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1 March 2016

Mr. Stephen McInnis
Director of Municipal Operations
County of Annapolis
271 Granville Street
PO Box 609
Bridgetown, NS B0S 1C0

Dear Mr. McInnis:

RE: Well Field Assessment – Summary and Recommendations

CBCL Limited and Terry W. Hennigar WATER have completed a desktop review of the following information concerning the Bridgetown Well Field:

- Site history and development of well field;
- Well construction characteristics and aquifer testing results;
- Daily pumping volumes;
- Daily high and low water levels in each well;
- Uranium concentrations;
- Area geology, water well records, and Town infrastructure.

Work focussed on determining trends (if any) in uranium concentrations in the raw and blended water that supplies the Town, and to determine if elevated uranium concentrations are related to the pumping regime or drawdown in the wells. The purpose of this assessment is to provide recommendations for further work to reduce uranium concentrations in the Bridgetown water supply.

The Guidelines for Canadian Drinking Water Quality (GCDWQ) provide a recommended maximum uranium concentration of 20 μg/L, a limit that is mandated by NSE. Although the concentration of uranium in the blended water supplied to the Town has historically been below 20 μg/L, reservoir samples from the summer and fall of 2015 showed concentrations of 20 to 25 μg/L. Samples from the distribution system exceeded the guideline concentration in June and November of 2015. The most recent samples from December 2015 and January 2016 showed uranium concentrations below the acceptable guideline. Figure 1 shows the Bridgetown area, the well field, bedrock geology mapping, and selected NSE water well records for the area.

Summary of Well Field Development

Source water for the Town was originally drawn from Croskill Lake. In 2002, CBCL Limited completed a Water Supply and Treatment Options Report that evaluated the existing surface water supply, and outlined options for the upgrade of the water storage and treatment systems. In addition, the report provided a preliminary hydrogeological evaluation of potential groundwater supply sources, and presented a conceptual groundwater supply servicing option.

In 2003, the Nova Scotia Department of Environment and Labour (NSEL), now Nova Scotia Environment (NSE) introduced Treatment Standards for Municipal Water Systems, and the requirements for a System Assessment Report. A System Assessment Report was completed by CBCL in March 2004, and recommended that the treatment process be upgraded to comply with the NSEL Treatment Standard, including the requirement for filter redundancy. As an alternative to constructing a surface water treatment plant to comply with the NSEL requirements, Council decided to pursue the groundwater option as outlined conceptually in the 2002 CBCL report.

In 2005 the Town requested a supplemental investigation into the potential for using existing drilled wells at the Bridgetown Development Complex (BDC) site as a new groundwater source to supply the Town. The study was performed by CBCL Limited in association with Terry W. Hennigar, Water Consulting. The option, however, was found to be infeasible due to various constraints and source water protection concerns associated with the use of the wells in this general area. The Town therefore decided to conduct hydrogeological testing to evaluate the groundwater supply option, as outlined in the 2002 Report.

Potential locations for a groundwater supply were discussed, and field reconnaissance was conducted in 2005 to locate a site for test drilling and construction of a well field. Discussions with the Town were held to identify the constraints, advantages, and other considerations with respect to the potential sites for groundwater exploration activities, including a preliminary assessment of potential water storage locations.

The land area consisting of the “pear orchard” site located west of Hampton Road was assessed and abandoned due to concerns over historical pesticide use and storage related to the farming operation. The investigation then focused on Municipality of Annapolis lands located to the east of Hampton Road, and north of the Town Limits. The necessary permits and agreements were then obtained to access the property, perform test drilling, and assess the aquifer potential in that area.

A work plan and specifications for the groundwater exploration activities were developed by CBCL Ltd. and Terry W. Hennigar Water Consulting. The groundwater exploration program involved the construction and testing of three wells (TOB-1, TOB-2, and TOB-3) located immediately north of the Adult Residential Centre (ARC) and east of Hampton Mountain Road, on lands owned by the Municipality of Annapolis County. The test wells intercepted various sedimentary materials of the Wolfville Formation, which consists of interbedded sequences of sandstone, conglomerate, siltstone, and shale. Each well was pumped for 24 hours to determine the yield and aquifer properties, and water samples were collected to provide a preliminary indication of water quality. This information was used to evaluate the feasibility of using the groundwater source to supply the Town of Bridgetown.

Pumping tests indicated that uranium concentrations were in the range of 14 ug/L to 15 ug/L, as measured at each of the open borehole test wells. Longer term aquifer testing was recommended to assess the effects of continuous pumping on uranium concentrations. A 30-day pumping test was conducted at TOB-3, during which the uranium concentration ranged from 11 to 15 ug/L. On this basis, it was agreed to proceed to the Well Construction and Development Phase.

Well field development involved commissioning of two production wells (Well 2 and Well 3) in March and April 2007. Discussions were held with Town Council regarding the diameter of the wells, arriving at consensus for the use of 254 mm wells to accommodate the required pumps and water level monitoring equipment. Casing and screens were necessary to prevent collapse of the borehole walls. Four screen intervals were selected on the basis of air lift yield testing and downhole camera inspections to identify major fracture zones and water production zones as identified during drilling.

- Test well TOB-2 was commissioned first, and designated as production well “PW1”. This well was later renamed “Well 2”.
- Test well TOB-3 was commissioned second and designated as production well “PW2”. This well was later renamed “Well 3”.
- Test well TOB-1 was later commissioned as production well “PW3”.This well was renamed “Well 1”.

Aquaterra Resource Services Ltd. conducted 72 hour aquifer tests on the two production wells in June 2007, and the results indicated higher concentrations of uranium in both wells, when compared to the previous results from the open borehole test wells. Uranium concentrations at Well 2 exceeded the Maximum Acceptable Concentration of 20 ug/L.

A Technical Steering Committee was established to provide guidance to the project and address the issue of elevated uranium concentrations. The Committee included the following members:

- A Hydrogeologist and the Water Quality Supervisor from NSE;
- A Hydrogeologist from NS Department of Natural Resources;
- The CAO and the Mayor of the Town of Bridgetown;
- The Project Hydrogeologist (Terry W. Hennigar, P.Eng., WATER); and
- The Project Manager (Willard D’Eon, P. Eng., CBCL Ltd.).

A Groundwater Supply Pre-Design Phase was initiated in June 2007, prior to the completion of the Groundwater Supply Development Phase, in an attempt to meet the Regulatory requirements of NSE. The purpose of the Pre-Design Investigation was to define the project and provide updated capital costs, and allow for the regulator to review the project prior to the initiation of detailed design.

The Pre-Design Phase included a topographic survey of the well site, of the proposed water main location, and of the proposed water storage site. Water demand was found to be consistently increasing, but Town personnel were unable to find the cause. As a last resort, the water meter manufacturer’s representative was requested to verify the accuracy of the unit. The accuracy was verified, but Town personnel subsequently located a leak on a commercial service line. Repair of the leak in August 2007 resulted in a substantial decrease in water demand from 1000 m^3/d to approximately 600 m^3/d.

Elevated uranium concentrations led to investigation of uranium removal technologies and costs. Most options were, however, proprietary, and some were in “experimental stages”. The Report was discussed with Town personnel and it was concluded that efforts be made to find a groundwater source that did not require uranium removal. Concerns included available funding from the senior levels of government for capital costs, increased operational costs, increased operator certification requirements, and resulting increases in water rates.

Pre-Design work was placed on "hold" while options to resolve the uranium issue were investigated. Discussions indicated that efforts would be put to better use in finding a source that would not require uranium treatment.

Subsequent work focused on determining the source/cause of elevated uranium concentrations. Local and outside companies were sourced, and with assistance from Steering Committee members, it was determined that an Ontario Well Drilling Company had a 254 mm (10 inch) packer, and that Environment Canada had a 150 mm (6 inch) packer. Environment Canada personnel indicated that they would be in the Maritimes in the spring or summer of 2008 and could complete a double packer test on the remaining open borehole (TOB-3). Preparatory work conducted in the fall of 2007 included video inspection of the wells. CBCL limited conducted depth specific sampling of Well 2, Well 3, and TOB-1 in December 2007. The highest uranium concentration (14 ug/L) was detected adjacent to the lowest fracture zone / deepest screen of Well 3.

Steering Committee meetings continued over the winter of 2008, and options were explored. One option selected, based on the depth specific sampling of the production wells, was to seal the bottom screen of Well 3, followed by a 72 hour aquifer test. It was also confirmed that Environment Canada was planning to conduct their investigation in late May or early June of 2008, and preparation for such was initiated.

In May 2008, the bottom screen in Well 3 was sealed and an aquifer test was conducted. The test confirmed that the sealing of the lowest well screen was successful in reducing uranium concentrations. In June 2008, Environment Canada conducted depth specific sampling in test well TOB-1. Depth-specific sampling results at Well 2 and TOB-1 showed a relatively uniform distribution of uranium concentrations drawn from each depth/zone, indicating that sealing or casing of specific zones in these wells was unlikely to improve raw water quality.

In October 2008, the findings of the water quality and quantity were presented to the Town. The Town requested that we attempt to replicate the results from TOB-1 when commissioning Well 1. Options were investigated and it was recommended that Well 1 be constructed as fully screened well. Well 1 was constructed in December 2008 with 24.4 metres of casing and 97.6 metres of 203 mm diameter, #40 slot, stainless steel, wire-wrapped well screen. Water quality testing indicated that the uranium results from TOB-1 were replicated (uranium concentrations were in the 10 to 15 μg/L range).

The Steering Committee agreed that the project would proceed with the blending of water from the three production wells. Table 1 shows pumping rates that were proposed in April 2009, together with the associated concentration of uranium in raw water from each well. The pumping rates shown were intended to optimize the quantity of water available from each well while seeking to achieve an acceptable concentration of uranium in the blended water.

Table 1. Proposed pumping rates and associated uranium concentrations observed at each production well.

Well No.	Proposed Pumping Rate (igpm)	Proposed Pumping Rate (m^3/min)	Maximum Recorded Uranium Concentration, April 2009 (µg/L)
Well 1	100	0.45	12 µg/L
Well 2	25	0.11	24 µg/L
Well 3	100	0.45	16 µg/L

Subsequent monitoring work and operation of the well field were completed by the Town.

Pumping Data and Uranium Concentrations

Figures 2.1 through 2.8 provide a summary of pumping volumes and uranium concentrations from 2010 to 2015. Total water use, measured as discharge from the reservoir is shown on Figure 2.1. Average pumping volumes varied from 500 m^3/d to 700 m^3/d from 2010 to 2013, and from 450 m^3/d to 650 m^3/d from 2013 to 2016. Uranium concentrations in the blended water were relatively uniform, reaching up to 20.9 µg/L in June 2011, but remaining generally below 20 µg/L. Water use patterns showed generally higher demand in the summer months of each year. Elevated uranium concentrations observed in the latter part of 2015 followed a period of higher water use, but this effect was not observed previously. Seasonal increases in demand were not consistently linked with higher uranium concentrations.

Pumping volumes at Wells 1 and 3 varied between 2010 and 2013, but were generally limited to 700 m^3/d on peak days. The pumping regime was stabilized in January 2013. The daily pumping volume at each well was on the order of 380 m^3/d until March 2014, when extraction rates increased to 420 m^3/d. Pumping volumes at Well 1 were reduced to 380 m^3/d in January 2016. Use of Wells 1 and 3 was often alternated, either from day to day or on cycles of up to four days.

Concentrations of uranium at Well 1 were below the guideline limit and showed no increases associated with pumping rates. The concentration of uranium in the raw water from Well 1 was at a relative maximum of 19 µg/L in August and December of 2015. Concentrations of uranium in water drawn from Well 3 were also generally below the guideline concentrations, but exceeded the guideline limit in June, July and October of 2011, and November-December 2015. Exceedances in 2011 were associated with higher than average daily pumping volumes, but elevated uranium concentrations observed at the end of 2015 appear unrelated to daily pumping volumes.

Pumping volumes at Well 2 were relatively consistent and generally did not exceed 88 m^3/day. Concentrations were consistently in the 22 to 26 µg/L range, and reached up to 32 µg/L in November 2015. Well 2 is pumped at a lower rate to minimize the effects of elevated uranium concentrations on the blended water supply, but is pumped on a more continuous basis than Wells 1 and 3. Long-term extraction rates and do not appear to be the cause of elevated uranium concentrations, but patterns of cycling within the well field may be significant.

Plots showing detail of the pumping records and uranium concentrations are provided on Figures 2.5, 2.6, 2.7 and 2.8. The detailed data show cycling of the pumps; Well 1 and Well 3 were often used on opposite cycles, allowing for a period of recovery in each well. Average pumping times varied from one to four days of continuous pumping from each well. Wells that were not in use when uranium samples were collected were turned on to allow for sampling. Flushing times and elevated turbidity have the potential to affect uranium concentrations when the wells are cycled on and off, effects which could have influenced uranium sampling data. The sample from November 19th was collected on a day when all of the wells were initially off.

The cycling of Wells 1 and 3 further indicates the potential for blended uranium concentrations to be highest at the end of a pumping cycle for Well 3. The sample collected on October 5 followed two days of pumping from Well 3, with Well 1 unused for the two days prior to sampling.

Drawdown and Uranium Concentrations

Daily high and low water levels were compared to daily pumping volumes in the reservoir and each of the production wells, shown on Figures 3.1 to 3.4. Sensor malfunctions and maintenance resulted in missing flow data for Well 2 in 2013, and missing water level data for Well 1 from October 2014 to January 2016 (the level sensor in Well 1 was restored in February 2016). The daily high water levels in each well represent non-pumping (static) conditions in the aquifer. The static head at each well was on the order of 72 to 73 feet geodetic. The daily minimum water levels show the elevation at which head stabilized in each well when the pumps were operating. Drawdown in each well was as follows:

- Well 1 – 12 to 15 feet until January 2014.
- Well 2 – 4 to 6 feet until January 2014; 9 to 10 feet after January 2014.
- Well 3 – 20 to 22 feet until January 2014; 26 feet after January 2014.

Differences in the stabilized pumping level throughout the monitoring period are attributed to cumulative drawdown caused by overlapping periods of pumping at each well. The daily pumping volumes at Well 1 and Well 3 were stepped up in January 2014, with associated increases in drawdown in the aquifer on the order of 5 feet. The 2-year delay between the increase in drawdown and the elevated uranium concentrations observed at the end of 2015 indicates that elevated uranium concentrations were not related to the 5-foot increase in drawdown.

Raw Water and Blended Uranium Concentrations

Figure 4.1 shows a summary of uranium concentrations over time. Concentrations of uranium in the reservoir approached or exceeded the guideline when concentrations in Well 2 were above 24 μg/L. The highest reservoir concentration was observed when both Well 2 and Well 3 exhibited uranium concentrations above 24 μg/L.

Figure 4.2 shows a direct comparison for each sampling event, between the uranium concentrations in each production well and the blended supply. Concentrations of uranium in the blended supply are affected most directly by the raw water supplied by Well 2.

Despite limited pumping volumes, elevated concentrations of uranium in Well 2 continue to have a significant effect on water supplied to the Town.

Summary and Recommendations
The desk-top review indicated the following:

- Total water withdrawals were within permitted 3-day average and maximum withdrawal rates from August 2013 to January 2016.
- Individual pumping rates at Wells 1 and 3 exceeded the permitted 3-day maximum rates by approximately 65 m^3/day from August 2013 to January 2016.
    - Operation of Wells 1 and 3 appears to be intermittent.
    - Reduced rates of pumping with simultaneous use of Wells 1 and 3 would be needed to meet demand and satisfy the existing Water Withdrawal Permit.
- There were no clear long term water level declines in the production wells, however, slight increases in drawdown resulted from stepped up pumping rates in January 2014.
- There was no long term trend or gradual increase in uranium concentrations in the raw water of each well.
- There was no clear relationship between declining head in the aquifer and elevated uranium concentrations.
- Concentrations of uranium in the blended water supply are affected significantly by water drawn from Well 2.
- Peaks in uranium concentrations appear to be sporadic, temporary events.

The following actions will provide short-term measures to help reduce uranium concentrations in the Bridgetown water supply.

➢ **Suspend pumping at Well 2.**

As Well 2 has a strong influence on uranium concentrations and provides a relatively low proportion of required demands, we recommend that this well be taken out of production.

➢ **Increase pumping rate at Well 1.**

Preliminary calculations indicate that Well 1 can sustain pumping rates of up to 700 m^3/day, with a total drawdown on the order of 70 feet. Although previous aquifer test pumping rates were in this range, a permit amendment would be required for this change. We recommend that increased withdrawal needs be communicated to NSE as soon as possible.

➢ **Determine continuous, simultaneous pumping rates for Well 1 and Well 3 that will optimize system performance.**

Lowered but continuous pumping would reduce water level fluctuations, which has the potential to introduce less disturbance to the water column and could improve longer term water quality. This recommendation is subject to the need for increased pumping rates at Well 1. It should also be possible to use existing SCADA infrastructure to allow the system to automatically lower continuous pumping rate when demand is reduced. Periodic reductions in the continuous pumping rate will allow the aquifer to recover during periods of lower demand. A redundancy measure may include purchase of a back-up pump to be stored until needed.

- **Monitor drawdown and uranium concentrations in Well 1 closely.**

Water level data in the SCADA system should be reviewed several times per day after the pumping rate is increased. The resulting drawdown curve should be analyzed to ensure that water levels are stabilizing in the well. With the additional drawdown that increased pumping will produce, the upper screen could be dewatered, which may affect water quality. Increased frequency of uranium sampling is recommended.

The following additional work is recommended to improve and maintain water quality and quantity over longer time frames:

- **Drill two test holes to locate alternative well locations.**

The two most cost effective options would be:

1. To site a test well 100 to 200 metres north of Well 3, which would intersect younger strata with potentially different geochemical conditions; or
2. A successful well located approximately 100 metres to the southwest of Well 1 could also provide redundancy for Well 1, with similar quality of raw water. Any work to install new test wells would need to include a plan for continuous assessment of uranium concentrations with depth.

- **Develop a contingency plan for occurrences of elevated uranium concentrations.**

A plan for retesting and resampling should be developed, including blank and duplicate sampling. A 24 hour ("rush") turn-around time on uranium samples would be needed in order for the Town to respond to elevated uranium concentrations. The contingency plan would also include potential modifications to pumping rates and communication to residents of Bridgetown.

Please don't hesitate to contact us with questions or concerns.

Yours very truly,

Willard D'Eon

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Cc Terry Hennigar, M.Sc., P.Eng., **WATER Consulting**

Attachments Figures: 1, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2.

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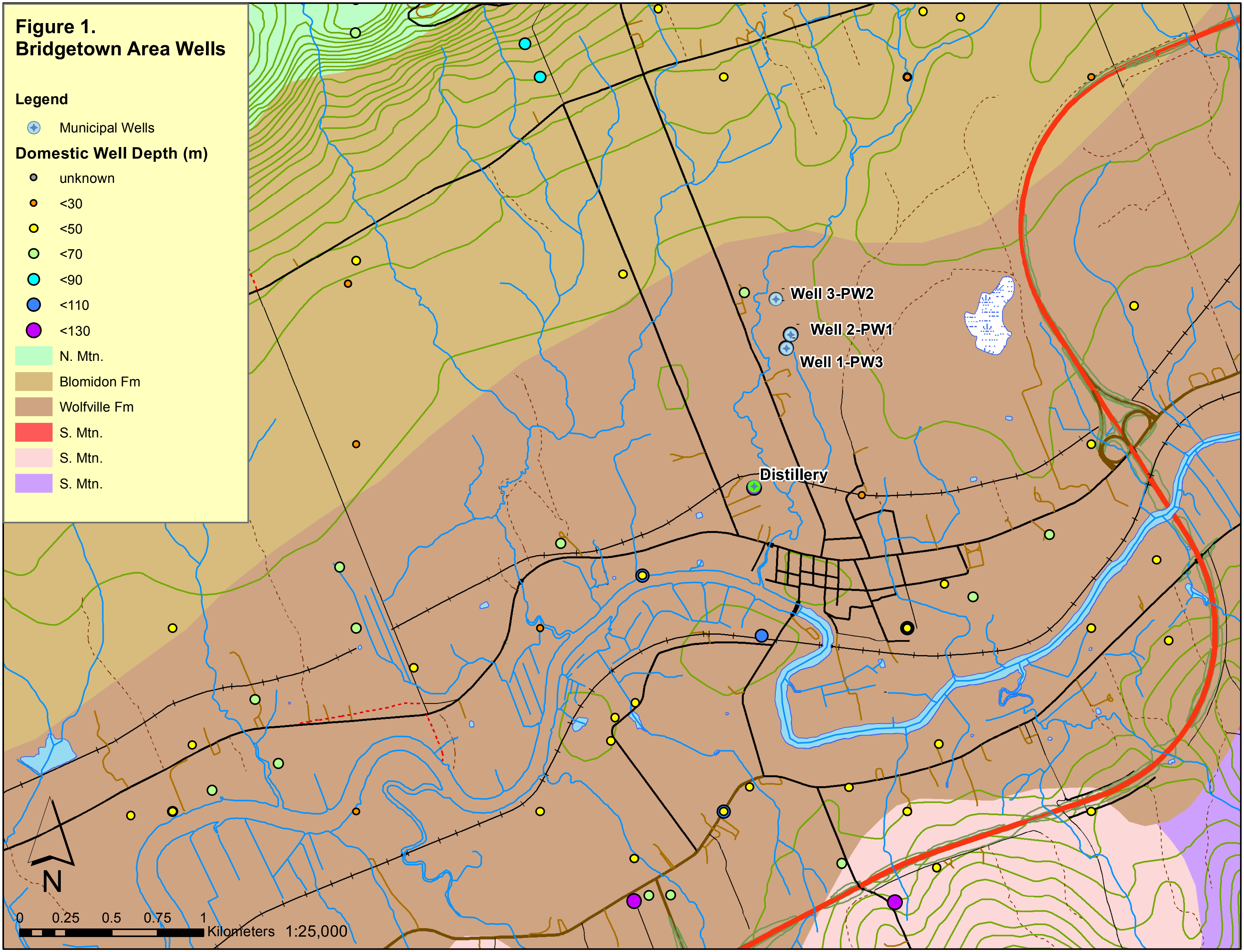


Figure 1.
Bridgetown Area Wells
Legend
Municipal Wells
Domestic Well Depth (m)
unknown
<30
<50
<70
<90
<110
<130
N. Mtn.
Blomidon Fm
Wolfville Fm
S. Mtn.
S. Mtn.
S. Mtn.
Well 3-PW2
Well 2-PW1
Well 1-PW3
Distillery
N
0 0.25 0.5 0.75 1
Kilometers 1:25,000

Figure 2.1: Daily Volume Discharged from Reservoir and Uranium Concentrations in Discharged Water

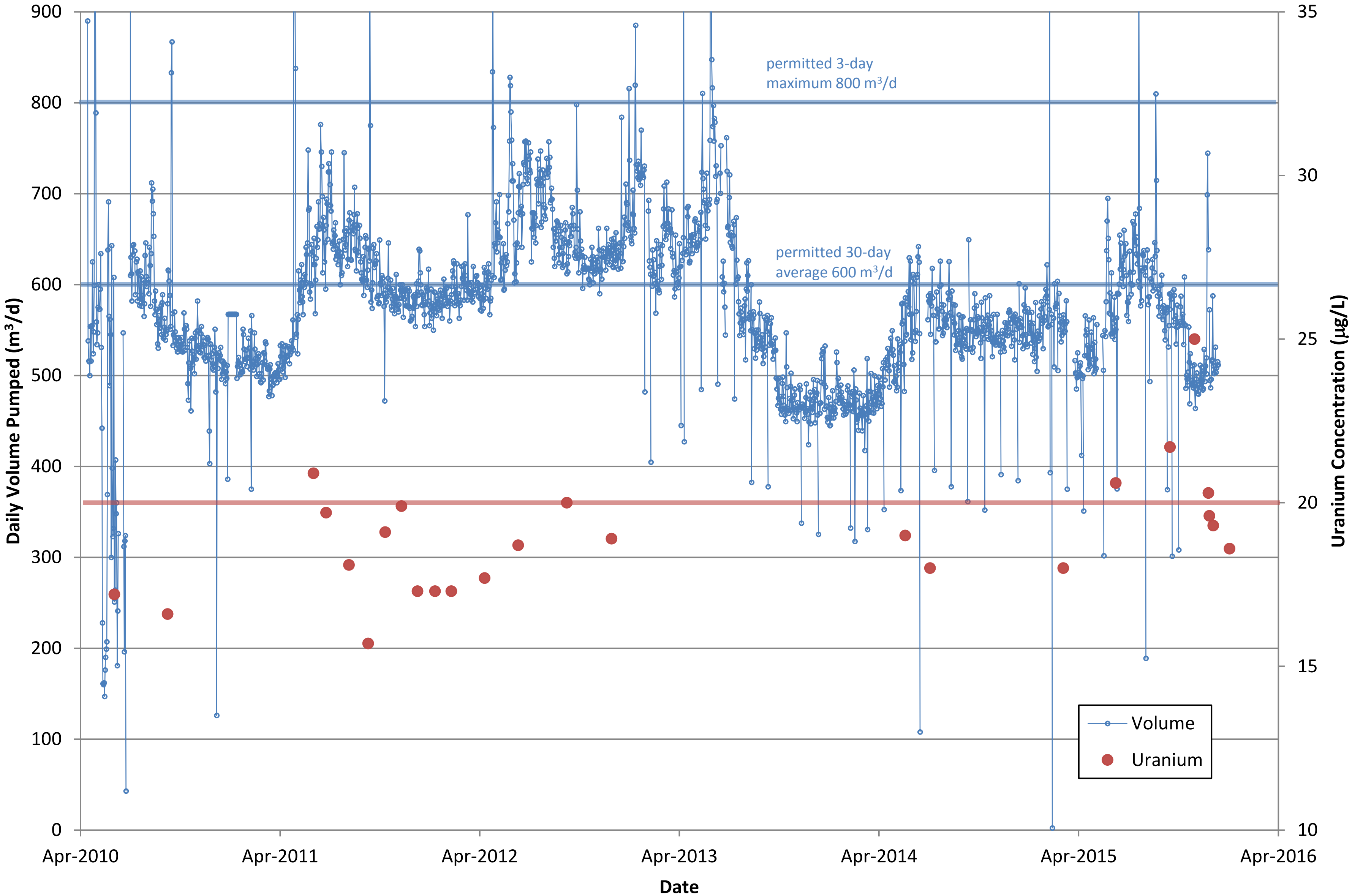


Figure 2.2: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 1 (PW3)

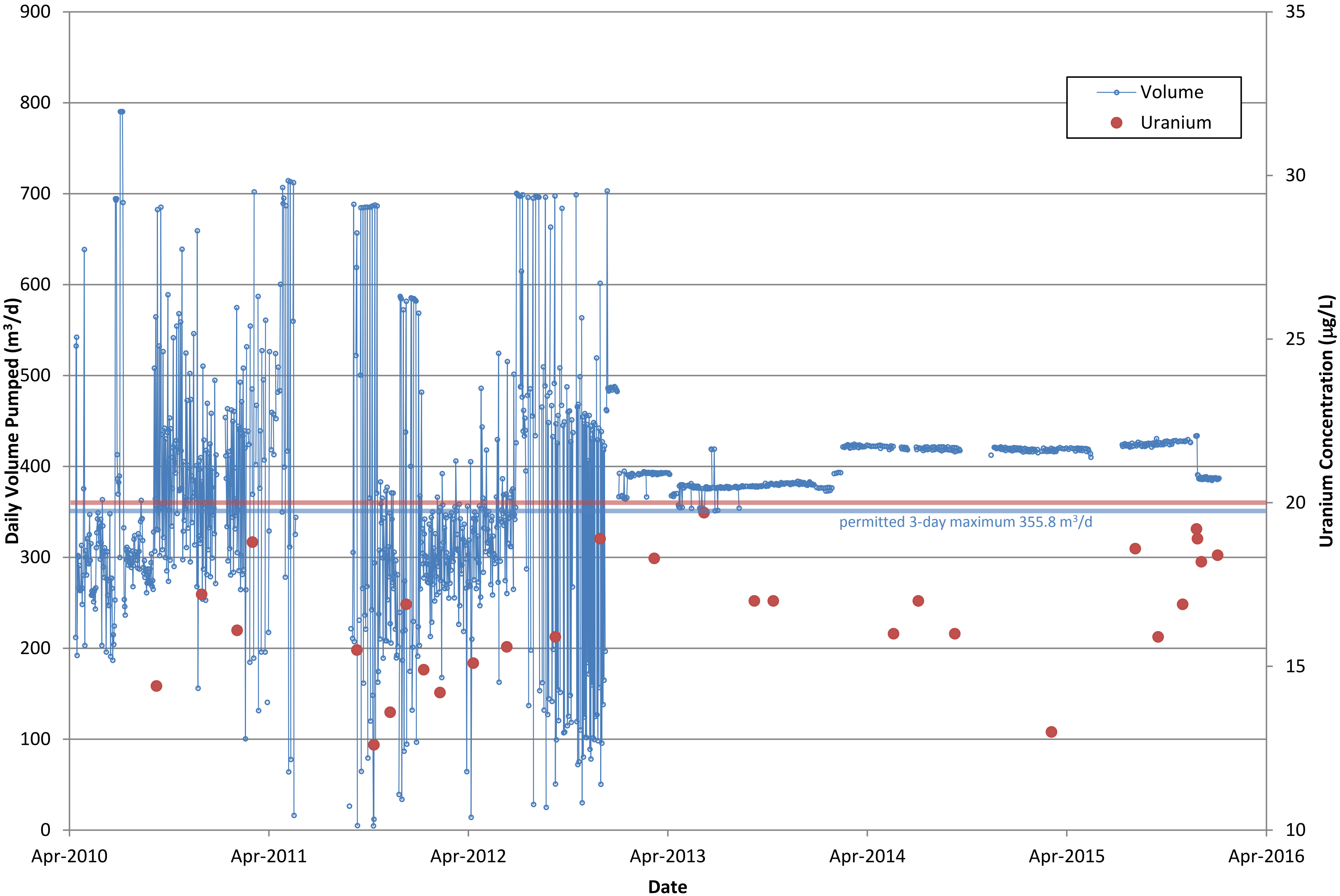


Figure 2.3: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 2 (PW1)

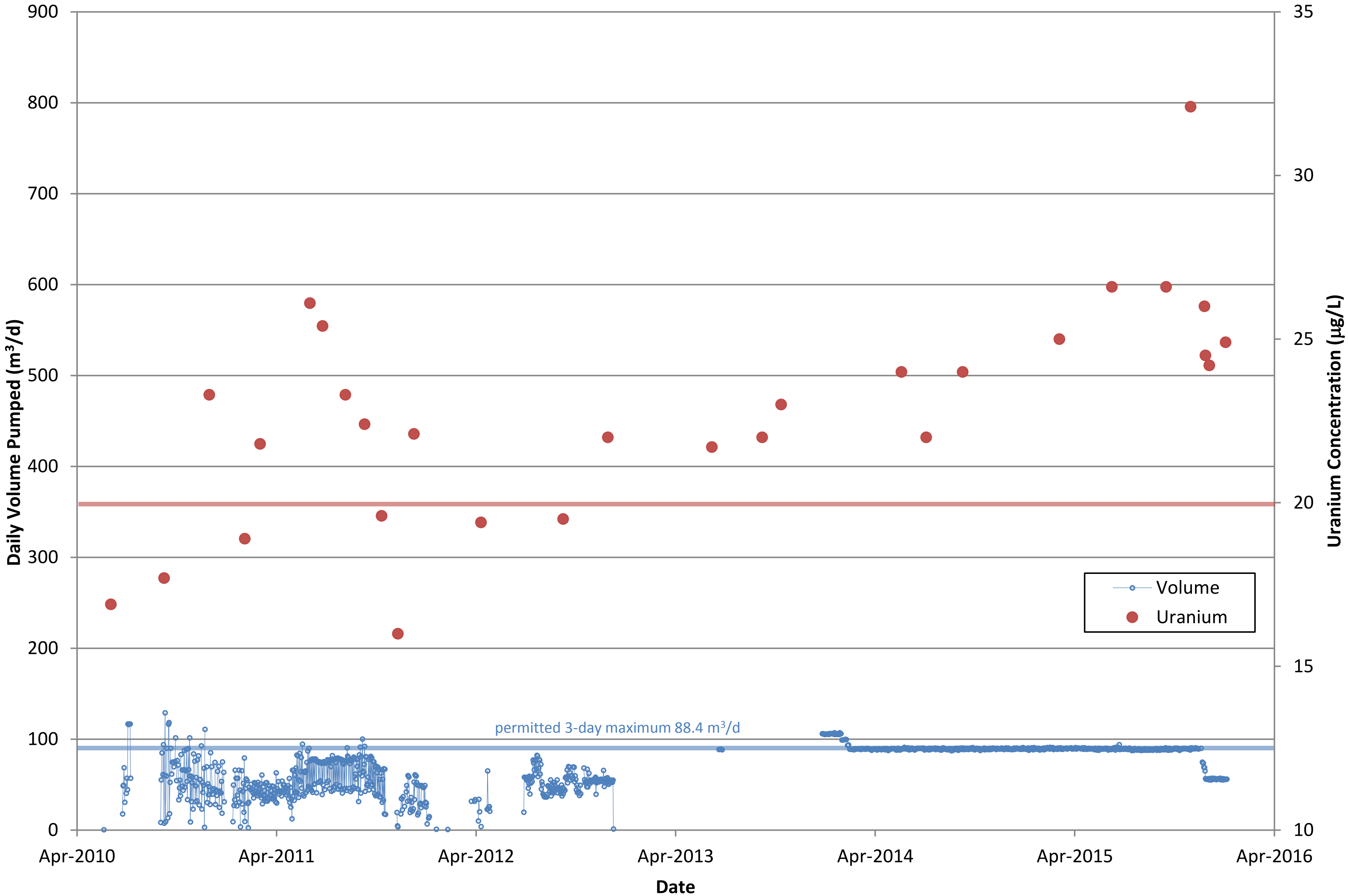


Figure 2.4: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 3 (PW2)

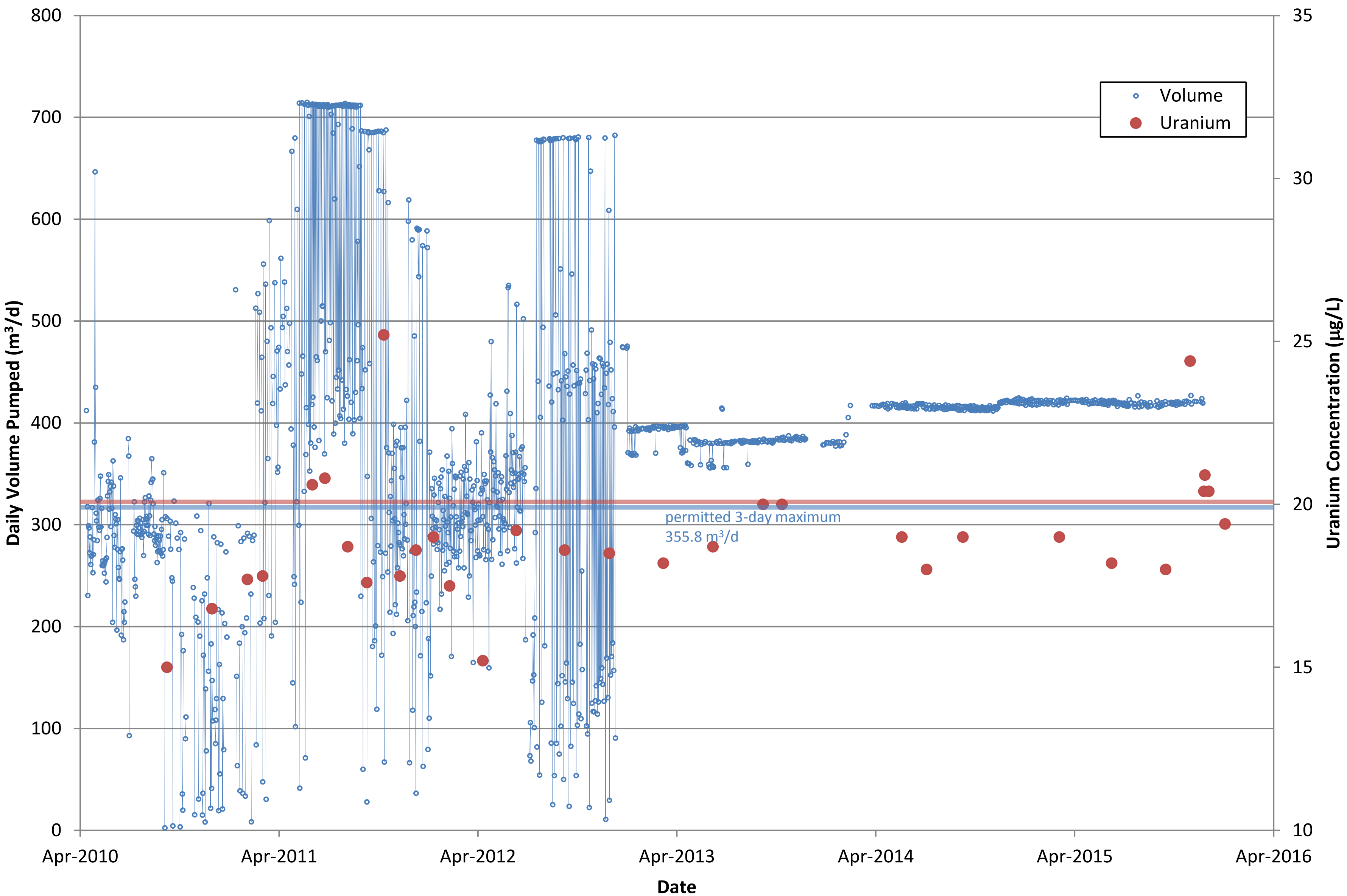
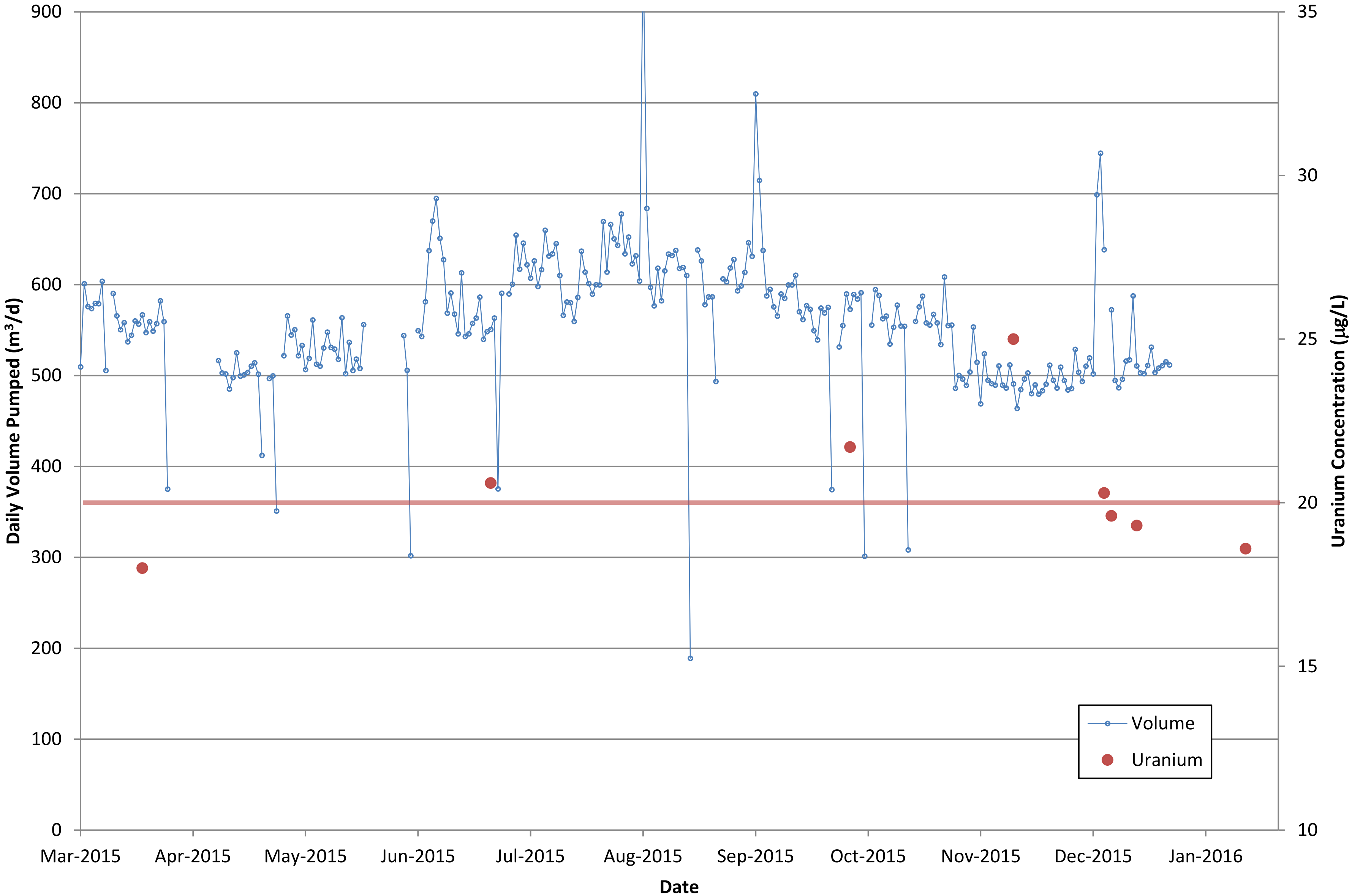


Figure 2.5: Daily Volume Discharged from Reservoir and Uranium Concentrations in Discharged Water; detail for March - December 2015



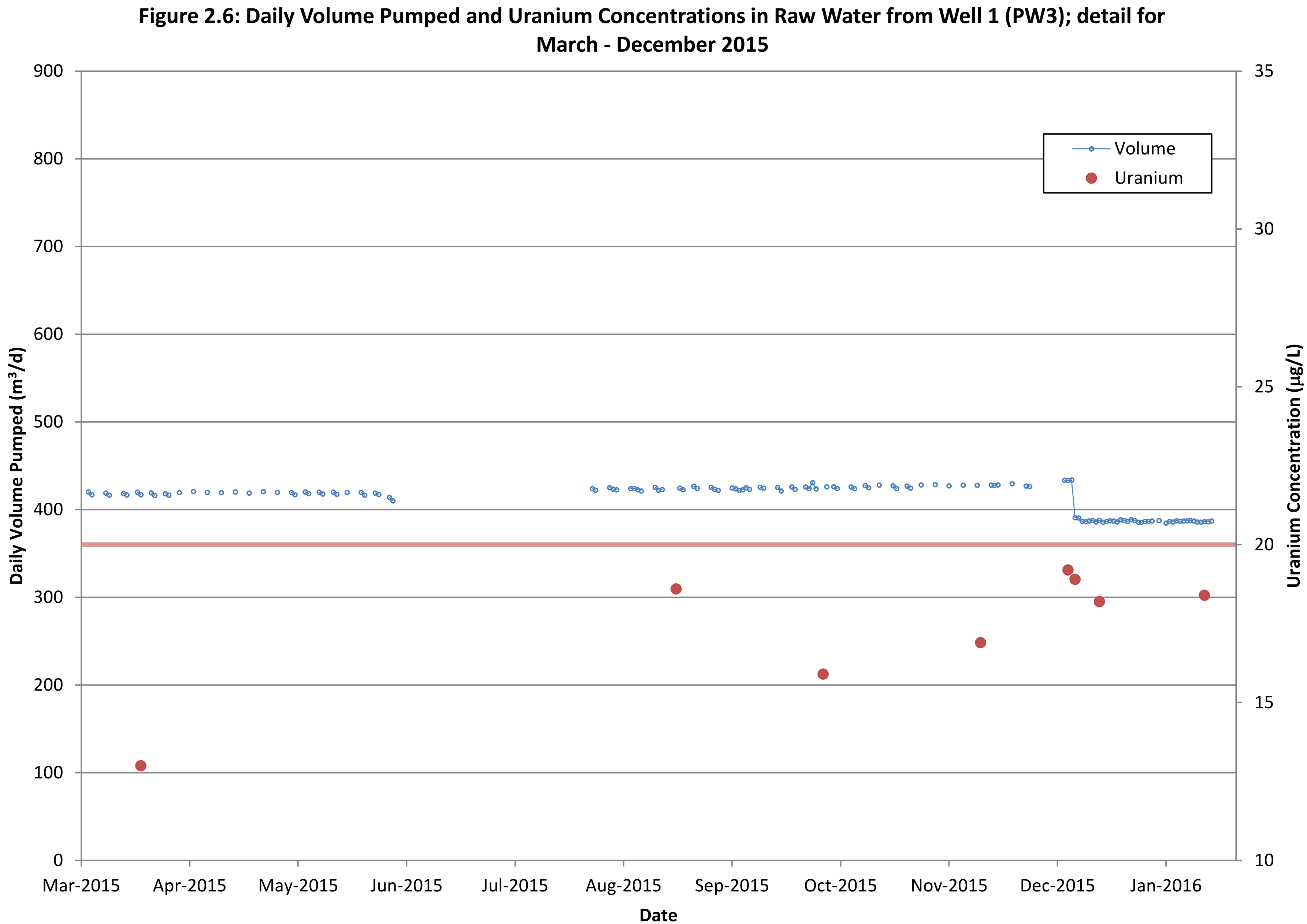


Figure 2.6: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 1 (PW3); detail for March - December 2015
Volume
Uranium
Daily Volume Pumped (m³/d)
Uranium Concentration (µg/L)
Date
0
100
200
300
400
500
600
700
800
900
10
15
20
25
30
35
Mar-2015
Apr-2015
May-2015
Jun-2015
Jul-2015
Aug-2015
Sep-2015
Oct-2015
Nov-2015
Dec-2015
Jan-2016

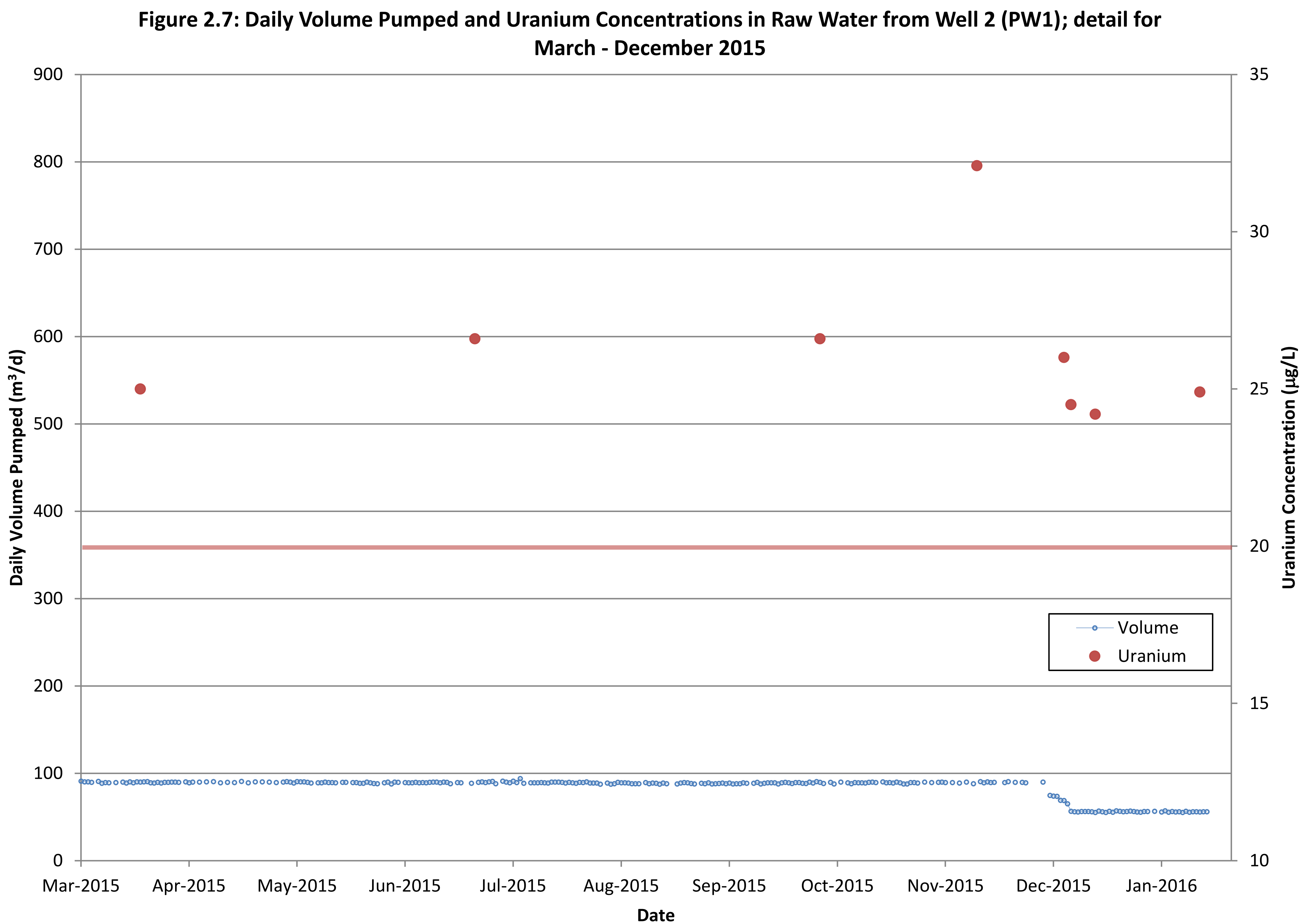


Figure 2.7: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 2 (PW1); detail for March - December 2015
Daily Volume Pumped (m3/d)
Uranium Concentration (µg/L)
Date
Volume
Uranium
900
800
700
600
500
400
300
200
100
0
35
30
25
20
15
10
Mar-2015
Apr-2015
May-2015
Jun-2015
Jul-2015
Aug-2015
Sep-2015
Oct-2015
Nov-2015
Dec-2015
Jan-2016

Figure 2.8: Daily Volume Pumped and Uranium Concentrations in Raw Water from Well 3 (PW2); detail for March - December 2015

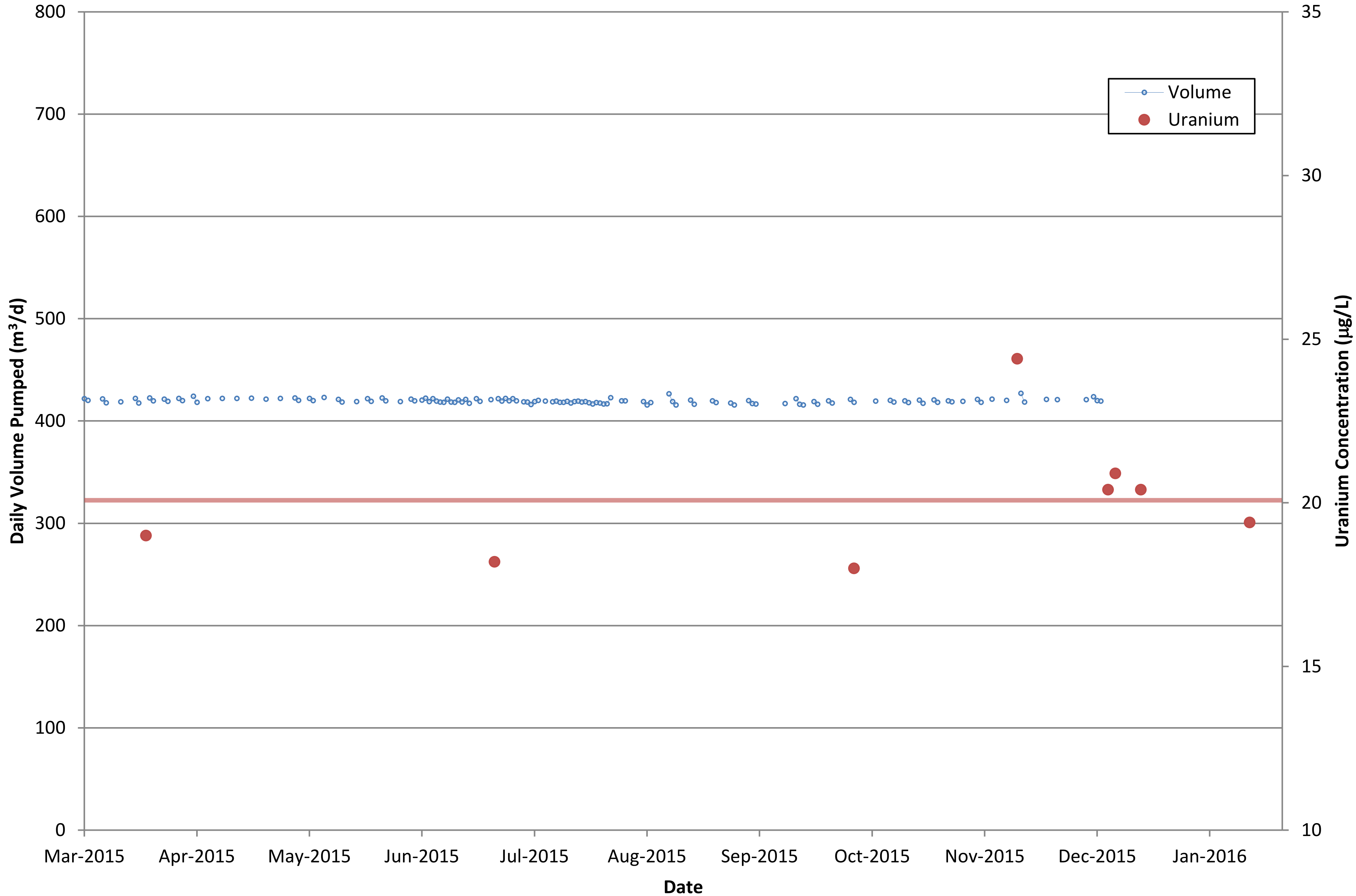
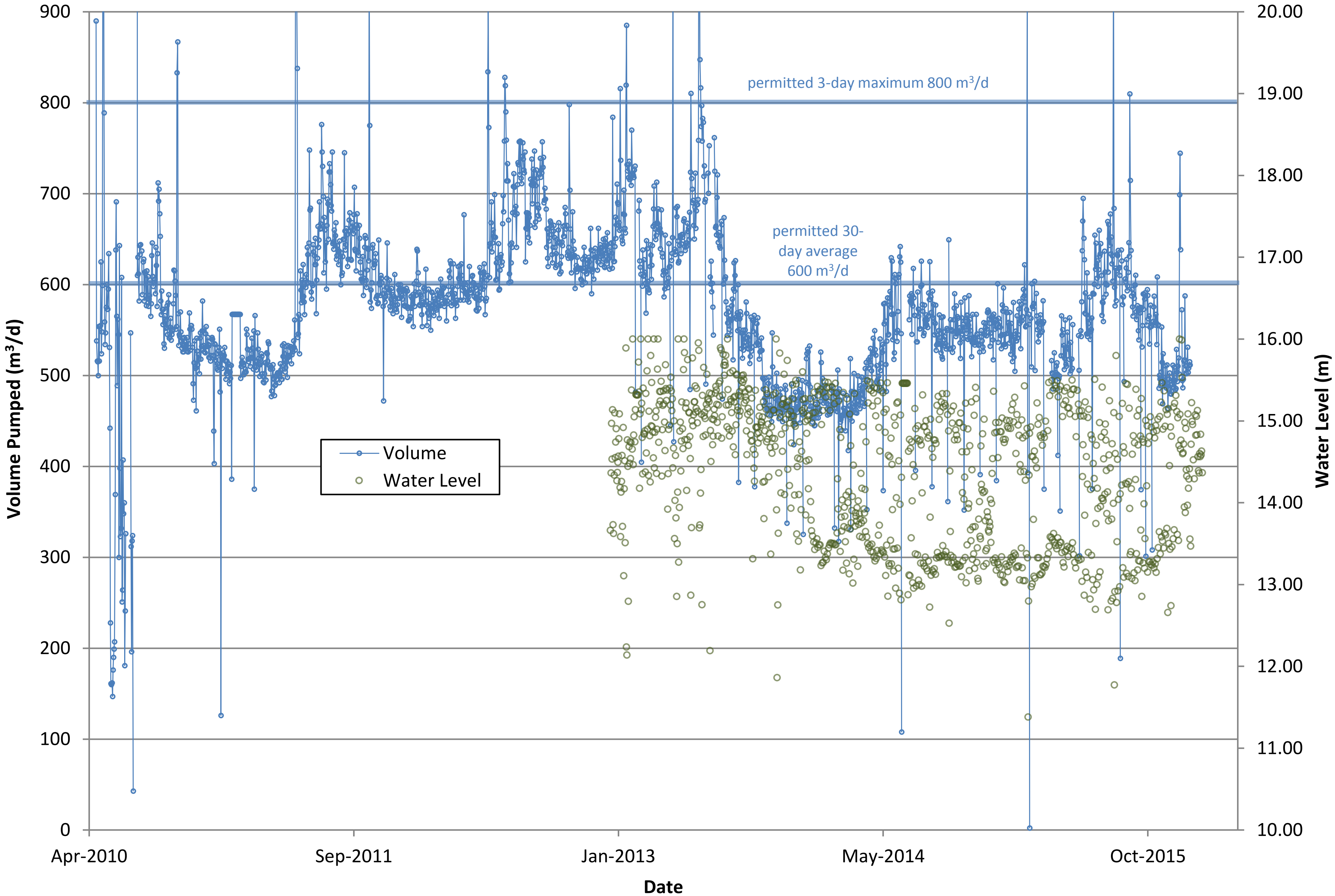


Figure 3.1: Daily Volume Pumped and Daily Maximum and Minimum Water Levels in Reservoir



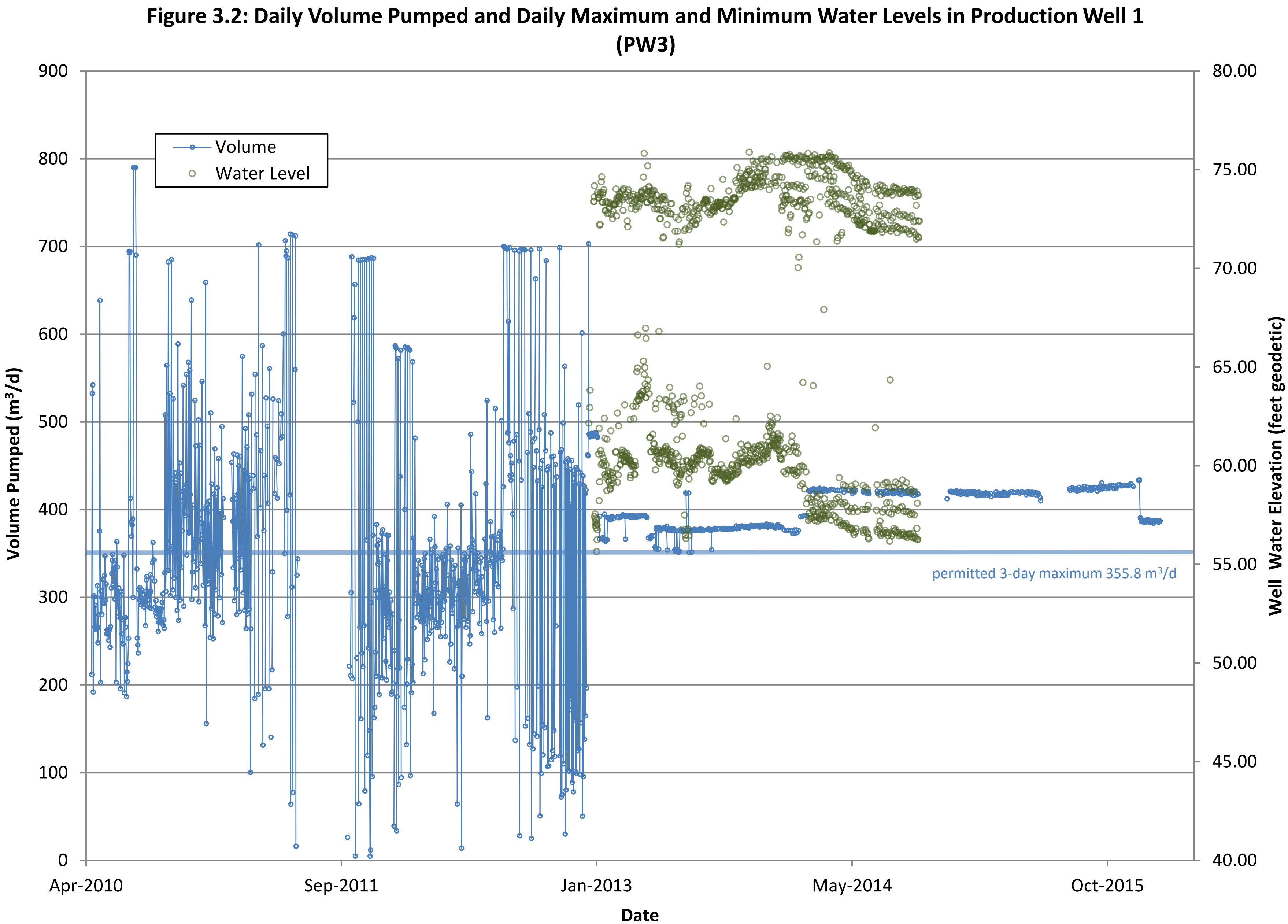


Figure 3.2: Daily Volume Pumped and Daily Maximum and Minimum Water Levels in Production Well 1 (PW3)
Volume
Water Level
permitted 3-day maximum 355.8 m³/d
Volume Pumped (m³/d)
Well Water Elevation (feet geodetic)
Date
900
800
700
600
500
400
300
200
100
0
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
Apr-2010
Sep-2011
Jan-2013
May-2014
Oct-2015

Figure 3.3: Daily Volume Pumped and Daily Maximum and Minimum Water Levels in Production Well 2 (PW1)

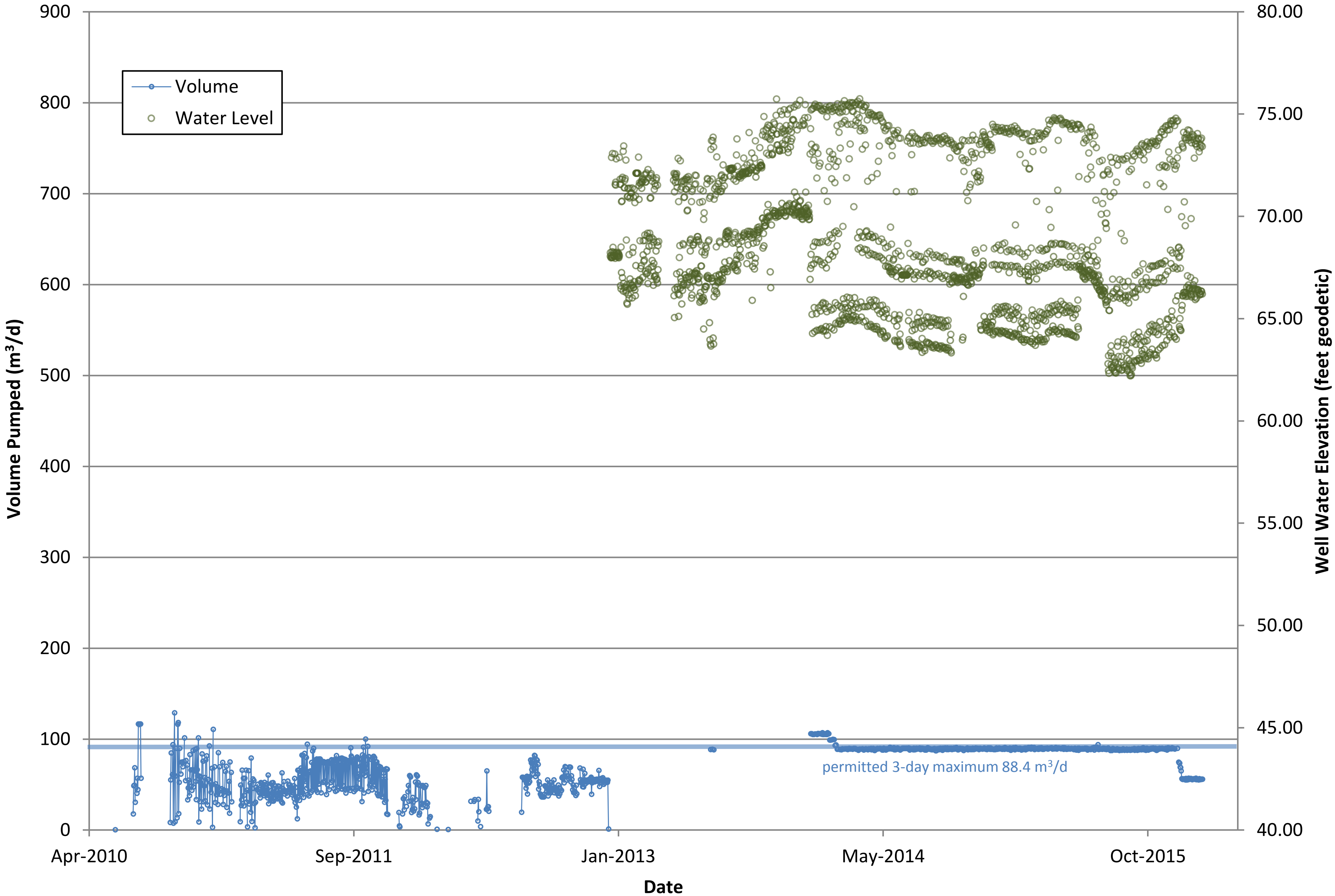


Figure 3.4: Daily Volume Pumped and Maximum and Minimum Water Levels in Production Well 3 (PW2)

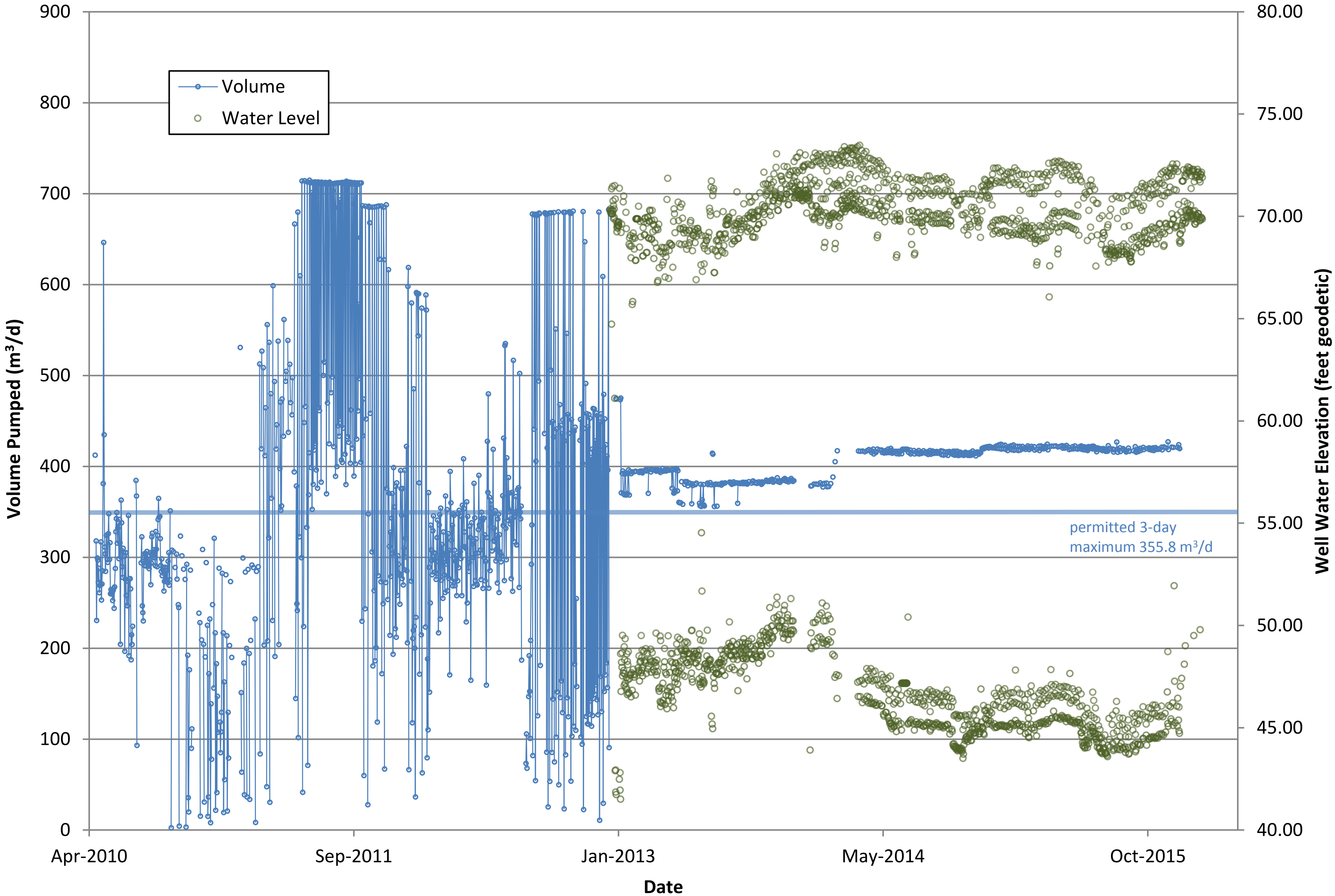


Figure 4.1: Uranium Concentrations in Raw and Water from Production Wells and Blended Water in Reservoir/Distribution System

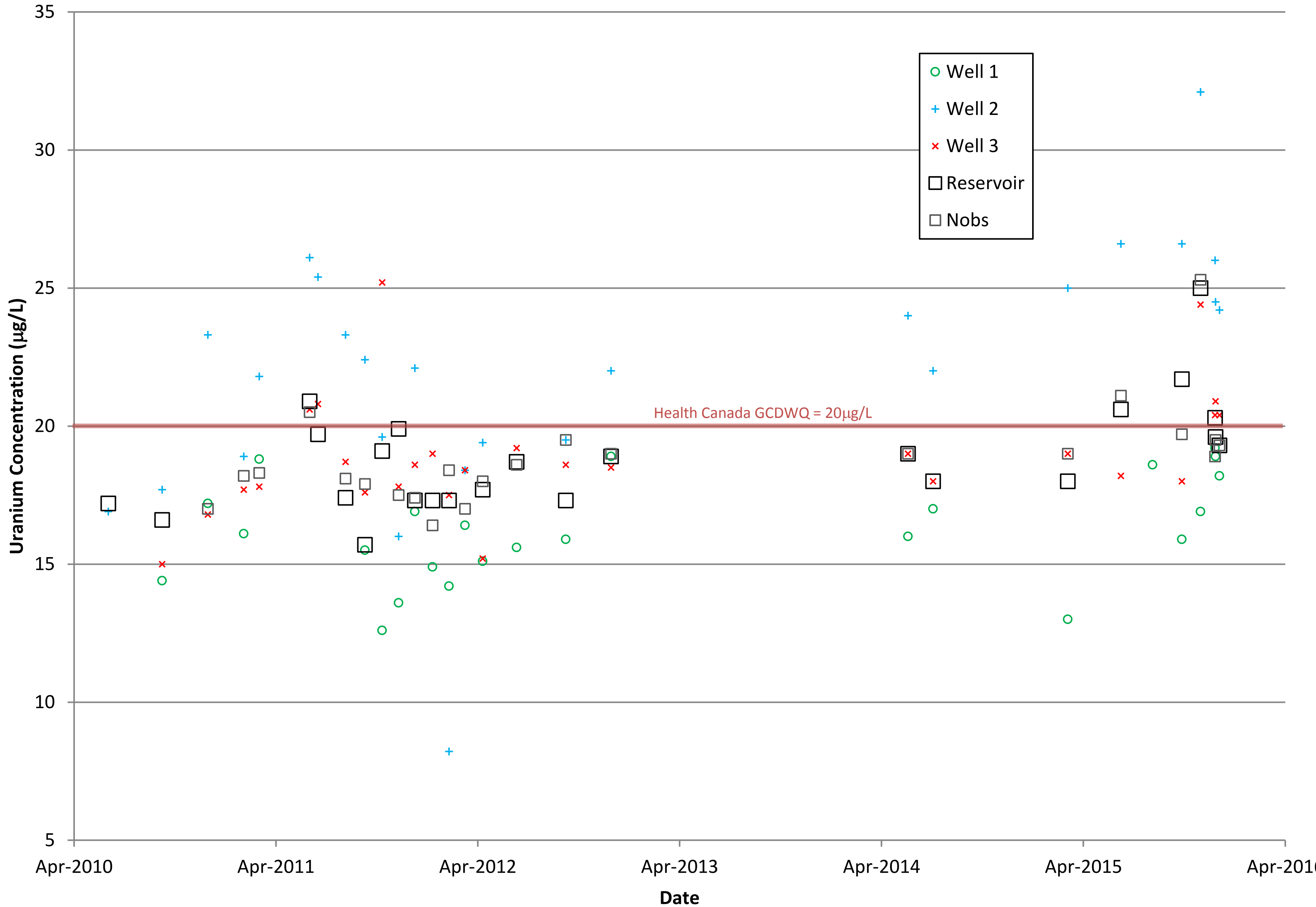


Figure 4.2: Uranium Concentration in Reservoir v.s. Raw Water Concentration in Production Wells