 mg/L and manganese ranging from 0.1 to 0.7 mg/L (Table 11). For both iron and manganese, the SMCL is set to minimize corrosion, staining, and undesirable taste and odor effects. Given the observed concentrations, treatment would be required for both iron and manganese. However, iron and manganese concentrations pumped by collector wells generally decrease over time as oxygenated river water is induced through the riverbed.

Table 10. Summary of field parameters observed prior to sample collection.

Parameter	Units	TW-1	TW-2
Date	-	6/28/2023	7/14/2023
Time	-	0850	1015
Temperature	degrees C	13.42	13.93
pH	-	7.43	7.84
Specific Conductance	uS/cm	795	792
Turbidity	NTU	184	0
Oxygen, Dissolved	mg/L	0	0
Oxygen Reduction Potential	mV	-79	-108
Total Dissolved Solids	mg/L	509	507

Notes: mg/L = milligrams per liter; uS/cm = microsiemens per centimeter
mV = millivolts; NTU = Nephelometric Turbidity Unit; '-' = Not Applicable

Table 11. Summary of inorganic analytes detected above reporting limits.

Parameter	Units	RL	MCL	SMCL	TW-1	TW-2
Inorganics, Major Metals						
Calcium	mg/L	0.10	-	-	110	100
Magnesium	mg/L	0.10	-	-	32	35
Potassium	mg/L	0.20	-	-	1.4	1.4
Sodium	mg/L	0.10	-	-	5.6	6.0
Inorganics, Major Non-Metals						
Alkalinity, Total	mg/L	1.0	-	-	290	270
Bromide	ug/L	10.0	-	-	41	48
Carbon Dioxide, Free	mg/L	0.1	-	-	25	11
Chloride	ug/L	2.0	-	-	17	16
Fluoride	mg/L	0.1	2	-	0.1	0.2
Oxygen, Dissolved	mg/L	1.00	-	-	2.9	5.5
Sulfate	mg/L	5.0	-	250	86	91
Inorganics, Minor Metals						
Aluminum	ug/L	2.0	-	50	< 2.0	5.1
Arsenic	ug/L	1.0	10	-	1.4	1.1
Barium	ug/L	2.0	2000	-	70	70
Chromium	ug/L	0.90	100	-	1.1	2.6
Iron	mg/L	0.010	-	0.3	**1.5**	**1.4**
Lithium	ug/L	2.0	-	-	4.0	< 2.0
Manganese	ug/L	2.0	-	50	**100**	**170**
Zinc	ug/L	5.0	-	5000	< 5.0	7.6
Inorganics, Minor Non-Metals						
Silica	mg/L	0.043	-	-	15	15
Perchlorate	ug/L	0.05	-	-	0.24	< 0.05

Notes: mg/L = milligrams per liter; RL = Reporting Limit; ug/L = micrograms per liter

MCL= Maximum Contaminant Level; SMCL = Secondary Maximum Contaminant Level

- = Not Applicable

Table 12. Summary of detections above reporting limits for physical parameters, nutrients, organics, and microbes.

Parameter/Analyte	Units	RL	MCL	SMCL	TW-1	TW-2
Physical						
Color	Color Units	3.0	-	15	35	NR
Langelier Index	LangSU	-	-	-	0.3	0.7
pH	SU	0.10	-	-	NR	7.7
Specific Conductance	uS/cm	2.0	-	-	720	720
Total Dissolved Solids	mg/L	10.0	-	500	490	460
Turbidity	NTU	0.1	-	-	10	15
Nutrients						
Ammonia, Nitrogen	mg/L	0.1	-	-	0.1	< 0.1
Nitrite (N)	mg/L	0.01	1	-	<0.01	<0.01
Nitrate (N)	mg/L	0.10	10	-	1.6	0.41
Organics, Other						
Dissolved Organic Carbon	mg/L	0.5	-	-	0.542	< 0.5
Total Organic Carbon	mg/L	0.5	-	-	0.55	NR
Ultraviolet Absorption, 254 nm	1/cm	0.009	-	-	0.021	0.033
Microbial						
Heterotrophic Plate Count	MPN/mL	2.0	-	-	33	17
Total Coliform	-	-	5%[1]	-	Present	Absent

Notes: mg/L = milligrams per liter; RL = Reporting Limit; NR = Not Reported; '-' = Not Applicable
uS/cm = microsiemens per centimeter; NTU = Nephelometric turbidity units; SU = Standard Units
MCL= Maximum Contaminant Level; SMCL = Secondary Maximum Contaminant Level
[1] total percent positives within a month; MPN/mL = most probable number per milliliter

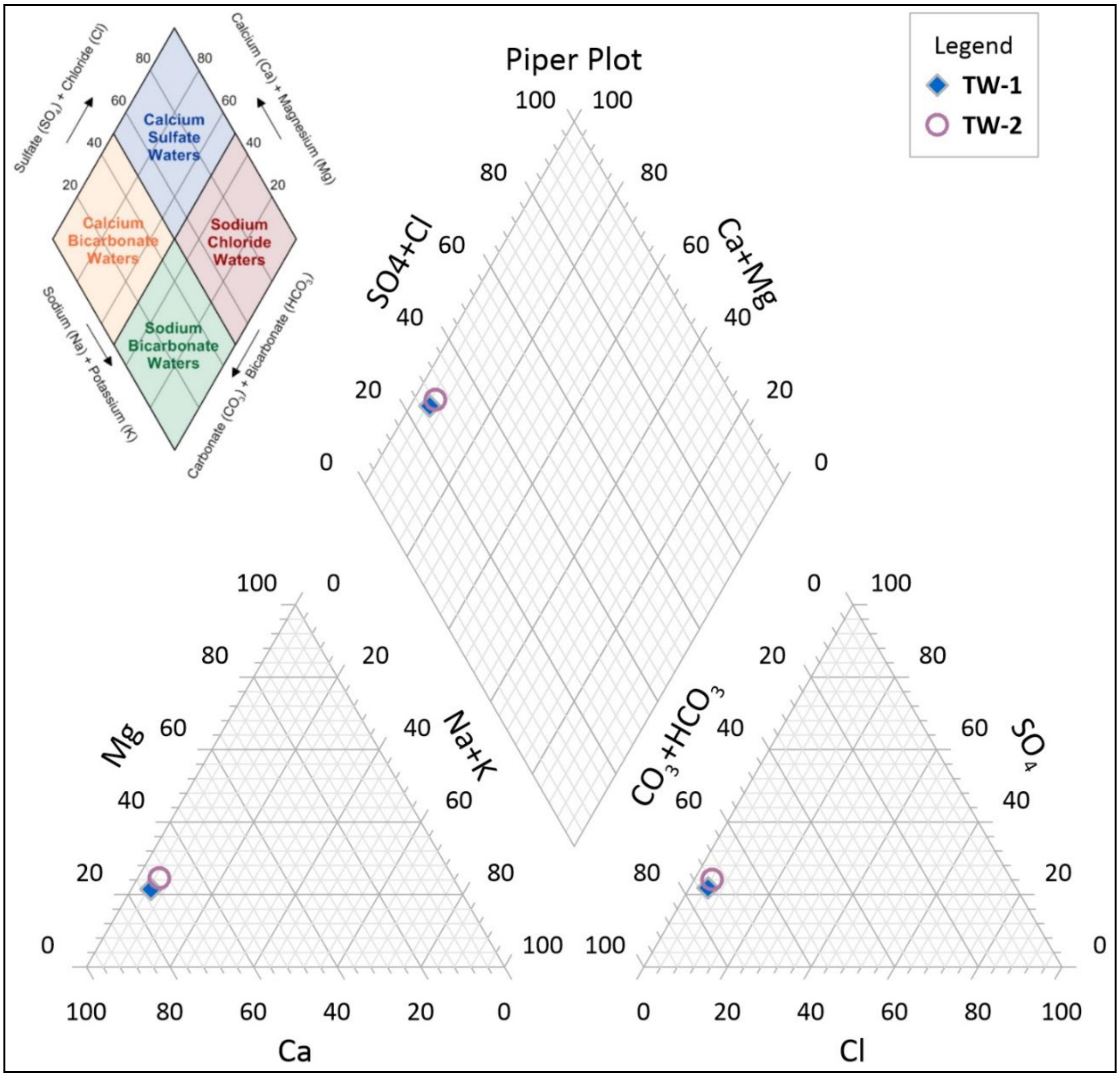


Figure 18. Piper plot of water-quality results from TW-1 and TW-2.

8.0 CONCLUSIONS

The field program at Parcel 1 has yielded valuable insights into the site's hydrogeological characteristics. Below we present conclusions for Sites 1 and 2 and a discussion of the additional steps needed to develop a design-level analysis for the two sites.

8.1 Sites 1 and 2

The field program encompassed drilling sonic test borings, logging geologic sediments, installing monitoring wells and test production wells, conducting aquifer tests, and collecting water-quality samples. These efforts have provided essential data to evaluate potential source-water quality, estimate yields, enhance the conceptual well field design.

- Results of the test drilling show that the underlying stratigraphy at the site is consistent with the regional setting. The aquifer system in the area consists of large bodies of highly permeable unconsolidated sand and gravel which were deposited as glacial outwash or alluvial valley fill. These permeable sediments fill both the recent alluvial valleys as well as the ancient valleys eroded into the bedrock by pre-glacial drainage.

- Two separate aquifer tests were conducted at Parcel 1. Each test well was pumped at a constant rate of approximately 2 MGD for a standard length of 72 hours. The testing results indicate that the water meets necessary criteria and is safe for use as a drinking water source. No VOC, SVOC, or pesticide was detected above a respective reporting limit. No primary USEPA standard was exceeded.

- The aquifer test results were analyzed to estimate hydraulic properties of the aquifer conductivity of the aquifer and the hydraulic resistance between the bed of the river and the aquifer. Results from the tests were incorporated into a predictive groundwater flow model analysis.

- The objective of the modeling was to provide a conservative, lower bound on collector well yield. Based on the modeling scenarios, a conservative lower bound on the yield of a single collector well at Parcel 1 was set at 11 MGD, and two collector wells at 20 MGD.

- Higher yields are possible from Parcel 1, with the summer scenarios predicting a total of approximately 40 MGD from two collector wells. These higher yields would be a seasonal phenomenon in the summer months when the river stage is at normal levels and the water is warm. Collector wells with capacity at or near 20 MGD would be the most prolific wells in all of Indiana.

8.2 Additional Steps for Design-Level Analysis

A preliminary design of horizontal collector wells was presented and used as a basis for developing preliminary design yields. A more detailed conceptual design is necessary prior to final design and construction of the wells. The conceptual design includes the following considerations:

1. **Site-specific conditions and stratigraphy.** Additional design considerations can be addressed with a more in-depth modeling analysis that includes location and total depth of the caisson, lateral alignment, the total number of laterals, and lateral elevation. The caisson can be moved toward the river to increase yields, and the lateral alignment may be adjusted to either maximize yield or maintain separation distances from the river.
2. **Mechanical Capacity of the well screens and laterals.** Screen inlet velocities – which depend on screen size, alignment, and maximum design yield – must be evaluated and limited to standard design capacities. If inlet velocities are too high for the preliminary design and yield, more feet of screen must be included. This can be accomplished by increasing individual lateral lengths or adding additional laterals in one or more tiers. Similarly, the maximum inline velocity within each lateral must be assessed and limited to standard design criteria.
3. **Allowable drawdown in the caisson.** Finally, the minimum water level in the caisson must be reassessed based on the results of items 1 and 2 above. A minimum of 5 feet of water in the caisson above the top of the laterals is typically required based on the construction technique used to install the laterals.

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Exhibits

Appendix A

Appendix B