Groundwater Availability Modeling for the City of Shenandoah, Iowa

Iowa Geological and Water Survey
Open File Report OFR-13-1

Iowa Department of Natural Resources
Chuck Gipp, Director
September 2013

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Groundwater Availability Modeling for the City of Shenandoah, Iowa

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Iowa Geological and Water Survey completed a hydrogeologic evaluation of the water resources surrounding the City of Shenandoah, Iowa. The evaluation involved conducting geophysical cross sections, calibrating a groundwater flow model that can be used to evaluate the expansion of the current city well field near the Shenandoah airport, and the feasibility of a new well field north of town in Rapp County Park.

Based on the results of this evaluation, additional water production may be possible from two or more additional wells in the airport well field. Total well field water production increased from 0.71 million gallons per day (mgd) to 1.3 mgd with the addition of proposed wells TW-1/TW-2 and River 1. Shutting off wells 23 and 25 allowed for an increase in water production in wells 21 [an increase of 134 gallons per minute (gpm)] and 22 (an increase of 16 gpm). The model also showed an increase in the induced recharge from the East Nishnabotna River to 38 percent or 494,000 gallons per day (gpd) (current induced recharge is 20 percent or 142,000 gpd). The final location and water production from any proposed wells will need to be determined following test drilling, test well installation, and aquifer pump tests.

Based on the groundwater flow model, the use of a proposed recharge ditch near the airport well field would substantially increase the total water production during a severe drought. Water quality data would need to be collected in Well 23 to see whether it would be classified as influenced groundwater (groundwater under the influence of surface water). The other option would be to simply shut off Well 23 when the recharge ditch is used. Well 23 is one of the lower producing wells, and shutting it down would reduce the well field production to 1.42 mgd. If proposed wells River 1 and TW-1/TW-2 are added, along with the recharge ditch, the well field production would increase to 1.84 mgd.

Based on the groundwater flow model, the use of a proposed low-head dam on the East Nishnabotna River would only increase the overall water production at the airport well field by 112,000 gpd. Wells 21, 22, 23, and 25 would provide most of the increase.

Based on the groundwater flow model, adding 3 to 4 new production wells at the proposed Rapp Park well field could provide an additional 700 to 1,000 gpm of water to the City of Shenandoah. Actual production would depend on the results of future test drilling, test well installation, and aquifer pump tests. The advantage of developing the proposed Rapp Park well field is the induced recharge available from the nearby former sand and gravel quarries.

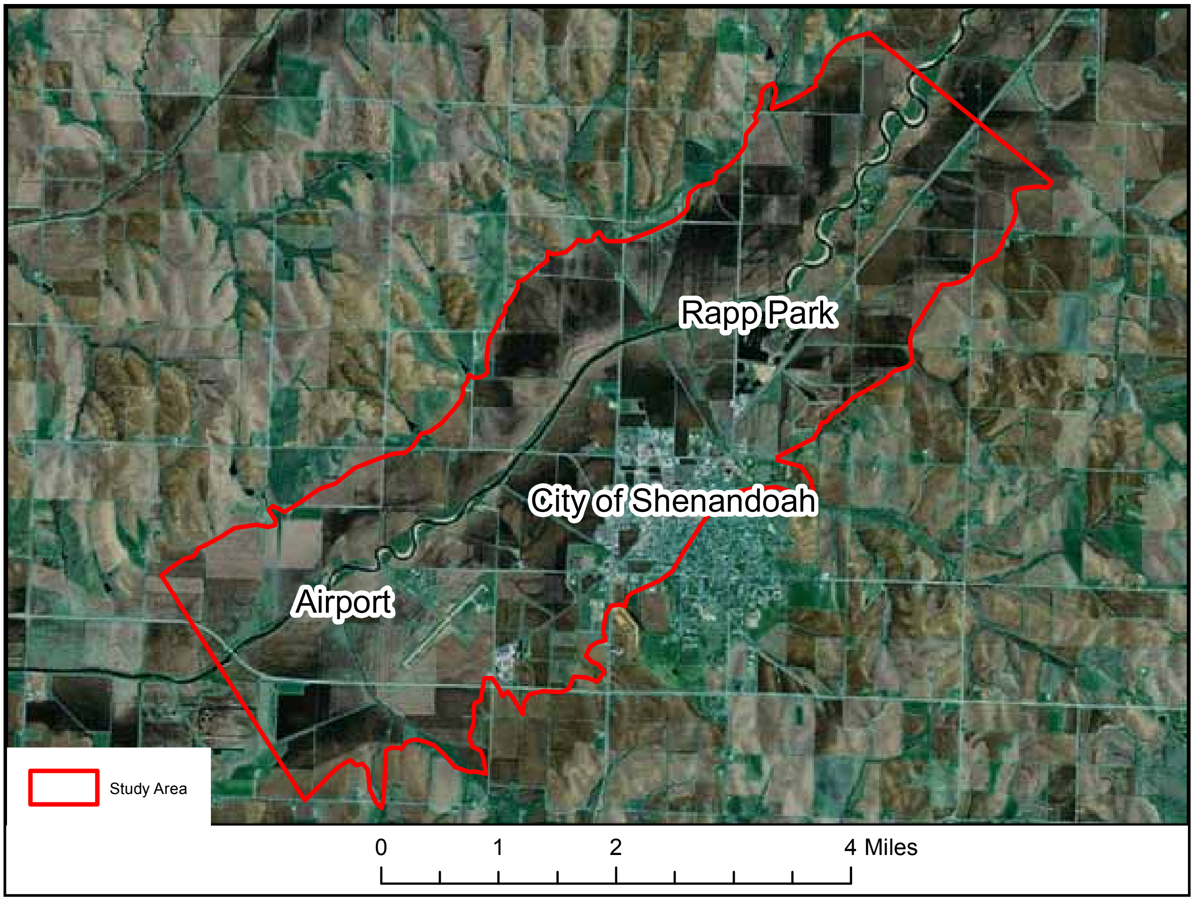

Figure 1. Shenandoah model area.

INTRODUCTION

The City of Shenandoah currently has nine shallow alluvial wells that vary in depth from 34 feet in Well 21 and Well 25, to 51 feet in Well 87-2 (Figures 1 and 2). Drought conditions during the summer of 2012 severely limited water production from the nine wells, especially in wells 07-1 and 25. On-site work completed by Fox Engineering Associates indicated overall well field capacity was approximately one-half the anticipated capacity (Fox Engineering Associates, Inc., 2013). On July 19, 2012, the City of Shenandoah used 1.48 million (mgd), and the water production from the well field was 1.3 mgd. The difference between the demand and the water production was made up by excess storage capacity. Two of the nine wells were taken out of service during this time due to low groundwater levels (within 1 foot of the top of the screen or lower). From July 2012 to February 2013 the well field capacity continued to decrease by approximately 18 percent. Future growth and economic development will continue to put strains on the City of Shenandoah well field and water production.

Fox Engineering Associates was hired by the City of Shenandoah to evaluate the possibility of expanding the existing airport well field, the development of a new well field near Rapp Park (Figure 3), and installing one or more wells in the Fremont aquifer (buried sand and gravel aquifer), which lies beneath

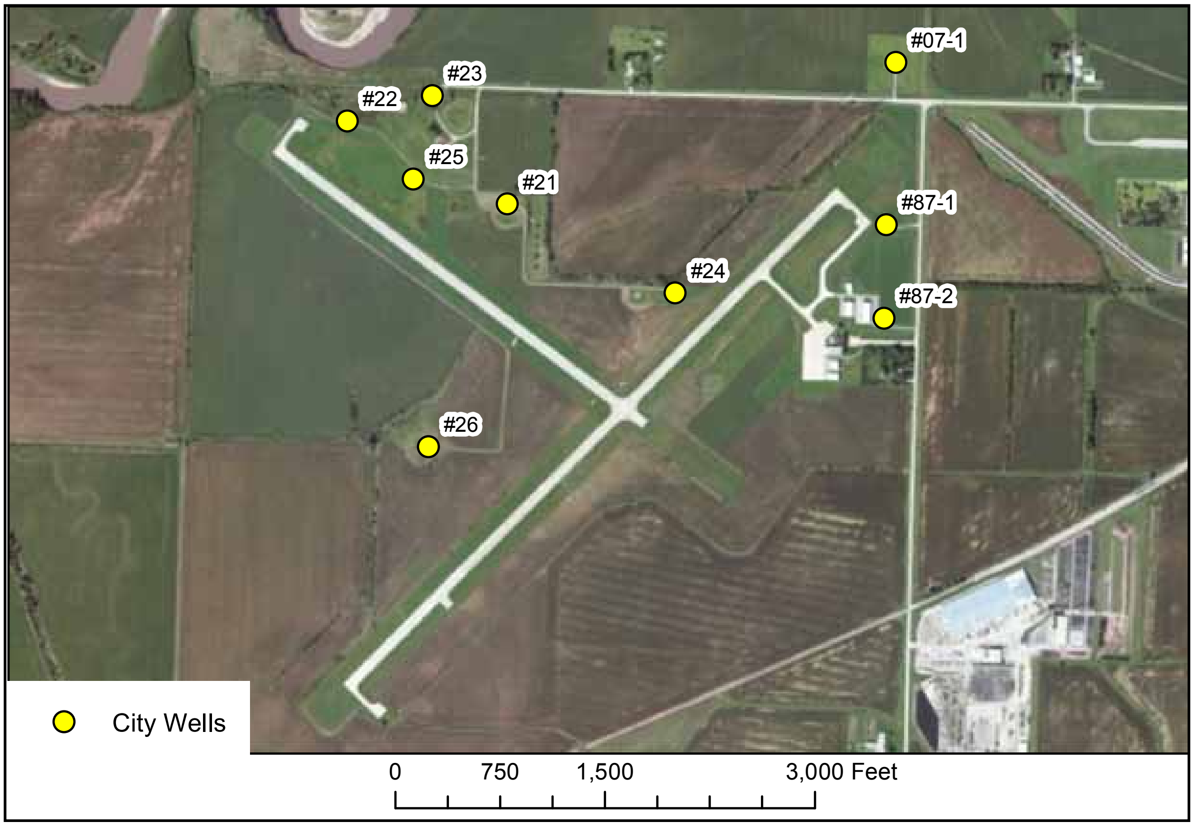

Figure 2. City of Shenandoah airport well field.

the alluvial aquifer. Martha Silks, Leggette, Brashears, & Graham (LBG), was hired by Fox Engineering Associates to evaluate the hydrogeology and perform the groundwater exploration and well siting.

The Geological and Water Survey of the Iowa Department of Natural Resources has offered to assist the City of Shenandoah, Fox Engineering Associates and Martha Silks by developing a groundwater flow model of the shallow alluvial aquifer along the East Nishnabotna River. The model will help Fox Engineering and Martha Silks evaluate the existing airport well field, evaluate the proposed Rapp Park well field, optimize future pumping rates, evaluate a proposed recharge ditch at the airport well field, and evaluate a proposed low head dam on the East Nishnabotna River near the airport well field.

GEOLOGY

The thickness of alluvial deposits along the East Nishnabotna River varies from 2 to 51 feet, but averages approximately 30 feet. The alluvial deposits are not uniform or homogeneous, but vary from silt and clay to cobbles and boulders. The alluvial aquifer along the East Nishnabotna River consists of sand, gravel, and cobbles deposited by the modern river system and is highly variable in both thickness and grain size. Based on existing data from 83 geologic logs (IGWS GEOSAM database and Martha Silks, QSSI), the sand and gravel thickness is shown on Figure 4. The sand and gravel varies from 1 to 35 feet. The sand and gravel is overlain by fine-grained sediments that consist of clay, silt, and silty-sand that range in thickness from 2 to 20 feet. The base of the sand and

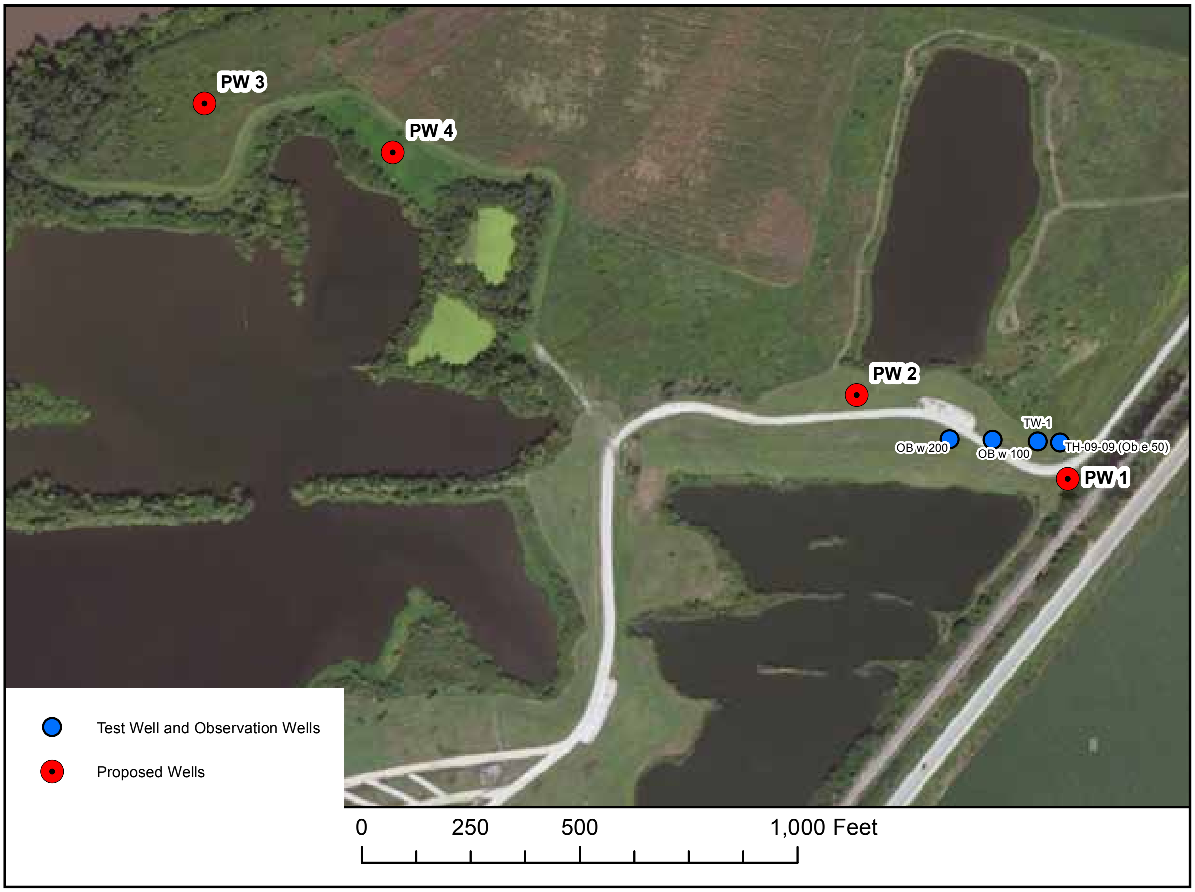

Figure 3. Proposed Rapp Park well field.

gravel aquifer is underlain by either glacial till, or Pennsylvanian shale throughout the study area.

HYDROGEOLOGY

Regional groundwater flow is in a south/southwesterly direction toward the East Nishnabotna River. The hydraulic gradient is assumed to be similar to the land surface topography in most locations, and during most of the year the East Nishnabotna River is a gaining stream. Exceptions to this likely occur during high river stage when temporary bank storage may cause a transient reversal in flow direction, and near high-capacity wells where pumping stress may reverse the groundwater flow direction and create induced recharge from the river into the aquifer. Groundwater recharge sources are precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall.

It is difficult to measure the groundwater recharge based on annual precipitation data. In Iowa much of the groundwater recharge occurs in the early spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of the precipitation events, and when they occur seasonally.

Aquifer Test Results

Hydraulic properties are used to define and characterize aquifers, and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer proper-

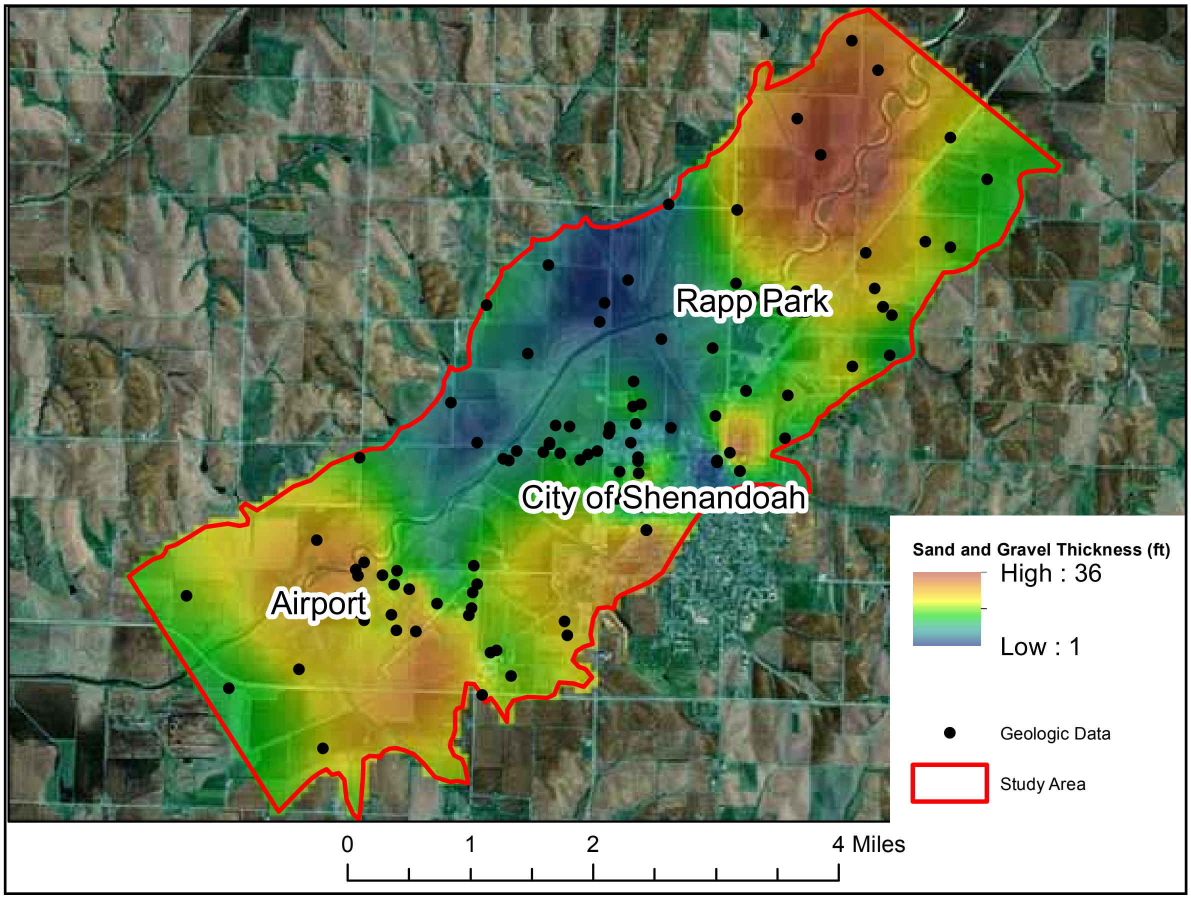

Figure 4. Sand and gravel thickness (isopach) in the East Nishnabotna River alluvium based on 83 geologic logs.

ties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Aquifer pump tests were conducted by Quad States Services for the City of Shenandoah, and include Well 07-01 (airport well field) and Test Well TW-1 (Rapp Park). The pump test conducted at Well 07-01 used one observation well, and the pump test at TW-1 used three observation wells. In addition to the aquifer parameter estimation, the observed drawdown data was also used to help calibrate the groundwater flow model. This will be discussed later in the report.

In addition to the aquifer pump tests, a total of eight specific capacity tests were found in the IGWS database GEOSAM. Table 1 lists the pump test results and the specific capacity results for each test, the method of analyses, transmissivity values, aquifer thickness, hydraulic conductivity values, and storativity values (aquifer pump test results only).

Based on aquifer test results, the transmissivity of the East Nishnabotna River aquifer was found to range from 2,580 ft.^{2}/day at Rapp Park observation well OB50E to 9,450 ft.^{2}/day at Rapp Park observation well OB200W. The transmissivity value at Well 07-01 (airport well field) was 2,730 ft.^{2}/day. The arithmetic mean transmissivity value is 4,530 ft.^{2}/day.

Hydraulic conductivity can be calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity was found to range from 83 to 364 ft./day, with an arithmetic mean of 173 ft./day.

Table 1. Results of aquifer pump tests and specific capacity tests for the Shenandoah groundwater study.

Well #	Type	Thickness (ft)	T (ft^2/day)	S	K (ft/day)
TW-1 (OB1E)	Pump Test	31	2,580	0.0003	83
TW-1 (OB1W)	Pump Test	29	3,369	0.0003	116
TW-1 (OB2W)	Pump Test	26	9,452	0.002	364
07-01 (OB Well))	Pump Test	21	2,730	0.01	130
Well 5	SPC	25	7,860	NA	314
Well 6	SPC	25	6,000	NA	240
Well 21	SPC	27	5,300	NA	196
Well 22	SPC	25	3,440	NA	137
Well 23	SPC	18	3,100	NA	172
Well 24	SPC	23.5	1,930	NA	82
Well 25	SPC	18.5	5,570	NA	301
Well 26	SPC	21	2,850	NA	149

GROUNDWATER MODELING

The model software Visual MODFLOW version 2011.1 was used to simulate the groundwater flow in the alluvial aquifer in the Shenandoah area under severe drought conditions. A three-layered model was used for the simulation. Borehole logs were obtained from the IDNR GEOSAM database, and elevation data were obtained from LiDAR (2-foot contour intervals). The model boundary conditions and inputs include the following:

- Layer 1 varies in thickness from 2 feet to 20 feet, and is primarily silt and clay. The horizontal hydraulic conductivity was assigned a value of 0.03 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 2 is the sand and gravel aquifer. The horizontal hydraulic conductivity was calibrated within the model. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 3 is primarily silty clay (glacial till or shale). The horizontal hydraulic conductivity was assigned a value of 0.03 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- The uplands were considered no-flow boundaries. This was represented by deactivating the grids outside the alluvial aquifer boundary. This was estimated using Natural Resource Conservation Service (NRCS) soils data and LiDAR elevation data.
- The East Nishnabotna River and its tributaries were represented as river boundaries. The surface water elevations were estimated using LiDAR data and subtracting 2 feet to represent drought conditions. A water level depth of 1 foot was used. The vertical conductivity of the streambed was estimated at 1/10 the average horzontal conductivity of the alluvial aquifer. The model represented baseflow (summertime) conditions, and the stage was kept the same throughout the simulated time period.
- General head boundaries were used in the numerous sand and gravel pits in the area. These general head values were obtained from LiDAR elevation data. For the drought simulations, a water level drop of 2 feet occurred during summer months.
- General head boundaries were used to represent smaller tributaries and benches. Groundwater elevations were estimated from the closest well or observation point.

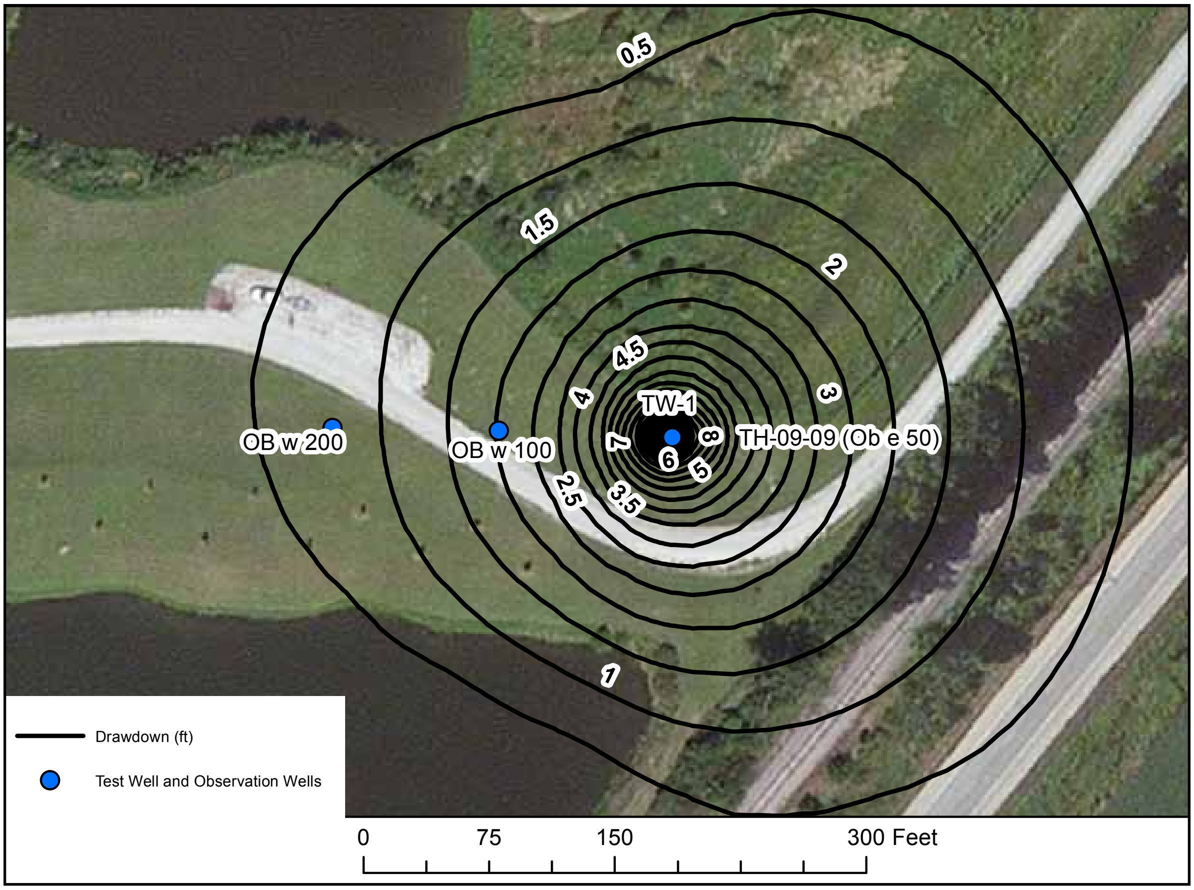

Figure 5. Simulated drawdown in the proposed Rapp Park well field for the pump test conducted at test well TW-1.

- Public wells were included in the model simulation. Usage was obtained from Fox Engineering Associates' well field evaluation (Table A and Appendix A Table A.1
- Specific yield values ranged from 0.1 to 0.3, and specific storage values ranged from 0.002 to 0.01.
- Average annual recharge was calibrated to be 6 inches per year for a normal year. Drought conditions were calibrated to be 4 inches per year. During the summer drought conditions (90 day period) 0 inches of recharge were used.
- The total number of rows and columns were 342 by 391. The grid size varied from 6.5 feet to 220 feet.

Table 2. Model calibration results for steady-state (non-pumping) conditions for Shenandoah groundwater study under drought conditions.

Well ID	Observed WL (ft)	Simulated PWL (ft)
W-42428	941.98	942.87
W-42429	943	944.02
W-42431	943	947.1
W-42427	945.98	950.45
W-601	951	949.63
PIT	951.2	950.51
W-42430	953.99	956.28
W-42417	957.1	960.97
W-43511	961.01	960.61
W-43516	968.42	970.49
W-11422	972	974.49
W-43512	972	973.7
W-39632	973.01	973.08

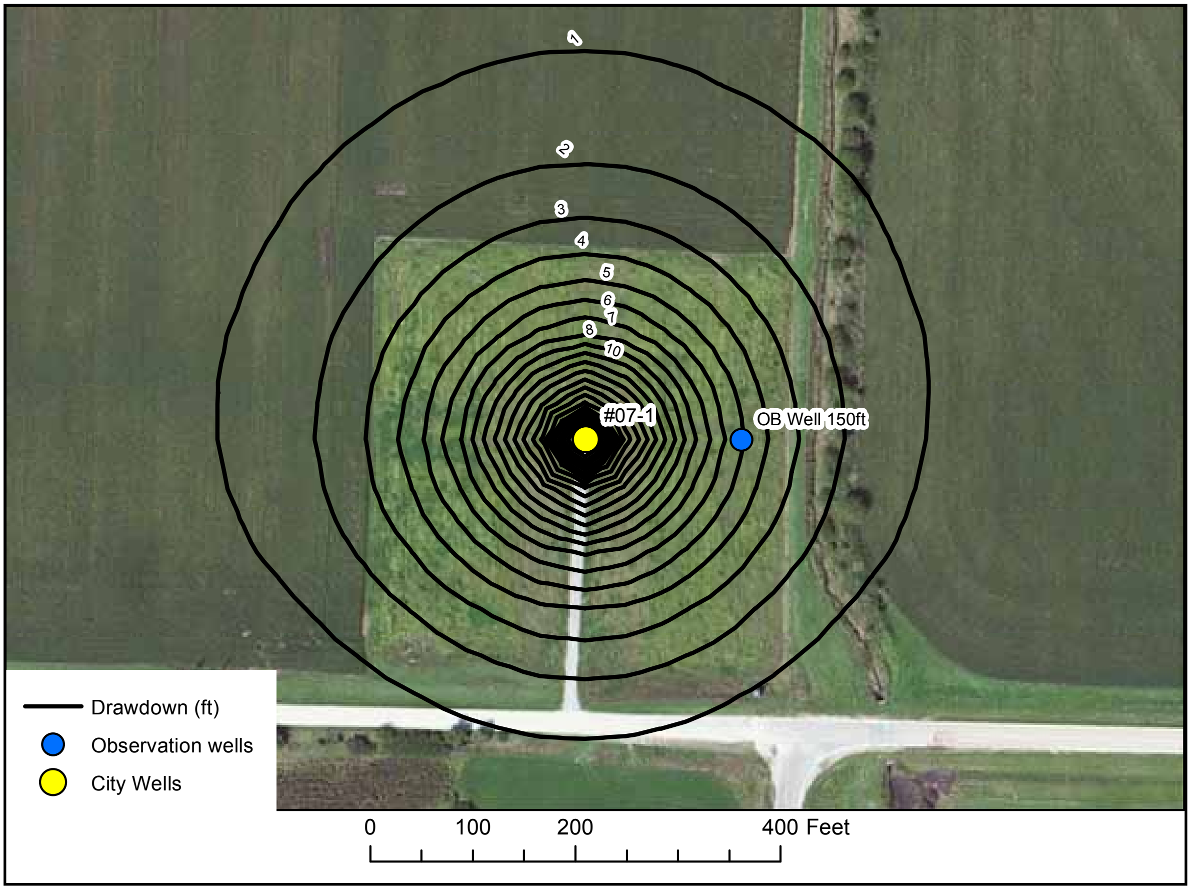

Figure 6. Simulated drawdown in the airport well field for the pump test conducted at well 07-1.

Calibration Results

The model was initially run to simulate non-pumping conditions. The model was calibrated using static water levels found in IGWS database GEOSAM. Table 2 compares simulated values to observed water levels.

The model was also used to simulate pumping or transient conditions. The model was calibrated using pumping water elevations provided by Fox Engineering Associates. Table 3 compares simulated values to observed water levels.

Local scale calibration was performed using pump test results from City Well 07-01 (one observation well used) and Test Well TW-1 (three observation wells used). Hydraulic conductivity and specific yield values were adjusted to match the simulated water levels to the observed values. Figures 5 and 6 show the simulated drawdown values for the two aquifer pump tests. The simulated versus observed

Table 3. Model calibration results for transient (pumping) conditions for Shenandoah groundwater study based on 2012 drought conditions.

Well ID	Observed PWL (ft)	Simulated PWL (ft)	Difference (ft)
21	935.72	934.54	-1.18
22	929.81	929.95	+0.14
23	928.14	928.14	+0.00
24	935.13	934.83	-0.3
25	930.21	930.01	-0.2
26	924.07	924.17	+0.10
87-1	934.5	933.98	-0.52
87-2	928.5	928.93	+0.43
07-1	926.5	926.96	+0.46

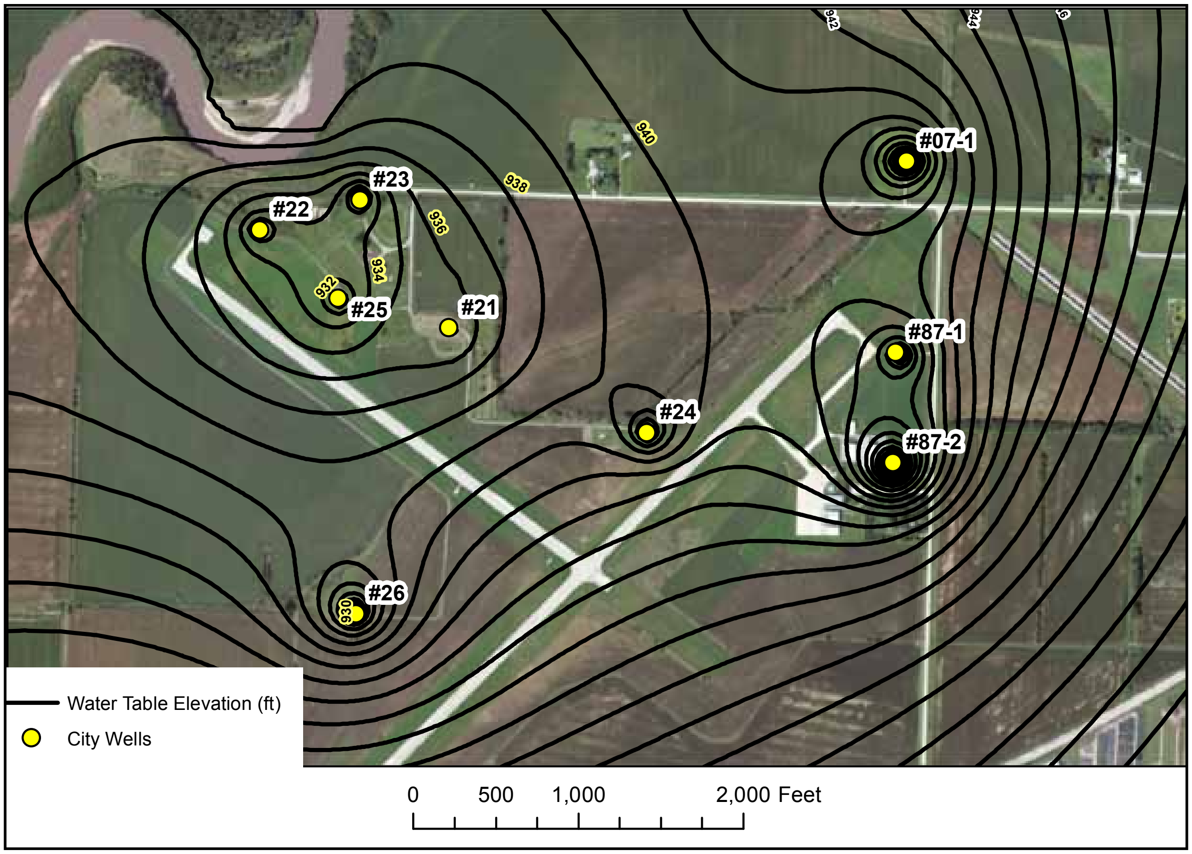

Figure 7. Simulated water table elevation map for the airport well field using pumping data from December 2012.

drawdowns are shown in Table 4. Figure 7 shows the simulated water table elevation map for the airport well field using water use data from December 2012.

Water Balance Analysis of Existing Well Field

Based on the mass balance output from Visual MODFLOW, the percentage of water production supplied by induced recharge from the East Nishnabotna River during a severe drought was approximately 20 percent. The remaining 80 percent of the water production is supplied by precipitation recharge and groundwater inflow into the model area. The relatively low percentage of induced recharge makes the current airport well field very susceptible to drought. Wells 22, 23, and 25 capture most of the induced recharge, and well 21 may capture induced recharge if one or more of the other wells are shut off. Several options exist to increase induced recharge. These include a proposed low-head dam and/or a recharge ditch. The potential benefits of both options were evaluated by the model and will be discussed later in the report.

Table 4. Model calibration results involving pump tests conducted using city well 07-1 and Rapp Park test well TW-1.

Well	Observed	Simulated
ID	Drawdown (ft)	Drawdown (ft)
07-1 OB 150'	5.5	5
TW-1 OB w200'	1.03	0.8
TW-1 OB w100'	2.4	1.6
TW-1 OB e50'	3.03	4.4

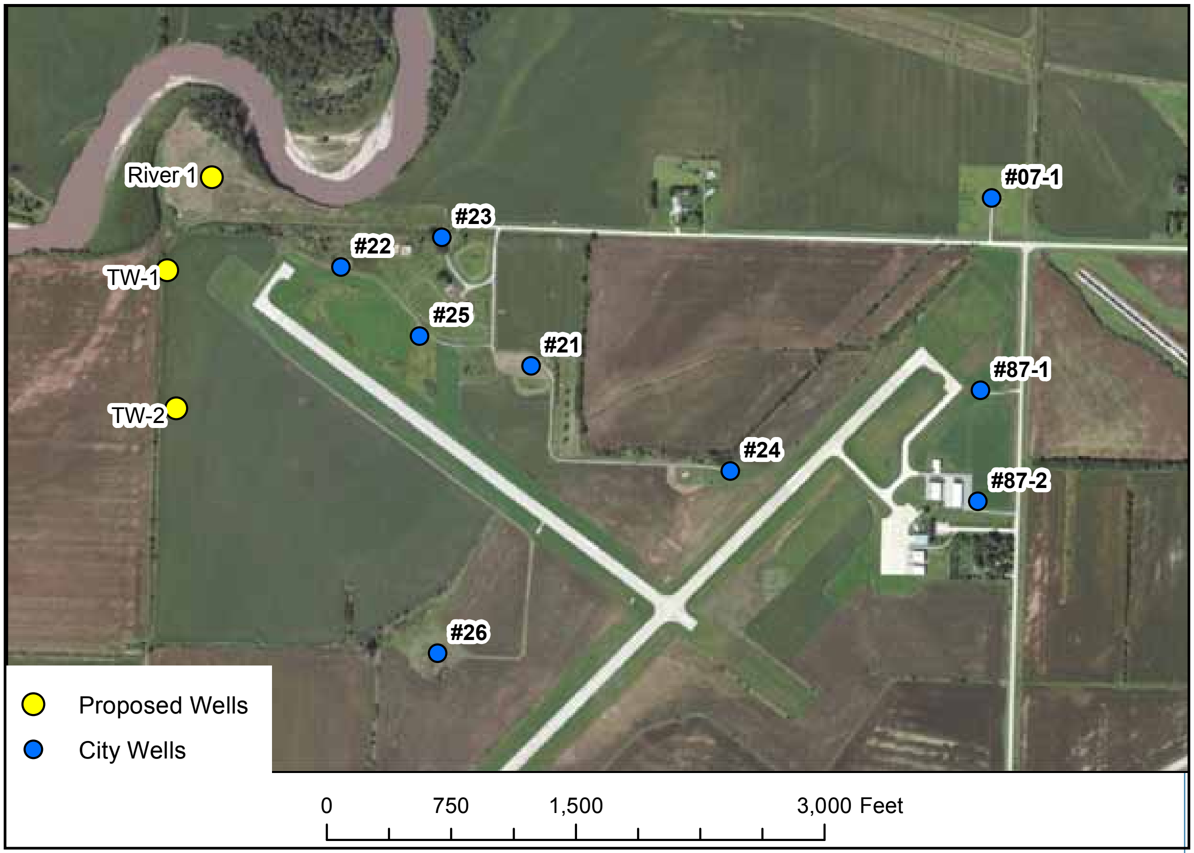

Figure 8. Additional proposed well locations at the airport well field.

Airport Well Field Model Simulations

The calibrated groundwater flow model was used to simulate the impact of adding additional production wells at the airport well field. Figure 8 shows the proposed locations of the additional wells, which were provided by Martha Silks of LBG. The aquifer parameters at these locations are unknown, so an average hydraulic conductivity (100 feet/day) and storage coefficient (0.003) were used at all three locations. These averages were obtained from the area around the airport.

Estimated Additional Pumping Capacity

The location of proposed well TW-1 is near former test hole TH-09-01. The location of proposed well River 1 was chosen to maximize induced recharge from the East Nishnabotna River and still maintain a 300-foot separation distance from the river. The location of proposed well TW-2 was approximately halfway between former test holes TH-09-01 and TH-09-02. At the direction of Martha Silks, existing wells 23, 25, and 07-01 were shut off in order to potentially increase the pumping rates in the remaining wells. The initial pumping rate for each proposed well was 100 gpm, and increase by 10 gpm until one of the simulated wells created a dry cell, or the pumping water level was within 1 foot of the top of the well screens.

Table 5 shows the simulated maximum pumping rates for the additional proposed wells, and the overall increase in production from the well field. Based on the model results, proposed well TW-1 and TW-2 had the same maximum pumping rate. Apparently the increase in induced recharge at TW-1 was offset by the

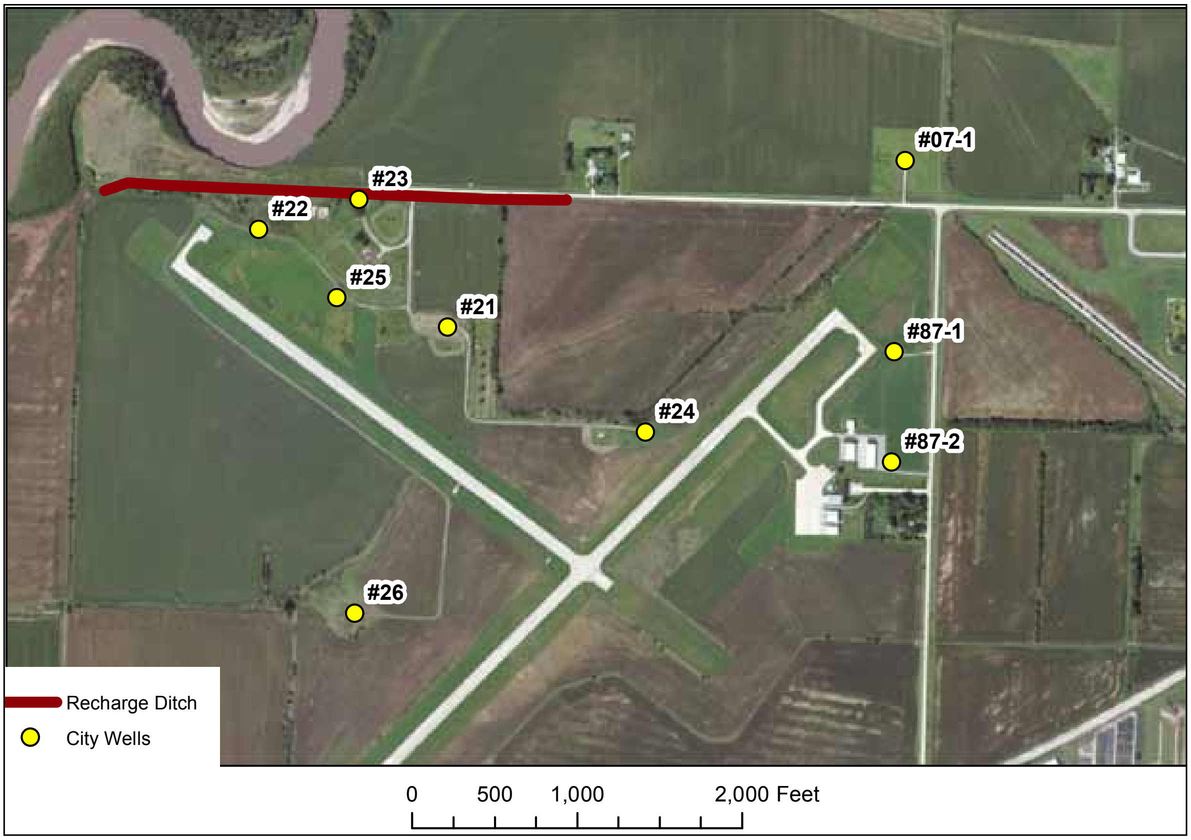

Figure 9. Location of the proposed recharge ditch near the airport well field.

increased well interference from proposed well River 1 and Well 22. The deciding factor in the final location of proposed wells TW-1, TW-2 or River 1 will be based on the results of the test drilling and the aquifer pump tests.

Table 5. Simulated maximum pumping rates after adding two additional production wells at the airport well field.

Well ID	Fox Projections 2013 (gpm)	Model Projections (gpm)
21	76	210
22	94	110
23	58	off
24	48	48
25	off	off
26	154	154
87-1	49	49
87-2	145	145
07-1	off	off
TW-1/TW-2	Not Available	180
River 1	Not Available	250
	total = 0.71 mgd$_2$	total = 1.3 mgd$_2$

$_2$ *based on 21 hours of use per day and 10% loss*

Based on the model results, total water production at the airport well field increased from 0.71 mgd to 1.3 mgd with the addition of proposed wells TW-1/TW-2 and River 1. Shutting off wells 23 and 25 allowed for an increase in water production in Wells 21 (increase of 134 gpm) and 22 (increase of 16 gpm). The model also showed an increase in the induced recharge from the East Nishnabotna River to 38 percent or 494,000 gpd (current induced recharge is 20 percent or 142,000 gpd). Actual production may be more or less than that shown in Table 5. Test drilling and aquifer pump test will be needed to verify the actual well field production.

Recharge Ditch Evaluation

An evaluation of a proposed recharge ditch was conducted using the calibrated

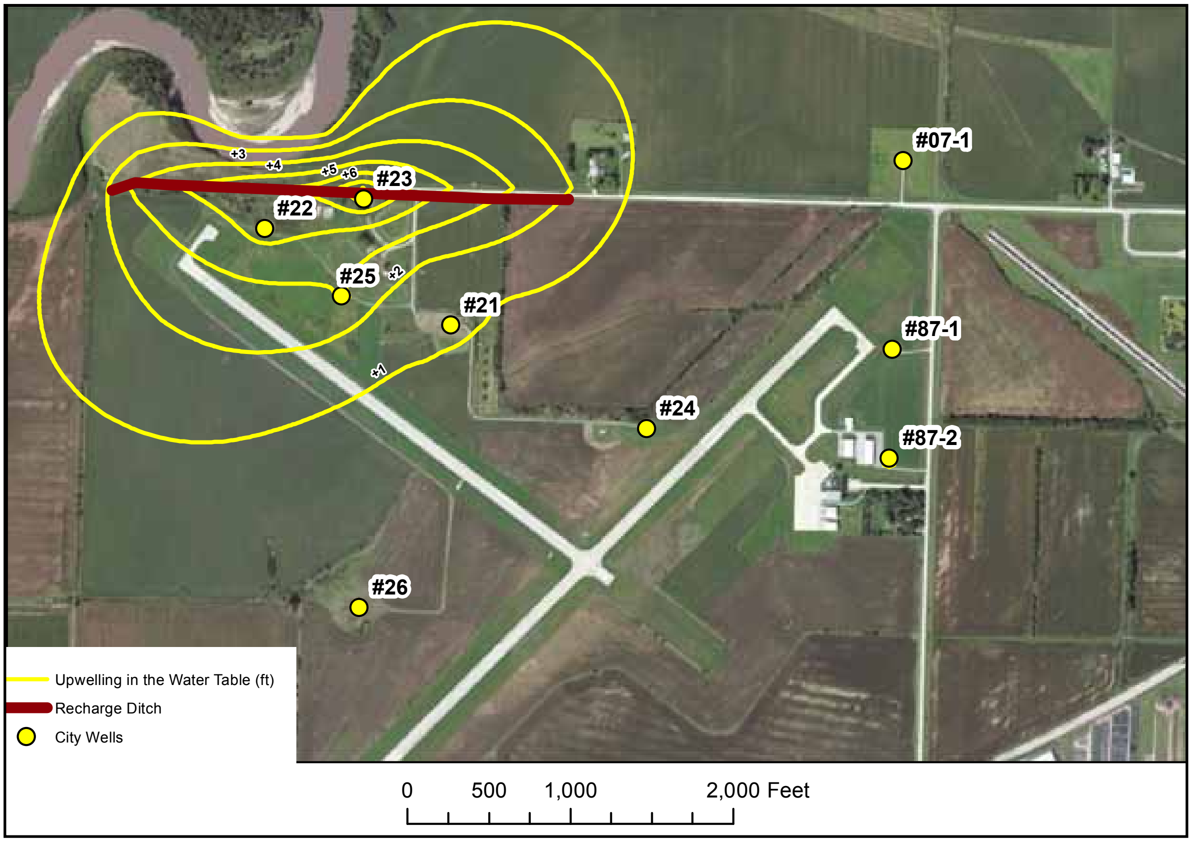

Figure 10. Rise (upwelling) in the water table caused by the proposed recharge ditch.

groundwater flow model. The location of the proposed recharge ditch is shown in Figure 9 (provided by Fox Engineering), and would use the existing drainage ditch located along the north side of the airport. Water from the East Nishnabotna River would be pumped into the ditch. This would require a temporary water use permit. For modeling purposes, the approximate water elevation in the ditch was assumed to be 942 feet above sea level based on the LiDAR data, and was maintained throughout a 90-day period. The recharge was assumed to enter directly into the aquifer (layer 2).

Figure 10 shows the upwelling in the water table at the end of the 90-day period caused by the recharge ditch. Increases in water table elevations range from 6 feet in Well 23 to 1 foot in Well 21. The recharge ditch would allow wells 24, 26, 87-1, 87-2, and 07-1 to be used during a severe drought, but would only increase water production slightly in each well. Based on the model results, the proposed recharge ditch would increase the water production at the airport well field to approximately 1.6 mgd.

Based on the mass balance output from Visual MODFLOW, the percentage of water production supplied by the induced recharge from the recharge ditch during a severe drought was approximately 58 percent or 890,000 gpd.

A pilot test would need to be conducted to verify the actual increase in water production. The model does indicate a substantial benefit of using a recharge ditch. Water quality data will need to be collected in Well 23 to see whether it would be classified as influenced groundwater. The other option would be to simply shut down Well 23 when the recharge ditch is being used. Well 23 is one of the lower producing wells, and shutting it down would reduce the well field production to 1.42 mgd.

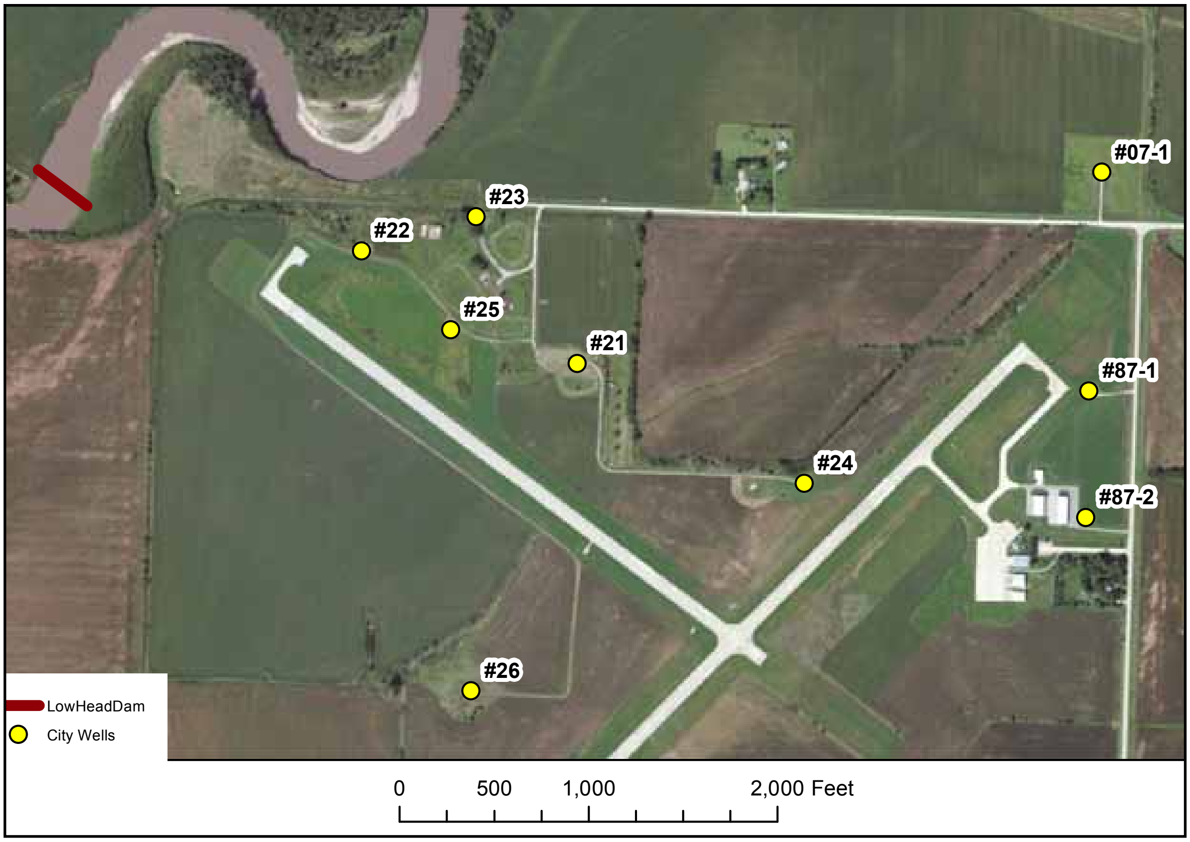

Figure 11. Location of the proposed low head dam near the airport well field.

If proposed wells River 1 and TW-1/TW-2 are added, along with the recharge ditch, the well field production would increase to 1.84 mgd.

Low Head Dam Evaluation

An evaluation of a proposed low-head dam was conducted using the calibrated groundwater flow model. The location of the proposed dam is shown in Figure 11. Figure 12 shows the increase in the water table caused by a 4 foot high low head dam. Increases in water table elevations range from 1 to 2 feet in Wells 21, 22, 23, and 25, and less than 0.5 feet in the remaining wells. Based on this upwelling, the

Table 6. Simulated maximum pumping rates after adding three additional proposed wells at the proposed Rapp Park well field.

Well ID	Drawdown @150 gpm (ft)	Drawdown @200 gpm (ft)	Drawdown @300 gpm (ft)
PW 1	7	9	13.5
PW 2	6	7	11
PW 3	6	9	dry
🟨	Estimated Maximum Yield per well		
Estimated total Maximum Production = 700 gpm			

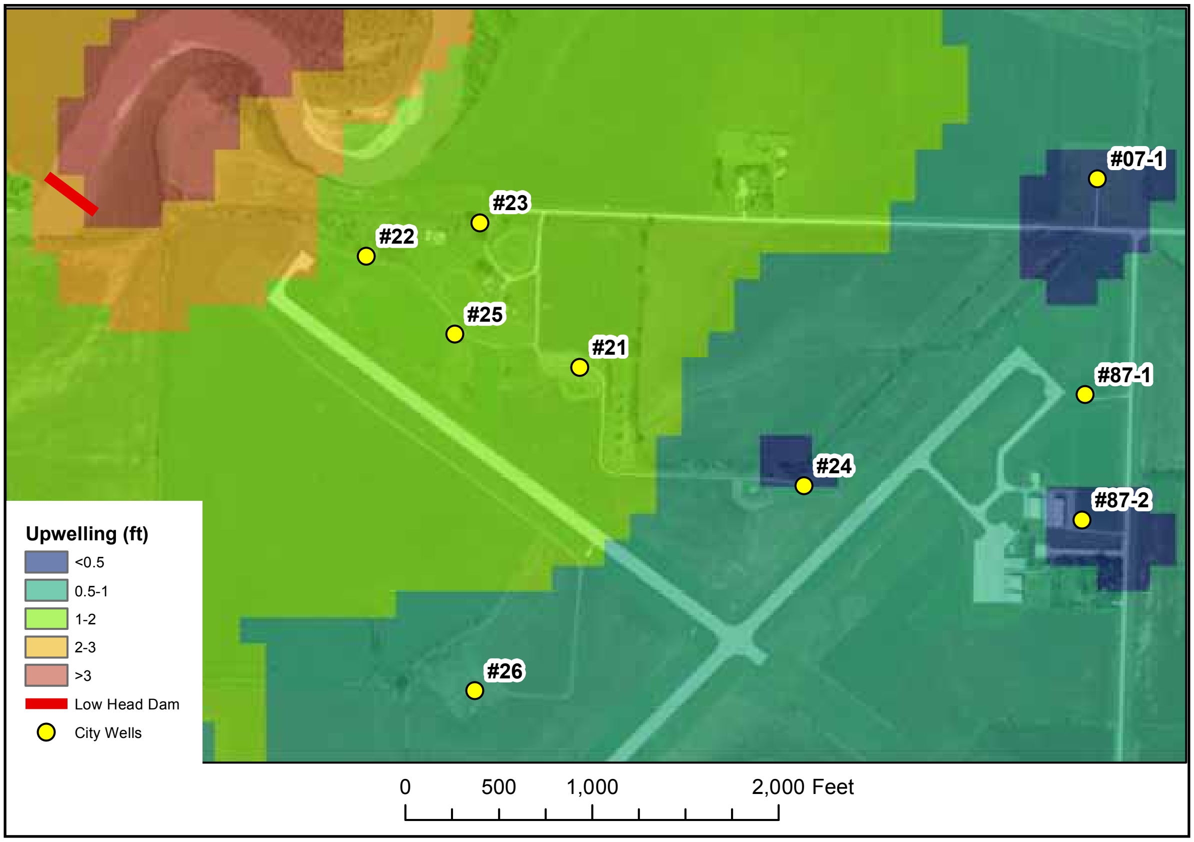

Figure 12. Rise (upwelling) in the water table caused by the proposed low head dam.

model shows an increase in water production of approximately 111,600 gpd, for a total water production of 821,600 gpd. Wells 07-1, 25 and 87-1 may contribute some minor additional water production, but the model indicated dry or near dry cells when the pumping rates increased 10 gpm or more.

Table 7. Simulated maximum pumping rates after adding four additional proposed wells at the proposed Rapp Park well field.

Well ID	Drawdown @200 gpm (ft)	Drawdown @300 gpm (ft)
PW 1	9	13.5
PW 2	8	11
PW 3	9	dry
PW 4	7	10
🟨	Estimated Yield per well	
Estimated Total Production = 1,000 gpm		

Rapp Park Model Simulations

To better understand the geology and hydrogeology of the Rapp Park area, four geophysical cross sections were conducted from August 5-6, 2013 (Figure 13). The goal for this work was to gather information on the alluvial aquifer surrounding Rapp Park, and to provide recommendations for test drilling. Using geophysics, an attempt was made to identify the thickest sand and gravel deposits, and whether the sand and gravel deposits might be hydraulically connected to the former quarries and/or the East Nishnabotna River.

The geophysical results produced from the electrical resistivity (ER) geophysical transects

Figure 13. Locations of the four geophysical cross sections at the proposed Rapp Park well field.

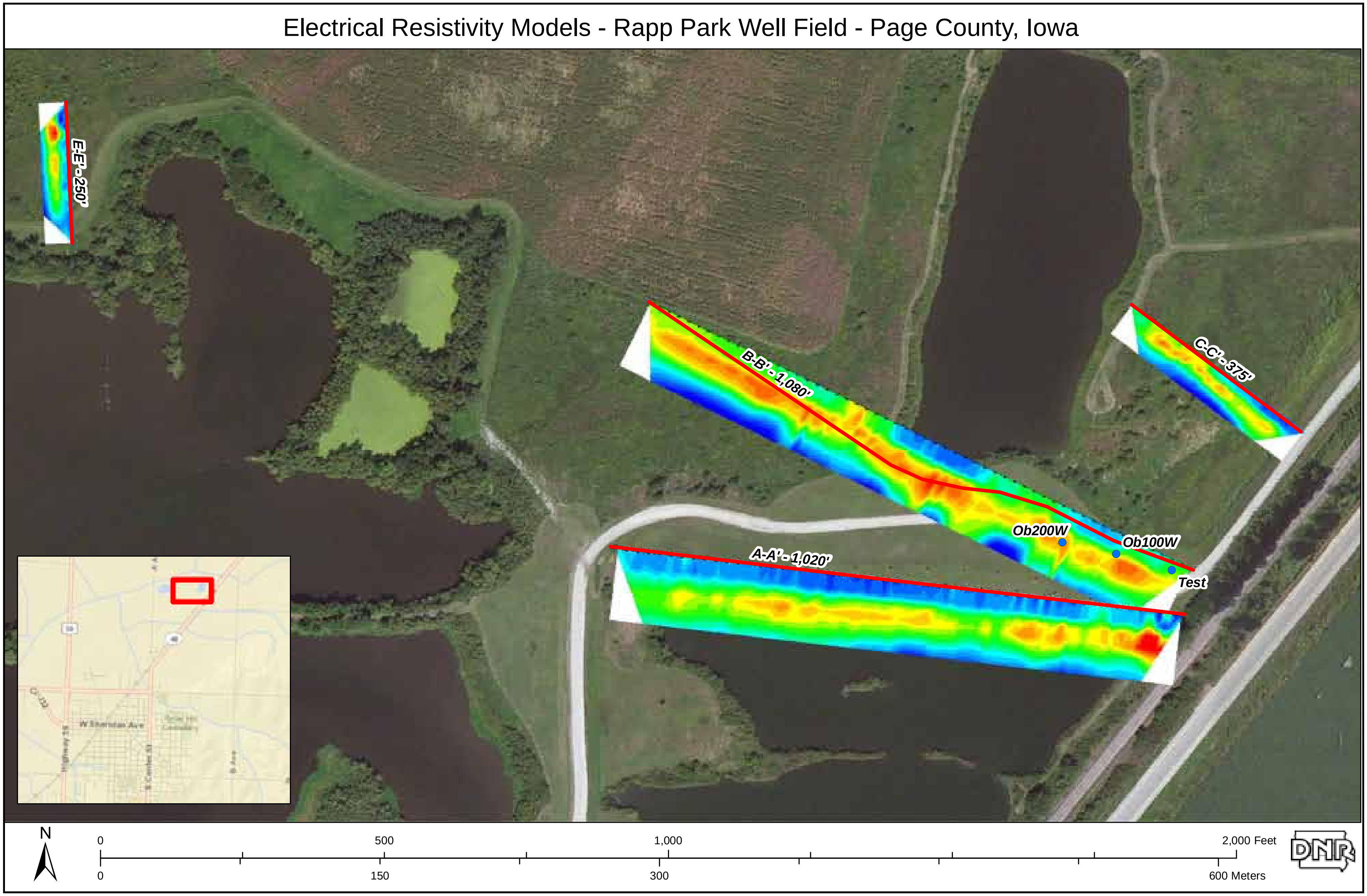

Figure 14. The geophysical (electrical resistivity) cross section results at the proposed Rapp Park well field. Sand and gravel is indicated by the yellow and red zones, and silt and clay are indicated by the blue and green zones.

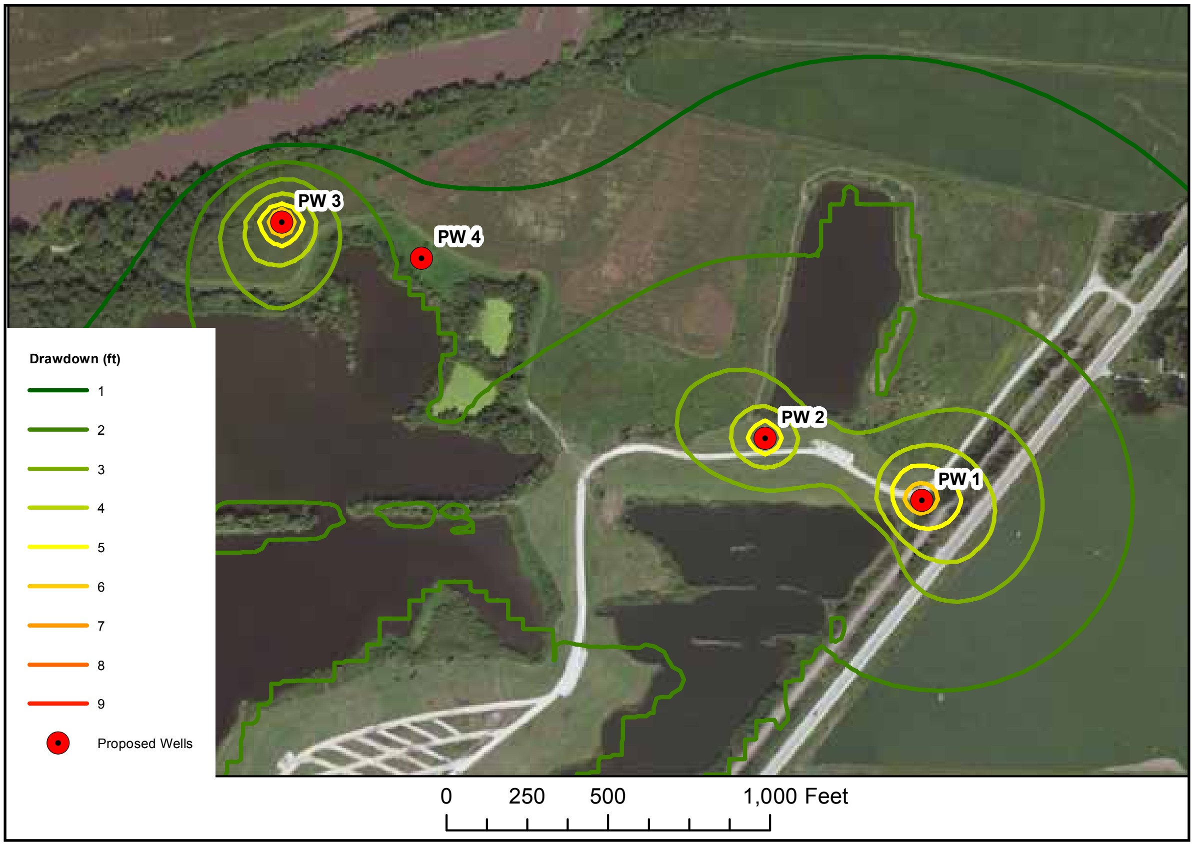

Figure 15. Simulated drawdown in feet using proposed wells PW-1, PW-2, and PW-3 at the proposed Rapp Park well field. Maximum simulated water production is 700 gpm.

are shown on Figure 14. Transect locations were chosen based on available 1930s aerial imagery, indicating where recent river channels might have deposited sand and gravel before straightening of the river was completed. While ER model results can be indicative of a number of variables, generally coarse sand and gravel are highly resistive (reds and yellows on models) while less permeable fine grained clay and silt are more conductive (blues and greens).

Figure 3 shows the proposed well locations at Rapp Park, which were provided by Martha Silks of LBG. The calibrated groundwater flow model was used to simulate the impact of adding production wells at the proposed Rapp Park well field. The aquifer parameters at these locations were obtained from a pump test conducted by Martha Silks in 2009. The initial pumping rate for each proposed well was 100 gpm, an increase by 10 gpm until one of the simulated wells created a dry cell, or the pumping water level was within 1 foot of the top of the well screens.

Tables 6 and 7 show the model simulated maximum pumping rates for the proposed wells at Rapp Park, and the overall maximum production from the well field. Based on the modeling results, the three-well simulation had a maximum production of 700 gpm, and the four-well simulation had a maximum production of 1,000 gpm.

The model simulated drawdowns are shown in Figures 15 and 16. The model results indicate a strong hydraulic connection between the former sand and gravel quarries and the proposed wells. Based on the ER cross sections, proposed wells PW-1, PW-2, and PW-4 appear to have the strongest hydraulic connection to the quarries. The deciding factor in the final locations of the proposed wells will be based

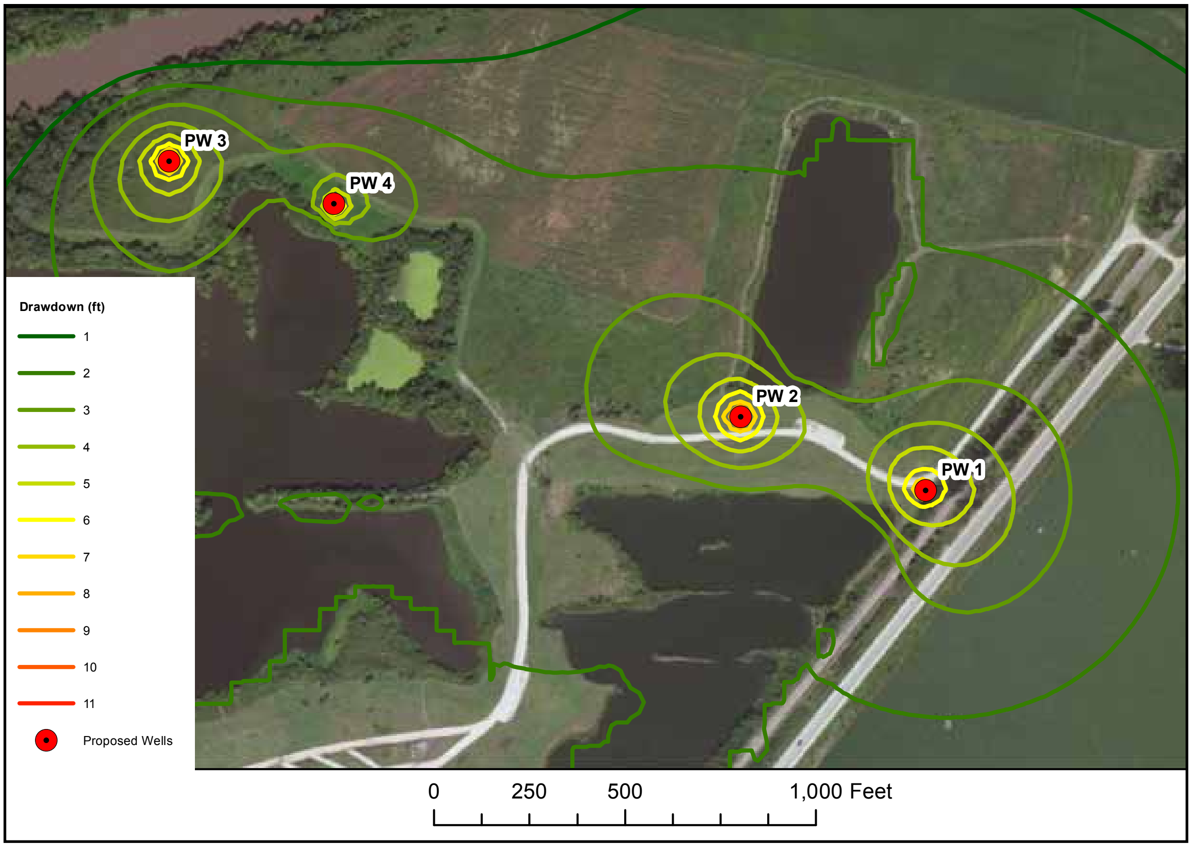

Figure 16. Simulated drawdown in feet using proposed wells PW-1, PW-2, PW-3, and PW-4 at the proposed Rapp Park well field. Maximum simulated water production is between 900 and 1,000 gpm.

on the results of test drilling and the aquifer pump tests.

ADDITIONAL FIELD WORK

Additional geophysical cross sections are planned for Rapp Park. IGWS was unable to conduct these cross sections in August because the land was being used to grow corn. At least two additional cross sections are planned west of Rapp Park, and one additional cross section is planned for the east side of Rapp Park.

Additional groundwater modeling can also be done at the airport wellfield. The calibrated model was used to estimate future water production at the airport wellfield with the addition of two new production wells. The groundwater model can also be used to estimate water production if more than two wells are planned.

CONCLUSIONS

The Iowa Geological and Water Survey completed a hydrogeologic evaluation of the water resources surrounding the City of Shenandoah, Iowa. The evaluation involved conducting geophysical cross sections, calibrating a groundwater flow model that can be used to evaluate the expansion of the current city well field near the Shenandoah airport, and the feasibility of a new well field north of town in Rapp County Park.

Based on the results of this evaluation, additional water production may be possible from two or more additional wells in the airport well field. Total well field water production increased from 0.71 mgd to 1.3 mgd with the addition of proposed wells TW-1/TW-2 and River 1. Shutting off wells 23 and 25 allowed for an increase in water production in wells 21 (increase of 134 gpm) and 22 (increase of 16 gpm). The model also showed an increase in the induced recharge from the East Nishnabotna River to 38 percent or 494,000 gpd (current induced recharge is 20 percent or 142,000 gpd). The final location and water production from any proposed wells will need to be determined following test drilling, test well installation, and aquifer pump tests.

Based on the groundwater flow model, the use of a proposed recharge ditch near the airport well field would substantially increase the total water production during a severe drought. Water quality data would need to be collected in Well 23 to see whether it would be classified as influenced groundwater. The other option would be to simply shut off Well 23 when the recharge ditch is being used. Well 23 is one of the lower producing wells, and shutting it down would reduce the wellfield production to 1.42 mgd. If proposed wells River 1 and TW-1/TW-2 are added, along with the recharge ditch, the wellfield production would increase to 1.84 mgd.

Based on the groundwater flow model, the use of a proposed low-head dam on the East Nishnabotna River would only increase the overall water production at the airport wellfield by 112,000 gpd. Wells 21, 22, 23, and 25 would provide most of the increase.

Based on the groundwater flow model, adding three to four new production wells at the proposed Rapp Park well field could provide an additional 700 to 1,000 gpm of water to the City of Shenandoah. Actual production would depend on the results of future test drilling, test well installation, and aquifer pump tests. The advantage of developing the proposed Rapp Park well field is the induced recharge available from the nearby former sand and gravel quarries.

REFERENCES

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