City of Pendleton

Aquifer Storage and Recovery (ASR) Annual Report

Water Year 2020 (Year 17 Pilot Testing)

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Abbreviations and Acronyms

ASR	aquifer storage and recovery
BG	billion gallons
cfs	cubic feet per second
City	City of Pendleton
DBP	disinfection by-product
DO	dissolved oxygen
ft	feet
gpm	gallons per minute
GSI	GSI Water Solutions, Inc.
MG	million gallons
mg/L	milligrams per liter
mgd	million gallons per day
NA	not applicable
NGVD29	National Geodetic Vertical Datum of 1929
NR	no record
NT	not tested
OAR	Oregon Administrative Rule
OHA DWP	Oregon Health Authority Drinking Water Program
ORP	oxidation reduction potential
OWRD	Oregon Water Resources Department
Rec	Recovery
SC	specific capacity
SCADA	supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SOC	synthetic organic compound
UMAT	Umatilla
µS/cm	micro Siemens per centimeter
VOC	volatile organic compound
WFP	water filtration plant
WY	Water Year

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Executive Summary

This annual report presents results from the 17th year of aquifer storage and recovery (ASR) pilot testing conducted by the City of Pendleton (City) during water year (WY) 2020. The City operates its ASR system to meet water system demands, manage the sustainability of the groundwater resource, and store drinking water in the basalt aquifer system. Pilot testing to date has shown positive results, and operation of the system has been beneficial to the City's management of its water resources.

The City has been pilot testing its ASR system since water year 2004, authorized by ASR Limited License #006 (ASR LL#006), which was originally issued in May 2003 and most recently renewed in October 2018. The current limited license expires October 2023 and a request for a 5-year renewal is anticipated early next year.

During Year 17 the City used its five ASR wells to recharge 511.6 million gallons (MG) of treated surface water to the basalt aquifer. A total of 474.1 MG was recovered from the ASR wells to meet demands later in the year; in addition, the City reported pumping 134.4 MG from Well 2, which is used for groundwater supply and not for recharge. Separate from the procedures specified in the limited license, the City has tracked its recharge and recovery volumes using a mass balance approach, considering the total recharge and total pumping from the basalt aquifer. Over the life of the ASR program the City has recharged over 9.98 billion gallons (BG) to the aquifer via its five ASR wells and has pumped 9.80 BG from the aquifer using a combination of the ASR wells, Well 2, and Well 3.

Before implementation of the ASR program, the groundwater level was observed to be dropping at a rate of more than 3 feet per year. At that time, the City derived about 62 percent of its supply from groundwater and about 38 percent from the City's former spring sources (a series of collector galleries located in the alluvium next to the Umatilla River). Since the ASR program began in December 2003, the City has been able to reduce its use of groundwater and now relies primarily on surface water available during the winter and spring months when flows are high and demand is low. The City's overall objective for the ASR program is to optimally and proactively manage the watershed and aquifer system toward sustainable use. Implementation of the City's ASR program benefits the aquifer in the following ways:

1. Reduces net consumption of groundwater.
2. Stores a greater volume of water than is recovered, providing a net benefit (through addition of water) to the aquifer system.
3. Reduces the rate of water-level decline observed in the aquifer system pre-ASR.

The City's water system operations have resulted in a reduction in the rate of water level decline in the aquifer by more than half and have provided a benefit to the groundwater resource by reducing withdrawals of native groundwater. The City's overall conservation of groundwater through the use of ASR provides a benefit to the local aquifer and improves the sustainability of the City's future water supply.

Water level changes in the network of wells monitored as part of the ASR program during WY 2020, Year 17 pilot testing were similar to previous pilot testing cycles, and concentrations of water quality parameters in recharge source water samples and recovered water samples were compliant with applicable regulatory standards. Results from water chemistry analyses continue to indicate no adverse water quality conditions and drinking water recovered from storage in the basalt aquifer system is suitable for the City's water distribution system and municipal uses.

SECTION 1: **Introduction**

The purpose of the City's ASR pilot testing program is to confirm ASR feasibility for the host basalt aquifer and to develop operational criteria for a full-scale ASR system. Pilot testing is being conducted in general accordance with the procedures and schedules identified in the City's ASR testing program (City of Pendleton, 2012 and 2014) and ASR limited license renewal (GSI, 2018a and 2018b).

Before developing its ASR pilot testing program, the City relied on a combination of spring water and groundwater sources to provide drinking water to its residents. Concerns with the quality of the spring water led to an increased dependence on groundwater sources, which were experiencing long-term regional declines. In 2003, the City constructed a membrane water filtration plant (WFP) to provide its residents with a reliable source of high-quality drinking water. The WFP filters water sourced from the Umatilla River and is the source of recharge water used for ASR.

The WFP initially provided up to 6 million gallons per day (mgd) from December to June and was expanded to 10 mgd in 2012. From mid-June to mid-December, water rights restrictions limited the WFP production capacity to 1.6 mgd, or 2.5 cubic feet per second (cfs). During most of the winter months, the WFP output exceeds demand, and the City uses its ASR system to store the excess water in the basalt aquifer system beneath the City for later recovery and beneficial use. The City began pilot testing its ASR system in December 2003 at three existing municipal production wells. In 2012, the addition of two more ASR wells was made possible by the expanded production capacity of the WFP.

The City began pilot testing of hydropower generation during ASR operations in 2012. Year 17 was the seventh year that all ASR wells were online for electrical generation, producing power during the ASR recharge phase to offset a portion of the system's energy consumption.

The City manages its ASR program to maximize the effectiveness and capacity of the WFP, optimize the use of existing water rights, and reduce groundwater declines in the basalt aquifer system underlying the City. Results from pilot testing have been positive, and the ASR system has been beneficial to the City's management of its water resources.

SECTION 2: **ASR System Operations Summary**

This section provides a brief description of the pilot testing operations, observation well network, and water level and water quality monitoring procedures. Additional information, including a description of the hydrogeologic setting, is provided in the ASR feasibility study report (CH2M HILL, 2002) and the most recent ASR limited license renewal request (GSI, 2018a). The City's yearly ASR cycles generally consist of 120 to 180 days of recharge, zero to 30 days of storage, and 120 to 180 days of recovery. Recharge operations typically begin mid-December and continue through May of each year. Recovery of the stored water occurs during summer and fall, typically June to mid-December. The actual recharge and recovery periods vary from year to year and are highly dependent on Umatilla River water levels (ASR source water availability) and customer demand.

2.1 Well Network

The ASR pilot testing well network consists of five ASR wells, one recovery well, and one observation well, as listed below (see **Figure 1** for well locations):

Well Name	Well Type / Use	Original OWRD Well Log	Alteration Well Log	Well Tag	Notes
Well 1 (Byers)	ASR	UMAT 531	--	L-94955	--
Well 4 (Hospital)	ASR	UMAT 55619	--	L-94958	--
Well 5 (Stillman)	ASR	UMAT 530	--	L-94959	--
Well 8 (Prison)	ASR	UMAT 554	UMAT 57128	L-102164	--
Well 14	ASR	UMAT 54072	UMAT 55925	L-94962	--
Well 2 (Roundup)	Recovery and Observation	UMAT 53635	--	L-94956	Recovery well used as an observation well during the recharge season
Well 3 (SW 21st)	Observation	UMAT 53636	--	L-94957	Occasional pumping occurs at this well

NOTES: OWRD is Oregon Water Resources Department; UMAT is Umatilla

2.2 Source Water

The WFP (**Figure 1**) filters water obtained from the Umatilla River via membranes and is the source of recharge water used for ASR. In winter months, excess treated drinking water from the WFP is stored in the basalt aquifer system beneath the City using the City's ASR wells, and recovered to the supply system during the high demand period later in the year. Source water availability is dependent on both Umatilla River levels and municipal demand, and recharge operations occur during periods of low demand and adequate river levels.

2.3 Recovered Water

With the exception of Well 5, the recovered water is pumped from the ASR wells and Well 2 directly to the City's water supply distribution system. Given a history of air entrainment problems during recovery pumping, stored water recovered at Well 5 is first pumped to an 80,000-gallon storage tank equipped with a diffuser. This allows time for entrained air to come out of solution before the recovered water is delivered to the water supply system.

2.4 Water Level Monitoring

Water levels are monitored at each well listed above to evaluate well performance and to observe the dynamic response of the aquifer to the City's ASR operations. Water levels are continuously monitored using electronic pressure transducers. The pressure transducers are connected to the City's supervisory control and data acquisition (SCADA) system to allow real-time monitoring and high-frequency data capture. Manual water level measurements are collected quarterly to validate the transducer data. Water level and flow data for Year 17 are provided in OWRD-specified electronic format with this report.

2.5 Water Quality Monitoring

The October 2018 limited license renewal included changes to the previously approved water quality monitoring program to be more consistent with the City's existing monitoring schedule developed by the Oregon Health Authority's (OHA) Drinking Water Program (DWP). Water quality monitoring program includes samples of source water (pre-recharge) and recovered water samples and consolidates the ASR sampling efforts with the samples already being collected for compliance with the City's DWP monitoring schedule.

SECTION 3: **ASR Pilot Testing Discussion**

Year 17 pilot testing took place from January 13, 2020 through December 18, 2020. A total of 511.6 million gallons (MG) of treated drinking water was recharged to the basalt aquifer using the City's five ASR wells; 1,676.9 MG of stored water were carried over from Year 16 (WY 2019). Per Condition No. 11 of the renewed ASR LL#006, 95 percent of the total storage volume at each well can be withdrawn. Of the 1,676.9 MG of stored water available for recovery during Year 17, a total of 608.5 MG was recovered from the ASR wells and Well 2, leaving 1,470.6 MG in the ASR account balance as carryover storage for the next ASR cycle (Year 18; WY 2021). No native groundwater was appropriated from the ASR wells under the City's water rights during Year 17 (WY 2020).

The method of accounting for the available volume of recovered water was changed in the 2018 ASR LL#006 renewal. **Table 1** shows the yearly storage and recovery volumes calculated for each individual well from Years 1 through 14 (WYs 2004 through 2017), and **Table 2** shows the storage and recovery volumes calculated on a wellfield basis and with the addition of Well 2, starting with Year 15 (WY 2018). **Table 3** summarizes the City's ASR pilot testing operations during Year 17 (WY 2020).

3.1 Aquifer Water Level Response During Year 17

Table 4 summarizes the water level response in the City's ASR wells during Year 17, which is generally consistent with past years of ASR pilot testing. ASR operations consisted of variable recharge and pumping rates and several stop/start events caused by changes in source water availability and variable demands. The stop/start events (summarized in **Table 3**) are the primary cause of the frequent abrupt water level changes observed in the hydrographs. These operational conditions make it difficult to accurately quantify the overall aquifer response to ASR testing and interpret the many notable water level changes observed during recharge and recovery.

When considering the water levels measured in the ASR wells, it is important to note that the water level drawup during recharge and/or drawdown during recovery does not reflect the water level in the aquifer just outside of the well borehole because of well hydraulic inefficiency, the piezometric surface of the confined basalt aquifer, and confined aquifer pressures. A portion of the drawup or drawdown observed in the ASR well is the result of the transmitting inefficiency between the well and the aquifer. As a result, the drawup during recharge (or the drawdown during recovery) in the aquifer just outside of the well borehole is less than what is measured in the well, often by 50 percent or more in basalt wells. In other words, well inefficiency amplifies the water level drawup and/or drawdown in the well compared to the actual water level in the aquifer immediately outside the wellbore. Observation wells are monitored to aid in interpretation of the aquifer water level response to ASR operations at wells where ASR recharge does not occur.

3.1.1 Recharge

The City delivered 511.6 MG of treated source water to the basalt aquifer from January 13, 2020 to June 6, 2020. **Figure 2** shows the daily average recharge rates and cumulative recharge volumes for each ASR well. The average recharge rate was 1.47 mgd overall, and the maximum was 1.95 mgd;45.4 percent of the total recharge occurred at Well 1.

This section presents observations of well performance and water level response during recharge at the ASR wells. **Figures 3 through 7** present detailed data plots grouped by well as follows:

- Figure 3: Well 1
- Figure 4: Well 4

- Figure 5: Well 5
- Figure 6: Well 8
- Figure 7: Well 14

Each figure includes 6 plots:

- Average daily recharge rate and cumulative recharge volume
- Hydrograph
- Hydrograph of inactive wells (shows water levels at observation wells and ASR wells that have been idle for at least six hours)
- Drawup during recharge
- Instantaneous recharge rate
- Recharge specific capacity

In general, drawup levels fluctuated largely in response to system on/off cycles and changes in flow rates and were consistent with previous years of testing. Water levels generally peaked in mid-April and then declined as the total recharge rate ramped down during the last weeks of recharge.

Well 1: Abrupt changes in drawup and specific capacity (SC) correlate with recharge rate changes and on/off cycling (**Figure 3**); however, the specific capacity trend appears to remain consistent with each on/off cycle, suggesting that well performance did not decline as a result of the on/off cycling during recharge.[1] The minimum SC observed near the end of the recharge period was approximately 29.2 gallons per minute per foot of drawup (gpm/ft) (**Table 5**), which is consistent with the SC observed during recent years of ASR pilot testing for similar recharge rates and durations. Some year-to-year SC variability is expected due to differences in recharge rates, durations, pumping at nearby wells, or fluid viscosity changes caused by source water temperature variations. Consequently, no declining trends in well performance are apparent.

Well 4: The response to recharge at Well 4 is consistent with previous years of ASR testing (**Figure 4**). The water level rose nearly 200 feet during recharge and came near 50 feet of ground surface. A maximum recharge level no higher than 30 feet below ground surface is recommended to prevent flowing conditions at the wellhead. The minimum SC observed near the end of the recharge period of approximately 5.1 gpm/ft is comparable to previous years of ASR pilot testing. No changes in well performance are apparent.

Well 5: Well 5 was only used briefly and observations are limited based on the short recharge period at this well (**Figure 5**). Historically, drawup levels fluctuated in response to system operations. Similarly, the SC fluctuates in response to variable system operations and recharge rates before reaching an end of recharge SC of 11.9 gpm/ft, which is comparable to the apparent trend of declining efficiency exhibited in recent years of ASR pilot testing (**Table 5**). This well is known to produce gas bubbles in recovered water, and entrained air is potentially a factor in reduced SC; however, other factors, such as entrained particulates from the distribution system, may also be degrading the well performance. Periodic backflushing during recharge operations can help maintain optimal well performance.

Well 8: Drawup levels and SC fluctuate in response to system operations, recharge rates, and recharge interference from operations at other ASR wells (**Figure 6**), particularly at Well 4. The minimum SC observed

[1] Observations made during previous years of pilot testing suggested that the on/off cycling could lead to declining well performance by introducing entrained air into the aquifer. The City noted the presence of air bubbles in recovered water near the end of recovery in Year 11. The City removed the pumping equipment on December 4, 2014, to diagnose the issue and found a water level probe lodged in the pump and several rocks wedged in the intake strainer blocking flow to the well. Although the obstructions could have contributed to well inefficiencies observed during Year 11, air entrainment from on/off recharge cycling may have been a contributing factor.

near the end of the recharge period was approximately 62.6 gpm/ft, which is greater than the SCs observed during recent years of ASR pilot testing, but likely a response to recharge operations at other wells and not a change in well efficiency (**Table 5**). Changes in drawup and SC resulting from hydraulic boundary effects or well performance declines are not apparent.

Well 14: Drawup levels and SC fluctuate largely in response to system operations, recharge rates, and potentially interference from operations at other wells (**Figure 7**). The minimum SC observed near the end of the recharge period of 13.2 gpm/ft is comparable to the SC values observed during recent years of ASR pilot testing for similar recharge rates and durations (**Table 5**).

Observation Wells: Hydrographs for the two observation wells, including brief periods of pumping at Well 2, are shown in **Figure 8**. Water level and pumping data for Well 3 during the recharge period are not available due to malfunctioning of the well's data logging system. Water levels at the Well 2 appear to respond to ASR operations and generally follow the same trend observed at the ASR wells (see Hydrograph of Inactive Wells, **Figures 3 through 7**). The water level at Well 2 rises approximately 8 feet during recharge, peaking in April, and very slowly declining as the combined daily recharge rate at the ASR wells declines.

3.1.2 Recovery

The City recovered a total of 608.5 MG of stored water (474.1 MG from the ASR wells and 134.4 MG from Well 2) from June 10, 2020 to December 18, 2020. **Figure 9** shows the daily average recovery rates and cumulative recovery volumes for each well. The overall average recovery rate was 1,021 gpm (0.71 mgd) and the maximum rate was 1,952 gpm (0.87 mgd). Wells 1 and 2 accounted for nearly 50 percent of the total volume of water recovered from storage.

This section presents observations of well performance and water level response during recovery at the ASR wells. **Figures 10 through 14** present detailed data plots grouped by well as follows:

- Figure 10: Well 1
- Figure 11: Well 4
- Figure 12: Well 5
- Figure 13: Well 8
- Figure 14: Well 14

Each figure includes 6 plots:

- Average daily recovery rate and cumulative recovery volume
- Hydrograph
- Hydrograph of inactive wells
- Drawdown during recovery
- Instantaneous recovery rate
- Recovery specific capacity

During Year 17 recovery the City pumped a total of 608.5 MG of stored water to deliver to its customers. Wells 1 and 2 produced 49 percent of the total recovery volume, with the other wells recovering 6 to 16 percent each. In general, drawdown levels and SC fluctuated largely in response to system on/off cycles and changes in flow rates were consistent with previous years of testing. The lowest water levels generally occurred in late August before the daily combined recovery rate tapered off at the end of the season.

Well 1: Overall, the drawdown and SC observed at Well 1 was variable during Year 17 and dependent on changes in pumping rate and frequent on/off cycling of the pump, as shown in **Figure 10**. The minimum SC observed near the end of the recovery period was approximately 25.3 gpm/ft (**Table 5**), which is consistent with observations from previous years of ASR pilot testing for similar recovery pumping rates and durations.

Well 4: Drawdown and SC at Well 4 were relatively stable during Year 17 (**Figure 11**). A gradual increase in SC beginning in August is associated with a decrease in pumping rate. The minimum SC observed near the end of the recovery period was approximately 11.1 gallons per minute per foot of drawdown (gpm/ft) (**Table 5**), which is consistent with observations from previous years of ASR pilot testing for similar recovery pumping rates and durations.

Well 5: Drawdown and SC at Well 5 were relatively stable during Year 17 (**Figure 12**), with drawdown increasing and SC decreasing with time due to an increasing pumping duration. The minimum SC observed near the end of the recovery period was approximately 42.9 gpm/ft (**Table 5**), which is consistent with observations from previous years of ASR pilot testing for similar recovery pumping rates and durations.

Well 8: Drawdown and SC at Well 8 were relatively stable during Year 17 (**Figure 13**), with drawdown and SC decreasing with time due to an increasing pumping duration. However, SC did increase near the end of the pumping event but likely a result of the on/off cycling. The average SC observed near the end of the recovery period was approximately 69.3 gpm/ft (**Table 5**), which is consistent with observations from previous years of ASR pilot testing for similar recovery pumping rates and durations.

Well 14: Drawdown and SC at Well 14 were relatively stable during Year 17 (**Figure 14**), with drawdown and SC remaining relatively steady despite an increasing pumping duration. The minimum SC observed near the end of the recovery period was approximately 14.2 gpm/ft (**Table 5**), which is consistent with observations from previous years of ASR pilot testing for similar recovery pumping rates and durations.

Observation Wells: Hydrographs for the two observation wells, including periods of pumping at Well 2, are shown in **Figure 15**. Water level and pumping data for Well 3 during the recovery period are not available due to malfunctioning of the well's data logging system. In general, the water levels at Well 2 follow the same trend observed at the ASR wells (see Hydrograph of Inactive Wells, **Figures 10 through 14**). Aquifer water levels dropped approximately 110 feet during recovery and partially rebounded after mid-September, when the daily total recovery rates declined (see **Figure 9**).

3.2 Long-Term Water Level Trends

Pre-recharge static water levels were used to assess the potential for ASR to have an effect on the overall water balance of the aquifer system. The pre-recharge water levels do not represent truly static aquifer conditions because they are influenced by several variables that change from year to year, such as time since the end of recovery, recharge and recovery at other wells, and regional aquifer recharge. The long-term trend in the pre-recharge water levels, however, is a reasonable indicator of the long-term trend of the overall water balance of the aquifer system.

Pre-recharge static water levels are summarized in **Table 6**. The average rate of change for each of the wells indicates an overall decline of approximately 1.3 feet per year, although the year-to-year changes are higher in some years and lower in other years. Overall, recent pre-recharge static water levels are roughly 18.3 feet lower than they were in 2004. This rate of decline, however, is nearly three times less than the decline rate of more than 3.4 feet per year reported before the City began its ASR program. Although ASR operations are clearly a net positive benefit to the aquifer system, the reduction in the City's groundwater demand is not large enough relative to groundwater use throughout the region to reverse the regional declining trend. Quantifying the significance of the City's impact on the annual water balance would require developing correlations with annual aquifer recharge and cumulative volumetric withdrawals that include non-ASR pumping on a regional scale.

3.3 Water Quality Monitoring

Water quality monitoring continued during Year 17 in accordance with the City's previously approved pilot testing work plan, revised in 2018. The objectives of the water quality monitoring are to (1) demonstrate that the source water and recovered water quality meets regulatory standards, (2) identify potential chemical reactions that could result in clogging of the recharge well, and (3) assess whether ASR storage degrades native groundwater quality. A summary of the water quality monitoring schedule is shown on **Table 7**. Laboratory analytical results are shown on **Table 8**.

The City's modified water quality monitoring program takes a wellfield approach, with regulatory compliance samples collected at Well 4[2]. A source water sample for volatile organic compounds (VOCs) is collected at the WFP in the fourth quarter of each year. All analytical results met the regulatory standards established for ASR operations [Oregon Administrative Rule (OAR) 690-350-0010(6)] and/or the regulatory standards required by the City's monitoring plan and were consistent with the high quality of water observed in previous years of ASR pilot testing.

Each ASR well was sampled during recovery for general geochemical parameters to serve as indicators of adverse chemical reactions that might contribute to a reduction of aquifer or well performance. The water quality test results from WY 2020 monitoring were consistent with previous water years and no adverse chemical reactions are apparent.

Field parameters were monitored at each well periodically during recovery pumping (**Table 9**). In general, electrical conductivity exhibited a gradual increase at the ASR wells during recovery indicating an increasing proportion of groundwater compared to source water as more water is recovered from storage. Values for the other field parameters remained relatively stable during recovery operations, with the exception of pH at Well 14, which increases during recovery.

Based on the water quality test results and field parameter monitoring, drinking water recovered from storage in the basalt aquifer system is suitable for the City's water distribution system and municipal uses.

3.4 Next Steps

The City will continue pilot testing its ASR program following the conditions and requirements of its recently renewed ASR LL#006. The City's current pilot testing goal is to recharge as much water as possible in any given year during a single season. The actual storage volume will depend on water availability, which is determined by precipitation patterns in the watershed.

The City is currently working on modifying an existing production well. This well, No. 11, presently serves the wastewater treatment and resource recovery facility and two other residences for domestic use only. Well No. 11 will be converted to a production well capable of supplying about 1,000 gpm, or 1.4 mgd to augment the City's current water supply. The City also is planning to add an additional water supply production well in the vicinity of Well No. 8. Both wells will be set up for future ASR consideration with the piping and electrical considerations.

[2] On the basis of missing well seal information from the well log, OHA identified Well 4 for representative sampling of recovered water because it was considered to be the ASR well that is most susceptible to potential contamination.

SECTION 4: **References**

CH2M HILL. 2002. Aquifer Storage and Recovery Hydrogeologic Feasibility Study for the City of Pendleton, Oregon, March 2002.

City of Pendleton. 2012. Aquifer Storage and Recovery Testing Program for the City of Pendleton, Oregon, February 2012.

City of Pendleton. 2013. City of Pendleton Aquifer Storage and Recovery Project Ninth Annual Report, Pilot Test, Cycle 10.

City of Pendleton. 2014. Letter from City to OWRD requesting water quality sampling schedule change. July 14, 2014.

Cooper, H.H., Jr. and C.E. Jacob. 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History: Transactions, American Geophysical Union, Vol. 27, No. 4.

GSI. 2012. Geochemical Compatibility of Well No. 8. April 15, 2012.

GSI. 2018a. Request for a 5-Year Renewal of City of Pendleton ASR Limited License #006. February 23, 2018.

GSI. 2018b. Request for a 5-Year Renewal of City of Pendleton ASR Limited License #006: Response to Agency Comments. July 27, 2018.

Jacob, C.E. 1950. Flow of Ground Water: In Engineering Hydraulics, ed. H. Rouse, 321-86. New York, John Riley.

Tables

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Figures

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