NORTHWEST Land & Water, INC.
Consulting in Hydrogeology

6556 37th Ave. NE
Seattle, WA 98115
206-525-0049 p
www.nlwinc.com

Memorandum

Date: September 7, 2020

To: Teri O'Neal and Jessica Wilson, City of Lacey

From: Jim Mathieu, Northwest Land & Water, Inc.

Re: TQu aquifer trends associated with pumping at S19 and S31, new production well(s) construction, and planning recommendations in the Hawks Prairie area

Contents

Background

This memo recaps the results of an investigation into the effects of pumping at City of Lacey production wells S19 and S31 on water level, yield, and specific capacity trends in wells completed in the TQu aquifer of the Hawks Prairie area. The goal of this work was to assess conditions that will guide the construction of new production wells at the Marvin Road (MR) and Meridian Campus (MC) sites and help the City plan for the ongoing development of its water rights. The locations, annual quantities (Qa), and instantaneous rates (Qi) of City water rights are shown in **Table 1** by quarter-quarter section; this table also includes the water rights for two nearby TQu production wells—the Golf Club (GC) irrigation and Silver Hawk (SH) supply wells.

This analysis involved the three main tasks:

- Plotting production, water level, and specific capacity data collected from 2012–2018 to assess trends at the wells and within the TQu aquifer.
- Analyzing a 57-day period of summer production and water level data (in 2016) to assess aquifer boundary conditions
- Plotting and reviewing specific conductance data, a key parameter for assessing seawater intrusion.

Figure 1 shows the City's TQu production and monitoring wells, along with the trace of hydrogeologic cross section A-A'; also shown on **Figure 1** are the GC and SH wells. **Figure 2** shows the cross section.

Production Wells

Hawks Prairie Treatment Plant Facility Wells

The City's water rights for the Hawks Prairie Treatment Plant Facility (HPTPF) site total 2,092 acre-feet (ac-ft; **Table 1**). This primary annual water right is distributed between two wells, S19 (1,026 ac-ft) and S31 (1,066 ac-ft), that provide water to City customers. During the most recent approximate 7-year period from December 1, 2011, to September 1, 2018, the City pumped a combined average annual volume of 862.9 ac-ft (281.2 MG) from the wells[1]—41% of the primary annual water right volume for the site.

Table 2 shows the last 7 years of individual and combined production from S19 and S31, along with the corresponding percentage of the annual water right volume. The highest years of combined production were 2015 (a drought year), 2016 (a dry year), and 2018. These 3 years

[1] From the City of Lacey Operations database.

represent about 45% to 55% of the annual water right production from S19 and S31 combined. Note that production during these years was curtailed because of sanding events at both S19 and S31.

Table 3 shows water-bearing Zones 1–5 (shallowest to deepest) in the TQu aquifer, where the wells are screened. Prior to March 2018, S31 yielded water from Zones 1, 2, and 3; after March, Zone 3 was shut down to mitigate sand production.

Other Production Wells

Two other production wells in the vicinity—the GC and SH wells, which are used for irrigation and community supplies, respectively—also yield groundwater from the TQu aquifer. **Table 3** shows that both wells are screened in TQu Zones 2 and 3.

Monitoring Wells

The City’s water rights for the MR site total 1,500 ac-ft/yr (annual). This site features monitoring well TW-MR, a former test well that was used to investigate water-bearing Zones 1–5 in the TQu aquifer in 2008. TW-MR is completed in Zones 1, 2, and 3 (**Table 3**). Several other City monitoring wells are completed in this aquifer (**Table 3**):

- TW-MC, which is located in the MC area, also has water rights (**Table 1**) and taps TQu Zones 1–3.
- TW-BC, which is located at Beachcrest, taps TQu Zones 1–3.
- The Shoreline Monitoring Well (SMW), which contains a down-well packer that separates upper Zones 1, 2, and 3 (SM-u) from lower Zones 4 and 5 (SM-l).

Key Data Trends

Production, Water Levels, and Conductance

Figure 3 shows production from wells S19 and S31, water levels in TW-MR, and water levels and specific conductance in the upper and lower SMW zones.

Water levels at each monitoring station (TW-MR, SM-u and SM-l) follow a general pattern—high in mid-winter, declining in late spring through mid-summer, and recovering in fall. This pattern corresponds to seasonal pumping to meet water demands, which are highest in mid-summer and lowest in mid-winter.

Production

Lacey’s water production (**Figure 3**) for high-demand seasons during the past 7 years (2012–2018) can be categorized in relative terms as “medium” or “high” (**Table 2**). For this analysis, we grouped production from both S19 and S31 as the total from Zones 1, 2, and/or 3 (the upper part of the TQu aquifer).

Production was high during the summers of 2015, 2016, and 2018, and medium during the summers of 2012, 2013, 2014, and 2017. During 4 of the past 7 years—2013, 2015, 2016, and 2018—production occurred from both S19 and S31; however, as previously noted, S31 yielded water only from Zones 1 and 2 after March 2018. During 2012, 2014, and 2017, only S19 produced water.

Water Levels

In general, water levels throughout the TQu aquifer show a response to pumping at S19 and S31. This response is observable in monitoring wells located 1 to 2 miles away. Furthermore, the drawdown response in the TQu aquifer is greatest during high production years and each summer when seasonal production rates increase.

Shoreline Monitoring Well. Water level monitoring at the SMW began in 2015 for combined Zones 1–5. By mid 2016, a packer was installed in this well to separate the upper and lower zones. Since 2015, water levels have remained above sea level in both SM-u and SM-1 (**Figure 3**). This bodes well for preventing seawater from intruding laterally from Puget Sound (north) toward the Hawks Prairie area production wells (south) for the pumping conditions that occurred from 2015–2018. Note that water level elevations were higher in SM-l than they were in SM-u, ranging from about 5 feet higher during the lowest pumping season to about 10 feet higher during the highest pumping season (see **Figure 3**, after 9/2017). This seasonal variation suggests that the combined summer pumping response of the four production wells propagates more laterally than vertically in the TQu aquifer. This is consistent with the hydraulic response of layered aquifers in the Puget Sound area, where horizontal to vertical hydraulic conductivity (permeability) ratios range from 10:1 to 100:1.

Monitoring well TW-MR. Also shown on **Figure 3** is the water level trend at TW-MR, located about 800 to 900 feet from S19/S31 (**Figure 1**). During three summer seasons (2015, 2016, and 2018), water levels in this well were near sea level. Note that 2015 and 2016 were the highest production years of the period from 2012–2017 and featured relatively warm summers with prolonged dry periods.

Monitoring wells TW-MC and TW-BC. Water level trends for TW-MC and TW-BC are shown on **Figure 4**. These wells are located approximately 8,000 feet from S19 and S31 (**Figure 1**). Trends for both wells show a high and low seasonal pattern related to water production, with the largest declines occurring in summer 2015 and 2018. Summer water levels in TW-MC were higher than those in TW-BC during much of the highest-demand periods in 4 of the 7 years (2013, 2015, 2016, and 2018). During these 4 years, both S19 and S31 operated to meet summer demands, whereas only S19 operated during 2012, 2014, and 2017. The analysis of the 57-day step-rate test (discussed in the "Aquifer Boundaries" section below) provides further evidence of the TW-BC and TW-MC water-level response from pumping at both S19 and S31.

Specific Conductance

The specific conductance values for TW-BC, SM-u, and SM-l are typical for groundwater in the TQu aquifer—i.e., in the range of 70 to 100 µmhos/cm (**Figure 3**). Specific conductance data indicate a relatively flat trend. This trend and the 2015 chloride concentrations of 1 to 2 mg/L in the SMW currently suggest a very low risk of seawater intrusion[2].

Production and Specific Capacity

Figure 5 includes two time-series graphs:

- An upper graph of water production for S19, S31, and combined S19 and S31 (same data used in **Figure 3 and 4**).
- A lower graph showing specific capacity for S19 and S31, constructed using the City's Operations database and overlain with data extracted from the City's SCADA system.

Specific capacity is a well's pumping rate divided by the difference in static and pumping water levels, or drawdown. A measure of well performance, it is a function of both well and aquifer hydraulic properties. The specific capacity trends on **Figure 5** indicate the following relationships:

- With the exception of S19 during 2015, specific capacity varies seasonally, declining in mid-year (summer), and then typically increasing in late-year (fall). The summer declines are caused by variations in the hydraulic properties of the TQu aquifer. These variations likely limit lateral recharge, a condition that is accentuated when S19 and S31 are pumped at higher rates to meet summer demands. In 2015, production from S19 was relatively small compared to other years; this may explain the lack of a seasonal summer decline in S19's specific capacity.

- Specific capacity generally declines (downward trend) in S19 from 2012–2108 and in S31 from 2012–2017. Note that the Zone 3 screen of S31 was blanked off in 2018[3], which resulted in a decrease in S31's specific capacity after 2018.

[2] See Ecology's seawater intrusion policy (Tibbot, 1992, Appendix B, section VI, referenced in NLW (2011)), which is referenced in the Record of Exam for the Marvin Road water right (MR G2-30251 ROE).

[3] See NLW's memo to the City of Lacey dated April 2020 re: Well S31 Sand Intrusion (Spring 2018).

Analysis

Limiting Factors

Two factors limit yields at these two wells, as discussed below:

- An aquifer boundary within the TQu, as suggested by the seasonal variation in specific capacity at S19 and S31, which declines in mid-summer and increases in fall
- Long-term declines in specific capacity at both wells, which indicate a potential reduction in their efficiency

Aquifer Boundaries

The pattern of mid-summer declines in specific capacity, followed by fall increases, in both S19 and S31, suggest the presence of an aquifer boundary that limits yield to some degree. Aquifer boundaries may occur because of the limited areal extent of Zones 1, 2, and 3, which may thin, pinch out, or be truncated. Alternately (or additionally), they may result from a directional reduction in hydraulic conductivity (permeability). Such physical limitations would tend to increase the rate of drawdown in response to prolonged pumping, particularly during the summer as pumping rates or volumes increase.

The stratigraphic evidence for a reduction in the thickness of aquifer zones in the S19/S31 region is apparent when comparing the pumping response at these production wells with the response at monitoring well TW-BC (**Figure 2**). To further investigate aquifer boundary effects, we analyzed pumping water levels for the period from July 12 to September 9, 2016 (57 days). This analysis assumed a "surrogate" well to consolidate pumping at the mid-point between S19 and S31 from Zones 1, 2, and 3 in the TQu aquifer. The 57-day period was effectively a long-term step-rate test, where the step-rates for the surrogate well were the combined monthly production for S19 and S31—namely, 640, 1035, and 1143 gpm—for July, August, and September, respectively.

Appendix A shows six graphs of drawdown versus time: one for early-time (<10 days of pumping) and late-time (>20 days of pumping) at each of the three monitoring wells (TW-MR, TW-MC, and TW-BC). Each graph shows a relatively shallow drawdown trend followed by a relatively steep one. The drawdown data was analyzed using the standard Theis method[4], with variable pumping rate curve matching. Note that the early-time type curves fit reasonably well to early data (0.1 to 10 days) and result in the transmissivities (T) shown in **Table 4**. However, late-time fits result in significantly smaller T values (**Table 4**).

[4] Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

T decreases by 40% to 50% from early- to late-time pumping between the surrogate well and both TW-MR and TW-BC—a notable contrast to the smaller 20% reduction between the surrogate well and TW-MC. Given the proximity of the MR site to the surrogate well, it is reasonable to expect similar behavior in a new production well that is completed in Zones 1, 2, and/or 3 at this site—that is, summer drawdowns would also have the lower T values estimated between the surrogate well and TW-BC. This directional difference in the aquifer properties of Zones 1, 2, and 3[5] (**Figure 6**) suggests that higher production rates and volumes may be achievable at the TW-MC site than at the TW-MR site.

Reductions in Well Efficiency

Based on down-well videos, the long-term declines (2012–2017) in specific capacity at S19 and S31 do not appear to be related to biofilm and/or incrustation growth on their screens. Instead, they are more likely due to one or both of the following factors:

- The re-arrangement of aquifer sediments outside of their screened intervals.
- The migration of silt and fine sand (sand events) toward, and through, their screens.

Work has been conducted at S19 and S31 to address silt / sand migration with the goal of halting further declines in specific capacity and maintaining well efficiency. Well operations and equipment configurations that promote well efficiency maintenance have also been recommended for S19 and/or S31 and apply to future TQu production wells. These measures include:

- Avoiding the down-well back-surging of water in the pump column at pump shutdown through use of a check valve.
- Slowly ramping pumping rates up and down (at startup and shutdown) to minimize water acceleration at the well screen, thereby minimizing the potential movement of silt and fine sand to, and through, the well screen.
- Minimizing the frequency of "off-on-off" pumping cycles, thereby reducing the frequency of water acceleration at the well screen.
- Minimizing drawdown in production wells and the TQu aquifer, thereby reducing the hydraulic gradient at the well screen / aquifer interface and potentially reducing silt and fine sand movement. Further analysis is required to quantify the optimal drawdown as discussed in Additional Analyses below.

[5] Note that this analysis lumps aquifer Zones 1, 2, and 3 together.

Recommendations

The following recommendations are intended to help guide the construction of future wells and the operation of existing wells in the TQu aquifer, which has a high degree of lateral hydraulic connection over 1 to 2 miles where the production and monitoring wells are currently completed.

- Distribute pumping stresses geographically, by well location and season, to the extent feasible, to minimize the hydraulic interference between wells completed in Zones 1, 2, and 3, thereby minimizing drawdown in the well and aquifer. Further analysis is required to quantify the optimal drawdown as discussed in Additional Analyses below.
- Proceed with construction of new production wells at the MR and MC sites, completing them in Zones 1, 2, and 3. A new production well at the MR site would likely make up the capacity lost at S19 and provide redundancy for S19 and S31. A new production well at MC would likely increase area-wide production capacity.
- Proceed carefully with testing or developing Zones 4 and 5 by isolating Zones 1, 2, and 3 until the water quality in the lower zones is better known. Testing should be conducted when drilling the next production well at the MR and MC sites using techniques that allow characterization of water quality unique to these zones.
- Distribute pumping stresses vertically to minimize hydraulic interference by potentially constructing production wells in Zones 4 and 5, thereby minimizing drawdown in the well and aquifer.

Additional Analyses

Updated analyses. To optimize the design of future TQu production wells, substantial pre-construction planning and analysis should include:

- Updating the production and water level analyses with post-2018 data. This will reveal any changes that have occurred after the period of record for this investigation and potentially inform the build-out scenario and/or construction sequence.
- Revisiting aquifer parameter and water quality data from nearby test wells to better understand site-specific conditions.
- Considering a range of screen design options to optimize each new well's performance and longevity.

Further characterization of TQu capacity. Analyses should be conducted to further characterize the geology and geometry of the TQu aquifer based on data from additional surveyed wells (and their logs) and the extensive SCADA and monitoring data available for the HP area wells. The geologic analysis may improve our understanding of the likelihood of Zones 4 and 5 being present at the HP and MC sites. Certain quantitative hydraulic analyses would be useful to better define the aquifer boundaries that appear to limit yields locally (and, potentially, from the regional aquifer). Identifying such boundaries and applying a quantitative model to simulate future pumping scenarios would not only help in locating additional TQu wells beyond the HP, MR, and MC sites (and property procurement), but it could also guide pumping operations from S19, S31, and any new production wells.

Monitoring. The City should continuously monitor specific conductance in S31, S19, and new wells.

- S31 will be outfitted with a specific conductance sensor during the installation of its new pump.
- A sensor should also be placed in S19 in 2020 if its pump is upgraded and space permits within its casing.
- New TQu production wells should be equipped with a specific conductance sensor. Each sensor should be housed in a downhole tube below the pump intake. Such a configuration would also provide access for a tag line or small-diameter camera.

Well locations are shown on **Figures 7 and 8**. Note that "_Z123" denotes screening in Zones 1, 2, and 3 of the TQu aquifer and "_Z45" denotes screening in Zones 4 and 5.

Supporting Information

Tables

Figures

Figure 8. Future TQu City Supply Wells at MC Site

Appendix

Appendix A. Drawdown Data from 57-day "Step-Rate" Test; Theis Analysis

Table 1. TQu Aquifer Water Rights, Hawks Prairie Area

City of Lacey

ID	Site Name	Quarter-Quarter Section Withdrawal Location	Qa primary (ac-ft)	Qa sup (ac-ft)	Qi (gpm)
S19	Hawks Prairie Treatment Plant	T19N-R01W-S35-NWSW	1,026	264	800
S31	Hawks Prairie Treatment Plant	T19N-R01W-S35-NWSW	1,066	---	800
MR	Marvin Road	T19N-R01W-S34-SENE	1,500	---	1,000
MC	Meridian Campus	T18N-R01W-S01-NENW	1,000	---	800
non-City of Lacey					
SH	Silver Hawk	T19N-R01W-S26-NESW	134	---	750
GC	Golf Course (1)	T19N-R01W-S35-SWNE	142	---	725

Notes: sup = supplemental
Qa = annual volume, acre-feet (ac-ft)
Qi = withdrawal rate, gallons per minute (gpm)
(1) Period of Use is 5/1 - 10/1

Table 2. TQu Aquifer Water Production v Water Rights, City of Lacey, Hawks Prairie Area

Year	Water Production at S19 (af/y)	as % Qa primary	at S31 (af/y)	as % Qa primary	at S19+S31 (af/y)	as % S19+S31 Qa primary	Total S19+S31 Production Rank
2018	579.9	57	349.0	33	928.9	44	3
2017	741.8	72	-	0	741.8	35	5
2016	465.5	45	637.1	60	1,102.6	53	1
2015	250.8	24	715.3	67	966.1	46	2
2014	757.8	74	27.7	3	785.5	38	4
2013	581.9	57	62.9	6	644.8	31	7
2012	717.6	70	-	0	717.6	34	6
Primary Qa	1,026.0		1,066.0				

Table 3. Water-Bearing Zones Screened in the TQu Aquifer Production and Monitoring Wells, Hawks Prairie Area

TQu Aquifer Zone	Production Well: S19	Production Well: S31	Production Well: GC	Production Well: SH	Monitoring Well: TW-MR	Monitoring Well: TW-MC	Monitoring Well: TW-BC	Monitoring Well: SM-u	Monitoring Well: SM-l
1	red	green	red	red	green	green	green	green	red
2	green	green	green	green	green	green	green	green	red
3	green	'18	green	green	green	green	green	green	red
4	red	red	red	red	red	red	red	red	green
5	red	red	red	red	red	red	red	red	green

deeper ------>

Notes:

- (green) *zone has well screen*
- (red) *zone has no well screen*
- '18 *S31 Zone 3 screen 'shutdown' March 2018*
- *S19 (HP1)*
- *S31 (HP2)*
- *GC (Golf Course Well)*
- *SH (Silver Hawk Well)*
- *TW-MR (MR site)*
- *TW-MC (MC site)*
- *TW-BC*
- *SM-u (Shoreline Monitoring Well upper zones)*
- *SM-l (Shoreline Monitoring Well lower zones)*

Table 4. Estimated Aquifer Parameters for July 12, 2016 'Step-Rate' Test

Observation Well	Distance from 'HP' Pumping Well (ft)	Trend Analyzed	Transmissivity (gpd/ft)	Early- to Late-Time Transmissivity Reduction (%)
MR	822	Early	46,000	
		Late	25,000	46%
MC	7,959	Early	45,000	
		Late	36,000	20%
BC	8,222	Early	24,000	
		Late	12,000	50%