B BOREHOLE REHABILITATION

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1 Introduction

A borehole is a structure that is submitted to physical, chemical and biological processes that depend on the quality of its construction, the way it is operated and the characteristics of the aquifer. The deterioration of a borehole is unavoidable but its intensity and its velocity will depend on the above factors and will be characterised by decreasing productivity (falling ratio of yield to draw-down) and water quality. It can lead to the borehole being abandoned. In many cases rehabilitation can reduce the deterioration or successfully repair the borehole.

Rehabilitating a borehole can be more economical than constructing a new one. It is simpler and faster, and can be an appropriate solution in an emergency situation (it doesn't require the mobilisation of a drilling rig); however if the rehabilitated borehole is to be used for a long time, it is important to estimate its life expectancy (the rehabilitation of damaged boreholes is not necessarily a long term solution).

In practice the need to rehabilitate a borehole arises when:

- a functioning borehole presents usage problems (low productivity, contamination of the water);
- carrying out a borehole programme (rehabilitation and drilling new boreholes are usually complementary); and
- carrying out a pump-maintenance project (small rehabilitation works, such as development, are often carried out at the same time).

The rehabilitation option chosen depends on the conditions of the existing borehole, the causes of the damage, the technical and logistic options, the existing alternatives (construction of other water points) and the opinion of the users (consumers and operators).

According to the severity of the borehole problems, the work required may vary from a simple repair at the surface to unclogging operations or re-equipment.

2 Description of the causes of borehole deterioration

The problems found depend on the age of the borehole, the quality of its construction, the way it has been used and the geological context (Table 8.XXII).

Table 8.XXII: Common problems and frequency of occurrence according to the geological context.

Aquifer	Frequent problems	Frequency of occurrence (frequency of maintenance required)
Alluvia	Clay-sand clogging Iron precipitation Incrustation Biological clogging	2 to 8 years
Sandstone	Clogging of the fissures Corrosion Sand intrusion and silting up	6 to 10 years
Calcaneous	Clogging by clays Precipitation of carbonates	6 to 12 years
Basalts	Clogging by clays	6 to 12 years
Metamorphic	Clogging by clays Mineralisation of the fissures	12 to 15 years

2.1 Electrochemical and bacterial corrosion

Corrosion is a chemical phenomenon that tends to destroy a material in a medium with which it is not in equilibrium. Metallic pipes are unstable in water and will corrode because of migration of positive ions from the metal into the water. Certain chemical reactions are frequently catalysed by bacterial activity.

In boreholes, corrosion may affect all the metallic and non-metallic parts (such as reinforced concrete and mortar). Only the plastics, the bituminous facing, and the stainless steel parts are not susceptible.

2.2 Mechanical, chemical and biological clogging

Clogging is a mechanical, chemical or biological phenomenon that causes a reduction in the permeability of the medium and increases the head-losses at the intake level. Chemical and biological clogging is directly related to corrosion phenomena.

The clogging of a borehole reduces its performance. It is accompanied by deposits whose nature is related to the type of clogging.

2.2.1 MECHANICAL CLOGGING

This consists of:

– *Sand intrusion and silting up*: a significant entry of fine materials into the borehole which may extend to the partial filling of the intake section. This is caused by poor installation of the borehole (screens not properly centred, gravel not properly distributed, large gravel pack grains and oversized slots), inappropriate operation of the borehole (insufficient development, an exploitation yield larger than the yield determined by the pumping test, dewatering of screens), wearing out (or breaking) of the screens or of other pipes.

– *Clogging of the gravel pack*: accumulation of materials on the outside of the gravel pack (external clogging due to suspended matter larger than the pores of the gravel pack), or on the inside (internal clogging of a gravel pack by layered grains due to suspended matter larger than certain pores of the gravel pack). This type of clogging is caused by an insufficient development, by over-pumping or by a gravel pack of bad quality (inhomogeneous grain size, gravel that is too angular etc.).

2.2.2 CHEMICAL CLOGGING

This consists of the precipitation of insoluble salts that obstructs the slots of the screens. It is caused essentially by the dewatering of the screen and provokes:

– *incrustation or scaling*: precipitation of carbonates by degassing of CO_2.

– *iron deposits*: precipitation of iron (II) hydroxides ($Fe(OH)_2$) due to the degassing of CO_2 or precipitation of iron (III) hydroxides ($Fe(OH)_3$) by addition of oxygen.

2.2.3 BIOLOGICAL CLOGGING

This type of clogging develops more often in alluvial or shallow layers and is caused by the development of bacteria that creates a compact sticky film that obstructs the screen slots.

Bacterial clogging may be caused by natural changes (e.g. drought, or flooding with nutrient-rich surface water) and by man-made changes (organic pollution, raised water table due to the construction of dams). They are also a consequence of screen-dewatering. However, iron and manganese bacteria are often naturally present in the water and soils, and develop significantly after the changes brought about by the borehole, namely the addition of nutrients brought in by the water during pumping.

The development of bacteria, and hence clogging, that may follow concern the gravel pack, the screen and also the surrounding formations within an area of several meters.

2.3 Erosion

Wearing out of the screen may occur by abrasion when the entry velocity of the water is very high (over 3 cm/s). This is essentially due to a insufficient open area of the screen (incorrect relations between slot openings, grain size of the gravel pack and grain size of the aquifer), an insufficient screen length or incorrect positioning of the pump within the screen (high water velocity at the level of the pump and vibration of the pump when it starts, thereby colliding against the screen).

3 Diagnosis

The diagnosis of the borehole is the first step in a rehabilitation programme and must be carried out with care. The objective is to analyse the degradation that affects the correct functioning of the borehole in order to understand the causes and to estimate the relevance of proceeding with rehabilitation.

3.1 Methodology

The different steps of diagnosis are described below:

1) *Preliminary information collection*

This determines the characteristics of the borehole when it was commissioned and how it has been used:

– review of the *borehole log sheet*: date of construction, geological conditions, drilling technique, problems at the time of drilling, casing plan (to check the position and type of screen), nature and positioning of the gravel pack, technique of development used and results of the pumping test and water analysis;

– general information *from operators and users*: depth of the pump installation, yields and time schedule of pumping, change of the performance of the borehole and of the quality of the pumped water (including taste, odour and colour);

– in case of *abandonment*: research into the cause and date of abandonment.

This data is not always easy to obtain, but a rapid examination of the borehole allows the preliminary information to be complemented (and verified).

2) *Rapid examination*

Several elements may be swiftly verified:

- Condition of the equipment and depth of pump installation.
- Quality of the water:
  - turbidity;
  - faecal contamination;
  - conductivity;
  - taste, odour, colour;
  - presence of sediments (bucket test, see Chapter 8A, Section 7.2.1).
- Analysis of the borehole:
  - lowering of the static level;
  - decrease in borehole depth;
  - decrease in performance (estimation of the yield and of the water level during pumping).
- State of the surface works.

This field information and its comparison with the initial data on the borehole allow a rapid initial diagnosis of the borehole condition and actions to be taken.

At this stage, the necessity to proceed with an in-depth diagnosis must be questioned and justified, because the work involved is costly and time-consuming, requiring highly specialised and expensive instruments, laboratory analyses, and mobilisation of human and material resources. The decision will be taken according to the cost and feasibility of the operations to be undertaken and after considering the relevance of rehabilitation rather than other alternatives.

3) *Use of inspection tools*

The most commonly used tools are *video cameras* (only used in clear water), that allow the detection of zones where pipes are damaged and where screens are clogged, as well as the presence of *incrustations,* and *diagraphy*[*], that allows an estimation of the pipe condition, of the cementation and, in certain contexts, of the aquifer.

Note. – In the absence of data about the borehole, it is important to identify where the screen is positioned, since this constrains the installation of the pump, the determination of the exploitation yield and the development process. The utilisation of diagraphy or a video camera allows this to be determined.

4) *Pumping test and water analysis*

A pumping test allows precise measurement of the hydrodynamic parameters of the borehole and calculation of head-losses, to determine the efficiency of the borehole (see Chapter 6).

In parallel with the pumping test, it is important to perform a water analysis as complete as possible, including nature and size of the suspended particles and physicochemical analyses (see Chapter 4).

3.2 Data analysis

Table 8.XXIII summarises the data to collect and analyse, and the corresponding activities to plan, when designing a rehabilitation operation.

4 Intervention techniques

Once the diagnosis is ready, it is necessary to estimate the feasibility and cost of the rehabilitation. The decision to rehabilitate or abandon the borehole must be taken in view of what the rehabilitation involves and the alternatives are.

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[*] *Diagraphy:* recording of physical parameters, established by survey techniques, that enable the production of information on the nature and structure of rocks and their contents.

Table 8.XXIII: Analysis, diagnosis and techniques for borehole rehabilitation.

Data	Diagnosis	Rehabilitation techniques
ANALYSIS OF YIELD AND LEVELS (PUMPING TESTS)		
Decrease of the borehole depth	Sand intrusion	*Analysis of deposits to finalise the diagnosis*
Decrease of specific yield (yield / dynamic level)	Clogging Sand intrusion	*Analysis of deposits to finalise the diagnosis*
Lowering of the static level	Aquifer drying up (long-term trend or seasonal fluctuation)	*If the aquifer allows*: Reinstallation of the pump (depth and/or model) Over-drilling and re-equipment *or abandoning*
Calculation of the quadratic head-losses (C) in $m/m^3/s$:	*These values must be considered as orders of magnitude and they will only make sense when compared with each other*	*Analysis of deposits to finalise the diagnosis*
$\rightarrow C < 5 x 10^{-3}$	There is no clogging	
$\rightarrow 5 x 10^{-3} < C < 1 x 10^{-4}$	Possible clogging	
$\rightarrow 1 x 10^{-4} < C < 4 x 10^{-4}$	Clogged well	
$\rightarrow C > 4 x 10^{-4}$	Unrecoverable well	
WATER ANALYSIS		
Conductivity increase	Perforation of the pipes	Re-equipment or abandoning
Modification of a parameter: temperature, sulphate, nitrate etc.	Cementation fault	Re-do the cementation
Increasing bacterial presence	Corrosion	Re-equipment or abandoning
High turbidity	Incorrect equipment Perforation of the pipe	*Analysis of deposits to finalise the diagnosis*
Faecal contamination	Problem on the superstructure Grouting/concreting fault	Rehabilitation of surface works
ANALYSIS OF DEPOSITS		
Sand of diameter smaller than the screen slots	Incorrect development Incorrect equipment	Bailing and development Bailing and re-equipment
Sand of diameter larger than the slots of the screen	Wearing/rupture of the screen Rupture of the casing	Bailing and re-equipment or abandoning
Presence of calcites in the form of grains or flakes	Scaling by precipitation of calcite (may be accompanied by corrosion)	See Section 4.4
Presence of iron in the form of oxide	Corrosion of the screens (may be accompanied by clogging, precipitation of iron)	Re-equipment *The methodology for protection against corrosion is difficult to be used in humanitarian intervention contexts*
Presence of gels, mud, flocs and smells	Clogging due to bacteria (may be accompanied by corrosion)	See Section 4.4
DIAGRAPHY		
Video camera	Clogging Rupture of the casing	See Section 4.4 Re-equipment or abandoning
Acoustic images	Scaling Corrosion	See Section 4.4 Re-equipment or abandoning

Electric log allows determination of the casing plan (positioning of the screens)

4.1 Development

Development is done at the beginning and at the end of each rehabilitation. It allows the borehole to be cleaned, certain clogging problems to be solved, and the efficiency of the rehabilitation work to be evaluated. The best techniques are air-lift, pistoning (surging) and jetting, see Chapter 8A Section 7.

4.2 Bailing and over-drilling

The bailing operation aims to remove all the accumulated deposits at the bottom of the borehole that can't be extracted by development (clay, sand, rock debris etc.). The operation consists of lowering a bailer into the borehole, that will trap the materials with a flap-valve system. It is a dangerous process for the casing.

Over-drilling is used if the borehole is filled with materials that cannot be removed by bailing. The technique used depends on whether or not the borehole has a screen.

If the borehole has no screen, drilling is performed inside the borehole with a diameter smaller or identical to the initial one. If the borehole is blocked by large-diameter debris, it is possible to drill by cable-tool or down-the-hole hammer (DTH).

If the borehole has a screen, it is necessary to drill (rotary or cable-tool) with a small diameter inside the existing borehole. A low progression velocity is used in order to extract all of the sediments. These operations damage the casing and screen, and it is often necessary to re-equip the borehole.

4.3 Re-equipment

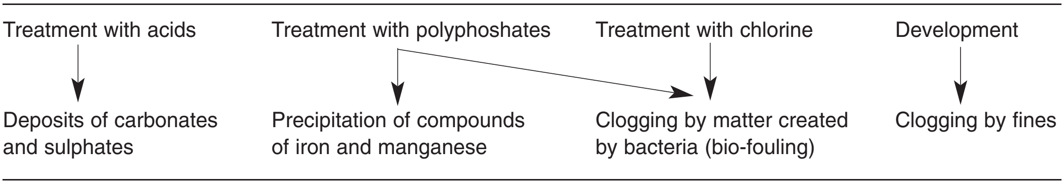
Re-equipment consists of placing new casing inside the existing one. The new casing has a diameter at least 4 to 6 centimetres less than the existing one, to allow installation of a sufficiently thick gravel pack.

This operation reduces the diameter of the borehole and increases the head-losses (creation of new interfaces with the aquifer). Grouting is done as for a new borehole.

4.4 Unclogging

Development may partially solve certain clogging problems, but nevertheless, chemical treatments are often required (treatment with acids or with chlorine). In general, for various reasons, it will be necessary to use different solutions (mixed treatment), see Table 8.XXIV.

Table 8.XXIV: Treatments for clogged boreholes.



The principle is to introduce into the borehole a solution that will act upon the screen, the gravel pack and the surrounding aquifer, for a certain time. During a contact period the water is agitated in order to improve the efficiency of the treatment. At the end of the treatment a long pumping step is performed in order to eliminate all traces of the chemical product used. The process is summarised in Table 8.XXV.

Table 8.XXV: Chemical treatment process.

Steps	Treatment with acids	Treatment with polyphosphates	Treatment with chlorine
Measure initial pH	X	X	
Prepare the stock solution (1.5 to 2 times the volume of the screen)	X	X	X
Pour the solution into the borehole via a PVC pipe (one half at the top part of the screen and one half at the bottom part)	X	X	X
Agitate the solution for 2 hours by blowing	X		
Perform a development process (air-lift or piston) for 12 to 24 hours		X	X
Pump in order to remove all the chemical products	X	X	X
Check that the water returns to the initial pH or residual chlorine level	X	X	
Measure the residual chlorine level			X

Treatment with acids

The acids normally used are *hydrochloric* acid and *sulphamic* acid. Note that hydrochloric acid is strongly advised against for metallic screens (namely zinc and galvanised steel). Furthermore, sulphamic acid is normally more efficient than hydrochloric acid.

For hydrochloric acid, the form commonly used is a 30% w/w. Sulphamic acid, which is sold as a solid in crystals, needs to be dissolved in water (at 15°C: 200 grams of crystals for 1 litre of water; at 30°C: 260 g of crystals for 1 litre of water).

Note. – Acids must be used with extreme care (gloves, appropriate clothes, glasses, mask) and according to local regulations.

Treatment with polyphosphates

Polyphosphates used are derived from sodium phosphates in solid or dust form. The dose is 2 to 4 kg of product in 100 litres of water. Note that it is effective to add chlorine to the polyphosphate solution, at the rate of 120 to 150 grams of HTH per 100 litres of water, in order to combine the effects of both products.

Treatment with chlorine

The concentrations of these products range from 1 000 to 2 000 mg/l of active chlorine, and the volumes of solutions used depend on the volume of water to be treated in the aquifer. It is assumed that this volume is at least 5 times higher than the volume of the water in the borehole. The chlorine products and the water to be treated must be thoroughly mixed and there must be a minimum contact time of 12 hours.

4.5 Rehabilitation of surface works

The rehabilitation of surface works may be considered if they are in bad condition or were poorly constructed. Depending on their condition, it may be better to destroy them than to repair them – a new layer of concrete over a structure that is not in a proper condition is not solid and will be deteriorated very fast. If repairs are carried out to concrete structures, the surface to be repaired should be roughened to ensure cohesion, and holes should be made to anchor new mortar or concrete.

Rehabilitation is done according to normal procedures for constructing borehole surface works (see Chapter 8A, Section 9), taking into consideration the causes of the observed deterioration (natural erosion, animal or human wear and tear, unsuitability to the needs and habits of the population etc.).

5 Preventive maintenance

It is preferable to prevent the problems of ageing in order to retard the deterioration of boreholes. In addition to the issues concerning the construction of the borehole (choice of materials, positioning of the pipes, quality of grouting), reasonable use and regular maintenance diminish and minimize the problems of deterioration:

Use

In order to obtain maximum longevity and to retard the appearance of ageing phenomena, it is necessary to follow the following rules:

- Avoid frequent start-ups and continuous pumping 24h/24.
- Do not exceed the maximum exploitation yield.
- Do not decrease the water level below the top of the screen.
- Periodical maintenance and monitoring: maintenance of the pumping system and of the surface works.
- Annually: complete analysis of the water (bacteriological and physicochemical), monitoring of the pumping system.
- Every 3 to 5 years: a pumping test, withdrawal and complete inspection of the rising main and measurement of the total depth of the borehole.

6 Condemning a borehole

When the rehabilitation of a borehole is not feasible (for technical or economic reasons), it is necessary to block it in an impermeable manner in order to avoid any contamination of the aquifer. In order to achieve this it is necessary to plug the whole of the borehole column (not only at the surface) with cement grout. In order to guarantee its integrity, and hence its impermeability, the grout must be poured through a pipe, starting at the bottom of the borehole and withdrawing the pipe gradually as work proceeds, rather than simply pouring it in at the top of the borehole and allowing it to fall to the bottom. This technique should be also used to condemn a new negative borehole (non exploitable) that has penetrated the aquifer zone.

Note. – The decision to condemn a borehole permanently should not be taken only on the basis of current conditions, but should also take into consideration the technical and financial possibilities of rehabilitation in the future. In particular, deep boreholes or boreholes in isolated areas should not be condemned without a lot of thought. In any case, this operation must not be done without the full agreement of the users and operators.

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The illustration on the cover is from Souffles du monde–BKK, Erik Sampers, ACF Liberia.

ISBN 2 7056 6499 8