www.wwbwc.org
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Shallow Aquifer Monitoring in the Walla Walla Basin

2017 Water Year

FINAL Report

Submitted: September 2017

In Cooperation with:

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Shallow Aquifer Monitoring in the Walla Walla Basin

Introduction

Overview

Since 2001 the Walla Walla Basin Watershed Council (WWBWC) has been building a network of monitoring wells in the Walla Walla River Valley as part of its long-term efforts to understand the shallow (unconfined) alluvial aquifer. The primary objectives of this network are to provide data necessary for informed water management in the bi-state basin and help water and fisheries managers in the basin better understand surface-groundwater interactions as they relate to salmon recovery and groundwater sustainability. The monitoring network is also used to track the effectiveness of artificial managed aquifer recharge projects currently in operation and provide data for modeling projects.

The WWBWC worked with the Oregon Water Resource Department (OWRD) and Washington Department of Ecology (WDOE) to develop protocols for monitoring well locations, measurement, and maintenance. Many of the original monitoring wells in the network were established or drilled by OWRD and WDOE. Other partners in the basin such as Hudson Bay District Improvement Company, Gardena Farms Irrigation District #13, Walla Walla River Irrigation District, Fruitvale Water Users Association, The Native Creek Society, the City of Walla Walla and dozens of private property owners have contributed to expansion of the monitoring network by providing well access, supplying historical information and making contact with prospective participants. Some of the dedicated monitoring wells were established as part of the growing managed aquifer recharge program throughout the valley. See Table 1 for a summary of the established monitoring wells.

Table 1. Overview of the Shallow Aquifer Monitoring Network.

Monitoring Group	State	Number of Wells
OWRD	Oregon	10
WWBWC	Oregon	62
WDOE	Washington	22
City of Walla Walla	Washington	4
WWBWC	Washington	35

Well monitoring consists of measuring the groundwater level (the depth to water), water temperature and specific conductance. The well monitoring network is comprised of two types of monitoring wells: continuous monitoring wells that are instrumented with pressure transducers that log water level at a programmed interval (typically every 15 or 60 minutes), and non-continuous wells, which are measured manually approximately every three months. Temperature and conductivity measurements are taken quarterly at both types of monitoring wells if access permits.

The WWBWC has continued to update and maintain a Monitoring Well Database with historical records and information about wells in the network. The database includes landowner contact information, water rights, well logs, USGS, WDOE and OWRD historical water level measurements, well GPS coordinates, elevation, maps, and photos of the wells. Wells in the monitoring network have been surveyed with survey-grade GPS units to determine accurate longitude, latitude and elevation data. The Monitoring Well Database serves as institutional memory of the monitoring network and gives insight into historical uses and conditions of the wells and aquifer. It also allows WWBWC to easily share well information with the community and other agencies.

Shallow Aquifer Monitoring Area

The Walla Walla River basin is a bi-state region located in northeastern Oregon and southeastern Washington (Figure 1). The river basin covers approximately 1,760 square miles, with an underlying shallow alluvial aquifer of about 200 square miles (Figure 2). Shallow depth-to-water in certain locations in the valley and year-round supply make the shallow aquifer a highly important source of water for irrigated agricultural lands as well as domestic and livestock uses.

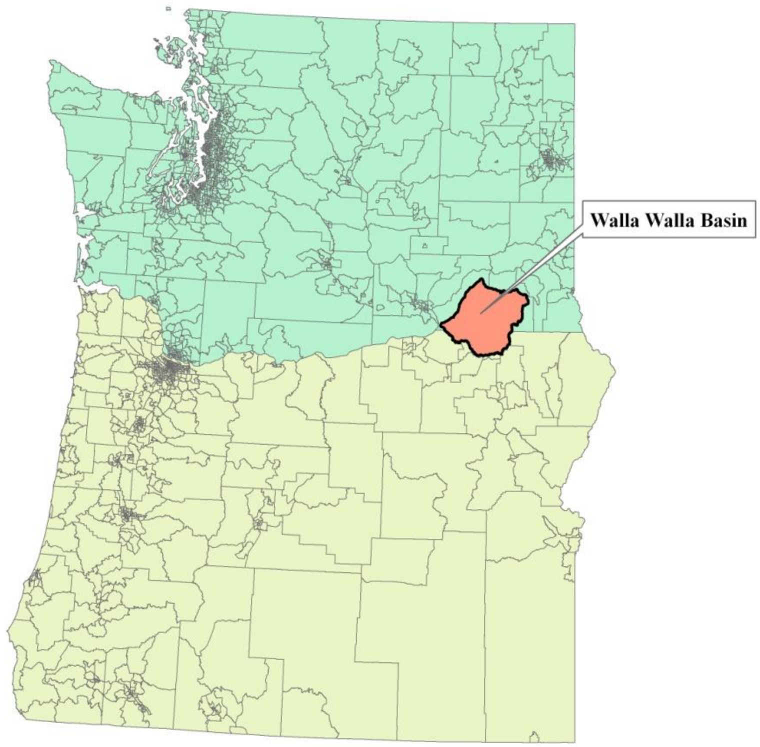

Figure 1. The bi-state Walla Walla River basin in northeastern Oregon and southeastern Washington.

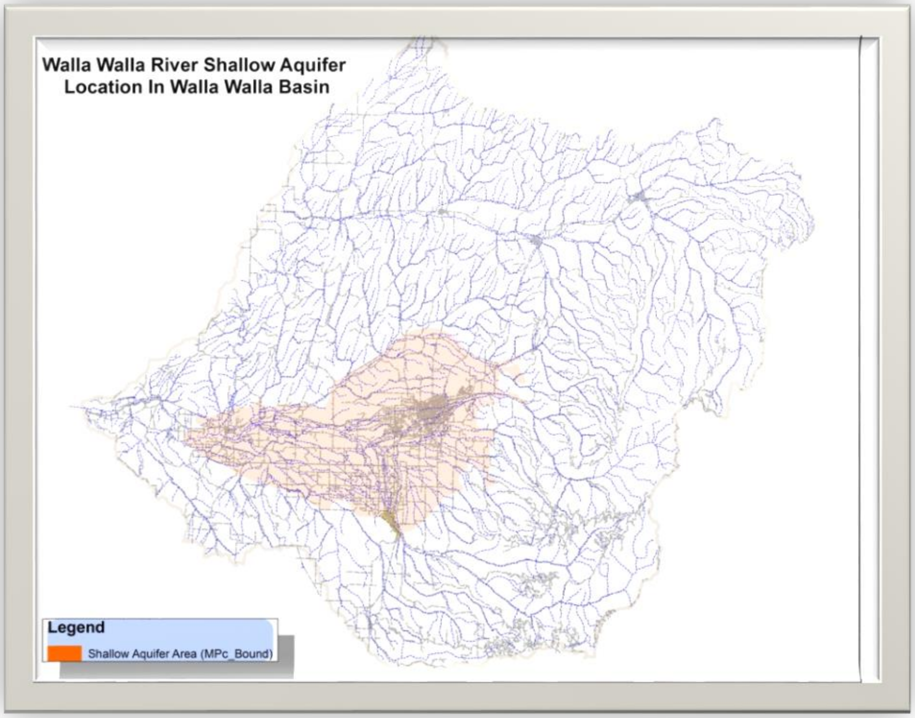

Figure 2. The Walla Walla River basin with the underlying shallow alluvial aquifer.

In addition to supplying water for the wells, the shallow alluvial aquifer also feeds the numerous springs, streams, and rivers of the Walla Walla basin. The high connectivity between the shallow aquifer and surface water bodies is important for enhancing base flows and cooling water temperatures for reintroduced salmon and threatened steelhead and bull trout in the basin.[1]

Since 2001, the WWBWC and its partners have been building a community-based groundwater monitoring network. This network was developed to enhance knowledge about long-term water level trends and provide hydrogeological information. In 2001, only a dozen shallow aquifer wells were monitored in Oregon and Washington. These wells were inadequate to effectively monitor and manage the vast aquifer which supplies hundreds of domestic and agricultural wells, provides water for the dozens of creeks and springs throughout the valley, and discharges cool water into the Walla Walla River during base flows. As of 2017, the WWBWC and its state and local partners monitor 133 wells (Figure 3).

Wells in the monitoring network include both urban and rural wells in and around Milton-Freewater and Umapine, OR, and Walla Walla, College Place, Lowden, and Touchet, WA. The wells are owned by a variety of water users, including government agencies (state, county, and city), businesses, universities, and private landowners within the basin. Prior to drilling dedicated monitoring wells, most of the monitoring wells were irrigation (both active and abandoned) or old domestic wells owned by private land owners. All of the well owners participate voluntarily, aiding in the effort to understand and mitigate the decline of the aquifer, a critically important economic and ecological resource to the communities located within the Walla Walla basin.

[1] Winter, T.C., *et al*. 1998. *Ground Water and Surface Water: A Single Resource.* U.S. Geological Survey Circular 1139.

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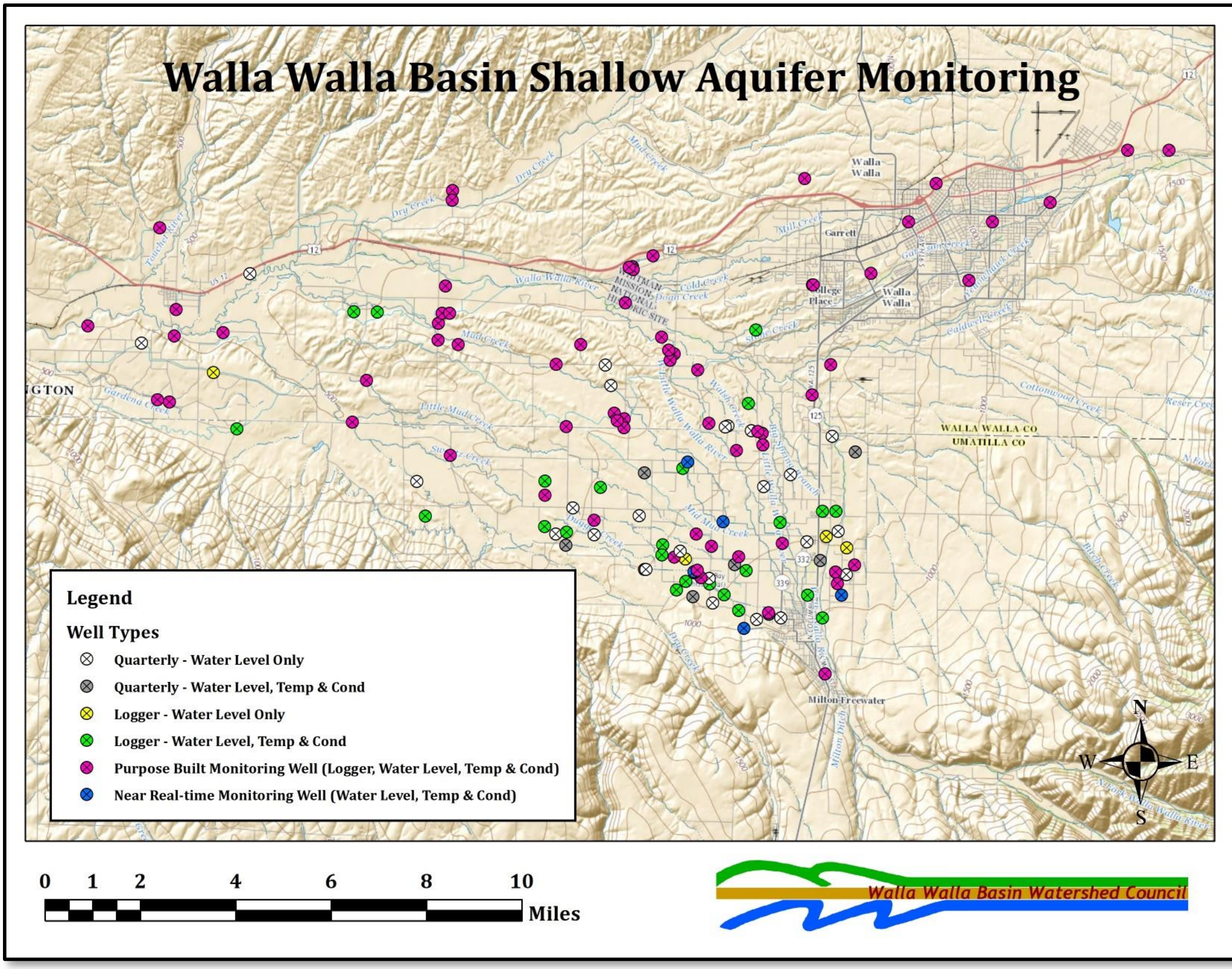

Figure 3. Map overview of wells in the Shallow Aquifer Monitoring Network as of September 2017.

Methodology

All monitoring was conducted according to our standard operating procedures[2] based on USGS, Washington and Oregon state methods for groundwater monitoring. [Click here for the WWBWC's Standard Operating Procedures]

Continuous and Non-continuous Wells

The WWBWC shallow groundwater alluvial aquifer well network includes both continuous and non-continuously monitored wells. As of September 2017, five of our groundwater monitoring locations have been equipped with a radio, solar panel, battery and datalogger capable of sending near-real time data through our telemetry network. The data are updated daily and available at the Groundwater Monitoring page on the WWBWC website. These data are available year around but are particularly useful for tracking aquifer recharge water when the Johnson

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[2] Patten, S.B. 2013. *WWBWC Standard Operating Procedures – Version 1.2.* Walla Walla Basin Watershed Council. www.wwbwc.org.

(GW_46), Lefore (GW_152), Chuckhole (GW_169), Mud Creek (GW_170) and Fruitvale (GW_171) recharge sites are operating during the winter months.

During the 2017 water year, over three-quarters of the monitoring wells were continuously monitored using one of four different pressure transducers (Figure 4) that were suspended below the water level but not resting on the bottom of the well. Pressure transducers were suspended using 1/16th inch aviation cable, 14 gauge speaker wire, fishing line or a communication cable provided by the manufacturer. The pressure transducers electronically determine and record the water pressure (pounds per square inch or feet of water) and water temperature (either °F or °C) on a programmed log interval (typically every 15 or 60 minutes). Transducer data were downloaded on a quarterly schedule. Manual water level measurements were made during the quarterly download to standardize the pressure transducer data. Water level measurements were collected manually using an e-tape (Solinst Water Level Meter, Model 102, www.solinst.com). All water level values were measured from an established measurement point, adjusted for top of grade ("stickup height") and recorded as "feet below ground surface."

Although it would be ideal to have all of the wells instrumented for continuous data collection, many abandoned and irrigation wells have small access ports or the pump is in the way, prohibiting deployment of a pressure transducer. Static (non-continuous) wells provide an inexpensive way to collect "snap shot" information of the aquifer and track trends throughout the valley. Wells not instrumented with a pressure transducer were monitored quarterly. Manual measurements were taken using the e-tape from an established measurement point, adjusted for top of grade ("stickup height") and recorded as "feet below ground surface." At irrigation wells, pump condition (on or off) was recorded during each visit. A summary of continuous and non-continuous monitoring wells is shown in Table 2.

Figure 4. Pressure transducers used in the Shallow Aquifer Monitoring Network. Continuously monitored wells were equipped with one of the above types of pressure transducers.

Table 2. Summary of well types in the Shallow Aquifer Monitoring Network.

Well Type	State	Number of Wells
Continuous, includes temperature and conductivity	Oregon / Washington	43/49
Continuous, without temperature and conductivity	Oregon / Washington	6/5
Non-continuous, includes temperature and conductivity	Oregon / Washington	6/1
Non-continuous, without temperature and conductivity	Oregon / Washington	17/6

Temperature and Conductivity Sampling

Where well access permitted, temperature and conductivity were measured on a quarterly basis. Water samples were taken when the pressure transducer was downloaded or a water level measurement was taken. Water samples were collected using a bailer and transferred into a graduated cylinder[3]. Temperature and conductivity values were measured using a handheld conductivity meter (YSI 30, www.ysi.com). At irrigation wells, pump condition (on or off) was also recorded during each visit. Further details regarding transducer downloading, deployment, maintenance, and quarterly data collection can be found in the WWBWC 2013 Standard Operating Procedures - Version 1.2[2].

Gathering temperature and conductivity data when monitoring wells allows the WWBWC to better understand the hydrogeological connections between groundwater and surface water. By knowing the temperature and conductivity we are able to map where groundwater is contributing to surface flows and where surface water is recharging the aquifer.

Data Processing and Analysis

Most loggers used by WWBWC for groundwater monitoring were absolute (non-vented) pressure transducers, creating a need to compensate the water level data for atmospheric pressure. Using the AQUARIUS time series software (www.aquaticinformatics.com), water level data were corrected by subtracting barometric pressure collected by transducers located at several barometric monitoring stations throughout the valley (Figure 5). Also using AQUARIUS, water level logger data were converted from PSI to feet of water when necessary and graphed with manual water level measurements. Water level logger data were adjusted to correspond with manual water level measurements. This visual correction, facilitated by AQUARIUS software, replaces our previous method of using estimated cable length to determine "depth to water." Pressure transducer "drift" was monitored and corrected in AQUARIUS by adjusting transducer data to manual water level measurements.

Data were graded to document logger hang-ups on pumps or other obstructions, well pumping during manual water measurement, and other irregularities affecting data quality.

[3] Oregon Department of Environmental Quality. 1998. *DEQ Lab's Field Sampling Reference Guide.*

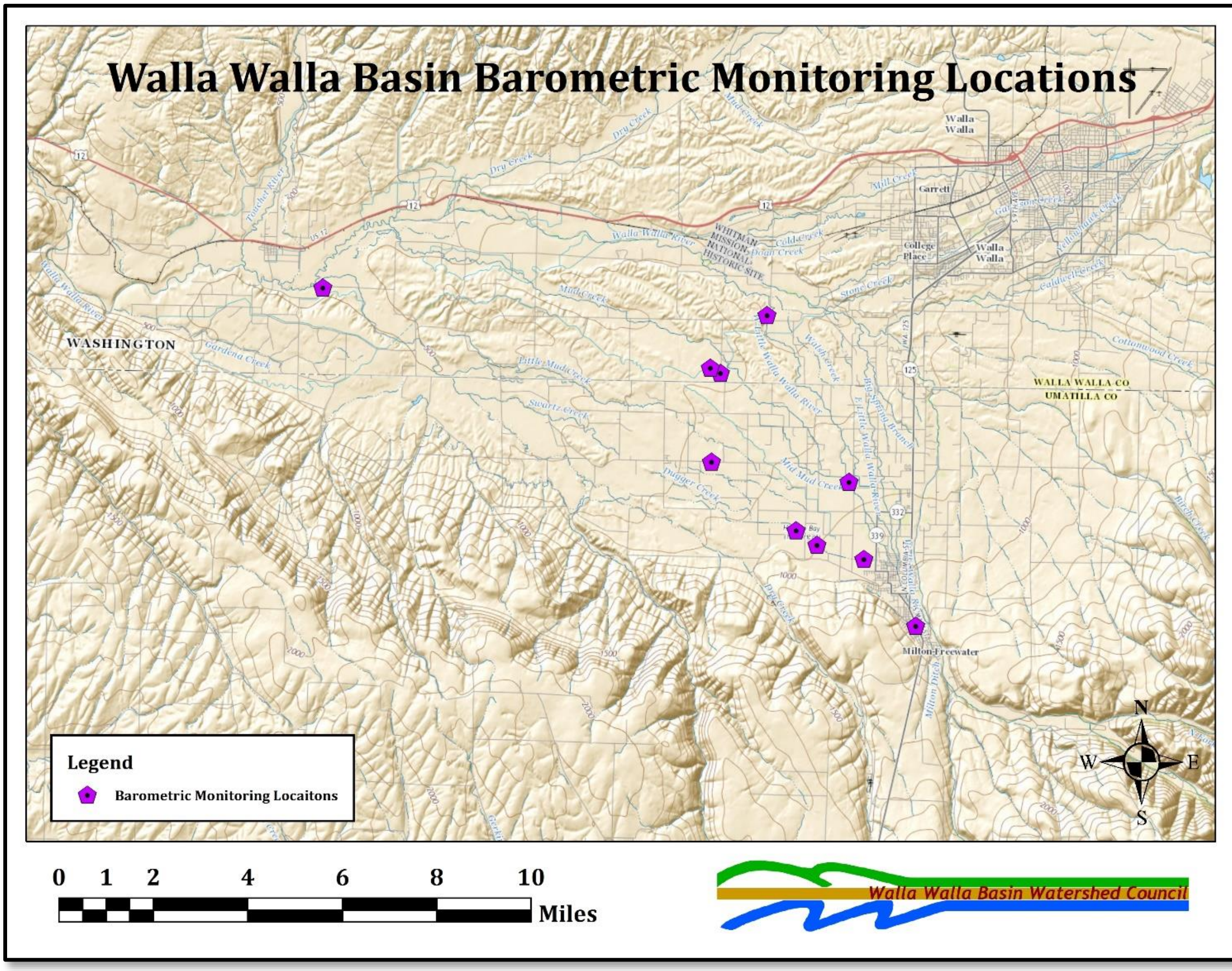

Figure 5. Barometric pressure transducer locations within the Shallow Aquifer Monitoring Network.

Results and Discussion

For all well data please visit the [WWBWC's Groundwater Monitoring Page](). There you can view hydrographs and download data for the wells.

EIM Data

Data from monitoring sites funded by the Washington Department of Ecology's Office of Columbia River have been prepared for inclusion in the state's EIM database but, by request of WDOE staff, should not be uploaded until a data coordinator is hired to assist with the process. Data ready for upload can be accessed by following this link: wwbwc.org/images/Monitoring/Reports/EIM_GroundwaterWY16-17.zip.

Historic Wells

Nine of the wells monitored in the shallow aquifer are historic wells with data going back as far as 1933 (Figure 6). These wells are used to see long term trends in the Walla Walla basin's shallow alluvial aquifer. All but two of these wells have shown a declining water level (GW_22 and GW_57, Figures 7-8). Groundwater declines could be related to the increasing number of wells and increasing water usage for domestic and agricultural activities requiring more water withdrawal than is sustainable for the basin's aquifer. Additionally, a significant water management change in 2001 could be having an effect on the basin's aquifer. In that year, the Civil Penalty

Settlement Agreement between U.S. Fish and Wildlife Service and the three irrigation districts in the Walla Walla basin (Walla Walla River Irrigation District, Hudson Bay Ditch Improvement Co, Gardena Farms Irrigation District #13) required that 18 cubic feet per second (cfs) remain in the Walla Walla River during summer months and be incrementally raised to 25 cfs during fall and spring. For the previous ~100 years, the Walla Walla River ran dry during the summer because all water was diverted for irrigation uses. This water flowed through the vast array of irrigation ditches in the basin, providing groundwater recharge as seepage occurred within the ditch systems. Since the Settlement Agreement in 2001, less water has been flowing through the Walla Walla/Gardena/Hudson Bay systems during the summer months leading to a reduced amount of groundwater recharge through the ditch system. However, since the decline in the aquifer seems to have started prior to the 2001 Settlement Agreement, the reduced recharged from surface flows in the irrigation system does not fully explain the downward trend. Increased efficiency for irrigation (ditch piping projects and modern irrigation methods) has further reduced the amount of groundwater recharge from irrigation ditches and canals. Historic irrigation practices included flood irrigation, which allowed for groundwater recharge, while newer drip and sprinkler systems only deliver as much water as is needed. Also, many irrigators have begun using supplemental wells more than in the past and new irrigation wells have been drilled.

Two wells, GW _17 and GW_20, were historically declining but, since water management changes in 2001 and the start of the WWBWC aquifer recharge program in the spring of 2004, have stabilized and possibly started to recover (Figures 9-10). Some of the historic wells are shallow hand-dug wells and have gone dry in the recent past. GW_25 has been dry since 2004 (Figure 11).

Declining Groundwater Levels in Touchet-Gardena Area Wells

Since 2011-2012, data indicate significant declines in groundwater levels in the Touchet-Gardena area (Figure 12). The monitoring wells south of the City of Touchet show declines of 0.25 to 0.5 feet per year from 2011 to 2017 (GW_86, 106, 123, and 125, Figures 13-17). Declines in the Gardena area are more dramatic, with annual drops of 1.5 to 4.2 feet beginning in 2011 (GW_82, 92, 93, 124, 137, and 138, Figures 18-23). Although the cause is not certain, the downward trend correlates with the timing of water management changes in the region including two major ditch piping projects on the Gardena Farms Irrigation District delivery system completed in 2010 and 2012. Seepage data indicate that groundwater contributions make up a meaningful portion of Walla Walla River flows downstream of Touchet during the summer months[4]. As Touchet-Gardena area groundwater levels drop, one might expect a decrease in groundwater contributions to the river. The potential impact of groundwater declines for water users and on Walla Walla River flows may warrant a focused study on the surface water and groundwater interactions in this region.

Near Real-time Groundwater Monitoring

Over the last three years, the WWBWC has significantly expanded its telemetry system. Included in this expansion is the near real-time monitoring of groundwater levels at several locations around the valley. Currently, the WWBWC has five near real-time groundwater monitoring locations (Figure 24). These sites allow landowners, water managers and other interested parties to get a more up-to-date understanding on current groundwater levels. These near real-time monitoring locations also allow for better operation and tracking of managed aquifer recharge sites. Figure 25 is an example of the near real-time groundwater monitoring pages.

[4] Baker T.W. 2017. *Walla Walla Basin Seasonal Seepage Assessments Report: Walla Walla River, Mill Creek, and Touchet River.* Walla Walla Basin Watershed Council. www.wwbwc.org.

Areas of Groundwater Stability and Potential Positive Trends

Not all wells in the valley are showing groundwater declines. Groundwater levels in the Walla Walla and College Place region and in the upper Milton-Freewater area (Figure 24) appear to be relatively stable (GW_74, 85, 90, 115, 128, 129, Figures 26-31). Some wells have shown moderate water level increases in previous years, especially wells near the lower East Little Walla Walla and Big Spring system (GW_102, 113, Figures 32-33). These systems have seen higher surface flows in recent years[5]. The East Little Walla Walla River and Big Spring systems and the nearby wells are likely benefitting from a combination of water management changes and large quantities of seepage from the mainstem Walla Walla River[6] between Nursery Bridge and Tum-A-Lum bridge.

Summary

The well monitoring network in the Walla Walla basin's shallow alluvial aquifer has been expanding every year, giving the WWBWC and basin partners a better understanding of changing groundwater conditions throughout the valley. One hundred thirty three wells are currently monitored in the Walla Walla basin shallow alluvial aquifer, up from only a dozen in 2001. WWBWC funders and basin partners continue to support and affirm the value of the Shallow Aquifer Monitoring Project as a vital component of current and future understanding of groundwater resources, aquifer decline and recharge, surface-groundwater interactions, and groundwater returns to the Walla Walla River. Using the well network, WWBWC and partners in the basin have quantitatively illuminated the decline of the shallow aquifer and shown the significant influence and response by the aquifer system to managed aquifer recharge projects and other water management changes. Furthermore, the well monitoring network data are being used to inform decisions about current and future aquifer recharge projects. The data were used for modeling projects which informed our 2013 *Walla Walla Basin Aquifer Recharge Strategic Plan*[7] and are currently informing the on-going Walla Walla Basin Integrated Flow Enhancement Study. The data being collected will continue to provide insight for water management professionals and local communities to make water related decisions into the future.

The Shallow Aquifer Monitoring Project is successful not only in compiling aquifer data and expanding the well network but also as a mechanism for community outreach because it depends heavily on voluntary land owner participation and local support. Many citizens have contributed vital information to the project and also have become more aware of the declining aquifer and other water issues in the Walla Walla basin.

Acknowledgments

We gratefully acknowledge the contributions of our generous funders including Bonneville Power Administration, Oregon Water Resources Department, Oregon Watershed Enhancement Board, and Washington State Department of Ecology and its Office of Columbia River. Thanks also to local collaborators including private landowners, irrigation districts, and the Cities of College Place, Milton-Freewater and Walla Walla for allowing property access for groundwater monitoring. Without their support this work would not be possible.

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[5] WWBWC, 2015. *Surface Water Monitoring in the Walla Walla Basin, 2014-15.* Walla Walla Basin Watershed Council. www.wwbwc.org.

[6] Baker T.W. 2017. *Walla Walla Basin Seasonal Seepage Assessments Report: Walla Walla River, Mill Creek, and Touchet River.* Walla Walla Basin Watershed Council. www.wwbwc.org.

[7] Henry, R. et al 2013. *Walla Walla Basin Aquifer Recharge Strategic Plan*. Walla Walla Basin Watershed Council. www.wwbwc.org.

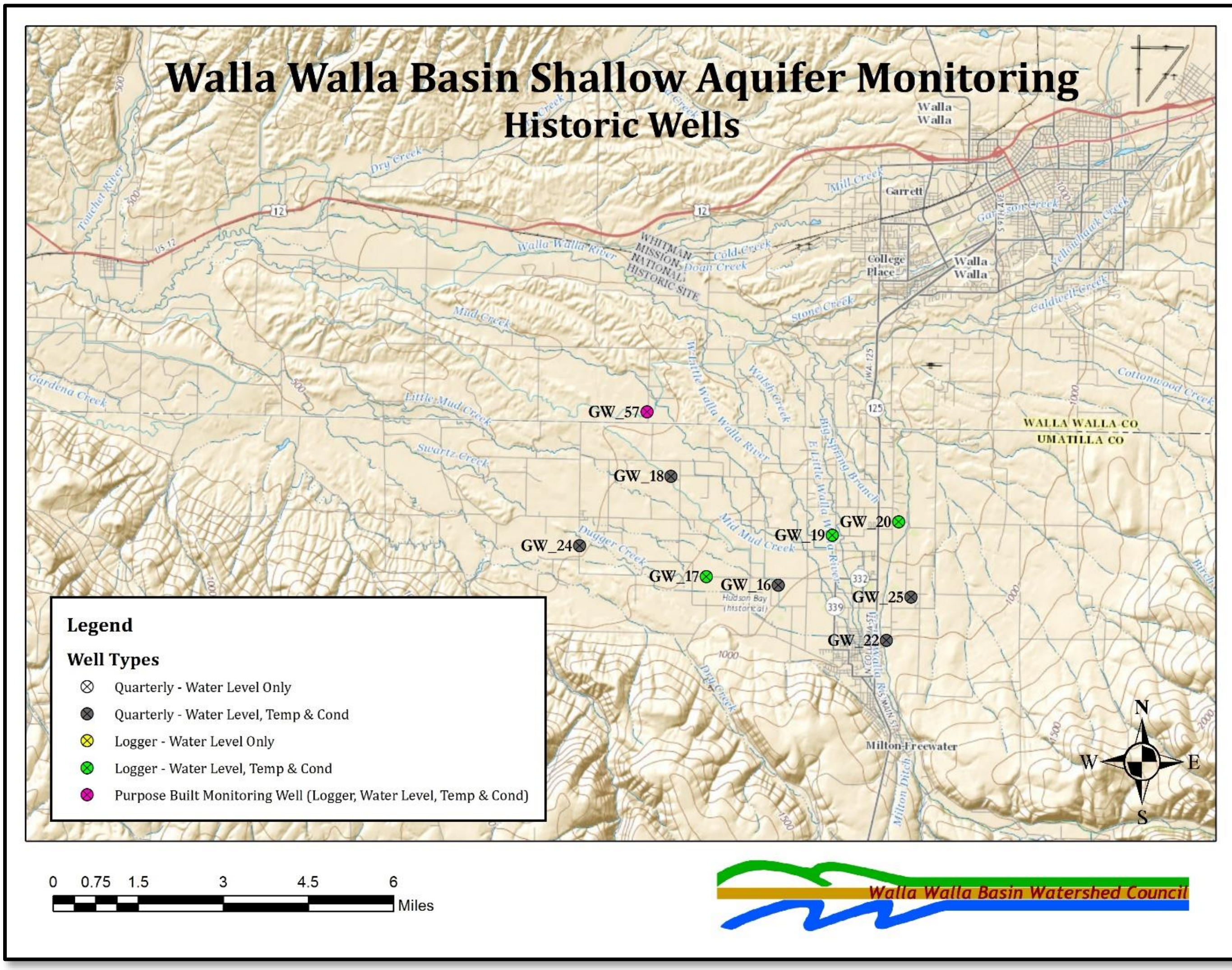

Figure 6. Historic wells included in the Shallow Aquifer Monitoring Network.

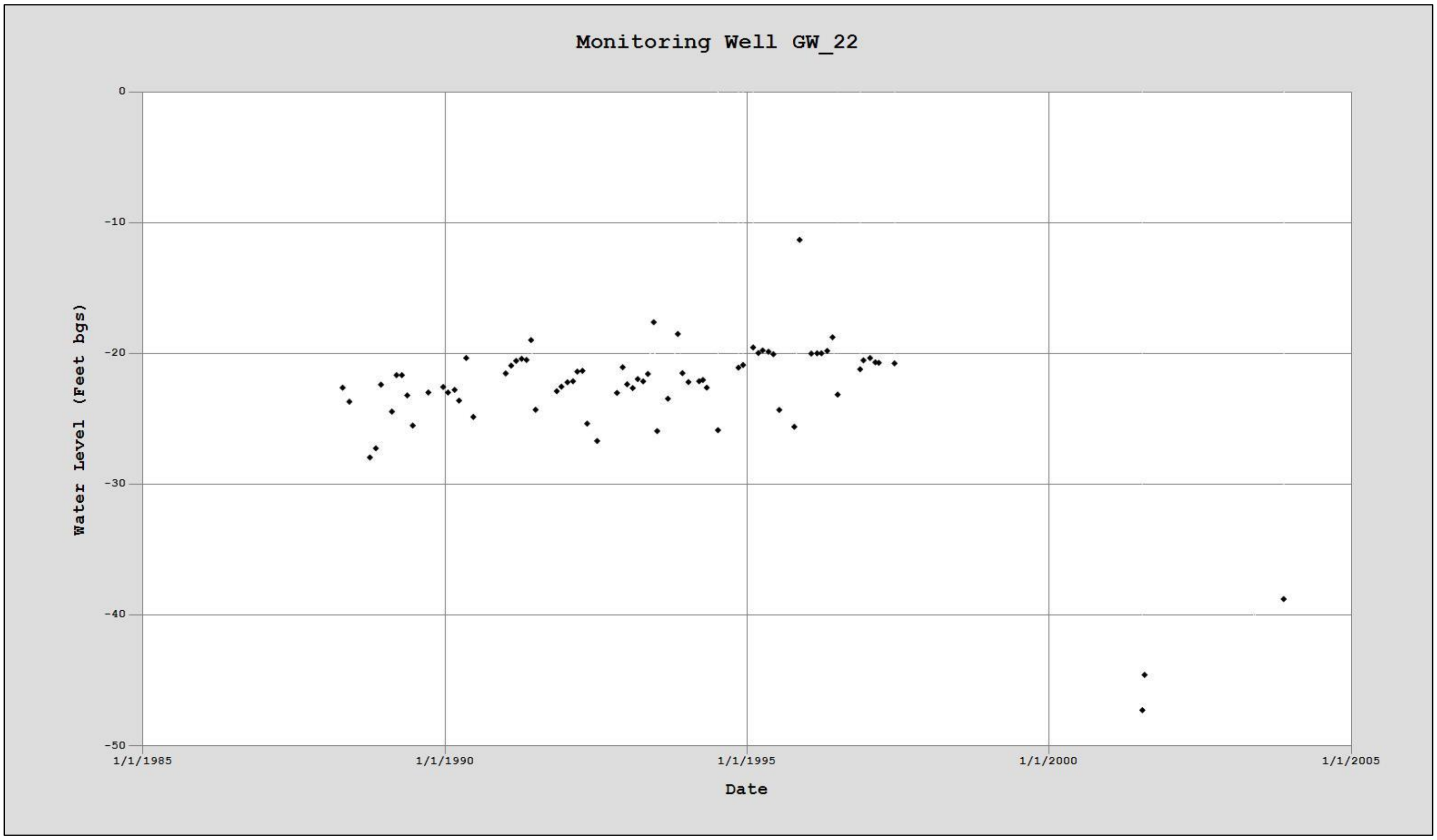

Figure 7. Manual water level measurements in feet below ground surface for the historic well GW_22 located in the WWBWC's Shallow Aquifer Monitoring Network.

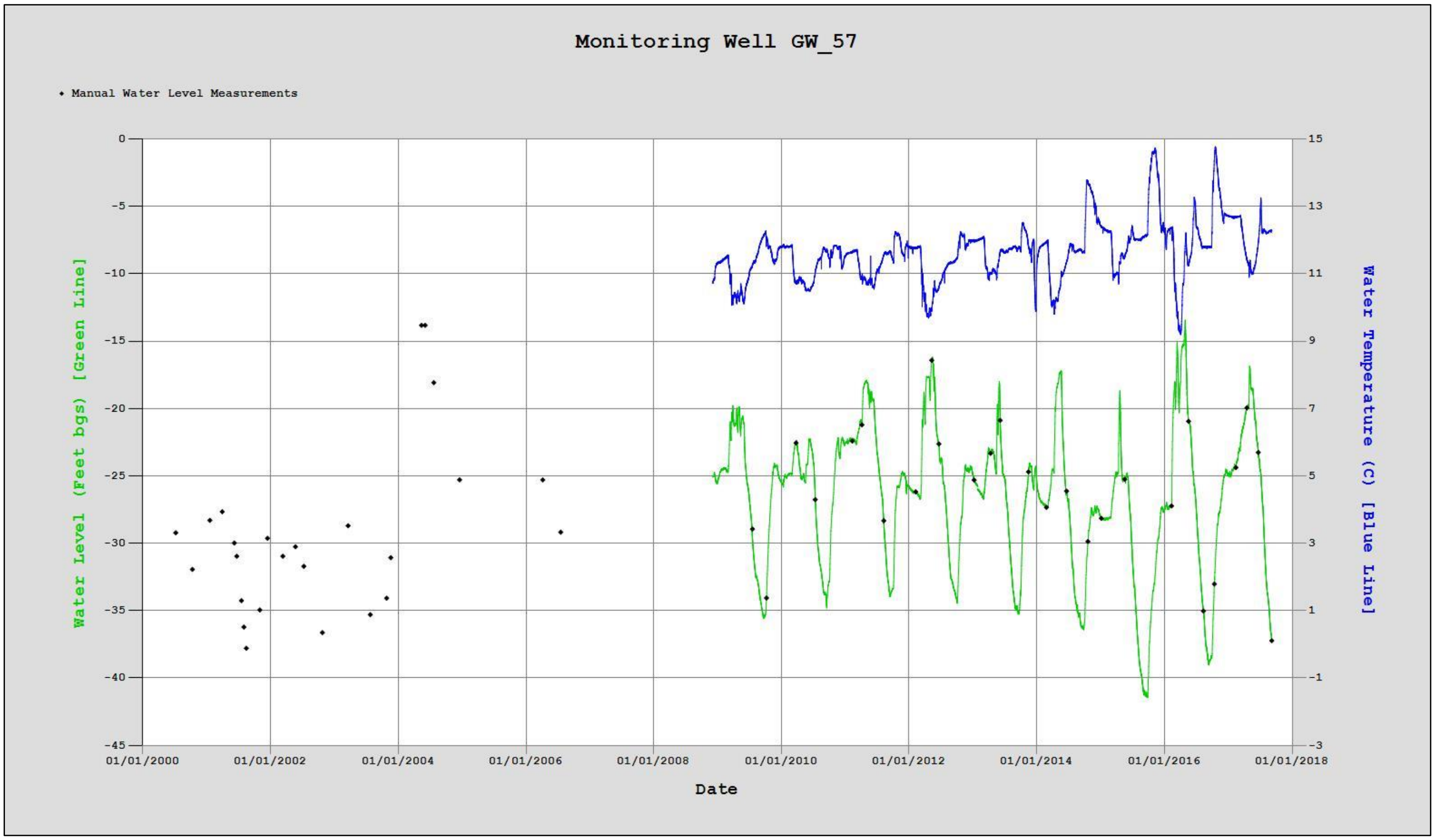

Figure 8. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the historic well GW_57 located in the WWBWC's Shallow Aquifer Monitoring Network.

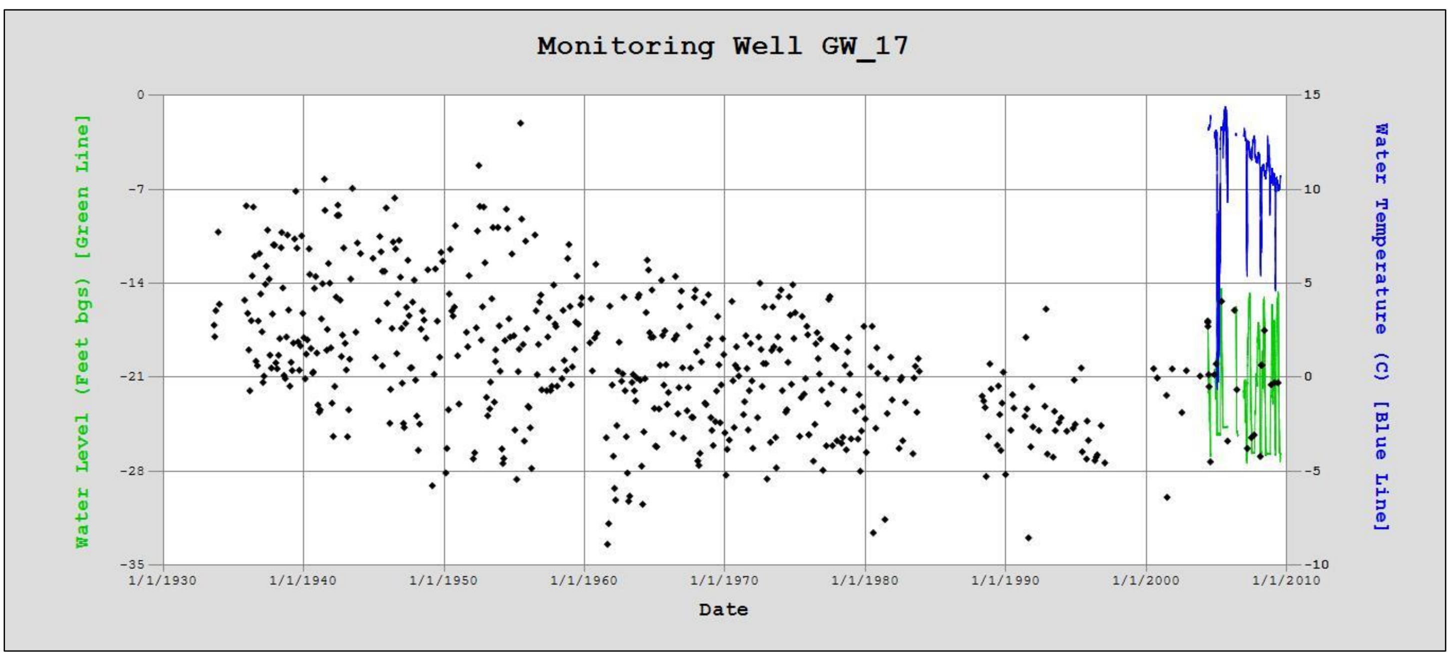

Figure 9. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the historic well GW_17 located in the WWBWC's Shallow Aquifer Monitoring Network.

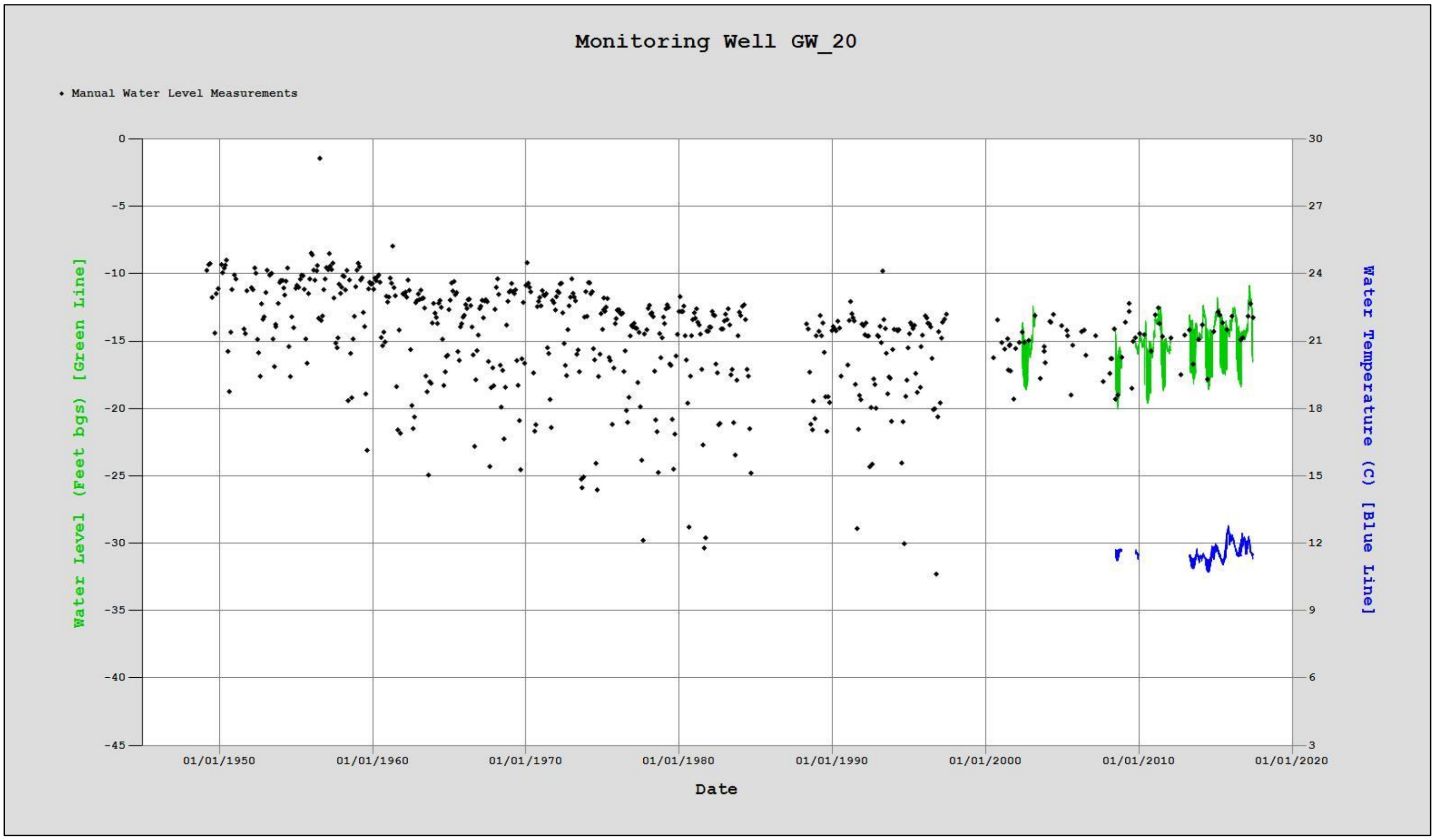

Figure 10. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the historic well GW_17 located in the WWBWC's Shallow Aquifer Monitoring Network.

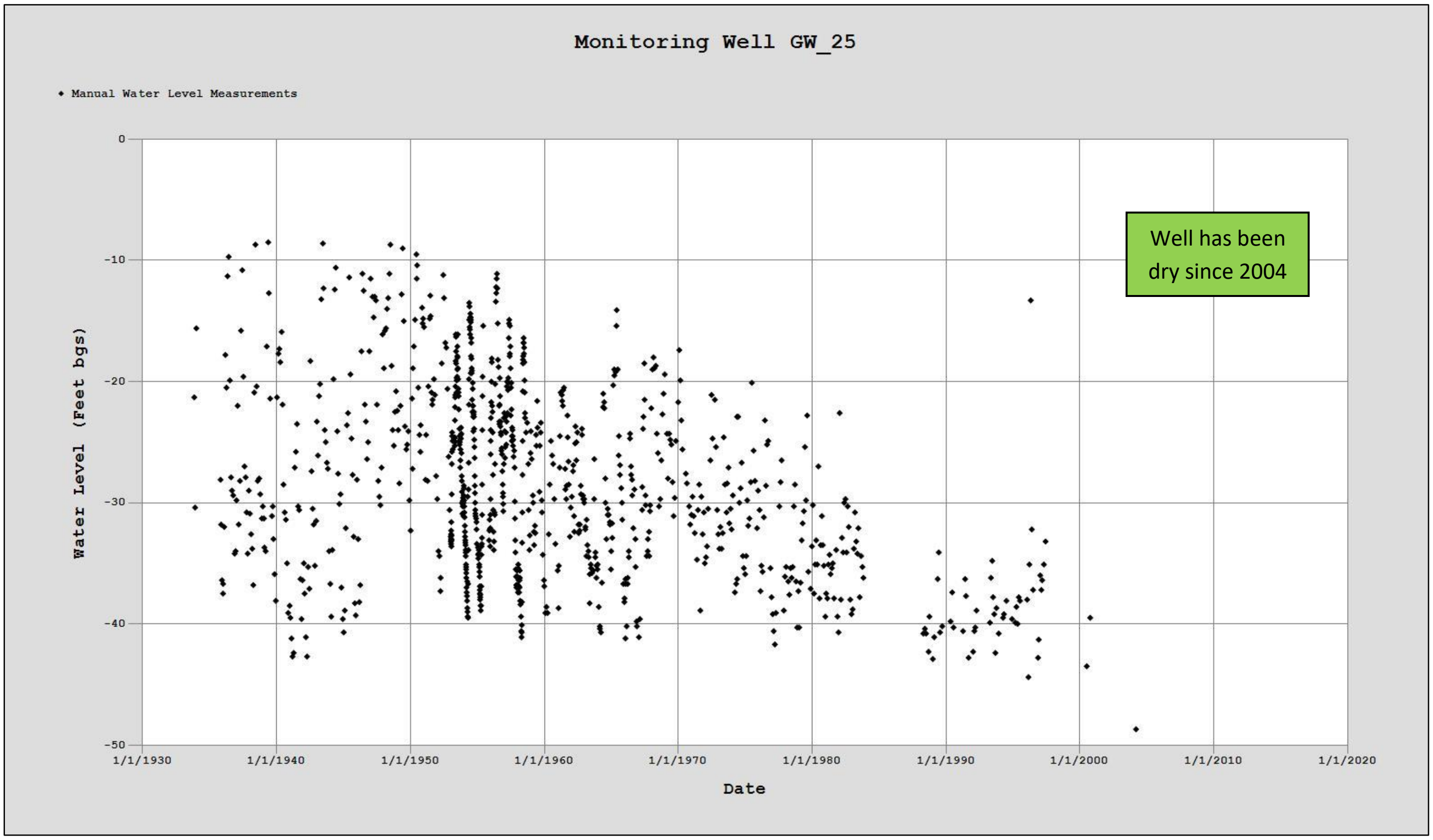

Figure 11. Manual water level measurements (black diamonds) in feet below ground surface for the historic well GW_25 located in the WWBWC's Shallow Aquifer Monitoring Network.

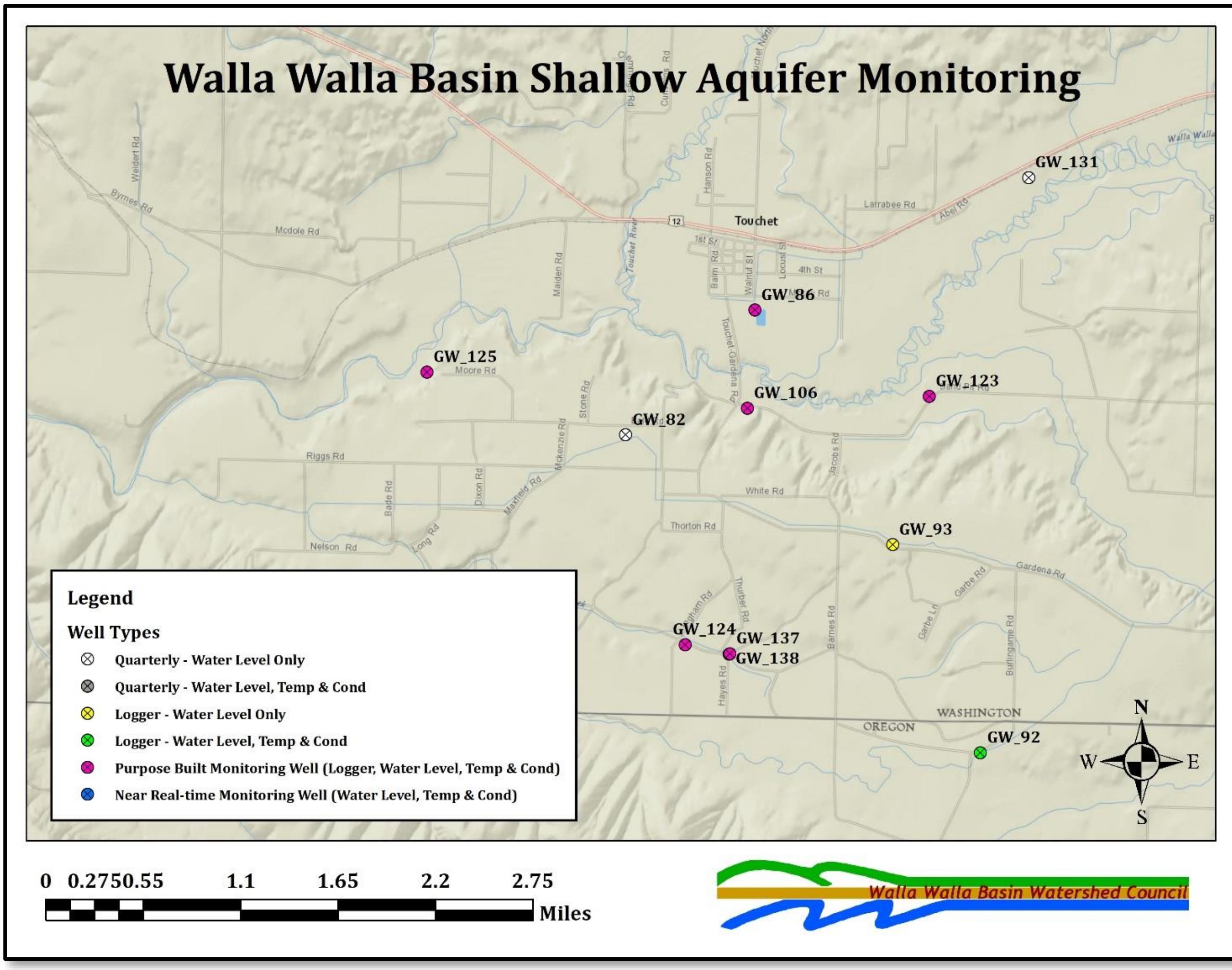

Figure 12. Monitoring wells in the Touchet-Gardena Area.

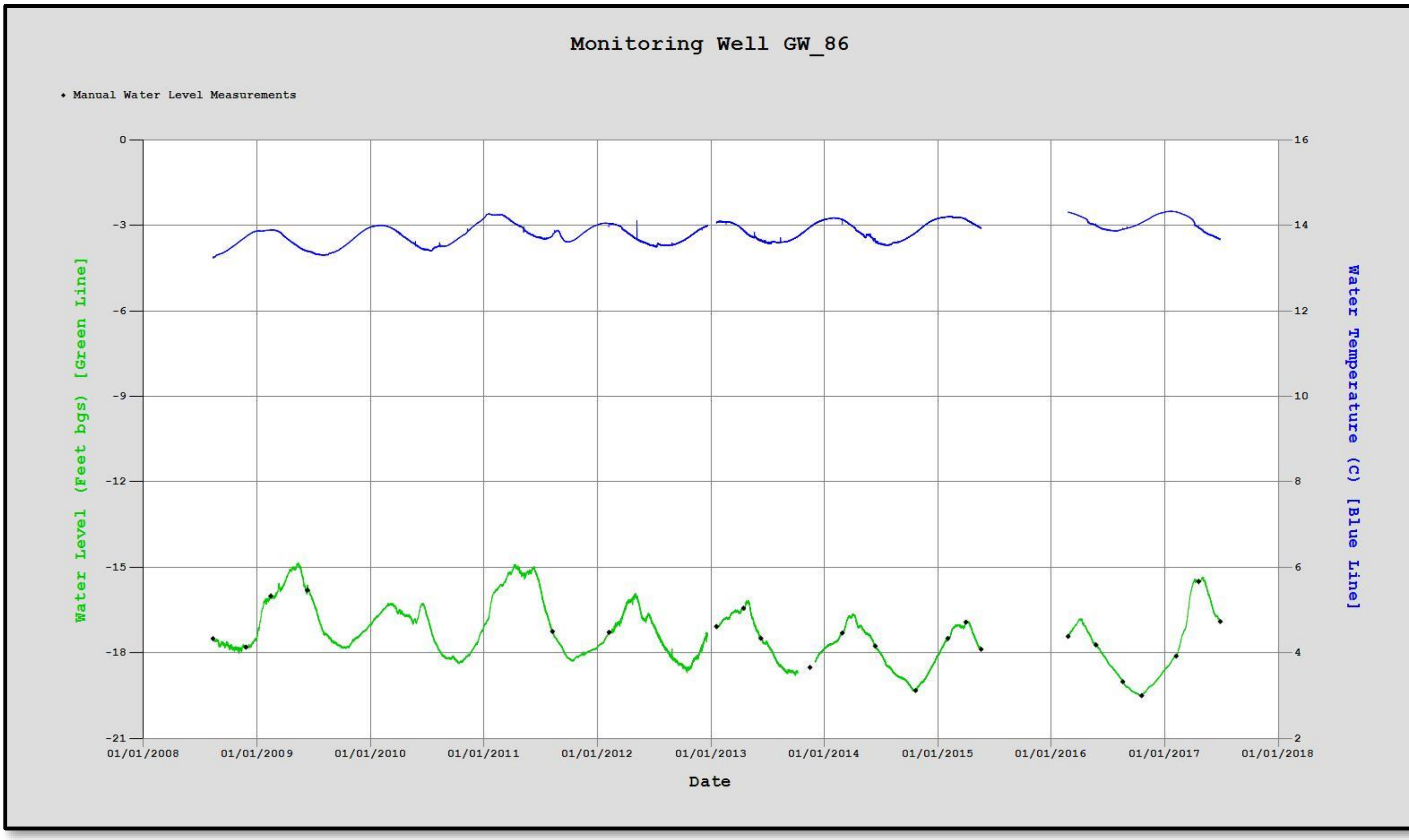

Figure 13. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_86 located in the WWBWC's Shallow Aquifer Monitoring Network.

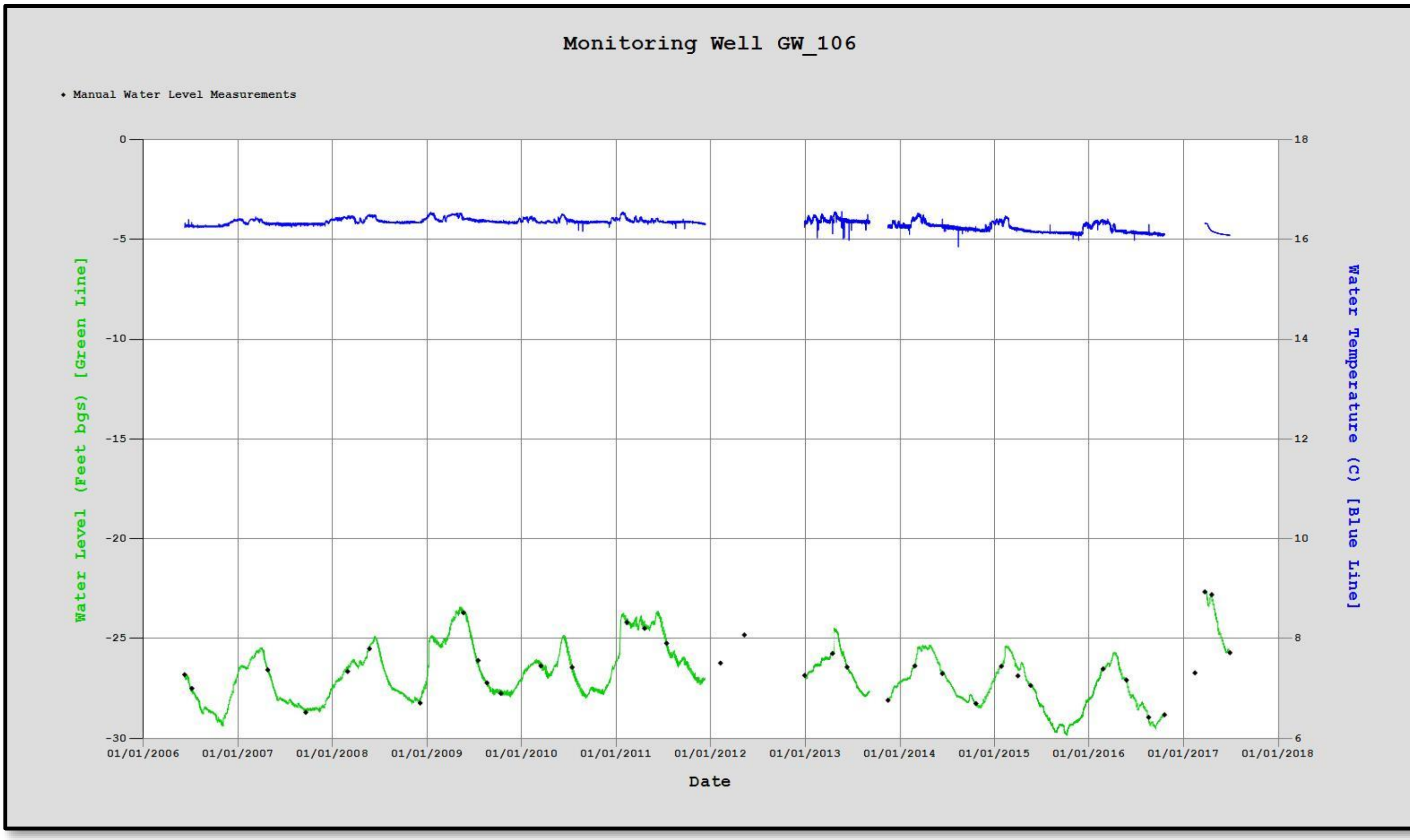

Figure 14. Manual water level measurements (black diamonds) in feet below ground surface for the well GW_106 located in the WWBWC's Shallow Aquifer Monitoring Network.

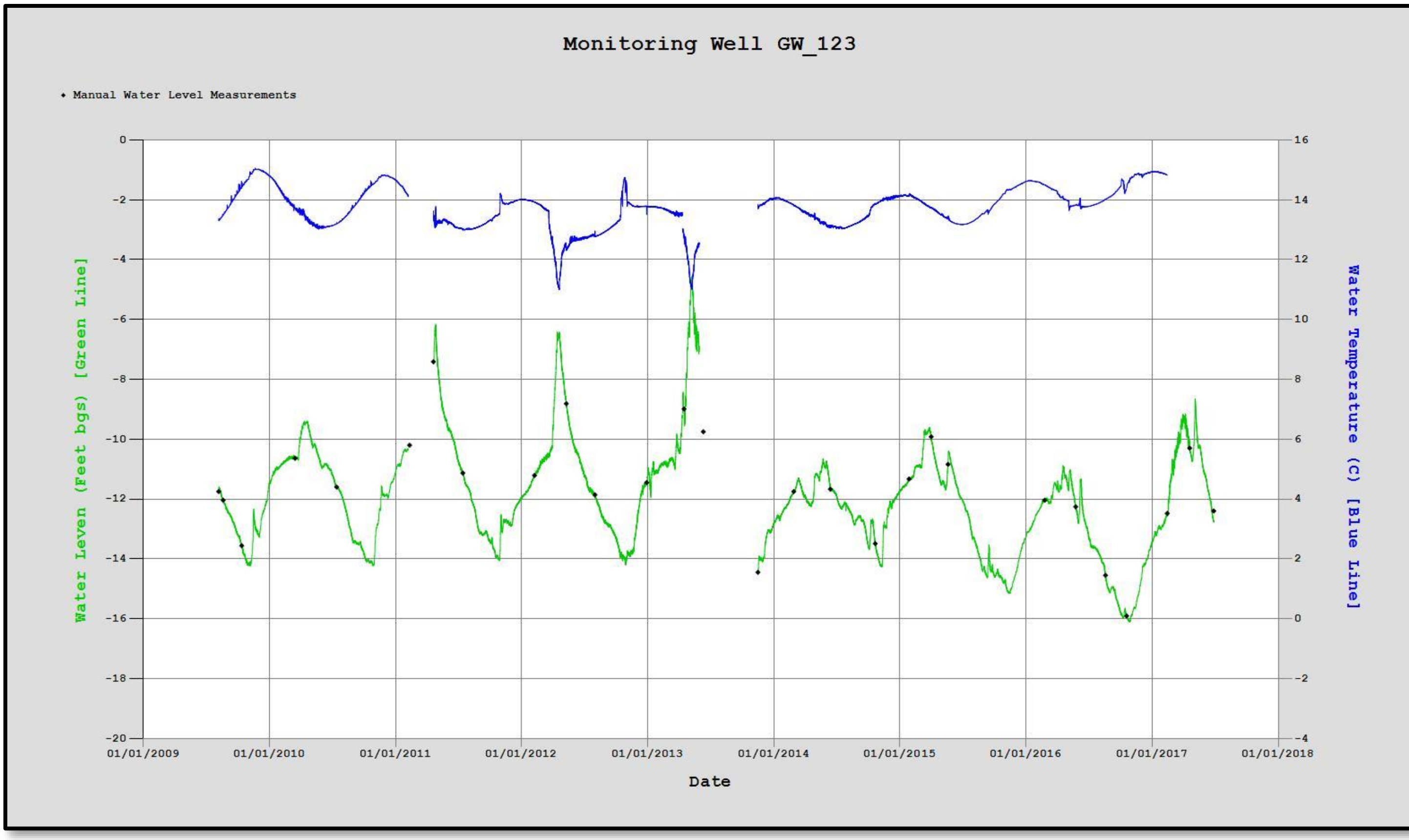

Figure 15. Pressure transducer data (blue line) in feet below ground surface for the near real-time well GW_123 located in the WWBWC's Shallow Aquifer Monitoring Network.

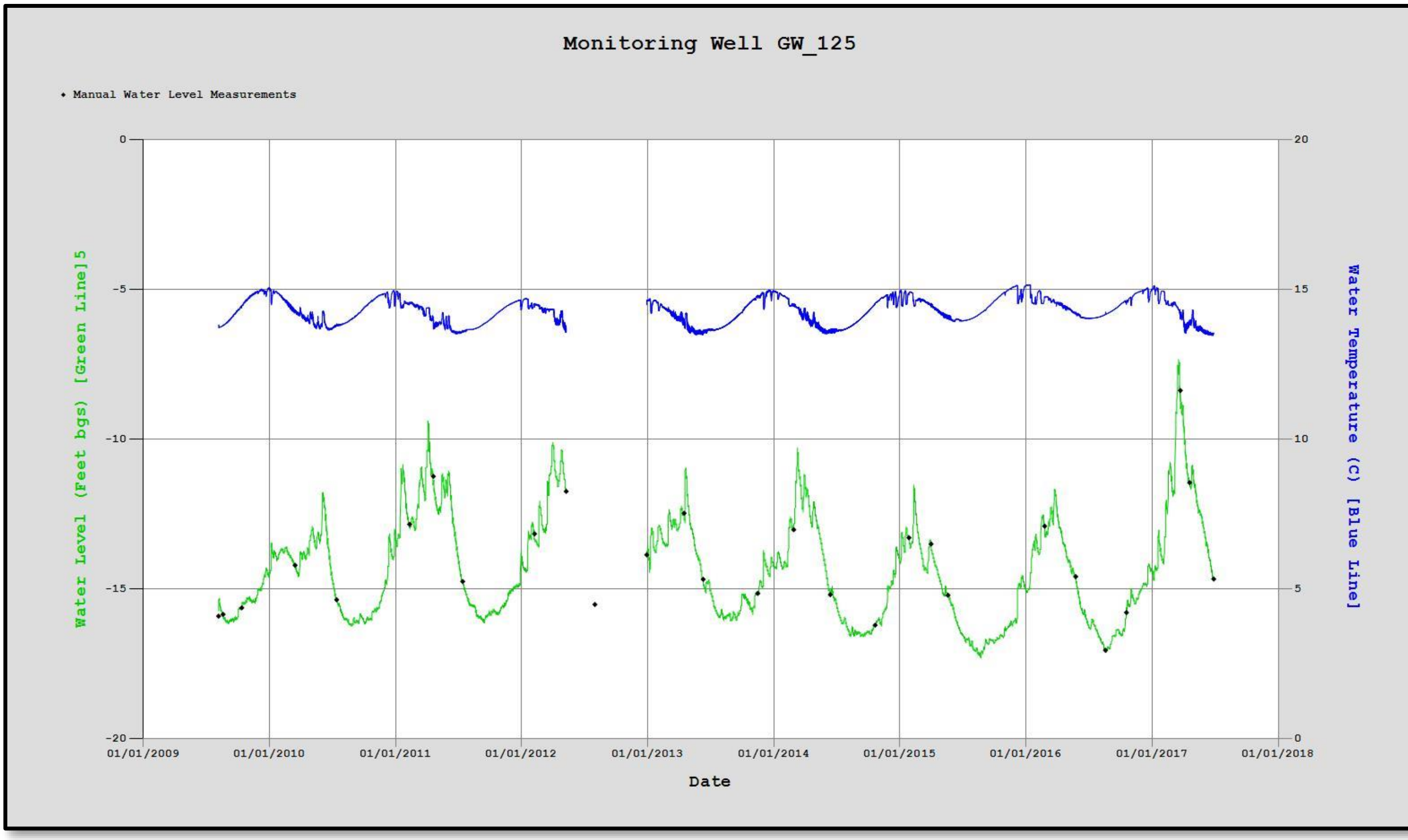

Figure 16. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_125 located in the WWBWC's Shallow Aquifer Monitoring Network.

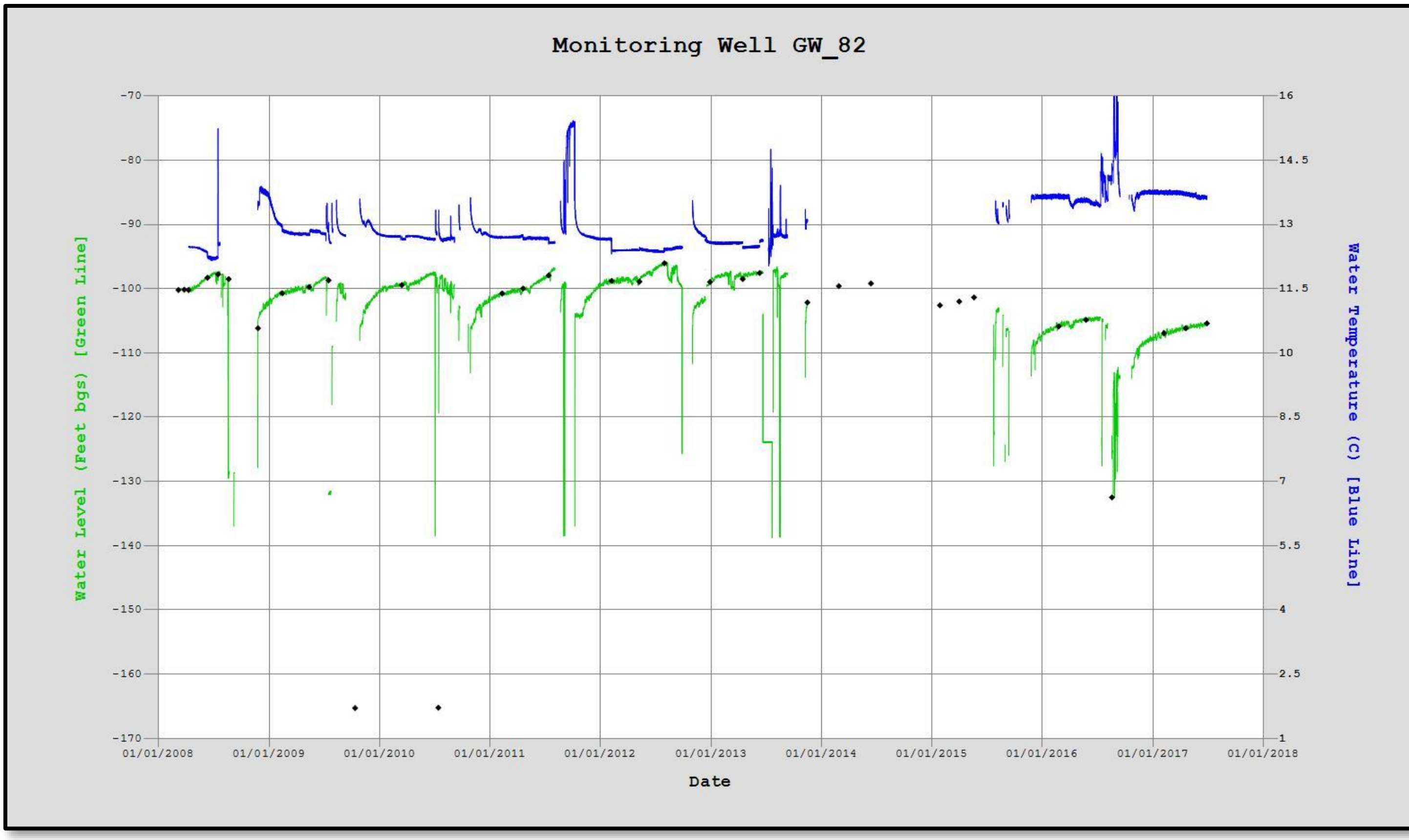

Figure 17. Manual water level measurements (black diamonds) in feet below ground surface for the well GW_82 located in the WWBWC's Shallow Aquifer Monitoring Network.

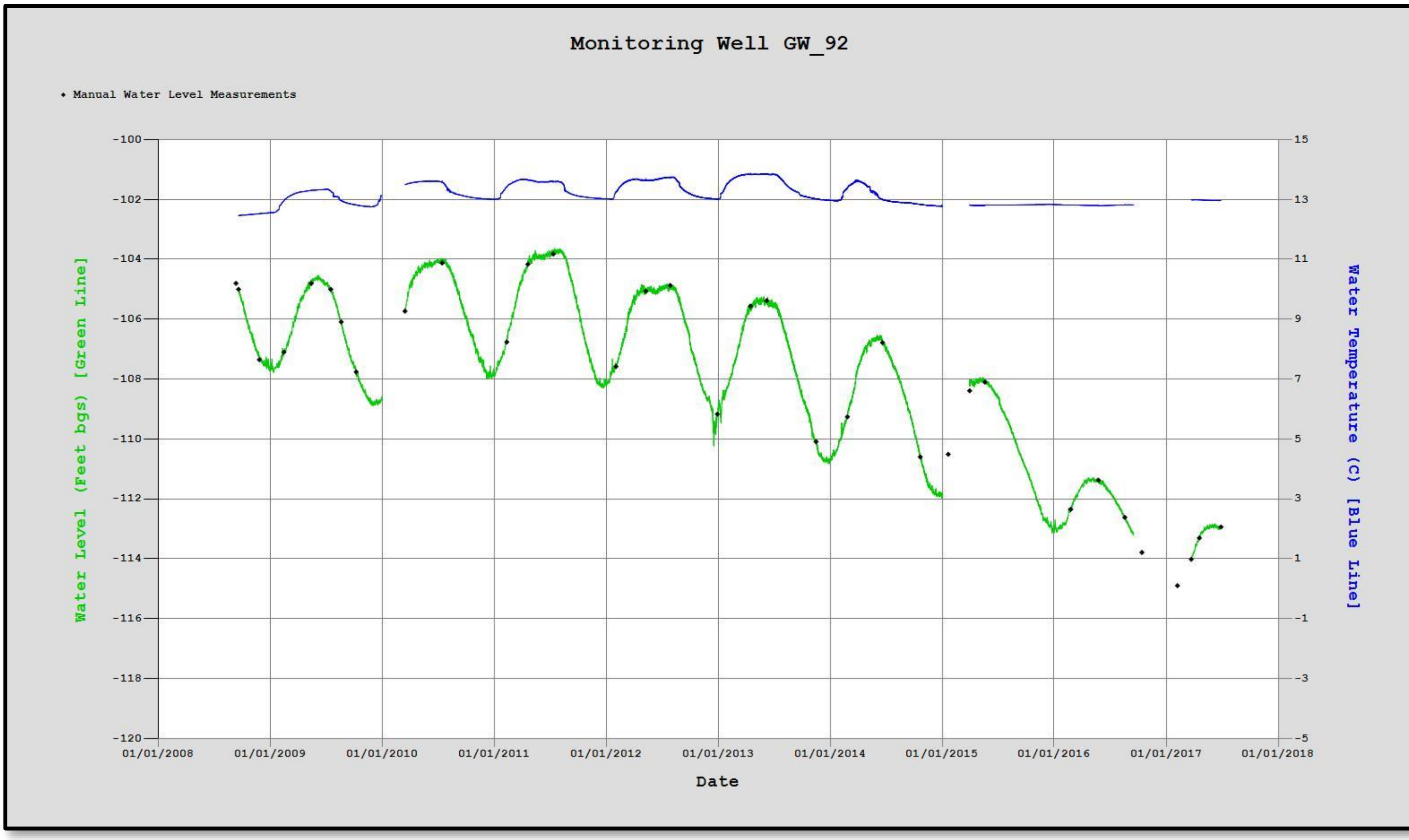

Figure 18. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_92 located in the WWBWC's Shallow Aquifer Monitoring Network.

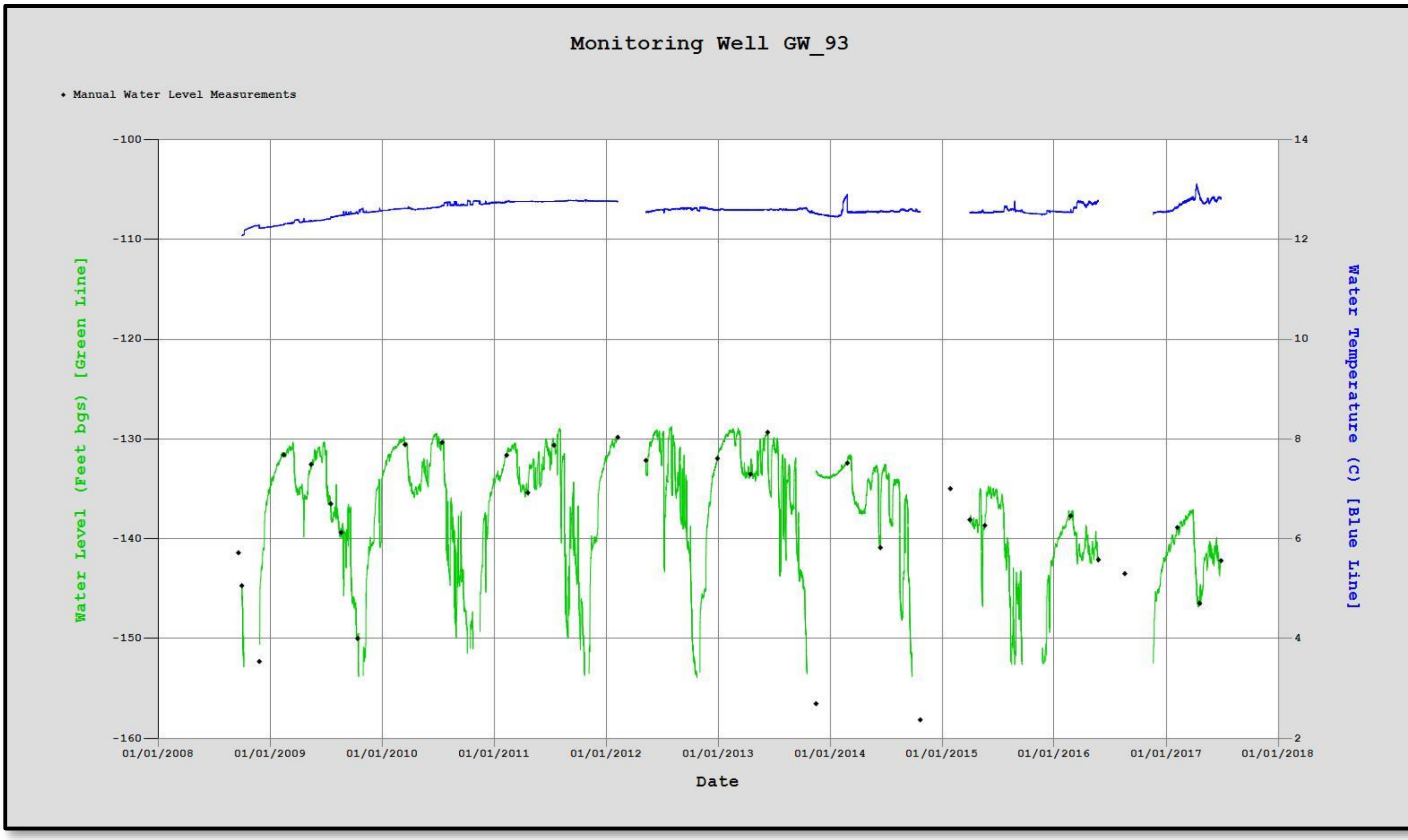

Figure 19. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_93 located in the WWBWC's Shallow Aquifer Monitoring Network.

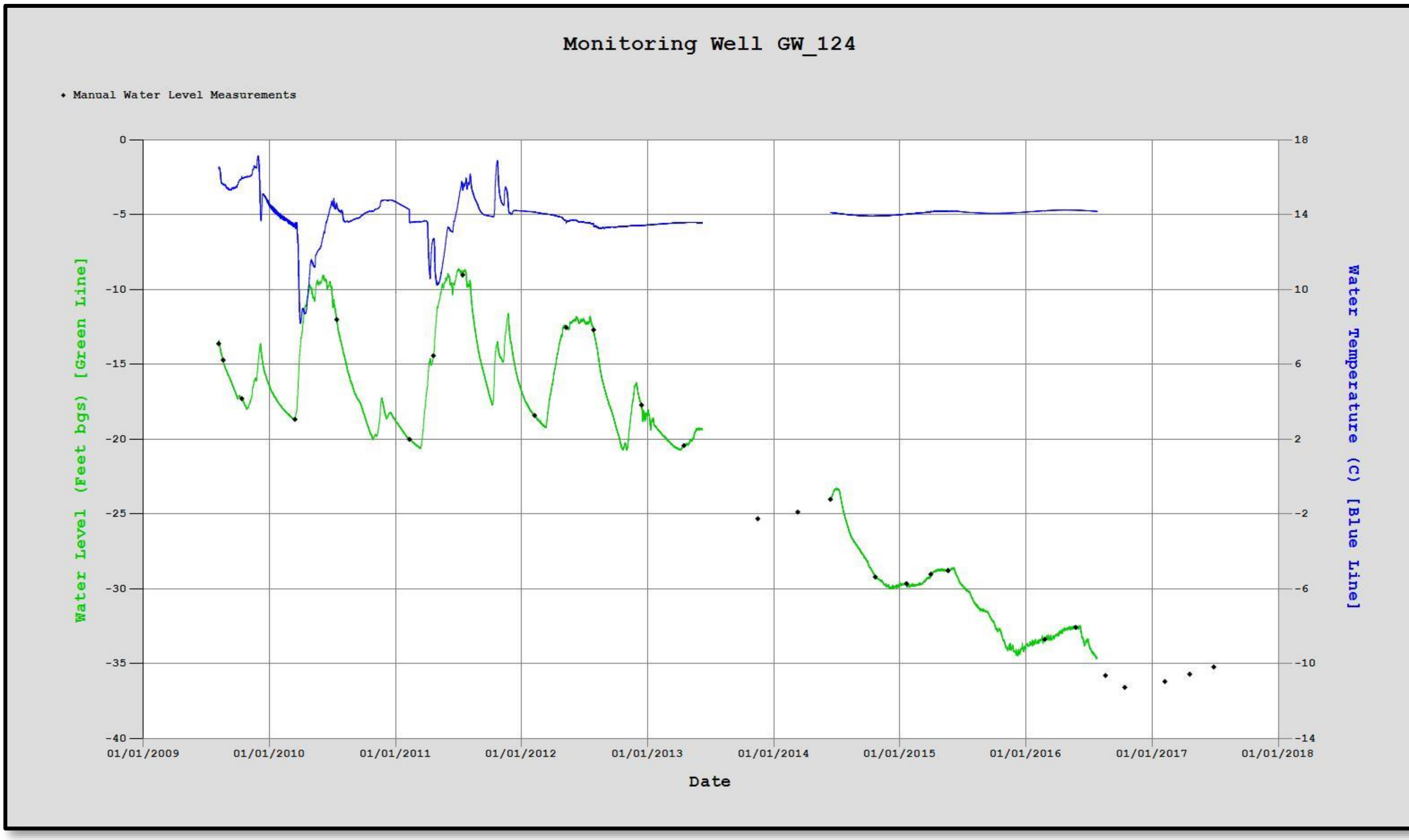

Figure 20. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_124 located in the WWBWC's Shallow Aquifer Monitoring Network.

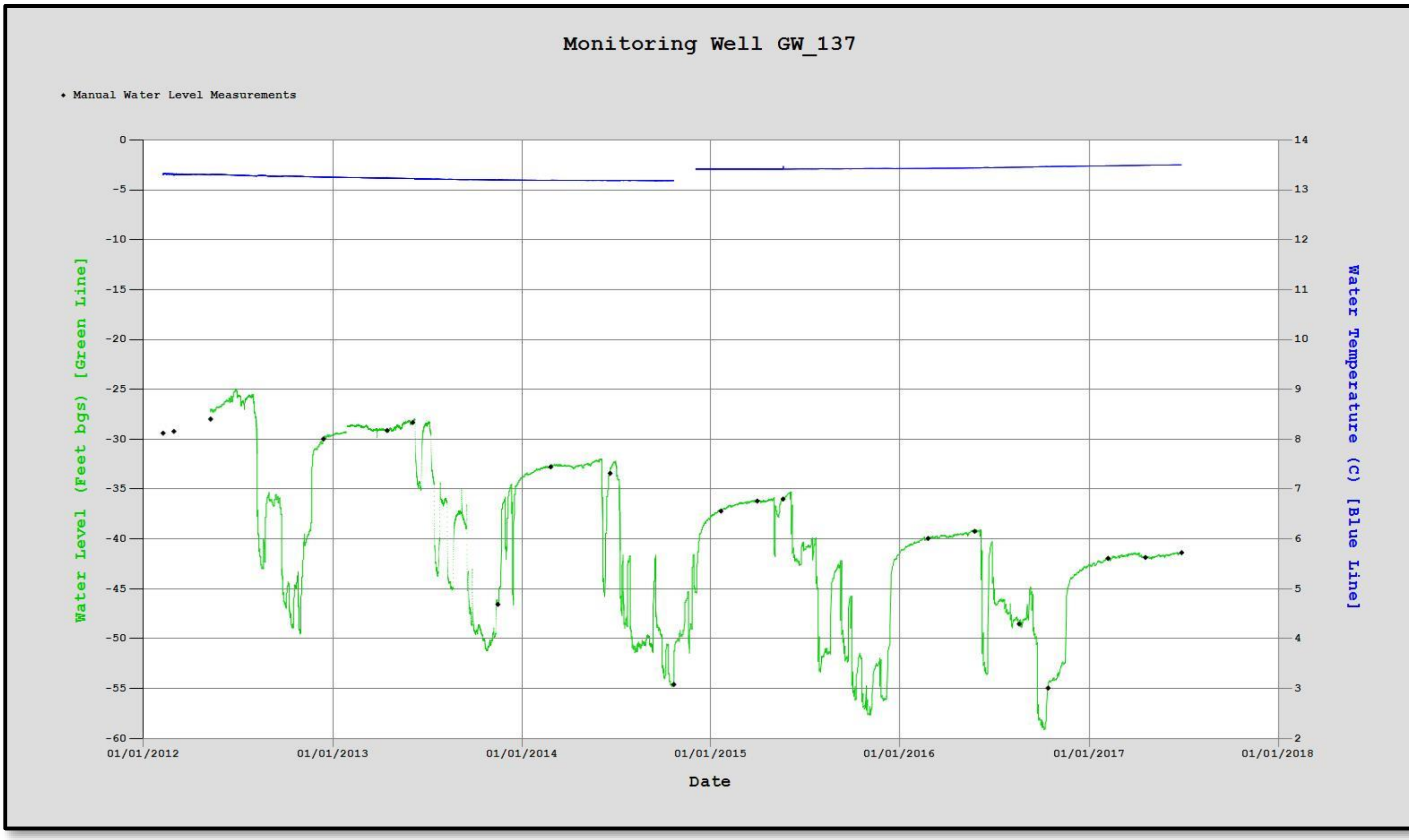

Figure 21. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_137 located in the WWBWC's Shallow Aquifer Monitoring Network.

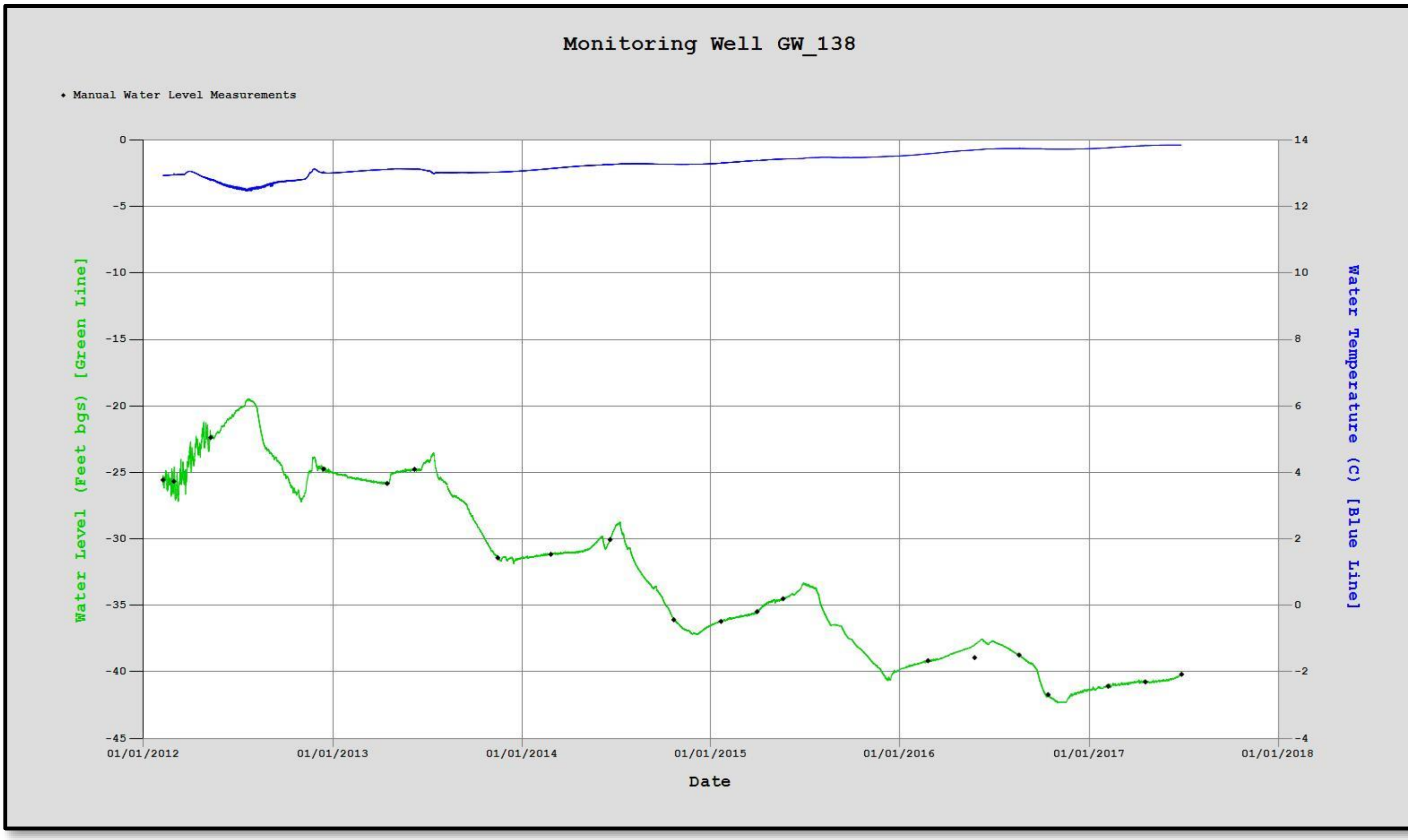

Figure 22. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_138 located in the WWBWC's Shallow Aquifer Monitoring Network.

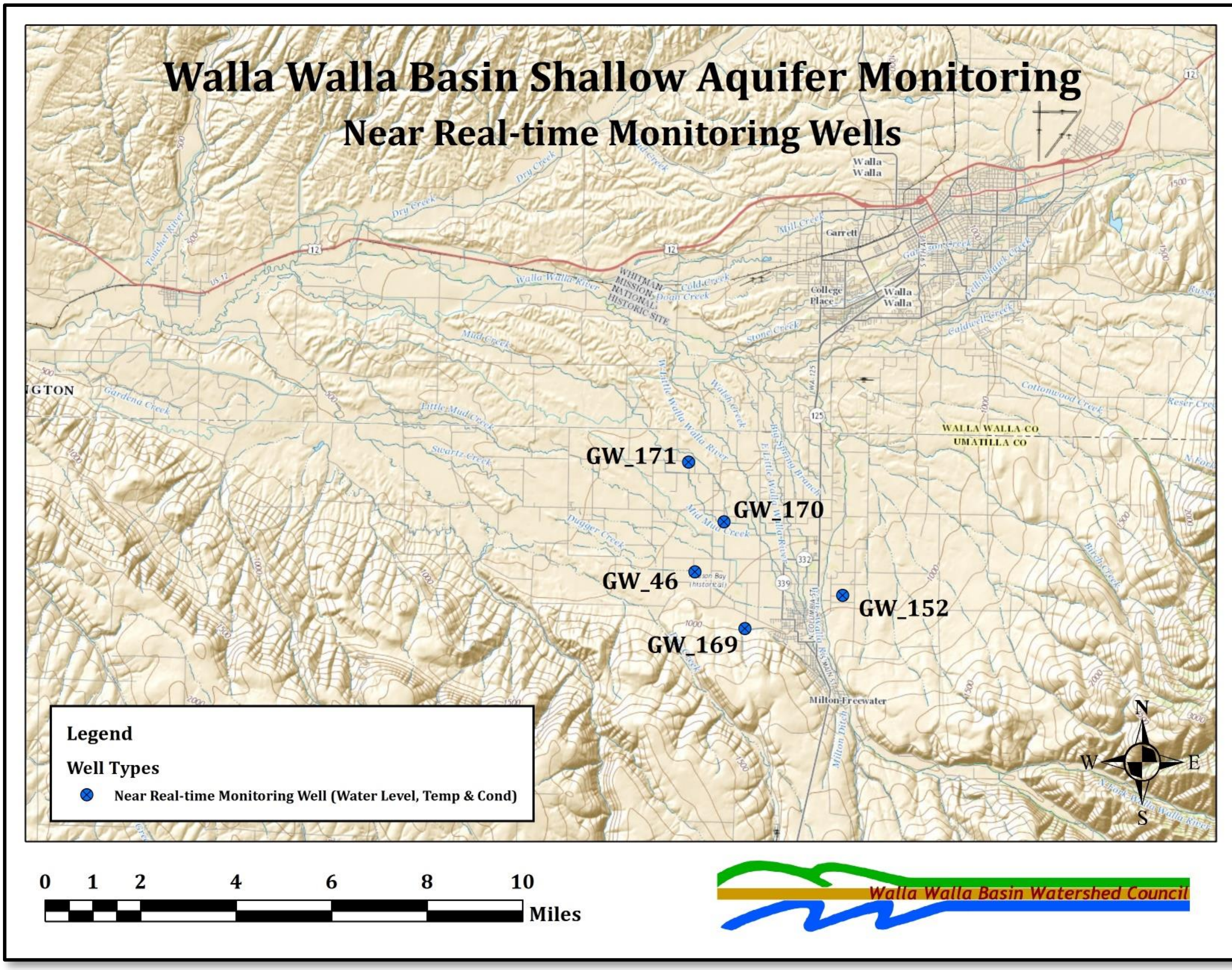

Figure 23. Near Real-time monitoring wells in the Walla Walla Valley.

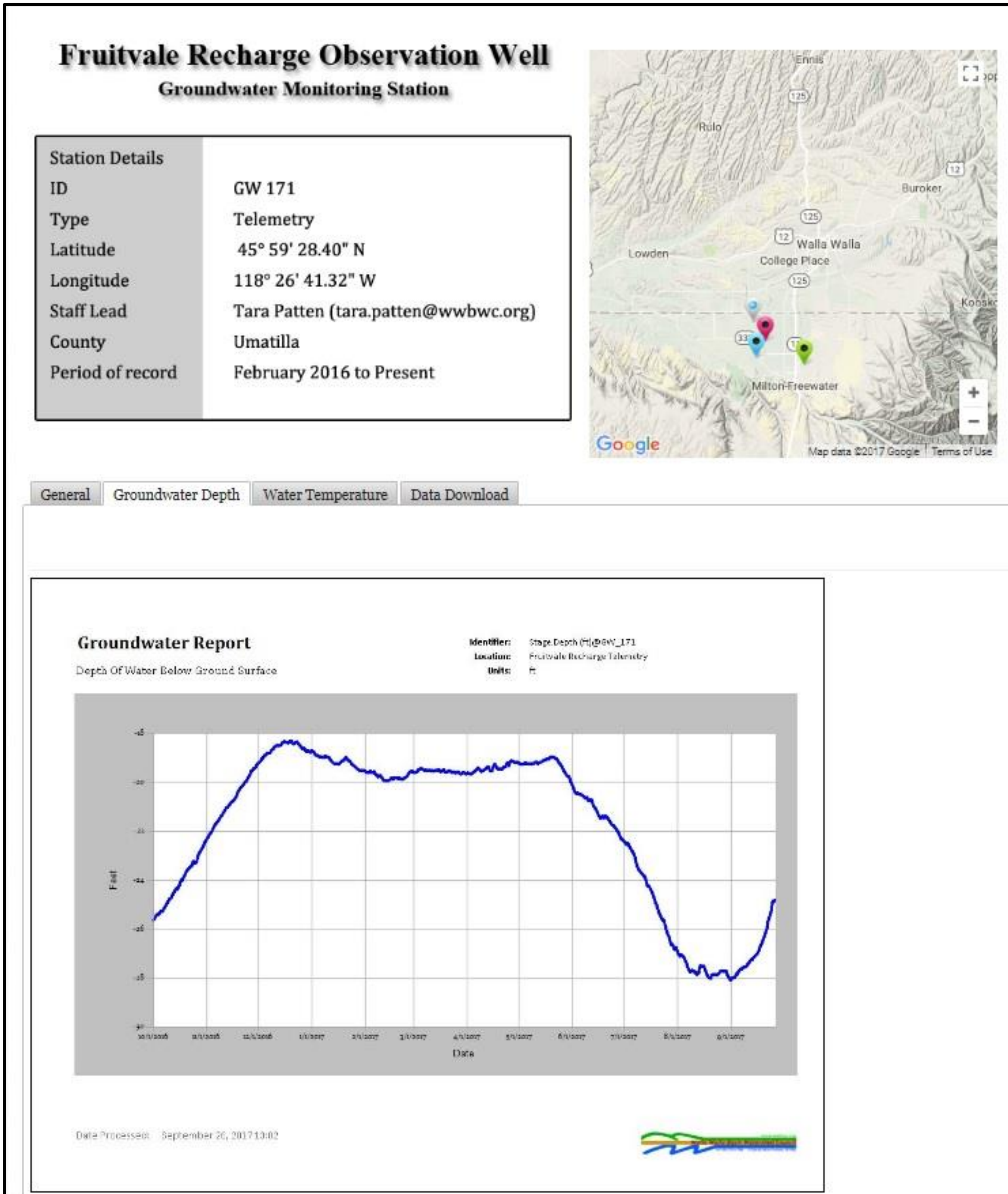

Figure 24. Example webpage for near real-time groundwater monitoring in the WWBWC's Shallow Aquifer Monitoring Network.

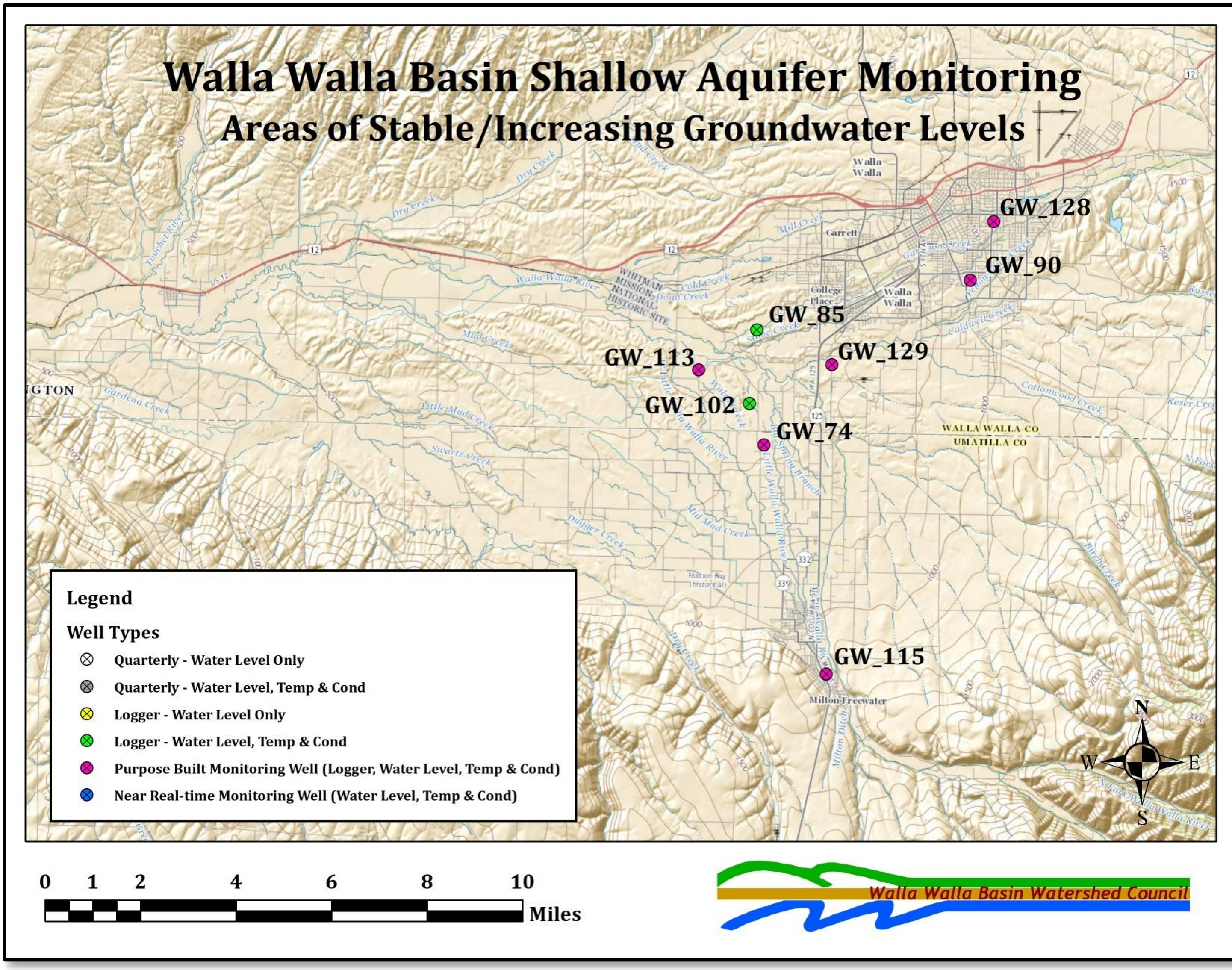

Figure 25. Monitoring wells showing stable and/or increasing groundwater levels in the Walla Walla Valley.

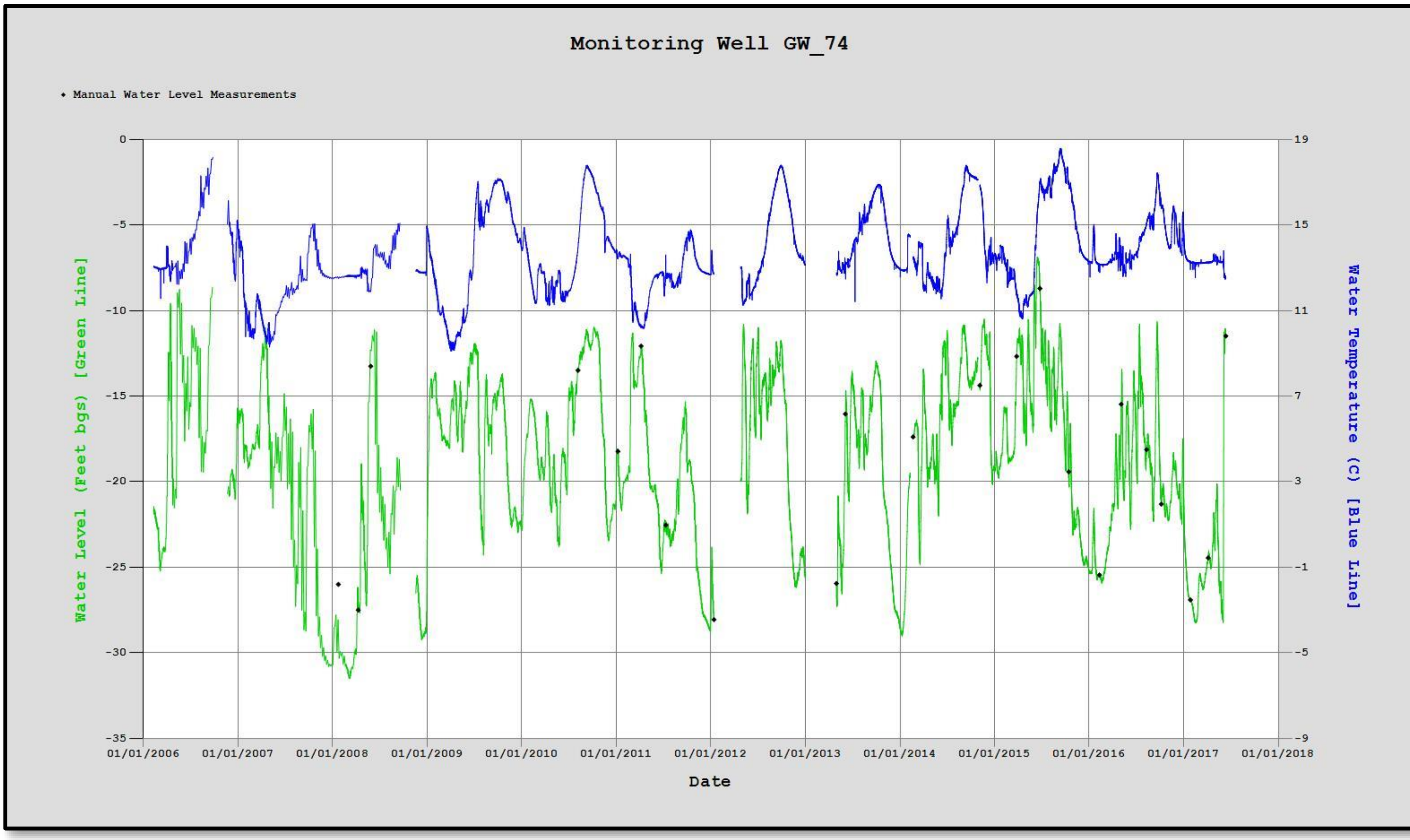

Figure 26. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_74 located in the WWBWC's Shallow Aquifer Monitoring Network.

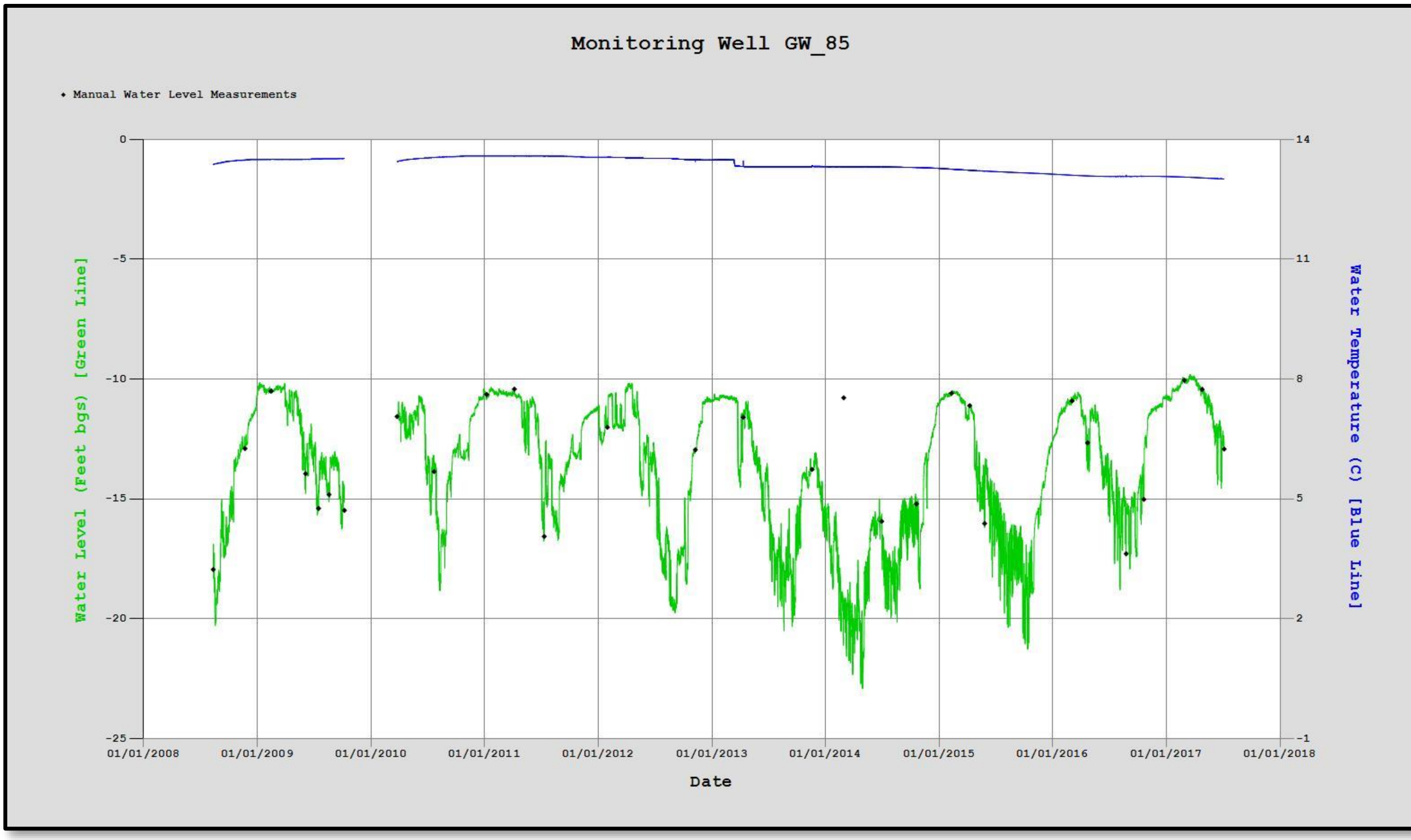

Figure 27. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_85 located in the WWBWC's Shallow Aquifer Monitoring Network.

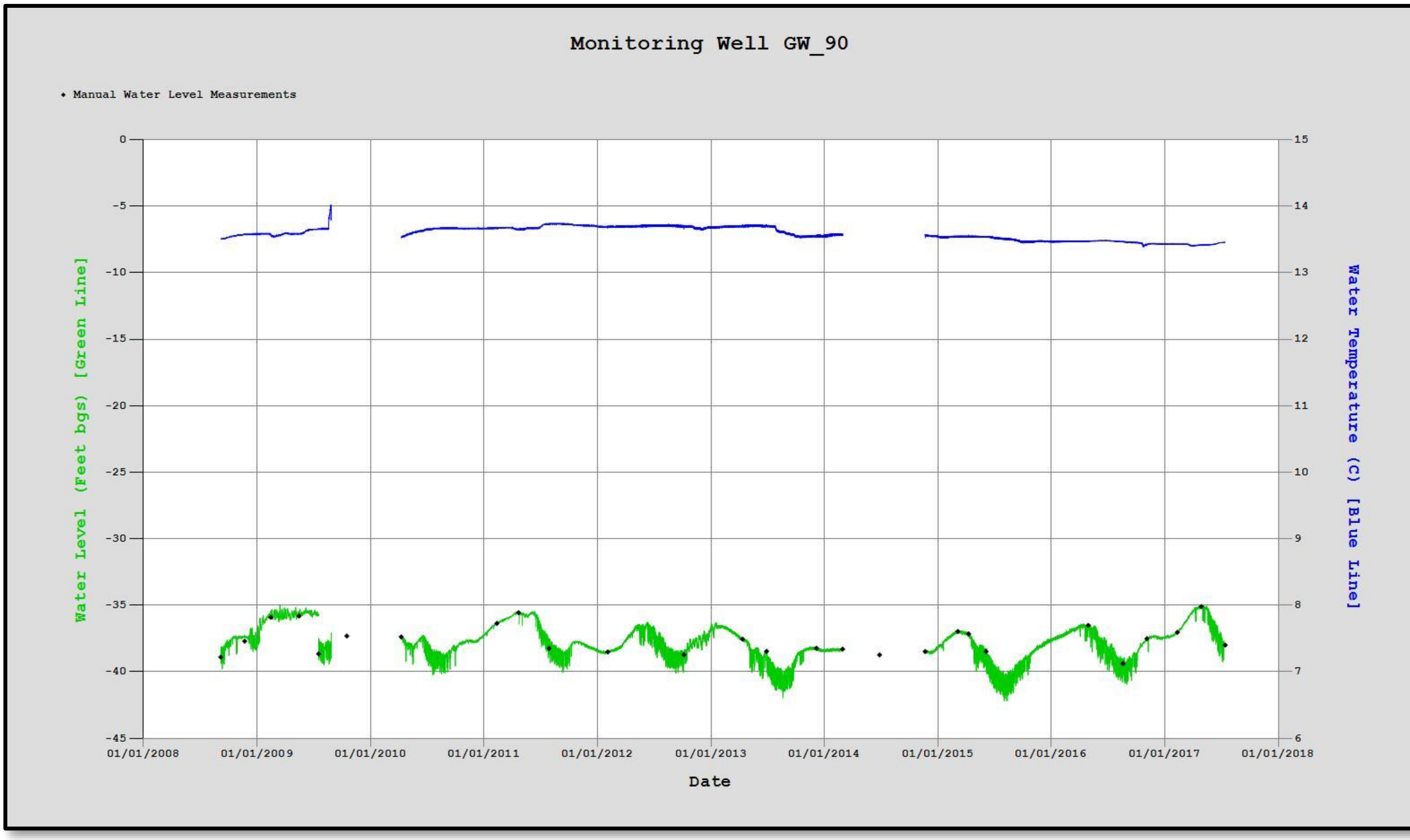

Figure 28. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_90 located in the WWBWC's Shallow Aquifer Monitoring Network.

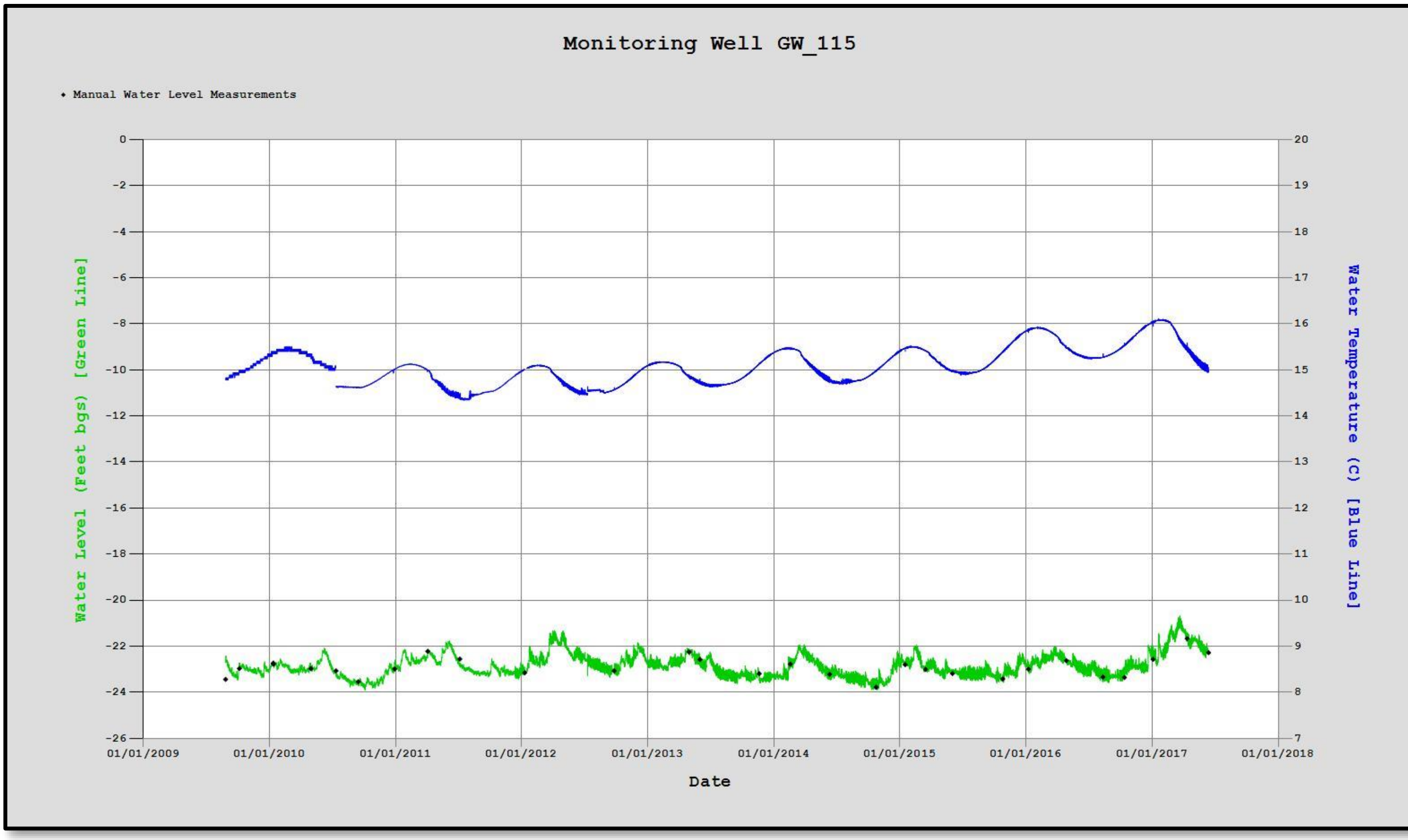

Figure 29. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_115 located in the WWBWC's Shallow Aquifer Monitoring Network.

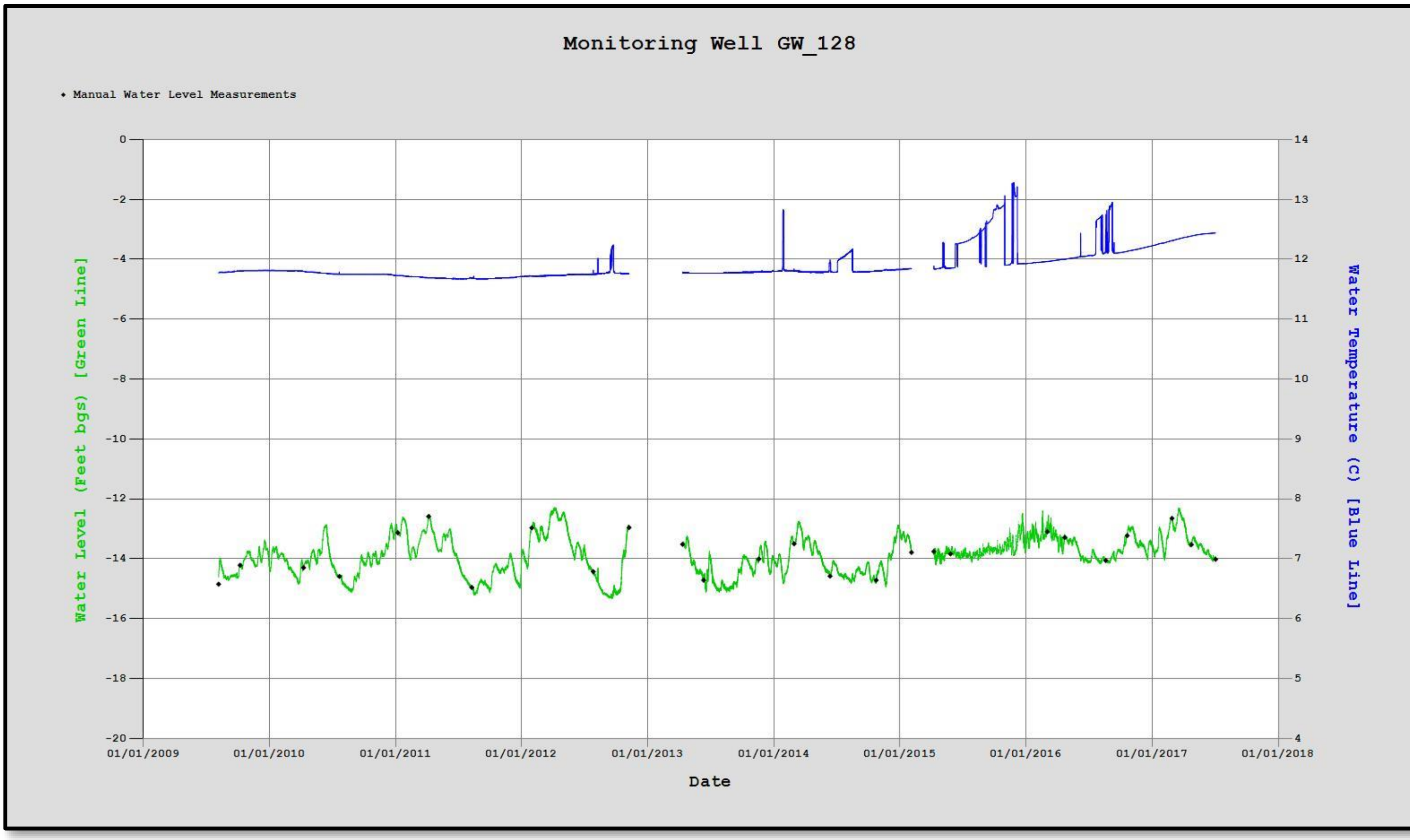

Figure 30. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_128 located in the WWBWC's Shallow Aquifer Monitoring Network.

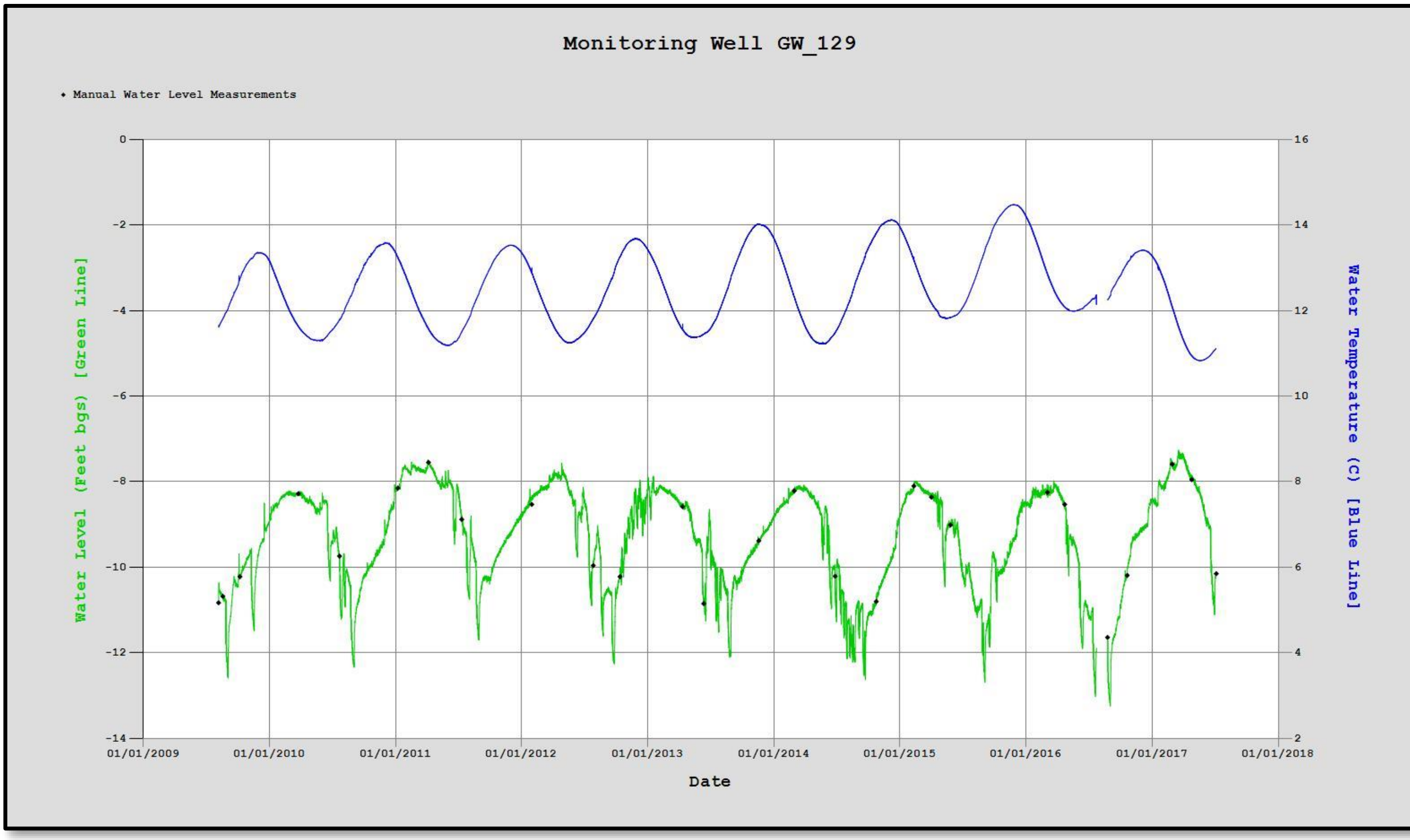

Figure 31. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_129 located in the WWBWC's Shallow Aquifer Monitoring Network.

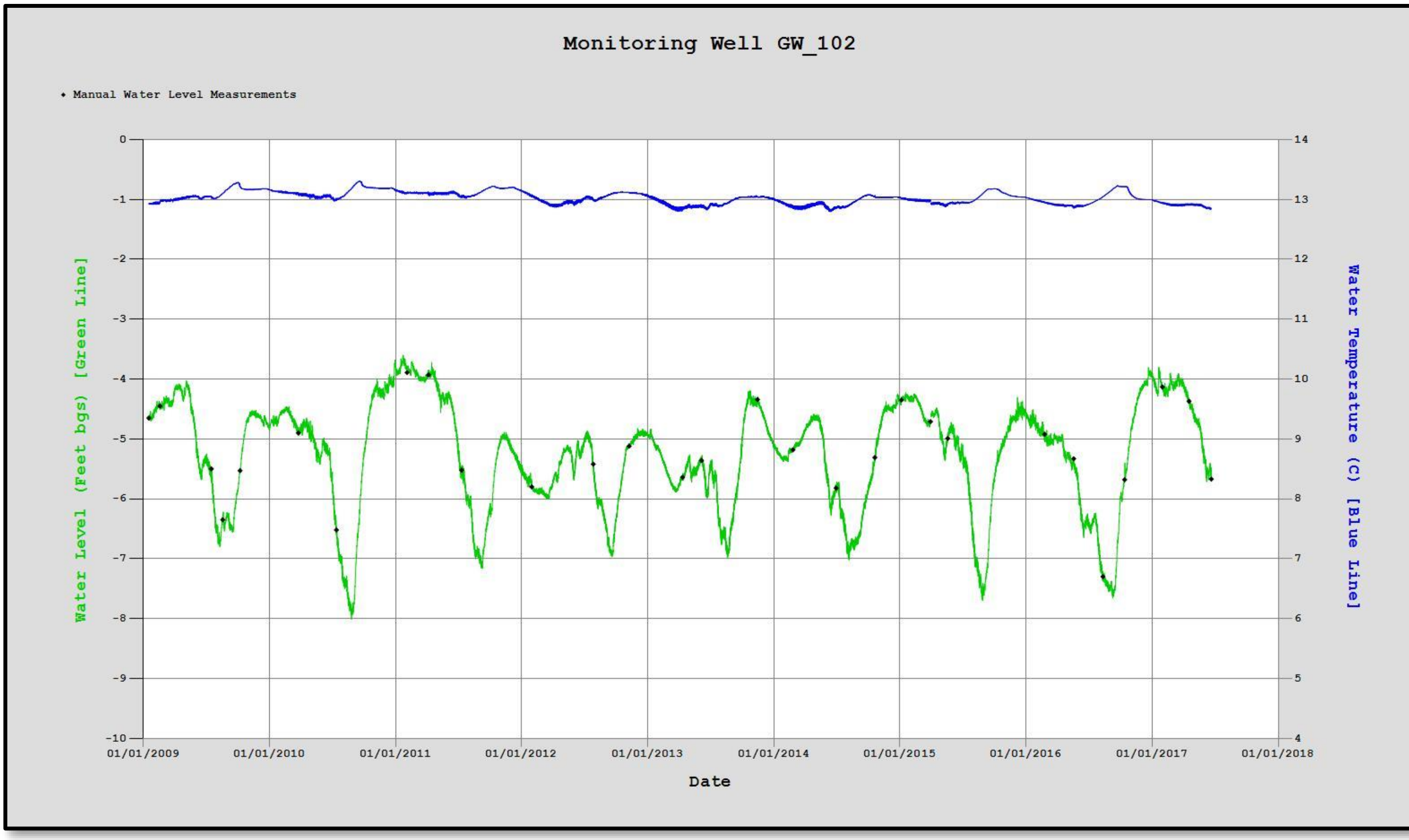

Figure 32. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_102 located in the WWBWC's Shallow Aquifer Monitoring Network.

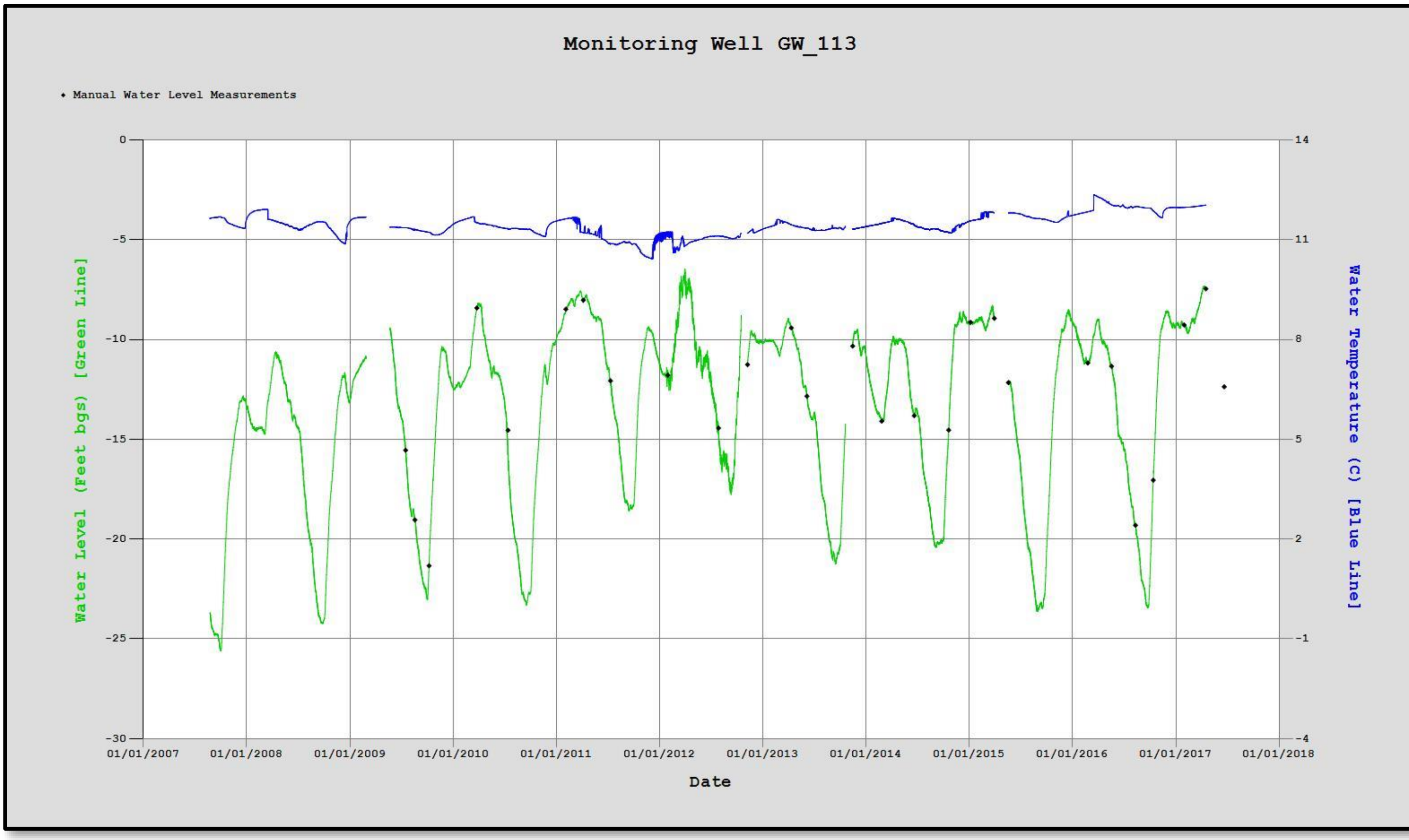

Figure 33. Manual water level measurements (black diamonds) and pressure transducer data (green line) in feet below ground surface for the well GW_113 located in the WWBWC's Shallow Aquifer Monitoring Network.

APPENDIX A

GPS coordinates for wells currently monitored in the Walla Walla Basin Shallow Aquifer.

Note: GPS coordinates are in UTM (Datum = NAD83 and NAVD88 for Elevation)

WELL_ID	Easting	Northing	Well Elevation in Meters	Well Elevation in Feet	Horizontal Confidence in Meters	Vertical Confidence in Meters
GW_03	393477.08	5091165.361	273.745	898.114	0.016	0.012
GW_04	393192.023	5091728.252	267.303	876.978	0.016	0.011
GW_05	393764.617	5094403.253	248.064	813.920	0.022	0.015
GW_06	392664.181	5092403.474	262.960	867.425	0.015	0.011
GW_07	392787.583	5091551.116	271.717	891.460	0.012	0.012
GW_09	392658.605	5088806.697	306.631	1006.007	0.014	0.01
GW_10	392132.402	5091372.824	273.696	897.950	0.022	0.019
GW_11	391570.533	5093637.708	247.687	812.621	0.015	0.017
GW_13	390667.86	5093232.622	250.852	823.004	0.013	0.015
GW_14	392157.683	5089568.006	295.488	969.449	0.012	0.009
GW_15	388945.465	5089304.752	272.057	892.575	0.003	0.003
GW_16	389690.237	5090610.166	269.610	884.545	0.003	0.004
GW_18	386647.989	5093698.759	225.360	739.367	0.005	0.006
GW_19	391225.116	5092022.761	265.289	870.369	0.014	0.018
GW_20	393114.775	5092400.73	264.392	867.428	0.096	0.101
GW_23	390432.546	5088757.822	292.342	959.125	0.006	0.007
GW_25	393463.723	5090261.704	284.451	933.238	0.013	0.015
GW_27	391245.146	5088811.531	298.777	980.239	0.008	0.009
GW_28	390083.217	5090403.42	274.565	900.803	0.005	0.004
GW_31	385163.051	5093209.972	218.535	716.976	0.006	0.007
GW_33	387947.465	5093853.935	230.034	754.702	0.008	0.006
GW_34	383288.818	5093418.243	201.734	661.855	0.011	0.008
GW_35	388031.533	5090796.498	255.362	837.799	0.09	0.089
GW_36	384946.272	5091616.019	220.534	723.534	0.01	0.012
GW_37	384227.715	5092519.703	208.416	683.780	0.008	0.01
GW_38	392985.262	5094932.606	248.083	812.122	0.021	0.014
GW_39	388823.228	5090045.31	266.394	873.993	0.004	0.002
GW_40	388846.149	5089945.789	266.979	875.913	0.004	0.002
GW_41	388830.34	5090133.816	265.537	871.182	0.004	0.002
GW_45	388555.543	5090167.255	262.553	861.394	0.003	0.003
GW_46	388325.733	5090362.964	259.118	850.123	0.004	0.002
GW_47	388335.675	5090331.38	259.507	851.400	0.003	0.002
GW_48	388432.429	5090413.757	259.608	851.732	0.004	0.002
GW_54	390256.169	5095118.764	231.915	760.873	0.01	0.012
GW_57	385964.995	5095524.821	205.082	672.840	0.003	0.003
GW_58	387261.534	5091269.173	245.655	805.953	0.005	0.004
GW_60	388039.791	5090041.577	257.473	844.726	0.003	0.003

GW_61	387730.609	5089747.583	255.862	839.440	0.003	0.003
GW_62	389834.806	5089059.234	283.305	929.478	0.006	0.004
GW_63	383280.245	5091893.17	203.980	669.226	0.014	0.01
GW_64	383657.595	5091641.274	208.550	684.218	0.011	0.013
GW_65	387239.855	5090936.276	246.133	807.520	0.005	0.003
GW_66	384016.598	5091700.048	209.851	688.485	0.014	0.01
GW_67	378968.413	5093403.081	175.056	574.330	0.019	0.02
GW_68	379255.547	5092242.311	181.305	594.831	0.022	0.018
GW_69	383991.427	5091254.854	212.394	696.829	0.013	0.013
GW_70	385959.296	5095225.597	206.799	678.472	0.003	0.003
GW_71	385628.631	5095705.396	202.314	663.757	0.003	0.003
GW_72	385729.547	5095463.305	204.567	671.152	0.004	0.002
GW_73	390621.47	5095033.16	232.761	763.651		
GW_74	390649.10	5094642.92	234.943	770.811		
GW_75	390474.91	5095093.45	230.702	756.897		
GW_82	369667.774	5098077.191	167.560	549.736	0.006	0.004
GW_83	395564.39	5102165.305	279.703	917.659	0.014	0.018
GW_84	392313.076	5100037.687	239.941	787.207	0.085	0.117
GW_85	390405.704	5098512.064	218.239	716.007	0.016	0.013
GW_86	370841.298	5099210.647	135.383	444.168	0.01	0.006
GW_87	402951.381	5104575.886	385.250	1263.942	0.006	0.004
GW_88	404352.529	5104571.294	402.095	1319.206	0.008	0.009
GW_89	400344.775	5102819.459	340.715	1117.829	0.004	0.004
GW_90	397598.227	5100192.121	295.908	970.825	0.012	0.014
GW_92	372892.083	5095185.179	170.620	559.775	0.017	0.016
GW_93	372093.92	5097078.055	177.130	581.135	0.014	0.01
GW_94	376840.306	5099135.812	151.368	496.613	0.032	0.021
GW_95	392050.438	5103625.036	257.941	846.261	0.022	0.027
GW_96	377627.97	5099120.23	151.895	498.342	0.03	0.02
GW_98	388276.158	5089528.166	263.425	864.255	0.021	0.014
GW_100	389461.838	5095285.116	226.025	741.552	0.011	0.008
GW_101	389376.906	5095242.378	227.345	745.881	0.009	0.01
GW_102	390157.378	5096042.65	222.966	731.513	0.013	0.01
GW_103	385326.833	5097329.298	195.595	641.715	0.005	0.006
GW_104	385521.562	5096636.159	198.959	652.752	0.004	0.003
GW_105	380175.563	5103218.696	169.084	554.736	0.027	0.025
GW_106	370775.076	5098318.612	137.985	452.704	0.009	0.006
GW_107	379927.288	5099999.592	159.637	523.741	0.024	0.017
GW_108	384498.967	5098025.066	189.354	621.238	0.008	0.008
GW_109	377261.415	5096816.914	157.012	515.130	0.026	0.021
GW_110	384010.342	5095258.424	203.024	666.089	0.006	0.005
GW_111	386005.353	5099434.302	185.580	608.857	0.011	0.01
GW_112	388823.342	5095371.845	223.286	732.565	0.007	0.008
GW_113	388445.622	5097173.405	207.196	679.776	0.01	0.006

GW_114	392310.456	5096321.561	228.461	749.544	0.02	0.015
GW_115	392743.234	5086919.977	326.984	1072.780	0.072	0.106
GW_116	391304.129	5091322.097	272.050	892.550	0.022	0.015
GW_117	389825.547	5090864.475	268.409	880.607	0.004	0.004
GW_118	387655.395	5090858.899	250.210	820.898	0.004	0.003
GW_119	384949.15	5092104.046	217.173	712.508	0.01	0.011
GW_120	380094.16	5094289.865	172.605	566.289	0.019	0.013
GW_121	376782.848	5095406.672	153.482	503.549	0.024	0.025
GW_122	383671.11	5097361.742	183.508	602.059	0.01	0.007
GW_123	372425.274	5098426.898	136.382	447.447	0.015	0.01
GW_124	370208.59	5096168.176	154.515	506.938	0.011	0.007
GW_125	367861.923	5098647.985	130.150	427.001	0.003	0.002
GW_126	370288.485	5101958.994	141.772	465.132	0.014	0.009
GW_127	396489.017	5103462.555	294.222	965.295	0.107	0.083
GW_128	398388.076	5102166.693	315.769	1035.986	0.013	0.008
GW_129	392937.709	5097342.666	235.127	771.414	0.023	0.016
GW_130	371006.475	5095051.067	170.546	559.535	0.015	0.011
GW_131	373332.024	5100415.423	138.554	454.571	0.018	0.013
GW_132	394298.127	5100424.793	265.044	869.565	0.031	0.022
GW_133	380163.278	5102894.259	167.725	550.277	0.024	0.026
GW_134	392341.464	5100035.082	240.01	787.433	0.022	0.021
GW_135	390848.356	5088932.953	294.177	965.146	0.01	0.01
GW_136	386245.67	5100648.717	196.332	644.133	0.016	0.012
GW_137	370617.096	5096091.17	155.118	508.915	0.004	0.002
GW_138	370615.025	5096090.092	155.146	509.008	0.003	0.003
GW_139	389698.944	5094468.304	234.345	768.848	0.011	0.011
GW_140	388116.677	5092574.411	243.582	799.154	0.006	0.007
GW_141	390842.948	5088970.697	293.484	962.874	0.011	0.01
GW_142	388923.795	5091216.075	258.721	848.822	0.003	0.003
GW_143	388395.621	5091633.293	252.996	830.039	0.005	0.003
GW_144	383287.34	5092945.899	200.103	656.506	0.012	0.018
GW_145	386133.553	5100615.318	192.241	630.712	0.015	0.013
GW_146	386269.928	5100552.009	195.996	643.032	0.015	0.013
GW_147	386941.292	5101006.784	196.592	644.987	0.018	0.012
GW_148	387648.811	5097711.718	201.481	661.027	0.006	0.008
GW_149	387231.23	5098276.467	194.812	639.147	0.01	0.006
GW_150	389352.667	5089573.785	274.086	899.232	0.003	0.003
GW_151	389744.387	5094445.287	234.767	770.233	0.015	0.009
GW_152	393286.724	5089571.48	296.604	973.110	0.015	0.011
GW_153	380349.06*	5098019.59*	171*	560*	*	*
GW_154	379683.97*	5098336.33*	161*	528*	*	*
GW_155	379687.07*	5098734.81*	162*	531*	*	*
GW_156	379817.65*	5099081.84*	160*	526*	*	*
GW_157	380065.39*	5099079.13*	161*	529*	*	*

GW_158	387505.89*	5097501.06*	206*	677*	*	*
GW_159	387467.63*	5097833.68*	207*	678*	*	*
GW_160	393147.417	5089956.004	290.045	951.591	0.003	0.003
GW_161	393734.325	5090589.237	278.018	912.133	0.003	0.004
GW_162	393090.749	5090347.905	284.768	934.278	0.003	0.003
GW_163	393084.789	5090347.965	284.814	934.429	0.003	0.003
GW_164	386472.034	5092250.3	230.158	755.112	0.01	0.006
GW_165	387848.965	5091049.631	251.695	825.771	0.004	0.002
GW_166	386644.834	5090448.375	243.503	798.894	0.006	0.004
GW_167	386674*	5090444*	244*	801*	*	*
GW_168	386698*	5090444*	244*	802*	*	*
GW_169	390001.583	5088453.461	290.135	951.887	0.006	0.006
GW_170	389307.391	5092050.988	255.411	837.963	0.007	0.004
GW_171	388106.856	5094086.999	228.983	751.257	0.013	0.008

* Well locations not yet surveyed. Values shown here were obtained from Google Earth.

Appendix B

Explanation of Data Gaps during the 2017 Water Year

Well ID	Gap Dates	Explanation
GW_07	5/1/17-7/26/17	Logger got stuck in well, communication cable broke.
GW_09	8/11/16-2/4/17	Logger failure. Failed to log measurements.
GW_33	10/18/16-4/5/17	Cows tampered with logger, then a logger communication error.
GW_46	12/22/16-3/3/17	Logger failure. Failed to log measurements.
GW_82	9/14/16-10/22/17	Water dropped below level of datalogger. Dry data were deleted.
GW_92	9/16/16-3/23/17	Water dropped below level of datalogger. Dry data were deleted.
GW_93	5/24/16-10/13/17	Logger failure. Couldn’t communicate.
GW_94	9/16/16-11/10/16	Water dropped below level of datalogger. Dry data were deleted.
GW_94	3/23/17-9/30/17	Removed pressure transducer, converted to static only mmt.
GW_106	10/18/16-3/23/17	Logger failure. Couldn’t download due to data corruption.
GW_112	5/4/16-1/26/17	Logger failure. Dead battery, failure to log, inaccurate data logged.
GW_113	4/17/17-9/30/17	Logger failure. Couldn’t communicate.
GW_124	7/25/16-9/7/17	Water dropped below level of datalogger. Dry data were deleted.
GW_148	7/27/17-9/13/17	Programming mistake. Logger ran out of memory.
GW_150	10/31/16-3/13/17	Water periodically dropped below level of datalogger. Dry data were deleted.
GW_152	2/1/17-4/3/17	Data not logged due to inadequate power availability.
GW_159	2/15/17-4/24/17	Logger failure. Failed to log measurements.
GW_159	7/5/17-7/27/17	Temperature sensor failure. Data deleted due to inaccuracy.
GW_159	7/27/17-9/13/17	Programming mistake. Logger ran out of memory.
GW_169	1/11/17-4/26/17	Water dropped below level of datalogger. Dry data were deleted.