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Managing the clogging of groundwater wells

Gérer le bouchage des puits d'eau souterraine

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ABSTRACT Groundwater wells are widely used in civil engineering projects for construction dewatering, open loop geothermal systems and for water supplies for buildings and facilities. Wells can suffer from clogging due to three main processes: physical (re-arrangement of particles); bacterial (growth of bacterial colonies); and chemical (precipitation of mineral deposits). The most common forms of clogging result from the presence of elevated levels of iron and carbonates in the pumped water. Clogging reduces the hydraulic efficiency of the well and increases the energy required for pumping. The most effective programmes to manage clogging include: pre-rehabilitation surveys; assessment of borehole condition; rehabilitation treatment; post-treatment survey; and continuing monitoring. Rehabilitation methods are typically a combination of mechanical and chemical treatments, and 40 to 60% of the performance gain can be from the chemical treatment. Case studies of a construction dewatering systems and an hydraulic barrier presented in the paper indicate that chemical treatments must be matched to the type of clogging encountered.

RÉSUMÉ Les puits d'eau souterraine sont largement utilisés dans des projets de génie civil pour l'assèchement de construction, les systèmes géothermiques à boucle ouverte et pour les réseaux de distribution des eaux pour les bâtiments et les installations. Les puits peuvent se boucher à travers trois processus principaux: physique (réarrangement des particules); bactérienne (une croissance de colonies bactériennes); et chimiques (précipitation des dépôts de minéraux). Les formes les plus courantes de bouchage est attribuable à la présence de concentrations élevées de fer et de carbonates dans l'eau pompée. Le bouchage réduit l'efficacité hydraulique des puits et augmente l'énergie requise pour le pompage. Les programmes les plus efficaces pour gérer le bouchage comprennent: les enquête de pré réadaptions; évaluation de condition de puits de forage; traitment d'après traitement et la surveillance continuelle. Les méthodes de réadaptation sont typiquement une combinaison de traitements mécaniques et chimiques, et 40 à 60% du gain peut être du traitement chimique. Les études de cas sur les systèmes d'assèchement de la construction et une barrière hydraulique présentées dans le document indiquent que les traitements chimiques doivent correspondre au type de bouchage rencontré.

1 INTRODUCTION

Groundwater wells are common to many civil engineering schemes and their operational performance can play a crucial role in the successful delivery of a project. The wells can be for a wide range of purposes (Table 1), such as construction dewatering system, open loop geothermal systems or alternative water supplies for buildings and facilities. Whatever the application, the well performance must be optimised and high levels of operational efficiency and service availability achieved.

Water quality issues can seriously compromise a well's operational performance. Naturally occurring chemical and bacterial processes within the well bore and filter can result in iron bacteria and carbonate scale contamination, which can clog screens and pumps, reducing water flow and yield, and eventually causing pump breakdowns and system stoppages.

Outside of the civil engineering industry, water supply companies routinely deploy planned groundwater well maintenance programmes, with proven benefits in terms of operational cost savings and continuity of pumping. However, the benefits of proactive planned maintenance of groundwater wells on civil engineering projects are not widely recognised.

This paper will describe the principal mechanisms of clogging and encrustation in groundwater wells, and outline best practice methodologies to predict, diagnose and remove mineral, chemical or bacterial clogging. Case studies of planned well maintenance programmes will be presented.

2 GROUNDWATER WELLS IN CIVIL ENGINEERING

Groundwater wells are very common, and are a routine part of water supply and other applications (Table 1). Wells may also be known as groundwater boreholes or tubewells. The key physical aspects of wells are shown on Figure 1.

Table 1. Groundwater well applications in civil engineering

Application	Description
Water source works and water supply wells	Supply of raw water to be treated for drinking water or process water
Aquifer Storage Recovery (ASR)	Injection of treated water into an aquifer to store it for later extraction
Irrigation systems	Supply of irrigation water
Construction dewatering and mine dewatering systems	Lowering of groundwater levels to allow excavation in dry and stable conditions
Artificial recharge systems	Injection of water into the ground, either for disposal purposes or to control groundwater levels
Permanent dewatering systems	Long term drainage and groundwater level lowering for structures and facilities
Groundwater remediation systems	Extraction of contaminated groundwater for treatment
Relief wells – dams and levees and landslides	Provide preferential flow paths to relieve high groundwater pressures and ensure geotechnical stability
Open loop geothermal systems	Extraction (and in some cases re-injection) of groundwater to provide low temperature heat energy

Typically, wells have a near surface section of well liner, from which groundwater is excluded. The deeper part of the well is the permeable well screen, through which water enters the well. In soils and weak rocks the well screen may be a perforated steel or plastic tube, surrounded by filter gravel. In hard rocks there may be no requirement for a perforated tube, and the screen section may simply be bare rock. Water enters the well exclusively through the well screen, and it is here that clogging processes occur.

The key performance requirement for a well is its 'yield' – the pumped flow rate it can deliver. However, the water level in the well during pumping is also important. Pumping lowers the water level in the well by an amount known as the drawdown (Figure 1). The drawdown in the well comprises the drawdown in the aquifer and the 'well loss', a head difference between the inside and outside the well that represents the resistance to flow of water into the well. An inefficient well (such as one that is clogged) will tend to have a higher well loss than an unclogged well,

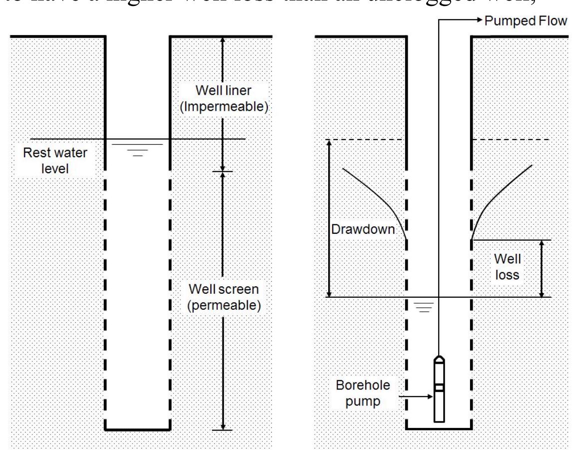

Figure 1. Principal features of groundwater wells in unpumped and pumped conditions

If a well becomes clogged, well losses will increase and drawdown will become greater for a given pumped flow rate. Specific capacity (defined as flow rate per metre drawdown) is a measure of well efficiency. As a well becomes clogged the specific capacity will increase as it becomes harder to pump water from the well, and the energy expended to pump a unit volume of groundwater will be increased. Clogging can become so severe that the practicable yield of the well is reduced, so that less water is available to users, or so that dewatering is less effective.

3 CLOGGING AND ENCRUSTATION PROCESSES

A groundwater well is a complex hydrodynamic environment. As water passes through the well and the downstream pumping system, it undergoes pressure changes, temperatures changes, is exposed to the atmosphere and comes into contact with artificial surfaces in well screens and pumps. Unfortunately, in many cases this creates ideal conditions for clogging to occur. Clogging of wells, and the resulting practical problems created, has been known for more than 100 years, and are documented in water industry guidance (Howsam et al. 1995; Sterrett 2008)..

Three main clogging processes occur in and around wells, where material is re-arranged or deposited to plug flow paths and restrict water flow:

- Physical clogging, where particulate matter is re-arranged;
- Bacterial clogging (commonly known as biofouling), where bacterial colonies grow in the well, feeding from dissolved material in the well, excreting a biomass; and
- Chemical clogging, where mineral compounds derived from dissolved material in the water are deposited.

The focus of this paper is on chemical and bacterial problems. These processes, including iron oxide encrustations, iron bacteria and calcium carbonate, are a common cause of well performance problems.

3.1 Bacterial clogging

Iron bacteria are one of the most common clogging processes in wells. They derive the energy they need by oxidising the soluble ferrous iron (Fe^{2+}) present in the groundwater to an insoluble ferric form (Fe^{3+}). The potentially turbulent, oxygenated environment in a well and pumping system can form an ideal environment in which this can occur (Howsam & Tyrell 1990). The life cycle of the bacteria produces a biofilm that typically appears as a slimy or gelatinous red-brown deposit (commonly known as biofouling) that can be difficult to remove (Figure 2).

Figure 2. Iron deposits on well pumping equipment

Possible reasons for iron bacteria infection include presence of bacteria before a bore is drilled, the introduction of bacteria via contaminated water used during the drilling process or changes in the chemistry of the groundwater, which provides an environment in which bacteria can become established.

3.2 Chemical clogging

Chemical clogging occurs by chemical precipitation induced by the natural pressure release on the water as it moves from the formation into the well bore and to the pump, combined with the oxygen available in the well. The most commonly reported chemical encrustations are iron oxyhydroxides (sometimes associated with manganese deposits), iron sulphides and calcium carbonates.

Carbonate clogging is different process to iron-related clogging. The natural carbon dioxide dissolved in solution is released resulting in an increase in water pH. As the pH increases in waters with high levels of calcium carbonates, rapid precipitation of white or pale grey calcareous deposits occur in the well and pump (Figure 3).

Figure 3. Carbonate deposits on well pumping equipment

3.3 Operational implications

Operational problems caused by clogging include reduction in the hydraulic efficiency of the well (increased drawdown, decreased yield, decreased specific capacity), deterioration of water quality, motor burn out of the submersible pump, and encrustation on the pump, column, well screen and reticulation systems (Table 2). As a result the energy costs of pumping will increase (due to increased drawdown) and maintenance costs will increase due to greater equipment wear and tear and well rehabilitation costs.

Without rehabilitation, over time the clogging can become so serious that a well has to be decommissioned. This can reduce water available for use, or reduce the drawdown achieved by dewatering systems. It is far cheaper, and more sustainable, to regularly maintain and rehabilitate boreholes than to have to drill a new well to replace a badly clogged well.

Table 2. Possible observed symptoms of well clogging

Problem	Observed symptoms
Iron oxide, iron oxy-hydroxide and iron bacteria	Red-brown slime inside pipes Reduced specific capacity Cloudy rusty water at pump start-up Slimy deposits blocking main lines and laterals. Smelly and poor quality water
Manganese oxide	Blackish-brown deposits blocking pipes Reduced specific capacity Cloudy water at pump start up. Smelly and poor quality water
Calcium carbonate	Deposits of distinct white scale more layered than iron oxide deposits Reduced specific capacity Iron oxide could also be present indicated by a red-brown coloured calcification. Smelly water if iron-related bacteria or biofouling also present

4 STRATEGIES TO MANAGE CLOGGING AND ENCRUSTATION

Poorly performing boreholes suffering from bacterial and chemical clogging can be rehabilitated by a range of mechanical and chemical methods. In recent decades there has been increased recognition of the potential benefits of chemical treatments, and a wide variety of products, as well as several patented commercial treatments, areis available on the market (Table 3). Chemical products include hydrochloric acid, which generates low pH and is moderately effective against encrustations. However, it is relatively ineffective against biofouling and can be very corrosive and dangerous to handle. There is a risk that the acid may attack metal pumps, equipment and well screen and require an inhibitor to control its aggressiveness. Chlorine is another product that has had limited success but it needs to be used very carefully because of the extreme level of chemical activity and the potential to form Trihalomethanes (THMs).

Research has shown that chemical rehabilitation can provide 40 to 60% of the total gain during a combined chemical and hydro- or mechanical rehabilitation (Houben 2001). The challenge for the well owner or operator is that each site will have unique aspects, requiring care in the choice of rehabilitation methods and chemical agents if well performance is to be returned to close to its original levels.

Table 3. Chemical treatments used in well rehabilitation (adapted from US Army Corps of Engineers 2000)

Chemical	Advantages	Disadvantages
Hydrochloric Acid (also known as Muriatic Acid) (HCI)	Effective against a range of mineral deposits and highly effective at removing scale. Widely used in groundwater well rehabilitation.	Corrosive to most metals, particularly stainless steel because of chloride content. Not effective against iron biofouling. Produces toxic fumes, requires careful handling, purity levels needed be defined before handling, lowers pH levels.
Sulfamic Acid (H_2NSO_3H)	Strong acid which reacts very quickly against carbonate scales. Powder form should be dissolved in water before adding. Safer to handle than muriatic acid.	Not effective against iron or manganese deposits. More effective as a combination chemical treatment against biofouling or metal oxides.
Phosphoric Acid (H_3PO_4)	Less corrosive than hydrochloric acid but slower acting. Effective against iron and manganese deposits.	Requires careful handling. Leaves phosphates behind which can provide nutrients for microbial growth.
Sodium hypochlorite (NaOCI)	Liquid product. Good disinfectant capabilities. Effective at oxidising and killing bacteria.	Not effective against mineral deposits. Short shelf life. Can increase the redox potential of the aquifer.
Acetic Acid (CH_3 COOOH)	Effective biocide and biofilm dispersing acid. Relatively safe to handle.	Glacial acetic is very corrosive to the skin and produces a pungent vapor that can cause mild to severe lung damage.
Oxalic Acid $(COOH)_2$	Strong, reducing acid and is excellent against iron and manganese oxide. Biodegradable. As a combination chemical works with even greater power.	Salts of the acid are poisonous but during a treatment converts to inert elements, with any residues easily removed from water body.

However, rehabilitation alone is not the optimal solution. The most effective programmes to manage well performance typically incorporate a monitoring and measurement plan alongside a regular chemical treatment.

The elements of a well rehabiltation can be illustrated by reference to the *BoreSaver* well management programme which is applied to wells to return performance to as close to the original drilled capacity as possible and to help maintain a continual, problem-free water supply. The elements of such a programme are:

- Pre-rehabilitation survey: Collation of operational data (pumping rates, water levels and water quality), visual inspection of pumps following removal, and a downhole camera survey (to allow operators to understand the specific areas in a well that may require attention). The camera system should have fixed sideview and downview lenses allowing for the close inspection of a well from different angles. The survey should be recorded to a DVD or digital recording device for later review
- Assessment of borehole condition and required rehabilitation: Review and analysis of key well performance parameters and benchmarking against historical data for each well and wellfield, allowing an individual maintenance plan to be projected. Key thresholds and set points are identified for the well, to be used as trigger levels in later monitoring programmes.
- Rehabilitation treatment: A combination of mechanical and chemical methods is usually the most effective approach. Mechanical treatments can include: scrubbing (a brush used to clean the screen); surging (a tight fitting tool used to create a piston effect in the screen); water or air jetting (high pressure jets used to clean the screen); vibration (percussion or sonic devices used to loosen and mobilise deposits). The chemical treatment component requires suitable chemical treatment products and specialist rehabilitation equipment to deliver the products to the relevant section of the well screen (Figure 4).
- Post-treatment survey: Downhole camera survey and monitoring of initial post-treatment pumping to provide an additional benchmark in the history of the well and its rehabilitation.
- Continuing monitoring and maintenance: Operational monitoring will provide the data to allow future rehabilitation treatments to be planned and scheduled.

Selection of the appropriate chemical treatments is important to ensure that they are effective against the type of clogging identified, have the necessary regulatory approvals and the post-treatment residues are harmless and can be safely disposed of.

Figure 4. Well rehabilitation rig used in BoreSaver maintenance programmes

5 CASE STUDIES

Some potential approaches to well rehabilitation to deal with clogging are given below.

5.1 Construction dewatering system, Australia

Construction of a new metro system was carried out through a section where groundwater level was within two metres of ground level, and dewatering (and associated artificial recharge) was required. Within the first six months of dewatering pumping, severe levels of iron-related clogging, as well as other organic residues, were discovered. After six months, the pumps and pipes were so badly clogged that the pumps could not be used to maximum efficiency.

There were additional problems with the back-pressure of the artificial recharge system, which reached 1,400 kPa, resulting in low rates of recharge flow. The pumps, pipes and recharge bore were treated with a combined mechanical and chemical treatment using *BoreSaver Ultra C* (a solid product with a main active ingredient of oxalic acid dehydrate, with various secondary ingredients) and a surging technique. This removed the iron-related deposits and within minutes of the chemical treatment the back-pressure in the recharge system reduced by 550 kPa. A regular chemical treatment regime was then implemented to maintain the recharge flow rates. A weekly treatment of the dewatering pumps with *BoreSaver Ultra C* was also initiated and the pumps were quickly brought back into full service and maintained at optimum operational levels.

5.2 Permanent dewatering system, UK

Castlehaven on the Isle of Wight, is one of the largest developed landslide systems in western Europe, about 12km long and extending up to 1km inland. In 2002, coastal erosion, high groundwater levels and the natural geology reactivated the landslide, putting local properties and infrastructure at risk.

Part of the geotechnical solution to stabilise the slope and limit maximum groundwater levels was a pumped groundwater control system. This comprised 35 electro-pneumatic pumps and 121 gravity-fed siphon wells installed in wells at depths of up to 25m below ground level. In 2005 groundwater contamination, possibly from septic tanks, was discovered, with iron-related bacteria growing in the dewatering wells and compromising the system. A treatment with limited environmental impact was required because of the sensitive setting. *BoreSaver Ultra C* combined with a mechanical surging process was used to clean the system, includeing the accumulators where most of the problem was occurring. Cleaning of the abstraction siphon wells also ensured that the wells continued to yield effectively. *BoreSaver* now forms part of the six monthly maintenance programme.

5.3 Hydraulic barrier, Italy

The hydraulic barrier used as part of a groundwater remediation scheme for an industrial site in Falconara, Italy, was significantly underperforming, achieving a pumping rate of only 12 m^3/hr with a drawdown of 8 m. CCTV inspection of a well (400 mm in diameter and 10.5 m deep) revealed algae, calcium carbonate and iron bacteria contamination, which had clogged up the well screen slots and the pump, as well as reducing the quality and output of the water.

The pump was removed from the well, which was then treated with *Boresaver IKL Pro* (a liquid product the base of which is hydrochloric acid with various secondary products), *Boresaver Ultra C Pro* (a solid product with a main active ingredient of oxalic acid dehydrate, with various secondary ingredients) and sodium hypochlorite in pearls using a piston cleaning technique. The pump was cleaned using a large barrel filled with water and *BoreSaver Ultra C*.

Following two treatments, 24 hours apart, CCTV inspection showed that the majority of the well screen slots were completely open and the algae, calcium carbonate and iron bacterial deposits almost completely eliminated. The submersible pump was re-installed and tested, and achieved 28 m^3/hr with a drawdown of only 4.7 m, increase in specific capacity by a factor of almost four.

6 CONCLUSION

The operational performance of groundwater wells can be detrimentally affected by clogging processes, including bacterial result from the presence of elevated levels of iron and carbonates in the pumped water. Clogging reduces the hydraulic efficiency of the well, increases wear and tear on pumps and equipment and increases the energy required for pumping. Programmes to manage clogging should include: prerehabilitation surveys; assessment of borehole condition; rehabilitation treatment; post-treatment survey; and continuing monitoring. The most effective rehabilitation methods are typically a combination of mechanical and chemical treatments, and with 40 to 60% of the performance gain likely to be from the chemical treatment. A wide range of chemical treatments are available, but must be carefully matched to the type of clogging encountered.

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