Appendix B. 2020 Lincoln Wellfield Groundwater Modeling

LAMP RYNEARSON

12596 W. Bayaud Ave., Ste. 330
Lakewood, CO 80228
[P] 303.971.0030
[F] 303.971.0077
LampRynearson.com

TECHNICAL MEMORANDUM

To: Andrew Hansen

From: Travis Zielke, CGWP

Date: 5/12/2020

Re: 2019 Lincoln Well Field Groundwater Modeling

CC:

Project No.: 0219047

PURPOSE

This memo summarizes groundwater modeling work conducted in support of the 2020 Lincoln Water Facilities Master Plan Update. This modeling effort was a continuation of prior modeling referred to as the Ashland Well Field Model and used in previous planning reports submitted to the City of Lincoln. Changes incorporated in the 2019 model include revisions to the precipitation recharge based on climate modeling by Martha Shulski, Nebraska State Climatologist, adjustments to the location of the Platte River at low flow rates, and the inclusion of two new wells proposed to be constructed sometime in the future as Lincoln's demands increase.

MODEL DESCRIPTION

The Ashland Well Field model encompasses a 34 square mile area centered on the US Highway 6 Bridge over the Platte River, just northeast of Ashland. The modeled well field includes 40 vertical wells in the North and South well fields, the four existing horizontal wells, and the two horizontal wells proposed for drilling at a future date. These well locations are shown on Figure 1.

The Ashland Well Field model was originally created in 1987 for the purposes of evaluating proposed well field expansion alternatives. The model has been updated a number of times since then, most recently in 2014 when the model was rebuilt to run in Groundwater Vistas with an enhanced level of detail. This work was described in reports and memos from TZA Water Engineers and others in 1987, 1989, 1994, 2004, 2013, and 2014.

MODEL REFINEMENT

For this modeling effort, two refinements were made to the model used in previous studies. One of these changes was made based on climate modeling conducted by Martha Shulski, which indicated that on average in the future, fall through spring would tend to be 15% wetter, and summers would be 12.5% dryer. These results were incorporated into the model by adjusting the precipitation recharge. The 15% wetter fall through springs were included by increasing the recharge during the Antecedent period by 15%. The dryer summers were included by reducing recharge during the Dry Spring antecedent condition and during each drought scenario by 12.5%. The scenario descriptions provide more details on antecedent condition modeling.

The second refinement made was regarding the location of the Platte River in low flow conditions. Observations made in support of previous modeling indicated that at flow rates less than 3000 cfs, the Platte River is no longer running bank-to-bank, and instead runs in smaller channels inside the river bed. In previous work, the river was modeled as running along the west bank north and south of Ashland Island, and east around the island. For this study, an analysis was conducted comparing results where the river was run fully along the east bank versus those where the river was running fully along the west bank. The river cells are shown for the two runs on Figure 1. It was found that the river running along the west bank resulted in lower sustainable production rates as compared to if the river ran along the east bank. To ensure a conservative analysis, the west bank configuration was used in this study. See the River Configuration section for more details.

Other model parameters are summarized on Table 1. Detailed descriptions of these parameters can be found in the report dated September 1, 1987.

Sensitivity Analysis

These two refinements were analyzed to evaluate to how the model results would be impacted by their incorporation into drought planning scenarios. The changes in precipitation recharge had little effect on well field production. This is attributable to the drought scenarios having a short duration and the prior model assumption that precipitation recharge is only 5% of the annual total precipitation during a drought. These combine to add very little water to simulation, and a reduction in that water supply had minimal impact on well field yields.

Placing the river to the west of Ashland Island had significant impact on yields compared to previous modeling. This is attributable to the increased distance between the horizontal wells and their water source. As the river moves further away from the horizontal wells, sustainable production from the wells drops considerably. These impacts are quantified later in this report.

SIMULATIONS FOR DROUGHT PLANNING PURPOSES

TZA previously performed modeling for drought planning purposes in response to the droughts and resulting river flow conditions that occurred in the summers of 2002 and 2012. Data gathered during those droughts was included in comprehensive modeling conducted in 2013, which were summarized in the Technical Memorandum dated January 23, 2014. Relevant results from the 2014 memo are included here in Table 3 as a baseline of comparison for the results of this modeling effort.

The primary focus of this 2019 modeling was to evaluate the addition of the two new horizontal wells proposed to be drilled in 2024. These wells are shown as Future-1 and Future-2 on the attached Figure 1. Three different well field configurations were studied: current conditions, current conditions plus the addition of well Future-1, and current conditions plus the addition of wells Future-1 and Future-2. After the previously discussed model refinements were made, each of the well field configurations were evaluated in a series of nine different droughts. These droughts corresponded to river flows of 1500 cfs, 700 cfs, or 200 cfs for periods of 30, 60, and 90 days.

For each of these droughts, the antecedent conditions prior to the modeled drought period are critical in getting valid results. For the 1500 cfs and 700 cfs scenarios, a 5000 cfs steady-state period is run before starting the drought period. These runs include average spring/fall pumping requirements for Lincoln. This portion of the run represents the spring run-off season, and allows the model to start with water table elevations reasonable for the beginning of a drought.

For the 200 cfs scenarios, an additional "Dry Spring" period of 60 days is added after the 5000 cfs steady-state period. This period has an elevated demand half-way in between spring and fall levels, and serves to reduce water table elevations at the beginning of the extremely low flows modeled in the 200 cfs drought scenarios. The 200 cfs drought also experiences increased severity from a total loss of recharge to the model from precipitation. These drought scenarios are discussed in more detail in the January 23, 2014 Model Update Memo.

The scenario settings are summarized below:

<u>Scenarios Considered</u>

For each of the three well configurations, nine drought scenarios were conducted:

Riverflow (cfs)	Duration (Days) 30	60	90	
1500				Normal Antecedent (4.4% Precip Recharge)
700				
200				Dry Spring Antecedent (Zero Precip Recharge)

<u>Well Capacities/Pumping Limitations</u>

Current well capacities were considered to be as shown on Table 2. The North and South Well Field capacities (32-1A to 86-2) were determined from well testing performed by Lincoln Water System staff during September and October of 2012, a time of the year when ground water levels and thus pumping capacities are typically the lowest.

The pumping withdrawals used within MODFLOW are considered to occur on a continuous basis. In order to provide a margin of safety for circumstances such as down-time for pump repairs and decreases in well capacities which may occur during peak use periods, it was decided that pumping from individual wells should be limited to an amount less than the full capacity. In addition, Lincoln Water System staff have determined from experience that individual wells within the South Well Field often experience excessive drawdown if they are operated more than 50% of the time. Based upon these considerations, pumping from individual wells was limited as follows; for steady state simulations the North Well Field wells are limited to 70% of the maximum capacity and the South Well Field wells are limited to 50% of the maximum capacity; for transient simulations the North Well Field wells are limited to 85% of the maximum capacity and the South Well Field wells are limited to 75% of the maximum capacity. Because all of the horizontal wells will include a sufficient number of pumps and sufficient capacity to allow production at rates in excess of the modeled capacities of 12,000 gpm, no further constraints were applied to the horizontal wells.

At the end of a model scenario, the model cells which contain wells are evaluated to determine if water levels have exceeded the allowed drawdown for that well. The amount of allowed drawdown is 25% of saturated thickness in vertical wells, and 50% of saturated thickness in horizontal wells. These criteria were developed for previous model studies and are described in detail in the Report dated September 1, 1987.

River Configurations

For these planning scenarios, river configurations used in previous modeling were changed. In previous modeling, the location of the river was based on field observations in 1988 and 2012. These observations indicated that, downstream of U.S. Highway 6, as flow rates increased the river filled the bank from east to west and transitioned to bank-to-bank flows at 3000 cfs. Below 1500 cfs, the river was observed to flow entirely through a channel east of Ashland Island. In the 2002 drought, the river was observed to flow west around Ashland Island. The 2002 configuration had been used in drought modeling since 2012.

For this series of model scenarios, a 700 cfs/60-day scenario was examined wherein the river was modeled as filling from the west rather than filling from the east as in previous modeling. Filling from the west caused the sustainable yields to decline considerably in the horizontal wells, which resulted in an overall decrease in the Well Field's production. To ensure a conservative analysis, this modeling effort uses a west to east filling methodology described in detail below.

For the stream reach between the U.S. Highway 6 bridge and the Interstate-80 bridge:

1) at flow rates less than about 1500 cubic feet per second (cfs), the entire river is flowing through a channel located west of Ashland Island;
2) at flow rates between about 1500 and 3000 cfs, the river begins flowing through a small channel east of and adjacent to Ashland Island, and gradually spreads over most of the streambed as flow rates approached 3000 cfs; and,
3) at flow rates greater than 3000 cfs, the river was flowing bank-to-bank and the entire streambed is generally submerged.

For the stream reaches upstream of the U.S. Highway 6 bridge and downstream of the Interstate-80 bridge, it is assumed that as flow rates increase, the river will fill from west to east across its channel, until it reaches bank-to-bank conditions at a flow rate of 3000 cfs. Based upon these assumptions, river depth versus river width relationships were developed by application of Manning's Equation.

The wetted areas for each river cell under bank-to-bank flow conditions (considered to occur at streamflows greater than 3000 cfs) were determined by utilizing recent NAIP aerial photography. Wetted areas for flow conditions less than 3000 cfs were calculated based on channel widths determined by Manning's Equation. A river stage-discharge relationship was developed based on records from the USGS gauging station at the

Highway 6 Bridge. An average river gradient for the modeled river reach was determined from USGS topographic maps. River stages for each river cell under various flow rates were determined based on the Highway 6 gauge stage-discharge relationship, the river gradient, and Manning's Equation.

RESULTS

The results of the modeling analyses based on the current production wells are summarized on Table 4. The entries marked as "OK" on Tables 4 through Table 6 indicate that the specified pumping rate could be maintained for the specified time period without exceeding the drawdown criteria. The entries marked as "Fails" on Tables 4 through Table 6 indicate that the specified pumping rate could not be maintained for the specified time period without exceeding the drawdown criteria.

Assuming the river runs to the west of Ashland Island has a significant effect on pumping rates for the well field. Comparing scenarios from Table 3 to those on Table 4 indicate that yields decline between 5 and 10 MGD due to this change. This is mainly attributable to the reduction in sustainable yield from the horizontal wells. While running the river west of the island improves recharge to the North and South well field, this effect is outweighed by the reduced yield from the horizontal wells.

For the current well configuration, sustainable production varied between 90 MGD and 115 MGD, depending on the drought scenario. The addition of Future-1 changes the sustainable production to between 95 MGD and 120 MGD depending on the drought scenario. The addition of both Future wells changes the sustainable production to between 105 MGD and 125 MGD depending on the drought scenario.

Attachments: Figure 1
Tables 1-6

REFERENCES

Ashland Well Field Comprehensive Development Plan Modeling Study, GMI Specialized Engineering Services, September 1, 1987

Ashland Well Field Comprehensive Development Plan Updated Groundwater Modeling Study, TZA Water Engineers, June 1989

Ground Water Modeling Analyses For The City Of Lincoln's Permit To Appropriate Natural Flow For Induced Ground Water Recharge, TZA Water Engineers, February 1994

2003 Well Field Modeling – Methodology and Results, TZA Water Engineers, April 3, 2004

Well Field Modeling for Drought Planning Purposes, TZA Water Engineers, March 22, 2013
Update of Groundwater Model and Well Field Modeling for Drought Planning Purposes, TZA Water Engineers, January 23, 2014

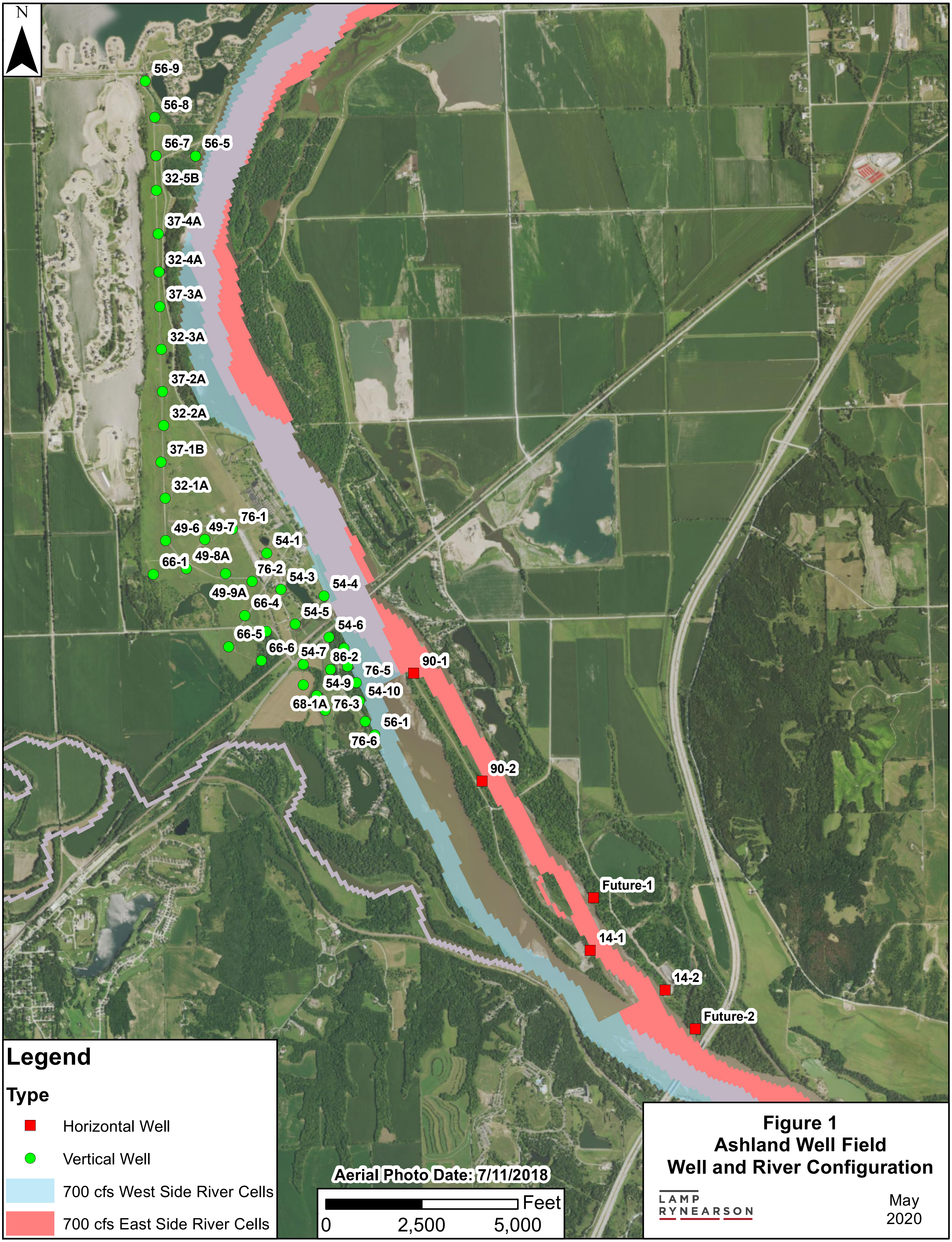

Figure 1
Ashland Well Field
Well and River Configuration

TABLE 1

SUMMARY OF INPUT DATA
ASHLAND WELL FIELD GROUND WATER MODEL

Parameter	Value	Units
Hydraulic Conductivity		
Sand/Gravel Aquifer	353	ft/day
Clay Unit	1.0×10^{-3}	ft/day
Storage Coefficient		
Sand/Gravel Aquifer	15	%
Clay Unit	5	%
Specific Storage for Confined Sand/Gravel Aquifer Conditions	3.0×10^{-5}	ft^{-1}
Hydraulic Conductivity of Riverbed Material/Thickness of Riverbed (K/M)		
Platte River	6	day^{-1}
Salt and Wahoo Creeks		
In Clay Unit	3.5×10^{-8}	day^{-1}
In Sand/Gravel Aquifer	0.014	day^{-1}
Drains		
In Clay Unit	10^{-3}	day^{-1}
In Sand/Gravel Aquifer	3.53	day^{-1}
Aquifer Recharge as a Percent of Total Precipitation		
In Clay Unit	1	%
In Sand/Gravel Aquifer	15	%
River/Creek Stage	Variable	ft
Well Pumpage	Variable	ft^3/day

Table 2
Modeled Well Capacities
Lincoln Ashland Well Fields

Well #	Maximum Modeled Well Capacity (gpm)	Well #	Maximum Modeled Well Capacity (gpm)
32-1A	2,500	66-4	2,500
32-2A	2,500	66-5	2,500
32-3A	2,500	66-6	2,500
32-4A	2,000	68-1	2,500
32-5B	2,000	76-1	3,000
37-1B	2,500	76-2	2,900
37-2A	2,600	76-3	2,500
37-3A	2,000	76-4	2,500
37-4A	2,000	76-5	2,500
49-6	2,500	76-6	2,500
49-7	2,500	86-1	2,500
49-8A	2,500	86-2	2,800
49-9	2,500	90-1	12,500
54-1	2,500	90-2	12,500
54-3	2,500	14-1	12,500
54-4	2,500	14-2	12,500
54-5	2,500	24-1	12,500
54-6	2,500	24-2	12,500
54-7	2,500		
54-8	2,500		
54-9	2,500		
54-10	2,500		
56-1	2,500		
56-5	2,000		
56-7	2,500		
56-8	2,500		
56-9	2,500		
66-1	2,500		
		Total (gpm)	173,800
		Total (mgd)	250.3

TABLE 3

Summary of Previous Ground Water Modeling Scenarios for Drought Planning Purposes

City of Lincoln Ashland Well Fields - Current 2019 Capacity

From 2014 Technical Memo - Previous River Configuration

River Flow: 1500 cfs

Simulation	Pumping Rate			
Period	**110 mgd**	**115 mgd**	**120 mgd**	**125 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 700 cfs

Simulation	Pumping Rate			
Period	**100 mgd**	**105 mgd**	**110 mgd**	**115 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	OK	Fails	Fails

River Flow: 200 cfs

Simulation	Pumping Rate			
Period	**90 mgd**	**95 mgd**	**100 mgd**	**105 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

TABLE 4

Summary of Transient Ground Water Modeling Scenarios for Drought Planning Purposes

City of Lincoln Ashland Well Fields - Current 2019 Capacity

River Flow: 1500 cfs

Simulation Period	Pumping Rate			
	105 mgd	**110 mgd**	**115 mgd**	**120 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 700 cfs

Simulation Period	Pumping Rate			
	90 mgd	**95 mgd**	**100 mgd**	**105 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	OK	Fails	Fails

River Flow: 200 cfs

Simulation Period	Pumping Rate			
	85 mgd	**90 mgd**	**95 mgd**	**100 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	OK	Fails	Fails

TABLE 5

Summary of Transient Ground Water Modeling Scenarios for Drought Planning Purposes

City of Lincoln Ashland Well Fields - Current 2019 Capacity plus Future-1

River Flow: 1500 cfs

Simulation Period	Pumping Rate			
	110 mgd	**115 mgd**	**120 mgd**	**125 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 700 cfs

Simulation Period	Pumping Rate			
	105 mgd	**110 mgd**	**115 mgd**	**120 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 200 cfs

Simulation Period	Pumping Rate			
	95 mgd	**100 mgd**	**105 mgd**	**110 mgd**
30 Days	OK	OK	OK	OK
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

TABLE 6

Summary of Transient Ground Water Modeling Scenarios for Drought Planning Purposes

City of Lincoln Ashland Well Fields - Current 2019 Capacity plus Future-1 and Future-2

River Flow: 1500 cfs

Simulation	Pumping Rate			
Period	**115 mgd**	**120 mgd**	**125 mgd**	**130 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 700 cfs

Simulation	Pumping Rate			
Period	**110 mgd**	**115 mgd**	**120 mgd**	**125 mgd**
30 Days	OK	OK	OK	Fails
60 Days	OK	OK	Fails	Fails
90 Days	OK	Fails	Fails	Fails

River Flow: 200 cfs

Simulation	Pumping Rate			
Period	**100 mgd**	**105 mgd**	**110 mgd**	**115 mgd**
30 Days	OK	OK	OK	OK
60 Days	OK	OK	Fails	Fails
90 Days	OK	OK	Fails	Fails