KOMPETENZZENTRUM WasserBerlin

# REPORT

**Contract : WELLMA2_WP3-4**

Cicerostr. 24
D-10709 Berlin
Germany
Tel +49 (0)30 536 53 800
Fax +49 (0)30 536 53 888
www.kompetenz-wasser.de

# D4.1.1
# TECHNICAL GUIDANCE FOR THE EVALUATION OF REGENERATION SUCCESS

PROJECT ACRONYM: WELLMA2_WP3-4

by
Hella Schwarzmüller

Department “Sustainable Use and Conservation of Groundwater Resources”
KompetenzZentrum Wasser Berlin, Cicerostraße 24, 10709 Berlin, Germany
Email: hella.schwarzmueller@kompetenz-wasser.de, Tel. ++49 (0)30-536-53814

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**Title**
Technical guidance for the evaluation of regeneration success

**Authors**
Hella Schwarzmüller, KWB

**Quality Assurance**
Gesche Grützmacher, KWB
Katia Besnard, VERI
Marc Alary, Veolia Eau
Guenter Scharl, pigadi GmbH
Andreas Wicklein, pigadi GmbH

**Publication/ dissemination approved by technical committee members:**
Katia Besnard, VERI
Marc Alary, Veolia Eau
Regina Gnirß, BWB FE
Elke Wittstock, BWB WV
Heidi Dlubek, BWB WV
Andreas Wicklein, pigadi GmbH
Gesche Grützmacher, KWB
Andreas Hartmann, KWB

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# Contents

# 1 Introduction

## 1.1 Objectives

This technical guidance document provides an overview of methods for evaluating the success of well regeneration. It is independent of the chosen regeneration method and shall document the improvement of well performance and/ or condition due to regeneration.

The objective of regeneration success evaluation is to standardize the documentation of well history and assist in future regeneration planning by learning from past experience.

## 1.2 Applicability

This guidance document applies to drinking water wells undergoing regeneration for either preventive or poor performance factors using standard regeneration technologies. This includes such technologies as mechanical, chemical or impulse generation. Wells where a component of the regeneration work included modification to the wells original construction design may require additional measures and documentation above those discussed in this document.

Prior to any regeneration, it needs to be carefully evaluated whether the well:

1) Requires regeneration (e.g. exclusion of other causes for failure) and;
2) Well condition is suitable for regeneration (e.g. able to resist against applied forces)

These preparative measures are not covered by this guideline.

## 1.3 Overview

The questions to be answered after regeneration are:

- What is the improvement in well performance based on a comparison of specific capacity before and after regeneration, or to original capacity at time well construction?
- Does the improvement in well performance justify the cost of regeneration (before / after m³/€)
- How much residuals/ deposits/solids were extracted/ generated?
- Did the regeneration work have an effect on water quality?
- How long did the improved performance last?

Accordingly, the minimum criteria for evaluating regeneration method success (Figure 1) include

1) Pumping tests before and after regeneration to calculate and compare specific capacity [Qs] changes which are calculated by dividing discharge rate [Q] by the drawdown [s].

2) Water sampling for chemical or hygienic parameters due to the regeneration effort. A water sample needs to be taken before and after regeneration. The analysis should include indicator parameters such as pH, Eh, electric conductivity, temperature and oxygen concentration as well as relevant cations and anions (sodium, calcium, magnesium, iron, manganese, chloride, nitrate, sulfate, hydrocarbonate), number of colony forming units and *E.coli*.

If it is not possible to monitor well performance during normal well operation to assess the sustainability of the effected treatment, the pumping test should be repeated at least once four to eight weeks after treatment.

# 2 General procedures

## 2.1 Terms and definitions

| | | |
|---|---|---|
| *Discharge* | Q | Also referred to as *yield* or *abstraction rate*.<br>Volume of water pumped from a borehole per unit of time, usually in m³ per hour |
| *Well performance* | | Also referred to as *well capacity*.<br>Maximum rate of yield for given conditions, usually for a given drawdown |
| *Specific capacity* | *Qs* | Abstraction rate Q divided by drawdown s, describes the yield per meter drawdown [m³/ h* m], is a function of time and discharge |
| *Entrance resistance* | *Δh* | Difference in water level [m] between the abstraction well and an observation well in the gravel pack during abstraction |
| *Monitoring* | | Routine investigation and analysis of quantitative, qualitative and structural condition of a well construction |
| *Diagnosis* | | Deduction of reasons for any change in well performance |
| *Well maintenance* | | Process, carried out on a regular basis, and intended to preserve a level of performance by keeping the components in good repair |
| *Preventive treatment* | | Measures, carried out on a regular basis, aimed to preserve a good level of performance by slowing down microbiological and chemical well ageing processes.<br>Most widespread are disinfection methods using strong oxidants such as $H_2O_2$. |
| *Regeneration* | | All measures aimed at the removal of mineral and organic deposits from the well including the interior, gravel pack and adjacent sediment to restore well performance to its original level. All regeneration technologies are subject to the following principles of action:<br>*Separation*: Disconnection (mechanical measures) or dissolution (chemical methods) of the deposits from the well material<br>*Discharge:* Removal of disconnected deposits from the well<br>*Control of removal:* Monitoring of progress to govern the work flow |
| *Reconstruction* | | Any modification to the wells original construction design aimed to preserve a good constructive condition and level of performance. |

Caution is advised when referring to American literature. In contrast to European nomenclature, the term R*ehabilitation* is typically used for regeneration methods. In Europe, rehabilitation refers to both, regeneration and reconstruction work.

Unless it is noted otherwise, wells are referred to as vertical filter wells constructed with a casing, screen and gravel pack behind the filter screen.

## 2.2 Minimum and ideal methodology

Each regeneration event has to include an active pumping component to remove detached deposits/materials, otherwise they might result in more rapid re-growth of biological material. The pumping allows for periodic sampling of discharge water to monitor removal efficiency and improvement in well performance. The sediment removal process can occur either simultaneous with the process/technology used to loosen the material plugging pore spaces, or alternating with the application of the regeneration process/technology. The monitoring of removed material quantities is used as one criterion in determining when regeneration efforts should stop. As turbidity clears in all screen intervals, this is one indication that regeneration work may be complete. If turbidity monitoring detects a sudden increase in the quantity of sand or gravel work should stop as this could indicate a well construction failure.

Monitoring the volume of removed material during regeneration (Figure 1, middle) is one criteria used to evaluate the regeneration progress. However, it cannot be compared to the initial measured volumes for the sole purpose of determining the success of the regeneration work. Additional criteria are necessary to compare the condition of the wells performance before and after regeneration. In general, pumping tests are the most useful method for determining regeneration success as they provide quantitative measurements on well capacity and efficiency independent of the applied regeneration technology.

Prior to starting any regeneration work, a video inspection of the well casing and screen is recommended to minimize the potential loss of regeneration equipment or damage to the well due to age related degradation or poor construction, (Figure 1, left). A post regeneration video inspection is also recommended in order get a visual observation of deposit removal (if deposits were located on the casing and/ or screen).

Ideally, a water quality and or biological deposit sample is collected before regeneration, to document the impact of the clogging processes. After completing the regeneration work, another water quality sample should be collected to document any changes in chemical or biological concentrations (Figure 1, right).

Additional monitoring criteria are sometimes used to evaluate the permeability of the gravel pack and how they were affected by regeneration.

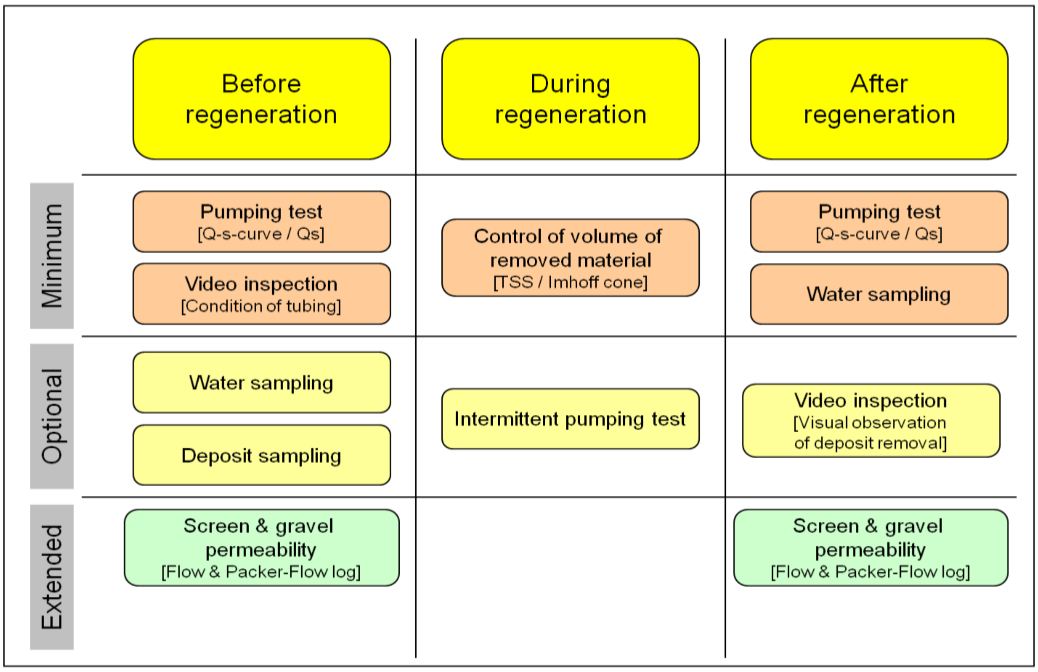


Figure 1: Range of monitoring criteria for regeneration success evaluation

When regeneration is done on wells with less than 10 percent loss of performance, pumping tests alone are not sufficient to evaluate success, because of the small difference in the pre and post specific capacity values. In these cases, the monitoring of sediment volumes removed through the process is important.

It is important to regularly determine static water levels in order to distinguish between well performance losses due to well clogging and that due to external factors such as declining aquifer water levels from over-exploitation or low seasonal recharge. This is accomplished by collecting water level measurements at the well during none pumping periods or by installing a network of dedicated piezometers for regional water level monitoring.

### 2.3 Documentation of Regeneration Work

After completion of the regeneration fieldwork, it is important to prepare a written report that documents the regeneration work process and results. At a minimum, the regeneration report should contain:

- Any tests and analyses conducted prior to regeneration;
- Regeneration process and technologies used;
- Comparison of pre and post regeneration specific capacities;
- Volume of sediment removed throughout the process;
- Discussion of any changes in water quality;
- Recommendations for future regeneration approach;
- Recommendations for long-term operation and monitoring.

For long term monitoring of well performance, setting up a well maintenance database (Figure 2) is strongly recommended as it provides a structured way to collect and store operational data that is easily accessible to well owners and their engineers.

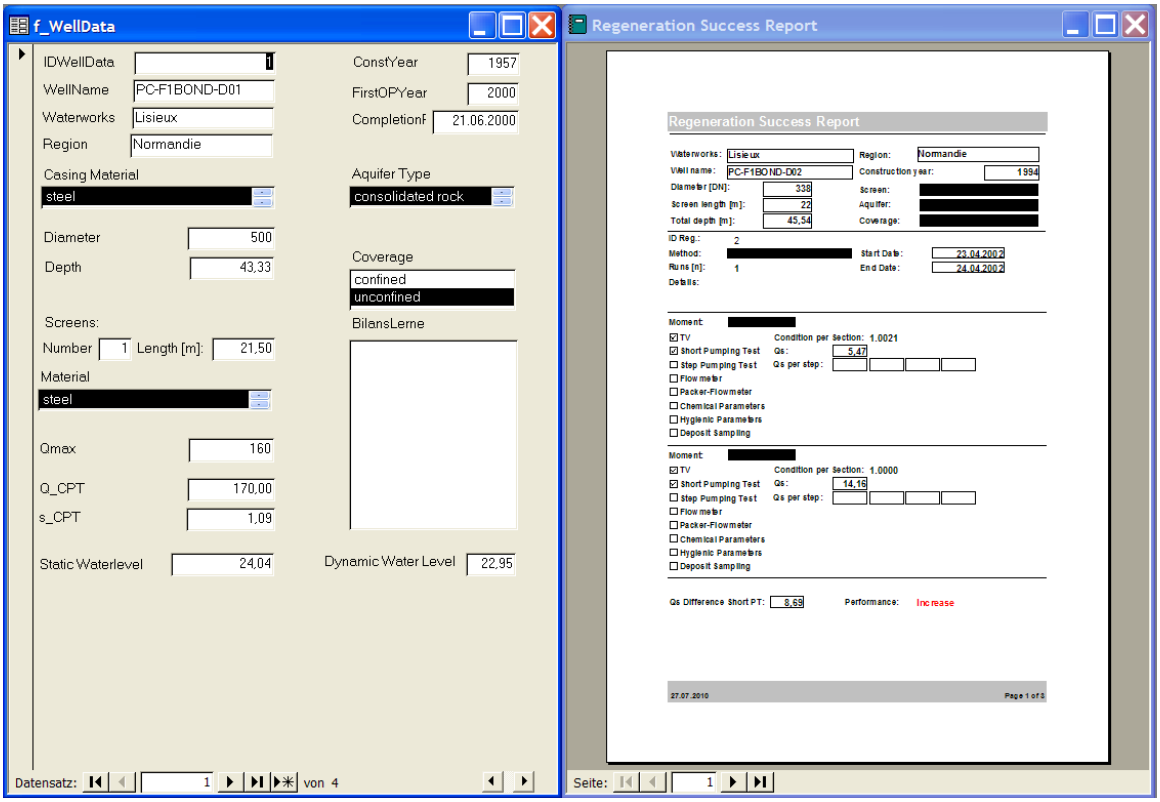


Figure 2: Example record sheets from a draft database containing well and maintenance data [KWB 2009 concept, not pursued]

| REGENERATION REPORT | | | | |
|---|---|---|---|---|
| Regeneration data | **Report date** | *dd.mm.yyyy* | | |
| | **Regeneration method applied** | ☐ Brushing | | |
| | | ☐ Hydromechanical method: *please specify* | | |
| | | ☐ Chemical: *please specify*<br>Type/ Name of product:<br>Volume of product used:<br>Concentration:<br>Application: *Open or under pressure, packered etc.*<br>Treatment cycles: | | |
| | **Contractor** | *please specify* | | |
| | **Cost of regeneration application** | *xx.xxx €* | | |
| | **Time, well was out of operation** | *xx days* | | |
| Evaluation | **Evaluation methods applied** | **Method** | **Before** | **After** |
| | | Constant-rate pumping test | ☐ | ☐ |
| | | Step pumping test | ☐ | ☐ |
| | | TV inspection | ☐ | ☐ |
| | | Packer flow meter log | ☐ | ☐ |
| | | Water analysis | ☐ | ☐ |
| | **Qs after regeneration compared to initial capacity** | *initial Qs:*<br>*Qs after regeneration: xxx ( x %)* | | |
| | **Qs after regeneration compared to before regeneration** | *Qs before regeneration::*<br>*Qs after regeneration: xxx ( x %)* | | |
| | **Qs after xx weeks** | *Qs after regeneration: xxx* | | |
| | **Removed solid matter** | *xx g/l (equiv. to kg/m³)* | | |
| | **evaluated by** | ☐ Imhoff cone | | |
| | | ☐ Mass balance calculation (for acidification) | | |
| | **Residuals &<br>Costs for their disposal** | *xx m³ (or kg)*<br>*xx.xxx €* | | |
| Additional remarks | **Peculiarities noted by TV inspection** | ☐ Casing/ screen broken | | |
| | | ☐ Casing/ screen corroded | | |
| | | ☐ Hardened deposits, not removed | | |
| | | ☐ Other: *please specify* | | |
| | **Peculiarities noted in Flow log** | ☐ Dislocation of annular seal | | |
| | | ☐ Large variation before/ after regeneration | | |
| | | ☐ Other: *please specify* | | |
| | **Peculiarities noted in water analysis** | ☐ Bacterial disturbance due to regeneration | | |
| | | ☐ Large variation before/ after regeneration | | |
| | | ☐ Other: *please specify* | | |
| | **Personal evaluation**<br>**Name:** *xxx*<br>**Comments:** *xxx* | ☐ Regeneration successful / Repetition recommended | | |
| | | ☐ Regeneration partly successful | | |
| | | Repetition recommended: ☐ yes ☐ no | | |
| | | ☐ Not recommended for repetition | | |

# 3 Methods to evaluate the success of well regeneration

### 3.1 Specific capacity before and after regeneration

The specific capacity of a well is calculated from pumping test data. They can be carried out as constant-rate discharge test or step-draw down pumping tests (varying discharge rate).

Step-draw down tests allow the determination of the Q-s-curve, from which the well loss coefficient can be calculated in addition to the specific capacity Q/s. A minimum three discharge steps are necessary, beginning with the lowest rate.

Short-term constant-rate pumping tests can be used in place of step-tests if well efficiency is not needed. The pumping rate should equal that of normal well operation. If possible, the well is pumped until the dynamic water level remains constant.

**Procedure**

1. Open the wellhead for access
2. Measure the static water level below pre-determined measuring point
3. Insert temporary pump into well at a depth where there is no risk of pumping water level dropping below pump intake during regeneration work
4. Re-measure water level to ensure equilibration following pump installation.
5. Initiate pumping, choose first discharge rate depending on the total number of steps and the maximum discharge rate (e.g. for 3 steps: 1st step is 1/3 of maximum discharge, 2nd step is 2/3 etc.)
6. Measure pumping rate and drawdown at pre-defined intervals (see attachment 1), and record on the specific capacity test form (attachment 1)
7. Pump until drawdown has stabilized (typically 1 to 2 hours per step; measurements within 1 cm over a ten minute interval can be considered stable)
8. Record time since start of pumping, discharge rate and drawdown

*for step-drawdown tests:*

9. Increase discharge rate to step n+1
10. Repeat steps 6 to 8 for at least two more pumping rates with equal duration for each pumping rate step

*otherwise:*

11. Terminate pumping
12. Measure water levels at pre-defined intervals(see attachment 1) during recovery; the water level measured when residual drawdown stabilized should be used as final static water level
13. Use software (e.g. excel spreadsheet, see attachment 1) to interpret pump test data (-> digitalize data, plot Q-s, determine specific capacity Qs, aquifer loss coefficient B and well loss coefficient C)

**Checklist**

Equipment:

- Suitable capacity pump and riser pipe
- Dip meter

- Water level meter
- Clock / Stop watch
- Field test data sheet (attachment 1)
- Location for discharge water

Approximate Effort:

Constant-rate pump tests: ~ 0.5 day; ~ €2.500 each
Step-discharge tests: ~ 1 day; ~ €3.500 each

Critical points:

- Determine true static water level, especially in case of constant-rate pump tests
- Use same reference point and units, e.g. meter below top of well head
- For unconfined wells: measure at same discharge rate before and after regeneration
- *If routine monitoring does not cover water level and discharge measurements:* Repeat pumping test (same discharge rate again) after two to eight weeks to evaluate sustainability

**Evaluation of regeneration success from pump tests**

The specific capacity Qs of a well is calculated by Qs = Q/s where Q is the discharge rate of step n and s the according steady-state drawdown of step n.

For the evaluation of regeneration success, Qs after regeneration is compared to Qs before. To determine the overall performance improvement of the well, Qs after regeneration is related to the initial specific capacity determined after initial well construction pumping test.

When evaluating step-discharge tests, the steady-state drawdown of each pumping rate is plotted against the corresponding pumping rate. Plotting the pre and post regeneration drawdown on one diagram (Figure 3), the Q-s-curve after regeneration should have less slope if the well performance has improved.

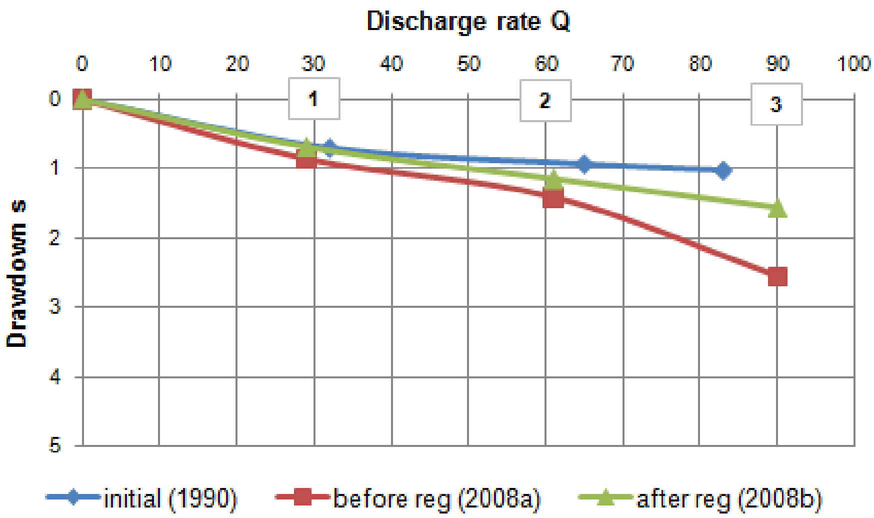


Figure 3: Example Q-s-curves for step-discharge-tests at initial operation, before and after regeneration

For wells completed in both, confined or unconfined aquifers, if drawdown is less than 10% of the overall aquifer thickness, the specific drawdown, calculated by steady-state drawdown s divided by discharge rate Q can be plotted against the pumping rates to determine the aquifer loss B (slope of the curve) and the well loss C (interception with s/Q-axis) (Figure 4).

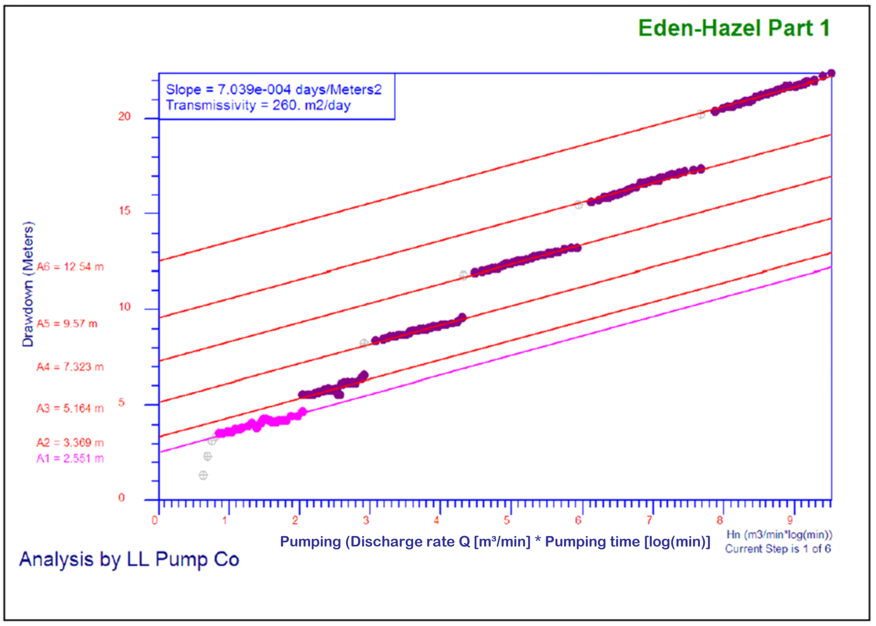


Figure 4: Example for computer-assisted step drawdown test analysis [Aitchison-Earl & Smith 2008: Aquifer test guidelines. $2^{nd}$ ed.]

Please note that a final assessment of the well condition requires the evaluation of the development of these values over time, and thus repeated measurements under constant boundary conditions. An increasing well loss after several regenerations indicates severe clogging, which cannot be treated indefinitely. A high, but more or less constant well loss is related to the screen and/ or gravel pack design.

During regeneration, Qs can be estimated at each pumping step by recording discharge rates and associated drawdown then calculating Qs as described above. Regeneration can be stopped, if Qs is not increased after several repeated treatment cycles.

### 3.2 Volume of removed material

The volume (or mass) of removed material is calculated from repeated measurement of either turbidity, suspended solids or of dissolved ionic concentrations (for chemical regeneration). These measurements are carried out during regeneration. Sample measurements should be depth-specific, to document regeneration progress in each screen interval.

For mechanical regeneration, the minimum requirement is to observe the volume of suspended solids with an Imhoff cone.

Figure 5: Imhoff cones [www.geologie-franken.de]

**Procedure**

1 Implement regeneration process;

2 Pump off regeneration residues;

3 Measure duration of pumping and discharge rate;

4 Every 5 minutes: fill 10l bucket from discharge

5 Wait 5 minutes to allow for sediment to settle;

6 Carefully decant upper 9l;

7 Fill remaining 1l in Imhoff cone;

8 Wait at least 5 minutes to allow for settlement;

9 Read scale of Imhoff cone after settlement [ml per 10l]

10 Record sampling time, value and discharge rate on a field data sheet;

11 Record total duration of pumping;

12 Plot cumulative volume against time or, plot volume against depth;

13 Calculate total volume of removed solids [litres]:
Pumping time [minutes] x discharge rate [m³/h] x suspended solids content [ml/ 10l] x 10 / 60

**Checklist**

Equipment:

- At least 3 to 5 sets of buckets and Imhoff cones
- Clock/ Stop watch
- Water meter
- Field data sheet

Effort:

- Assign person in charge. Sampling is performed during regeneration.

Critical points:

- Sample if possible during maximum pumping rate (for very high discharge rates, sampling from substream might be necessary)
- Record discharge rate

## Alternative measures

An alternative for extended sediment monitoring could include using an in-line sand tester such as a Rossum sand tester (if particle sizes <100µm and low concentration expected) or a turbidity meter with continuous measurement of suspended solids concentration (Figure 6).

Chemical regenerations are evaluated based upon a mass balance of dissolved ionic concentrations (Figure 7). Multiplying the concentration by the volume of pumped water gives the total mass of removed material. For correction, the naturally occurring ion concentration is subtracted from the measured concentration prior to multiplication.

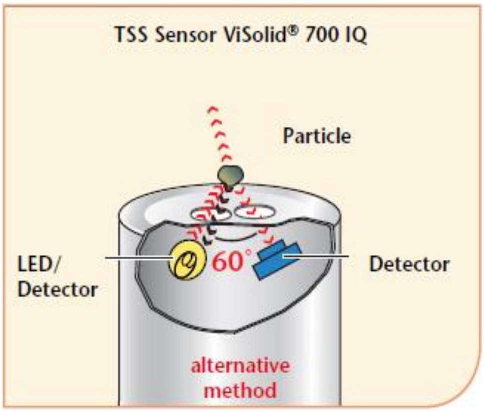


Figure 6: in-line turbidity sensor [www.wtw.com]

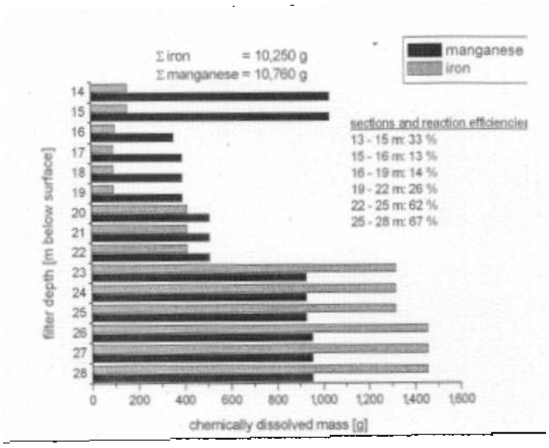


Figure 7: Balancing iron/ manganese concentrations [(Houben & Treskatis 2007):178]

## Evaluation of regeneration success from volume of removed material

The calculation of total volume of removed material does not provide a reliable indication of regeneration success. The main reason is that the amount of source material present in the well remains unknown. For example, removing 10 out of 12 litres suspended solids would be quite successful, while removing 10 out of 100 litres could be seen as rather unsuccessful.

Therefore, the sediment removal volume data needs to be evaluated in light of the other criteria collected from pumping tests, down-hole video inspections and / or logging the flow distribution.

Time-volume-diagrams help illustrating the regeneration progress. At the end of the regeneration process, volume of suspended solids should trend to zero. If the value remains high, either regeneration has been stopped too early, or the well might have been damaged.

For wells whose screens are regenerated based on screen interval, depth-concentration profiles illustrate at which sections the well was clogged most severely and/ or treated most efficiently. Data from video inspections or flow logs are needed in addition to determine if all clogging material has been removed.

### 3.3 Key water quality parameters

Water sampling fulfills two objectives. After regeneration work has been finished, chemical and biological water quality is determined. At the same time, given that all regeneration residual material was carefully removed, any changes in the chemical composition indicate changed flow paths towards the well.

The key water quality parameters are colour, odour, temperature, electric conductivity, pH, turbidity, iron, manganese, calcium, hydrocarbonate, nitrate and chloride. Some of these parameters can be measured along with geophysical logging, e.g. temperature and electric conductivity.

If the well is screened in different aquifers or a vertical zonation can be expected (from regional geology, neighbour well examination or previous experience), depth-oriented sampling is recommended. To do so, the well is pumped at different depths from bottom to top.

**Procedure**

1. Determine the extent of analysis (parameters, needed sample volume etc.) depending on well characteristics; depth specific sampling might be necessary, if the well is screened in different aquifers and previous analyses are available
2. Install pump and sampling port (or bypass)
3. Start pumping and measuring key parameters pH, T and EC in a by-pass flow-through cell.
4. Wait until key parameters have stabilized (± 10 %)
5. Start sampling
6. Control water level, after sampling has been finished
7. Record well ID, time, discharge rate, water level, sample IDs
8. Note any specific conditions at time of sample collection

**Checklist**

Equipment:

- ☞ Sampling port
- ☞ Measuring devices for pH, EC, T
- ☞ Flow-through cell
- ☞ Sterile glass bottles for microbiological analysis
- ☞ Plastic bottles for chemical analysis
- ☞ Equipment for filtration and field analyses (depending on the extent of analysis)
- ☞ $HNO_3$ (conc.) for conservation

Figure 8: In-situ measurement of geochemical properties [Menz 2009]

Approximate Effort and Cost:

- ☞ Sampling 2 hours, ~€300
- ☞ Data Analysis ~€250 - €500, depending on extent

Critical points:

- Measure at steady-state conditions
- Measure the same set of parameters before and after regeneration to allow direct comparison

**Evaluation of regeneration success from key water quality parameters**

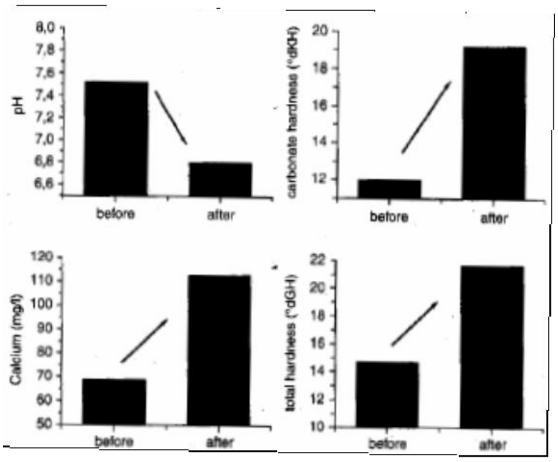


Figure 9: Example of changed water quality due to $CO_2$ treatment [(Houben & Treskatis 2007):225]

In addition to demonstrating safe drinking water quality, the comparison of the chemical concentrations before and after regeneration is used to evaluate any changes due to regeneration (Figure 9).

Any changes in water quality could affect the water treatment scheme implying the need for an adaptation of operation (e.g. mixing with water from other sources). This is especially important for the regeneration of wells used for mineral water production.

Observed changes in the water quality during regeneration can have several different reasons. Most common are an incomplete removal of regeneration residues and/ or a changed composition due to the opening of flow paths for chemically different water. In case of chemical regeneration, an incomplete removal can be determined from the characteristics of the raw water (e.g. low pH) and the regeneration agent. In that case, the well should be further developed.

If a flow log is available, the correlation between water flow distribution in the screen interval(s) and water quality can be evaluated.

### 3.4 Control of deposit removal from tubing and gravel pack

**Video Inspection**

It is recommended to check the condition of the well prior to the application of any regeneration device by down-hole video inspections. This allows easy and quick evaluation of chemical or biological occurrence and location within the well. A repetition second inspection after regeneration provides a visual assessment of deposit removal from the well casing and screen.

**Procedure**

1. After well pump is removed, abstract water if necessary to clear turbidity of water
2. Install down-hole video camera with centralizers
3. Move camera from top to bottom of the well; start right at the well head (above the water level); record reference points such as water level, top/ end of screen sections, total well depth (with/ without sediments)
4. Take pictures if any peculiarities are noticed (e.g. signs of corrosion, damaged connections etc.)
5. Record complete video on DVD
6. Summarize findings in a short report

**Checklist**

Equipment:

- Down-hole video camera allowing axial and radial view (Figure 10)
- Tripod

Estimated effort and cost:

- Depending on well depth and condition
- For 100m deep well: ~ 2hours; ~ €2.500

Figure 10: Down-hole video camera system for wells [www.ehle-hd.com]

Critical points:

- Use uniform and comparable classification system, e.g. an index for location, appearance, colour of deposits etc.

**Evaluation of regeneration success**

The visible condition of casing and screen before and after regeneration is compared (Figure 11).

Particular attention should be paid to deposits and incrustations not removed by regeneration.

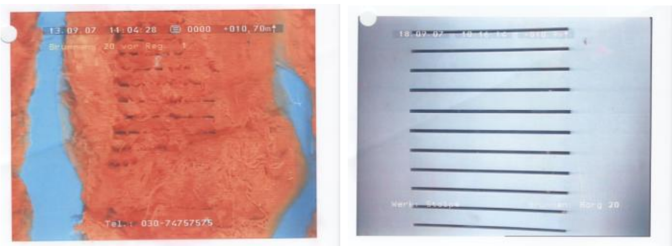

Figure 11: Screen section (PVC with iron ochres) before (left) and after (right) regeneration [pigadi 2007]

**Geophysical logging (flow logging)**

In addition to the visible control of the well interior, geophysical logging can help evaluating the condition of the gravel pack (or near-well aquifer). For regeneration success evaluation, checking the permeability by flow meter and packed flow meter logs is recommended. While the flow meter measurement is needed for data analysis, packed flow meters directly measure the permeability (Figure 12).

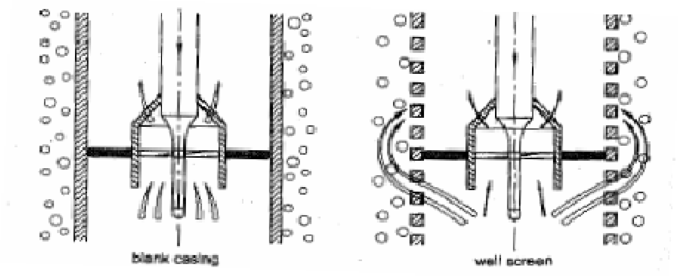


Figure 12: Principle of packed flow meter measurement [(Houben & Treskatis 2007):170]

### Procedure

1 After TV inspection, switch off well and allow for recovery

2 Start with flow meter to log intake distribution

3 Set logging speed (e.g. 10m per minute)

4 Move flow meter with constant speed from top to bottom with pump switched off

5 Repeat under pumping conditions. Pump must be located above the top-screen and flowrate must be adapted so the ascendant flow velocity is detectable by the impeller (> 1 cm/sec)

6 Install packer disc (in screen diameter) at flow meter

7 Move packed flow meter under pumping conditions (see above) with constant speed from top to bottom

8 Plot impeller rotational speed against depth for flow meter and packed flow meter log

### Checklist

Equipment:

- Flow meter
- Packer
- Tripod

Effort:

- Depending on well depth and constructive condition
- For 100m deep well: ~ 2hours; ~ €2.500

Figure 13: Packed flow meter [Wiacek 2003]

Critical points:

- Consider well condition and expected ageing type and deposit location to determine usefulness and feasibility of geophysical logging
- Evaluate economic benefit
- Use same equipment and identical measurement parameters before and after regeneration to allow direct comparison

### Evaluation of regeneration success

The distribution of intake and permeability before and after regeneration is compared (Figure 14). If logs from the initial operation are available, long-term changes in the intake distribution and permeability can be evaluated. Particular attention should be paid to sections with highly increased intake, but also to screened sections with still low permeability after treatment.

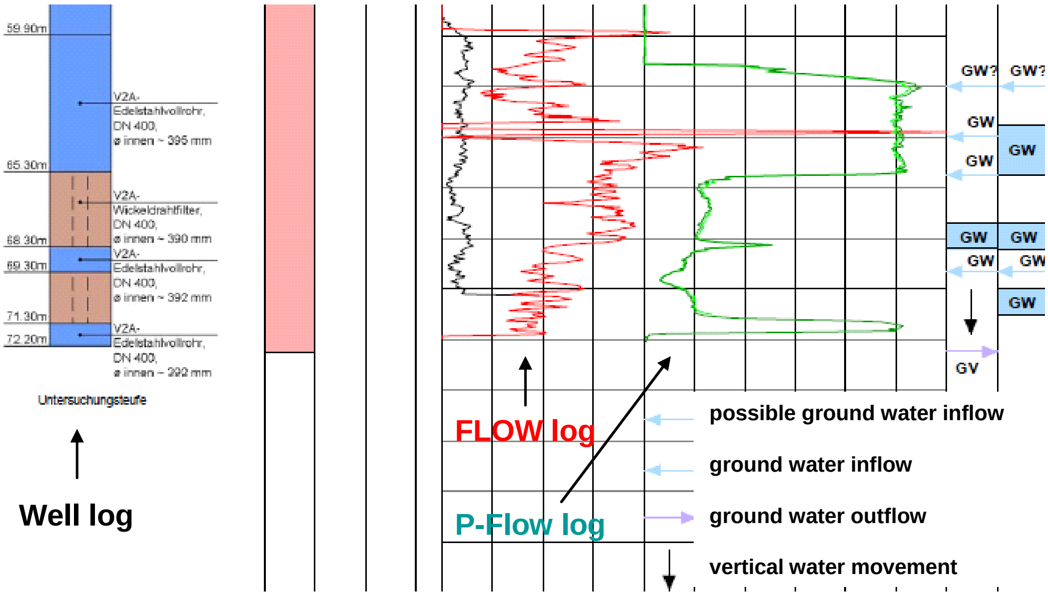


Figure 14: Example of a flow- and packed flow meter log [modified after www.blm-storkow.de]

# 4 What to do if the regeneration was not successful

| Indication | Possible causes | Proposed solution |
|---|---|---|
| **No performance increase** | Hardened incrustation<br><br>Clogging out of reach of applied regeneration technology | Deposit sampling & optimized chemical regeneration<br>Application of more powerful method, if well is able to resist applied forces |
| **Performance increase not sustainable** | Opening of flow paths for e.g. near-surface oxic water, enhancing (iron-related) clogging<br><br>Incomplete removal of incrustations ("seed crystal"), which represent a source of crystalline re-growth either of homogeneous or heterogeneous nucleation / crystals | Lower discharge rate<br>In extreme situations: Block off intake from near-surface water<br>Well re-development |
| **Repeated regeneration, but only short-lived performance increase** | Well design issue:<br>Screen too long<br>Annular seal leaky<br>Entrance velocity too high<br>Hydrochemical condition:<br>vertical zonation & mixing of incompatible water | Lower discharge rate<br>In extreme situations: Block off intake from near-surface water |
| **Regeneration-induced problems:**<br>**Deterioration of chemical composition of the raw water** | Opening of flow paths for chemically different water layers or intake from nearby surface water | Lower discharge rate<br>In extreme situations: Block off intake from near-surface water |
| **Regeneration-induced problems:**<br>**Hygienic-relevant raw water pollution** | Incomplete removal of organic regeneration agents or debris functioning as nutrient source<br>Use of erroneous cleaned equipment/ tools | Potentially:<br>Well re-development<br><br>Disinfection |
| **Regeneration-induced problems:**<br>**Mechanical damage** | Faulty Insertion/ Recovery of equipment<br>High mechanical stress during regeneration | Reconstruction work, e.g. placing of pressure sleeve<br>In worst case: Abandonment |
| **Regeneration-induced problems:**<br>**Deterioration of raw water quality by increasing turbidity, colour etc.** | Discharge rate/ entrance velocity too high<br>Mechanical damage | Lower discharge rate<br><br>Reconstruction work, e.g. placing of pressure sleeve<br>In worst case: Abandonment |

# 5 References


Aitchison-Earl and Smith:
Aquifer test guidelines. Canterbury, E. Canterbury, NZ. Report No. R08/25.2008

DVGW:
Entnahme von Wasserproben bei der Erschließung, Gewinnung und Überwachung von Grundwasser. DVGW, DVGW. Merkblatt W 112.2001

DVGW:
Brunnenbewirtschaftung - Betriebsführung von Wasserfassungen, DVGW. Arbeitsblatt W 125.2004

DVGW:
Brunnenregenerierung, DWGV. Arbeitsblatt W130.2007

Houben, G. and Treskatis, C:
Water well regeneration and reconstruction, Mcgraw-Hill Publ.Comp.2007

Howsam, P., Misstear, B., et al.:
Monitoring, maintenance and rehabilitation of water supply boreholes. London, Construction Industry Research and Information Association.1995

Lennox, J. B.:
Application of Well Condition Assessment and Rehabilitation Techniques, American Water Works Association Research Foundation.2006

## Attachment 1 A - Short-term constant-rate discharge test

**Test location** ______________ **Well no.** ______________ **Sheet** ______ **of** ______

**Test started:** Date ________ Time ________ Pre-test static water level ________ m

**Test ended:** Date ________ Time ________ Final water level ________ m

Reference point for depth to water ________

**Initial flow meter reading** ________ m³ **Final flow meter reading** ________ m³

**Average Pumping Rate** ________ m³ / h

**Test Conducted by** ______________________________

(Print name and title, then sign)

| DRAWDOWN DATA | | | | | RECOVERY DATA | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Time since pump started | Depth to water below measuring point | Drawdown | Pump rate | Time | Time since pump stopped | Depth to water below measuring point | Drawdown | Comments |
| [hh:mm] | [min] | [m] | [m] | [m³/ h] | [hh:mm] | [min] | [m] | | |
| | 0 | | | | | 0 | | | |
| | 1 | | | | | 1 | | | |
| | 2 | | | | | 2 | | | |
| | 3 | | | | | 3 | | | |
| | 4 | | | | | 4 | | | |
| | 5 | | | | | 5 | | | |
| | 6 | | | | | 6 | | | |
| | 7 | | | | | 7 | | | |
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| | 9 | | | | | 9 | | | |
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| | 30 | | | | | 30 | | | |
| | 45 | | | | | 45 | | | |
| | 60 | | | | | 60 | | | |
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**Final drawdown s** ________ m **at discharge rate Q** ________ m³/h -> **Qs** ________ [m³/h * m]

## Attachment 1 B - Step-discharge test

**Test location** ______ **Well no.** ______ **Sheet** ______ **of** ______

**Test started:** **Date** ______ **Time** ______ **Pre-test static water level** ______ m
Step 2 started: Date ______ Time ______ Step 1 - final water level ______ m
Step 3 started Date ______ Time ______ Step 2 - final water level ______ m
**Test ended:** **Date** ______ **Time** ______ **Final water level** ______ m
**Reference point for depth to water** ______

**Initial flow meter reading** ______ m³ **Final flow meter reading** ______ m³

**Pump rate:** **Step 1:** ______ **Step 2:** ______ **Step 3:** ______ m³ / h

**Test Conducted by** ______
**(Print name and title, then sign)**

| DRAWDOWN DATA | | | | | RECOVERY DATA | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Time since pump started | Depth to water below measuring point | Drawdown | Pump rate | Time | Time since pump stopped | Depth to water below measuring point | Drawdown | Comments |
| [hh:mm] | [min] | [m] | [m] | [m³/ h] | [hh:mm] | [min] | [m] | [m] | |
| | 0 | | 0 | 0 | | 0 | | | |
| | 1 | | | | | 1 | | | |
| | 2 | | | | | 2 | | | |
| | 3 | | | | | 3 | | | |
| | 4 | | | | | 4 | | | |
| | 5 | | | | | 5 | | | |
| | 6 | | | | | 6 | | | |
| | 7 | | | | | 7 | | | |
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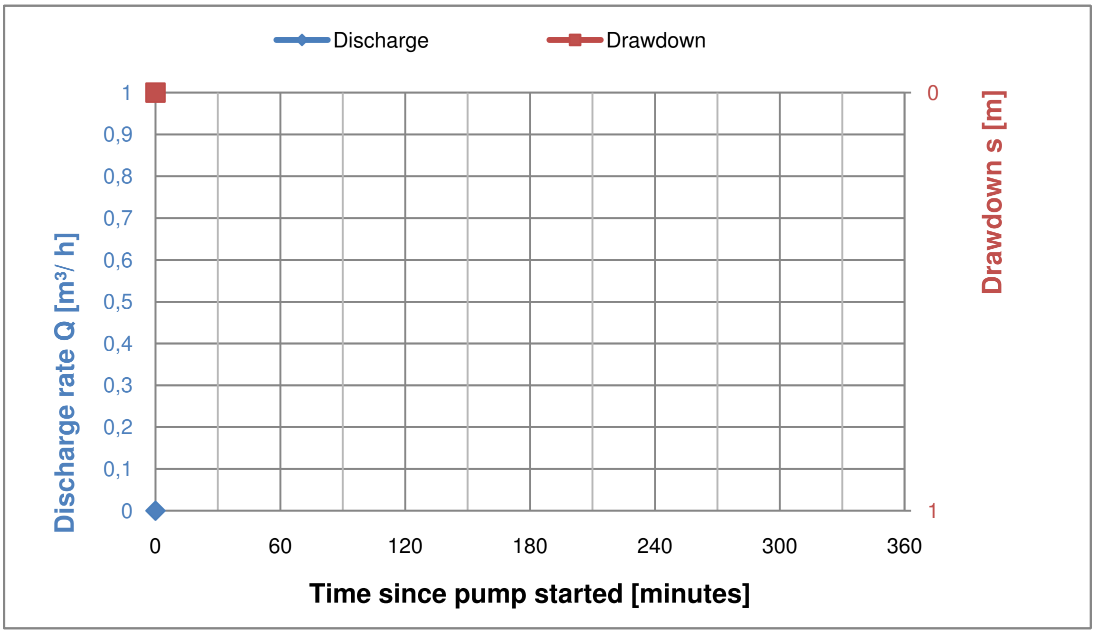
**Final drawdown s** ______ **m** **at discharge rate Q** ______ **m³/h** **->** **Qs** ______ **[m³/h * m]**

1) Time line




2) Q-s-curve