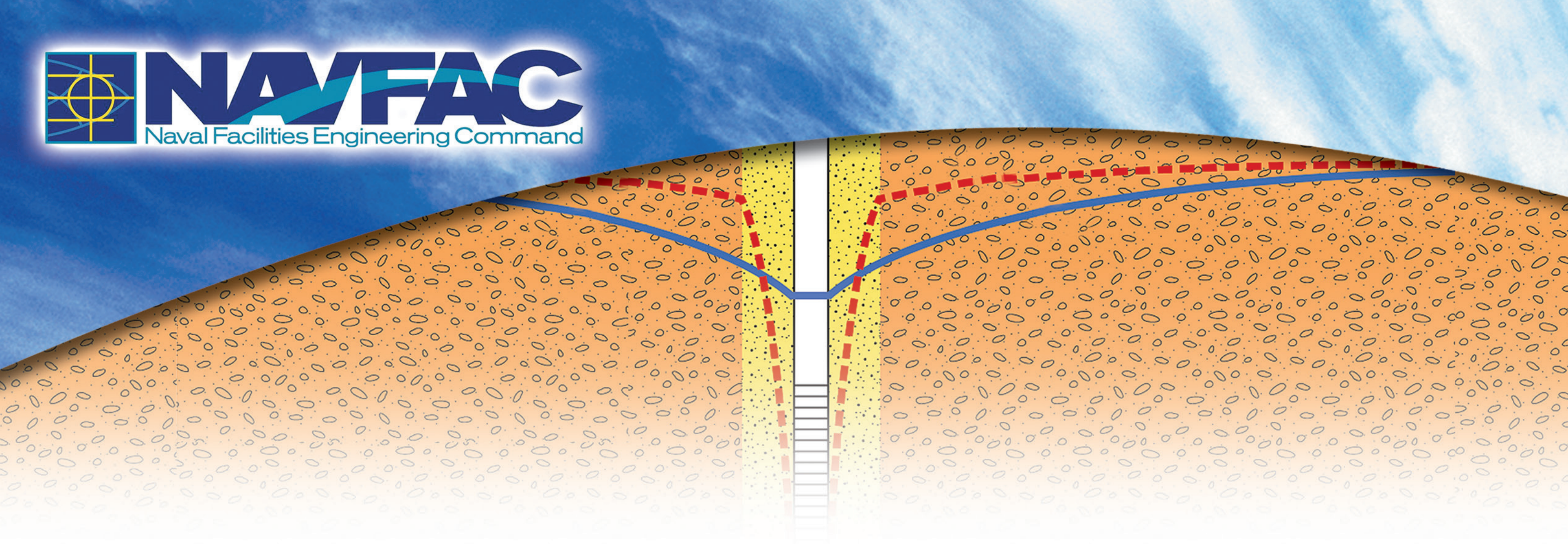

Production Well Construction and Maintenance

Groundwater extraction and reagent injection wells (broadly, production wells) are deployed at many of the Navy's groundwater remediation sites. These wells require significant investments and they can function very effectively for many years if they are constructed and maintained effectively. Inadequate design and maintenance can generate a significant cost burden for projects through high operating costs and premature replacements.

Production well design and construction requirements are very different from monitoring wells. Many of us have become accustomed to monitoring well construction and development, where our main objective is to develop silt-free water. Production wells, whether they are intended for extraction or injection, are constructed and developed very differently from monitoring wells, with the primary goal of establishing a free-flowing connection between the well and aquifer.

Here are a few tips and tools for remediation project teams.

Screen design – Use high-flow screen materials whenever possible. Slotted PVC well screens have become very popular for their low cost, but their flows are quite limited compared with wire-wound screens. Figure 1 is a to-scale comparison of the openings for 4-inch diameter, 20-slot PVC and wire-wound screen sections. The open area for PVC is 6.33 in^2/ft and 31.1 in^2/ft for stainless wire-wound – nearly 5-fold greater opening at outside of the wall. The larger cross-sectional area in a wire-wound screen generates a much greater flow than through a slotted PVC screen.

Submerged screen – Whenever possible, the well screen should be set so that the top of the screened interval remains below the water table surface while pumping. When water levels fall into the screened interval, the exposure to air promotes the development of bacteria populations and formation of mineral precipitation that clogs the well screen and filter pack.

Casing design and installation – Natural electrical currents can pass through well casings and screens, causing electrochemical precipitation of minerals and corrosion of the well construction materials. To avoid these corrosion effects:

1. Use PVC casing (schedule 80), which in not an electrical conductor. This is feasible in most well installations, with the main limitations being the tensile strength and susceptibility to high temperatures. Schedule 80 PVC can withstand the temperatures typically associated with grout curing and chemical well rehabilitation. The tensile strength may be a factor in very deep well installations and should be a design consideration.
2. Dielectric couplers should be applied at the junction of dissimilar metals (mild steel casing connecting to stainless screen for example).
3. Cathodic protection may be required to minimize these processes, especially in cases where metal casing is used. In cases where mineral content of the groundwater is high, precipitation in wells and associated piping can be very significant, as shown in Figure 2. Cathodic protection can limit this precipitation in some cases.

Regardless of the well construction materials, production wells must be plumb and stabilized within the borehole. The use of centralizers is highly recommended to achieve these requirements. Well completions, whether above-ground or in subsurface vaults, must accommodate well maintenance and redevelopment.

DISTRIBUTION STATEMENT A : Approved for Public Release; Distribution is unlimited.
April 2017

Filter pack design – The filter pack provides a gradual transition from the formation to the surface of the production well screen. The packing design must be based on the particle size distribution for the aquifer in the zone where the screen contacts the formation. Drillers with suitable qualifications will carry sieves on their drill rigs and will match screen and well packing material as a field determination.

Well installation practices – The techniques used in water well construction are directly applicable to remediation production wells and environmental drilling contractors are often unfamiliar with them. A few considerations:

- Drillers with experience installing municipal water supply wells should be used to install production wells.
- For production wells, mud rotary drilling is often effective, but the drillers must be knowledgeable in the selection and application of drilling fluids, and the development of wells following their use.
- Sonic and air rotary drilling methods can also be used effectively to construct production wells.
- Drilling pilot borings is advisable, to determine the target interval for screen placement and to obtain formation samples to support filter pack and screen selection. If a pilot boring is not constructed, the driller must obtain formation samples from the interval to be produced and run field sieve analysis to select filter pack and well screen sizing.

Well development – As a rule of thumb, project teams should plan for drillers to spend twice as much time developing as they do drilling production wells. The driller should test-pump the well after initial completion to obtain a benchmark flow rate, and continue developing and testing until there is no further gain in production flow rates. The final, fully-developed production rate becomes the well performance benchmark for long-term performance tracking.

Specific capacity – The pumping efficiency of a well can be defined by the drop-in water elevation across the well screen and packing at a specified injection or extraction flow rate. This is the specific capacity and it is commonly reported as gpm/ft drawdown. Specific capacity measures the resistance to flow across the screen and well pack, and that resistance increases as minerals and biomass accumulate over time. Specific capacity can decrease to levels at which the desired flow rate can't be achieved.

Figure 3 shows a formation cross-section with a production well and filter pack installed. If the filter pack is properly developed, it will match (or better) the hydraulic conductivity of the formation and the drawdown curve from the formation to the well will be similar to curve 1 on the figure. When the well screen and filter pack become clogged, the pumping rate declines, decreasing the drawdown through the formation, while the drawdown increases substantially through the filter pack and well screen. This situation is depicted in curve 2 on the figure.

When the drawdown reaches a point where the well screen is exposed to air, the rate of clogging can rapidly accelerate, as aerobic biomass and mineral precipitation accumulates on the well screen and in the filter pack.

Performance tracking and routine maintenance are needed to keep production rates at required levels and to protect production wells against irreversible fouling.

Performance tracking – Every production well should be on a performance tracking plan that monitors the operating efficiency, not simply the flow rates. Specific capacity (flow rate per unit water level drop across the screen and well pack) is a good metric for performance tracking. In Figure 3, curve 1 represents highly efficient pumping and curve 2 shows very poor pumping efficiency.

For newly constructed wells, a performance benchmark should be established when the initial well development is completed. For existing wells that are just being put into a performance tracking program, a benchmark should be set immediately following well rehabilitation. Two performance tracking examples are shown below. Example 1 shows performance tracking and well maintenance effects for an extraction well and Example 2 shows tracking and maintenance for a continuous-operation injection well. In each case, decreases in specific capacity signaled the need for action.

Well maintenance – Project teams should plan on the need for regular well maintenance to remove biological growth, chemical precipitates that are deposited on the well screen filter pack, and fine formation particles that migrate into the filter pack over extended operating intervals. There are several modes of well maintenance that can be employed by project teams:

- Additives – There are numerous additives that can be injected continuously or added periodically to suppress biofouling or chemical precipitation in well screens and filter packs. These would be considered by project teams on a site-specific basis.
- Backwash – For both injection and extraction wells, flow reversals (backwashing) at regular intervals can improve well performance and extend the intervals between rehabilitation

events. Flow reversals can also be combined with the use of additives.

- Rehabilitation – Cleaning tools such as surge blocks, pressure jets, and swabs can be used to dislodge fouling materials from well screens and from the filter pack immediately adjacent to the well screen. PVC screens cannot withstand the physical stress of the most effective tools (high-pressure jets and swabs), so the rehabilitation prospects are not good for these installations. Also, the PVC slot structure severely restricts pressure jet flows, so the filter pack cannot be fully engaged in the rehabilitation of these wells.
- Re-development – Full re-development is an extended version of the rehabilitation process, with the intent of not only cleaning the well screen, but re-establishing the entire filter pack connection to the formation.
- Screen replacement – In some wells, the screens are smaller in diameter than the casing and are locked into the bottom of the casing with a K-packer or similar construction. If they deteriorate beyond recovery, these screens can be extracted and replaced without rebuilding the entire well.

Well failure – When specific capacity cannot be restored through conventional rehabilitation measures, a well might be restored through aggressive redevelopment or chemical additives. There are several mechanisms that reduce specific capacity – corrosion, biofouling, mineral fouling, and intrusion of fines into the filter pack – any of which could contribute to persistent specific capacity reductions and well failure. It is very important to determine the root cause of the fouling before embarking on aggressive redevelopment.

When wells haven't responded to conventional rehabilitation, project teams may need to engage specialized laboratories and well production professionals to determine the root cause and to select the most cost-effective course of action. Because it is possible to cause irreversible loss of capacity through aggressive redevelopment actions, project teams are advised to seek assistance in identifying, selecting, and implementing well recovery measures when conventional rehabilitation measures have failed. It is also important to consider that well replacement may be the most cost-effective solution.

Reference materials – There are several publications on production well construction, maintenance, and rehabilitation decision-making. Among these are:

- Groundwater and Wells, 3rd Edition. 2007. R. Sterrett, editor.
- Well Replacement Decisions, Parts 1 and 2. Water Well Journal, 2014.

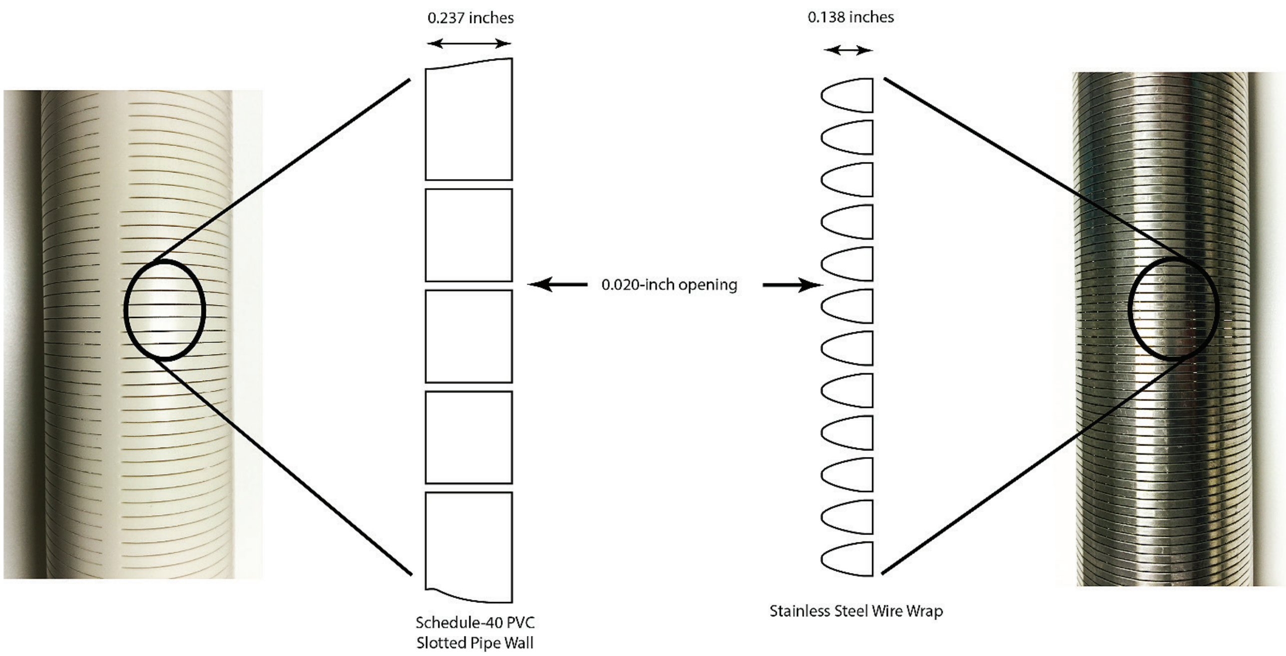

Figure 1. Comparison of slot and side wall dimensions for 4-inch diameter PVC (schedule 40) and stainless steel (#90 wire) well screens. Each screen has a nominal 0.020-inch ("20"-slot) opening.

All graphics provided courtesy of Arcadis unless specified otherwise

Figure 2. Manganese and related mineral deposition in a groundwater extraction system at Sierra Army Depot.

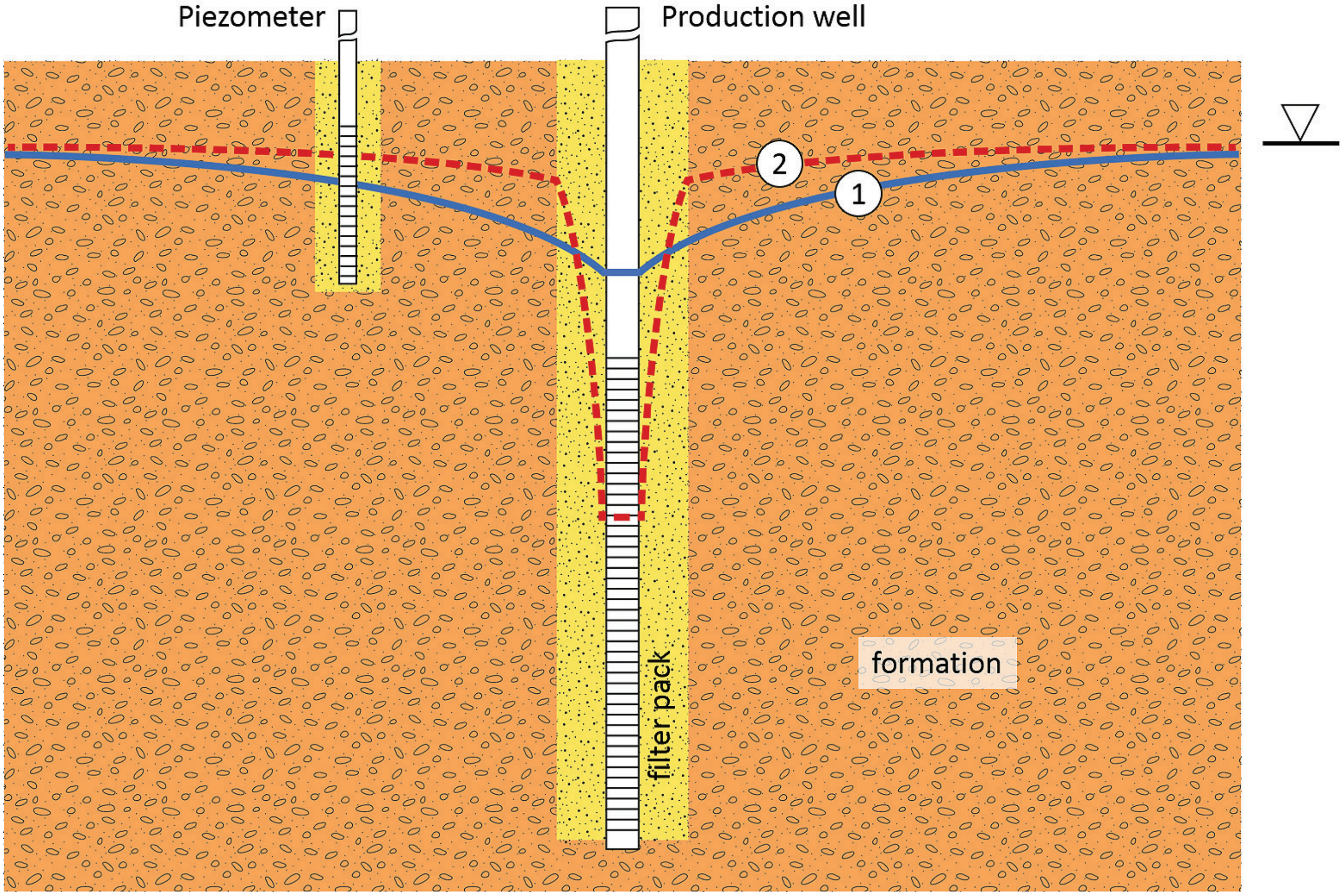

Figure 3. Change in well efficiency due to fouling in the well screen and filter pack. In the initial pumping (1), drawdown through the filter pack and screen match the formation. When fouling occurs in the well screen and filter pack (2), the pumping rate declines (note the decrease in formation drawdown), while drawdown through the filter pack and well screen increases dramatically. A piezometer provides tracking of drawdown in the formation and a transducer placed in the production well measures drawdown through the filter pack and well screen.

Example 1: Performance tracking and well maintenance for a groundwater extraction well.

This example shows performance tracking data for a groundwater extraction well over a 3-year interval. The well is fitted with a transducer below the pump, to determine the in-well drawdown during pumping, and a continuous reading flow meter. The flow (gpm) and in-well drawdown (ft) are combined to calculate the specific capacity (gpm/ft).

Figure 4 shows the data track for this well. The well initially yielded up to 150 gpm, with a specific capacity of up to 4 gpm/ft. Over the first 18 months of operation, the specific capacity declined to less than 50 percent of its initial value and the well was taken out of service. Following rehabilitation, the specific capacity increased to greater than the original level and has remained at or above 4 gpm/ft in the succeeding two years.

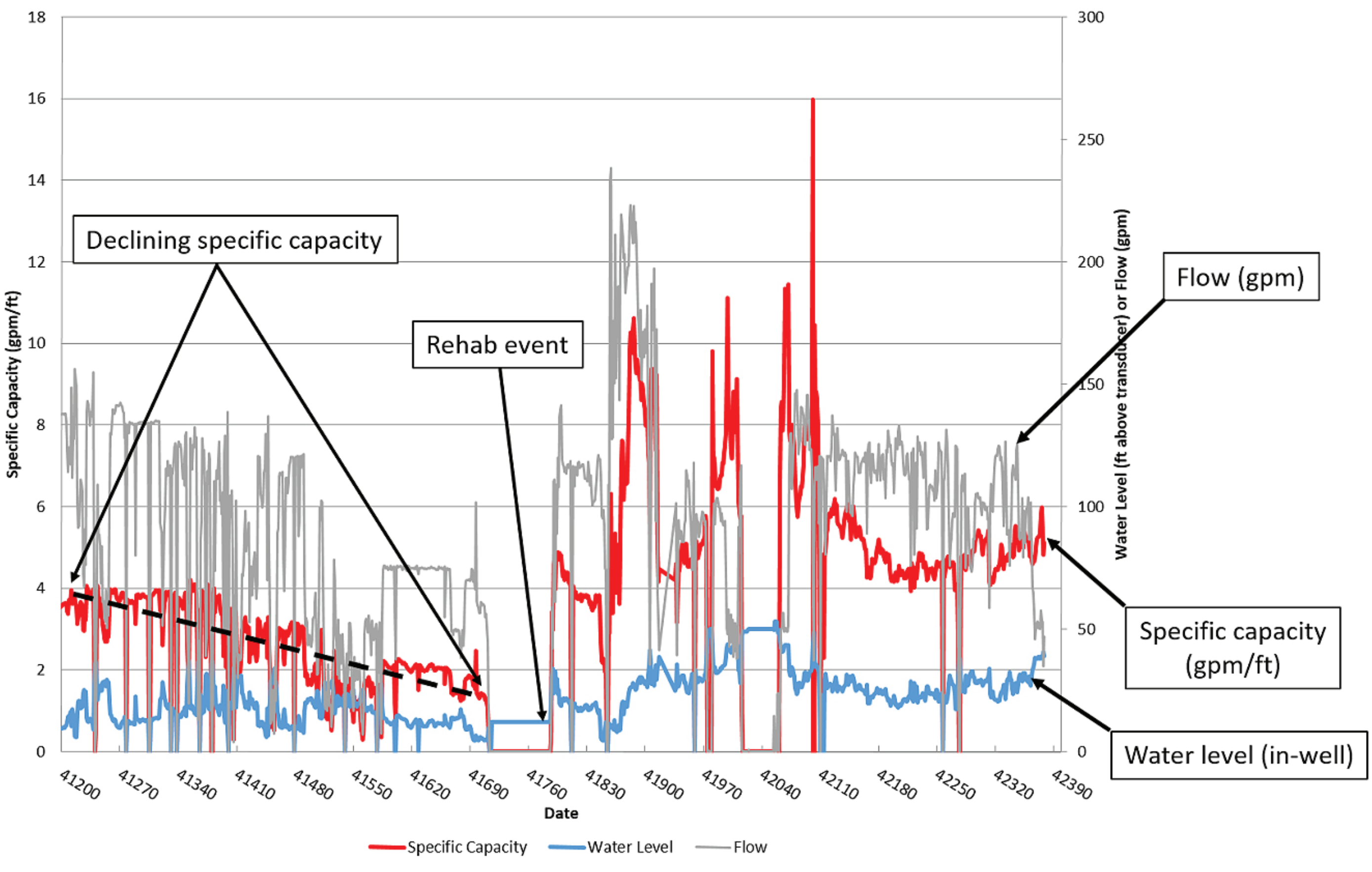

Figure 4. Groundwater extraction well performance tracking over a 3-year period. The specific capacity of this well was declining and reached levels at which pumping could not be sustained. The well was taken out of service and rehabilitated, after which the specific capacity was restored. The in-well water level is tracked with a transducer placed below the pump.

Example 2: Performance tracking and well maintenance for a continuous injection well.

In this example, groundwater amended with reagent is continuously injected into an aquifer with a target rate of 10 gpm. The well is fitted with a transducer to continuously measure the hydraulic head inside the well (driving the injection process) and the well is equipped with flow metering to constantly track the injection rate. The well is also fitted with an extraction pump placed at the bottom of the screened interval to periodically reverse flows, backwashing the well screen and filter pack. Backwashing is automated and occurs every two weeks.

Figure 5 shows the monitoring and maintenance supporting sustained operation of the well in this example. The well performance is measured by the specific injectability, which is calculated as flow rate (gpm) divided by the water elevation (ft) above the center of the screen. When the well was first developed, its specific injectability was 0.29 gpm/ft. Based on that, 0.23 gpm/ft (80-percent of the initial injectability) was set as the benchmark for this well. When specific injectability falls below the benchmark, a full rehabilitation event is conducted.

During the period shown on Figure 5, the injection flows were beginning to fall below the 10 gpm target and the specific injectability had fallen far below the benchmark. A full well rehabilitation was undertaken and the injectability recovered to the range observed when the well was placed into service.

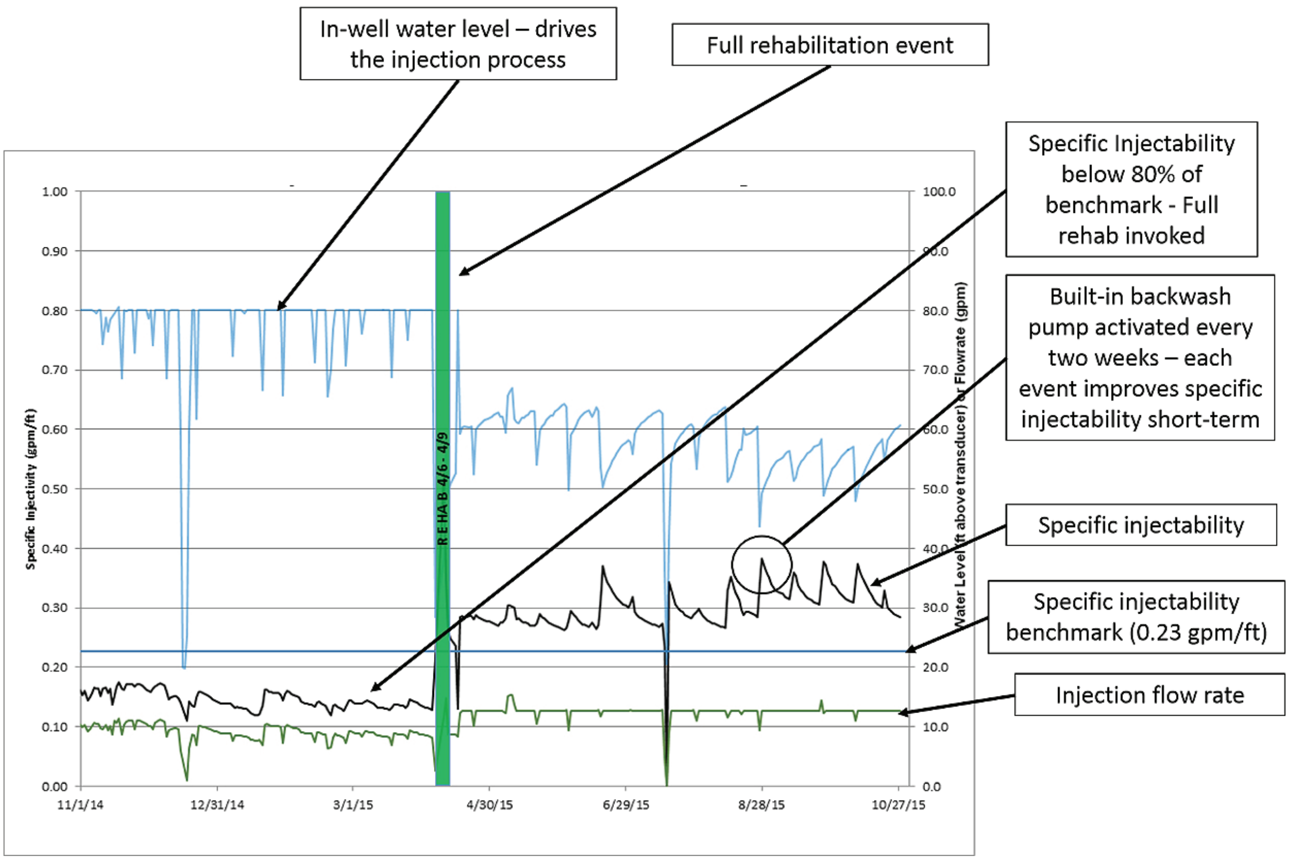

Figure 5. Injection well maintenance tracking using well efficiency as a benchmark. Maintenance includes: 1) bi-weekly backwashing and 2) full rehabilitation when specific injectability falls below 80% of the benchmark level.

The effects of bi-weekly backwashing events can also be seen in **Figure 5**, particularly following the rehabilitation event. A sharp increase in specific injectability occurs following each backwash.

ESAT N62583-11-D-0515